

Curs 11

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 personală

Documentatie

■ <http://rf-opto.etti.tuiasi.ro>

Laboratorul de Microunde si Optica

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

RF-OPTO

Universitatea Tehnica "Gheorghe Asachi" din Iasi

English | Romana

Start Didactic Master Colectiv Cercetare Studenti Admin

Microunde Comunicatii Optice Optoelectronica Internet Antene Practica Retele Soft didactic

Dispozitive si circuite de microunde pentru radiocomunicatii

Disciplina: DCMR (2017-2018)

Coordinator Disciplina: conf. dr. Radu-Florin Damian

Cod: DOS412T

Tip Disciplina: DOS; Disciplina Optionala, Disciplina de Specialitate

Credite: 4

An de Studiu: 4, Sem. 7

Activitati

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

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

Evaluare

Tip: Examen

A: 50%, (Examen/Colocviu)

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

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

Note

[Rezultate totale](#)

Prezenta

[Curs](#)

[Laborator](#)

Liste

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

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

Bibliografie

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

Examen: Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Examen: Operatii cu numere complexe

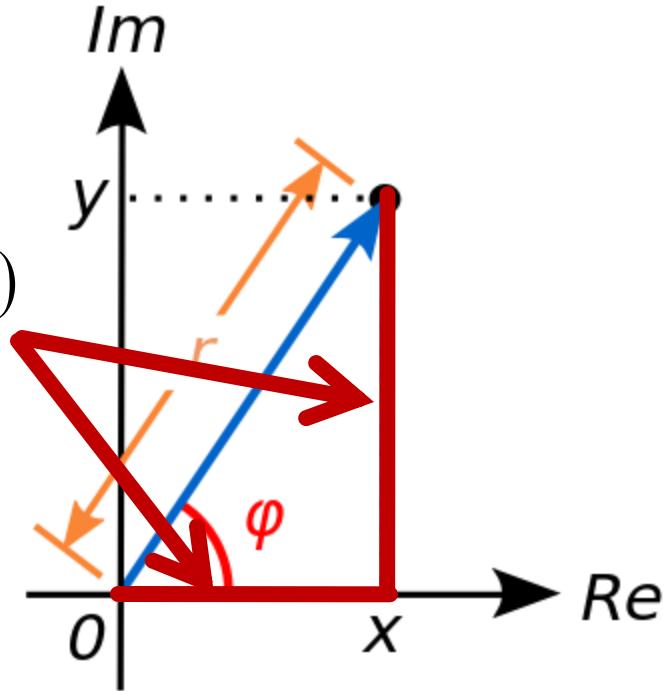
■ Reprezentare polară

- modul
- faza

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

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

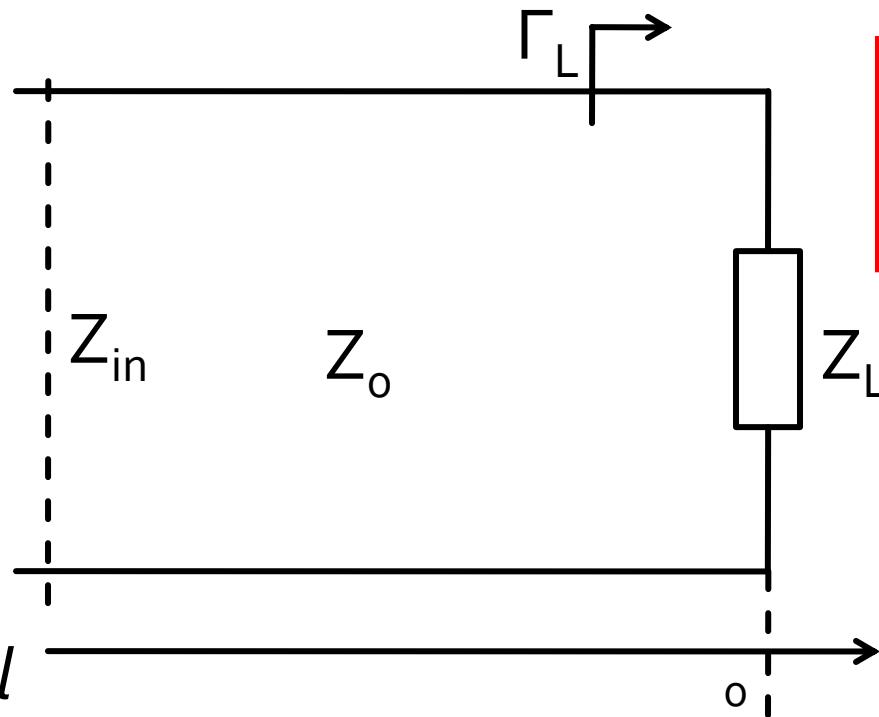
$$\varphi = \arg(z) = \begin{cases} \arctan\left(\frac{b}{a}\right), & a > 0 \\ \arctan\left(\frac{b}{a}\right) + \pi, & a < 0, b \geq 0 \\ \arctan\left(\frac{b}{a}\right) - \pi, & a < 0, b < 0 \\ \frac{\pi}{2}, -\frac{\pi}{2}, \text{nedefinit} & a = 0 \end{cases}$$



Linii de transmisie in mod TEM

Linie fara pierderi

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

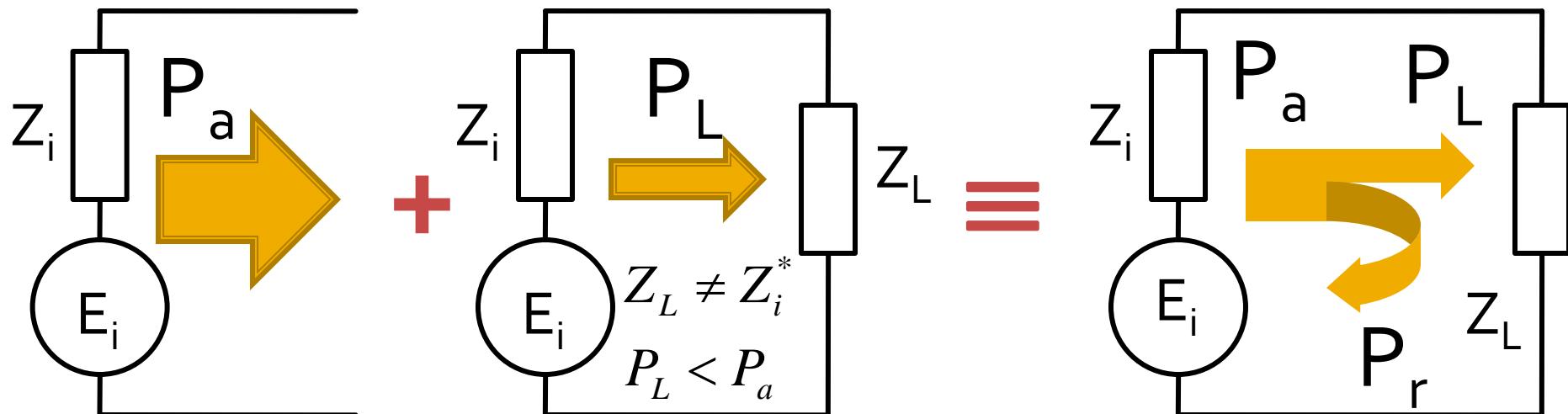


$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Transfer de putere

Adaptarea de impedanță

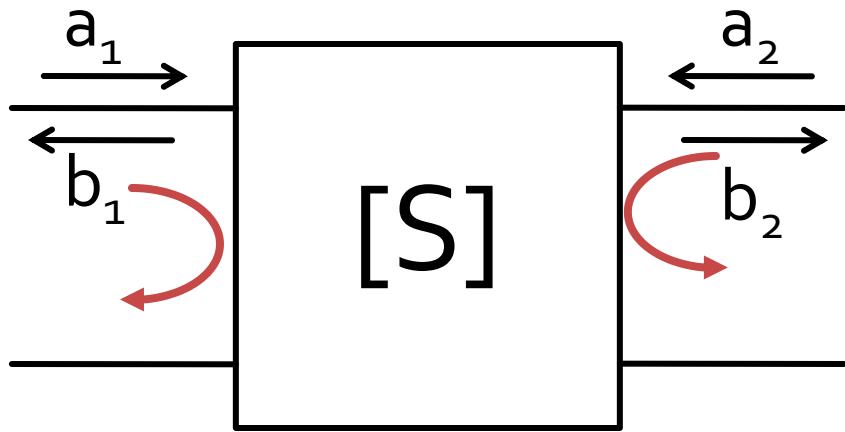
Reflexie de putere / Model



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

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

Matricea S (repartitie)

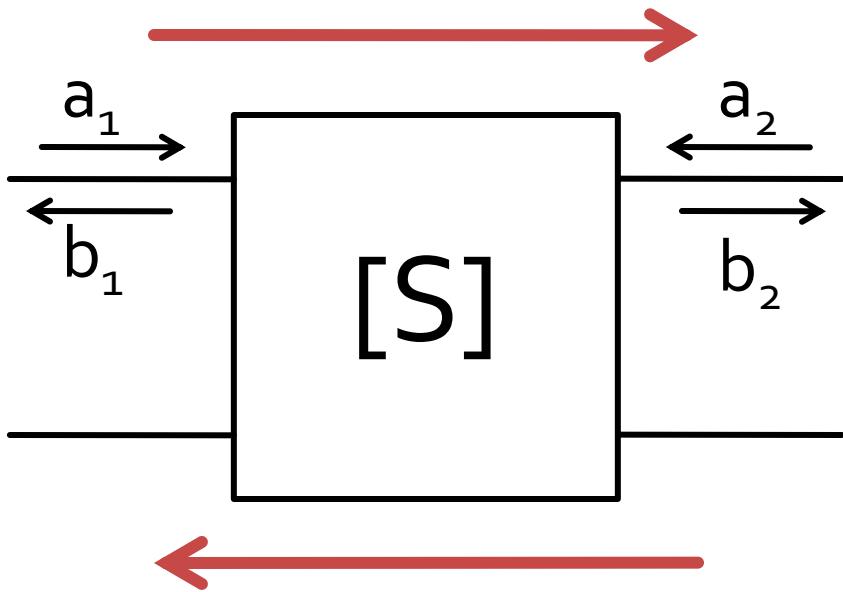


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

Matricea S (repartitie)



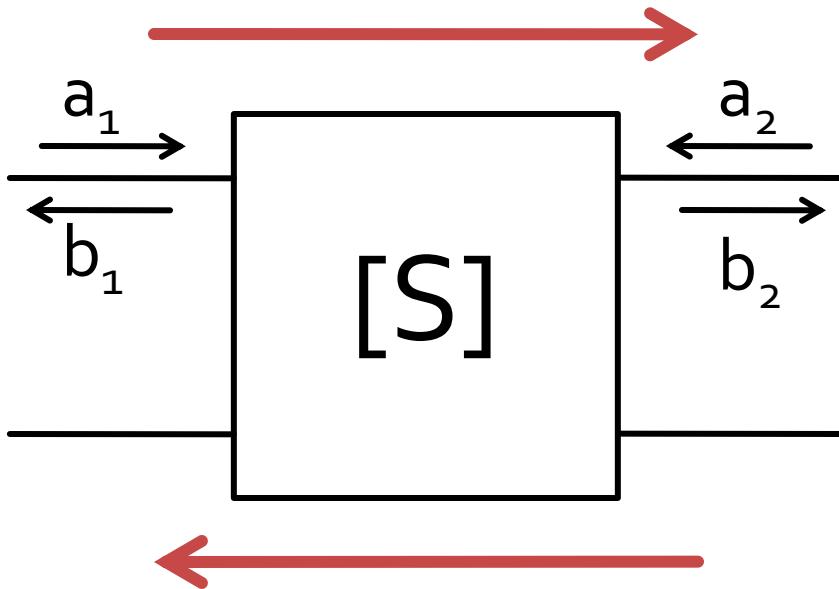
$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

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

Matricea S (repartitie)



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

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

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

Adaptarea de impedanță

Diagrama Smith

Diagrama Smith

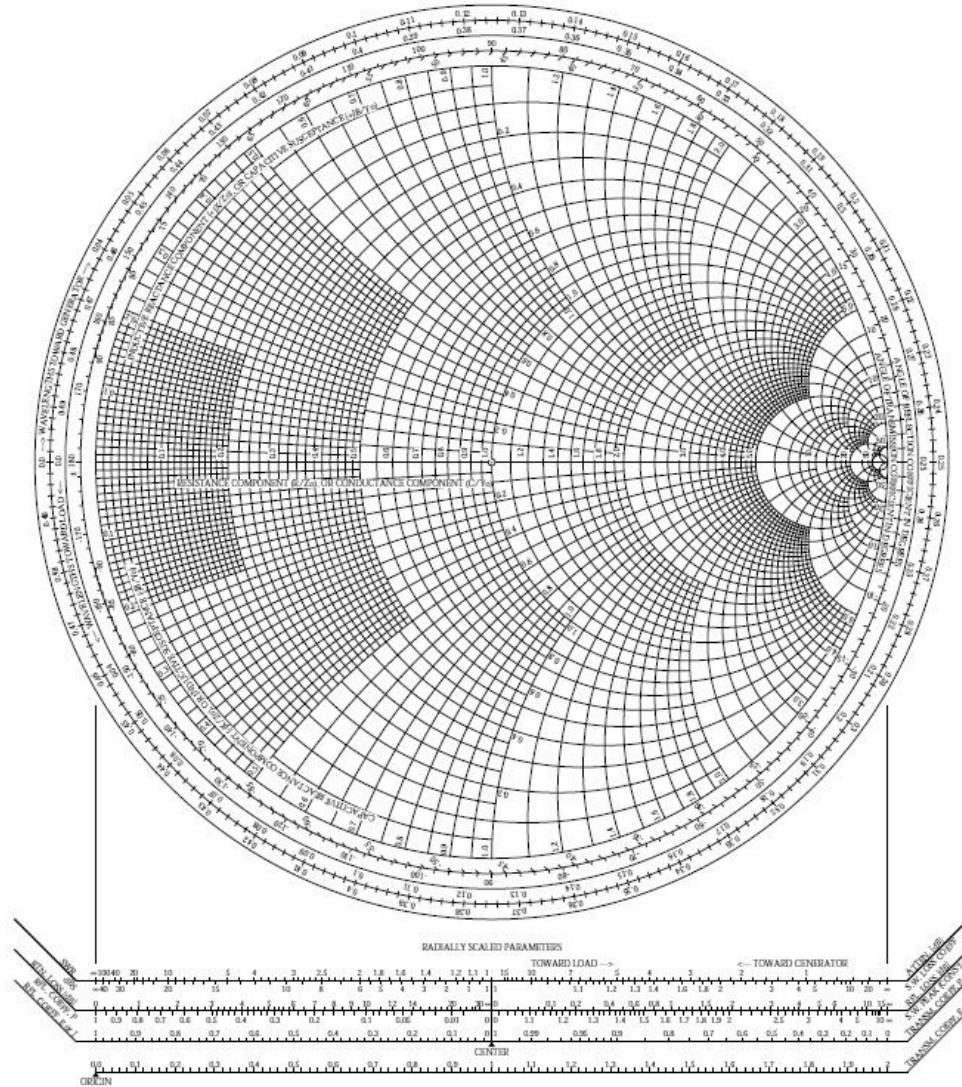


Diagrama Smith

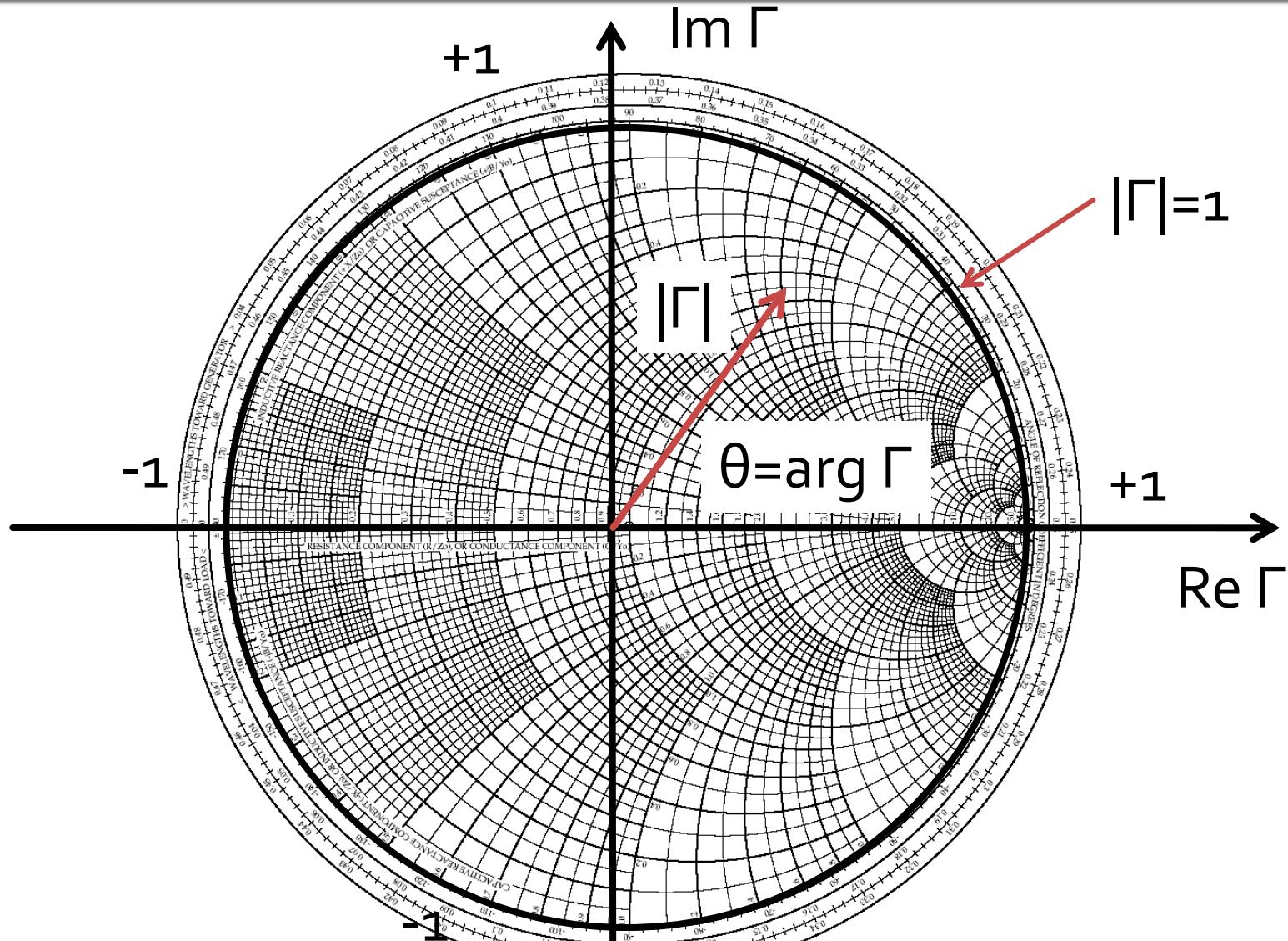
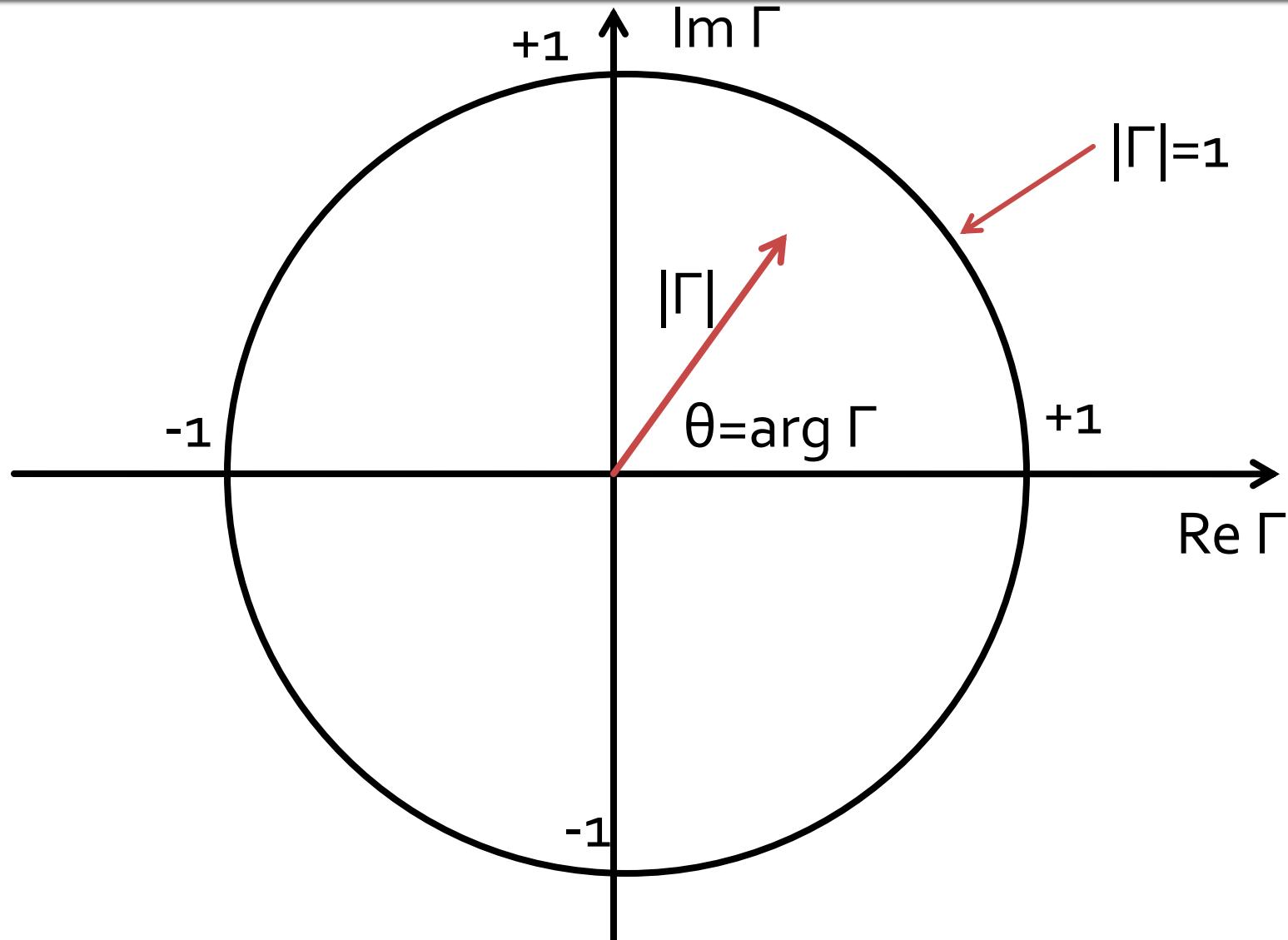


Diagrama Smith

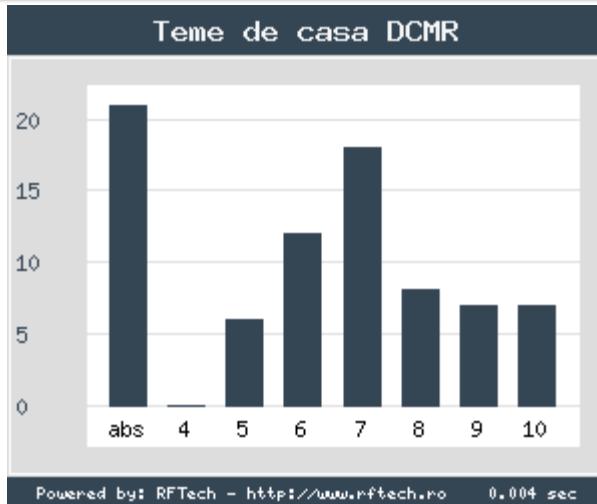


Adaptarea cu sectiuni de linii (stub)

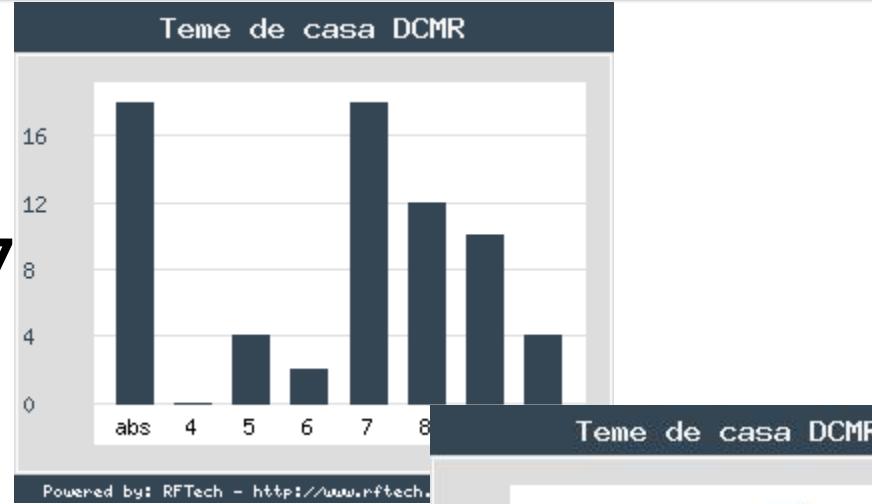
Adaptarea de impedanță

Efect? – factorul “andrei”

