

Curs 11

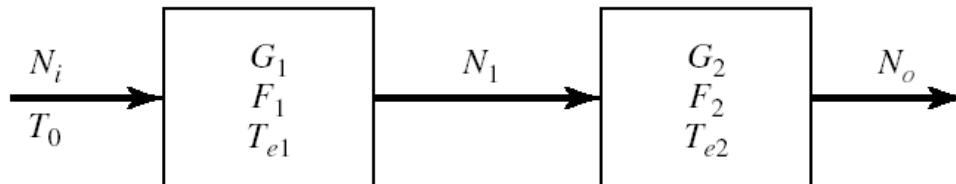
2014/2015

Dispozitive și circuite de microunde pentru radiocomunicații

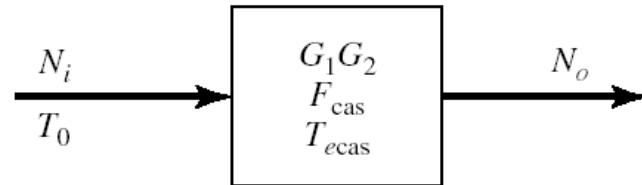
Proiectare pentru zgomot redus

Amplificatoare de microunde

Factor de zgomot al circuitelor cascade



(a)



(b)

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

- Ecuatia Friis (!coordonate liniare)

$$G_{cas} = G_1 \cdot G_2 \cdot G_3 \cdot G_4 \cdots$$

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

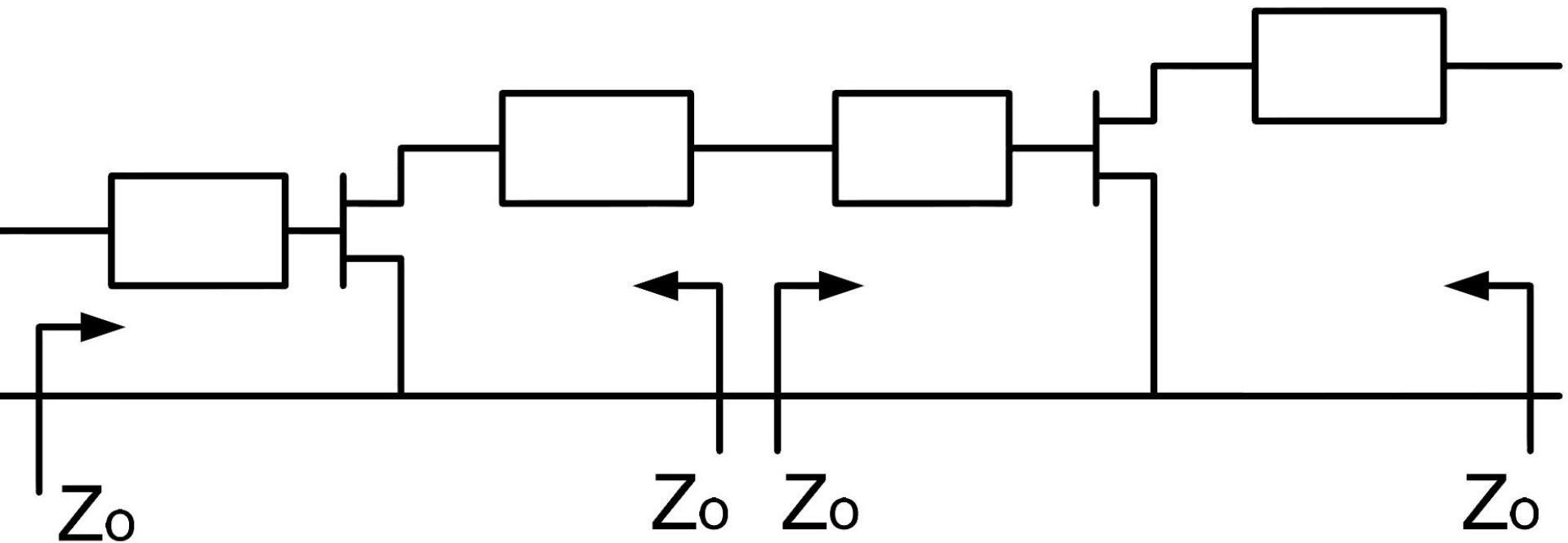
Formula lui Friis (zgomot)

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

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

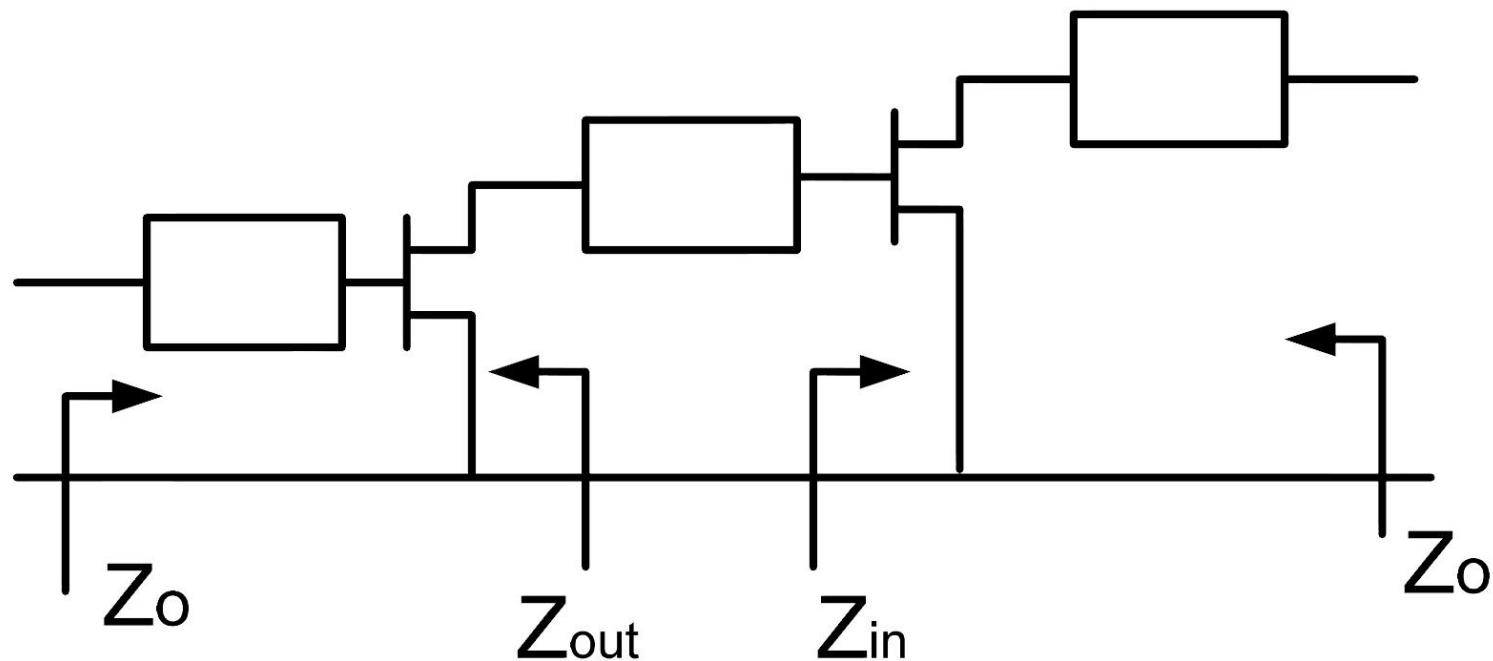
Amplificatoare in cascada

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



Amplificatoare in cascada

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

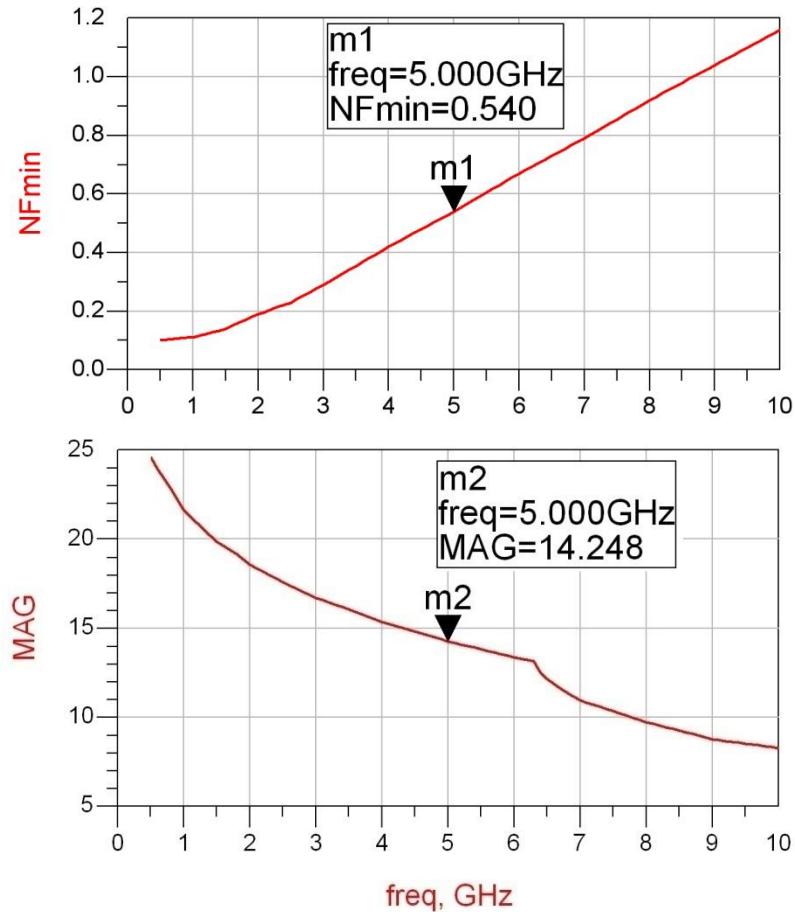


Exemplu LNA cascada

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

Exemplu

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



Amplificatoare in cascada

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

Formula lui Friis (zgomot)

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

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

Formula lui Friis (zgomot)

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

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

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

Formula lui Friis (zgomot)

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

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

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

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

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

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

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

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

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

Proiectare etaje cascade

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

Exemplu C10, LNA @ 5 GHz

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

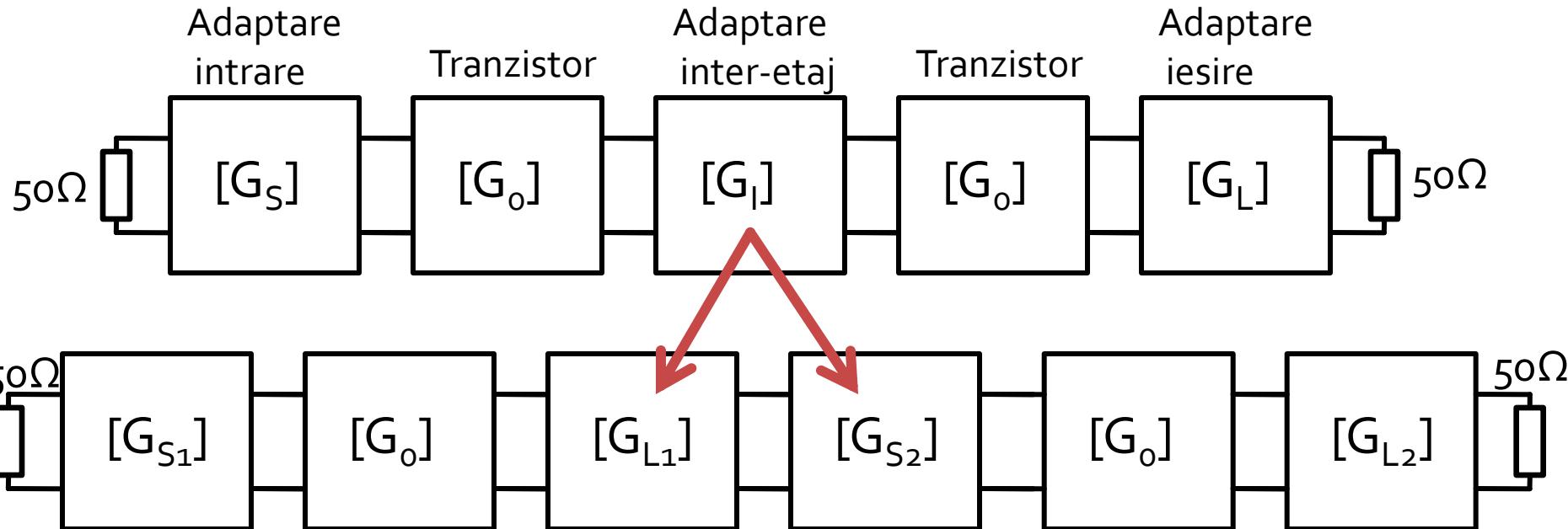
$$G_{TU\max} = \frac{1}{1 - |S_{11}|^2} \cdot |S_{21}|^2 \cdot \frac{1}{1 - |S_{22}|^2} = 17.83 \quad G_{TU\max}[\text{dB}] = 12.511 \text{ dB}$$

