

Curs 12

2019/2020

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2019/2020

- 2C/1L, DCMR (CDM)
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
 - Marti 14-16, P7
 - E – 50% din nota
 - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
 - primul test L1 (t2 si t3 neanuntate)
 - 3pz (C) = +0.5p
 - toate materialele permise

Disciplina 2019/2020

- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
 - Miercuri 10-14 impar II.12 (par eng.)
 - Joi 14- 16 par
 - L – **25%** din nota
 - prezenta + rezultate personale
 - P – **25%** din nota
 - tema personala

Documentatie

■ <http://rf-opto.etti.tuiasi.ro>

Laboratorul de Microunde si Optica

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

RF-OPTO

English | Romana

Start **Didactic** Master Colectiv Cercetare Studenti Admin

Microunde Comunicatii Optice Optoelectronica Internet Antene Practica Retele Soft didactic

Dispozitive si circuite de microunde pentru radiocomunicatii

Disciplina: DCMR (2017-2018)

Coordonator Disciplina: conf. dr. Radu-Florin Damian
Cod: DOS412T
Tip Disciplina: DOS; Disciplina Optionala, Disciplina de Specialitate
Credite: 4
An de Studiu: 4, Sem. 7

Activitati

Curs: Cadru Didactic: conf. dr. Radu-Florin Damian, 2 Ore/Saptamana, Sectie Specializare, Orar:
Laborator: Cadru Didactic: conf. dr. Radu-Florin Damian, 1 Ore/Saptamana, Grupa, Orar:

Evaluare

Tip: **Examen**

A: 50%, (Examen/Colocviu)
B: 25%, (Activitate Seminar/Laborator/Proiect)
D: 25%, (Teme de casa/Lucrari de specialitate)

Note

[Rezultate totale](#)

Prezenta

[Curs](#)
[Laborator](#)

Liste

[Bonus-uri acumulate \(final\)](#)
[Studenti care nu pot intra in examen](#)

Bibliografie

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

Examen: Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Examen: Operatii cu numere complexe

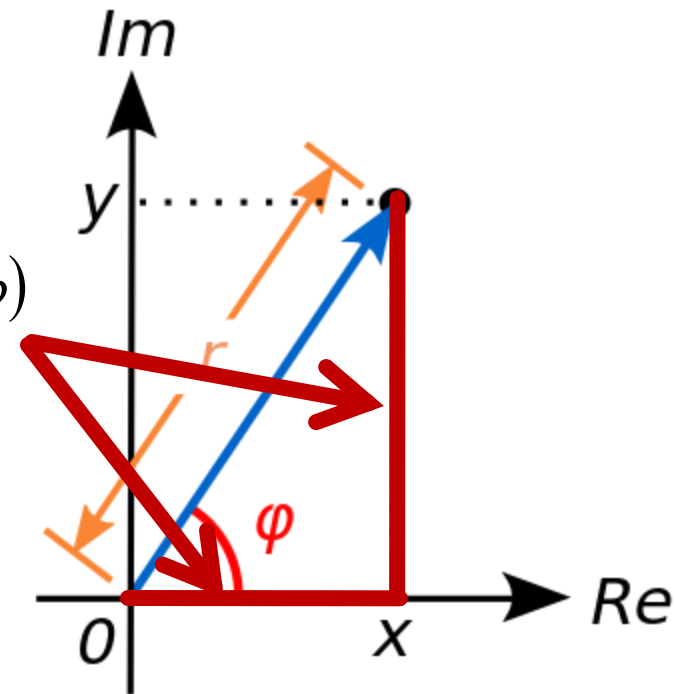
■ Reprezentare polara

- modul
- faza

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

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

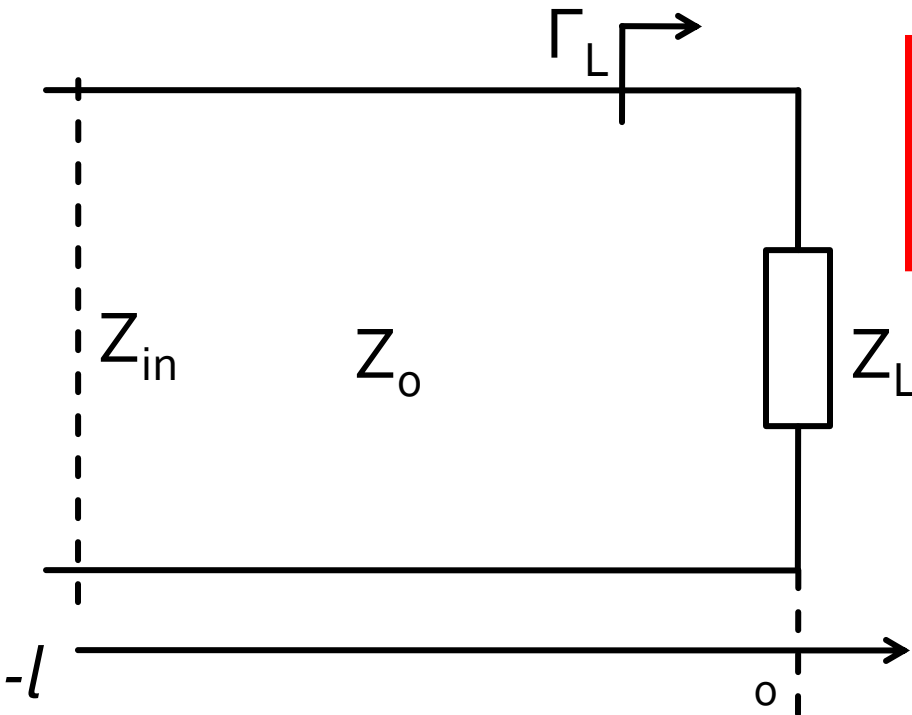
$$\varphi = \arg(z) = \begin{cases} \arctan\left(\frac{b}{a}\right), & a > 0 \\ \arctan\left(\frac{b}{a}\right) + \pi, & a < 0, b \geq 0 \\ \arctan\left(\frac{b}{a}\right) - \pi, & a < 0, b < 0 \\ \frac{\pi}{2}, -\frac{\pi}{2}, \text{ nedefinit} & a = 0 \end{cases}$$



Linii de transmisie in mod TEM

Linie fara pierderi

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

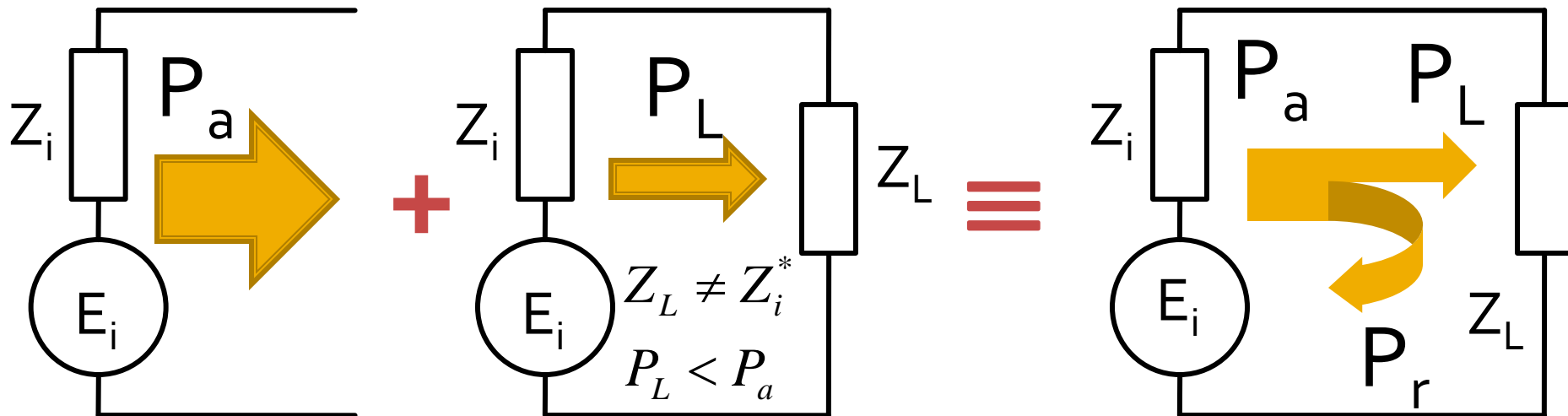


$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Transfer de putere

Adaptarea de impedanță

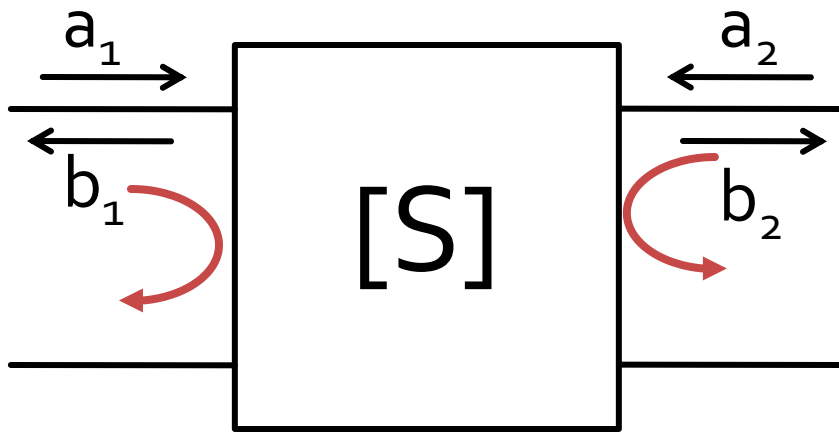
Reflexie de putere / Model



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

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

Matricea S (repartitie)

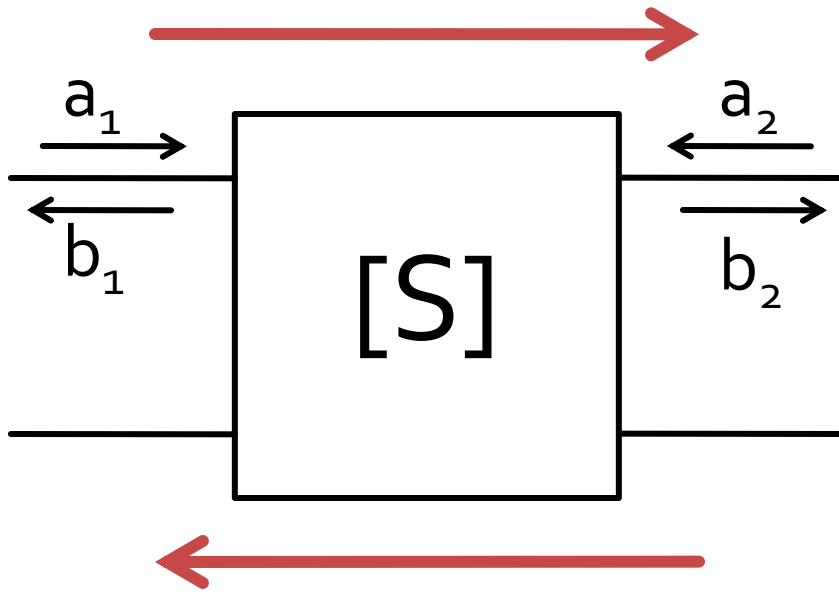


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

Matricea S (repartitie)

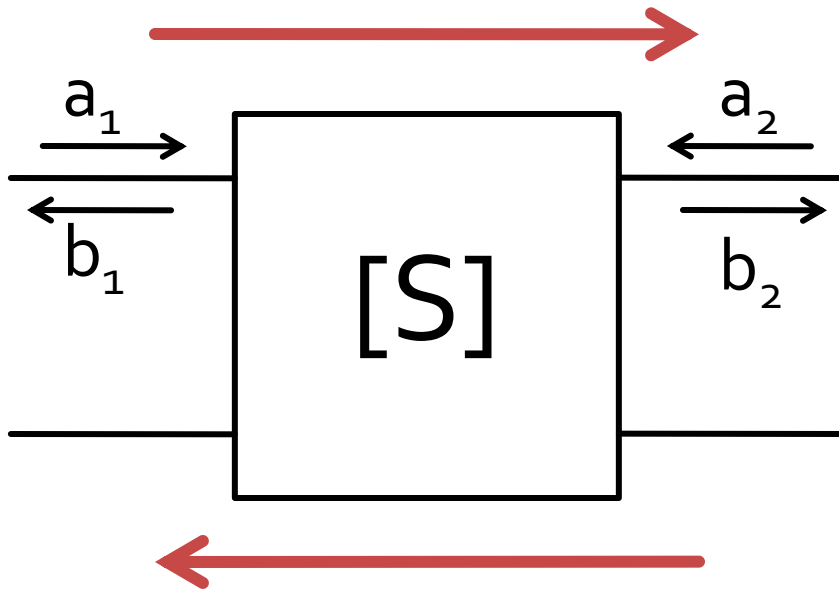


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

- S_{21} si S_{12} sunt amplificari de semnal cand celalalt port este adaptat

Matricea S (repartitie)



