

Curs 13

2023/2024

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2023/2024

- 2C/1L (+1), **DCMR (CDM)**
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
 - Miercuri 08(:**15**)-17, ~~Online~~/**Video (istoric)**, P5
 - E – **50%** din nota
 - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
 - primul test L1: 04.10.2023 (t2 si t3 neanuntate la **curs**)
 - 3pz (C) \approx +0.5p (**2p** max)
 - toate materialele permise

Disciplina 2023/2024

- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
 - Miercuri/Joi/Vineri, par/impar, **II.13**
 - L – **25%** din nota
 - ADS, 4 sedinte aplicatii
 - prezenta + **rezultate personale!**
 - P – **25%** din nota
 - ADS, 3 sedinte aplicatii (-1? 21-22.12.2022)
 - tema personala

Cuprins

- Linii de transmisie
- Adaptarea de impedanță
- Cuploare direcționale
- Divizoare de putere
- Amplificatoare de microunde
- Filtre de microunde
- Oscilatoare de microunde ?

Bibliografie

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

Examen: Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$-30 \text{ dBm} = 1 \mu\text{W}$$

$$-60 \text{ dBm} = 1 \text{ nW}$$

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

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

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

Adaptarea de impedanță

Diagrama Smith

Cuprins

- Linii de transmisie
- **Adaptarea de impedanță**
- Cuploare direcționale
- Divizoare de putere
- Amplificatoare de microunde
- Filtre de microunde
- Oscilatoare de microunde ?

[illegible]

Diagrama Smith

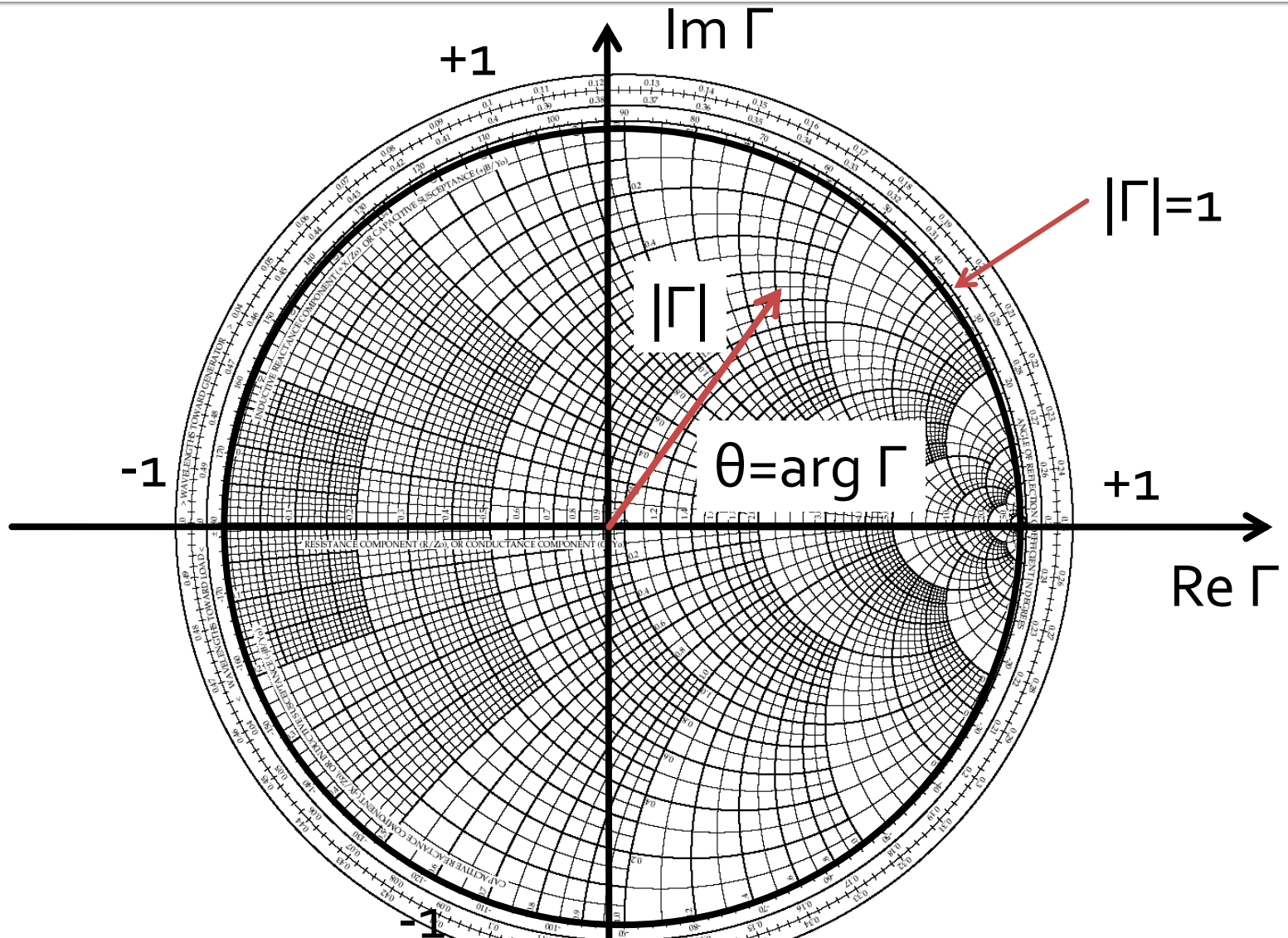
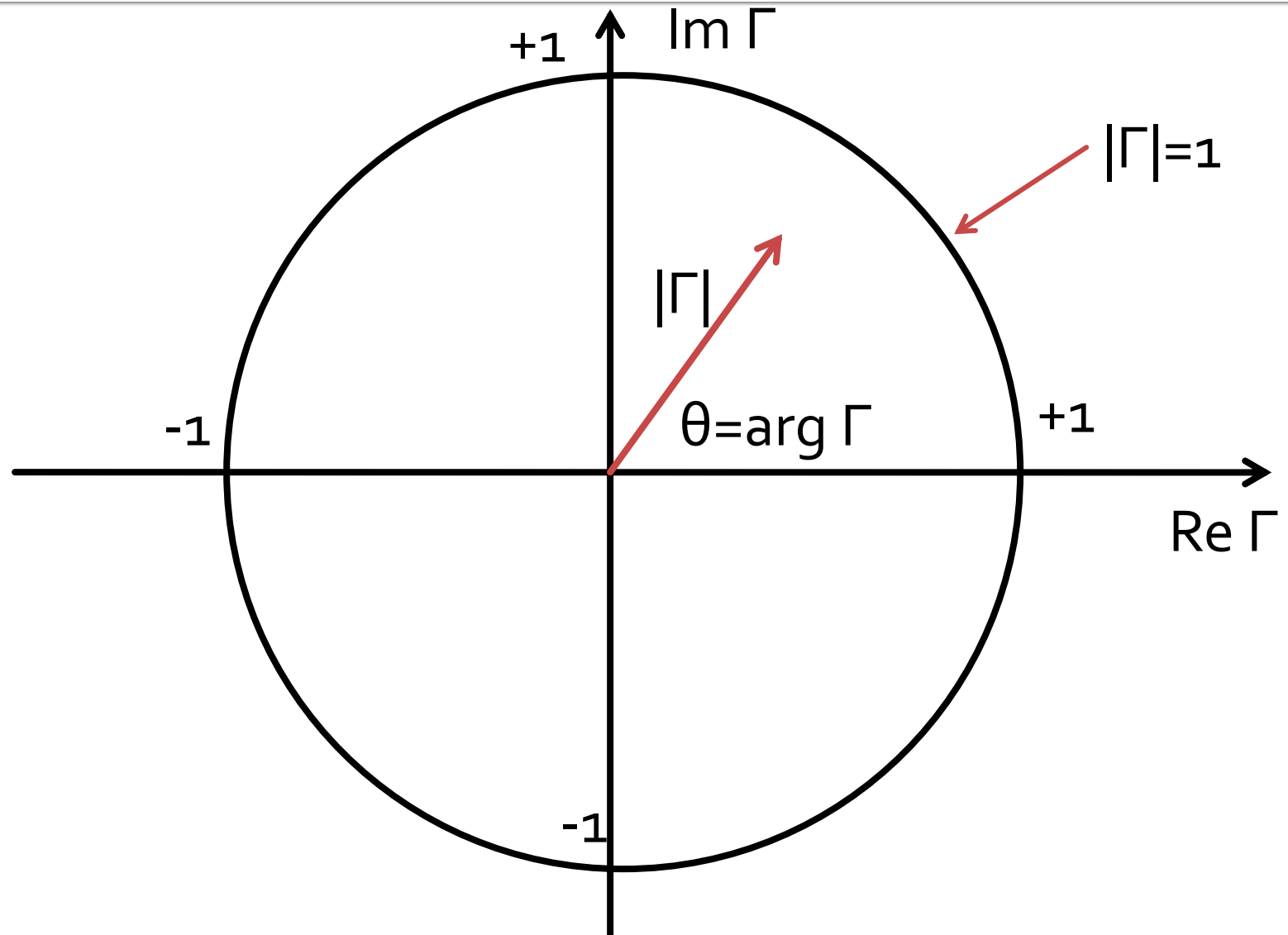


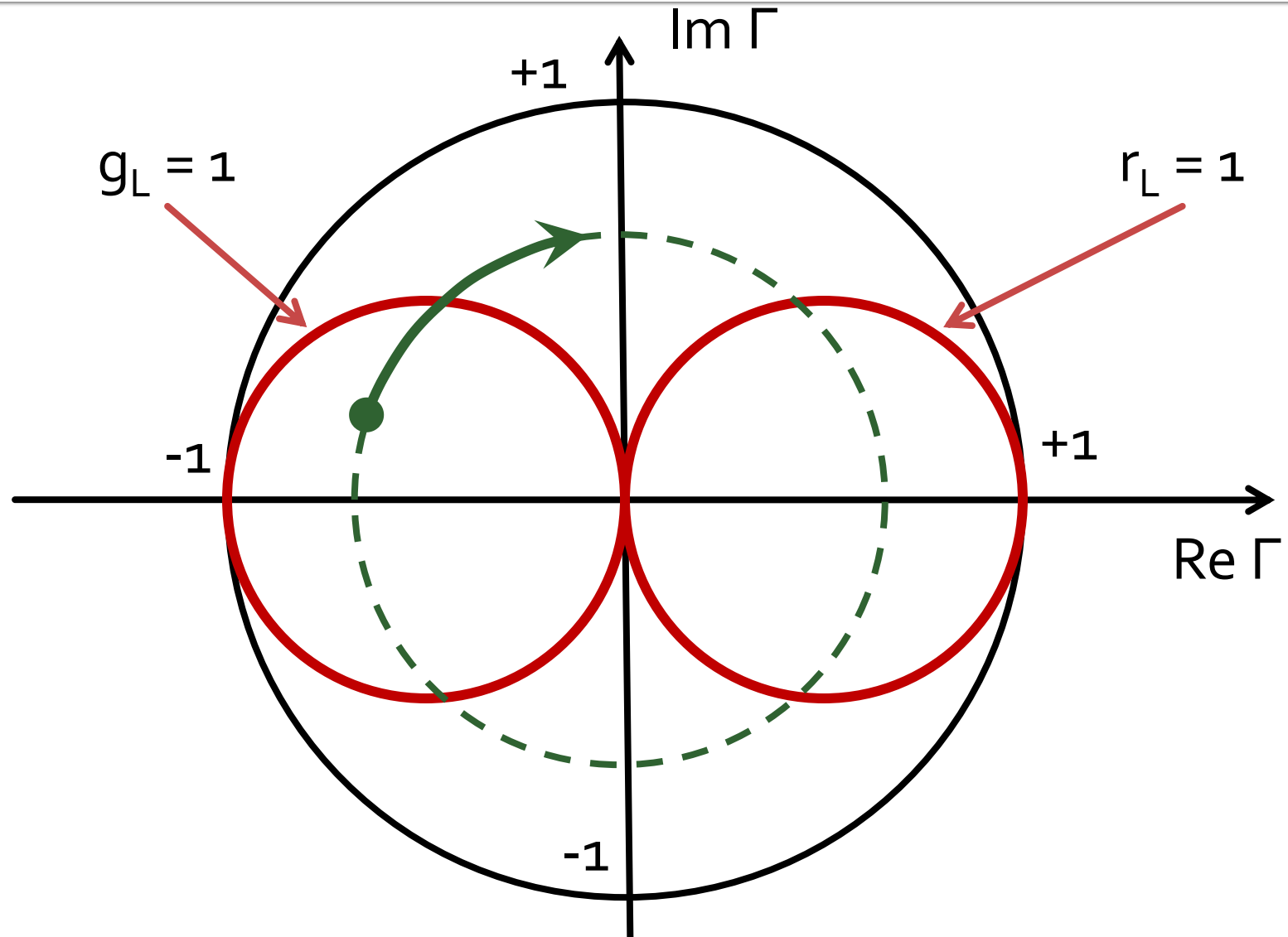
Diagrama Smith



Adaptarea cu sectiuni de linii (stub)

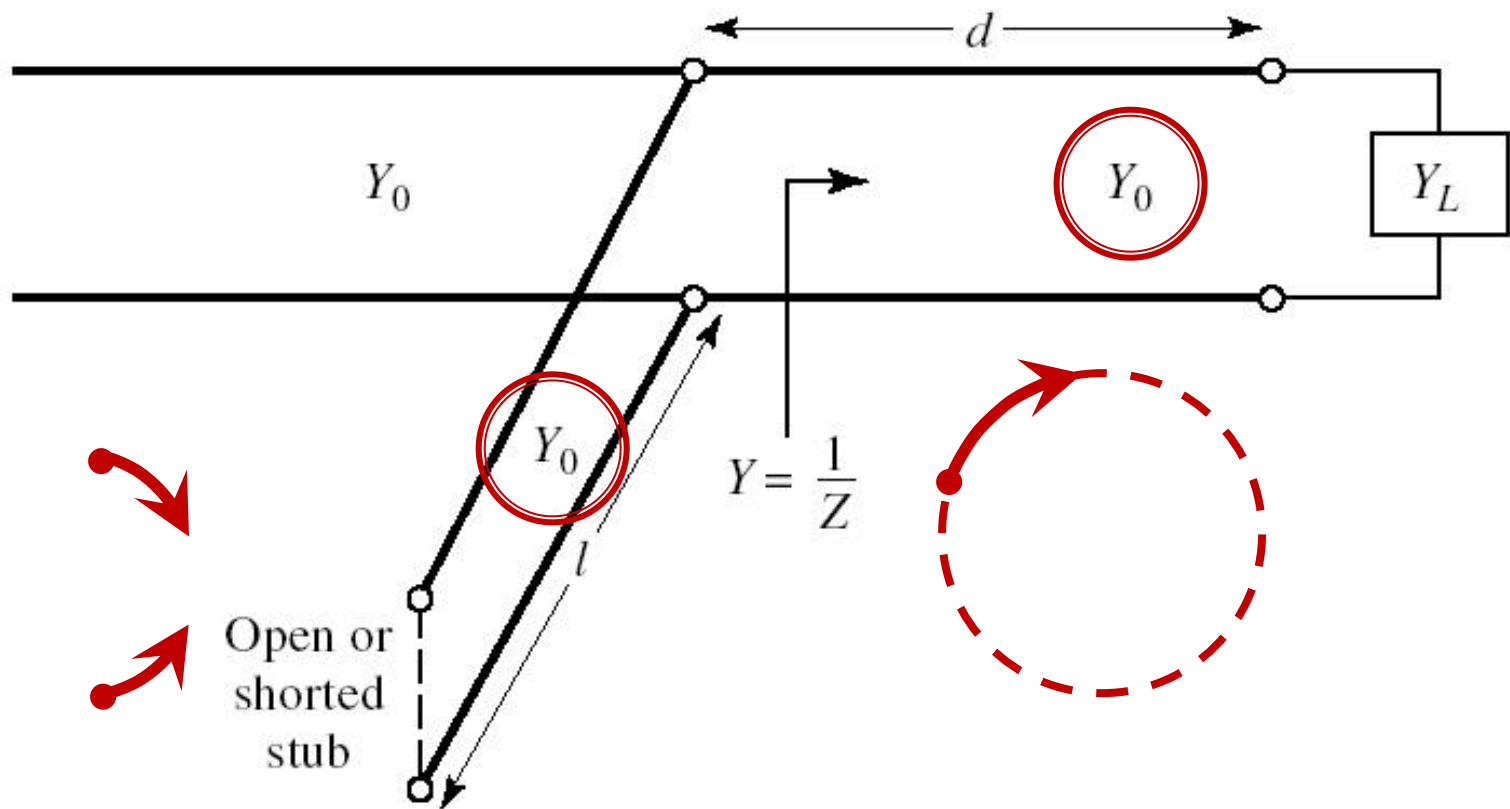
Adaptarea de impedanță

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



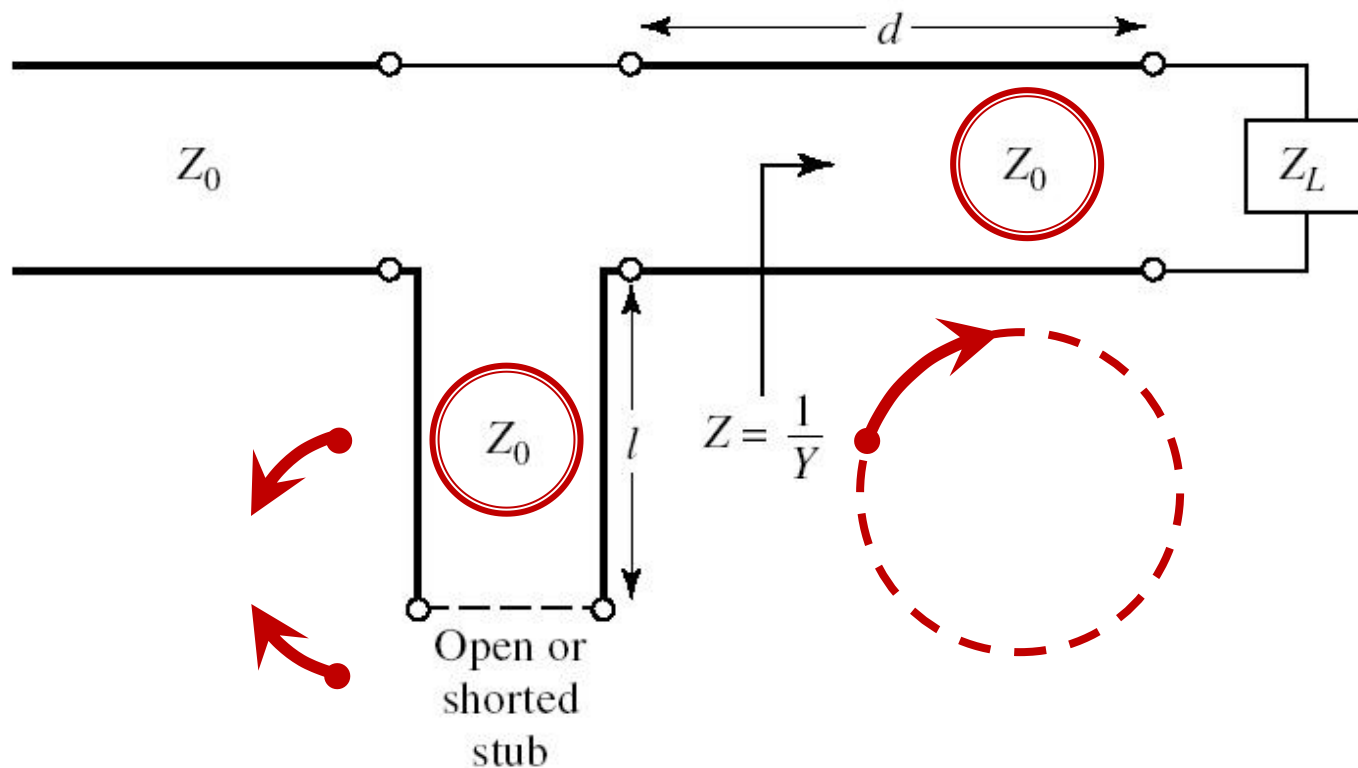
Single stub tuning

- Shunt Stub (sectiune de linie in paralel)



Single stub tuning

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

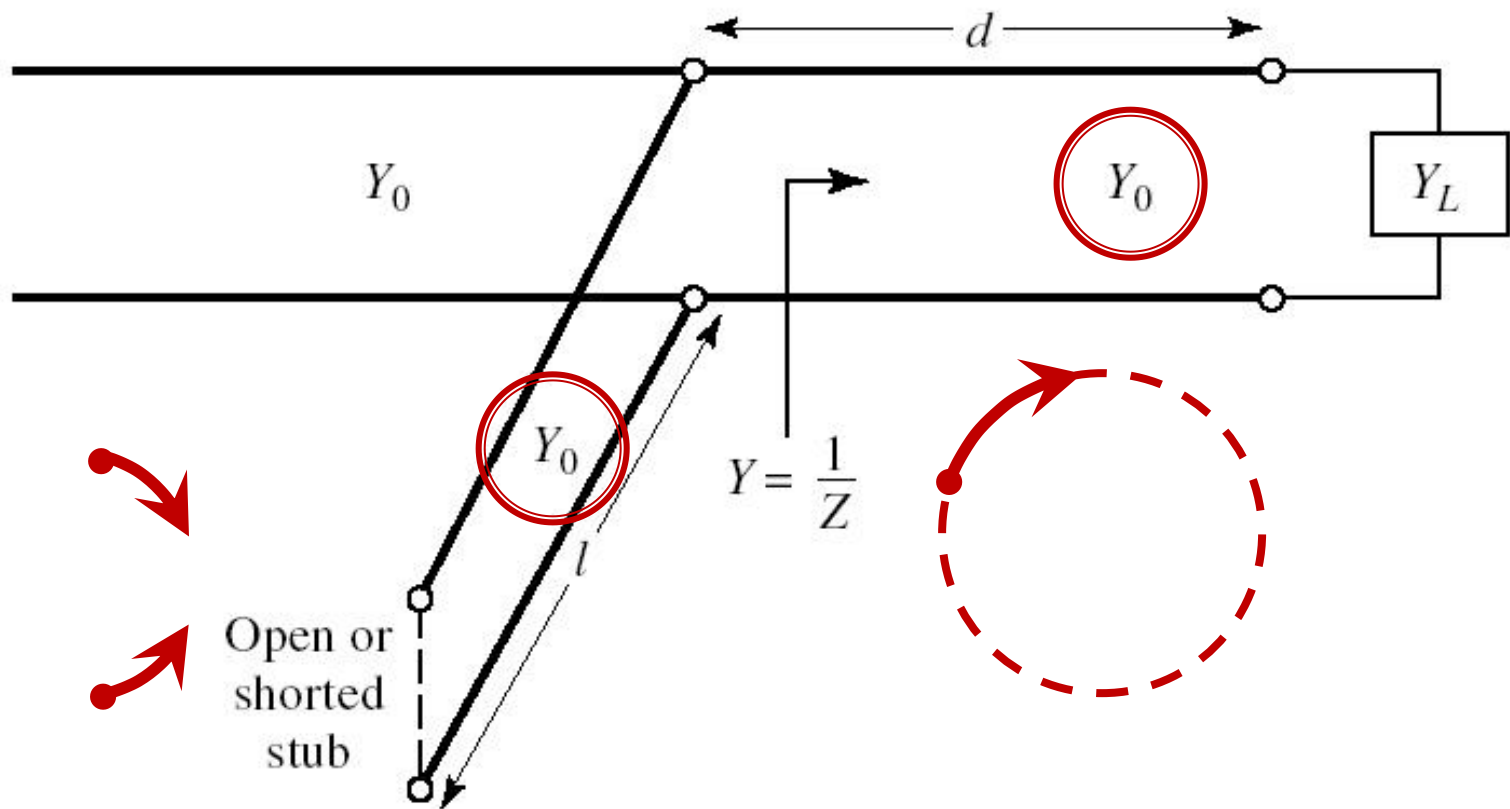


Solutii analitice

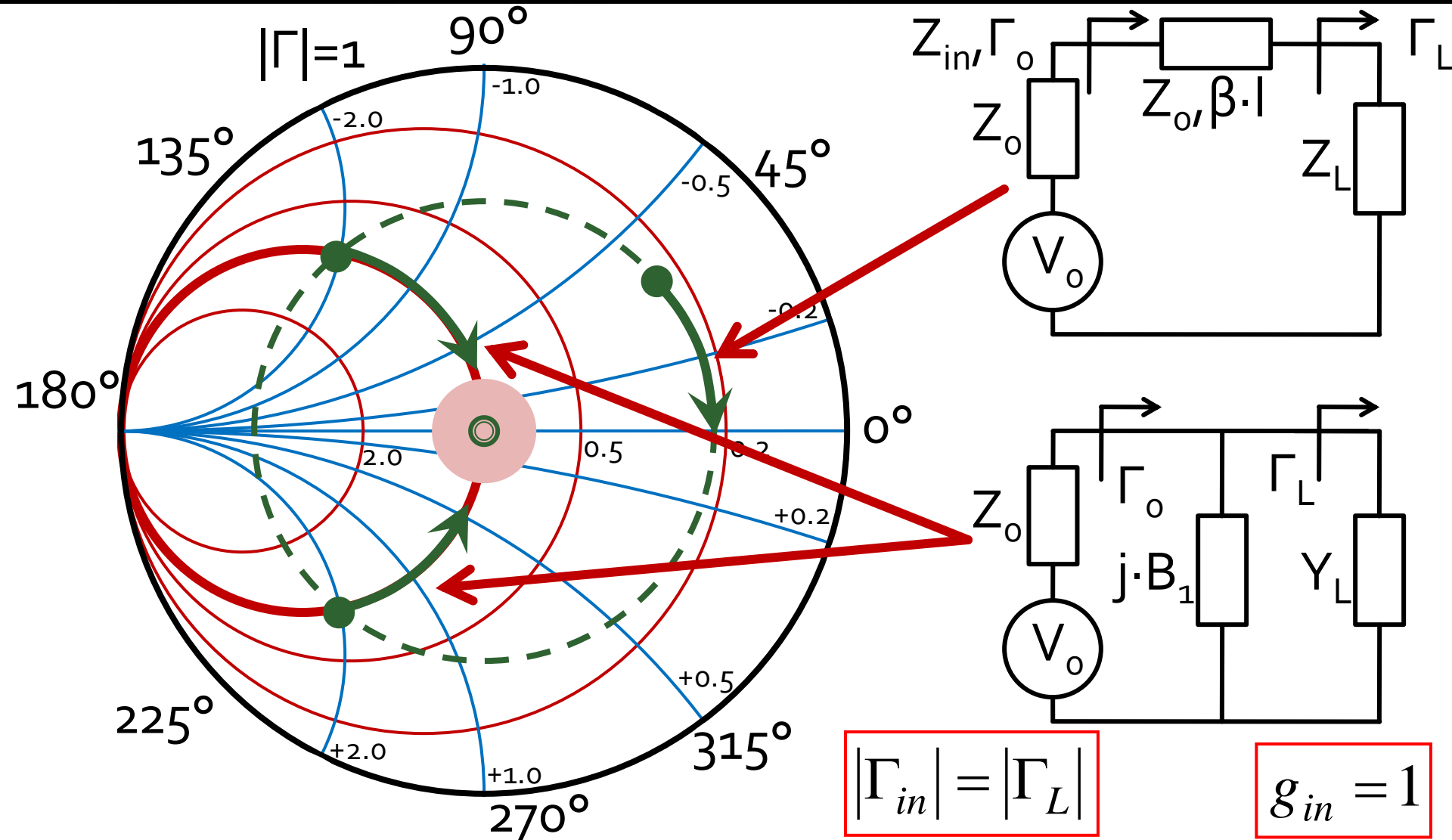
Examen / Proiect

Caz 1, Shunt Stub

- Shunt Stub (sectiune de linie in paralel)



Adaptare, linie serie + susceptanta in paralel



Calcul analitic (calcul efectiv)

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

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

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

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

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

- **solutia "cu +"** ↓

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

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

- **solutia "cu -"** ↓

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

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

Calcul analitic (calcul efectiv)

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

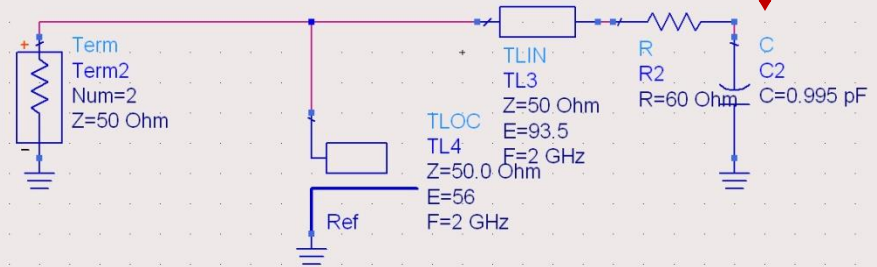
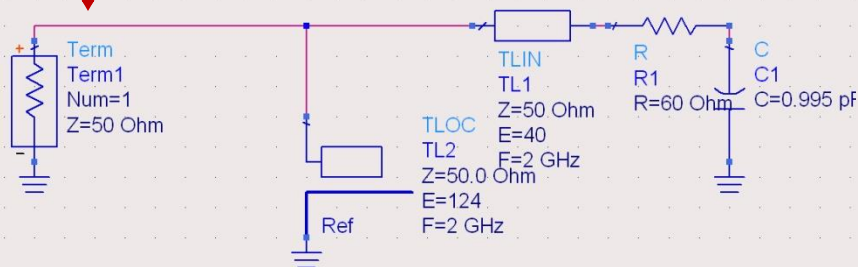
- Se alege **una** din cele doua solutii posibile
- **Semnul** (+/-) solutiei alese la **prima** ecuatie impune **semnul** solutiei utilizate la a **doua** ecuatie

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

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

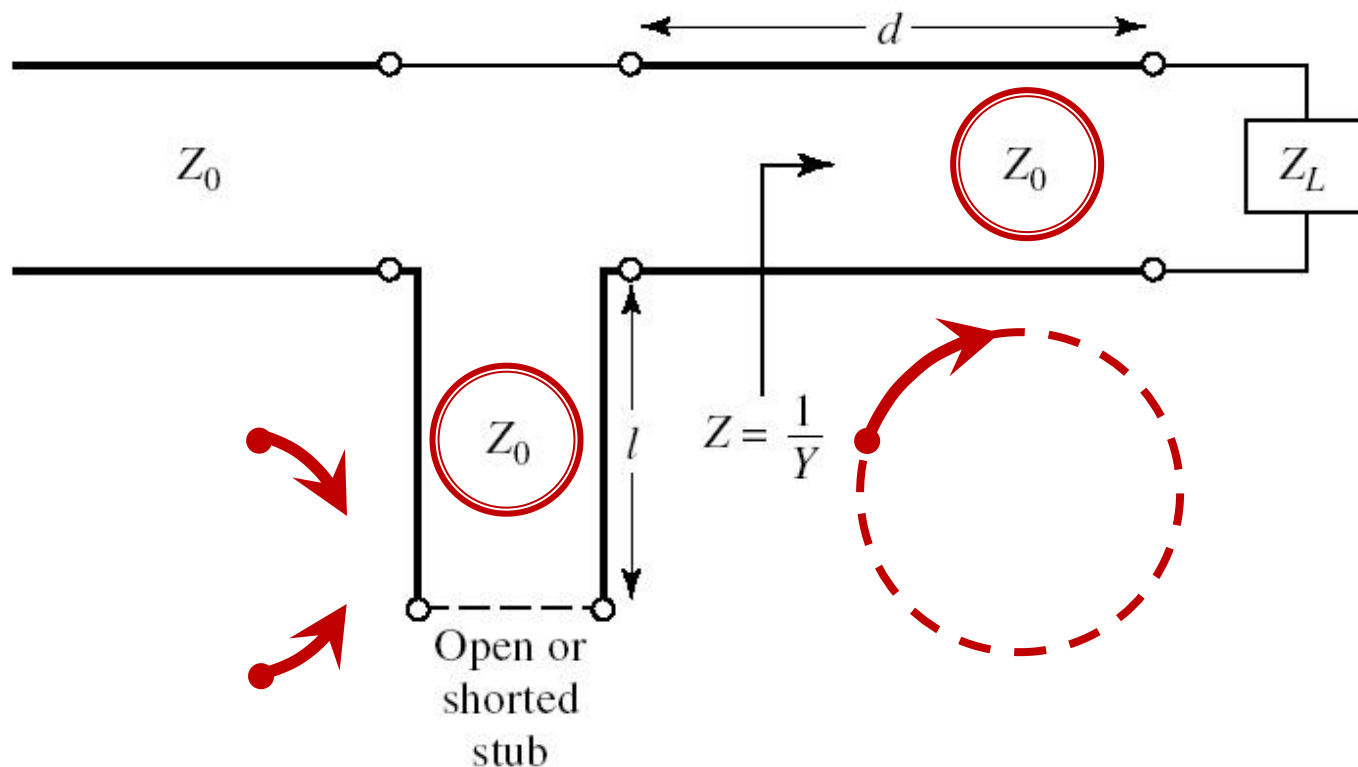
$$l_1 = \frac{93.4^\circ}{360^\circ} \cdot \lambda = 0.259 \cdot \lambda$$

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

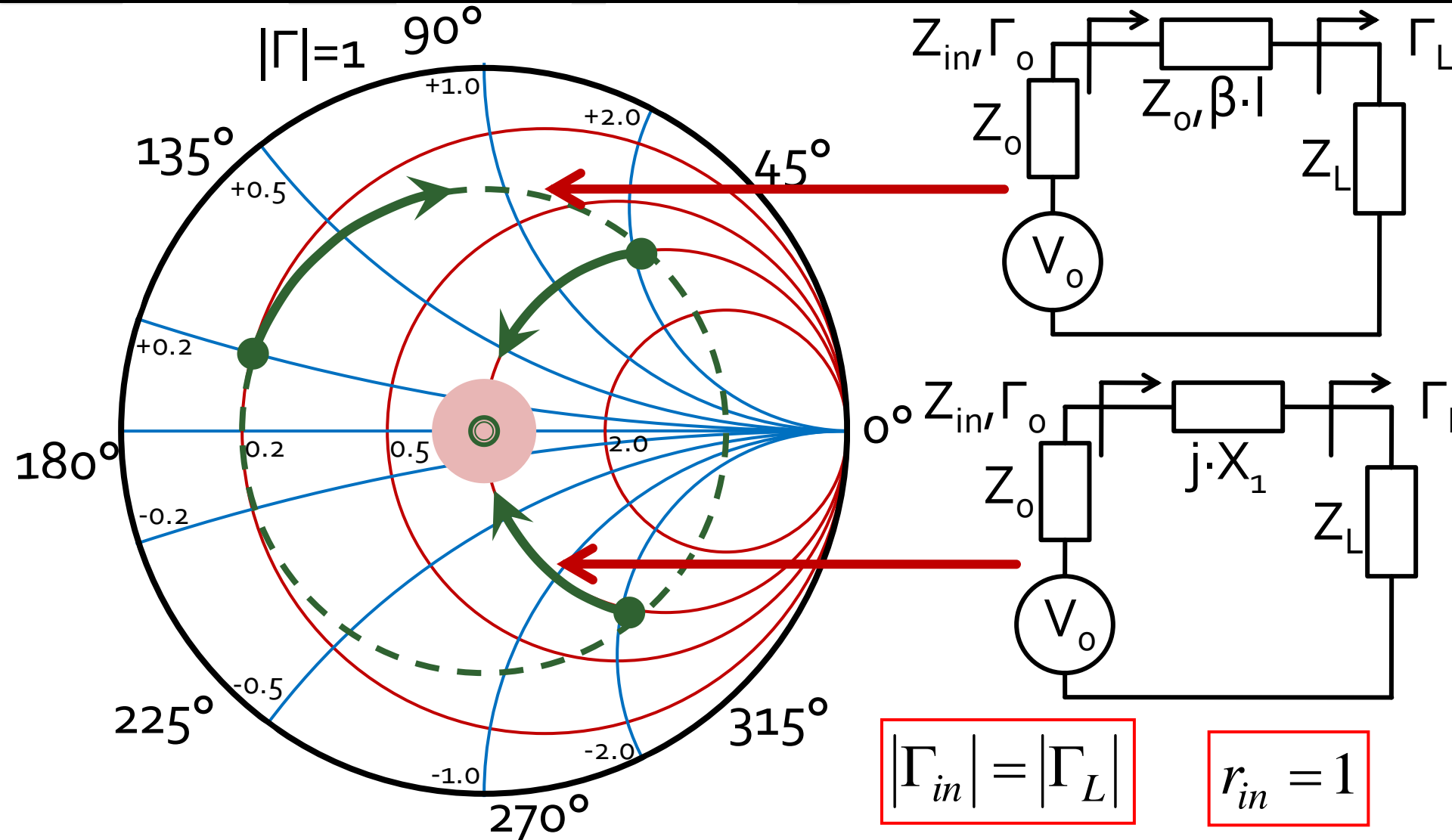


Caz 2, Series Stub

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



Adaptare, linie serie + reactanta in serie



Calcul analitic (calcul efectiv)

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

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

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

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

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

- **solutia "cu +"** ↓

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

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

- **solutia "cu -"** ↓

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

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

Calcul analitic (calcul efectiv)

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

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

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

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

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

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



Stub, observatii

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

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

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

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

- pentru stub se poate adauga/scadea 90° ($\lambda/4$) simultan cu schimbare **gol** \Leftrightarrow **scurtcircuit**

Filtre pentru microunde

Filtre pentru microunde

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

Sinteza filtrelor

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

Metoda pierderilor de insertie

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

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

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

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

- Alegerea corespunzatoare a polinoamelor M si N determina comportarea filtrului

Metoda pierderilor de insertie

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

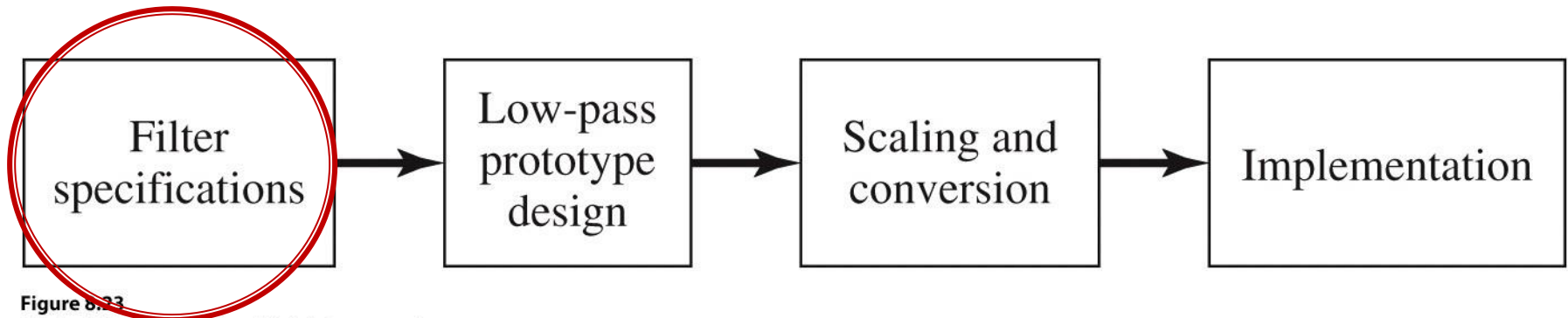


Figure 8.23
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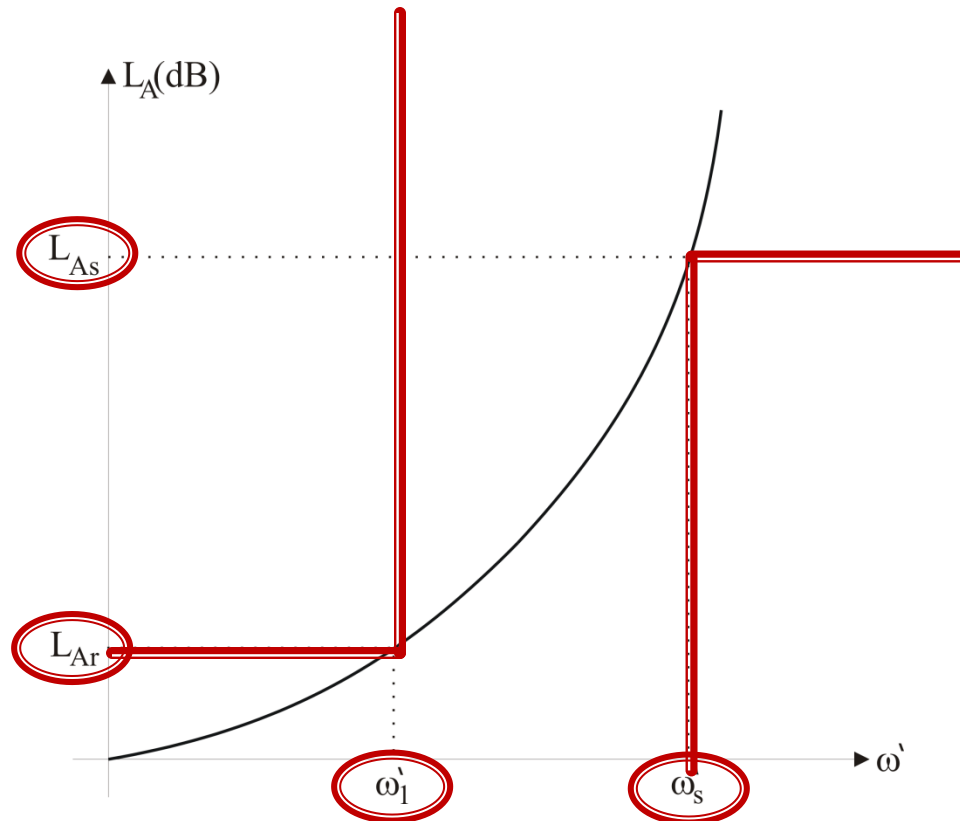
Date de proiectare

