

Curs 10

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 (t2 si t3 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 personala

Documentatie

■ <http://rf-opto.etti.tuiasi.ro>



Laboratorul de Microunde si Opti

Not secure | rf-opto.etti.tuiasi.ro/microwave_cd.php?chg_lang=1

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)

Coordonator 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.etti.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

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

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

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

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

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

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

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

Examen: Operatii cu numere complexe

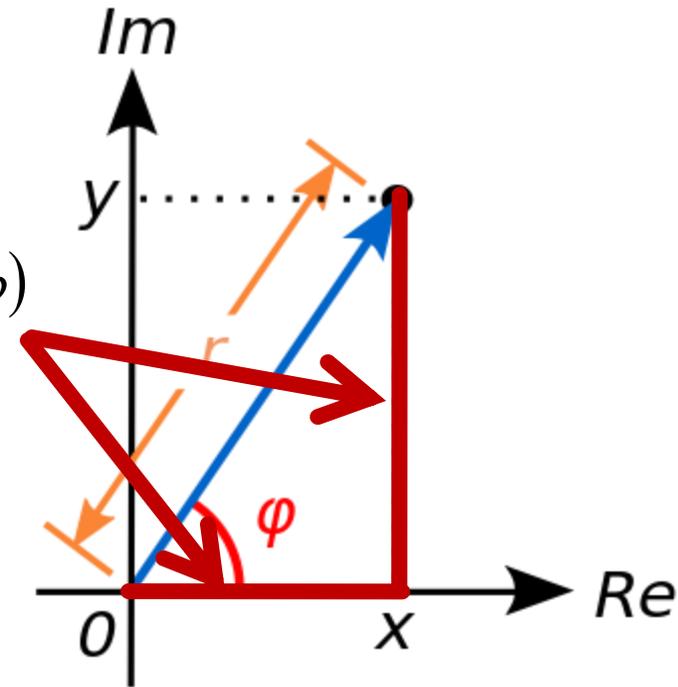
■ Reprezentare polara

- modul
- faza

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

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

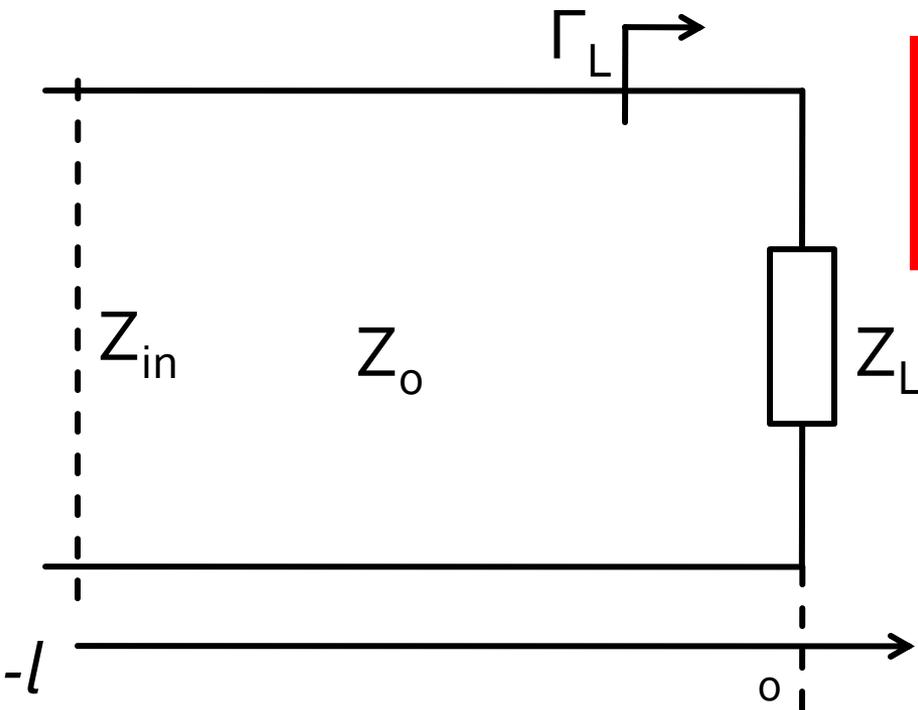
~~$$\varphi = \arg(z) = \begin{cases} \arctan\left(\frac{b}{a}\right), & a > 0 \\ \arctan\left(\frac{b}{a}\right) + \pi, & a < 0, b \geq 0 \\ \arctan\left(\frac{b}{a}\right) - \pi, & a < 0, b < 0 \\ \frac{\pi}{2}, -\frac{\pi}{2}, \text{nedefinit} & a = 0 \end{cases}$$~~



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

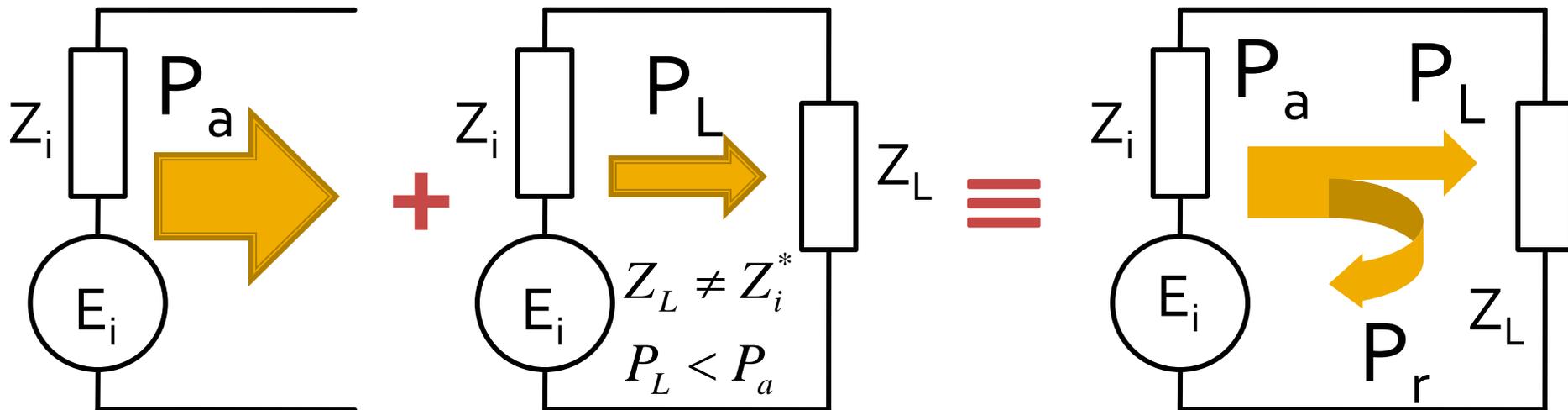


$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Transfer de putere

Adaptarea de impedanță

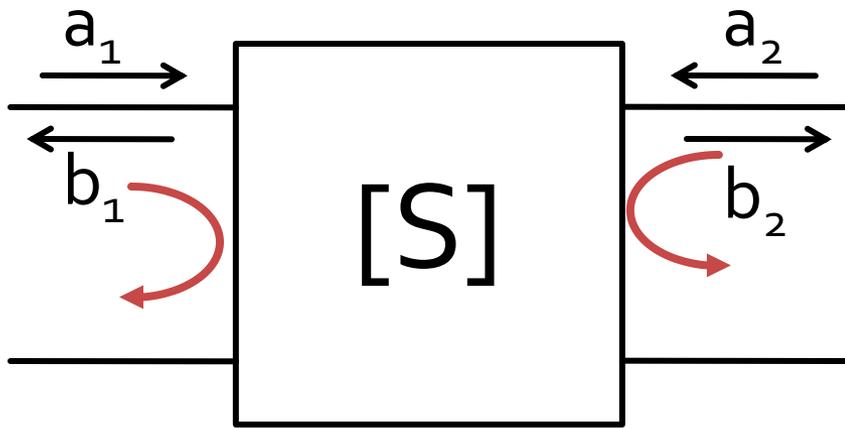
Reflexie de putere / Model



- Generatorul are posibilitatea de a oferi o anumita putere maxima de semnal P_a
- Pentru o sarcina oarecare, acestuia 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)

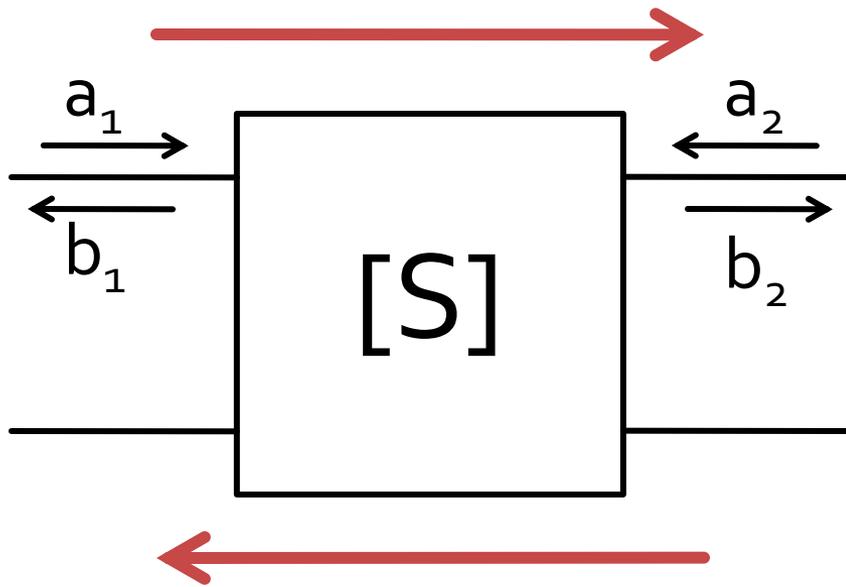


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

Matricea S (repartitie)

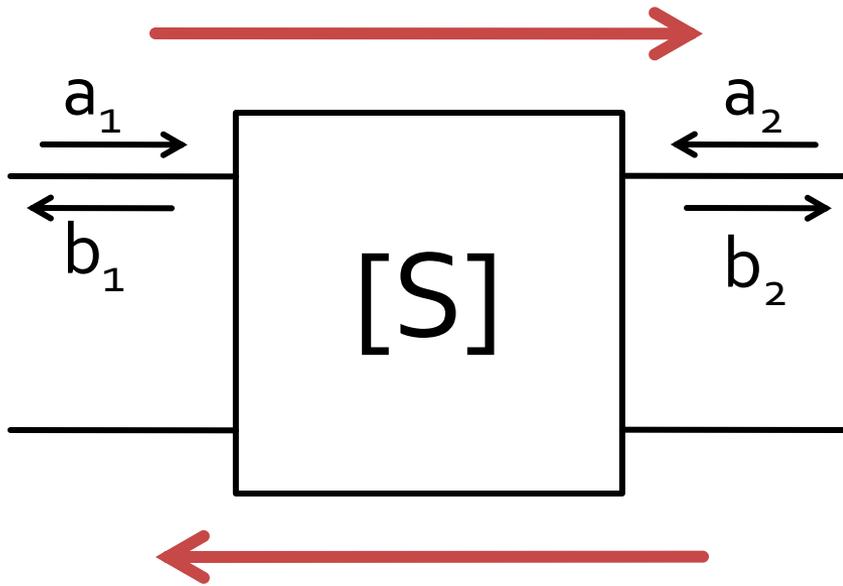


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

- S_{21} si S_{12} sunt amplificari 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

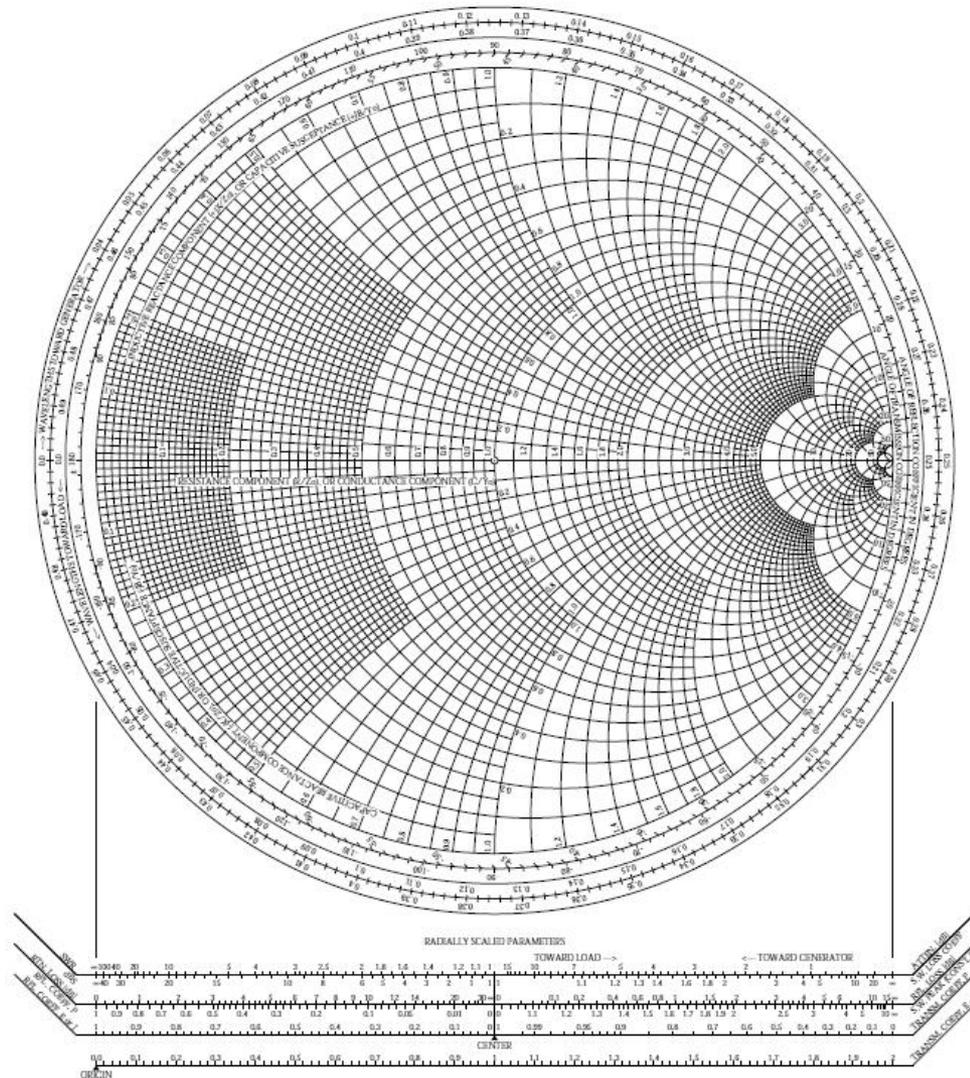
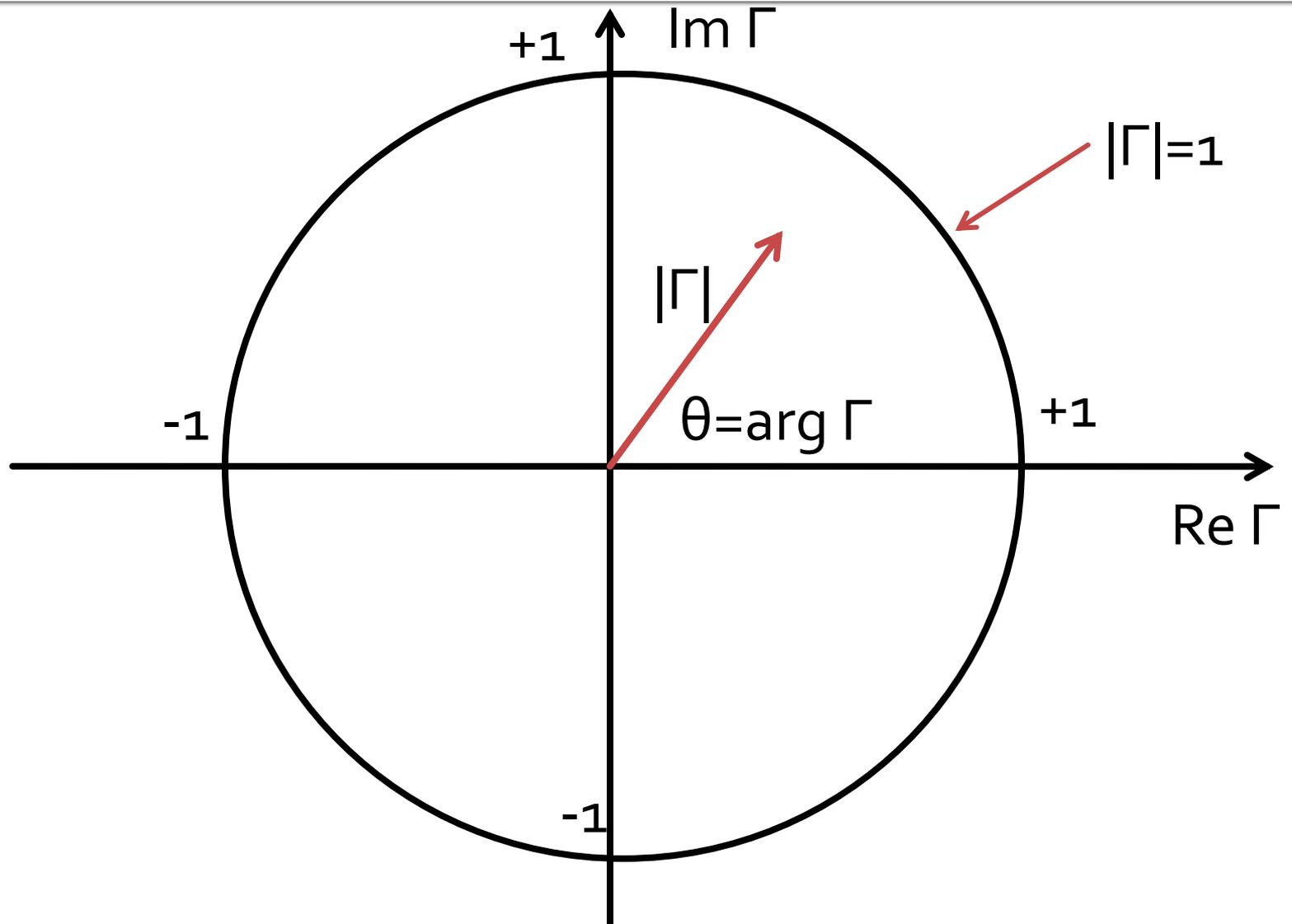


Diagrama Smith

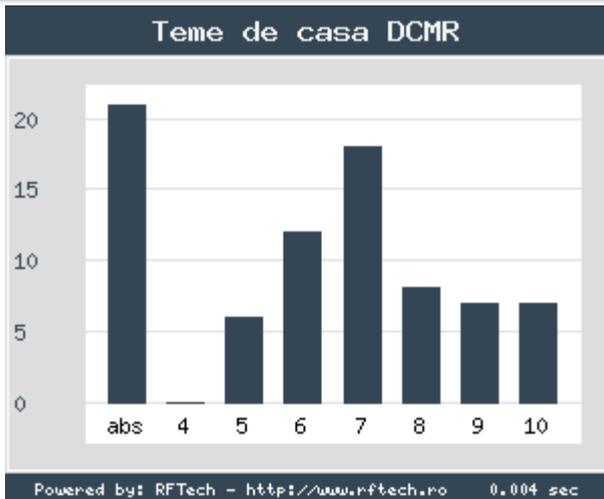


Adaptarea cu sectiuni de linii (stub)

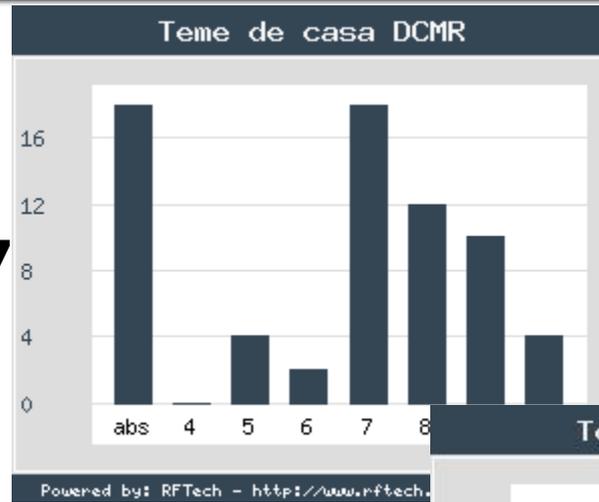
Adaptarea de impedanța

Efect? – factorul "andrei"

15/6



16/7



17/8



18/9

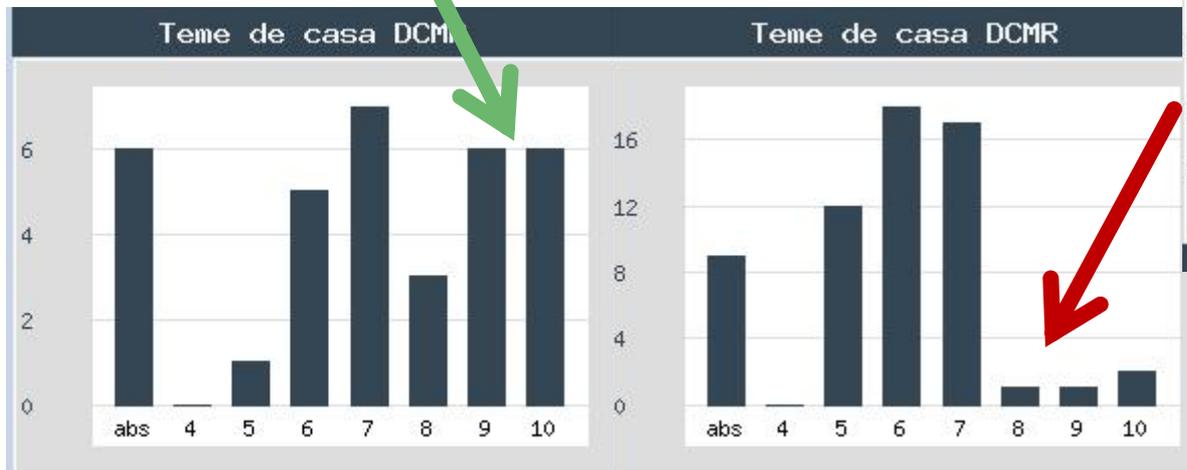
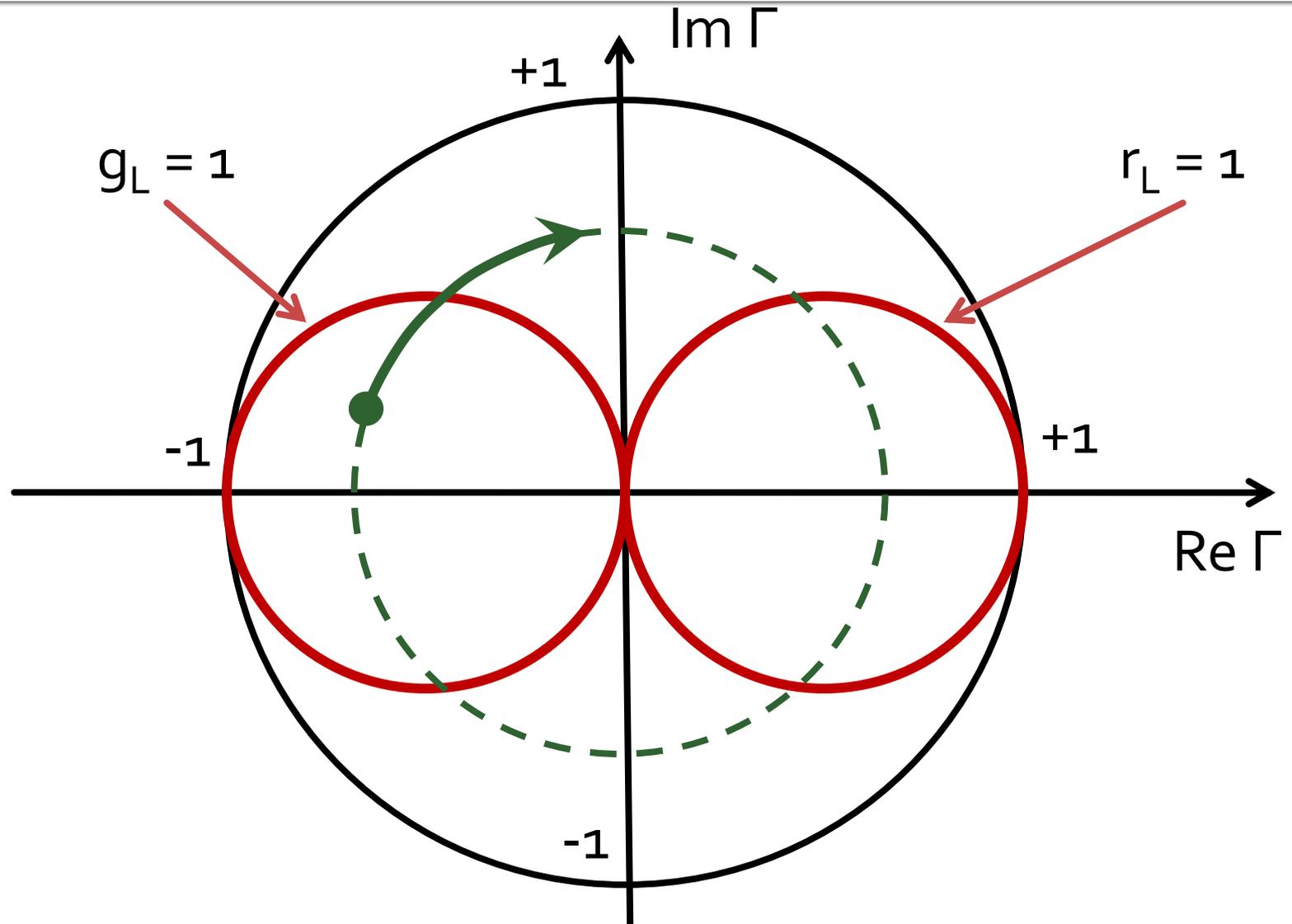
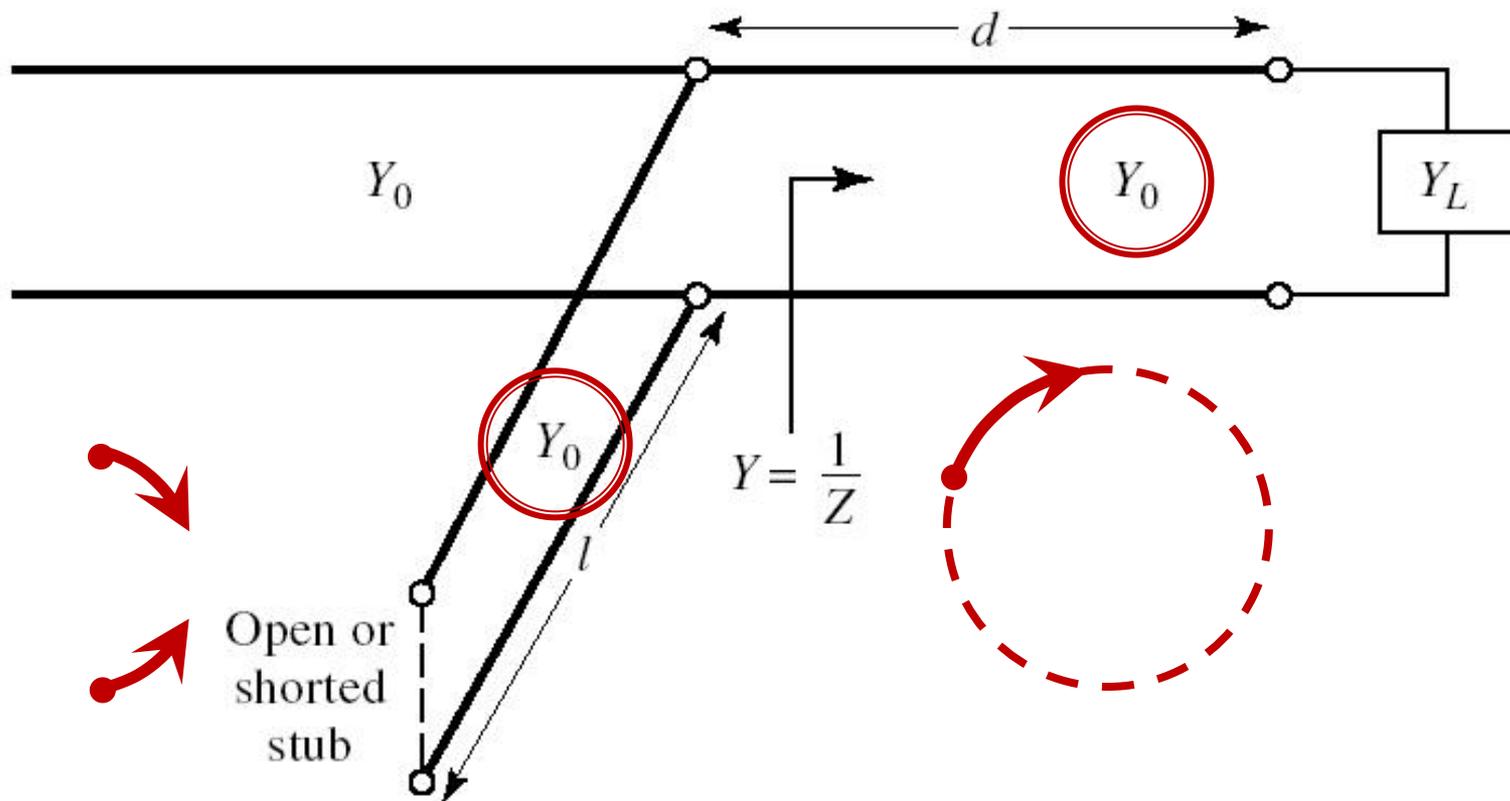


Diagrama Smith, $r=1$ si $g=1$



Caz 1, Shunt Stub

- Shunt Stub (sectiune de linie in paralel)



Calcul analitic (calcul efectiv)

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

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

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

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

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

- **solutia "cu +"** ↓

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

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

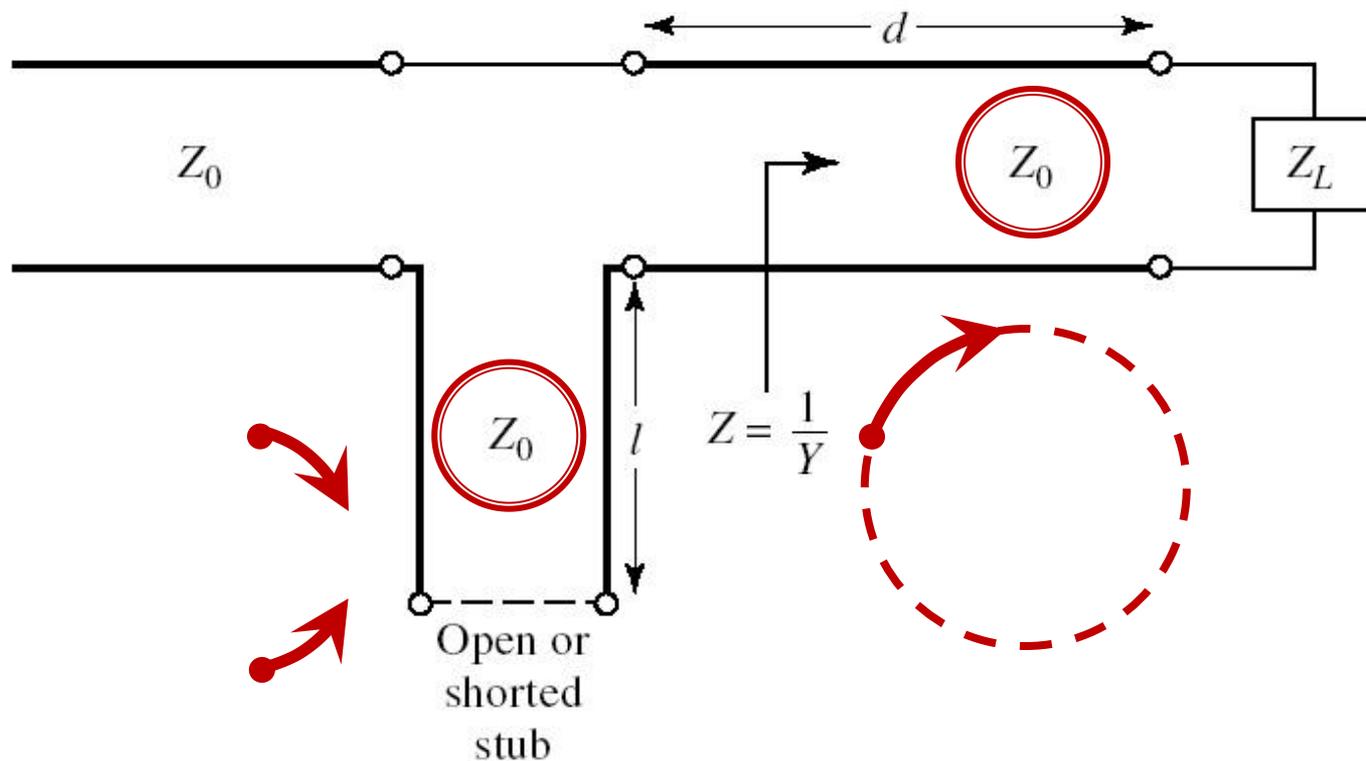
- **solutia "cu -"** ↓

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

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

Caz 2, Series Stub

- Series Stub (sectiune de linie in 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 alege la ecuatia **liniei serie** impune **semnul** solutiei utilizate la ecuatia **stub-ului serie**

- **solutia "cu +"** ↓

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

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

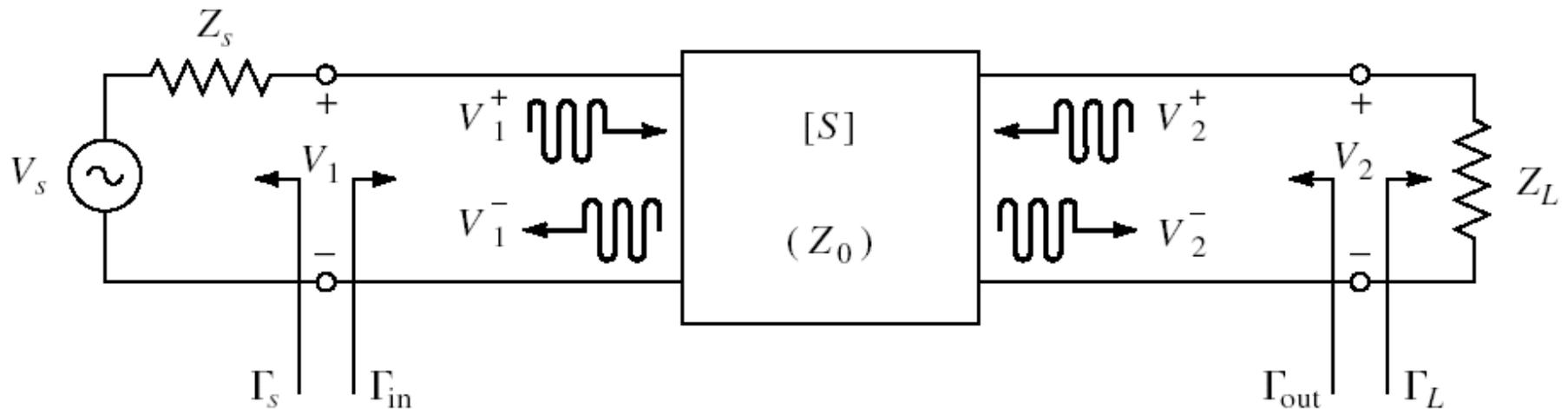
- **solutia "cu -"** ↓

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

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

Amplificatoare de microunde

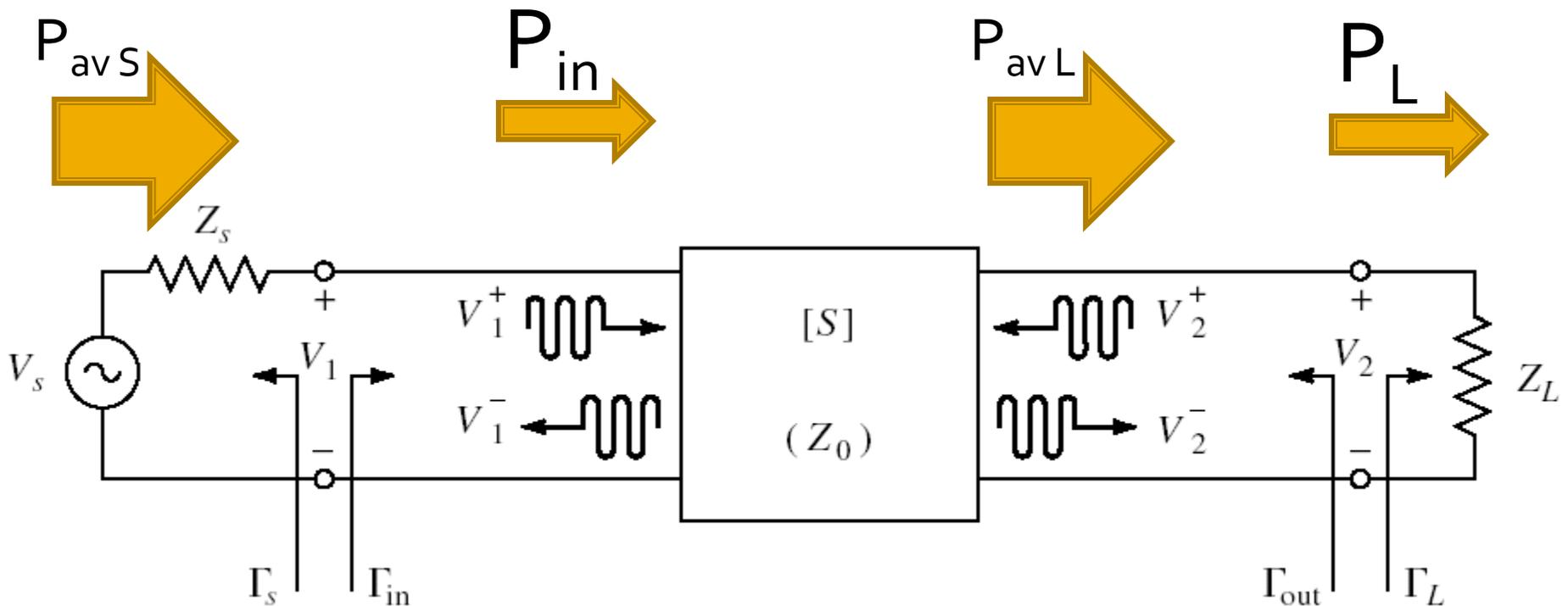
Cuadripol Amplificator (diport)



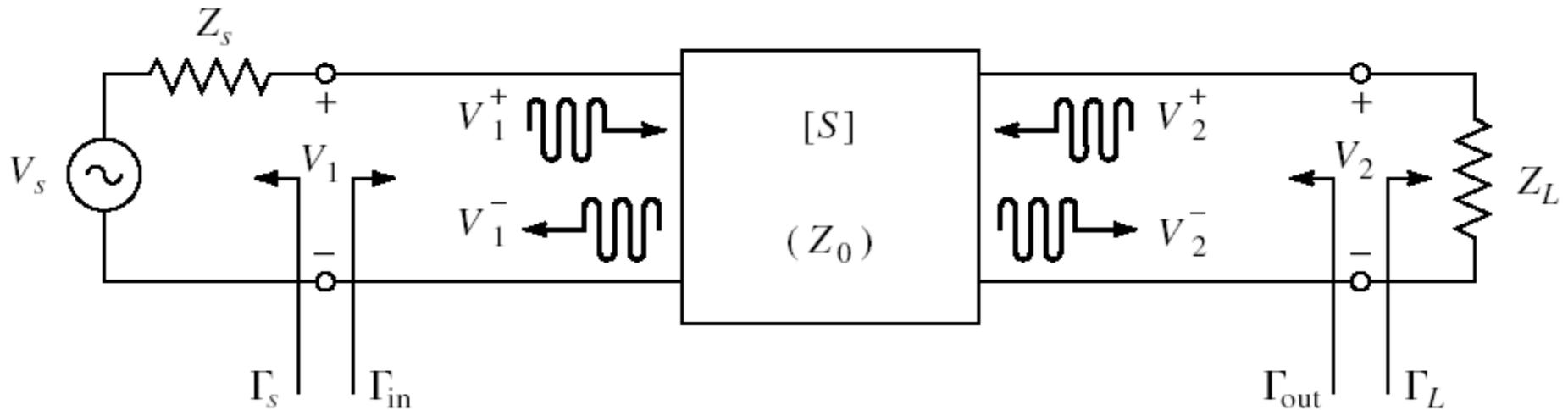
- Caracterizare cu parametri S
- Normalizati la Z_0 (implicit 50Ω)
- Cataloage: parametri S pentru anumite polarizari

Puteri / Adaptare

- Doua porturi in care adaptarea influenteaza transferul de putere



Diport amplificator



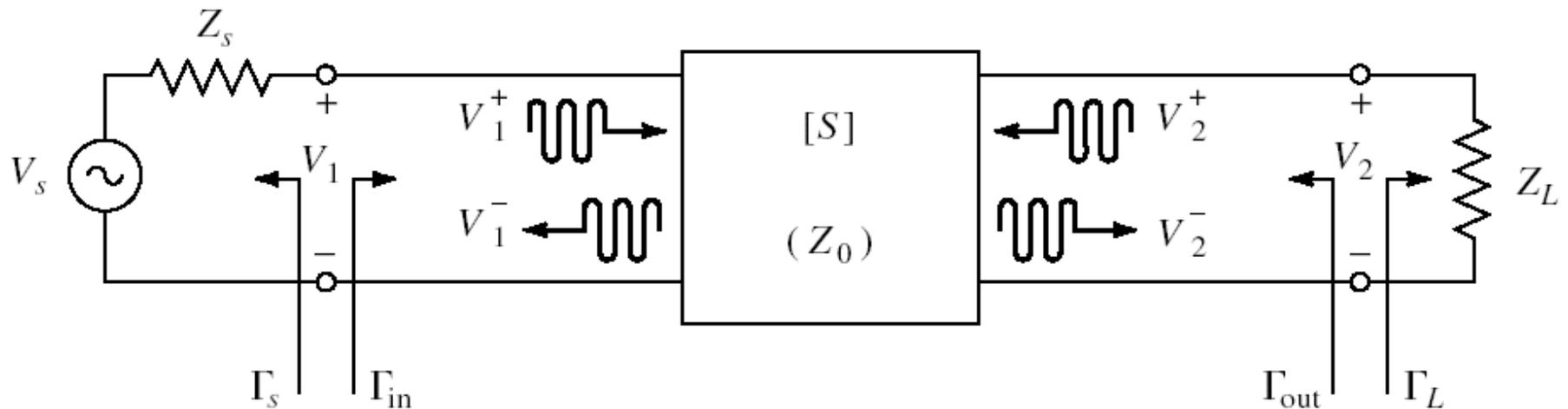
$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