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

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

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

Adaptarea de impedanță

Diagrama Smith

Diagrama Smith

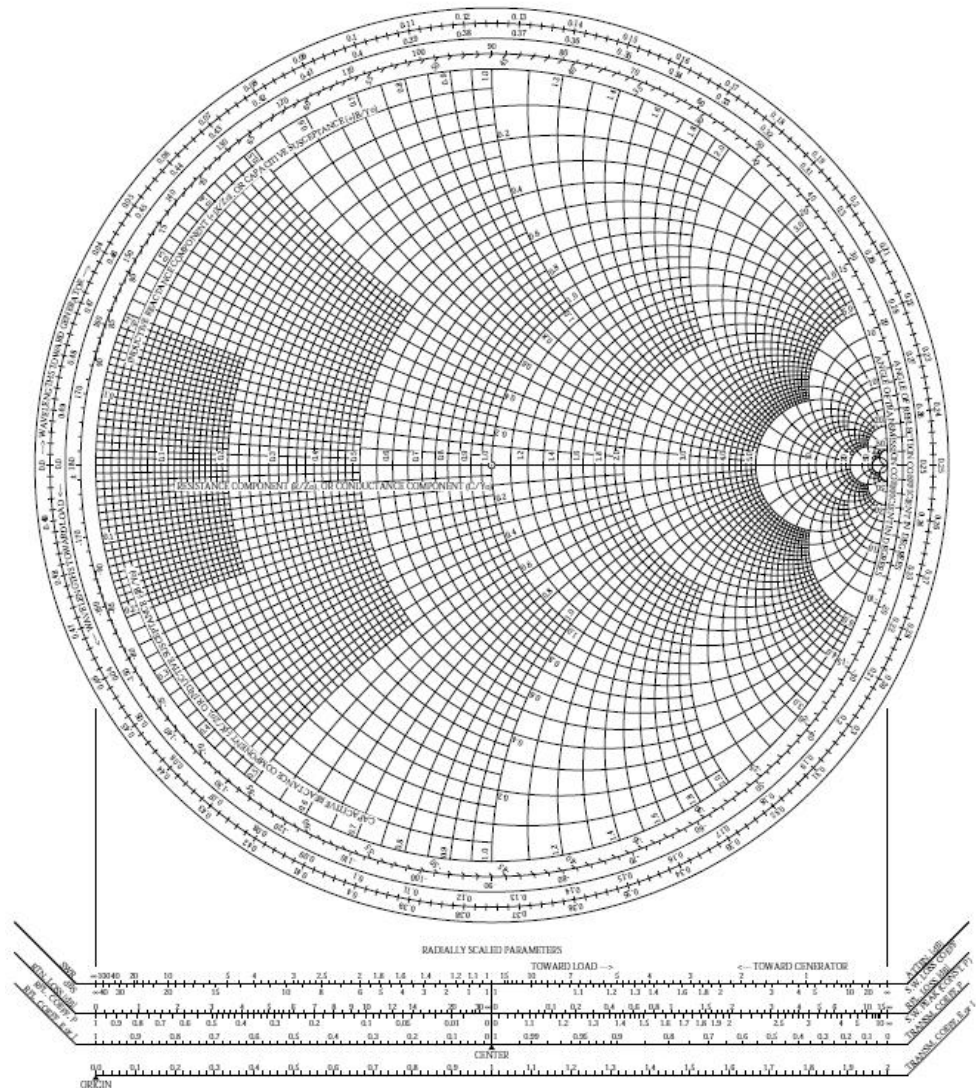


Diagrama Smith

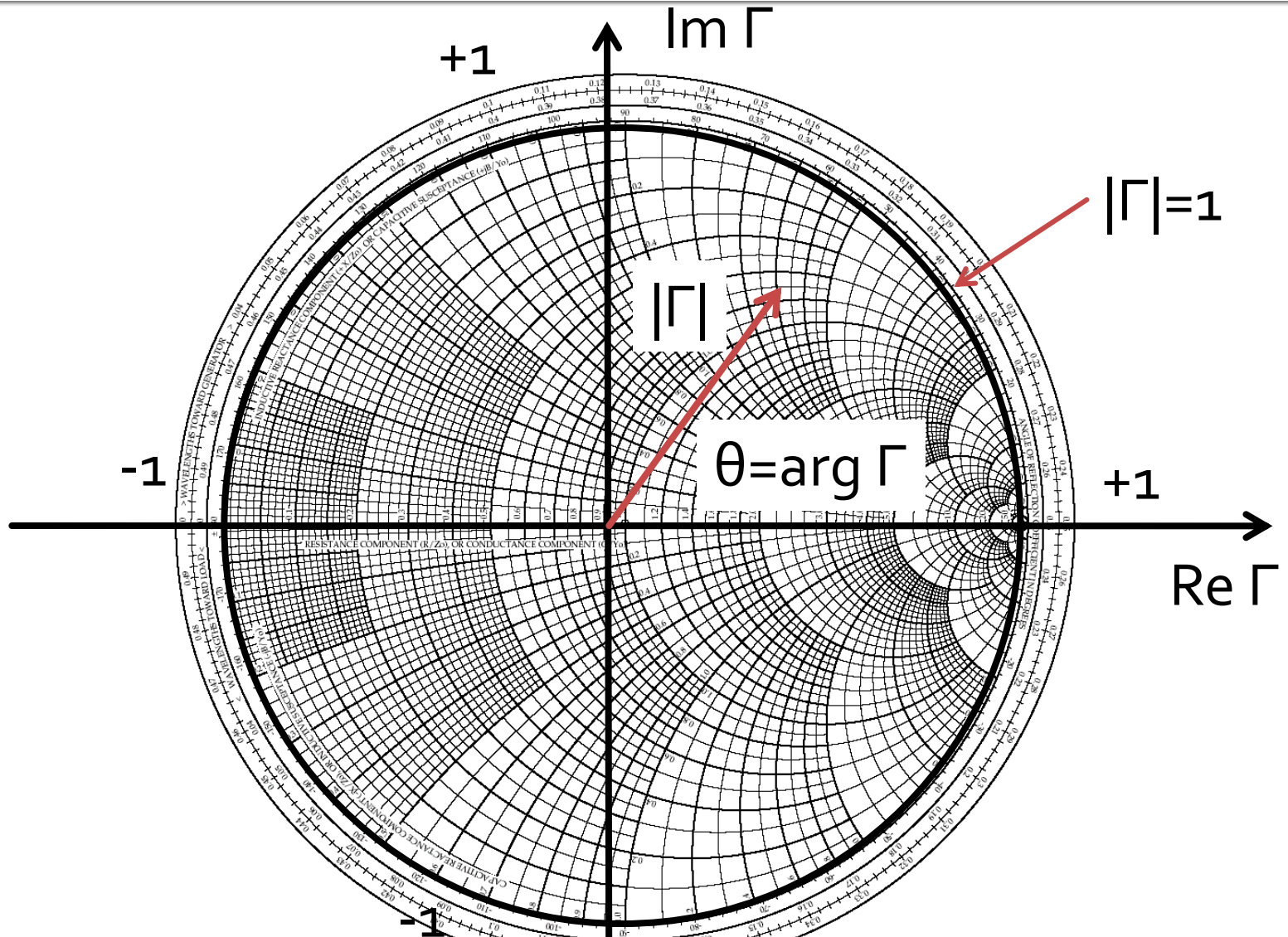
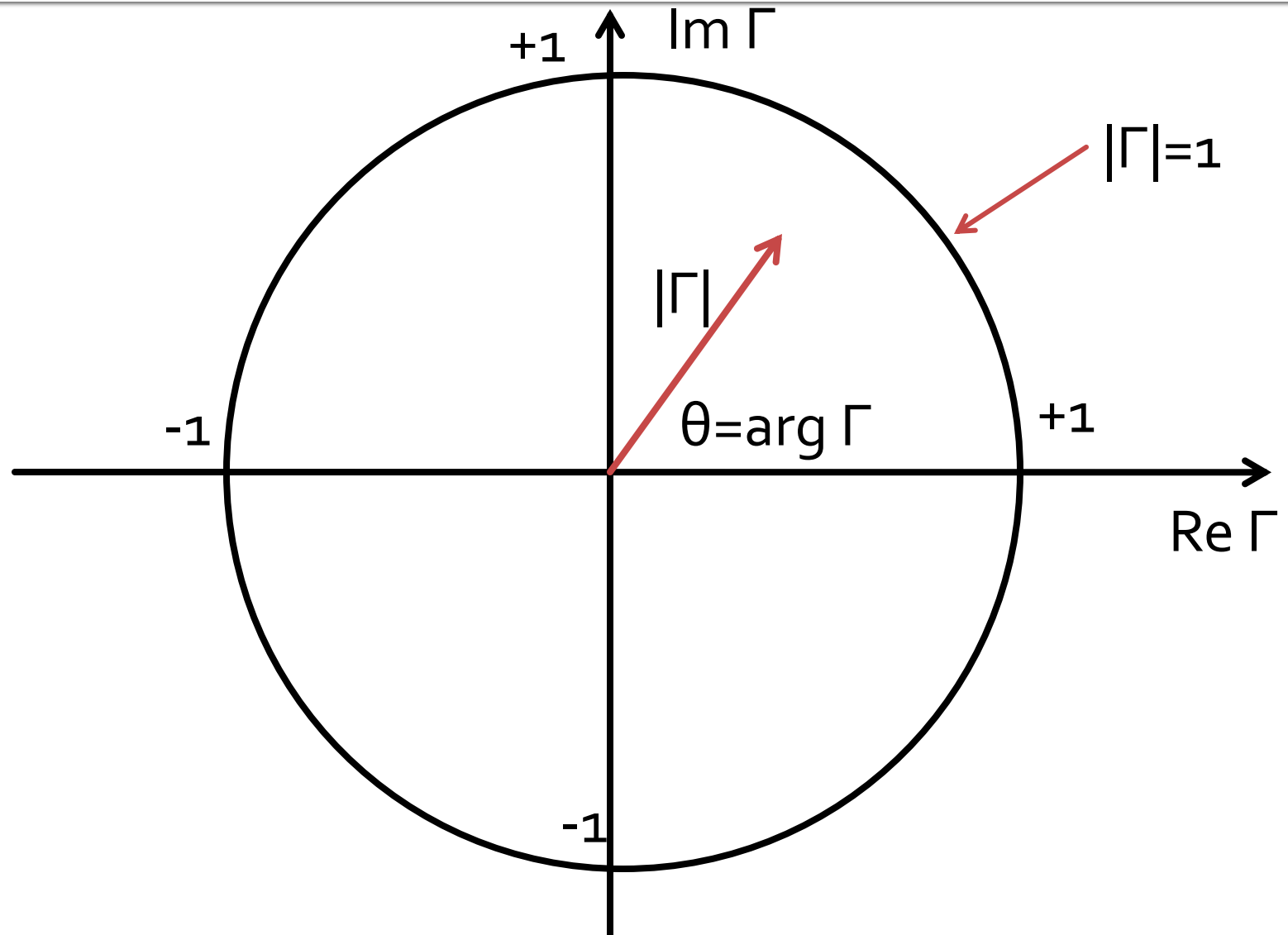


Diagrama Smith

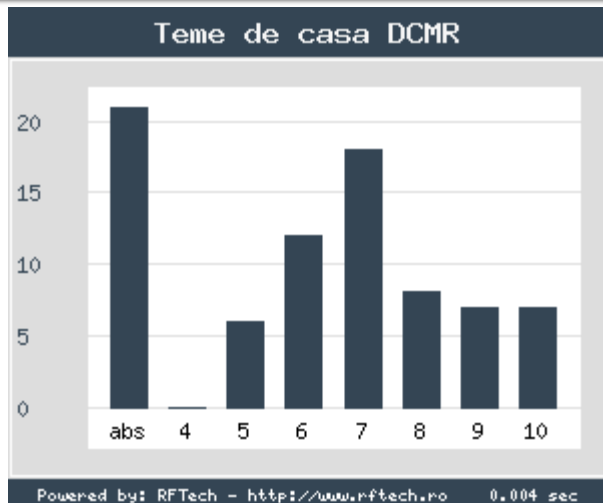


Adaptarea cu sectiuni de linii (stub)