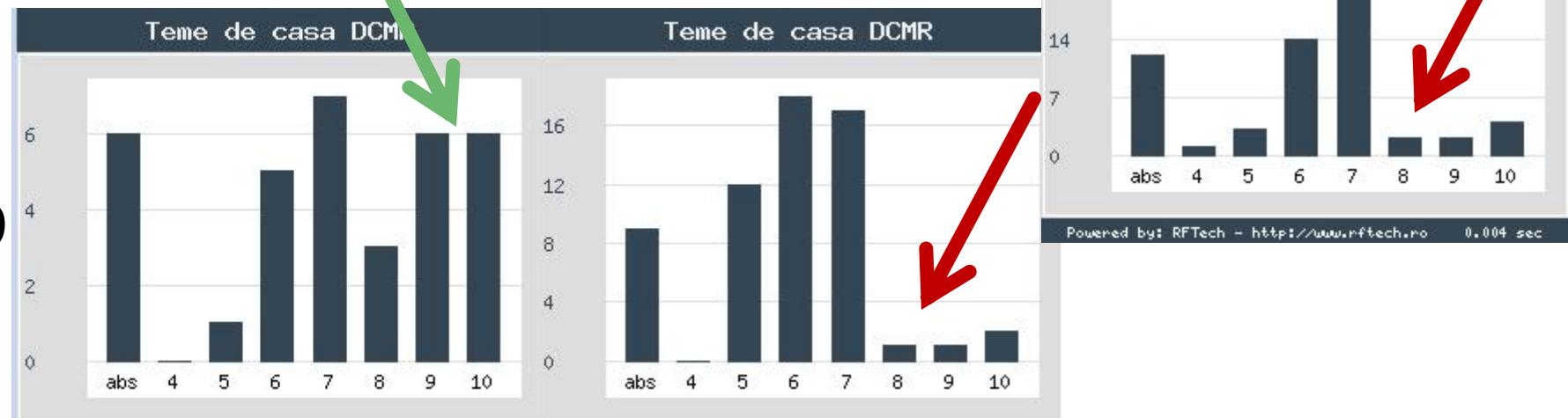
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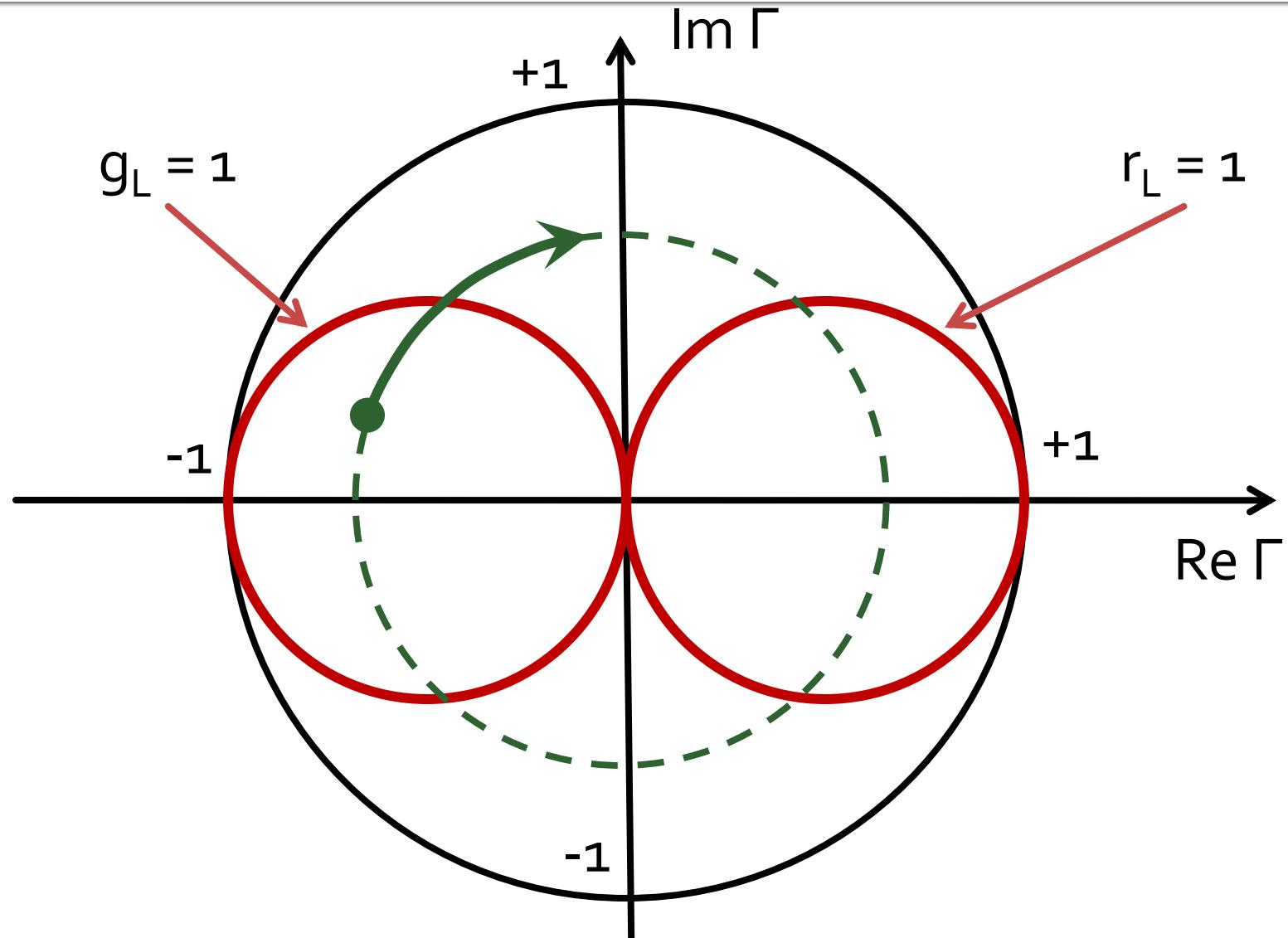


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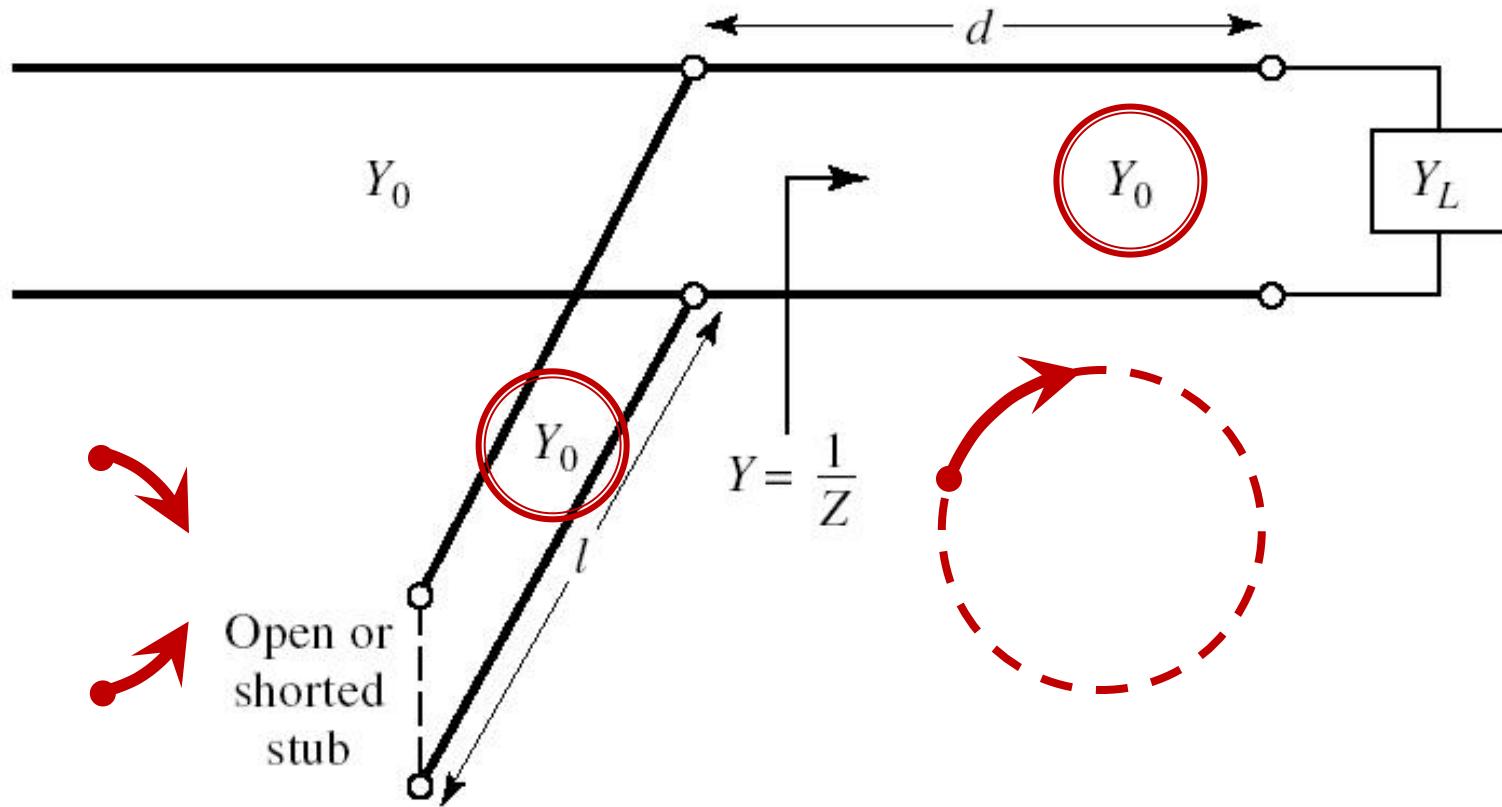
18/9

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



Caz 1, Shunt Stub

- Shunt Stub (secțiune de linie în paralel)



Calcul analitic (calcul efectiv)

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

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

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

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

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

- **solutia "cu +"** 

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

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

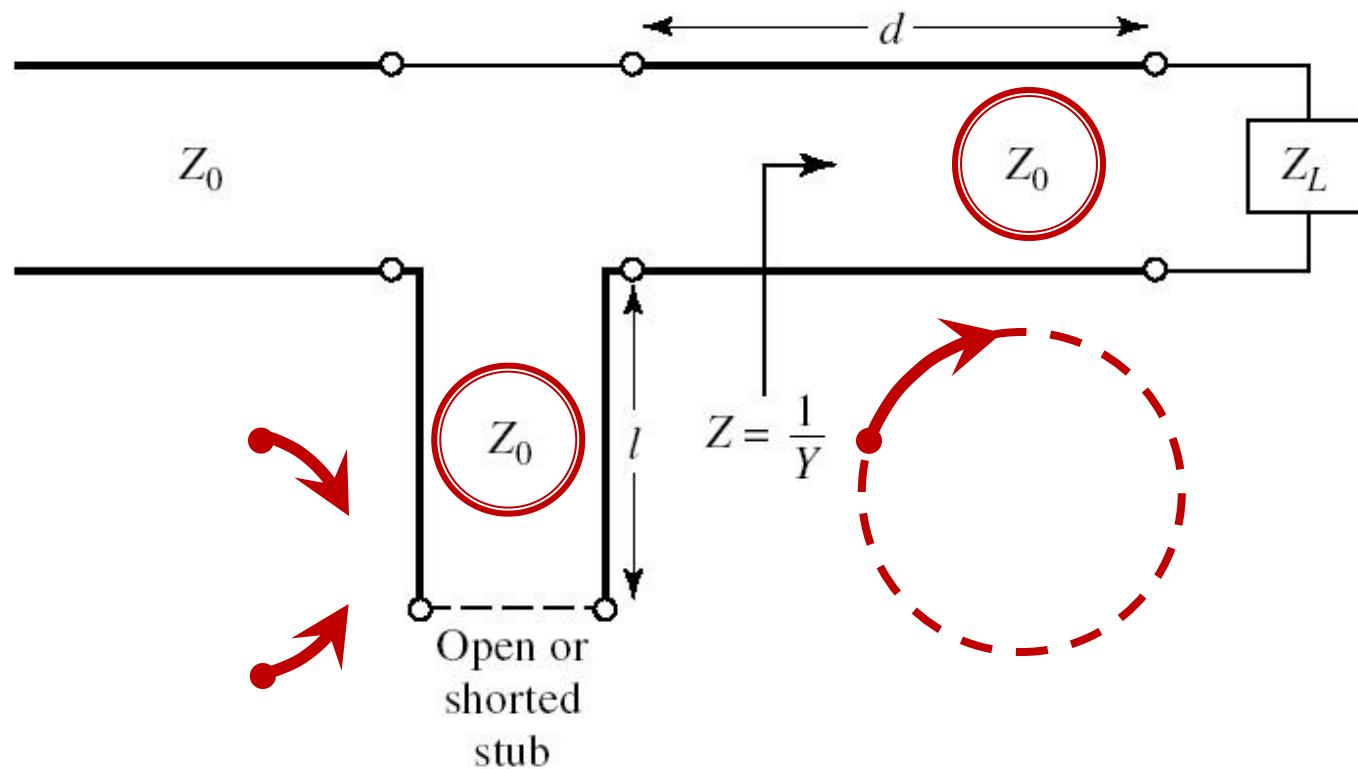
- **solutia "cu -"** 

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

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

Caz 2, Series Stub

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



Calcul analitic (calcul efectiv)

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

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

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

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

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

- **solutia "cu +"**

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

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

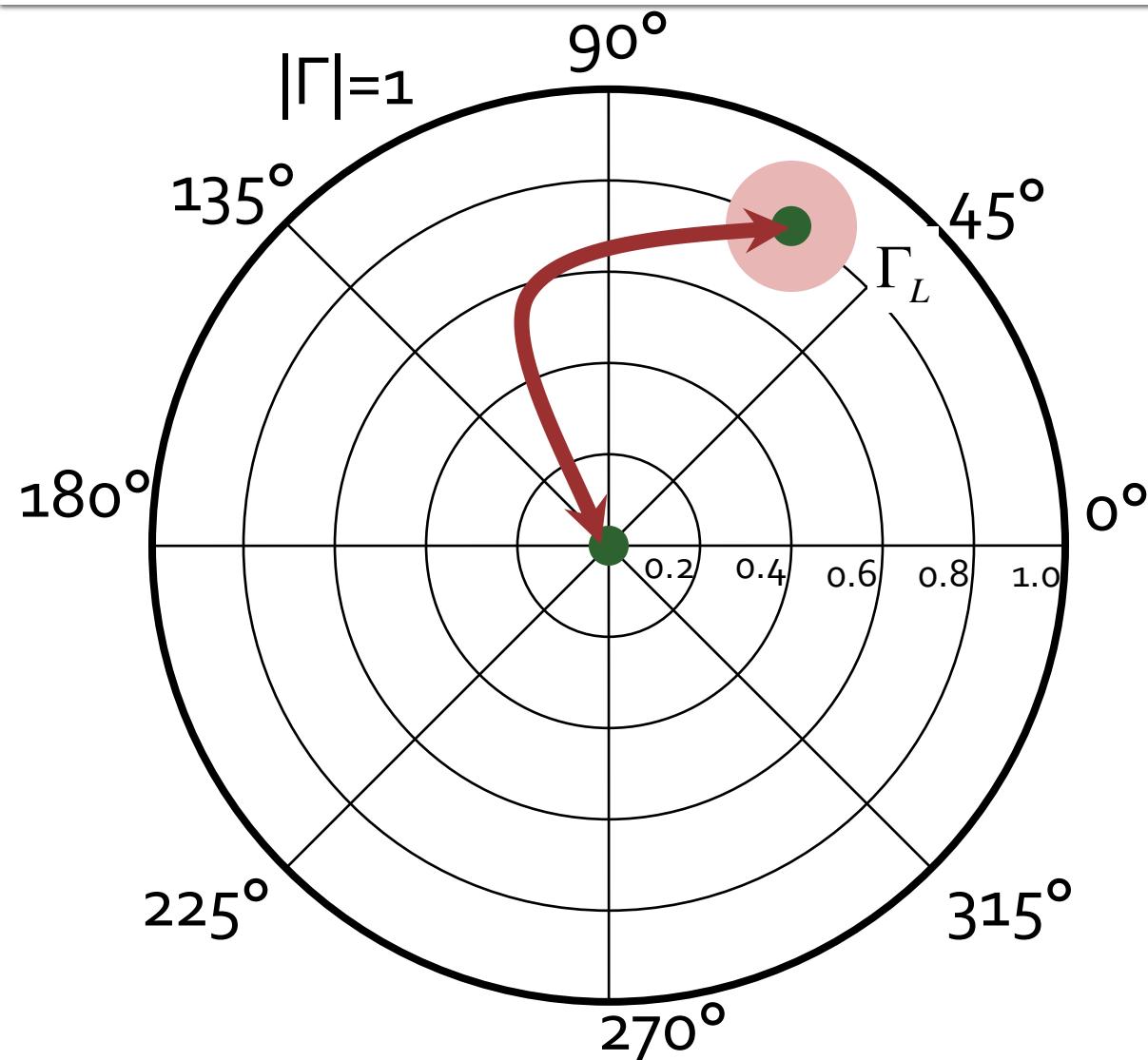
- **solutia "cu -"**

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

$$\text{Im } z_s = \frac{-2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}} = -1.335$$

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

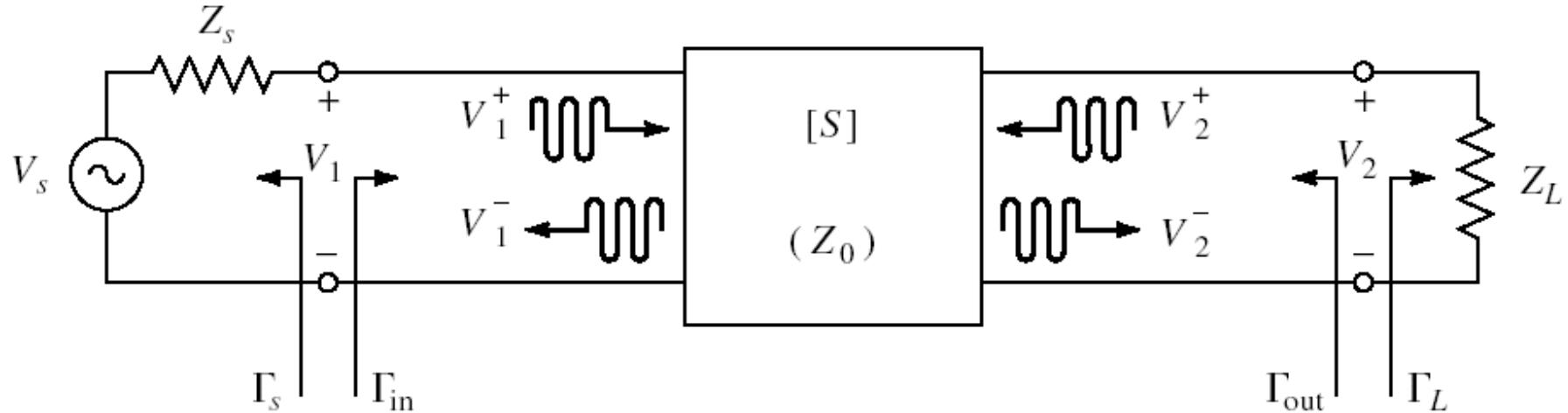
Diagrama Smith, adaptare, $Z_L = Z_o$



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

Amplificatoare de microunde

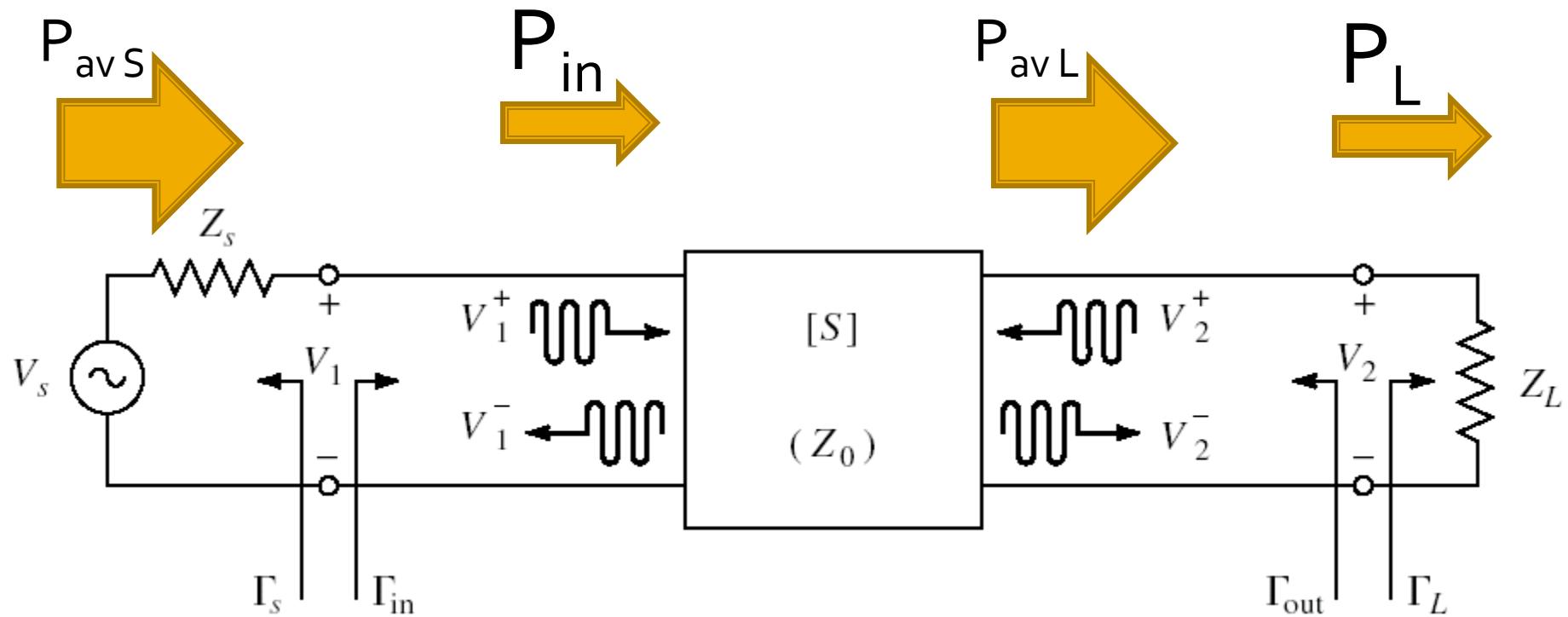
Cuadripol Amplificator (diport)



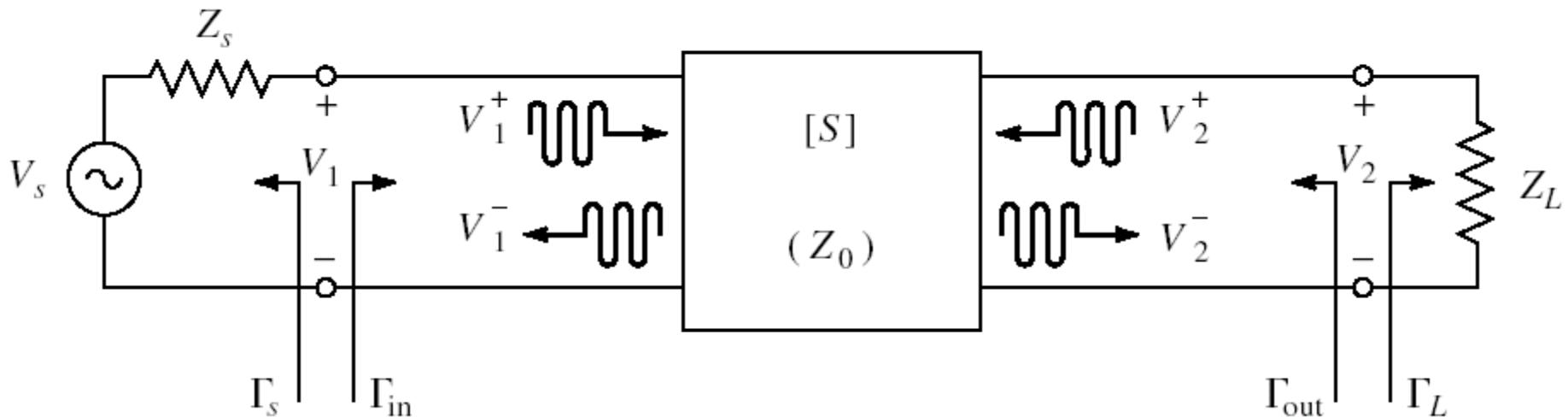
- Caracterizare cu parametri S
- Normalizati la Z_0 (implicit 50Ω)
- Catalogage: parametri S pentru anumite polarizari

Puteri / Adaptare

- Doua porturi in care adaptarea influenteaza transferul de putere



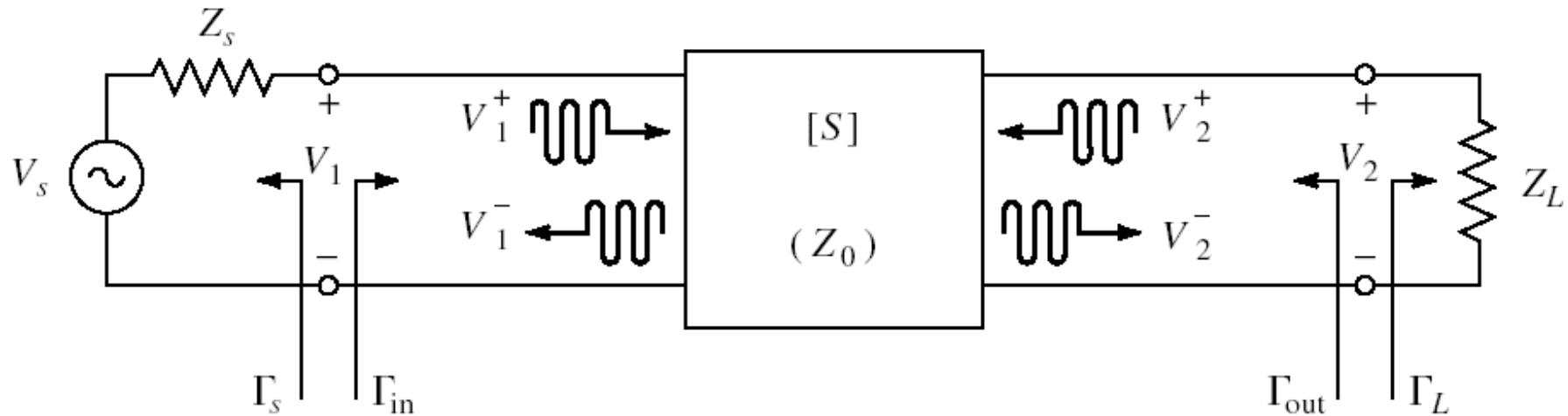
Dipole amplifier



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

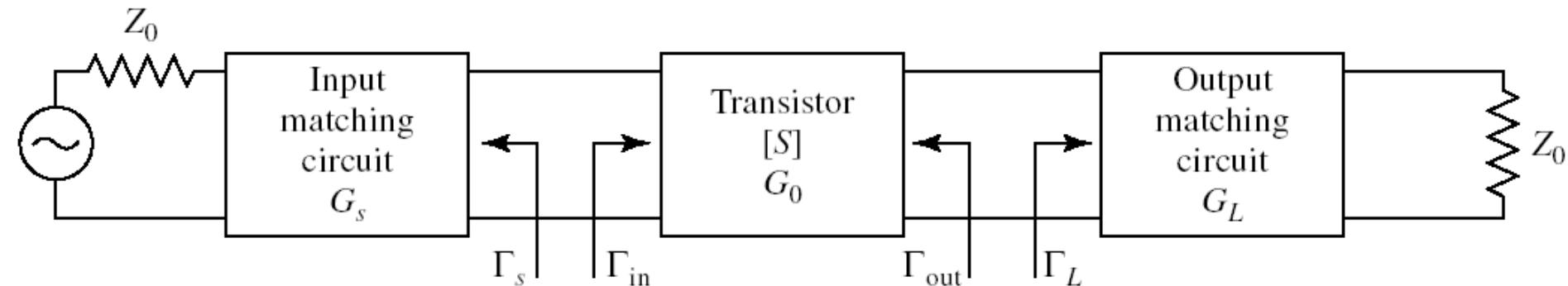
$$\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_S}{1 - S_{11} \cdot \Gamma_S}$$