■ Atenuarea

- in banda de trecere
- in banda de oprire
- cel mai des cu atenuarile in **dB**

■ Frecventa

- banda de trecere
- banda de oprire
- frecventa de trecere ω_1' (ω_c : cuttoff) de obicei normalizata (= 1)



Metoda pierderilor de insertie

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

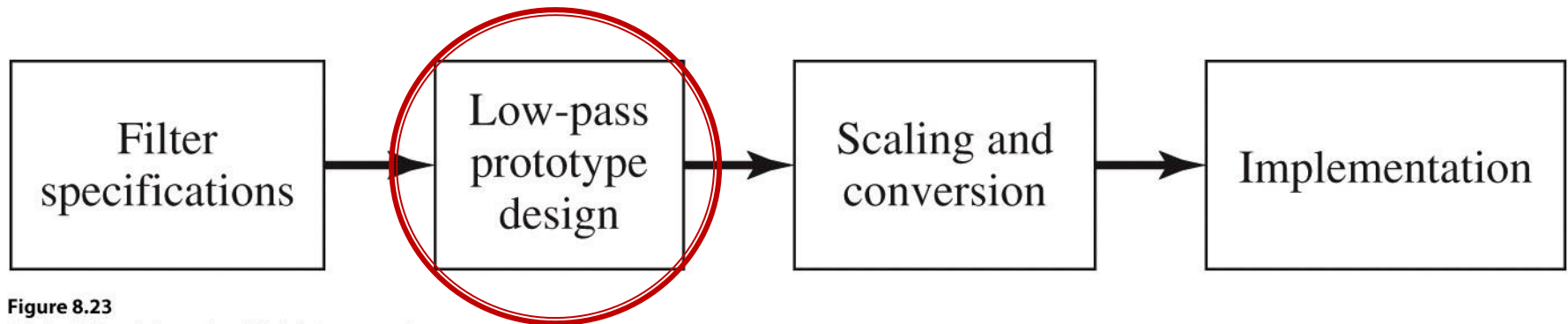


Figure 8.23

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

FTJ prototip Maxim plat/Echiriplu

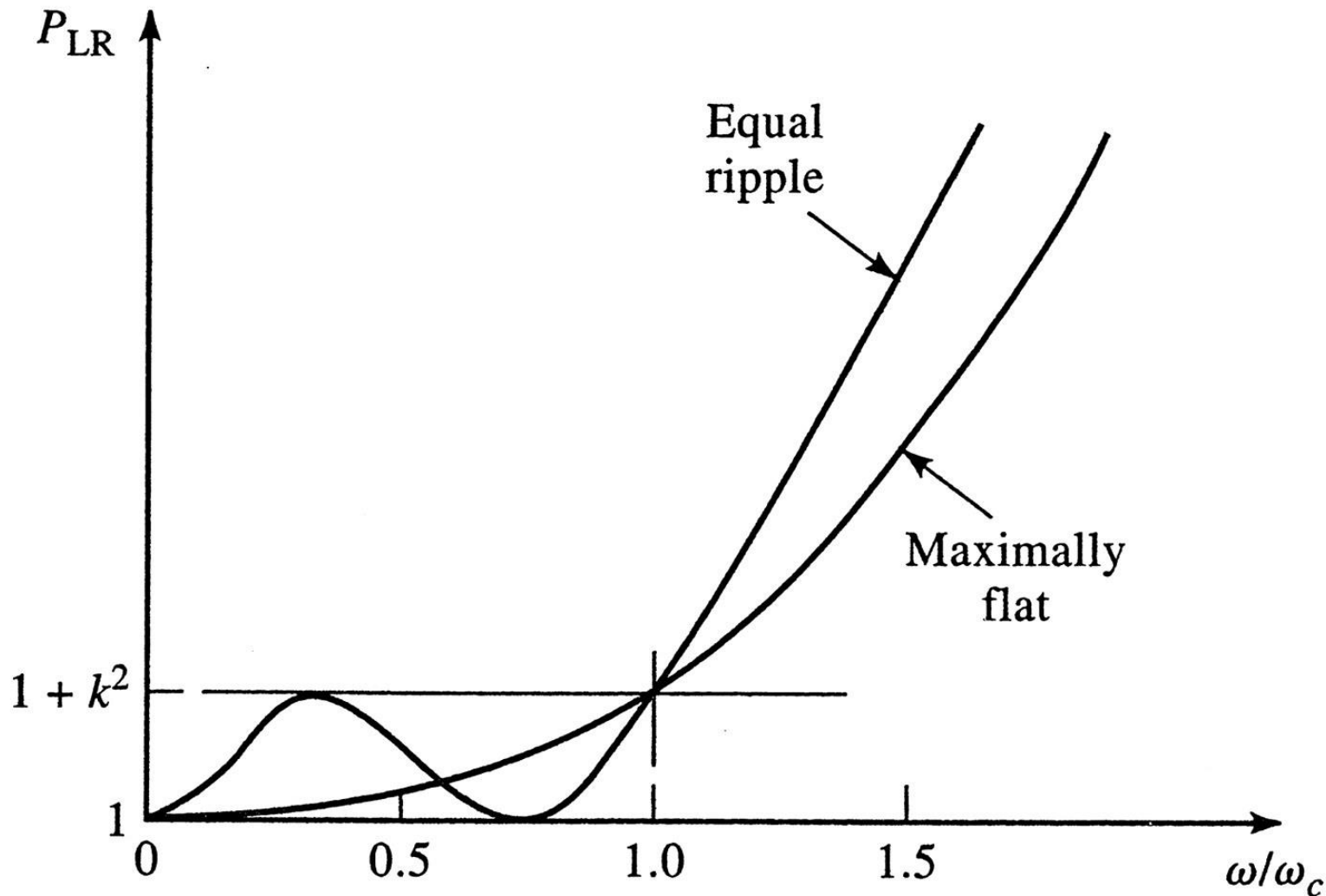


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FTJ elliptic prototip

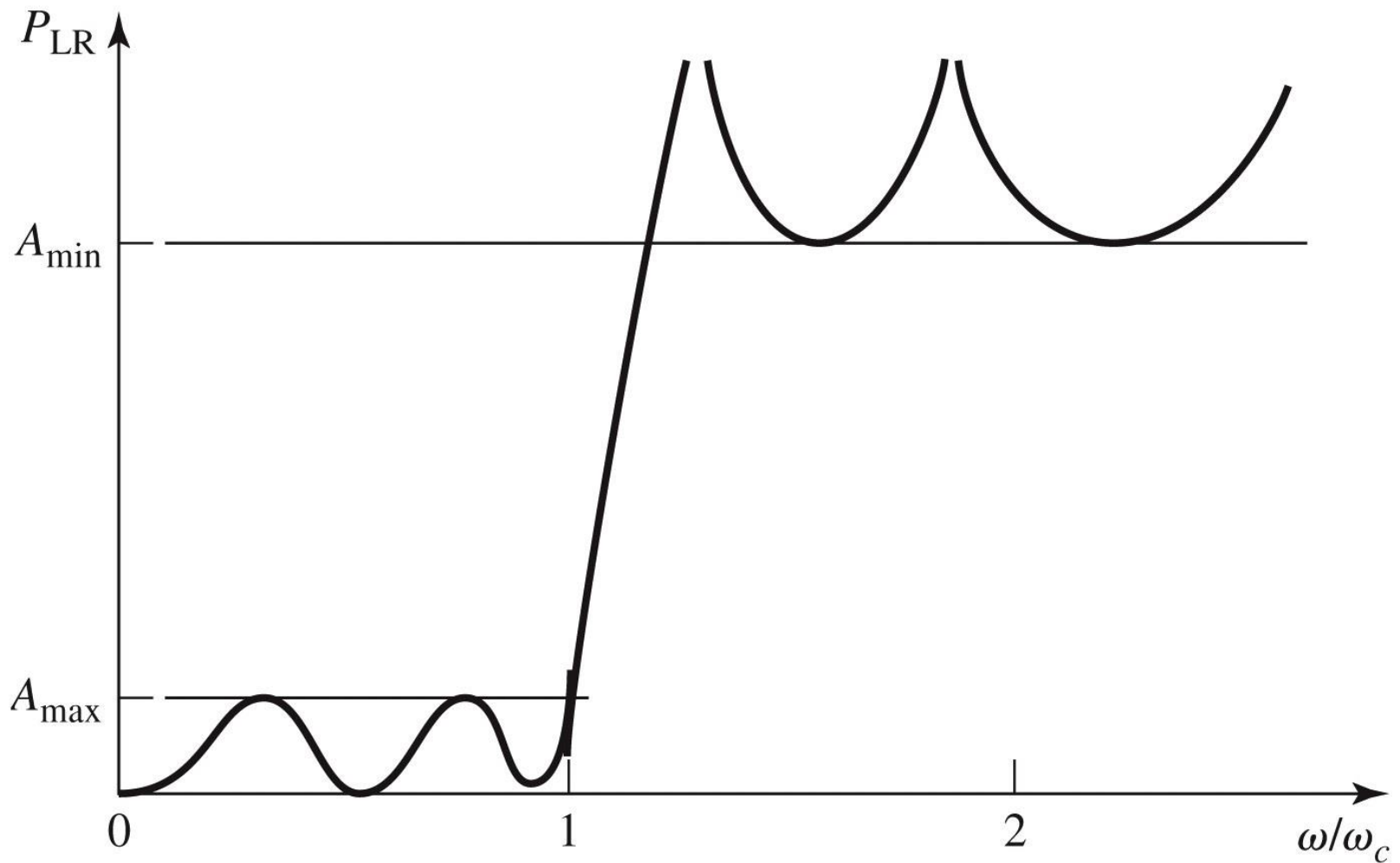


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FTJ de tip maxim plat

- Polinomul

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

- pentru $\omega \gg \omega_c$

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

- atenuarea creste cu $20 \cdot N$ dB/decada

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

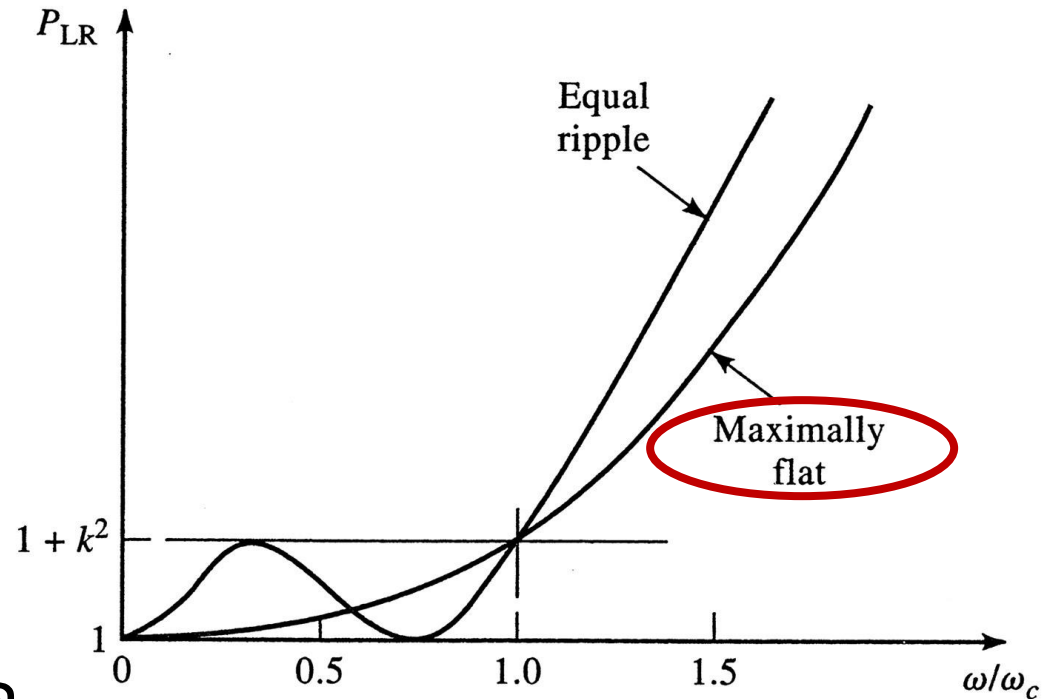


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FTJ de tip echiriplu

- Polinomul

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

- pentru $\omega \gg \omega_c$

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

- atenuarea crește cu $20 \cdot N$ dB/decada

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

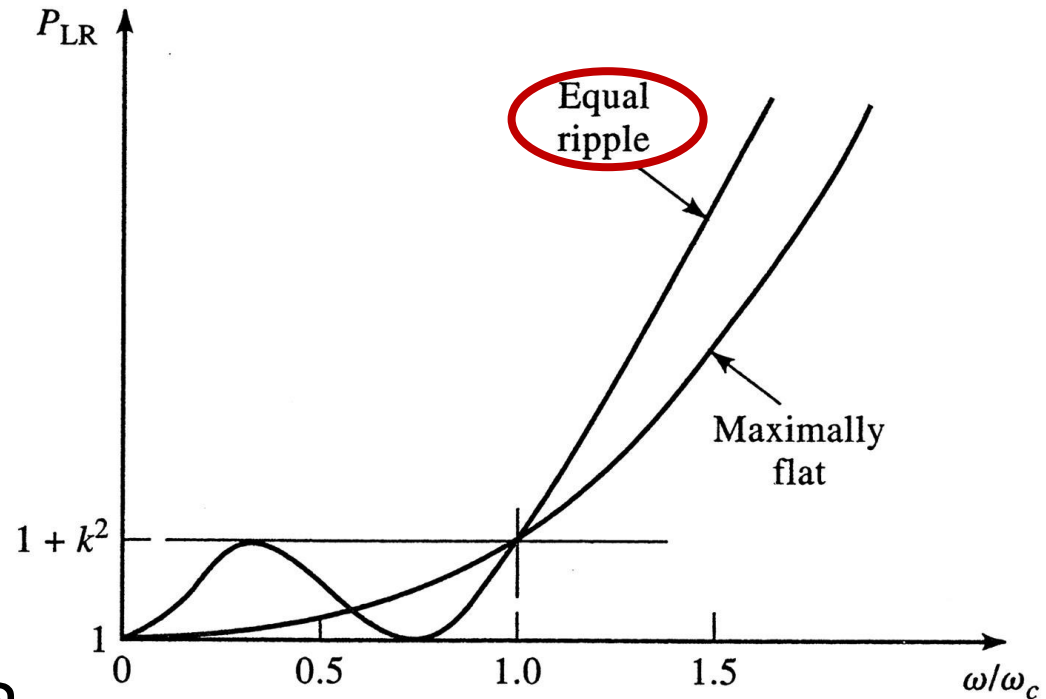
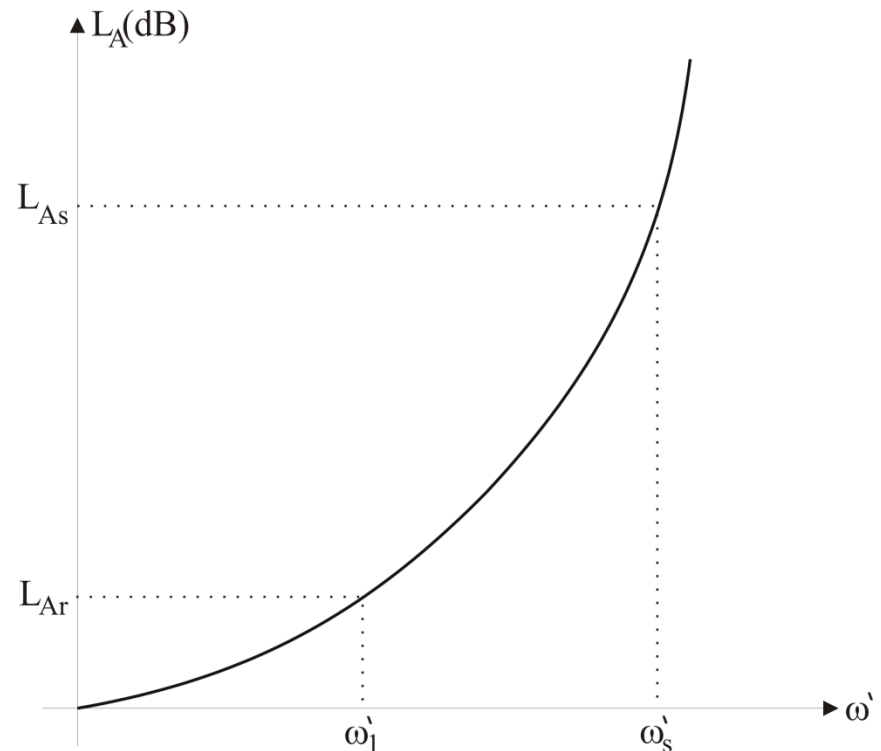


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Calculul ordinului filtrului maxim plat

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

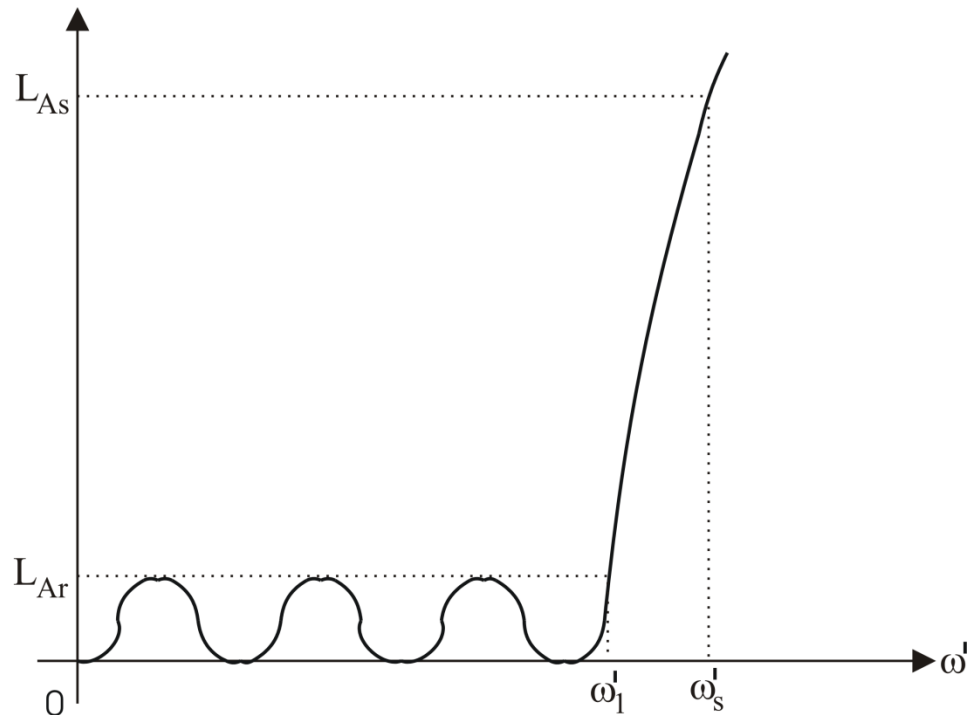
- cu atenuarile in **dB**



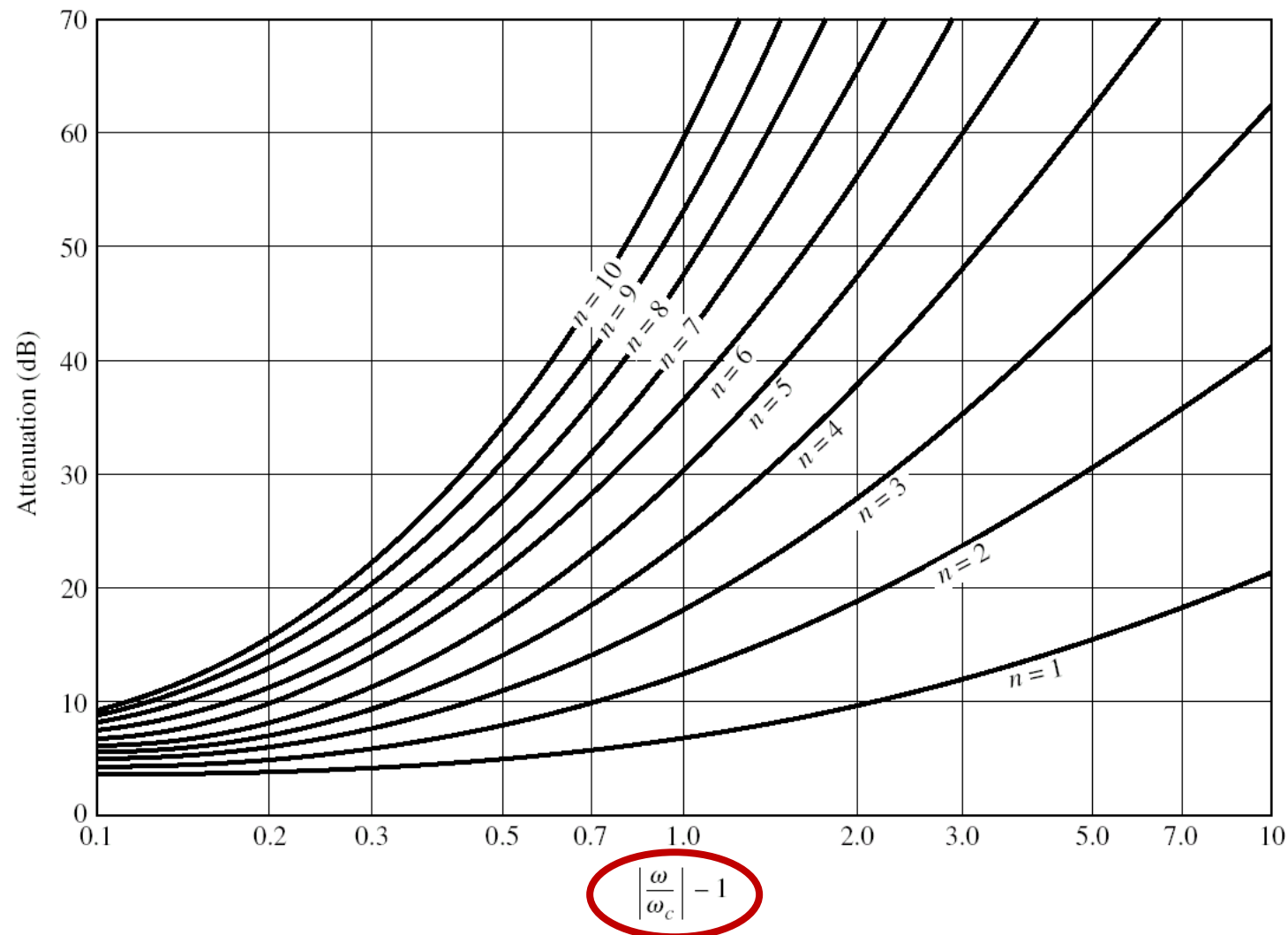
Calculul ordinului filtrului echiriplu

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

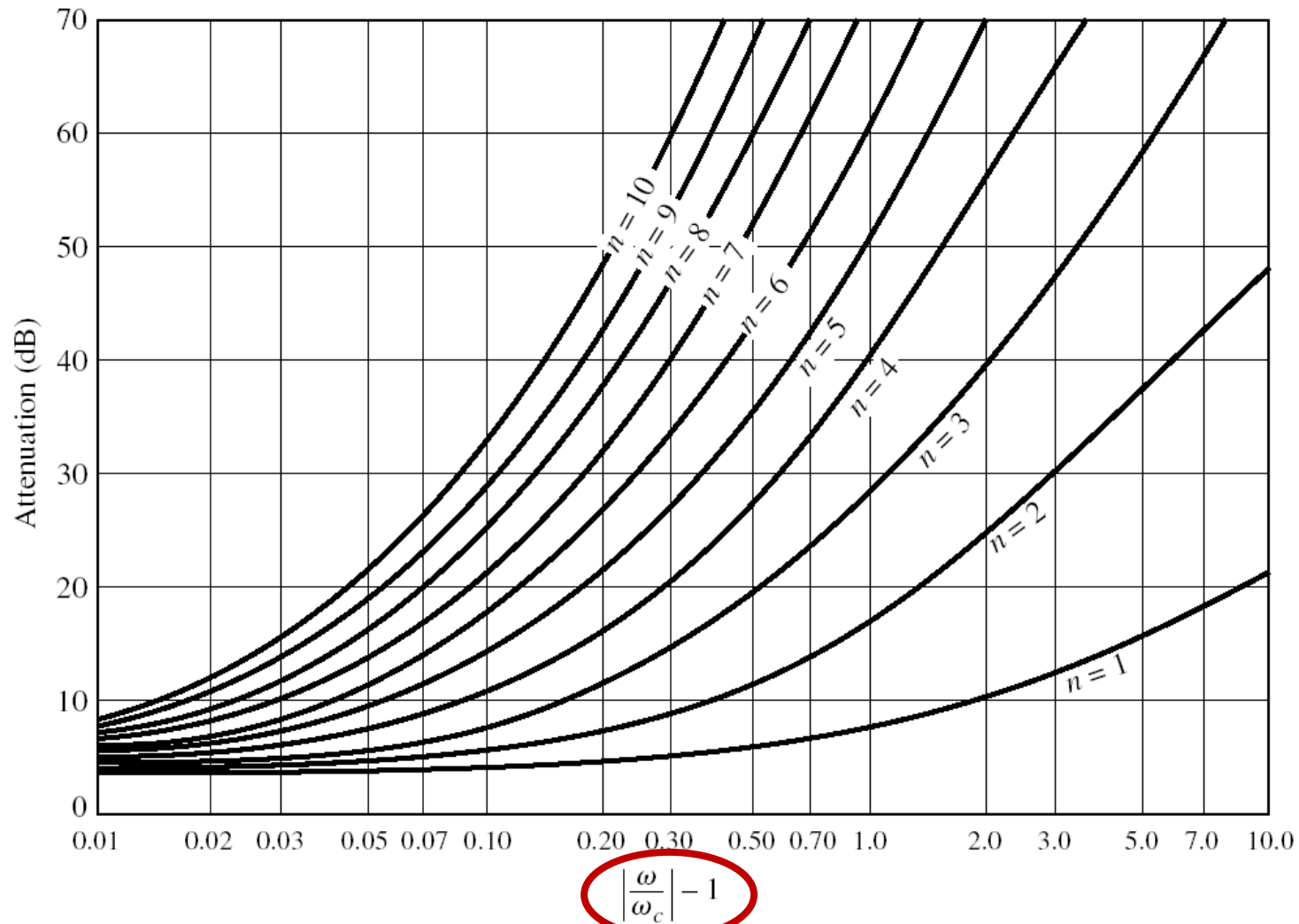
■ cu atenuările in **dB**



Raspunsul filtrului maxim plat

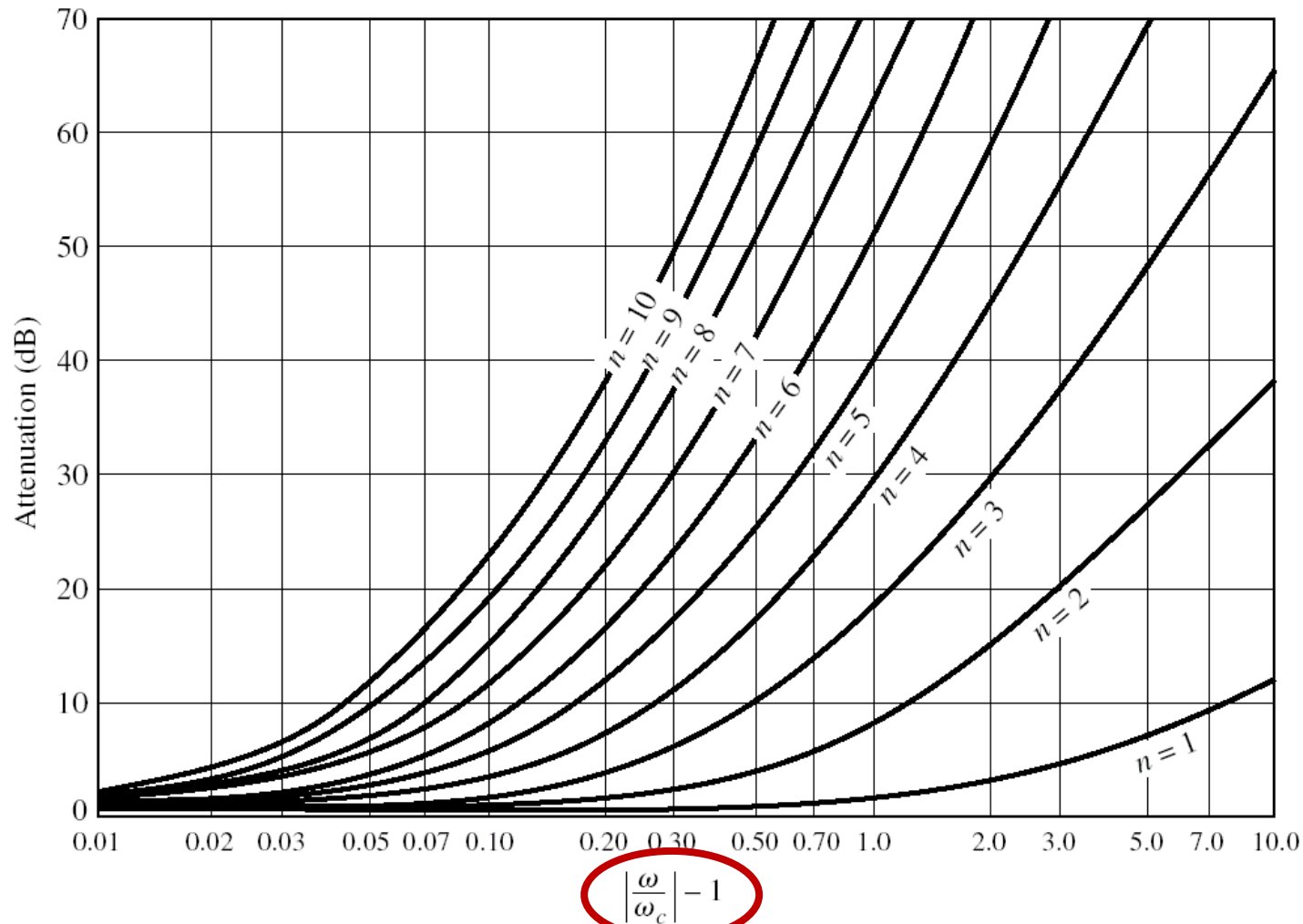


Raspunsul filtrului echiriplu 3 dB



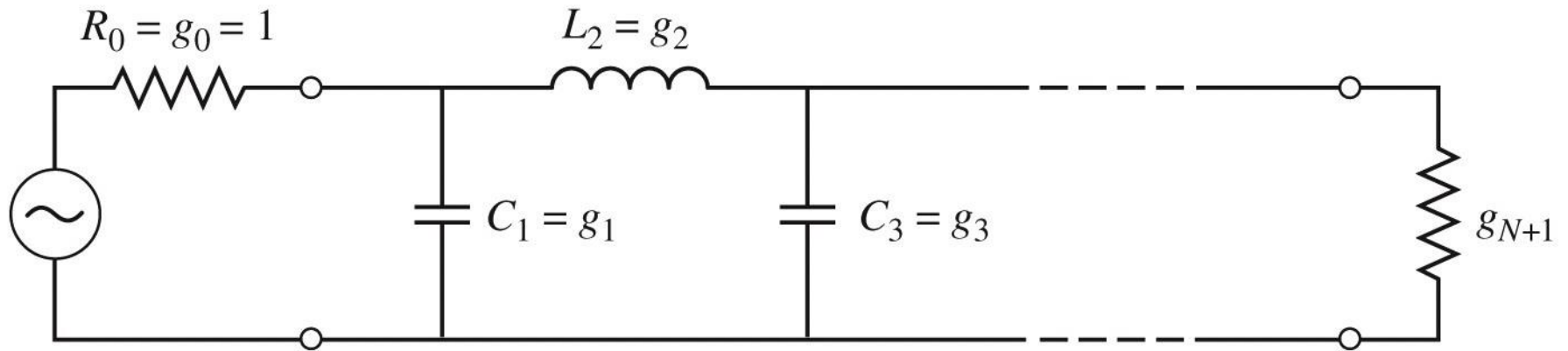
(b)

Raspunsul filtrului echiriplu 0.5 dB

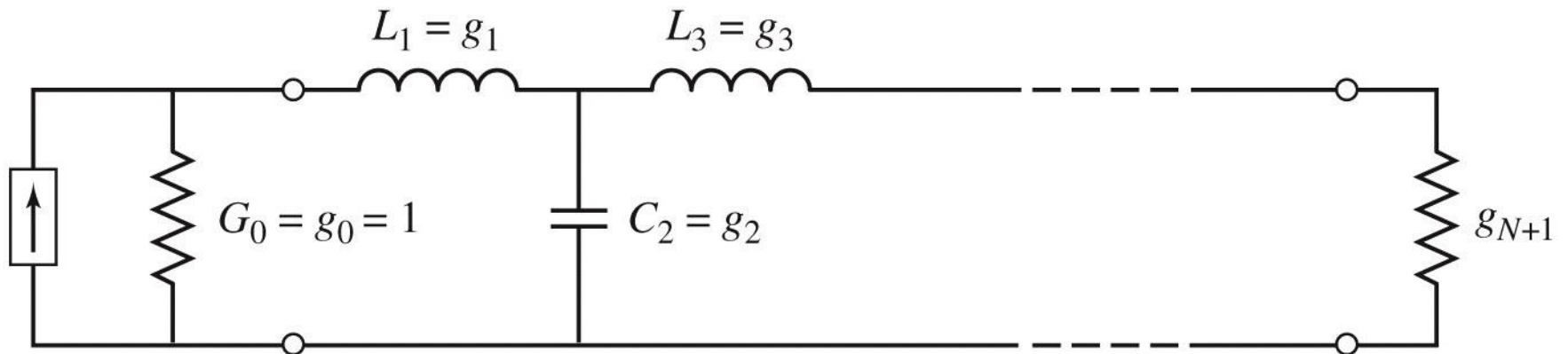


(a)

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 , $i=0, N+1$

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

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

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

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)

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

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

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

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

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

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 ...)

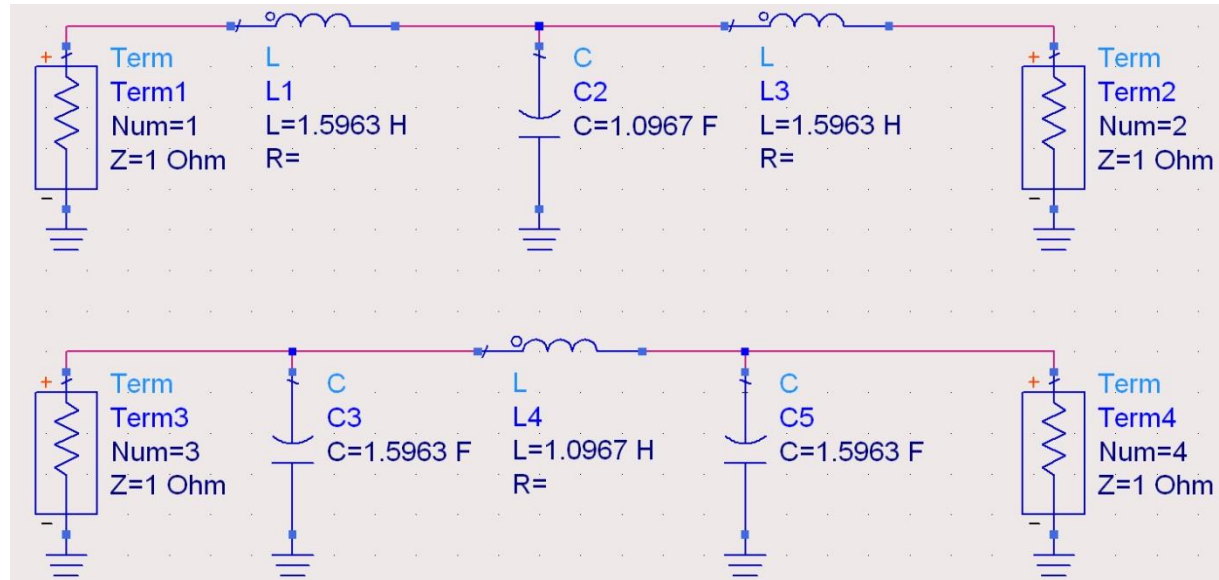
Exemplu

- Să se proiecteze un filtru trece-bandă **de ordinul 3**, 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 Ω .~~

Filtru prototip

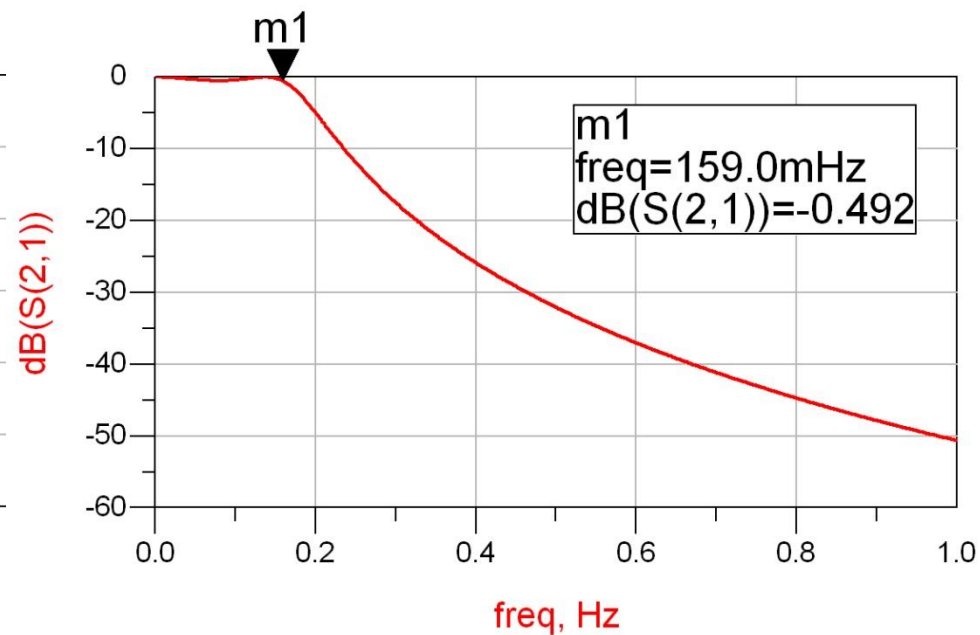
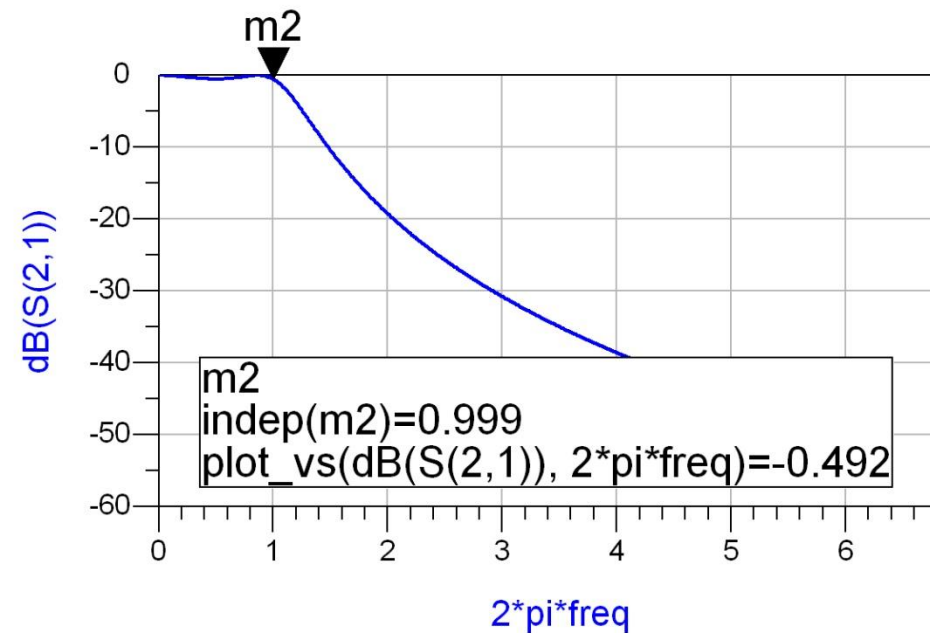
- Tabel echiriplu 0.5dB sau relatii de calcul:

- $g_1 = 1.5963 = L_1/C_3,$
- $g_2 = 1.0967 = C_2/L_4,$
- $g_3 = 1.5963 = L_3/C_5,$
- $g_4 = 1.000 = R_L$



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 $\omega_o = 1 \text{ rad/s}$ ($f_o = 0.159 \text{ Hz}$)
 - 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 taiere $\omega_o = 1 \text{ rad/s}$ ($f_o = 0.159 \text{ Hz}$)
 - conectate la intrare la o rezistenta $R = 1$