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

Stabilitate

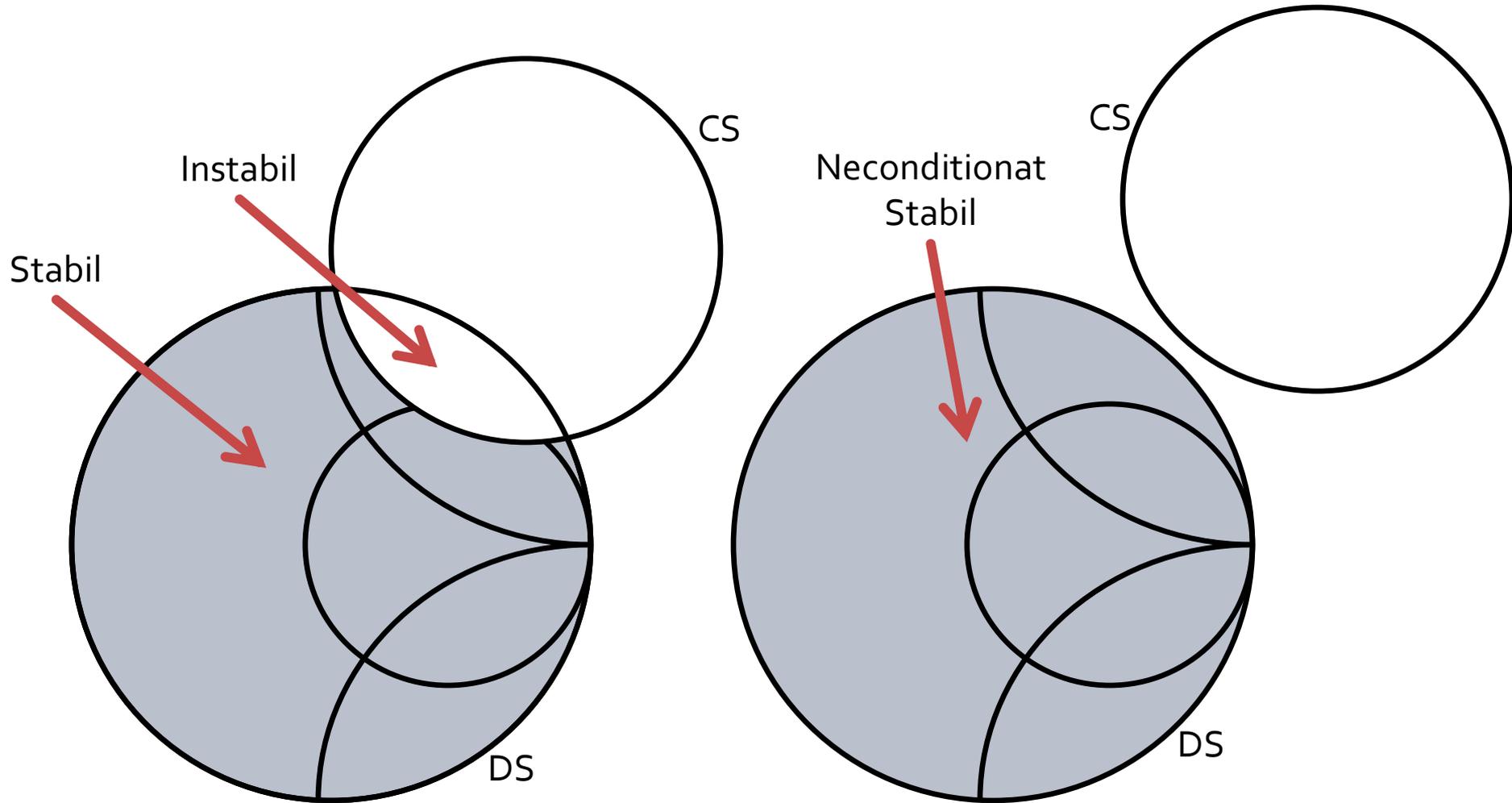
Amplificatoare de microunde

Cuadripol Amplificator



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

Mai multe pozitionari posibile



Conditia Rollet

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

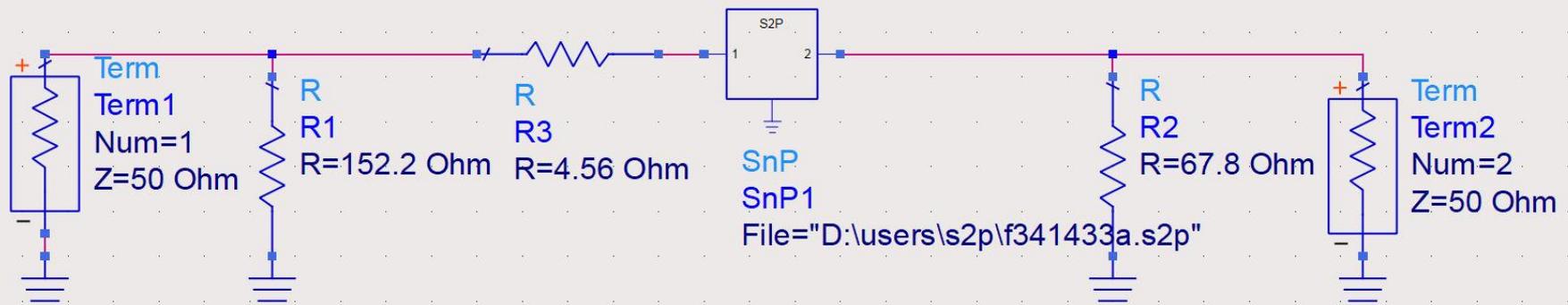
$$\Delta = S_{11} \cdot S_{22} - S_{12} \cdot S_{21}$$

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

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

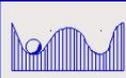
$$|\Delta| = |S_{11} \cdot S_{22} - S_{12} \cdot S_{21}| < 1$$

Stabilizarea unui diport



 **S-PARAMETERS**

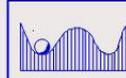
S_Param
SP1
Start=0.5 GHz
Stop=10.0 GHz
Step=0.1 GHz

 **StabFact**

StabFact
K
K=stab_fact(S)

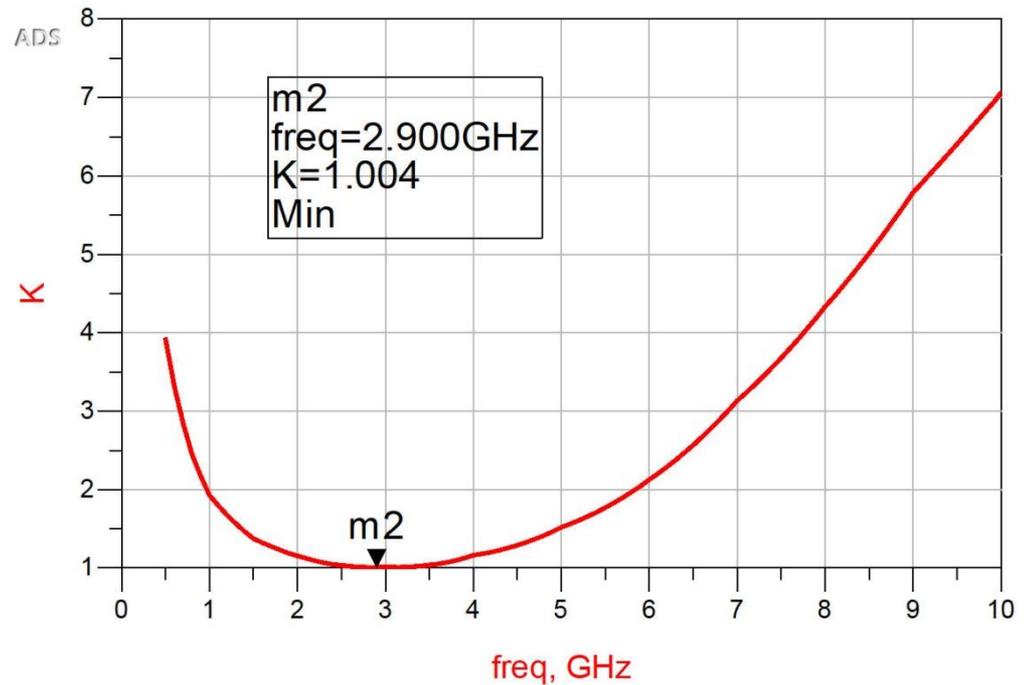
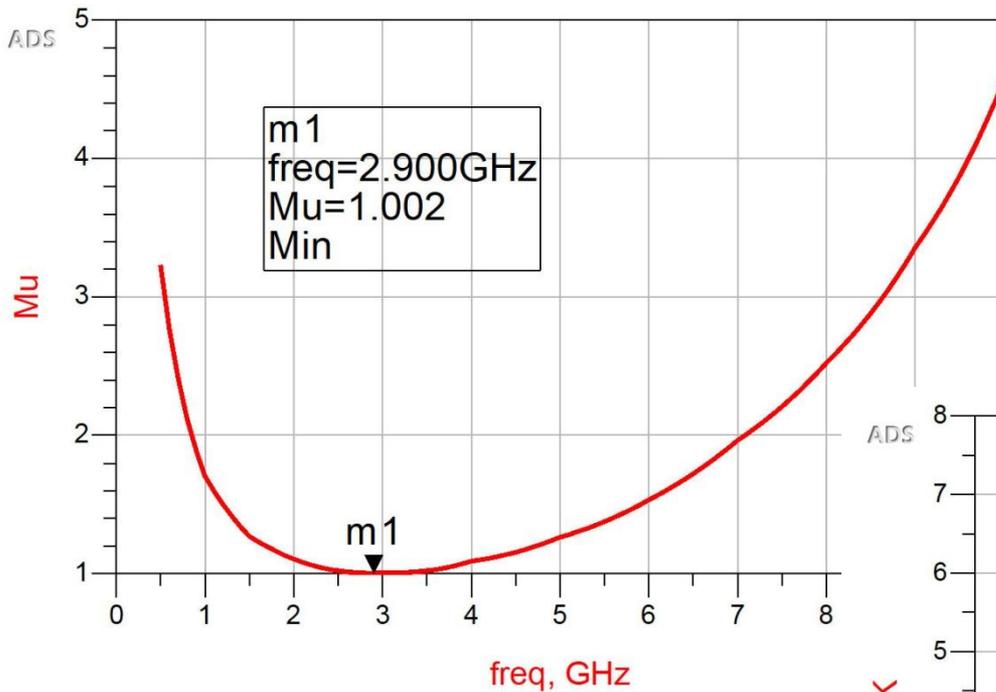
 **MaxGain**

MaxGain
MAG
MAG=max_gain(S)

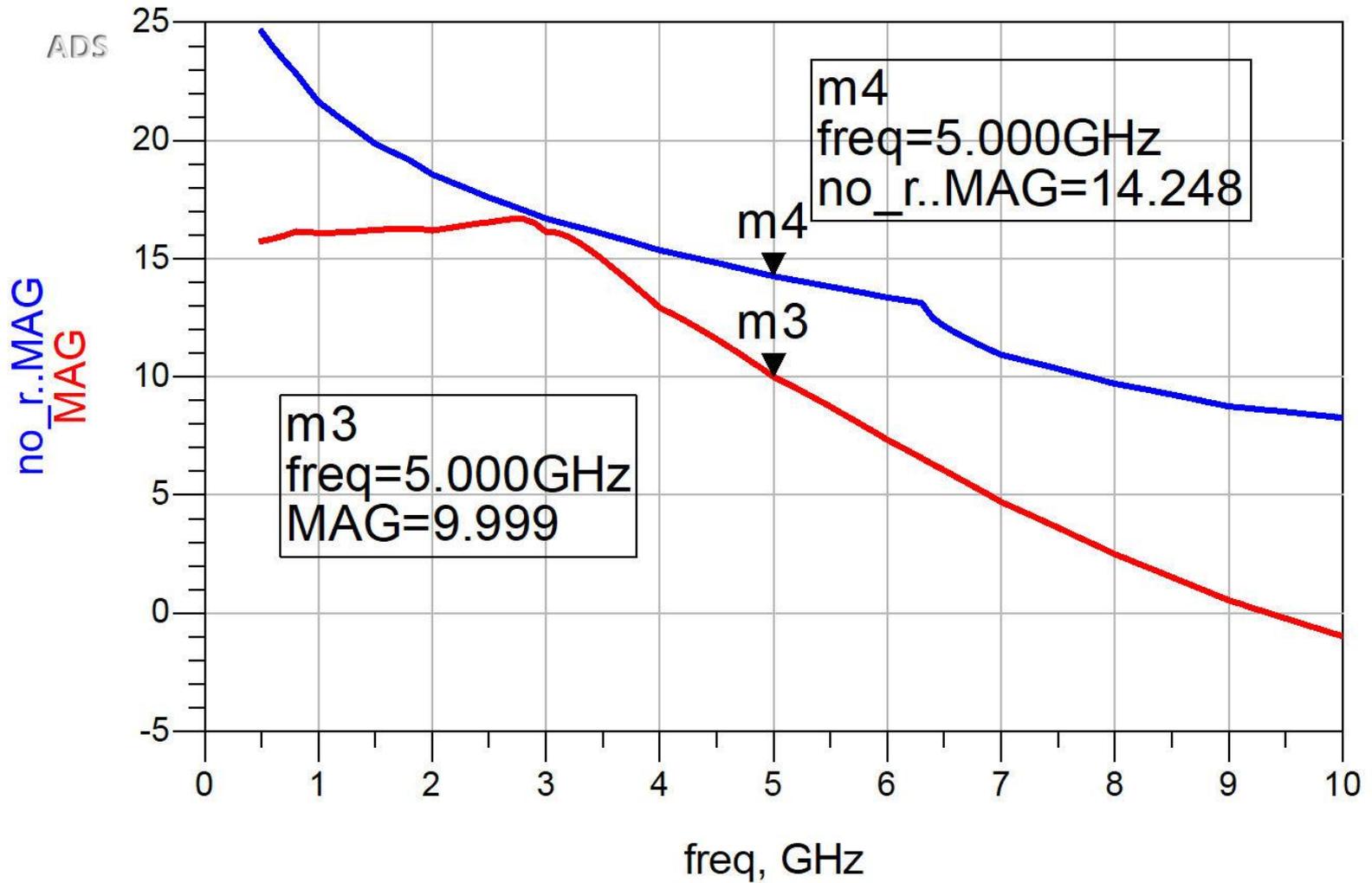
 **Mu**

Mu
Mu1
Mu=mu(S)

Stabilizarea unui diport



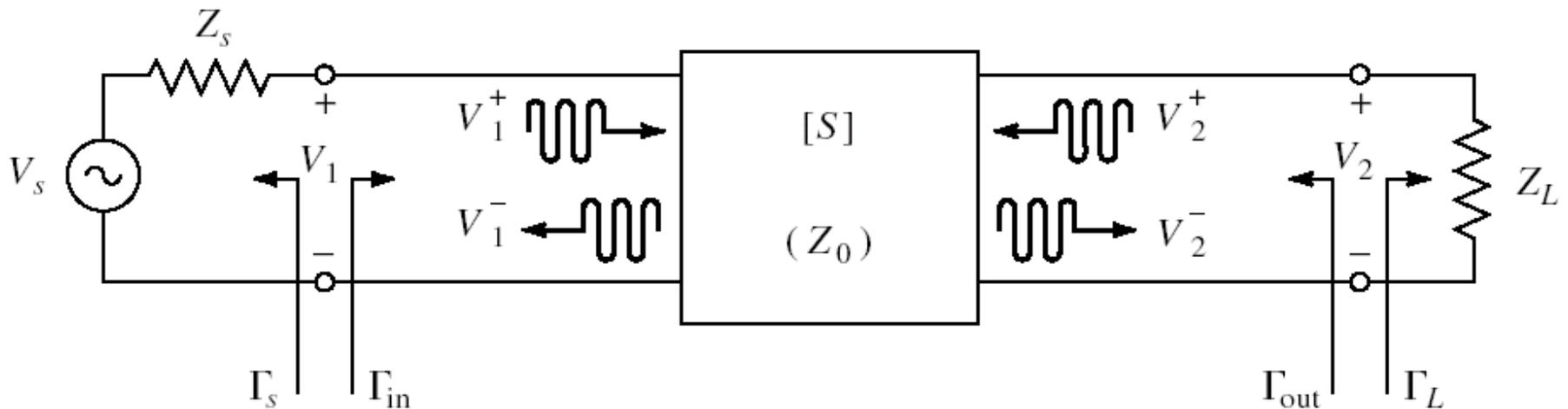
Stabilizarea unui diport



Castigul amplificatoarelor de microunde

Amplificatoare de microunde

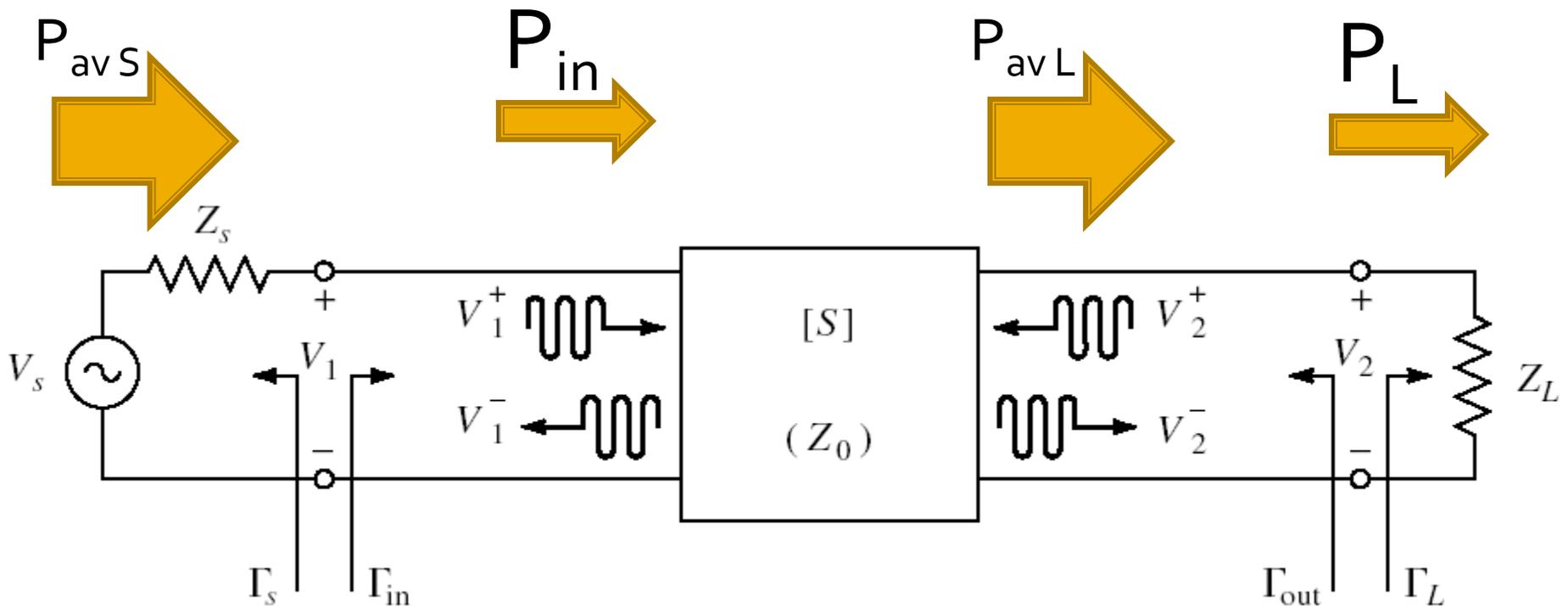
Cuadripol Amplificator



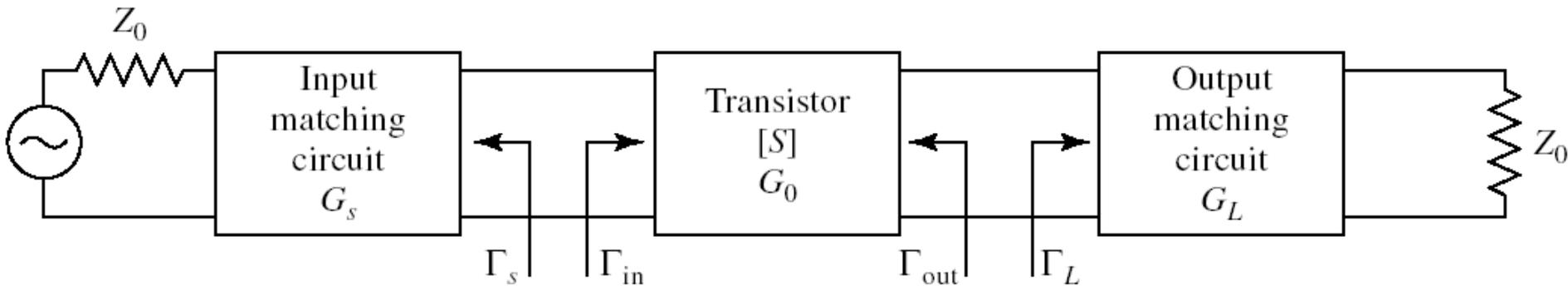
- marimi care intereseaza:
 - stabilitate
 - **castig de putere**
 - zgomot (uneori – semnal mic)
 - liniaritate (uneori – semnal mare)

Puteri / Adaptare

- Doua porturi in care adaptarea influenteaza transferul de putere



Proiectare pentru castig maxim



- Castig maxim de putere se obtine cand

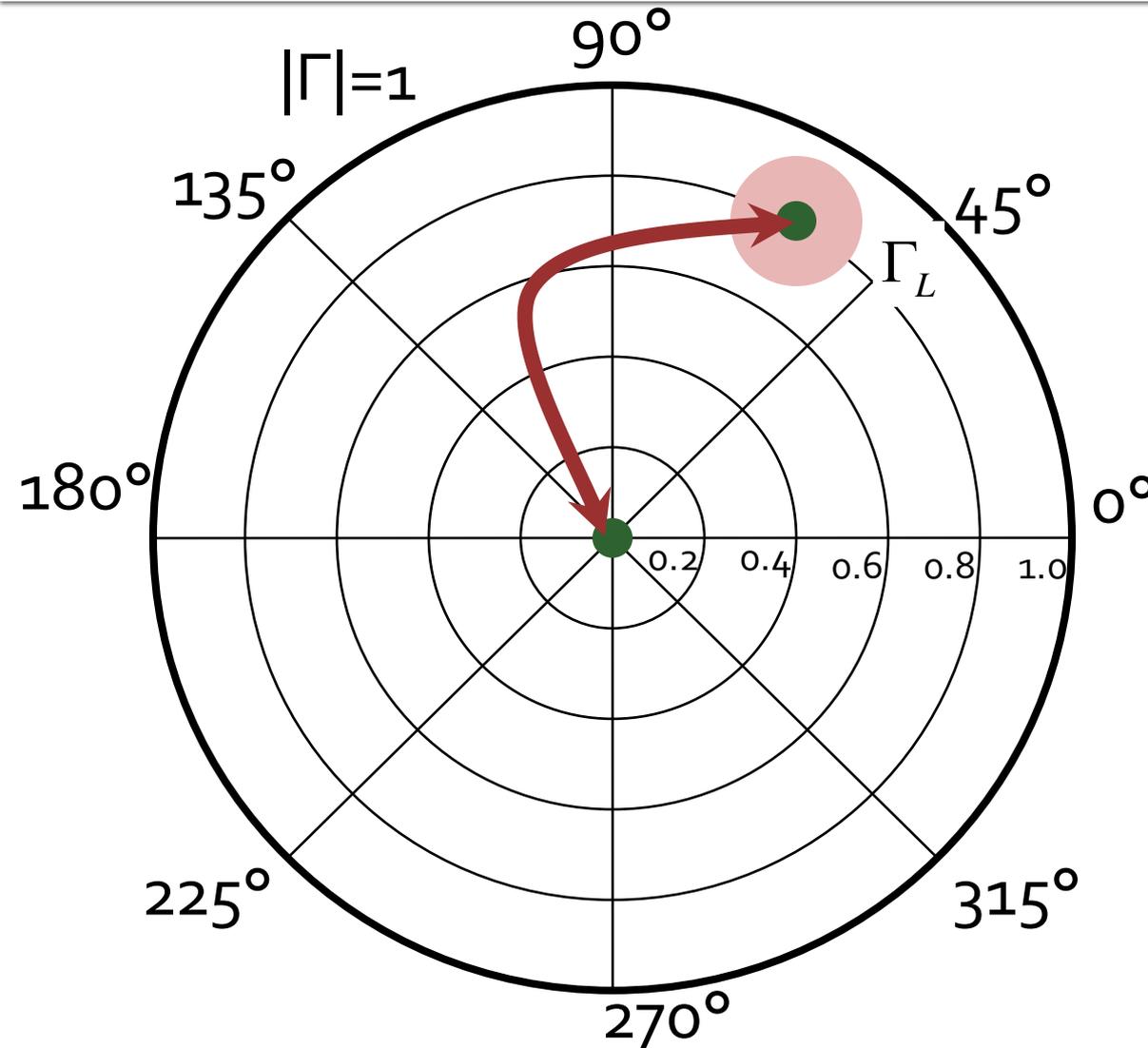
$$\Gamma_{in} = \Gamma_S^* \quad \Gamma_{out} = \Gamma_L^*$$

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

Diagrama Smith, adaptare, $Z_L = Z_o$



- Circuitele de adaptare care muta
 - Γ_L in Γ_o
 - Γ_o in Γ_L
- sunt **identice** ca realizare. Diferă doar prin **ordinea** în care se introduc elementele în circuitul de adaptare
- Ca urmare se pot folosi în proiectarea circuitelor de adaptare aceleași:
 - **metode**
 - **relatii**

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

- In conditiile adaptarii simultane se obtine castigul de transfer maxim pentru tranzistorul bilateral

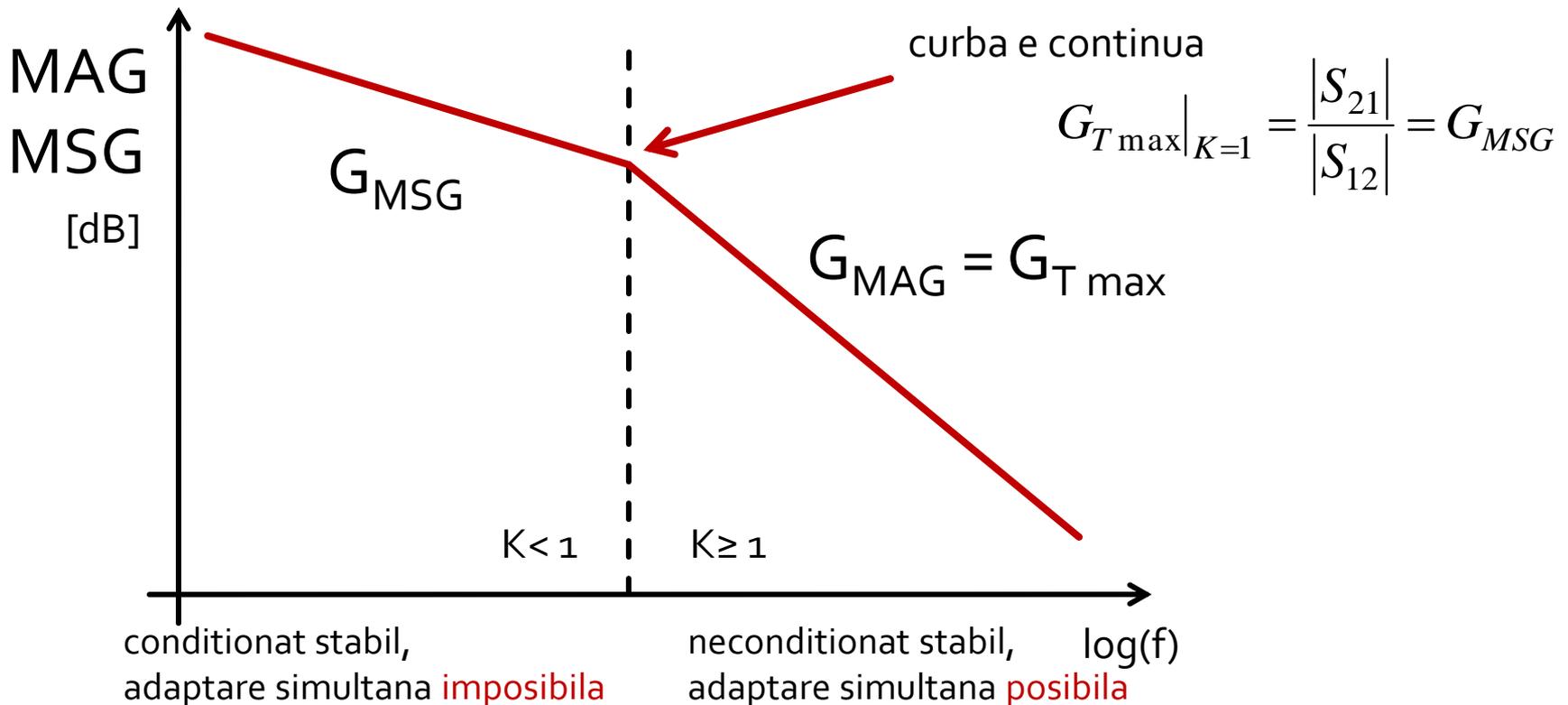
$$G_{T \max} = \frac{|S_{21}|}{|S_{12}|} \cdot (K - \sqrt{K^2 - 1})$$

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

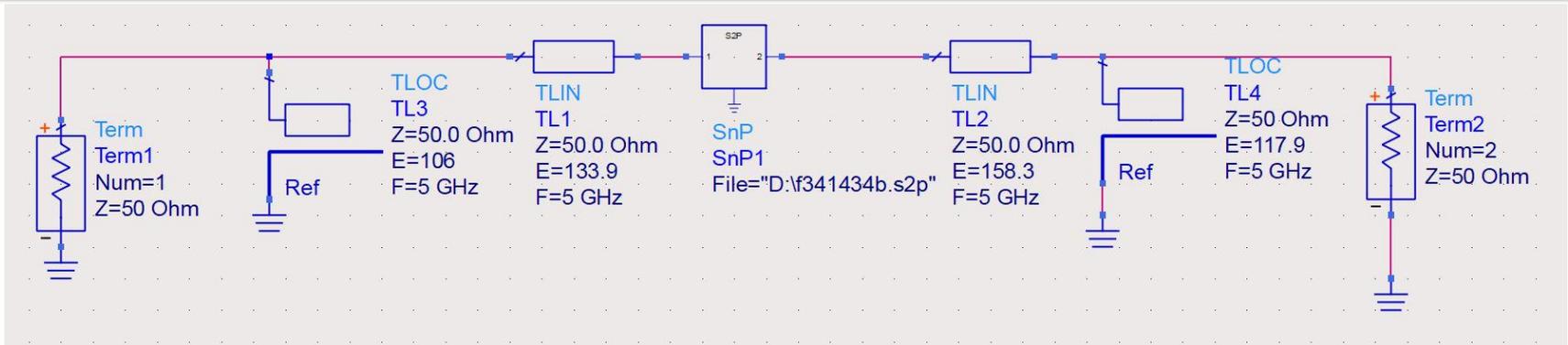
$$G_{MSG} = \frac{|S_{21}|}{|S_{12}|}$$

Maximum Available Gain

- Indicator in the entire frequency range of the ability to obtain gain

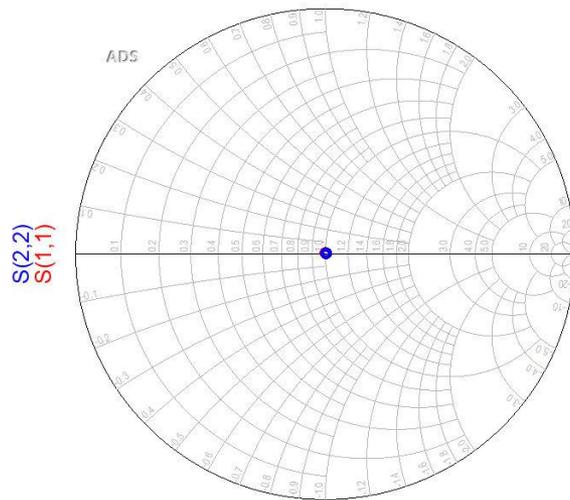


ADS



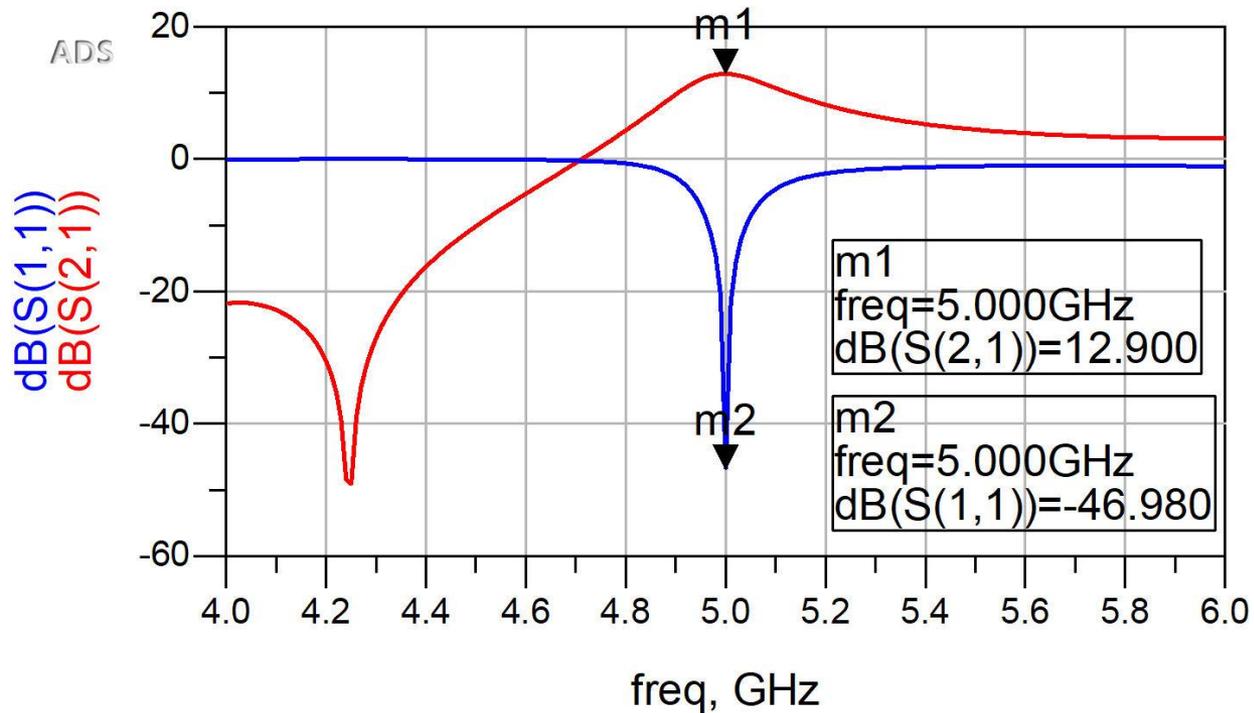
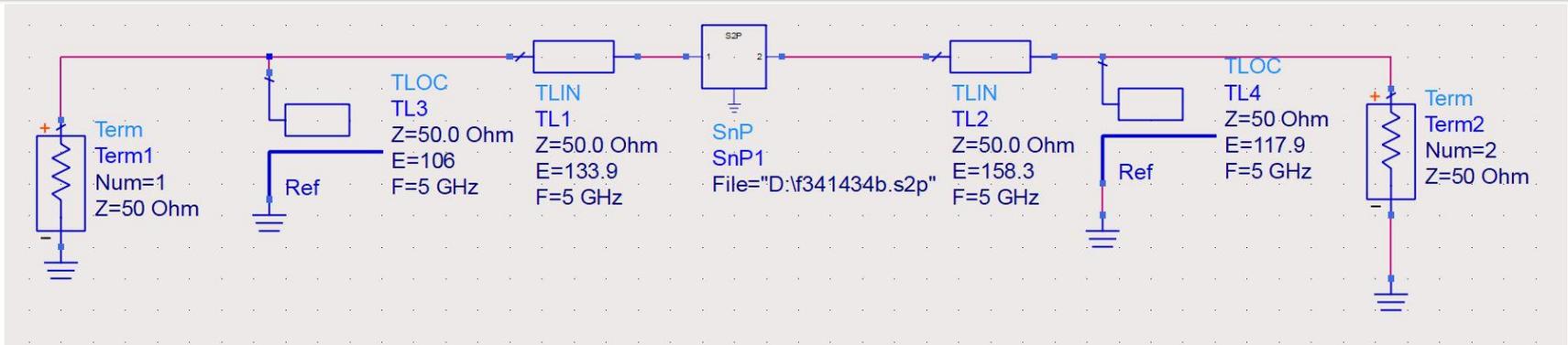
$$Eqn\ GT=10*\log(\text{mag}(S(2,1))^*2)$$

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



freq (5.000GHz to 5.000GHz)

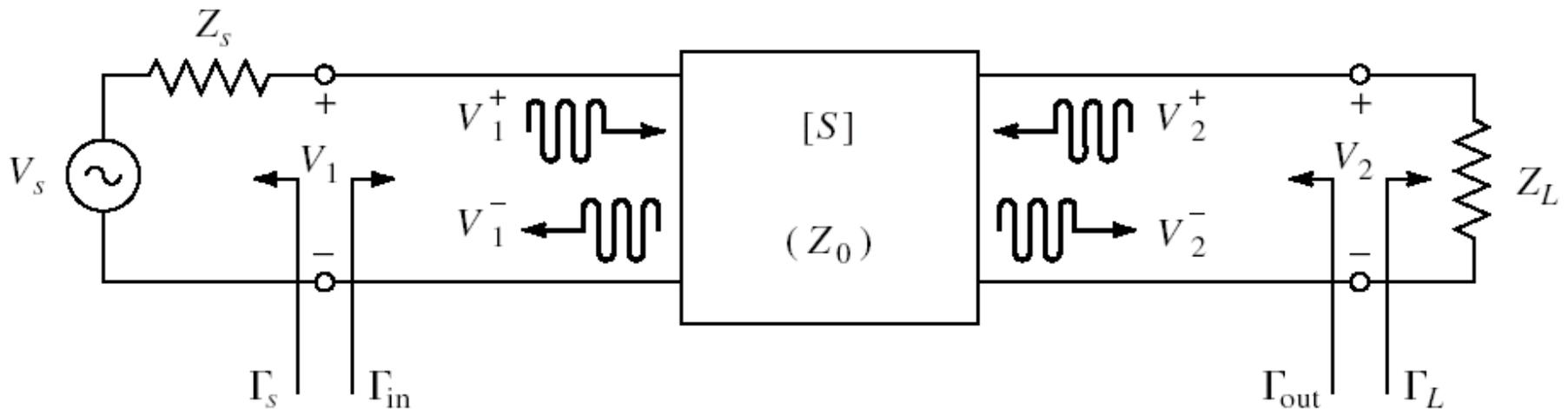
ADS



Proiectare pentru castig impus

Amplificatoare de microunde

Cuadripol Amplificator



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

Proiectare pentru castig impus

- Se realizeaza cu asumarea unilaterala a amplificatorului

Permite tratarea separata a intrarii si iesirii

$$G_{TU} = |S_{21}|^2 \cdot \frac{1 - |\Gamma_S|^2}{|1 - S_{11} \cdot \Gamma_S|^2} \cdot \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2} \quad S_{12} \cong 0 \quad \Gamma_{in} = S_{11}$$

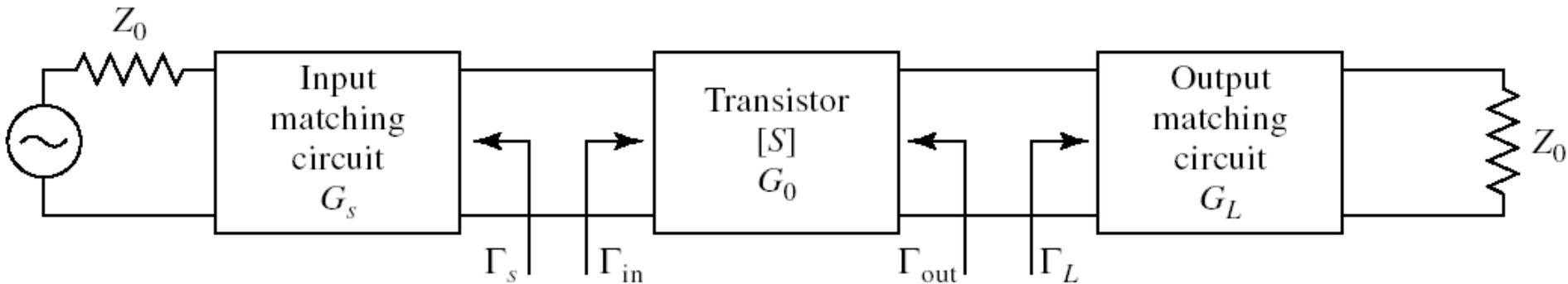
- Castig maxim

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

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

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

Proiectare pentru castig impus



- Daca ipoteza tranzistorului unilateral este justificata:

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

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

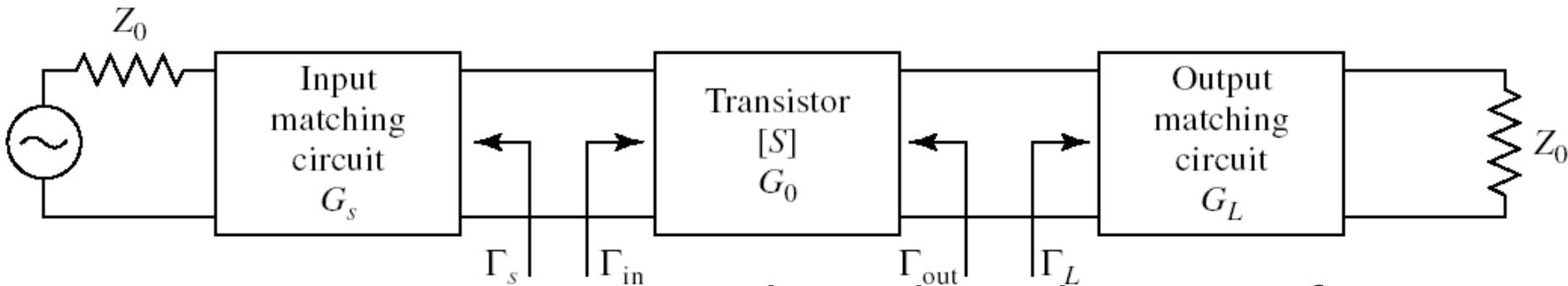
$$G_S = G_S(\Gamma_S)$$

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

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

$$G_L = G_L(\Gamma_L)$$

Proiectare pentru castig impus

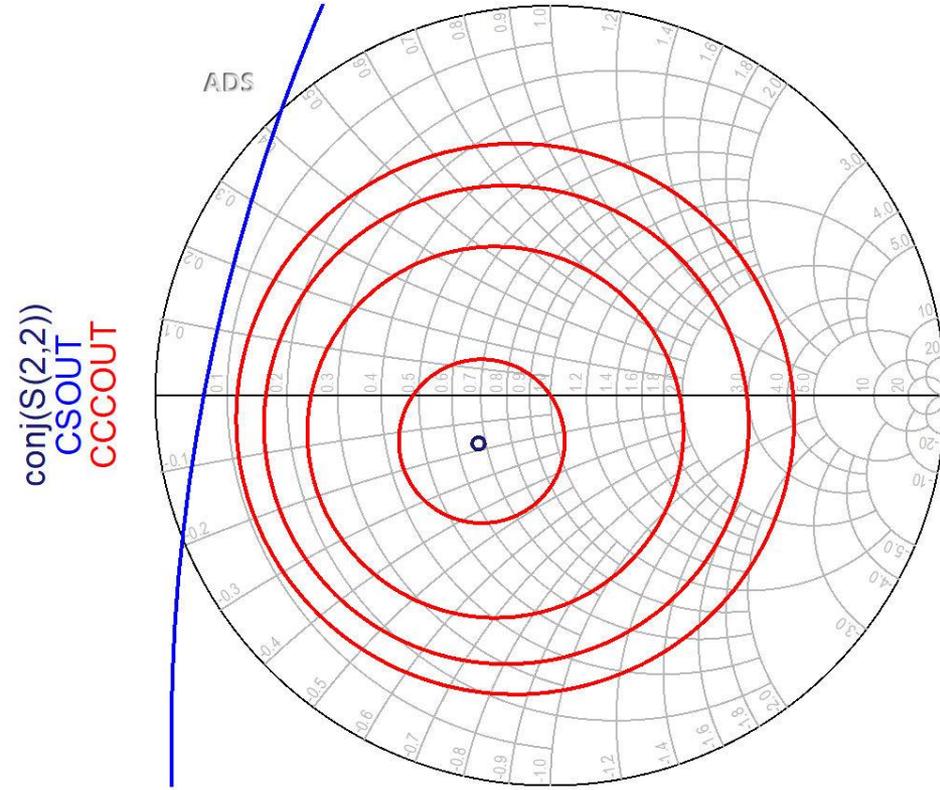
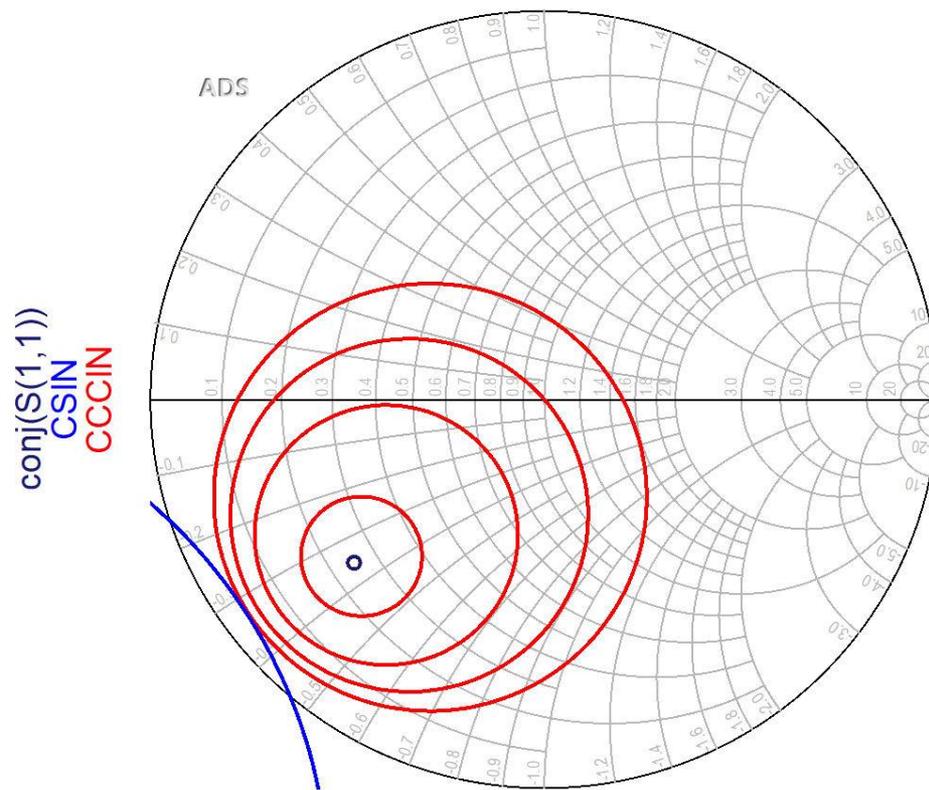


- **Daca** ipoteza tranzistorului unilateral este justificata:
 - castigul adaugat prin adaptare mai buna la intrare **nu** depinde de adaptarea la iesire $G_S = G_S(\Gamma_S)$
 - castigul adaugat prin adaptare mai buna la iesire **nu** depinde de adaptarea la intrare $G_L = G_L(\Gamma_L)$
- Adaptarile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

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

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

ADS



- Cercurile 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

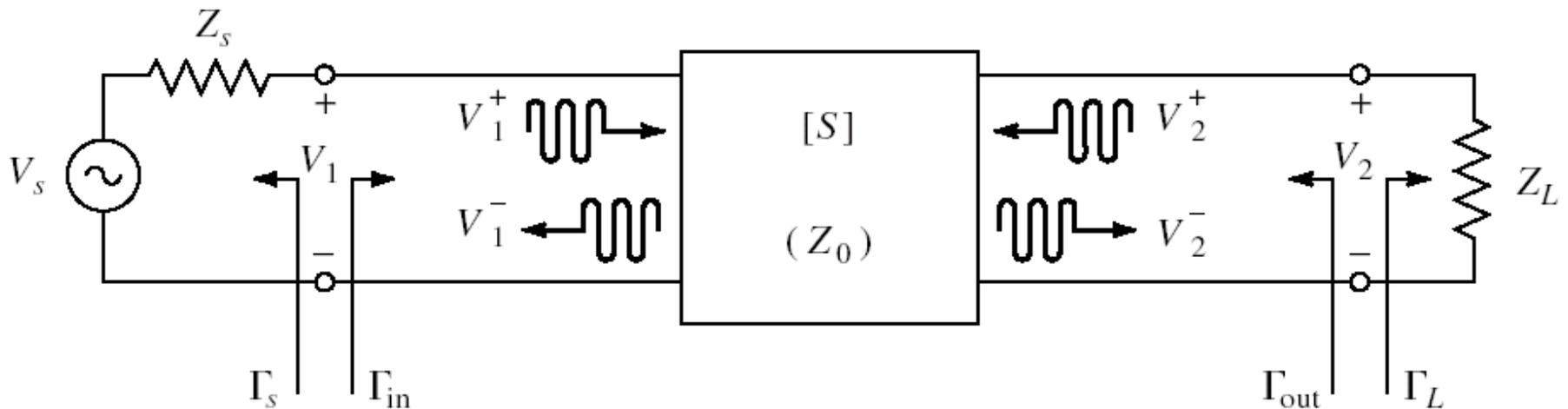
$$G_{dorit} [dB] = G_{S_dorit} [dB] + G_o [dB] + G_{L_dorit} [dB]$$

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

Proiectare pentru zgomot redus

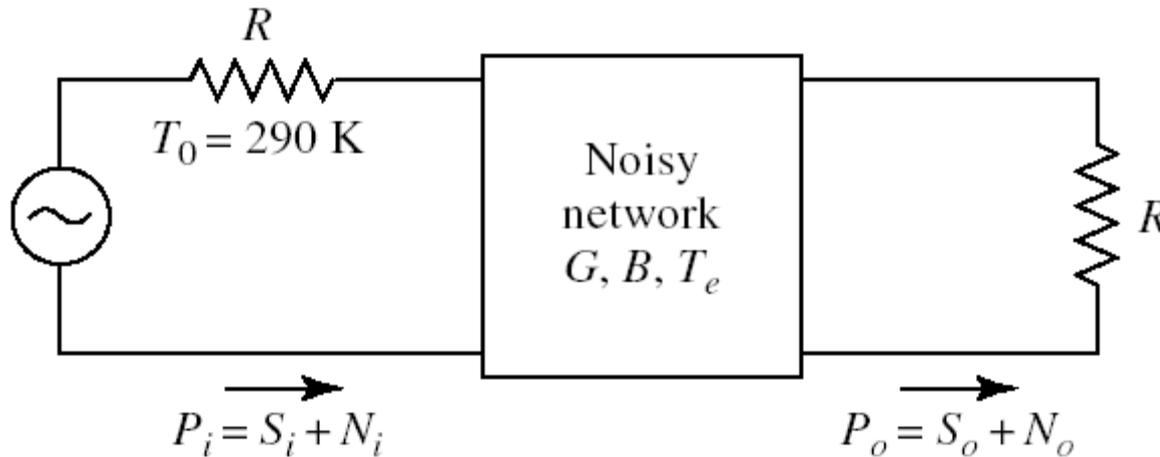
Amplificatoare de microunde

Cuadripol Amplificator



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

Factor de zgomot



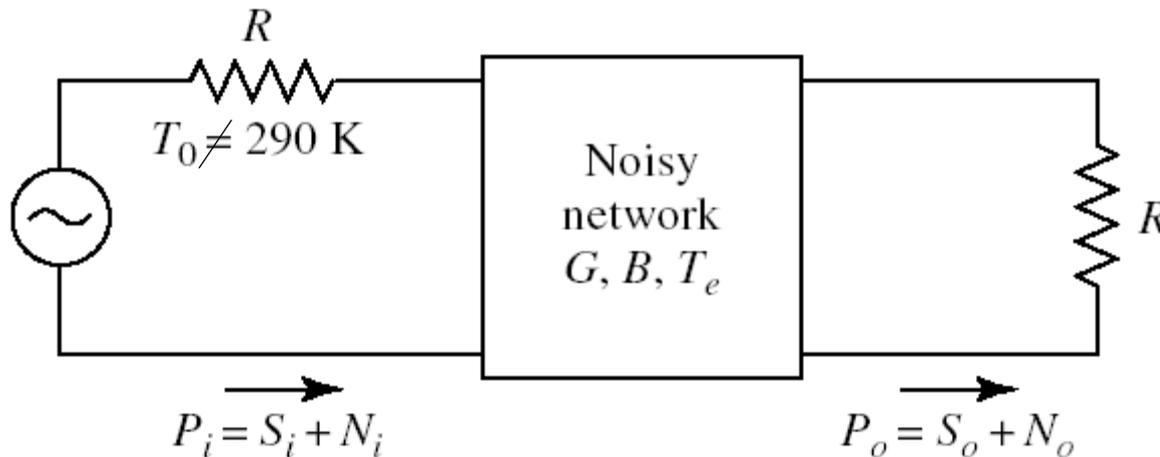
- Factorul de zgomot F caracterizeaza degradarea raportului semnal/zgomot intre intrarea si iesirea unei componente, cand la intrare se aplica o putere de zgomot de referinta ($T_0 = 290\text{K}$)

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

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

$$P_n = kTB$$

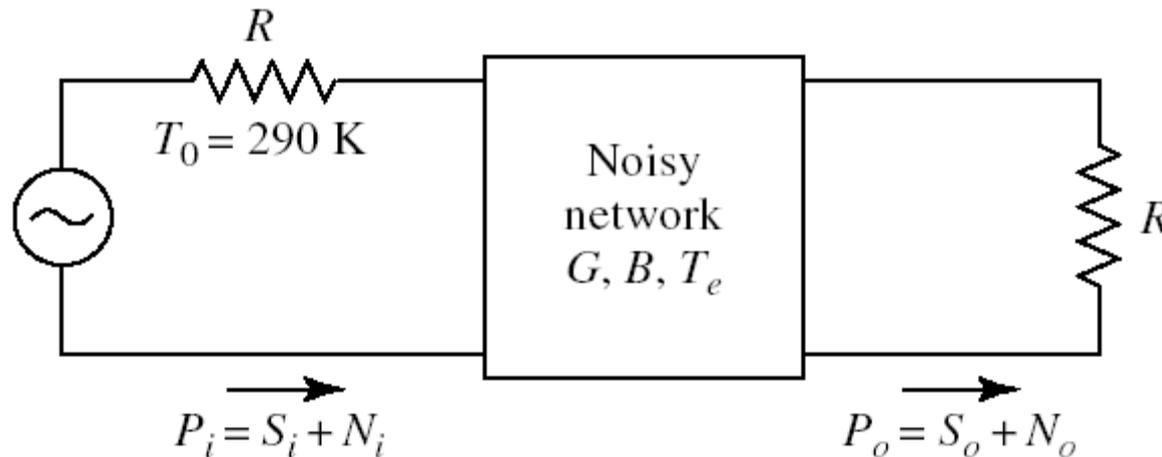
Factor de zgomot



- 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

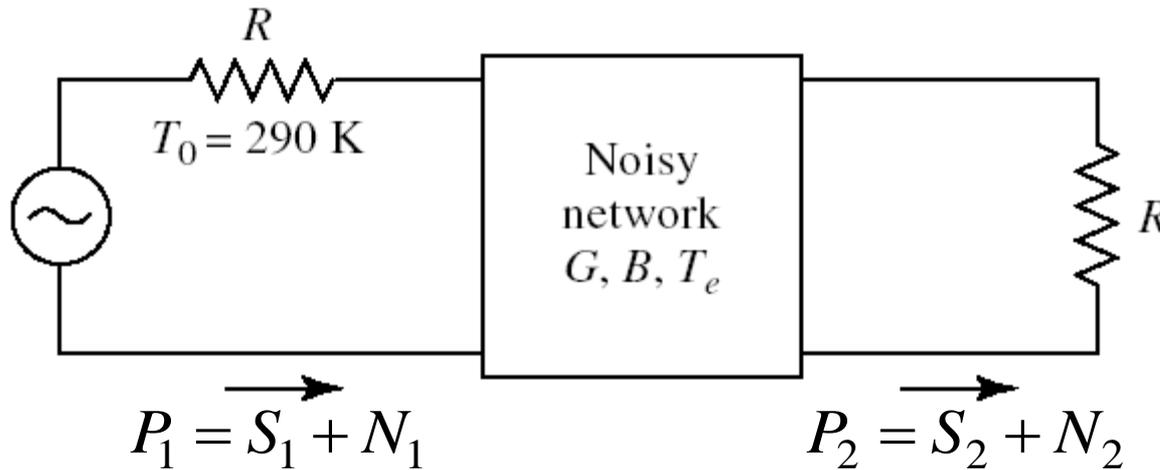
$$F \neq \left. \frac{S_i/N_i}{S_o/N_o} \right|_{T_0 \neq 290K}$$

Factor de zgomot



- In general, puterea de zgomot la iesire se obtine cu doua componente:
 - o putere datorata zgomotului de intrare amplificat cu castigul G (depinde de puterea de zgomot de la intrare)
 - o putere de zgomot generata intern de dispozitiv (care **nu** depinde de puterea de zgomot de la intrare)

Factor de zgomot



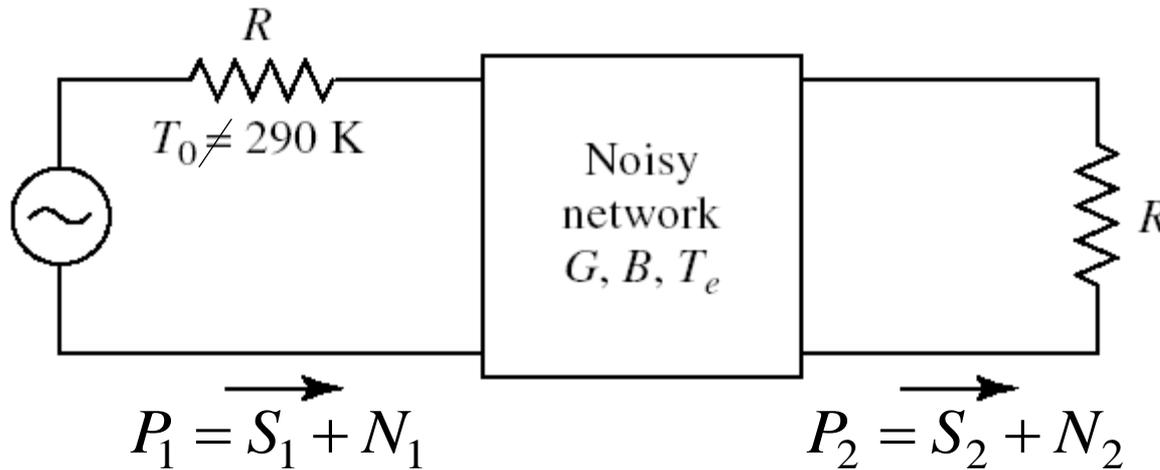
- Estimarea puterii de zgomot adaugate se poate face plecand de la definitia factorului de zgomot:

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

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

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

Factor de zgomot



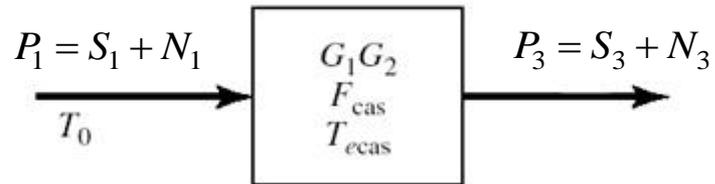
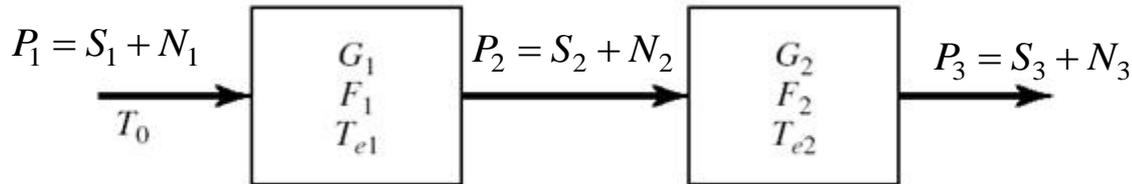
- Se identifica cei doi termeni:
 - zgomotul de intrare amplificat
 - zgomotul adaugat intern
- Pentru o situatie in care la intrare nu am zgomotul de referinta ($N_1 \neq N_0$)

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

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



Factor de zgomot al circuitelor cascade



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

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

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

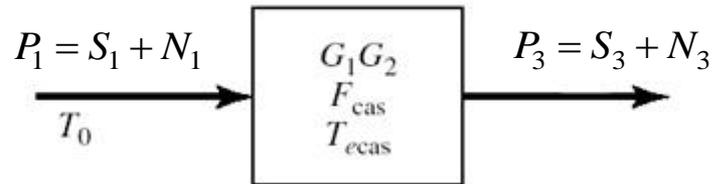
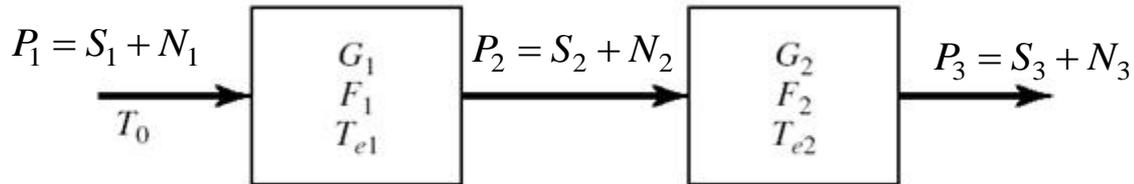
$$N_3 = N_1 \cdot G_{cas} + (F_{cas} - 1) \cdot N_0 \cdot G_{cas}$$



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

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

Factor de zgomot al circuitelor cascade



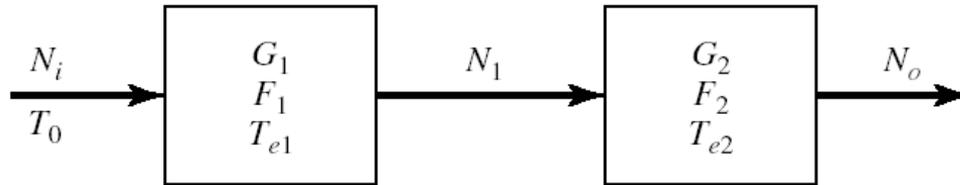
$$N_3 = N_1 \cdot G_1 \cdot G_2 + (F_1 - 1) \cdot N_0 \cdot G_1 \cdot G_2 + (F_2 - 1) \cdot N_0 \cdot G_2$$

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

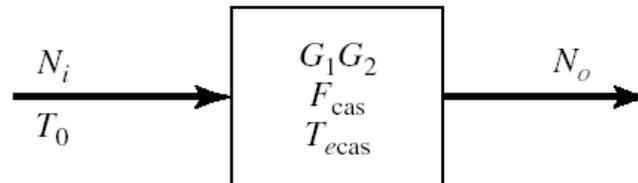
$$(F_1 - 1) \cdot N_0 \cdot G_1 \cdot G_2 + (F_2 - 1) \cdot N_0 \cdot G_2 = (F_{cas} - 1) \cdot N_0 \cdot G_1 \cdot G_2$$

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

Factor de zgomot al circuitelor cascade



(a)



(b)

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

- Ecuația 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)

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

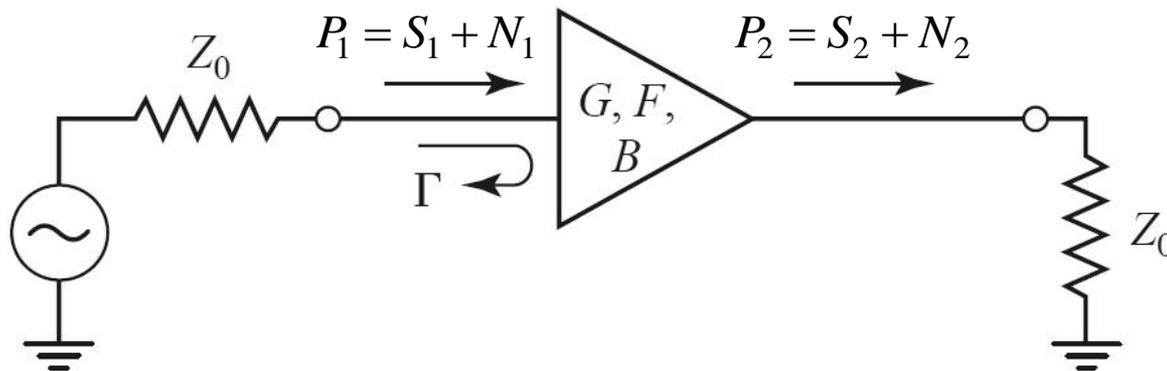
- Formula lui Friis, efecte:
- in amplificatoare multietaj:
 - e esential ca primul etaj de amplificare sa fie nezegomotos, chiar cu sacrificarea in parte a castigului
 - urmatoarele etaje pot fi optimizate pentru castig
- pentru un singur amplificator:
 - la intrare e important sa introducem elemente nezegomotoase (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)

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

$$P_n = kTB$$

Zgomotul amplificatoarelor dezadaptate

- Un amplificator dezadaptat la intrare ($\Gamma \neq 0$)



$$G_{ech} = G \cdot (1 - |\Gamma|^2)$$

$$N_2 = N_1 \cdot G \cdot (1 - |\Gamma|^2) + (F - 1) \cdot N_0 \cdot G = N_1 \cdot G \cdot (1 - |\Gamma|^2) + \frac{F - 1}{1 - |\Gamma|^2} \cdot N_0 \cdot G \cdot (1 - |\Gamma|^2)$$

$$N_2 = N_1 \cdot G_{ech} + (F_{ech} - 1) \cdot N_0 \cdot G_{ech} \quad F_{ech} = 1 + \frac{F - 1}{1 - |\Gamma|^2} \geq F$$

- Obținerea unui zgomot redus **necesita** o buna adaptare de impedanta

Exemplu

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

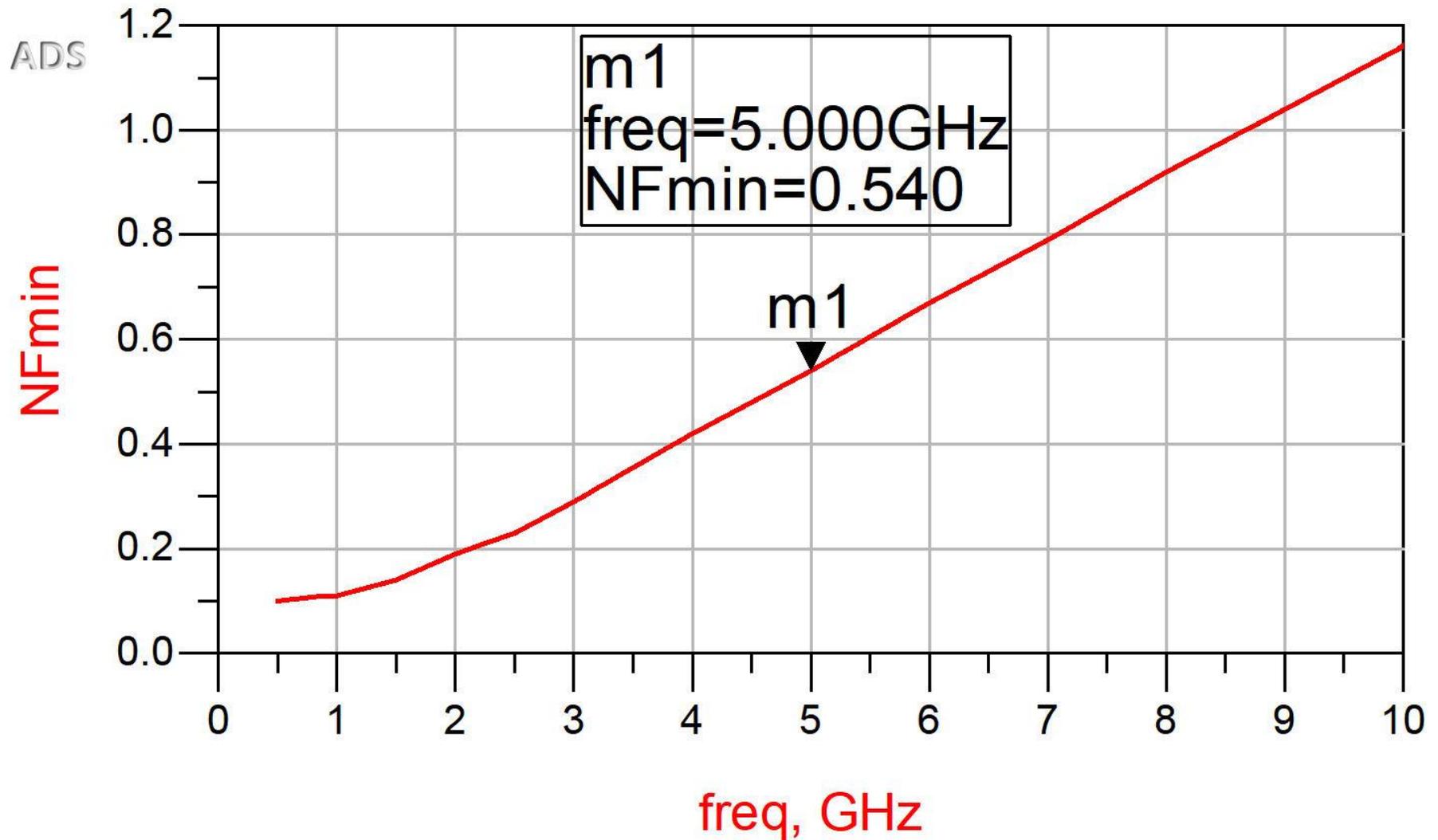
```
IATF-34143
IS-PARAMETERS at Vds=3V Id=20mA. LAST UPDATED 01-29-99

# ghz s ma r 50

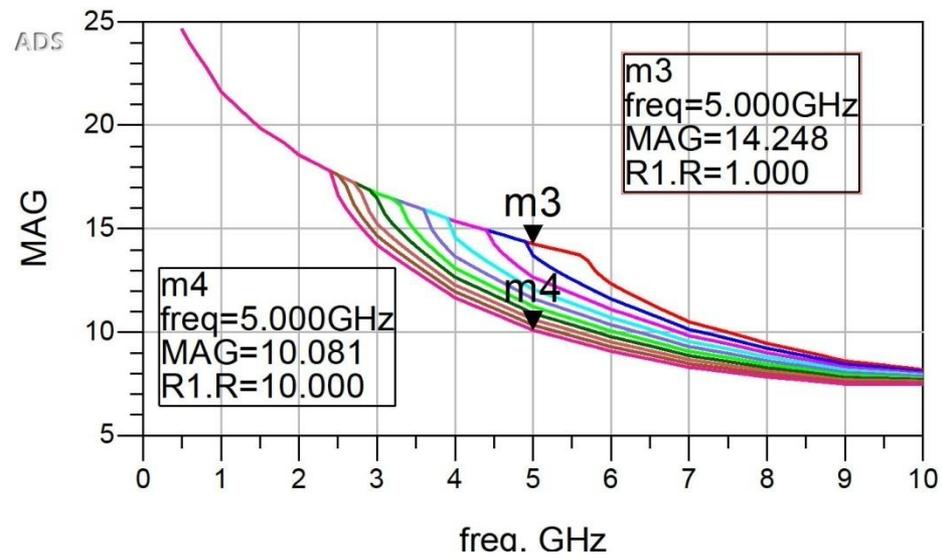
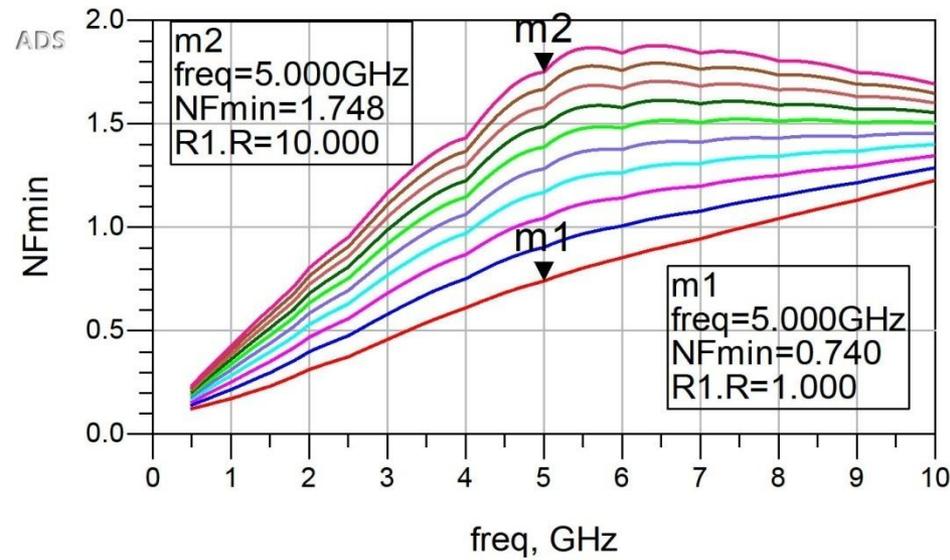
2.0 0.75 -126 6.306 90 0.088 23 0.26 -120
2.5 0.72 -145 5.438 75 0.095 15 0.25 -140
3.0 0.69 -162 4.762 62 0.102 7 0.23 -156
4.0 0.65 166 3.806 38 0.111 -8 0.22 174
5.0 0.64 139 3.165 16 0.119 -21 0.22 146
6.0 0.65 114 2.706 -5 0.125 -35 0.23 118
7.0 0.66 89 2.326 -27 0.129 -49 0.25 91
8.0 0.69 67 2.017 -47 0.133 -62 0.29 67
9.0 0.72 48 1.758 -66 0.135 -75 0.34 46

!FREQ Fopt GAMMA OPT RN/Zo
!GHZ dB MAG ANG -
2.0 0.19 0.71 66 0.09
2.5 0.23 0.65 83 0.07
3.0 0.29 0.59 102 0.06
4.0 0.42 0.51 138 0.03
5.0 0.54 0.45 174 0.03
6.0 0.67 0.42 -151 0.05
7.0 0.79 0.42 -118 0.10
8.0 0.92 0.45 -88 0.18
9.0 1.04 0.51 -63 0.30
10.0 1.16 0.61 -43 0.46
```

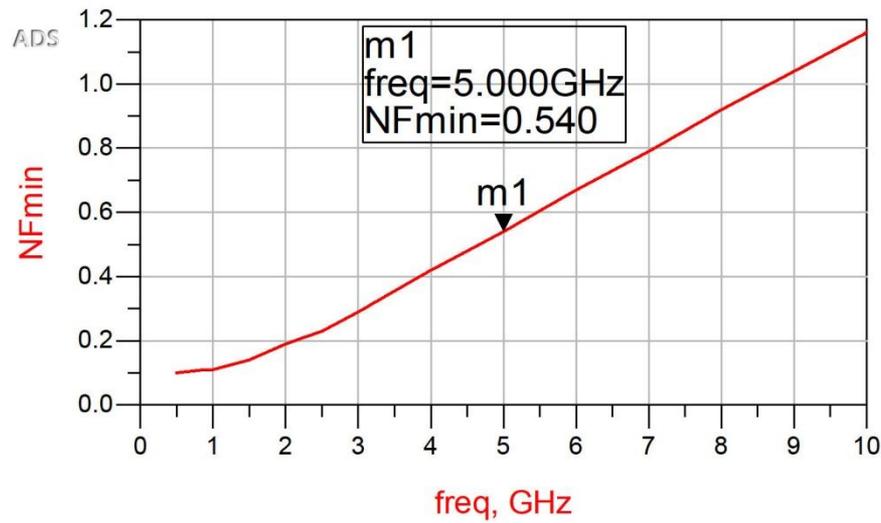
Exemplu



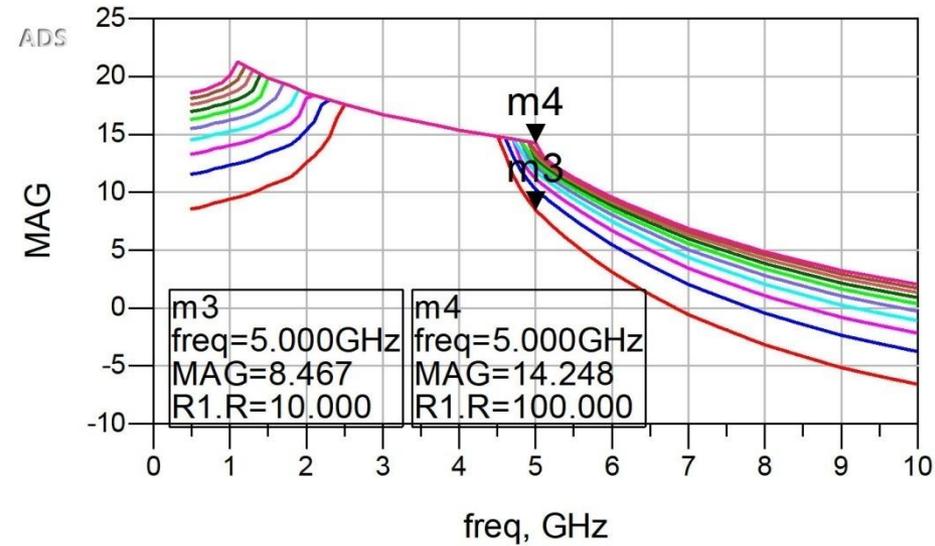
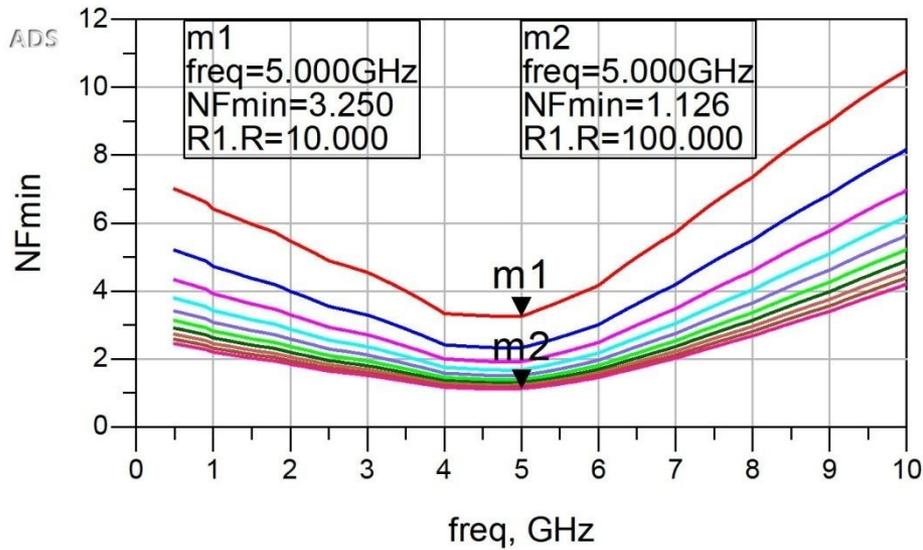
Stabilizare R serie la intrare



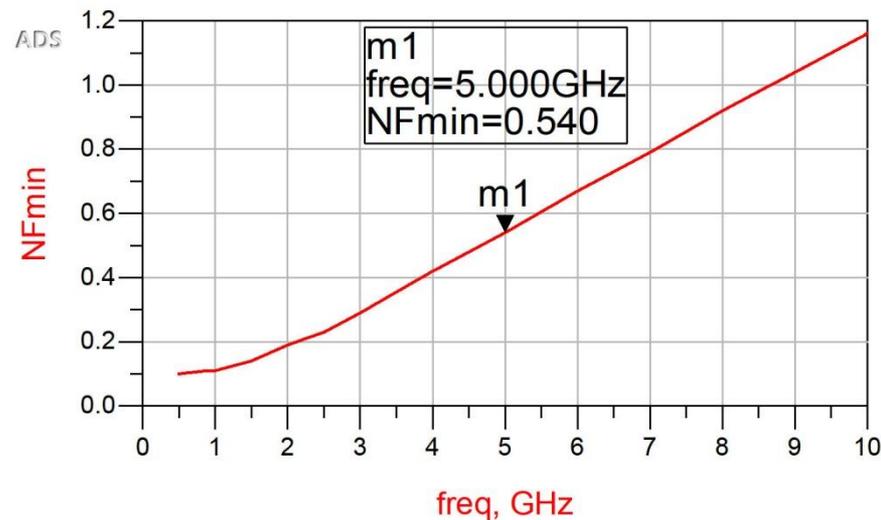
$$R_{SS} = 1 \div 10 \Omega$$



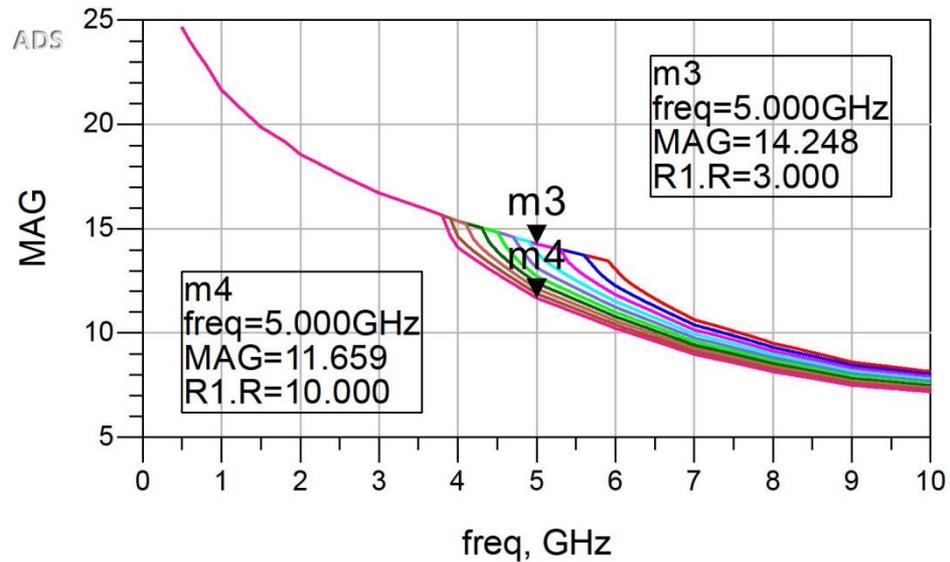
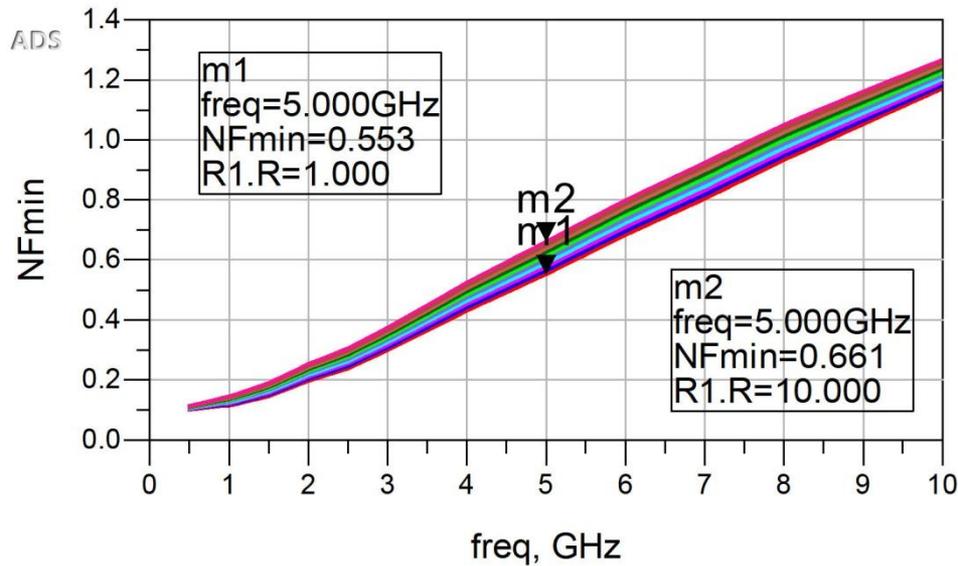
Stabilizare R paralel la intrare