Cuadripol Amplifier



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

Proiectare pentru castig maxim



- Castig maxim de putere se obtine cand

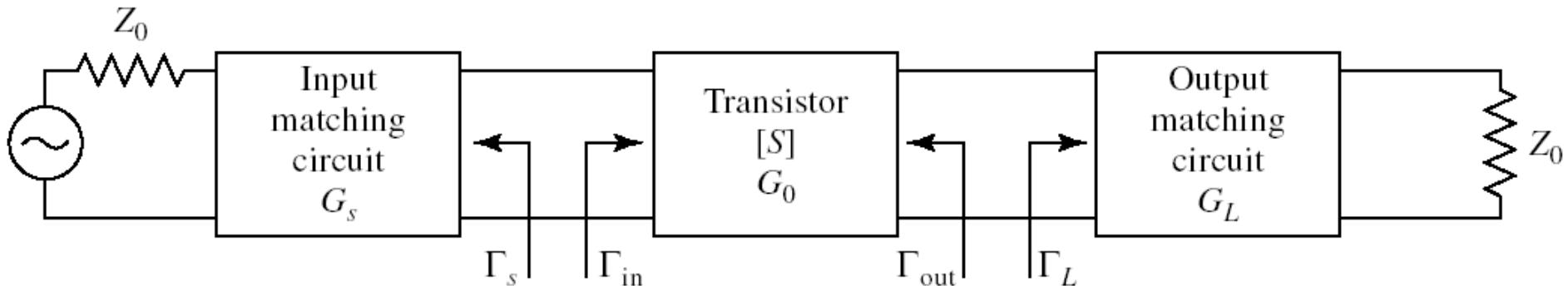
$$\Gamma_{in} = \Gamma_s^* \quad \Gamma_{out} = \Gamma_L^*$$

- 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

Proiectare pentru castig impus



- Daca ipoteza tranzistorului unilateral este justificata:

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

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

$$G_s = G_s(\Gamma_s)$$

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

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

$$G_L = G_L(\Gamma_L)$$

Formula lui Friis (zgomot)

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

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

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

$$P_n = kTB$$

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

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

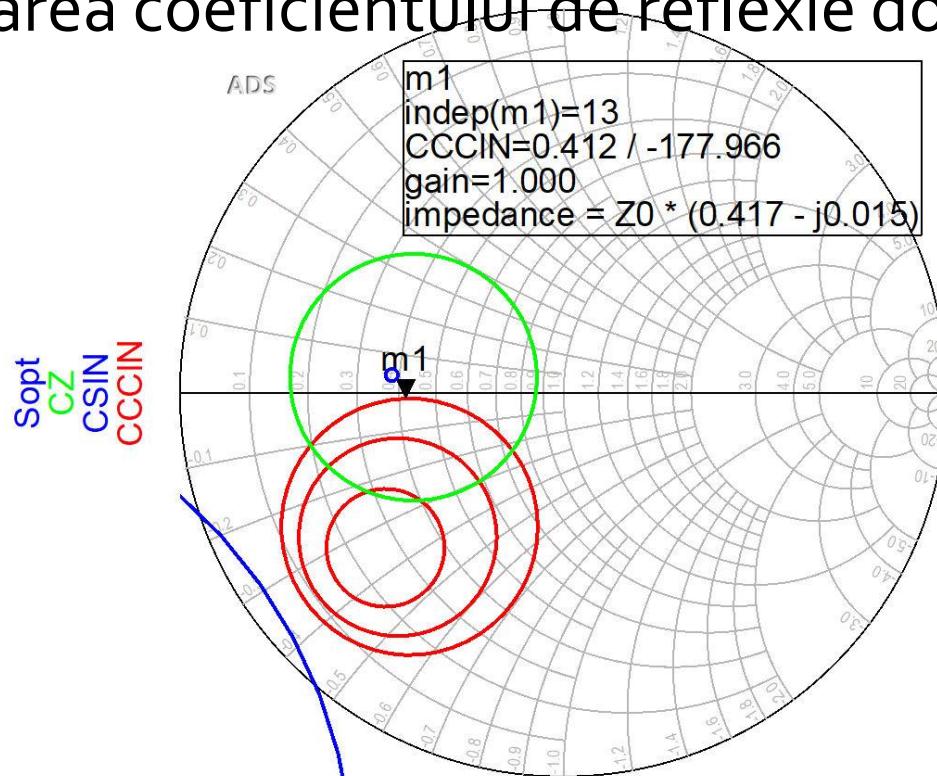
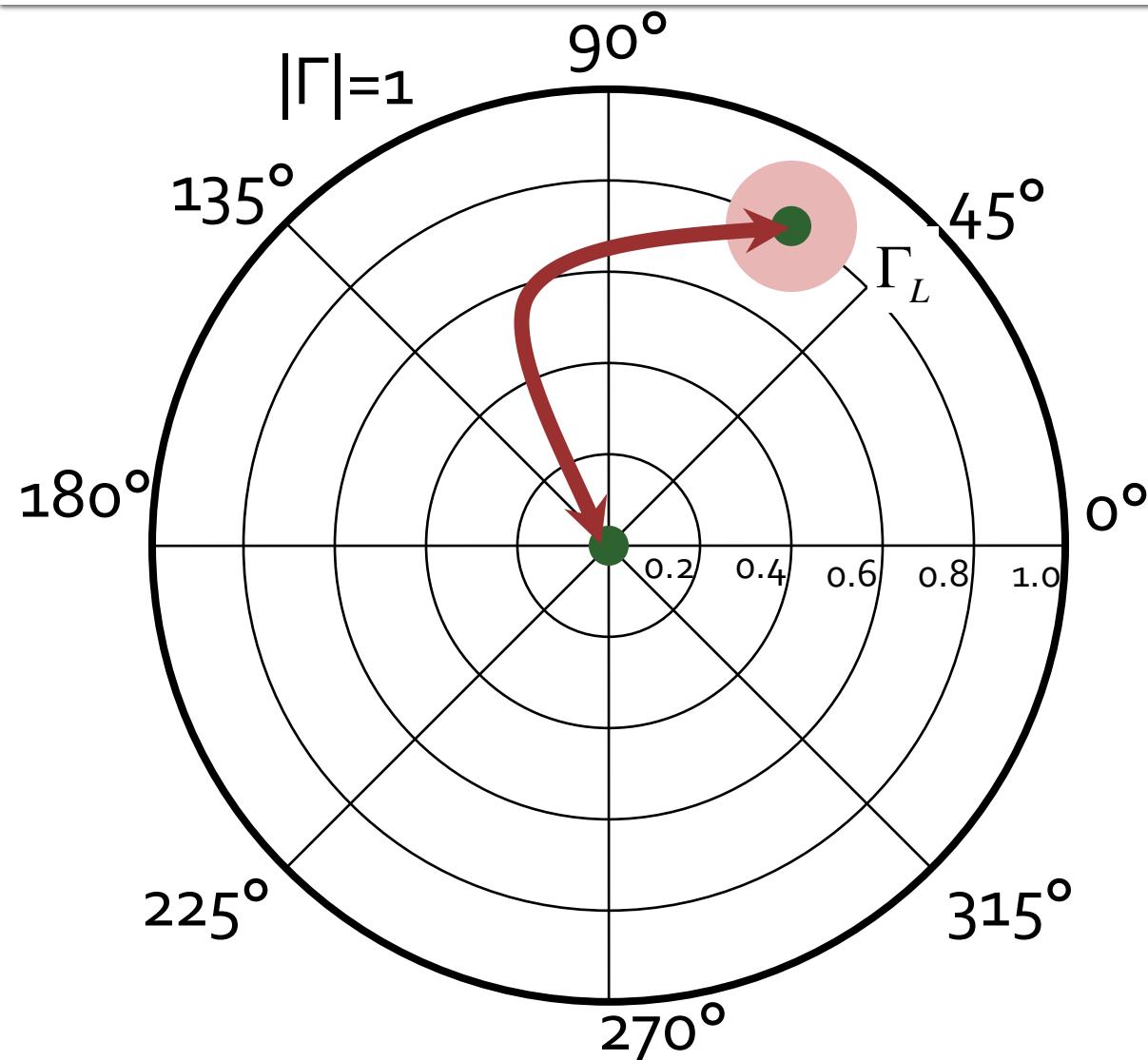


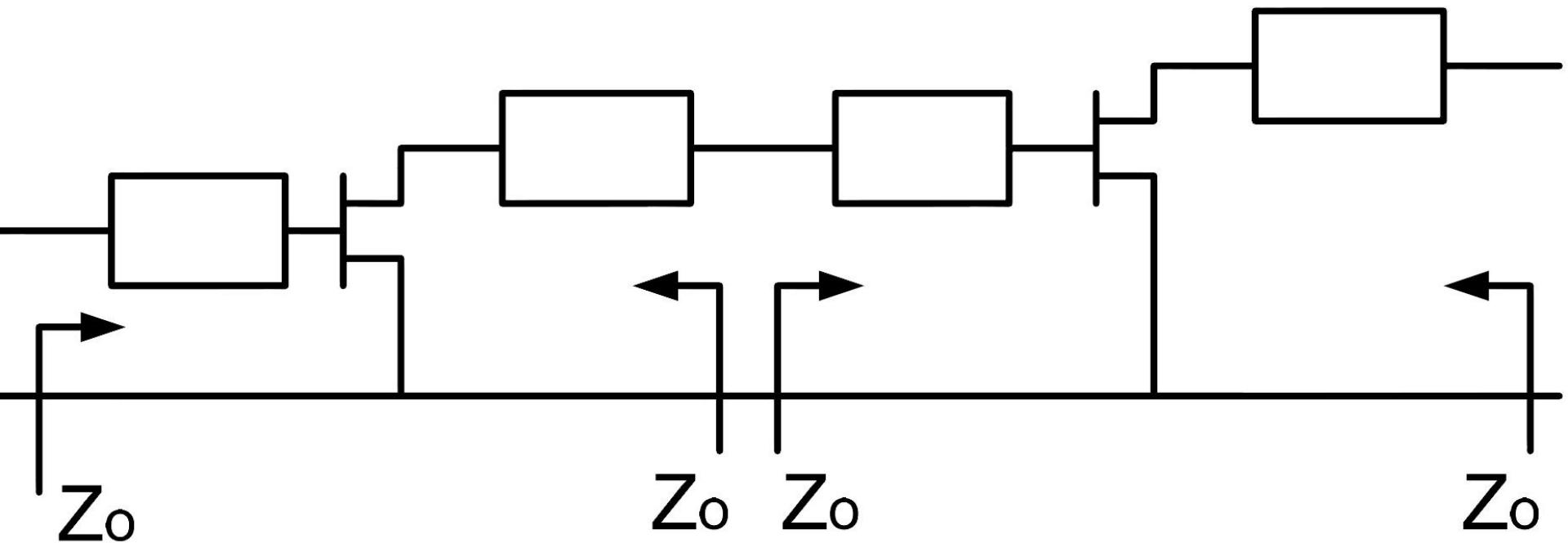
Diagrama Smith, adaptare, $Z_L = Z_o$



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- sunt **identice** ca realizare. Difera doar prin **ordinea** în care se introduc elementele în circuitul de adaptare
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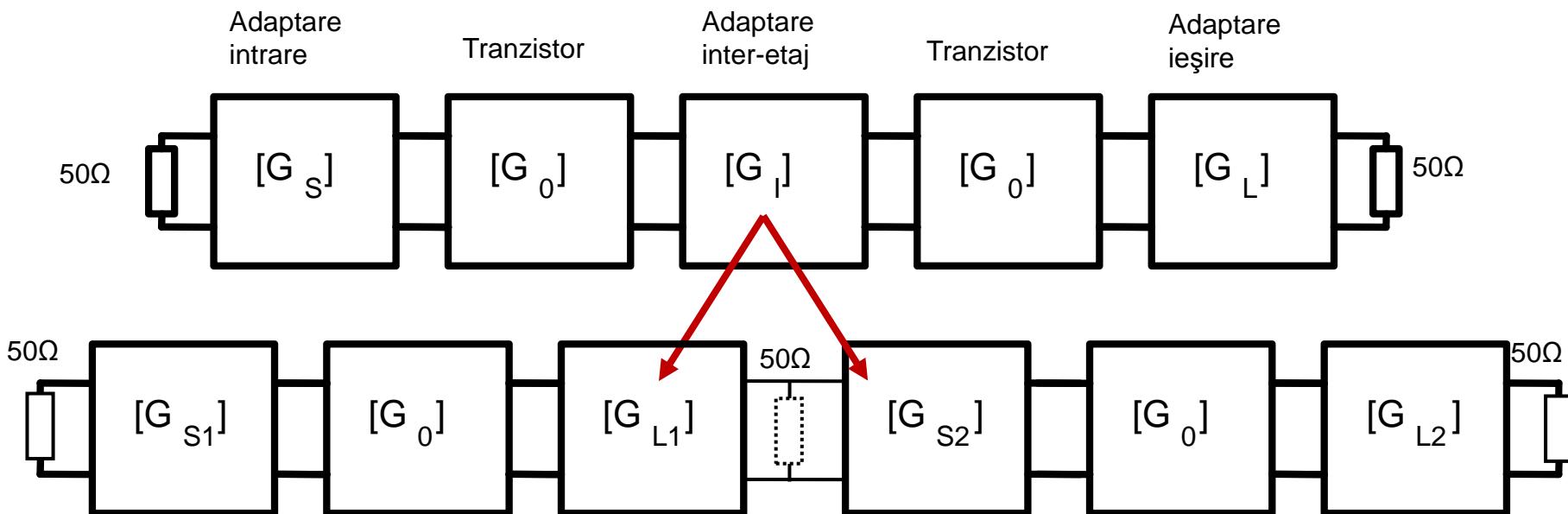
Amplificatoare in cascada

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



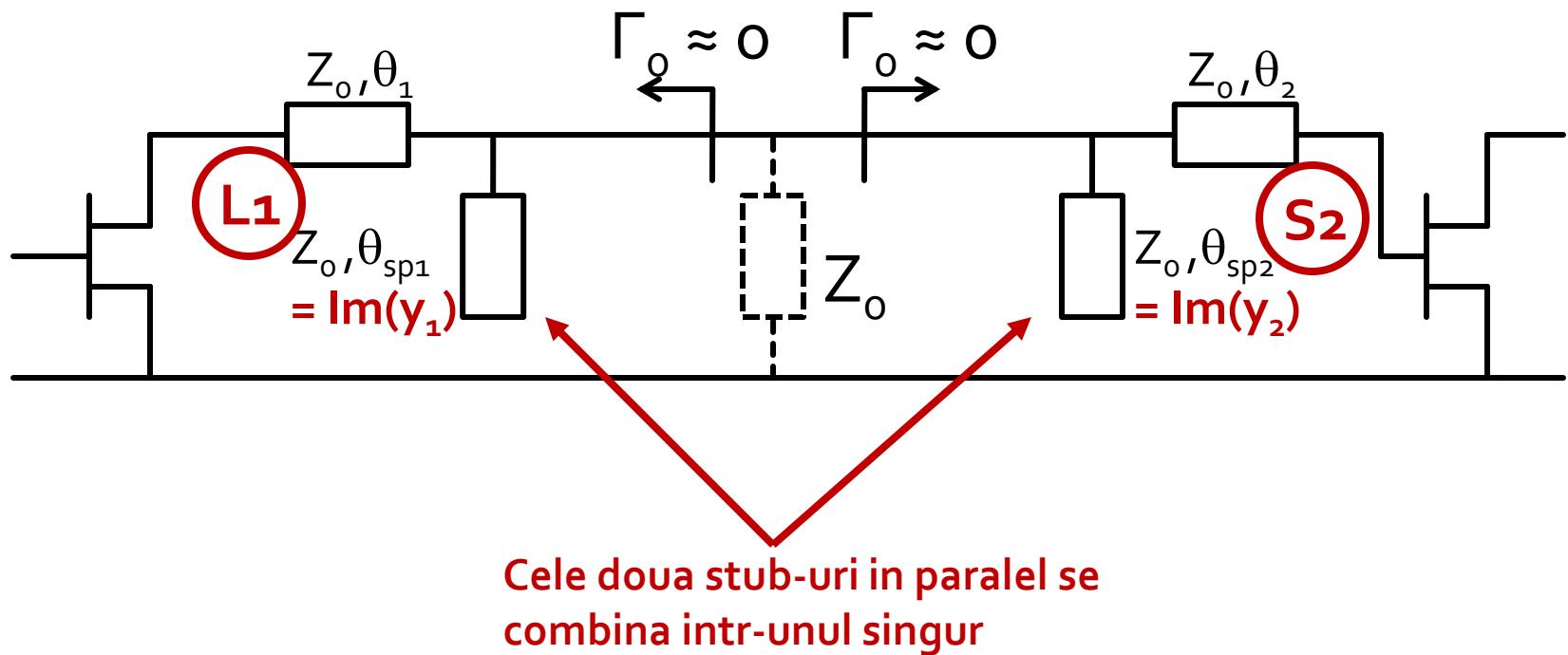
Adaptare inter-etaje 2

- 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



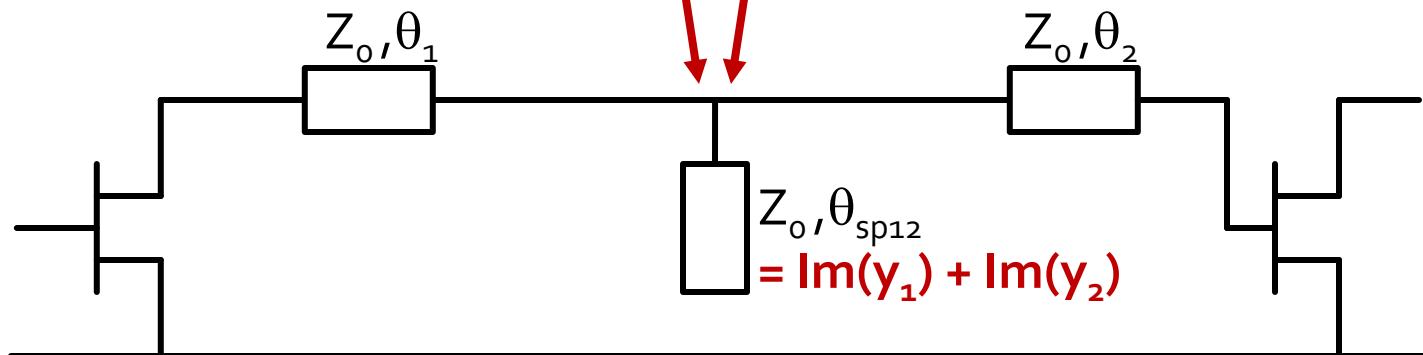
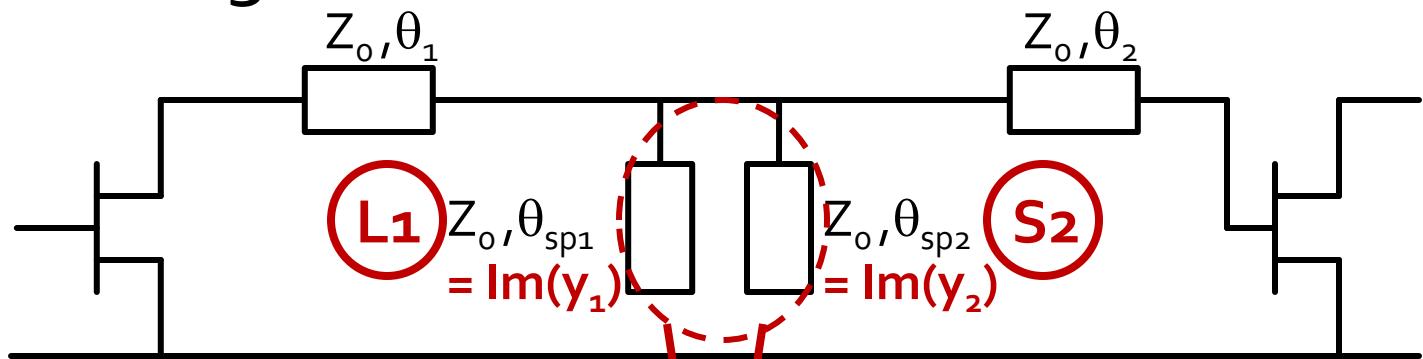
Adaptare inter-etaje 2

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



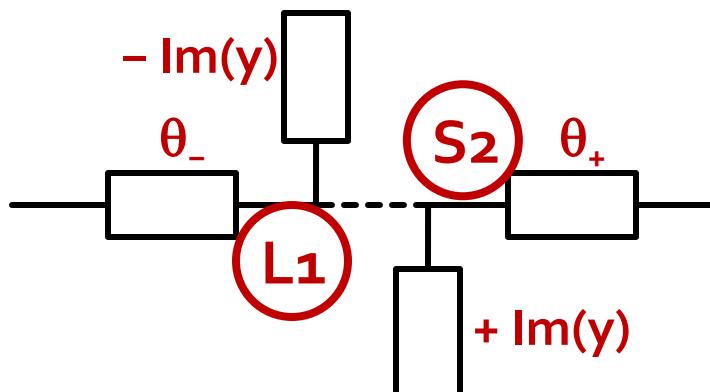
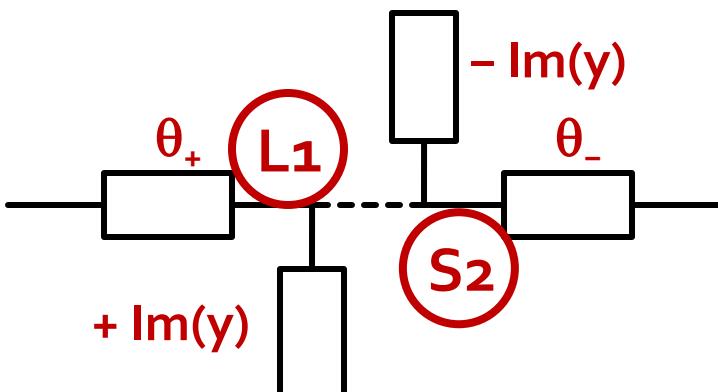
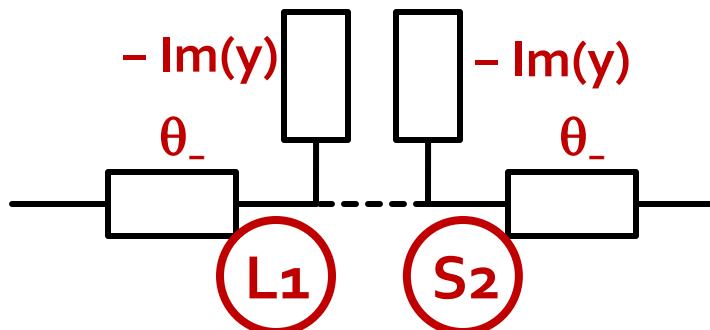
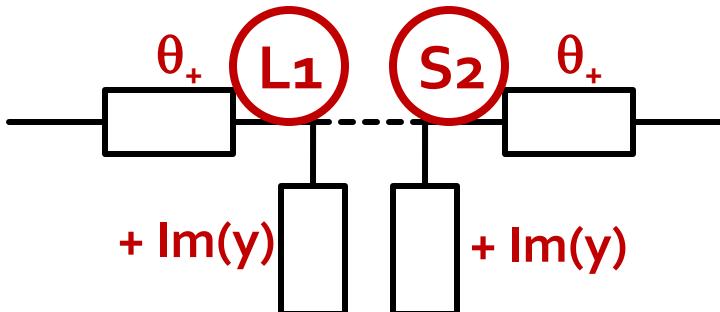
Adaptare inter-etaje 2