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

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

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

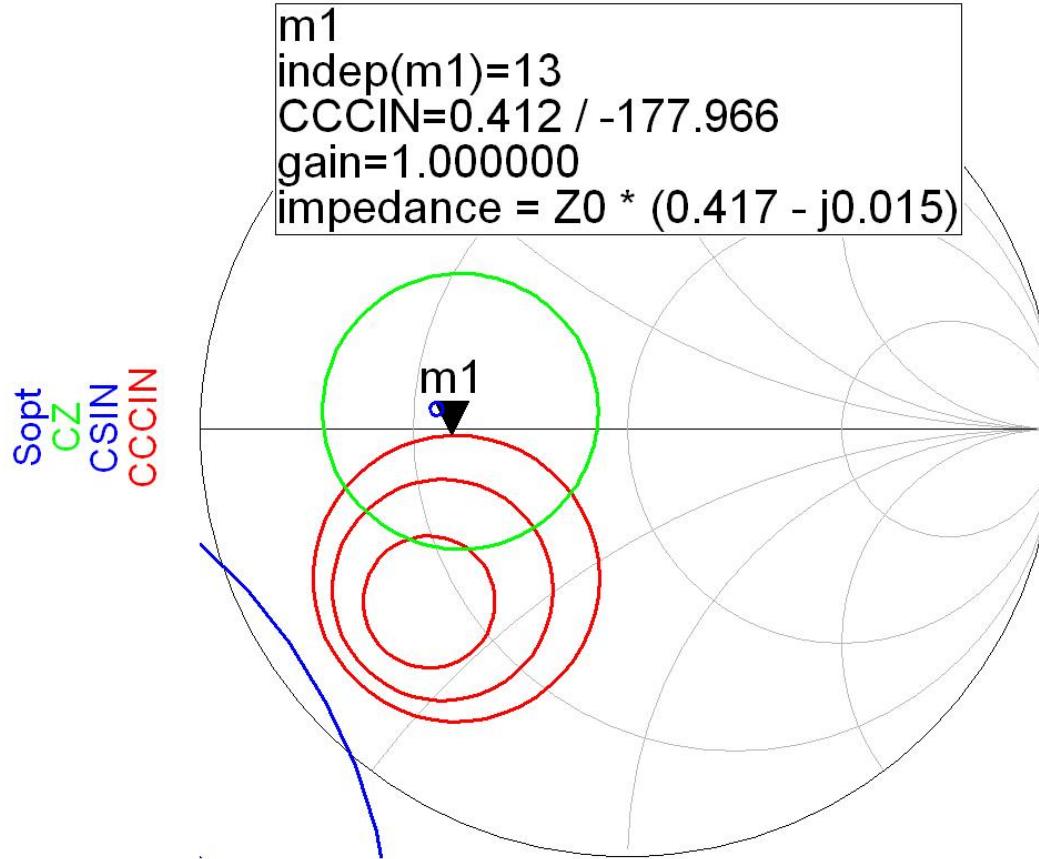
Proiectare etaje cascade



■ Calcul castig

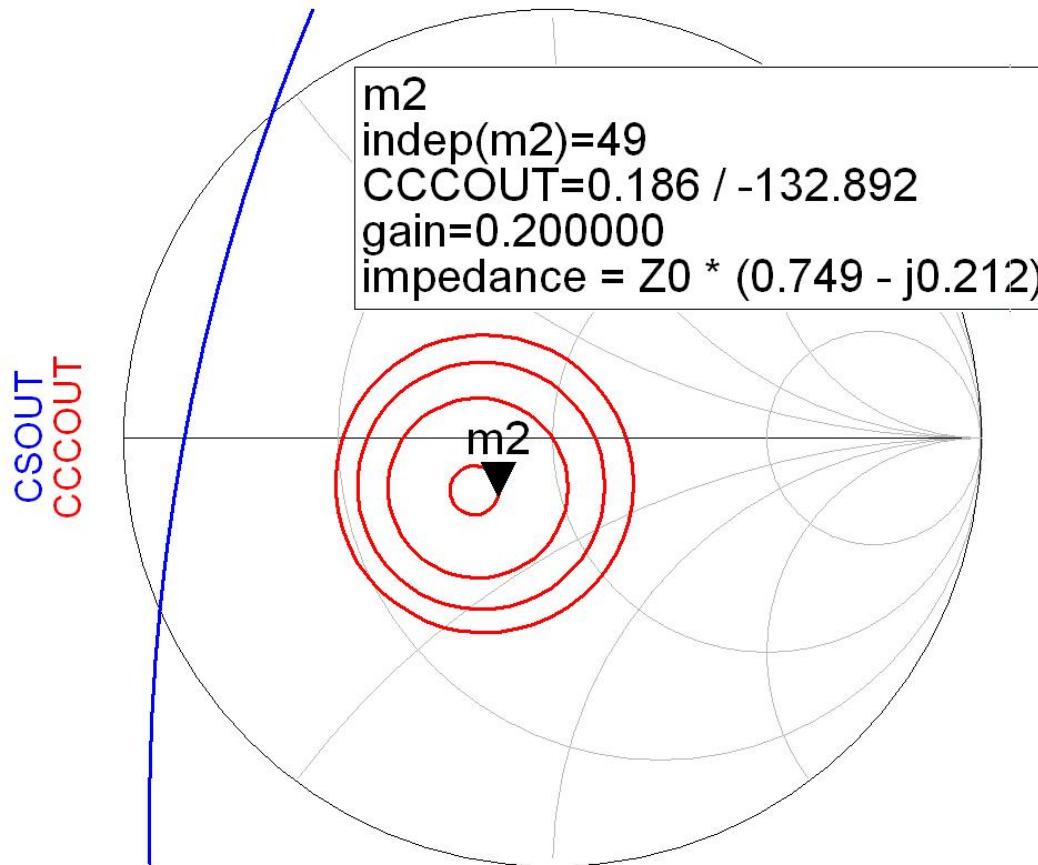
- adaptarea inter-etaje poate aduce un supliment de castig la ambele etaje de amplificare
- Proiectarea pentru etajele de intrare si iesire e recomandabil sa se faca pe schema mai simpla cu un singur tranzistor

Adaptare la intrare, C10



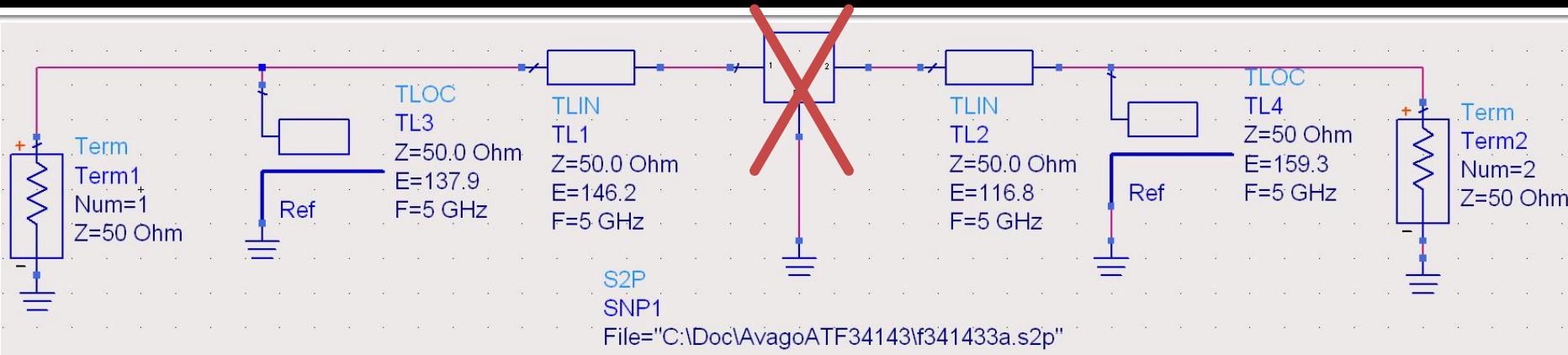
- $G_{S1} = 1 \text{ dB}$
- $F_1 = 0.55 \text{ dB}$

Adaptare la ieșire, C10



- $G_{L2} = 0.2 \text{ dB}$

Realizare cu linii, intrare si iesire



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

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

$$(\varphi + 2\theta) = \begin{cases} +114.33^\circ \\ -114.33^\circ \end{cases} \quad \theta = \begin{cases} 146.2^\circ \\ 31.8^\circ \end{cases}$$

$$\text{Im}[y_s(\theta)] = \begin{cases} -0.904 \\ +0.904 \end{cases} \quad \theta_{sp} = \begin{cases} 137.9^\circ \\ 42.1^\circ \end{cases}$$

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

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

$$(\varphi + 2\theta) = \begin{cases} +100.72^\circ \\ -100.72^\circ \end{cases} \quad \theta = \begin{cases} 116.8^\circ \\ 16.1^\circ \end{cases}$$

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

Proiectare etaje cascade

- Castig

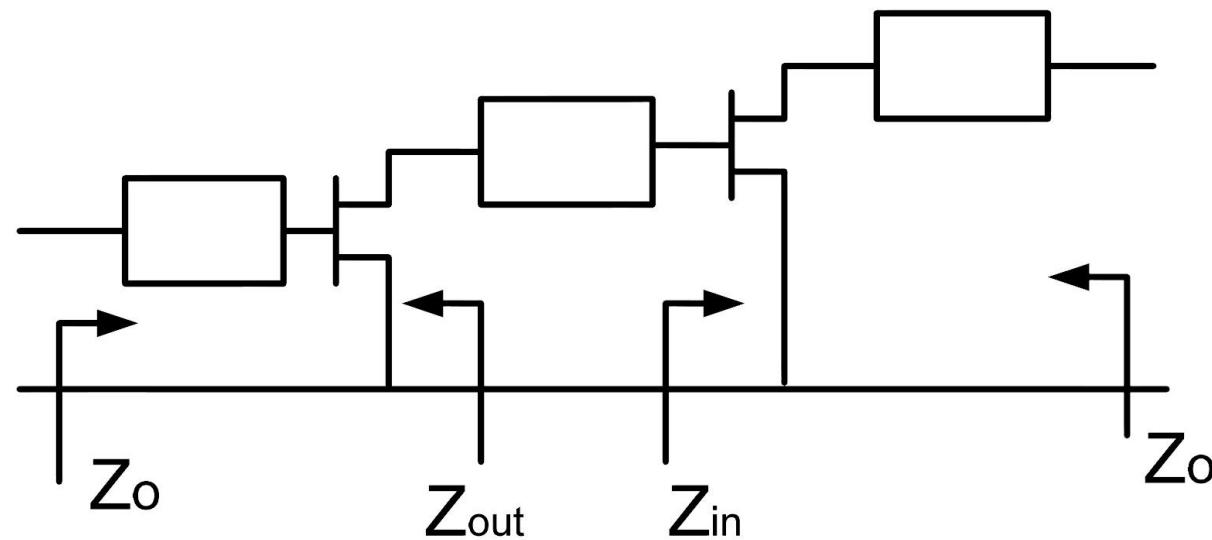
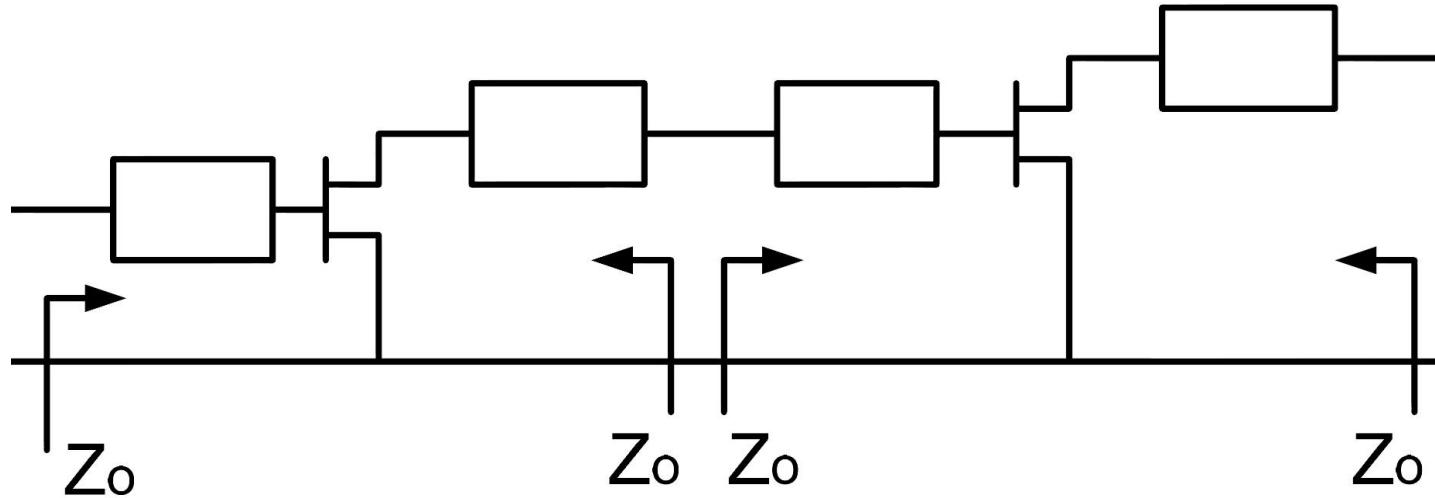
$$G_T[dB] = G_{S1}[dB] + G_0[dB] + G_{L1}[dB] + G_{S2}[dB] + G_0[dB] + G_{L2}[dB]$$

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

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

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

Adaptare inter-etaje

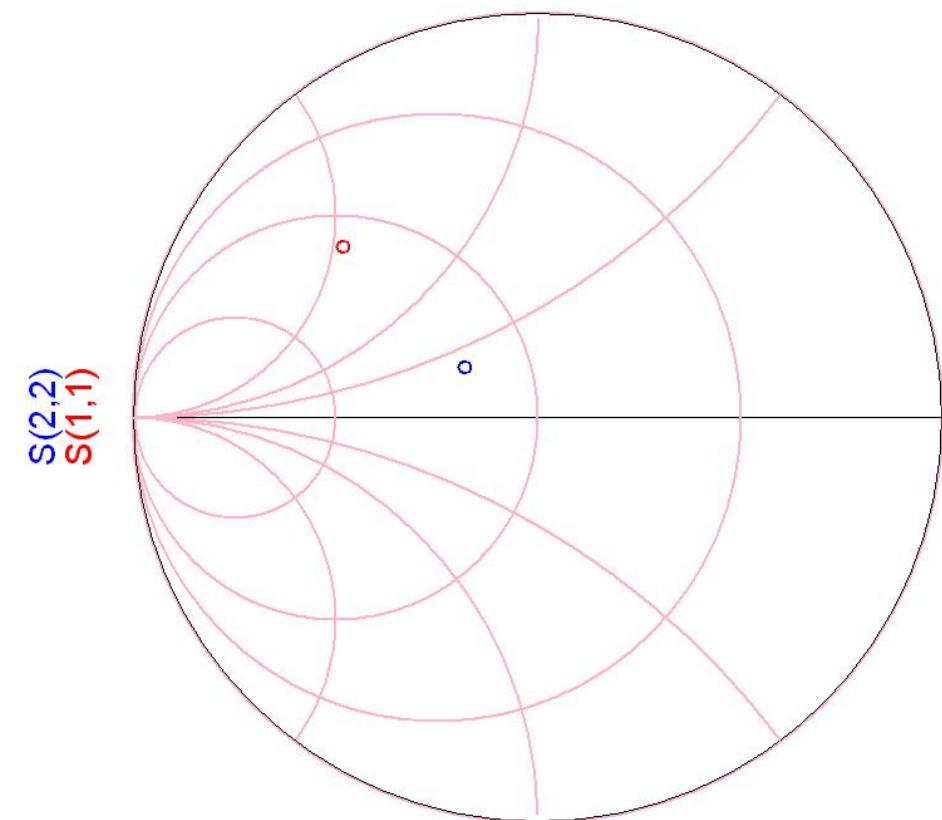
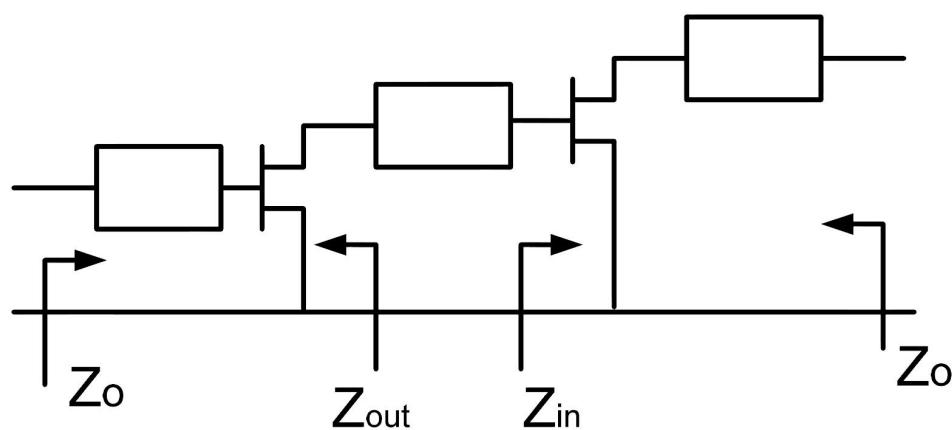


Adaptare inter-etaje

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

Adaptare inter-etaje

- O singura linie de transmisie pastreaza modulul coeficientului de reflexie



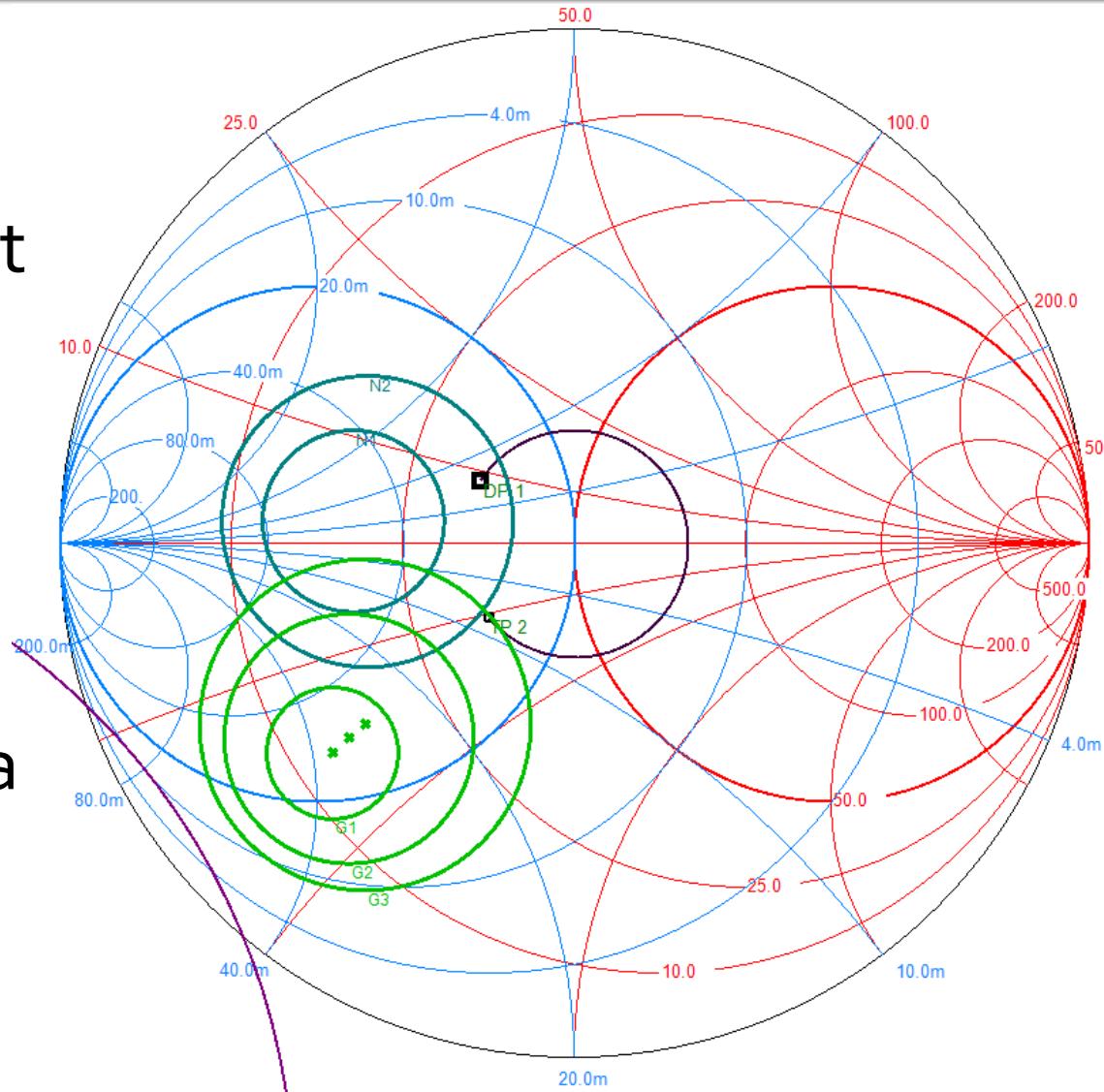
freq (5.000GHz to 5.000GHz)