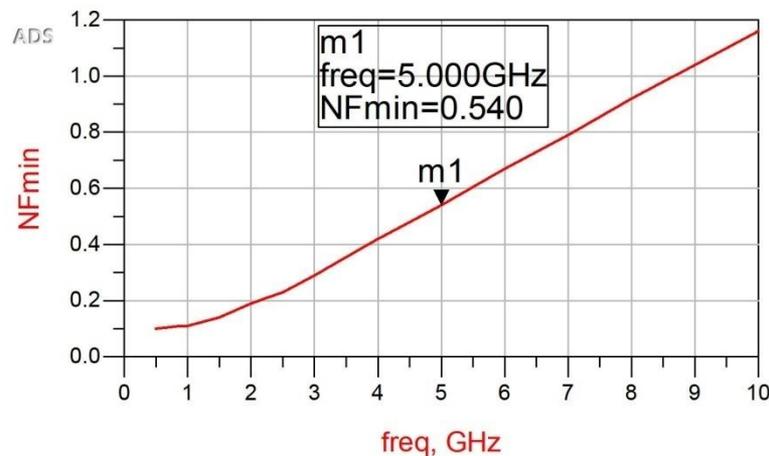
$$R_{PS} = 10 \div 100 \Omega$$



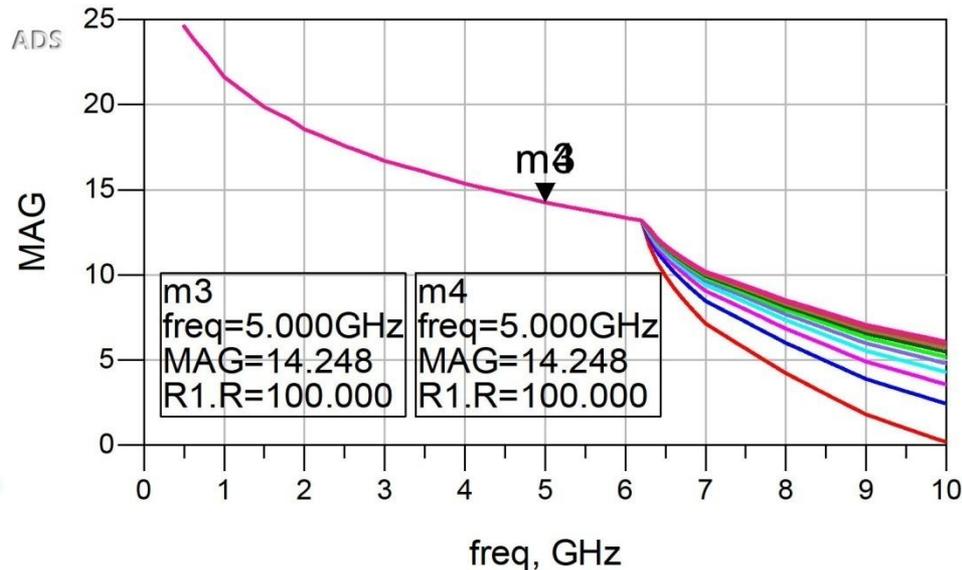
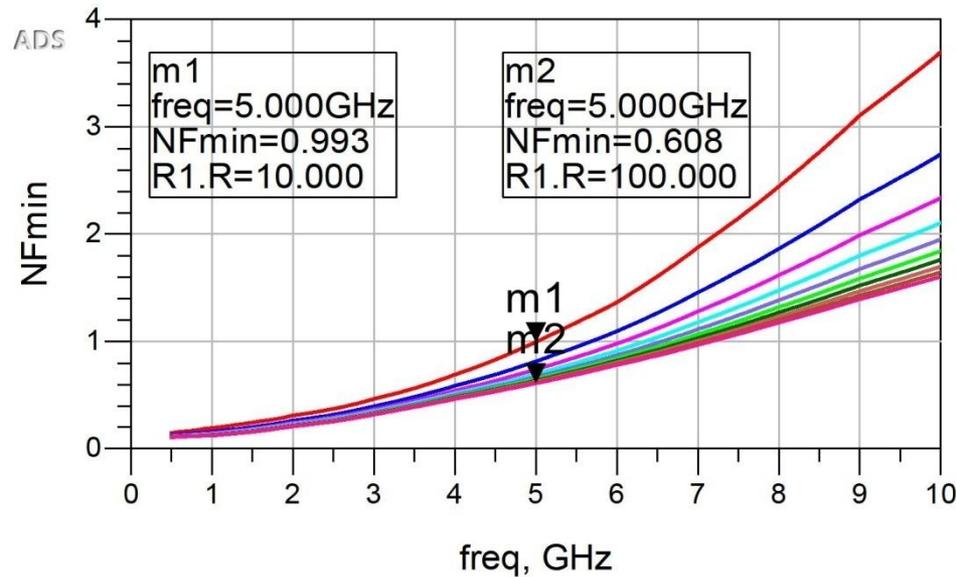
Stabilizare R serie la iesire



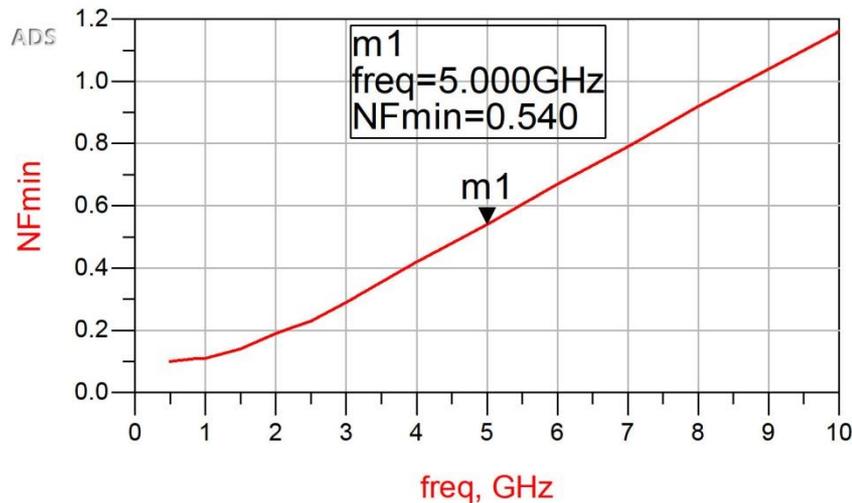
$$R_{SL} = 1 \div 10 \Omega$$



Stabilizare R paralel la iesire



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



Zgomotul unui amplificator

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

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

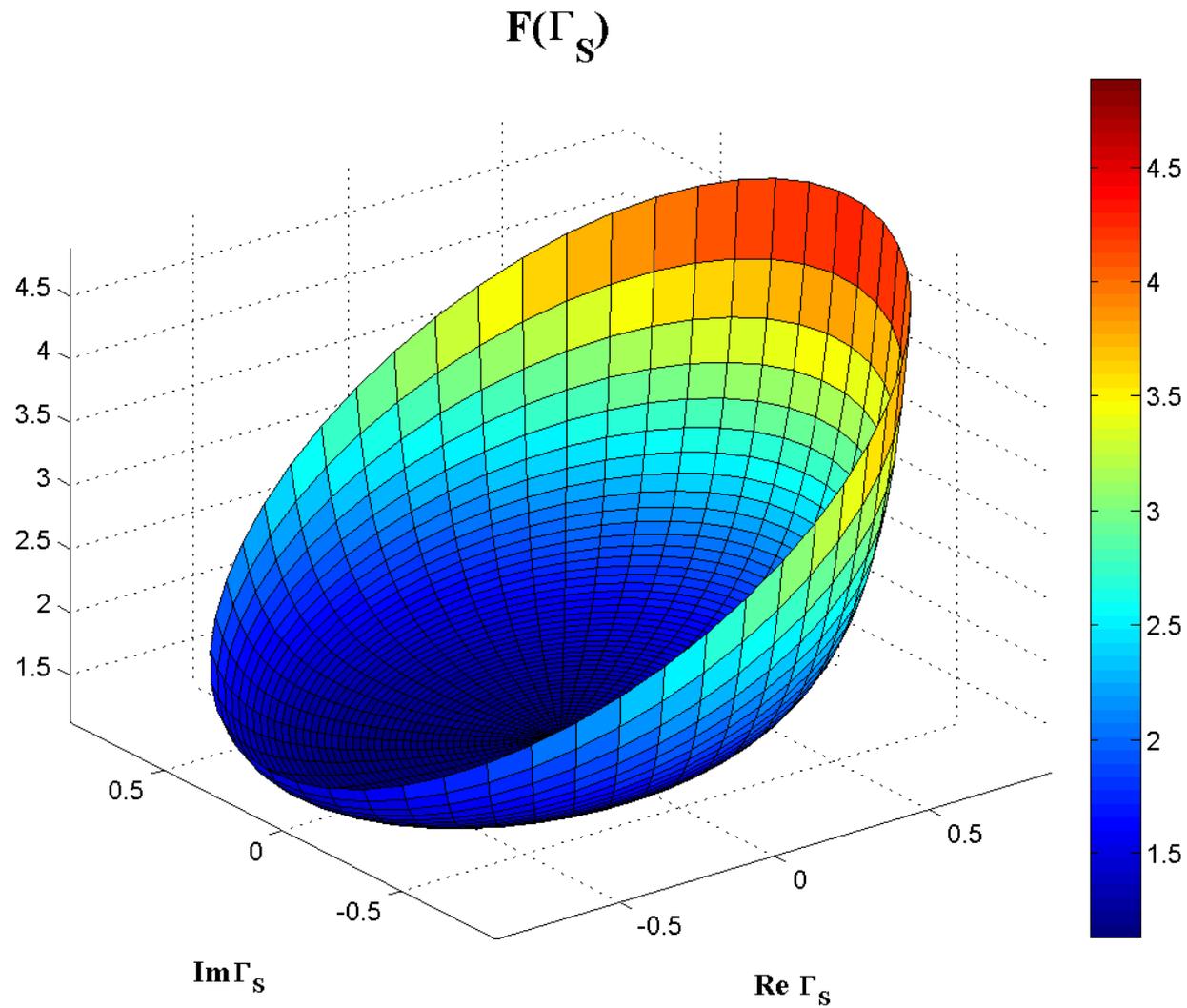
$$F = F_{\min} + \frac{R_N}{G_S} \cdot |Y_S - Y_{opt}|^2 \quad Y_S = \frac{1}{Z_0} \cdot \frac{1 - \Gamma_S}{1 + \Gamma_S} \quad Y_{opt} = \frac{1}{Z_0} \cdot \frac{1 - \Gamma_{opt}}{1 + \Gamma_{opt}}$$

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

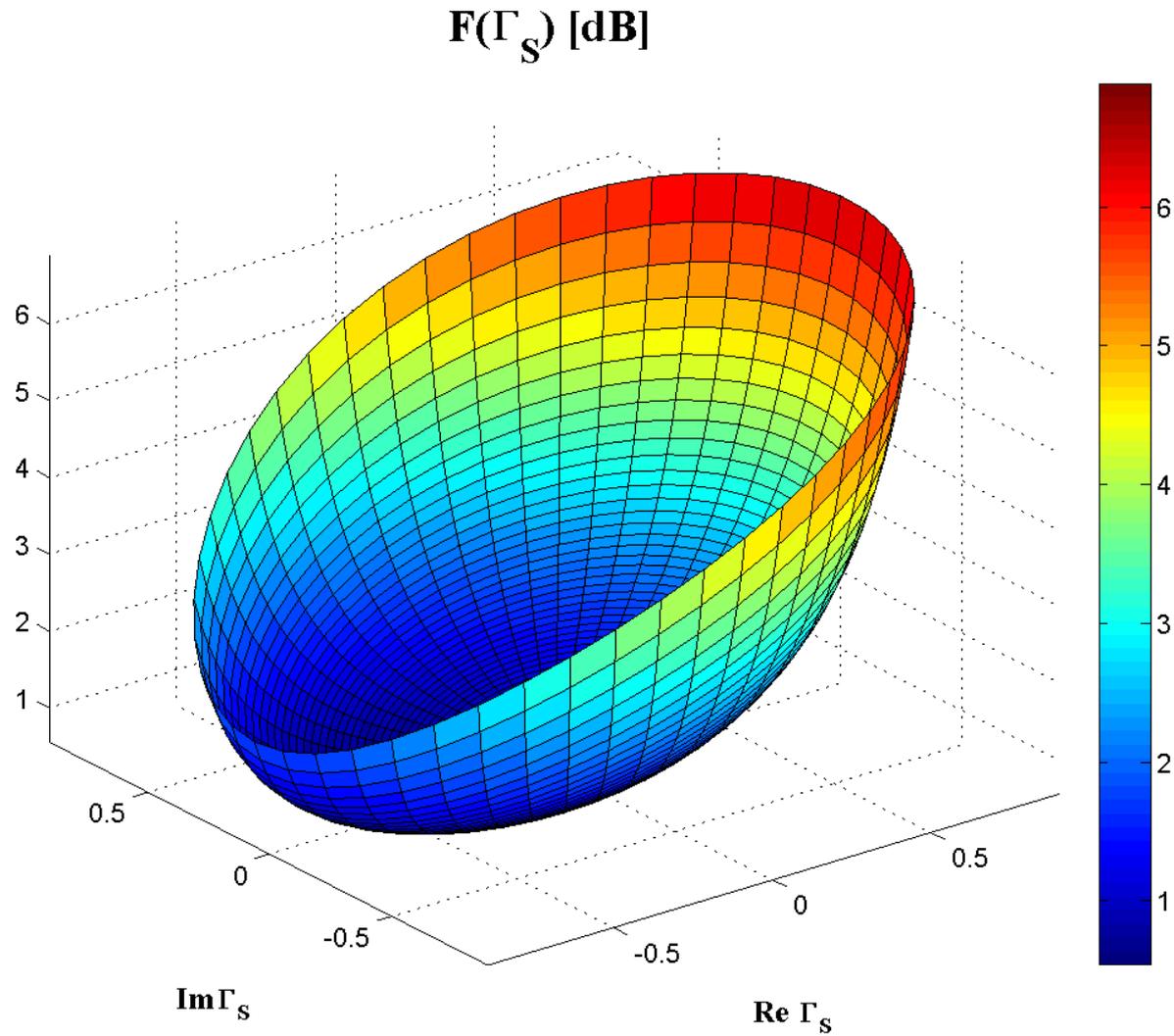
- Γ_{opt} reprezinta coeficientul optim de reflexie la intrare

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

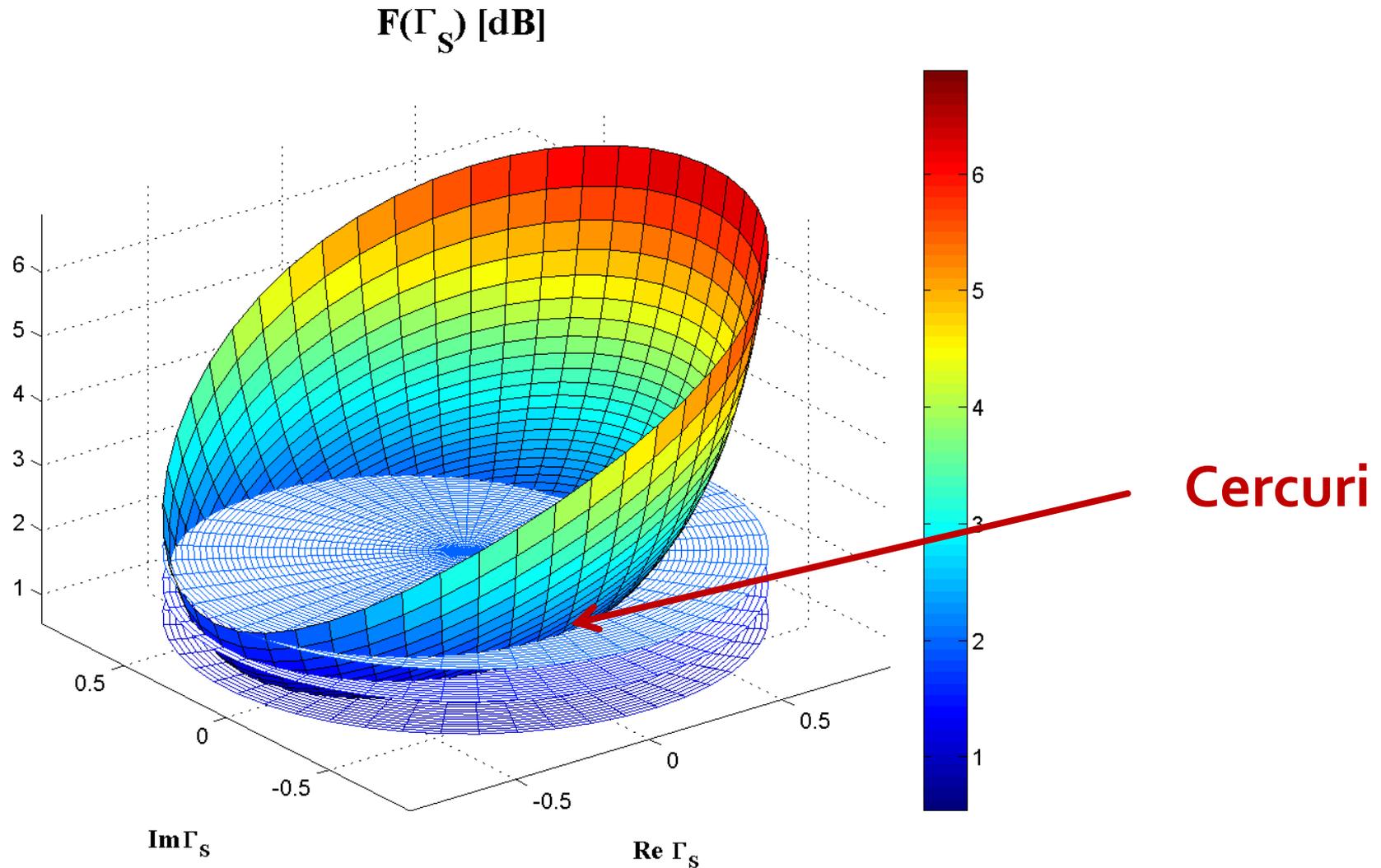
$F(\Gamma_S)$



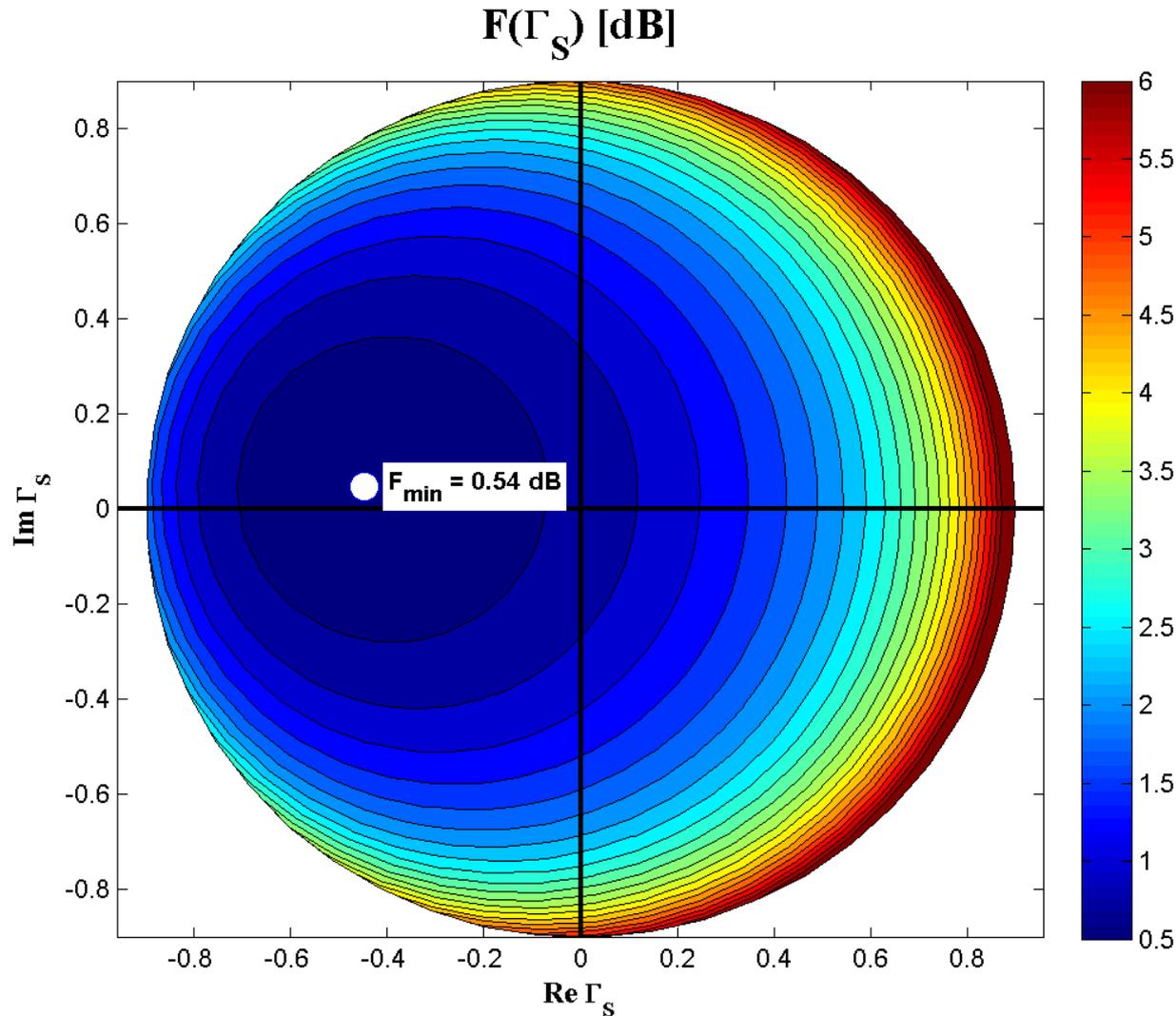
$F[\text{dB}](\Gamma_S)$



$F[\text{dB}](\Gamma_s)$, diagrama de nivel



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



$$\Gamma_{\text{opt}} = 0.45 \angle 174^\circ$$

Cercuri de zgomot constant

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

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

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

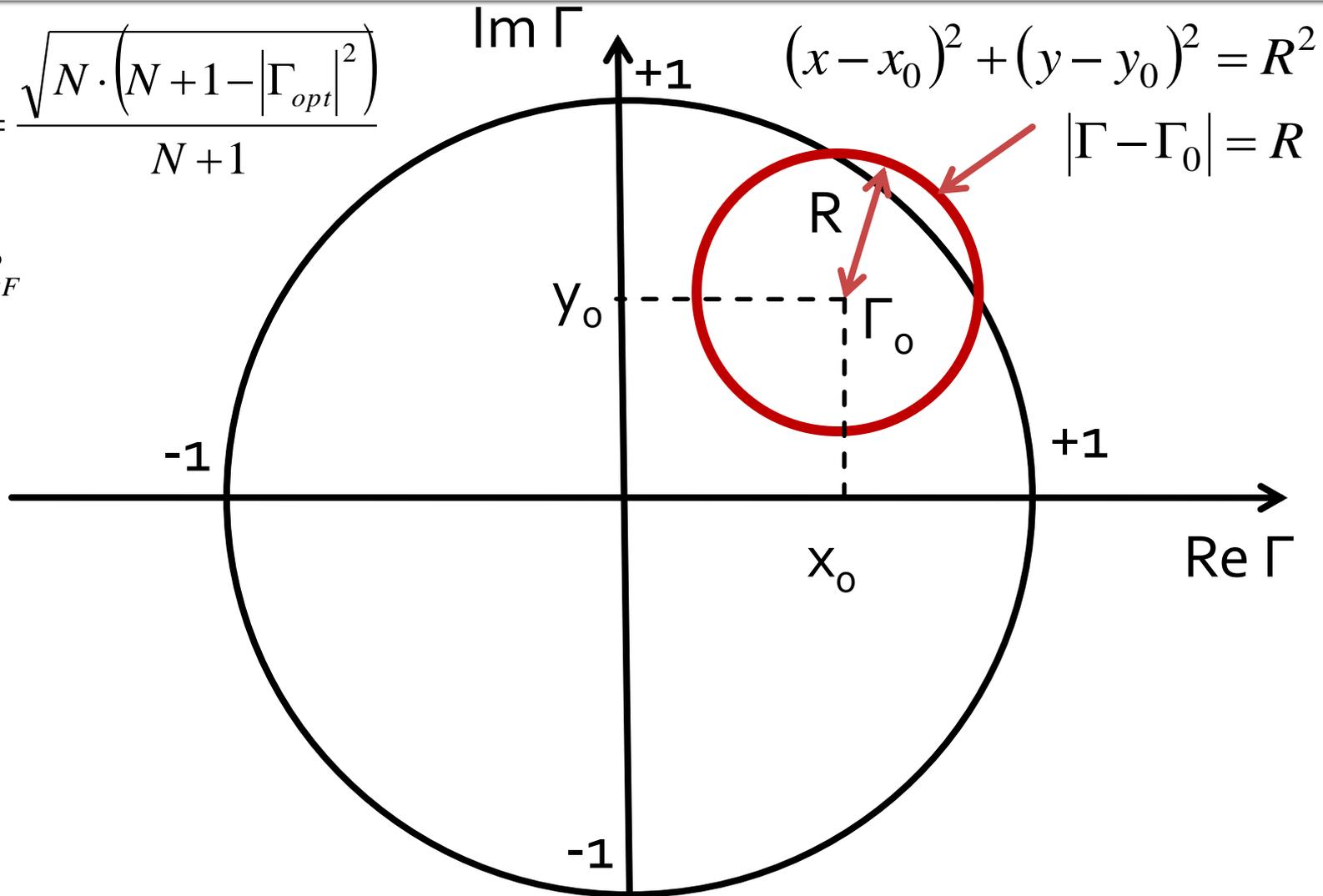
$$\Gamma_S \cdot \Gamma_S^* + N \cdot |\Gamma_S|^2 - (\Gamma_S \cdot \Gamma_{opt}^* - \Gamma_S^* \cdot \Gamma_{opt}) + \Gamma_{opt} \cdot \Gamma_{opt}^* = N$$

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

Zgomot

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

$$|\Gamma_S - C_F| = R_F$$

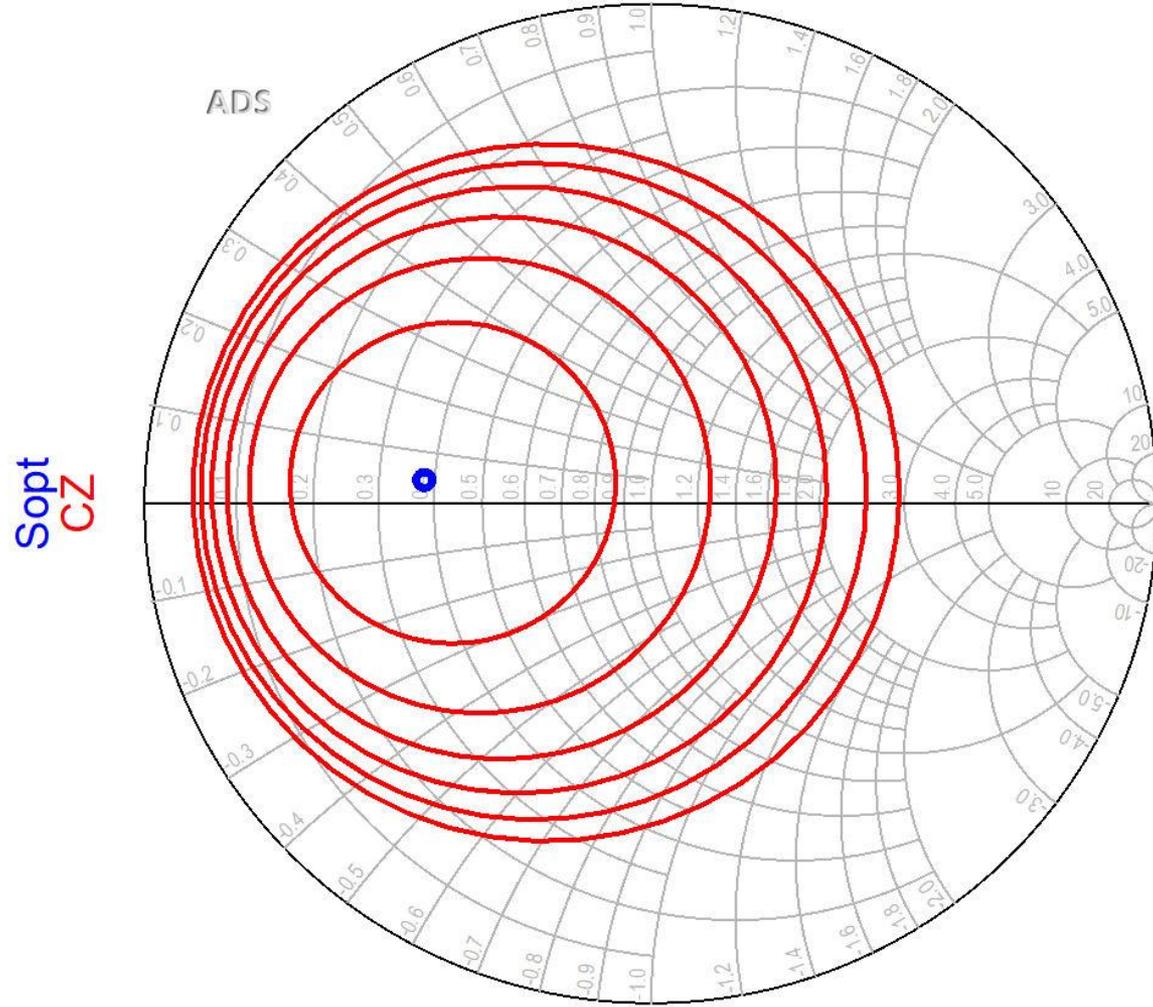


Cercuri de zgomot constant

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

- Locul geometric al punctelor caracterizate de factor de zgomot constant este un cerc
- **Interpretare:** Orice punct Γ_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

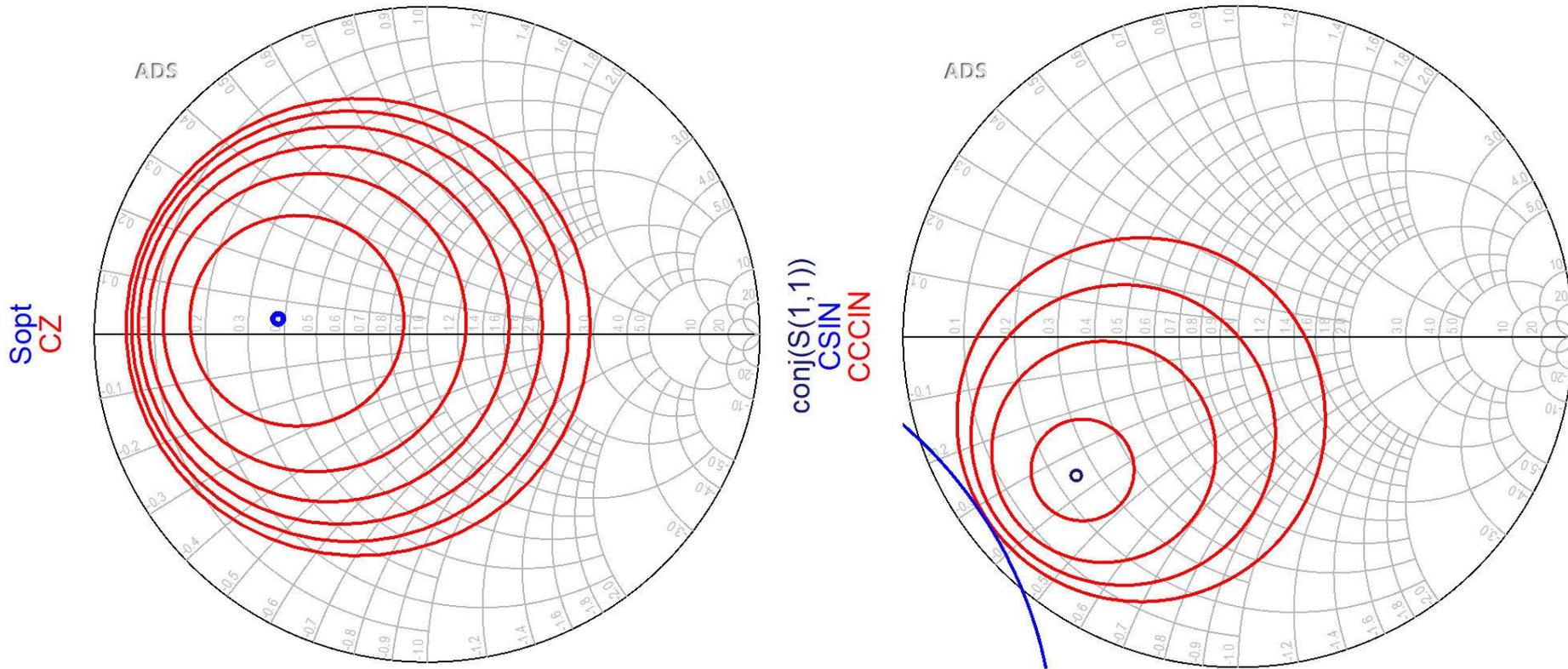


Cercuri de zgomot constant

- 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)

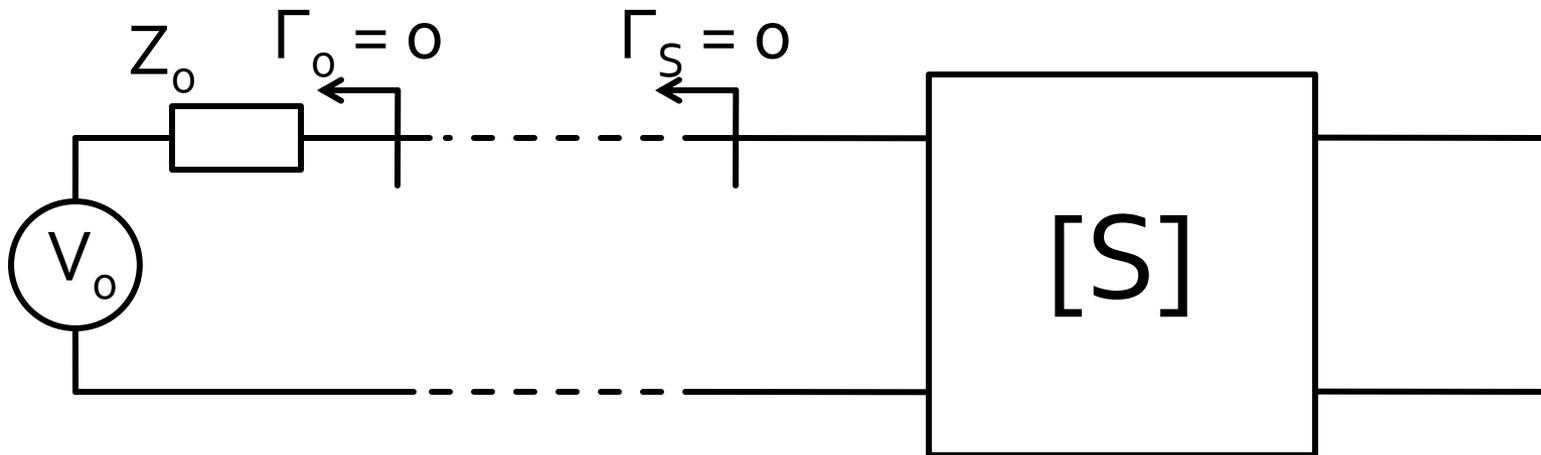
LNA – Low Noise Amplifier

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



Adaptare – 1

- Conectarea amplificatorului (tranzistorului) direct la sursa de semnal oferă un coeficient de reflexie la intrarea tranzistorului egal cu 0 (complex, $\Gamma_o = 0 + 0 \cdot j$)
 - de cele mai multe ori acest coeficient de reflexie nu oferă condiții optime de câștig și/sau zgomot

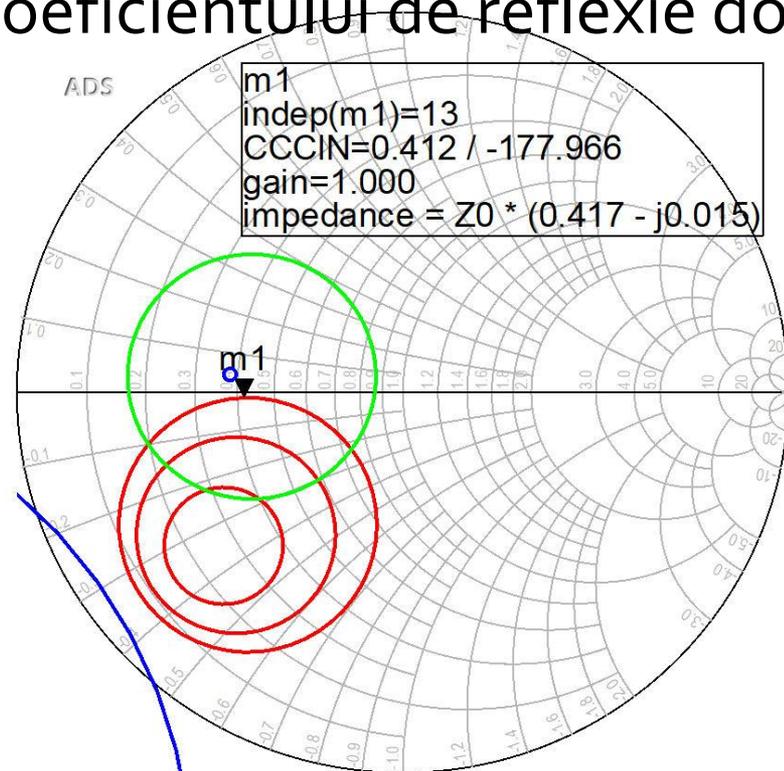


Adaptare – 2

- Se deseneaza pe diagrama Smith cercurile de stabilitate/castig/zgomot, in functie de aplicatia
- Se alege punctul cu o pozitionare dorita relativ la aceste cercuri (de asemenea dependent de aplicatie)
- Se determina valoarea coeficientului de reflexie dorit la intrare Γ_S

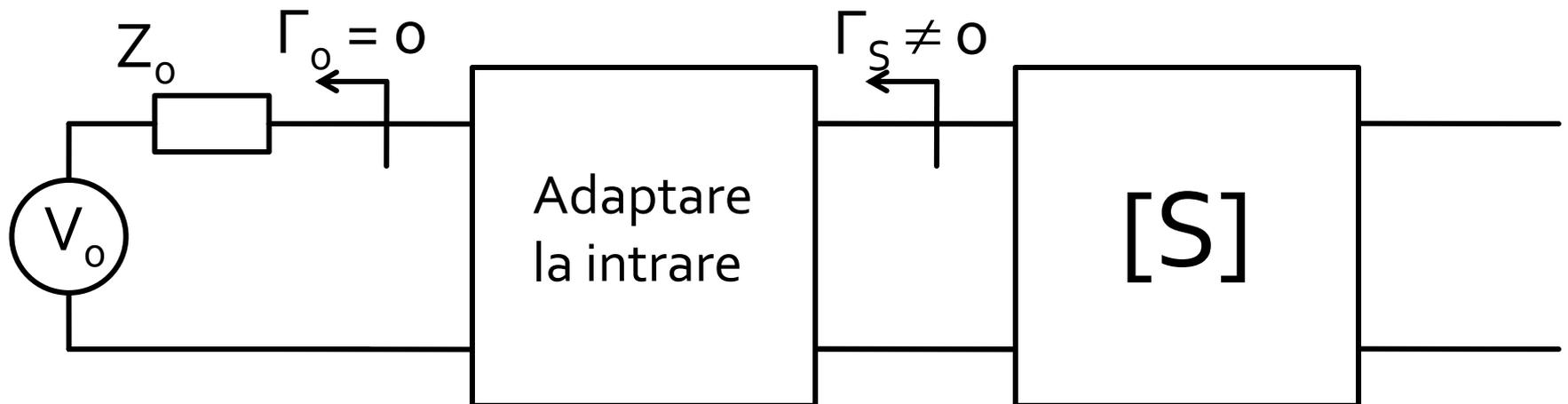
$$\Gamma_S = 0.412 \angle -177.966^\circ$$

Sopt
CZ
CSIN
CCCIN



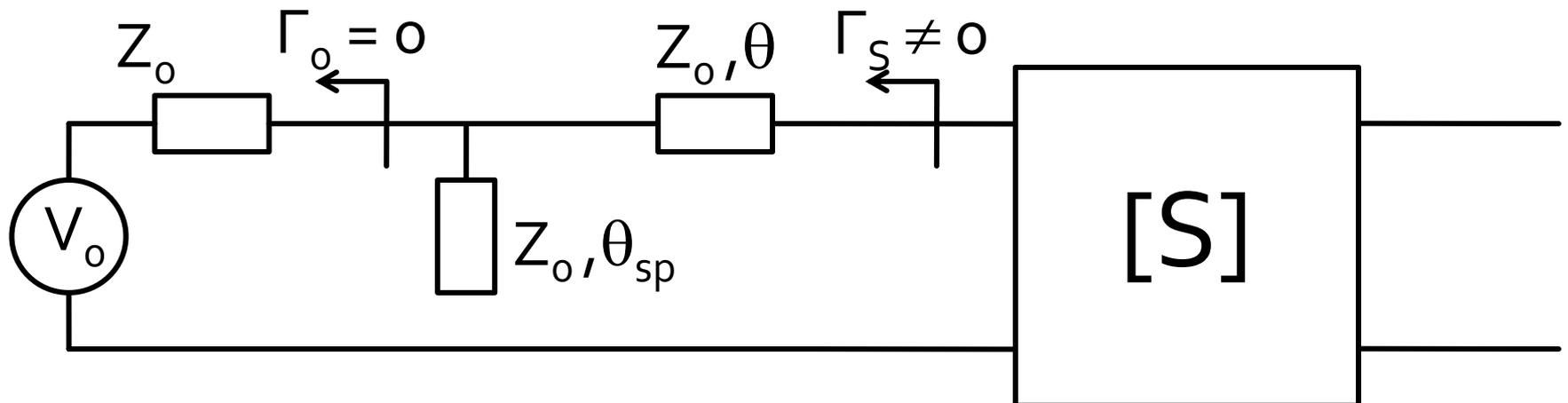
Adaptare – 3

- Se interpune rețeaua de adaptare la intrare care permite obținerea lui $\Gamma_S \neq 0$ determinat anterior