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



Combinarea celor 2 stub-uri paralel

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



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

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

Combinarea celor 2 stub-uri paralel

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

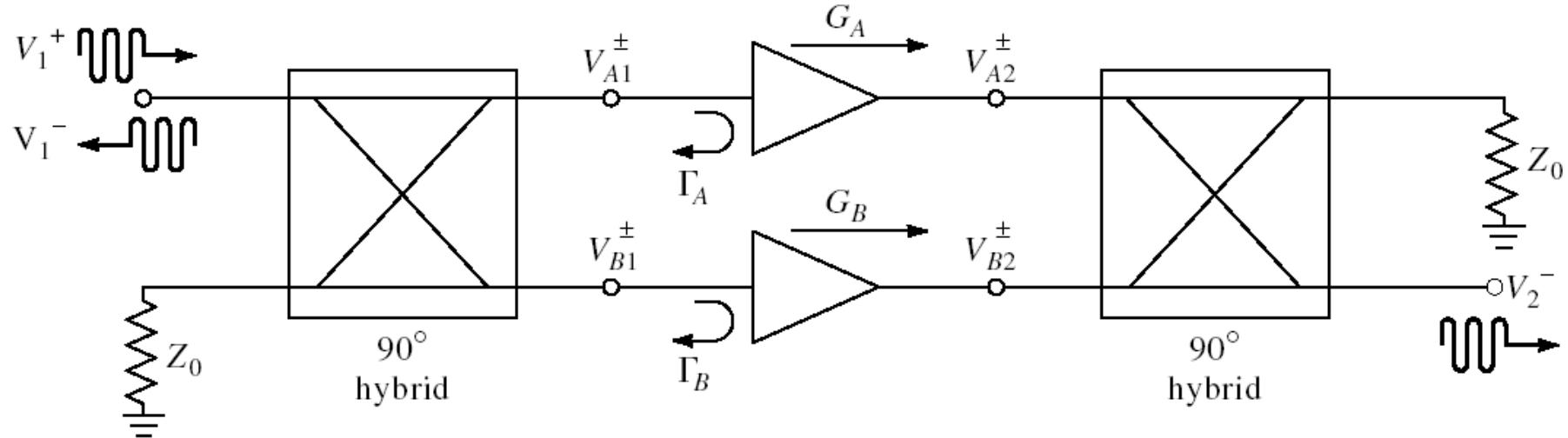
Amplificatoare de banda largă

Amplificatoare de microunde

Amplificatoare de banda largă

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

Amplificatoare echilibrate



- 2 Amplificatoare (identice) cu două cuploare hibride $3 \text{ dB} / 90^\circ$ la intrare și ieșire

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

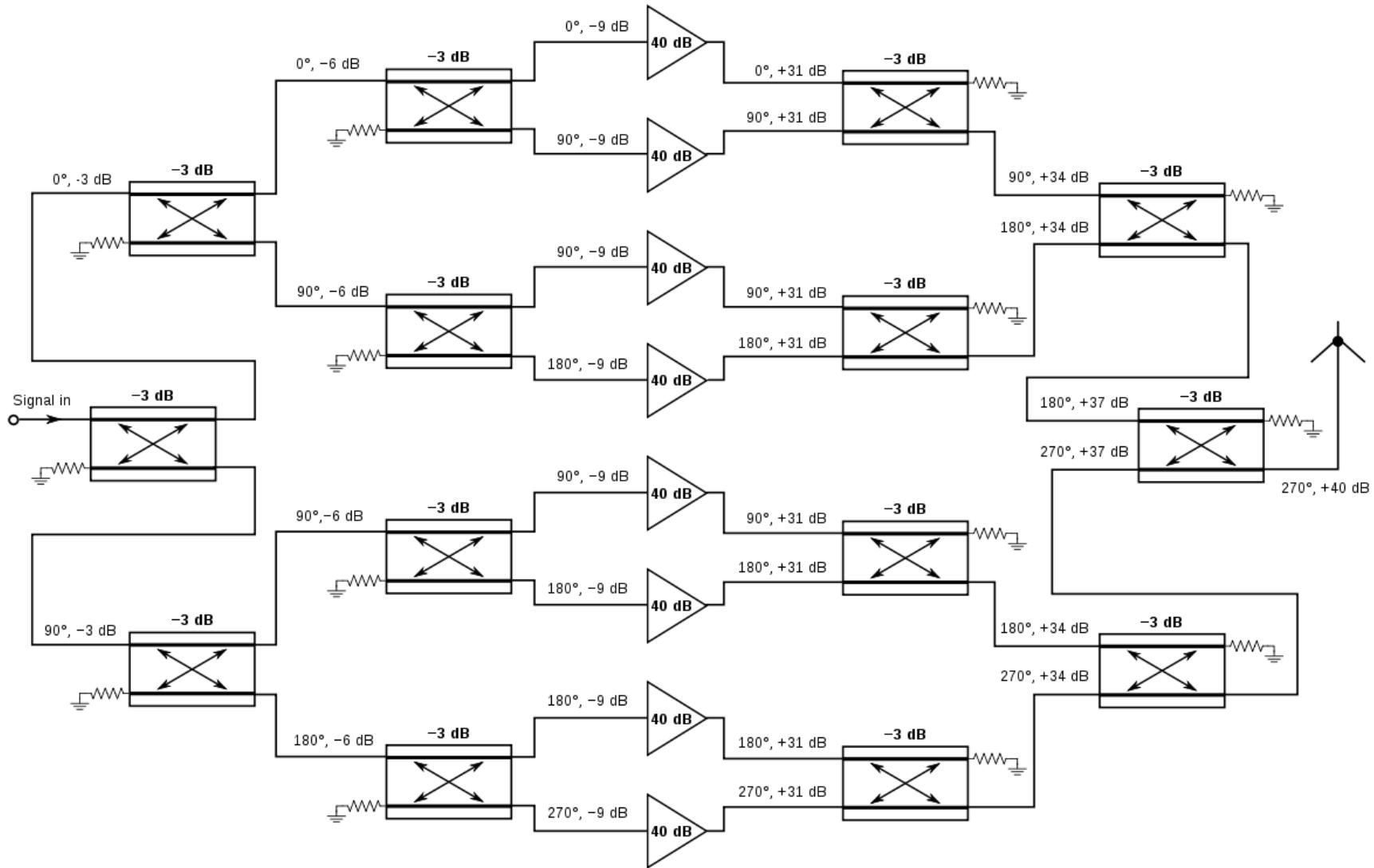
$$S_{11} = \frac{1}{2} \cdot (\Gamma_A - \Gamma_B)$$

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

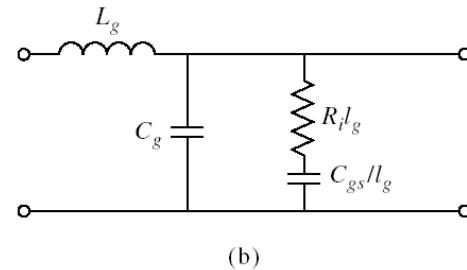
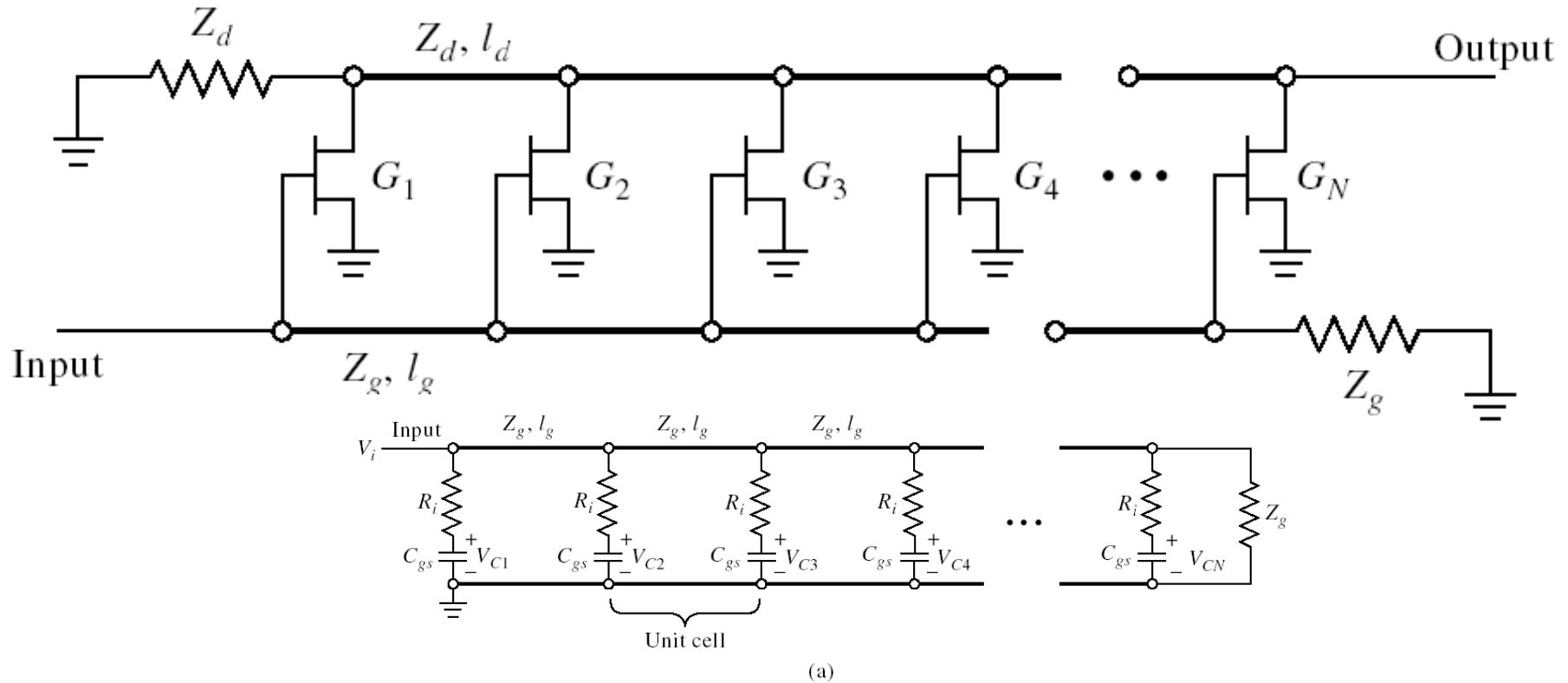
$$S_{21}|_{A=B} = -j \cdot G$$

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

Amplificatoare echilibrate



Amplificatoare distribuite



Amplificatoare distribuite

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

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

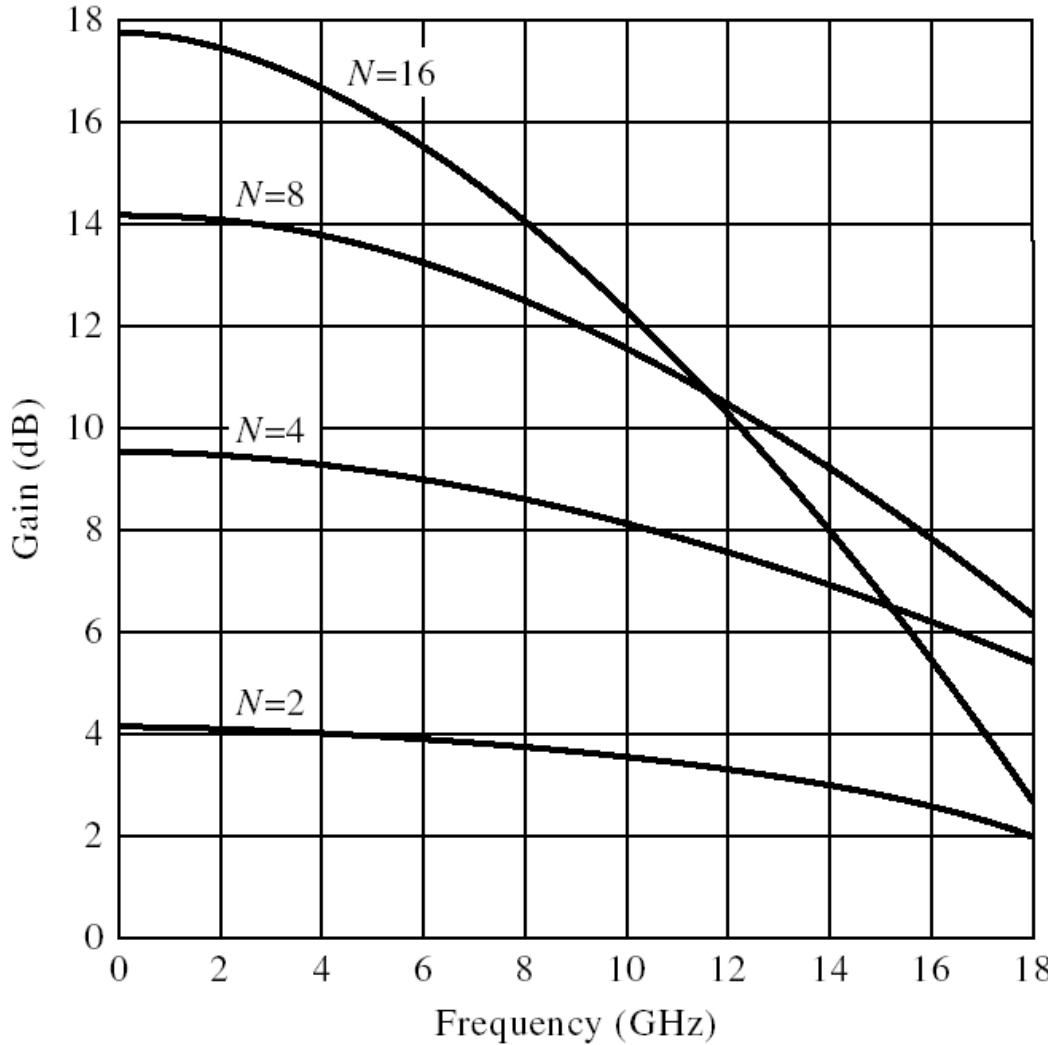
- Castigul de putere

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

- Castigul de putere fara pierderi

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

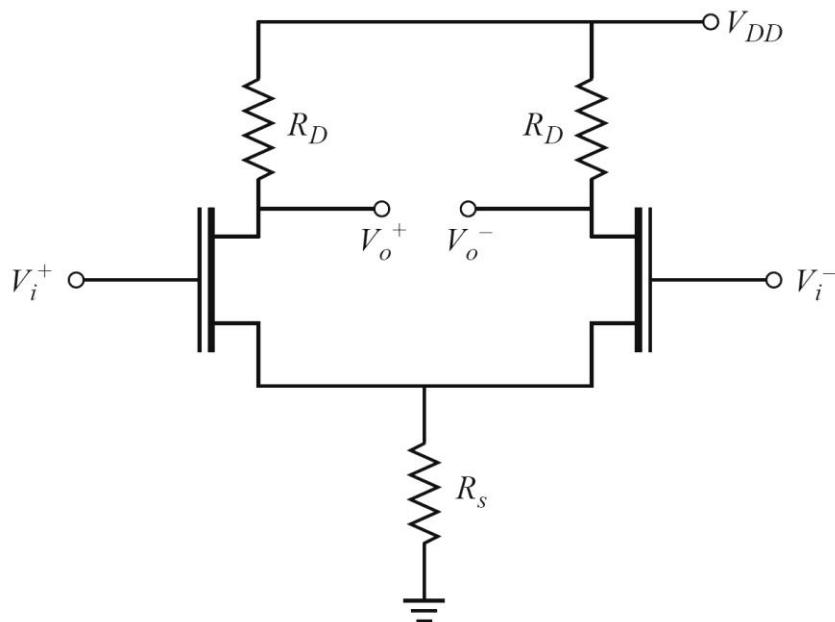
Amplificatoare distribuite



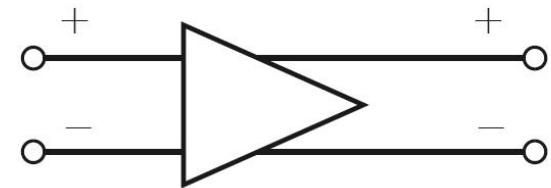
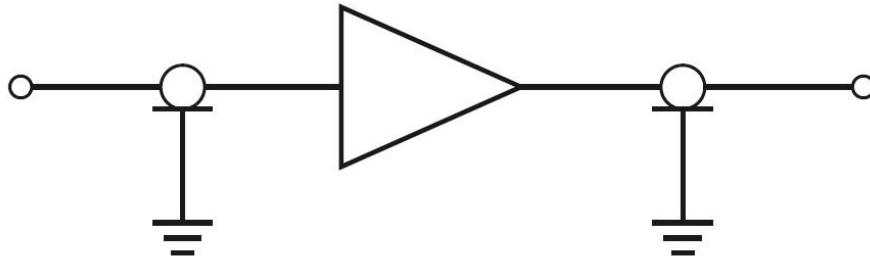
$$N_{opt} = \frac{\ln(\alpha_g \cdot l_g) - \ln(\alpha_d \cdot l_d)}{\alpha_g \cdot l_g - \alpha_d \cdot l_d}$$

Amplificatoare diferențiale

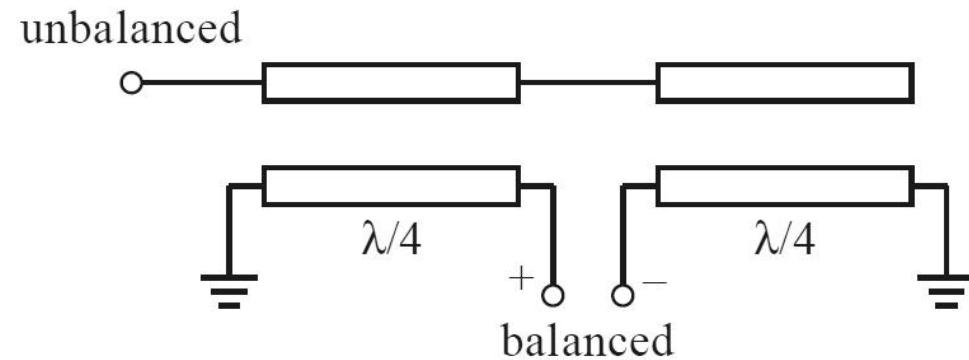
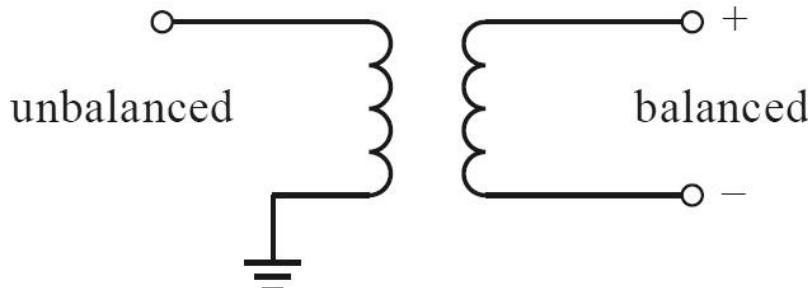
- Capacitatile de intrare în cele două tranzistoare în conexiune diferențială apar conectate în serie
- Se dublează astfel frecvența unitată



Amplificatoare diferențiale



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

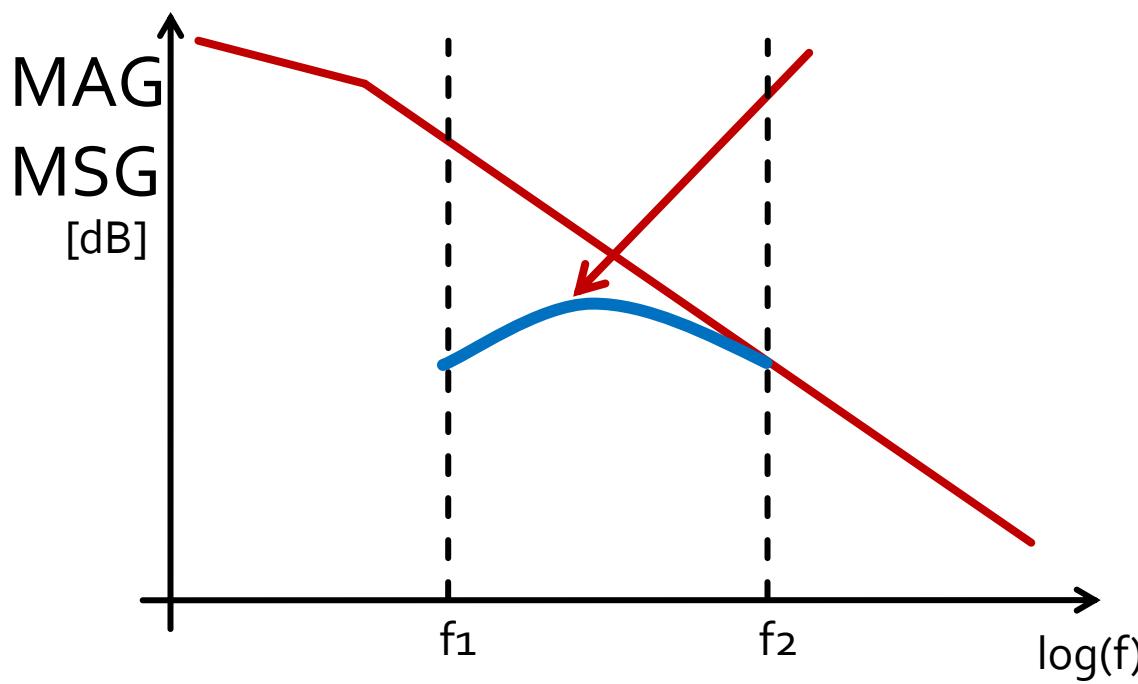


Amplificatoare de banda largă

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

Amplificatoare de banda largă

1. **Retele de adaptare care să compenseze scaderea castigului cu frecventa**
- Metoda utilizata este de a repeta proiectarea la mai multe (macar 2) frecvente si impunerea unui castig egal la acestea



Filtre pentru microunde

Filtre pentru microunde

- În domeniul microundelor se utilizează două 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 obținerea unor filtre mai eficiente dar este caracterizată de
 - generalitate mai mică
 - proiectare deseori dificila (lipsa relațiilor 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 aleg polinoamele pentru implementarea unui FTJ (prototip)
- Acest filtru poate fi convertit la alte functii, scalat in frecventa pentru a obtine alte tipuri de functii

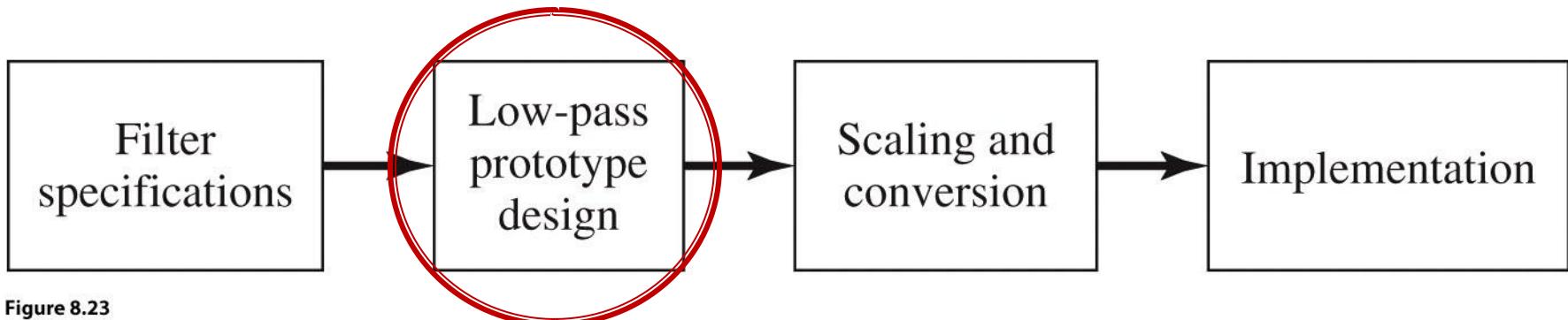


Figure 8.23

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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 fază**, ofera intarziere de grup de maxim plat, cu dezavantajul unei atenuari in putere mai mica, necesar in anumite aplicatii