Adaptare inter-etaje

- O singura linie de transmisie permite atingerea unui punct care nu poate fi optimizat

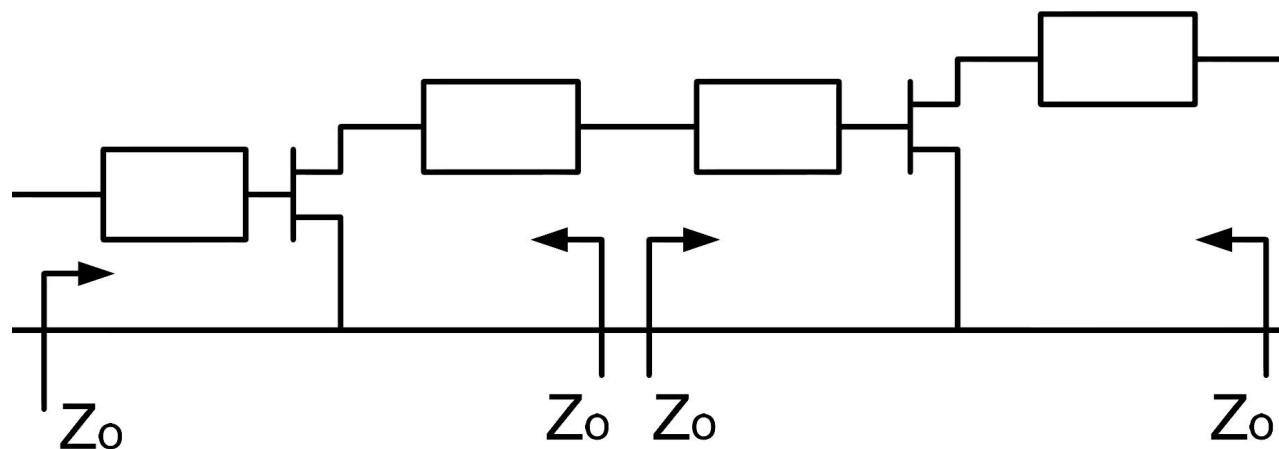
- $G_{L_1} = 0.2 \text{ dB}$
- $G_{S_2} = 1 \text{ dB}$
- $F_2 = 0.7 \text{ dB}$

- Elimina posibilitatea de reglaj pentru controlul in banda larga a amplificarii



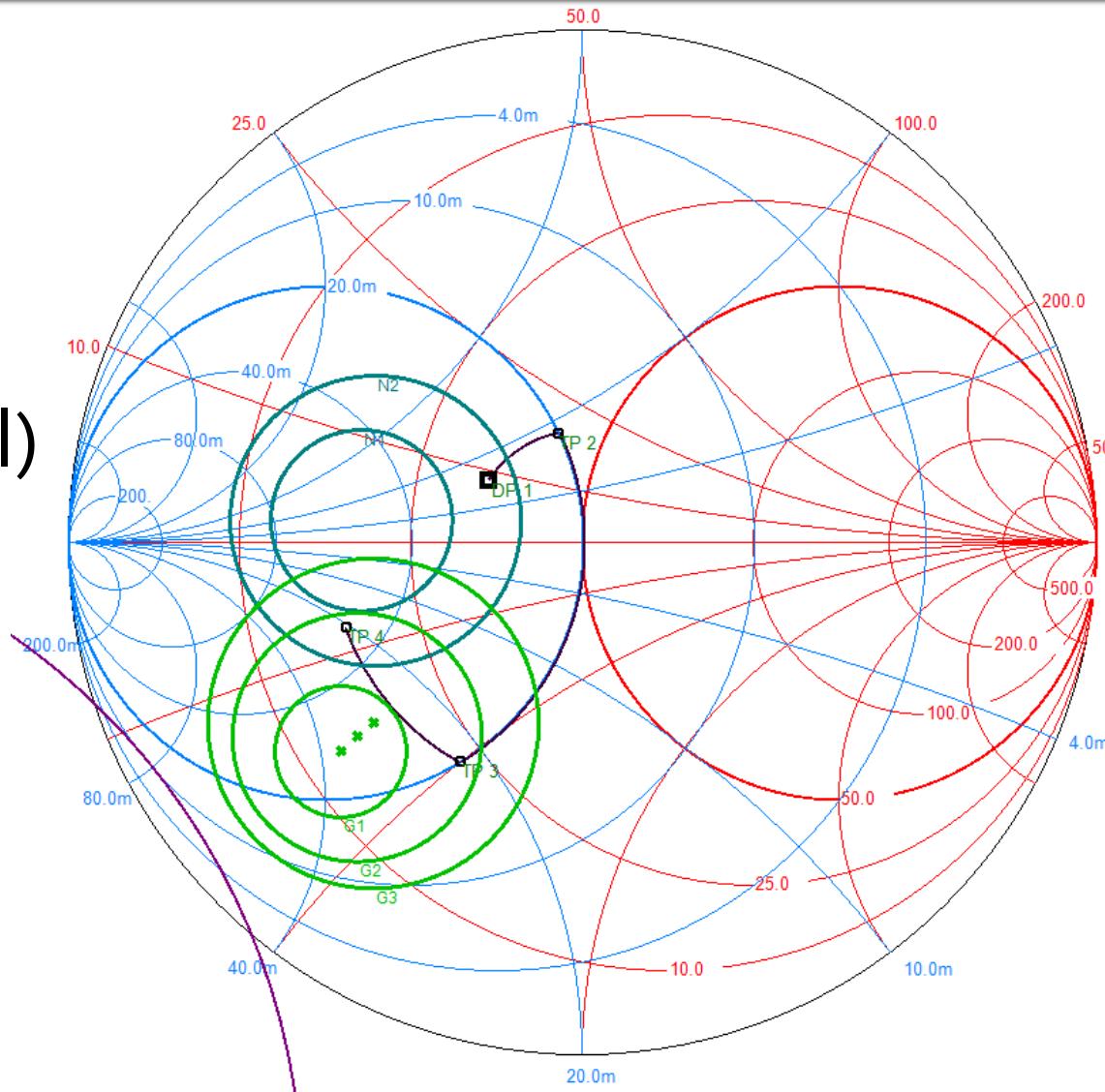
Adaptare inter-etaje

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



Adaptare inter-etaje

- Prima linie mută coeficientul de reflexie pe cercul unitate
- A doua (stub în gol) trece prin centrul diagramei (adaptare la Z_0)
 - $G_{L1} = 0.2 \text{ dB}$
 - $G_{S2} = 1.5 \text{ dB}$
 - $F_2 = 0.6 \text{ dB}$



Calcul analitic

- G_{L_1} (plecare din S_{22} spre origine)

$$S_{22} = 0.22 \angle 146^\circ$$

$$|S_{22}| = 0.22; \quad \varphi = 146^\circ$$

$$\cos(\varphi + 2\theta) = -|S_{22}|$$

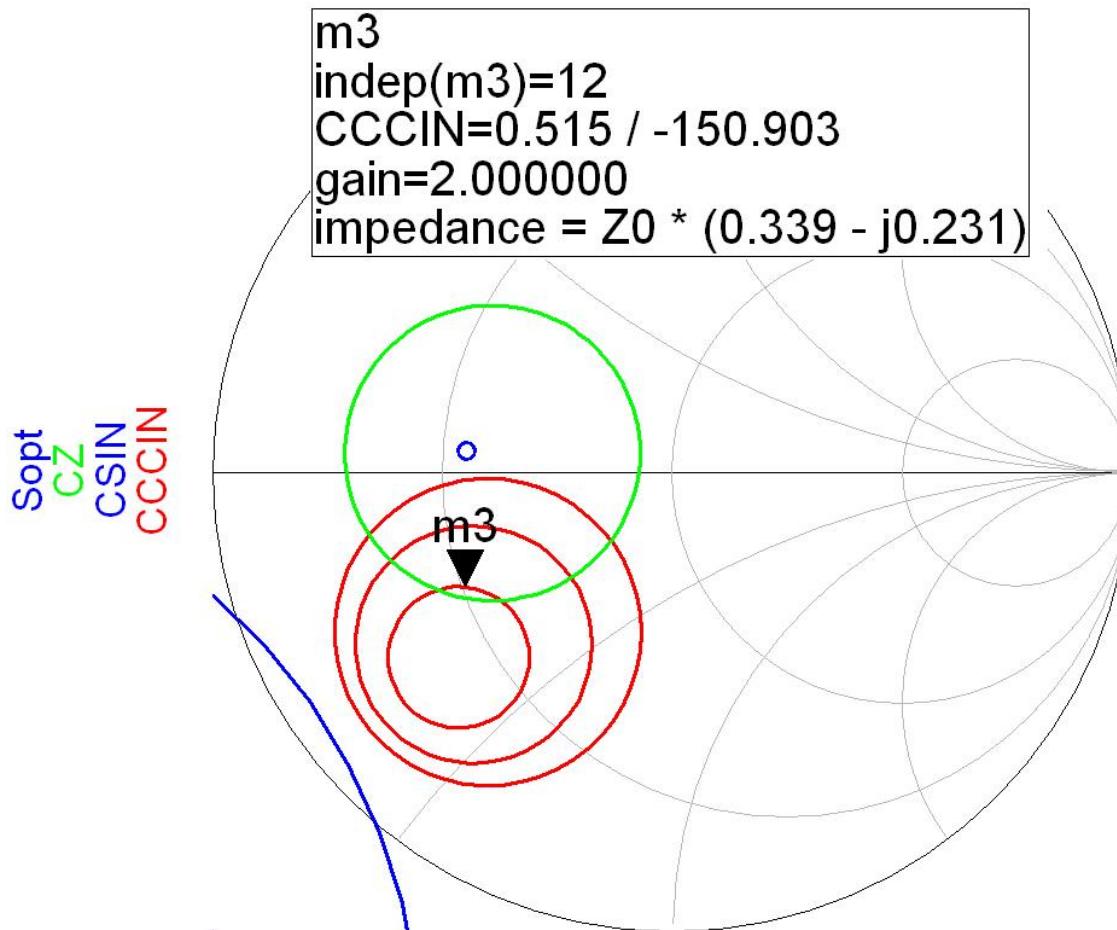
$$\text{Im}[y_{L1}(\theta)] = \frac{\mp 2 \cdot |S_{22}|}{\sqrt{1 - |S_{22}|^2}}$$

$$\cos(\varphi + 2\theta) = -0.22 \Rightarrow (\varphi + 2\theta) = \pm 102.71^\circ$$

$$(\varphi + 2\theta) = \begin{cases} +102.71^\circ \\ -102.71^\circ \end{cases} \quad \theta = \begin{cases} 158.4^\circ \\ 55.6^\circ \end{cases} \quad \text{Im}[y_{L1}(\theta)] = \begin{cases} -0.451 \\ +0.451 \end{cases} \quad \theta_{sp} = \begin{cases} 155.7^\circ \\ 24.3^\circ \end{cases}$$

Calcul analitic

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



Calcul analitic

- G_{S_2} (plecare din 2 spre origine)

$$\Gamma_{S_2} = 0.515 \angle -150.9^\circ$$

$$|\Gamma_{S_2}| = 0.515; \quad \varphi = -150.9^\circ$$

$$\cos(\varphi + 2\theta) = -|\Gamma_{S_2}|$$

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

$$\cos(\varphi + 2\theta) = -0.515 \Rightarrow (\varphi + 2\theta) = \pm 121^\circ$$

$$(\varphi + 2\theta) = \begin{cases} +121^\circ \\ -121^\circ \end{cases} \quad \theta = \begin{cases} 135.9^\circ \\ 15^\circ \end{cases} \quad \text{Im}[y_{S_2}(\theta)] = \begin{cases} -1.202 \\ +1.202 \end{cases} \quad \theta_{sp} = \begin{cases} 129.8^\circ \\ 50.2^\circ \end{cases}$$

Calcul analitic

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

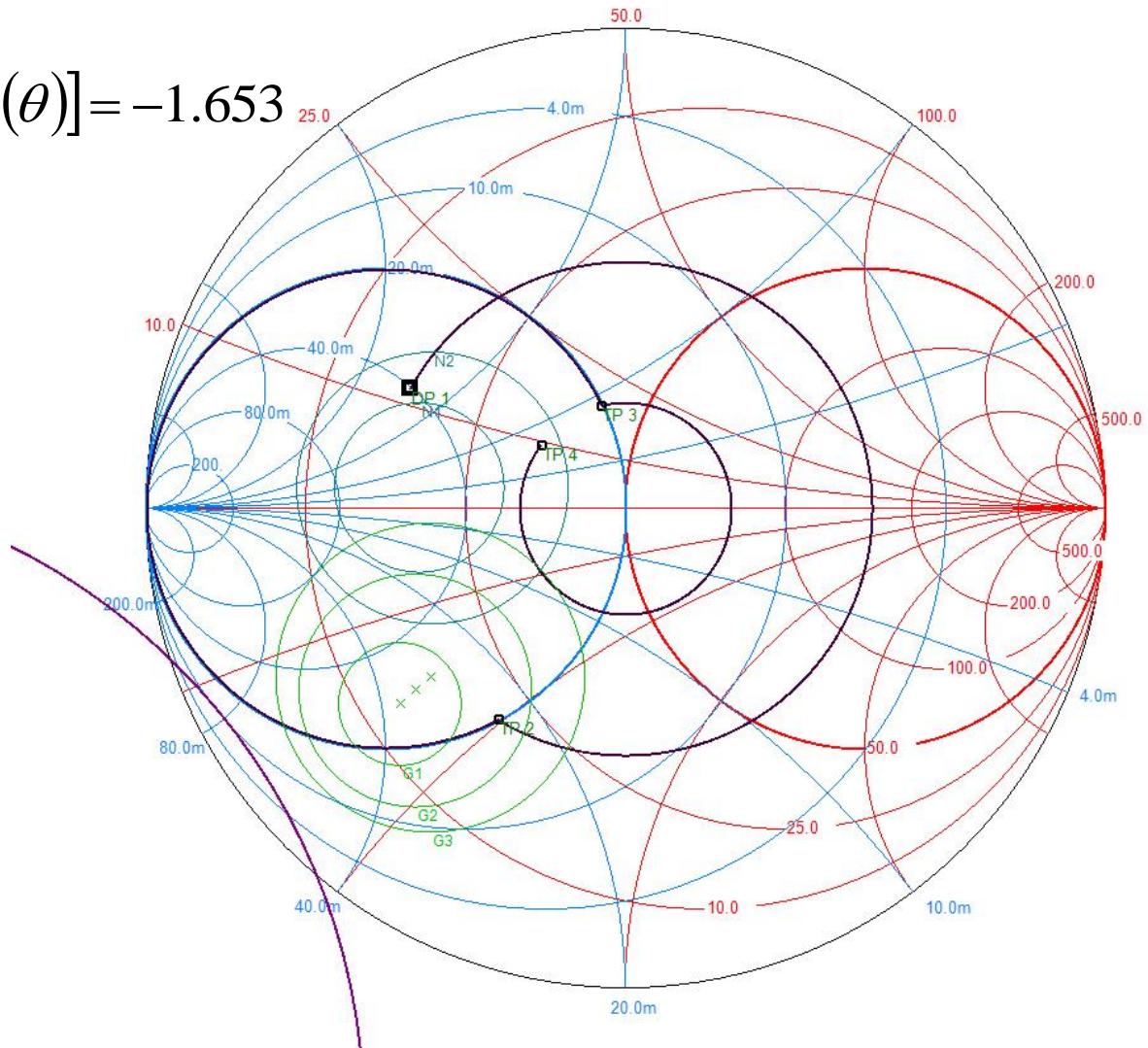
$$\theta_{L1} = 158.4^\circ \quad \theta_{S2} = 135.9^\circ \quad \text{Im}[y_{sp}] = \text{Im}[y_{L1}(\theta)] + \text{Im}[y_{S2}(\theta)] = -1.653$$
$$\theta_{sp} = \tan^{-1}(\text{Im}[y_{sp}]) \quad \theta_{sp} = 121.2^\circ$$