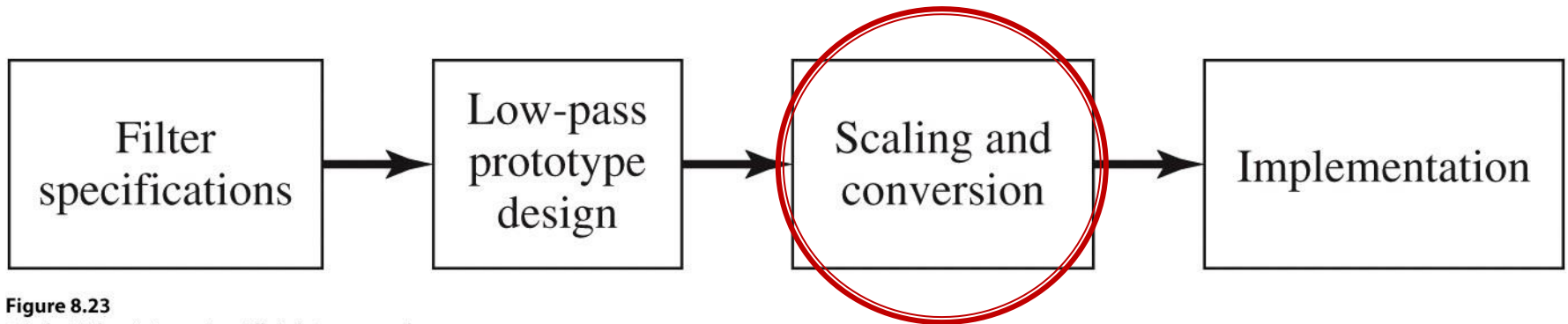


Figure 8.23

Scalarea in impedanta

- Pentru a determina filtrul care lucreaza cu o alta rezistenta de intrare (R_0) se multiplica toate impedantele din circuit cu aceasta impedanta (cu " ' " se noteaza elementele noi)

$$R'_s = R_0 \cdot (R_s = 1)$$

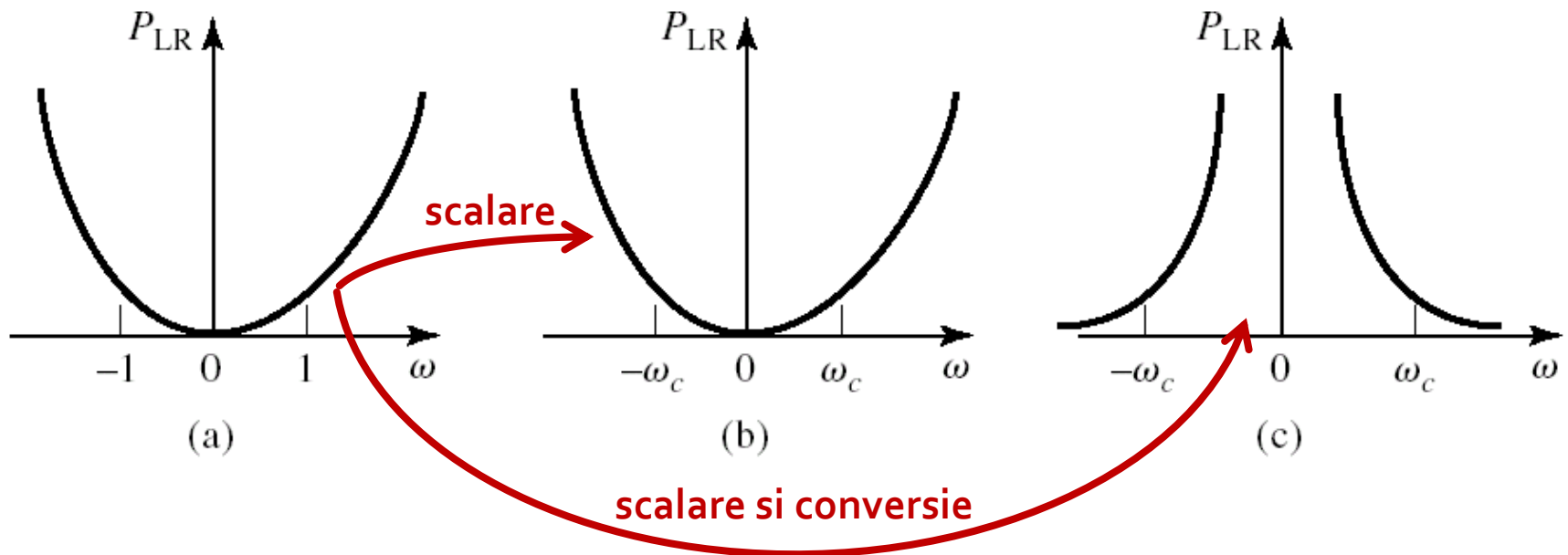
$$R'_L = R_0 \cdot R_L$$

$$L' = R_0 \cdot L$$

$$C' = \frac{C}{R_0}$$

Scalarea in frecventa

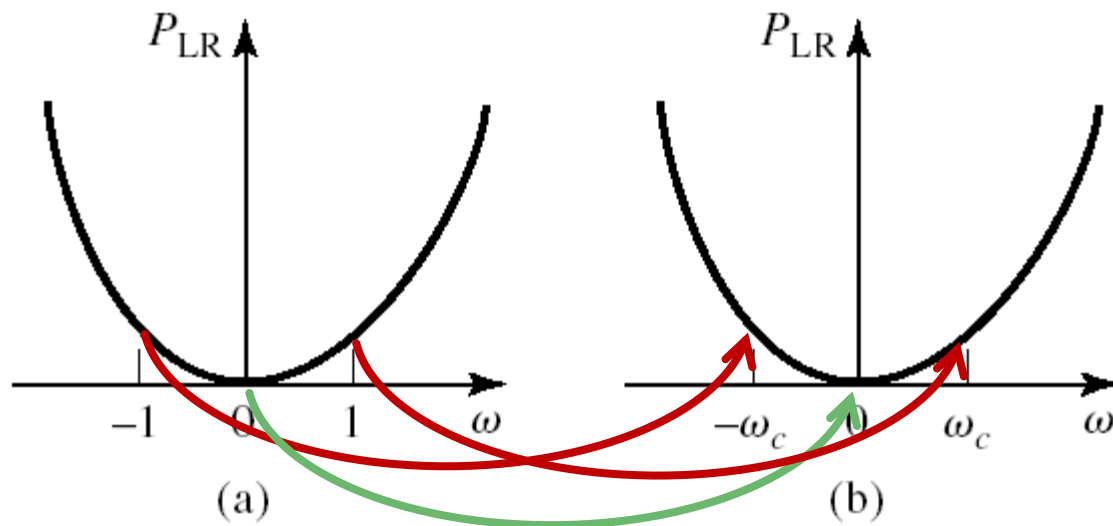
- modificarea frecventei de taiere – (fig. b)
- modificarea caracteristicii de atenuare (de exemplu FTJ \rightarrow FTS – fig. c)



Scalarea in frecventa

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

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



Scalarea in frecventa

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

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

- Echivalent cu largirea caracteristicii de frecventa

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

$$j \cdot X_k = j \cdot \frac{\omega}{\omega_c} \cdot L_k = j \cdot \omega \cdot L'_k$$

$$j \cdot B_k = j \cdot \frac{\omega}{\omega_c} \cdot C_k = j \cdot \omega \cdot C'_k$$

Scalarea FTJ \rightarrow FTJ

- Noile valori cu scalarea in frecventa

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

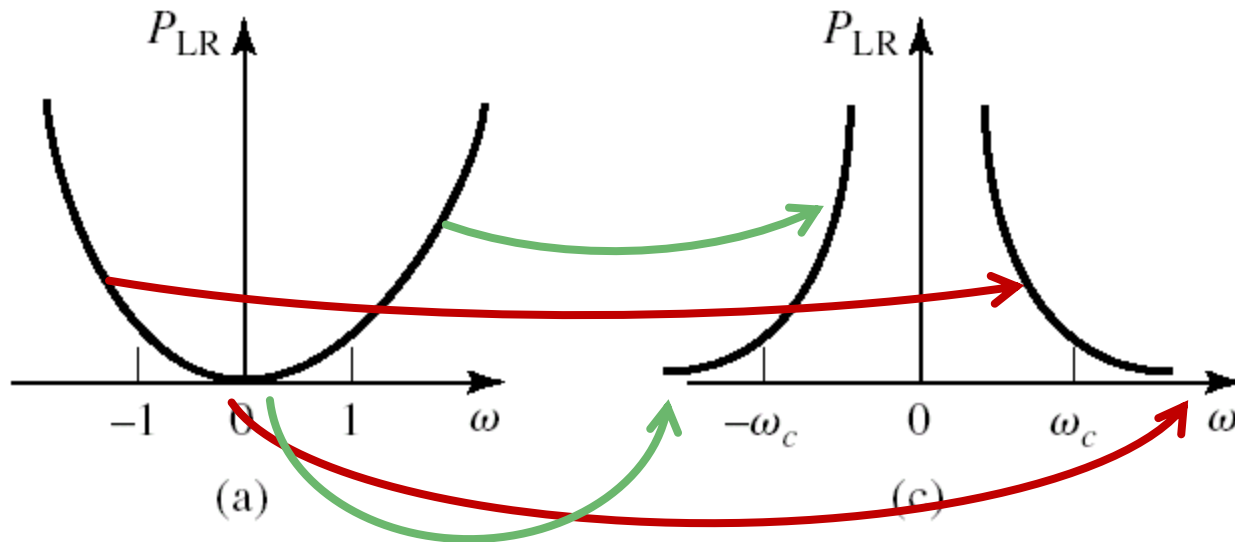
- Daca se aplica simultan si scalarea in impedanta

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

Conversie si scalare FTJ \rightarrow FTS

- Se face schimbarea de variabila:

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



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 capacitati serie, iar capacitatile paralel se transforma in inductante paralel

Conversie si scalare FTJ \rightarrow FTB

- Se face schimbarea de variabila:

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

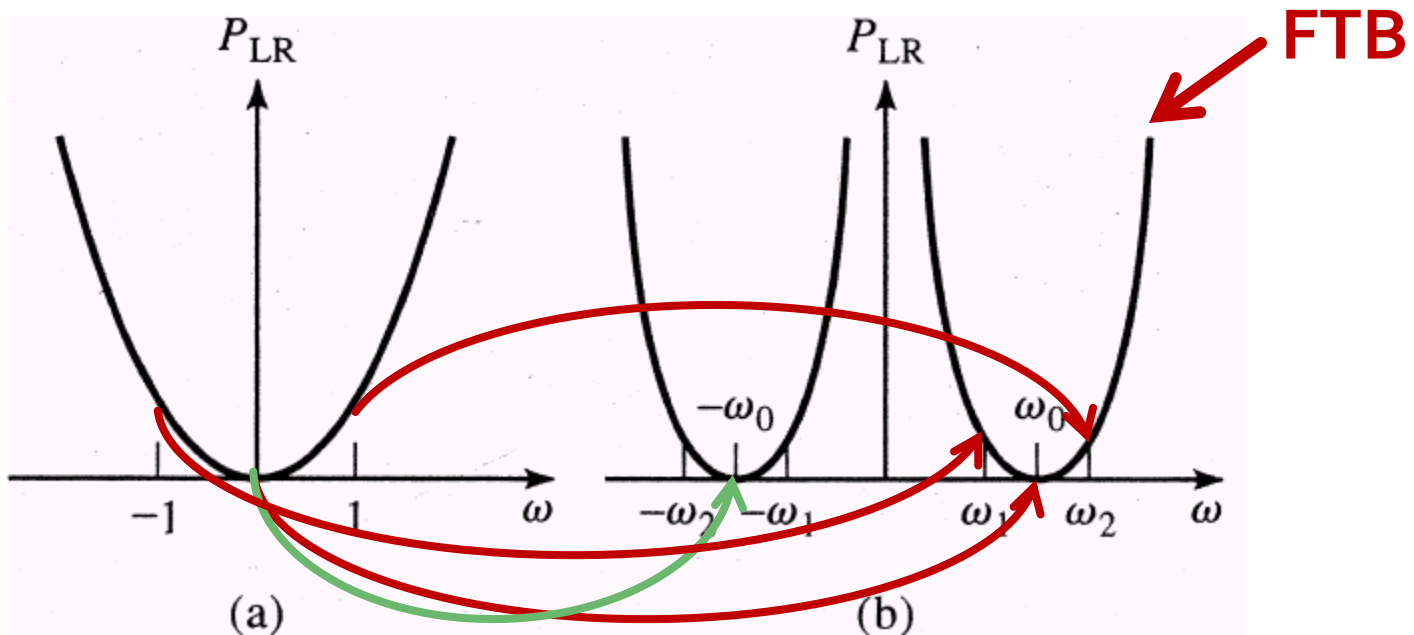
- unde intervin banda fractionara si frecventa centrala

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

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

Conversie si scalare FTJ \rightarrow FTB

$$\begin{aligned}\omega = \omega_0 &\rightarrow \frac{1}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) = \frac{1}{\Delta} \left(\frac{\omega_0}{\omega_0} - \frac{\omega_0}{\omega_0} \right) = 0 & \omega = -\omega_0 &\rightarrow \frac{1}{\Delta} \left(\frac{-\omega_0}{\omega_0} - \frac{\omega_0}{-\omega_0} \right) = 0 \\ \omega = \omega_1 &\rightarrow \frac{1}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) = \frac{1}{\Delta} \left(\frac{\omega_1^2 - \omega_0^2}{\omega_0 \cdot \omega_1} \right) = -1 \\ \omega = \omega_2 &\rightarrow \frac{1}{\Delta} \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) = \frac{1}{\Delta} \left(\frac{\omega_2^2 - \omega_0^2}{\omega_0 \cdot \omega_2} \right) = 1\end{aligned}$$



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**

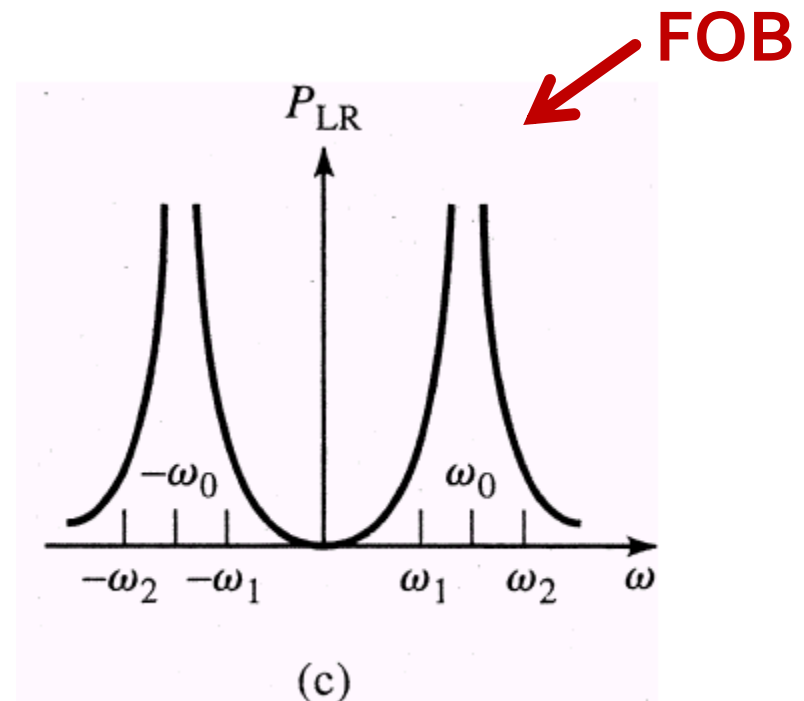
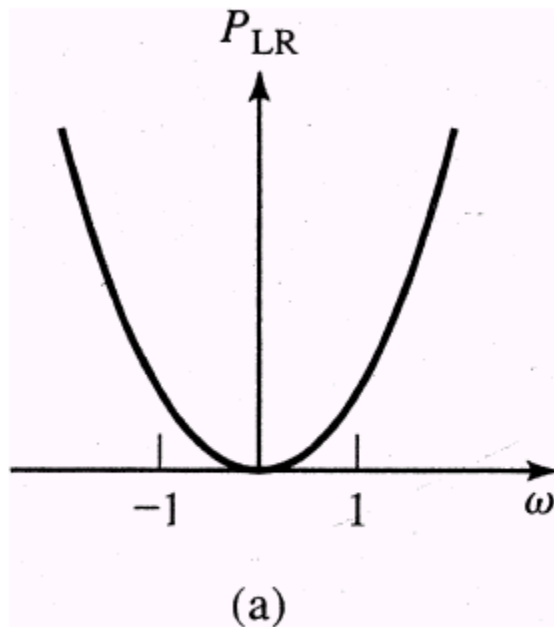
$$L'_k = \frac{L_k}{\Delta \cdot \omega_0} \quad C'_k = \frac{\Delta}{\omega_0 \cdot L_k}$$

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

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

Conversie si scalare FTJ \rightarrow FOB

$$\omega \leftarrow -\Delta \cdot \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right)^{-1} \quad \omega = \omega_0 \rightarrow \frac{-\Delta}{\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right)} = \frac{-\Delta}{\left(\frac{\omega_0}{\omega_0} - \frac{\omega_0}{\omega_0} \right)} \rightarrow \pm\infty$$



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


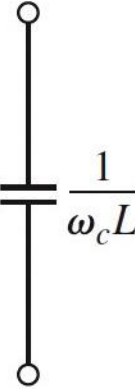
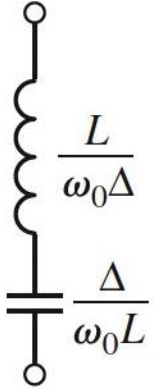
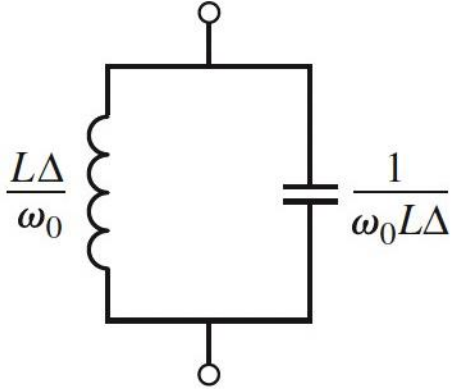
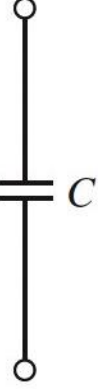
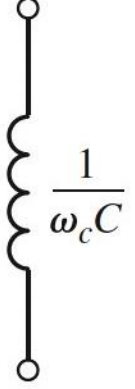
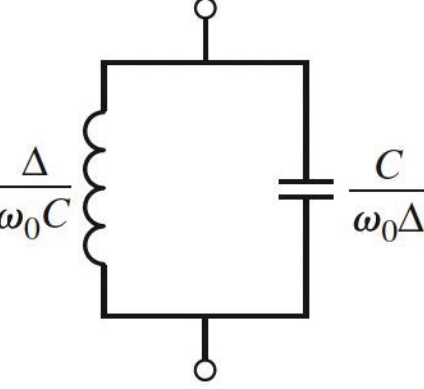
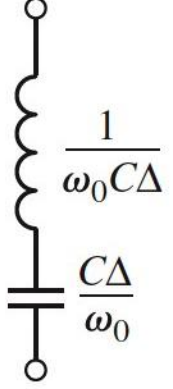
Low-pass	High-pass	Bandpass	Bandstop
			
			

Table 8.6

Exemplu

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

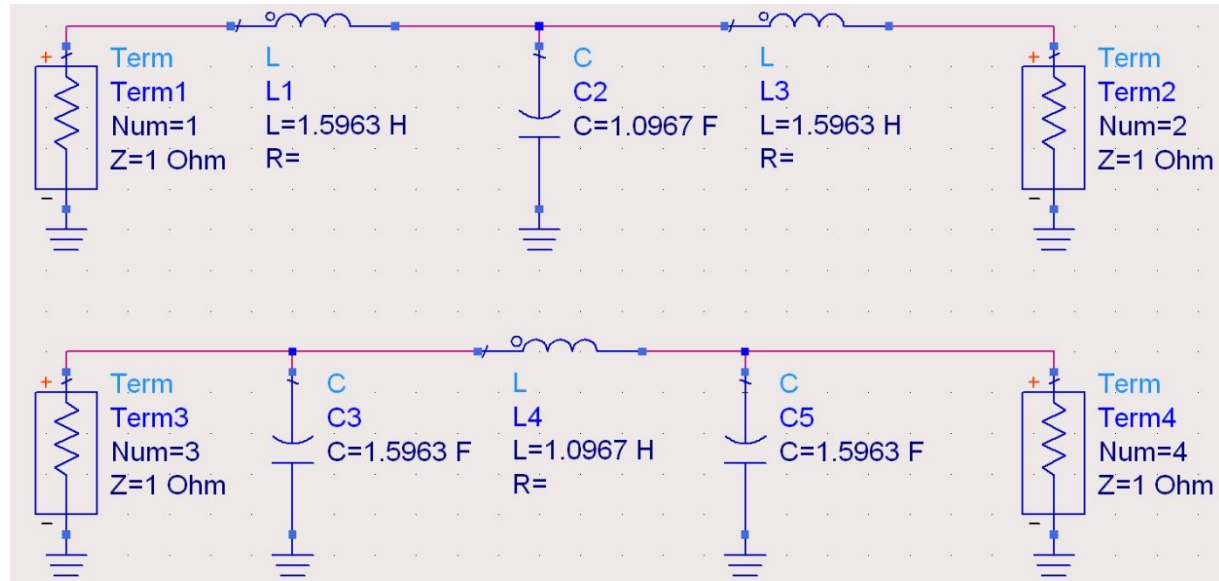
$$\omega_0 = 2 \cdot \pi \cdot 1 \text{ GHz} = 6.283 \cdot 10^9 \text{ rad} / \text{s}$$

$$\Delta = 0.1$$

Filtru prototip

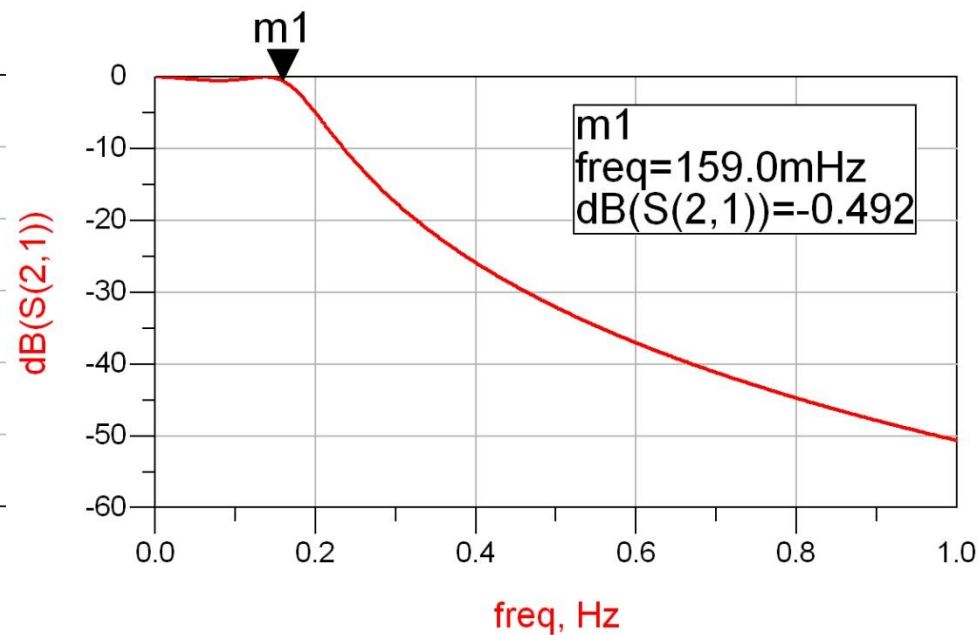
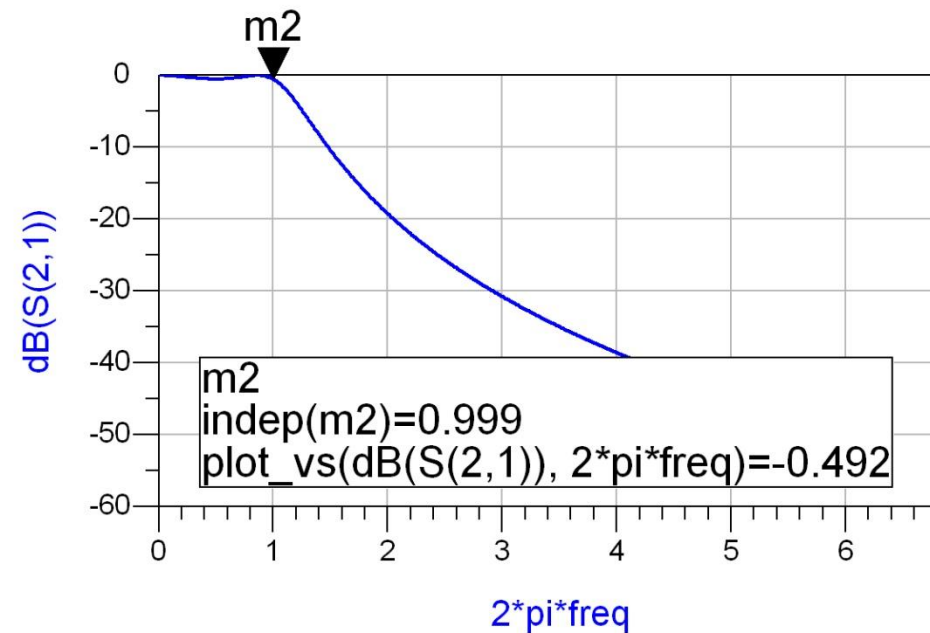
- Tabel echiriplu 0.5dB sau relatii de calcul:

- $g_1 = 1.5963 = L_1/C_3,$
- $g_2 = 1.0967 = C_2/L_4,$
- $g_3 = 1.5963 = L_3/C_5,$
- $g_4 = 1.000 = R_L$



Filtru prototip

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



Scalare frecventa / FTB

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

$$g_1 = 1.5963 = L_1,$$

$$g_2 = 1.0967 = C_2,$$

$$g_3 = 1.5963 = L_3,$$

$$g_4 = 1.000 = R_L$$

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

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

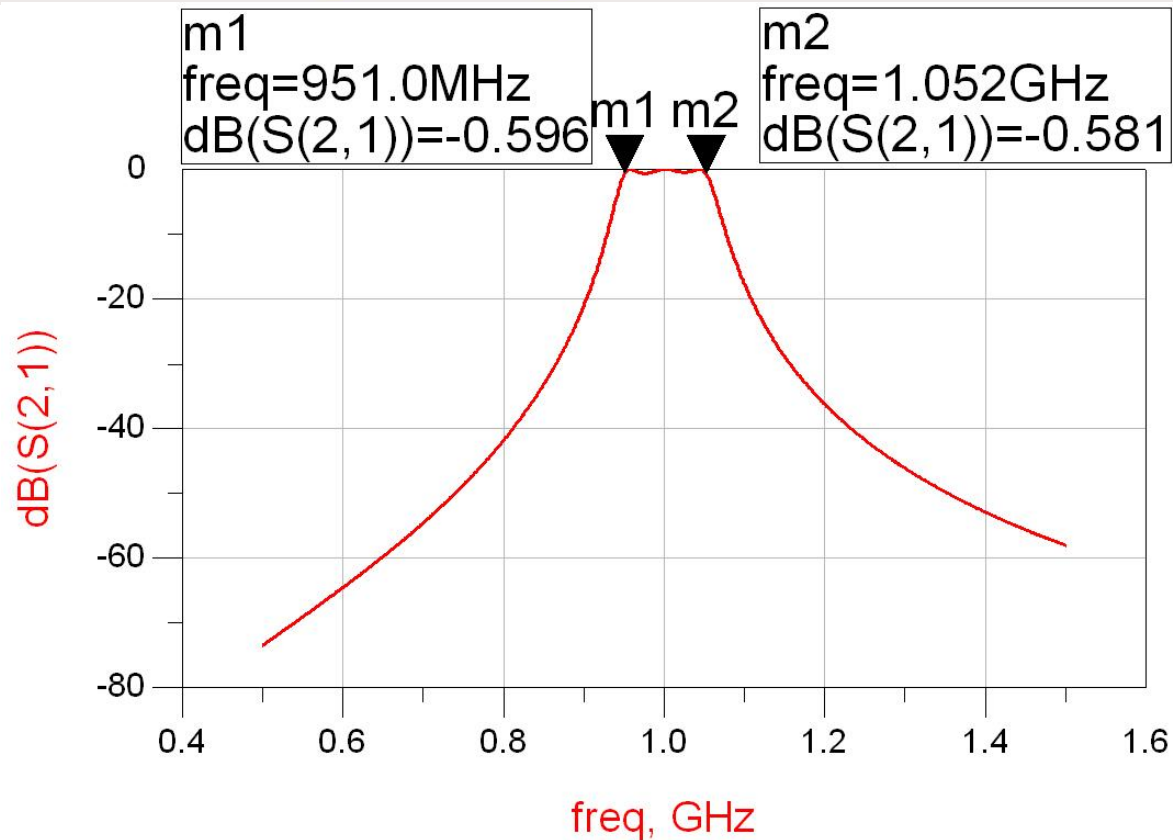
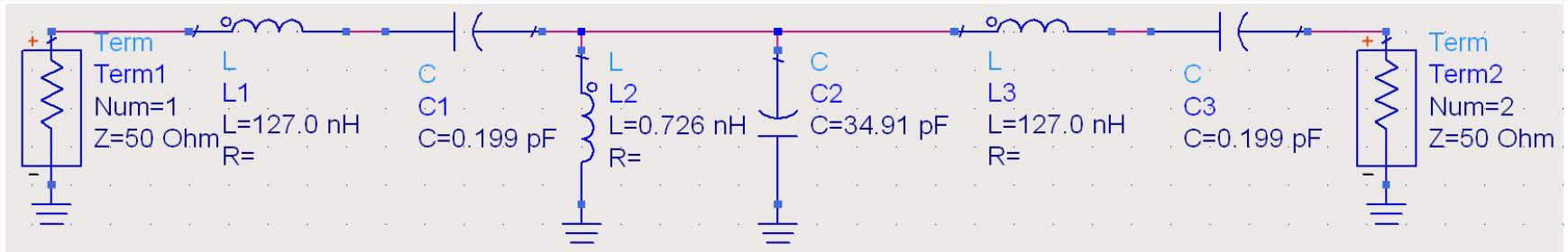
$$L'_2 = \frac{\Delta \cdot R_0}{\omega_0 \cdot C_2} = 0.726 \text{ nH}$$

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

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

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

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

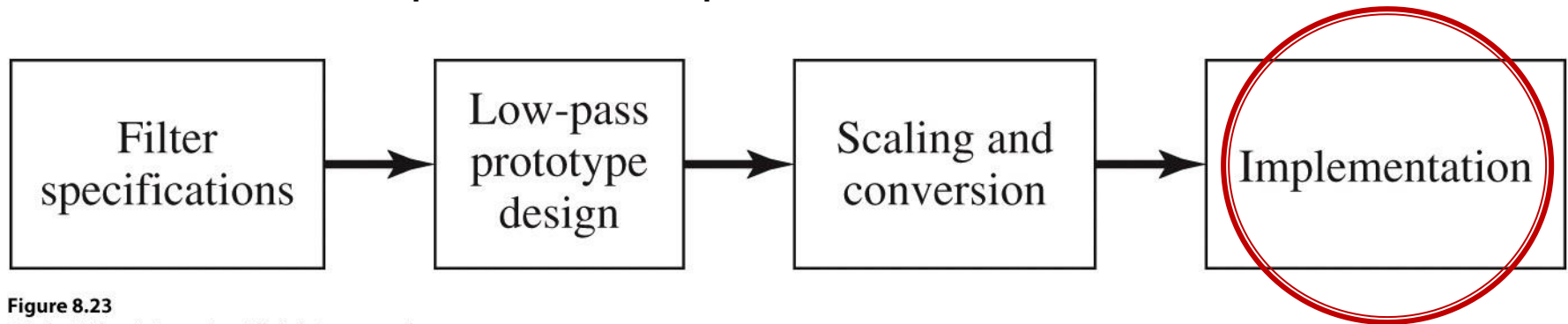


Figure 8.23

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 $Z_{in,g} = j \cdot X_C = \frac{1}{j \cdot B_C}$

- inductiva $Z_{in,sc} = j \cdot X_L$

$$Z_0 \leftrightarrow \frac{1}{C} \quad \tan \beta \cdot l \leftrightarrow \omega$$

$$Z_0 \leftrightarrow L \quad \tan \beta \cdot l \leftrightarrow \omega$$

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 capacitati

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

- Filtrul echivalent in Ω are frecventa de taiere la:

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

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 $4 \cdot \omega_c$

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

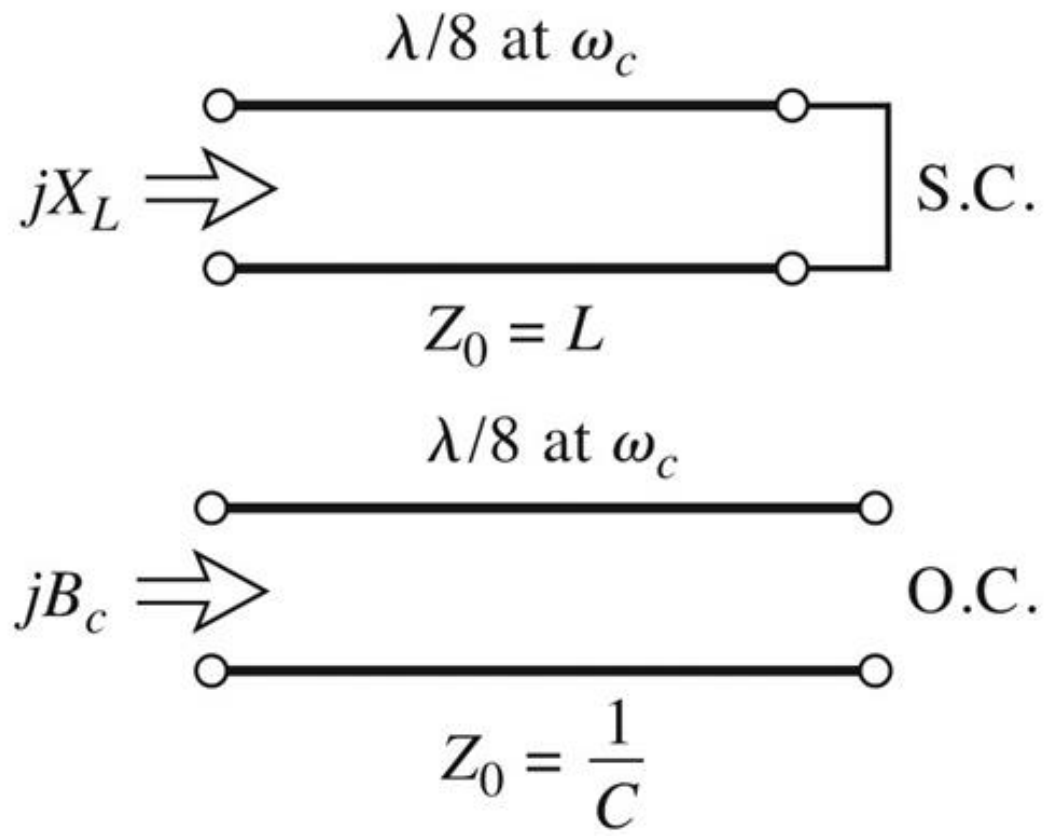
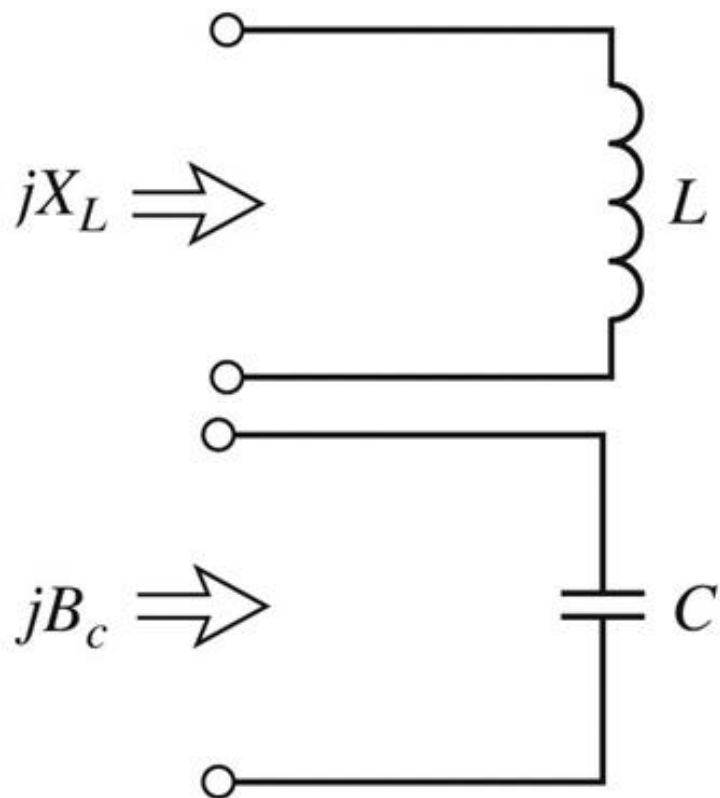
$$\beta \cdot l \Big|_{\omega=\omega_c} = \frac{\pi}{4} \Rightarrow \frac{\omega_c \cdot l}{v_p} = \frac{\pi}{4} \Rightarrow \pi = \frac{(4 \cdot \omega_c) \cdot l}{v_p}$$

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

$$P_{LR}(4 \cdot \omega_c) = P_{LR}(0) \qquad P_{LR}(3 \cdot \omega_c) = P_{LR}(-\omega_c) \qquad P_{LR}(5 \cdot \omega_c) = P_{LR}(\omega_c)$$

Transformarea Richards

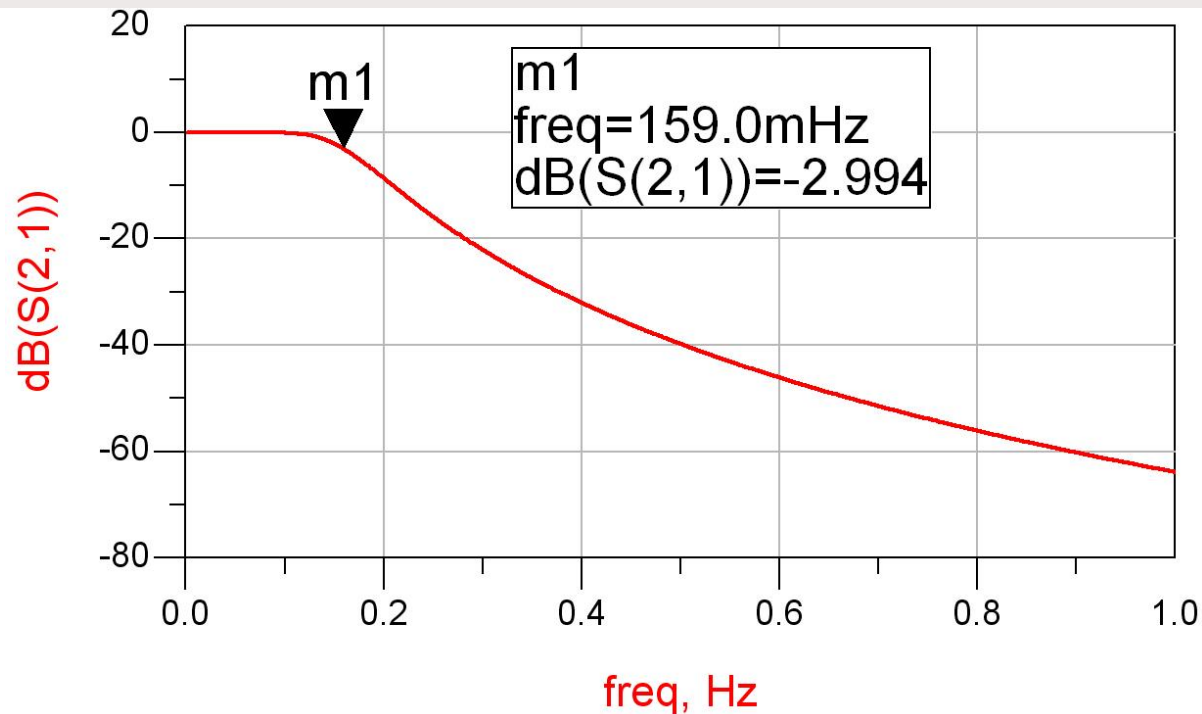
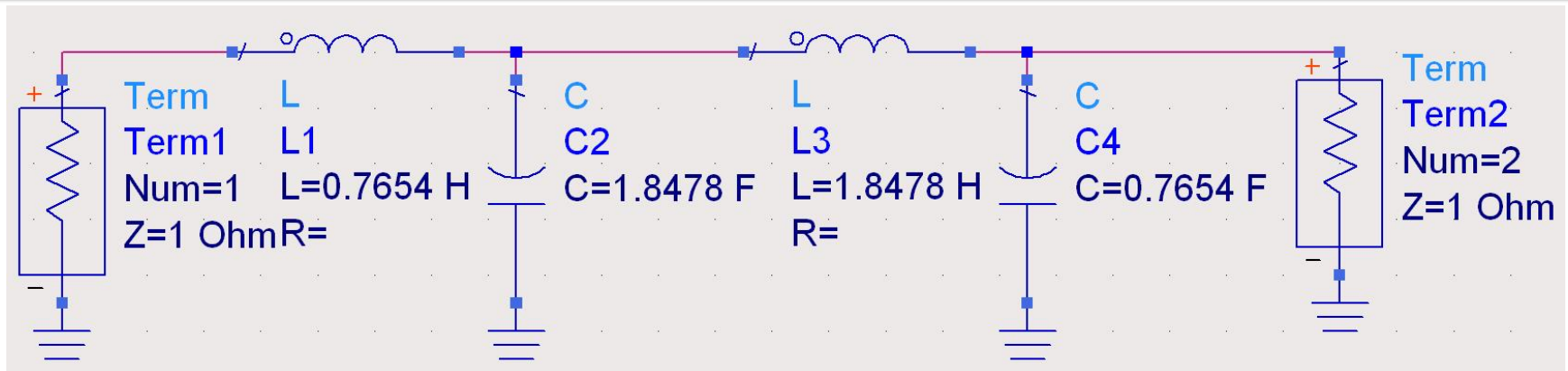
- permite obtinerea cu sectiuni de linii a inductantelor si capacitatilor **dupa** scalarea prototipului pentru functia corespunzatoare (FTJ/FTS/FTB /FOB)