FTJ prototip Maxim plat/Echiriplu

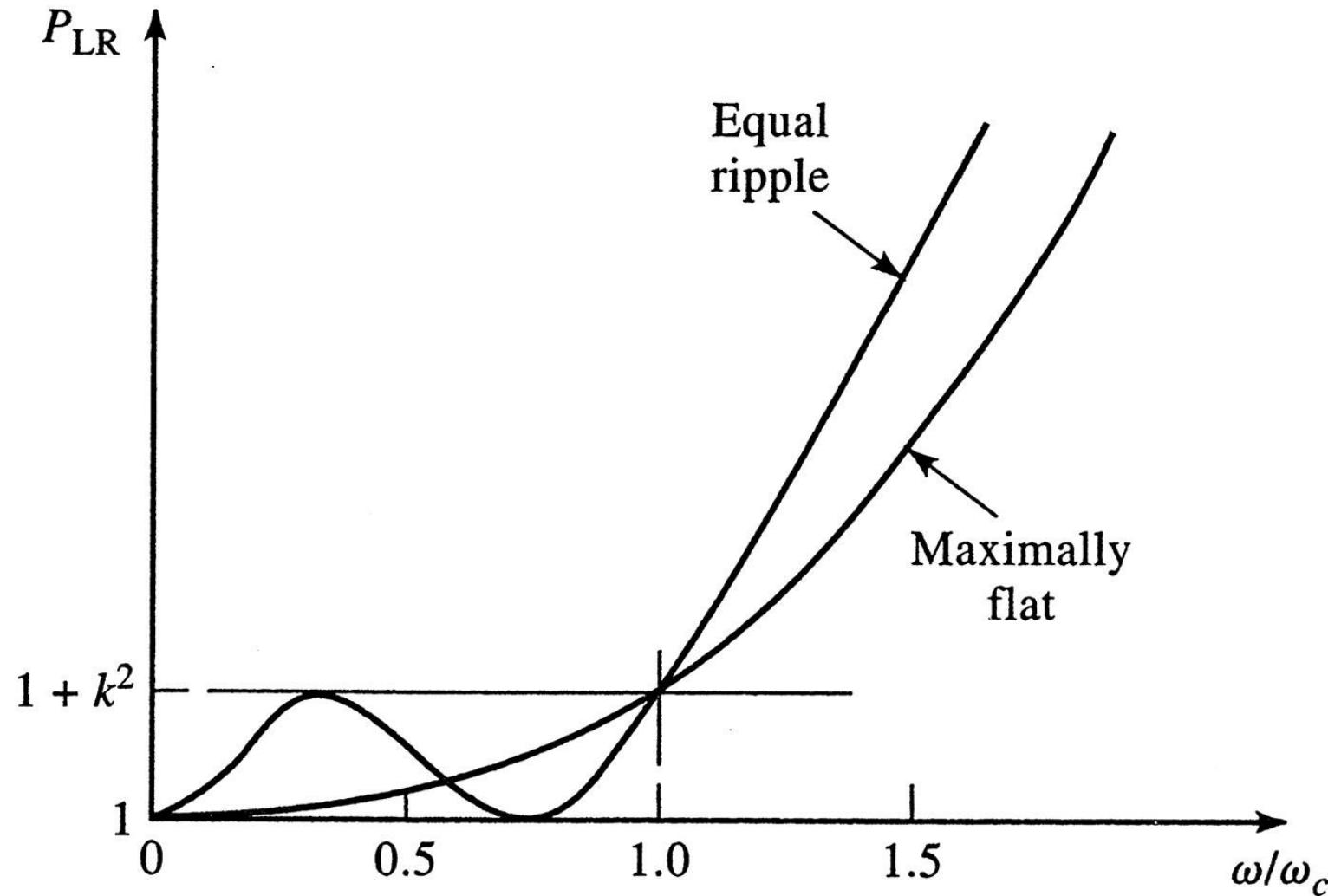


Figure 8.21

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FTJ elliptic prototip

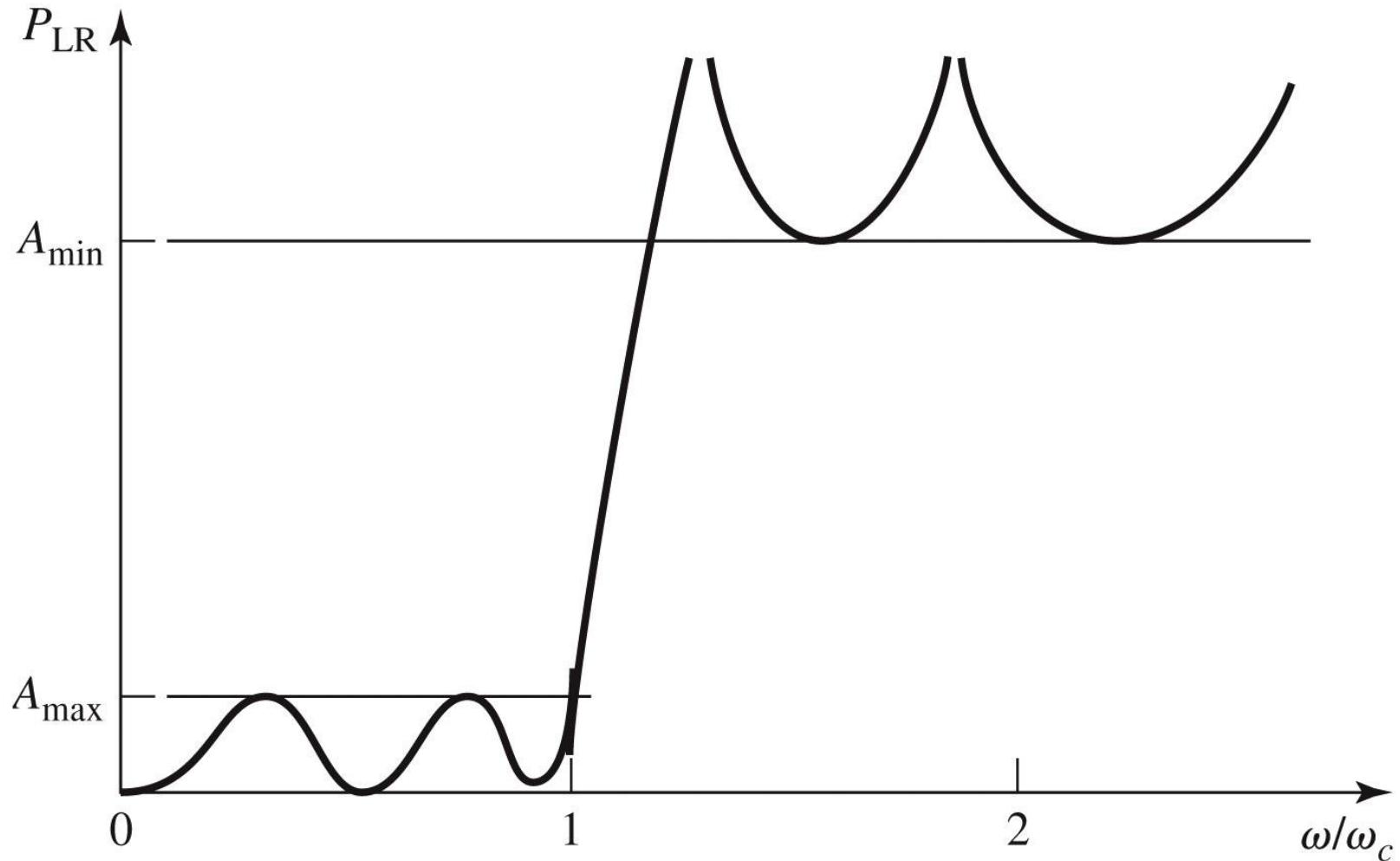


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FTJ de tip maxim plat

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

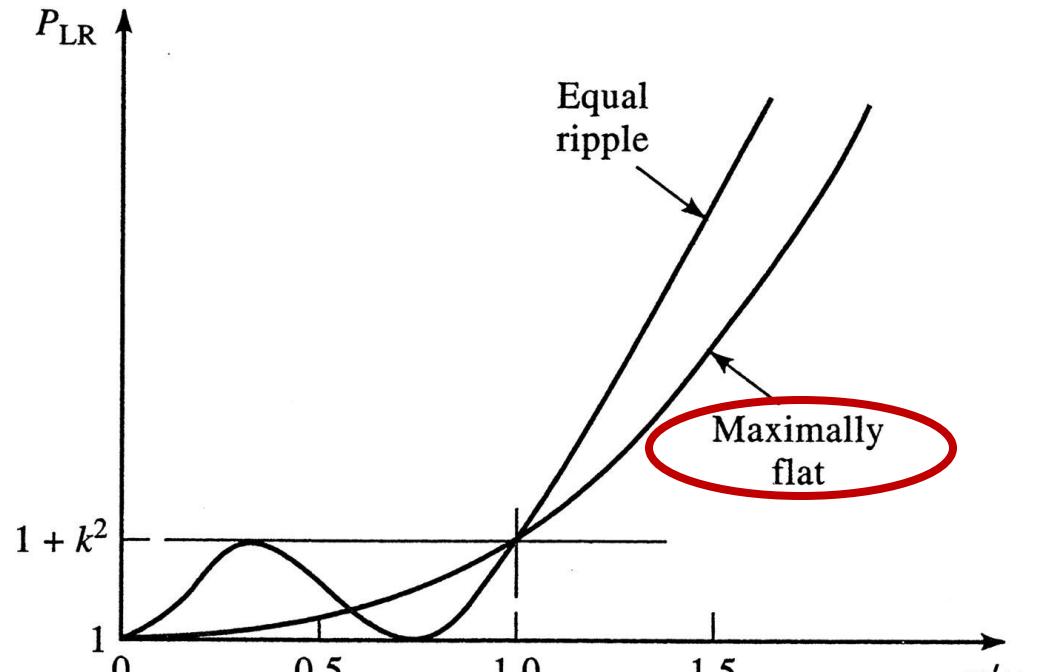


Figure 8.21
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FTJ de tip echiriplu

- Polinomul

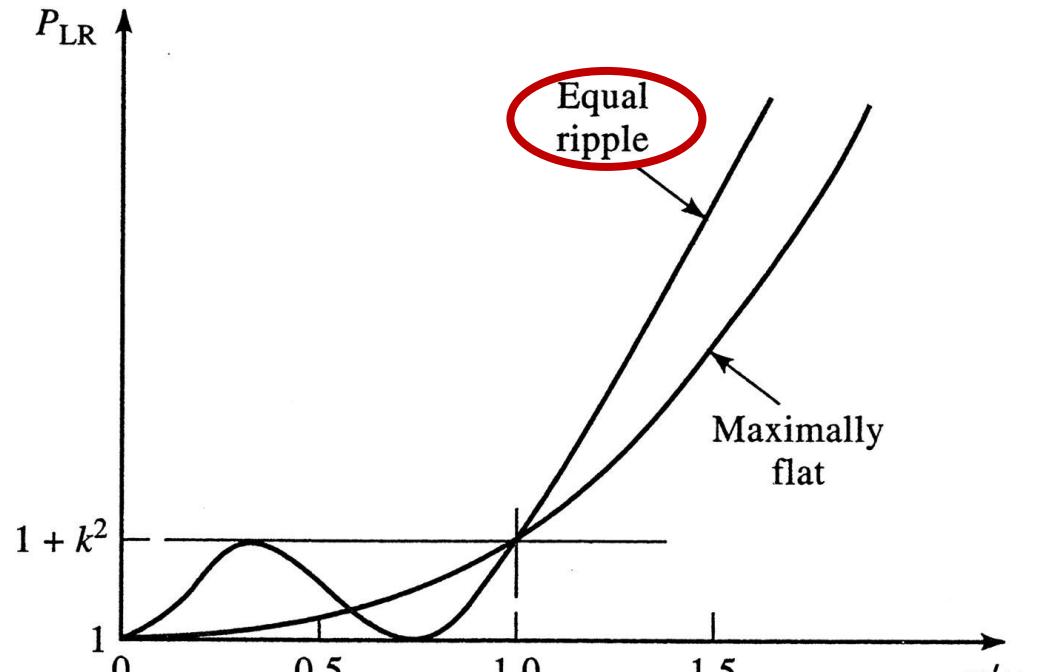
$$P_{LR} = 1 + k^2 \cdot T_N^2 \left(\frac{\omega}{\omega_c} \right)$$

- pentru $\omega >> \omega_c$

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

- atenuarea creste cu $20N$ dB/decada

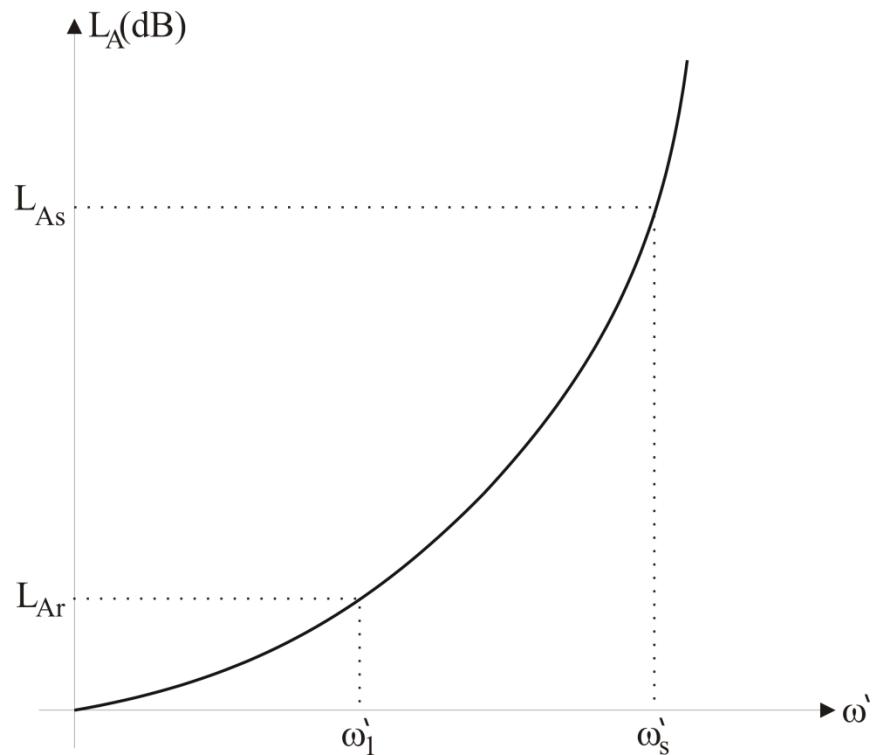
- atenuarea este mai mare de $(2^{2N})/4$ decat cea a filtrului binomial la frecventele $\omega >> \omega_c$



Calculul ordinului filtrului maxim plat

$$n \geq \frac{\log \left(\frac{10^{\frac{L_{As}}{10}} - 1}{10^{\frac{L_{Ar}}{10}} - 1} \right)}{2 \cdot \log \frac{\omega_s'}{\omega_1'}}$$

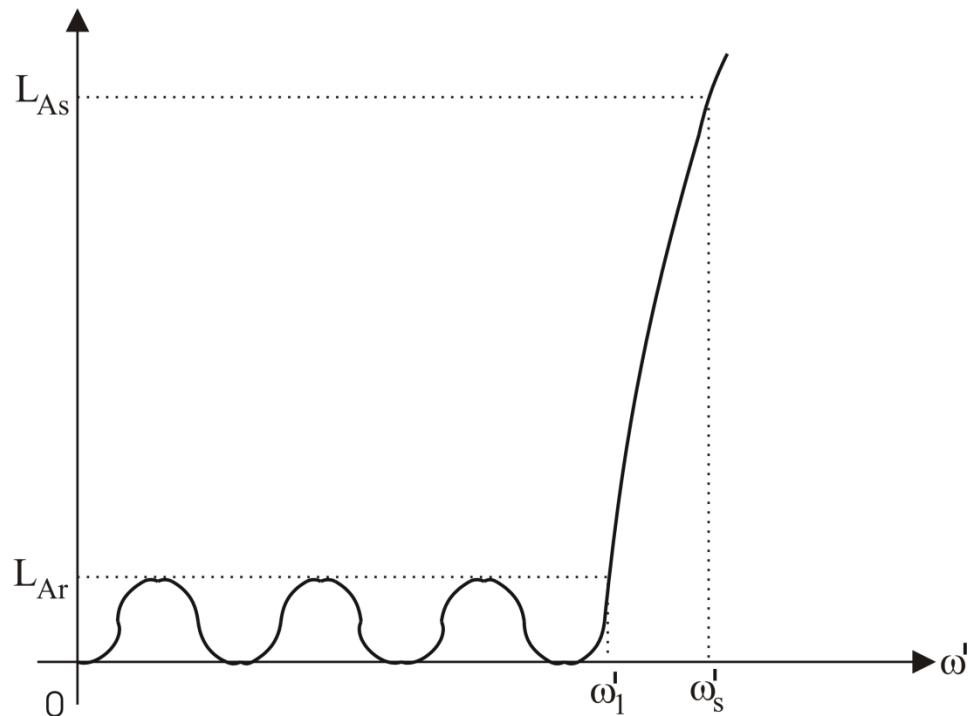
- cu atenuările in **dB**



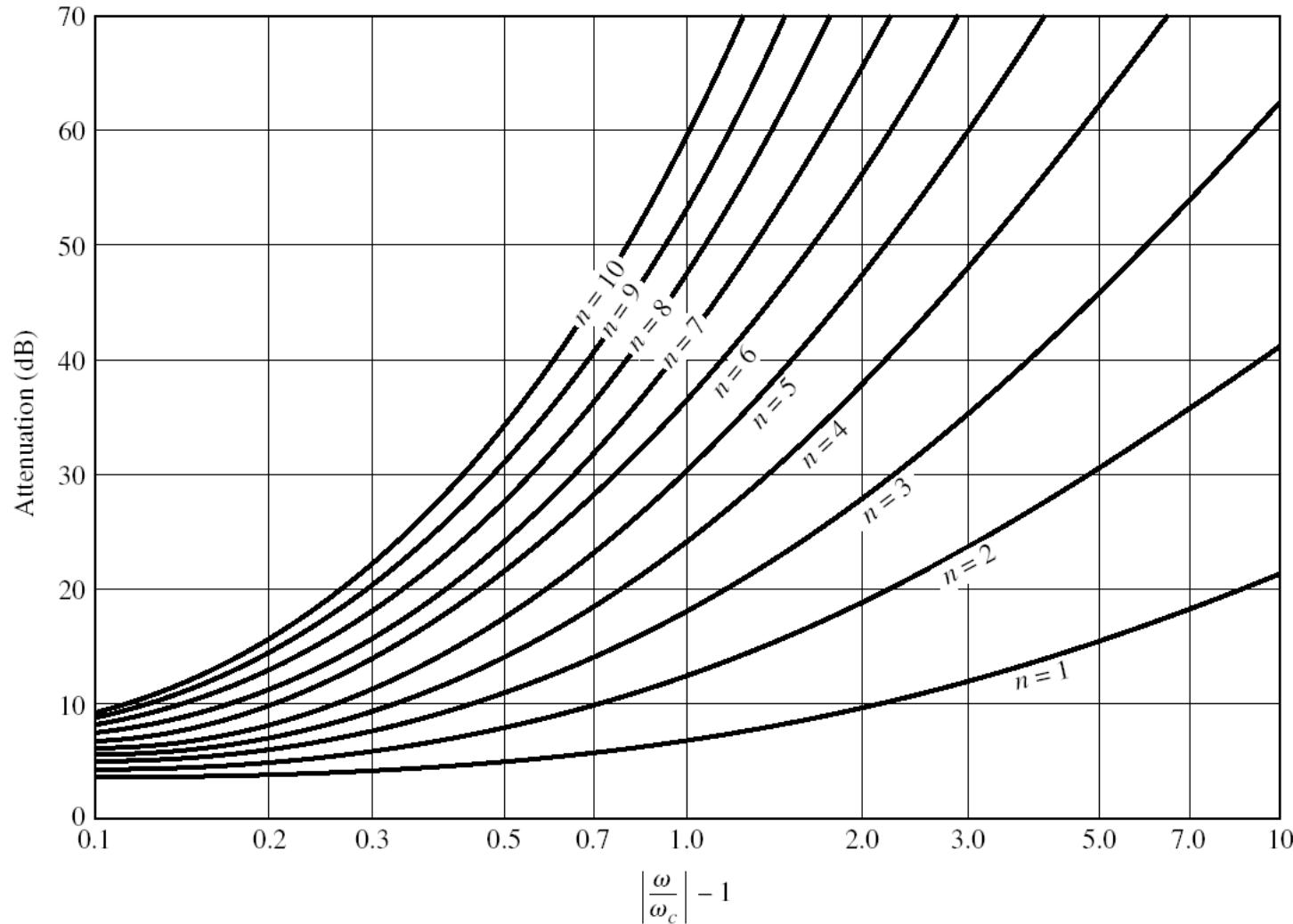
Calculul ordinului filtrului echiriplu

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

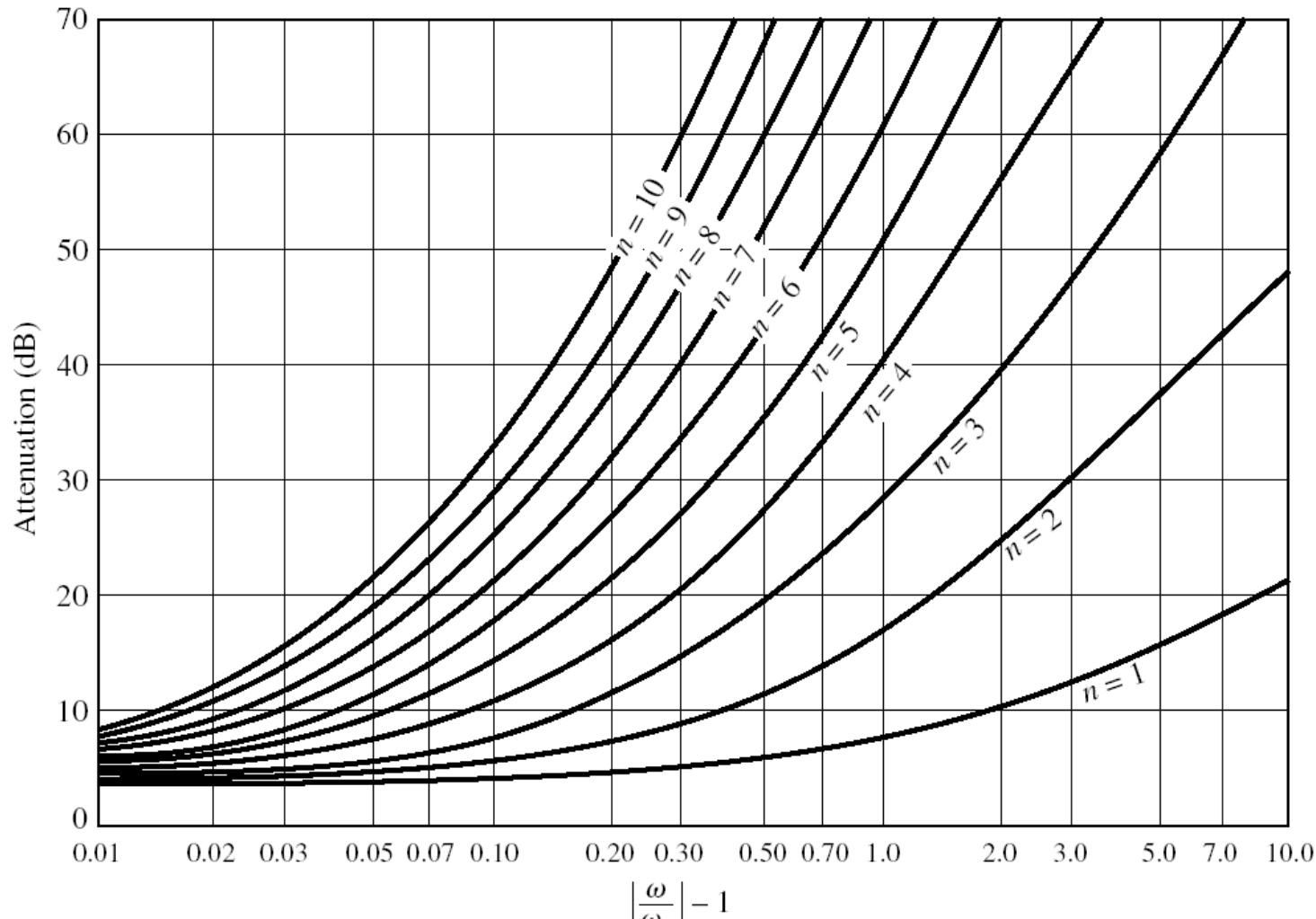
- cu atenuările in **dB**



Raspunsul filtrului maxim plat

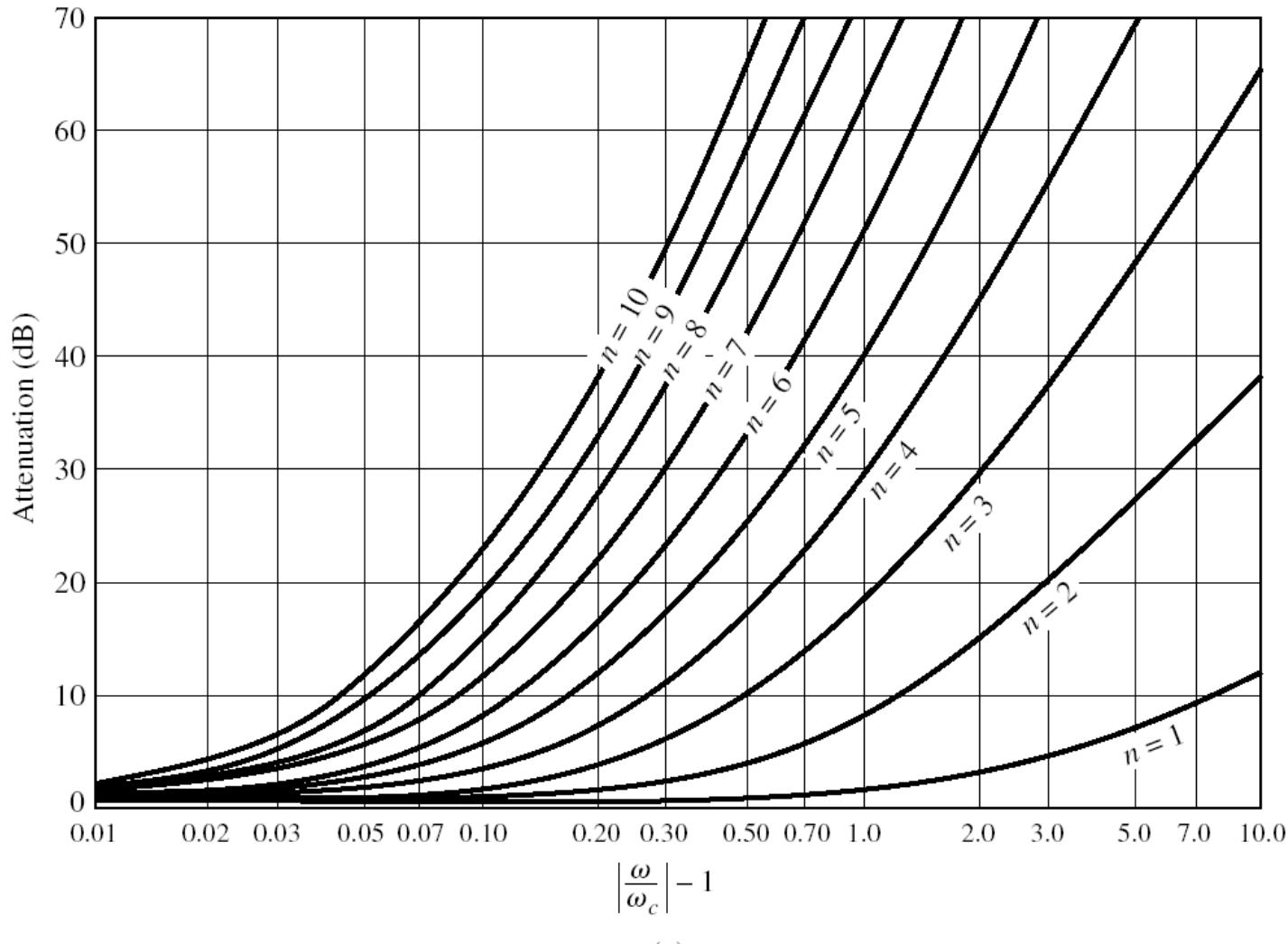


Raspunsul filtrului echiriplu 3 dB



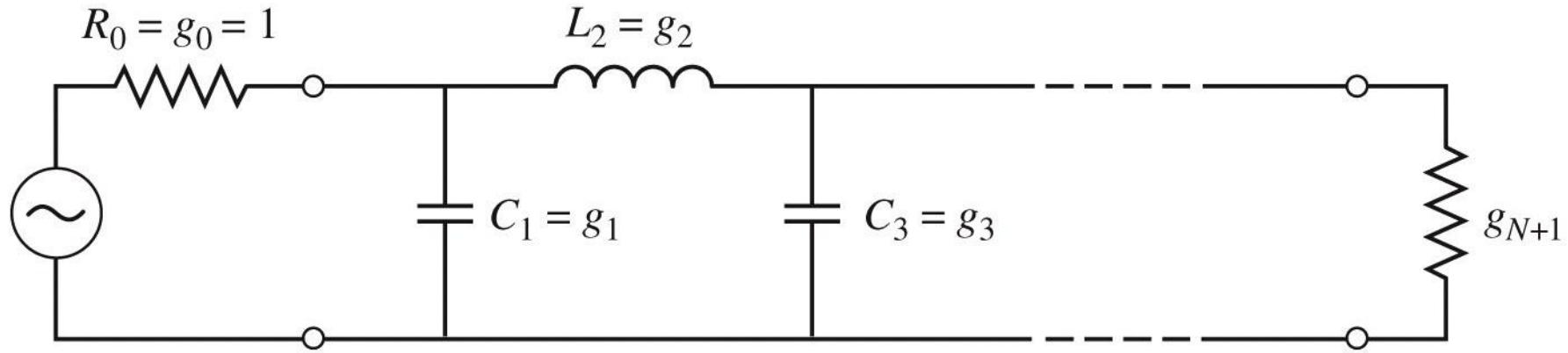
(b)

Raspunsul filtrului echiriplu 0.5 dB

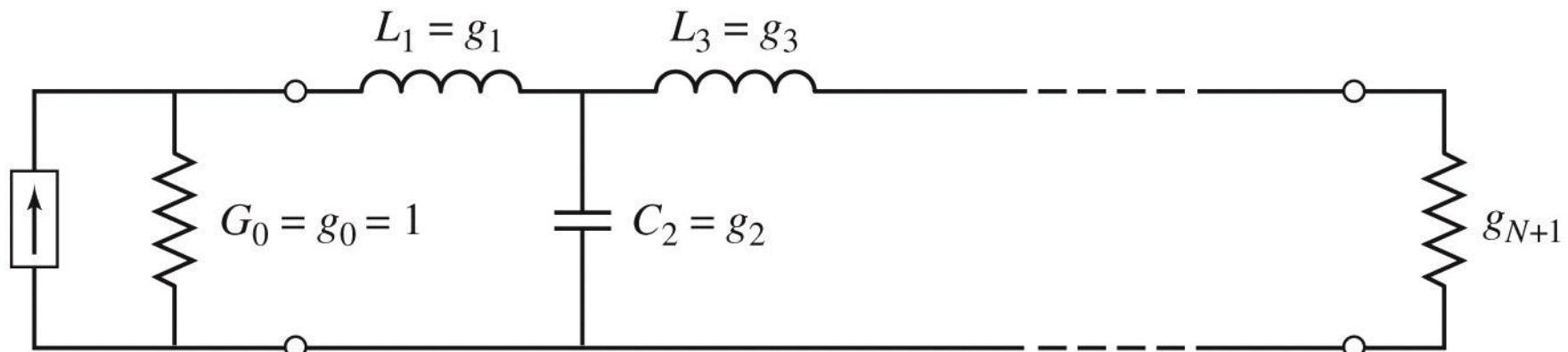


(a)

Filtre prototip



(a)



(b)

Filtre prototip

- Filtrele prototip sunt filtre care implementeaza :
 - filtru FTJ
 - frecventa de taiere $\omega_0 = 1 \text{ rad/s}$ ($f_0 = 0.159 \text{ Hz}$)
 - 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 , $i=0, N+1$

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

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

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

Filtru prototip maxim plat

- Calculul elementelor filtrului

$$g_0 = 1$$

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

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

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.