Adaptare – 4

- Varianta cea mai simpla de implementare, si pentru care exista relatii analitice de calcul consta in introducerea (in ordine, de la tranzistor spre sursa Z_0):
 - o sectiune de linie serie, cu impedanta caracteristica Z_0 si lungime electrica θ
 - un stub paralel, lasat in gol la capat, realizat dintr-o linie cu impedanta caracteristica Z_0 si lungime electrica θ_{sp}

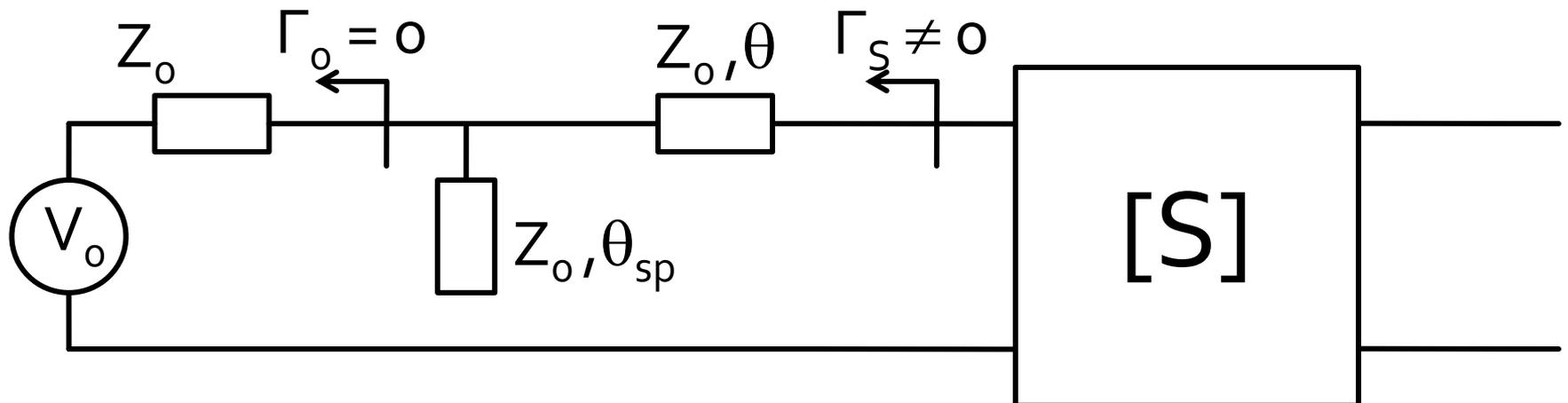


Adaptare – 5

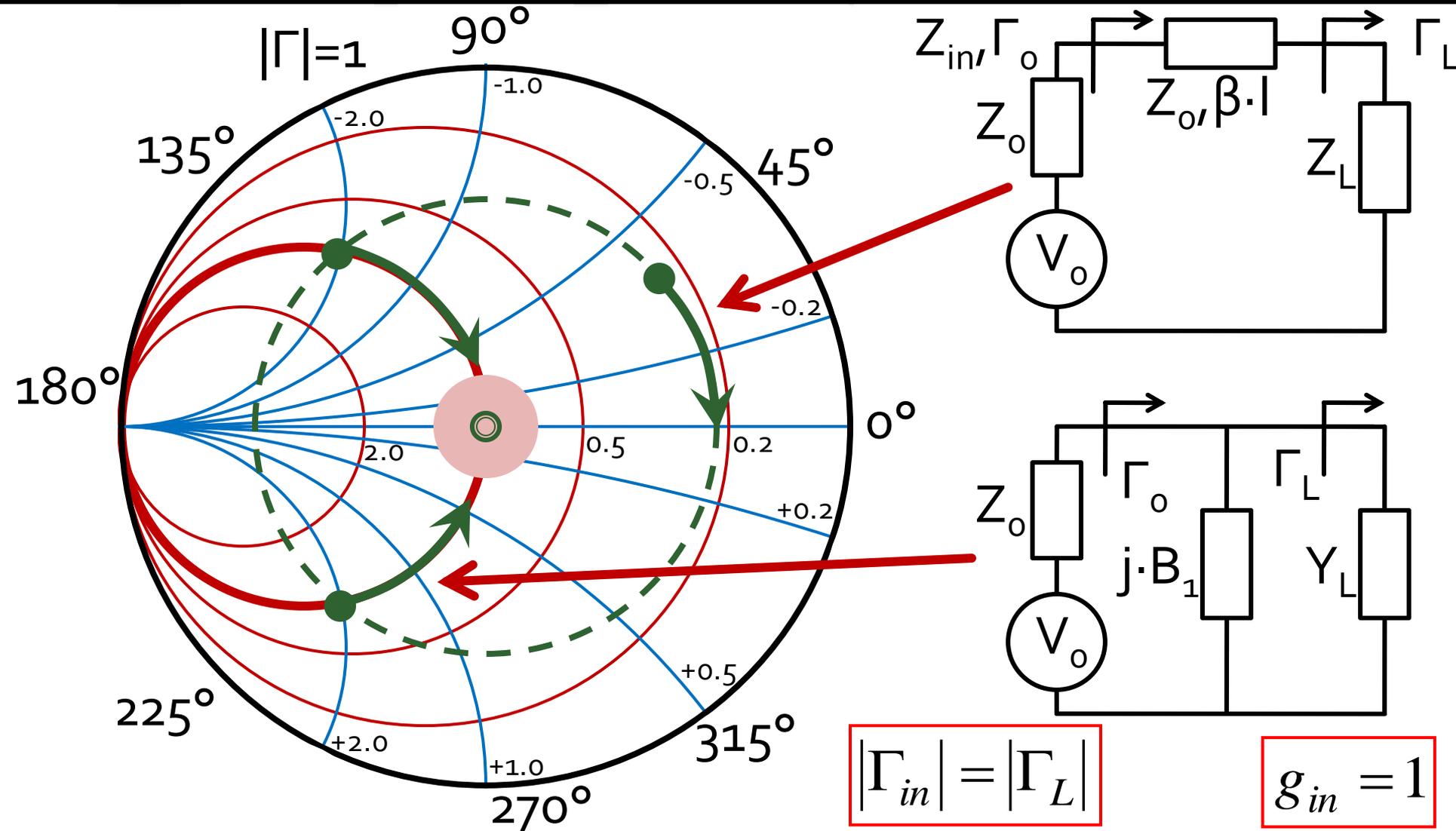
- Relatiile de calcul depind numai de Γ_S (modul si faza)

$$\cos(\varphi_S + 2\theta) = -|\Gamma_S| \quad \tan \theta_{sp} = \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}$$

- Prima ecuatie are doua solutii, semnul solutiei alese impune semnul utilizat in a doua ecuatie



Adaptare cu stub-uri, C6-7



Exemplu, LNA @ 5 GHz

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

```
IATF-34143
IS-PARAMETERS at Vds=3V Id=20mA. LAST UPDATED 01-29-99

# ghz s ma r 50

2.0 0.75 -126 6.306 90 0.088 23 0.26 -120
2.5 0.72 -145 5.438 75 0.095 15 0.25 -140
3.0 0.69 -162 4.762 62 0.102 7 0.23 -156
4.0 0.65 166 3.806 38 0.111 -8 0.22 174
5.0 0.64 139 3.165 16 0.119 -21 0.22 146
6.0 0.65 114 2.706 -5 0.125 -35 0.23 118
7.0 0.66 89 2.326 -27 0.129 -49 0.25 91
8.0 0.69 67 2.017 -47 0.133 -62 0.29 67
9.0 0.72 48 1.758 -66 0.135 -75 0.34 46

!FREQ Fopt GAMMA OPT RN/Zo
!GHZ dB MAG ANG -
2.0 0.19 0.71 66 0.09
2.5 0.23 0.65 83 0.07
3.0 0.29 0.59 102 0.06
4.0 0.42 0.51 138 0.03
5.0 0.54 0.45 174 0.03
6.0 0.67 0.42 -151 0.05
7.0 0.79 0.42 -118 0.10
8.0 0.92 0.45 -88 0.18
9.0 1.04 0.51 -63 0.30
10.0 1.16 0.61 -43 0.46
```

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

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

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

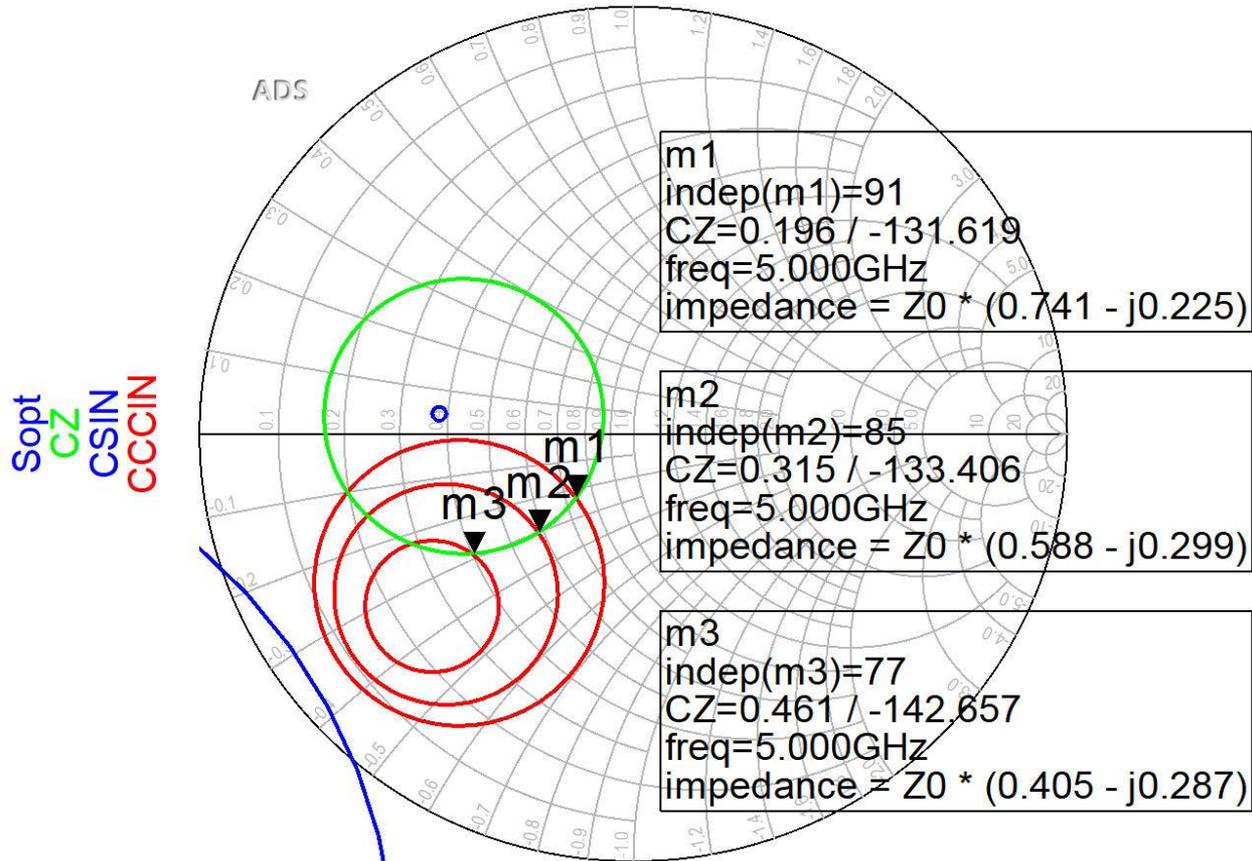
$$G_0 = |S_{21}|^2 = 10.017 = 10.007 \text{ dB}$$

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

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

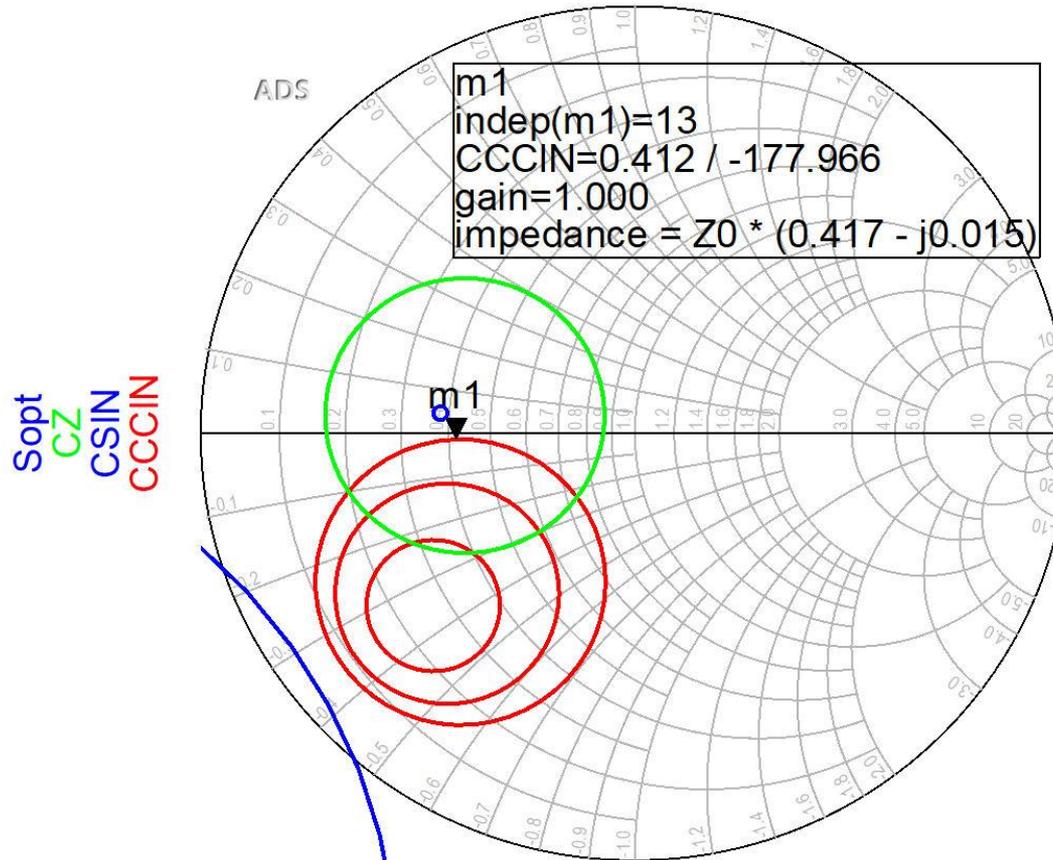
- In cazul particular prezent $G_{L \text{ max}} = 0.21 \text{ dB}$, amplificatorul ar putea functiona cu iesirea conectata direct la o sarcina de 50Ω
- Absenta retelei de adaptare la iesire nu conduce la o pierdere importanta de castig, dar elimina posibilitatea ca prin reglaj sa se compenseze compromisul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

Adaptare la intrare



- Pentru rețeaua de adaptare la intrare
 - CZ: 0.75dB
 - CCCIN: 1dB, 1.5dB, 2 dB
- Aleg (Q mic → banda larga) poziția m1

Adaptare la intrare



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

Adaptare la intrare

- Pozitia m_1 de pe grafic

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

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

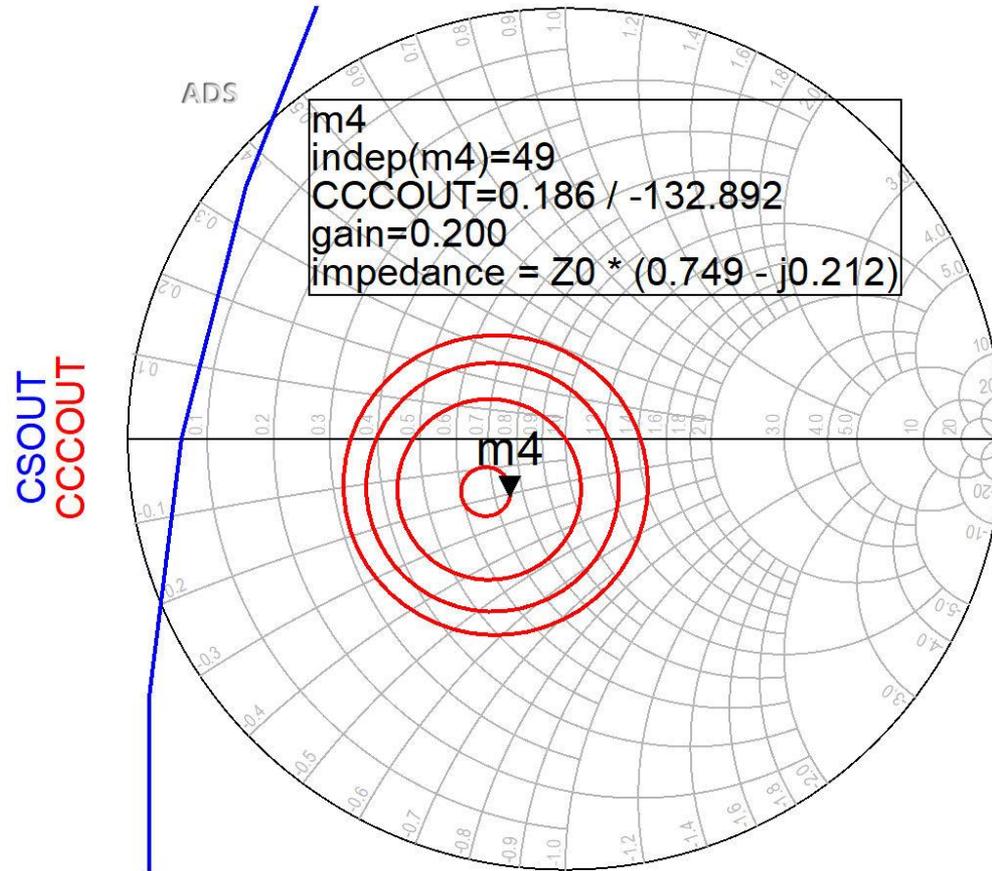
$$\cos(\varphi + 2\theta) = -|\Gamma_S|$$

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

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

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

Adaptare la iesire



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

Adaptare la iesire

- Pozitia m_4 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

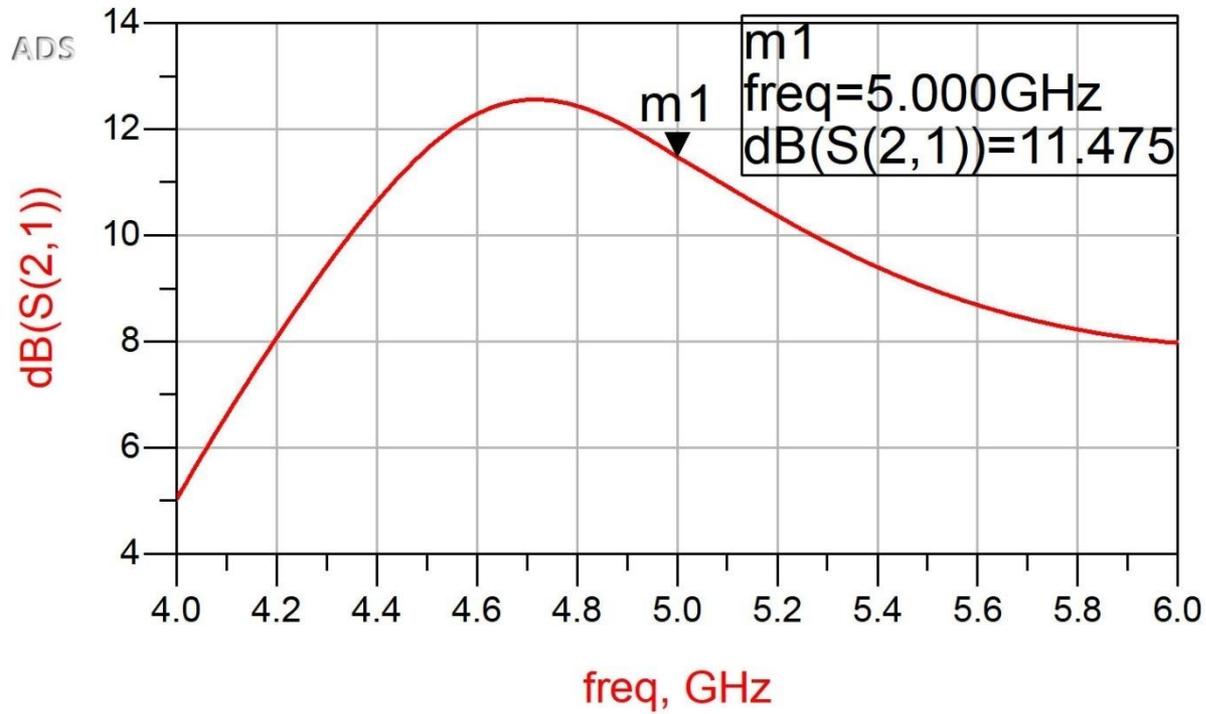
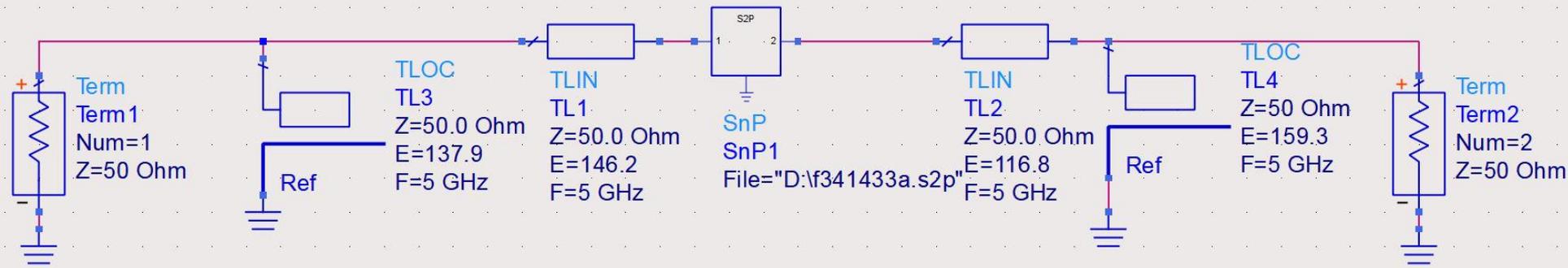
- Se estimeaza obtinerea unui castig (in ipoteza unilaterala, ± 0.9 dB)

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

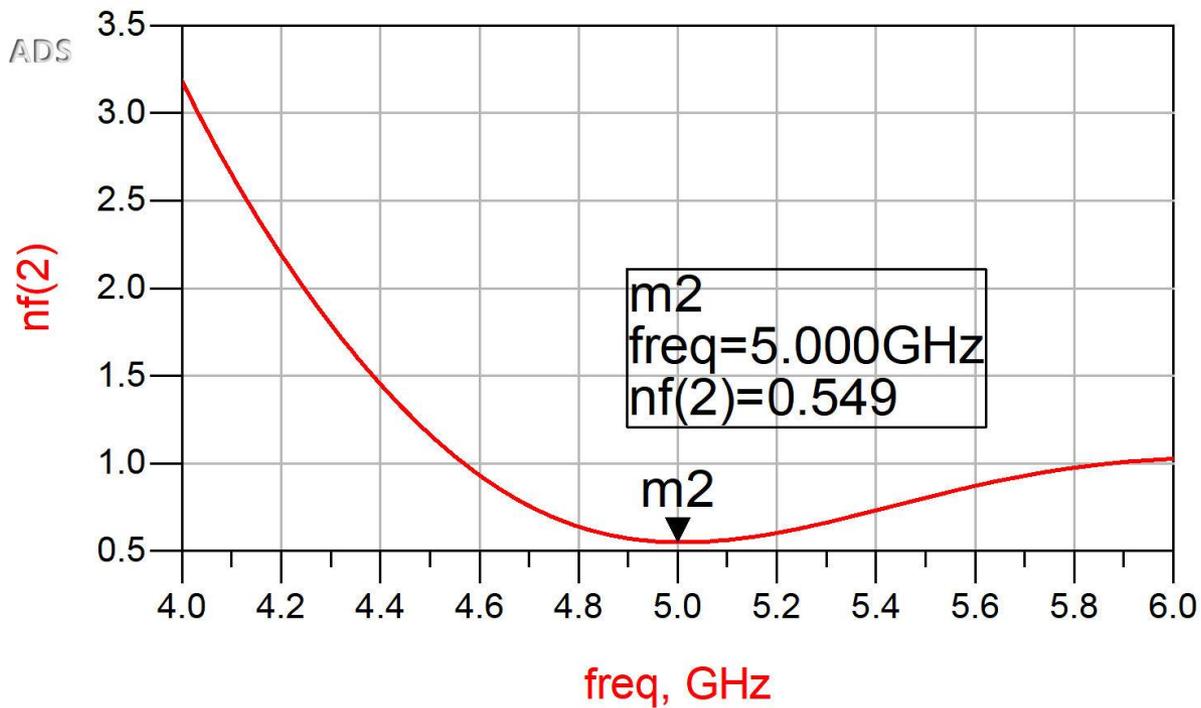
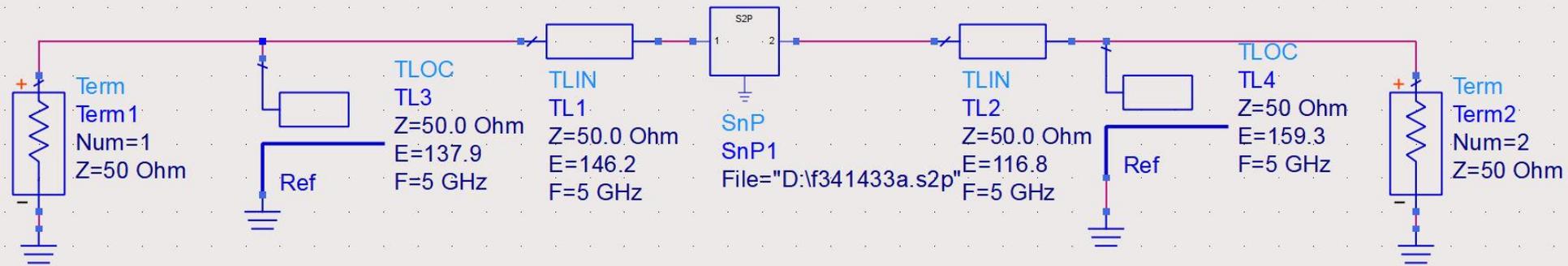
$$G_T [dB] = 1 \text{ dB} + 10 \text{ dB} + 0.2 \text{ dB} = 11.2 \text{ dB}$$

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

ADS



ADS



Amplificatoare in cascada

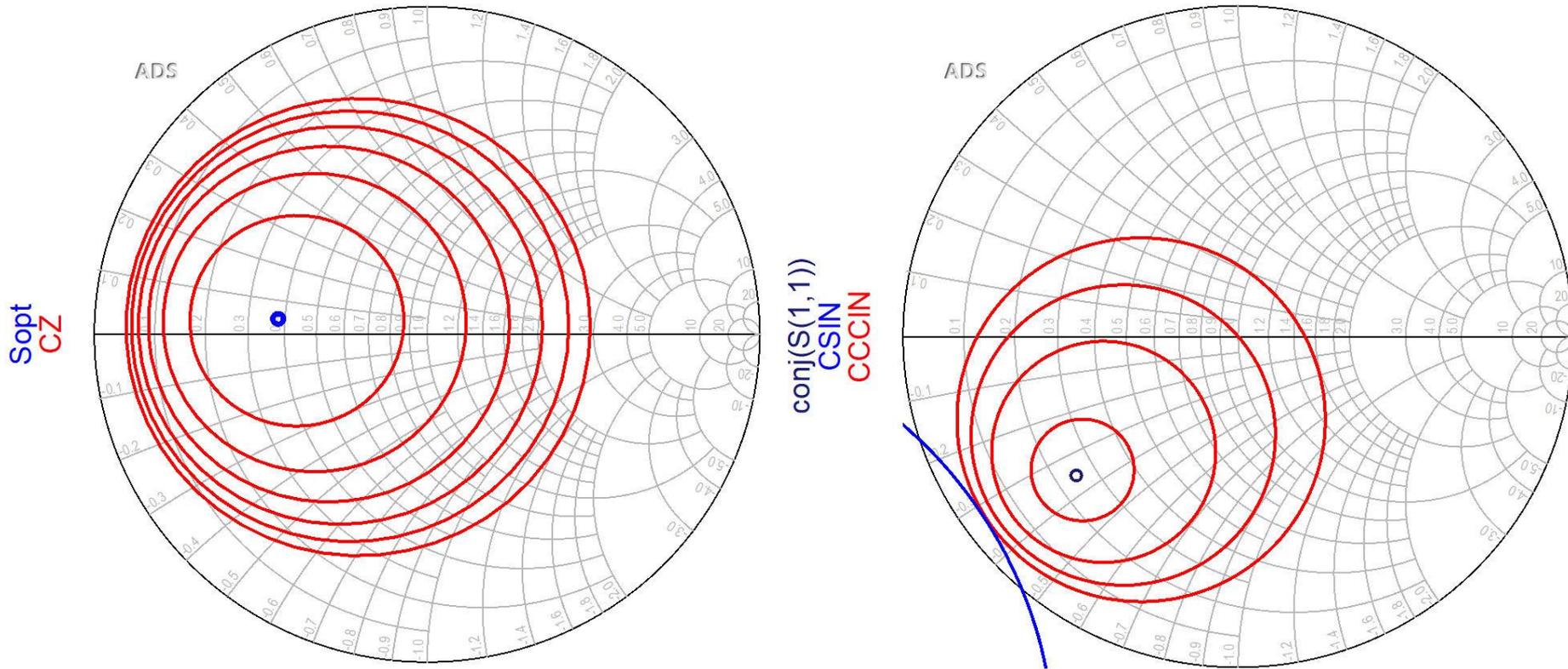
Amplificatoare de microunde

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)

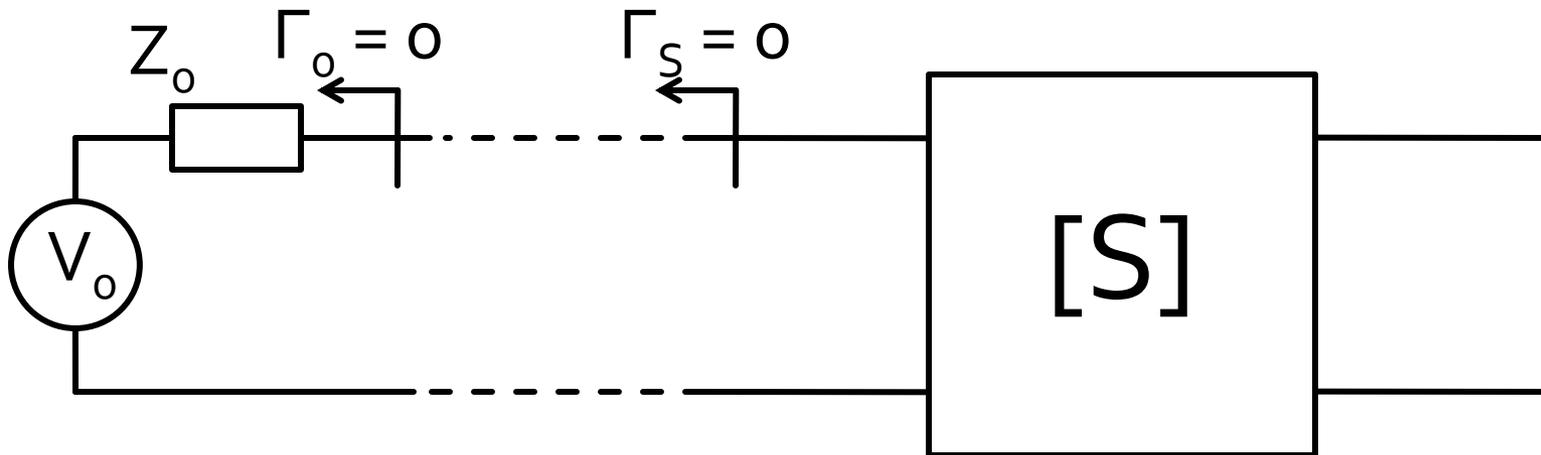
LNA – Low Noise Amplifier

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



Adaptare – 1

- Conectarea amplificatorului (tranzistorului) direct la sursa de semnal oferă un coeficient de reflexie la intrarea tranzistorului egal cu 0 (complex, $\Gamma_o = 0 + 0 \cdot j$)
 - de cele mai multe ori acest coeficient de reflexie nu oferă condiții optime de câștig și/sau zgomot

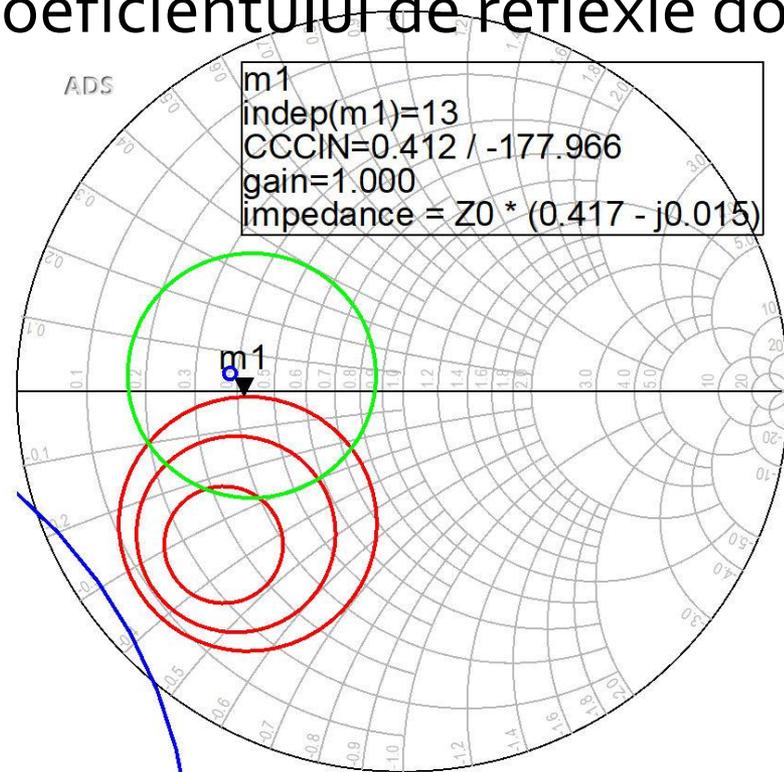


Adaptare – 2

- Se deseneaza pe diagrama Smith cercurile de stabilitate/castig/zgomot, in functie de aplicatia
- Se alege punctul cu o pozitionare dorita relativ la aceste cercuri (de asemenea dependent de aplicatie)
- Se determina valoarea coeficientului de reflexie dorit la intrare Γ_S

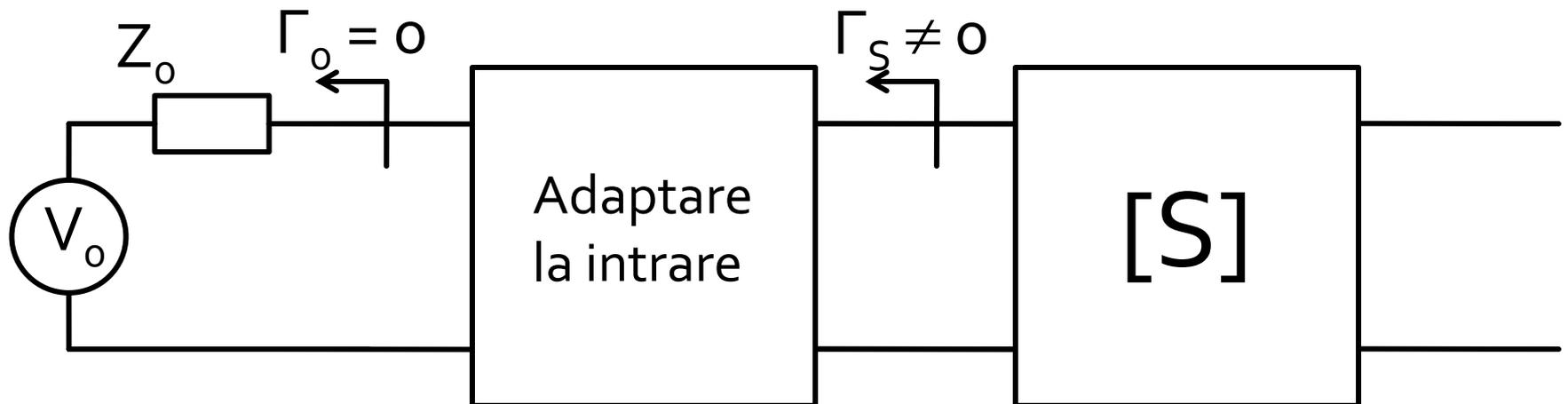
$$\Gamma_S = 0.412 \angle -177.966^\circ$$

Sopt
CZ
CSIN
CCCIN



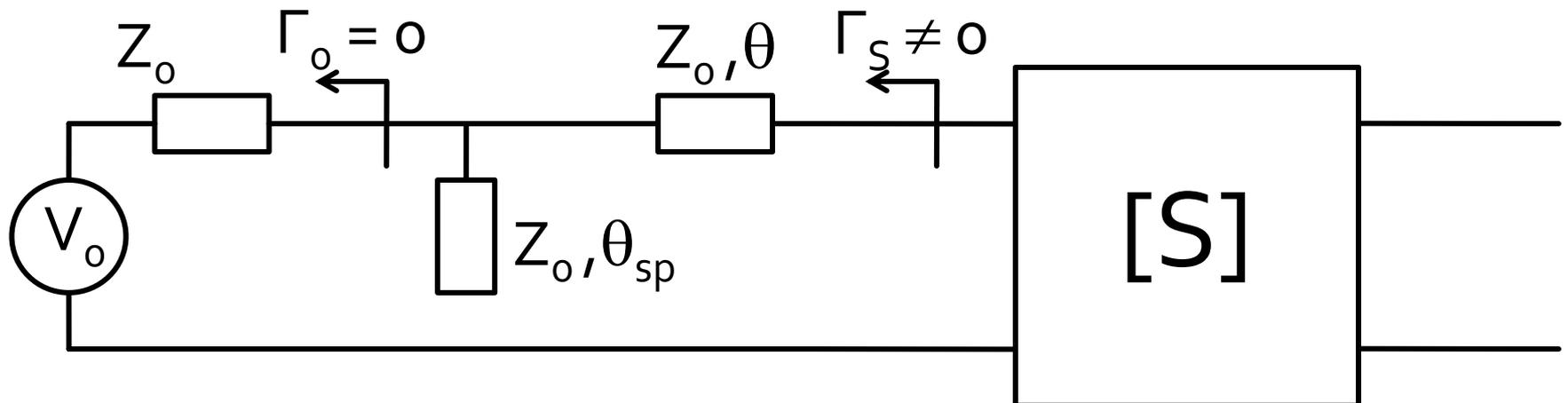
Adaptare – 3

- Se interpune rețeaua de adaptare la intrare care permite obținerea lui $\Gamma_S \neq 0$ determinat anterior



Adaptare – 4

- Varianta cea mai simpla de implementare, si pentru care exista relatii analitice de calcul consta in introducerea (in ordine, de la tranzistor spre sursa Z_0):
 - o sectiune de linie serie, cu impedanta caracteristica Z_0 si lungime electrica θ
 - un stub paralel, lasat in gol la capat, realizat dintr-o linie cu impedanta caracteristica Z_0 si lungime electrica θ_{sp}