Exemplu

- Filtru trece jos de ordinul 4, cu frecventa de taiere 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

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

$$g_1 = 0.7654 = L_1,$$

$$g_2 = 1.8478 = C_2,$$

$$g_3 = 1.8478 = L_3,$$

$$g_4 = 0.7654 = C_4,$$

$$g_5 = 1 = RL$$

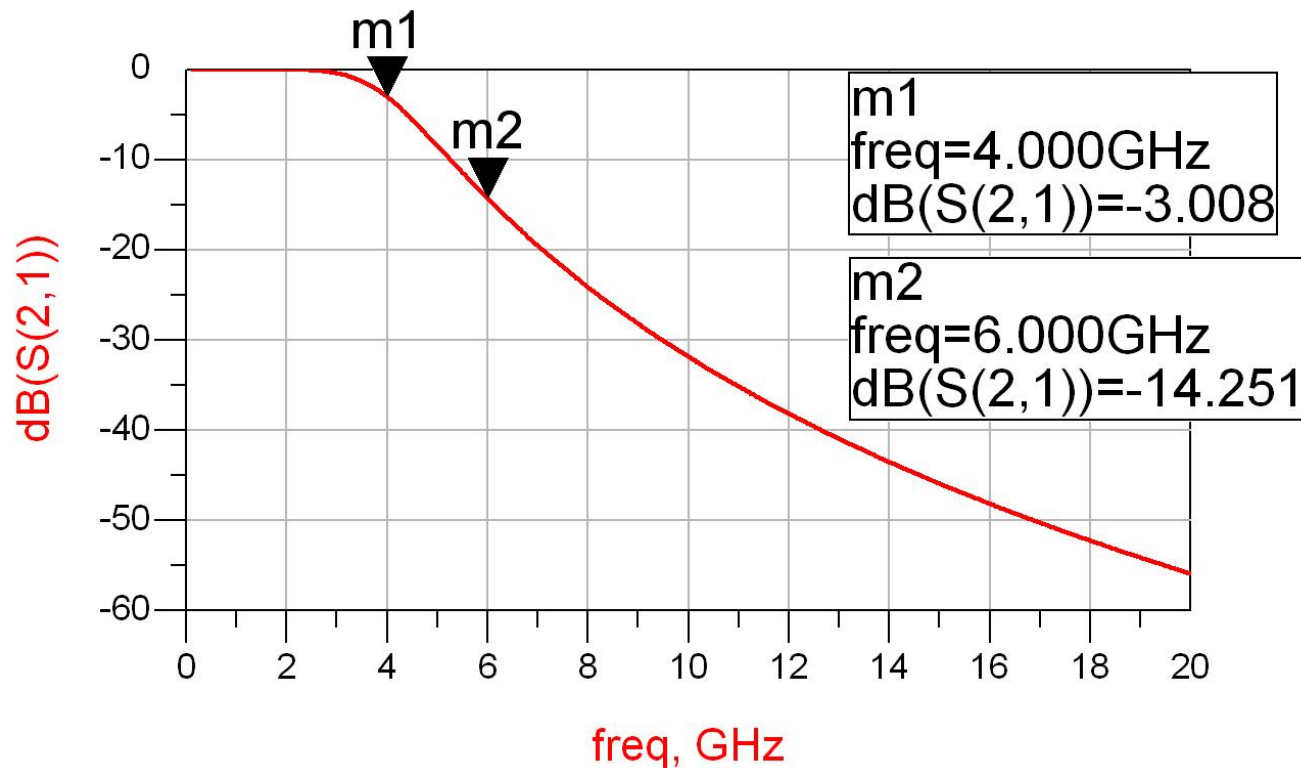
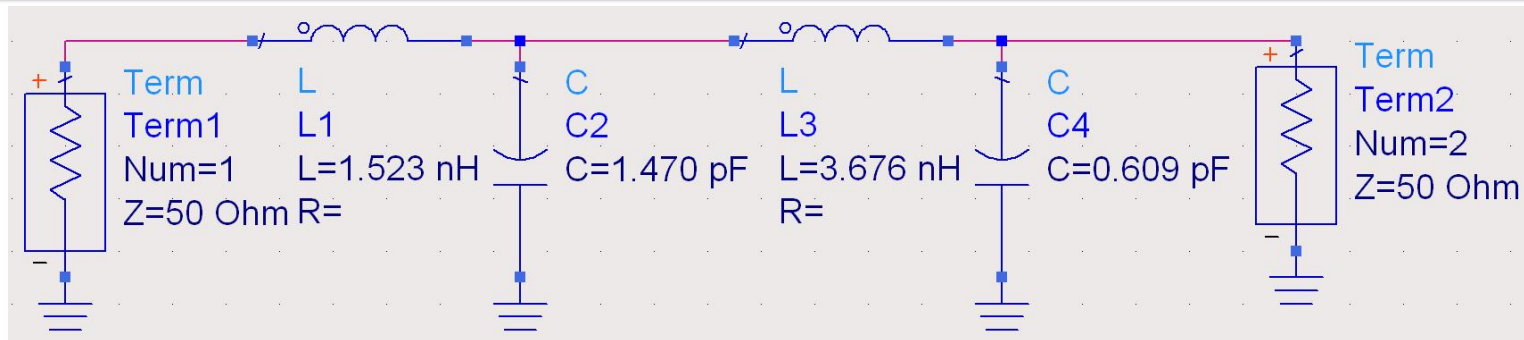
$$L'_1 = \frac{R_0 \cdot L_1}{\omega_c} = 1.523 \text{ nH}$$

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

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

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

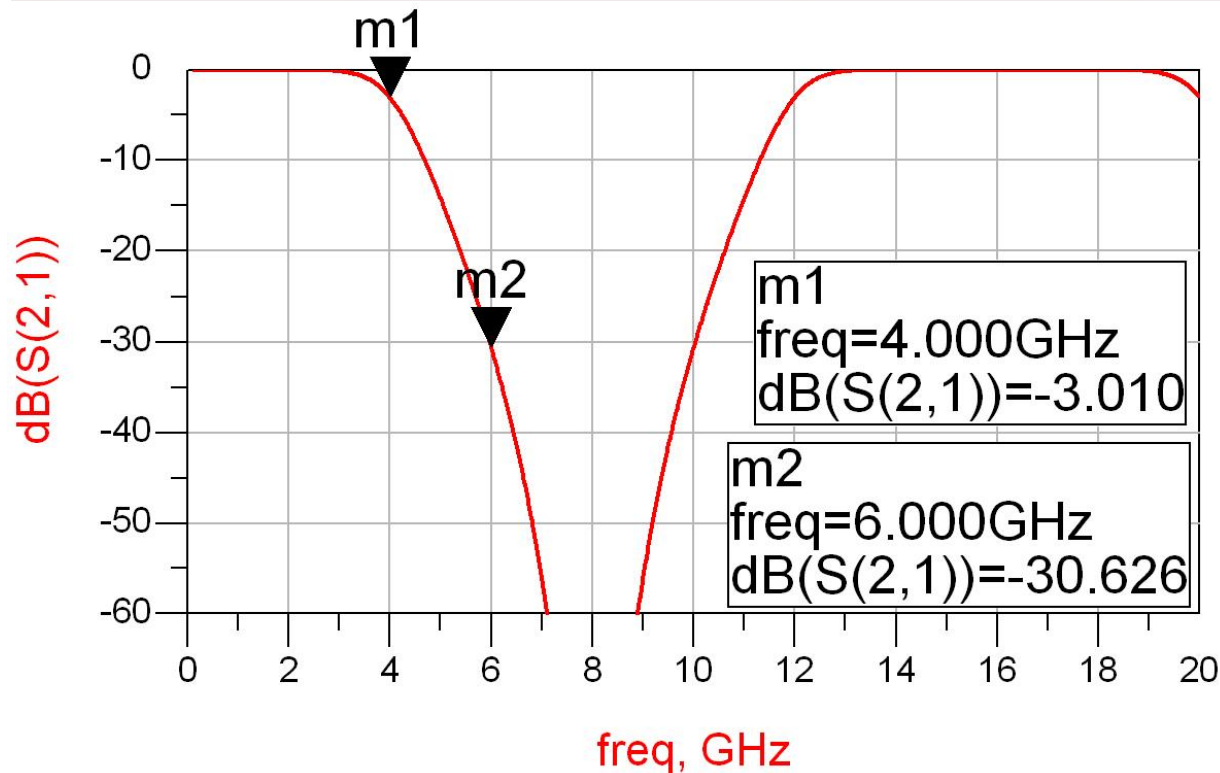
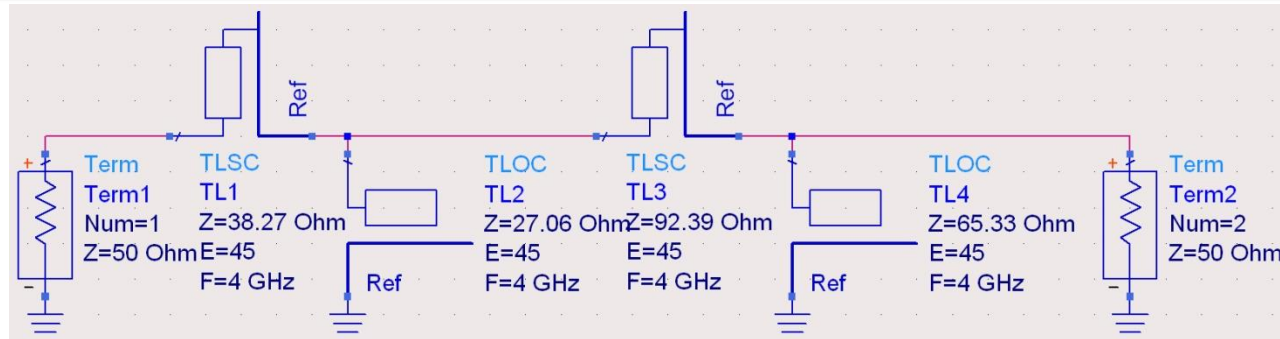
Elemente concentrate – ADS



Transformarea Richards

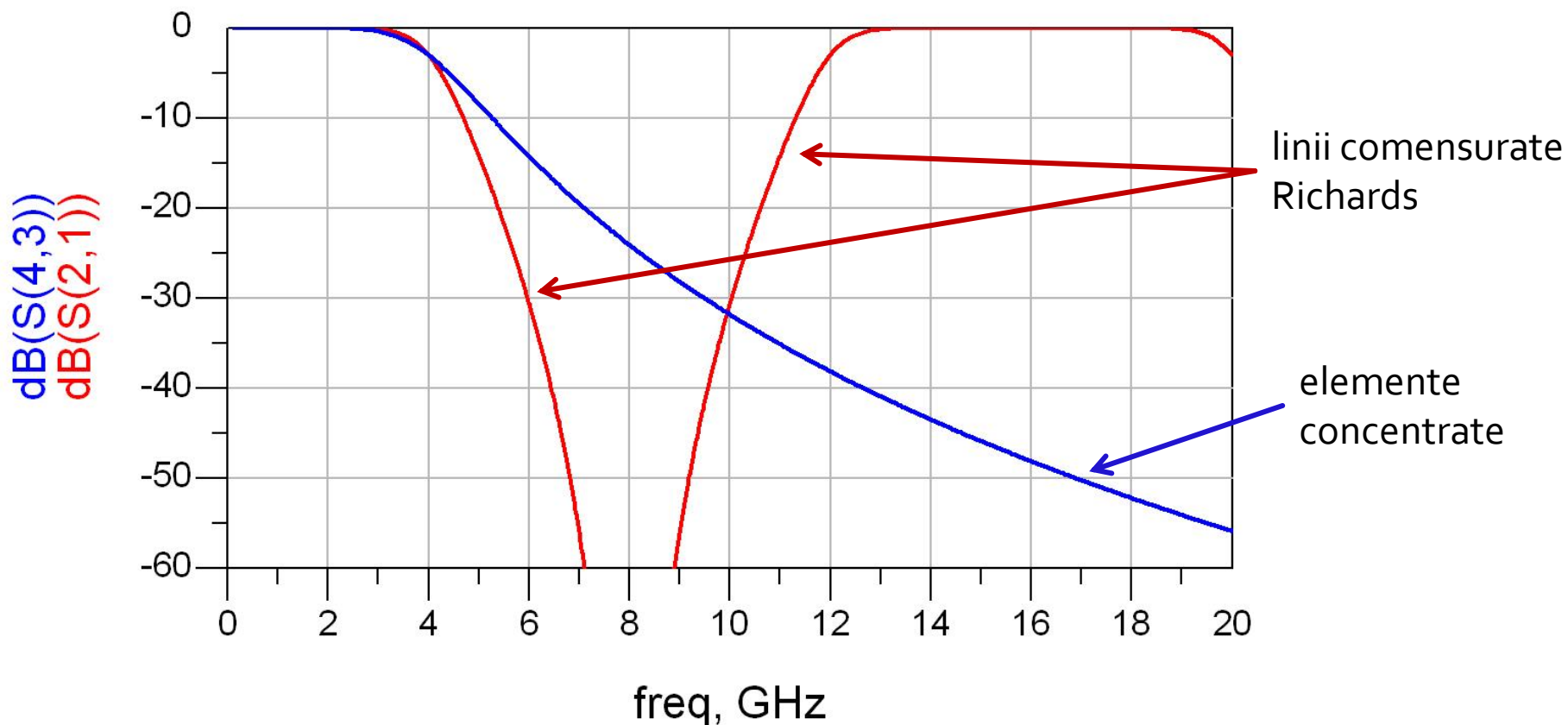
- Parametrii filtrului prototip:
 - $g_1 = 0.7654 = L_1$
 - $g_2 = 1.8478 = C_2$
 - $g_3 = 1.8478 = L_3$
 - $g_4 = 0.7654 = C_4$
- Impedantele raportate ale liniilor
 - $z_1 = 0.7654 = \text{serie / scurt circuit}$
 - $z_2 = 1 / 1.8478 = 0.5412 = \text{paralel / gol}$
 - $z_3 = 1.8478 = \text{serie / scurt circuit}$
 - $z_4 = 1 / 0.7654 = 1.3065 = \text{paralel / gol}$
- 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

- Filtre 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

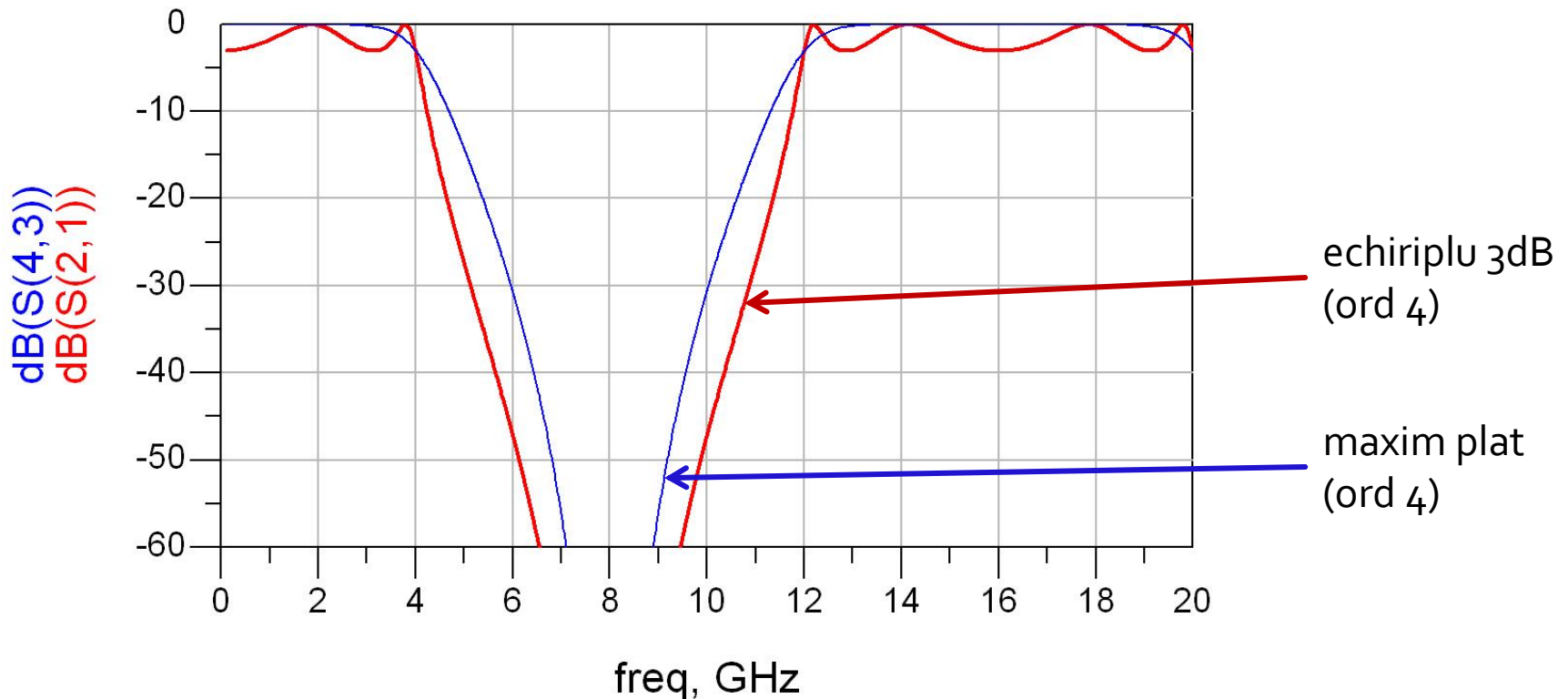
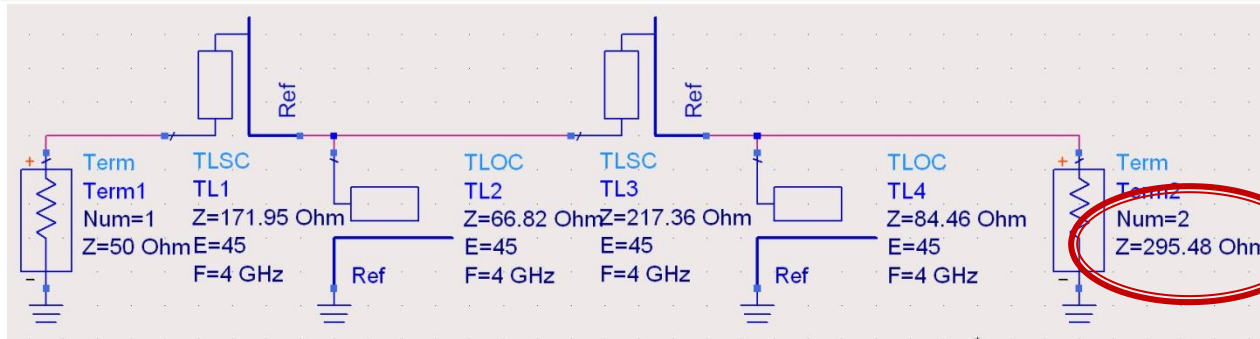
- Pentru ordin par al filtrului ($N = 2, 4, 6, 8 \dots$) filtrele echiriplu **trebuie** sa fie inchise pe o impedanta de terminatie diferita de cea standard
- Daca aplicatia nu suporta aceasta comportare, e necesara introducerea unei adaptari de impedanta suplimentare (transformator in sfert de lungime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

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

Observatie: ordin par/echiriplu

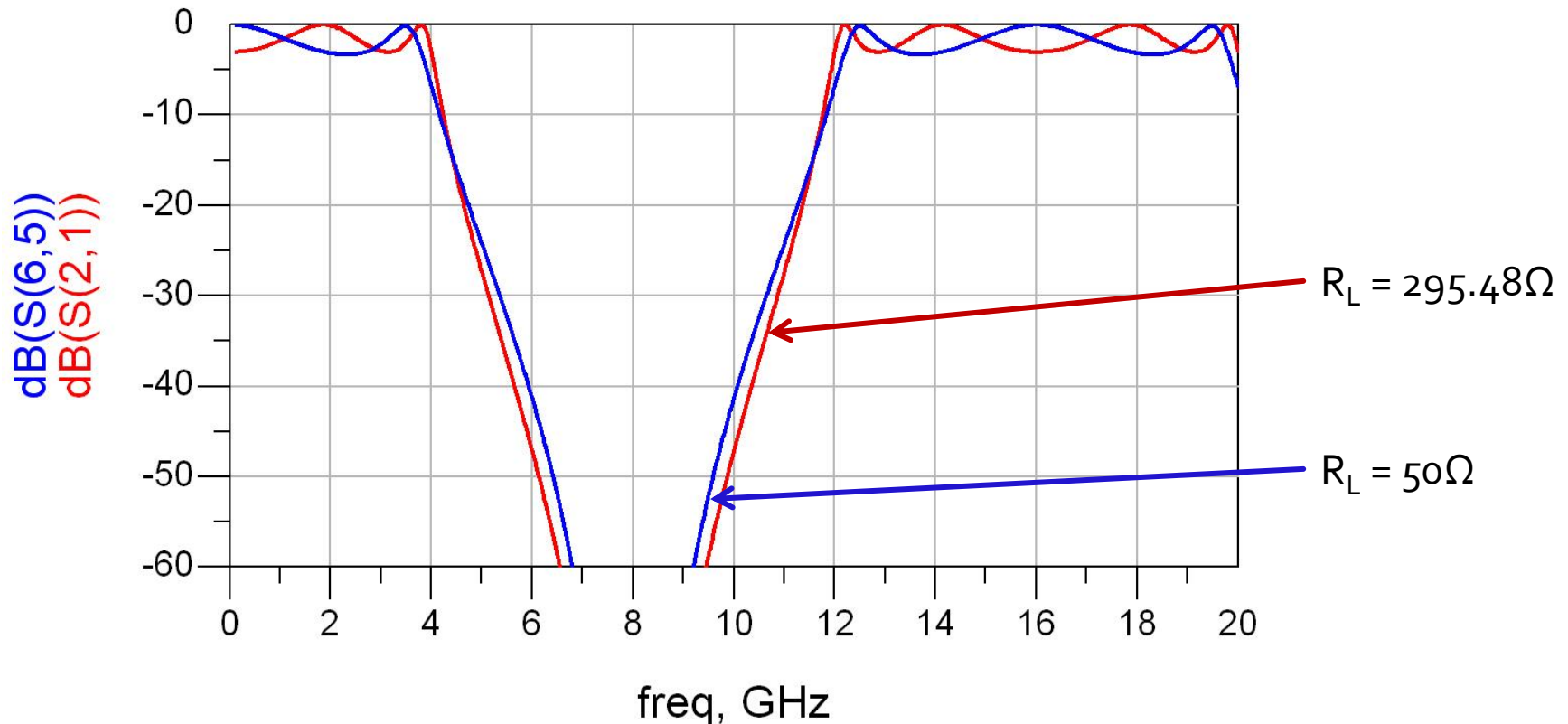
- Acelasi filtru, echiriplu 3dB
- Tabel echiriplu 3dB sau relatii de calcul:
 - $g_1 = 3.4389 = L_1$
 - $g_2 = 0.7483 = C_2$
 - $g_3 = 4.3471 = L_3$
 - $g_4 = 0.5920 = C_4$
 - $g_5 = 5.8095 = R_L$
- Impedantele liniilor
 - $Z_1 = 3.4389 \cdot 50\Omega = 171.945\Omega = \text{serie / scurt circuit}$
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

Ordin par/echiriplu – ADS



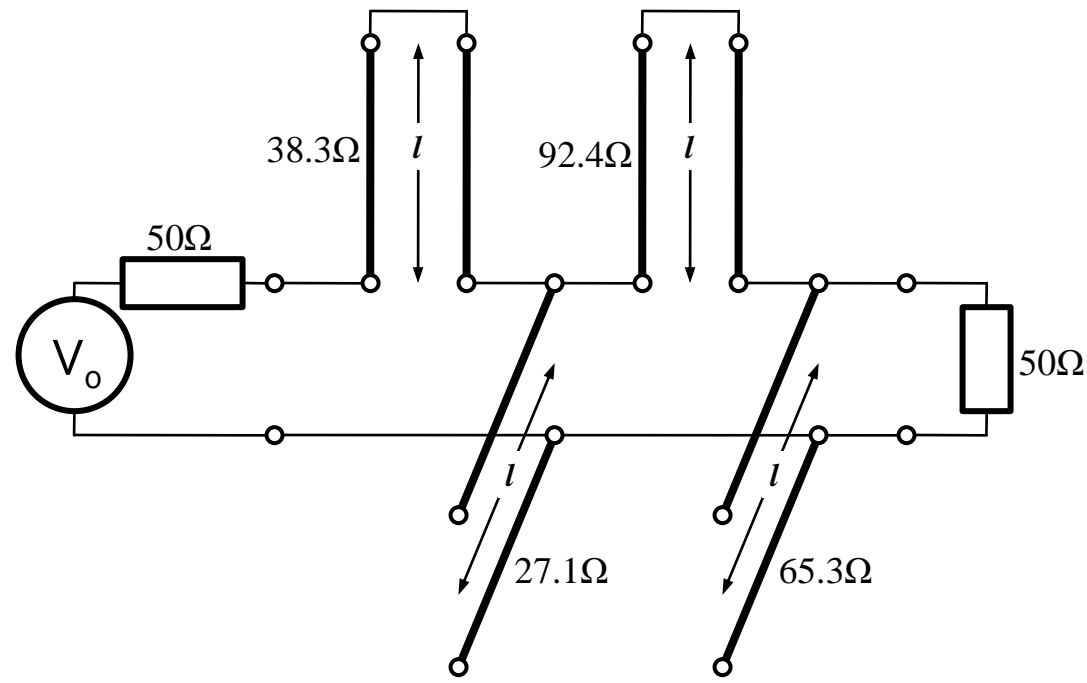
Observatie: ordin par/echiriplu

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



Identitatile Kuroda

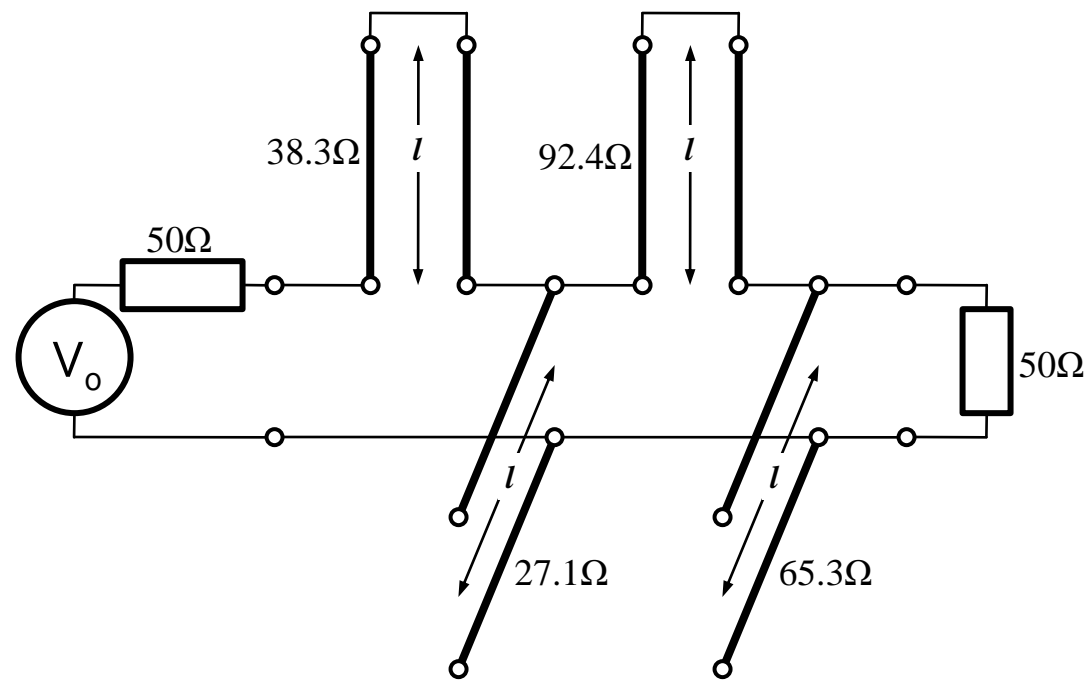
- Filtre implementate cu transformarea Richards au anumite dezavantaje in ceea ce priveste implementarea practica
- Identitatile/Transformarile Kuroda pot fi utilizate pentru a elimina o parte din aceste dezavantaje
- Se utilizeaza sectiuni de linie suplimentare pentru a obtine sisteme mai simplu de implementat in practica
- Liniile suplimentare se numesc elemente unitare si au lungimi de $\lambda/8$ la frecventa de taiere dorita (ωc) fiind comensurate cu celelalte sectiuni de linie



Identitatile Kuroda

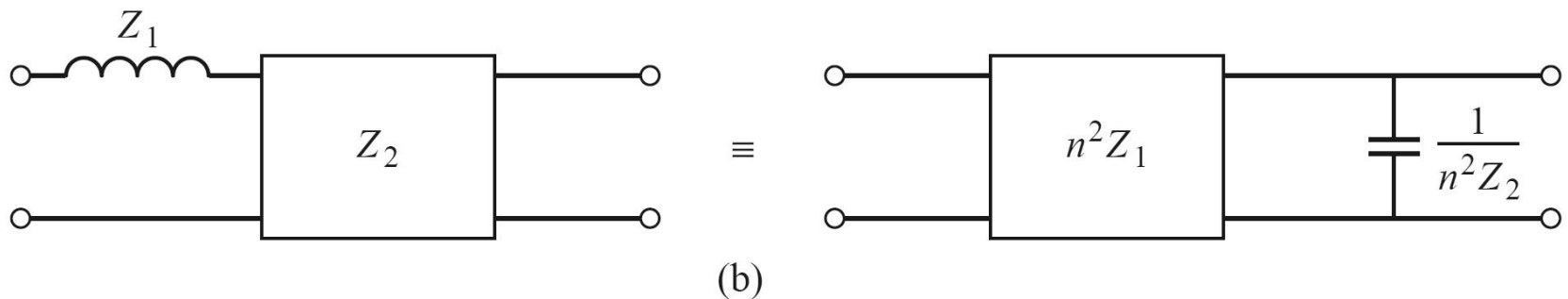
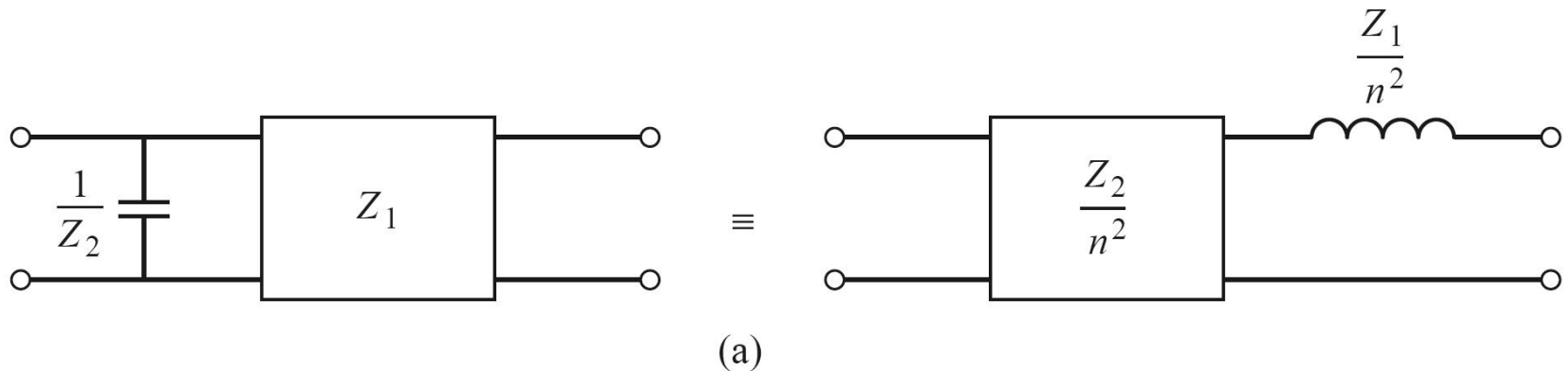
- Identitatile Kuroda pot fi utilizate pentru a realiza urmatoarele operatii:

- Separarea fizica a diferitelor stub-uri
- Transformarea stub-urilor serie in stub-uri paralel sau invers
- Obținerea unor impedante caracteristice mai "realizabile" pentru linii ($\sim 50\Omega$)



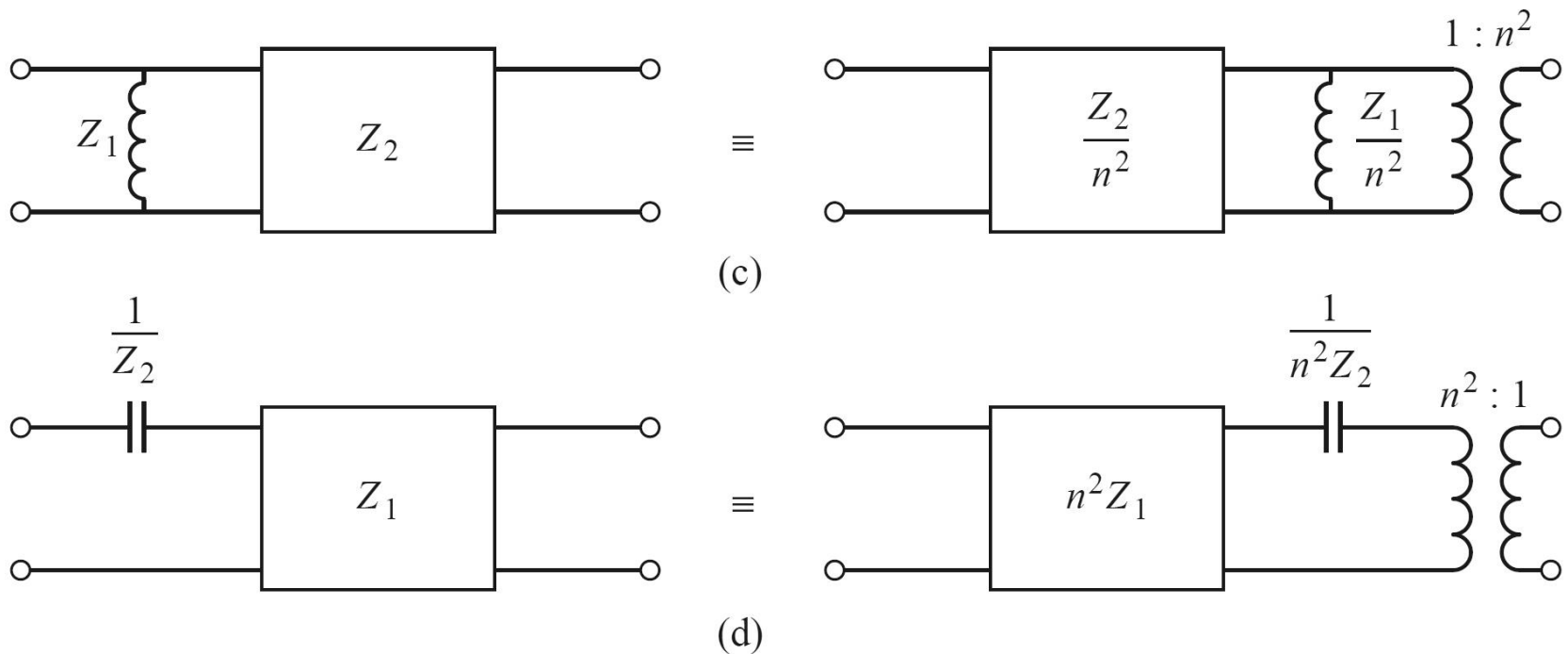
Identitatile Kuroda

- 4 echivalente de circuit (a,b)



Identitatile Kuroda

- 4 echivalente de circuit (c,d)



Identitatile Kuroda

- In toate echivalentele de scheme Kuroda:

- n:

$$n^2 = 1 + \frac{Z_2}{Z_1}$$

- inductantele si capacitatile reprezinta stub-uri scurtcircuitate sau in gol (obtinute prin transformarea Richards, de lungime $\lambda/8$)
- blocurile reprezinta elemente unitare (linii de transmisie de impedanta caracteristica indicata si lungime $\lambda/8$)

Prima Identitate Kuroda

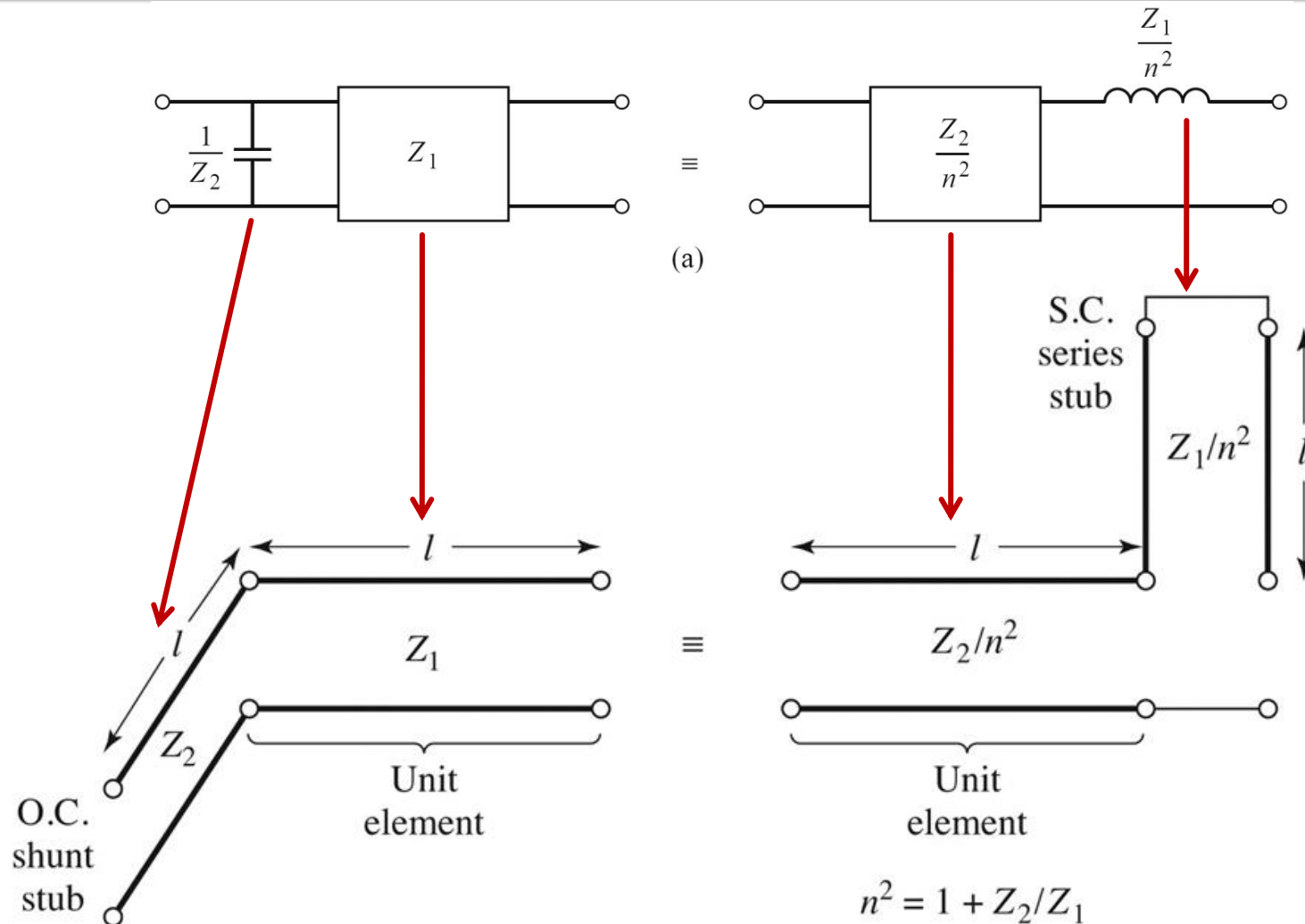
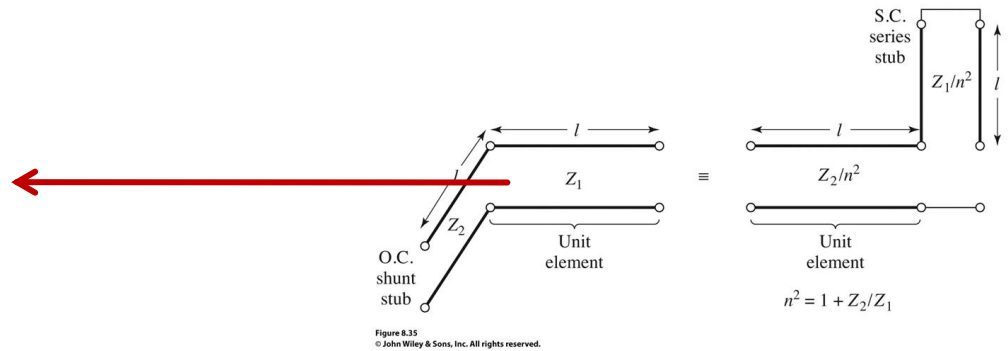
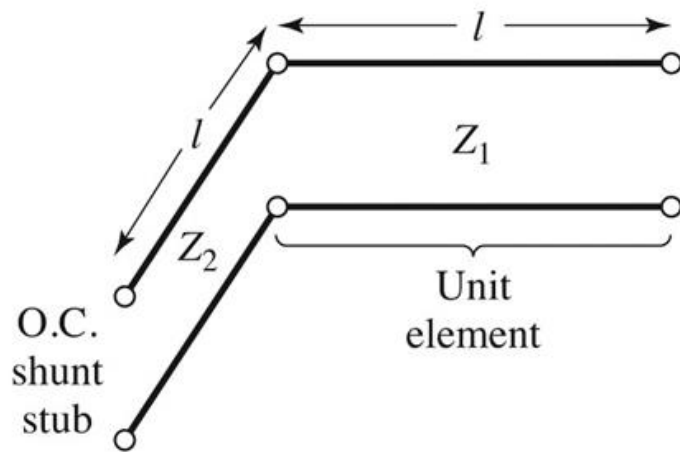
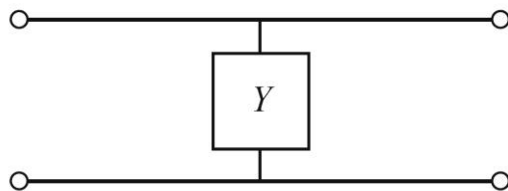