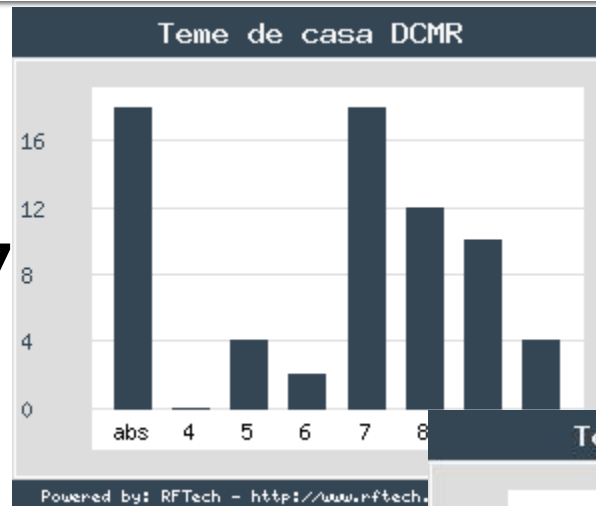
Adaptarea de impedanță

Efect? – factorul “andrei”

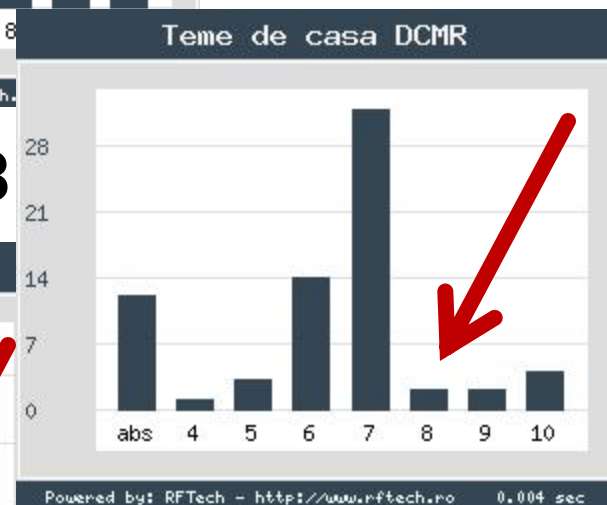
15/6



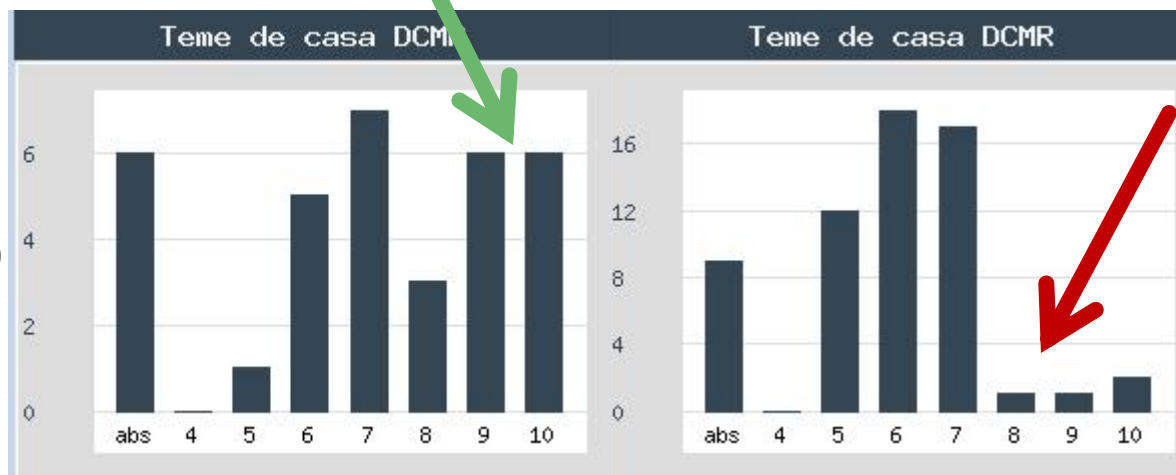
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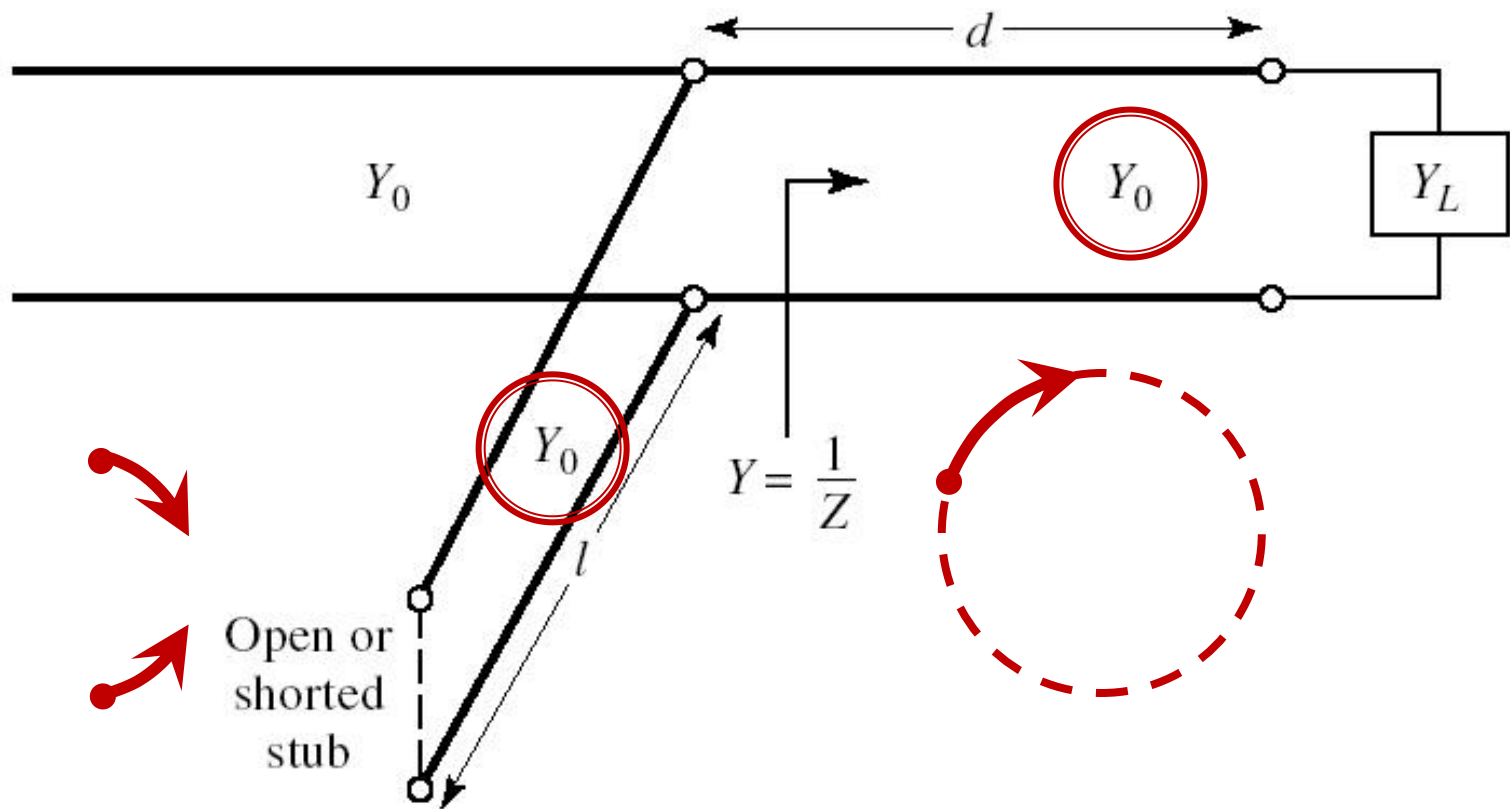


18/9



Caz 1, Shunt Stub

- Shunt Stub (sectiune de linie in paralel)



Calcul analitic (calcul efectiv)

