Curs 11
2025/2026

Dispozitive şi circuite de microunde pentru radiocomunicații

Disciplina 2025/2026

- 2C/1L (+1), **DCMR (CDM)**
- **Minim 7 prezente (curs+laborator)**
- Curs - **conf. Radu Damian**
  - Vineri 10-12/**Video (istoric)**, C1, corp C
  - E – **50%** din nota
  - **probleme** + (2p prez. curs) + (3 teste) + (bonus activitate)
    - primul test L1: ~01.10.2025 (t2 si t3 neanuntate la **curs**)
    - 3pz (C) ≈ +0.5p (**2p** max)
  - **toate materialele permise**

Disciplina 2025/2026

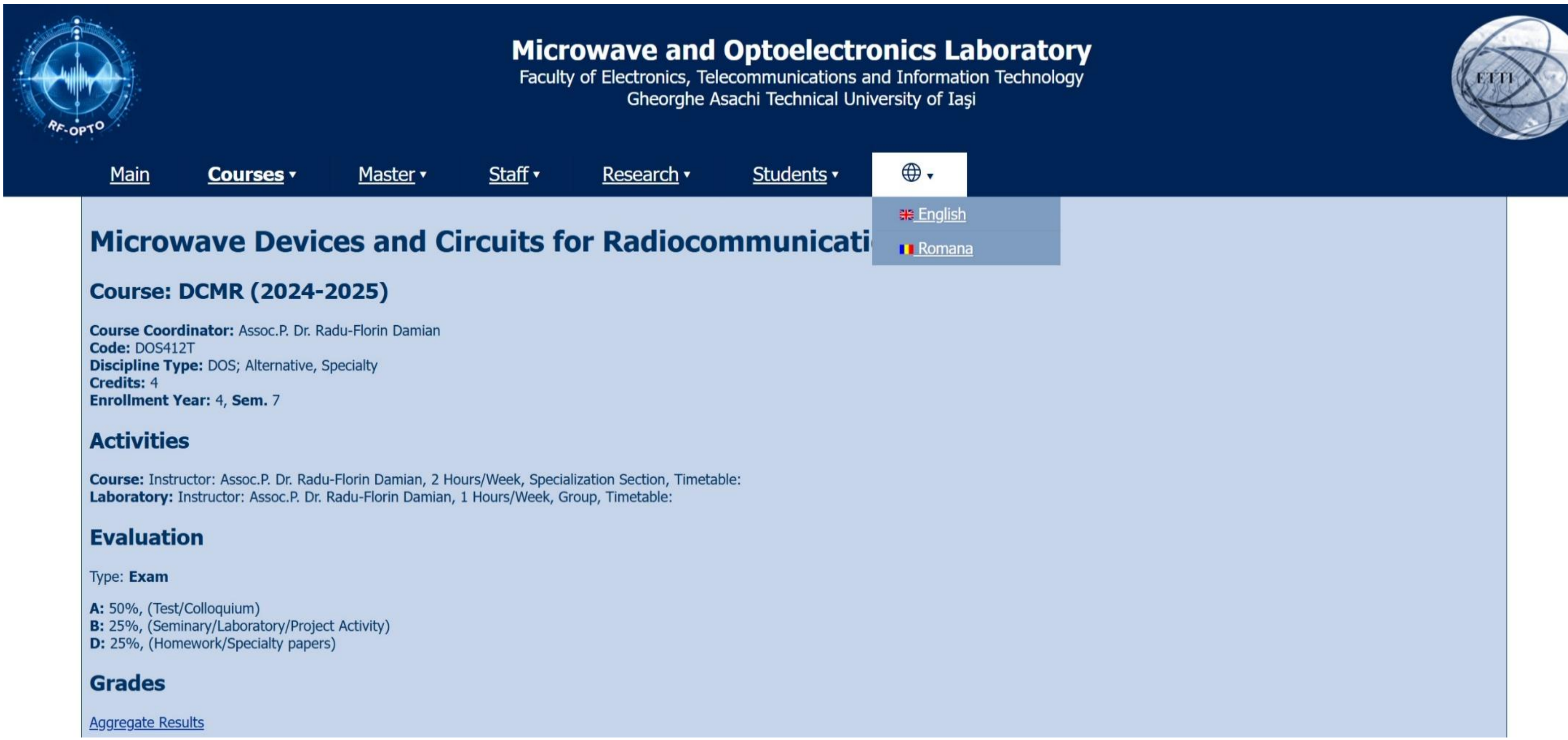
- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
  - L – **25%** din nota
    - ADS, 4 sedinte aplicatii
    - prezenta + **rezultate personale!**
  - P – **25%** din nota
    - ADS, 3 sedinte aplicatii (-1? 21-22.12.2022)
    - tema personala

Programare examen

- **NU** ultimul examen din sesiune
- Toate grupele: P2 sau P6 (C1)
- **Termen**: 10.12

Documentatie

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



Microwave and Optoelectronics Laboratory
Faculty of Electronics, Telecommunications and Information Technology
Gheorghe Asachi Technical University of Iaşi

Main | **Courses** ▾ | Master ▾ | Staff ▾ | Research ▾ | Students ▾

English
Romana

Microwave Devices and Circuits for Radiocommunicati

Course: DCMR (2024-2025)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DOS412T
Discipline Type: DOS; Alternative, Specialty
Credits: 4
Enrollment Year: 4, **Sem.** 7

Activities

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

Evaluation

Type: **Exam**

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

Grades

Aggregate Results

Bibliografie

- https://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

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

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

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 μW
-30 dBm	= 1 μW
-60 dBm	= 1 nW

[dBm] + [dB] = [dBm]

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

[x] + [dB] = [x]

Examen: Reprezentare logaritmică

- $P_0 = 1\text{mW}$
  - $P[\text{dBm}] = 10 \cdot log\left(\frac{P}{P_0}\right)$
  - $P = P_0 \cdot 10^{\frac{P[\text{dBm}]}{10}}$
- Cu unitati de masura
  - $P[\text{mW}] = 1[\text{mW}] \cdot 10^{\frac{P[\text{dBm}]}{10}} = 10^{\frac{P[\text{dBm}]}{10}}$
  - $P[\mu\text{W}] = 1000[\mu\text{W}] \cdot 10^{\frac{P[\text{dBm}]}{10}} = 10^3 \cdot 10^{\frac{P[\text{dBm}]}{10}}$
  - $P[\mu\text{W}] = 10^{\frac{30+P[\text{dBm}]}{10}}$

Examen: Reprezentare logaritmică

- Relatii empirice
  - $\lambda[\mu m] = \frac{1.240}{E_g[eV]}$
  - uneori cu corespondenta fizica $E_g = h\nu; \lambda = \frac{hc}{E_g}$
- Puteri
  - $1mW = 10^3 \mu W; 1\mu W = 10^{-3} mW$
- Empiric
  - $P[\mu W] = 10^3 \cdot P[mW]$**!!**
  - Ex: P = **1.2**mW = **1200**μW

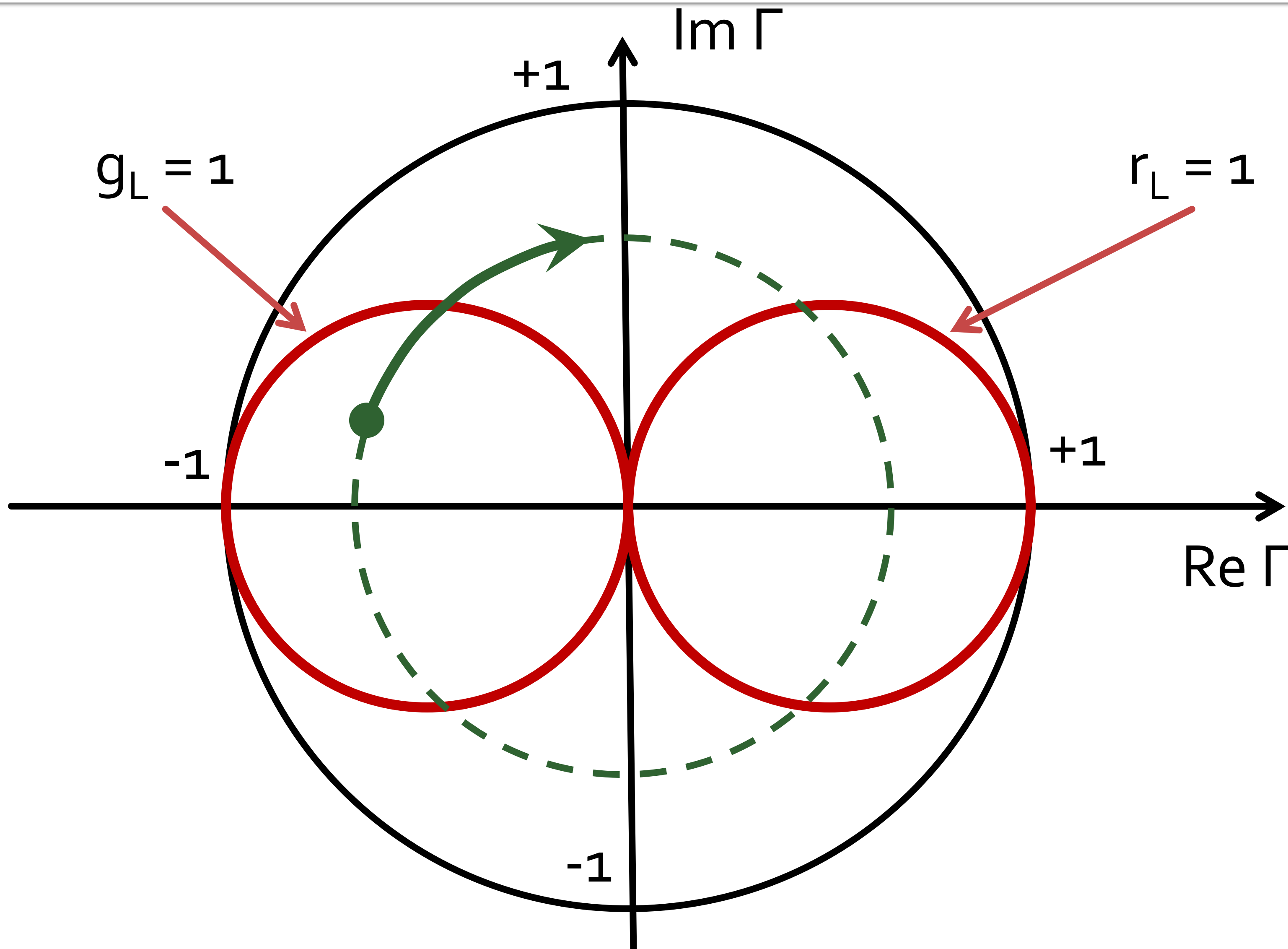
Examen

- Operatii cu numere complexe!
- $z = a + j \cdot b$; **$j^2 = -1$**

Adaptarea cu sectiuni de linii (stub)

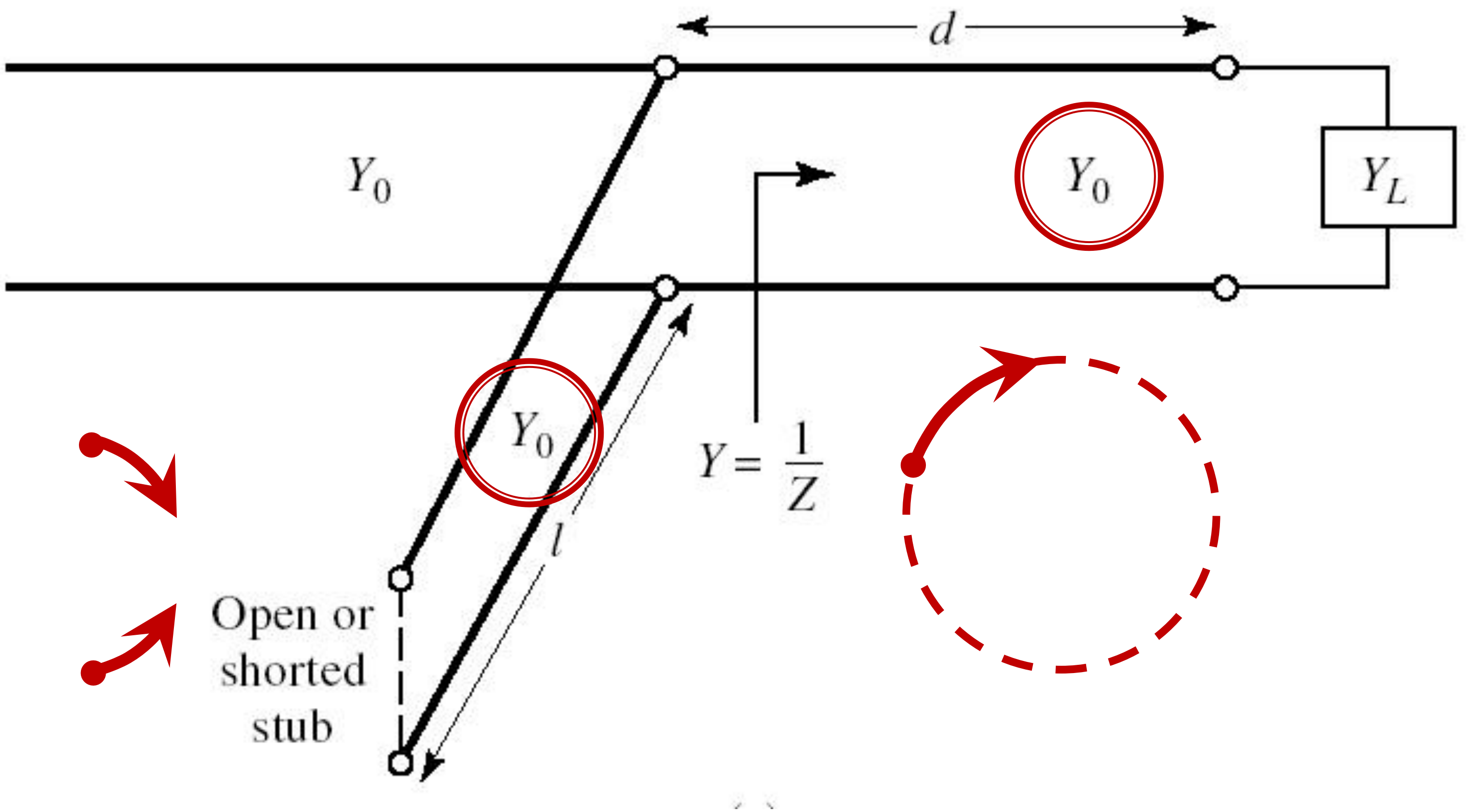
Adaptarea de impedanța

Diagrama Smith, r=1 si g=1



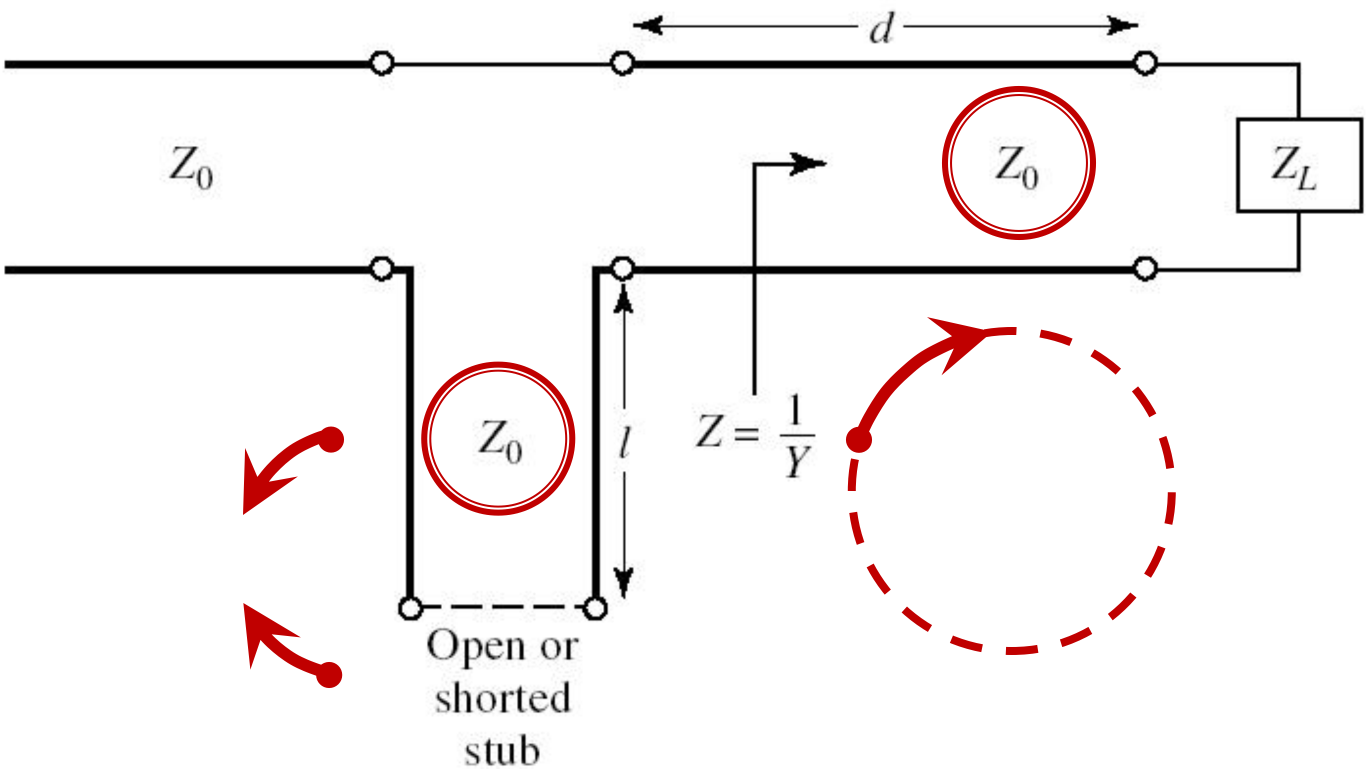
Single stub tuning

- Shunt Stub (sectiune de linie in paralel)



Single stub tuning

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

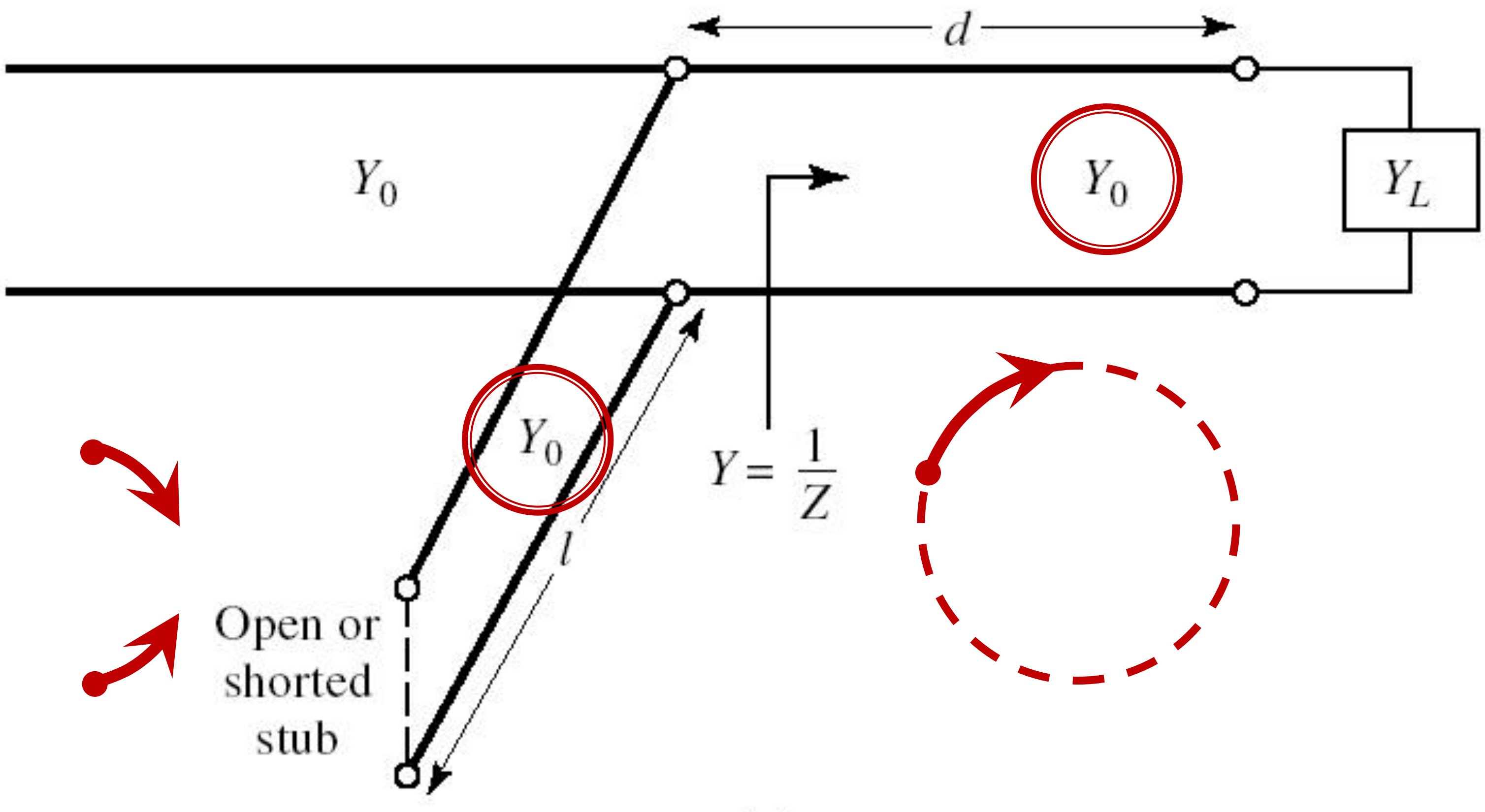


Solutii analitice

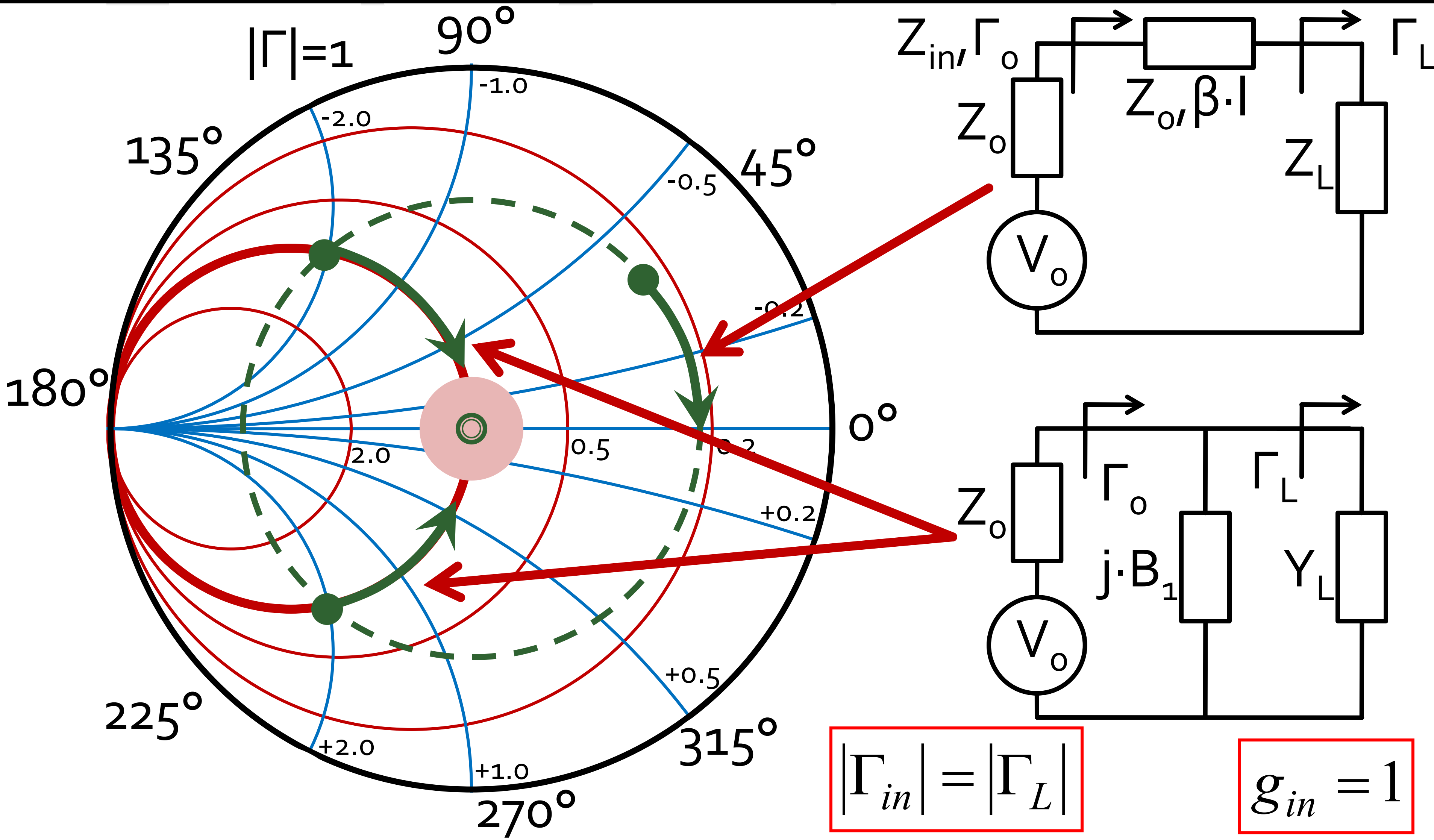
Examen / Proiect

Caz 1, Shunt Stub

- Shunt Stub (sectiune de linie in paralel)



Adaptare, linie serie + susceptanta in paralel



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

$$g_{in} = 1$$

Calcul analitic (calcul efectiv)

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

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

$$\Gamma_S = 0.593\angle 46.85°$$

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

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

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

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

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

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

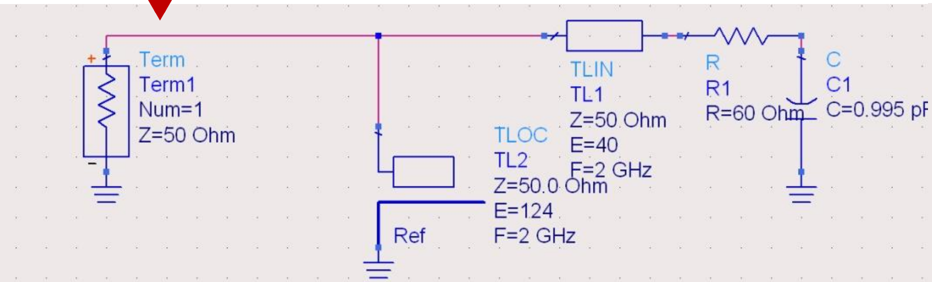
Calcul analitic (calcul efectiv)

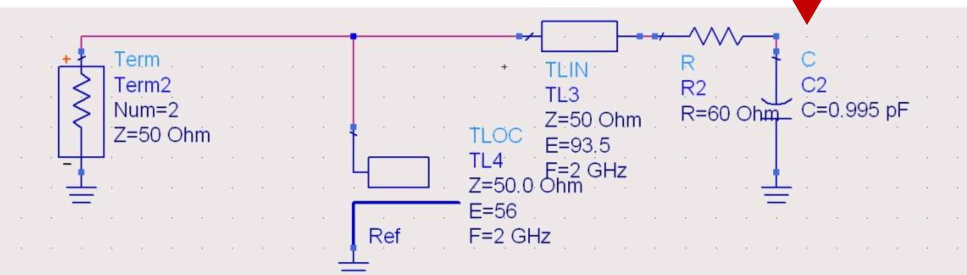
$$(\varphi+2\theta)=\begin{cases}+126.35^\circ\\-126.35^\circ\end{cases}\quad \theta=\begin{cases}39.7^\circ\\93.4^\circ\end{cases}\quad \mathrm{Im}[y_S(\theta)]=\begin{cases}-1.472\\+1.472\end{cases}\quad \theta_{sp}=\begin{cases}-55.8^\circ+180^\circ=124.2^\circ\\+55.8^\circ\end{cases}$$

- Se alege **una** din cele doua solutii posibile
- **Semnul** (+/-) solutiei alese la **prima** ecuatie impune **semnul** solutiei utilizate la a **doua** ecuatie

$$l_1=\frac{39.7^\circ}{360^\circ}\cdot\lambda=0.110\cdot\lambda \qquad l_1=\frac{93.4^\circ}{360^\circ}\cdot\lambda=0.259\cdot\lambda$$

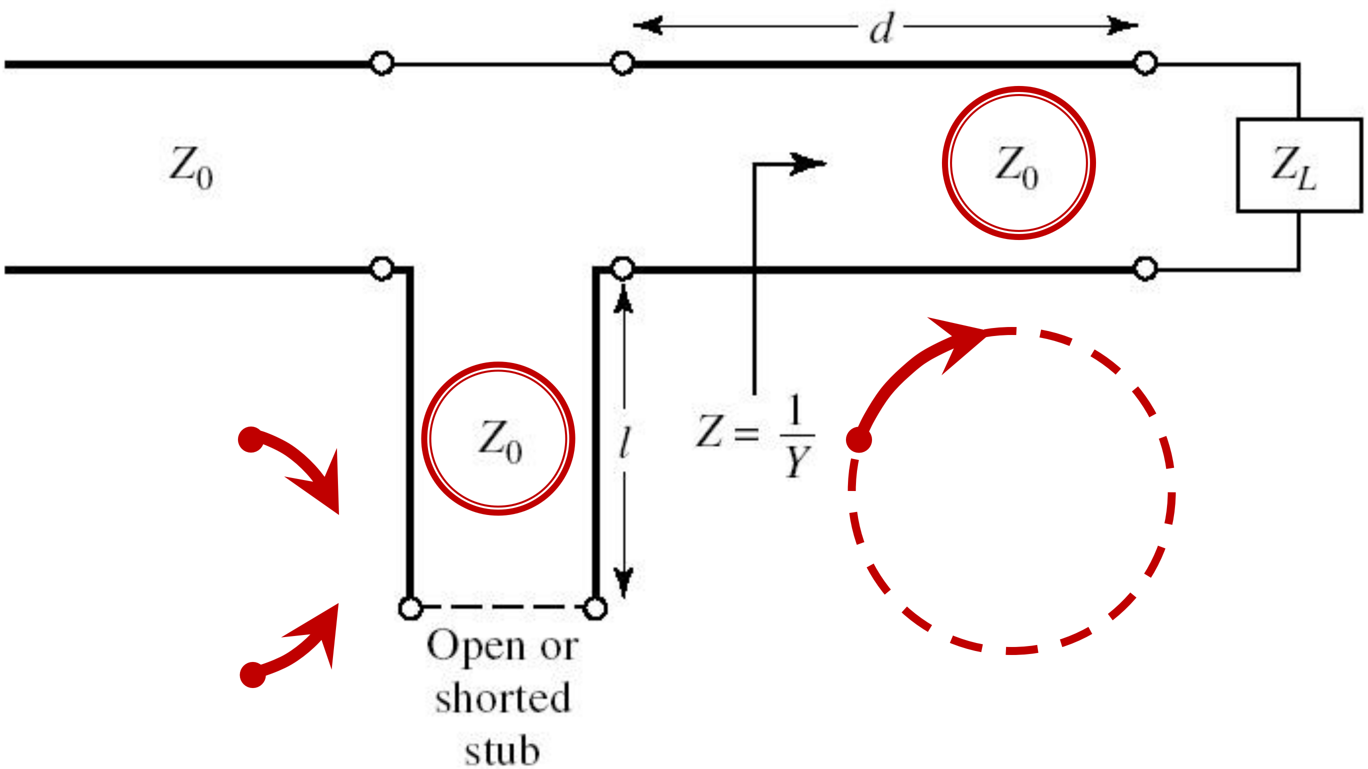
$$l_2=\frac{124.2^\circ}{360^\circ}\cdot\lambda=0.345\cdot\lambda \qquad l_2=\frac{55.8^\circ}{360^\circ}\cdot\lambda=0.155\cdot\lambda$$