Diagrama Smith

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

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

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



ADS

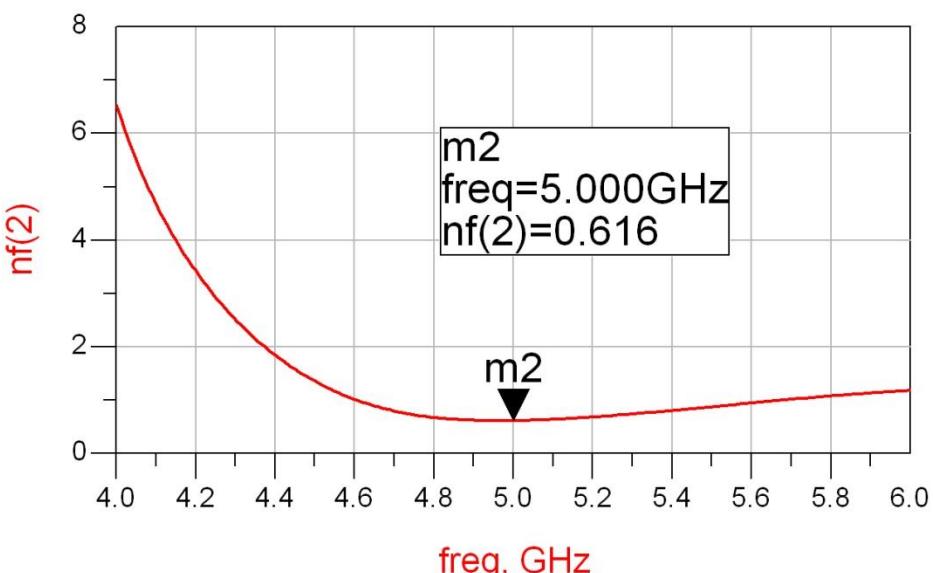
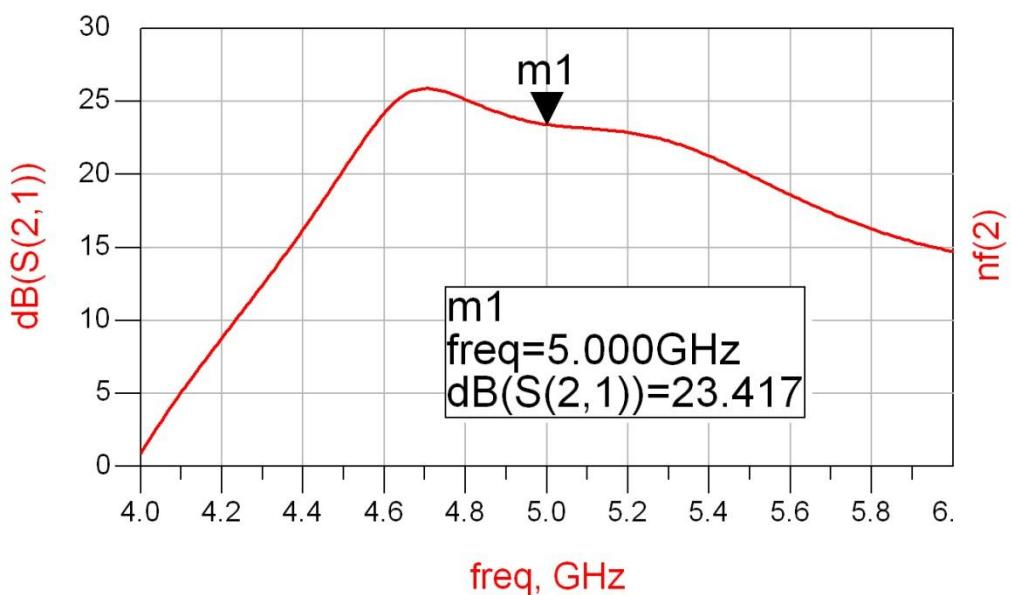
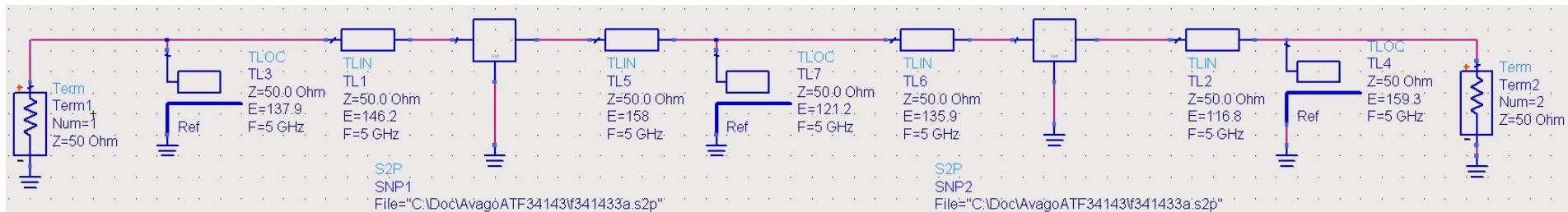
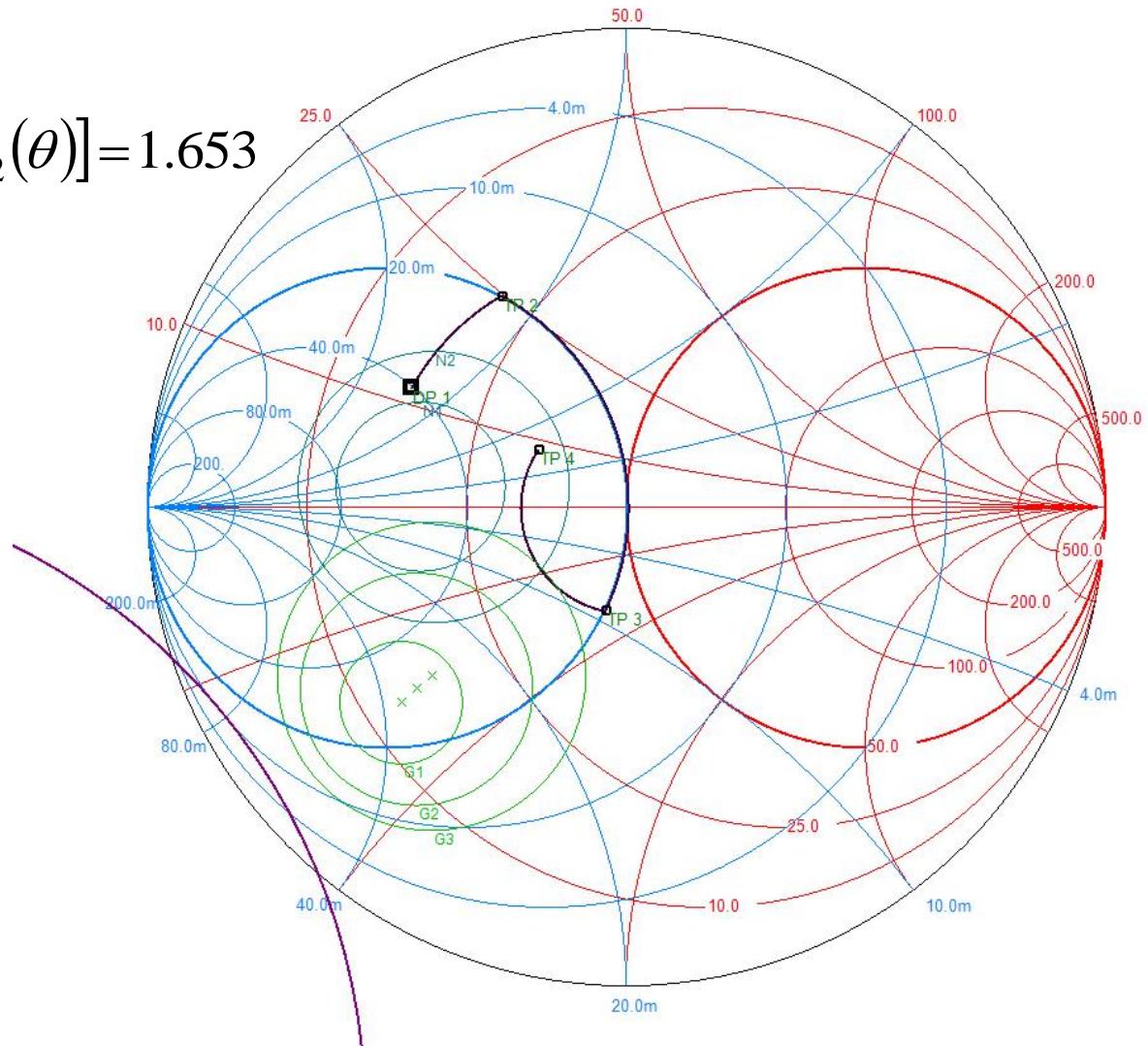


Diagrama Smith 2

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

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

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



ADS 2

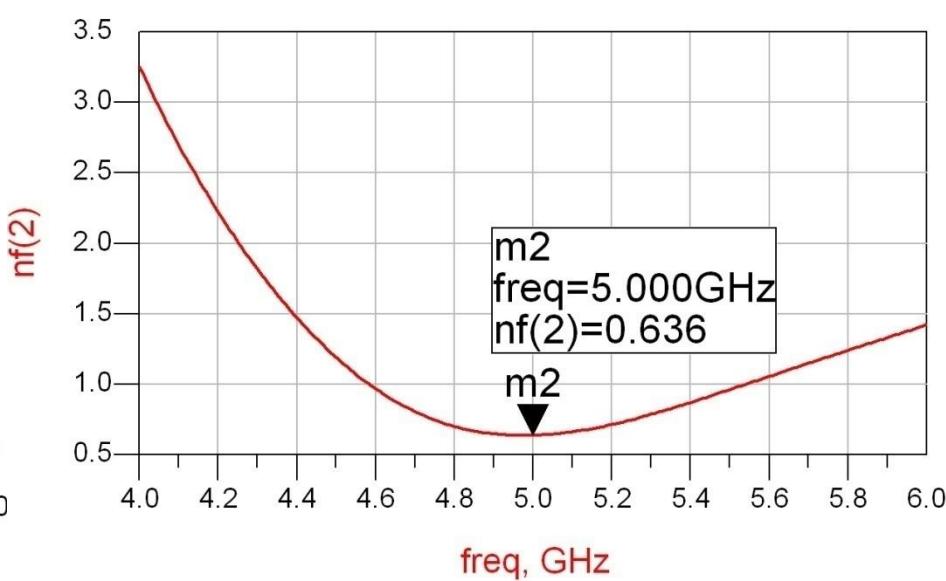
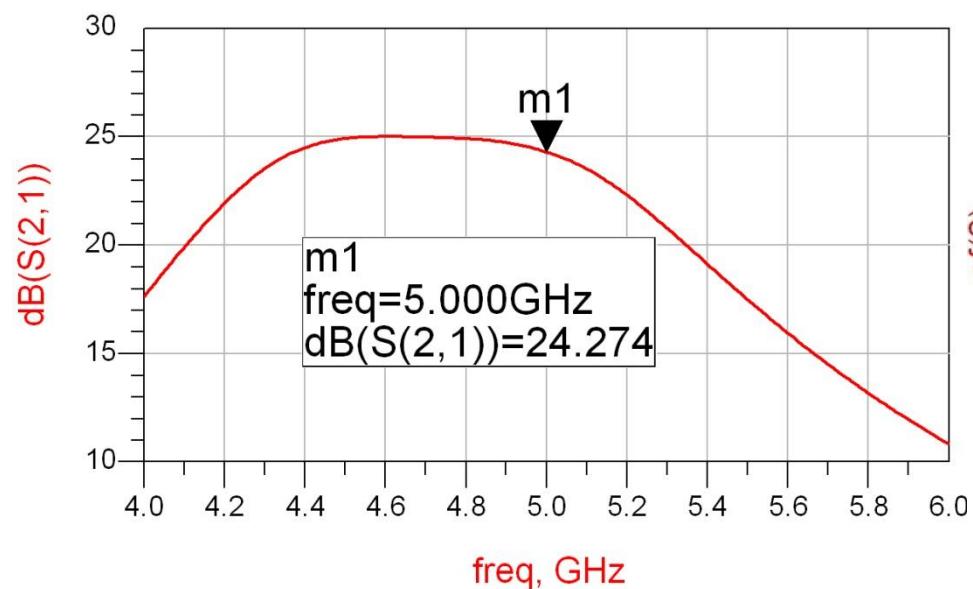
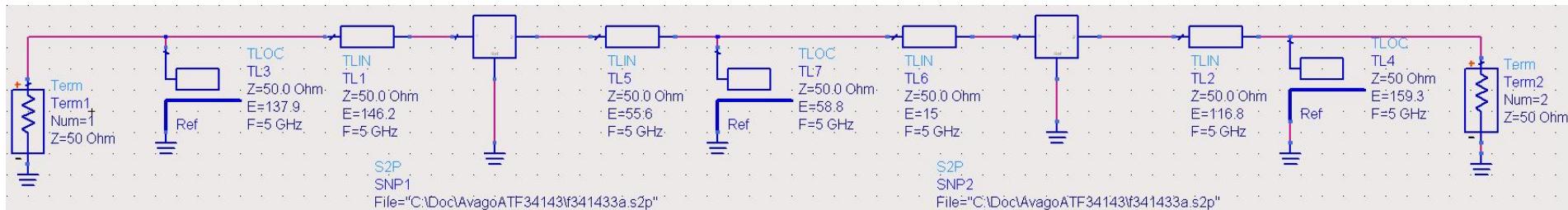
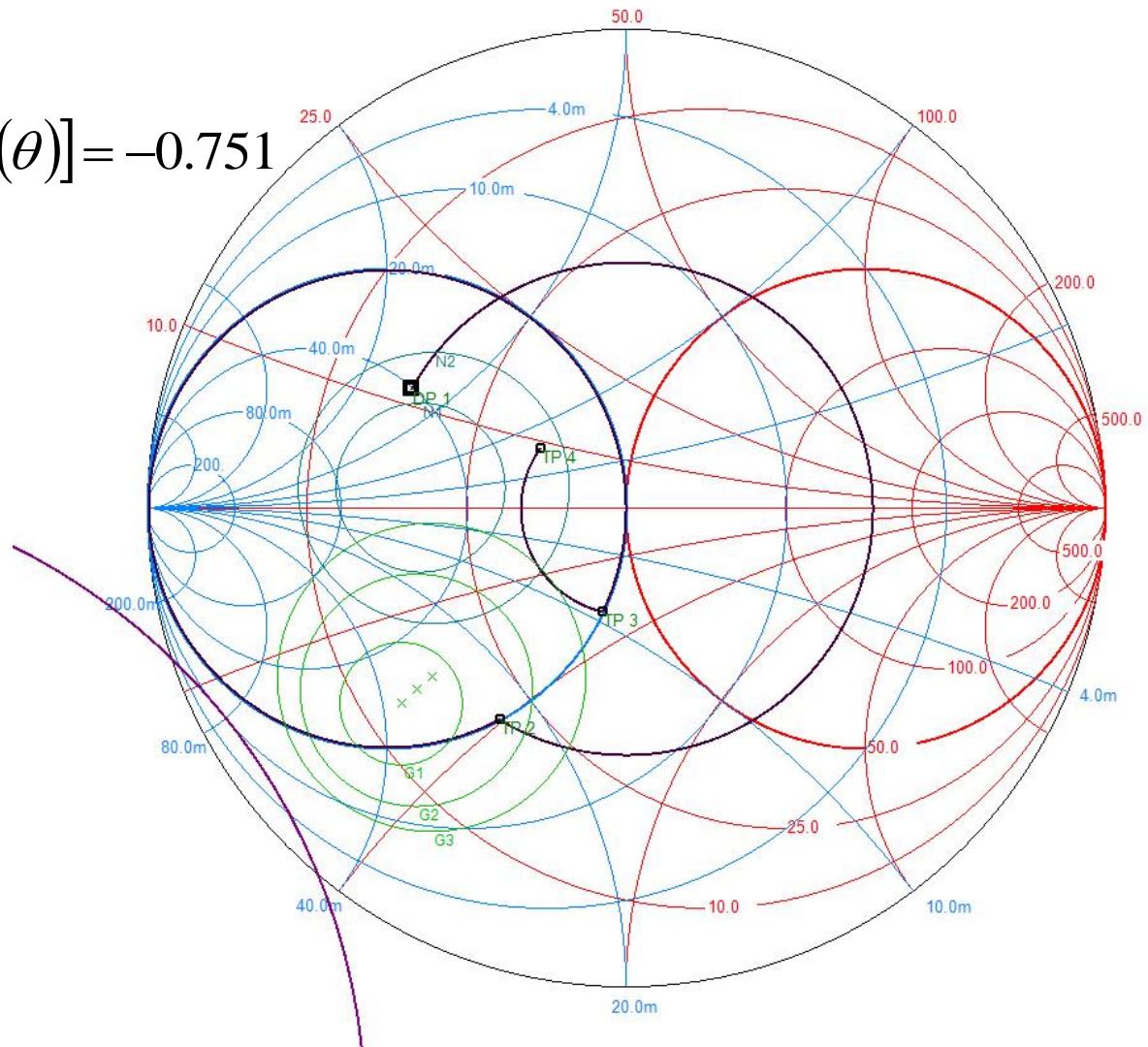