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

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

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

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

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

- **solutia "cu +"** ↓

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

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

- **solutia "cu -"** ↓

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

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

Filtre pentru microunde

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

FTJ prototip Maxim plat/Echiriplu

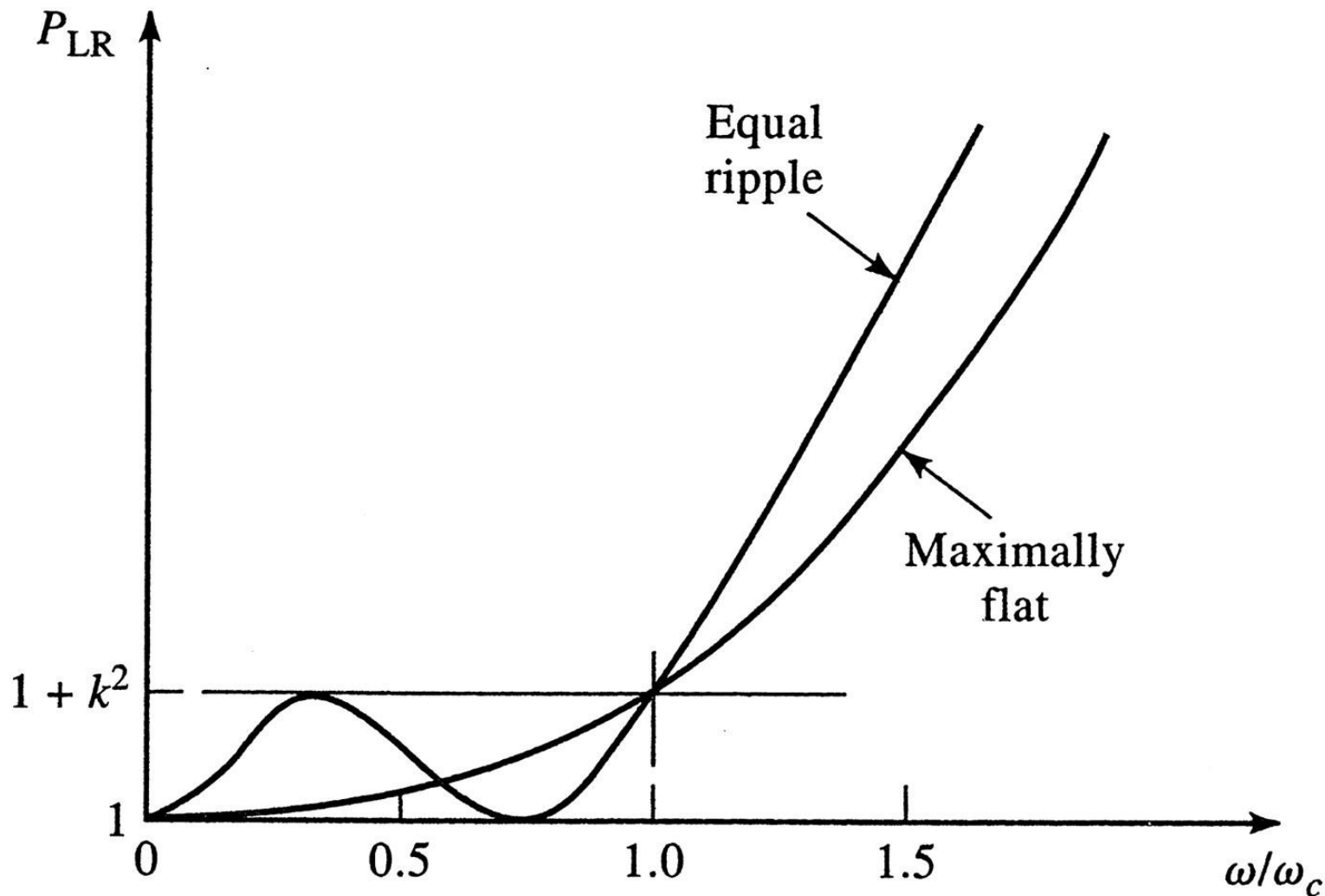


Figure 8.21

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

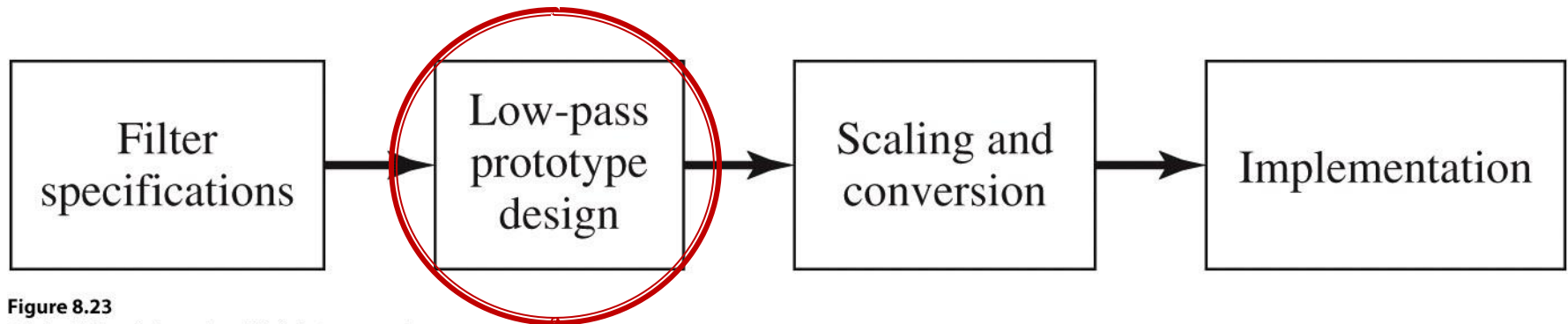


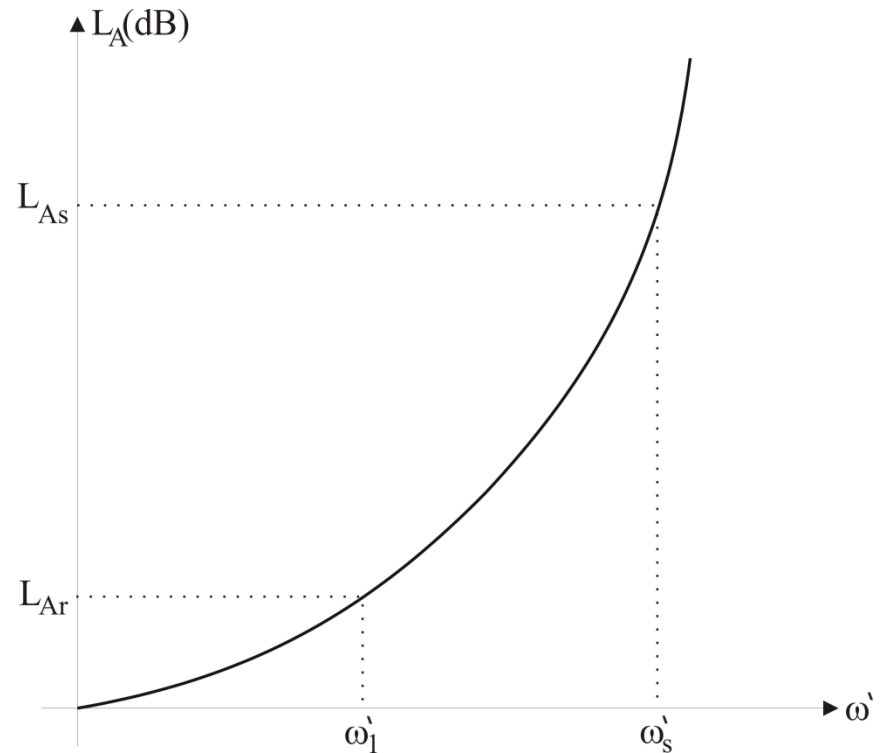
Figure 8.23

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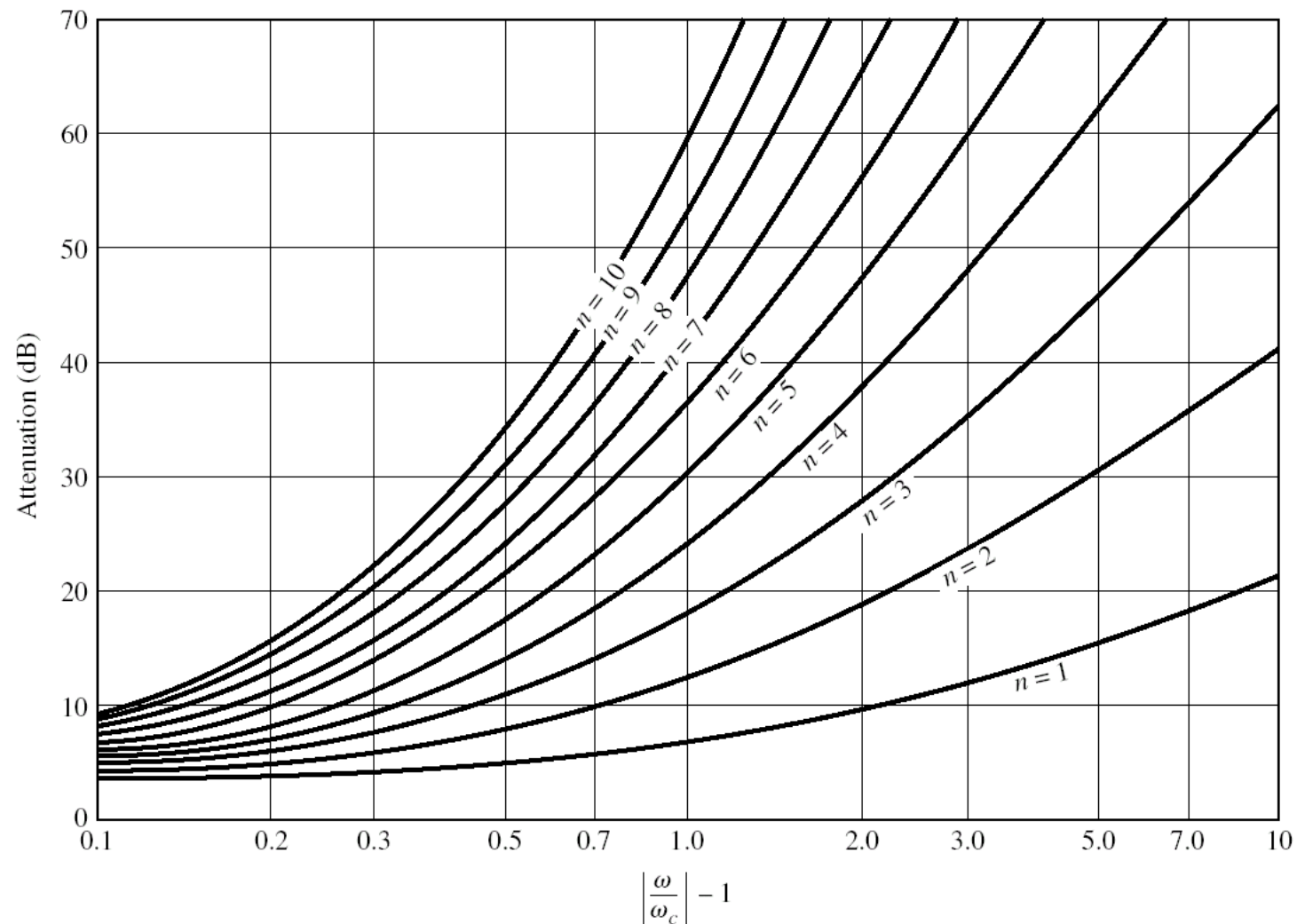
Calculul ordinului filtrului maxim plat

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

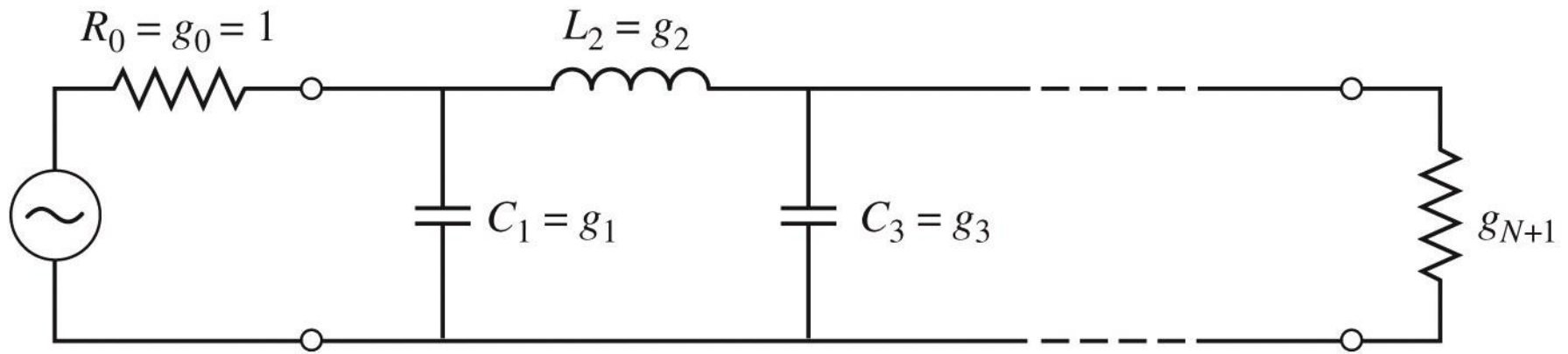
- cu atenuarile in **dB**



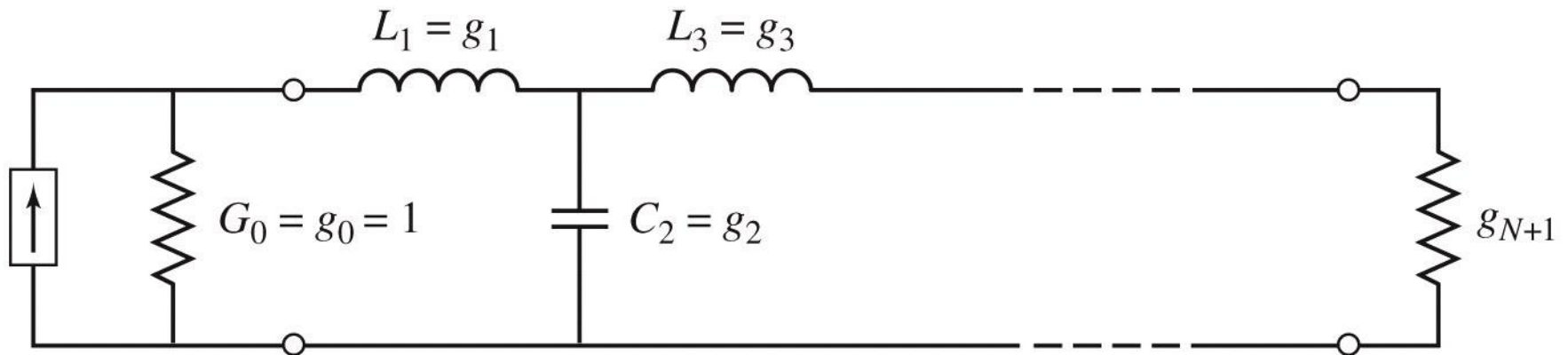
Raspunsul filtrului maxim plat



Filtre prototip



(a)



(b)

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)

N	0.5 dB Ripple										
	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

N	3.0 dB Ripple										
	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	1.9953	1.0000									
2	3.1013	0.5339	5.8095								
3	3.3487	0.7117	3.3487	1.0000							
4	3.4389	0.7483	4.3471	0.5920	5.8095						
5	3.4817	0.7618	4.5381	0.7618	3.4817	1.0000					
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095				
7	3.5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1.0000			
8	3.5277	0.7745	4.6575	0.8089	4.6990	0.8018	4.4990	0.6073	5.8095		
9	3.5340	0.7760	4.6692	0.8118	4.7272	0.8118	4.6692	0.7760	3.5340	1.0000	
10	3.5384	0.7771	4.6768	0.8136	4.7425	0.8164	4.7260	0.8051	4.5142	0.6091	5.8095