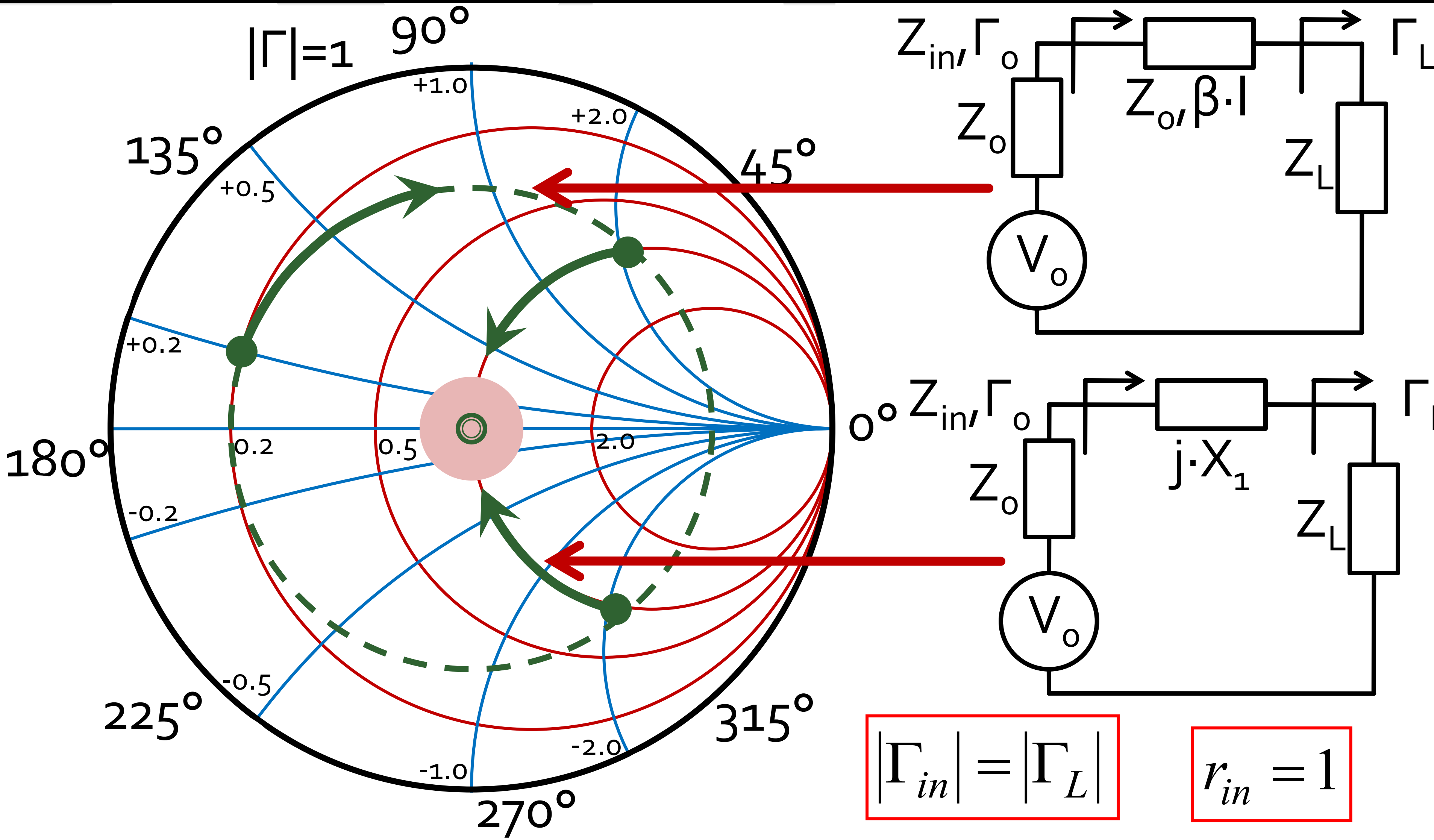


Caz 2, Series Stub

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



Adaptare, linie serie + reactanta in serie



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

$$r_{in} = 1$$

Calcul analitic (calcul efectiv)

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

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

$$\Gamma_S = 0.555 \angle -29.92°$$

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

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

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

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

  - **solutia "cu -"**

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

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

Calcul analitic (calcul efectiv)

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

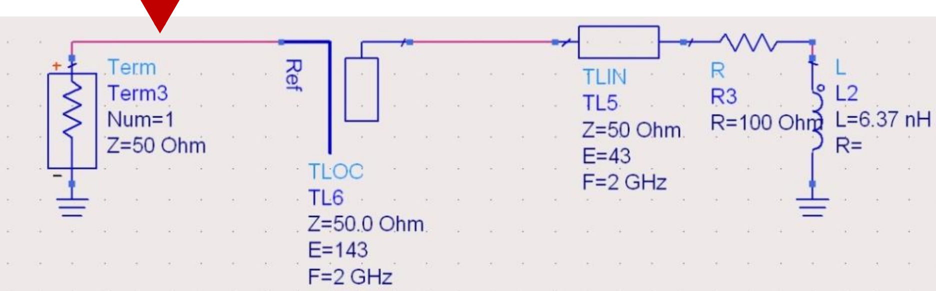
- Se alege **una** din cele doua solutii posibile
- **Semnul** (+/-) solutiei alese la **prima** ecuatie impune **semnul** solutiei utilizate la a **doua** ecuatie

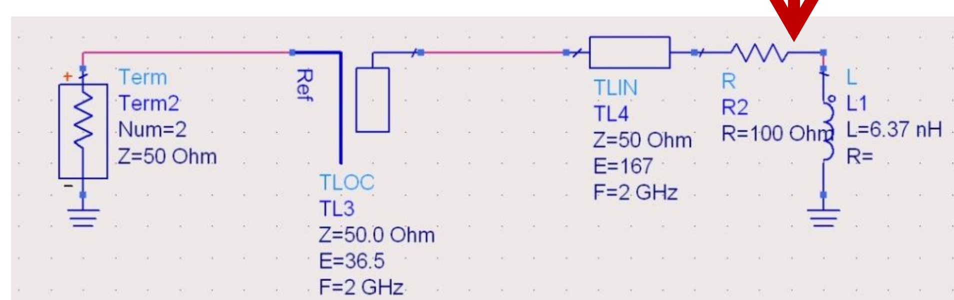
$$l_1 = \frac{43.1°}{360°} \cdot \lambda = 0.120 \cdot \lambda$$

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

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

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





Stub, observatii

- adunarea si scadere de **180°** (λ/2) nu schimba rezultatul (rotatie completa in jurul diagramei

$$E = \beta \cdot l = \pi = 180^\circ \qquad l = k \cdot \frac{\lambda}{2}, \forall k \in \mathbf{N}$$

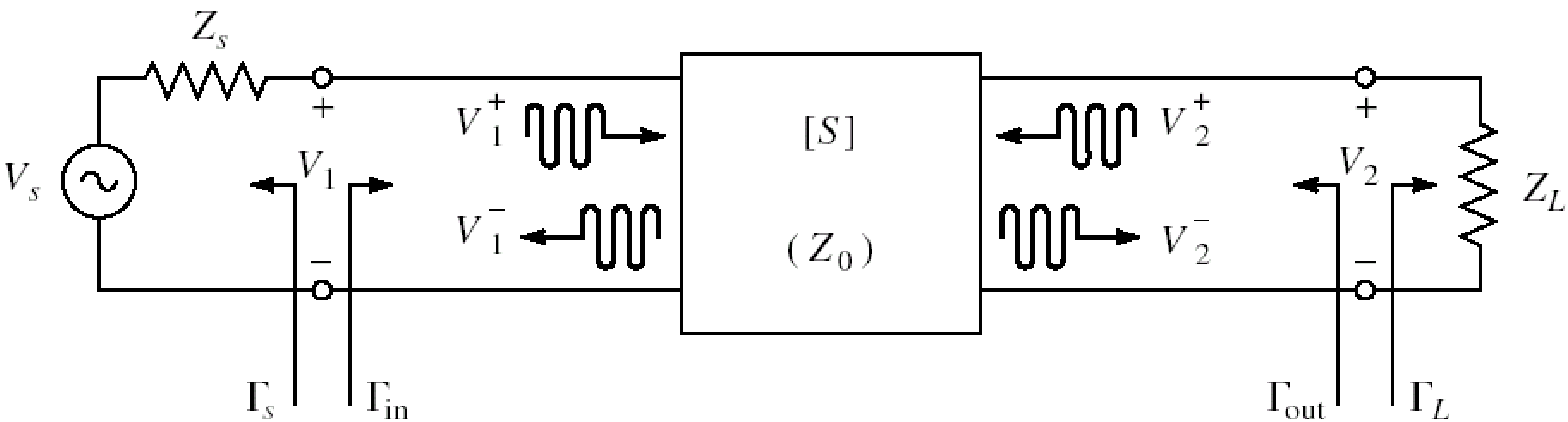
  - pentru linii de “lungime” / “lungime electrica” **negative** se adauga λ/2 / 180° pentru a avea valoare pozitiva (realizabila fizic)
- o adaugare sau scadere de **90°** (λ/4) transforma impedanta stub-ului:

$$Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l \quad \Leftrightarrow \quad Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

  - pentru stub se poate adauga/scadea 90° (λ/4) simultan cu schimbare **gol** ⇔ **scurtcircuit**

Amplificatoare de microunde

Diport amplificator

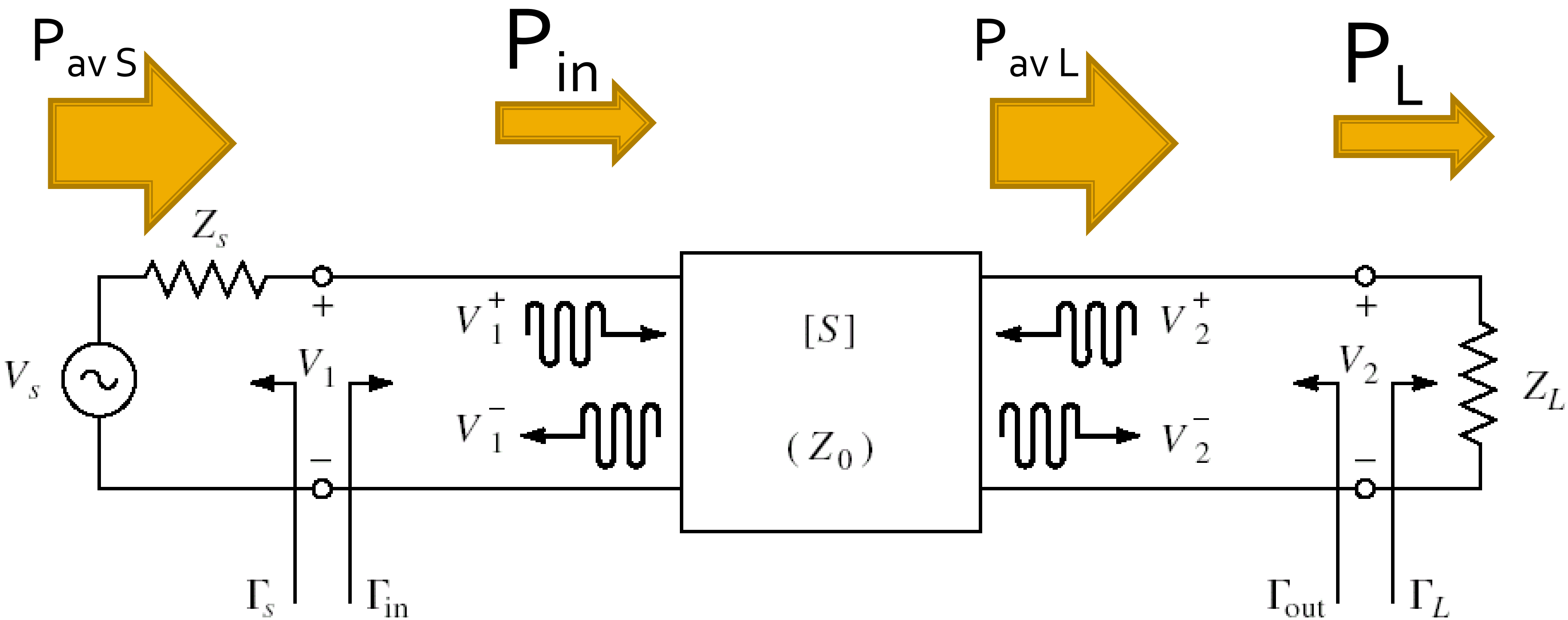


$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

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

Puteri / Adaptare

- Doua porturi in care adaptarea influențează transferul de putere



Castig de putere

- Castigul de putere **disponibil**

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

- Castigul de putere de **transfer** (transducer power gain)

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

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

- Castigul de putere de **transfer unilateral**

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

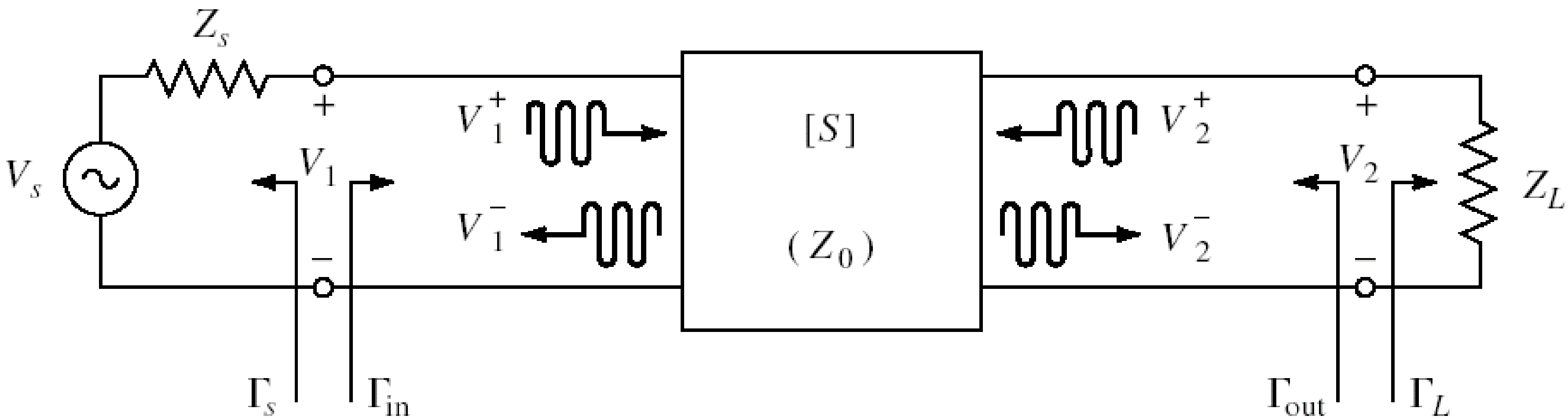
$$S_{12} \cong 0 \qquad \Gamma_{in} = S_{11}$$

Permite tratarea separata a intrarii si iesirii

Amplificatoare de microunde

Stabilitate

Cuadripol Amplificator



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

Cerc de stabilitate la iesire (CSOUT)

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

- Ecuatia unui cerc, care reprezinta locul geometric al punctelor Γ_L pentru **limita** de stabilitate
- Cercul se numeste **cerc de stabilitate la iesire** (Γ_L)

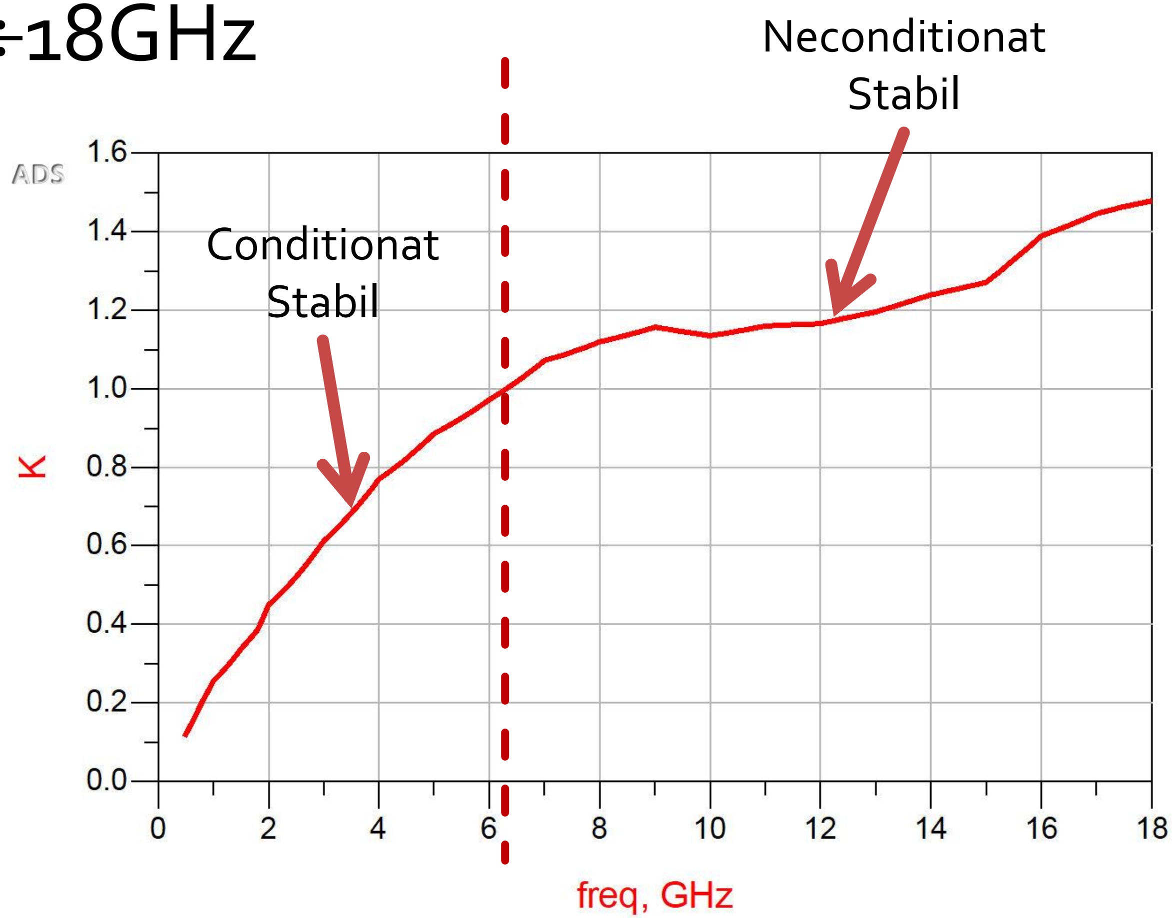
$$C_L = \frac{\left(S_{22} - \Delta \cdot S_{11}^*\right)^*}{|S_{22}|^2 - |\Delta|^2} \qquad R_L = \frac{|S_{12} \cdot S_{21}|}{\left||S_{22}|^2 - |\Delta|^2\right|}$$

Stabilitate

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

Conditia Rollet

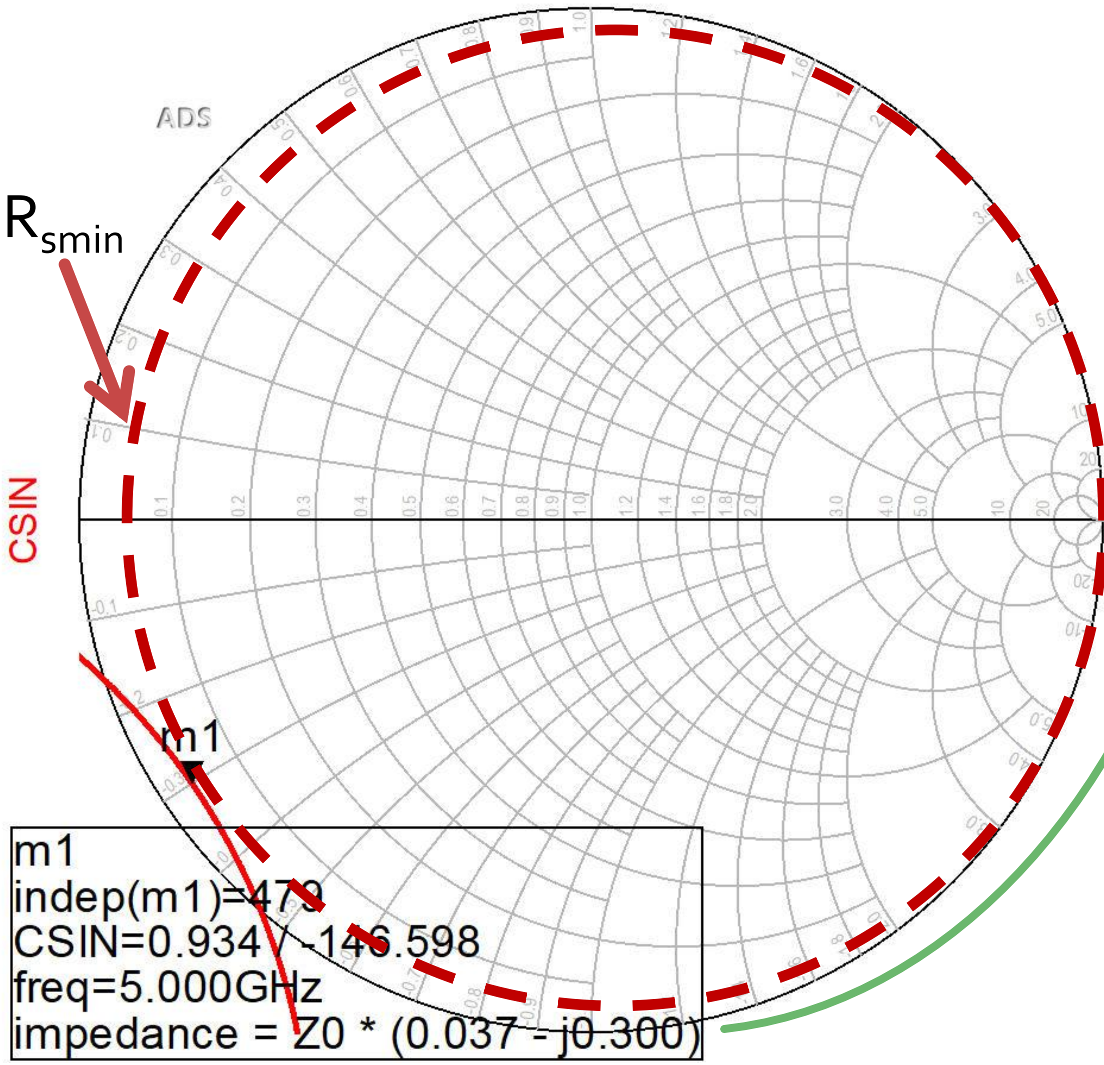
- ATF-34143 **at Vds=3V Id=20mA**.
- @0.5÷18GHz

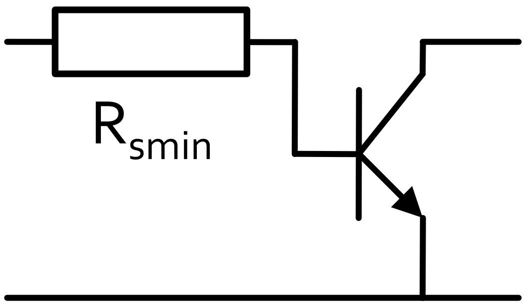


Stabilizarea unui diport

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

Rezistenta serie la intrare

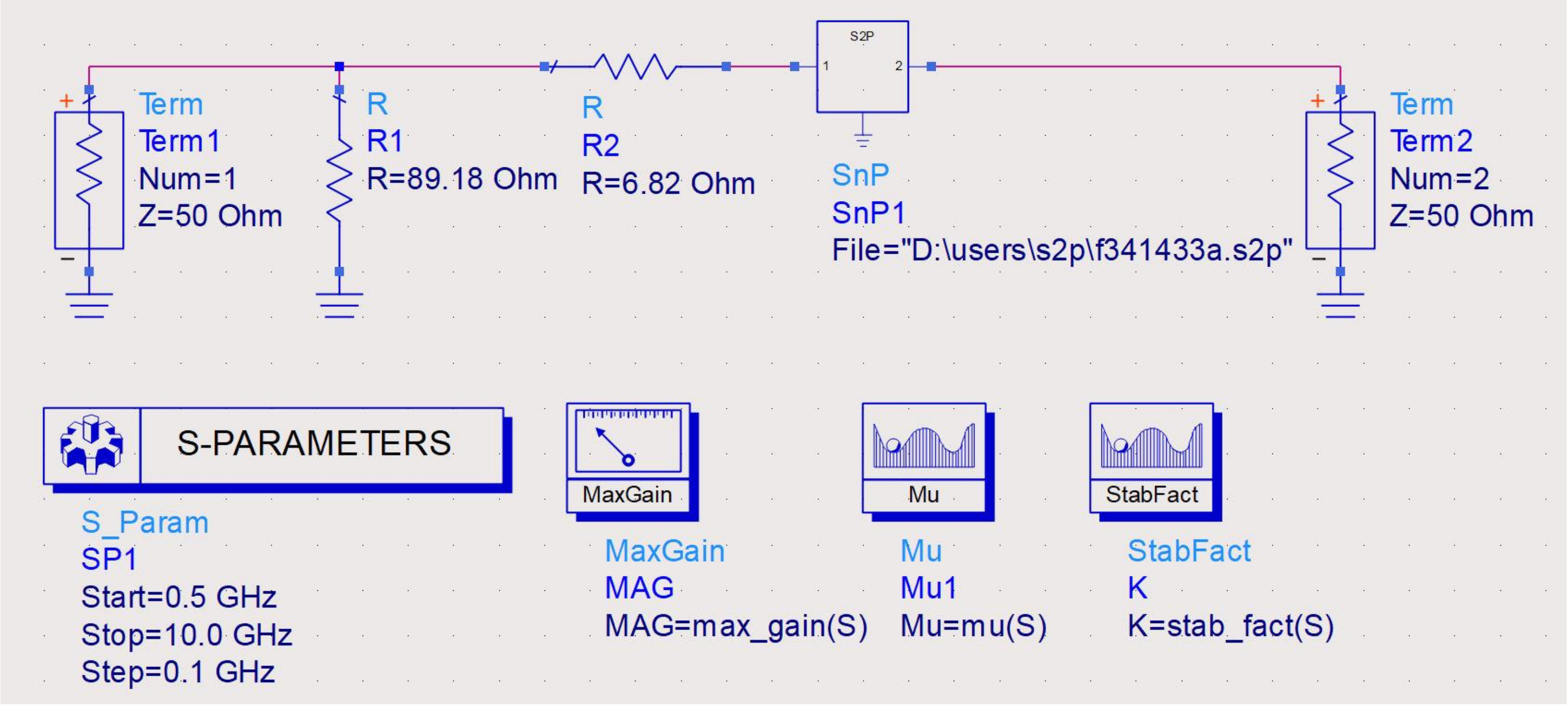




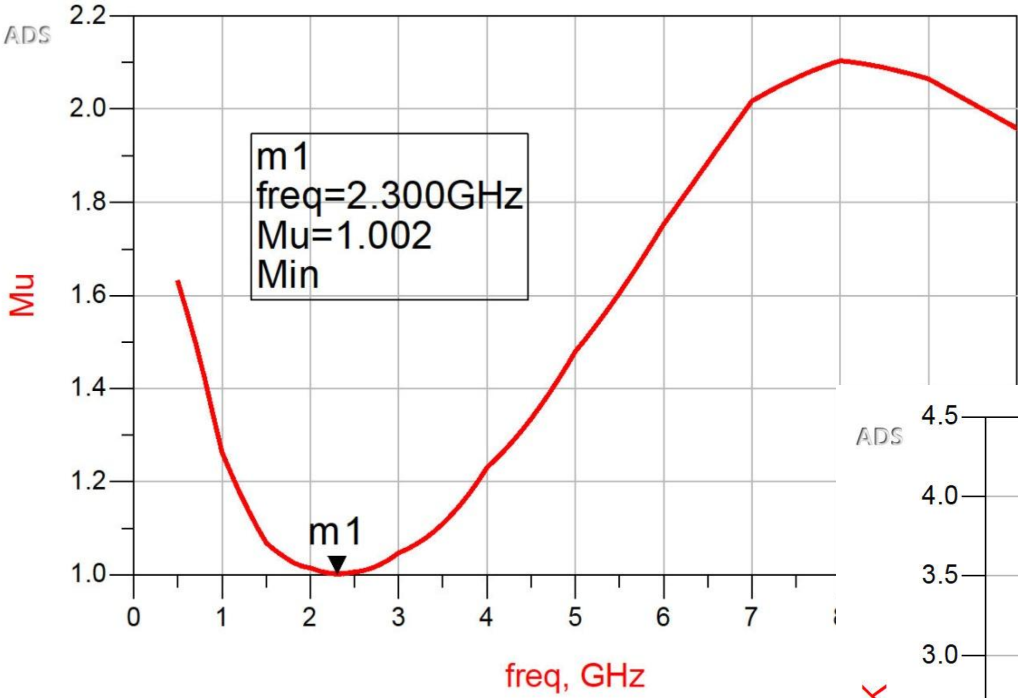
$$z = 0.037 - j \cdot 0.3$$

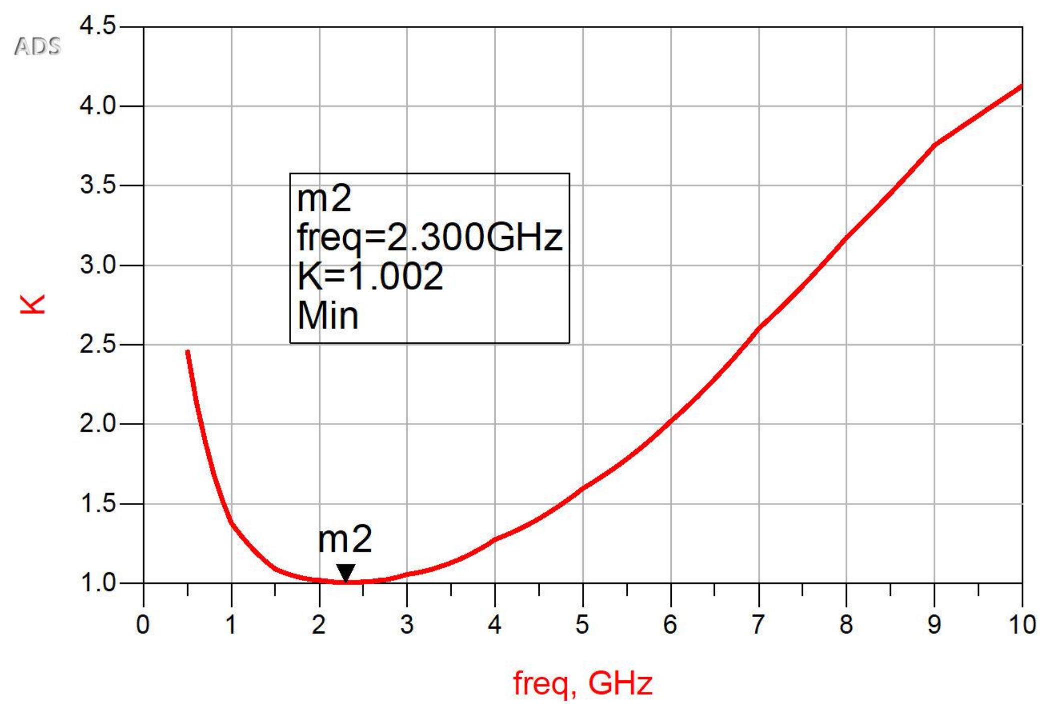
$$R_{s\,min} = 0.037 \cdot 50\Omega = 1.85\Omega$$