Filtru prototip echiriplu

■ Calculul elementelor filtrului (iterativ)

$$a_k = \sin\left[\frac{(2 \cdot k - 1) \cdot \pi}{2 \cdot N}\right] , \quad k = 1, N \qquad \beta = \ln\left(\coth\frac{L_{Ar}}{17,37}\right)$$

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

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

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

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

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)

0.5 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	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.

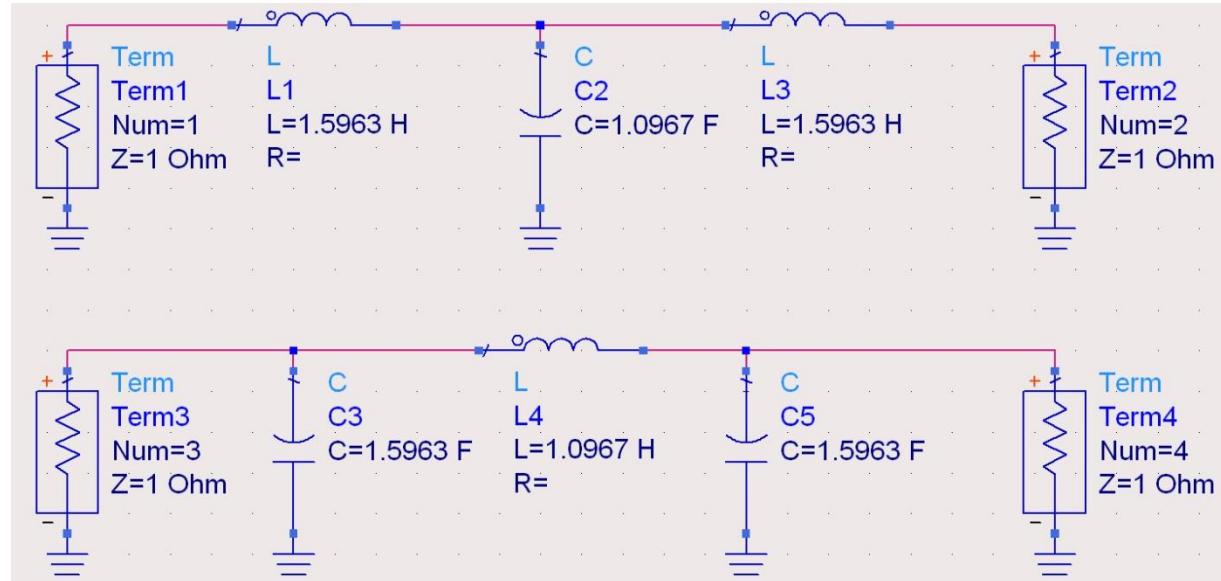
- Pentru ordin par al filtrului ($N = 2, 4, 6, 8 \dots$) filtrele echiriplu **trebuie** sa fie inchise pe o impedanta de terminatie diferita de cea standard $g_{N+1} \neq 1$. Daca aplicatia nu suporta aceasta comportare, e necesara introducerea unei adaptari de impedanta suplimentare (transformator in 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 centrală a filtrului să fie de 1 GHz. Banda să fie de 10%, și impedanță de $50\ \Omega$.
- Tabel echiriplu 0.5dB sau relații de calcul:
 - $g_1 = 1.5963 = L_1$,
 - $g_2 = 1.0967 = C_2$,
 - $g_3 = 1.5963 = L_3$,
 - $g_4 = 1.000 = R_L$

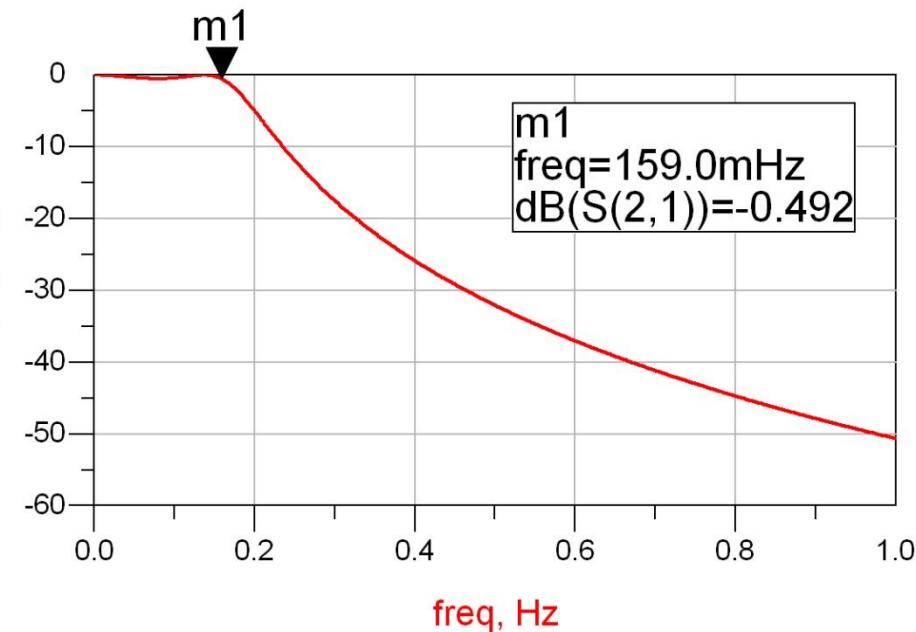
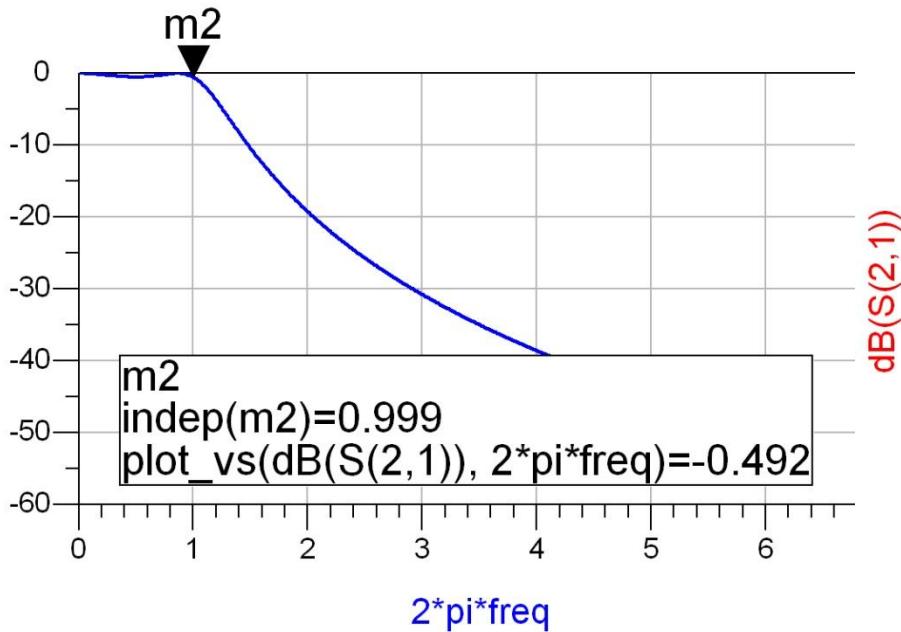
Filtru prototip

- Tabel echiriplu o.5dB sau relatii de calcul:
 - $g_1 = 1.5963 = L_1/C_3$,
 - $g_2 = 1.0967 = C_2/L_4$,
 - $g_3 = 1.5963 = L_3/C_5$,
 - $g_4=1.000 = R_L$



Filtru prototip

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



Scalarea in impedanta si frecventa

- Dupa determinarea coeficientilor filtrului prototip
 - filtru FTJ
 - frecventa de taiere $\omega_0 = 1 \text{ rad/s}$ ($f_0 = 0.159 \text{ Hz}$)
 - 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 tariere $\omega_0 = 1 \text{ rad/s}$ ($f_0 = 0.159 \text{ Hz}$)
 - conectate la intrare la o rezistenta $R = 1$

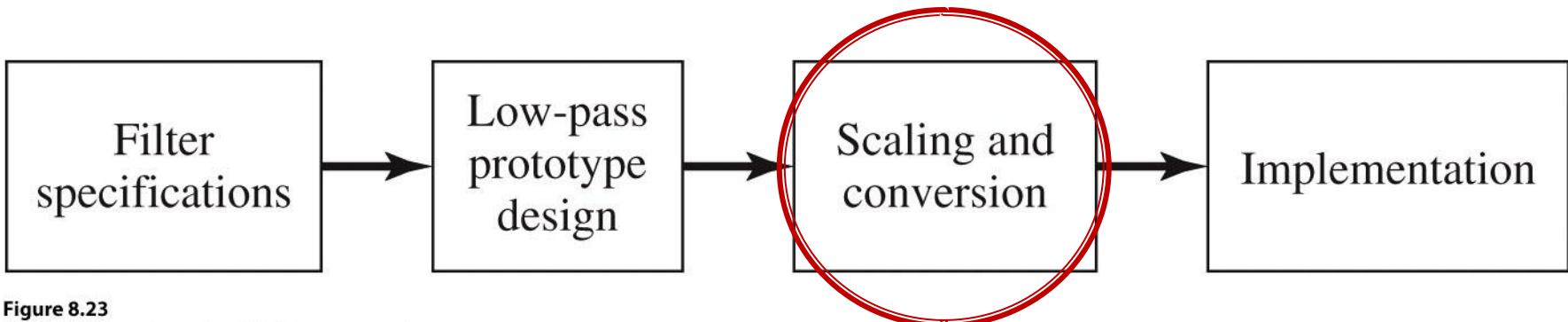


Figure 8.23

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Scalarea in impedanta

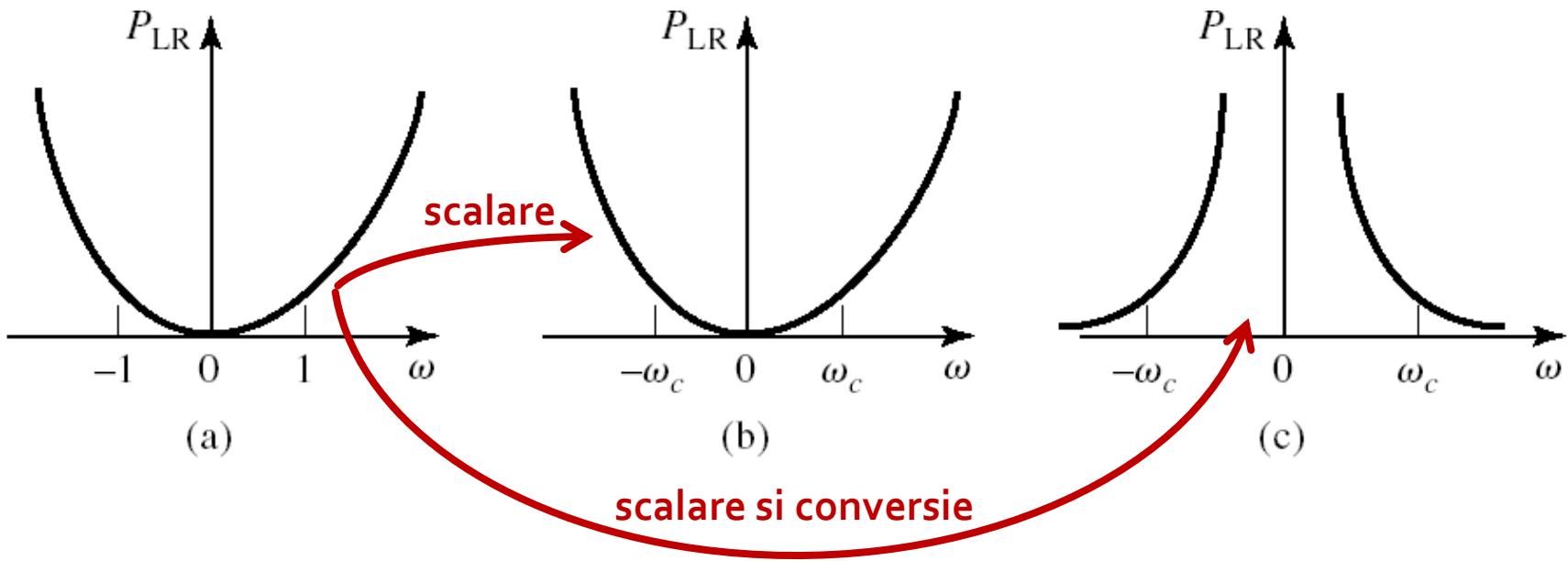
- Pentru a determina filtrul care lucreaza cu o alta rezistenta de intrare (R_o) se multiplica toate impedantele din circuit cu aceasta impedanta (cu " " se noteaza elementele noi)

$$R'_s = R_0 \quad R'_L = R_0 \cdot R_L$$

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

Scalarea în frecvență

- modificarea frecvenței de taiere – (fig. b)
- modificarea caracteristicii de atenuare (de exemplu FTJ \rightarrow FTS – fig. c)



Scalarea in frecventa

- Pentru FTJ cu alta frecventa de taiere se face schimarea de variabila:

$$\omega \leftarrow \frac{\omega}{\omega_c}$$

- Echivalent cu largirea caracteristicii de frecventa

$$P'_{LR}(\omega) = P_{LR}\left(\frac{\omega}{\omega_c}\right)$$

$$j \cdot X_k = j \cdot \frac{\omega}{\omega_c} \cdot L_k = j \cdot \omega \cdot L'_k \quad j \cdot B_k = j \cdot \frac{\omega}{\omega_c} \cdot C_k = j \cdot \omega \cdot C'_k$$

Scalarea FTJ \rightarrow FTJ

- Noile valori cu scalarea in frecventa

$$L'_k = \frac{L_k}{\omega_c} \quad C'_k = \frac{C_k}{\omega_c}$$

- Daca se aplica simultan si scalarea in impedanta

$$L'_k = \frac{R_0 \cdot L_k}{\omega_c} \quad C'_k = \frac{C_k}{R_0 \cdot \omega_c}$$

Conversie si scalare FTJ \rightarrow FTS

- Se face schimbarea de variabila:

$$\omega \leftarrow -\frac{\omega_c}{\omega}$$

$$j \cdot X_k = -j \cdot \frac{\omega_c}{\omega} \cdot L_k = \frac{1}{j \cdot \omega \cdot C'_k} \quad j \cdot B_k = -j \cdot \frac{\omega_c}{\omega} \cdot C_k = \frac{1}{j \cdot \omega \cdot L'_k}$$

- Daca se aplica simultan si scalarea in impedanta

$$C'_k = \frac{1}{R_0 \cdot \omega_c \cdot L_k} \quad L'_k = \frac{R_0}{\omega_c \cdot C_k}$$

- In schema inductantele serie se transforma in capacitatii serie, iar capacitatatile paralel se transforma in inductante paralel

Conversie si scalare FTJ \rightarrow FTB

- Se face schimbarea de variabila:

$$\omega \leftarrow \frac{\omega_0}{\omega_2 - \omega_1} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) = \frac{1}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right)$$

- unde intervin banda fractionara si frecventa centrala

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0}$$

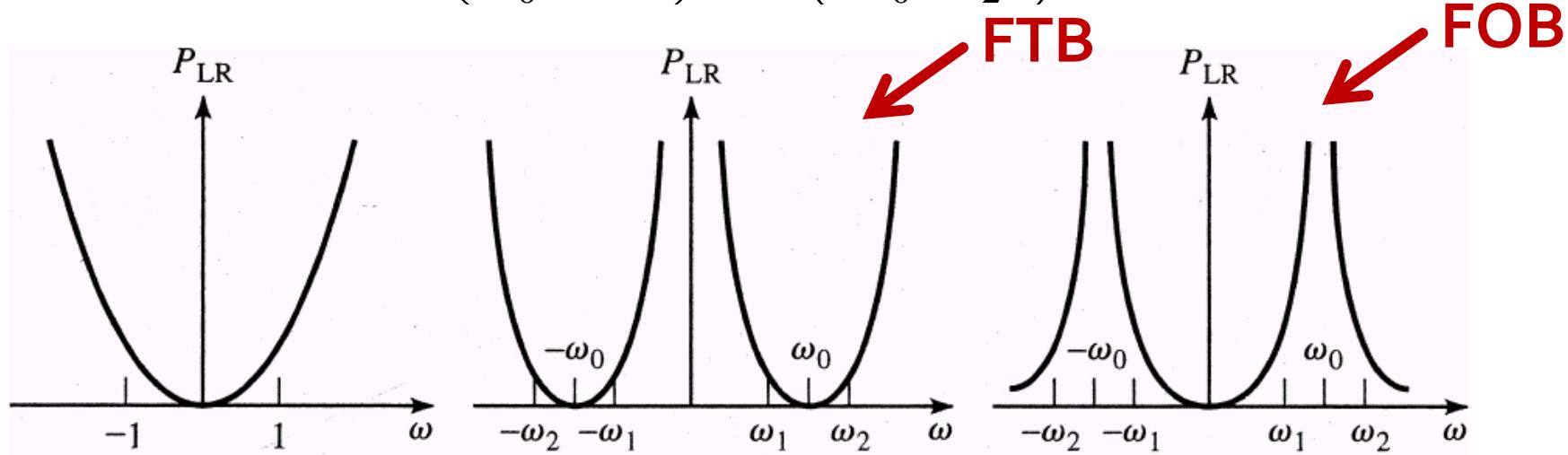
$$\omega_0 = \sqrt{\omega_1 \cdot \omega_2}$$

Conversie si scalare FTJ \rightarrow FTB

$$\omega = \omega_0 \rightarrow \frac{1}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) = 0$$

$$\omega = \omega_1 \rightarrow \frac{1}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) = \frac{1}{\Delta} \left(\frac{\omega_1^2 - \omega_0^2}{\omega_0 \cdot \omega_1} \right) = -1$$

$$\omega = \omega_2 \rightarrow \frac{1}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) = \frac{1}{\Delta} \left(\frac{\omega_2^2 - \omega_0^2}{\omega_0 \cdot \omega_2} \right) = 1$$



Conversie si scalare FTJ → FTB

$$j \cdot X_k = \frac{j}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) \cdot L_k = j \cdot \frac{\omega \cdot L_k}{\Delta \cdot \omega_0} - j \cdot \frac{\omega_0 \cdot L_k}{\Delta \cdot \omega} = j \cdot \omega \cdot L'_k - j \frac{1}{\omega \cdot C'_k}$$

$$j \cdot B_k = \frac{j}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) \cdot C_k = j \cdot \frac{\omega \cdot C_k}{\Delta \cdot \omega_0} - j \cdot \frac{\omega_0 \cdot C_k}{\Delta \cdot \omega} = j \cdot \omega \cdot C'_k - j \frac{1}{\omega \cdot L'_k}$$

- O **inductanta** serie in filtrul prototip se transforma intr-un circuit **LC serie**

$$L'_k = \frac{L_k}{\Delta \cdot \omega_0} \qquad C'_k = \frac{\Delta}{\omega_0 \cdot L_k}$$

- O **capacitate** paralel in filtrul prototip se transforma intr-un circuit **LC paralel**

$$L'_k = \frac{\Delta}{C_k \cdot \omega_0} \qquad C'_k = \frac{C_k}{\omega_0 \cdot \Delta}$$

Conversie si scalare FTJ → FOB

$$\omega \leftarrow -\Delta \cdot \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right)^{-1}$$

- O **inductanta** serie in filtrul prototip se transforma intr-un circuit **LC paralel**

$$L'_k = \frac{\Delta \cdot L_k}{\omega_0} \quad C'_k = \frac{1}{\omega_0 \cdot \Delta \cdot L_k}$$

- O **capacitate** paralel in filtrul prototip se transforma intr-un circuit **LC serie**

$$L'_k = \frac{1}{\Delta \cdot \omega_0 \cdot C_k} \quad C'_k = \frac{\Delta \cdot C_k}{\omega_0}$$

Transformari ale filtrului prototip

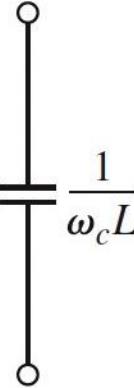
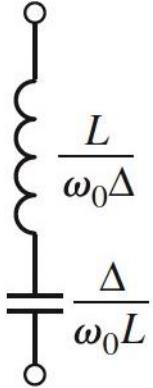
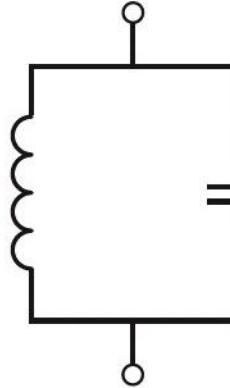
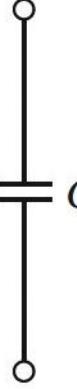
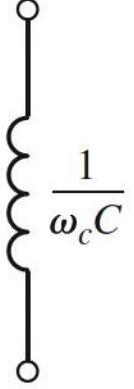
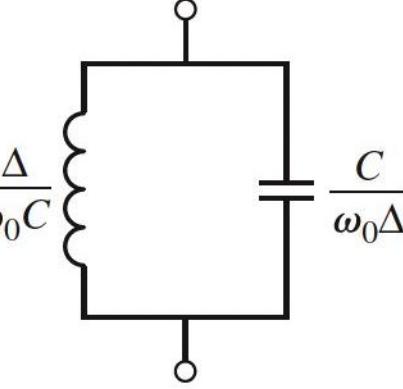
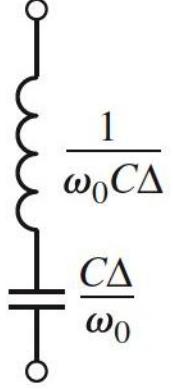
Low-pass	High-pass	Bandpass	Bandstop
 L	 $\frac{1}{\omega_c L}$	 $\frac{L}{\omega_0 \Delta}$ $\frac{\Delta}{\omega_0 L}$	 $\frac{L \Delta}{\omega_0}$ $\frac{1}{\omega_0 L \Delta}$
 C	 $\frac{1}{\omega_c C}$	 $\frac{\Delta}{\omega_0 C}$ $\frac{C}{\omega_0 \Delta}$	 $\frac{1}{\omega_0 C \Delta}$ $\frac{C \Delta}{\omega_0}$