Figure 8.35
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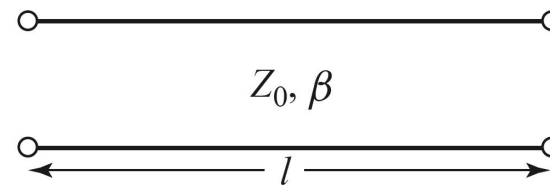
Prima Identitate Kuroda – Demonstratie



■ Matrici ABCD, C5



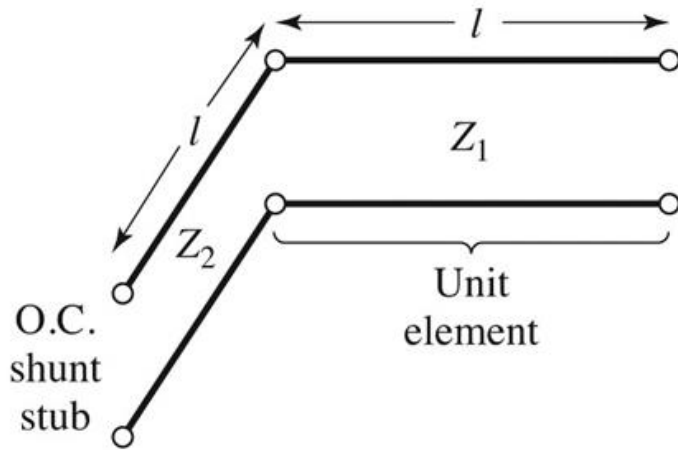
+



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos \beta \cdot l & j \cdot Z_0 \cdot \sin \beta \cdot l \\ j \cdot Y_0 \cdot \sin \beta \cdot l & \cos \beta \cdot l \end{bmatrix}$$

Prima Identitate Kuroda – Demonstratie



$$\Omega = \tan \beta \cdot l$$

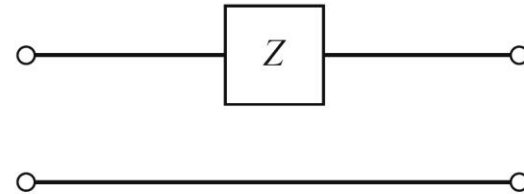
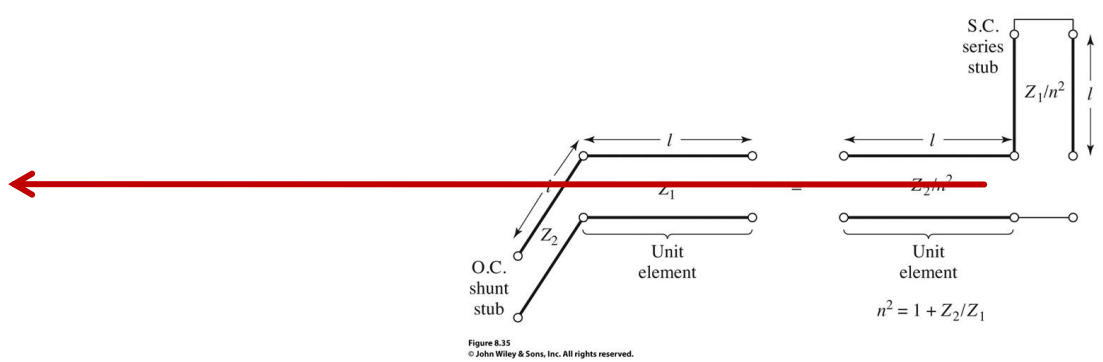
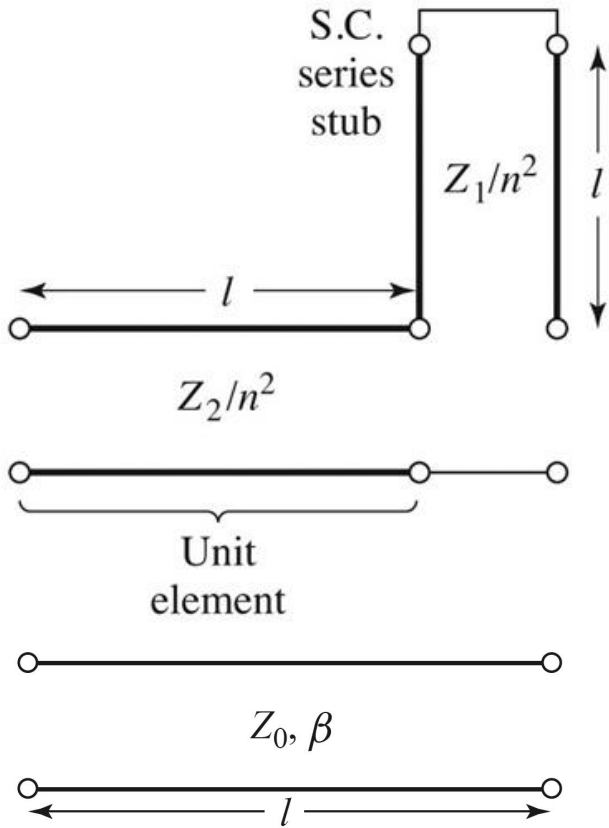
$$\cos \beta \cdot l = \frac{1}{\sqrt{1 + \Omega^2}} \quad \sin \beta \cdot l = \frac{\Omega}{\sqrt{1 + \Omega^2}}$$

$$Z_{in,g} = -j \cdot Z_2 \cdot \cot \beta \cdot l = -j \cdot \frac{Z_2}{\Omega}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{j \cdot \Omega}{Z_2} & 1 \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{\sqrt{1 + \Omega^2}} & j \cdot Z_1 \cdot \frac{\Omega}{\sqrt{1 + \Omega^2}} \\ j \cdot \frac{1}{Z_1} \cdot \frac{\Omega}{\sqrt{1 + \Omega^2}} & \frac{1}{\sqrt{1 + \Omega^2}} \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \frac{1}{\sqrt{1 + \Omega^2}} \cdot \begin{bmatrix} 1 & 0 \\ \frac{j \cdot \Omega}{Z_2} & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & j \cdot \Omega \cdot Z_1 \\ \frac{j \cdot \Omega}{Z_1} & 1 \end{bmatrix} = \frac{1}{\sqrt{1 + \Omega^2}} \cdot \begin{bmatrix} 1 & j \cdot \Omega \cdot Z_1 \\ j \cdot \Omega \cdot \left(\frac{1}{Z_1} + \frac{1}{Z_2} \right) & 1 - \Omega^2 \cdot \frac{Z_1}{Z_2} \end{bmatrix}$$

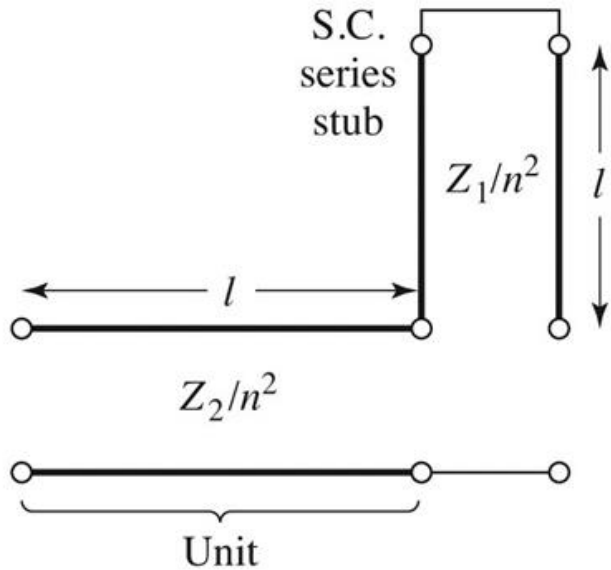
Prima Identitate Kuroda – Demonstratie



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos \beta \cdot l & j \cdot Z_0 \cdot \sin \beta \cdot l \\ j \cdot Y_0 \cdot \sin \beta \cdot l & \cos \beta \cdot l \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

Prima Identitate Kuroda – Demonstratie



$$\Omega = \tan \beta \cdot l$$

$$\cos \beta \cdot l = \frac{1}{\sqrt{1 + \Omega^2}} \quad \sin \beta \cdot l = \frac{\Omega}{\sqrt{1 + \Omega^2}}$$

$$Z_{in,sc} = j \cdot \left(\frac{Z_1}{n^2} \right) \cdot \tan \beta \cdot l = \frac{j \cdot \Omega \cdot Z_1}{n^2}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & j \cdot \frac{Z_2}{n^2} \cdot \frac{\Omega}{\sqrt{1 + \Omega^2}} \\ j \cdot \frac{n^2}{Z_2} \cdot \frac{\Omega}{\sqrt{1 + \Omega^2}} & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & \frac{j \cdot \Omega \cdot Z_1}{n^2} \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \frac{1}{\sqrt{1 + \Omega^2}} \cdot \begin{bmatrix} 1 & j \cdot \Omega \cdot \frac{Z_2}{n^2} \\ \frac{j \cdot \Omega \cdot n^2}{Z_2} & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & j \cdot \Omega \cdot \frac{Z_1}{n^2} \\ 0 & 1 \end{bmatrix} = \frac{1}{\sqrt{1 + \Omega^2}} \cdot \begin{bmatrix} 1 & j \cdot \frac{\Omega}{n^2} \cdot (Z_1 + Z_2) \\ \frac{j \cdot \Omega \cdot n^2}{Z_2} & 1 - \Omega^2 \cdot \frac{Z_1}{Z_2} \end{bmatrix}$$

Prima Identitate Kuroda – Demonstratie

- Prima schema

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \frac{1}{\sqrt{1+\Omega^2}} \cdot \begin{bmatrix} 1 & j \cdot \Omega \cdot Z_1 \\ j \cdot \Omega \cdot \left(\frac{1}{Z_1} + \frac{1}{Z_2} \right) & 1 - \Omega^2 \cdot \frac{Z_1}{Z_2} \end{bmatrix}$$

- A doua schema

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \frac{1}{\sqrt{1+\Omega^2}} \cdot \begin{bmatrix} 1 & j \cdot \frac{\Omega}{n^2} \cdot (Z_1 + Z_2) \\ \frac{j \cdot \Omega \cdot n^2}{Z_2} & 1 - \Omega^2 \cdot \frac{Z_1}{Z_2} \end{bmatrix}$$

- Rezultatele sunt identice daca alegem

$$n^2 = 1 + \frac{Z_2}{Z_1}$$

- Similar se pot demonstra si celelalte trei identitati

(Acelasi) Exemplu

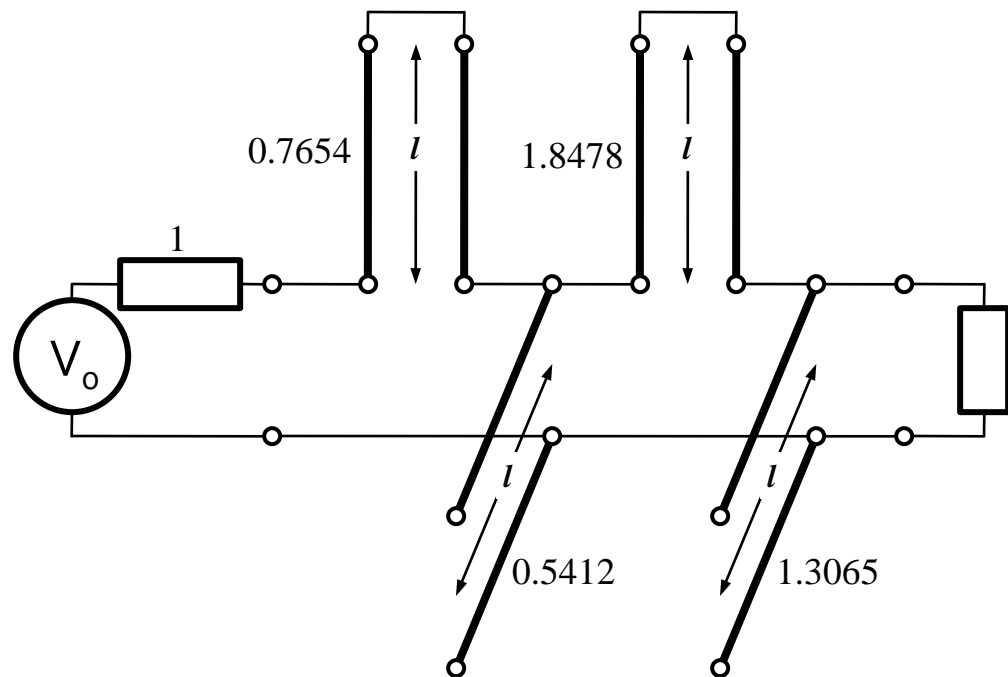
- Filtru trece jos de ordinul 4, cu frecventa de taiere de 4 GHz, de tip maxim plat (care sa functioneze pe 50Ω la intrare si iesire)
- Tabel maxim plat sau relatii de calcul:
 - $g_1 = 0.7654 = L_1$
 - $g_2 = 1.8478 = C_2$
 - $g_3 = 1.8478 = L_3$
 - $g_4 = 0.7654 = C_4$
 - $g_5 = 1$ (**nu** are nevoie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

Exemplu

■ Se aplica transformarea Richards

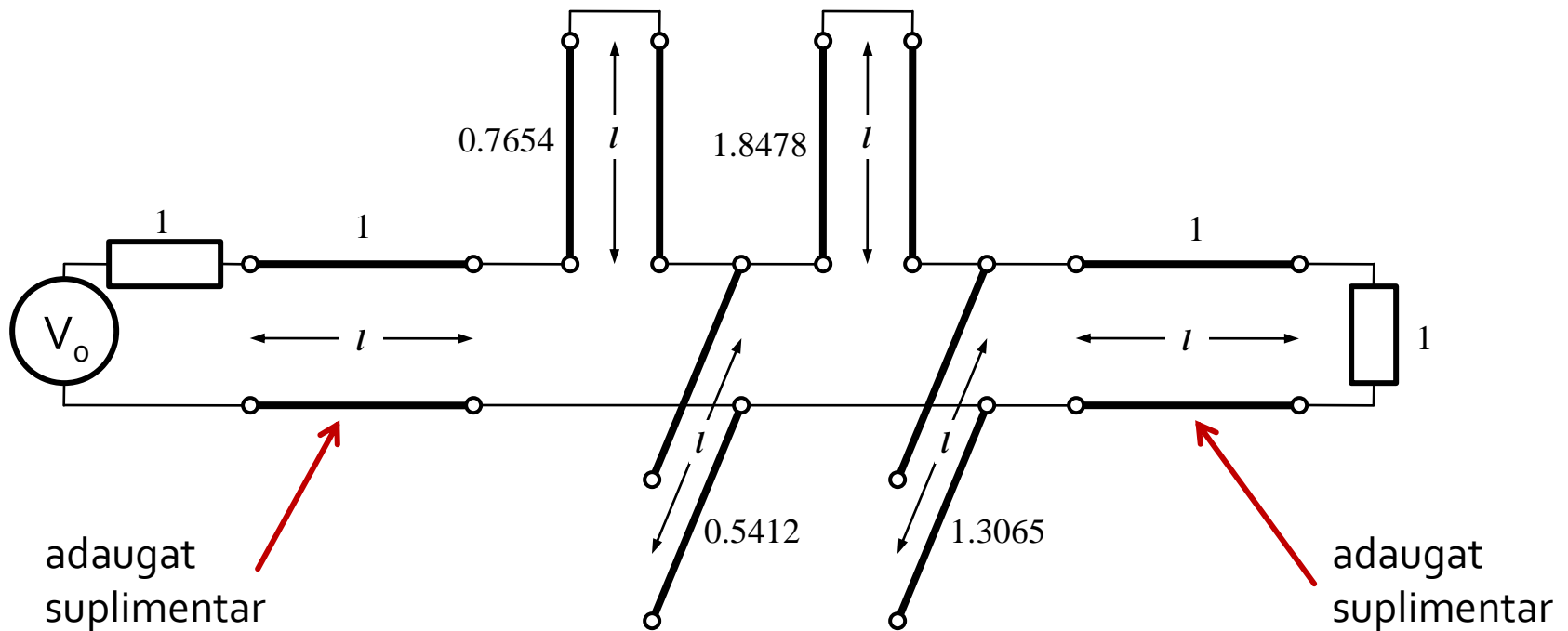
■ Probleme:

- stub-urile in serie sunt **extrem de dificil** de implementat in tehnologie microstrip
- cu tehnologia microstrip e preferabil sa avem stub-uri in gol (scurtcircuit necesita un **via-hole** spre planul de masa)
- cele 4 stub-uri sunt conectate in acelasi punct, o implementare care sa elimine/micsoreze **cuplajul** intre aceste linii e imposibila
- nu e cazul aici, dar pot aparea situatii cand impedantele raportate sunt mult diferite de 1. Majoritatea tehnologiilor sunt concepute pentru linii cu impedante caracteristice in jur de 50Ω



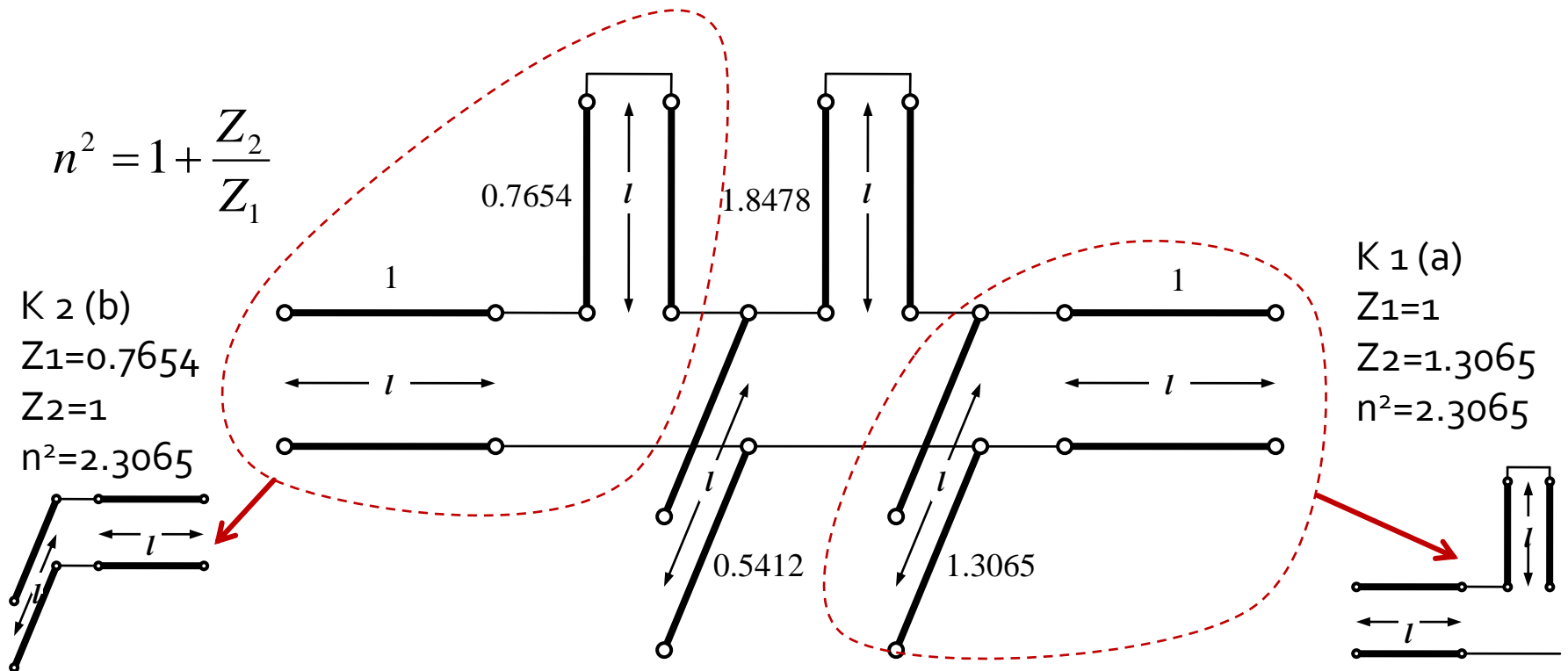
Exemplu

- Identitățile Kuroda se referă **intotdeauna** la o schema cu o secțiune de linie în serie:
 - se **adauga** elementele unitare ($z = 1, l = \lambda/8$) la fiecare capăt al circuitului (adaugarea nu modifică proprietățile filtrului acesta fiind adaptat la $z = 1$ la fiecare capăt)
 - se **aplică** una din identitățile Kuroda la fiecare capăt și se **continuă**
 - un indicator al **opririi** procedurii este apariția unei secțiuni de linie între toate stub-urile obținute cu transformarea Richards



Exemplu

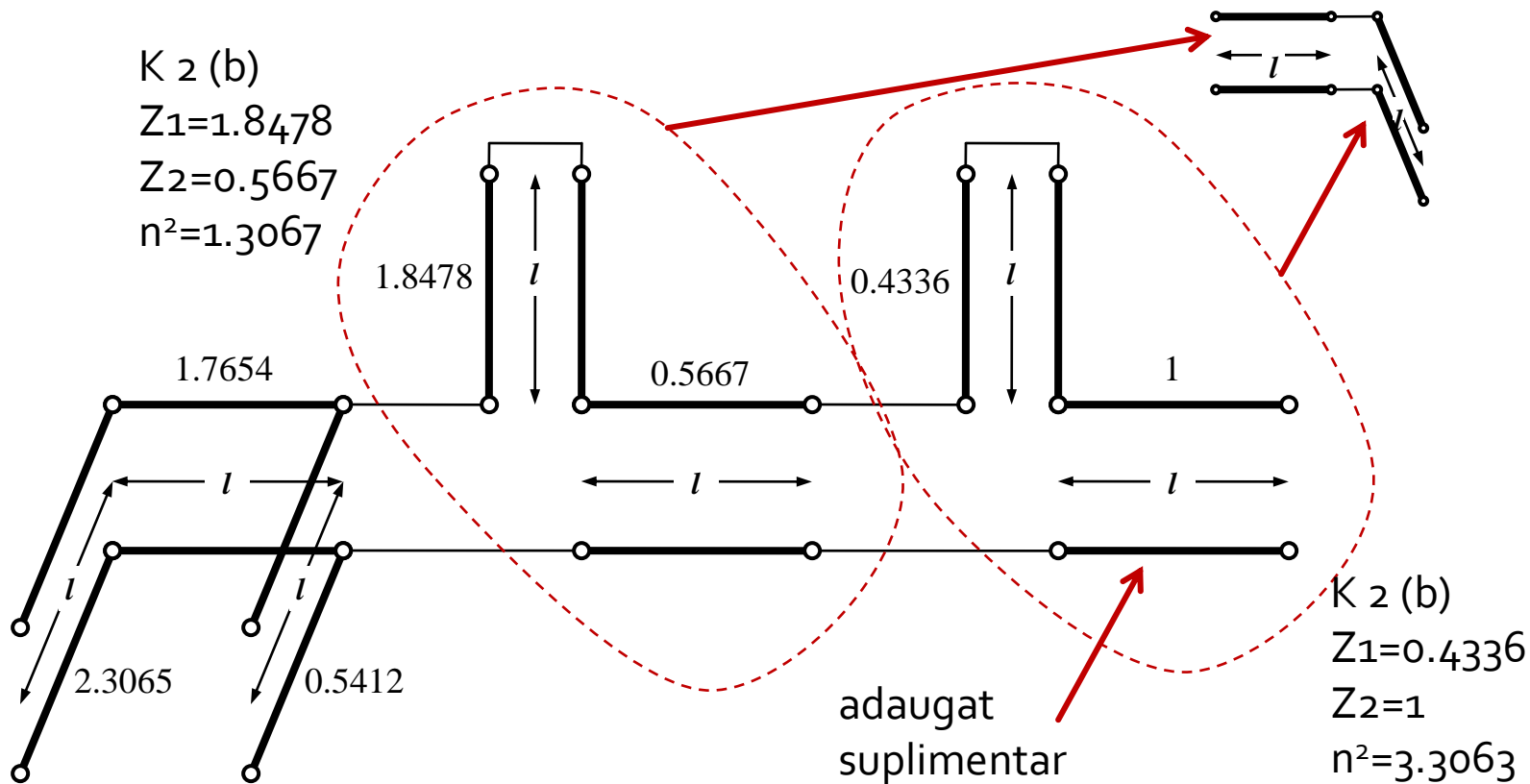
- Se aplica :
 - Kuroda 2 (L, Z cunoscut $\rightarrow C, Z$) in partea stanga
 - Kuroda 1 (C, Z cunoscut $\rightarrow L, Z$) in partea dreapta



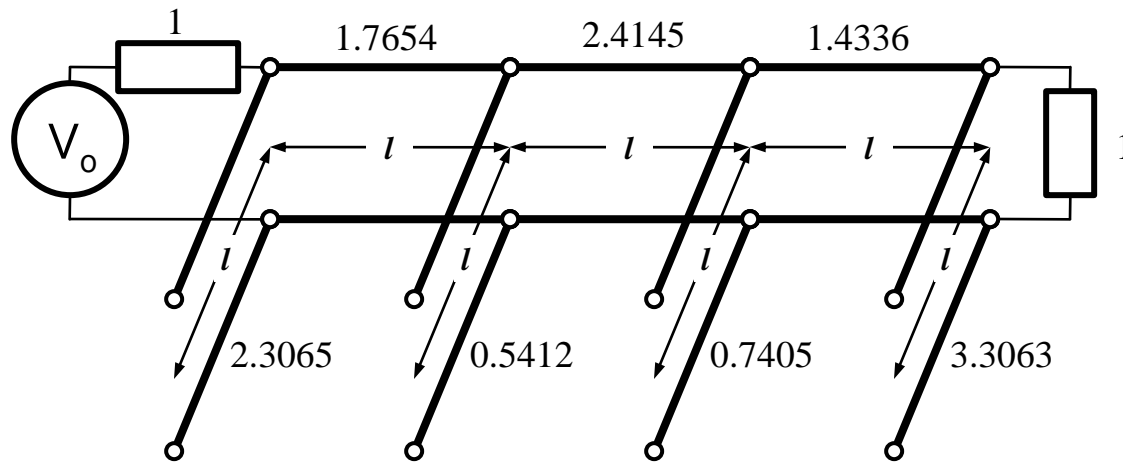
Exemplu

- Se mai adauga un element unitar in partea dreapta si se aplica Kuroda 2 de doua ori

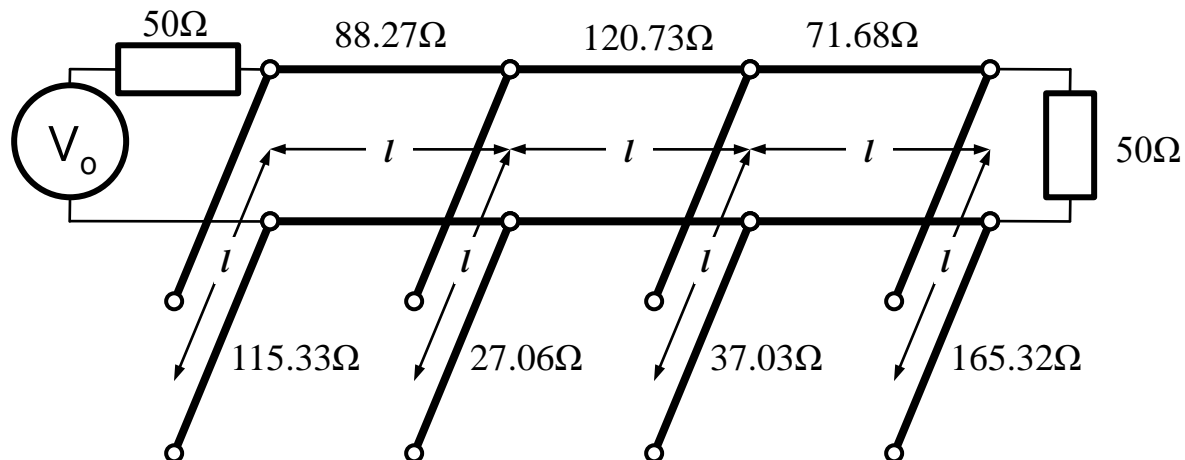
$$n^2 = 1 + \frac{Z_2}{Z_1}$$



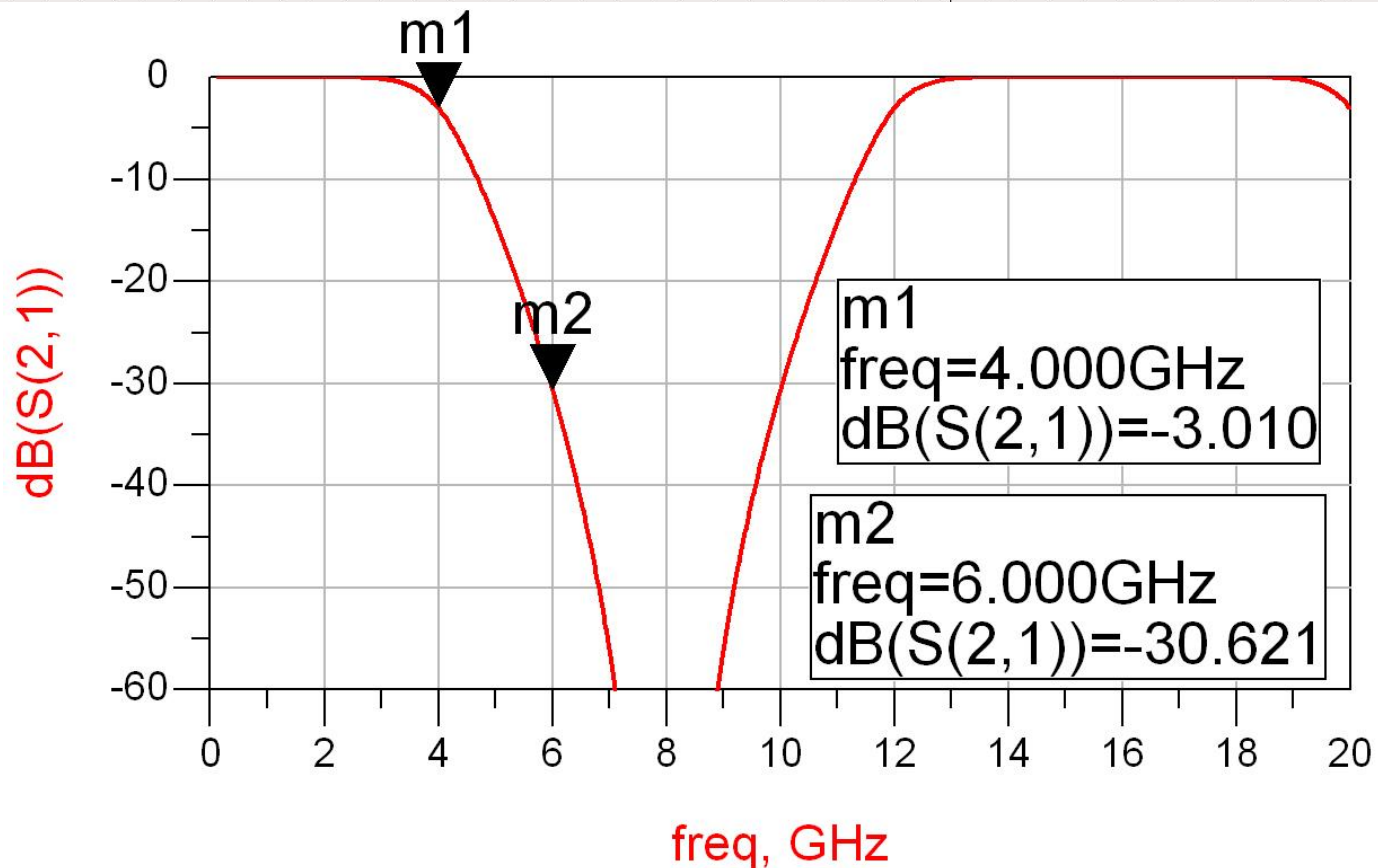
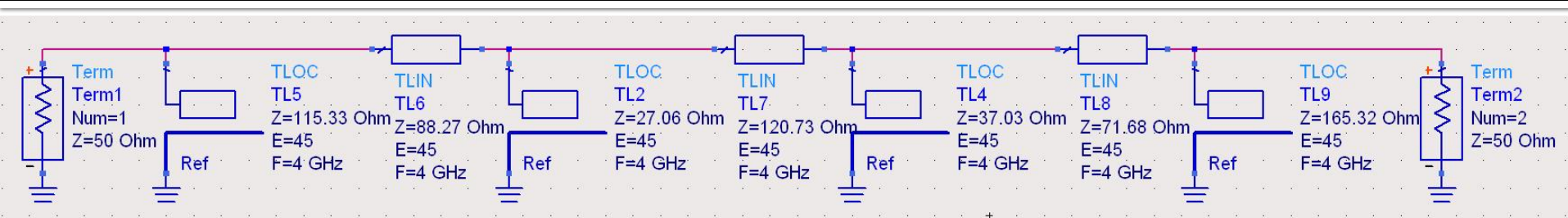
Exemplu



- Scalare la 50Ω



Identitatile Kuroda – ADS



Example

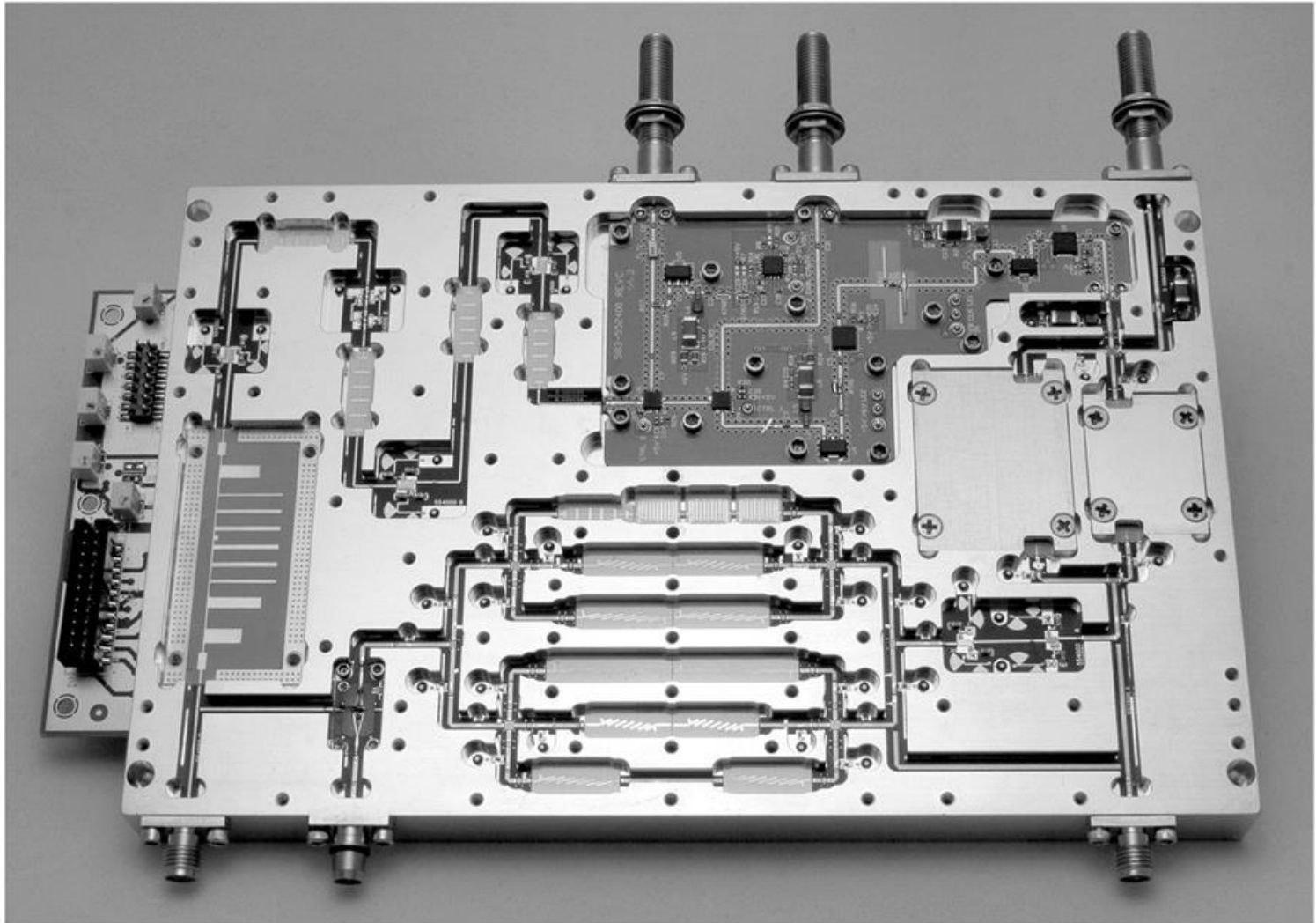


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.

Example

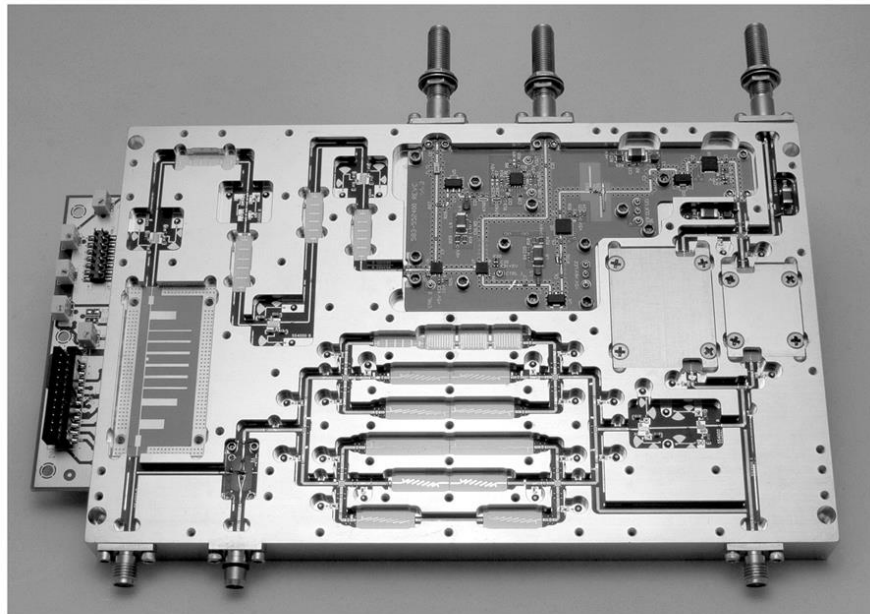
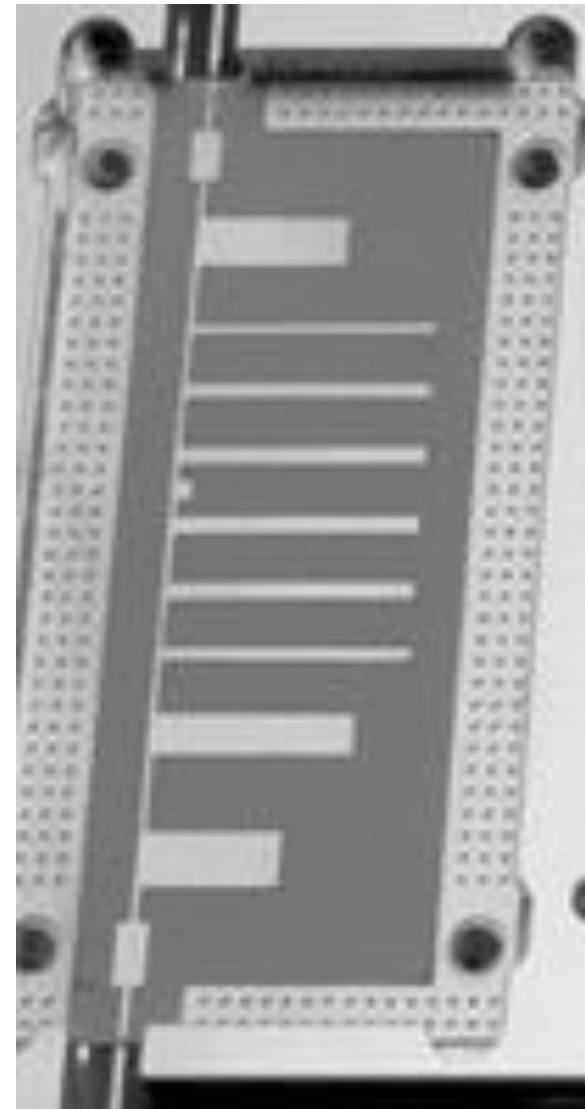
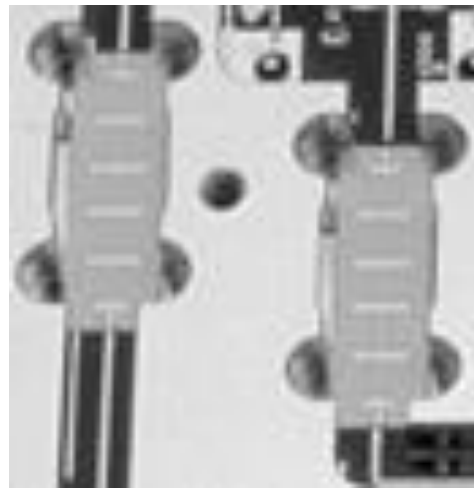
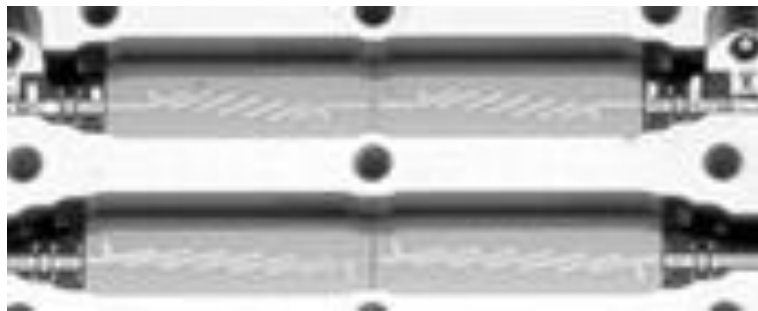


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.