Stabilizarea unui diport

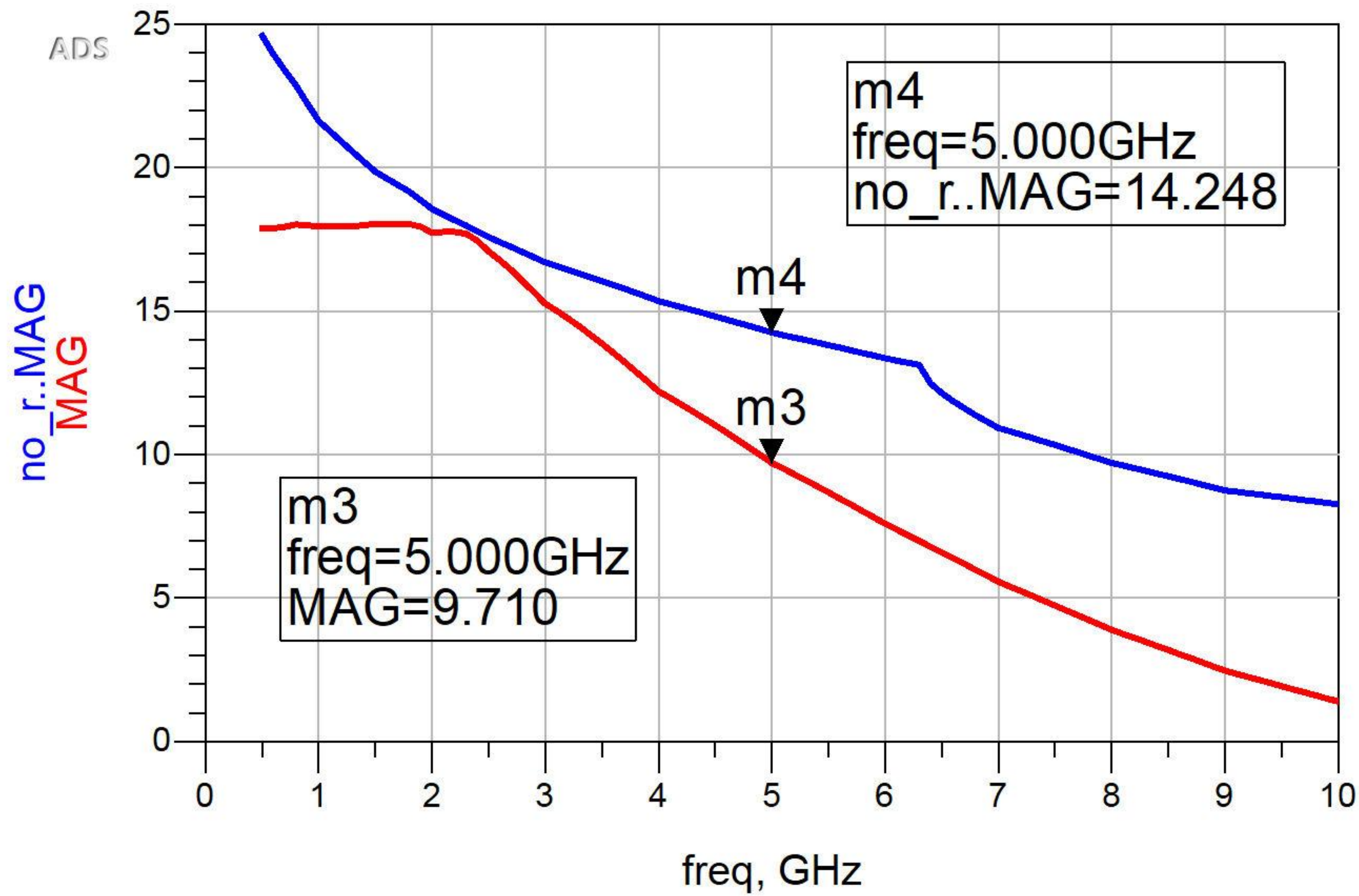


Stabilizarea unui diport





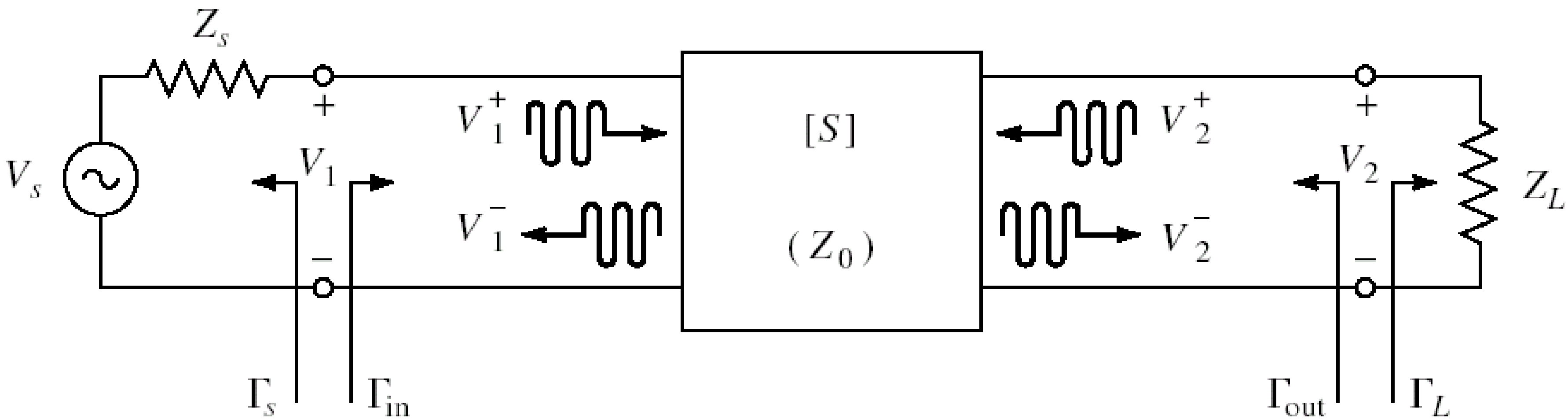
Stabilizarea unui diport



Amplificatoare de microunde

Castigul amplificatoarelor de microunde

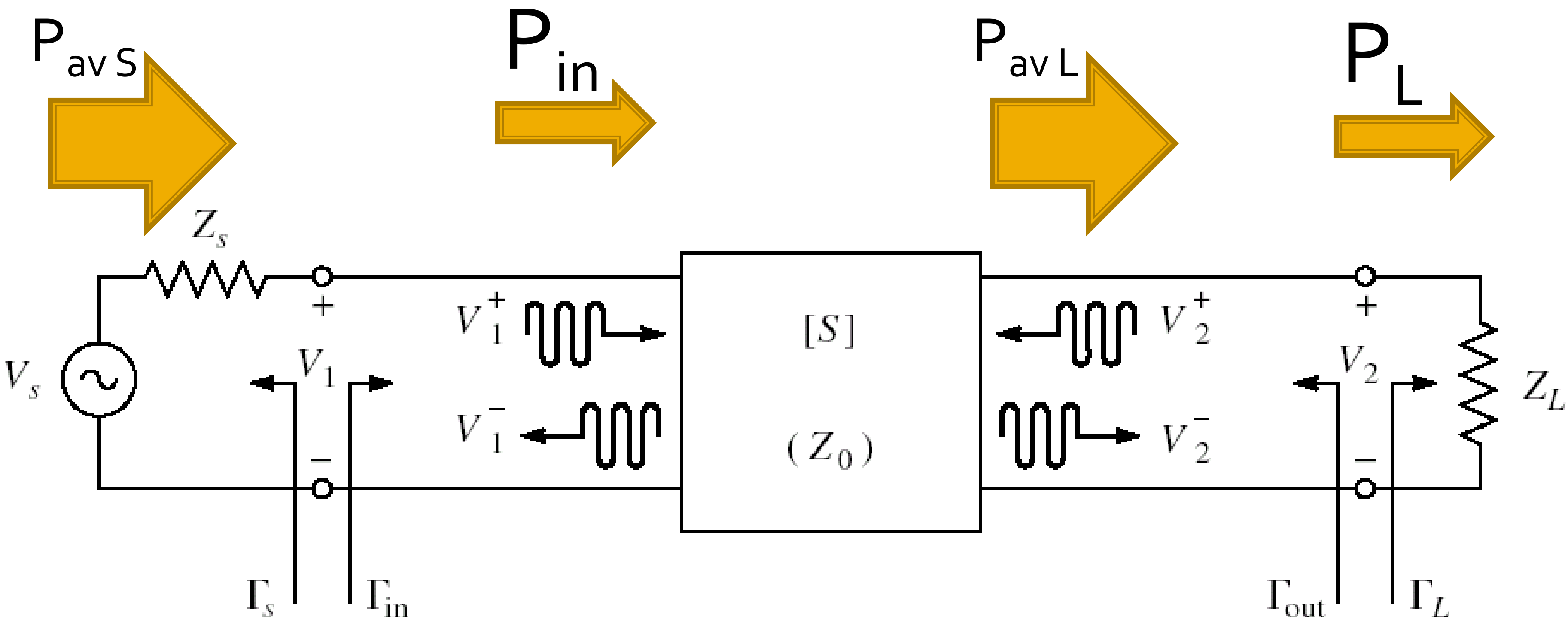
Cuadripol Amplificator



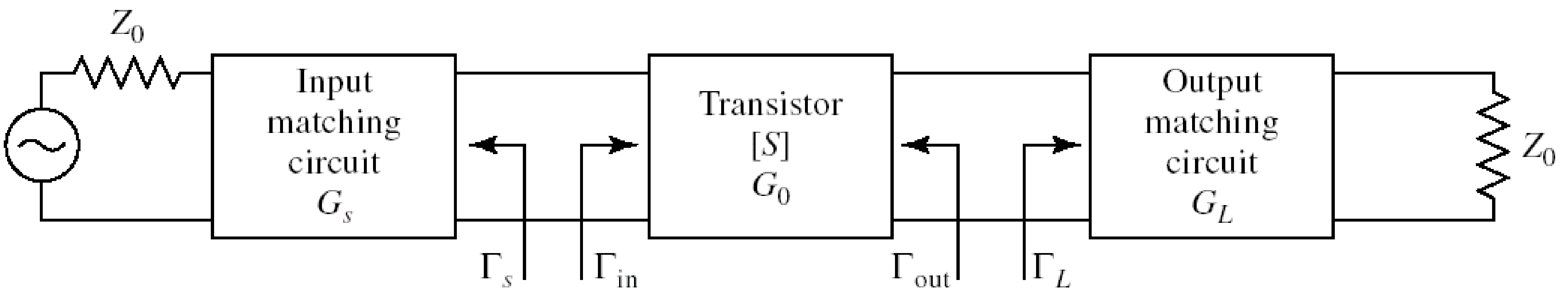
- marimi care intereseaza:
  - stabilitate
  - **castig de putere**
  - zgomot (uneori – semnal mic)
  - liniaritate (uneori – semnal mare)

Puteri / Adaptare

- Doua porturi in care adaptarea influenteaza transferul de putere



Proiectare pentru castig maxim



- Castig maxim de putere se obtine cand

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

- Pentru retele de adaptare fara pierderi

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

- Pentru tranzistor bilateral (S12 ≠ 0) Γ_{in} si Γ_{out} se influenteaza reciproc deci adaptarea trebuie sa fie simultana

Adaptare simultana

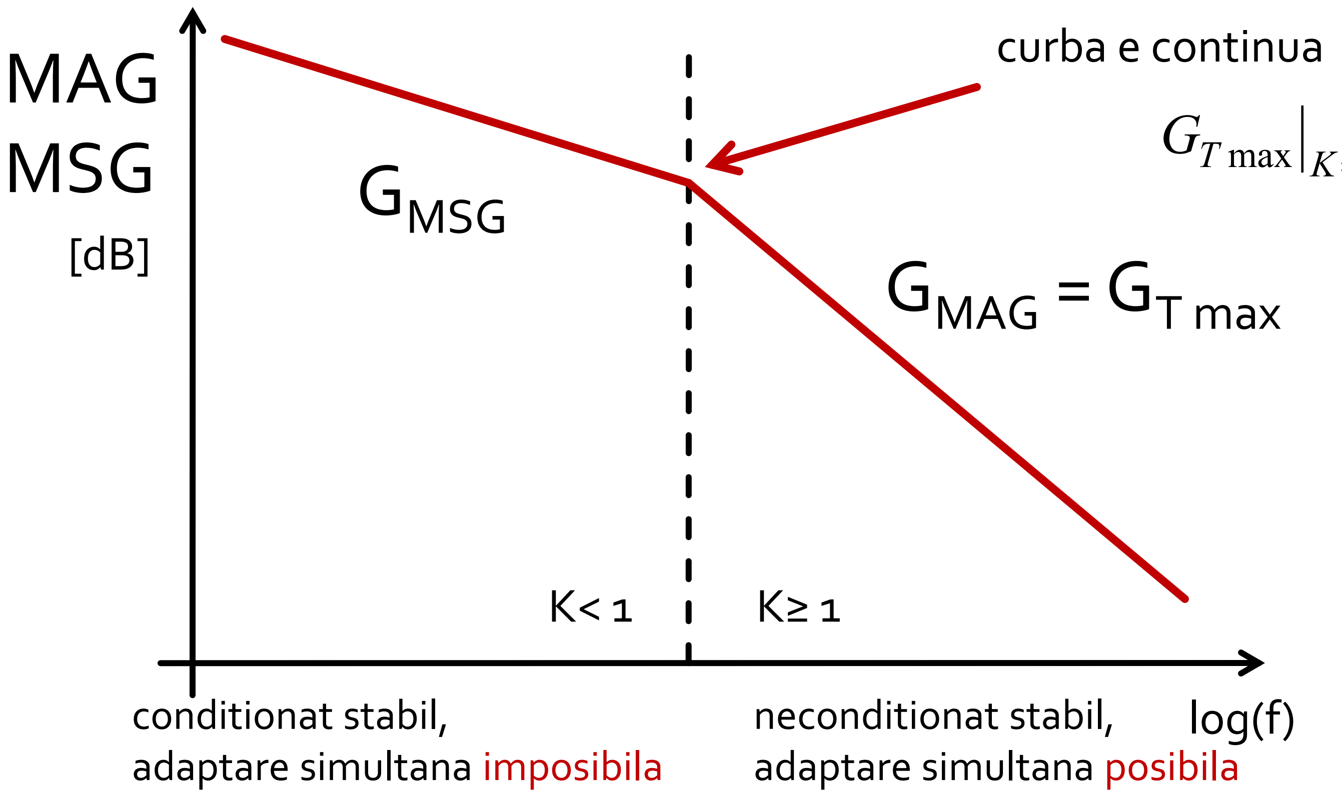
- Adaptarea simultana se poate realiza **numai** pentru amplificatoarele **neconditionat stabile** la frecventa de lucru, si solutia cu $|\Gamma|<1$ se obtine cu semnul "–"

$$\Gamma_S = \frac{B_1 - \sqrt{B_1^2 - 4\cdot|C_1|^2}}{2\cdot C_1} \qquad \Gamma_L = \frac{B_2 - \sqrt{B_2^2 - 4\cdot|C_2|^2}}{2\cdot C_2}$$

$$\begin{cases} B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \\ C_1 = S_{11} - \Delta\cdot S_{22}^* \end{cases} \qquad \begin{cases} B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \\ C_2 = S_{22} - \Delta\cdot S_{11}^* \end{cases}$$

Maximum Available Gain

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

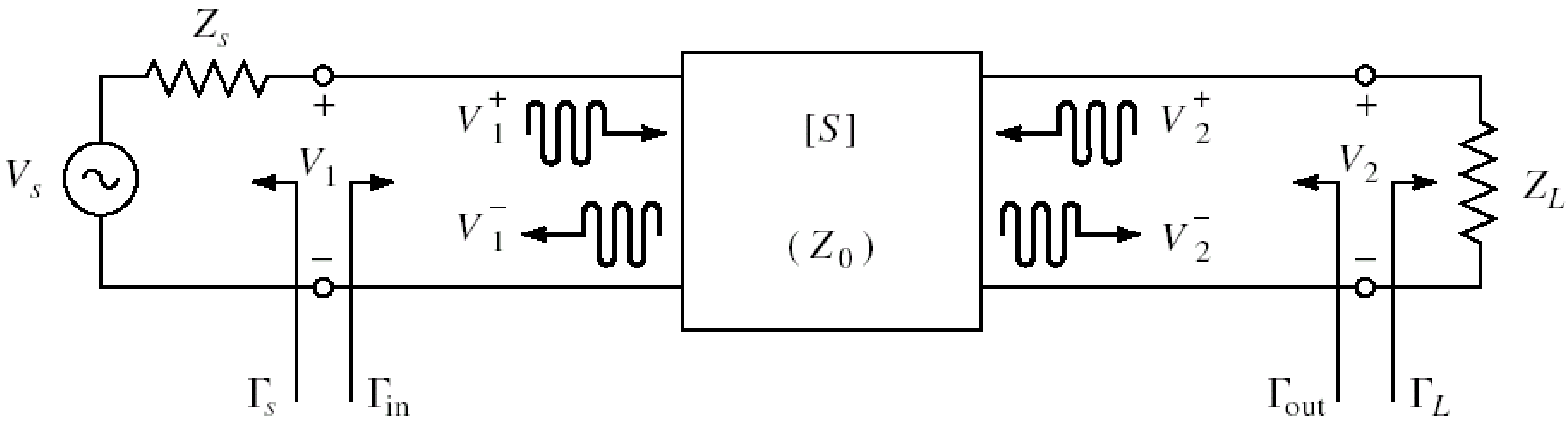


$$G_{T\max}\Big|_{K=1} = \frac{|S_{21}|}{|S_{12}|} = G_{MSG}$$

Amplificatoare de microunde

Proiectare pentru castig impus

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

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

- 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 $S_{12} \cong 0$

$$\frac{1}{(1+U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1-U)^2} \qquad U = \frac{|S_{12}|\cdot|S_{21}|\cdot|S_{11}|\cdot|S_{22}|}{\left(1-|S_{11}|^2\right)\cdot\left(1-|S_{22}|^2\right)}$$

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

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

Cercuri de castig constant la intrare

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

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

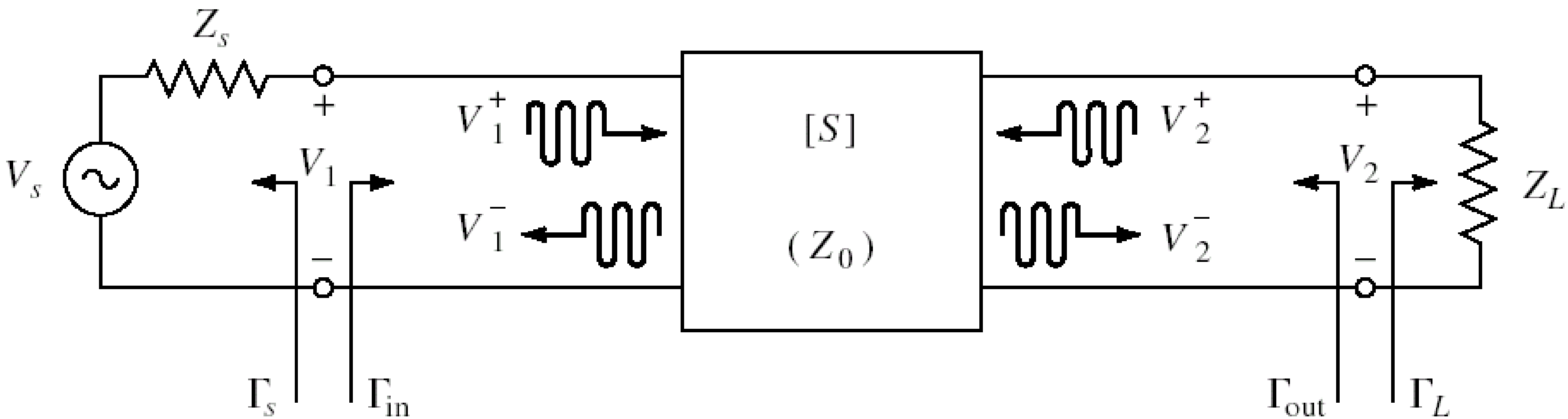
- Ecuatia unui cerc in planul complex in care reprezint Γ_S
- **Interpretare**: Orice punct Γ_S care reprezentat in planul complex se gaseste **pe** cercul desenat pentru $g_{cerc} = G_{cerc}/G_{Smax}$ va conduce la obtinerea castigului $G_S = G_{cerc}$
  - Orice punct **in exteriorul** acestui cerc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

Continuare

Amplificatoare de microunde

Proiectare pentru zgomot redus

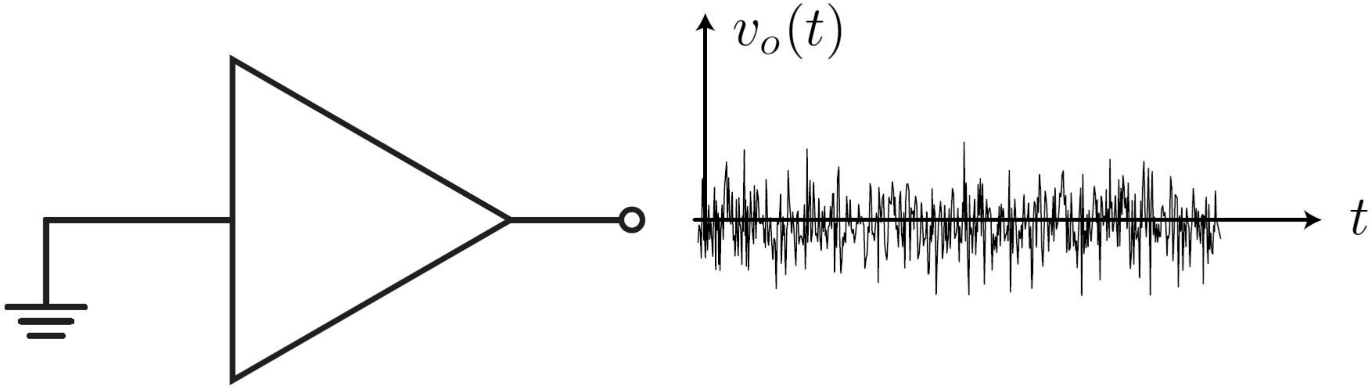
Cuadripol Amplificator



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

Zgomot

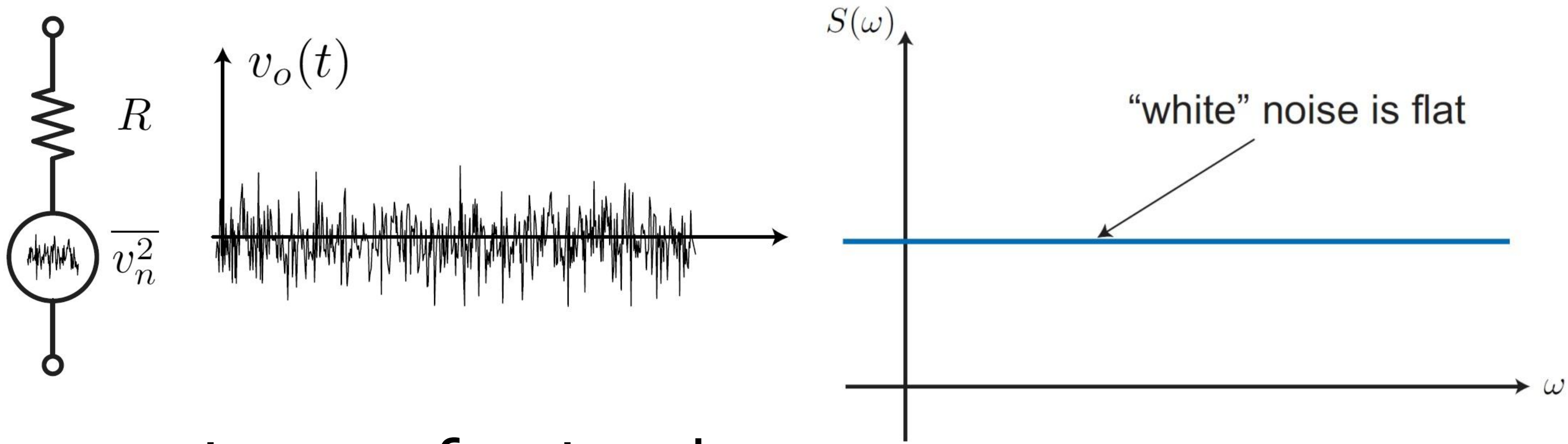
- Zgomot: variatii aleatorii ale semnalului



$$\overline{v_n(t)} = \langle v_n(t) \rangle = \frac{1}{T}\int_0^T v_n(t)\,dt = 0$$

$$\overline{v_n^2(t)} = \langle v_n^2(t) \rangle = \frac{1}{T}\int_0^T v_n^2(t)\,dt \neq 0 \qquad V_{n(ef)} = \sqrt{\overline{v_n^2(t)}}$$

Zgomot



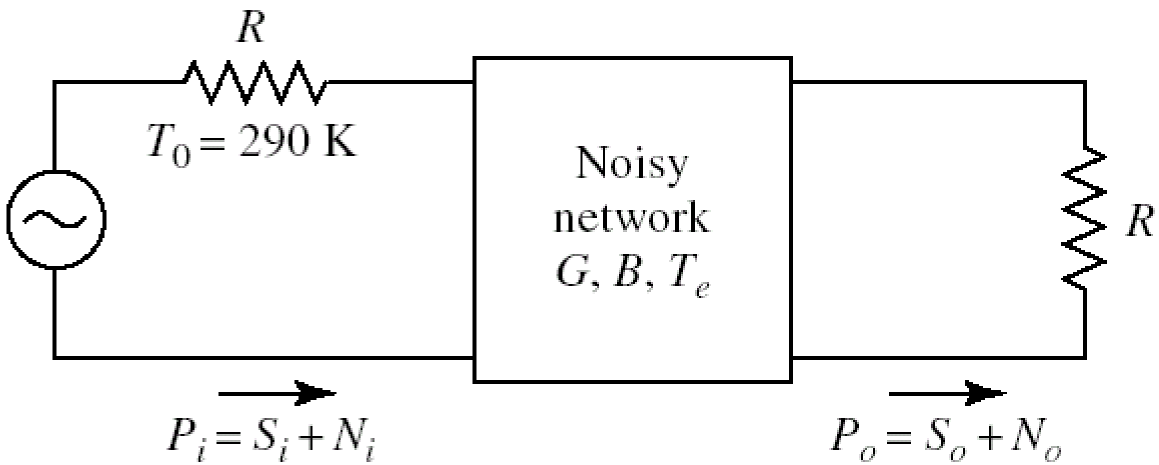
- tensiunea efectiva de zgomot

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

- puterea disponibila de zgomot (furnizata restului circuitului - maxim)

$$P_n = kTB$$

Factor de zgomot



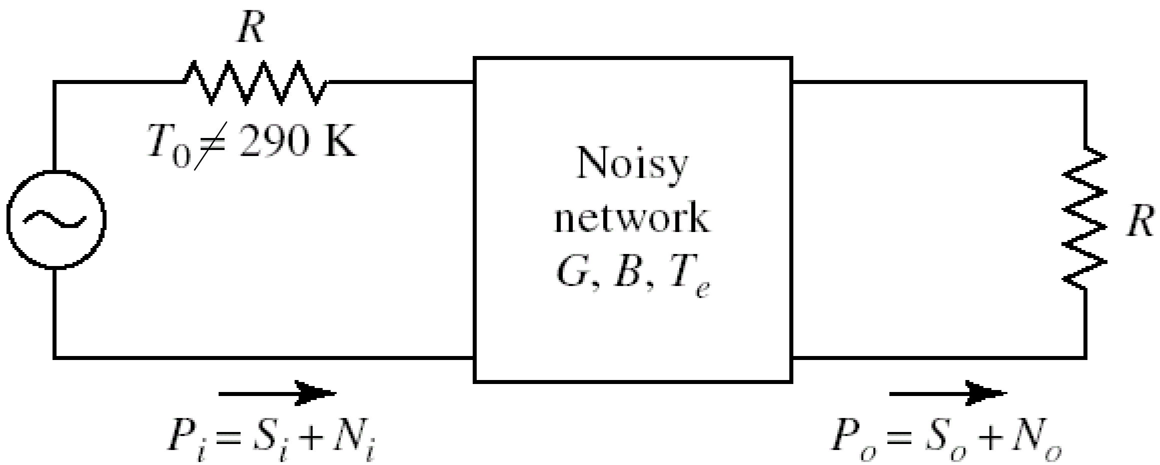
- Factorul de zgomot F caracterizeaza degradarea raportului semnal/zgomot intre intrarea si iesirea unei componente, cand la intrare se aplica o putere de zgomot de referinta (T_o = 290K)

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

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

$$P_n = kTB$$

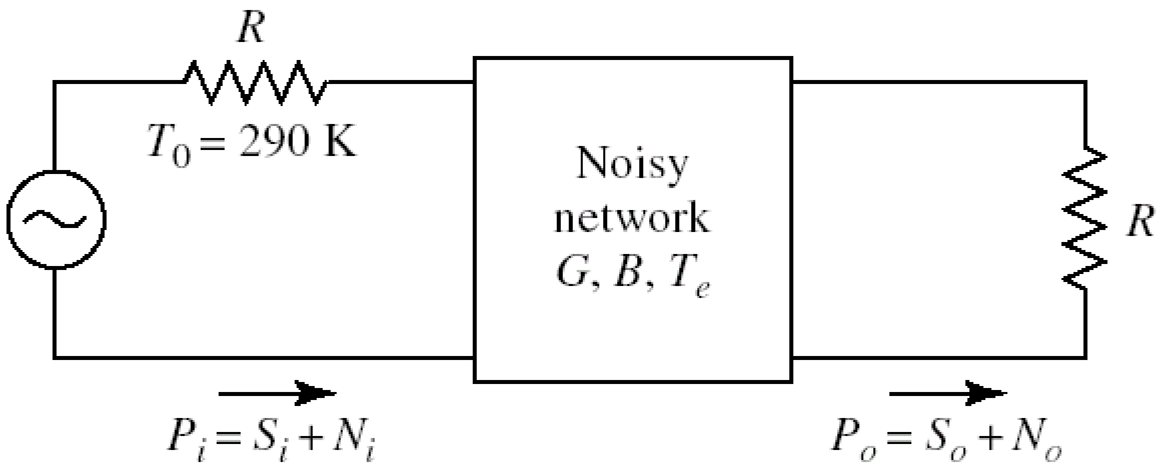
Factor de zgomot



- 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

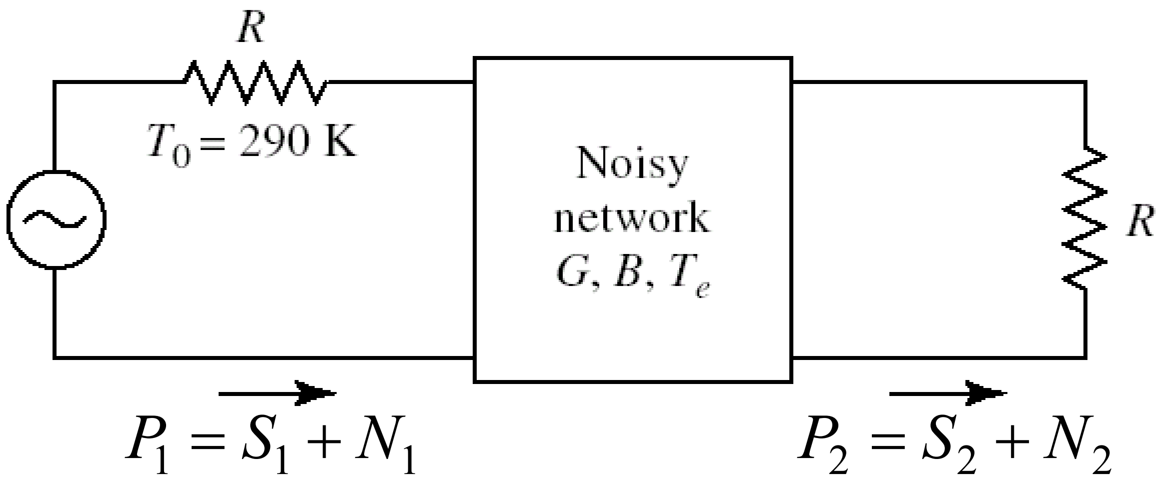
$$F \neq \left. \frac{S_i / N_i}{S_o / N_o} \right|_{T_0 \neq 290K}$$

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



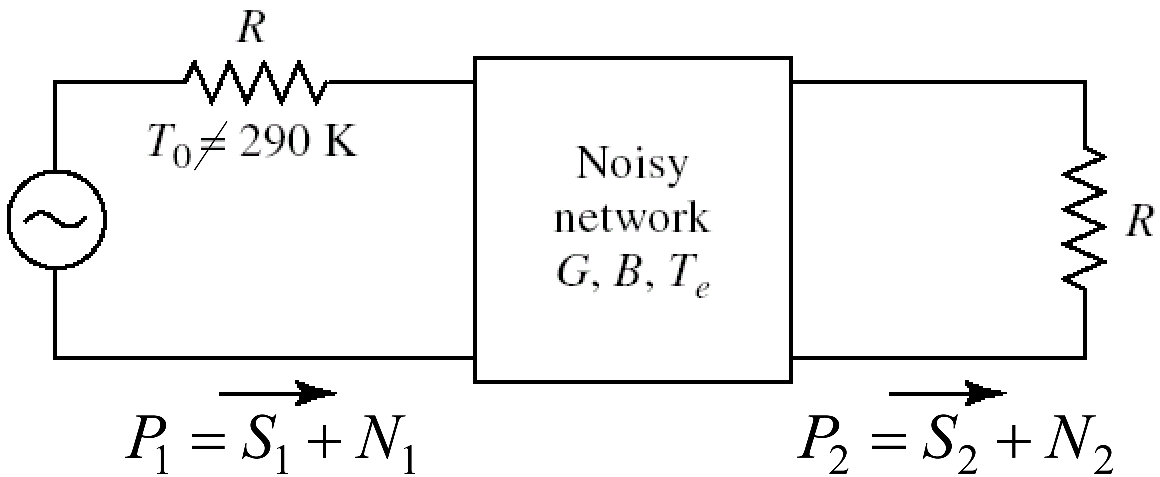
- Estimarea puterii de zgomot adaugate se poate face plecand de la definitia factorului de zgomot:

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

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

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

Factor de zgomot



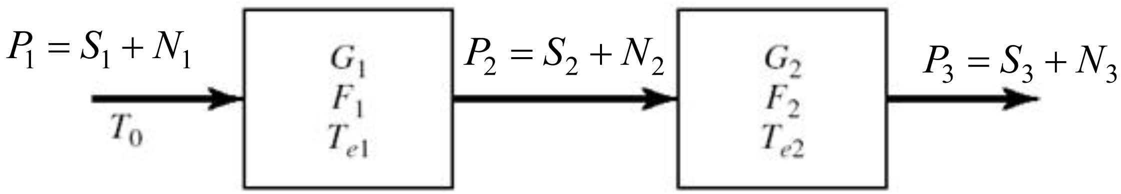
- Se identifica cei doi termeni:
  - zgomotul de intrare amplificat
  - zgomotul adaugat intern

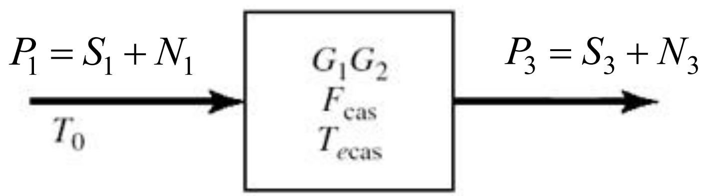
$$N_2 = N_0 \cdot G + (F-1) \cdot N_0 \cdot G$$

- Pentru o situatie in care la intrare nu am zgomotul de referinta (N1 ≠ No)

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

Factor de zgomot al circutelor cascadate





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

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

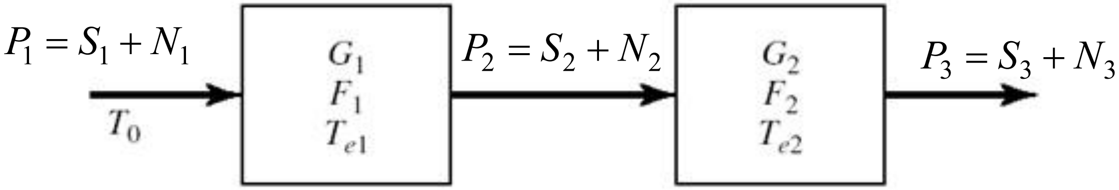
$$G_{cas} = G_1 \cdot G_2$$

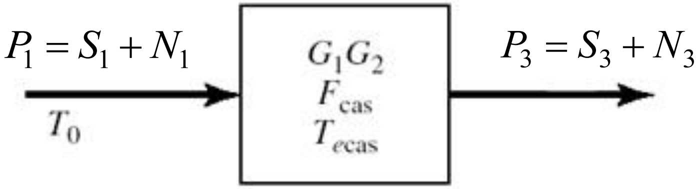
$$N_3 = N_1 \cdot G_{cas} + (F_{cas} - 1) \cdot N_0 \cdot G_{cas}$$

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

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

Factor de zgomot al circutelor cascadate





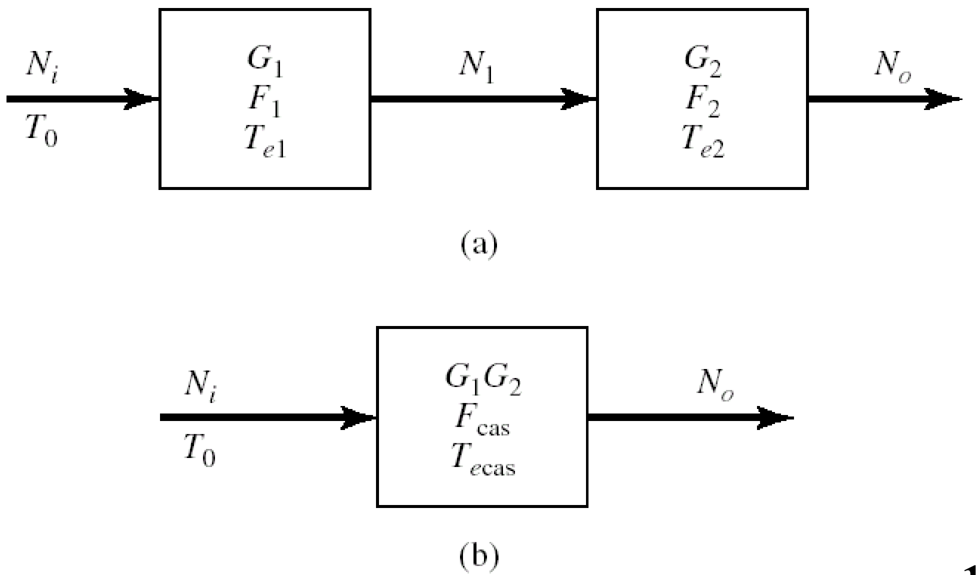
$$N_3 = N_1 \cdot G_1 \cdot G_2 + (F_1 - 1) \cdot N_0 \cdot G_1 \cdot G_2 + (F_2 - 1) \cdot N_0 \cdot G_2$$

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

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

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

Factor de zgomot al circutelor cascadate



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

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

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

Formula lui Friis (zgomot)

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

- 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)

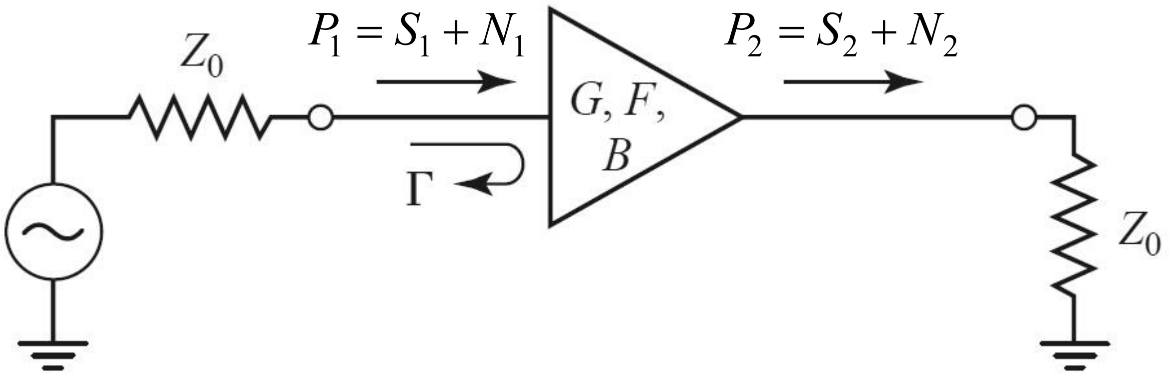
$$F_{cas} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \frac{F_4 - 1}{G_1 \cdot G_2 \cdot G_3} + \cdots$$

- 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)

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

Zgomotul amplificatoarelor dezadaptate

- Un amplificator dezadaptat la intrare (Γ≠o)



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

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

$$N_2 = N_1 \cdot G_{ech} + (F_{ech} - 1) \cdot N_0 \cdot G_{ech}$$

$$F_{ech} = 1 + \frac{F-1}{1-|\Gamma|^2} \geq F$$

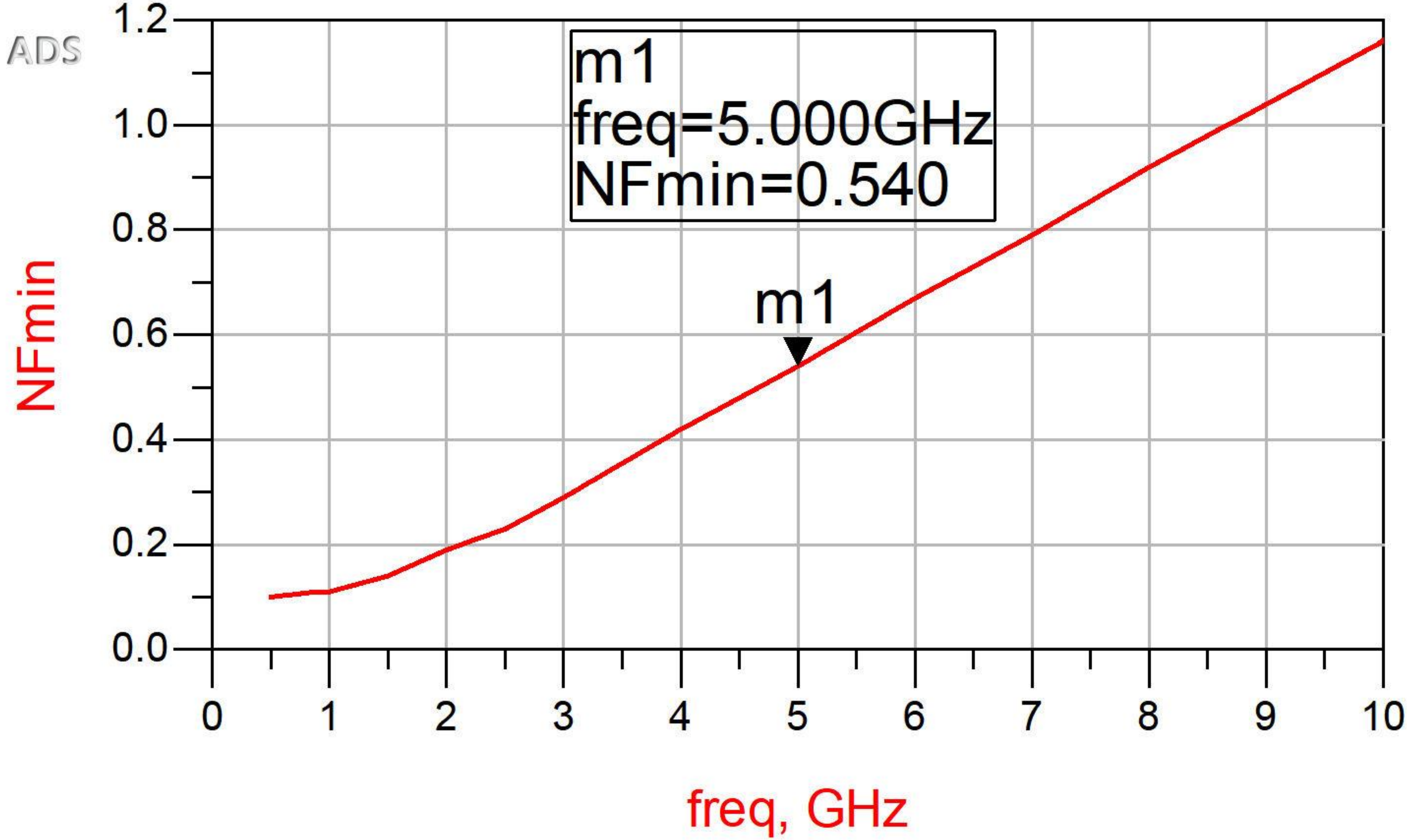
- Obtinerea unui zgomot redus **necesita** o buna adaptare de impedanta

Exemplu

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

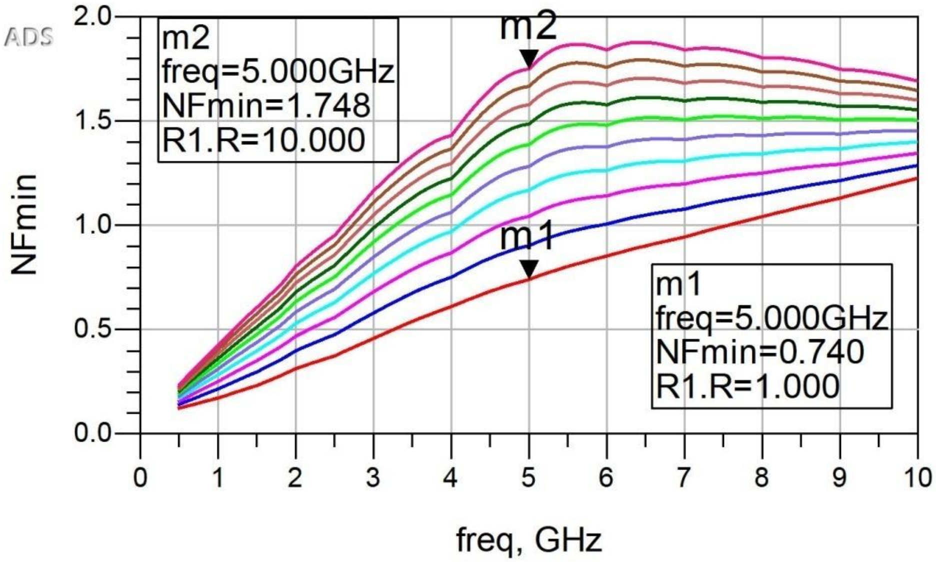
```
!ATF-34143
!S-PARAMETERS at Vds=3V  Id=20mA.   LAST UPDATED 01-29-99

# 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
```

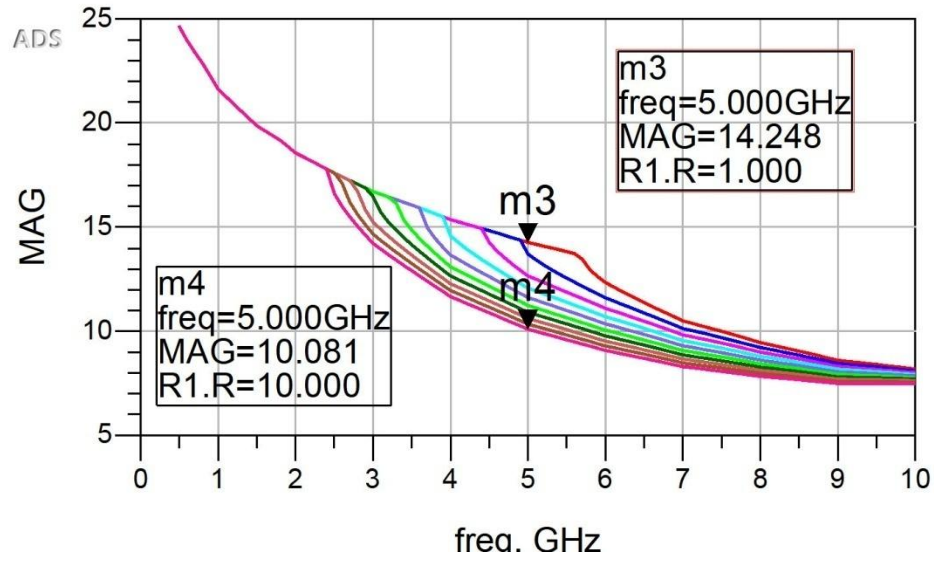
Exemplu



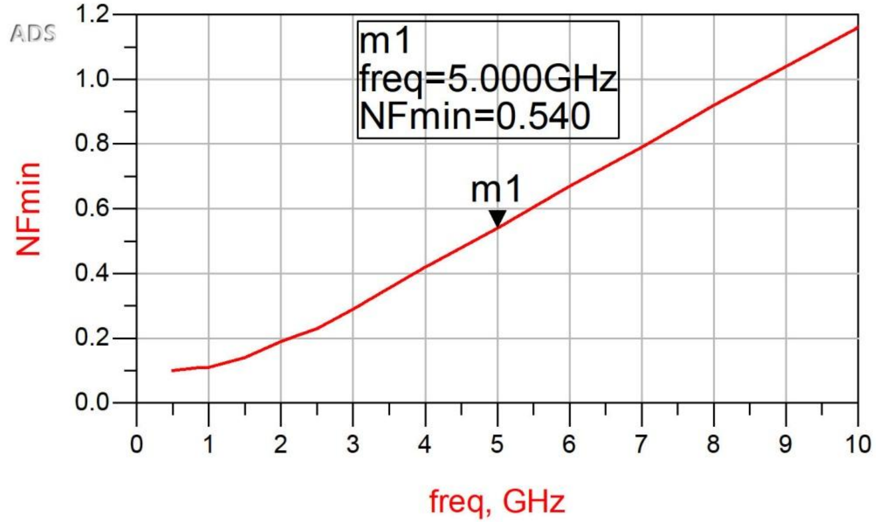
ADS
m1
freq=5.000GHz
NFmin=0.540
m1
NFmin
freq, GHz
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10

Stabilizare R serie la intrare

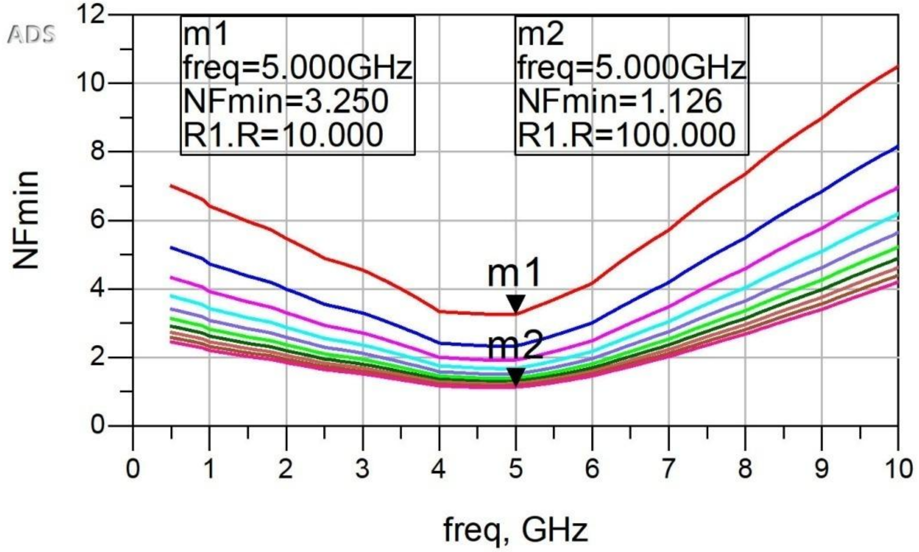


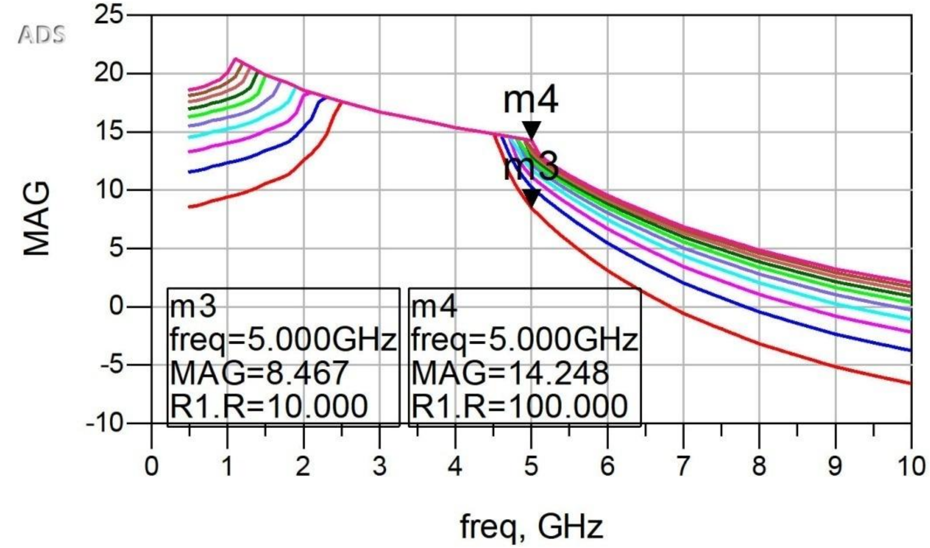


$$R_{SS} = 1 \div 10\,\Omega$$

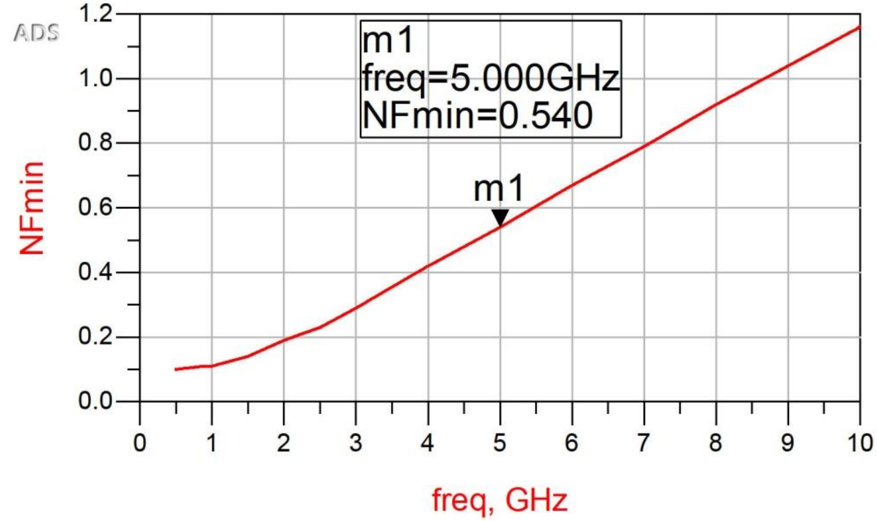


Stabilizare R paralel la intrare

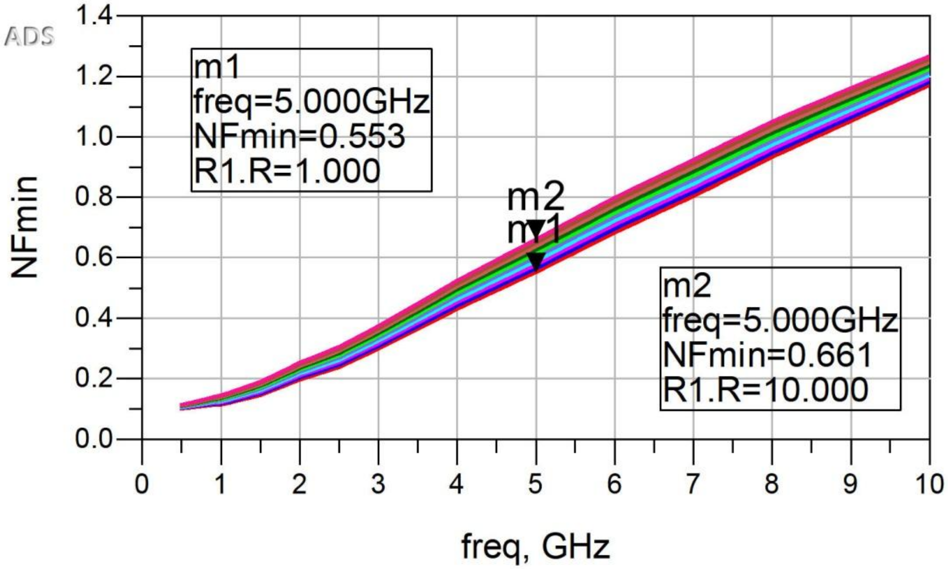


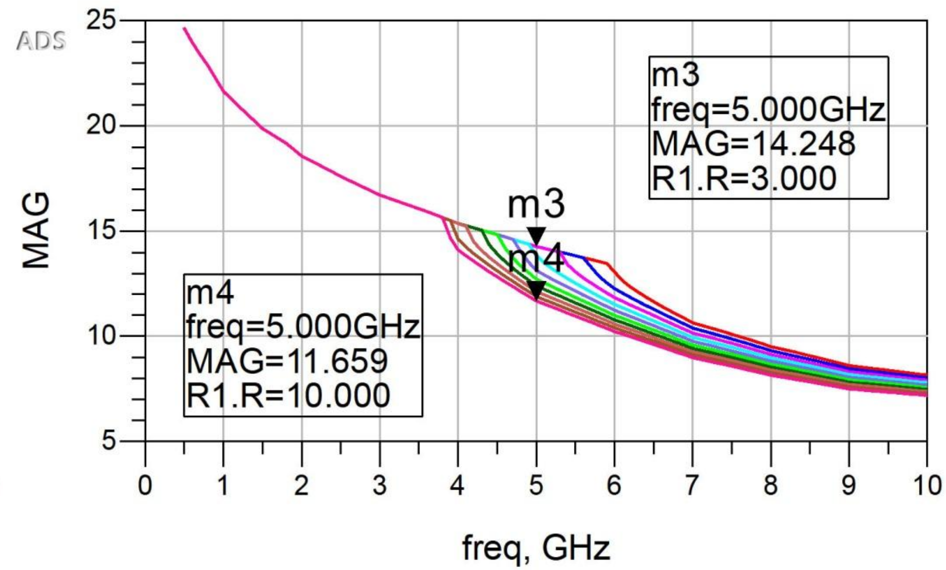


$$R_{PS} = 10 \div 100\,\Omega$$

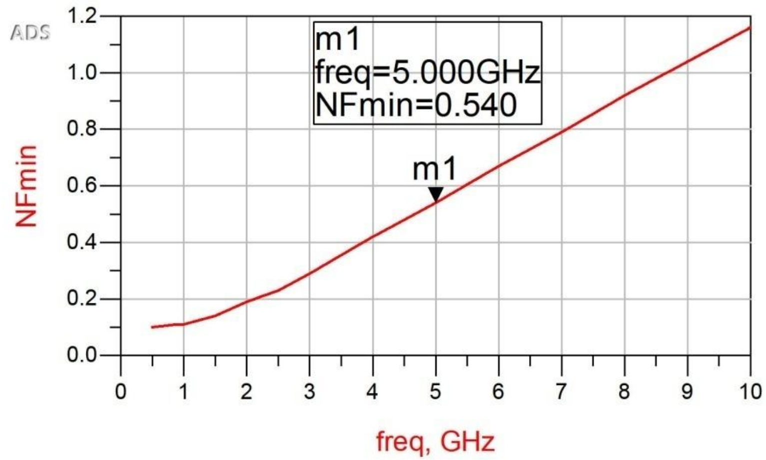


Stabilizare R serie la iesire

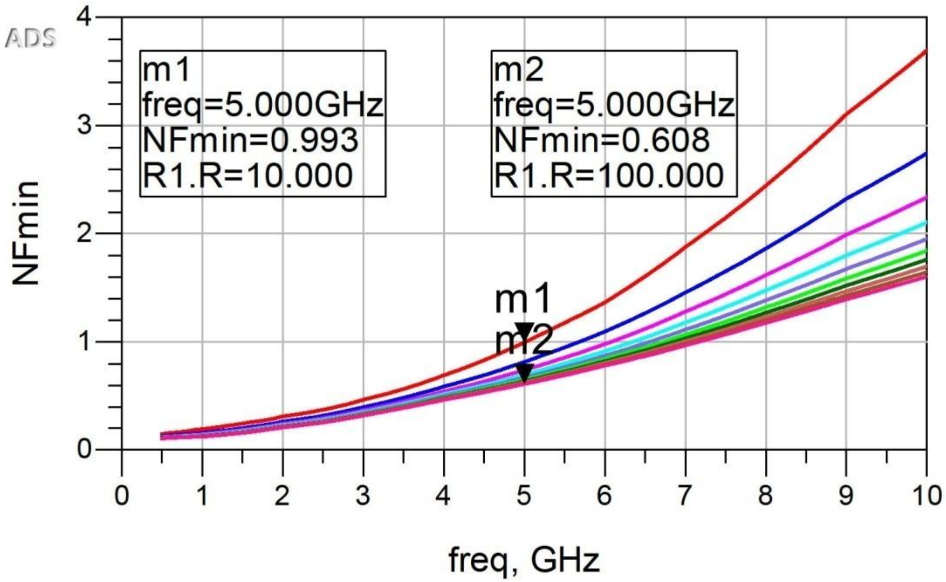


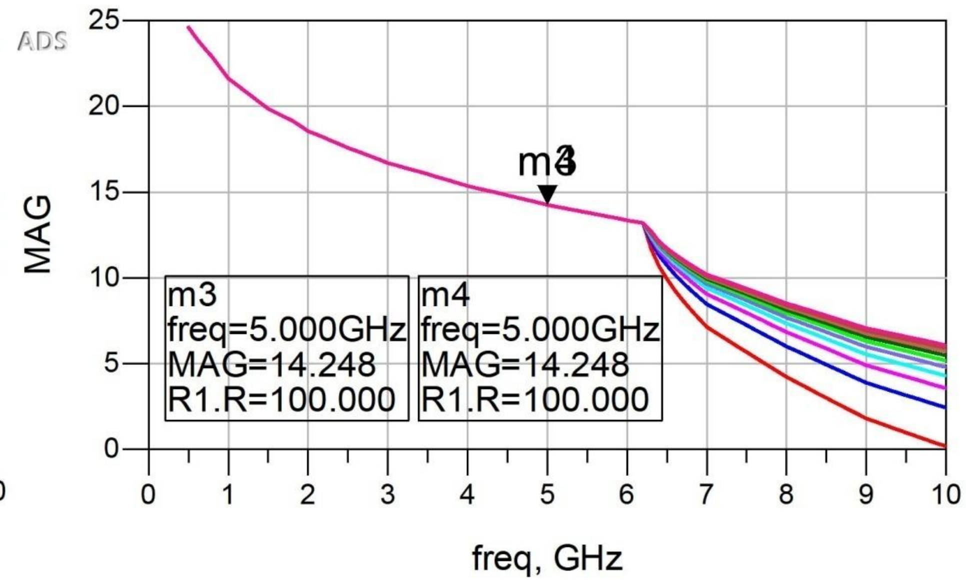


$$R_{SL} = 1 \div 10\,\Omega$$

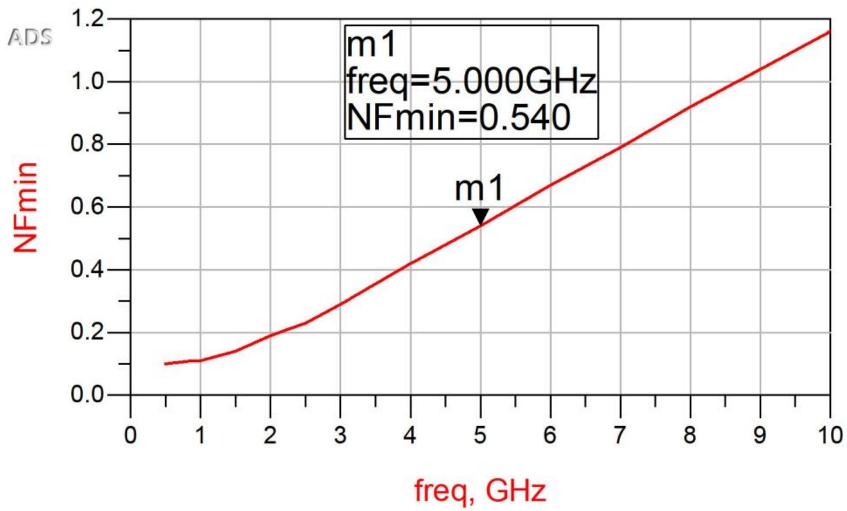


Stabilizare R paralel la iesire





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



Zgomotul unui amplificator

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

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

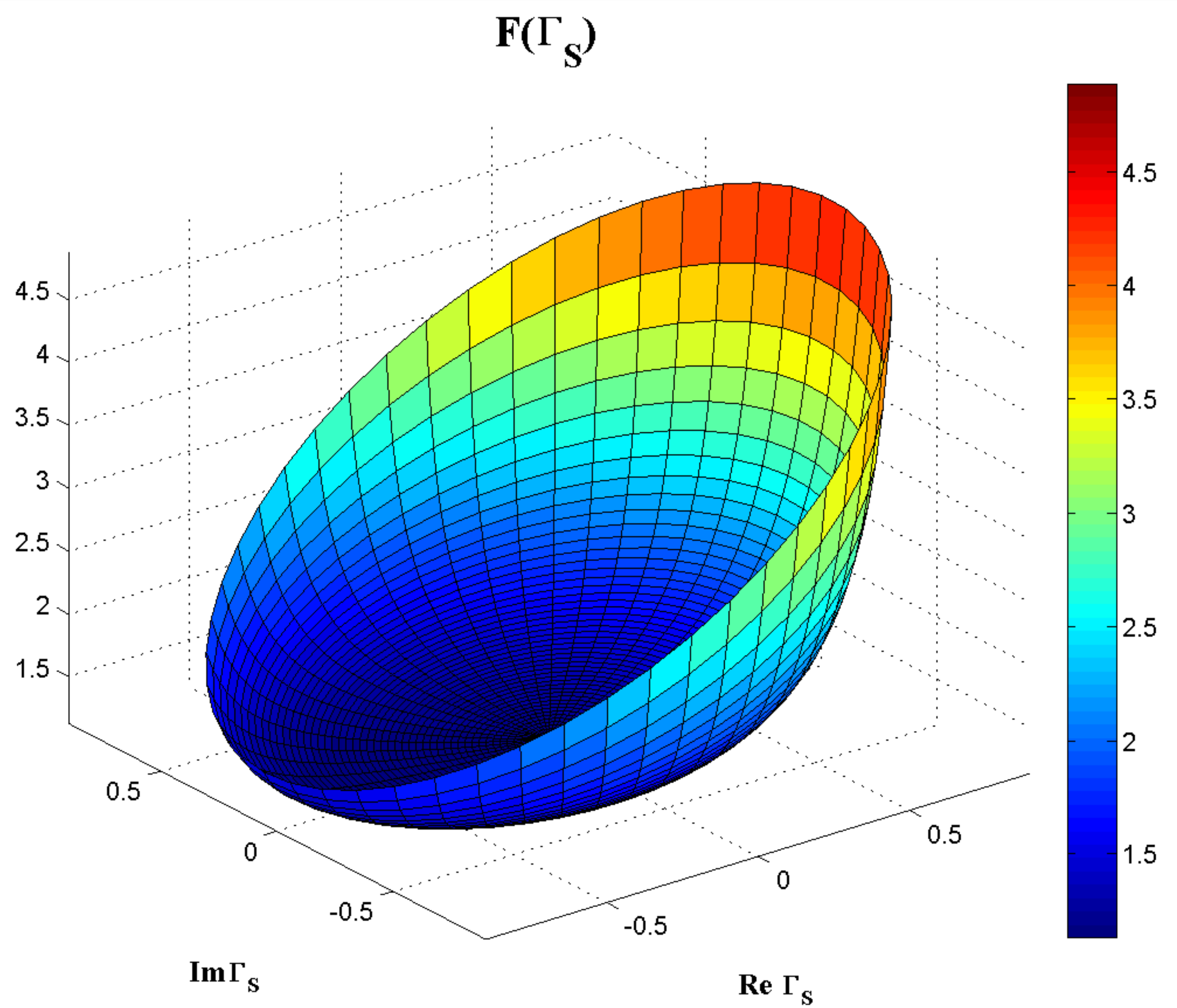
$$F = F_{\min} + \frac{R_N}{G_S} \cdot \left| Y_S - Y_{opt} \right|^2 \qquad Y_S = \frac{1}{Z_0} \cdot \frac{1-\Gamma_S}{1+\Gamma_S} \qquad Y_{opt} = \frac{1}{Z_0} \cdot \frac{1-\Gamma_{opt}}{1+\Gamma_{opt}}$$