Table 8.6

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Exemplu

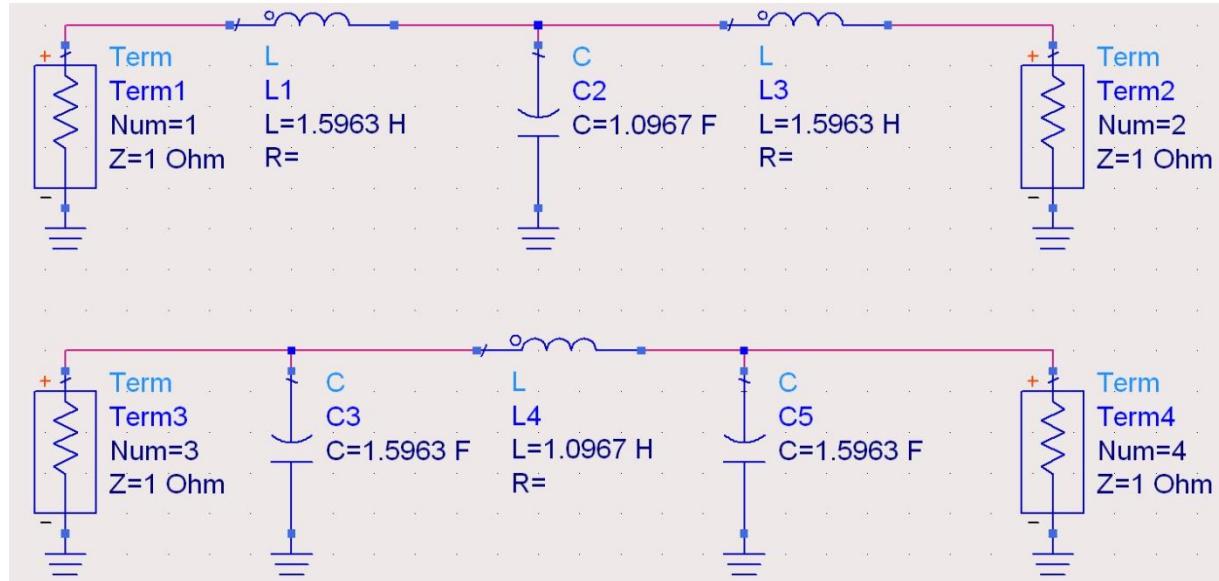
- Să se proiecteze un filtru **trece-bandă** de ordinul 3, având riplurile în bandă de 0.5 dB.
Frecvența centrală a filtrului să fie de 1 GHz.
Banda să fie de 10%, și impedanță de 50Ω .

$$\omega_0 = 2 \cdot \pi \cdot 1 \text{GHz} = 6.283 \cdot 10^9 \text{ rad/s}$$

$$\Delta = 0.1$$

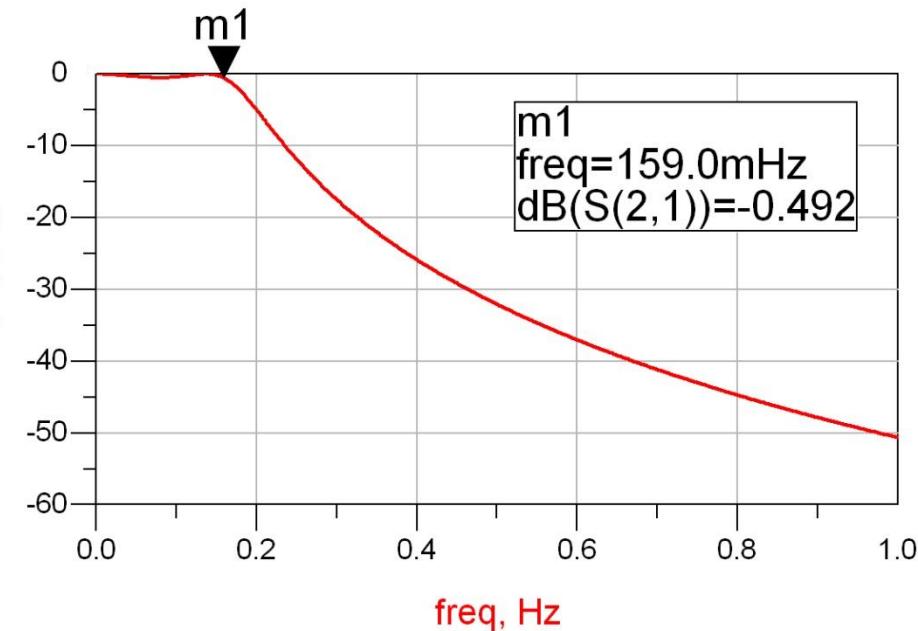
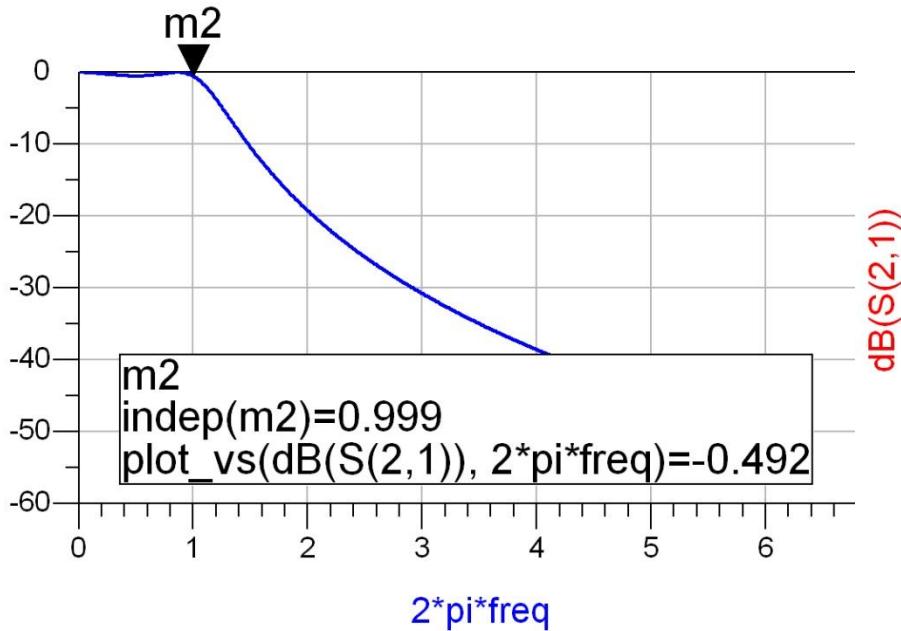
Filtru prototip

- Tabel echiriplu o.5dB sau relatii de calcul:
 - $g_1 = 1.5963 = L_1/C_3$,
 - $g_2 = 1.0967 = C_2/L_4$,
 - $g_3 = 1.5963 = L_3/C_5$,
 - $g_4=1.000 = R_L$



Filtru prototip

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



Scalare frecventa / FTB

$$\omega_0 = 2 \cdot \pi \cdot 1 \text{GHz} = 6.283 \cdot 10^9 \text{rad/s}$$
$$\Delta = \frac{\Delta\omega}{\omega_0} = \frac{\Delta f}{f_0} = 0.1$$
$$R_0 = 50 \Omega$$

$$g_1 = 1.5963 = L_1,$$
$$g_2 = 1.0967 = C_2,$$

$$g_3 = 1.5963 = L_3,$$
$$g_4 = 1.000 = R_L$$

$$L'_1 = \frac{L_1 \cdot R_0}{\Delta \cdot \omega_0} = 127.0 \text{nH}$$

$$C'_1 = \frac{\Delta}{\omega_0 \cdot L_1 \cdot R_0} = 0.199 \text{ pF}$$

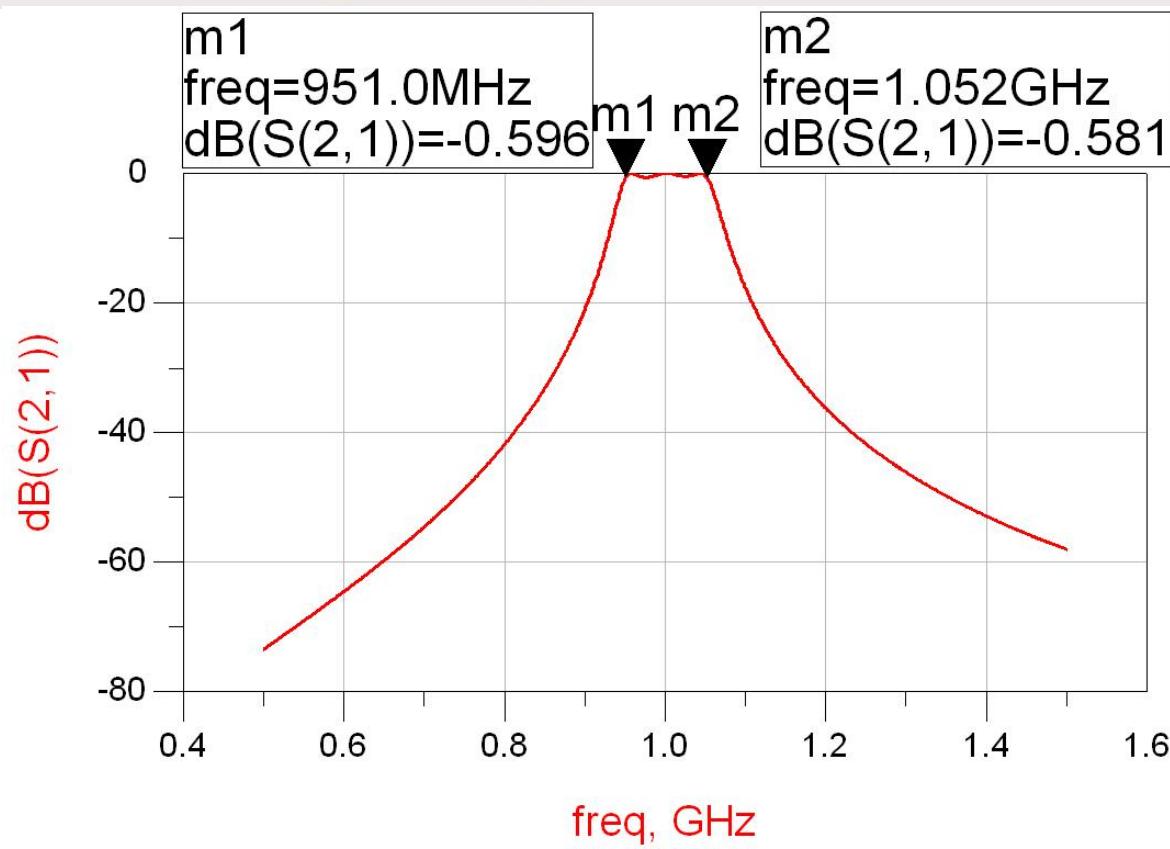
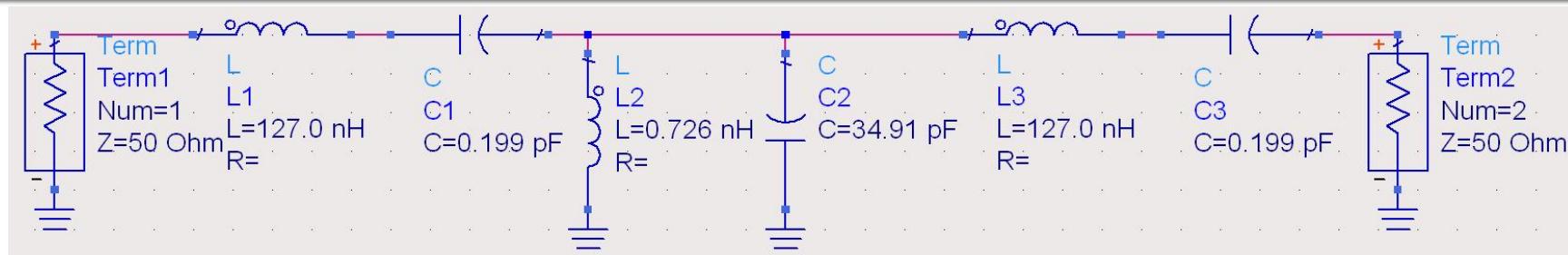
$$L'_2 = \frac{\Delta \cdot R_0}{\omega_0 \cdot C_2} = 0.726 \text{nH}$$

$$C'_2 = \frac{C_2}{\Delta \cdot \omega_0 \cdot R_0} = 34.91 \text{ pF}$$

$$L'_3 = \frac{L_3 \cdot R_0}{\Delta \cdot \omega_0} = 127.0 \text{nH}$$

$$C'_3 = \frac{\Delta}{\omega_0 \cdot L_3 \cdot R_0} = 0.199 \text{ pF}$$

ADS



Implementarea filtrelor pentru microunde

Implementare filtre pentru microunde

- Implementarea cu elemente concentrate (L, C) este utilizabila mai ales in zona frecventelor ceva mai reduse (RF) datorita:
 - dificultatii de implementare a valorilor rezultante pentru componente
 - dificultatii de a asigura toleranta (foarte mica) necesara pentru componente

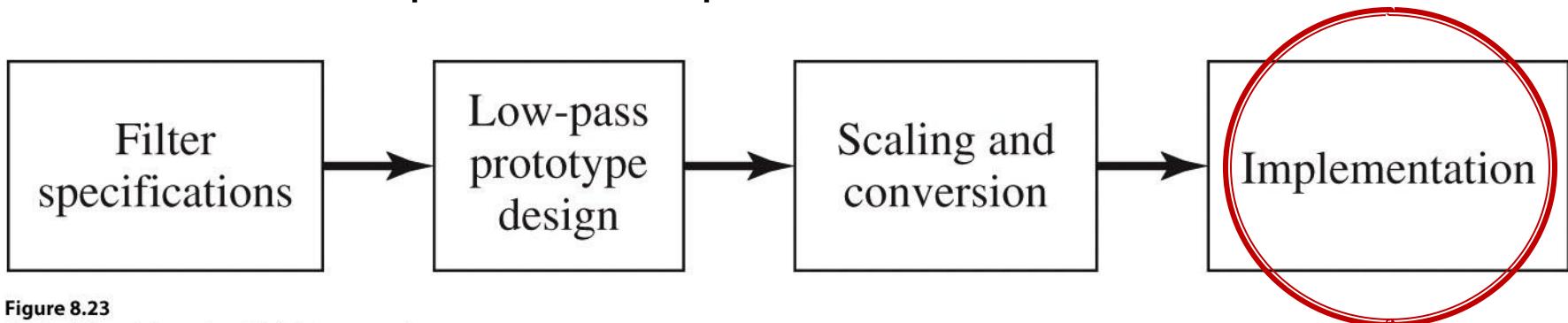


Figure 8.23

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Transformarea Richards

- Impedanta vazuta la intrarea unei linii terminate cu Z_L

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

- Tehnologic e preferabil ca impedanta de capat sa fie:

- gol ($Z_L = \infty$) $Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$
- scurtcircuit ($Z_L = 0$) $Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l$

- Se obtine comportare:

- capacitiva $Z_{in,g} = j \cdot X_C = \frac{1}{j \cdot B_C}$ $Z_0 \leftrightarrow \frac{1}{C}$ $\tan \beta \cdot l \leftrightarrow \omega$
- inductiva $Z_{in,sc} = j \cdot X_L$ $Z_0 \leftrightarrow L$ $\tan \beta \cdot l \leftrightarrow \omega$

Transformarea Richards

- Schimbare de variabila

$$\Omega = \tan \beta \cdot l = \tan \left(\frac{\omega \cdot l}{v_p} \right)$$

- Cu aceasta schimbare de variabila definim

- reactanta unei inductante

$$j \cdot X_L = j \cdot \Omega \cdot L = j \cdot L \cdot \tan \beta \cdot l$$

- susceptanta unei capacitatii

$$j \cdot B_C = j \cdot \Omega \cdot C = j \cdot C \cdot \tan \beta \cdot l$$

- Filtrul echivalent in Ω are frecventa de taiere la:

$$\Omega = 1 = \tan \beta \cdot l \quad \rightarrow \quad \beta \cdot l = \frac{\pi}{4} \quad \rightarrow \quad l = \frac{\lambda}{8}$$

Transformarea Richards

- Alegand sectiunile de linie in gol sau scurtcircuit sa fie $\lambda/8$ la frecventa de taiere dorita (ω_c) si impedantele caracteristice corespunzatoare (L/C) vom obtine foarte precis la frecvente in jurul lui ω_c o comportare similara cu a filtrului prototip
 - La frecvente departate de ω_c comportarea filtrului nu va mai fi identica cu a prototipului (in situatii specifice trebuie **verificata** o comportare potrivita cu tipul de filtru dorit)
 - Scalarea in frecventa se simplifica: alegerea lungimii fizice pentru indeplinirea lungimii electrice $\lambda/8$ la frecventa dorita
- Toate sectiunile de linii vor avea lungimi electrice egale ($\lambda/8$) si lungimi fizice comparabile, deci liniile se numesc linii **comensurabile**

Transformarea Richards

- la frecventa $\omega=2\cdot\omega_c$ lungimile liniilor sunt $\lambda/4$

$$l = \frac{\lambda}{4} \Rightarrow \beta \cdot l = \frac{\pi}{2} \Rightarrow \tan \beta \cdot l \rightarrow \infty$$

- apare un pol suplimentar de atenuare la $2\cdot\omega_c$ (FTJ)
 - inductantele (de obicei in serie) $Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l \rightarrow \infty$
 - capacitatile (de obicei in paralel) $Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l \rightarrow 0$

Transformarea Richards

- periodicitatea functiei tangenta genereaza periodicitatea raspunsului in frecventa al circuitelor cu linii
 - raspunsul filtrului se repeta la fiecare $4 \cdot \omega_c$

$$\tan(\alpha + \pi) = \tan \alpha$$

$$\beta \cdot l \Big|_{\omega=\omega_c} = \frac{\pi}{4} \Rightarrow \frac{\omega_c \cdot l}{v_p} = \frac{\pi}{4} \Rightarrow \pi = \frac{(4 \cdot \omega_c) \cdot l}{v_p}$$

$$Z_{in}(\omega) = Z_{in}(\omega + 4 \cdot \omega_c) \Rightarrow P_{LR}(\omega) = P_{LR}(\omega + 4 \cdot \omega_c)$$

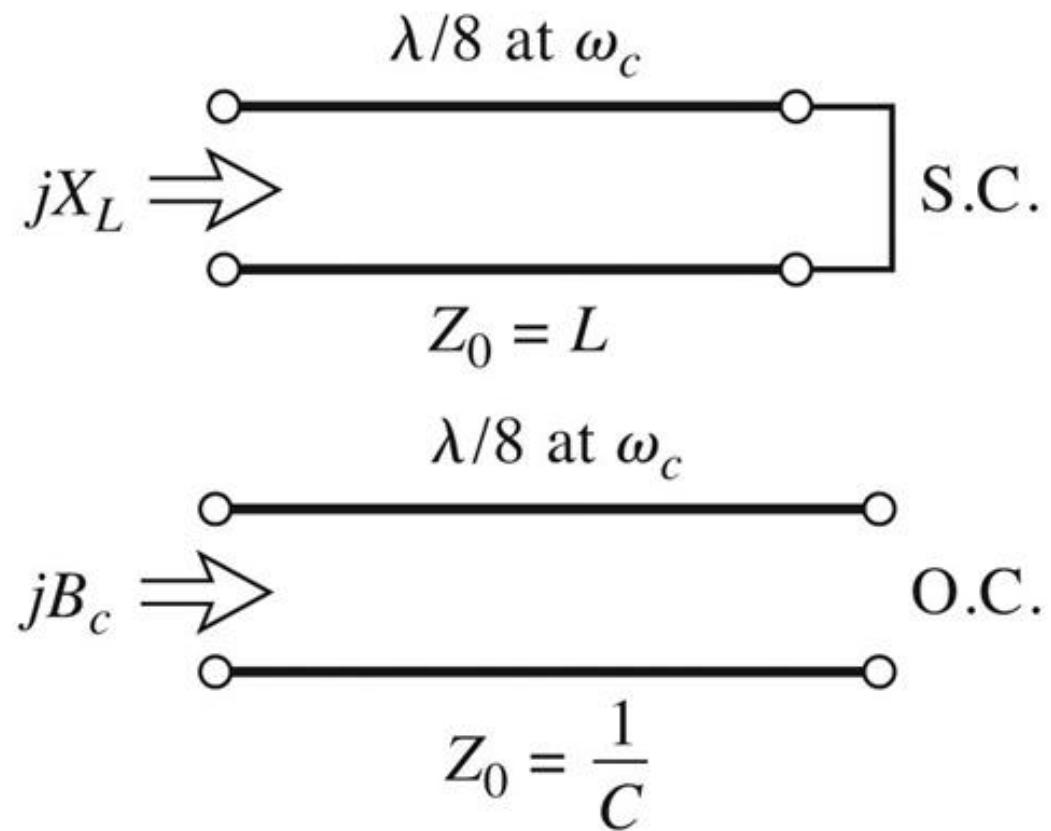
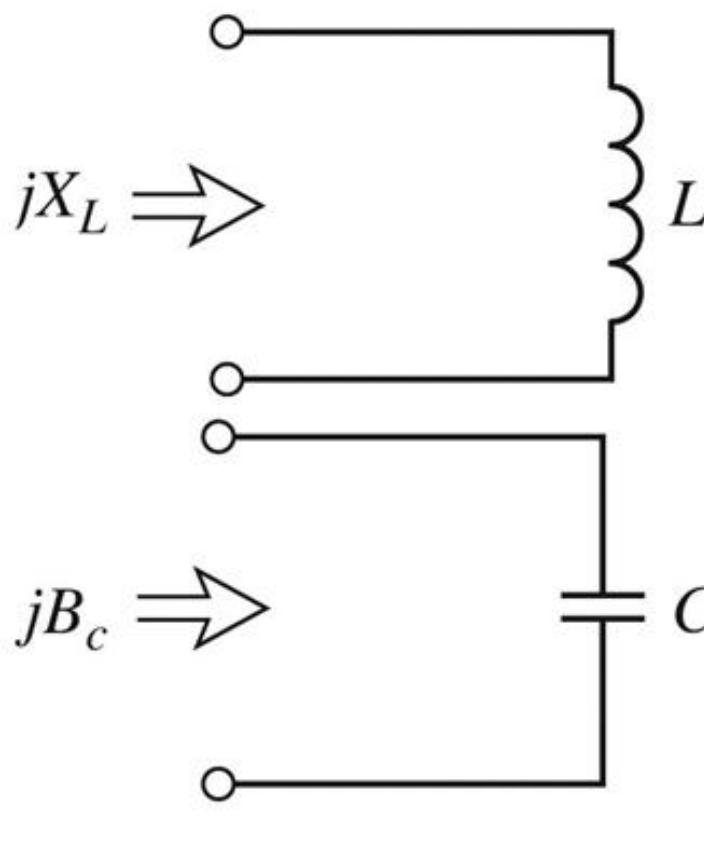
$$P_{LR}(4 \cdot \omega_c) = P_{LR}(0)$$

$$P_{LR}(3 \cdot \omega_c) = P_{LR}(-\omega_c)$$

$$P_{LR}(5 \cdot \omega_c) = P_{LR}(\omega_c)$$

Transformarea Richards

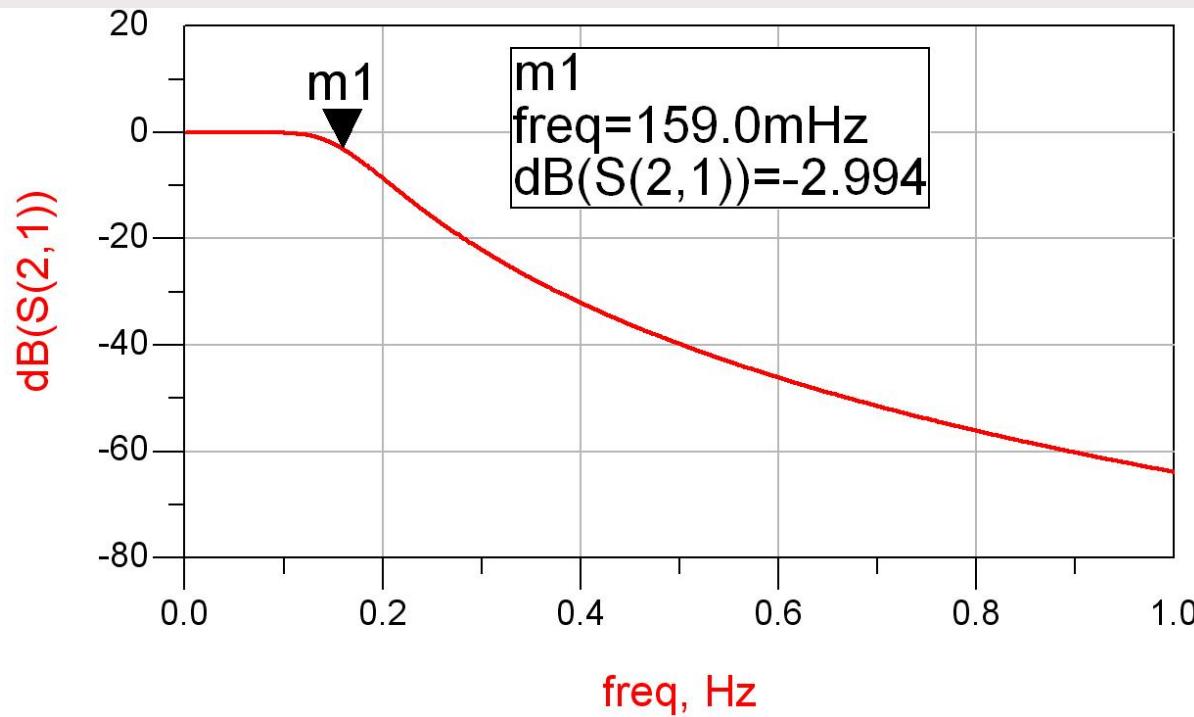
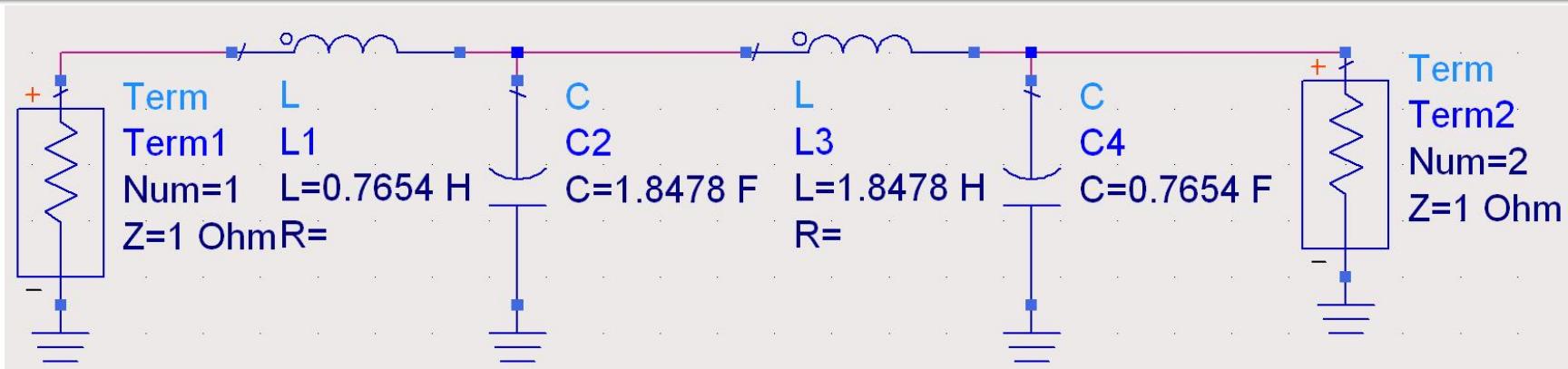
- permite obtinerea cu sectiuni de linii a inductantelor si capacitatilor **dupa** scalarea prototipului pentru functia corespunzatoare (FTJ/FTS/FTB /FOB)