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

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

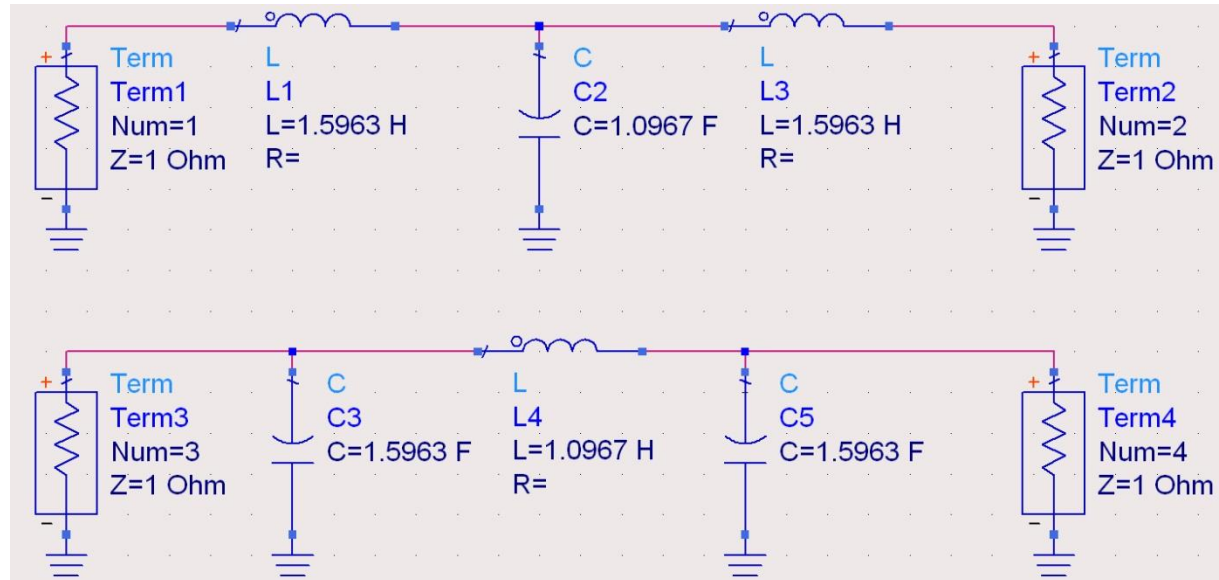
Exemplu

- Să se proiecteze un filtru ~~trece-bandă~~ **de ordinul 3**, avand **riplurile** în bandă **de 0.5 dB**.
~~Frecvența centrală a filtrului să fie de 1 GHz.~~
~~Banda să fie de 10%, și impedanța de 50 Ω .~~
- Tabel echiriplu 0.5dB sau relatii de calcul:
 - $g_1 = 1.5963 = L_1$,
 - $g_2 = 1.0967 = C_2$,
 - $g_3 = 1.5963 = L_3$,
 - $g_4 = 1.000 = R_L$

Filtru prototip

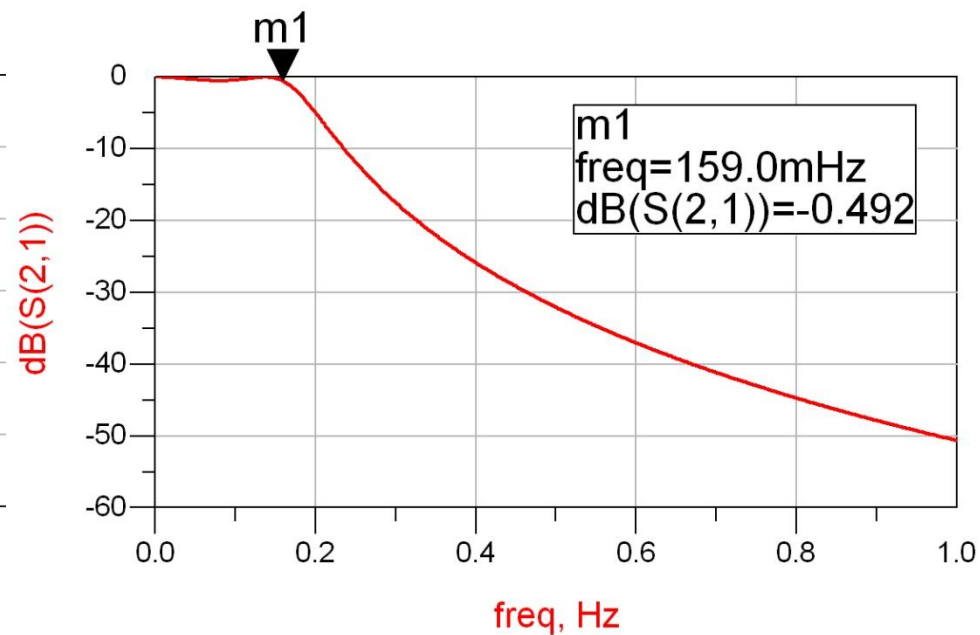
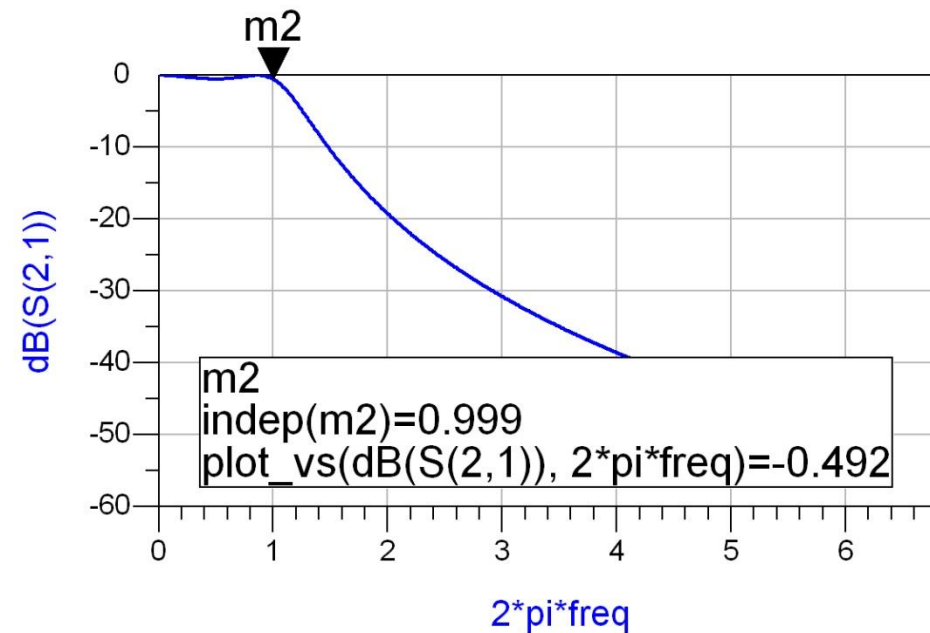
- Tabel echiriplu 0.5dB sau relatii de calcul:

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



Filtru prototip

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



Scalare 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 $R = 1$

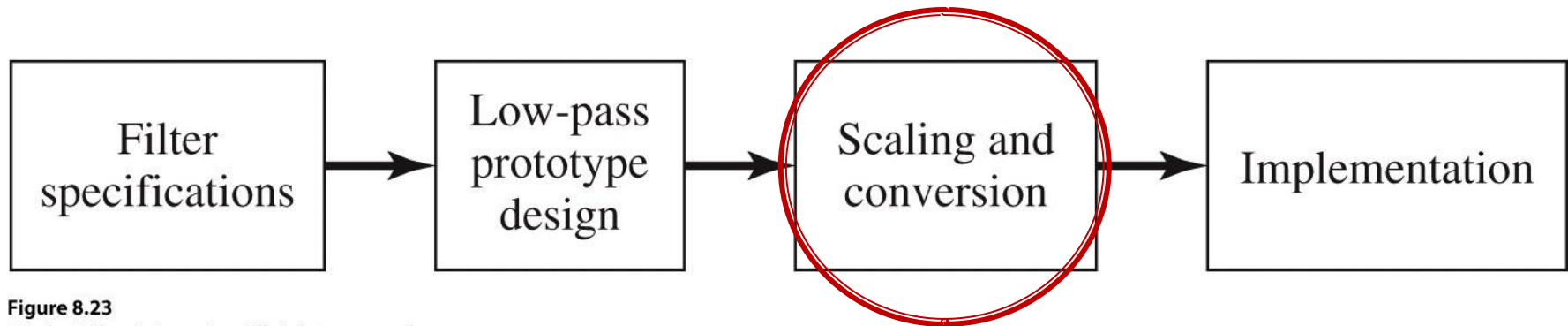


Figure 8.23

Transformari ale filtrului prototip


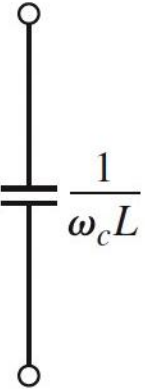
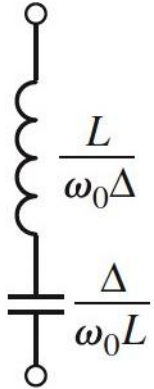
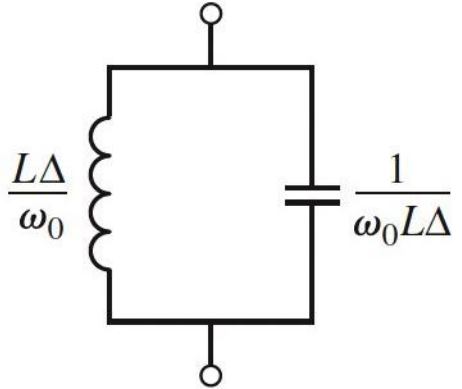
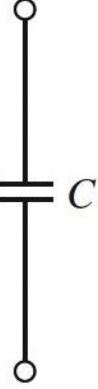
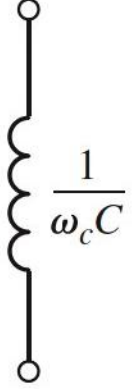
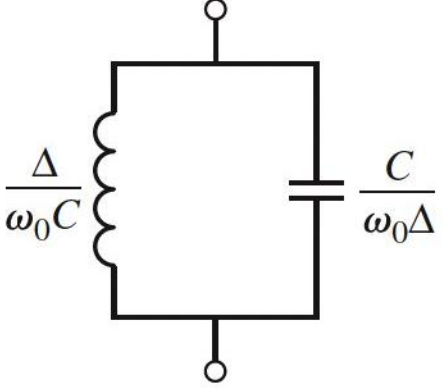
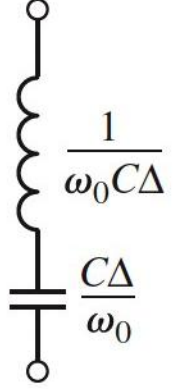
Low-pass	High-pass	Bandpass	Bandstop
			
			

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 .

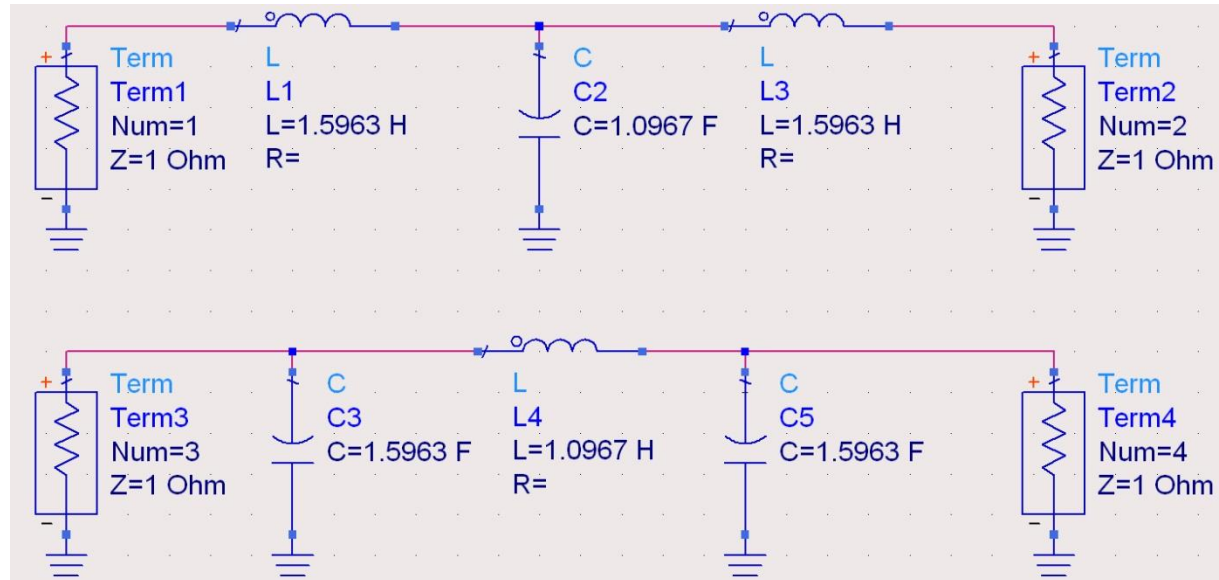
$$\omega_0 = 2 \cdot \pi \cdot 1 \text{ GHz} = 6.283 \cdot 10^9 \text{ rad} / \text{s}$$