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

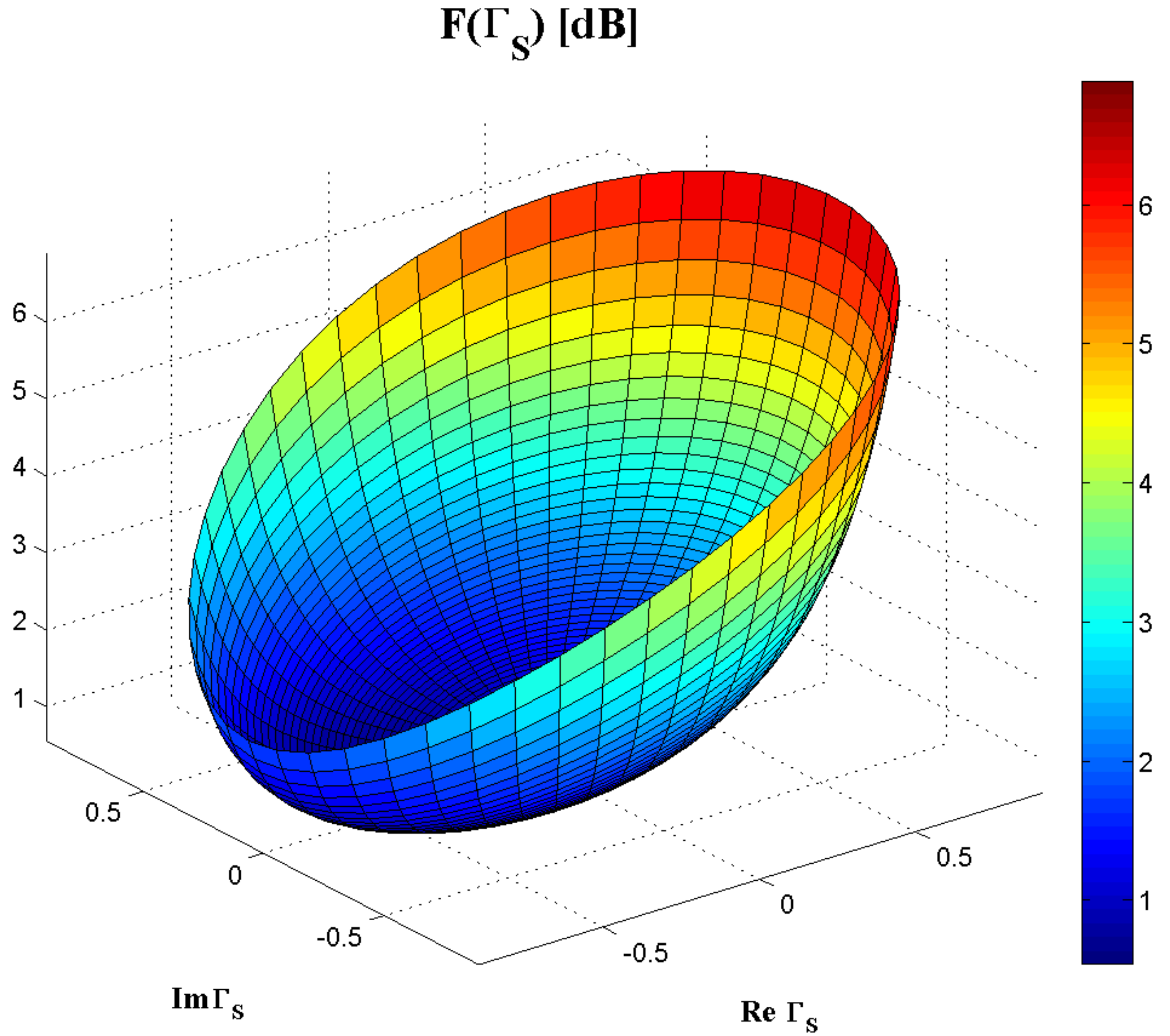
- Γ_{opt} reprezinta coeficientul optim de reflexie la intrare

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

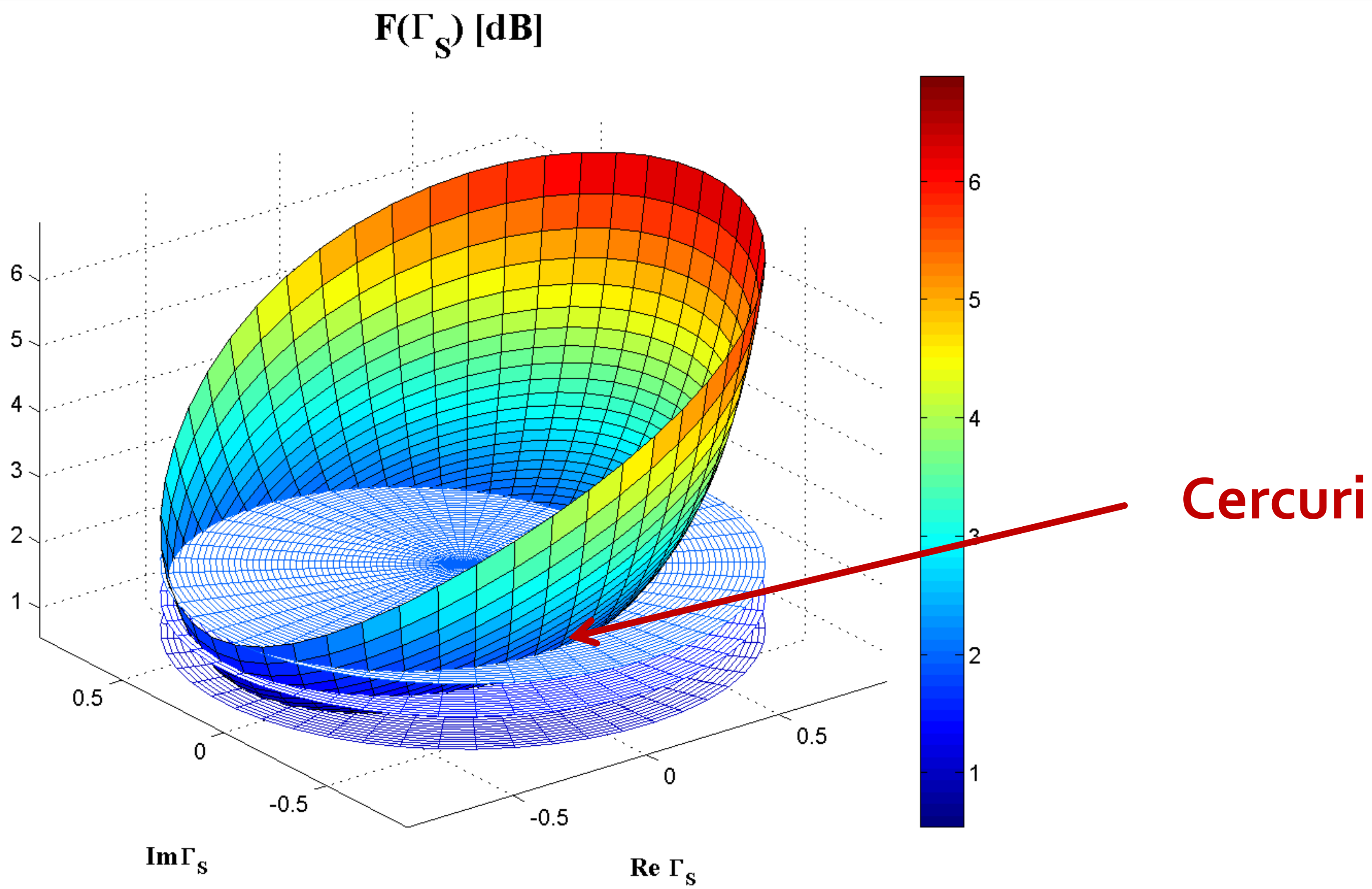
$F(\Gamma_S)$



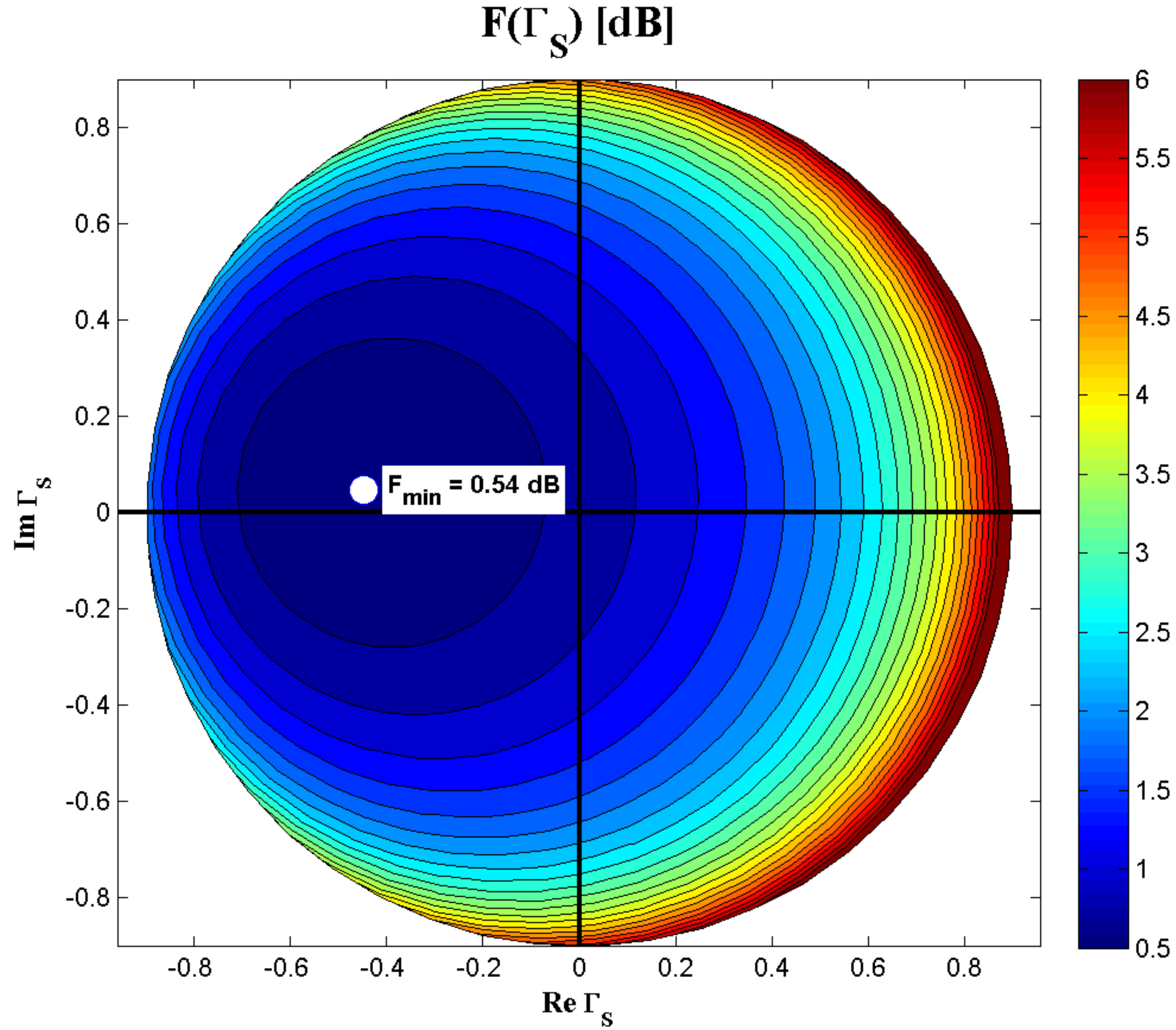
F[dB](Γ_S)



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



G_S[dB](Γ_S), diagrama de nivel



$\Gamma opt = 0.45 \angle 174°$

Cercuri de zgomot constant

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

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

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

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

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

$$+ \frac{\left|\Gamma_{opt}\right|^2}{\left(N+1\right)^2}$$

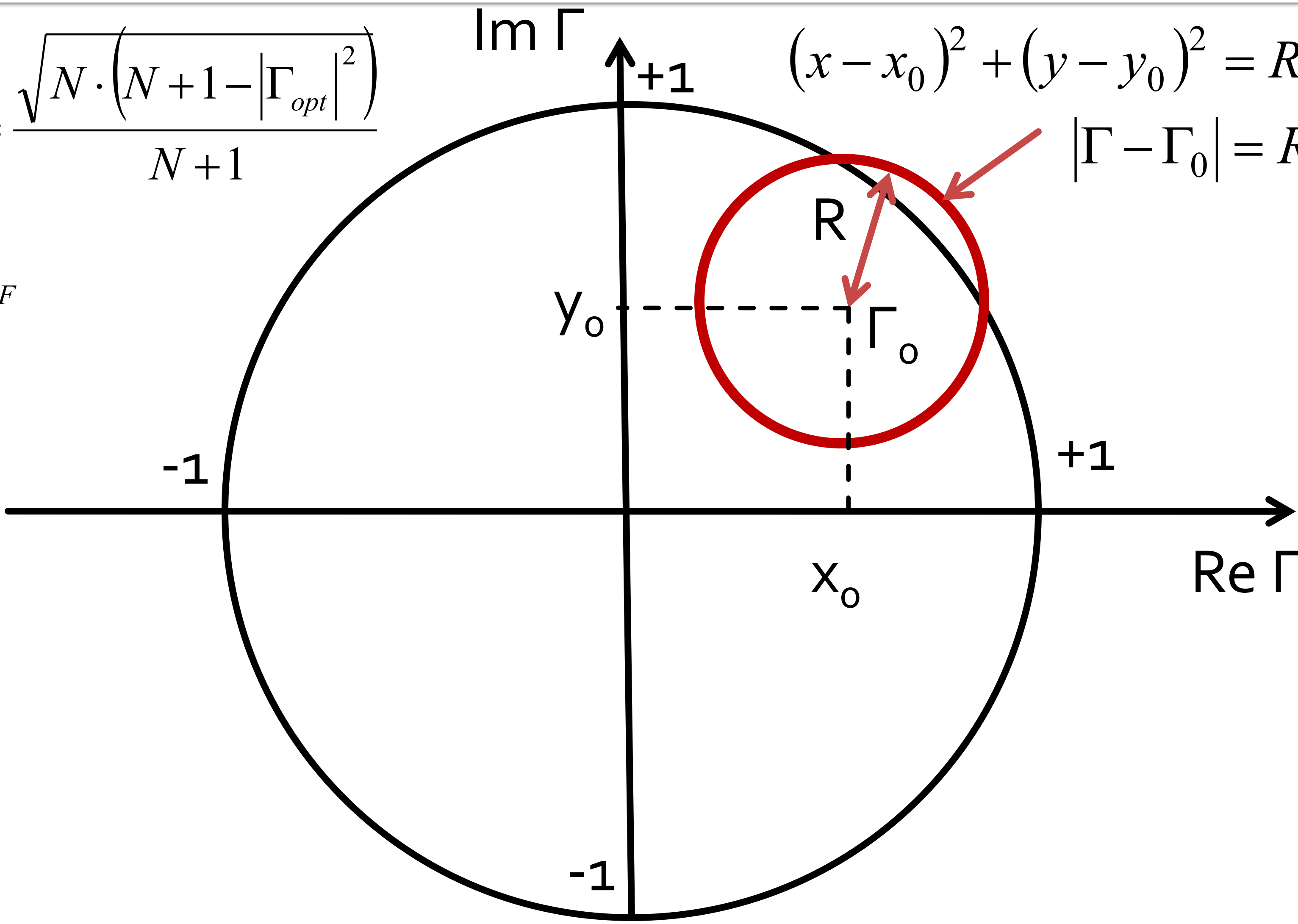
Zgomot

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

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

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

$$\left|\Gamma-\Gamma_0\right|=R$$



Cercuri de zgomot constant

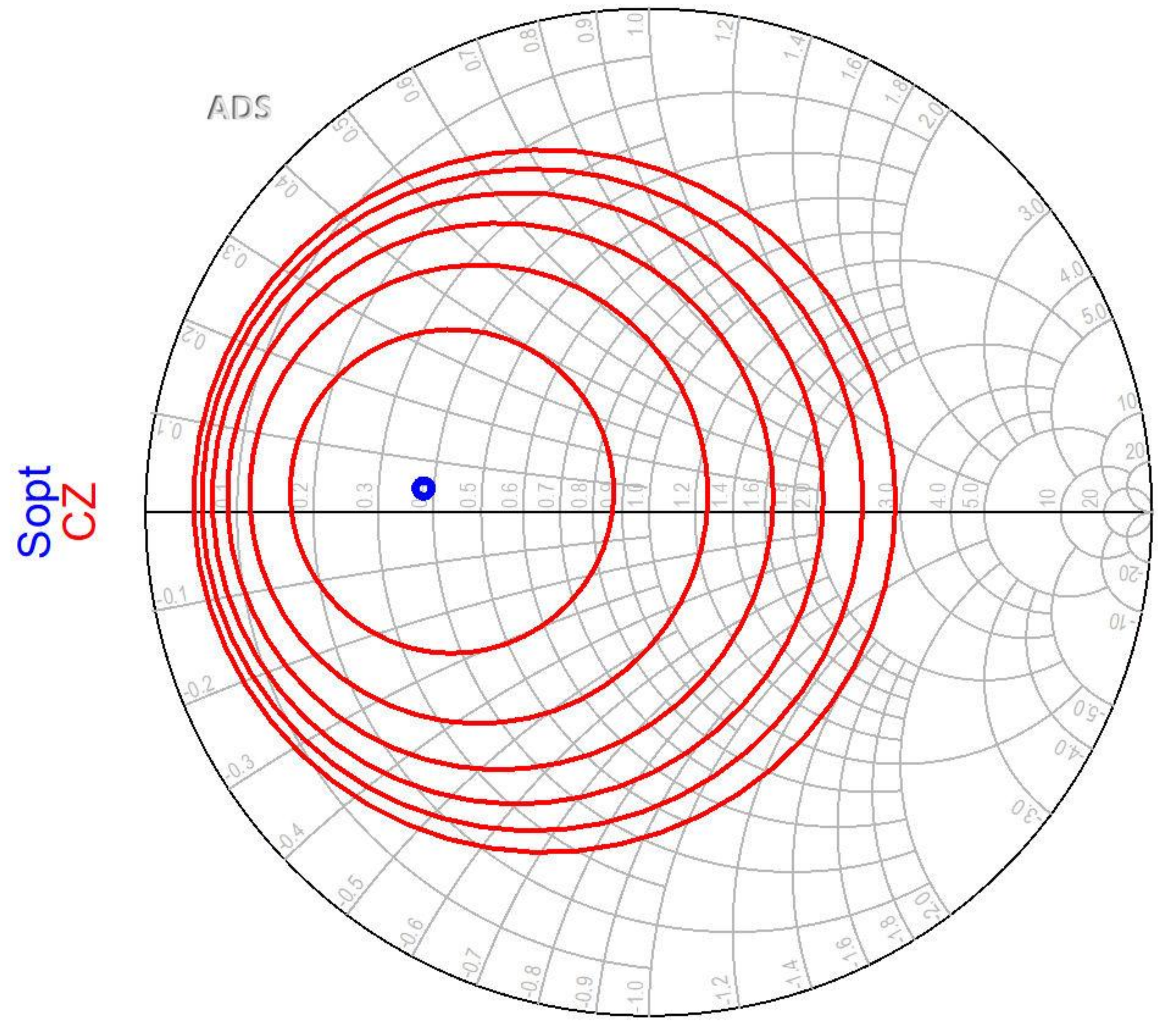
$$N = \frac{F - F_{\min}}{4 \cdot r_n \left|1 + \Gamma_{opt}\right|^2}$$

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

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

- 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

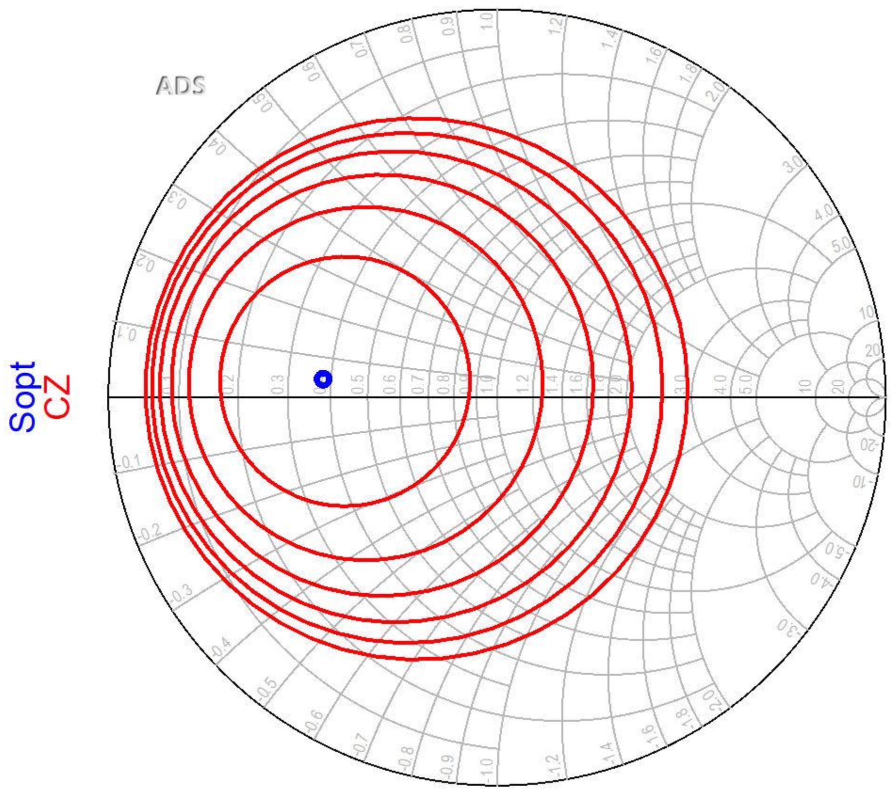


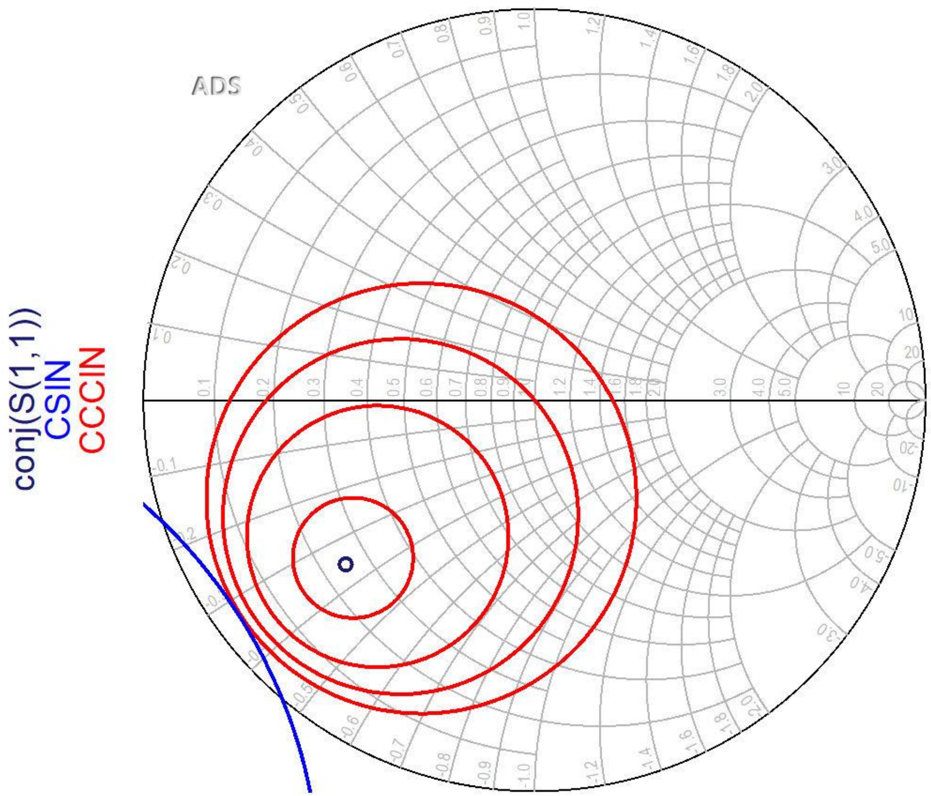
Cercuri de zgomot constant

- 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

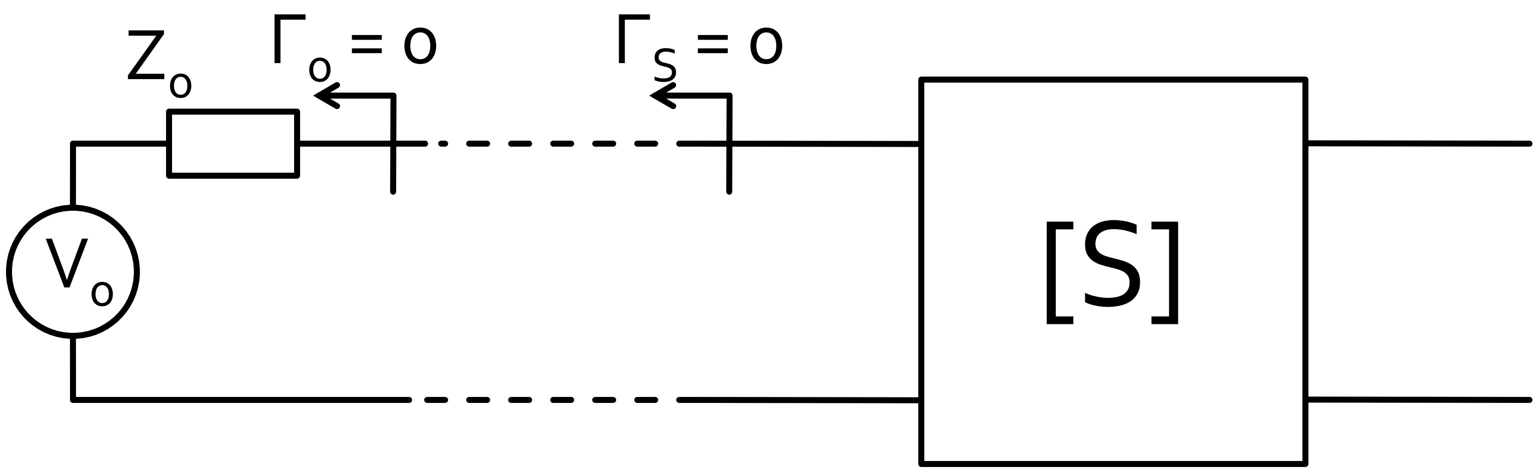
- De obicei un tranzistor potrivit pentru implementarea unui LNA la o anumita frecventa va avea cercurile de castig la intrare si cercurile de zgomot in aceeasi zona pentru Γ_S





Adaptare – 1

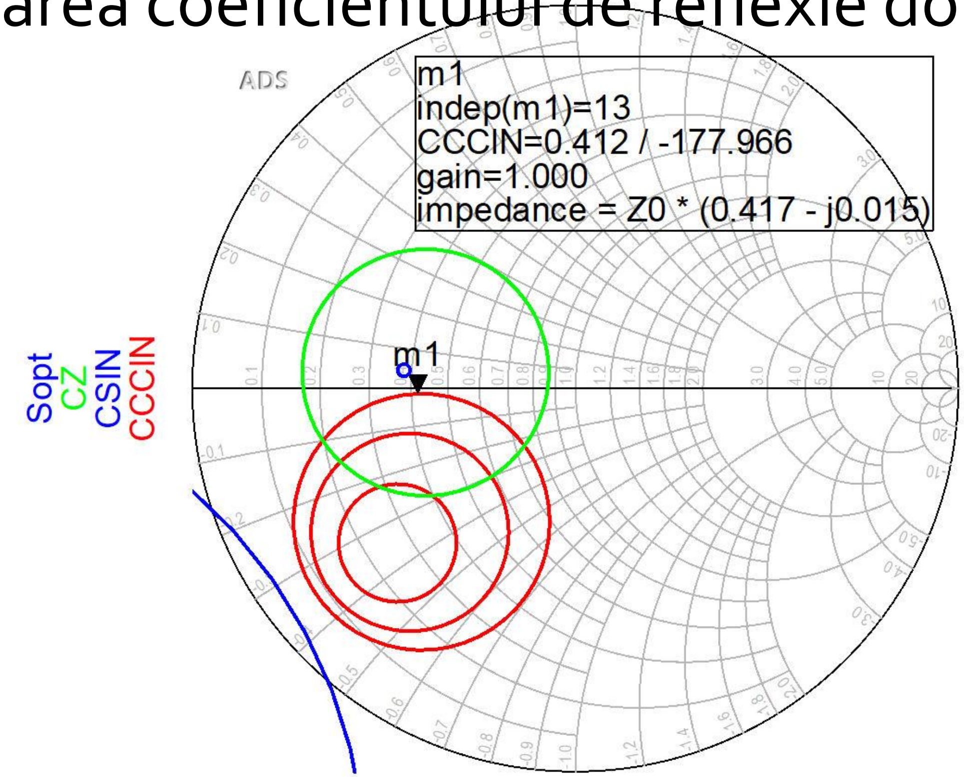
- Conectarea amplificatorului (tranzistorului) direct la sursa de semnal oferă un coeficient de reflexie la intrarea tranzistorului egal cu **0** (complex, $\Gamma_0 = 0 + 0 \cdot j$)
  - de cele mai multe ori acest coeficient de reflexie nu oferă conditii optime de castig si/sau zgomot