Exemplu

- Filtru trece jos de ordinul 4, cu frecventa de tajere de 4 GHz, de tip maxim plat (care sa functioneze pe 50Ω la intrare si iesire)
- Tabel maxim plat sau relatii de calcul:
 - $g_1 = 0.7654 = L_1$
 - $g_2 = 1.8478 = C_2$
 - $g_3 = 1.8478 = L_3$
 - $g_4 = 0.7654 = C_4$
 - $g_5 = 1$ (**nu** are nevoie de adaptare suplimentara la iesire – apare la filtrele de ordin par echiriplu)

Prototip FTJ



Elemente concentrate

$$\omega_c = 2 \cdot \pi \cdot 4 \text{GHz} = 2.5133 \cdot 10^{10} \text{rad/s}$$

$$g_1 = 0.7654 = L_1,$$

$$g_2 = 1.8478 = C_2,$$

$$g_3 = 1.8478 = L_3,$$

$$g_4 = 0.7654 = C_4,$$

$$g_5 = 1 = RL$$

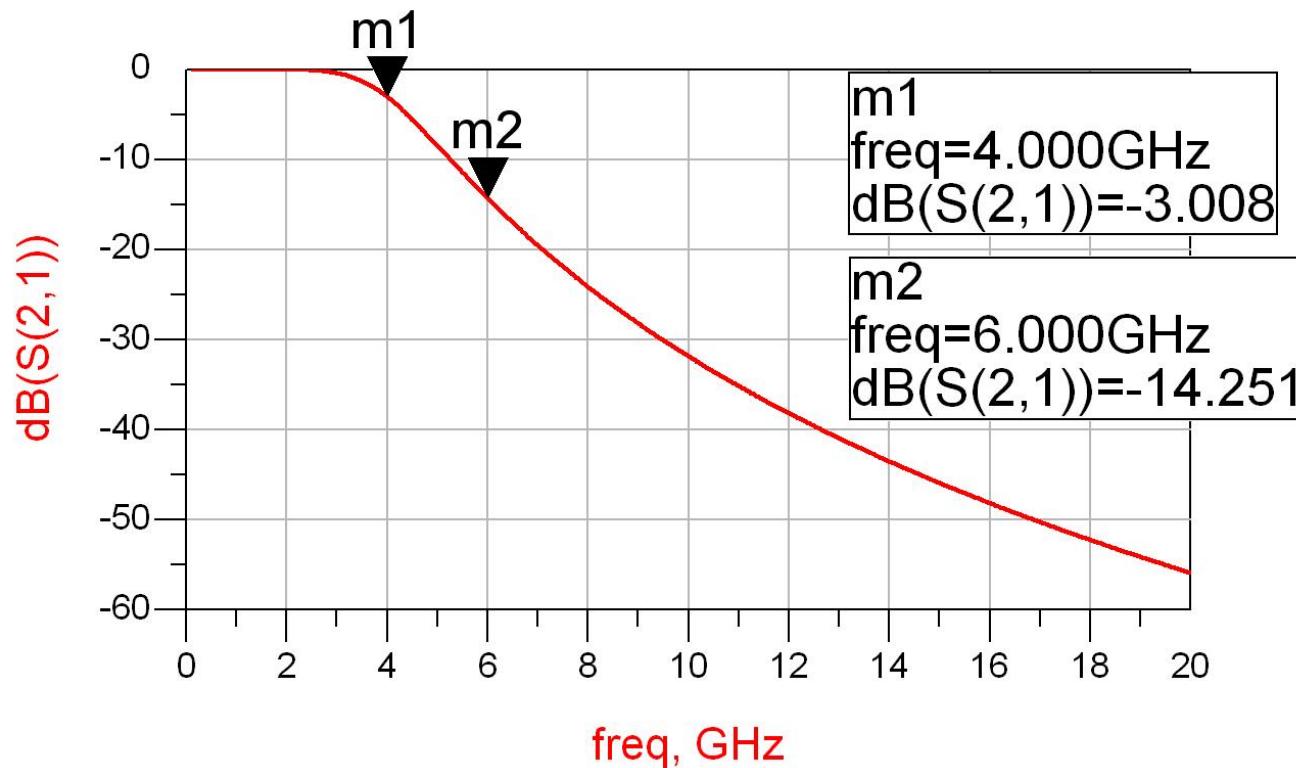
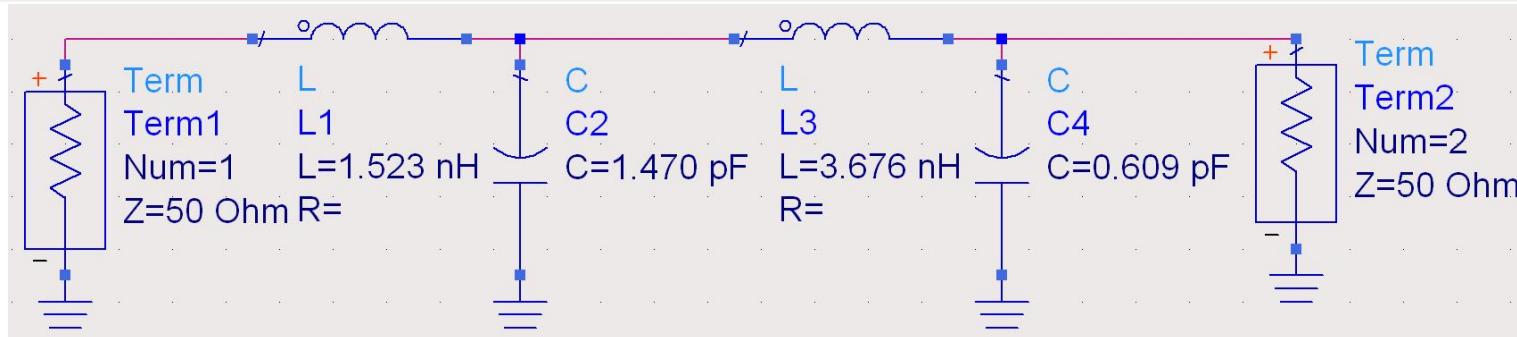
$$L'_1 = \frac{R_0 \cdot L_1}{\omega_c} = 1.523 \text{nH}$$

$$C'_2 = \frac{C_2}{R_0 \cdot \omega_c} = 1.470 \text{ pF}$$

$$L'_3 = \frac{R_0 \cdot L_3}{\omega_c} = 3.676 \text{nH}$$

$$C'_4 = \frac{C_4}{R_0 \cdot \omega_c} = 0.609 \text{ pF}$$

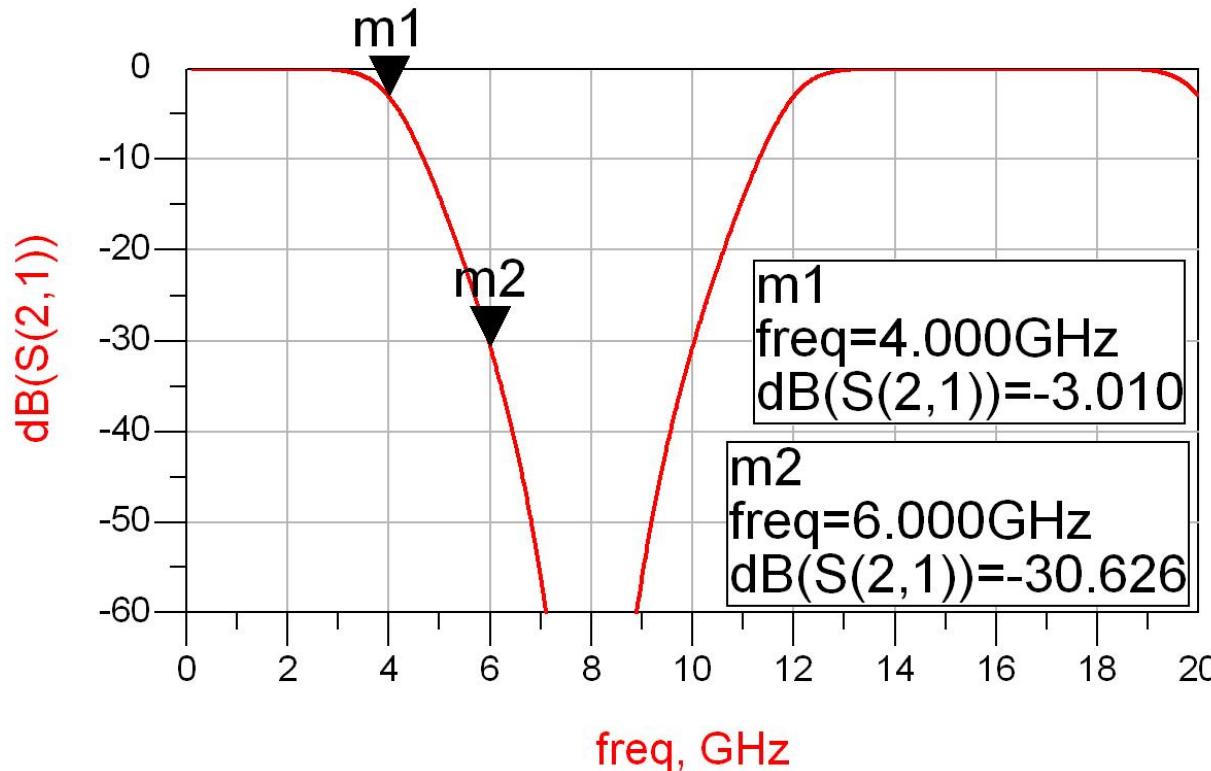
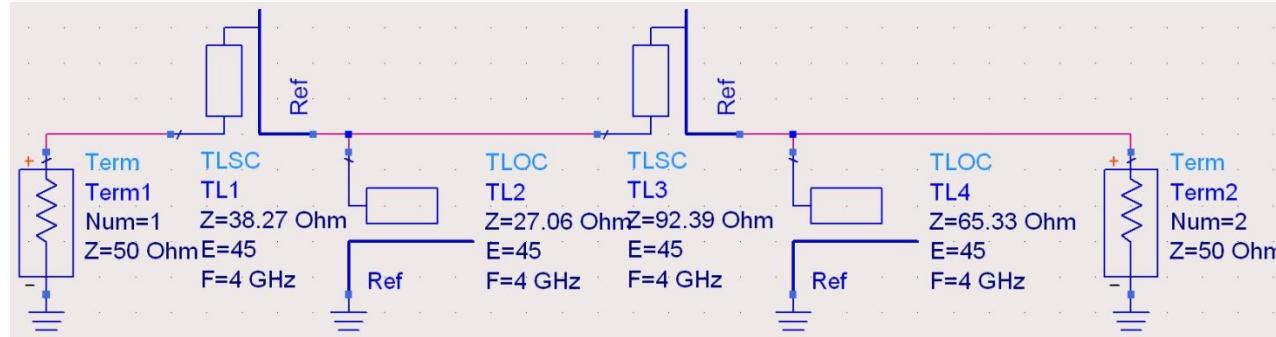
Elemente concentrate – ADS



Transformarea Richards

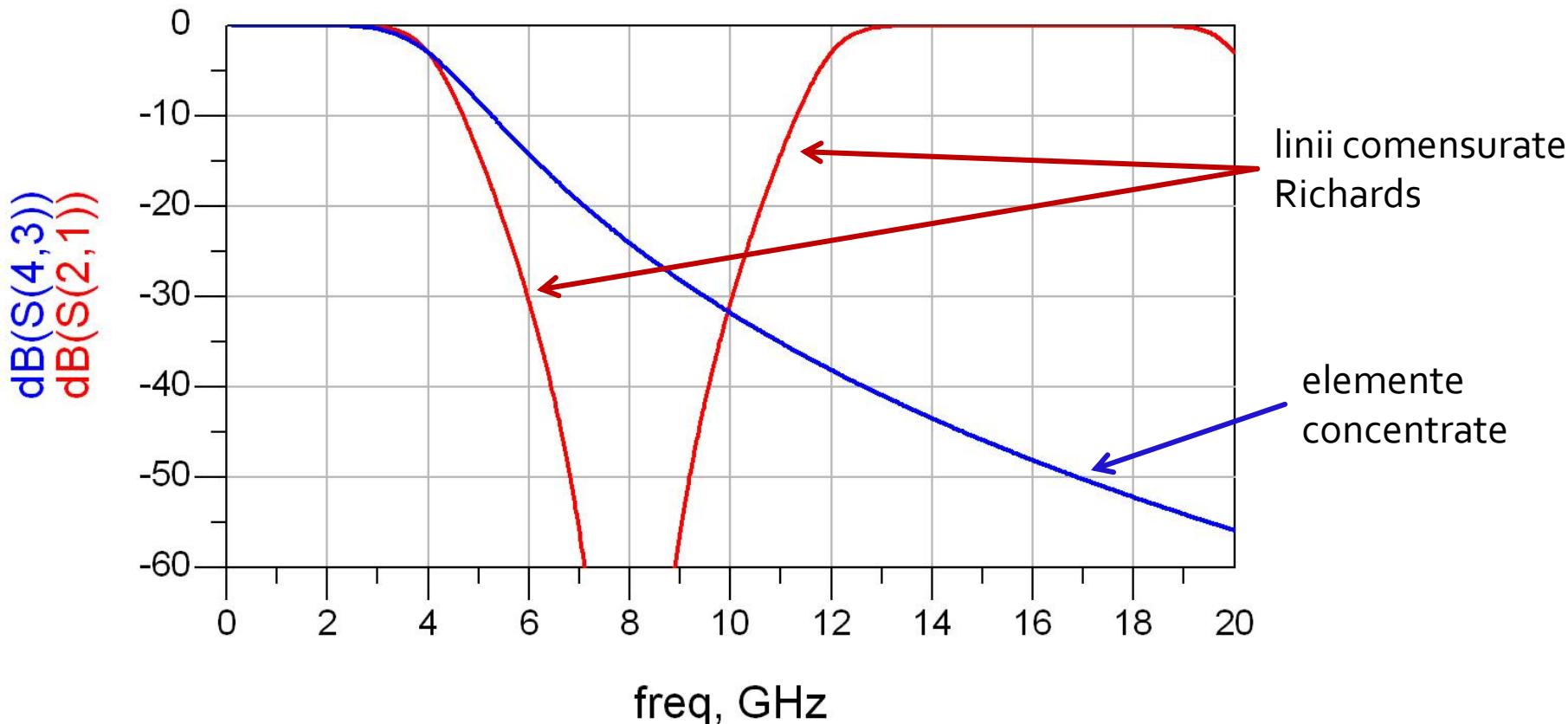
- Parametrii filtrului prototip:
 - $g_1 = 0.7654 = L_1$
 - $g_2 = 1.8478 = C_2$
 - $g_3 = 1.8478 = L_3$
 - $g_4 = 0.7654 = C_4$
- Impedantele raportate ale liniilor
 - $z_1 = 0.7654 = \text{serie / scurt circuit}$
 - $z_2 = 1 / 1.8478 = 0.5412 = \text{paralel / gol}$
 - $z_3 = 1.8478 = \text{serie / scurt circuit}$
 - $z_4 = 1 / 0.7654 = 1.3065 = \text{paralel / gol}$
- Scalarea in impedanta presupune inmultirea cu $Z_0 = 50\Omega$
- Toate liniile au lungimea $\lambda/8$ (lungime electrica 45°) la 4GHz

Transformarea Richards – ADS



Transformarea Richards

- Filtrele realizate cu transformarea Richards
 - beneficiaza de polul suplimentar de atenuare $2 \cdot \omega_c$
 - au dezavantajul periodicitatii in frecventa, de obicei se prevede un filtru trece jos suplimentar neperiodic daca e necesar



Filtru prototip echiriplu

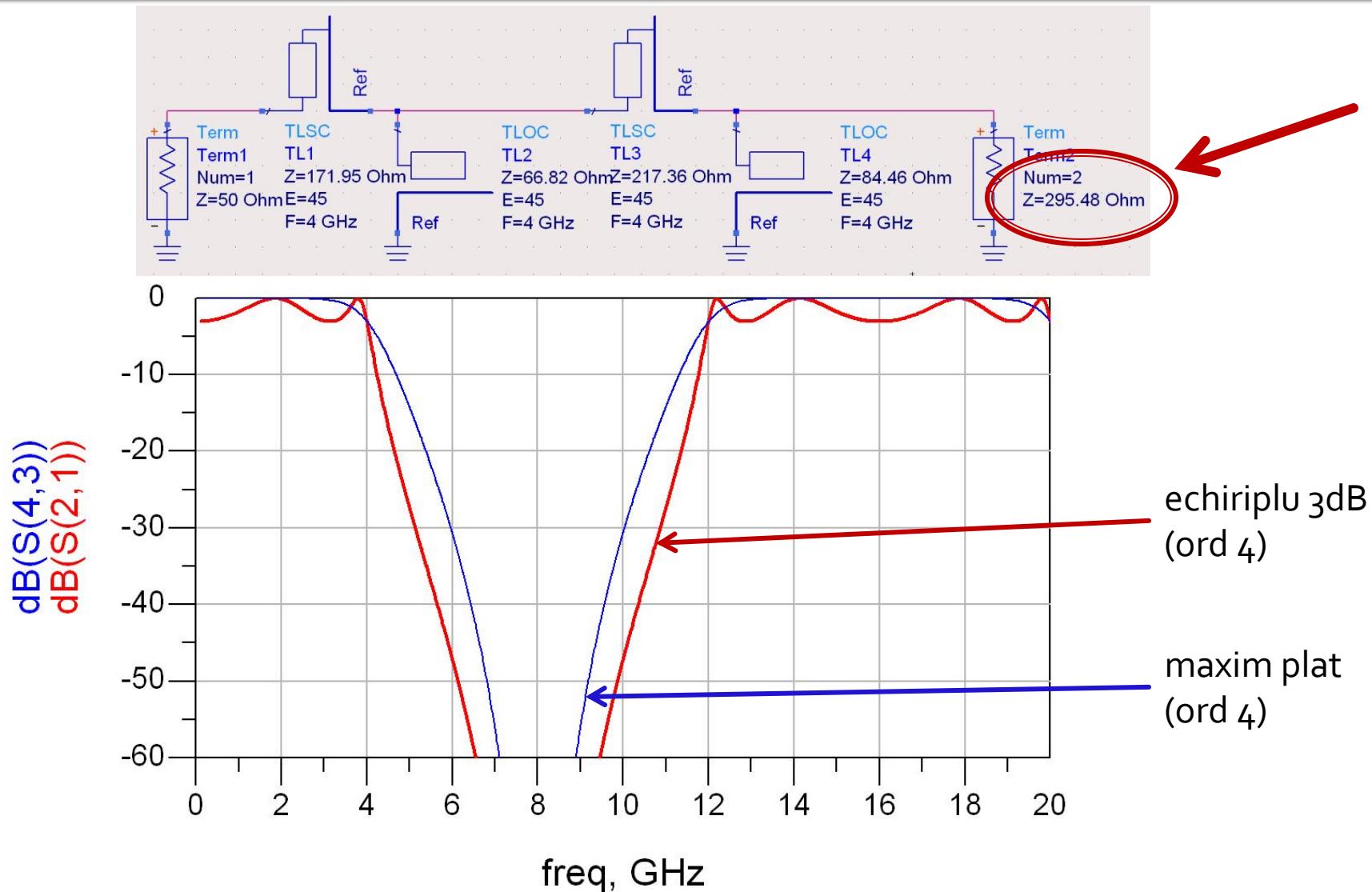
- Pentru ordin par al filtrului ($N = 2, 4, 6, 8 \dots$) filtrele echiriplu **trebuie** sa fie inchise pe o impedanta de terminatie diferita de cea standard
- Daca aplicatia nu suporta aceasta comportare, e necesara introducerea unei adaptari de impedanta suplimentare (transformator in sfert de lungime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

$$g_{N+1} \neq 1 \rightarrow R \neq R_0 \quad (50\Omega)$$

Observatie: ordin par/echiriplu

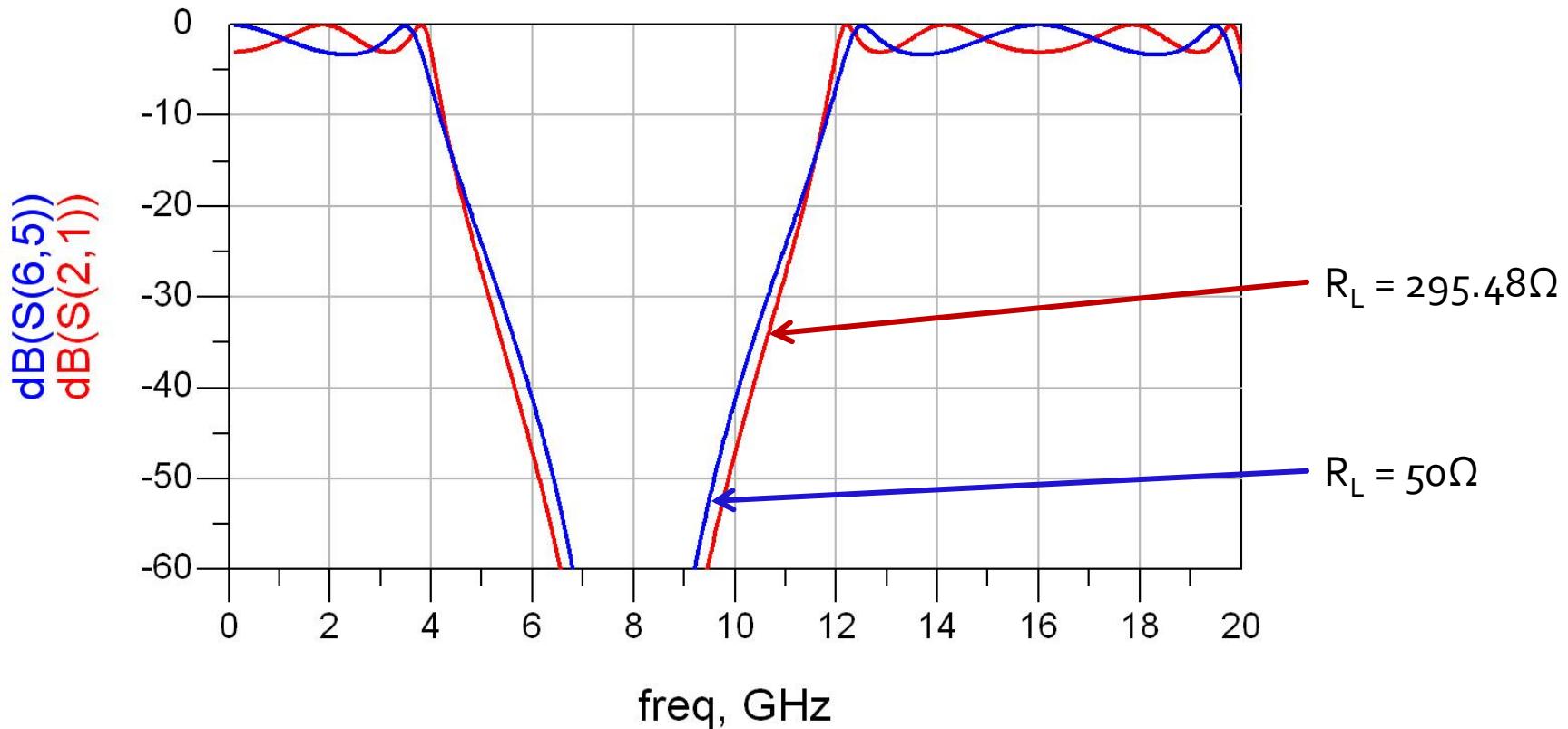
- Acelasi filtru, echiriplu 3dB
- Tabel echiriplu 3dB sau relatii de calcul:
 - $g_1 = 3.4389 = L_1$
 - $g_2 = 0.7483 = C_2$
 - $g_3 = 4.3471 = L_3$
 - $g_4 = 0.5920 = C_4$
 - $g_5 = 5.8095 = R_L$
- Impedantele liniilor
 - $Z_1 = 3.4389 \cdot 50\Omega = 171.945\Omega$ = serie / scurt circuit
 - $Z_2 = 50\Omega / 0.7483 = 66.818\Omega$ = paralel / gol
 - $Z_3 = 4.3471 \cdot 50\Omega = 217.355\Omega$ = serie / scurt circuit
 - $Z_4 = 50\Omega / 0.5920 = 84.459\Omega$ = paralel / gol
 - $R_L = 5.8095 \cdot 50\Omega = 295.475\Omega$ = sarcina

Ordin par/echiriplu – ADS



Observatie: ordin par/echiriplu

- Filtrele echiriplu au nevoie de adaptare la ieșire spre 50Ω pentru a functiona precis.
Exemplu:



Contact

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