$$\Delta = 0.1$$

Filtru prototip

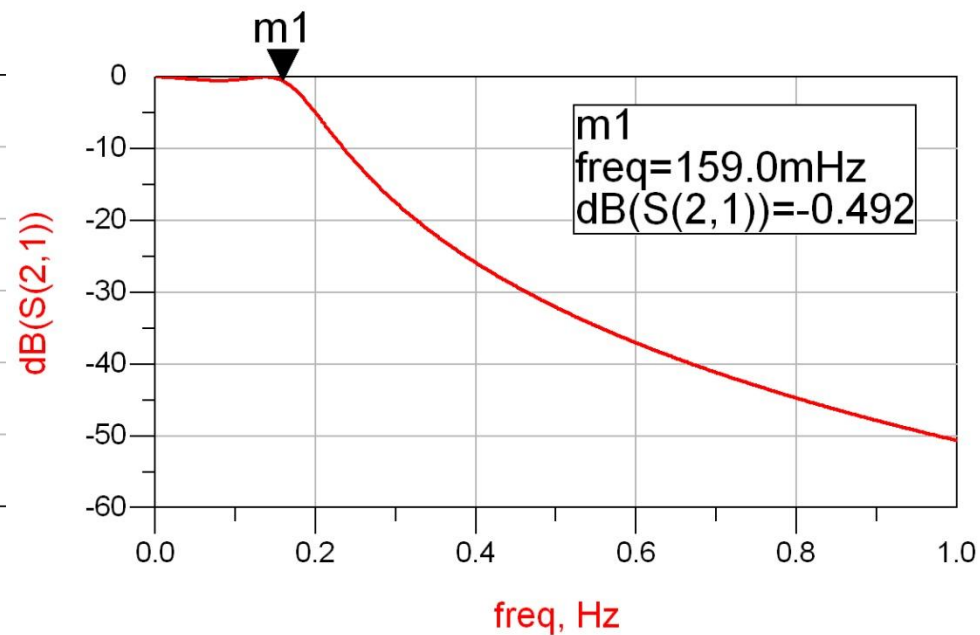
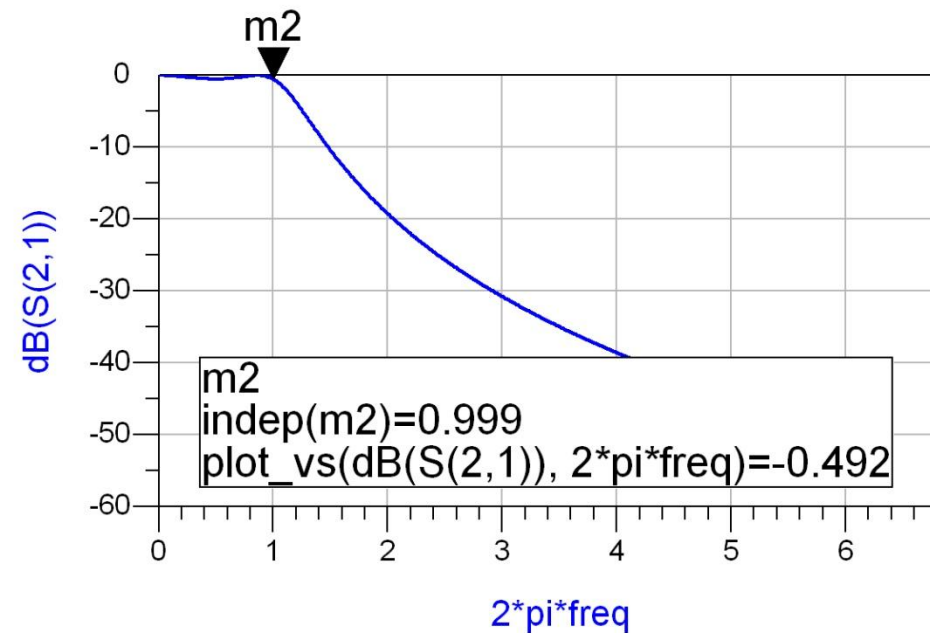
- Tabel echiriplu 0.5dB sau relatii de calcul:

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



Filtru prototip

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



Scalare frecventa / FTB

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

$$g_1 = 1.5963 = L_1,$$

$$g_2 = 1.0967 = C_2,$$

$$g_3 = 1.5963 = L_3,$$

$$g_4 = 1.000 = R_L$$

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

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

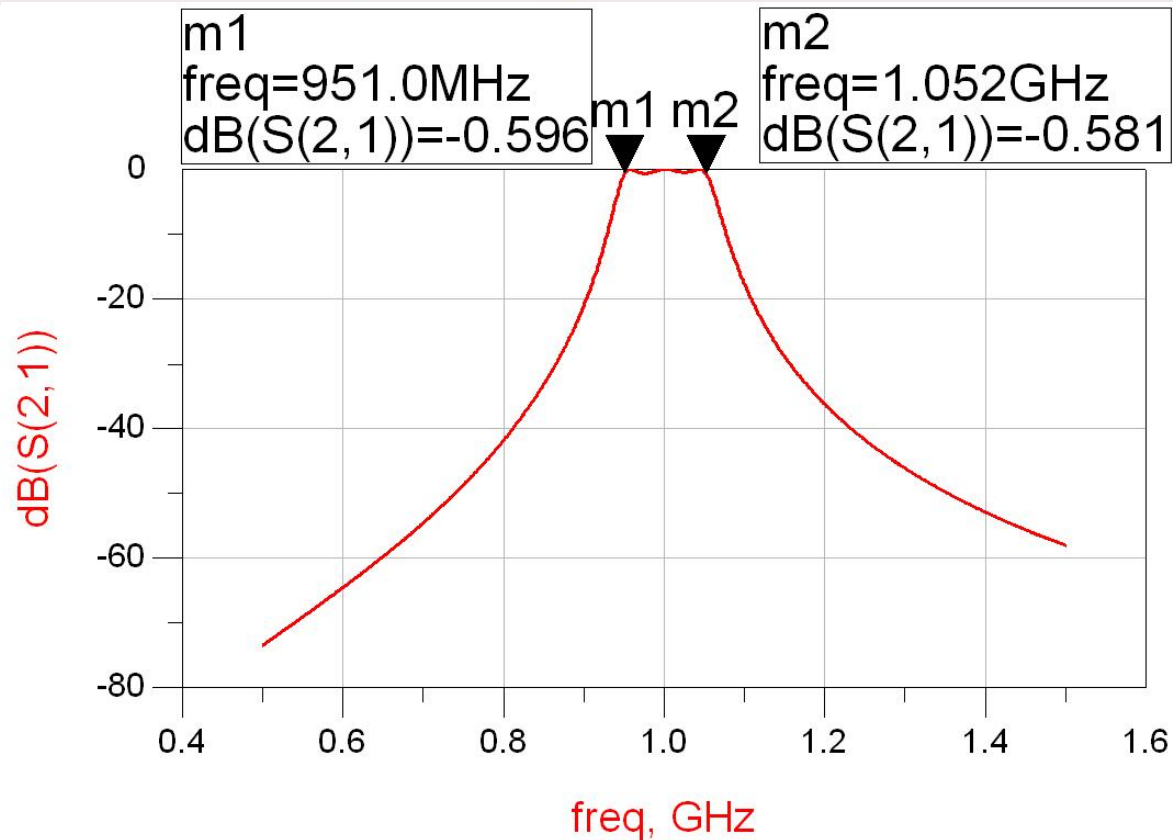
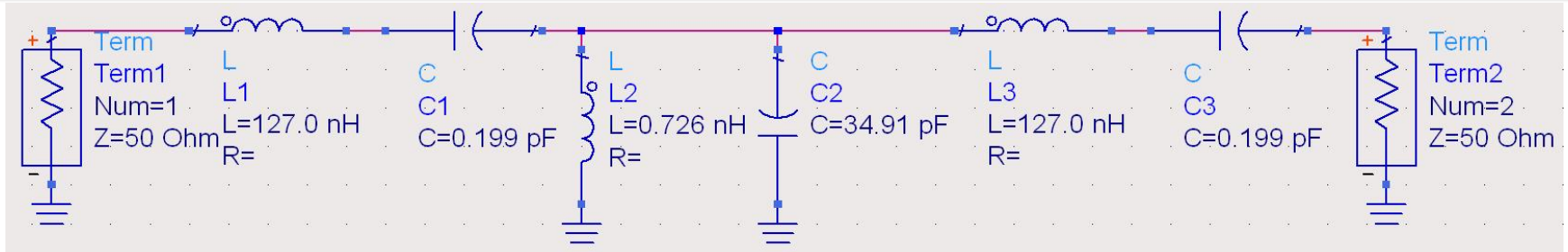
$$L'_2 = \frac{\Delta \cdot R_0}{\omega_0 \cdot C_2} = 0.726 \text{ nH}$$