Adaptare – 2

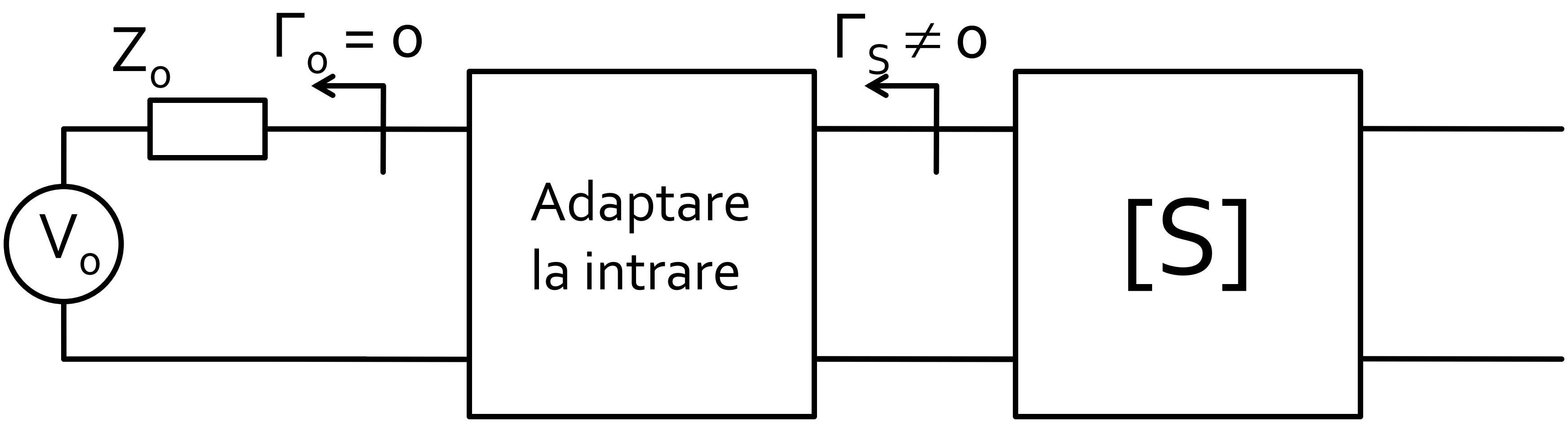
- Se deseneaza pe diagrama Smith cercurile de stabilitate/castig/zgomot, in functie de aplicatia
- Se alege punctul cu o pozitionare dorita relativ la aceste cercuri (de asemenea dependent de aplicatie)
- Se determina valoarea coeficientului de reflexie dorit la intrare Γ_S

$$\Gamma_S = 0.412\angle -177.966°$$



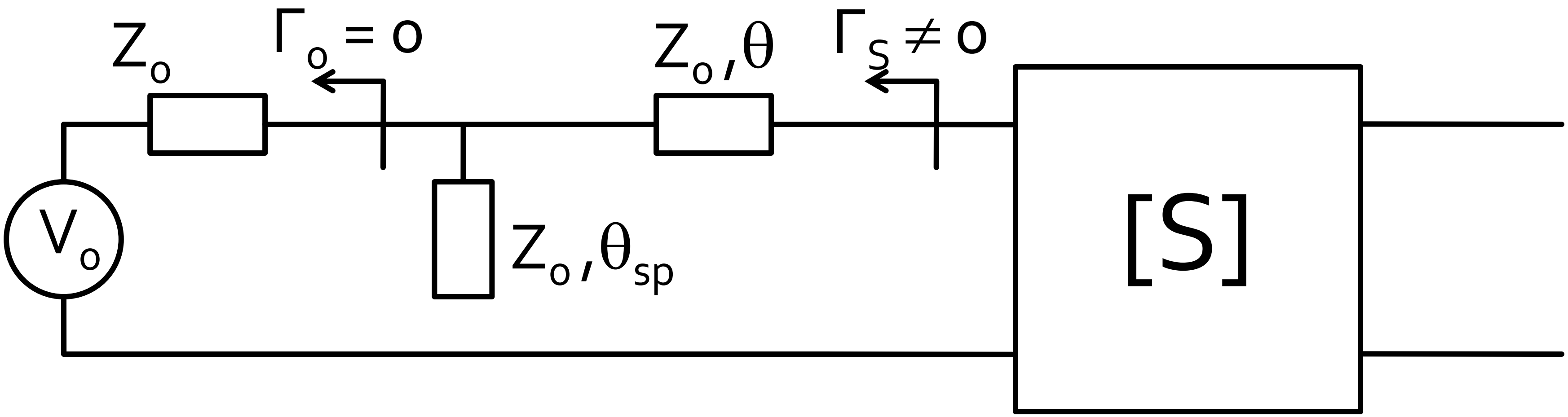
Adaptare – 3

- Se interpune reteaua de adaptare la intrare care permite obtinerea lui Γ_S 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 **s**tub **p**aralel, lasat in gol la capat, realizat dintr-o linie cu impedanta caracteristica Z_0 si lungime electrica θ_{sp}

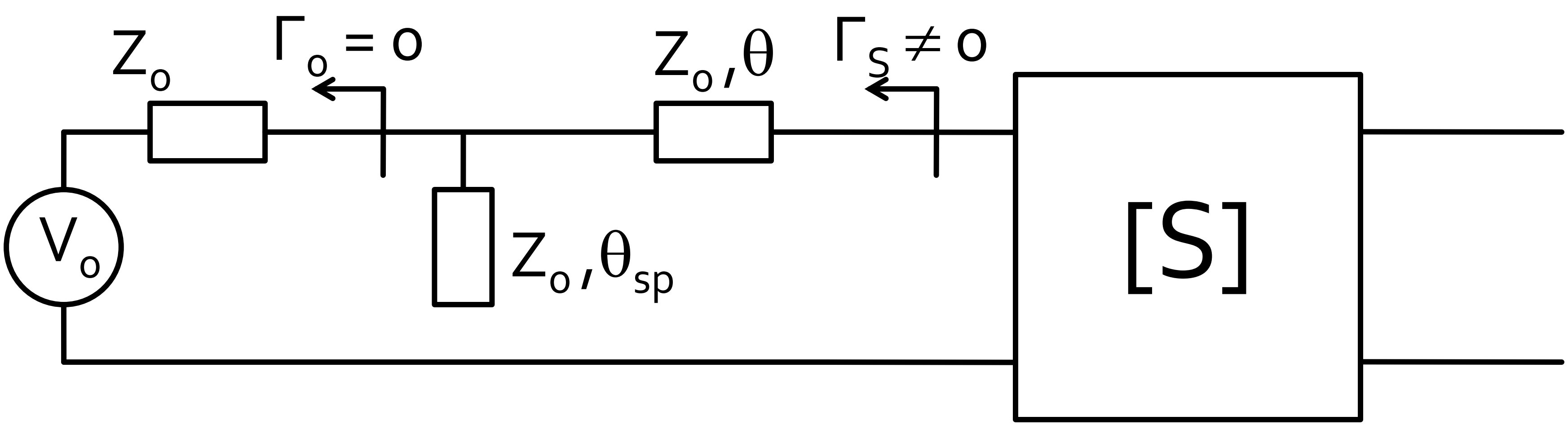


Adaptare – 5

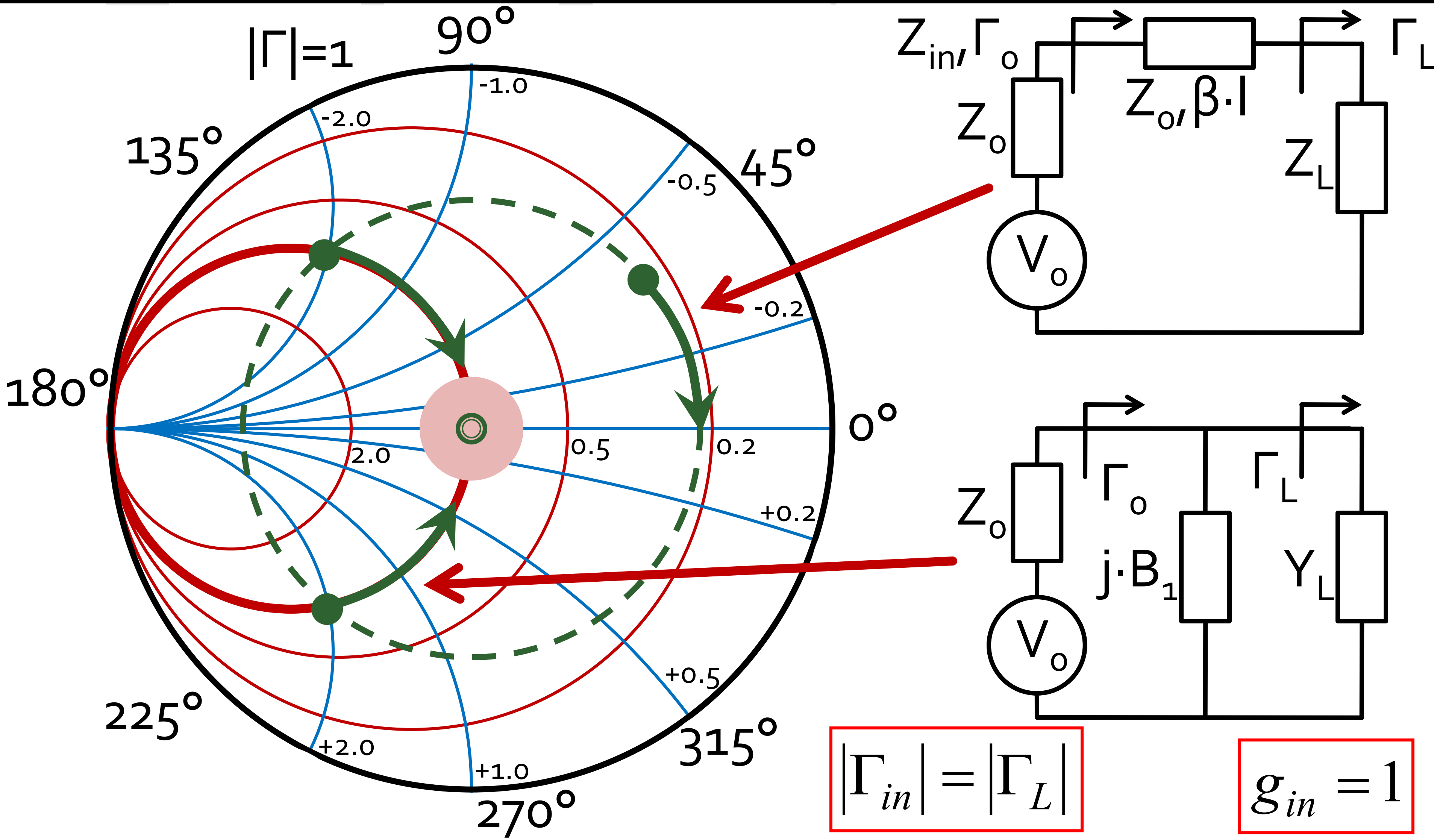
- Relatiile de calcul depind numai de Γ_S (modul si faza)