Inversoare de impedanta si admitanta

- Transformarea Richard si identitatile Kuroda sunt utile mai ales pentru filtrele trece jos in tehnologiile in care stub-urile serie sunt dificil/imposibil de realizat (microstrip)
- De exemplu in cazul filtrului trece banda de ordinul 3:
 - se poate implementa inductanta serie utilizand K1-K2
 - capacitatea serie in schimb nu poate fi echivalata cu un stub paralel

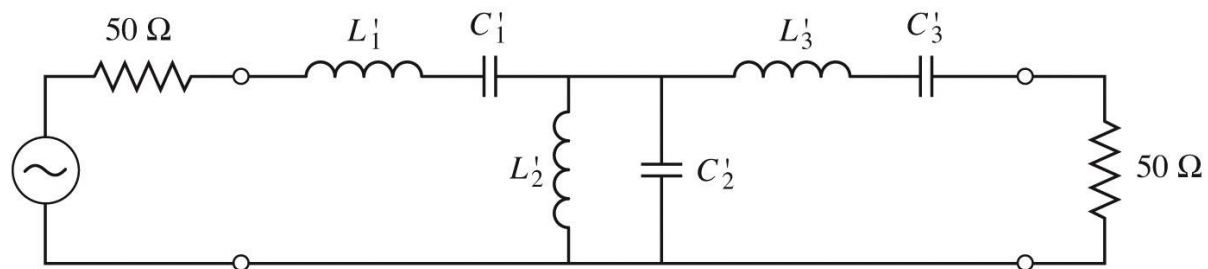


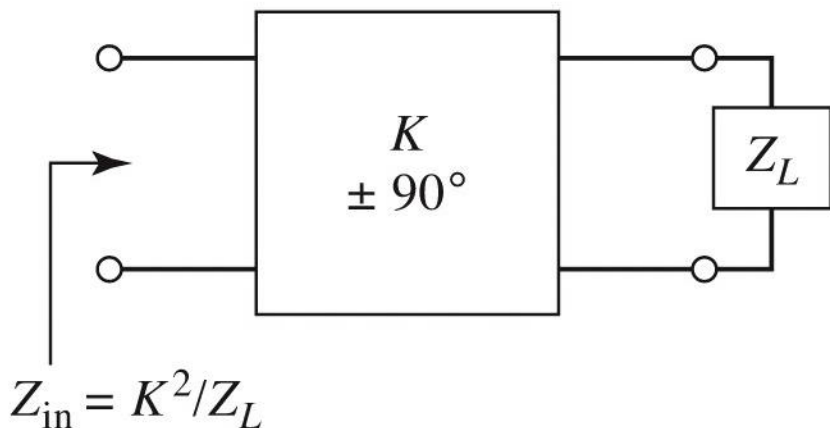
Figure 8.32
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Inversoare de impedanta si admitanta

- Pentru situatiile in care implementarea cu Richards + Kuroda nu ofera solutii practice se folosesc structuri de circuit numite **inversoare de impedanta si admitanta**

$$Z_{in} = \frac{K^2}{Z_L}$$

Impedance inverters



$$Y_{in} = \frac{J^2}{Y_L}$$

Admittance inverters

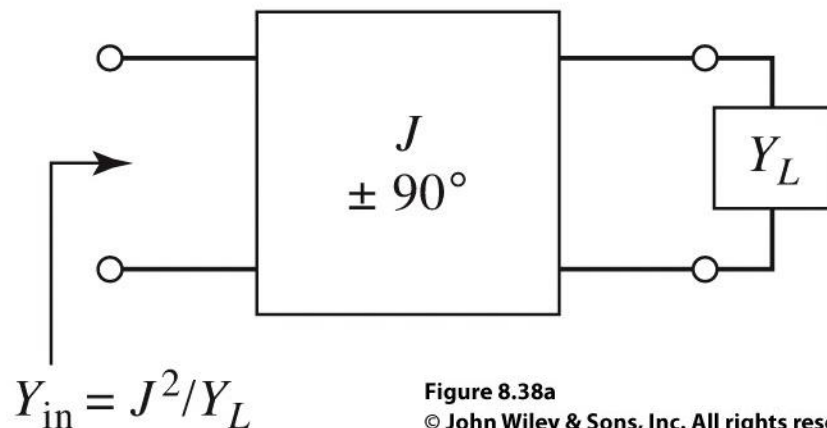


Figure 8.38a

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Inversoare de impedanta si admitanta

- Cel mai simplu exemplu de inversor de impedanta/admitanta este **transformatorul in sfert de lungime de unda** (C_4)

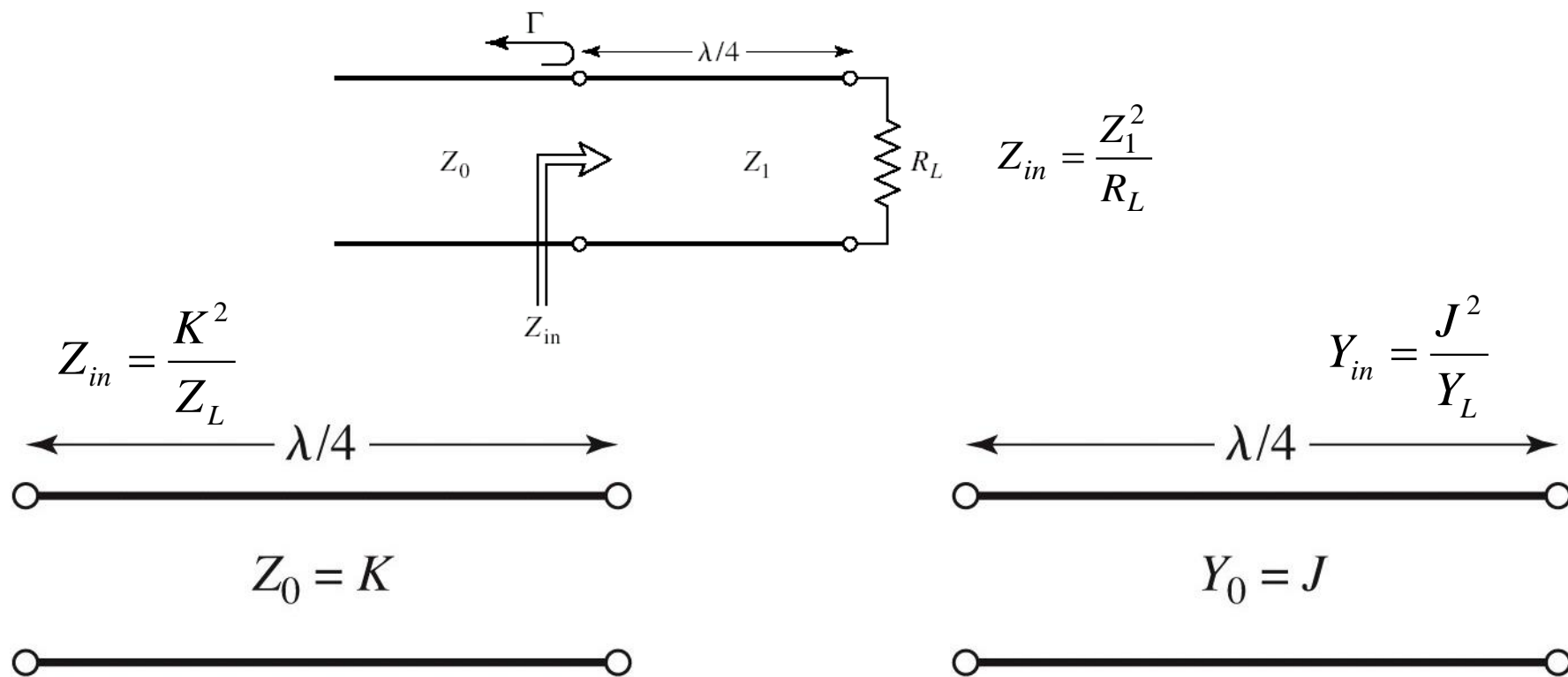
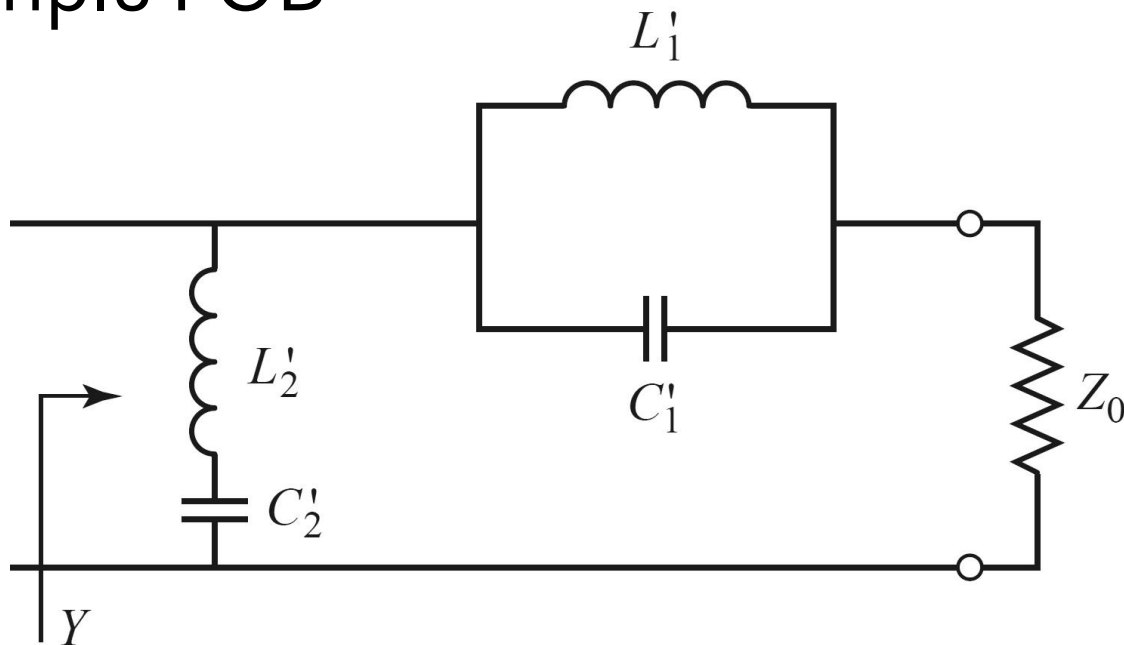


Figure 8.38b

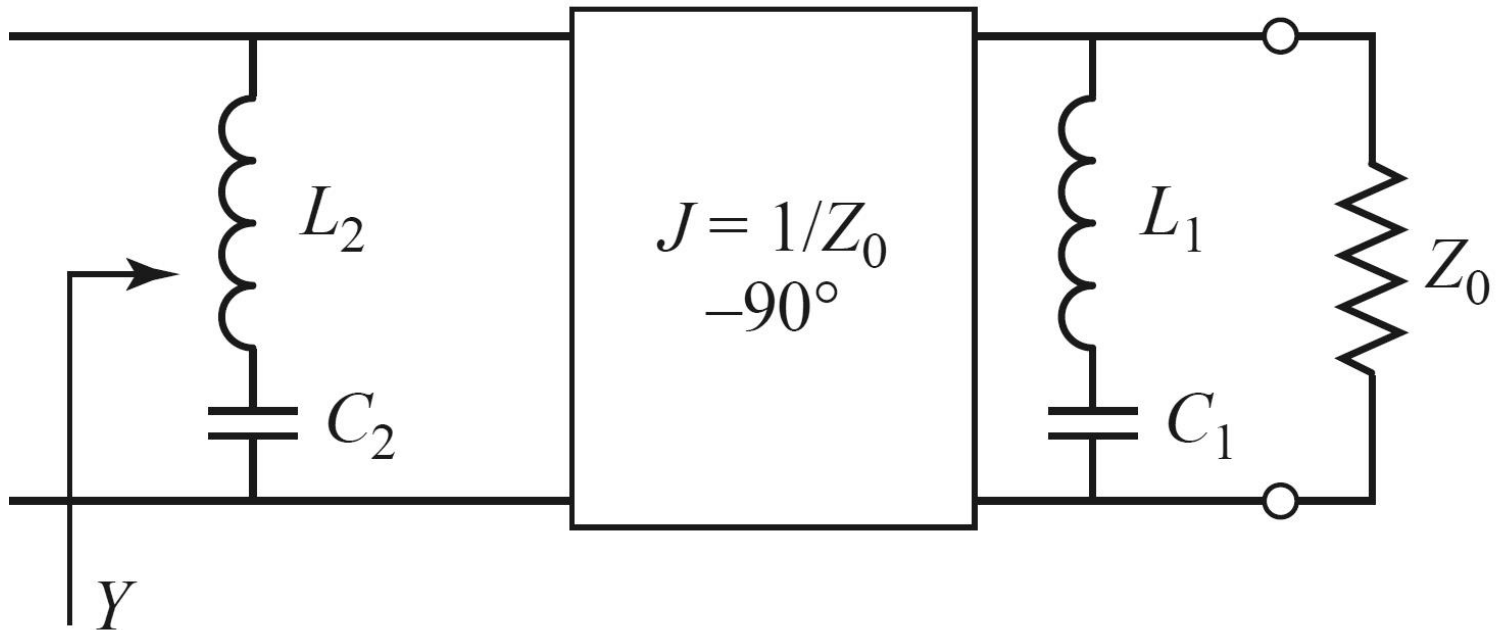
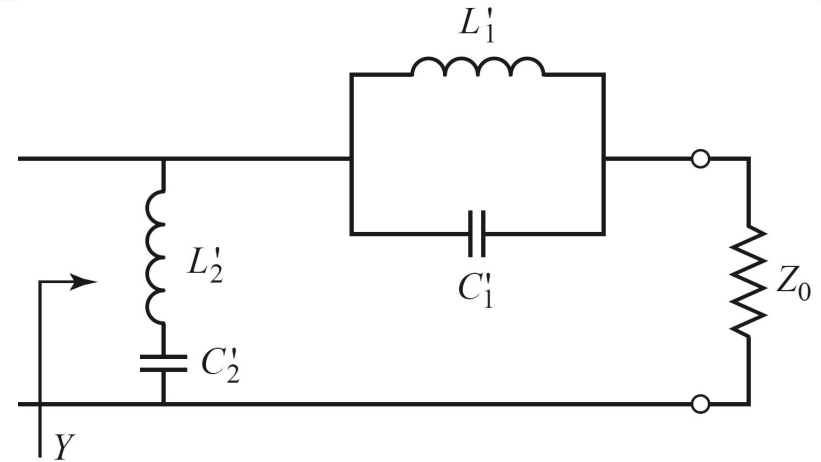
Inversoare de impedanta si admitanta

- Inversoarele de impedanta/admitanta pot fi utilizate pentru a schimba structura filtrelor in forme realizabile
- Exemplu FOB



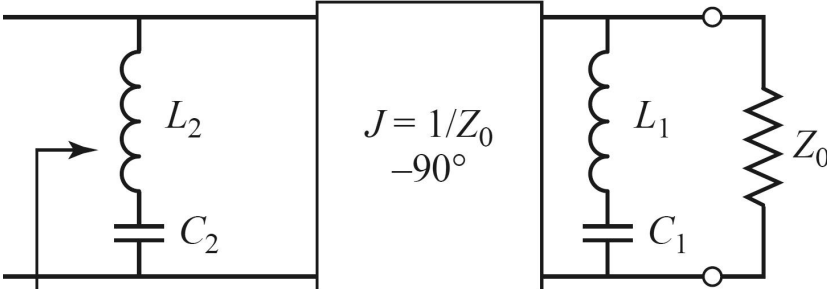
Inversoare de impedanta si admitanta

- Elementele serie pot fi eliminate prin introducerea unui inversor de admitanta



Inversoare de impedanta si admitanta

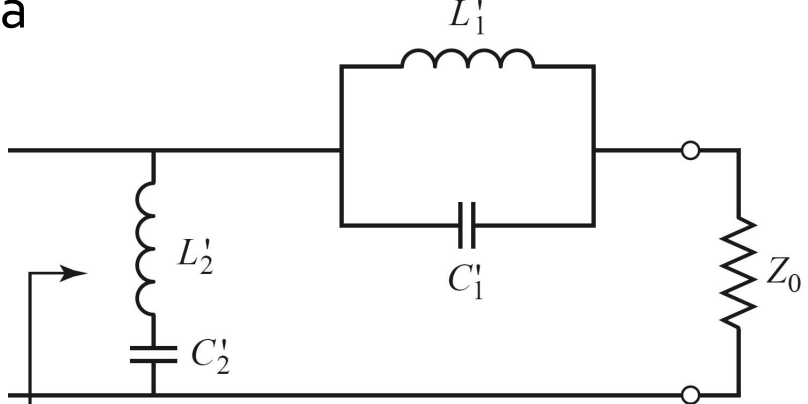
- Echivalenta celor doua scheme se demonstreaza prin obtinerea aceleiasi admitante de intrare
- Echivalenta completa se obtine prin incadrarea grupului simulat intre doua invertoare de admitanta



$$Y = \frac{1}{j \cdot \omega \cdot L_2 + \frac{1}{j \cdot \omega \cdot C_2}} + \frac{1}{Z_0} \cdot \left(\frac{1}{j \cdot \omega \cdot L_1 + \frac{1}{j \cdot \omega \cdot C_1}} + \frac{1}{Z_0} \right)^{-1}$$

$$L_n \cdot C_n = L'_n \cdot C'_n = \frac{1}{\omega_0^2} \Rightarrow \frac{1}{Z_0^2} \cdot \sqrt{\frac{L_1}{C_1}} = \sqrt{\frac{C'_1}{L'_1}} \Rightarrow Y = Y'$$

$$\sqrt{\frac{L_2}{C_2}} = \sqrt{\frac{L'_2}{C'_2}}$$

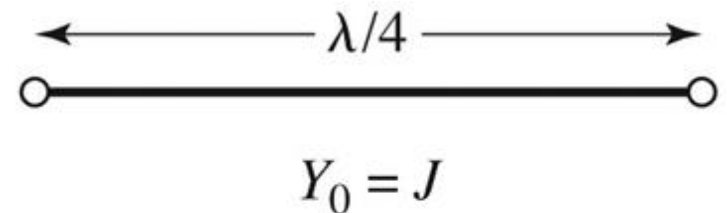
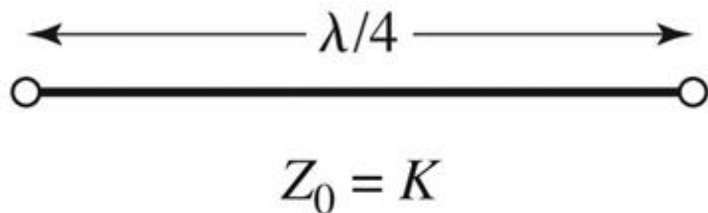


$$Y' = \frac{1}{j \cdot \omega \cdot L'_2 + \frac{1}{j \cdot \omega \cdot C'_2}} + \left(\frac{1}{j \cdot \omega \cdot C'_1 + \frac{1}{j \cdot \omega \cdot L'_1}} + Z_0 \right)^{-1}$$

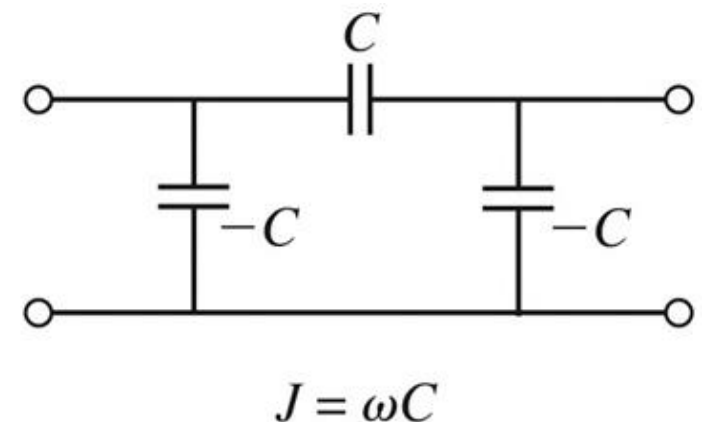
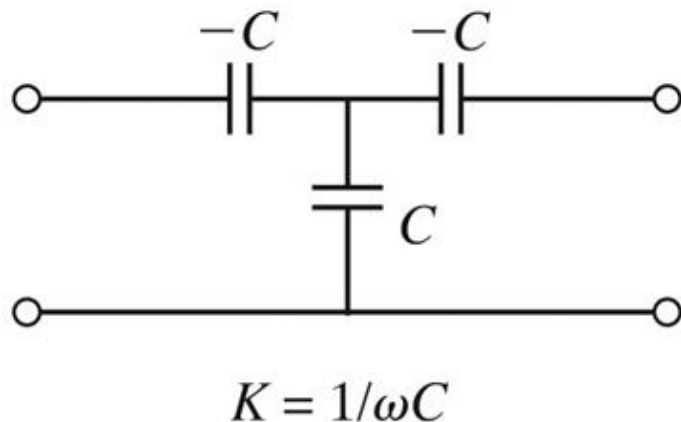
- Rezultat similar se obtine si pentru filtrul trece banda
- Un grup **LC serie** introdus in serie se poate inlocui cu un grup **LC paralel** introdus in paralel incadrat de doua invertoare de admitanta

Realizari practice de inversoare de impedanta/admitanta

- Cel mai uzual se foloseste transformatorul in sfert de lungime de unda

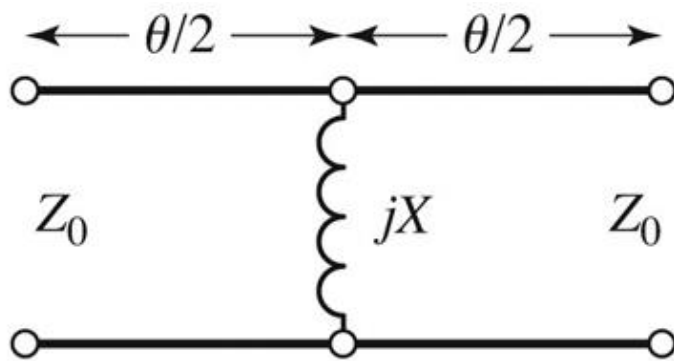


- Realizare cu elemente concentrate



Realizari practice de inversoare de impedanta/admitanta

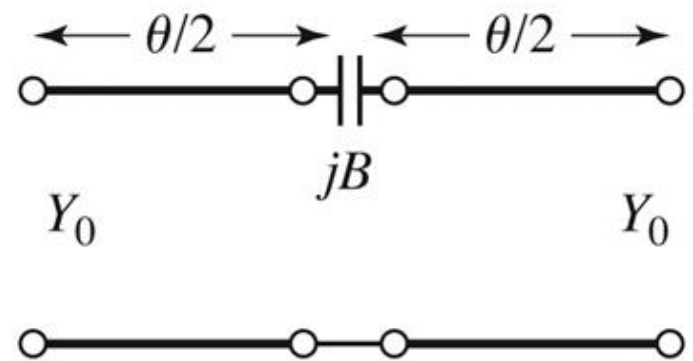
■ Realizare cu linii



$$K = Z_0 \cdot \tan \left| \frac{\theta}{2} \right|$$

$$X = \frac{K}{1 - \left(\frac{K}{Z_0} \right)^2}$$

$$\theta = -\tan^{-1} \frac{2 \cdot X}{Z_0}$$



$$J = Y_0 \cdot \tan \left| \frac{\theta}{2} \right|$$

$$B = \frac{J}{1 - \left(\frac{J}{Y_0} \right)^2}$$

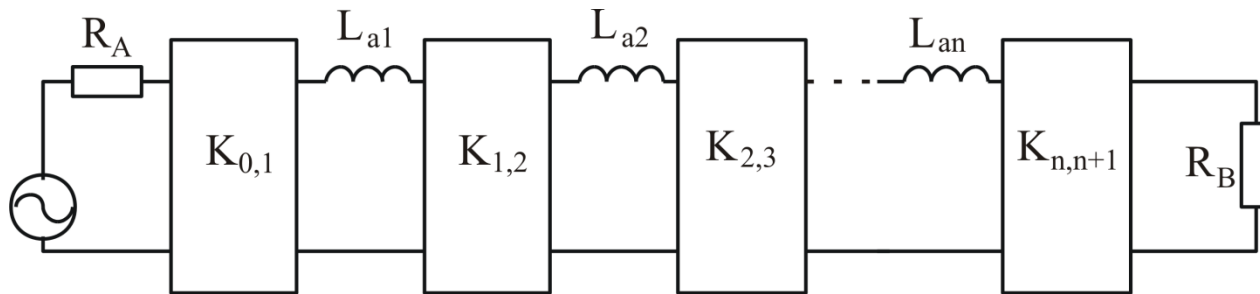
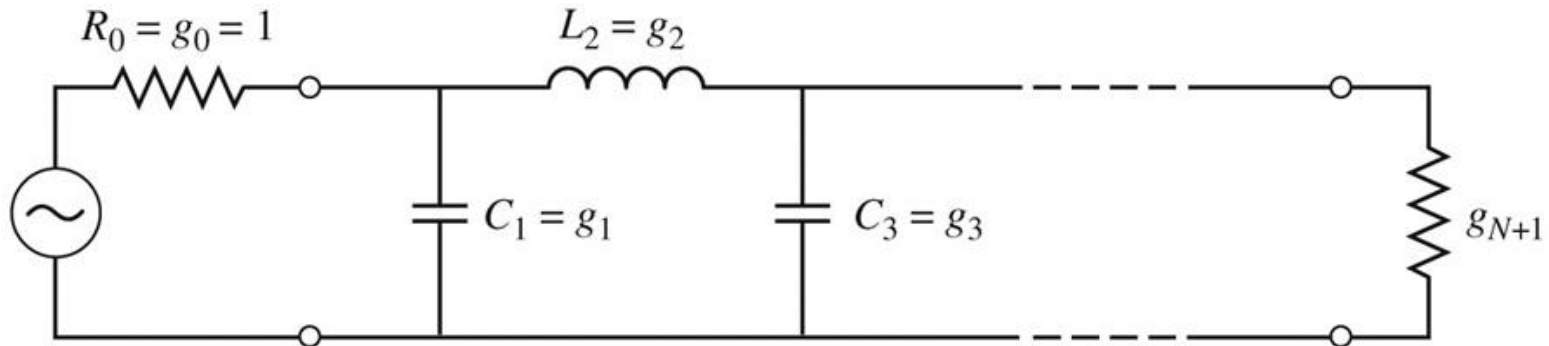
$$\theta = -\tan^{-1} \frac{2 \cdot B}{Y_0}$$

Red arrows from the theta terms in the equations above point to this result:

$$\theta < 0$$

Filtre prototip cu inversoare

- Utilizand inversoare de admitanta se pot implementa filtrele prototip utilizand un singur tip de element



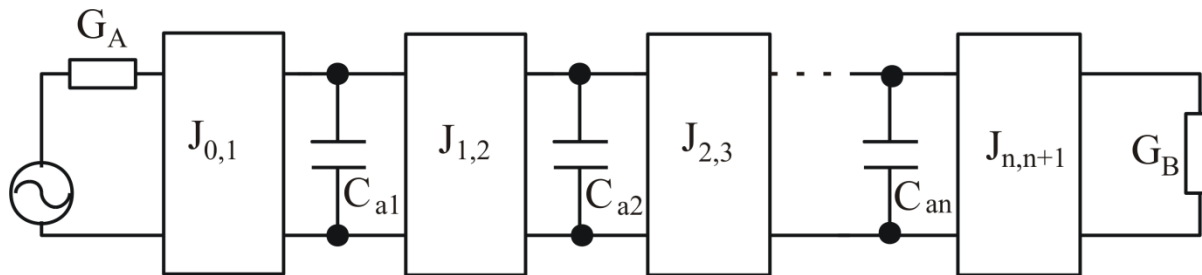
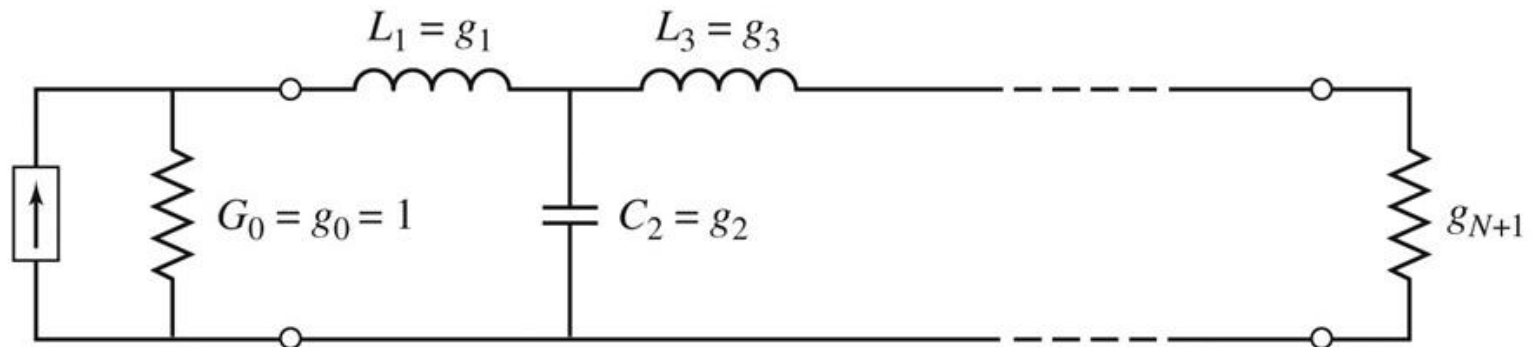
$$K_{0,1} = \sqrt{\frac{R_A \cdot L_{a,1}}{g_0 \cdot g_1}}$$

$$K_{k,k+1} \Big|_{k=1, n-1} = \sqrt{\frac{L_{a,k} \cdot L_{a,k+1}}{g_k \cdot g_{k+1}}}$$

$$K_{n,n+1} = \sqrt{\frac{L_{a,n} \cdot R_B}{g_n \cdot g_{n+1}}}$$

Filtre prototip cu inversoare

- Utilizand inversoare de admitanta se pot implementa filtrele prototip utilizand un singur tip de element



$$J_{0,1} = \sqrt{\frac{G_A \cdot C_{a,1}}{g_0 \cdot g_1}}$$

$$J_{k,k+1} \Big|_{k=1, n-1} = \sqrt{\frac{C_{a,k} \cdot C_{a,k+1}}{g_k \cdot g_{k+1}}}$$

$$J_{n,n+1} = \sqrt{\frac{C_{a,n} \cdot g_B}{g_n \cdot g_{n+1}}}$$

Filtre prototip cu inversoare

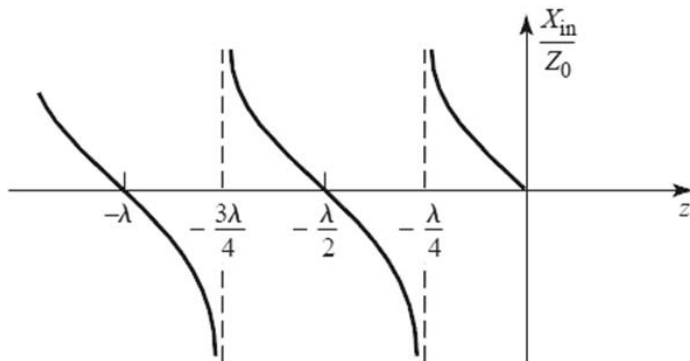
- Pentru filtrele prototip cu inversoare exista $2 \cdot N + 1$ parametri si $N + 1$ ecuatii care asigura echivalenta raspunsului deci N parametri pot fi alesi din considerente oarecare
 - se pot alege valorile reactantelor, urmand ca parametrii inversoarelor sa rezulte din calcul
 - se pot alege convenabil inversoarele, urmand ca reactantele sa rezulte din ecuatiile de echivalare
- Principiul se poate aplica si pentru filtrele trece banda/opreste banda, acestea putand fi realizate din $N + 1$ inversoare si N rezonatori (grupuri LC serie sau paralel cu frecventa de rezonanta ω_0) conectate fie in serie fie in paralel intre inversoare
 - FTB se realizeaza cu
 - grup LC serie conectat in serie intre inversoare
 - grup LC paralel conectat in paralel intre inversoare
 - FOB se realizeaza cu
 - grup LC paralel conectat in serie intre inversoare
 - grup LC serie conectat in paralel intre inversoare

Linii ca rezonatoare

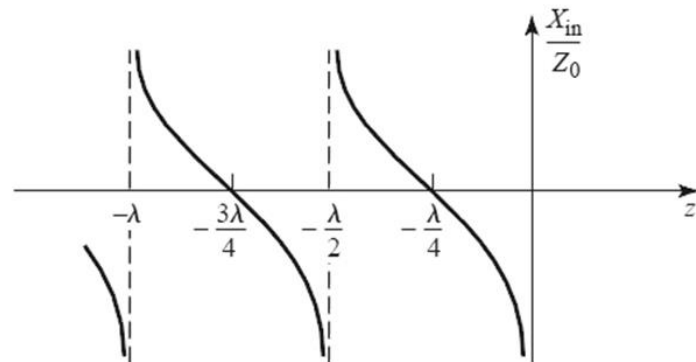
- Impedanta de intrare intr-o linie (stub) scurtcircuitata sau lasata in gol la capat manifesta comportament rezonant care poate fi utilizat pentru implementarea rezonatoarelor

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

$$Z_{in,sc} = j \cdot Z_0 \cdot \tan \beta \cdot l$$

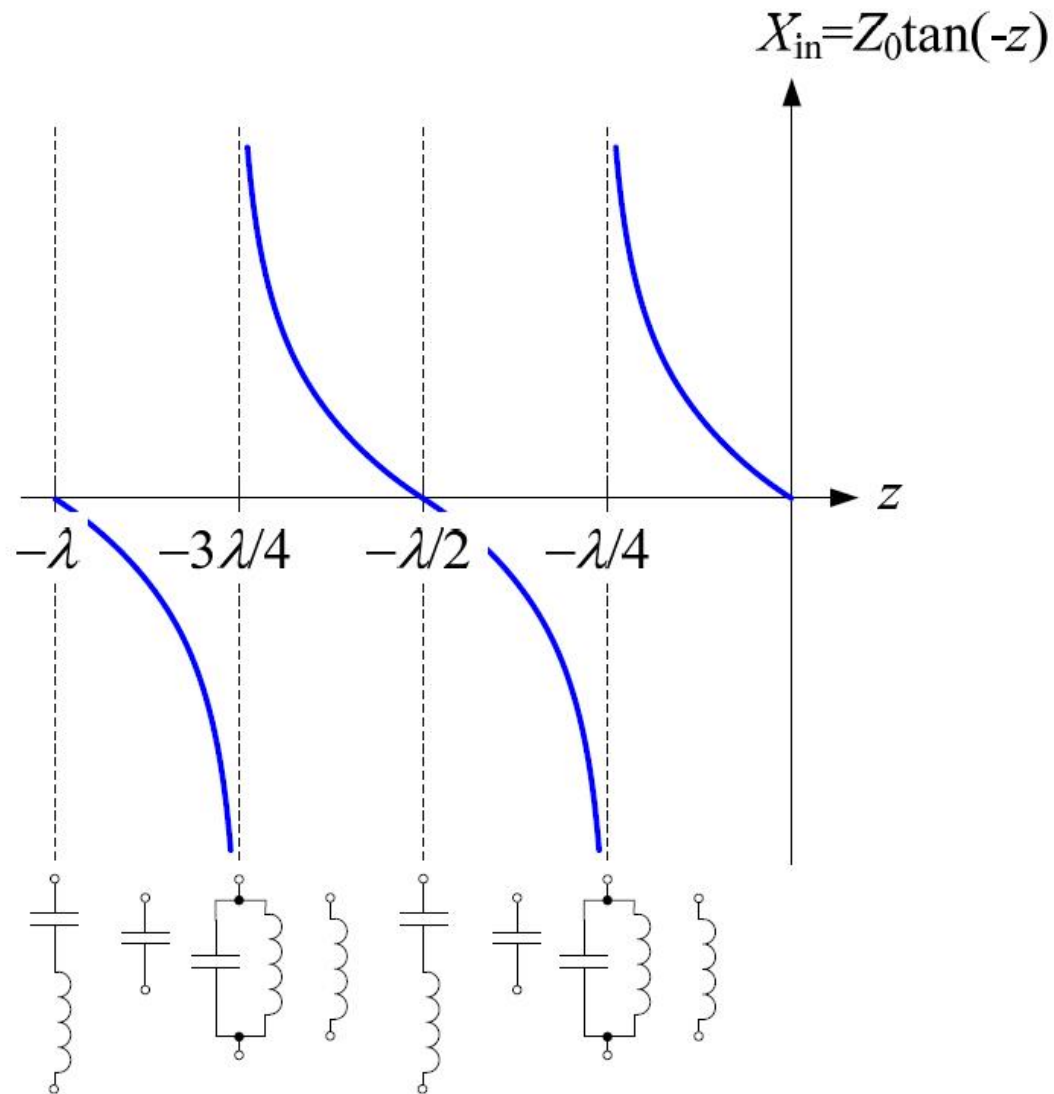


$$Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$



Linii ca rezonatoare

- Linie în scurtcircuit
- Pentru frecvența (ω_0) la care $l = \lambda/4$ se obține un circuit rezonant LC paralel
 - linia are comportament capacitiv pentru frecvențe mai mici ($l > \lambda/4$)
 - linia are comportament inductiv pentru frecvențe mai mari ($l < \lambda/4$)
- Discuție similară pentru linia în gol (LC serie la frecvența la care $l = \lambda/4$)



FTB/FOB relatii de proiectare

- Pentru cazul particular in care se implementeaza inversoarele de admitanta cu transformatoare in sfert de lungime de unda si impedanta caracteristica Z_0