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

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

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

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

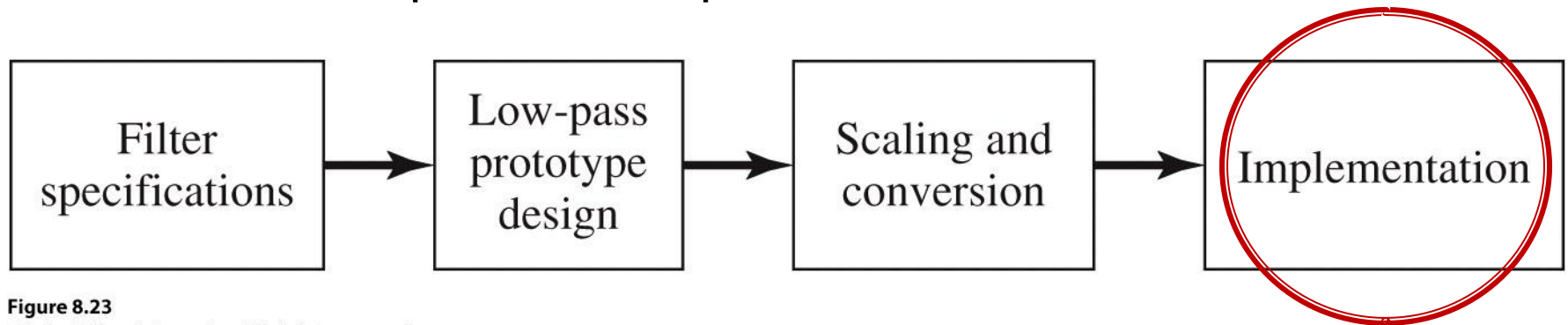


Figure 8.23

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 $4 \cdot \omega_c$

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

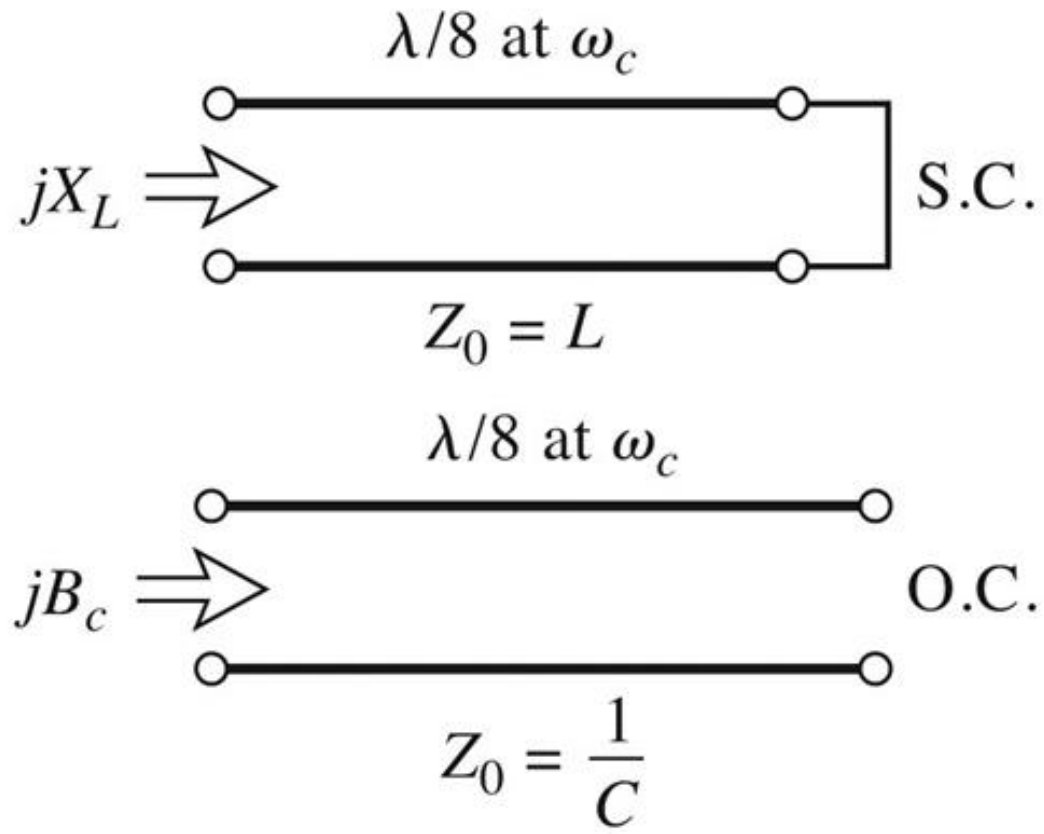
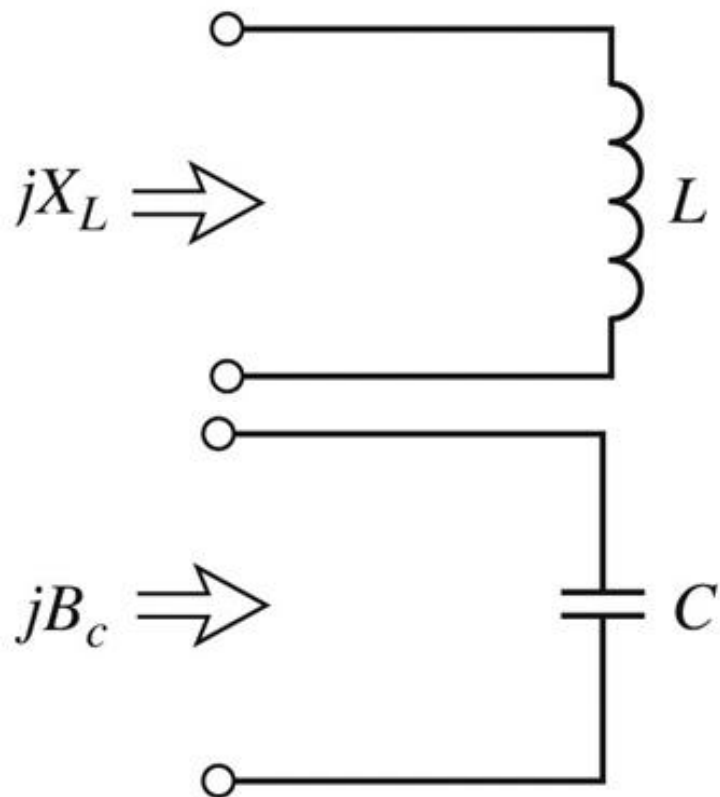
$$\beta \cdot l \Big|_{\omega=\omega_c} = \frac{\pi}{4} \Rightarrow \frac{\omega_c \cdot l}{v_p} = \frac{\pi}{4} \Rightarrow \pi = \frac{(4 \cdot \omega_c) \cdot l}{v_p}$$

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

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

Transformarea Richards

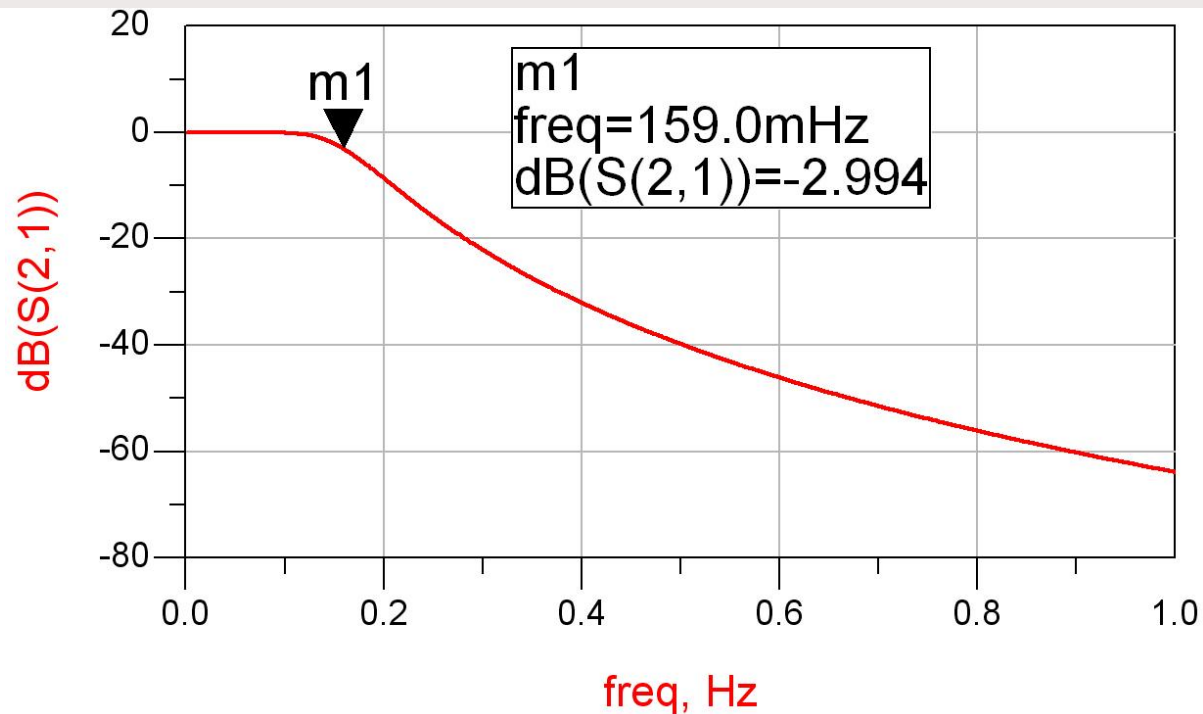
- permite obtinerea cu sectiuni de linii a inductantelor si capacitatilor **dupa** scalarea prototipului pentru functia corespunzatoare (FTJ/FTS/FTB /FOB)



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

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

$$g_1 = 0.7654 = L_1,$$

$$g_2 = 1.8478 = C_2,$$

$$g_3 = 1.8478 = L_3,$$

$$g_4 = 0.7654 = C_4,$$

$$g_5 = 1 = RL$$

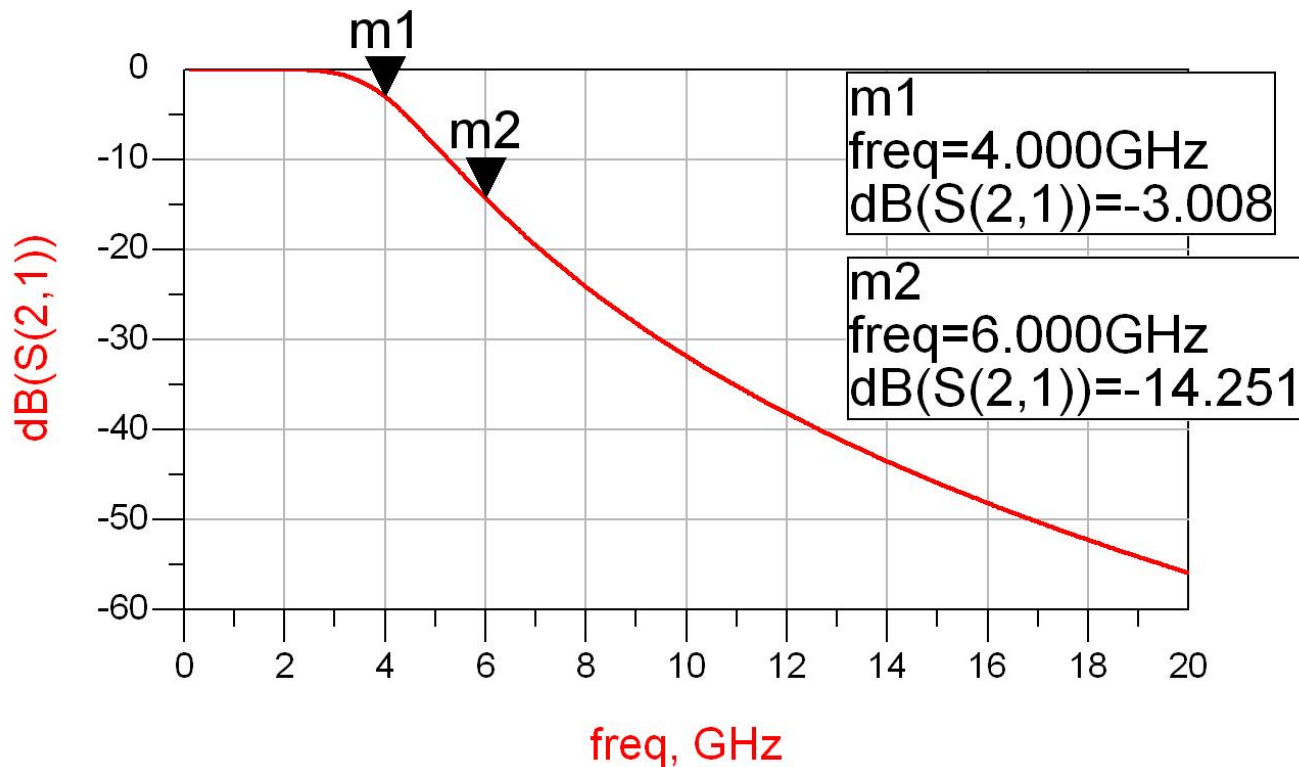
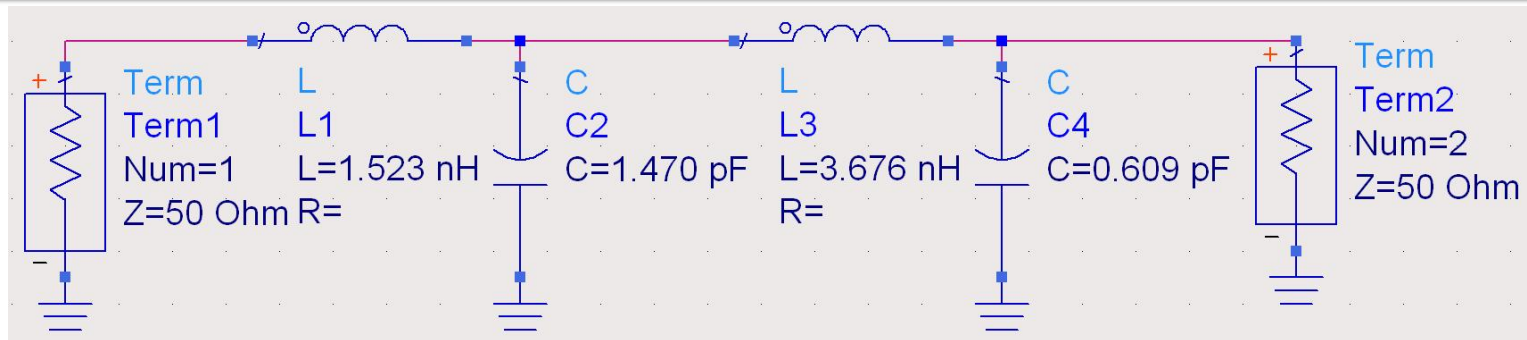
$$L'_1 = \frac{R_0 \cdot L_1}{\omega_c} = 1.523 \text{ nH}$$