Diagrama Smith 3

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

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

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



ADS 3

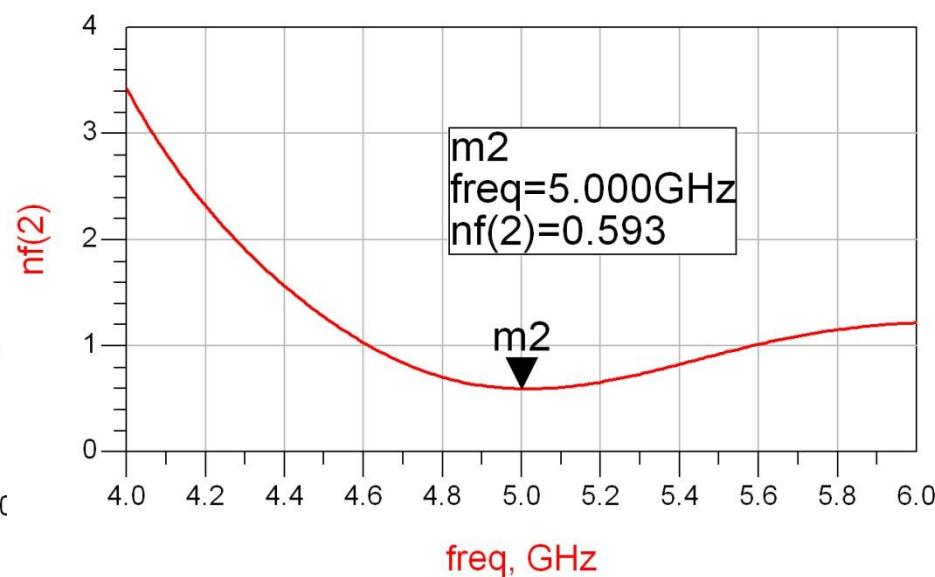
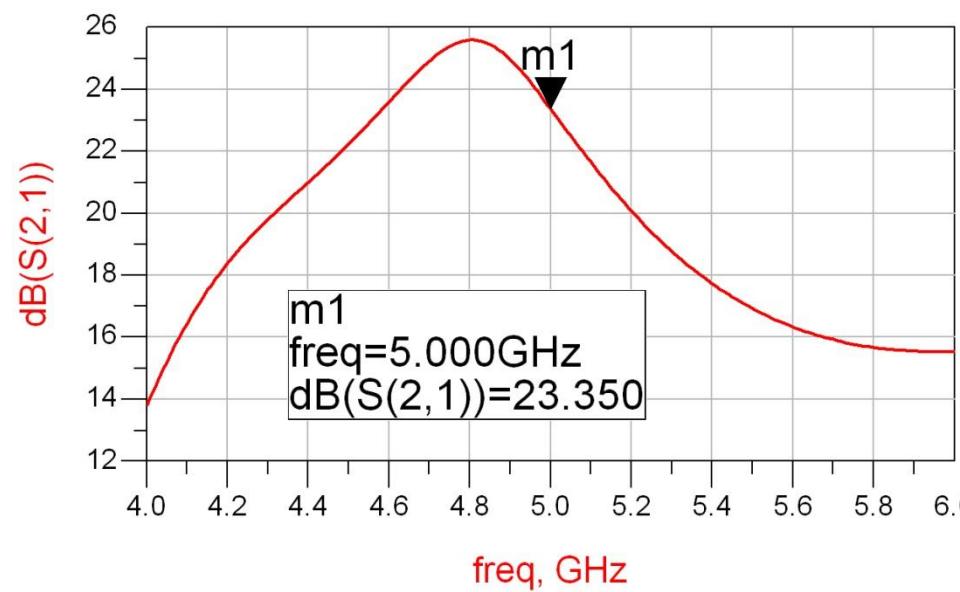
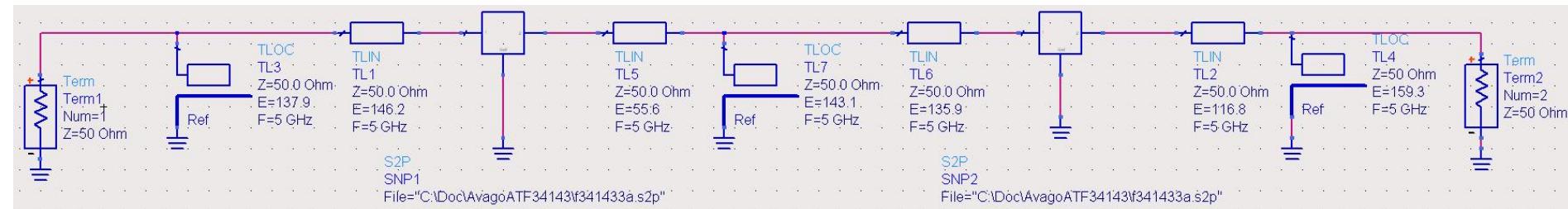
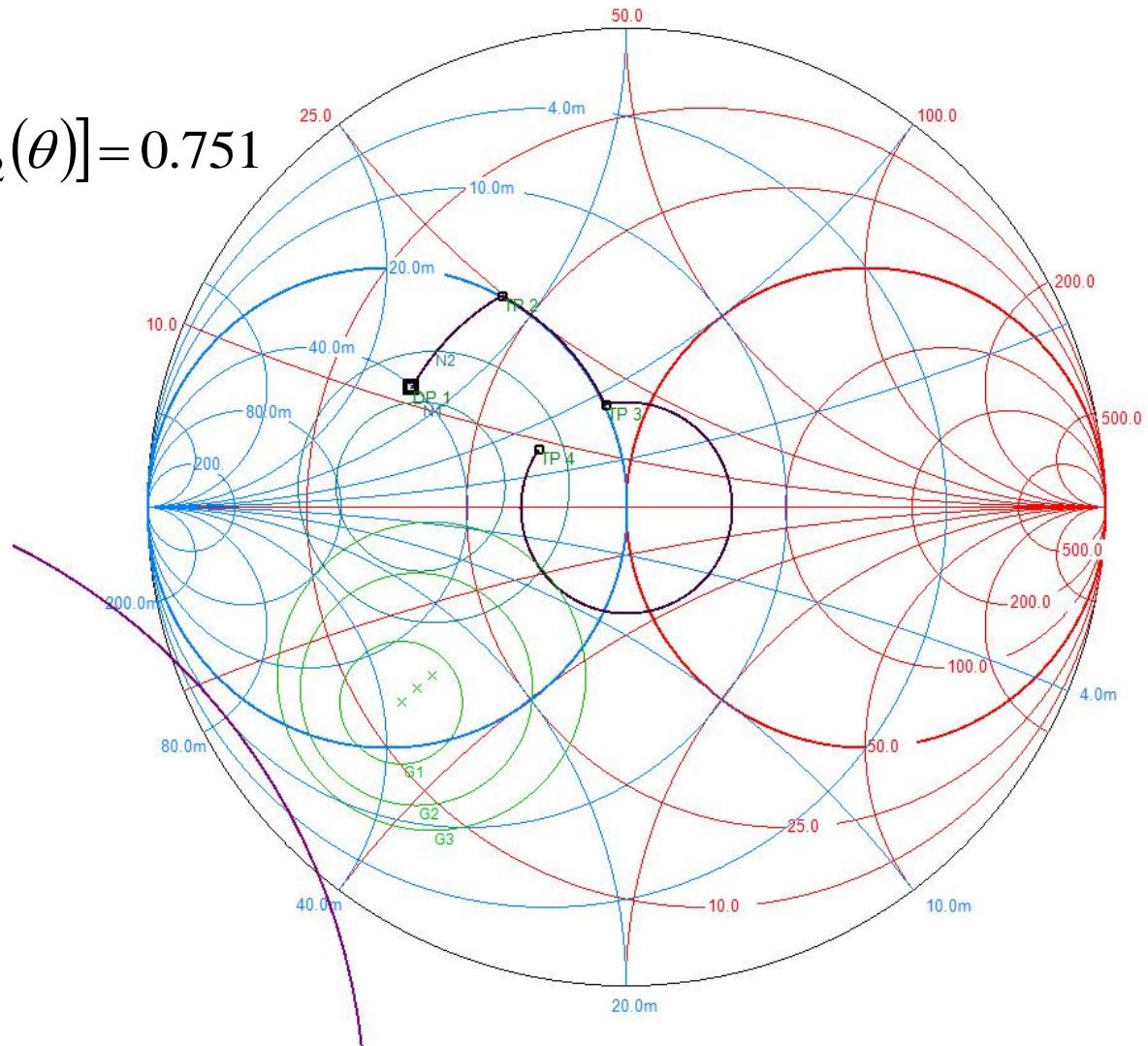


Diagrama Smith 4

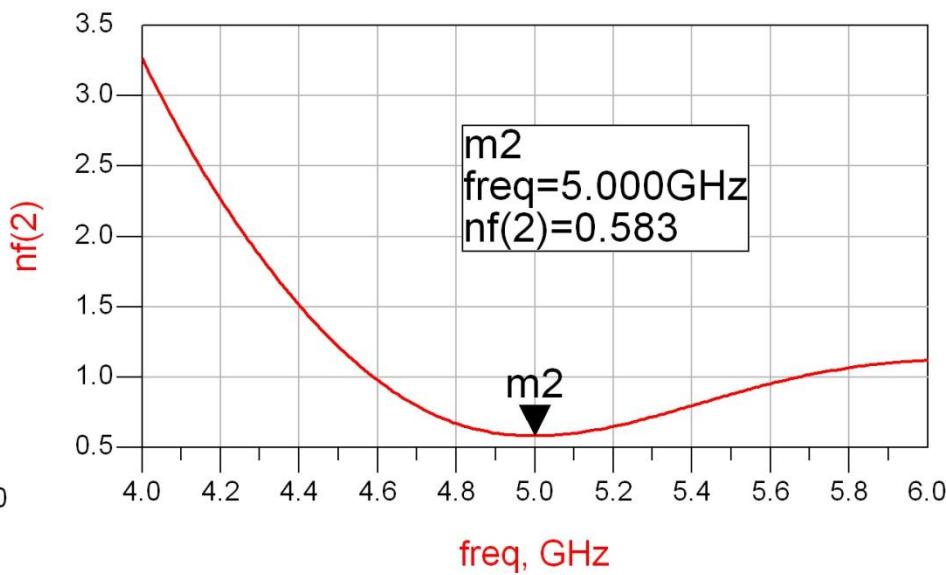
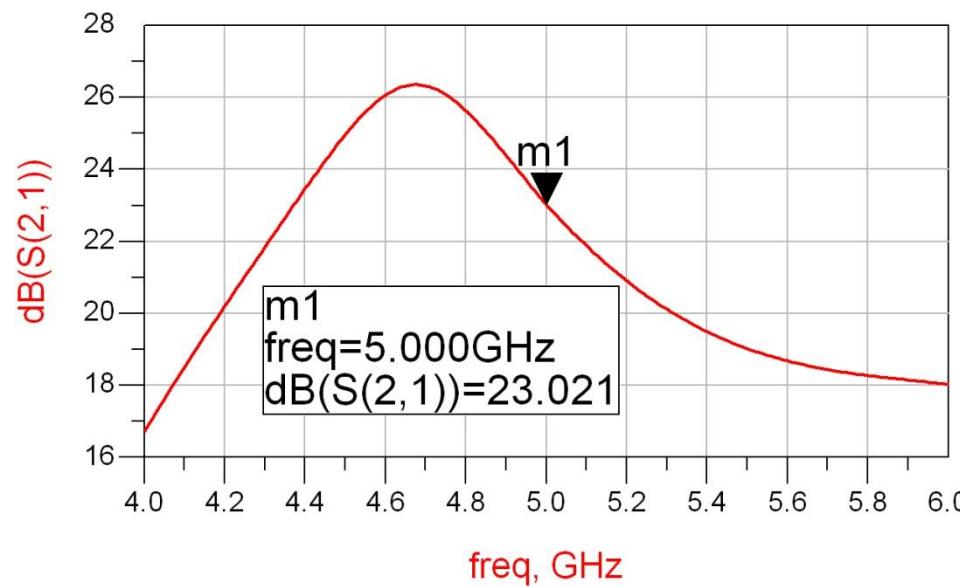
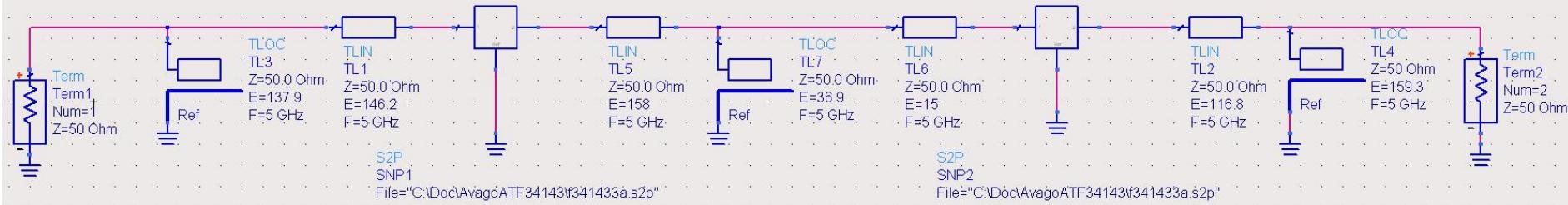
$$\theta_{L1} = 158.4^\circ \quad \theta_{S2} = 15^\circ$$