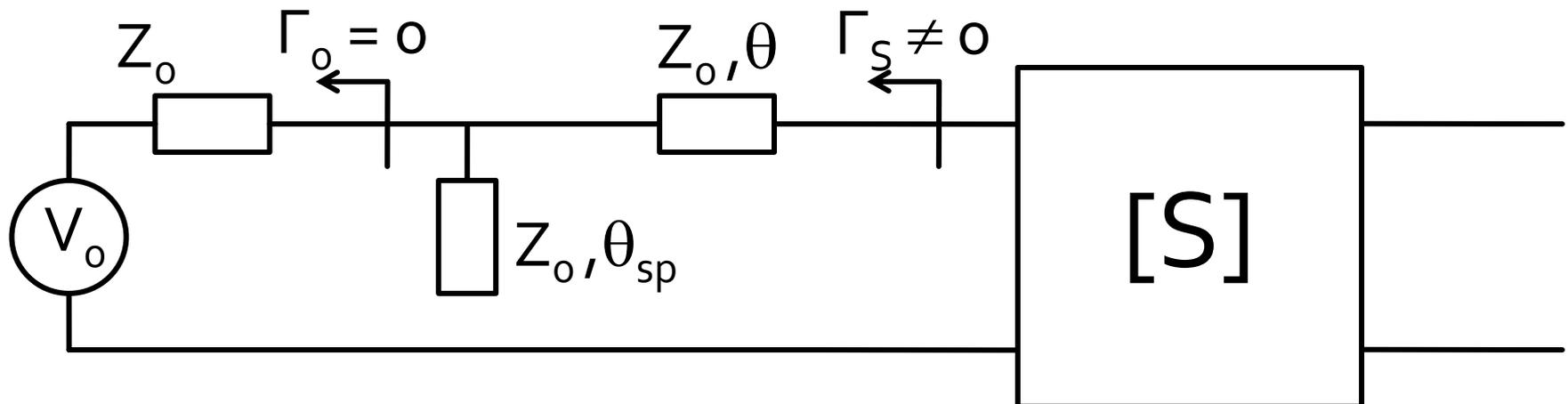


Adaptare – 5

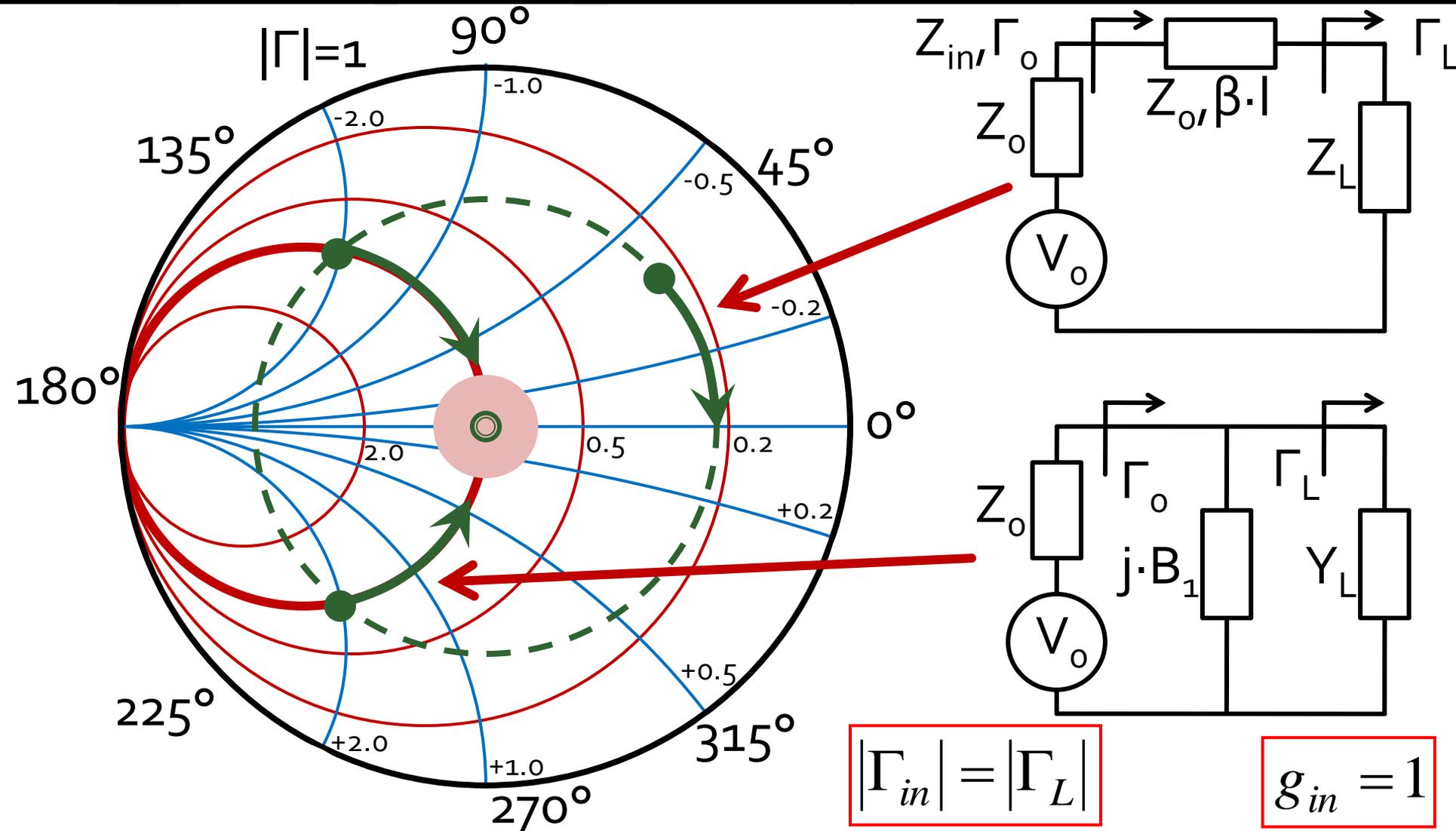
- Relatiile de calcul depind numai de Γ_S (modul si faza)

$$\cos(\varphi_S + 2\theta) = -|\Gamma_S| \quad \tan \theta_{sp} = \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}$$

- Prima ecuatie are doua solutii, **semnul** solutiei alese **impune semnul** utilizat in a doua ecuatie



Adaptare cu stub-uri, C6-7

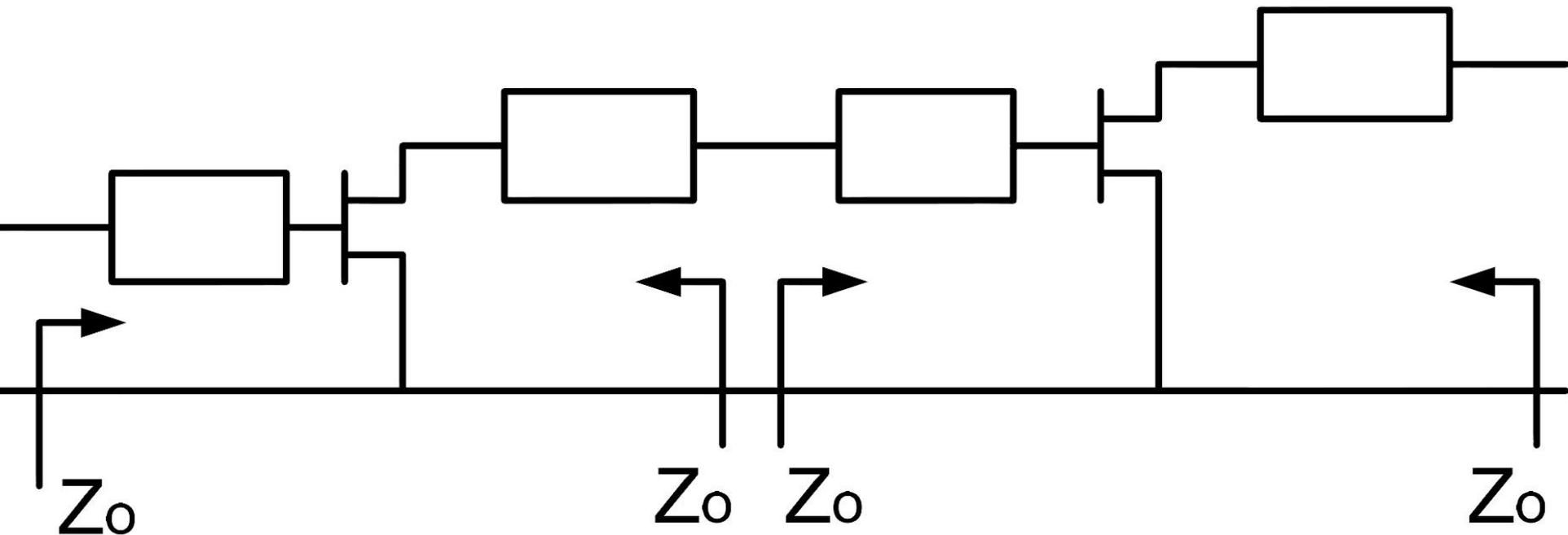


Amplificatoare in cascada

Amplificatoare de microunde

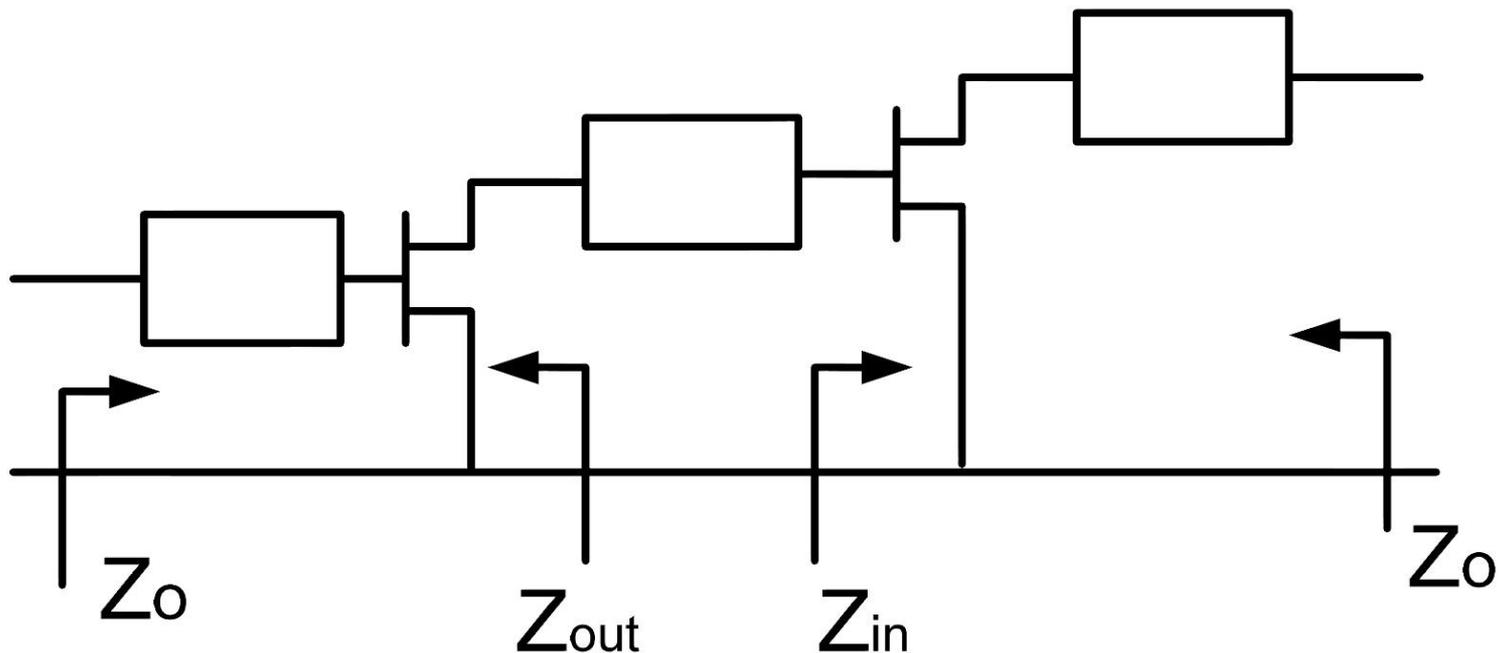
Amplificatoare in cascada

- Adaptarea inter-etaje se poate proiecta in doua moduri:
 - adaptarea fiecarui etaj spre un $\Gamma = 0$ intermediar



Amplificatoare in cascada

- Adaptarea inter-etaje se poate proiecta in doua moduri:
 - adaptarea unui etaj spre Γ necesar pentru celalalt

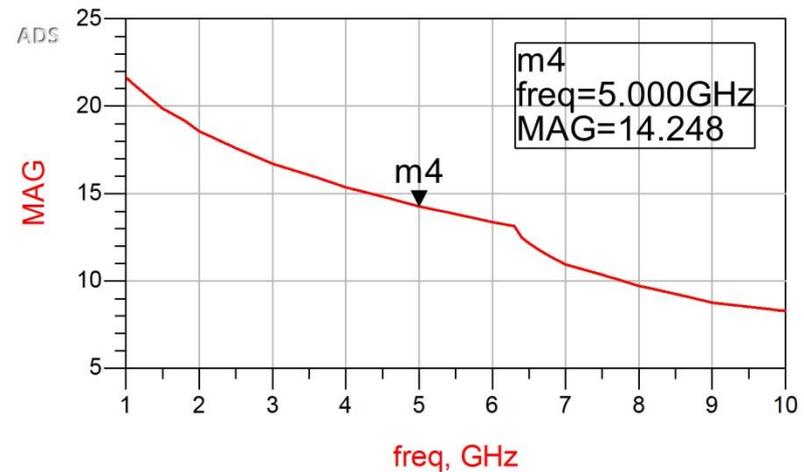
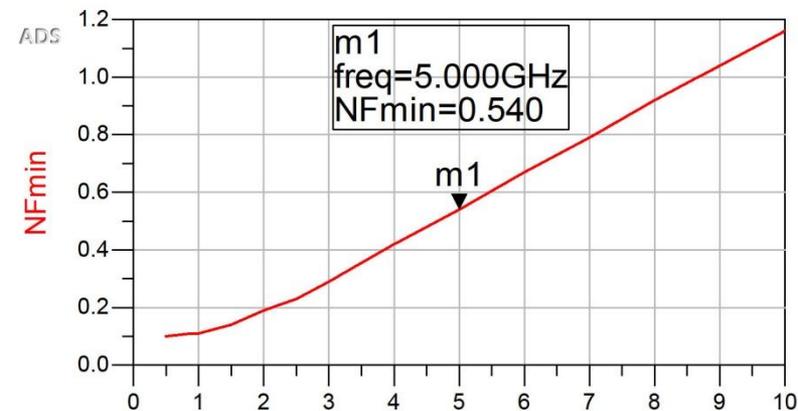


Exemplu LNA cascada

- Similar cu tema de la mini-proiect
- Amplificator LNA cu ATF-34143 avand caracteristicile:
 - $G = 20\text{dB}$
 - $F = 1\text{dB}$
 - $@f = 5\text{GHz}$

Exemplu

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



Exemplu, LNA @ 5 GHz

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

```
IATF-34143
IS-PARAMETERS at Vds=3V Id=20mA. LAST UPDATED 01-29-99

# ghz s ma r 50

2.0 0.75 -126 6.306 90 0.088 23 0.26 -120
2.5 0.72 -145 5.438 75 0.095 15 0.25 -140
3.0 0.69 -162 4.762 62 0.102 7 0.23 -156
4.0 0.65 166 3.806 38 0.111 -8 0.22 174
5.0 0.64 139 3.165 16 0.119 -21 0.22 146
6.0 0.65 114 2.706 -5 0.125 -35 0.23 118
7.0 0.66 89 2.326 -27 0.129 -49 0.25 91
8.0 0.69 67 2.017 -47 0.133 -62 0.29 67
9.0 0.72 48 1.758 -66 0.135 -75 0.34 46

!FREQ Fopt GAMMA OPT RN/Zo
!GHZ dB MAG ANG -
2.0 0.19 0.71 66 0.09
2.5 0.23 0.65 83 0.07
3.0 0.29 0.59 102 0.06
4.0 0.42 0.51 138 0.03
5.0 0.54 0.45 174 0.03
6.0 0.67 0.42 -151 0.05
7.0 0.79 0.42 -118 0.10
8.0 0.92 0.45 -88 0.18
9.0 1.04 0.51 -63 0.30
10.0 1.16 0.61 -43 0.46
```

Amplificatoare in cascada

- Daca e necesar un castig mai mare decat cel care poate fi oferit de un singur tranzistor
 - necesar 20dB
 - $MAG @5GHz = 14.248 \text{ dB} < 20\text{dB}$
- Se utilizeaza formula lui Friis pentru a imparti necesarul de:
 - castig
 - zgomot
- pe cele doua etaje individuale

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:
 - e esential ca primul etaj de amplificare sa fie **nezgomotos**, chiar cu sacrificarea in parte a castigului
 - urmatoarele etaje pot fi optimizate pentru **castig**
- Formula lui Friis trebuie utilizata in **coordonate liniare**
- **Avago/Broadcom AppCAD**
 - AppCAD Free Design Assistant Tool for Microsoft Windows → Google

Formula lui Friis (zgomot)

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

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

- Formula lui Friis
 - primul etaj factor de zgomot mai mic, probabil insotit de un castig mai mic
 - al doilea etaj castig mare, probabil insotit de un factor de zgomot mai mare
- Este esential sa se pastreze o rezerva
 - $G = G_{tema} + \Delta G$
 - $F = F_{tema} - \Delta F$
- Tema se interpreteaza
 - $G > G_{tema}$, mai bine, fara a fi nevoie sa se sacrifice alti parametri pentru castiguri mult mai mari
 - $F < F_{tema}$, mai bine, cu cat mai mic cu atat mai bine, e util sa se incerce obtinerea unui **zgomot cat mai mic, cu indeplinirea** celorlalte conditii

Formula lui Friis (zgomot)

- Formula lui Friis
 - primul etaj factor de zgomot mai mic, probabil insotit de un castig mai mic
 - al doilea etaj castig mare, probabil insotit de un factor de zgomot mai mare
- Impartire pe cele doua etaje (Estimat)
 - intrare: $F_1 = 0.7 \text{ dB}$, $G_1 = 9 \text{ dB}$
 - iesire: $F_2 = 1.2 \text{ dB}$, $G_2 = 13 \text{ dB}$
- Transformare **in coordonate liniare !**

$$F_1 = 10^{\frac{F_1[dB]}{10}} = 10^{0.07} = 1.175$$

$$F_2 = 10^{\frac{F_2[dB]}{10}} = 10^{0.12} = 1.318$$

$$F_{cas} = F_1 + \frac{1}{G_1} (F_2 - 1) = 1.215$$

$$F_{cas} = 10 \cdot \log(1.215) = 0.846 \text{ dB}$$

$$G_1 = 10^{\frac{G_1[dB]}{10}} = 10^{0.9} = 7.943$$

$$G_2 = 10^{\frac{G_2[dB]}{10}} = 10^{1.3} = 19.953$$

$$G_{cas} = G_1 \cdot G_2 = 158.49$$

$$G_{cas} = 10 \cdot \log(158.49) = 22 \text{ dB}$$

Formula lui Friis (zgomot)

- Avago/Broadcom AppCAD

The screenshot shows the AppCAD - [NoiseCalc] software interface. The main window displays a table of noise calculation results for two stages. The 'Stage Data' table is circled in red, highlighting the Noise Figure and Gain values for Stage 1 and Stage 2. Below the table, there are three sections: 'Enter System Parameters', 'System Analysis', and a summary table. The 'System Analysis' section also has a red circle around the Gain and Noise Figure values.

AppCAD - [NoiseCalc]

File Calculate Application Examples Options Help

NoiseCalc Set Number of Stages = 2 Calculate [F4]

		Stage 1	Stage 2
Stage Data	Units		
Stage Name:		Avago Duplexer	Avago ATF-36xxx
Noise Figure	dB	0.7	1.2
Gain	dB	9	13
Output IP3	dBm	100	14.5
dNF/dTemp	dB/°C	0	0
dG/dTemp	dB/°C	0	0
Stage Analysis:			
NF (Temp corr)	dB	0.70	1.20
Gain (Temp corr)	dB	9.00	13.00
Input Power	dBm	-50.00	-41.00
Output Power	dBm	-41.00	-28.00
d NF/d NF	dB/dB	0.97	0.15
d NF/d Gain	dB/dB	-0.03	0.00
d IP3/d IP3	dBm/dBm	0.00	1.00

Enter System Parameters:

Input Power	-50	dBm
Analysis Temperature	25	°C
Noise BW	1	MHz
Ref Temperature	25	°C
S/N (for sensitivity)	10	dB
Noise Source (Ref)	290	*K

System Analysis:

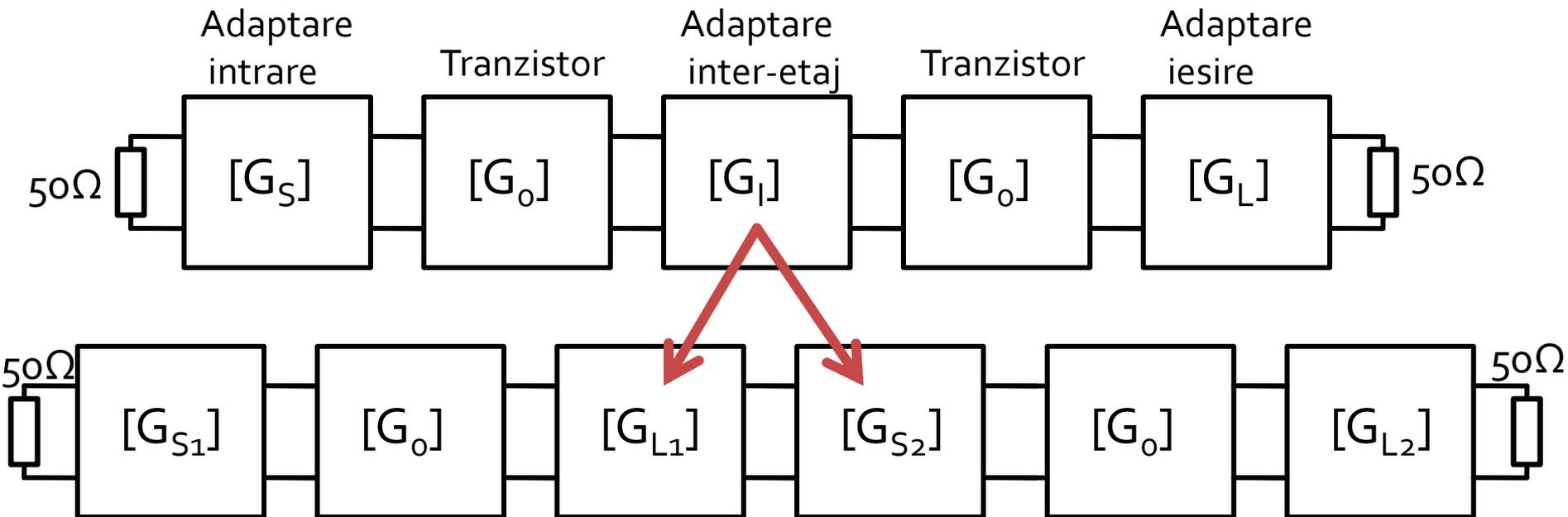
Gain =	22.00	dB
Noise Figure =	0.85	dB
Noise Temp =	82.34	*K
SNR =	63.13	dB
MDS =	-113.13	dBm
Sensitivity =	-103.13	dBm
Noise Floor =	-173.13	dBm/Hz

Input IP3 =	-7.50	dBm
Output IP3 =	14.50	dBm
Input IM level =	-135.00	dBm
Input IM level =	-85.00	dBc
Output IM level =	-113.00	dBm
Output IM level =	-85.00	dBc
SFDR =	70.42	dB

Proiectare etaje cascade

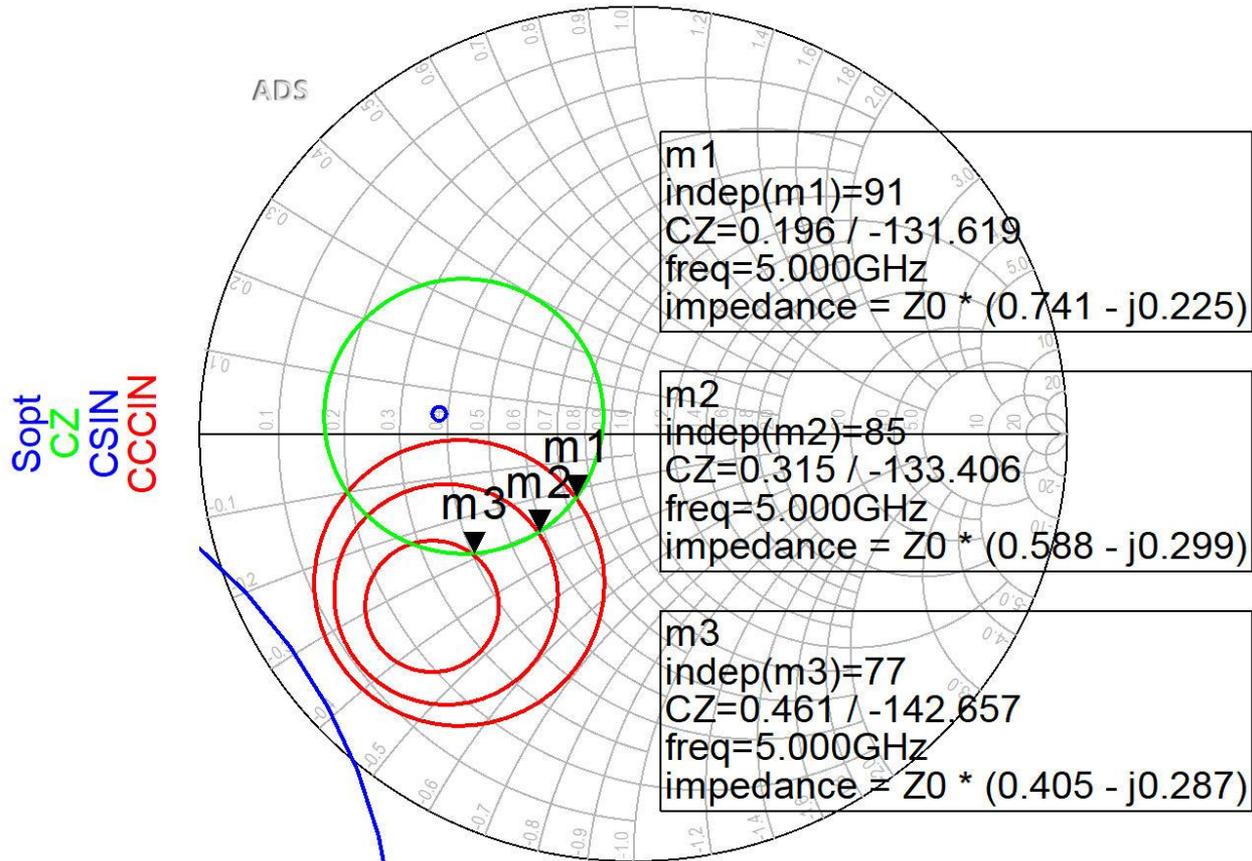
- Impartire pe cele doua etaje (Estimat)
 - intrare: $F_1 = 0.7 \text{ dB}$, $G_1 = 9 \text{ dB}$
 - iesire: $F_2 = 1.2 \text{ dB}$, $G_2 = 13 \text{ dB}$
 - total: $F = 0.85 \text{ dB}$, $G = 22 \text{ dB}$
- Indeplineste conditiile din tema (cu rezerva corespunzatoare)
- Se poate refolosi o parte din calculul amplificatorului cu un singur etaj (C9-10)
 - adaptarea la intrare anterioara este potrivita la intrarea amplificatorului multietaj – zgomot f. mic, castig onorabil
 - adaptare la iesire este conceputa pentru castig maxim
 - intrarea si iesirea erau proiectate pentru 50Ω la intrare si iesire (similar cu situatia curenta)

Proiectare etaje cascade



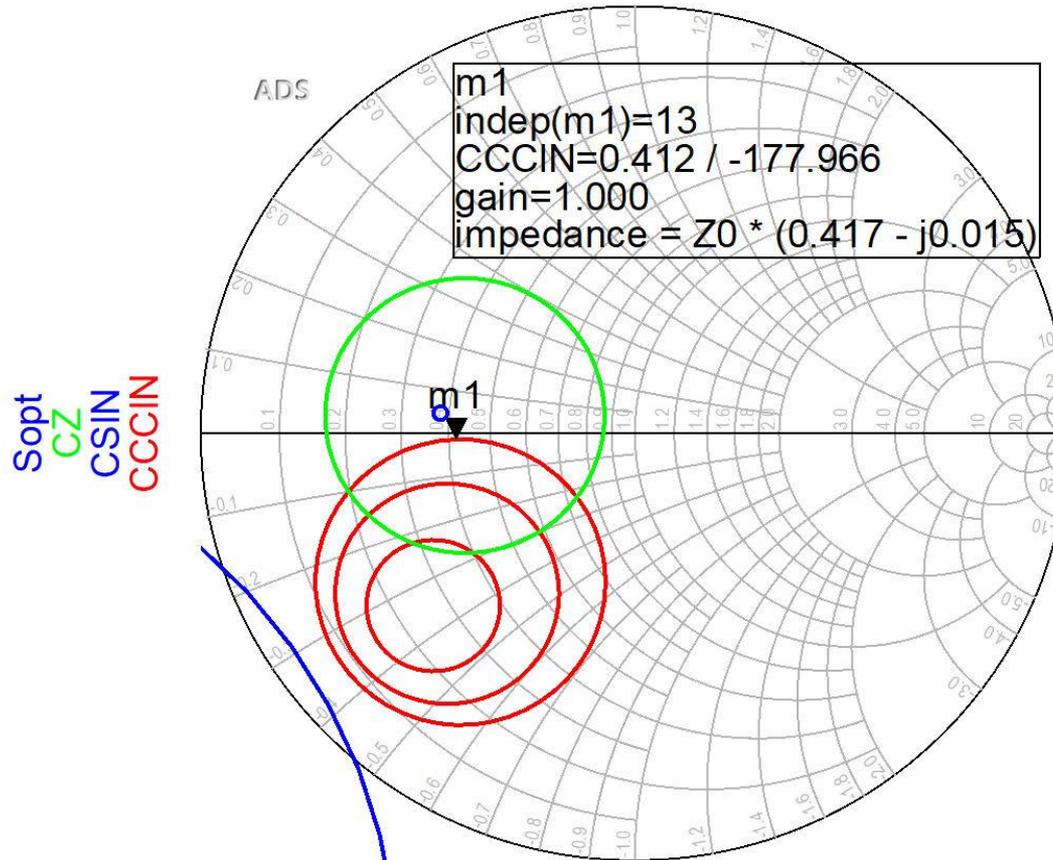
- Calcul castig
 - adaptarea inter-etaje poate aduce un supliment de castig la ambele etaje de amplificare
 - Proiectarea pentru etajele de intrare si iesire e recomandabil sa se faca pe schema mai simpla cu un singur tranzistor

Adaptare la intrare



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

Adaptare la intrarea etajului 1 (S₁)



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

Adaptare la intrarea etajului 1 (S1)

- G_{S_1} : Pozitia m_1 de pe grafic

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

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

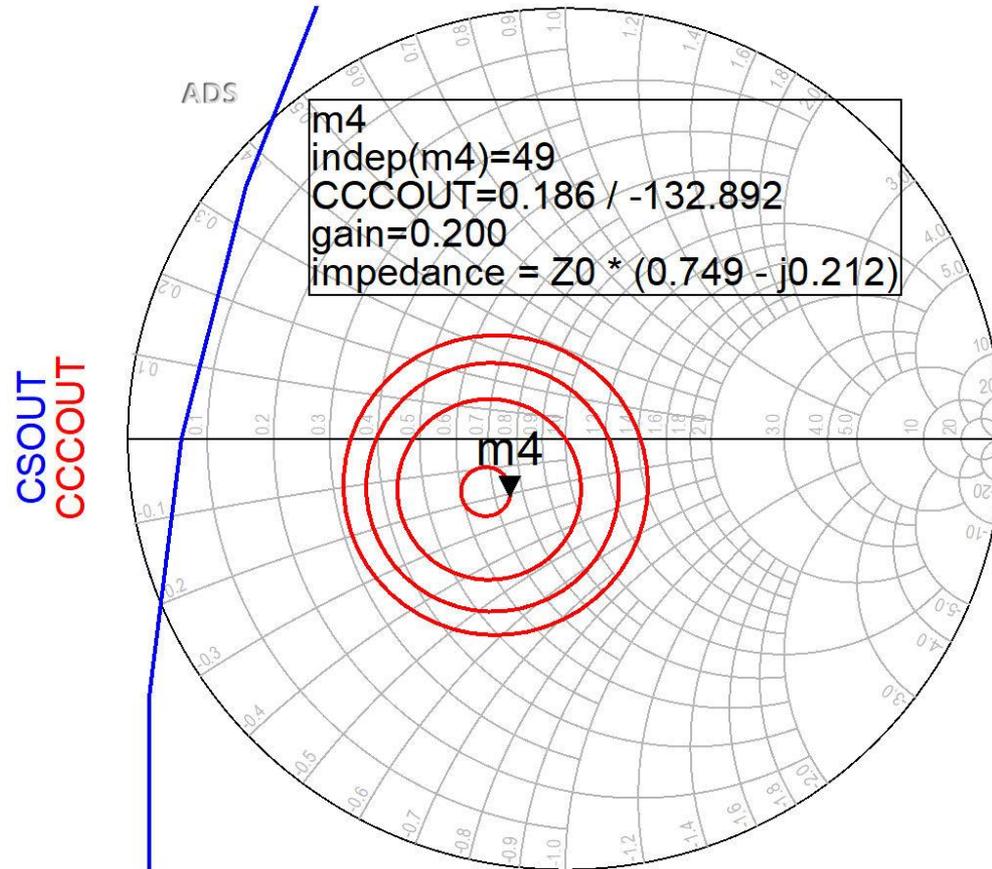
$$\cos(\varphi + 2\theta) = -|\Gamma_S| \quad \text{Im}[y_S(\theta)] = \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}$$

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

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

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

Adaptare la iesirea etajului 2 (L2)



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

Adaptare la iesirea etajului 2 (L2)

- G_{L2} : Pozitia m_4 de pe grafic

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

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

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

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

$$\theta_{sp} = \tan^{-1}(\text{Im}[y_L(\theta)]) = \tan^{-1}\left(\frac{\mp 2 \cdot |\Gamma_L|}{\sqrt{1 - |\Gamma_L|^2}}\right)$$

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

Proiectare etaje cascade

- Castig

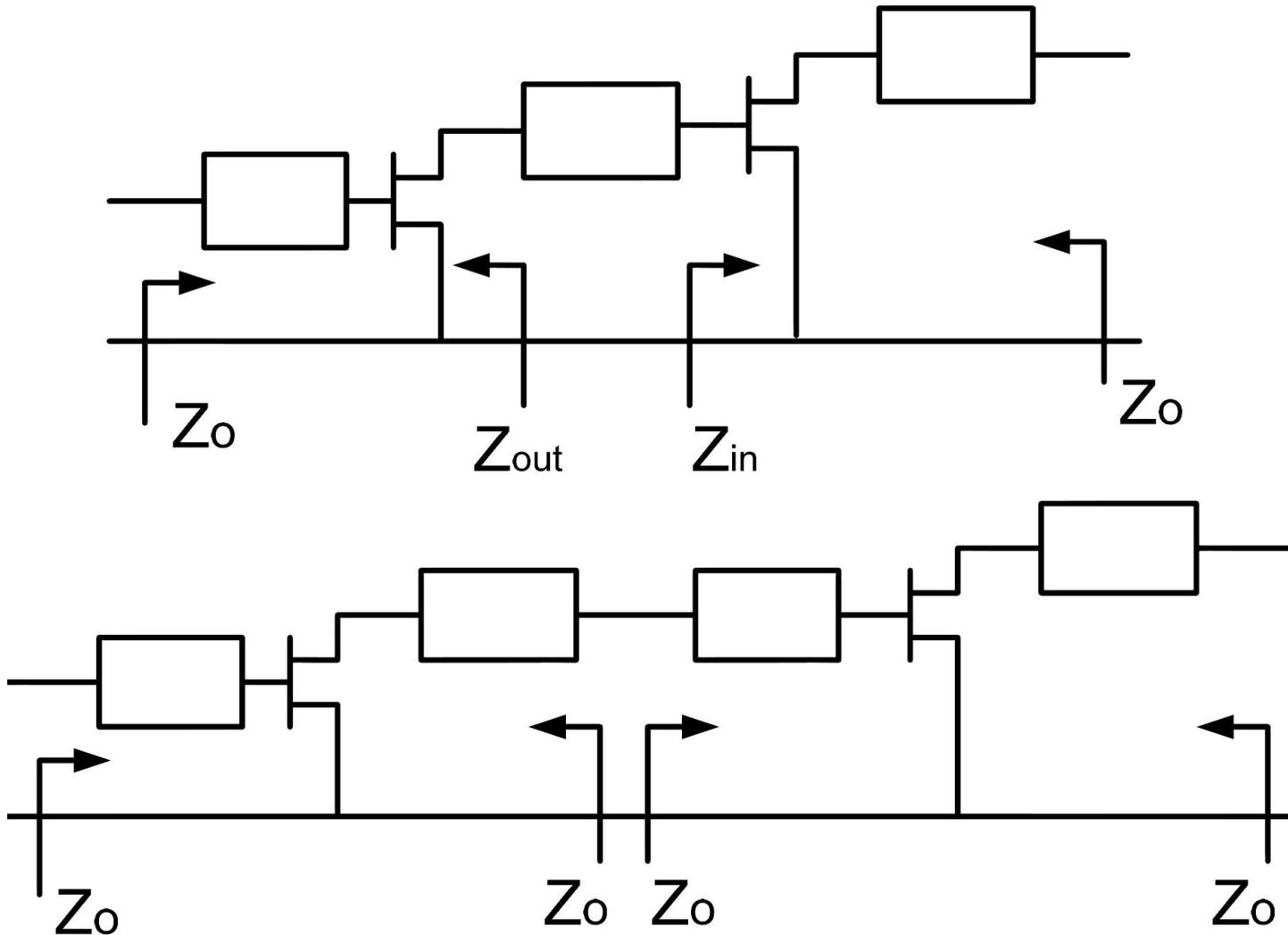
$$G_T [dB] = G_{S1} [dB] + G_0 [dB] + G_{L1} [dB] + G_{S2} [dB] + G_0 [dB] + G_{L2} [dB]$$

$$G_T [dB] = 1 \text{ dB} + 10 \text{ dB} + G_{L1} [dB] + G_{S2} [dB] + 10 \text{ dB} + 0.2 \text{ dB}$$

$$G_T [dB] = 21.2 \text{ dB} + G_{L1} [dB] + G_{S2} [dB]$$

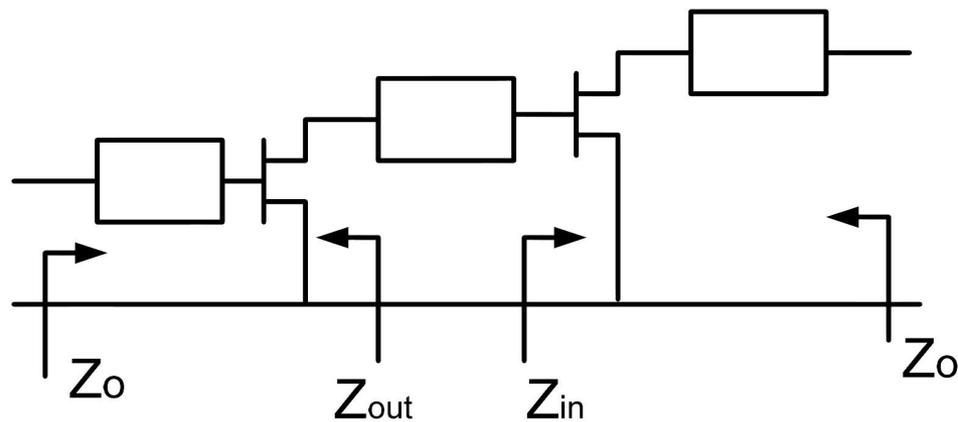
- Prin proiectarea inter-etaje trebuie obtinut un castig de minim 0.8dB prin adaptare mai buna a primului etaj la iesire si a celui de-al doilea la intrare

Adaptare inter-etaje 1/2

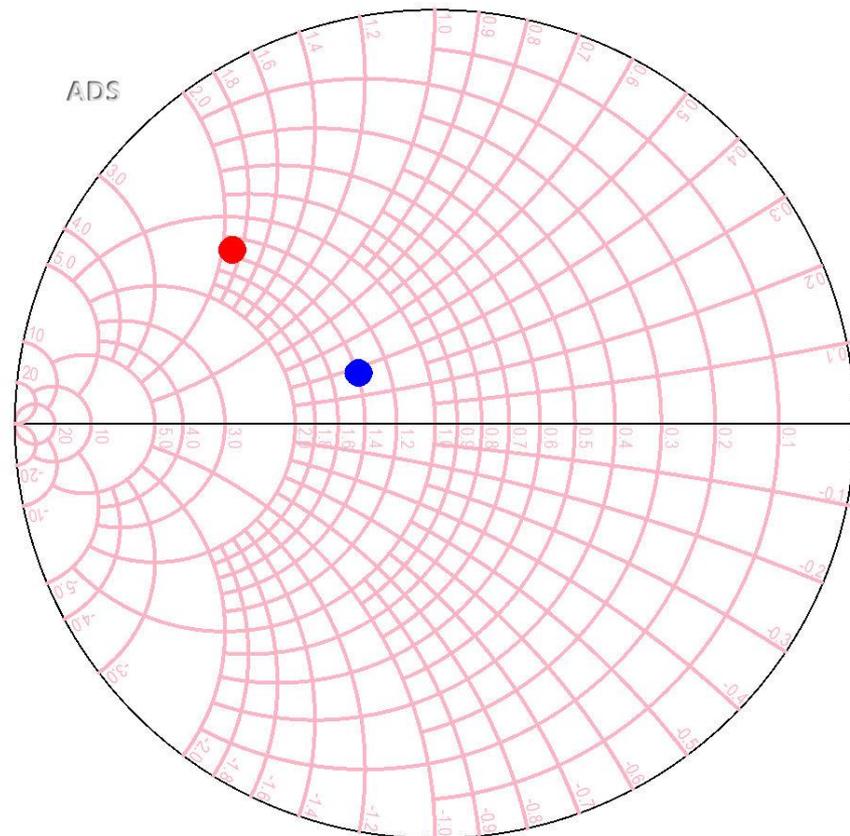


Adaptare inter-etaje 1

- O singura linie de transmisie pastreaza modulul coeficientului de reflexie



$s(2,2)$
 $s(1,1)$



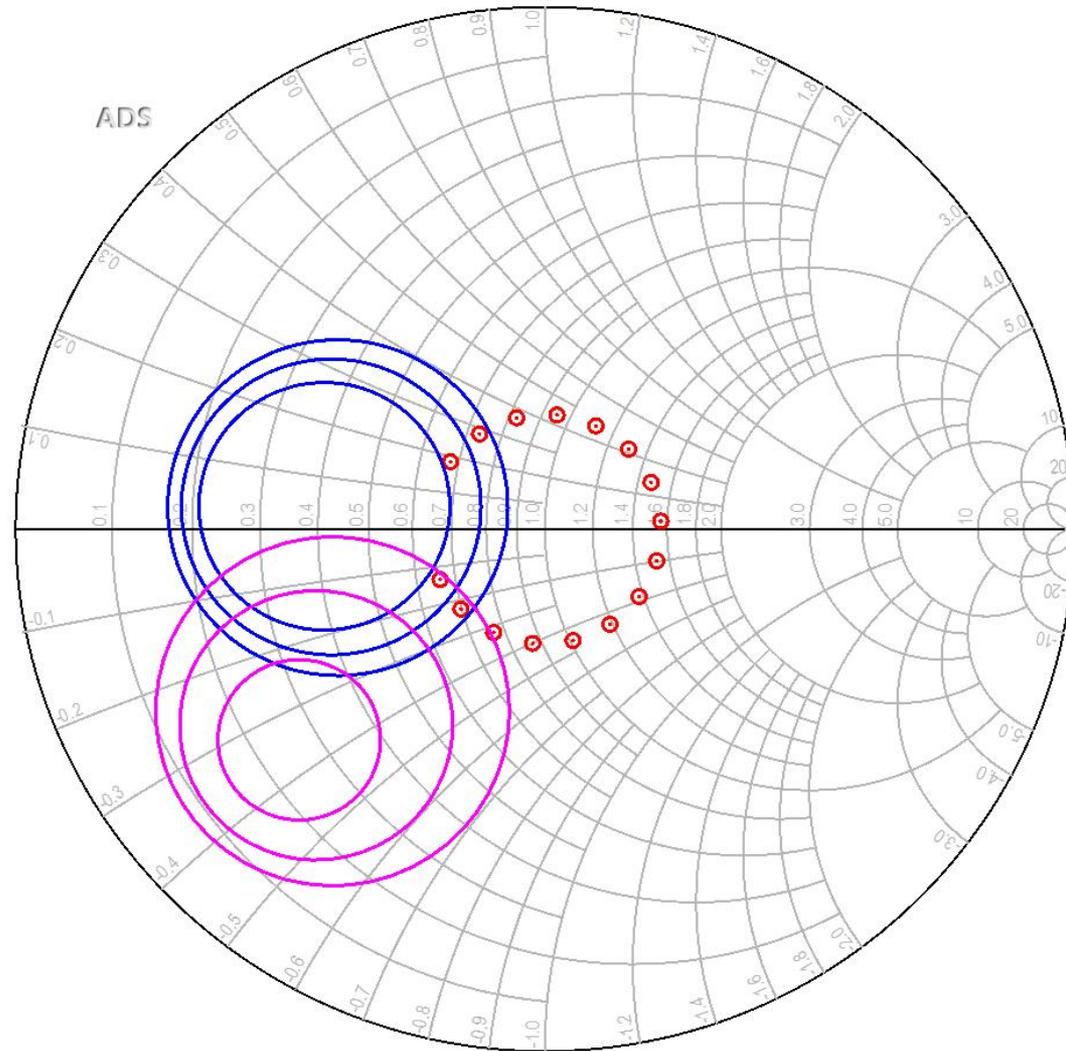
Adaptare inter-etaje 1

- Se poate face in doua moduri:
 - plecand de la iesirea primului etaj (coeficient de reflexie S_{22}) spre cercurile (desenate pentru etajul al doilea) de:
 - stabilitate
 - castig
 - zgomot
 - plecand de la intrarea celui de-al doilea etaj (coeficient de reflexie S_{11}) spre cercurile (desenate pentru primul etaj) de:
 - stabilitate
 - castig
- Prima varianta are avantajul de a controla zgomotul introdus de al doilea etaj