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

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



Adaptare cu stub-uri, C8



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

$$g_{in} = 1$$

Exemplu, LNA @ 5 GHz

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

```
!ATF-34143
!S-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

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

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

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

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

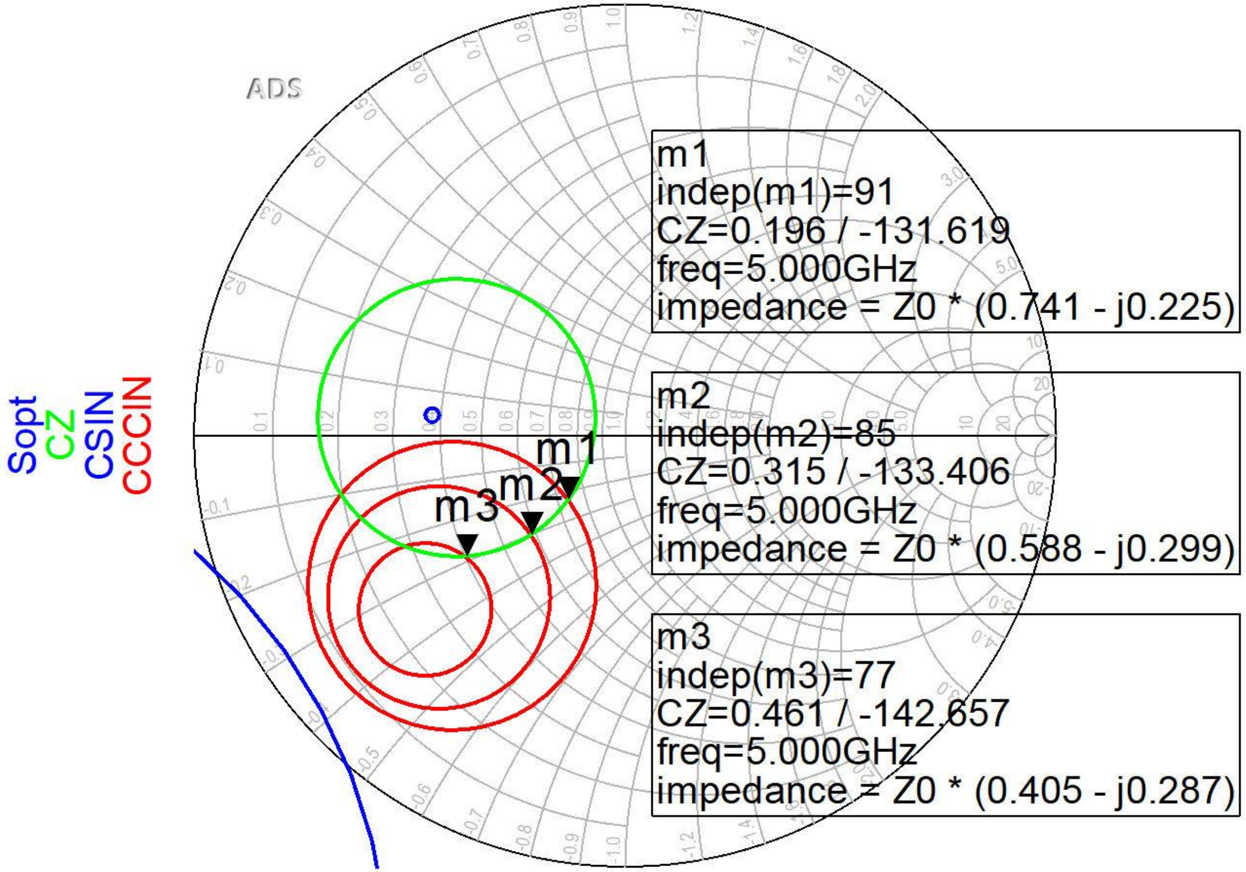
$$G_0 = |S_{21}|^2 = 10.017 = 10.007\ dB$$

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

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

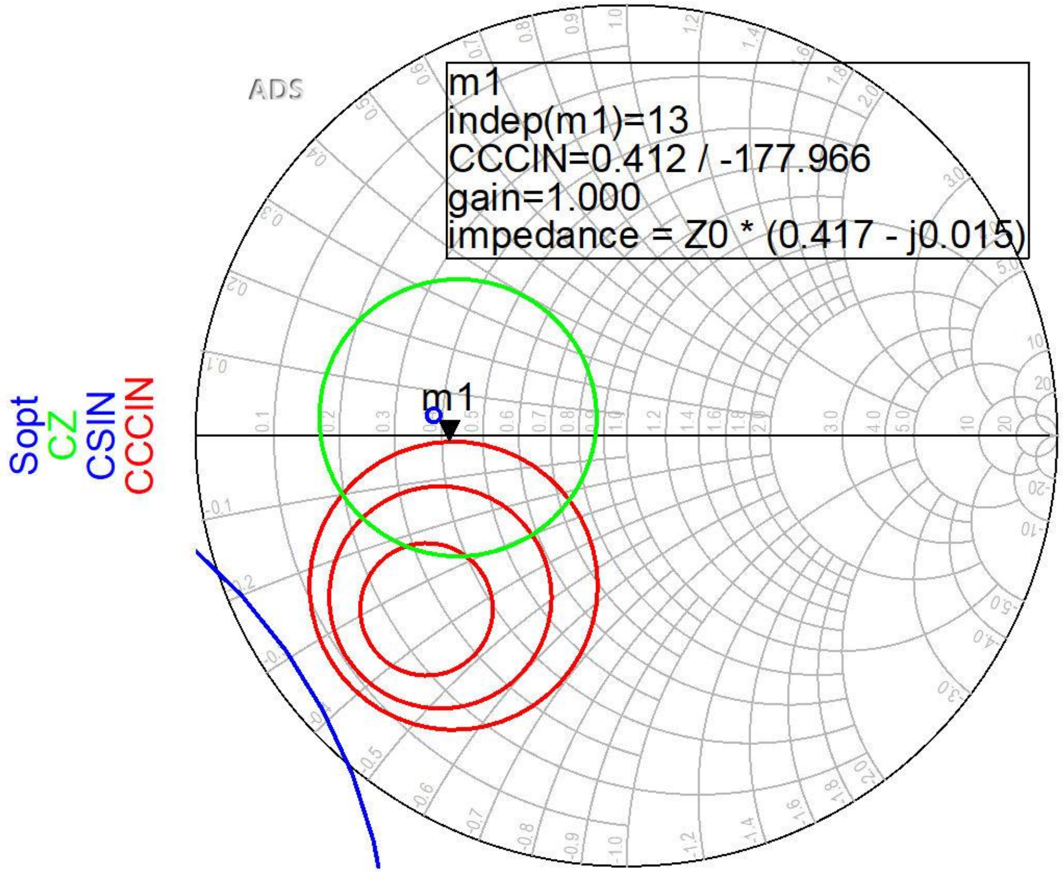
- In cazul particular prezent G_{Lmax} = 0.21 dB, amplificatorul ar putea functiona cu iesirea conectata direct la o sarcina de 50Ω
- Absenta retelei de adaptare la iesire nu conduce la o pierdere importanta de castig, dar elimina posibilitatea ca prin reglaj sa se compenseze compromisul castig/zgomot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

Adaptare la intrare



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

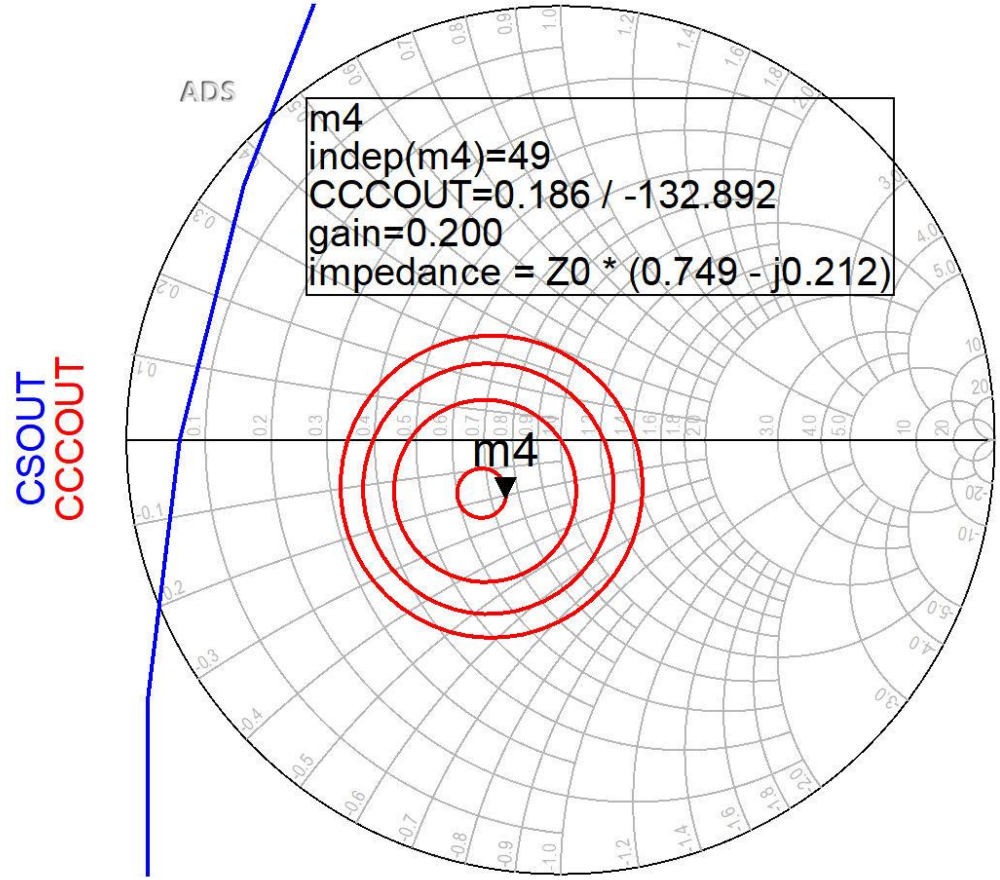
$$\Gamma_S = 0.412\angle -178^\circ \qquad |\Gamma_S| = 0.412; \quad \varphi = -178^\circ$$

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

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

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

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 m4 de pe grafic

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

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

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

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

LNA

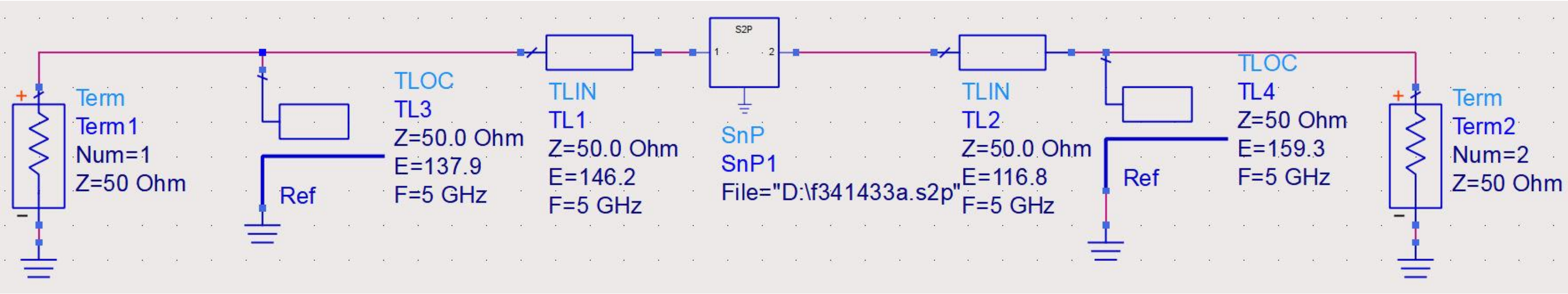
- Se estimeaza obtinerea unui castig (in ipoteza unilaterala, ±0.9 dB)

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

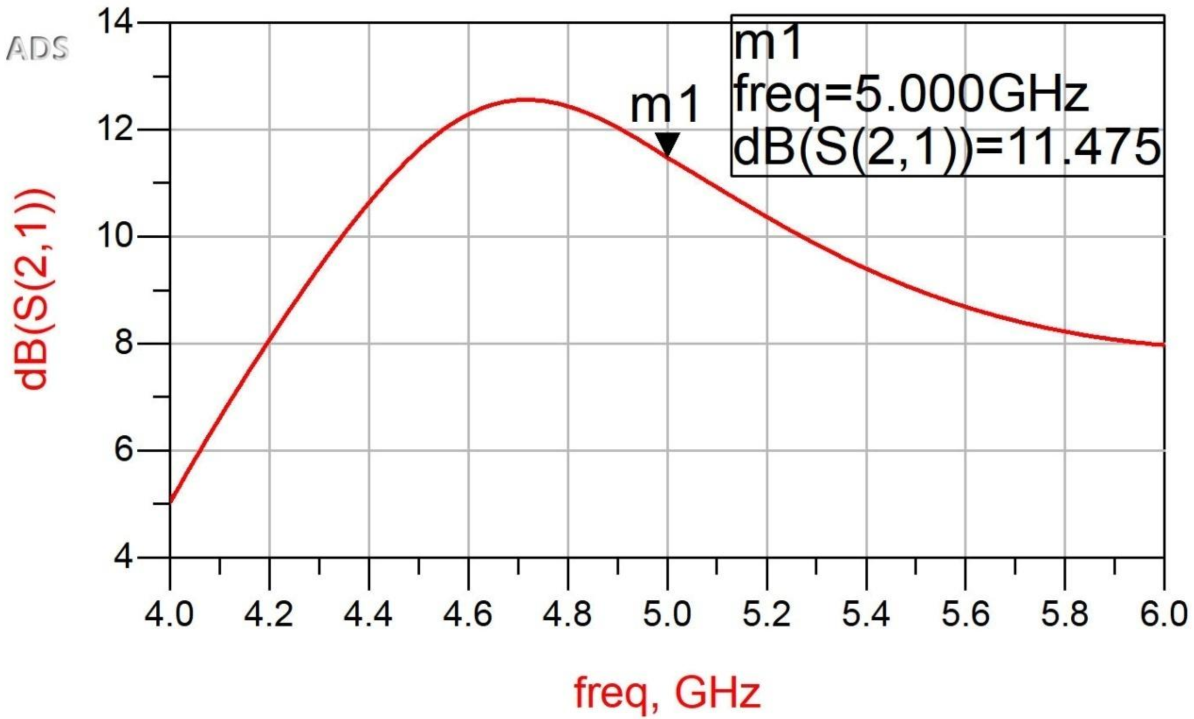
$$G_T[dB] = 1\ dB + 10\ dB + 0.2\ dB = 11.2\ dB$$

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

ADS

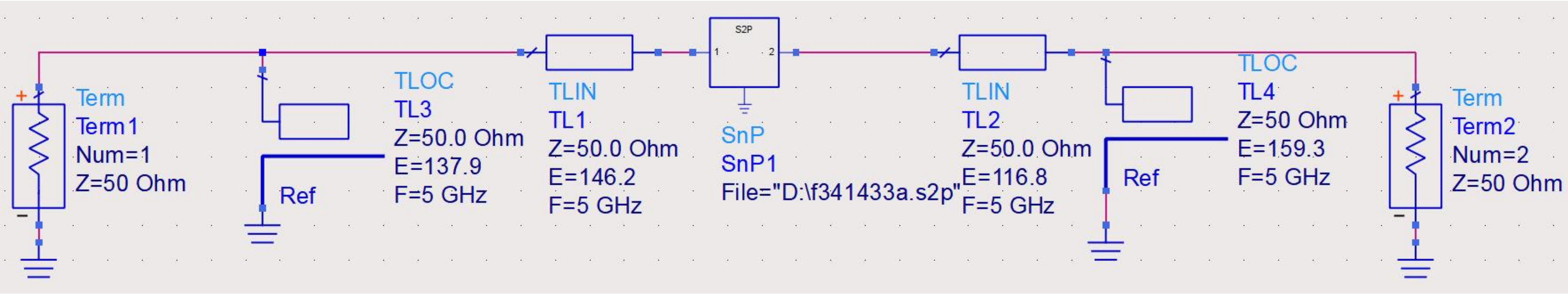


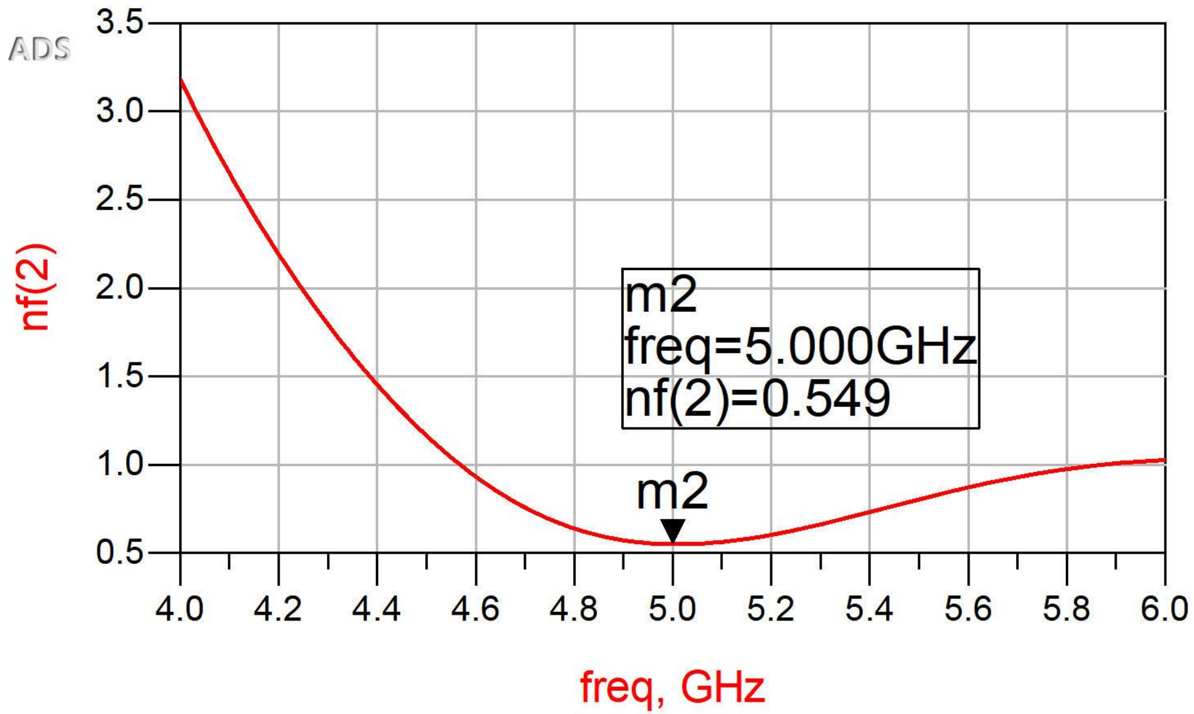
Term
Term1
Num=1
Z=50 Ohm
Ref
TLOC
TL3
Z=50.0 Ohm
E=137.9
F=5 GHz
TLIN
TL1
Z=50.0 Ohm
E=146.2
F=5 GHz
S2P
SnP
SnP1
File="D:\f341433a.s2p"
TLIN
TL2
Z=50.0 Ohm
E=116.8
F=5 GHz
Ref
TLOC
TL4
Z=50 Ohm
E=159.3
F=5 GHz
Term
Term2
Num=2
Z=50 Ohm



ADS
m1
freq=5.000GHz
dB(S(2,1))=11.475
m1
dB(S(2,1))
freq, GHz
14
12
10
8
6
4
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0

ADS

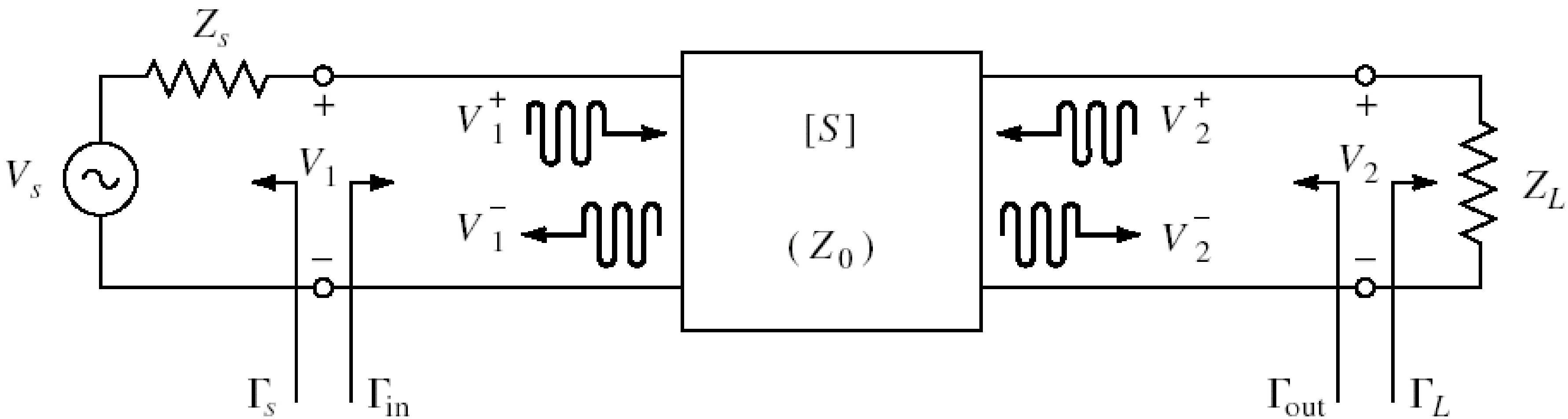

S2P
Term
Term1
Num=1
Z=50 Ohm
Ref
TLOC
TL3
Z=50.0 Ohm
E=137.9
F=5 GHz
TLIN
TL1
Z=50.0 Ohm
E=146.2
F=5 GHz
SnP
SnP1
File="D:\f341433a.s2p"
TLIN
TL2
Z=50.0 Ohm
E=116.8
F=5 GHz
Ref
TLOC
TL4
Z=50 Ohm
E=159.3
F=5 GHz
Term
Term2
Num=2
Z=50 Ohm


ADS
nf(2)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
m2
freq=5.000GHz
nf(2)=0.549
m2
4.0
4.2
4.4
4.6
4.8
5.0
5.2
5.4
5.6
5.8
6.0
freq, GHz

Amplificatoare de microunde

Castigul amplificatoarelor de microunde

Cuadripol Amplificator



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

Bibliografie

- https://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)

Pozar, Microwave Engineering

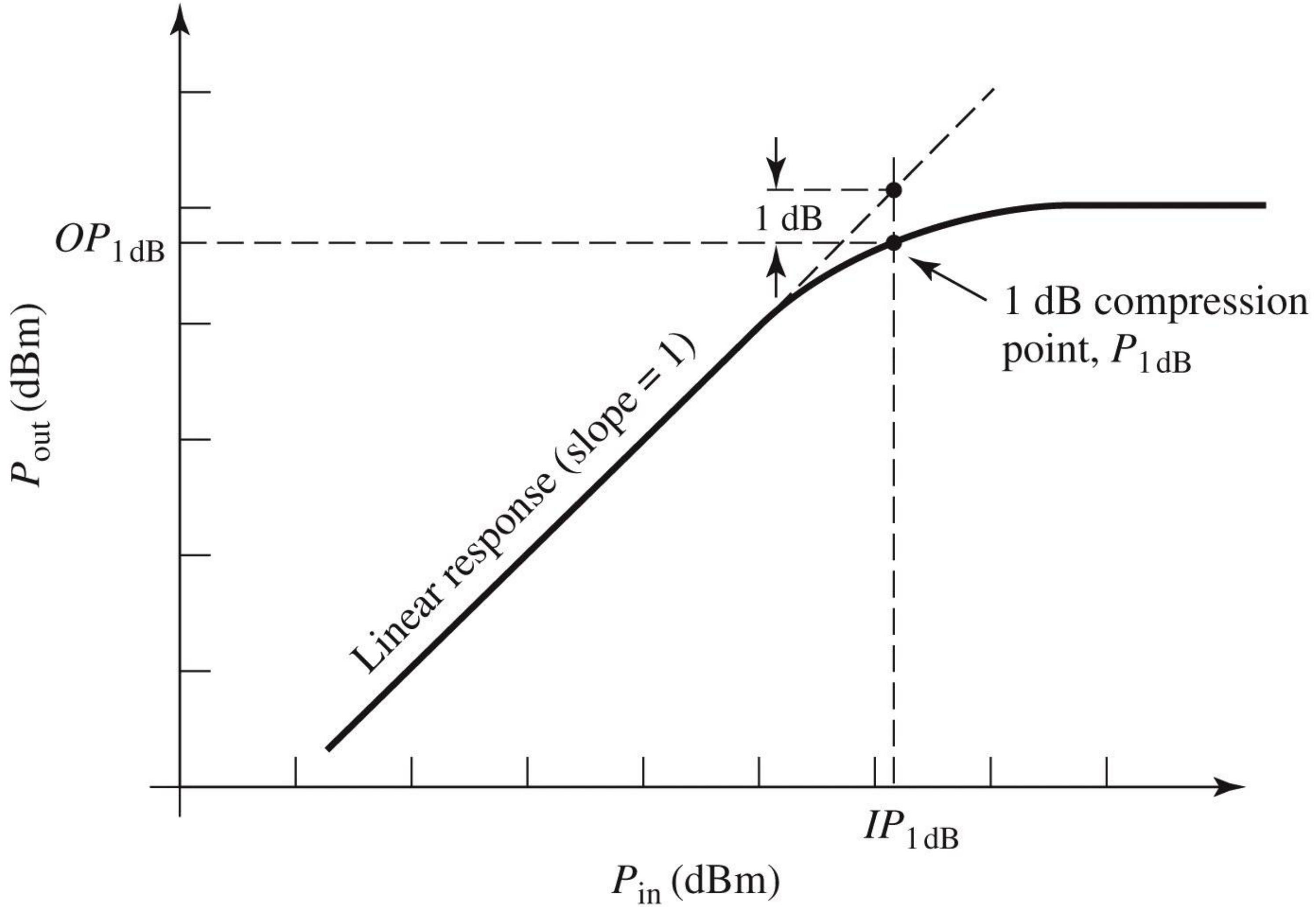


Figure 10.15

Pozar, Microwave Engineering

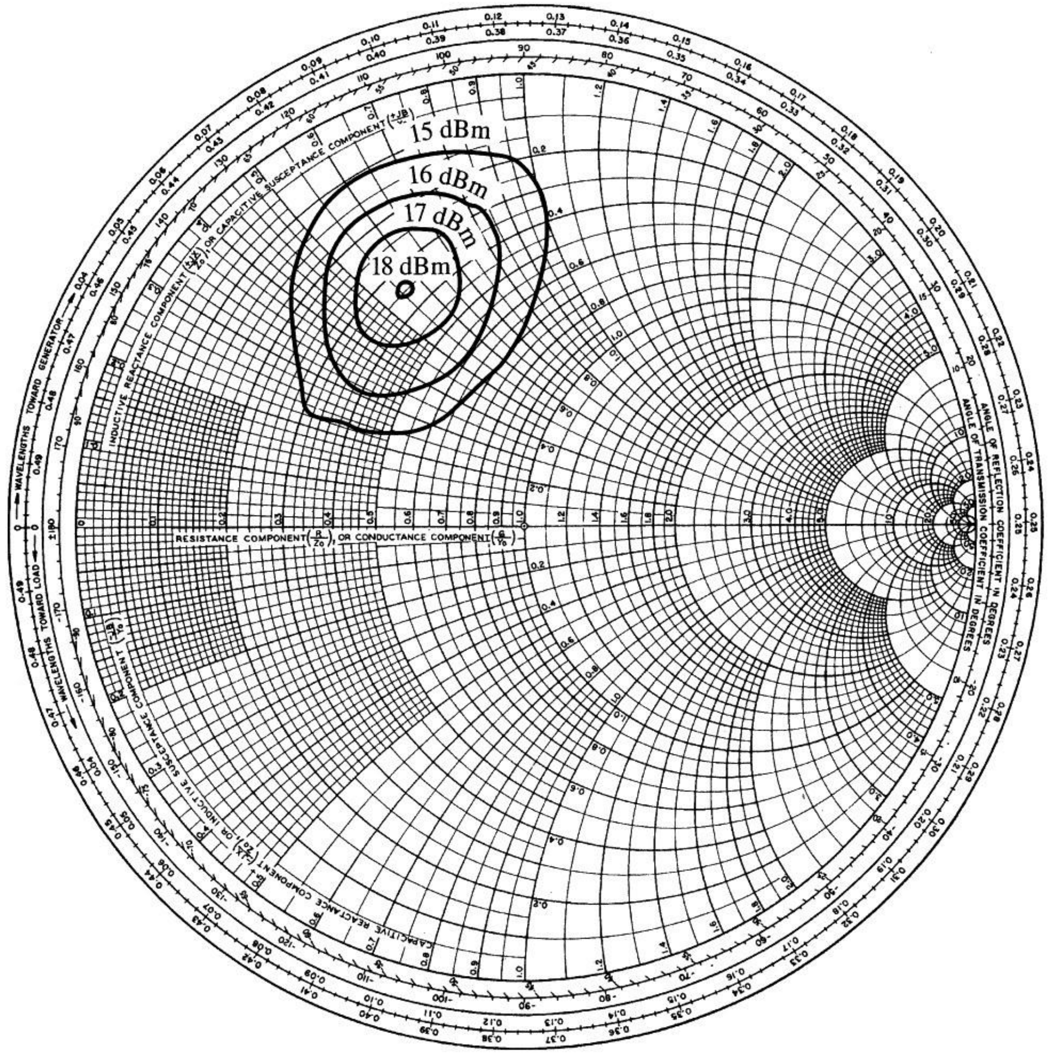


Figure 12.21

Filtre pentru microunde

Filtre pentru microunde

- In domeniul microundelor se utilizeaza doua strategii de implementare a filtrelor
  - structuri specifice microundelor (linii cuplate, rezonatori dielectrici, structuri periodice)
  - **sinteza de filtre** cu elemente concentrate urmate de implementare cu linii de transmisie
- prima strategie duce la obtinerea unor filtre mai eficiente dar e caracterizata de
  - generalitate mai mica
  - proiectare deseori dificila (lipsa relatiilor analitice)

Sinteza filtrelor

- Sinteza filtrelor cu elemente concentrate, urmata de implementarea acestora cu elemente distribuite (linii)
  - generala
  - relatii analitice usor de implementat pe calculator
  - eficienta
- Metoda preferata este metoda pierderilor de insertie

Metoda pierderilor de insertie

$$P_{LR} = \frac{P_S}{P_L} = \frac{1}{1 - |\Gamma(\omega)|^2}$$

- $|\Gamma(\omega)|^2$ este o functie para de ω

$$|\Gamma(\omega)|^2 = \frac{M(\omega^2)}{M(\omega^2) + N(\omega^2)}$$

$$P_{LR} = 1 + \frac{M(\omega^2)}{N(\omega^2)}$$

- Alegerea corespunzatoare a polinoamelor M si N determina comportarea filtrului

Metoda pierderilor de insertie

- Se controleaza atenuarea introdusa de filtru
  - in banda de trecere
  - in banda de oprire

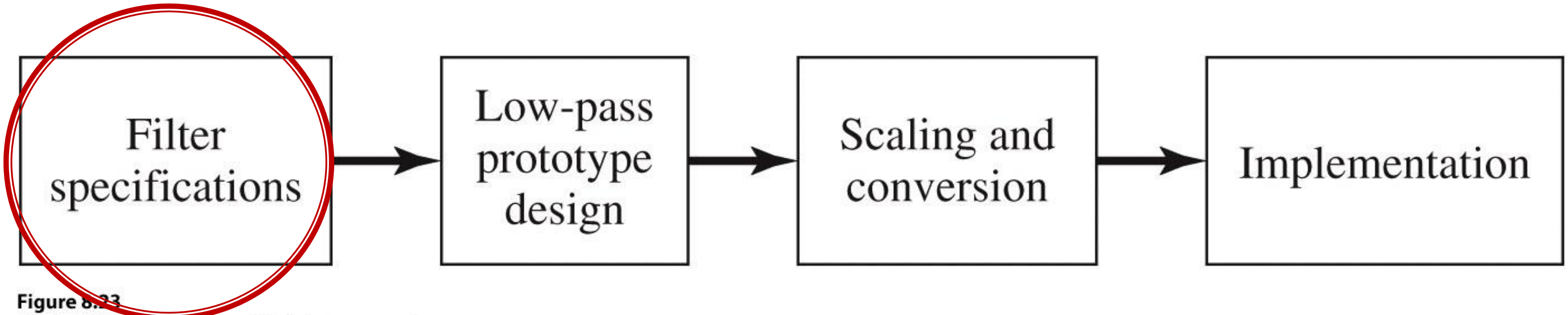
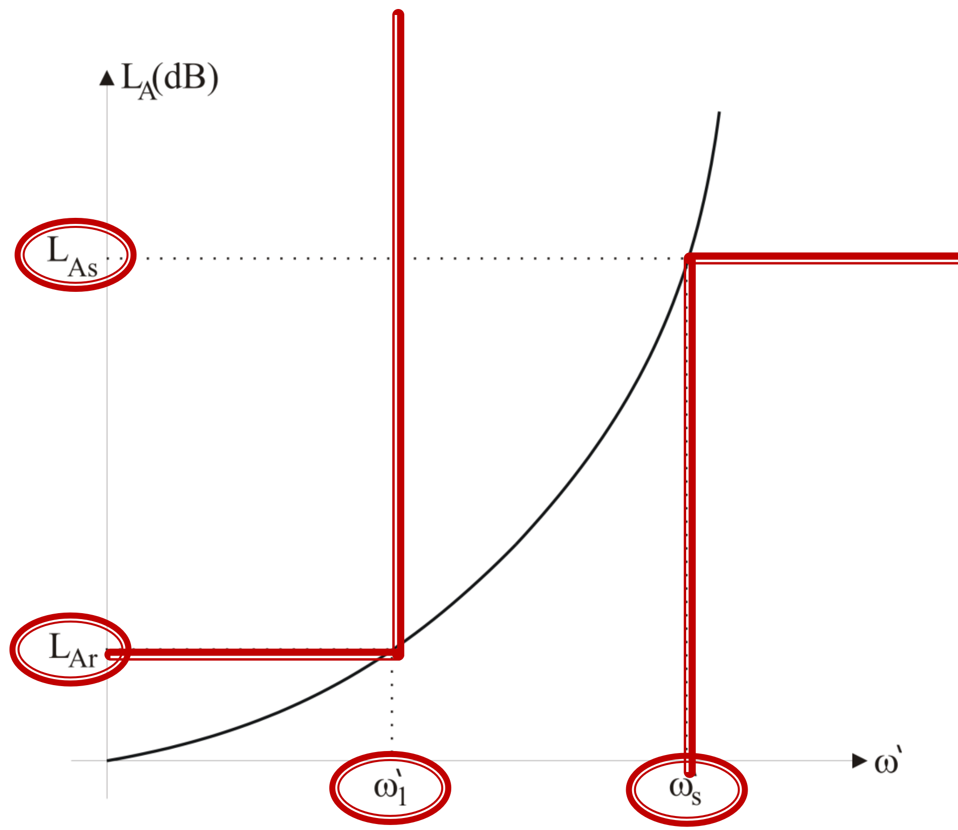


Figure 8.23

Date de proiectare

- Atenuarea
  - in banda de trecere
  - in banda de oprire
  - cel mai des cu atenuarile in **dB**
- Frecventa
  - banda de trecere
  - banda de oprire
  - frecventa de trecere ω_1' (ω_c : cuttoff) de obicei normalizata (= 1)



Metoda pierderilor de insertie

- Se aleg polinoamele pentru implementarea unui FTJ (prototip: **pas intermediar**)
- Acest filtru poate fi convertit la alte functii, scalat in frecventa pentru a obtine alte tipuri de functii

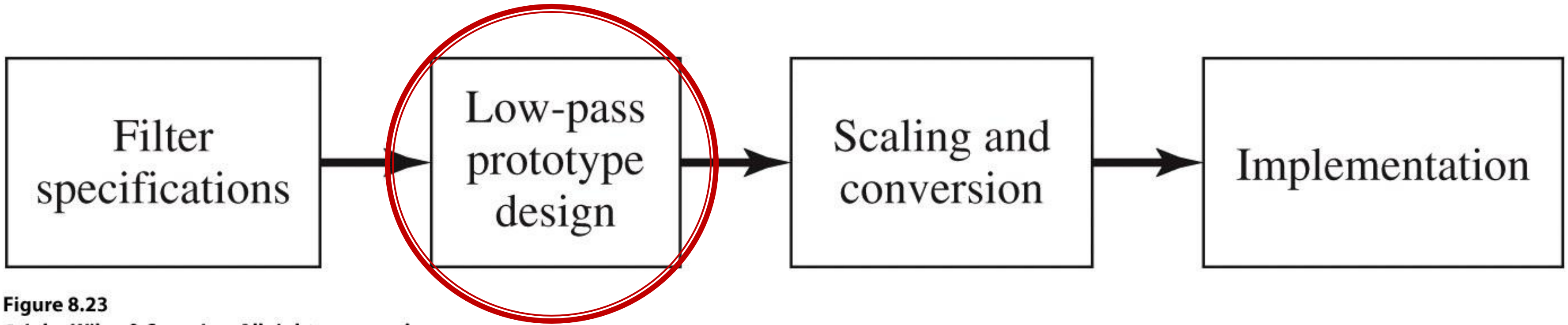


Figure 8.23

Caracteristici de filtru trece jos prototip

- **Maxim plat** (Butterworth, binomial) ofera cea mai plata comportare in banda de trecere
- **Echiriplu** (Cebasev) ofera atenuare mai mare in banda de taiere cu dezavantajul existentei unor variatii (riplu) in banda de trecere
- **Filtre eliptice**, caracterizate de variatii (riplu) si in banda de taiere si in banda de trecere
- **Filtru cu raspuns liniar in faza**, ofera intarziere de grup de maxim plat, cu dezavantajul unei atenuari in putere mai mica, necesar in anumite aplicatii

FTJ prototip Maxim plat/Echiriplu

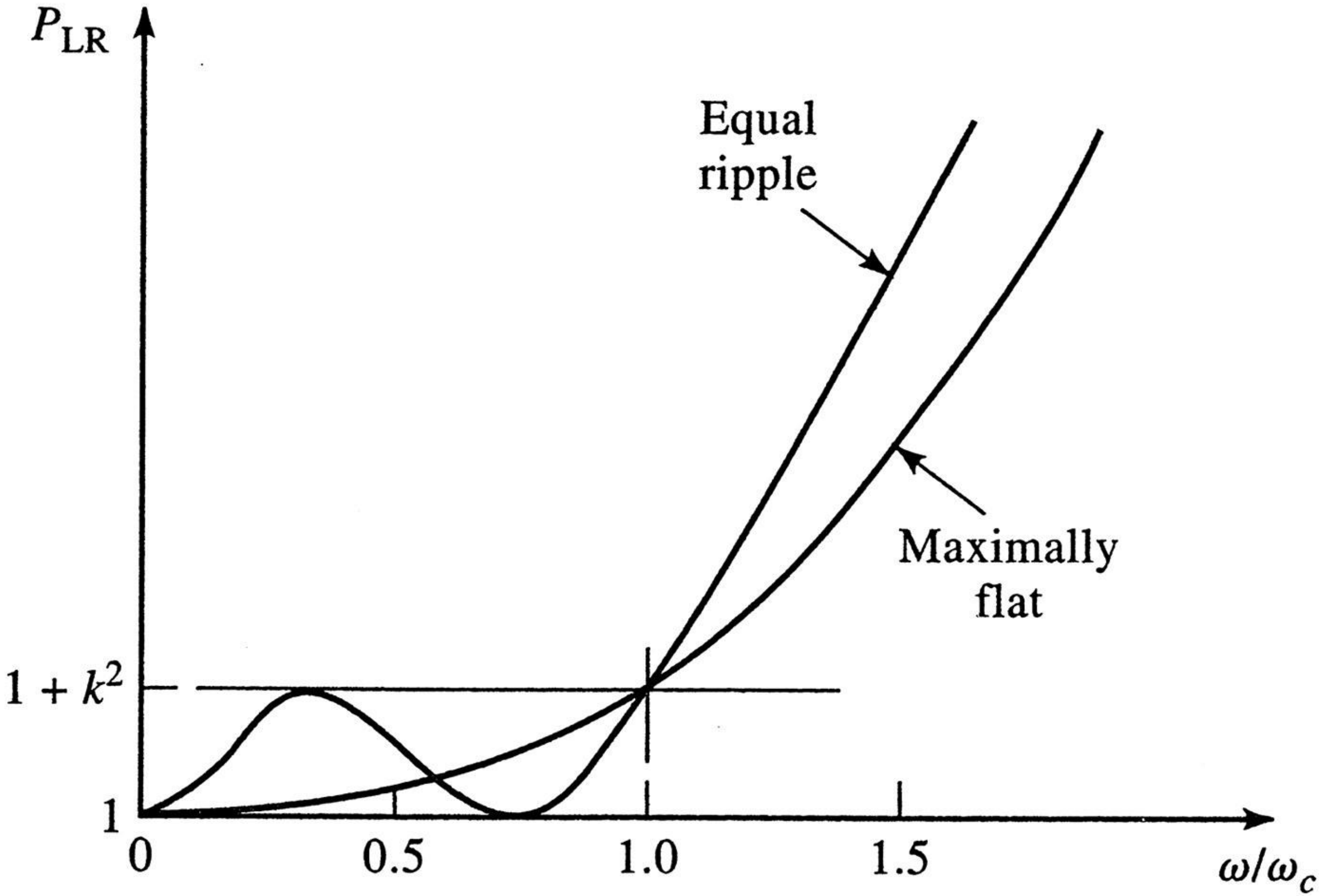


Figure 8.21

FTJ eliptic prototip

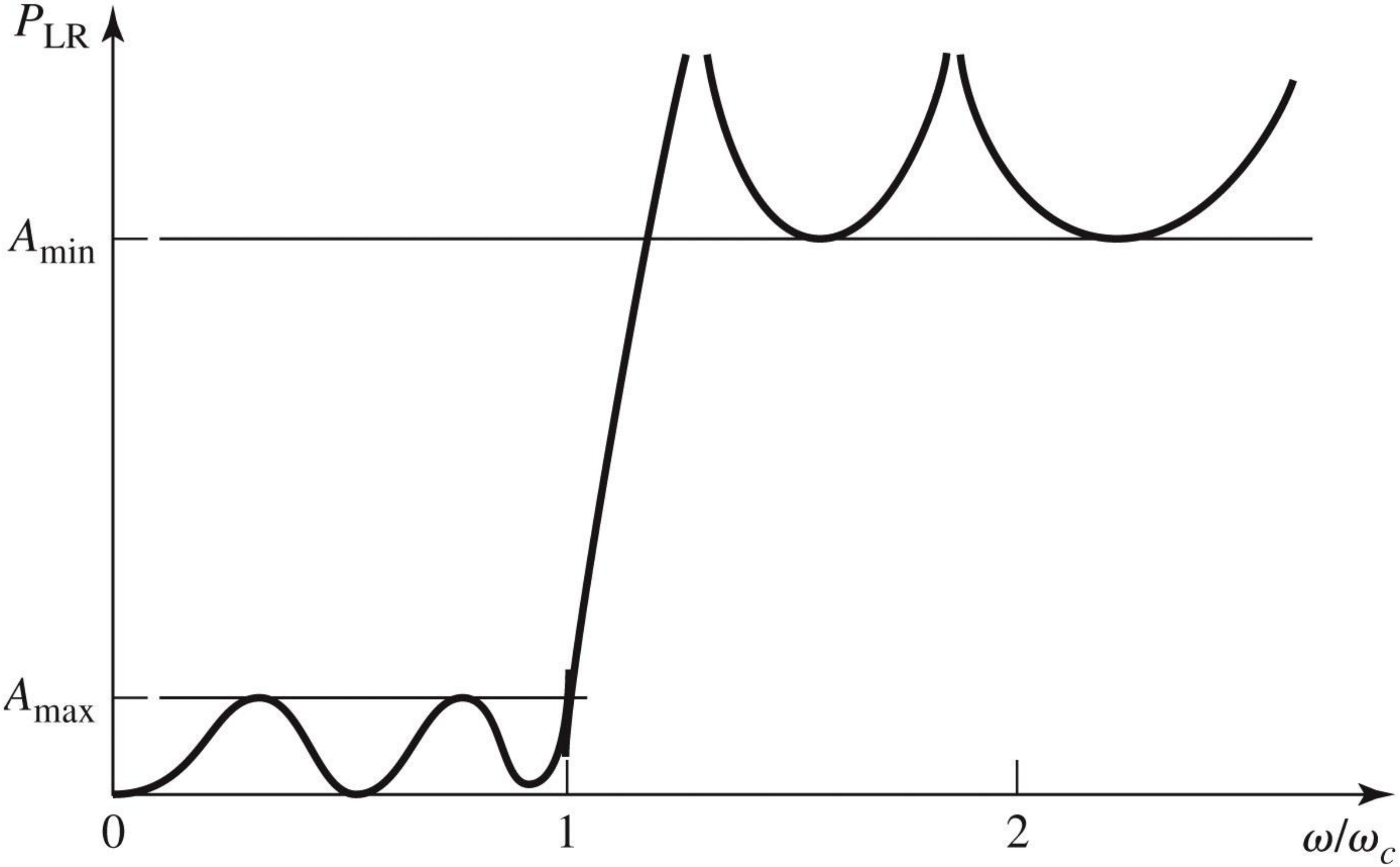


Figure 8.22

FTJ de tip maxim plat

- Polinomul

$$P_{LR} = 1 + k^2 \cdot \left(\frac{\omega}{\omega_c} \right)^{2N}$$

- pentru $\omega >> \omega_c$

$$P_{LR} \approx k^2 \cdot (\omega / \omega_c)^{2N}$$

- atenuarea creste cu 20·N dB/decada
- k ofera atenuarea la limita benzii de trecere (3dB implica k = 1)

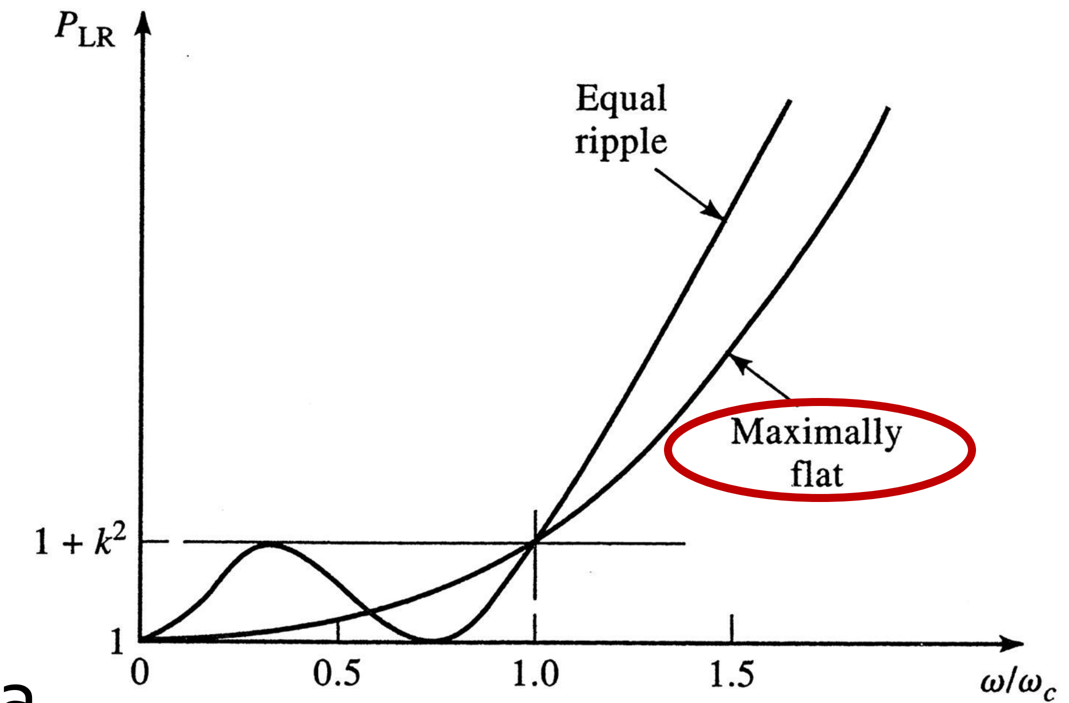