- FTB – stub-uri paralel scurtcuite la $l = \lambda/4$

$$Z_{0n} \approx \frac{\pi \cdot Z_0 \cdot \Delta}{4 \cdot g_n}$$

- FOB – stub-uri paralel in gol de lungime $l = \lambda/4$

$$Z_{0n} \approx \frac{4 \cdot Z_0}{\pi \cdot g_n \cdot \Delta}$$

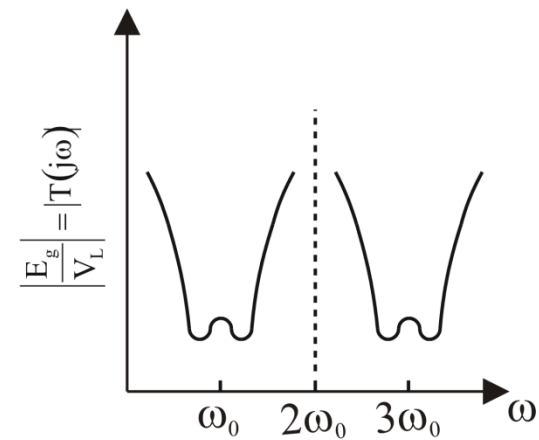
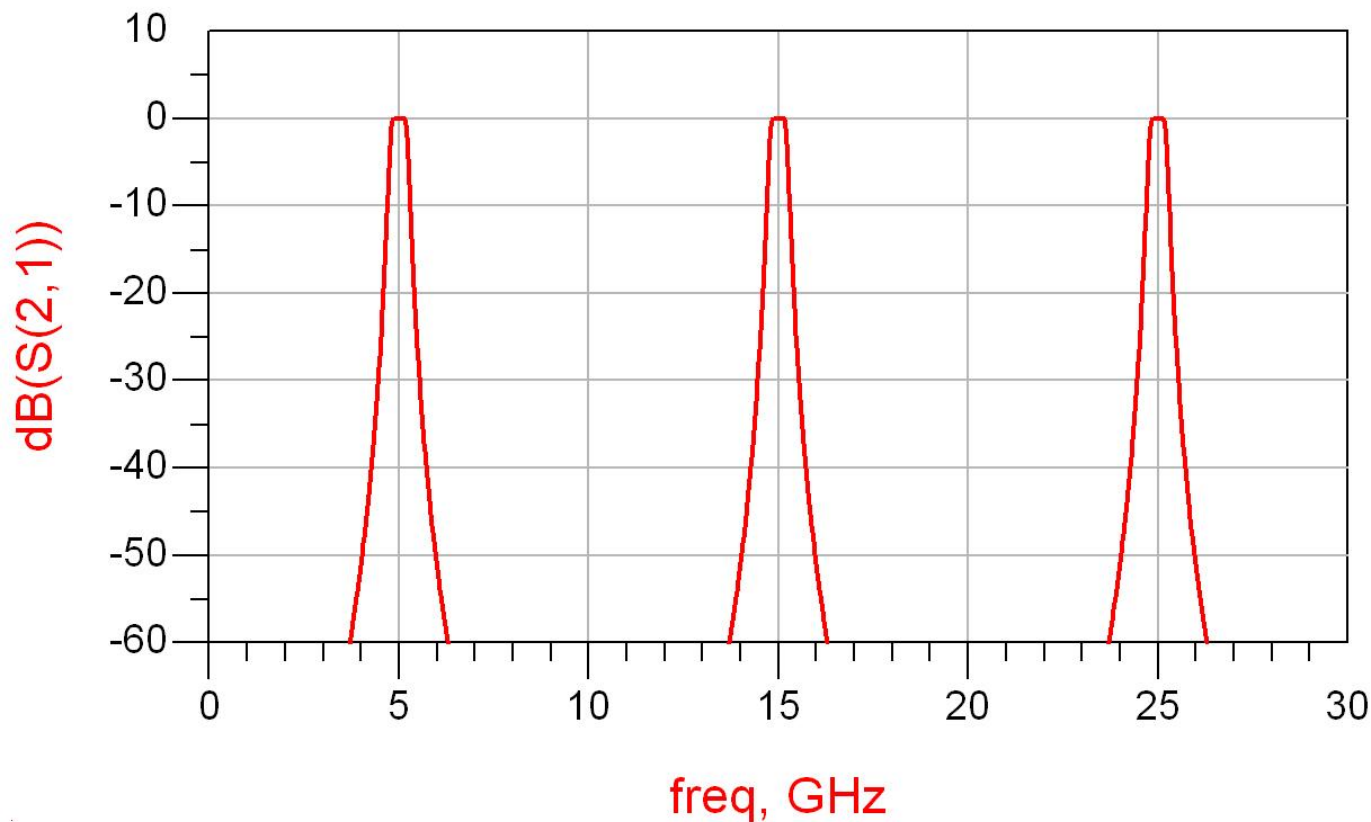
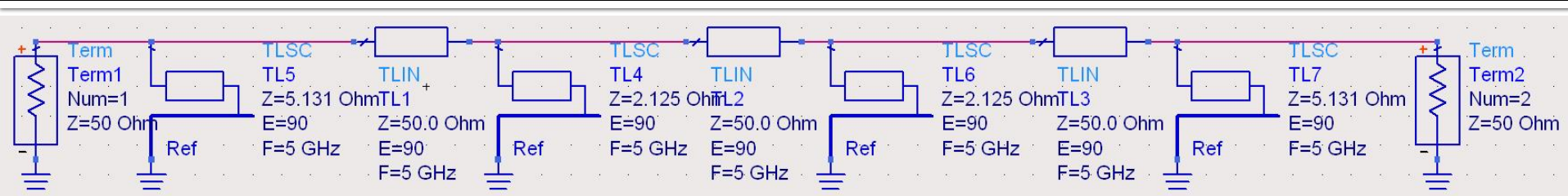
Exemplu

- Similar cu o tema de proiect
- Continuarea amplificatorului C9
- Filtru trece banda de ordinul 4, $f_0 = 5\text{GHz}$, banda 10 %
- Tabel maxim plat sau relatii de calcul:

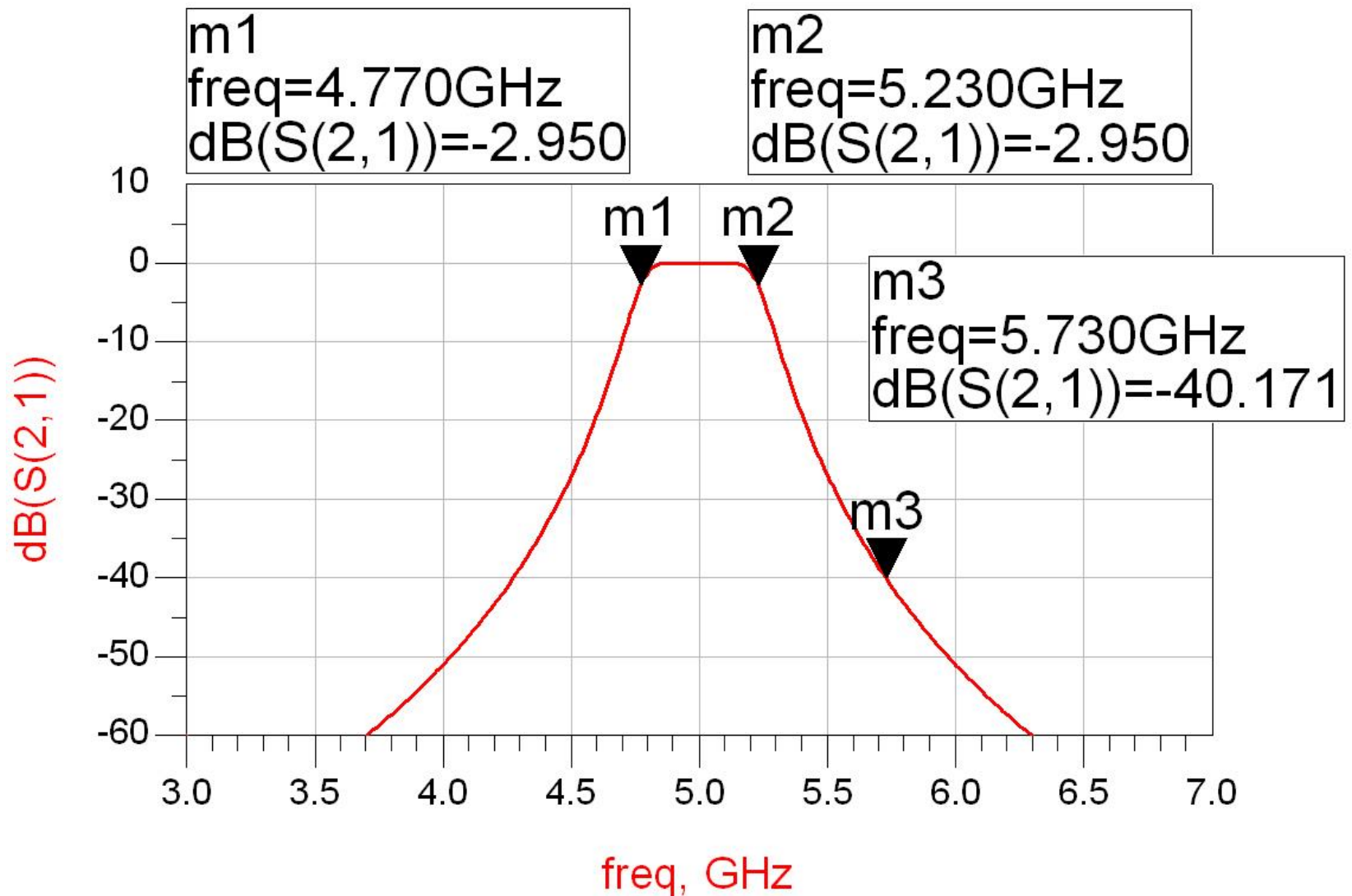
n	g_n	$Z_{on}(\Omega)$
1	0.7654	5.131
2	1.8478	2.125
3	1.8478	2.125
4	0.7654	5.131

$$Z_{on} \approx \frac{\pi \cdot Z_0 \cdot \Delta}{4 \cdot g_n}$$

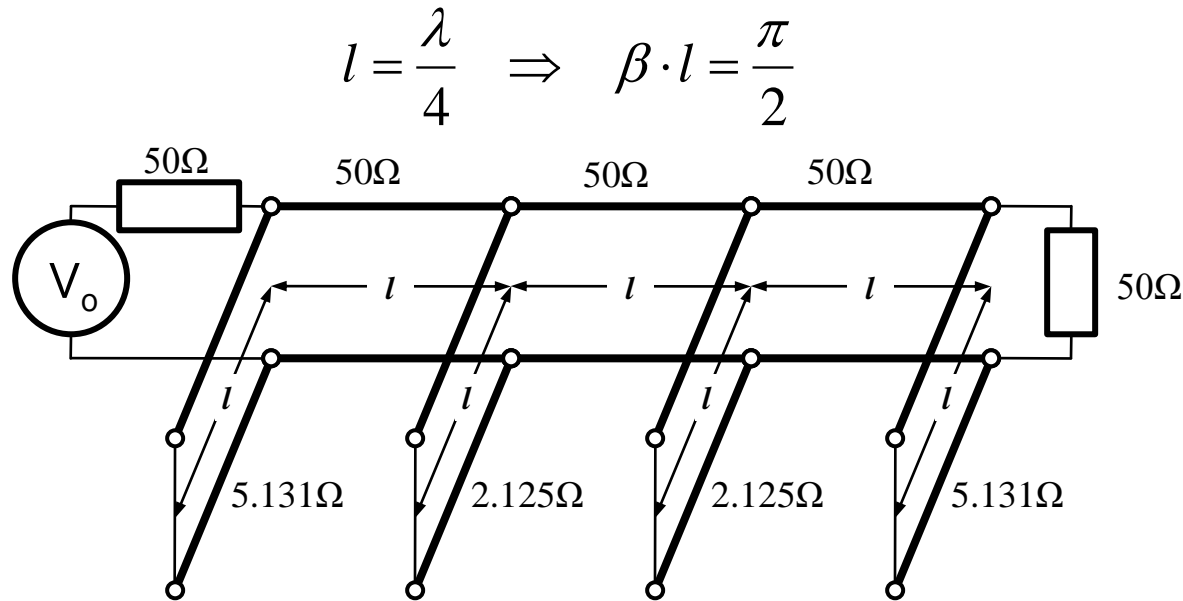
ADS – FTB



ADS – FTB



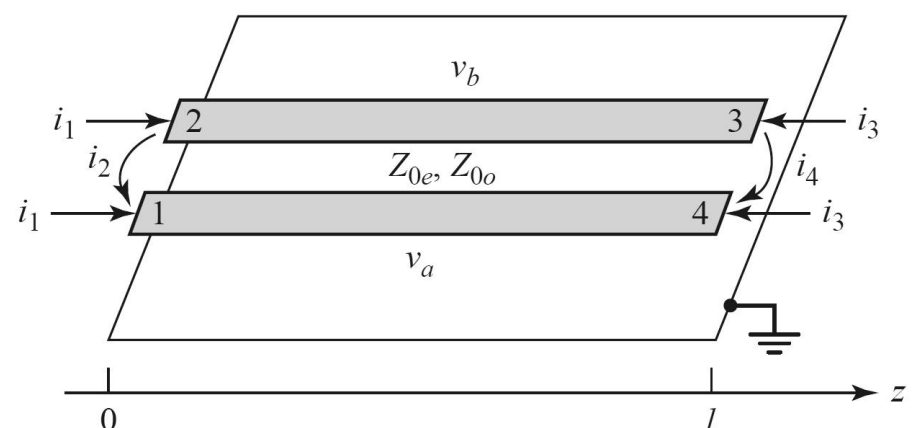
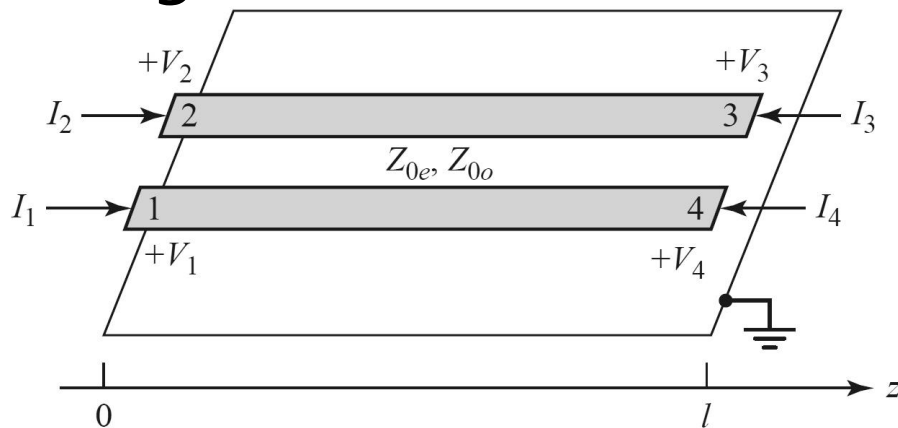
Exemplu



- Problemele filtrelor realizate cu linii ca rezonatoare si invertoare de impedanta
 - stub-uri in scurtcircuit (via-hole) pentru FTB
 - deseori impedantele caracteristice pentru stub-uri rezulta de **valori** dificil de realizat in practica (2.125Ω)

Filtre cu linii cuplate

- Analiza sectiunilor de linii cuplate se face punand in evidenta comportarea pe modul par si pe modul impar
- Aceste moduri sunt caracterizate de impedantele caracteristice de mod par/impar a caror valoare va impune in functie de tehnologia utilizata geometria liniilor (latime/distanta dintre linii)



Linii cuplate

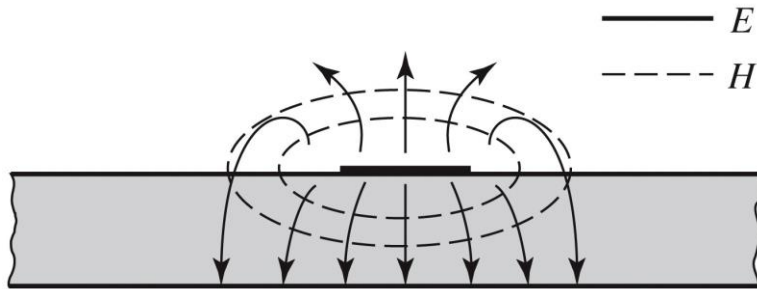
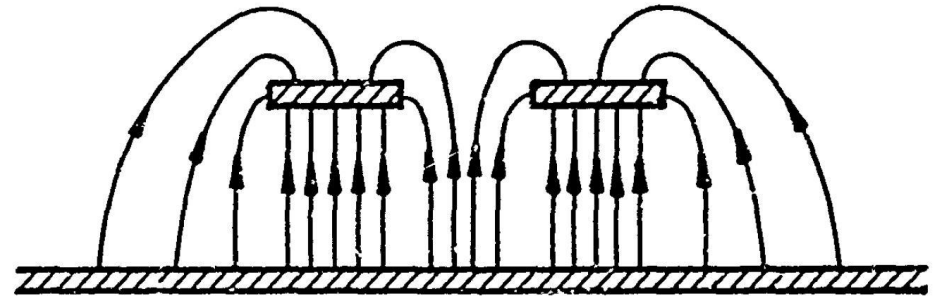
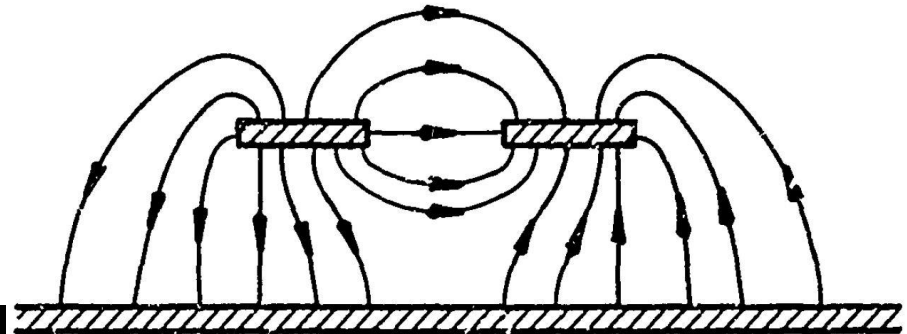


Figure 3.25b
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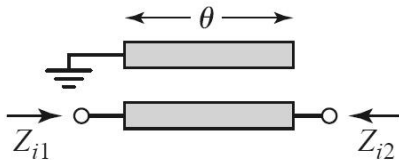
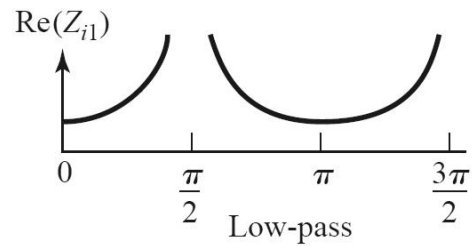
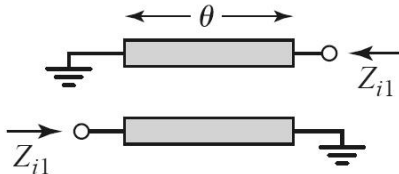
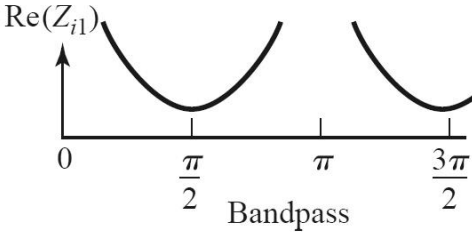
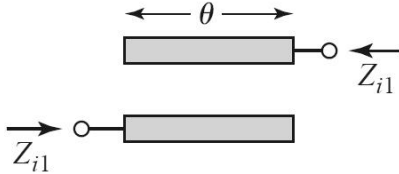
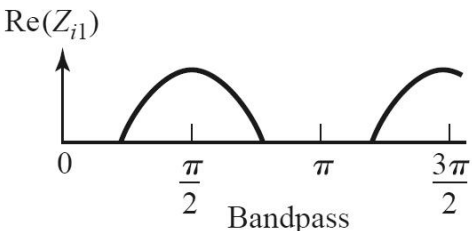
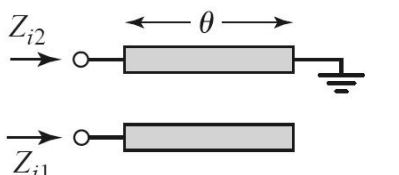
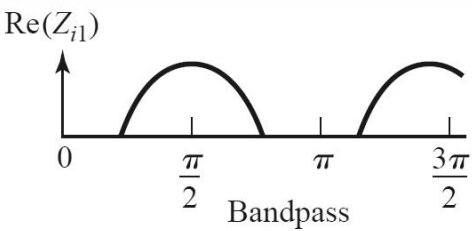
b) EVEN MODE ELECTRIC FIELD PATTERN (SCHEMATIC)



c) ODD MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

- Mod par – caracterizeaza semnalul de mod comun de pe cele doua linii
- Mod impar – caracterizeaza semnalul de mod diferential dintre cele doua linii

Filtre cu linii cuplate

Circuit	Image Impedance	Response
	$Z_{i1} = \frac{2Z_{0e}Z_{0o} \cos \theta}{\sqrt{(Z_{0e} + Z_{0o})^2 \cos^2 \theta - (Z_{0e} - Z_{0o})^2}}$ $Z_{i2} = \frac{Z_{0e}Z_{0o}}{Z_{i1}}$	 <p>Low-pass</p>
	$Z_{i1} = \frac{2Z_{0e}Z_{0o} \sin \theta}{\sqrt{(Z_{0e} - Z_{0o})^2 - (Z_{0e} + Z_{0o})^2 \cos^2 \theta}}$	 <p>Bandpass</p>
	$Z_{i1} = \frac{\sqrt{(Z_{0e} - Z_{0o})^2 - (Z_{0e} + Z_{0o})^2 \cos^2 \theta}}{2 \sin \theta}$	 <p>Bandpass</p>
	$Z_{i1} = \frac{\sqrt{Z_{0e}Z_{0o}} \sqrt{(Z_{0e} - Z_{0o})^2 - (Z_{0e} + Z_{0o})^2 \cos^2 \theta}}{(Z_{0e} + Z_{0o}) \sin \theta}$ $Z_{i2} = \frac{Z_{0e}Z_{0o}}{Z_{i1}}$	 <p>Bandpass</p>

Filtre cu linii cuplate

- Filtru trece banda cu rezonanta la $\theta = \pi/2$ ($l = \lambda/4$)

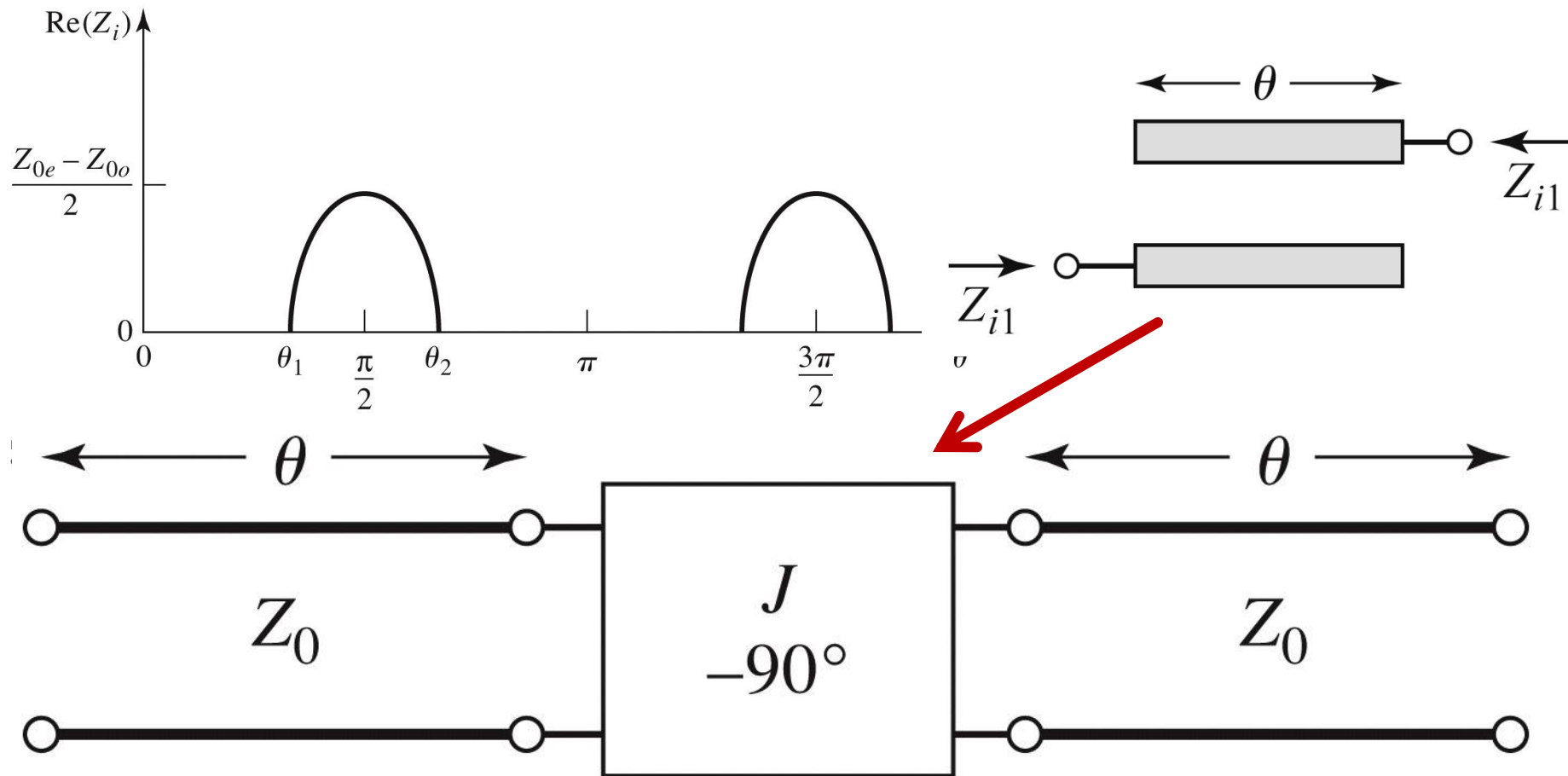
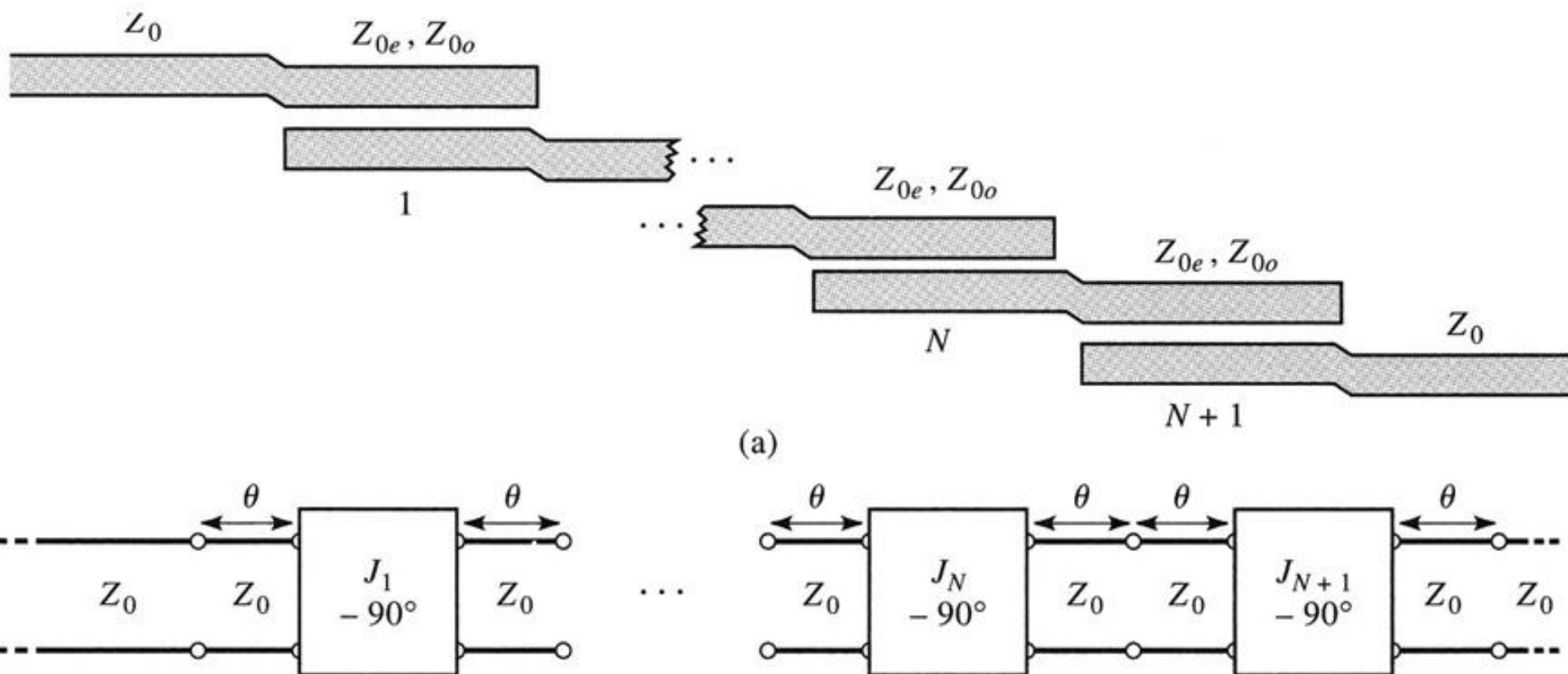


Figure 8.44

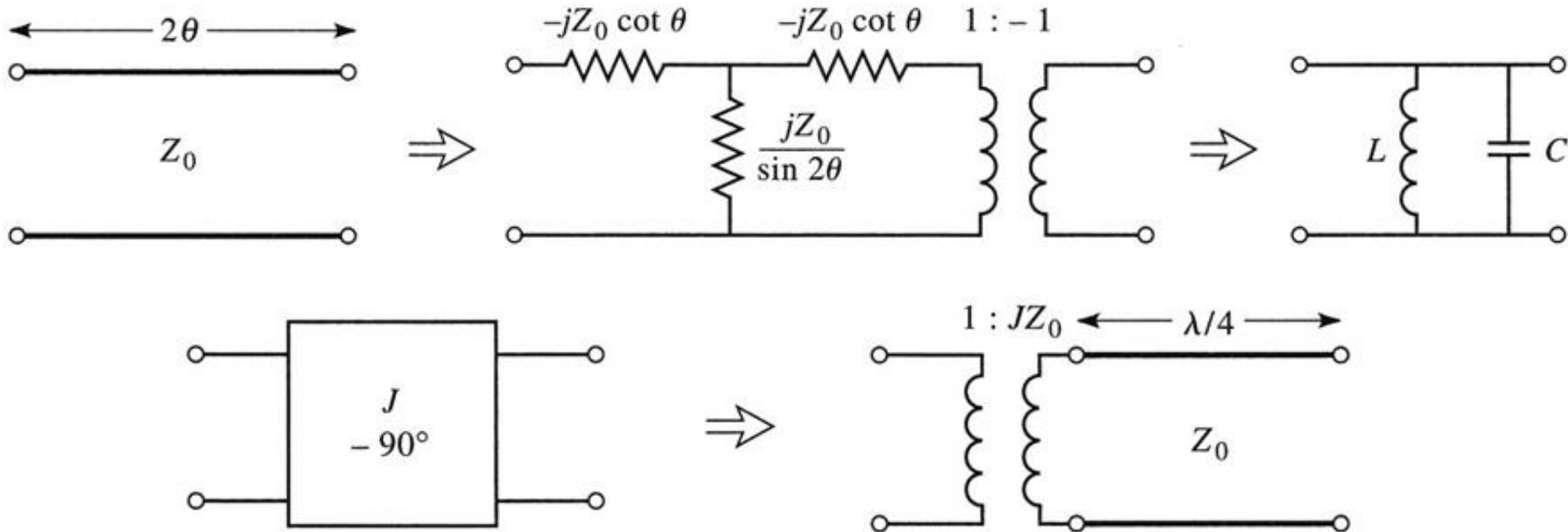
Filtre cu linii cuplate

- Un filtru cu $N+1$ sectiuni de linii cuplate



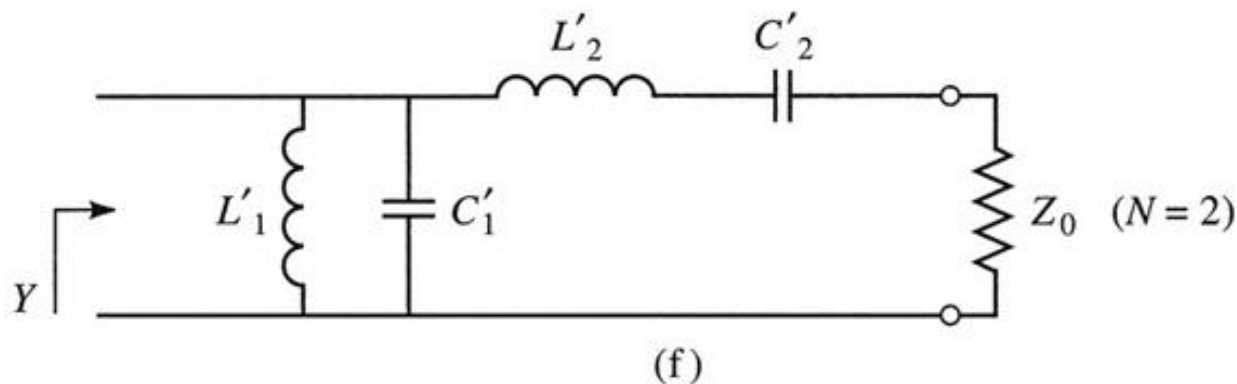
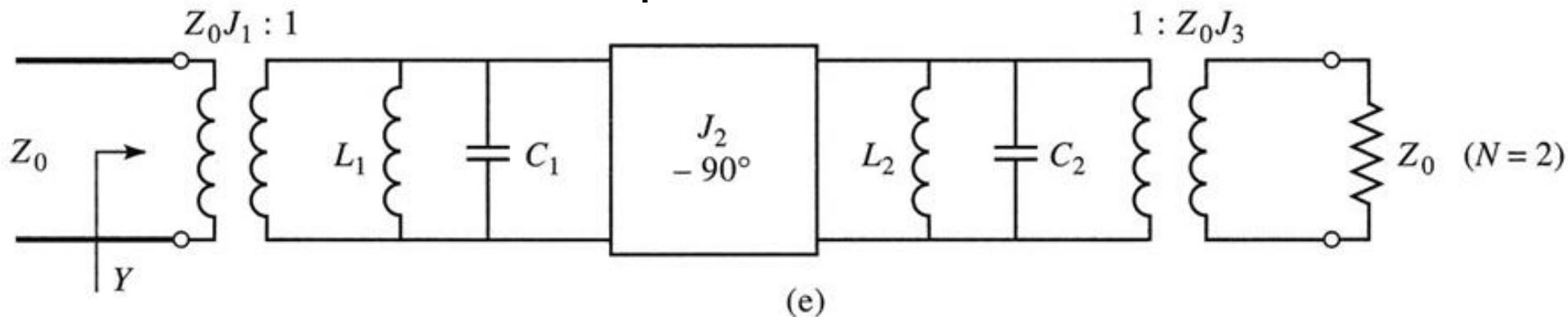
Filtre cu linii cuplate

- Se modeleaza
 - liniile
 - inversoarele



Filtre cu linii cuplate N=2

- Se obtine comportare de tip FTB de ordin 2 cu 3 sectiuni de linii cuplate



Proiectare filtre cu linii cuplate

- Se calculeaza inversoarele

$$Z_0 \cdot J_1 = \sqrt{\frac{\pi \cdot \Delta}{2 \cdot g_1}} \quad Z_0 \cdot J_n = \frac{\pi \cdot \Delta}{2 \cdot \sqrt{g_{n-1} \cdot g_n}}, n = \overline{2, N} \quad Z_0 \cdot J_{N+1} = \sqrt{\frac{\pi \cdot \Delta}{2 \cdot g_N \cdot g_{N+1}}}$$

- Se calculeaza liniile cuplate (toate de lungime $l = \lambda/4$)

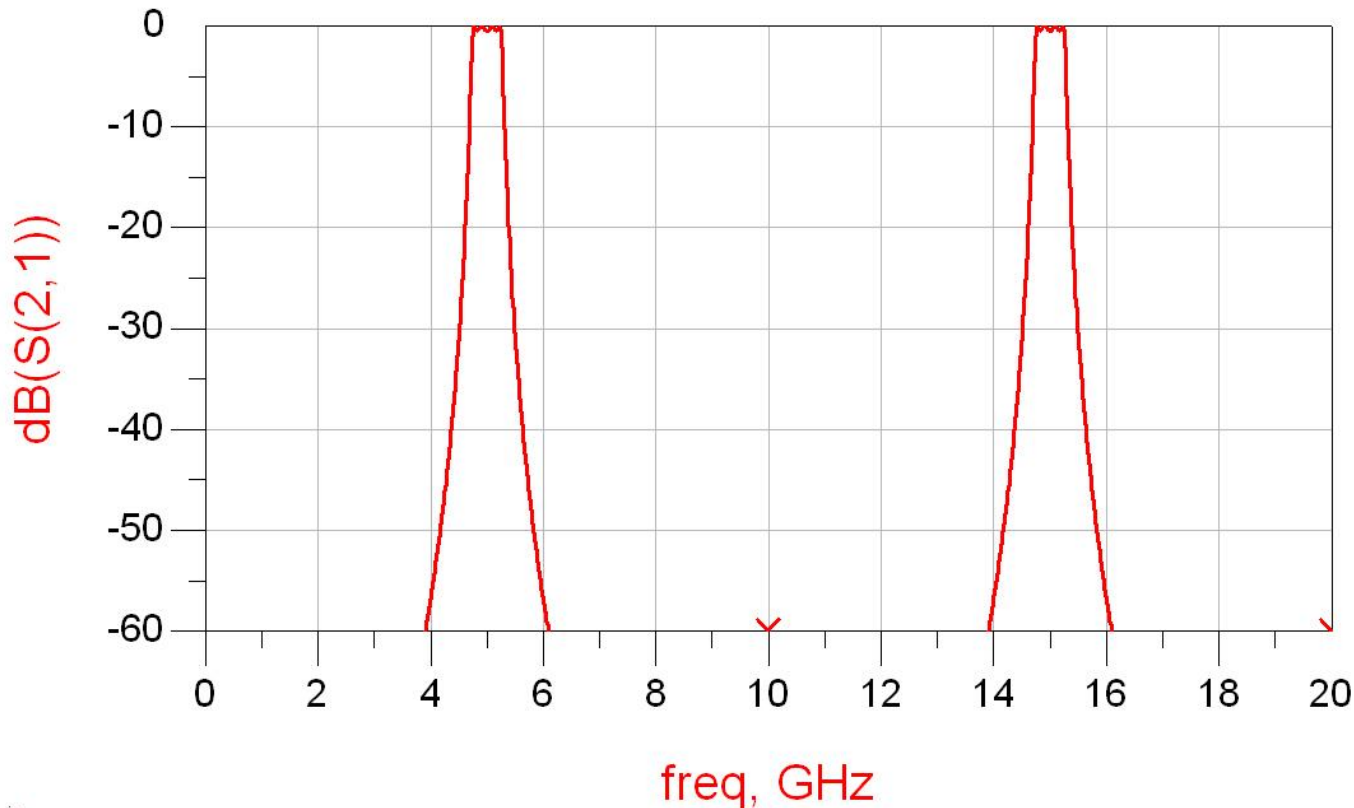
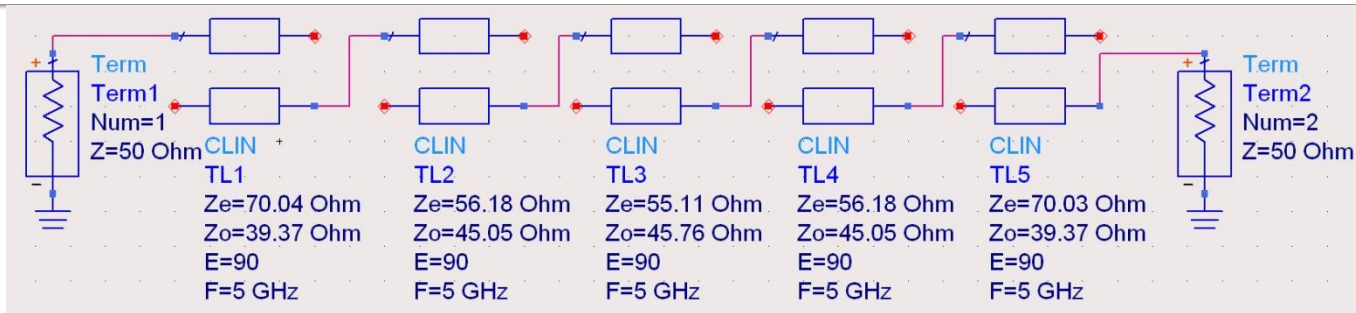
$$\begin{aligned} Z_{0e,n} &= Z_0 \cdot \left[1 + J_n \cdot Z_0 + (J_n \cdot Z_0)^2 \right] \\ Z_{0o,n} &= Z_0 \cdot \left[1 - J_n \cdot Z_0 + (J_n \cdot Z_0)^2 \right] \end{aligned} \quad n = \overline{1, N+1}$$