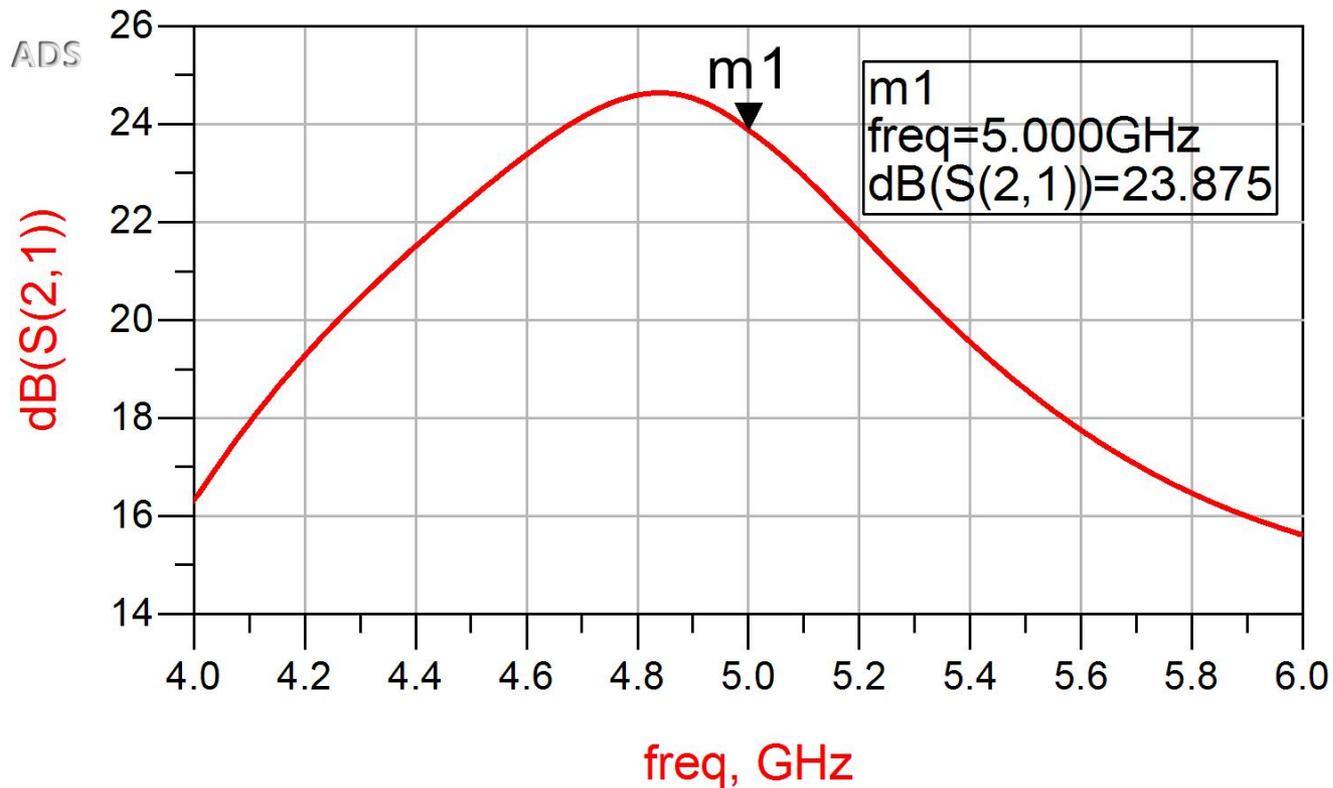
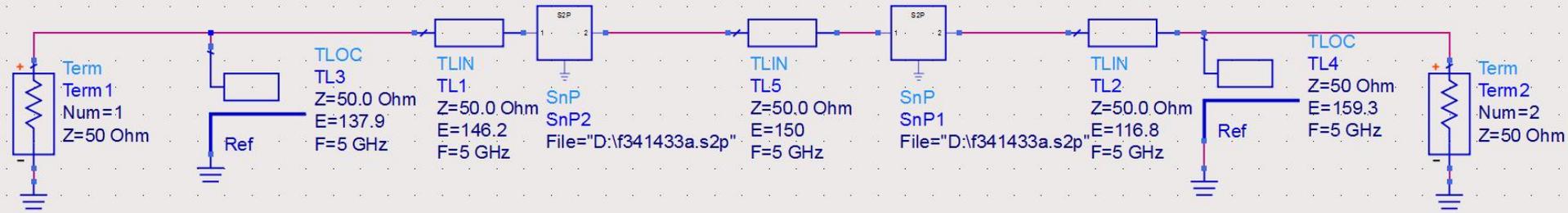
Adaptare inter-etaje 1

- O **singura** linie de transmisie permite atingerea unui punct care nu poate fi optimizat
 - $G_{L1} = 0.2 \text{ dB}$
 - $G_{S2} = 1 \text{ dB}$
 - $F_2 = 0.7 \text{ dB}$
- Elimina posibilitatea de reglaj pentru controlul in banda larga a amplificarii

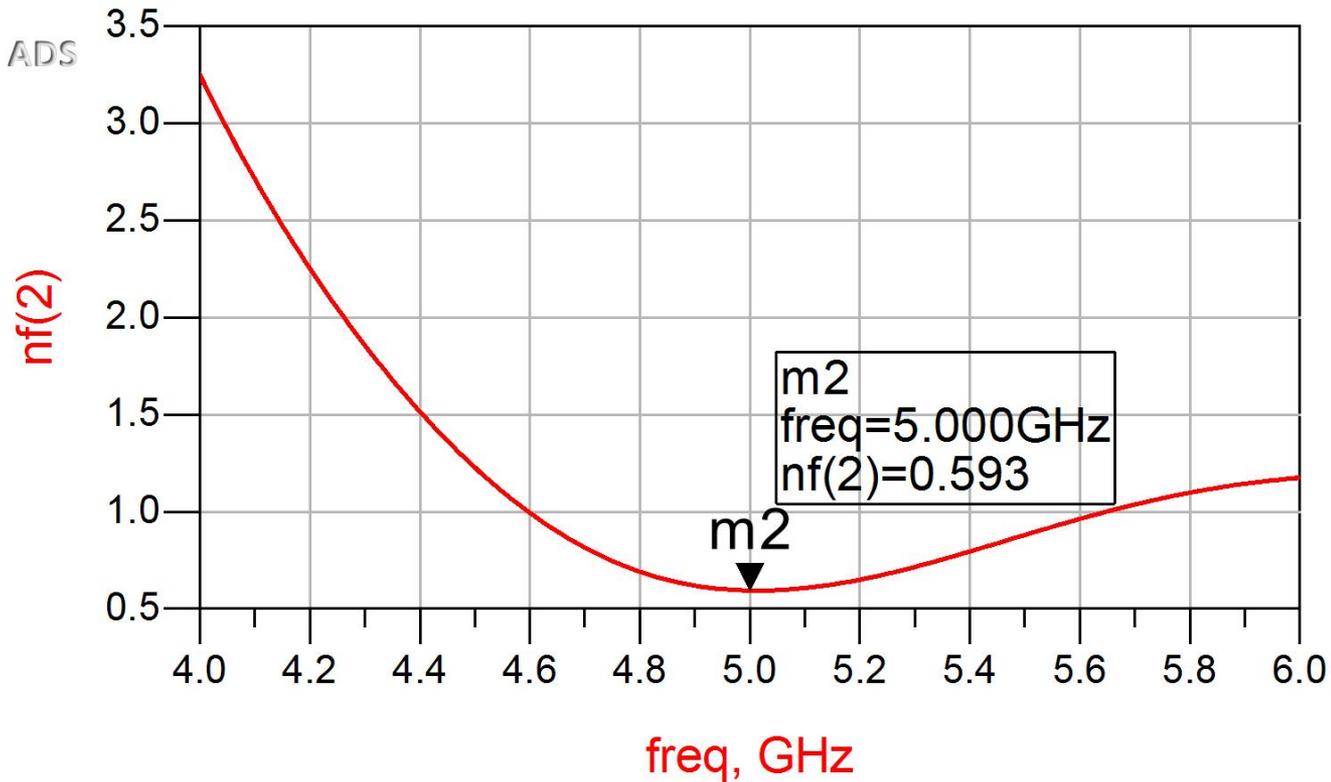
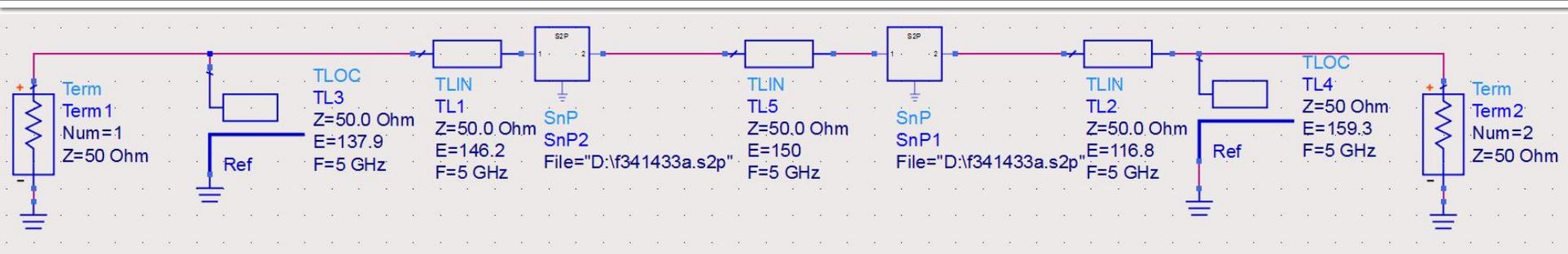
ref..CCCIN
ref..CZ
S(2,2)



ADS

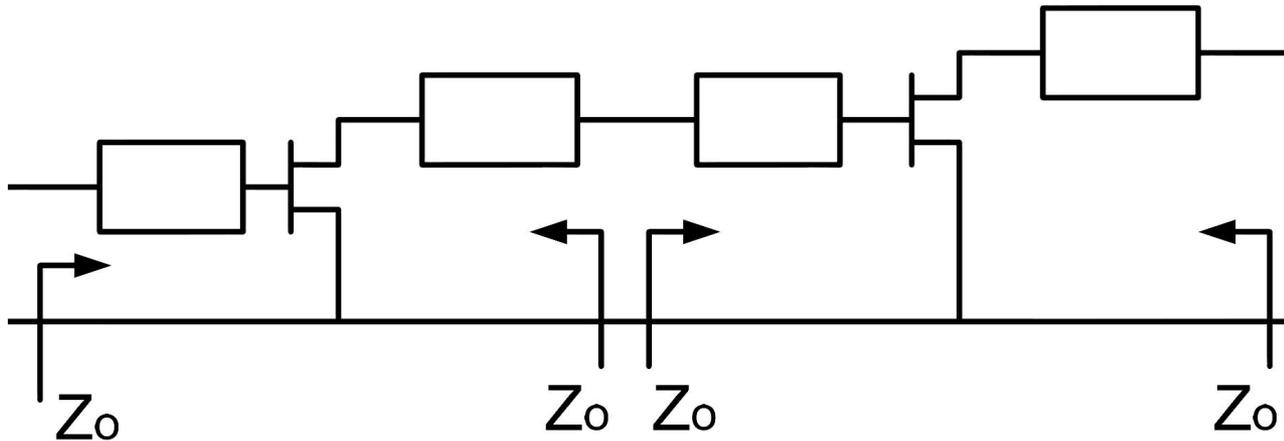


ADS



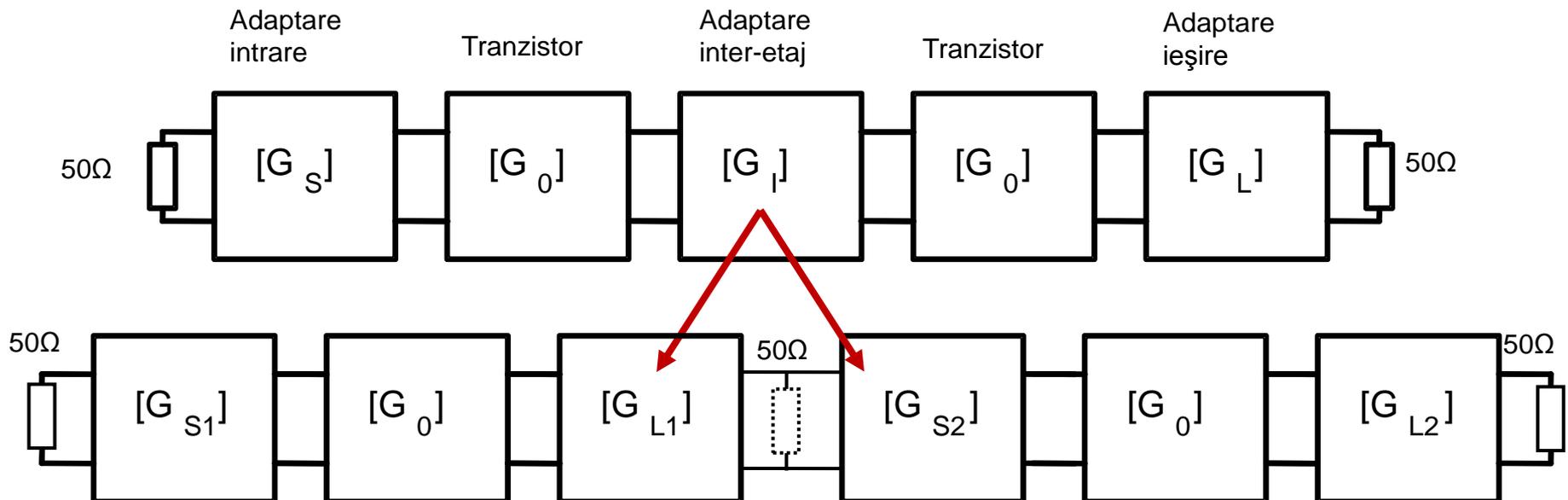
Adaptare inter-etaje 2

- Utilizarea mai multor linii de transmisie pentru adaptarea la un punct intermediar cu coeficient de reflexie $\Gamma=0$ permite controlul in detaliu al punctului final



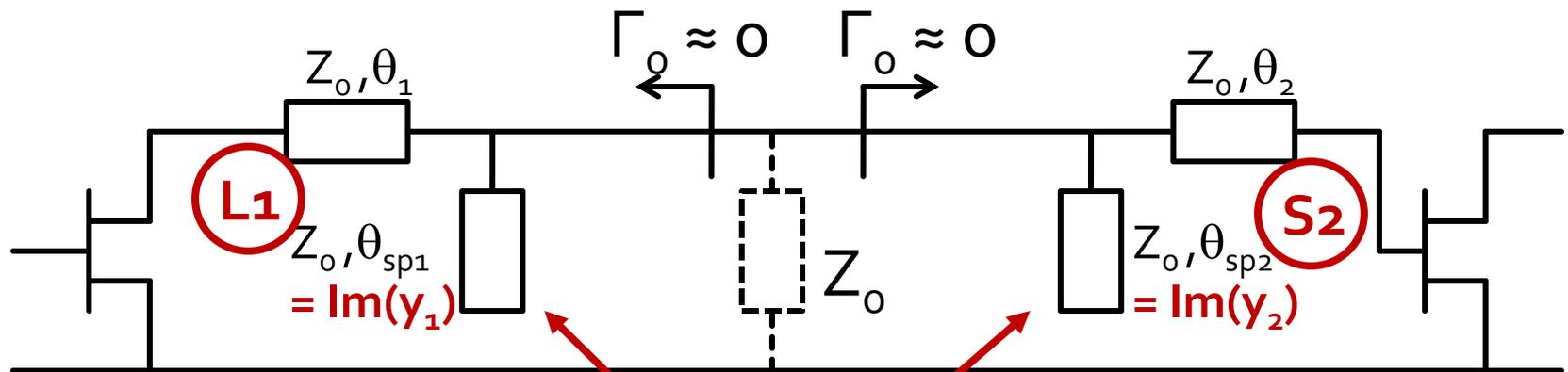
Adaptare inter-etaje 2

- Utilizarea mai multor linii de transmisie pentru adaptarea la un punct intermediar cu coeficient de reflexie $\Gamma=0$ permite controlul in detaliu al punctului final



Adaptare inter-etaje 2

- Unul din etaje creaza prin reteaua sa de adaptare un coeficient de reflexie $\Gamma=0$ la care apoi se adapteaza celalalt etaj



Cele doua stub-uri in paralel se combina intr-unul singur

Adaptare inter-etaje 2

- Cele doua stub-uri in paralel se combina intr-unul singur

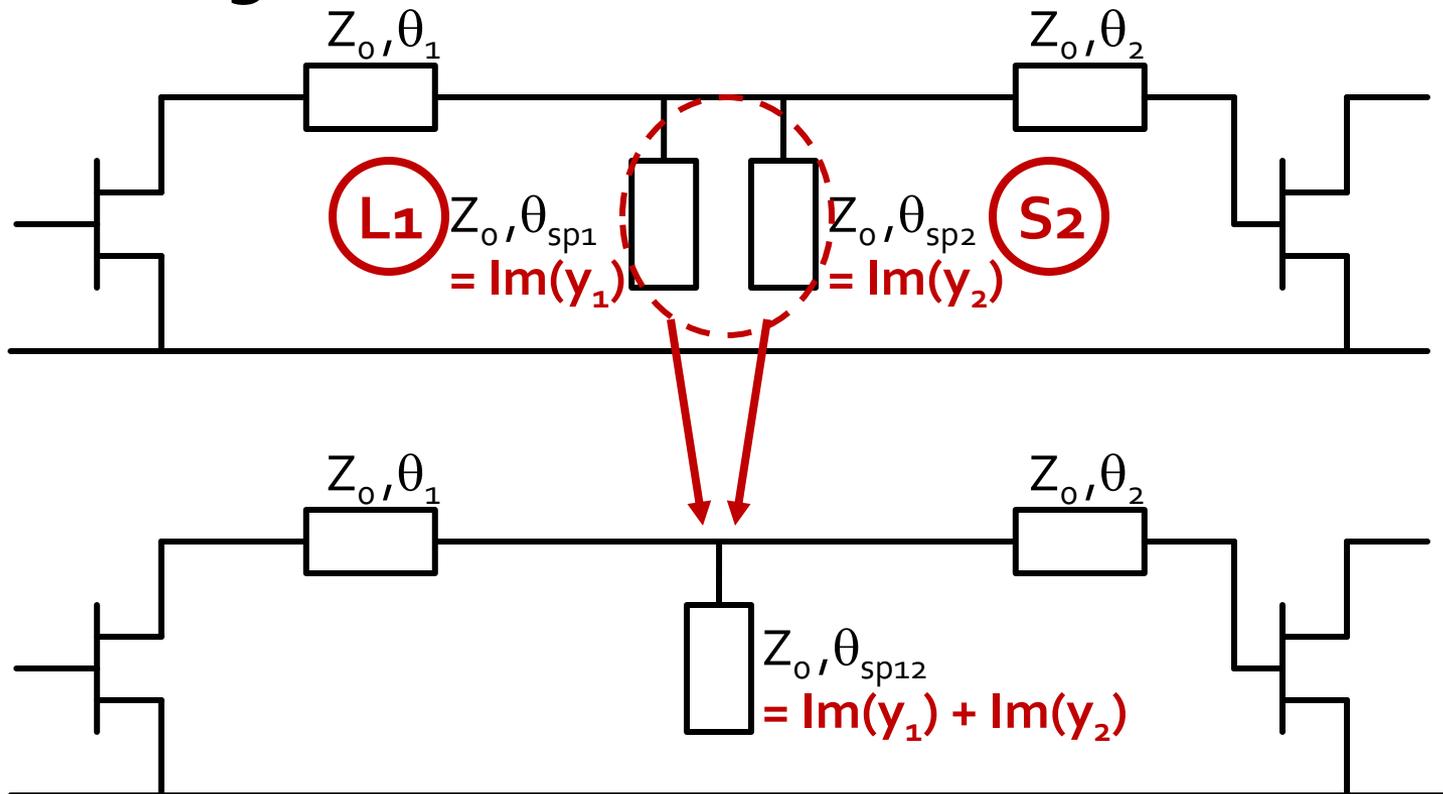
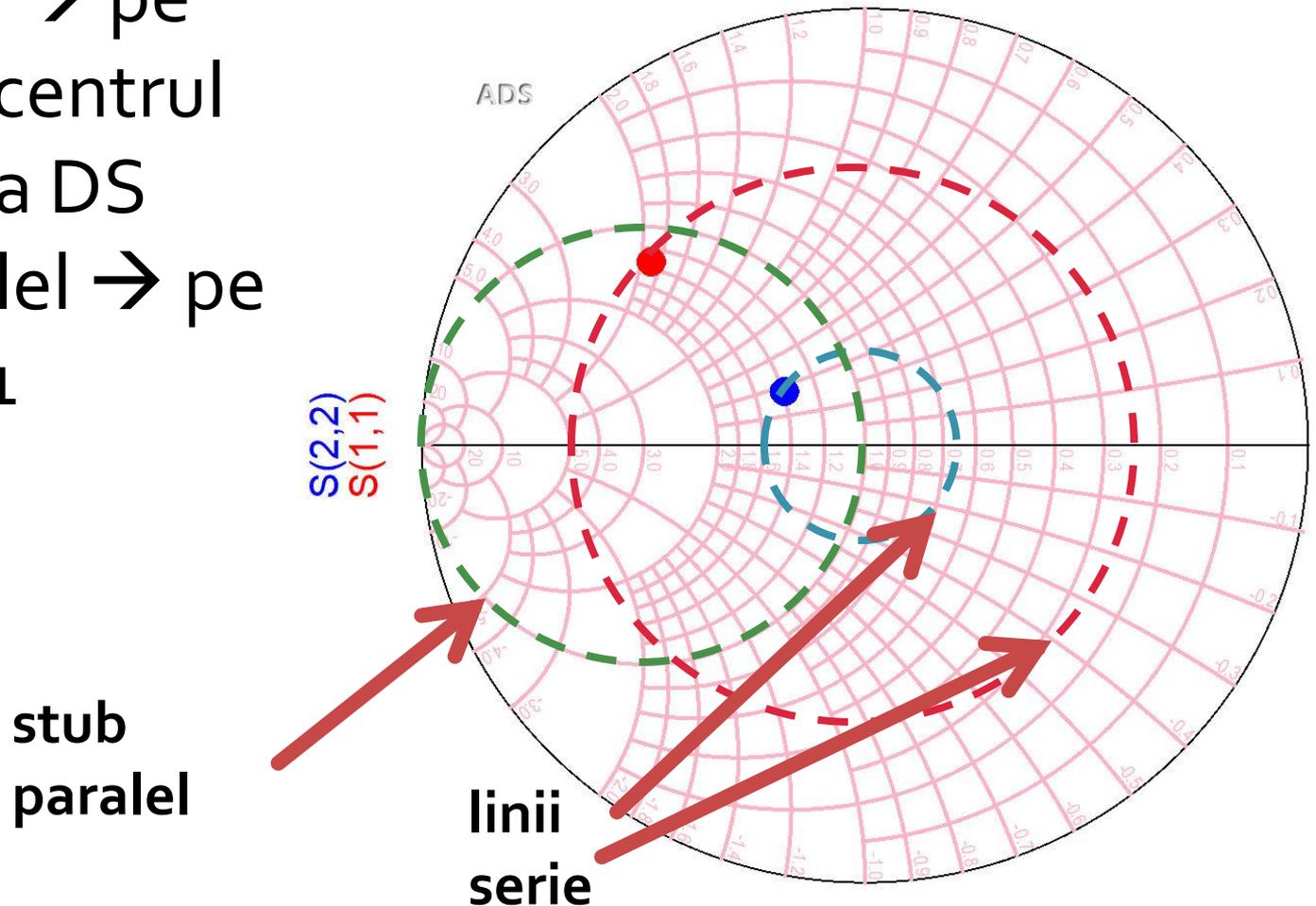


Diagrama Smith

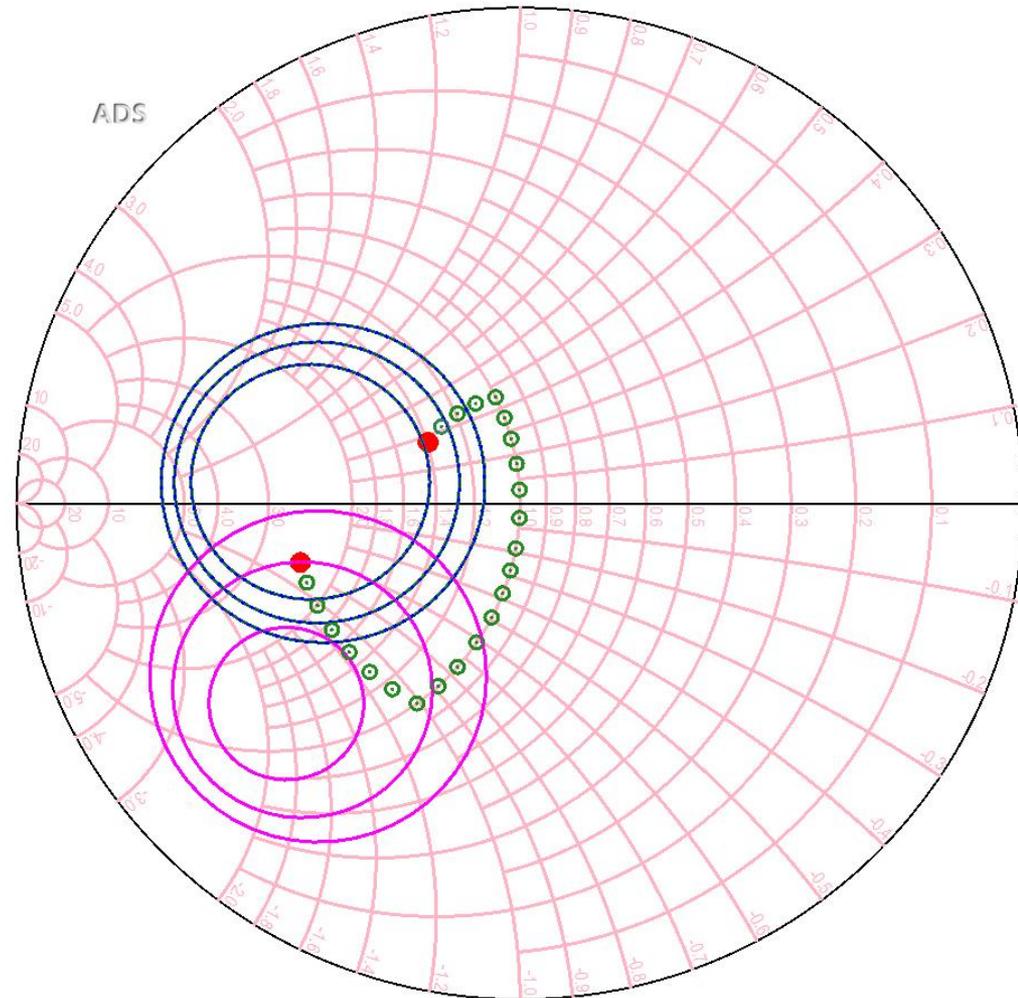
- linie serie \rightarrow pe cercul cu centrul in originea DS
- stub paralel \rightarrow pe cercul $g=1$



Adaptare inter-etaje 2

- Pentru fiecare etaj utilizam o linie serie si un stub paralel
 - Linia serie muta coeficientul de reflexie pe cercul unitate $g=1$
 - Stub-ul paralel muta punctul in centrul diagramei (adaptare la Z_0)
- Cele doua stub-uri in paralel se combina intr-unul singur

ref..CCCIN
ref..CZ
S(2,2)



Adaptare la iesirea etajului 1 (L1)

- G_{L1} (putem folosi tot punctul de la iesirea L2)

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

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

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

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

- nu se mai calculeaza θ_{sp} deoarece **nu** va fi necesar

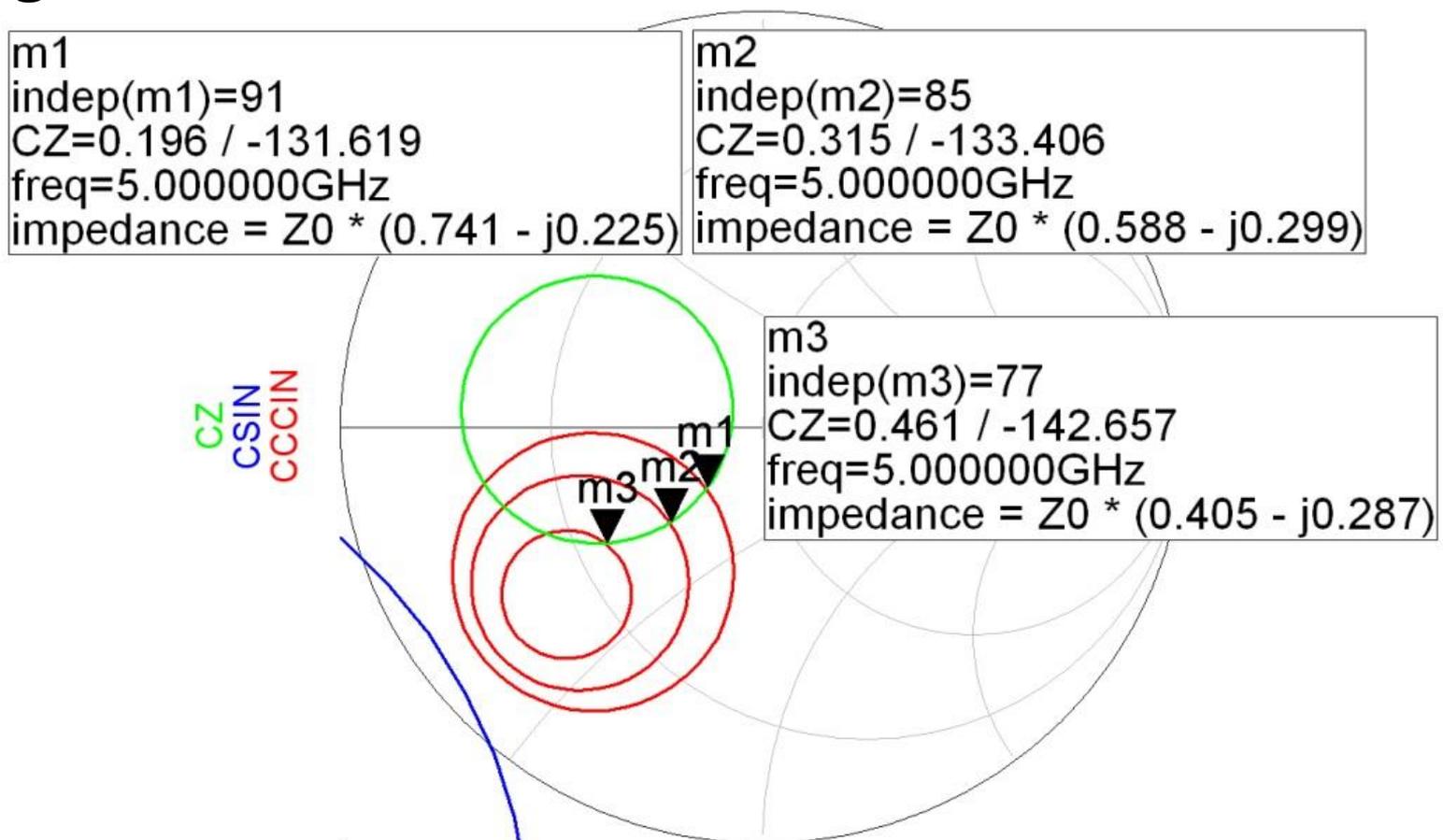
$$(\varphi + 2\theta) = \begin{cases} +100.72^\circ \\ -100.72^\circ \end{cases} \quad \theta = \begin{cases} 116.8^\circ \\ 16.1^\circ \end{cases} \quad \text{Im}[y_L(\theta)] = \begin{cases} -0.379 \\ +0.379 \end{cases}$$

Adaptare la iesirea etajului 1 (L1)

Ecuatie	Soluția L1A	Soluția L1B
$\Phi+2\theta$	$+100.72^\circ$	-100.72°
θ	116.8°	16.1°
$\text{Im}[y(\theta)]$	-0.379	$+0.379$

Adaptare la intrarea etajului 2 (S2)

- G_{S_2} (plecare din Γ_{S_2} ales spre origine – m3 – castig 2dB)



Adaptare la intrarea etajului 2 (S2)

- G_{S_2} (plecare din m_3 spre origine)

$$\Gamma_{S_2} = 0.461 \angle -142.66^\circ \quad |\Gamma_{S_2}| = 0.461; \quad \varphi = -142.66^\circ$$

$$\cos(\varphi + 2\theta) = -|\Gamma_{S_2}| \quad \text{Im}[y_{S_2}(\theta)] = \frac{\mp 2 \cdot |\Gamma_{S_2}|}{\sqrt{1 - |\Gamma_{S_2}|^2}}$$

$$\cos(\varphi + 2\theta) = -0.461 \Rightarrow (\varphi + 2\theta) = \pm 117.45^\circ$$

- nu se mai calculeaza θ_{sp} deoarece **nu** va fi necesar

$$(\varphi + 2\theta) = \begin{cases} +117.45^\circ \\ -117.45^\circ \end{cases} \quad \theta = \begin{cases} 130.1^\circ \\ 12.6^\circ \end{cases} \quad \text{Im}[y_{S_2}(\theta)] = \begin{cases} -1.039 \\ +1.039 \end{cases}$$

Adaptare la intrarea etajului 2 (S2)

Ecuatie	Soluția S2A	Soluția S2B
$\Phi+2\theta$	+117.45°	-117.45°
θ	130.1°	12.6°
$\text{Im}[y(\theta)]$	-1.039	+1.039

Combinarea celor 2 stub-uri paralele

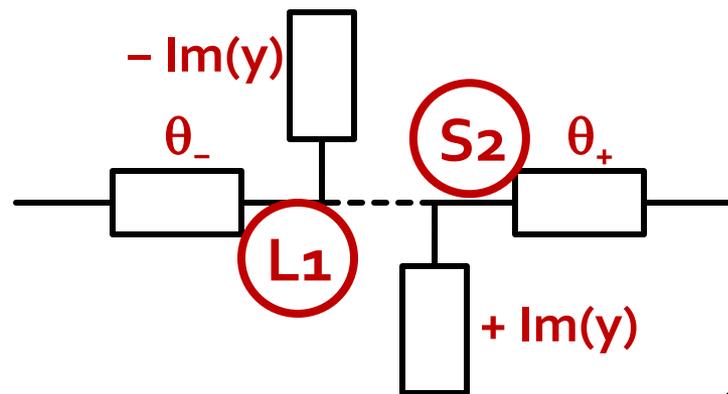
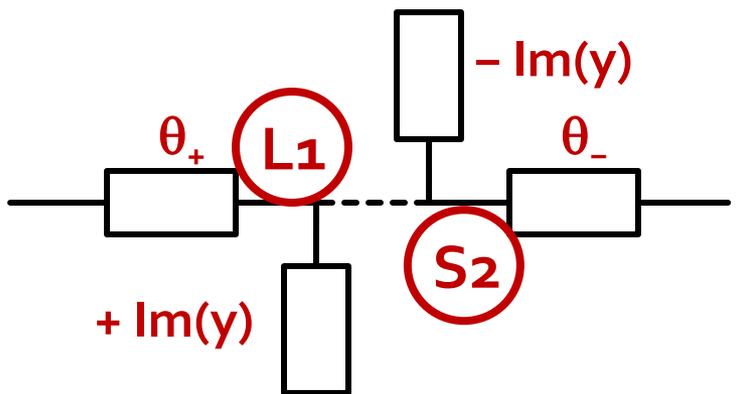
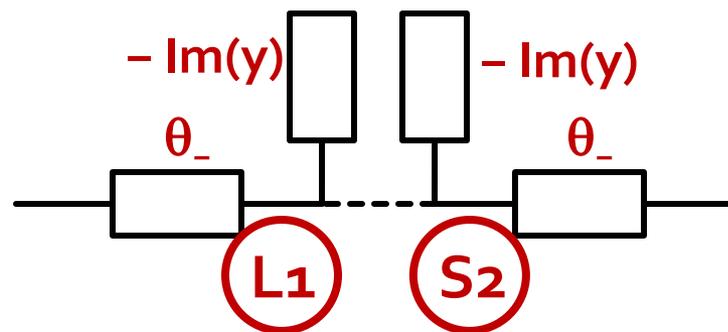
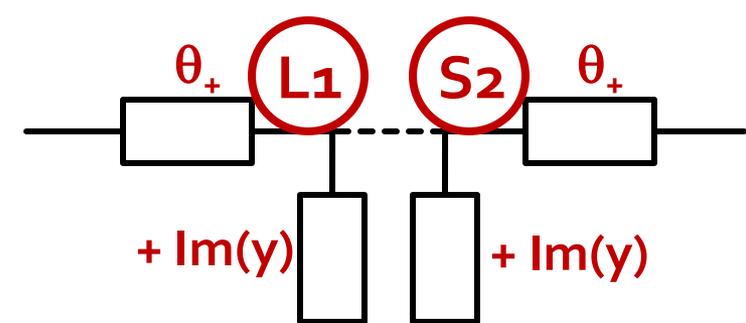
- Cele doua stub-uri in paralel se combina intr-unul singur
- Exista **4 combinatii posibile** in functie de cum se combina lungimile electrice alese pentru cele doua linii serie
 - pentru fiecare lungime electrica aleasa (θ) se foloseste obligatoriu $\text{Im}[y(\theta)]$ corespunzator

■ Ex:

$$\theta_{L1} = 158.4^\circ \quad \theta_{S2} = 135.9^\circ \quad \text{Im}[y_{sp}] = \text{Im}[y_{L1}(\theta)] + \text{Im}[y_{S2}(\theta)] = -1.653$$
$$\theta_{sp} = \tan^{-1}(\text{Im}[y_{sp}]) \quad \theta_{sp} = 121.2^\circ$$

Combinarea celor 2 stub-uri paralele

- 4 combinatii posibile
 - admitantele sunt in paralel si se **aduna**, nu lungimile electrice



$$Im[y_{sp}] = Im[y_{L1}(\theta)] + Im[y_{S2}(\theta)]$$

$$\theta_{sp} = \tan^{-1}(Im[y_{sp}])$$

Combinarea celor 2 stub-uri paralele

		Soluția S2A	Soluția S2B
		$\theta = 130.1^\circ$ $\text{Im}[y(\theta)] = -1.039$	$\theta = 12.6^\circ$ $\text{Im}[y(\theta)] = +1.039$
Soluția L1A	$\theta = 116.8^\circ$ $\text{Im}[y(\theta)] = -0.379$	$\theta_{L1} = 116.8^\circ$ $\text{Im}[y(\theta)] = -1.418$ $\theta_p = 125.2^\circ$ $\theta_{S2} = 130.1^\circ$	$\theta_{L1} = 116.8^\circ$ $\text{Im}[y(\theta)] = +0.66$ $\theta_p = 33.4^\circ$ $\theta_{S2} = 12.6^\circ$
Soluția L1B	$\theta = 16.1^\circ$ $\text{Im}[y(\theta)] = +0.379$	$\theta_{L1} = 16.1^\circ$ $\text{Im}[y(\theta)] = -0.66$ $\theta_p = 146.6^\circ$ $\theta_{S2} = 130.1^\circ$	$\theta_{L1} = 16.1^\circ$ $\text{Im}[y(\theta)] = -0.66$ $\theta_p = 146.6^\circ$ $\theta_{S2} = 12.6^\circ$

O combinatie posibila

- pentru adaptarea la intrare alegem soluția S1A, în ordine de la intrare spre ieșire:
 - stub paralel cu $E = 137.9^\circ$
 - linie serie cu $E = 146.2^\circ$
- pentru adaptarea dintre etaje alegem combinația L1A/S2A, în ordine de la intrare spre ieșire:
 - linie serie cu $E = 116.8^\circ$
 - stub paralel cu $E = 125.2^\circ$
 - linie serie cu $E = 130.1^\circ$
- pentru adaptarea la ieșire alegem soluția L2A, în ordine de la intrare spre ieșire:
 - linie serie cu $E = 116.8^\circ$
 - stub paralel cu $E = 159.3^\circ$