Figure 8.21

FTJ de tip echiriplu

- Polinomul

$$P_{LR} = 1 + k^2 \cdot T_N^2\left(\frac{\omega}{\omega_c}\right)$$

- pentru $\omega >> \omega_c$

$$P_{LR} \approx \frac{k^2}{4} \cdot \left(\frac{2 \cdot \omega}{\omega_c}\right)^{2N}$$

- atenuarea creste cu 20·N dB/decada

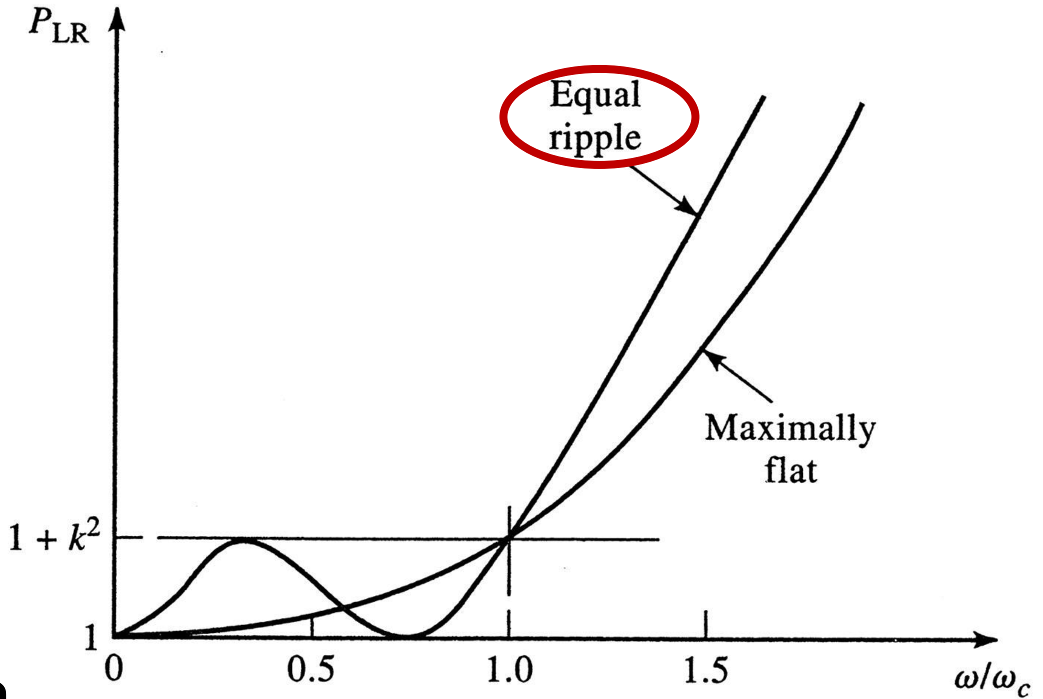


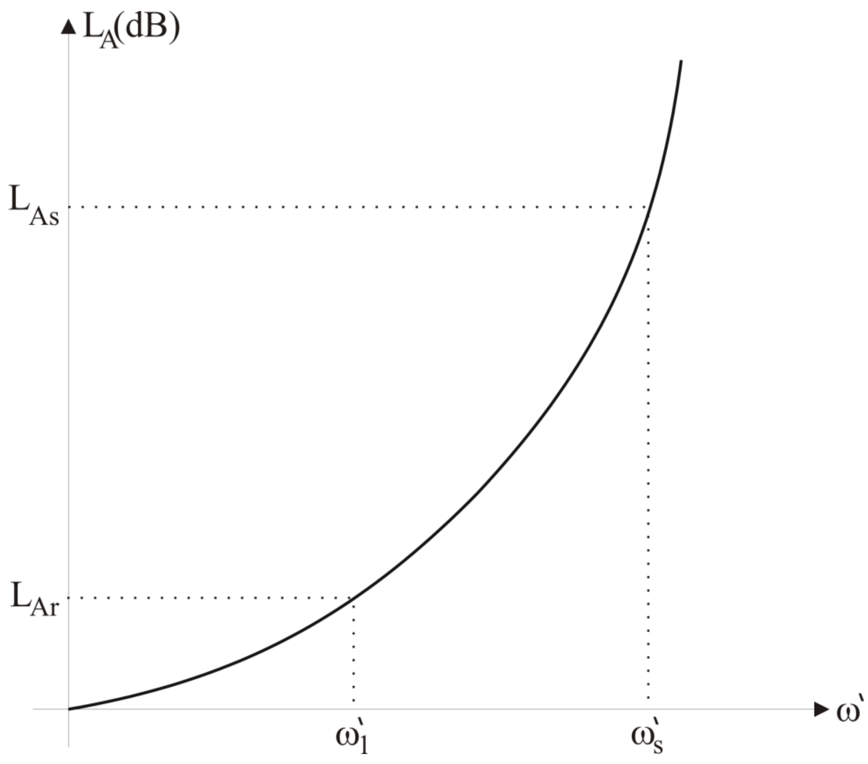
Figure 8.21

- atenuarea este mai mare de $(2^{2N})/4$ decat cea a filtrului binomial la frecventele $\omega >> \omega_c$

Calculul ordinului filtrului maxim plat

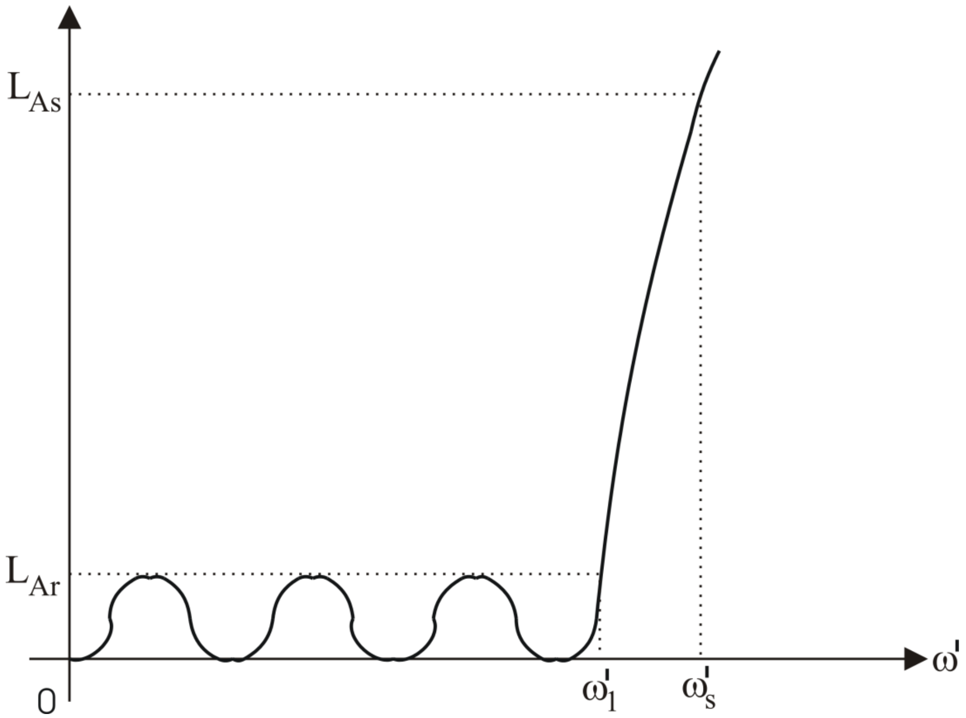
$$n \geq \frac{\log\left(\dfrac{10^{\frac{L_{As}}{10}}-1}{10^{\frac{L_{Ar}}{10}}-1}\right)}{2 \cdot \log \dfrac{\omega'_s}{\omega'_1}}$$

- cu atenuarile in **dB**



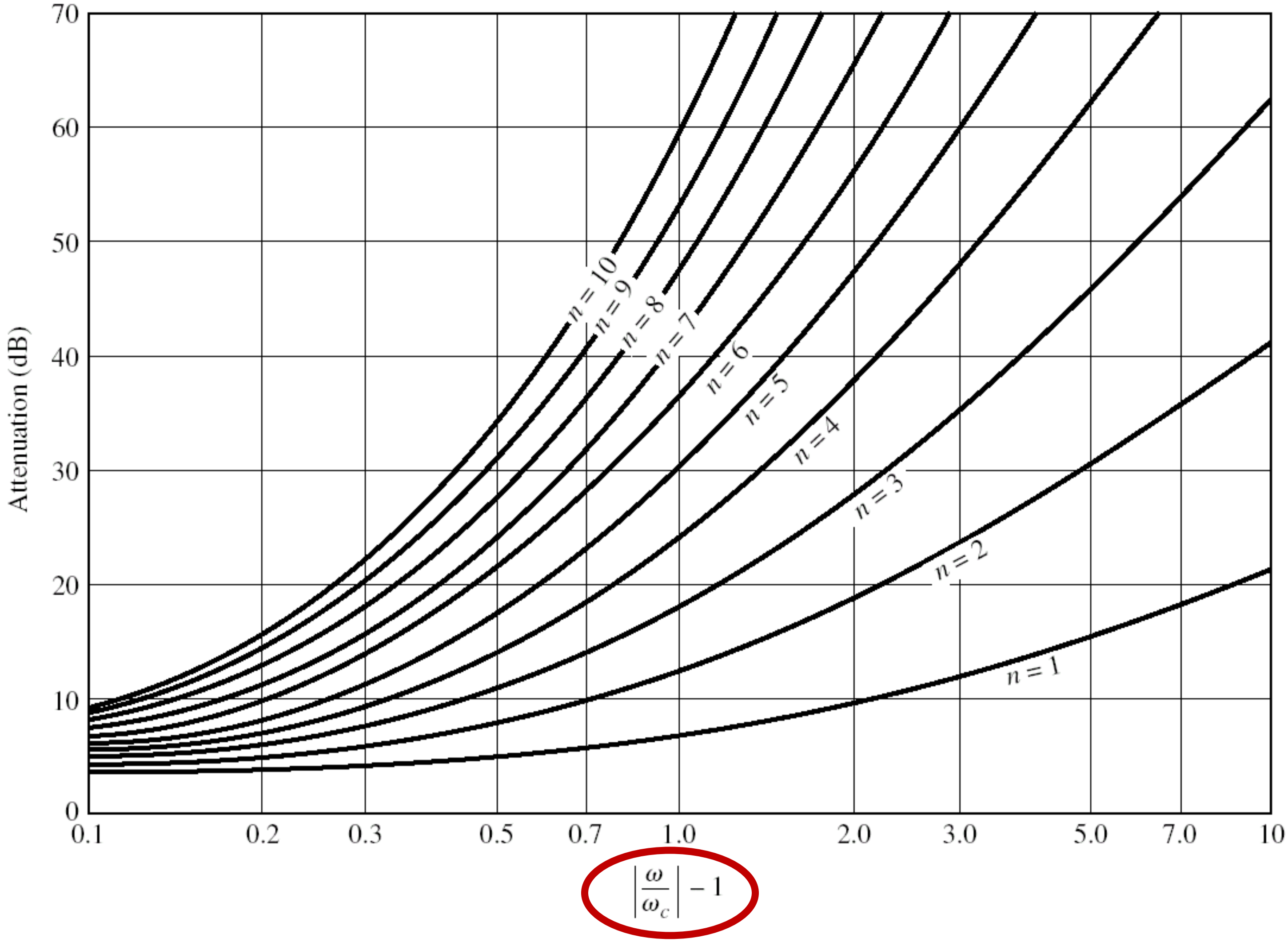
Calculul ordinului filtrului echiriplu

$$n \geq \frac{\cosh^{-1}\left(\sqrt{\dfrac{10^{\frac{L_{As}}{10}}-1}{10^{\frac{L_{Ar}}{10}}-1}}\right)}{\cosh^{-1}\left(\dfrac{\omega'_s}{\omega'_1}\right)}$$

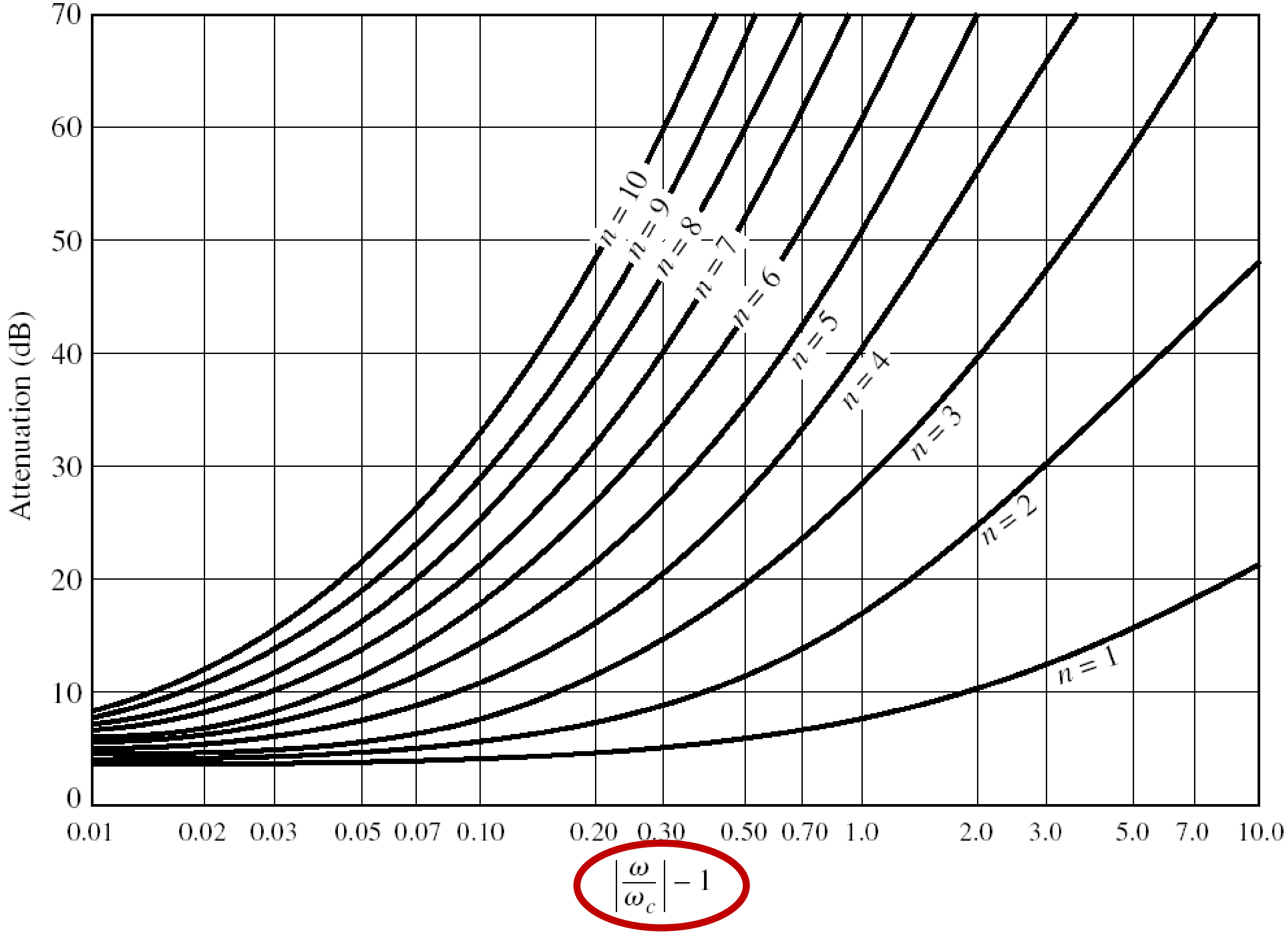


- cu atenuarile in **dB**

Raspunsul filtrului maxim plat

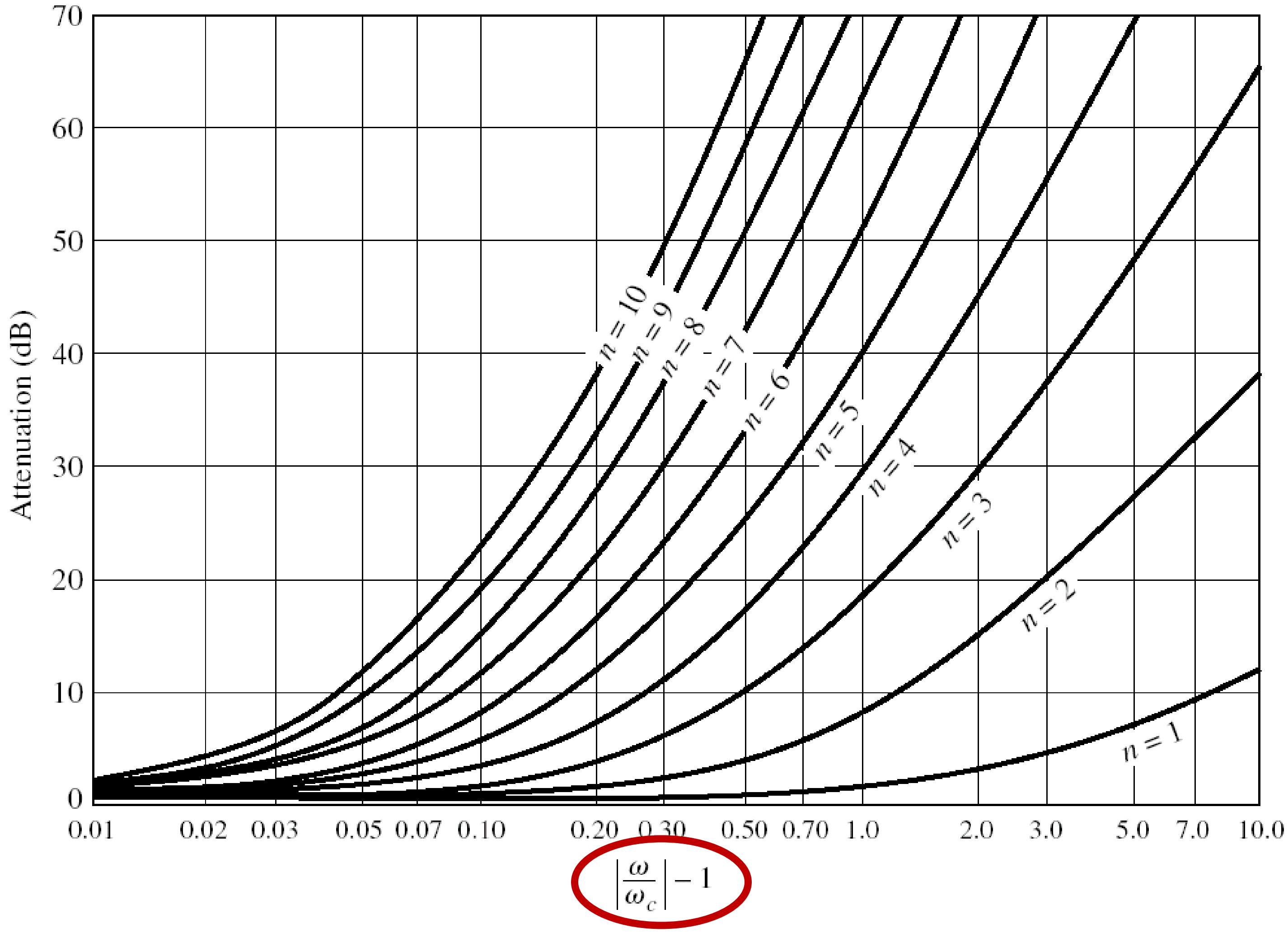


Raspunsul filtrului echiriplu 3 dB



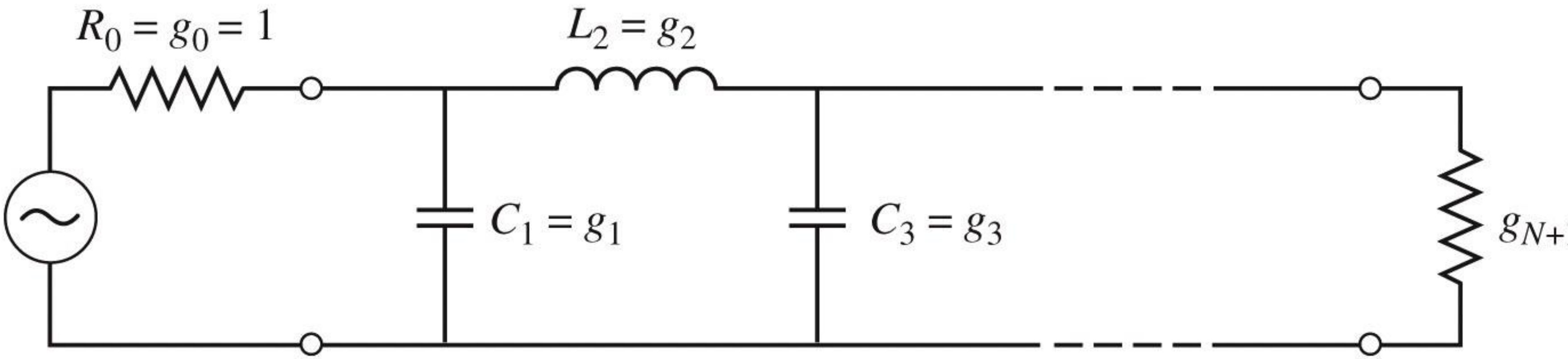
(b)

Raspunsul filtrului echiriplu 0.5 dB

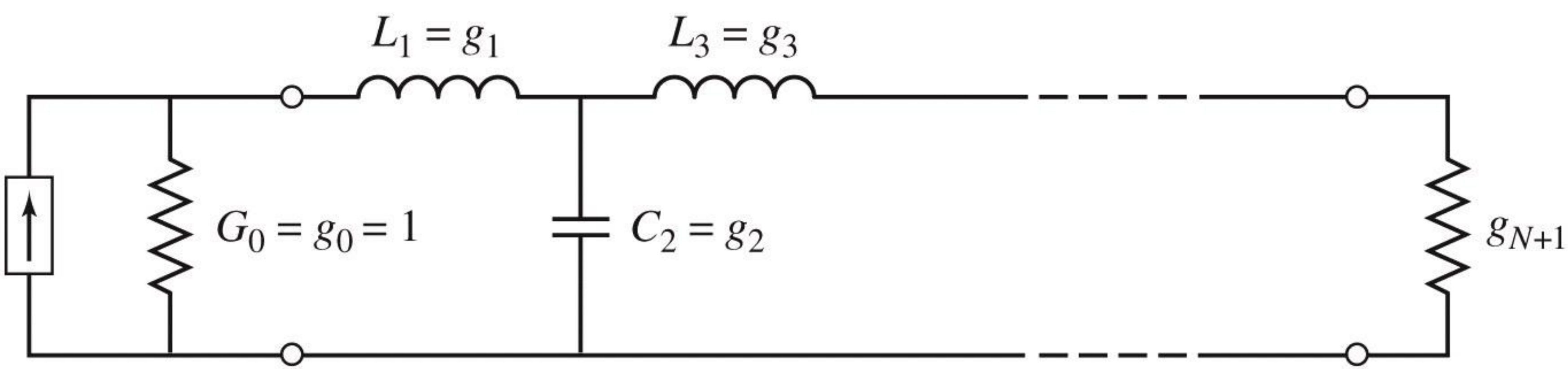


(a)

Filtre prototip



(a)



(b)

Filtre prototip

- Filtrele prototip sunt filtre care implementeaza :
  - filtru FTJ
  - frecventa de taiere $\omega_0 = 1$ rad/s ($f_0 = 0.159$ Hz)
  - conectate la intrare la o rezistenta R = 1
- Numarul total de elemente reactive (L/C) este ordinul filtrului
- Elementele se introduc in alternanta L serie / C paralel
- Exista doua filtre prototip care ofera acelasi raspuns, o varianta care incepe cu C, o varianta care incepe cu L

Filtru prototip

- Se definesc parametrii g_i, i=0,N+1

$$g_0 = \begin{cases} rezistenta\ generatorului\ R'_0\ daca\ g_1 = C'_1 \\ conductanta\ generatorului\ G'_0\ daca\ g_1 = L'_1 \end{cases}$$

$$g_k\Big|_{k=\overline{1,N}} = \begin{cases} inductanta\ unei\ bobine\ serie \\ capacitatea\ unui\ condensator\ paralel \end{cases}$$

$$g_{N+1} = \begin{cases} rezistenta\ de\ sarcina\ R'_{N+1}\ daca\ g_N = C'_N \\ conductanta\ de\ sarcina\ G'_{N+1}\ daca\ g_N = L'_N \end{cases}$$

Filtru prototip maxim plat

- Calculul elementelor filtrului

$$g_0 = 1$$

$$g_k = 2 \cdot \sin\left[\frac{(2 \cdot k - 1) \cdot \pi}{2 \cdot N}\right] \quad , \quad k = 1, N$$

$$g_{N+1} = 1$$

Filtru prototip maxim plat

TABLE 8.3 Element Values for Maximally Flat Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10)

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

Source: Reprinted from G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, Artech House, Dedham, Mass., 1980, with permission.

Table 8.3

Filtru prototip echiriplu

- Calculul elementelor filtrului (iterativ)

$$a_k = \sin\left[\frac{(2\cdot k-1)\cdot \pi}{2\cdot N}\right] \quad , \quad k = 1, N$$

$$\beta = \ln\left(\coth\frac{L_{Ar}}{17{,}37}\right)$$

$$\gamma = \sinh\left(\frac{\beta}{2\cdot N}\right)$$

$$b_k = \gamma^2 + \sin^2\left(\frac{k\cdot \pi}{N}\right) \quad , \quad k = 1, N$$

$$g_1 = \frac{2\cdot a_1}{\gamma}$$

$$g_k = \frac{4\cdot a_{k-1}\cdot a_k}{b_{k-1}\cdot g_{k-1}} \quad , \quad k = 2, N$$

$$g_{N+1} = \begin{cases} 1 & pentru\ N = impar \\ \coth^2\left(\frac{\beta}{4}\right) & pentru\ N = par \end{cases}$$

TABLE 8.4 Element Values for Equal-Ripple Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10, 0.5 dB and 3.0 dB ripple)

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
0.5 dB Ripple											
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.9841
3.0 dB Ripple											
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	1.9953	1.0000									
2	3.1013	0.5339	5.8095								
3	3.3487	0.7117	3.3487	1.0000							
4	3.4389	0.7483	4.3471	0.5920	5.8095						
5	3.4817	0.7618	4.5381	0.7618	3.4817	1.0000					
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095				
7	3.5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1.0000			
8	3.5277	0.7745	4.6575	0.8089	4.6990	0.8018	4.4990	0.6073	5.8095		
9	3.5340	0.7760	4.6692	0.8118	4.7272	0.8118	4.6692	0.7760	3.5340	1.0000	
10	3.5384	0.7771	4.6768	0.8136	4.7425	0.8164	4.7260	0.8051	4.5142	0.6091	5.8095

Source: Reprinted from G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, Artech House, Dedham, Mass.,1980, with permission.

Table 8.4

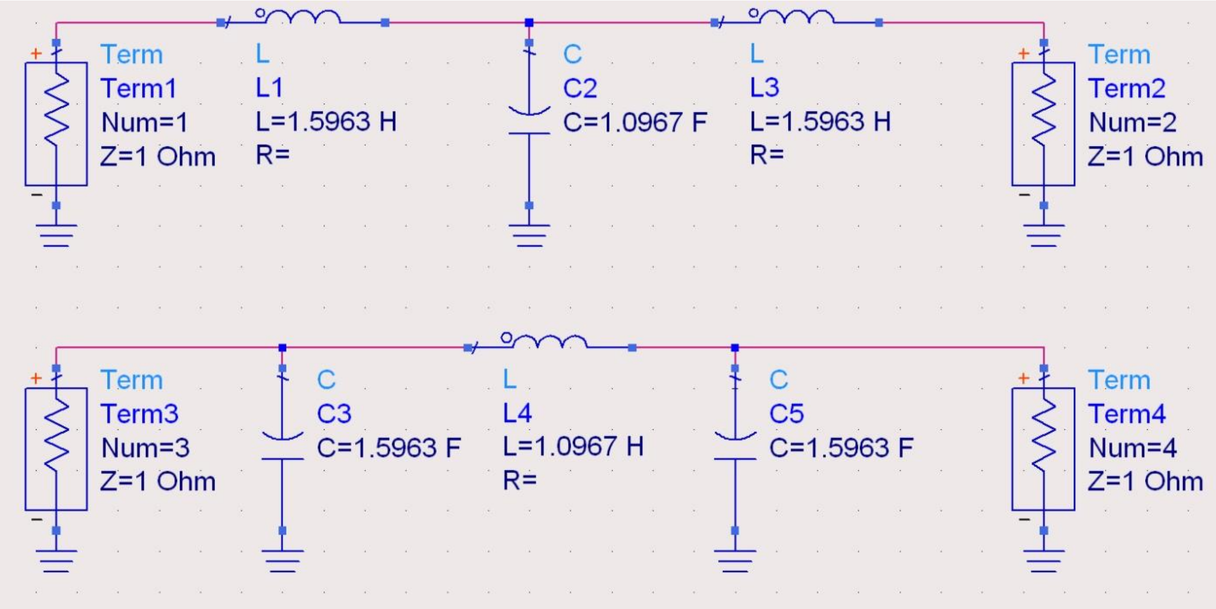
- Pentru ordin par al filtrului (N = 2, 4, 6, 8 ...) filtrele echiriplu **trebuie** sa fie inchise pe o impedanta de terminatie diferita de cea standard $g_{N+1} \neq 1$
- Daca aplicatia nu suporta aceasta comportare, e necesara introducerea unei adaptari de impedanta suplimentare (transformator in sfert de lungime de unda, binomial ...)

Exemplu

- Să se proiecteze un filtru ~~trece-bandă~~ **de ordinul 3**, avand **riplurile** ~~în bandă~~ **de 0.5 dB**. ~~Frecvența centrala a filtrului sa fie de 1 GHz. Banda să fie de 10%, şi impedanța de 50 Ω.~~

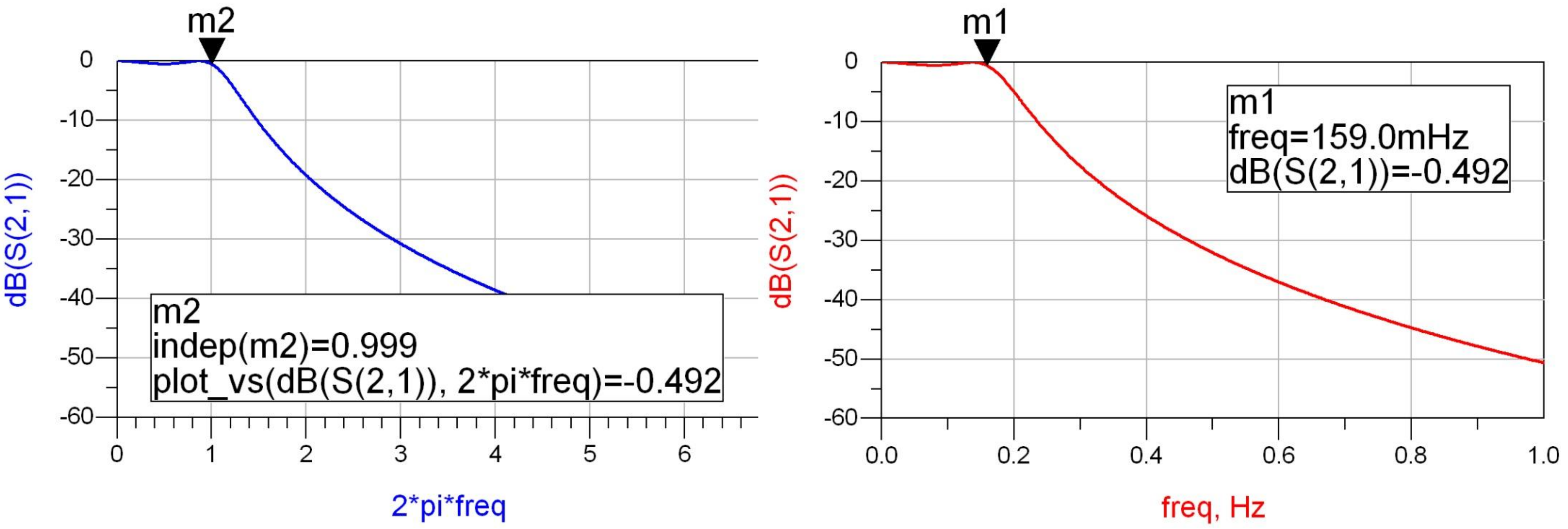
Filtru prototip

- Tabel echiriplu 0.5dB sau relatii de calcul:
  - g1 = 1.5963 = L1/C3,
  - g2 = 1.0967 = C2/L4,
  - g3 = 1.5963 = L3/C5,
  - g4=1.000 =R_L



Filtru prototip

- ω_o = 1 rad/s ($f_o = \omega_o / 2\pi$ = 0.159 Hz)



Scalarea in impedanta si frecventa

- Dupa determinarea coeficientilor filtrului prototip
  - filtru FTJ
  - frecventa de taiere $\omega_0 = 1$ rad/s ($f_0 = 0.159$ Hz)
  - conectate la intrare la o rezistenta R = 1
- Se pot calcula valorile necesare pentru componente pentru implementarea altor conditii

Scalare si conversie

- FTJ (prototip) are utilitate doar ca **pas intermediar**
  - filtru FTJ
  - frecventa de taiere $\omega_0 = 1$ rad/s ($f_0 = 0.159$ Hz)
  - conectate la intrare la o rezistenta R = 1

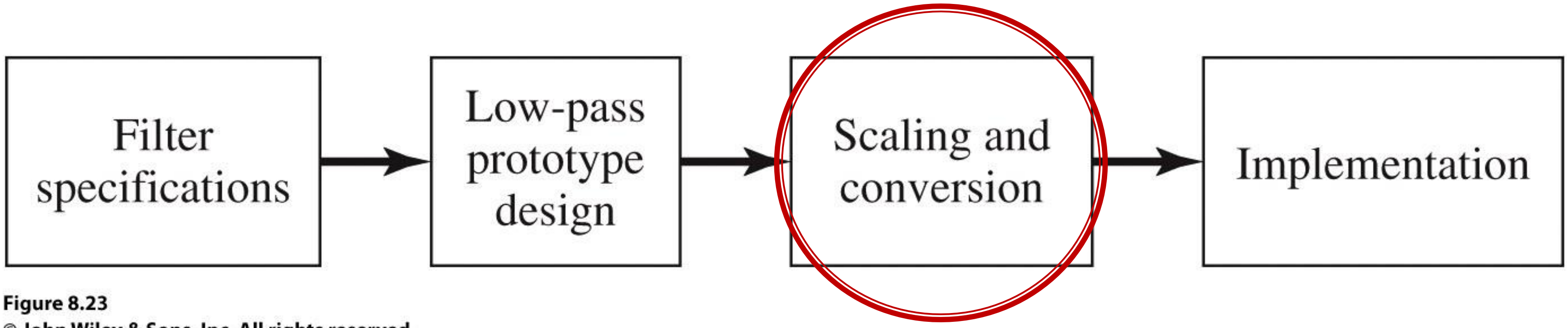


Figure 8.23

Scalarea in impedanta

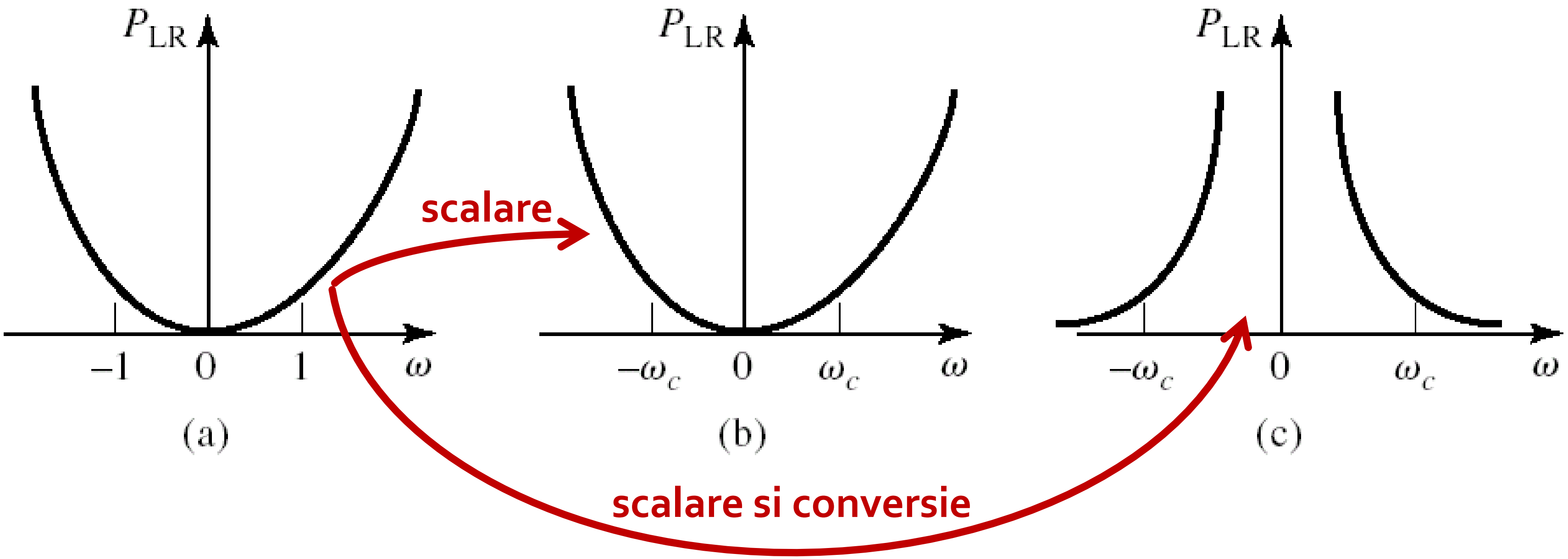
- Pentru a determina filtrul care lucreaza cu o alta rezistenta de intrare (R_o) se multiplica toate impedantele din circuit cu aceasta impedanta (cu " ' " se noteaza elementele noi)

$$R_s' = R_0 \cdot (R_s = 1) \qquad R_L' = R_0 \cdot R_L$$

$$L' = R_0 \cdot L \qquad C' = \frac{C}{R_0}$$

Scalarea in frecventa

- modificarea frecventei de taiere – (fig. b)
- modificarea caracteristicii de atenuare (de exemplu FTJ → FTS – fig. c)



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