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

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



ADS 4



Adaptare inter-etaje

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

Amplificatoare de banda largă

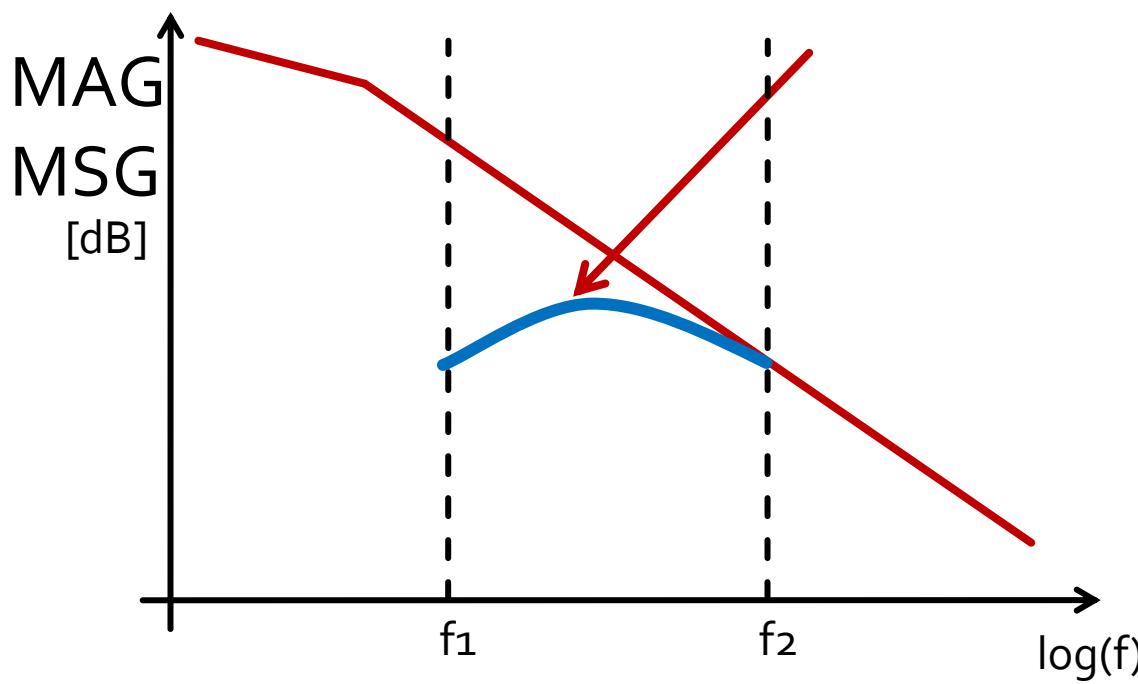
Amplificatoare de microunde

Amplificatoare de banda largă

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

Amplificatoare 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

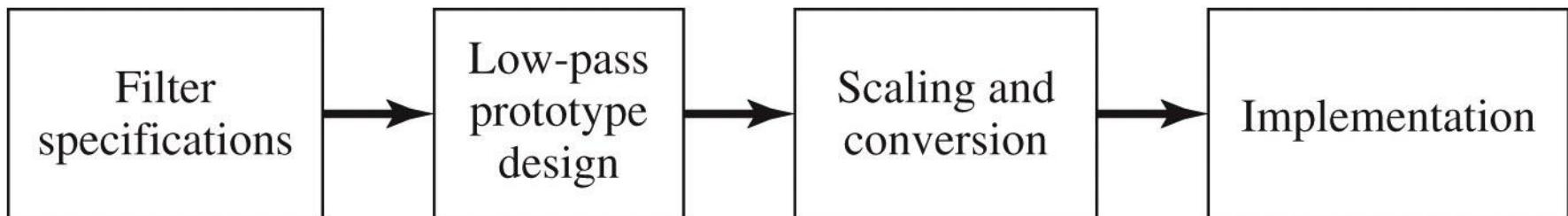


Figure 8.23

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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

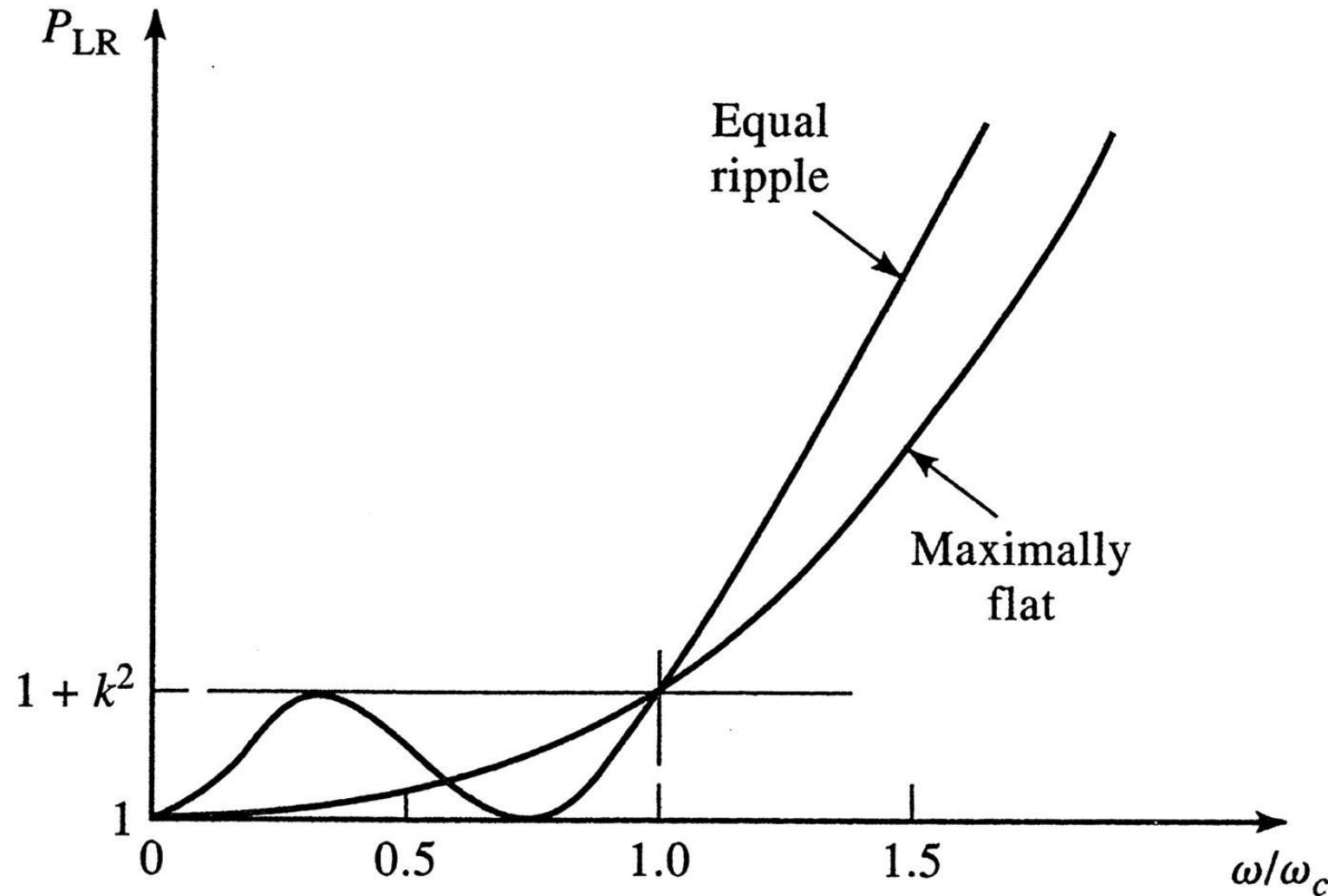


Figure 8.21

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FTJ elliptic prototip

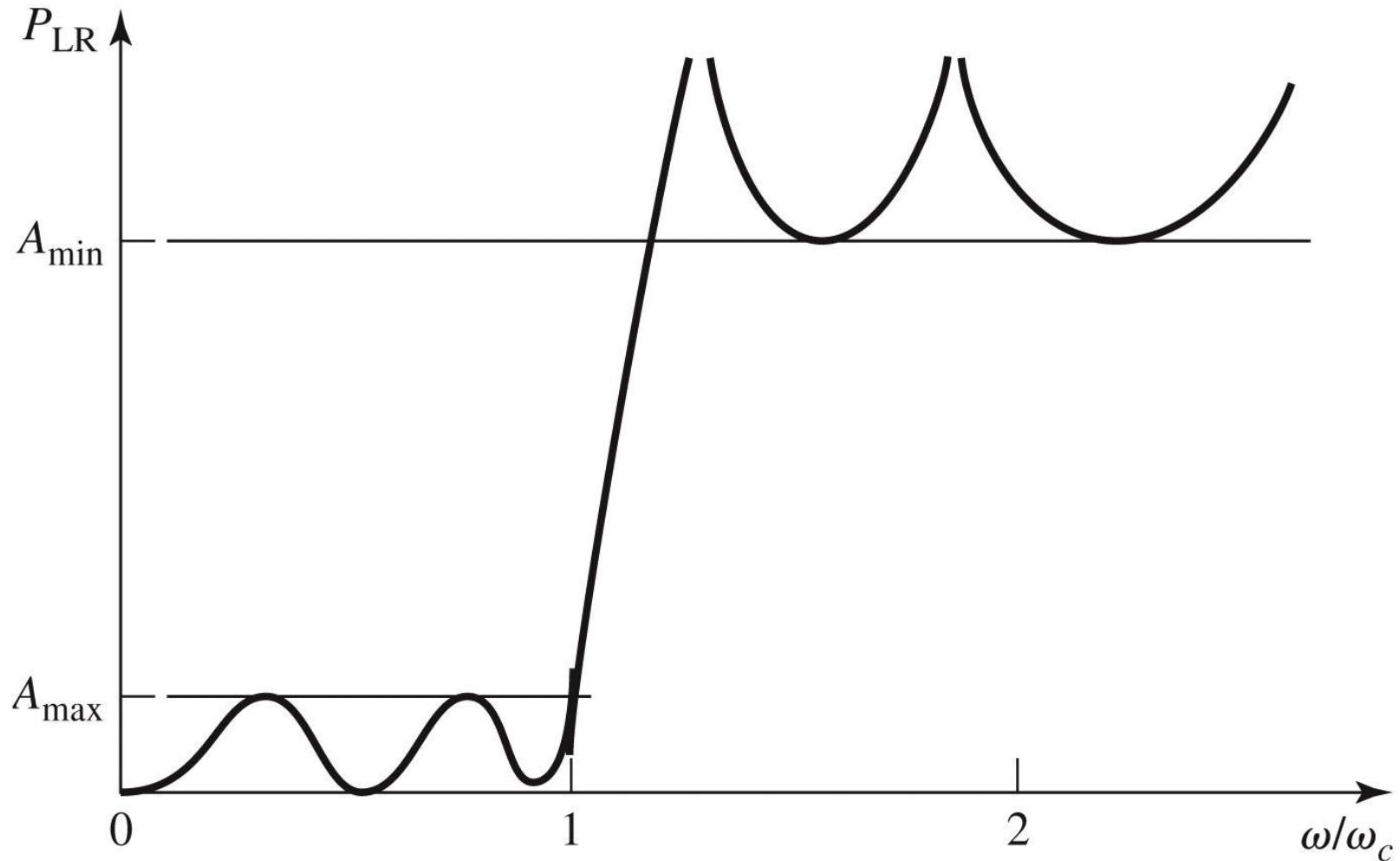


Figure 8.22

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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 $k = 1$)

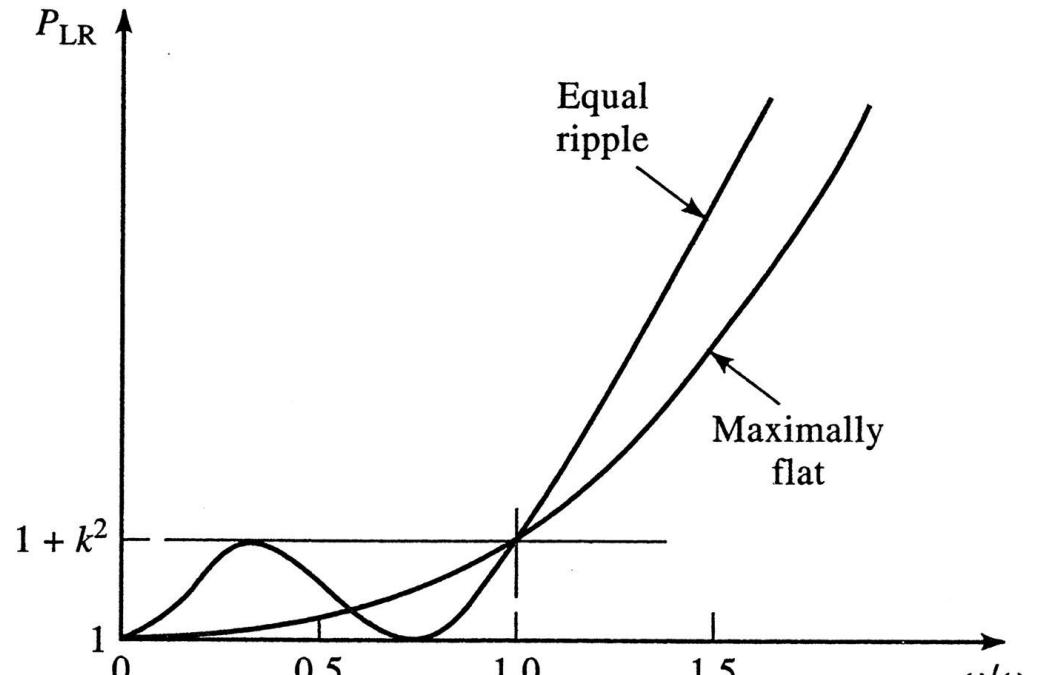


Figure 8.21
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FTJ de tip echiriplu

- 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 $\omega >> \omega_c$

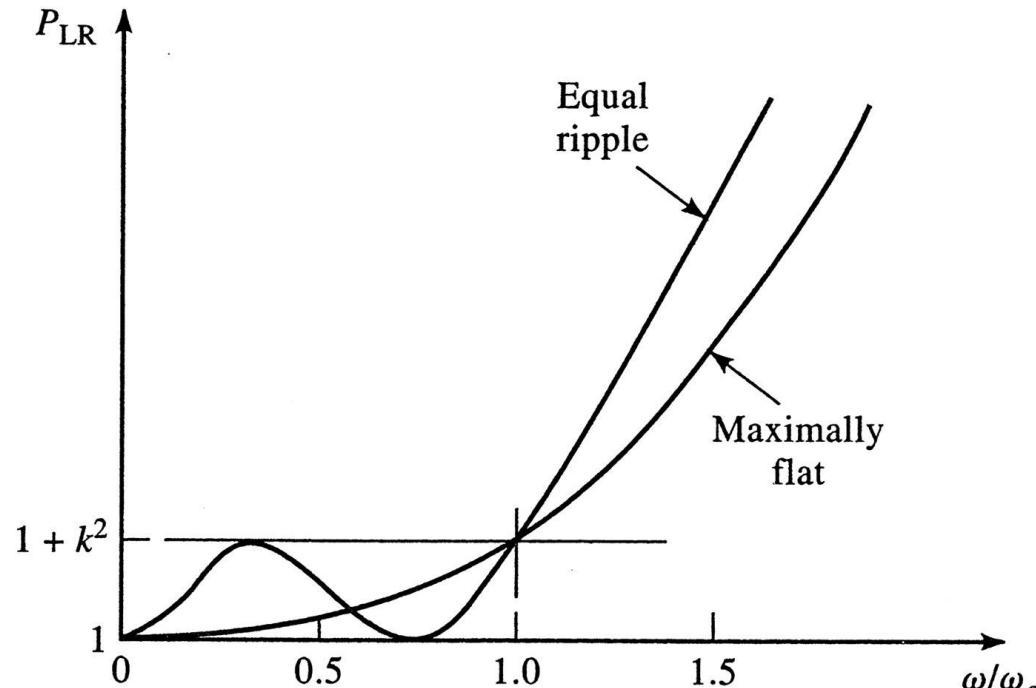
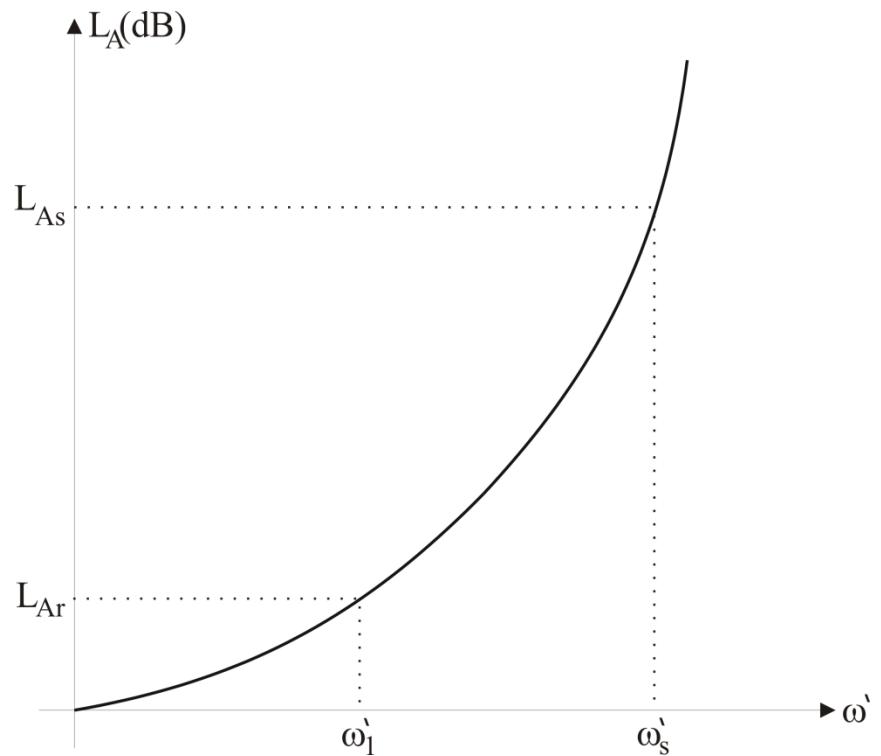