Rezultat

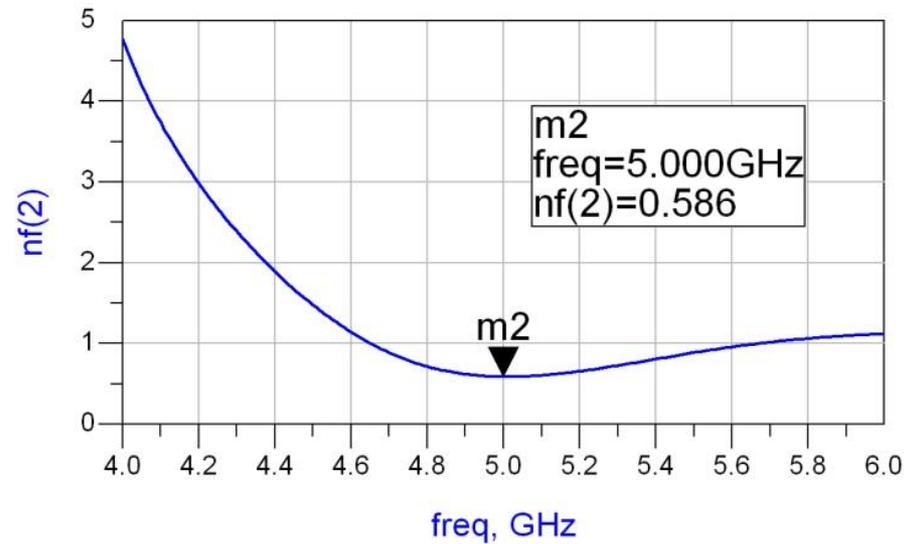
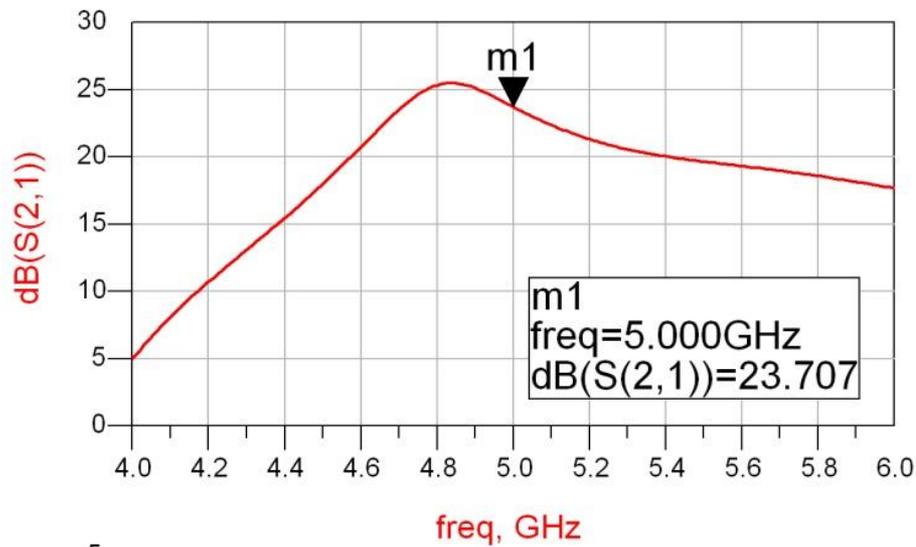
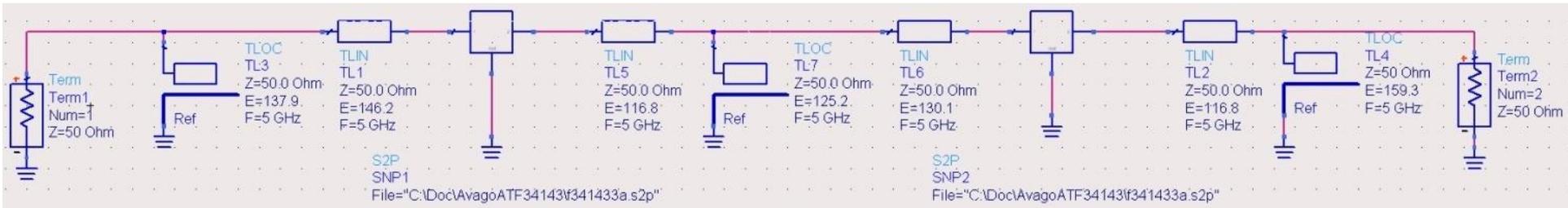


Diagrama Smith

- linie serie \rightarrow pe cercul cu centrul in originea DS
- stub paralel \rightarrow pe cercul $g=1$

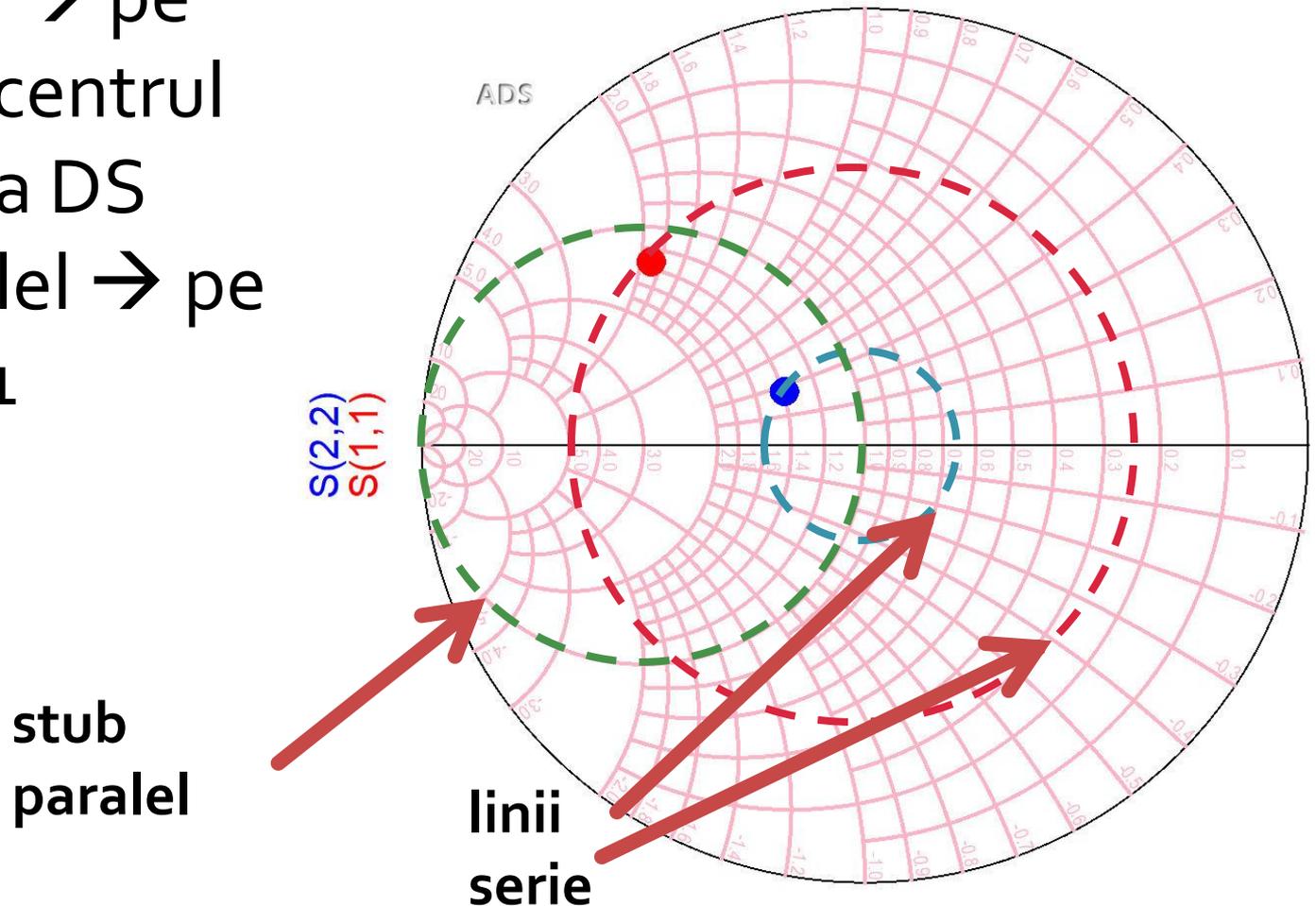


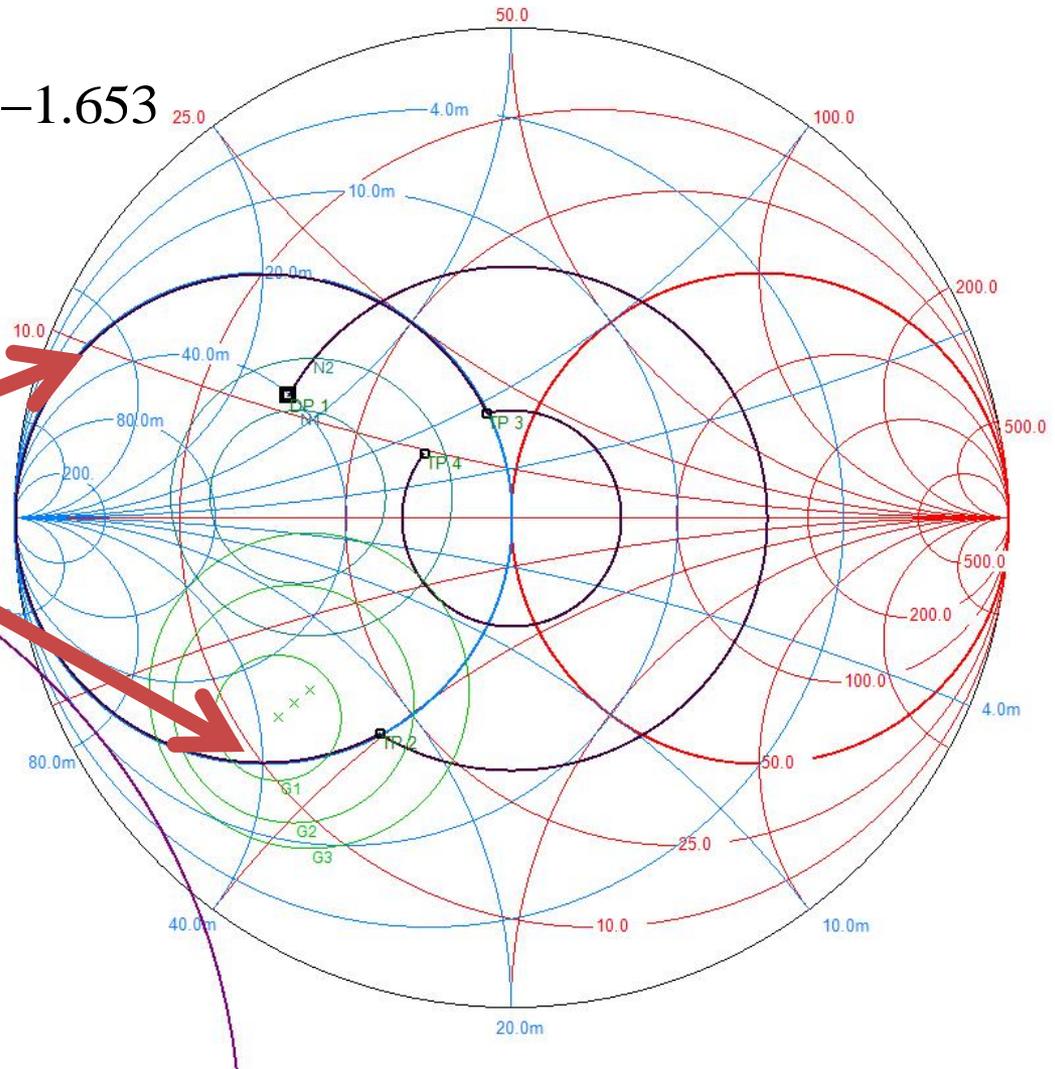
Diagrama Smith 1

$$\theta_{L1} = 158.4^\circ \quad \theta_{S2} = 135.9^\circ$$

$$\text{Im}[y_{sp}] = \text{Im}[y_{L1}(\theta)] + \text{Im}[y_{S2}(\theta)] = -1.653$$

$$\theta_{sp} = 121.2^\circ$$

stub
"combinat"



ADS 1

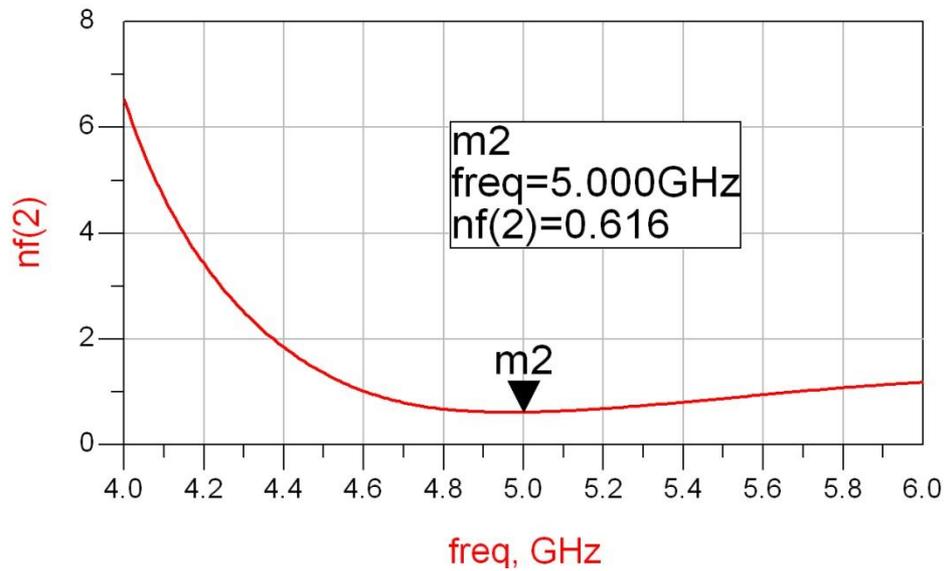
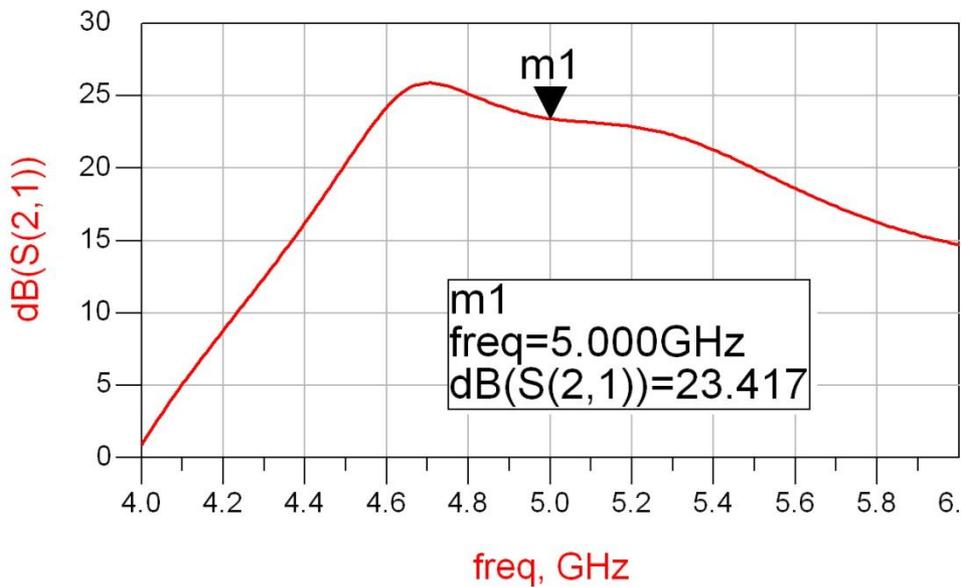
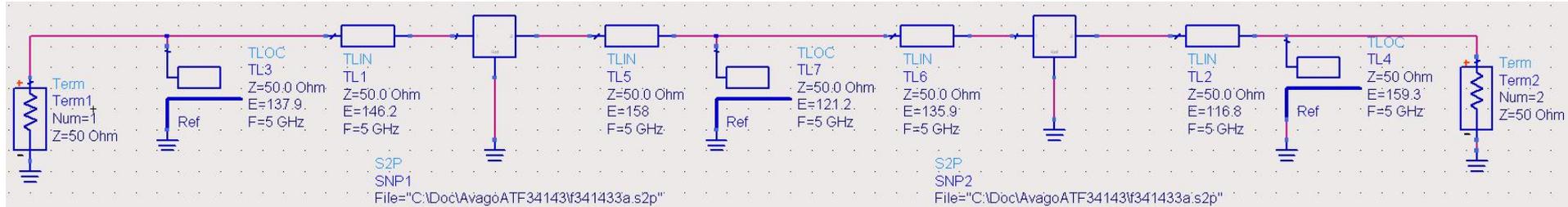


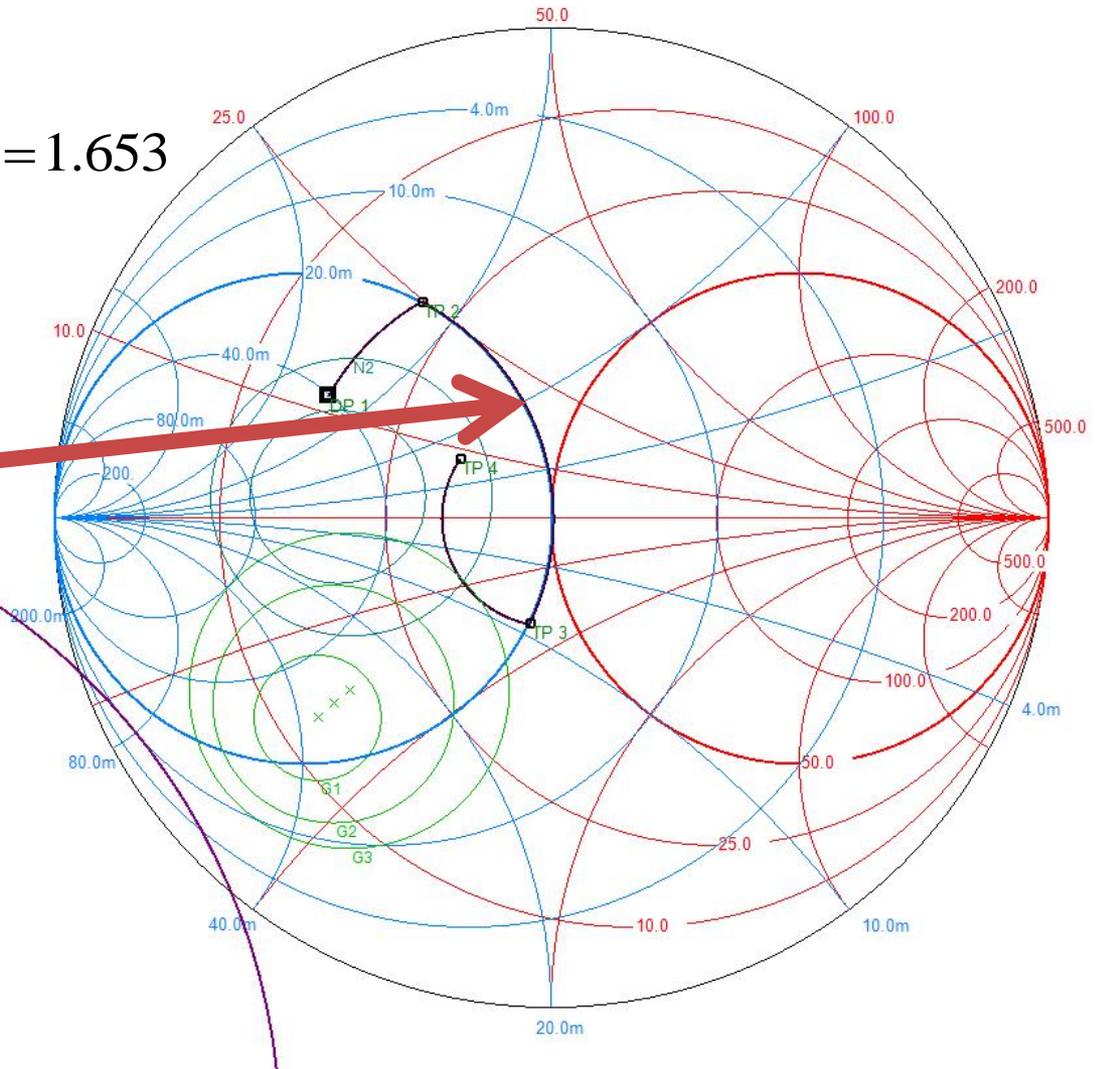
Diagrama Smith 2

$$\theta_{L1} = 55.6^\circ \quad \theta_{S2} = 15^\circ$$

$$\text{Im}[y_{sp}] = \text{Im}[y_{L1}(\theta)] + \text{Im}[y_{S2}(\theta)] = 1.653$$

$$\theta_{sp} = 58.8^\circ$$

stub
"combinat"



ADS 2

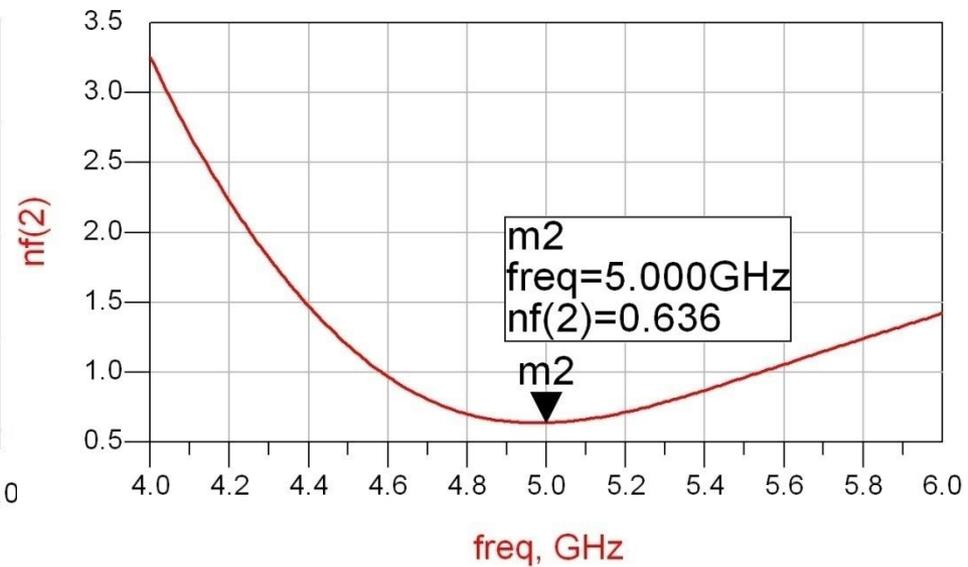
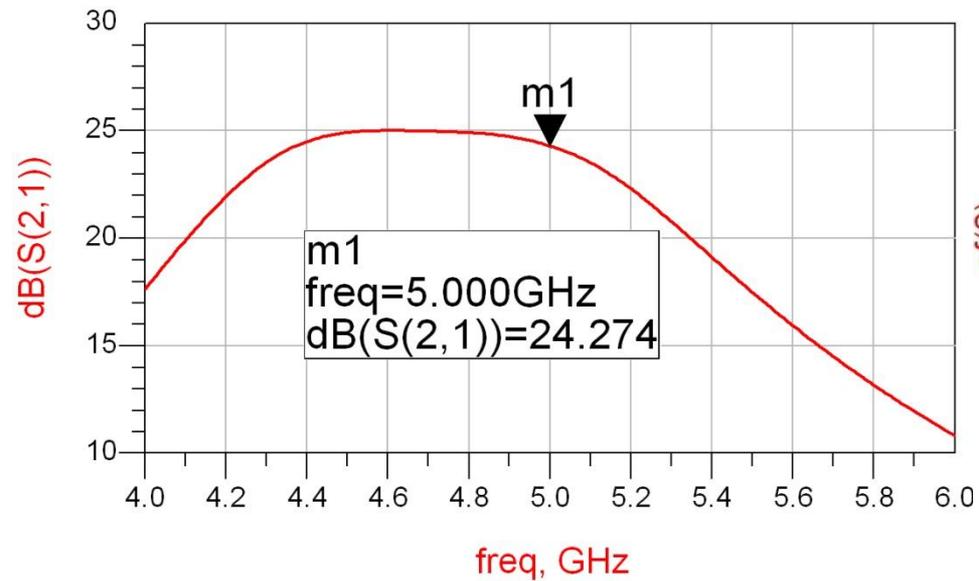
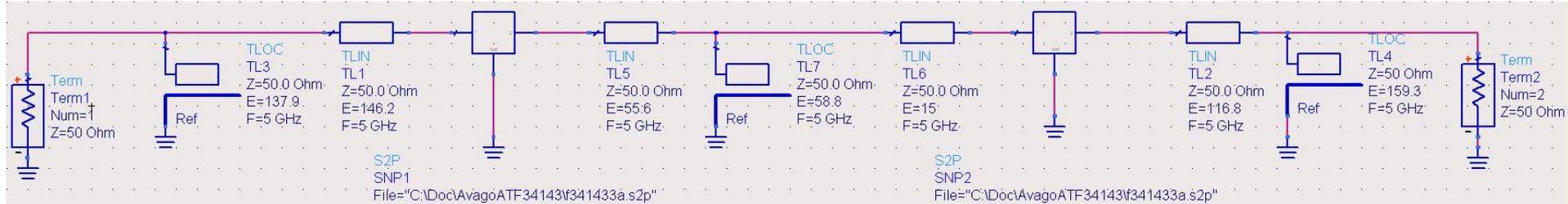


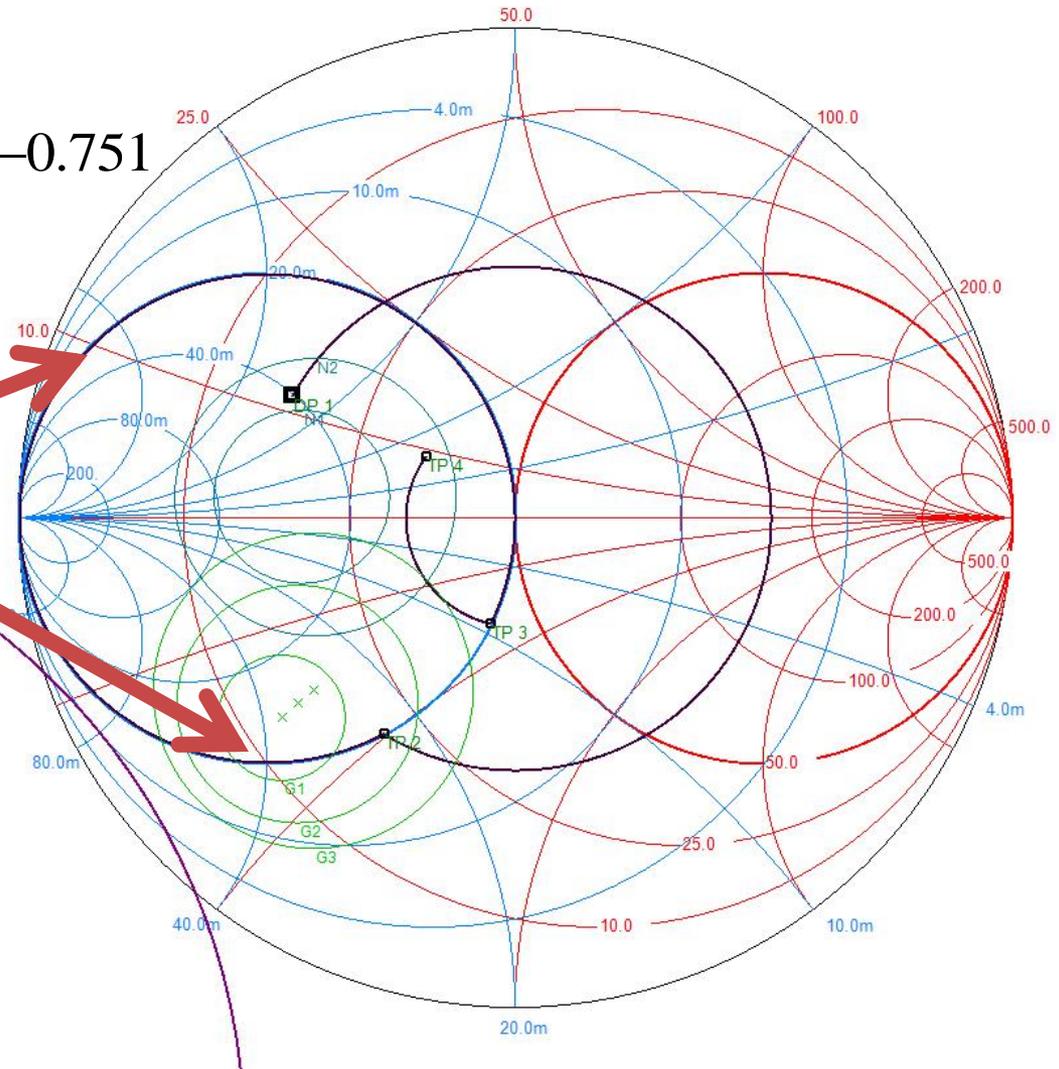
Diagrama Smith 3

$$\theta_{L1} = 55.6^\circ \quad \theta_{S2} = 135.9^\circ$$

$$\text{Im}[y_{sp}] = \text{Im}[y_{L1}(\theta)] + \text{Im}[y_{S2}(\theta)] = -0.751$$

$$\theta_{sp} = 143.1^\circ$$

stub
"combinat"



ADS 3

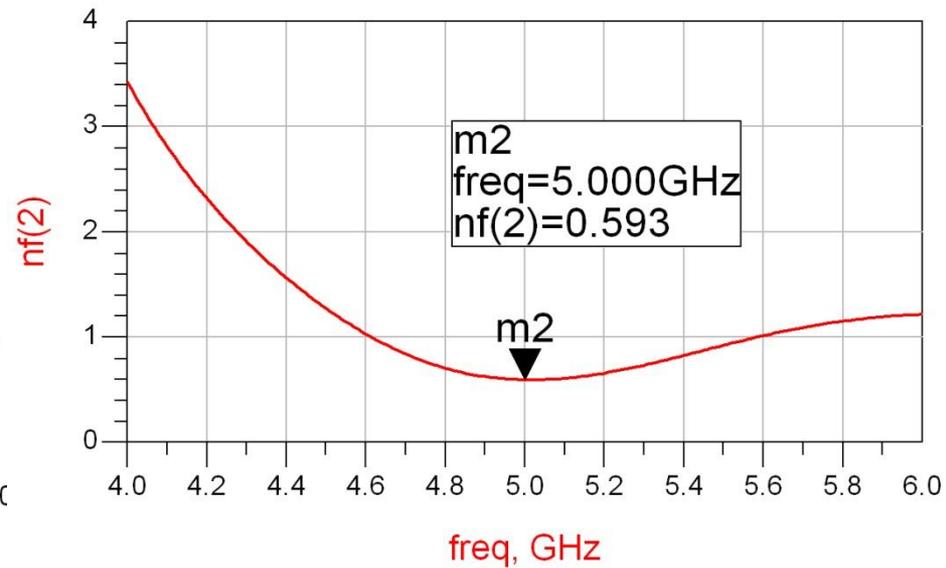
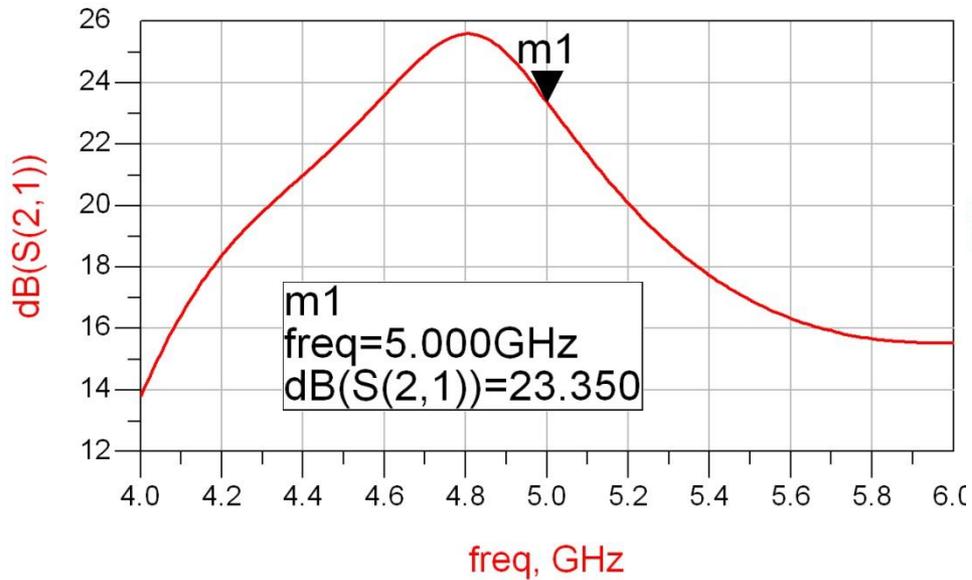
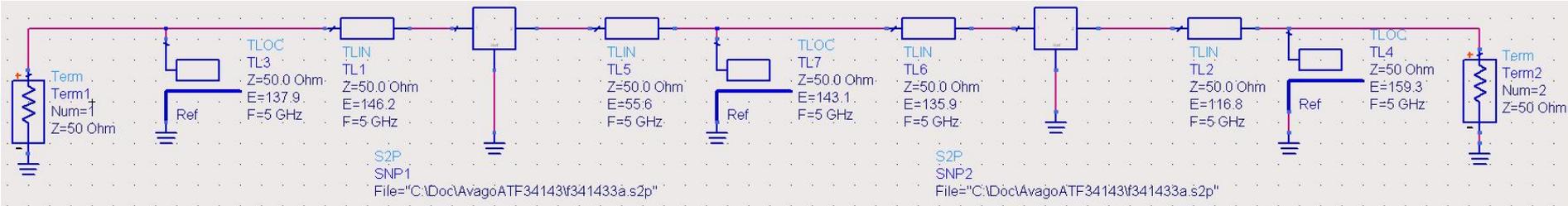


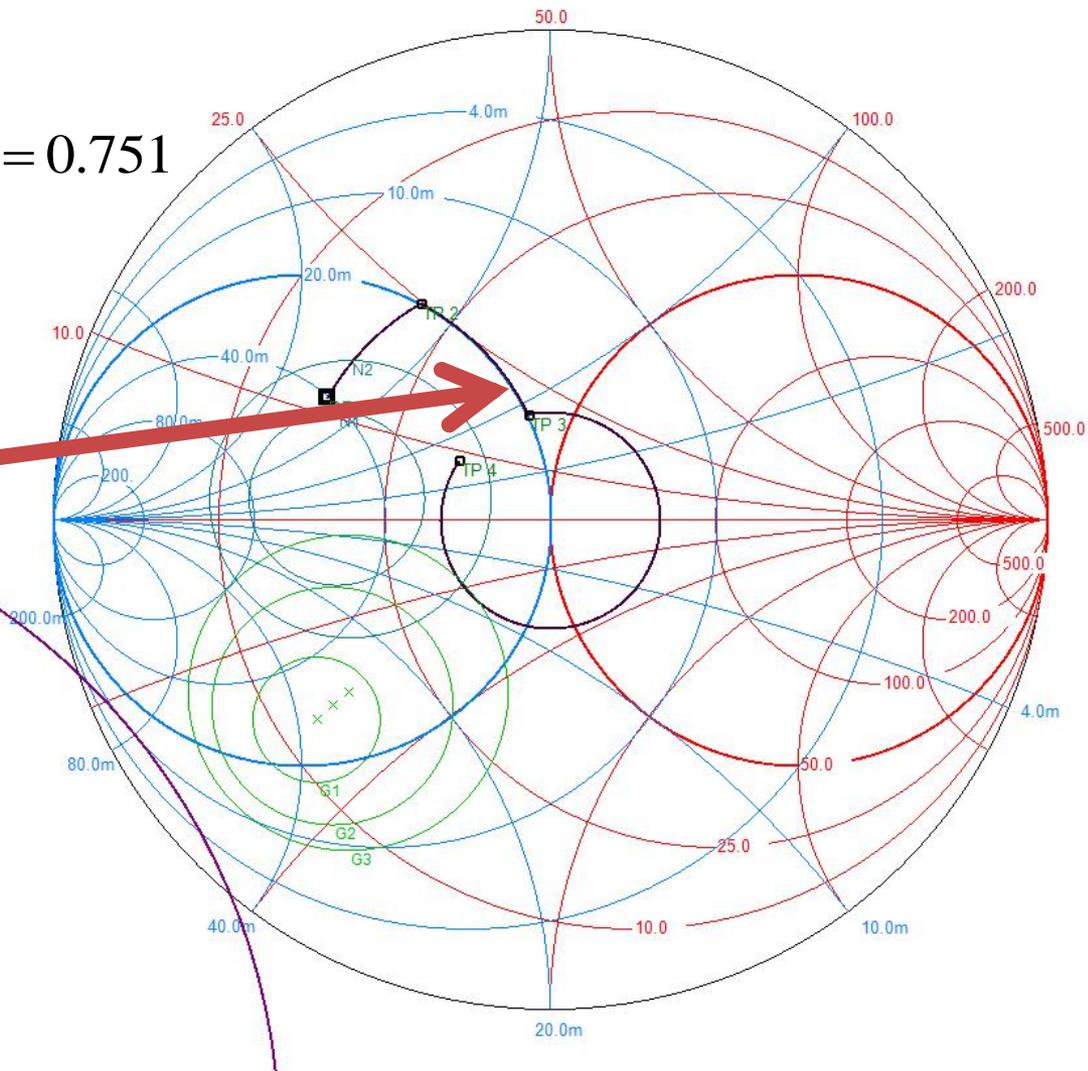
Diagrama Smith 4

$$\theta_{L1} = 158.4^\circ \quad \theta_{S2} = 15^\circ$$

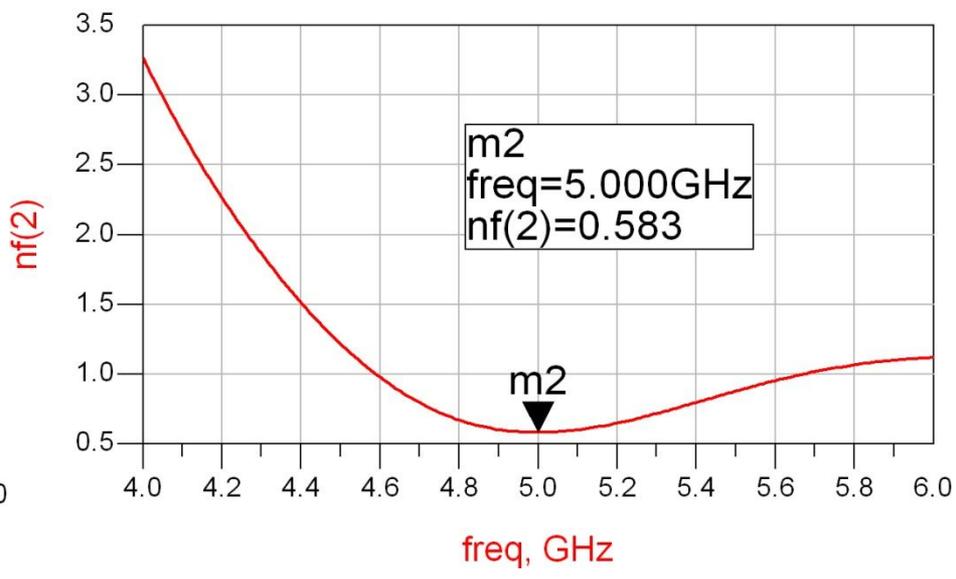
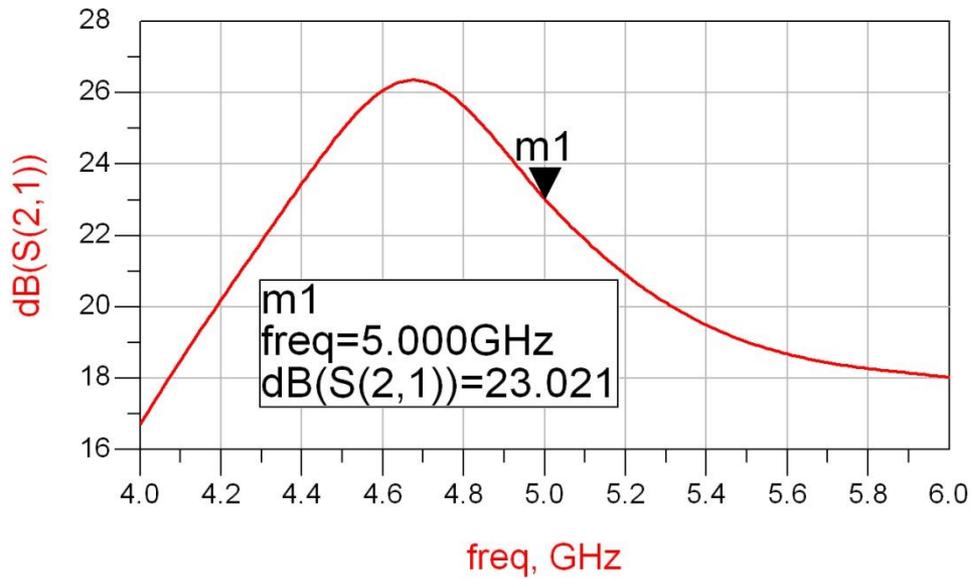
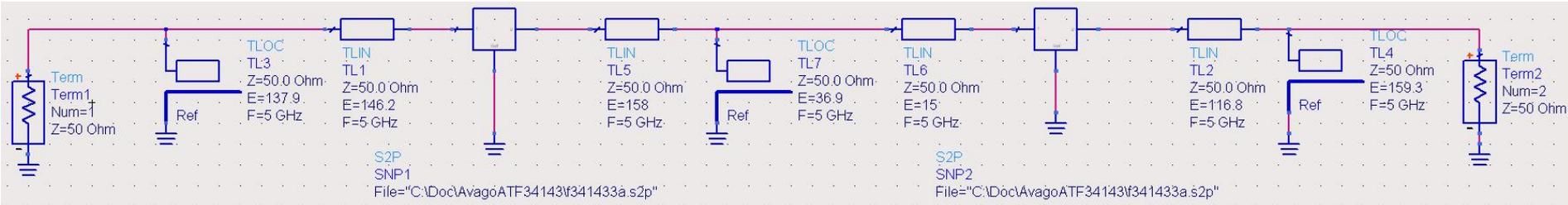
$$\text{Im}[y_{sp}] = \text{Im}[y_{L1}(\theta)] + \text{Im}[y_{S2}(\theta)] = 0.751$$

$$\theta_{sp} = 36.9^\circ$$

stub
"combinat"



ADS 4



Adaptare inter-etaje

- Toate variantele obtinute indeplinesc conditiile de castig si zgomot
- Se alege una convenabila in functie de:
 - dimensiunile fizice ale liniilor $l = \frac{\theta}{360^\circ} \cdot \lambda$
 - comportare in frecventa
 - stabilitate
 - performanta (zgomot/castig)
 - reflexie intrare iesire
 - etc.

Contact

- Laboratorul de microunde si optoelectronica
- <http://rf-opto.etti.tuiasi.ro>
- rdamian@etti.tuiasi.ro