Exemplu

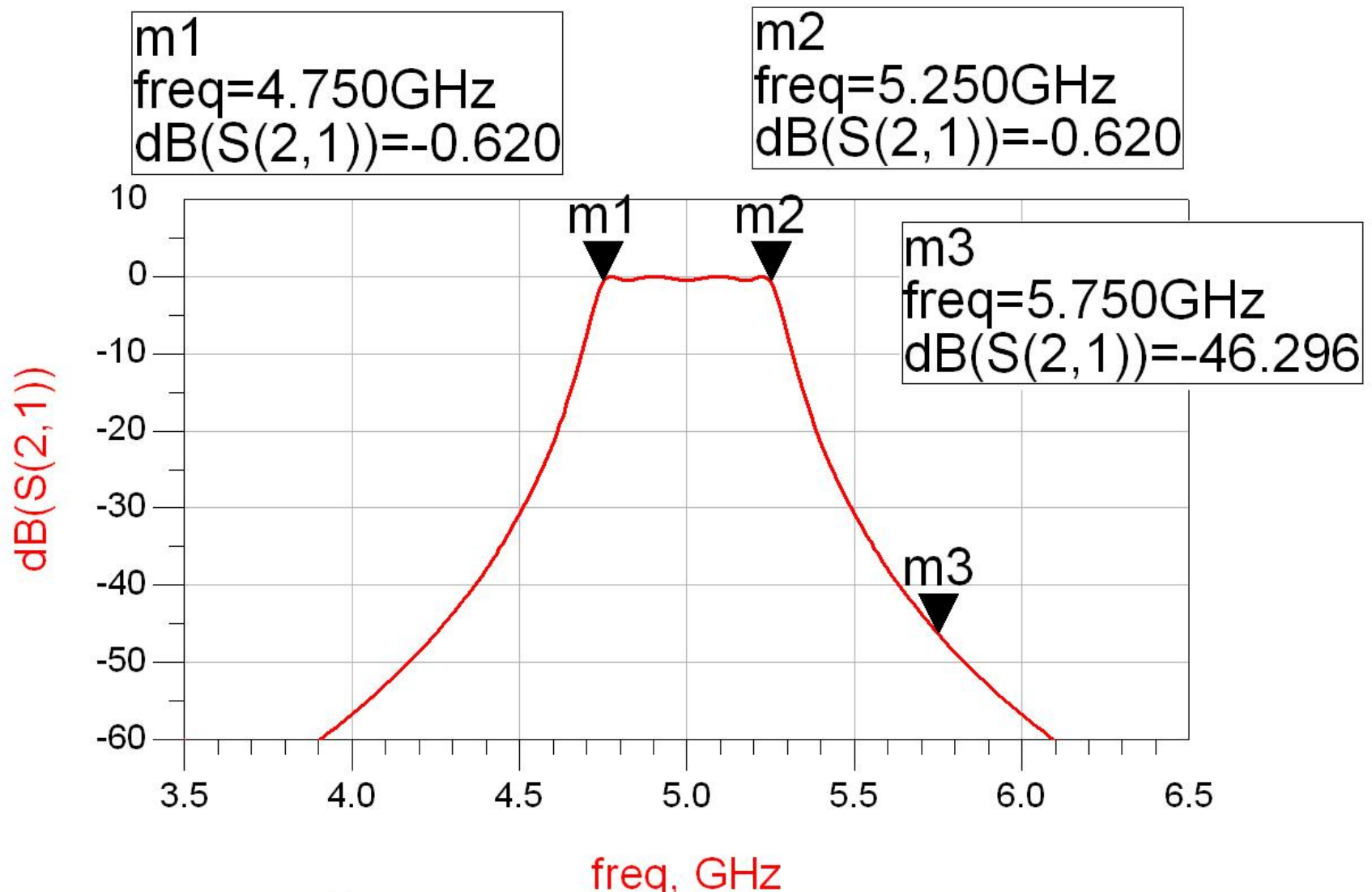
- Similar cu o tema de proiect
- Continuarea amplificatorului C10
- Filtru trece banda de ordinul 4, $f_0 = 5\text{GHz}$, banda 10 %
- Tabel echiriplu 0.5dB (g_i) plus relatii de calcul:

n	g	$Z_0 J_n$	Z_{0e}	Z_{0o}
1	1.6703	0.306664	70.04	39.37
2	1.1926	0.111295	56.18	45.05
3	2.3661	0.09351	55.11	45.76
4	0.8419	0.111294	56.18	45.05
5	1.9841	0.306653	70.03	39.37

ADS – FTB coupled line



ADS – FTB coupled line



Example

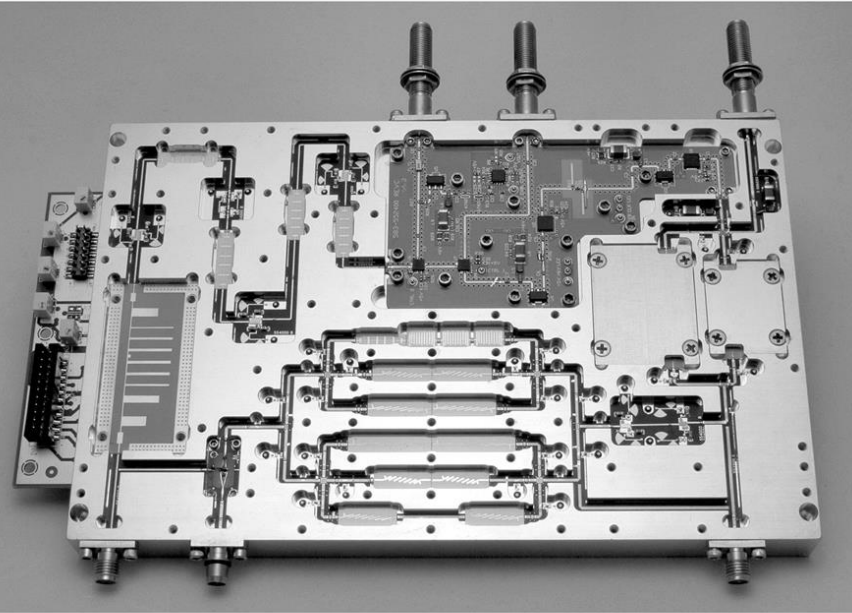
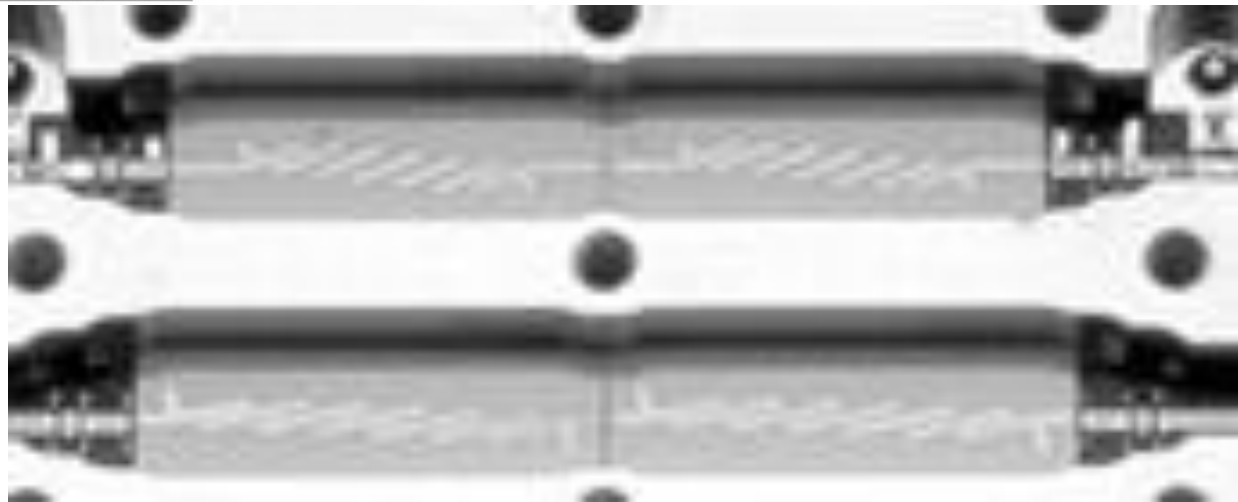
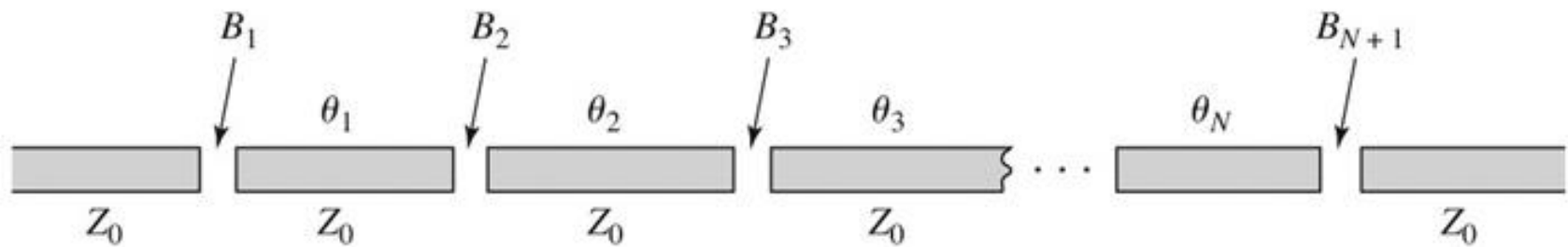


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.

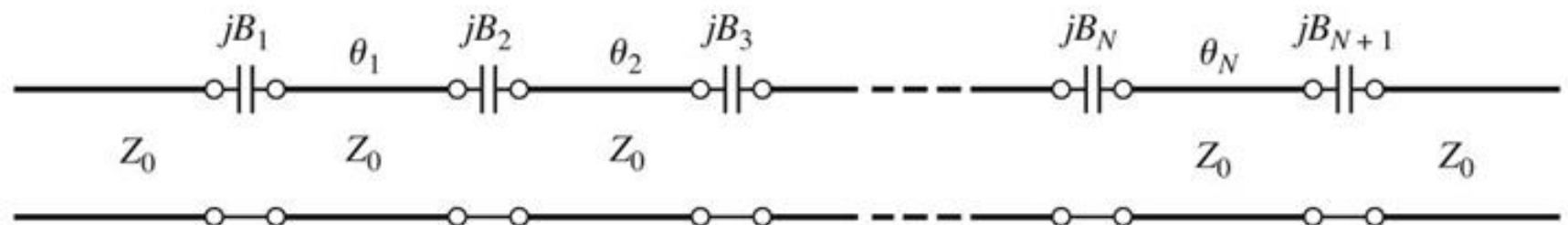


Filtru cu rezonatoare serie cuplate capacitiv

- Separarea fizica a doua sectiuni de linie produce un cuplaj capacitiv intre cele doua linii



(a)



(b)

Filtru cu rezonatoare serie cuplate capacitiv

- Din lungimea fizica a rezonatoarelor o portiune se foloseste pentru a crea schema de inversor (ramane $\phi = \pi$, $l = \lambda/2$)

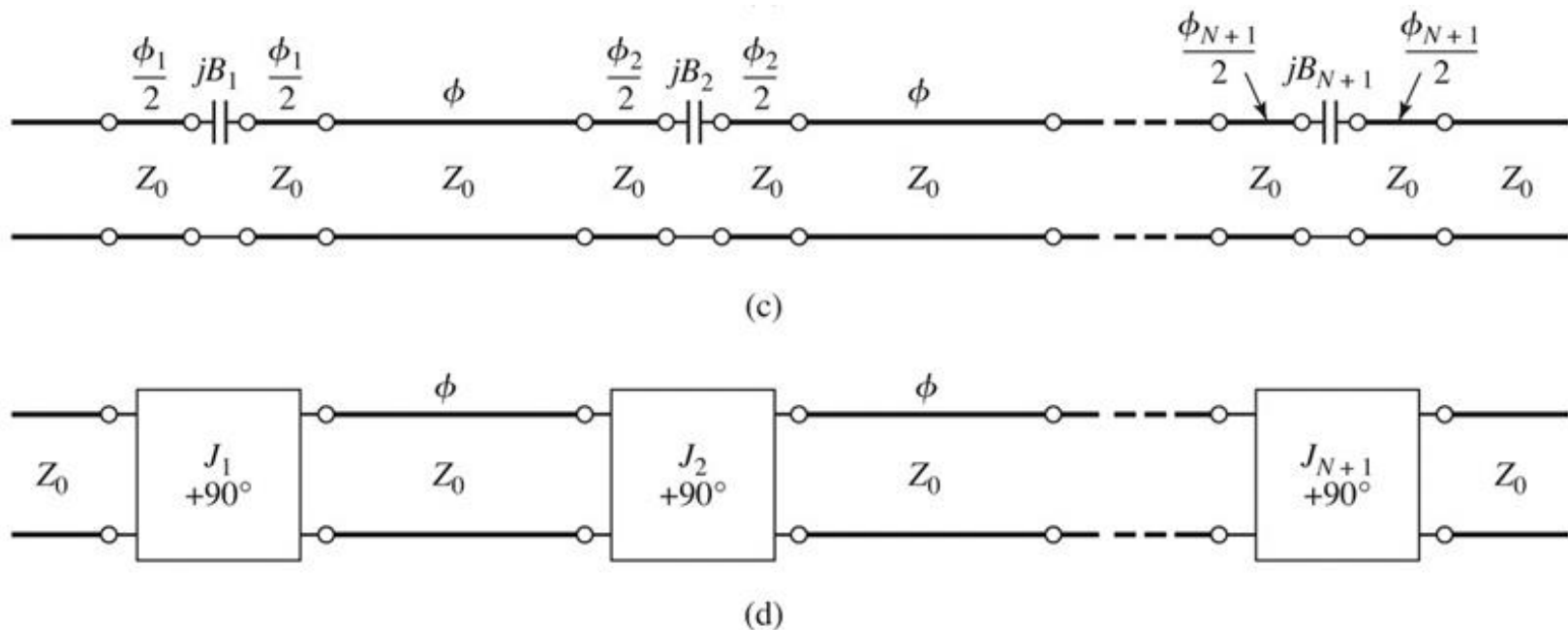


Figure 8.50

Proiectare filtru cu rezonatoare serie cuplate capacitiv

- Se calculeaza inversoarele (similar linii cuplate)

$$Z_0 \cdot J_1 = \sqrt{\frac{\pi \cdot \Delta}{2 \cdot g_1}} \quad Z_0 \cdot J_n = \frac{\pi \cdot \Delta}{2 \cdot \sqrt{g_{n-1} \cdot g_n}}, n = \overline{2, N} \quad Z_0 \cdot J_{N+1} = \sqrt{\frac{\pi \cdot \Delta}{2 \cdot g_N \cdot g_{N+1}}}$$

- Se calculeaza susceptantele cuplajului

$$B_n = \frac{J_n}{1 - (Z_0 \cdot J_n)^2}, n = \overline{1, N+1}$$

- Se calculeaza lungimile de linii care trebuie "imprumutate" pentru realizarea inversoarelor

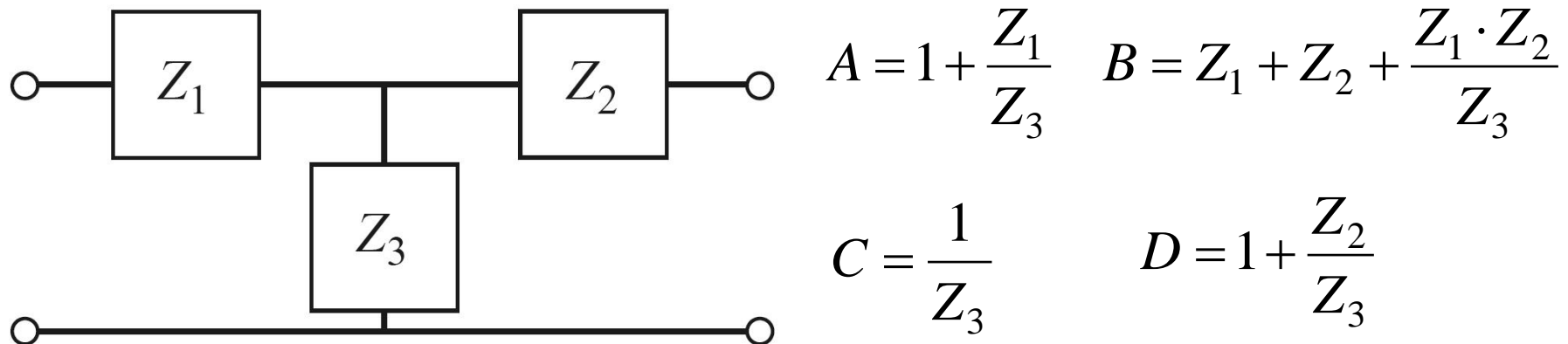
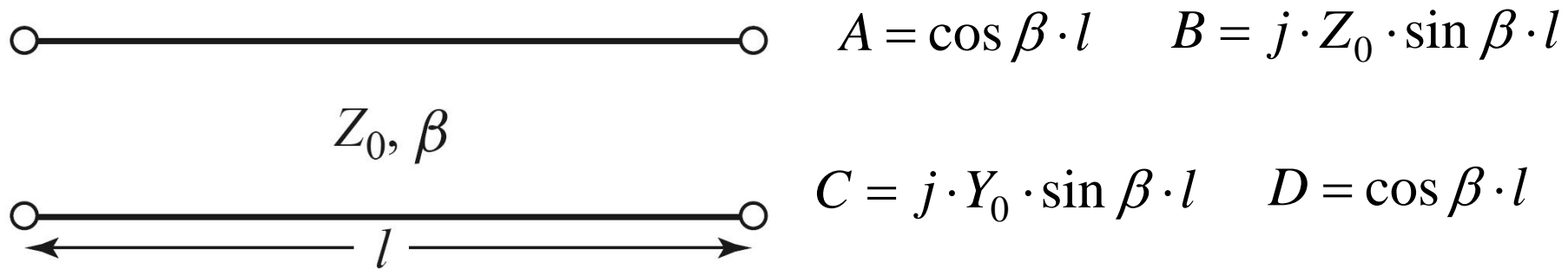
$$\phi_n = -\tan^{-1}(2 \cdot Z_0 \cdot B_n), n = \overline{1, N+1} \quad \phi_n < 0, n = \overline{1, N+1}$$

- Se calculeaza lungimile electrice ale liniilor

$$\theta_i = \pi + \frac{1}{2} \cdot (\phi_i + \phi_{i+1}) = \pi - \frac{1}{2} \cdot [\tan^{-1}(2 \cdot Z_0 \cdot B_i) + \tan^{-1}(2 \cdot Z_0 \cdot B_{i+1})], i = \overline{1, N}$$

Circuite echivalente pentru sectiuni scurte de linii

- Parametri ABCD (C_4)
- linie scurta, model cu elemente concentrate valid



Circuite echivalente pentru sectiuni scurte de linii

- Element paralel capacitiv

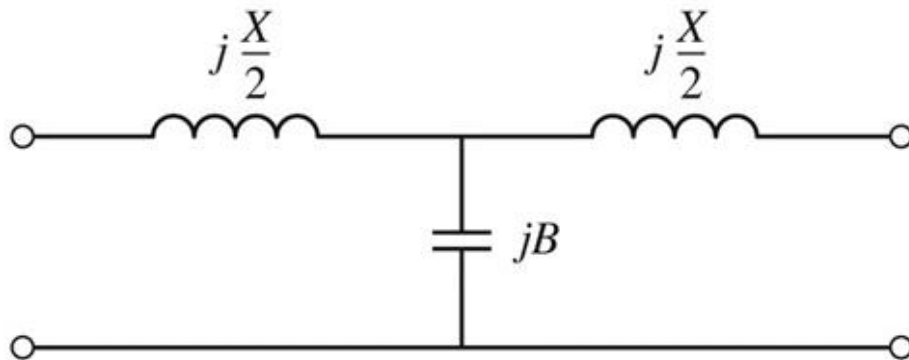
$$Z_3 = \frac{1}{j \cdot Y_0 \cdot \sin \beta \cdot l}$$

- Elementele in serie egale, inductive

$$\cos \beta \cdot l = 1 + \frac{Z_1}{Z_3} = 1 + \frac{Z_2}{Z_3}$$

$$Z_1 = Z_2 = Z_3 \cdot (\cos \beta \cdot l - 1) = -j \cdot Z_0 \cdot \frac{\cos \beta \cdot l - 1}{\sin \beta \cdot l} = j \cdot Z_0 \cdot \tan \frac{\beta \cdot l}{2}$$

- Schema echivalenta

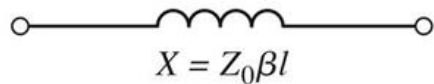


$$\frac{X}{2} = Z_0 \cdot \tan \frac{\beta \cdot l}{2}$$
$$B = \frac{1}{Z_0} \cdot \sin \beta \cdot l$$

Circuite echivalente pentru sectiuni scurte de linii

- In functie de valoarea impedantei caracteristice

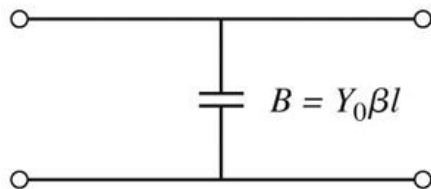
- impedanta ridicata $Z_0 \gg$



$$X \cong Z_0 \cdot \beta \cdot l \quad \beta \cdot l < \frac{\pi}{4} \quad Z_0 = Z_h$$



- impedanta scazuta $Z_0 \ll$



$$B \cong Y_0 \cdot \beta \cdot l \quad \beta \cdot l < \frac{\pi}{4} \quad Z_0 = Z_l$$

Filtre cu variatii treapta a impedantei

- Se pot crea filtre trece jos
- Se utilizeaza
 - linii cu impedanta caracteristica mare pentru a implementa o inductanta

$$\beta \cdot l = \frac{L \cdot R_0}{Z_h}$$

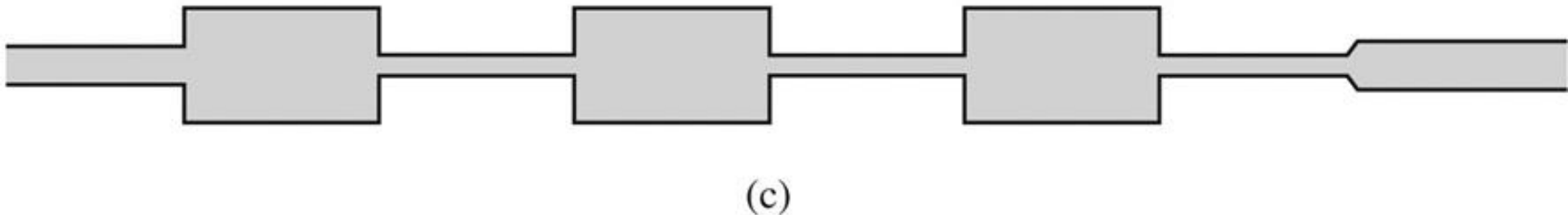
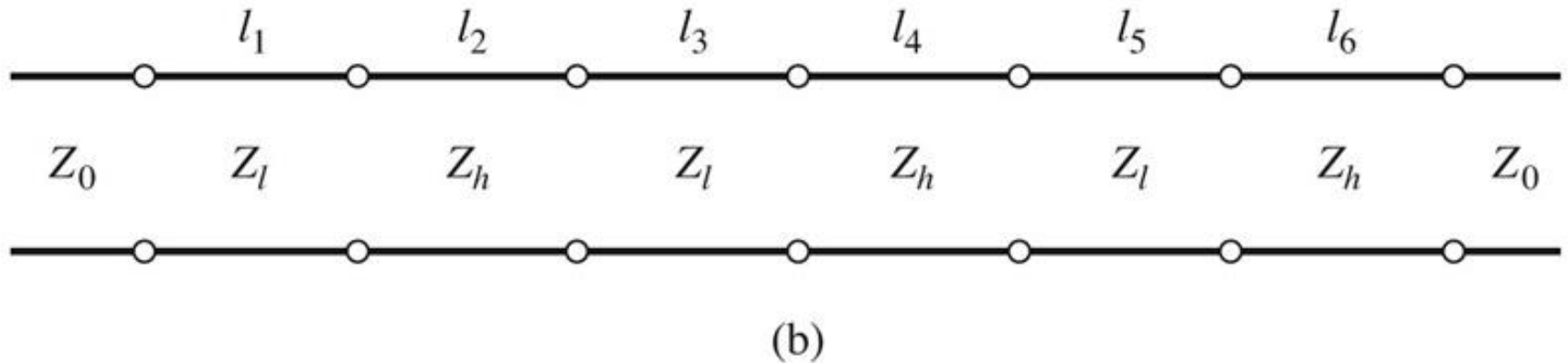
- linii cu impedanta caracteristica mica pentru a implementa o capacitate

$$\beta \cdot l = \frac{C \cdot Z_l}{R_0}$$

- De obicei se utilizeaza cea mai mare si cea mai mica impedanta permisa de tehnologie

Filtre cu variatii treapta a impedantei

- Nu toate liniile au aceeași lungime deci problema periodicității în frecvență a răspunsului este mai puțin importantă

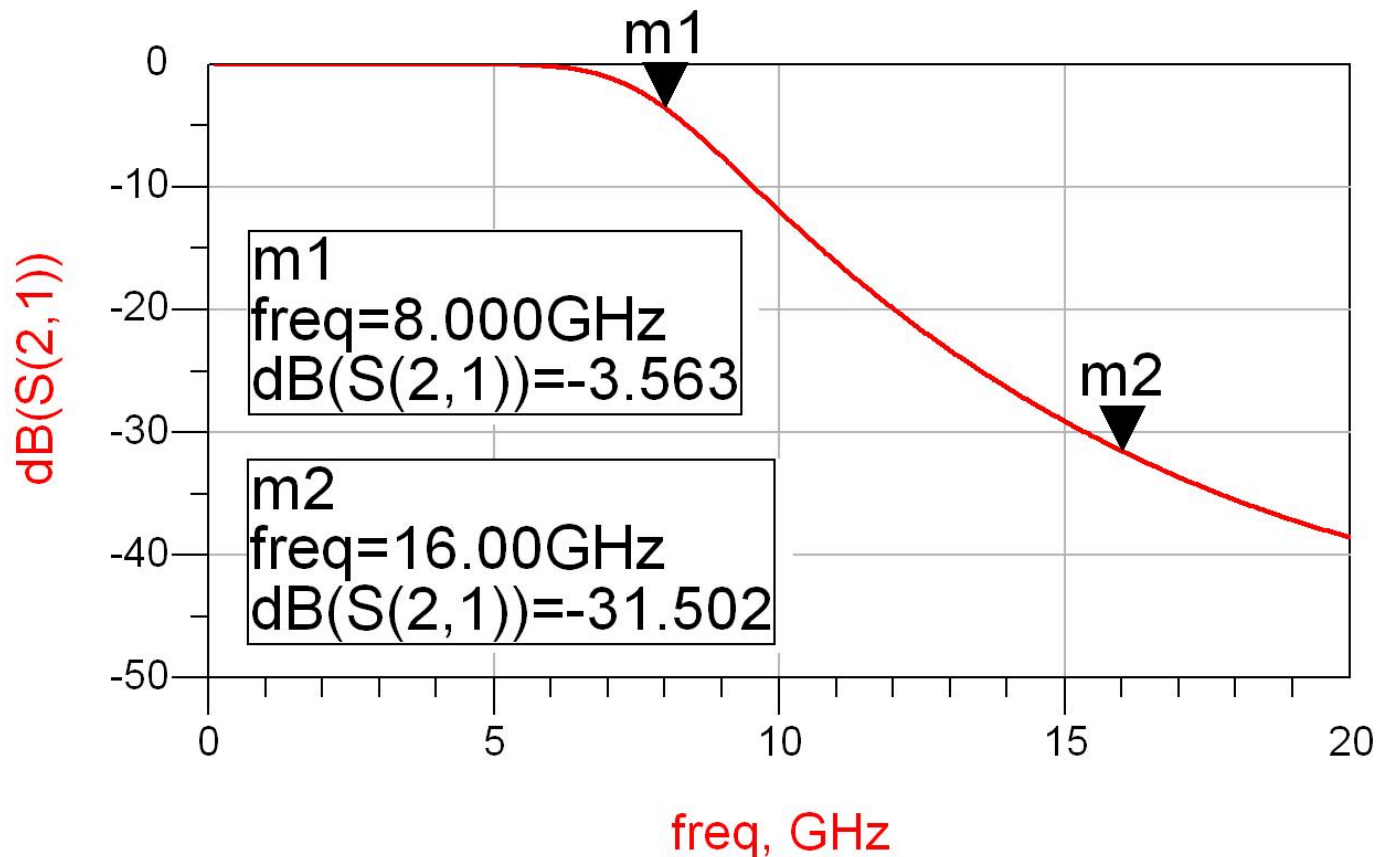
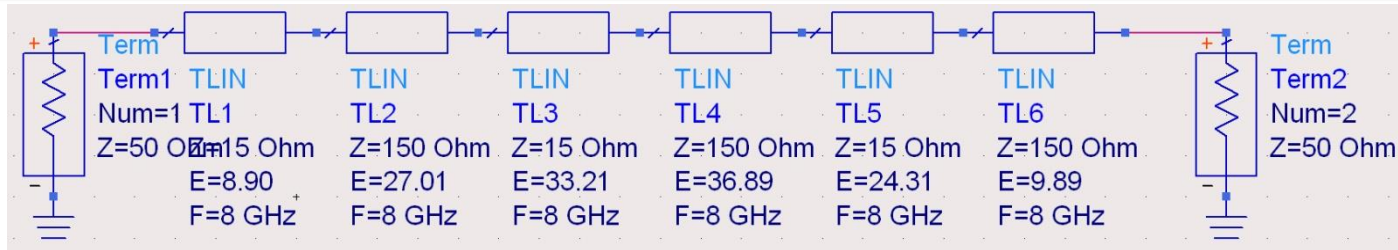


Exemplu

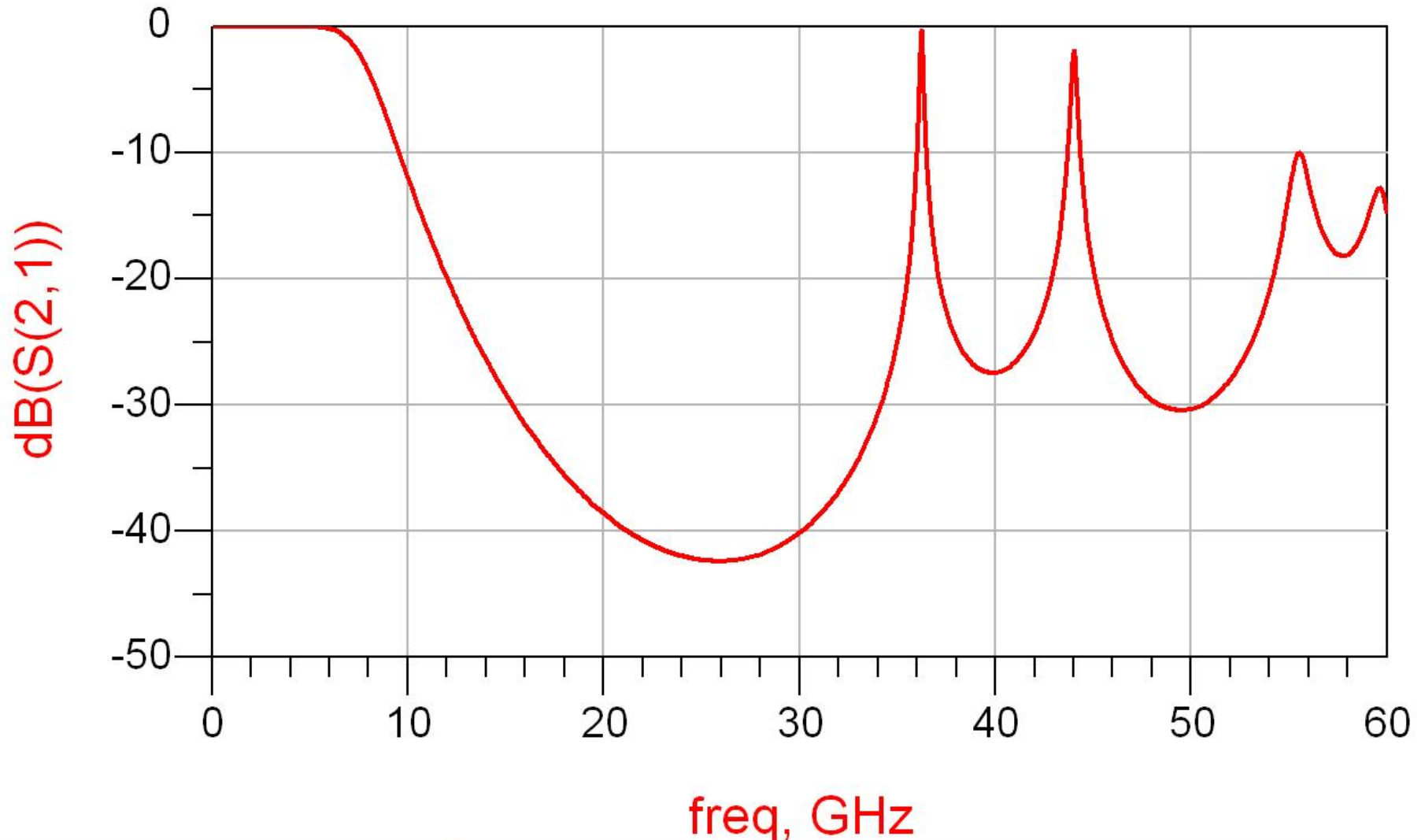
- FTJ cu frecventa de taiere 8GHz, de ordinul 6. Impedanta maxima realizabila este 150Ω iar cea minima 15Ω .

n	g_n	L/C_n	Z	$\theta_n[\text{rad}]$	$\theta_n[^\circ]$
1	0.5176	0.206pF	15	0.155	8.90
2	1.4142	1.407nH	150	0.471	27.01
3	1.9318	0.769pF	15	0.580	33.21
4	1.9318	1.922nH	150	0.644	36.89
5	1.4142	0.563pF	15	0.424	24.31
6	0.5176	0.515nH	150	0.173	9.89

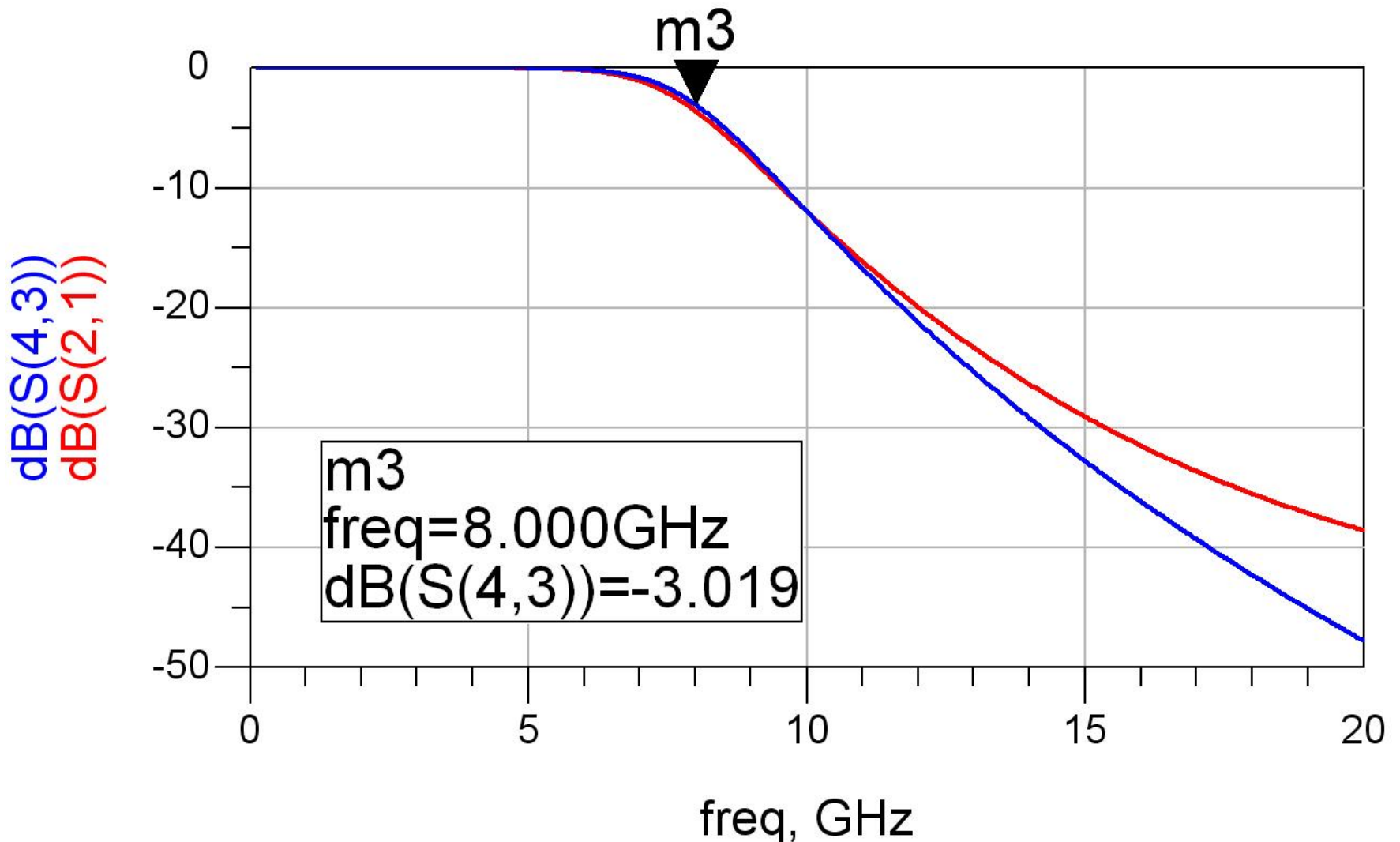
ADS – FTJ stepped impedance



ADS – FTJ stepped impedance



ADS – FTJ comparatie cu elemente concentrate



Example

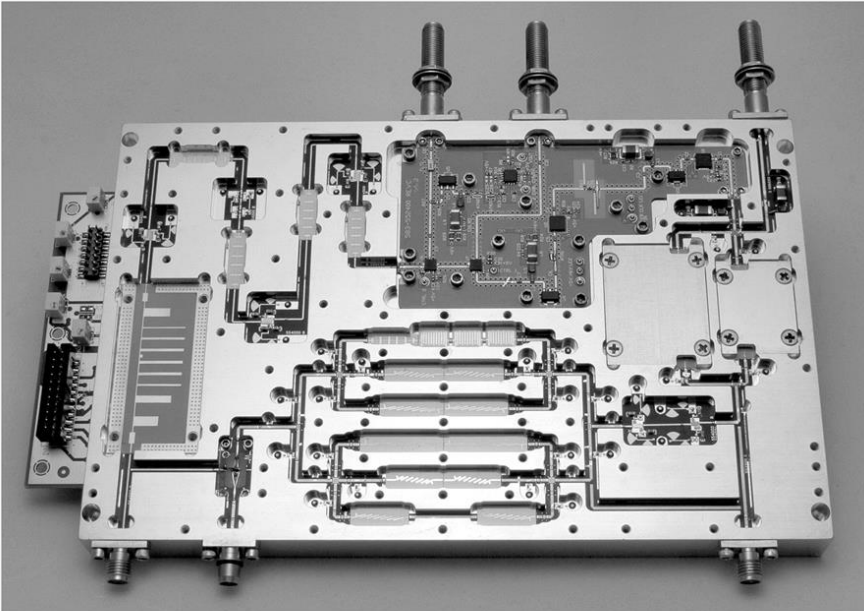
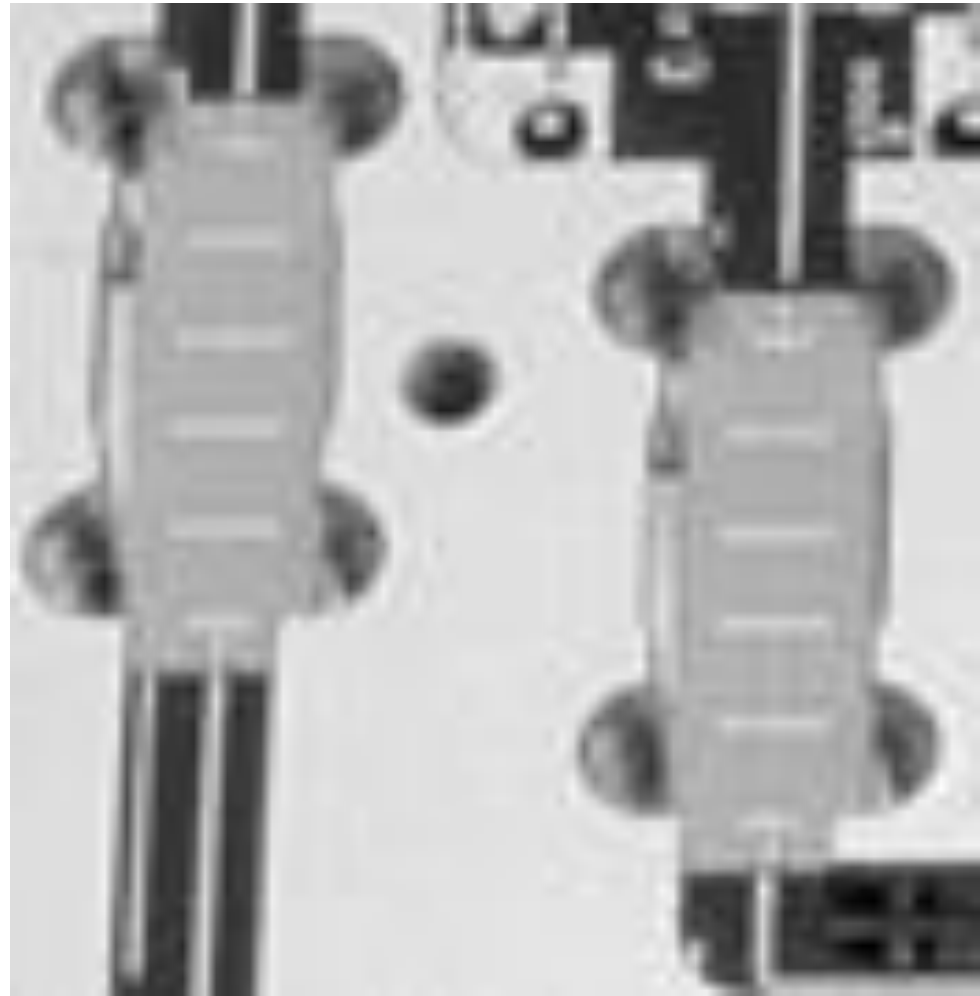


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.



Contact

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