Figure 8.21
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Calculul ordinului filtrului maxim plat

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

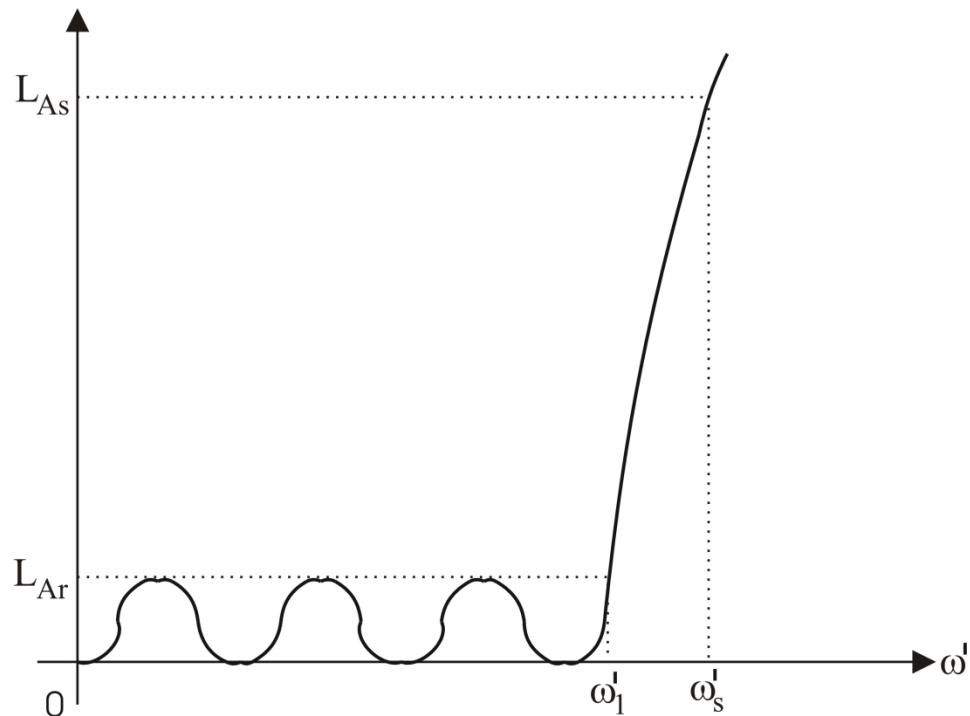
- cu atenuările in dB



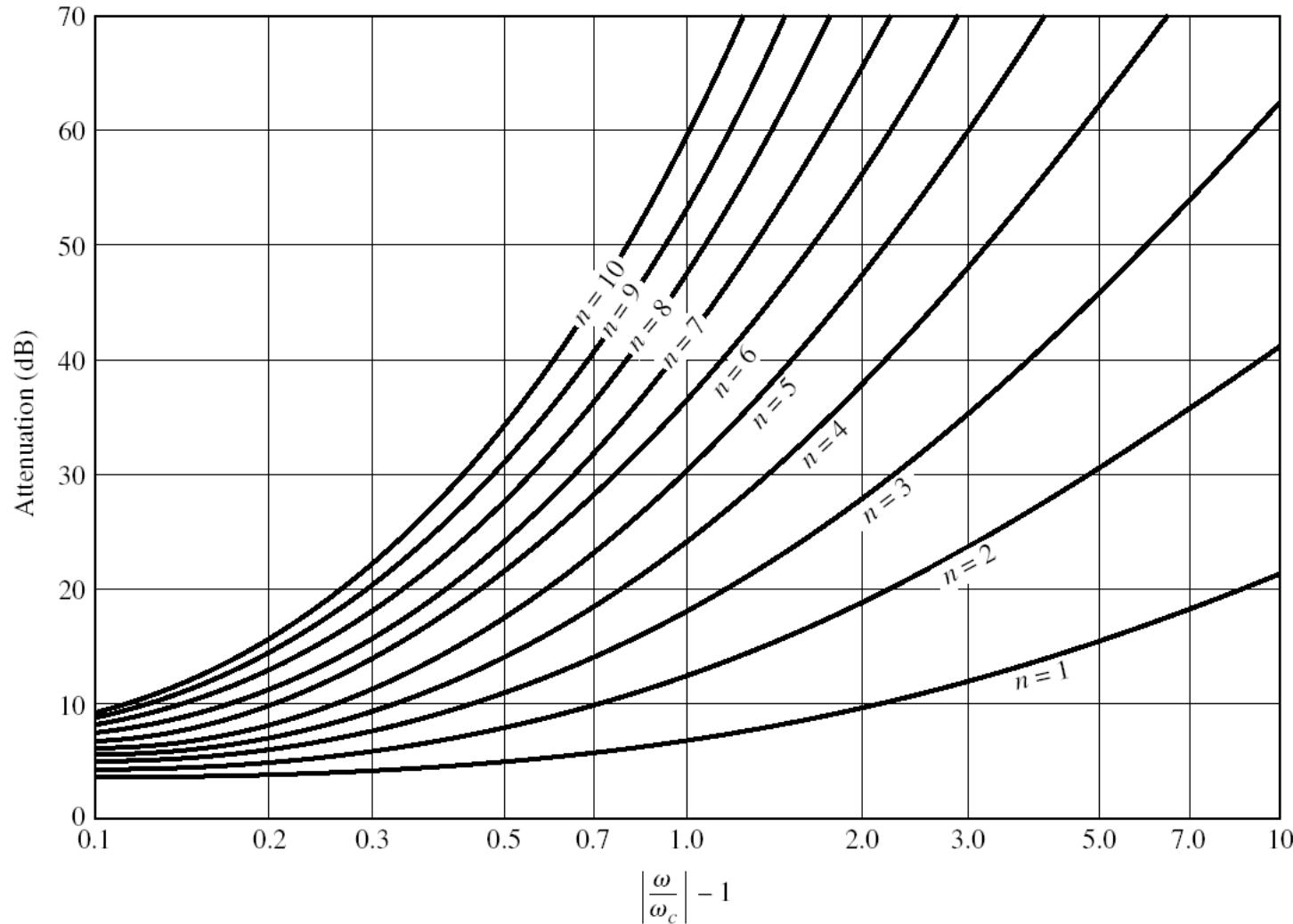
Calculul ordinului filtrului echiriplu

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

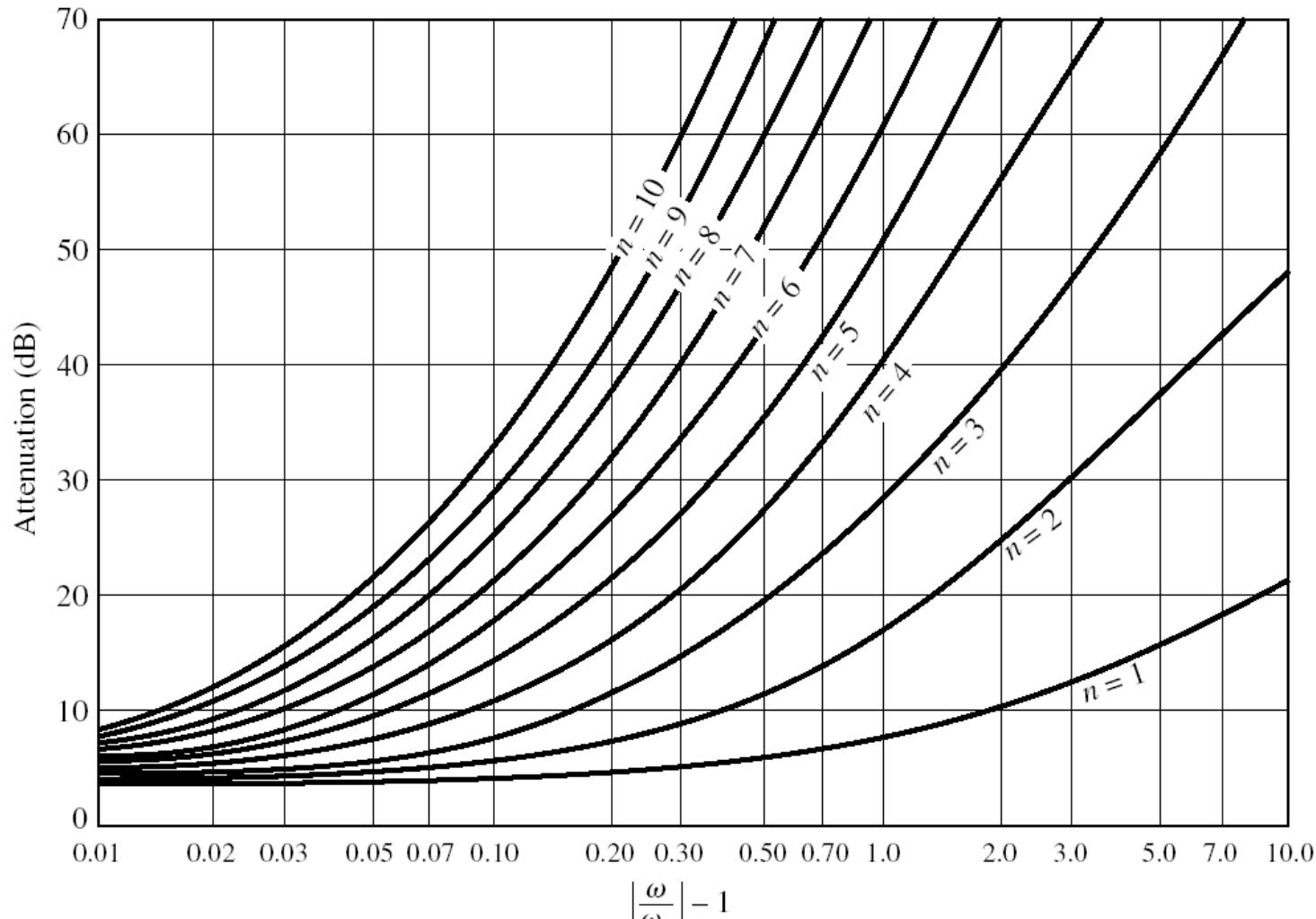
- cu atenuările in dB



Raspunsul filtrului maxim plat

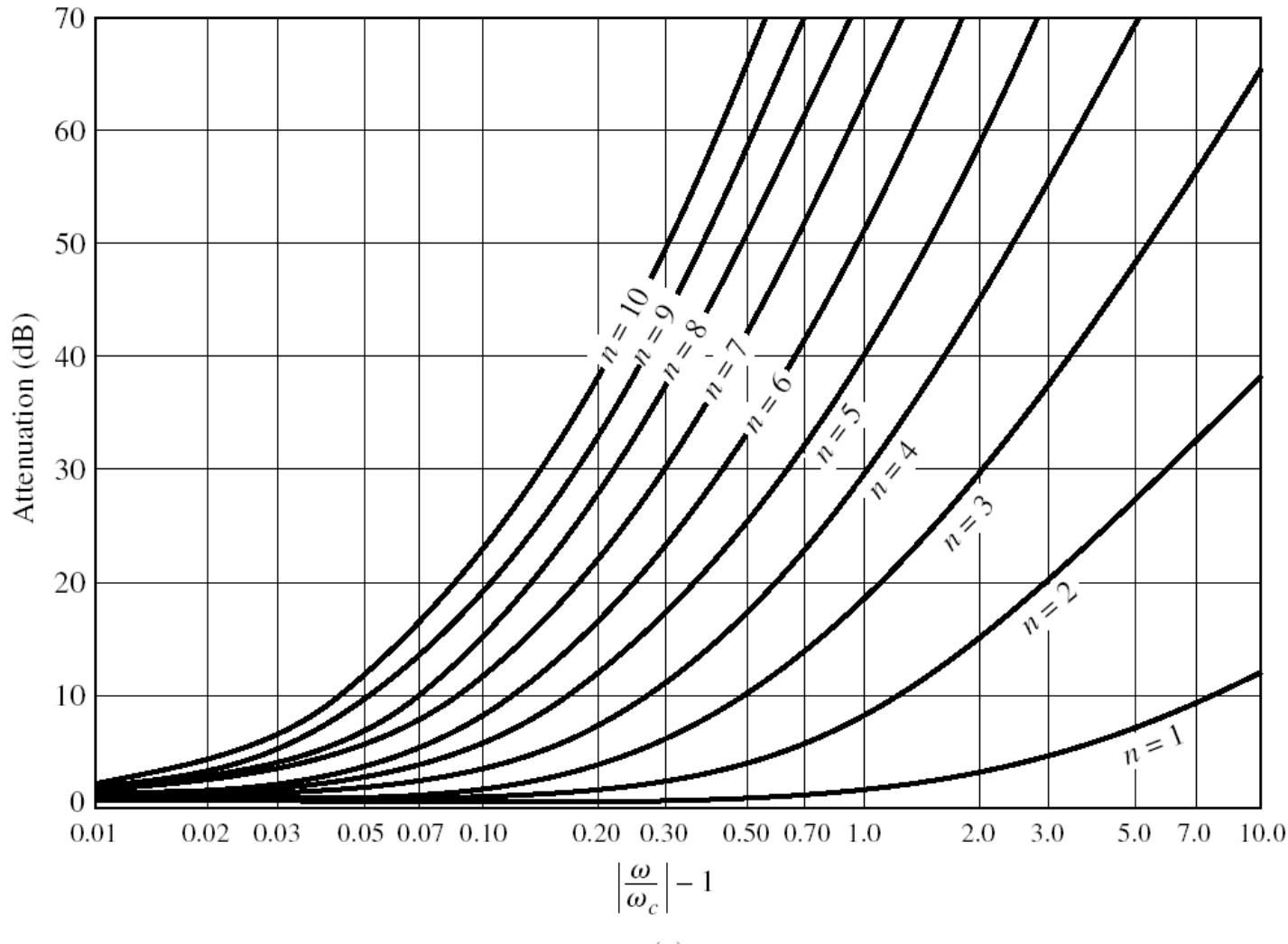


Raspunsul filtrului echiriplu 3 dB

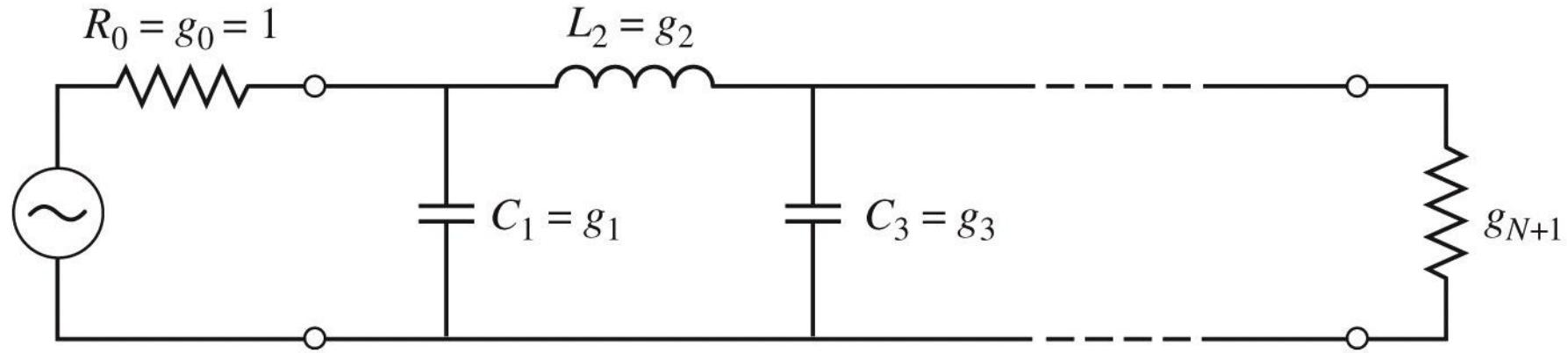


(b)

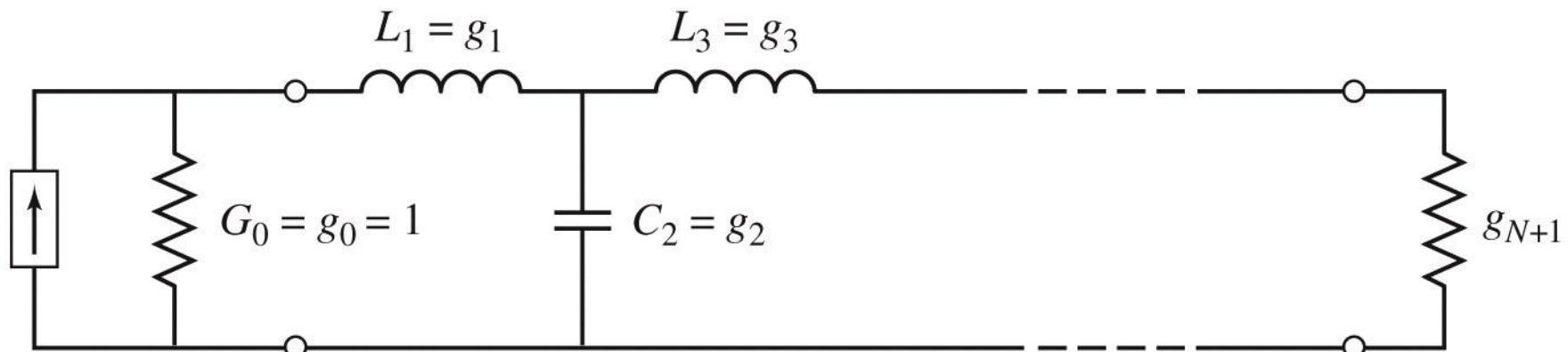
Raspunsul filtrului echiriplu 0.5 dB



Filtre prototip



(a)



(b)

Filtre prototip

- Filtrele prototip sunt filtre care implementeaza :
 - filtru FTJ
 - frecventa de taiere 1 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 , $i=0, N+1$

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

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

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

Filtru prototip maxim plat

- Calculul elementelor filtrului

$$g_0 = 1$$

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

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

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.

Scalarea in impedanta si frecventa

- Dupa determinarea coeficientilor filtrului prototip
 - filtru FTJ
 - frecventa de tariere ω_0 Hz
 - conectate la intrare la o rezistenta $R = 1$
- Se pot calcula valorile necesare pentru componente pentru implementarea altor conditii

Scalarea in impedanta

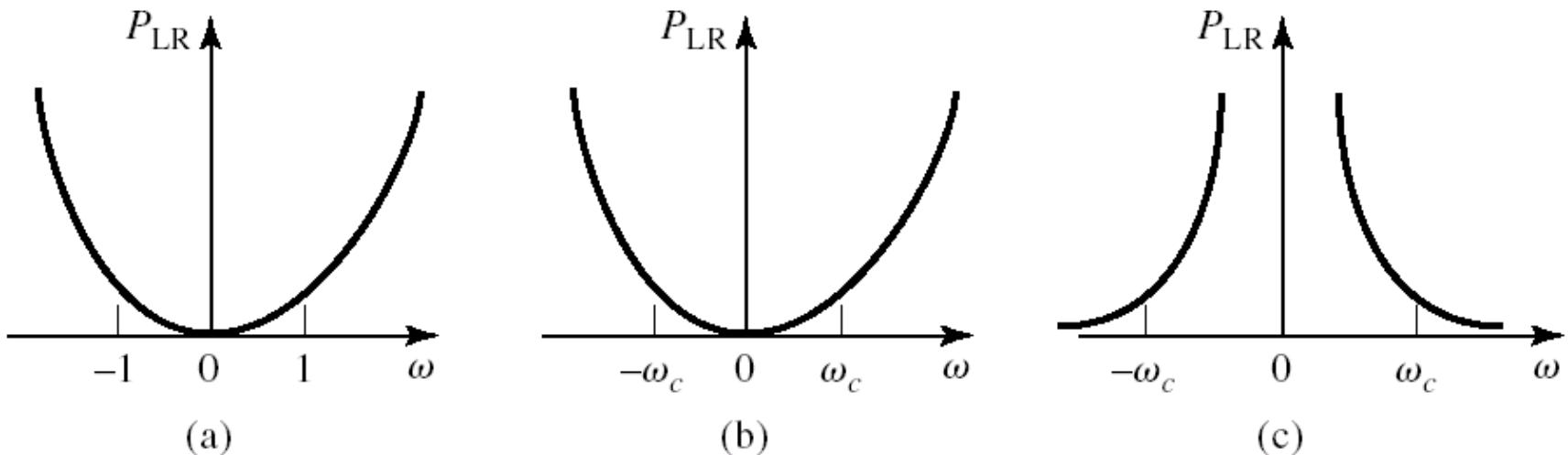
- Pentru a determina filtrul care lucreaza cu o alta rezistenta de intrare (R_o) se multiplica toate impedantele din circuit cu aceasta impedanta (cu " " se noteaza elementele noi)

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

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

Scalarea in frecventa

- modificarea frecventei de taiere
- modificarea caracteristicii de atenuare (de exemplu FTJ \rightarrow FTS)



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

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

Scalarea 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

Scalarea 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

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

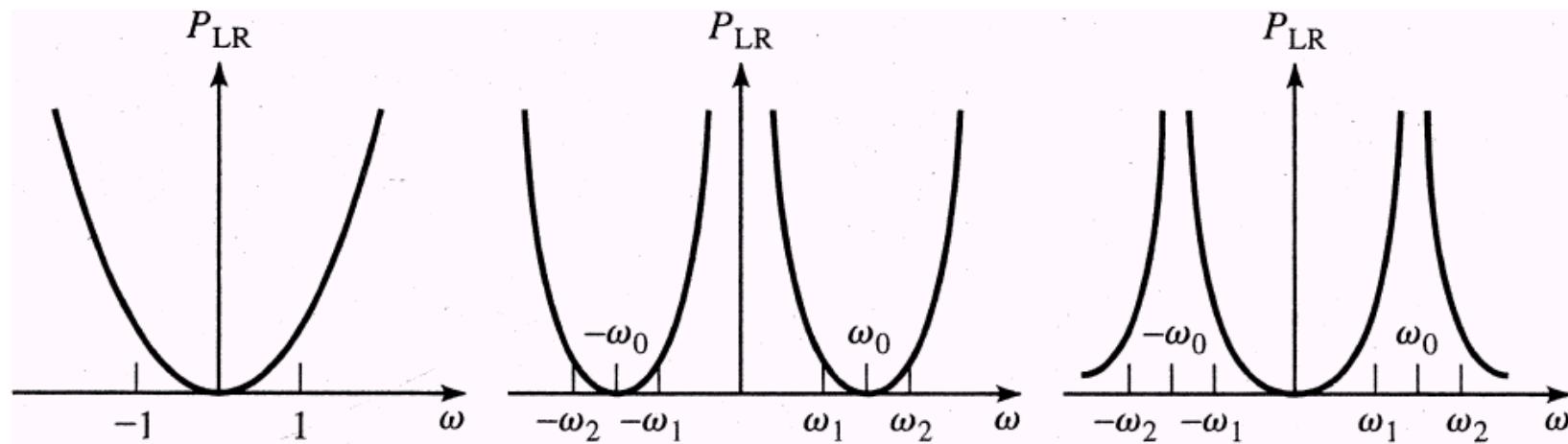
$$\omega_0 = \sqrt{\omega_1 \cdot \omega_2}$$

Scalarea FTJ \rightarrow FTB

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

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

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



Scalarea 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**

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

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

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

Scalarea 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

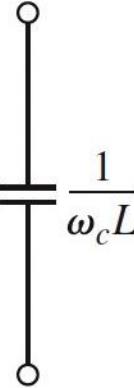
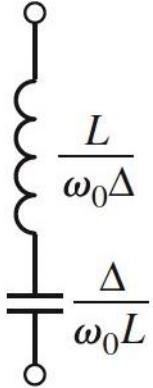
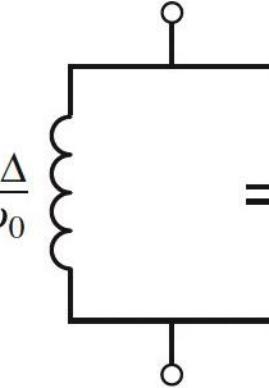
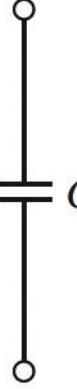
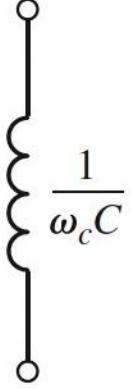
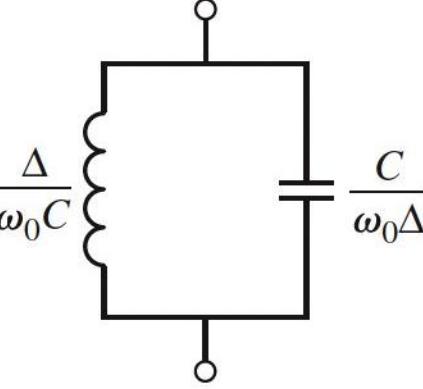
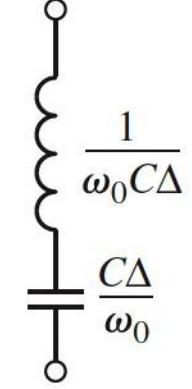
Low-pass	High-pass	Bandpass	Bandstop
 L	 $\frac{1}{\omega_c L}$	 $\frac{L}{\omega_0 \Delta}$ $\frac{\Delta}{\omega_0 L}$	 $\frac{L \Delta}{\omega_0}$ $\frac{1}{\omega_0 L \Delta}$
 C	 $\frac{1}{\omega_c C}$	 $\frac{\Delta}{\omega_0 C}$ $\frac{C}{\omega_0 \Delta}$	 $\frac{1}{\omega_0 C \Delta}$ $\frac{C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

Table 8.6

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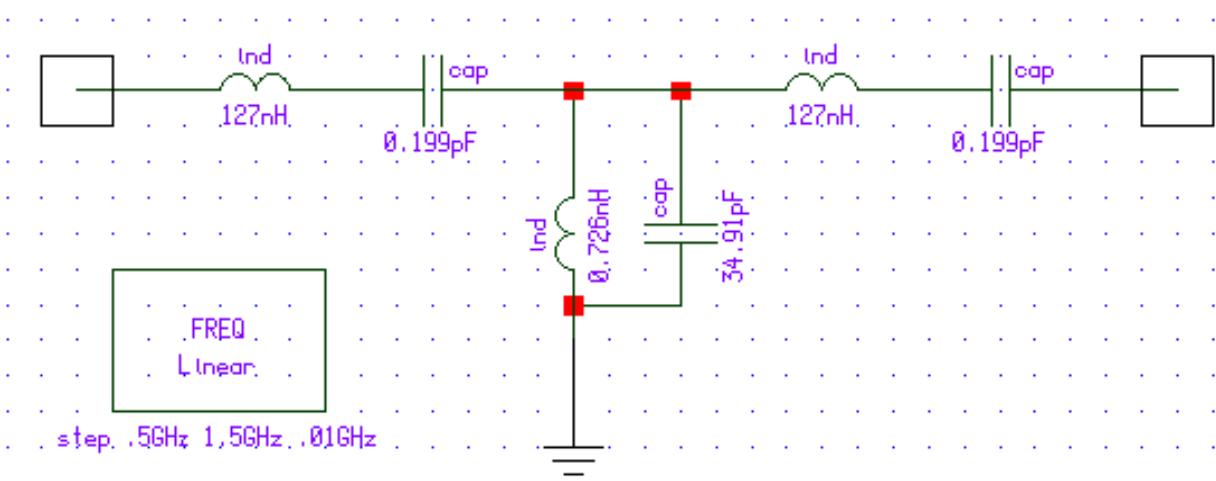
Exemplu

- 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 impedanța de $50\ \Omega$.

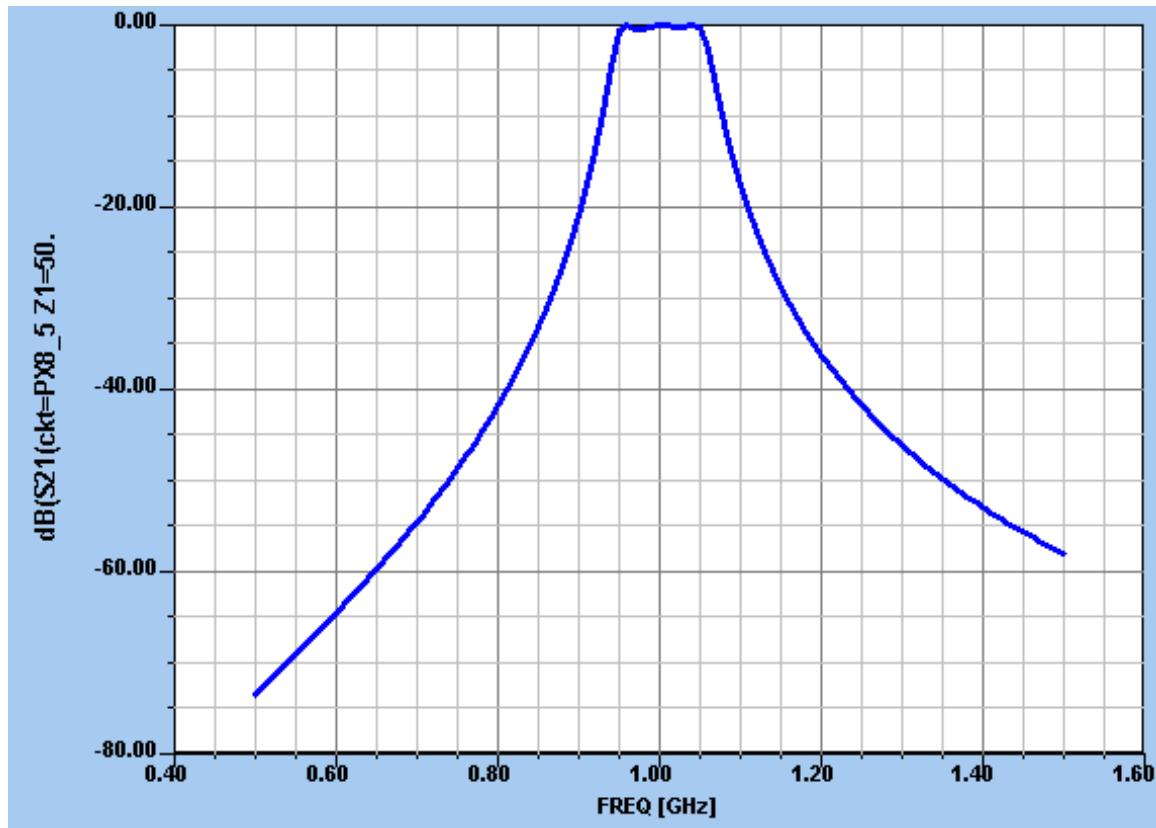
Solutie

$$g_1 = 1.5963 = L_1,$$
$$g_2 = 1.0967 = C_2,$$
$$g_3 = 1.5963 = L_3,$$
$$g_4 = 1.000 = R_L$$

$$L'_1 = 127.0 \text{ nH},$$
$$C'_1 = 0.199 \text{ pF},$$
$$L'_2 = 0.726 \text{ nH},$$
$$C'_2 = 34.91 \text{ pF},$$
$$L'_3 = 127.0 \text{ nH},$$
$$C'_3 = 0.199 \text{ pF}.$$



Simulare



Contact

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