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

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

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

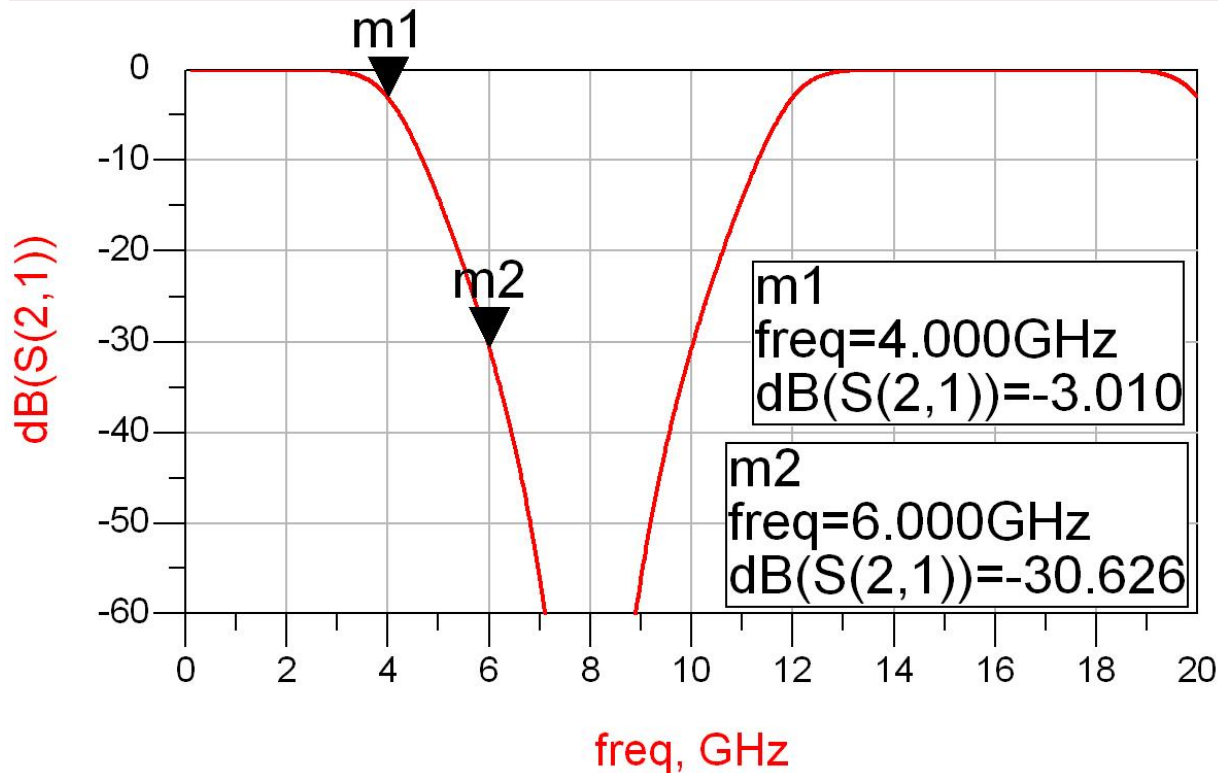
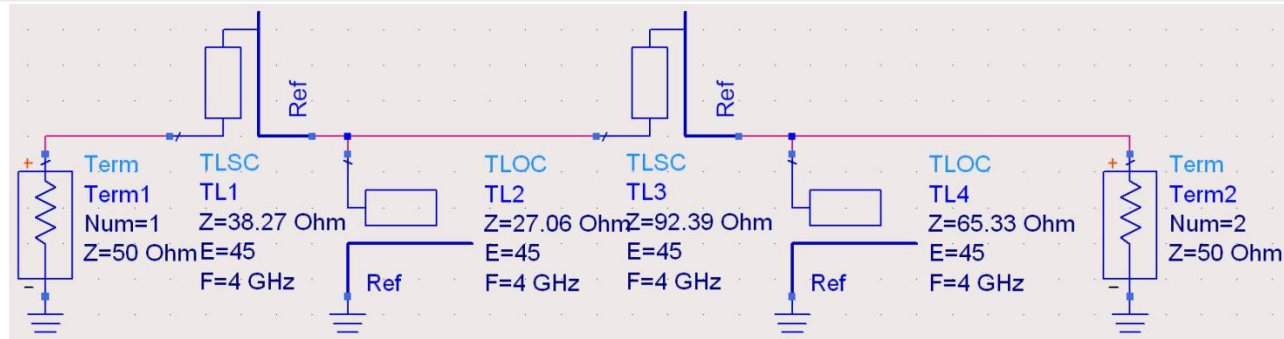
Elemente concentrate – ADS



Transformarea Richards

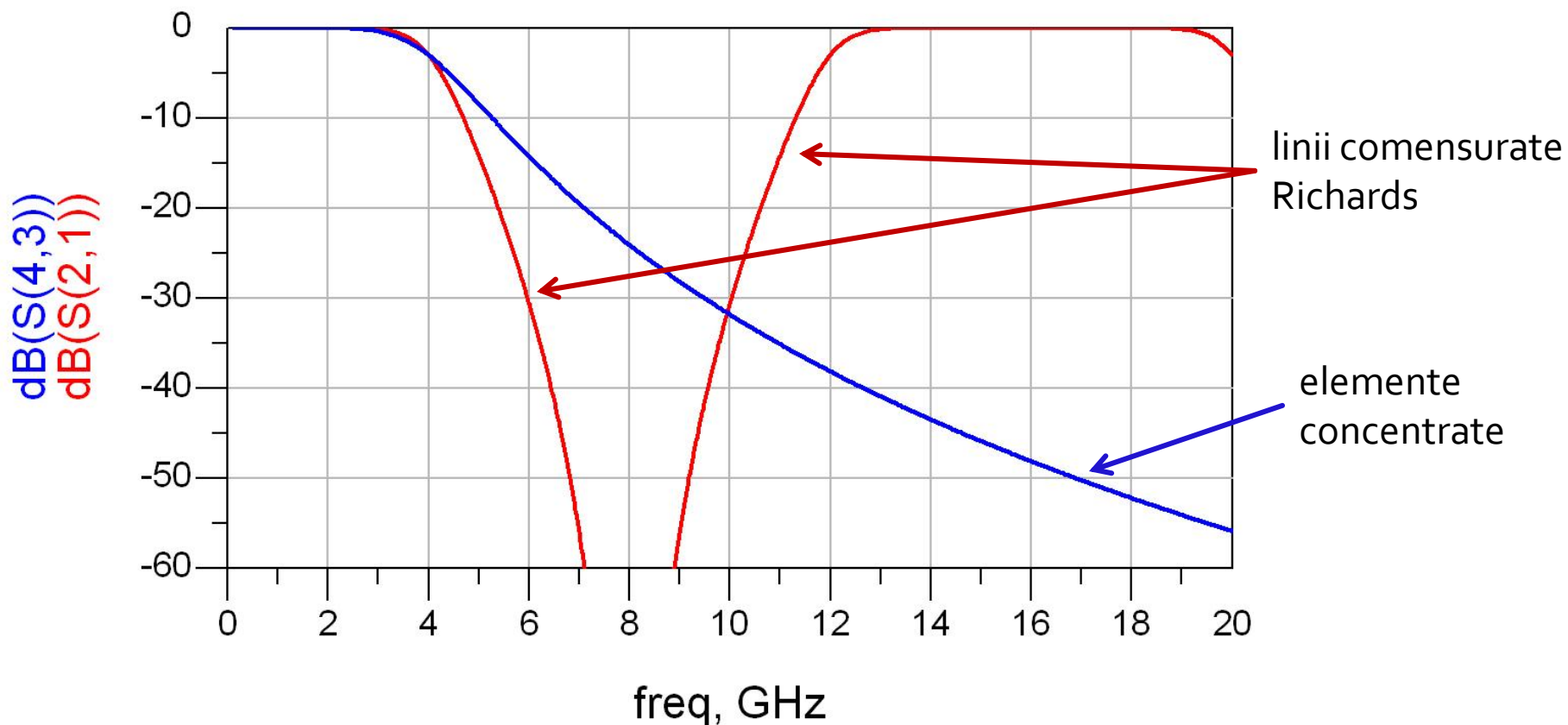
- Parametrii filtrului prototip:
 - $g_1 = 0.7654 = L_1$
 - $g_2 = 1.8478 = C_2$
 - $g_3 = 1.8478 = L_3$
 - $g_4 = 0.7654 = C_4$
- Impedantele raportate ale liniilor
 - $z_1 = 0.7654 = \text{serie / scurt circuit}$
 - $z_2 = 1 / 1.8478 = 0.5412 = \text{paralel / gol}$
 - $z_3 = 1.8478 = \text{serie /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

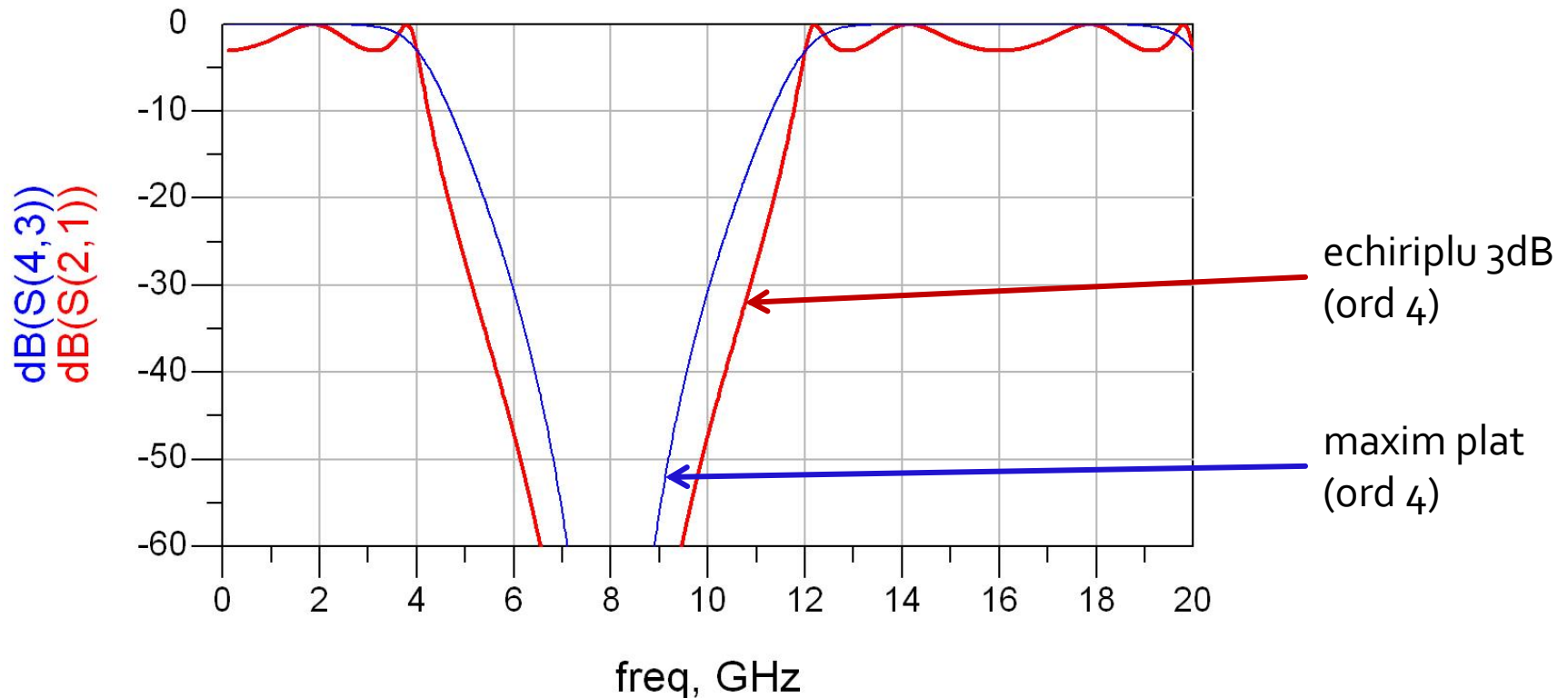
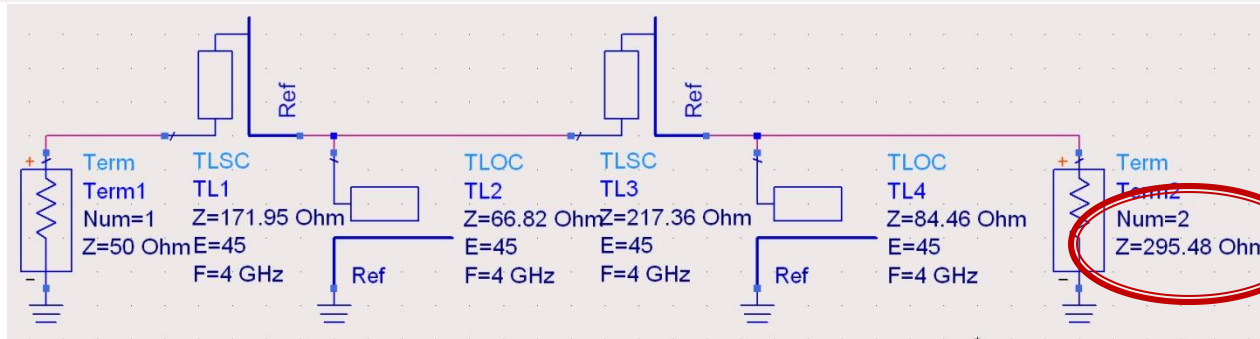
- Pentru ordin par al filtrului ($N = 2, 4, 6, 8 \dots$) filtrele echiriplu **trebuie** sa fie inchise pe o impedanta de terminatie diferita de cea standard
- Daca aplicatia nu suporta aceasta comportare, e necesara introducerea unei adaptari de impedanta suplimentare (transformator in sfert de lungime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

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

Observatie: ordin par/echiriplu

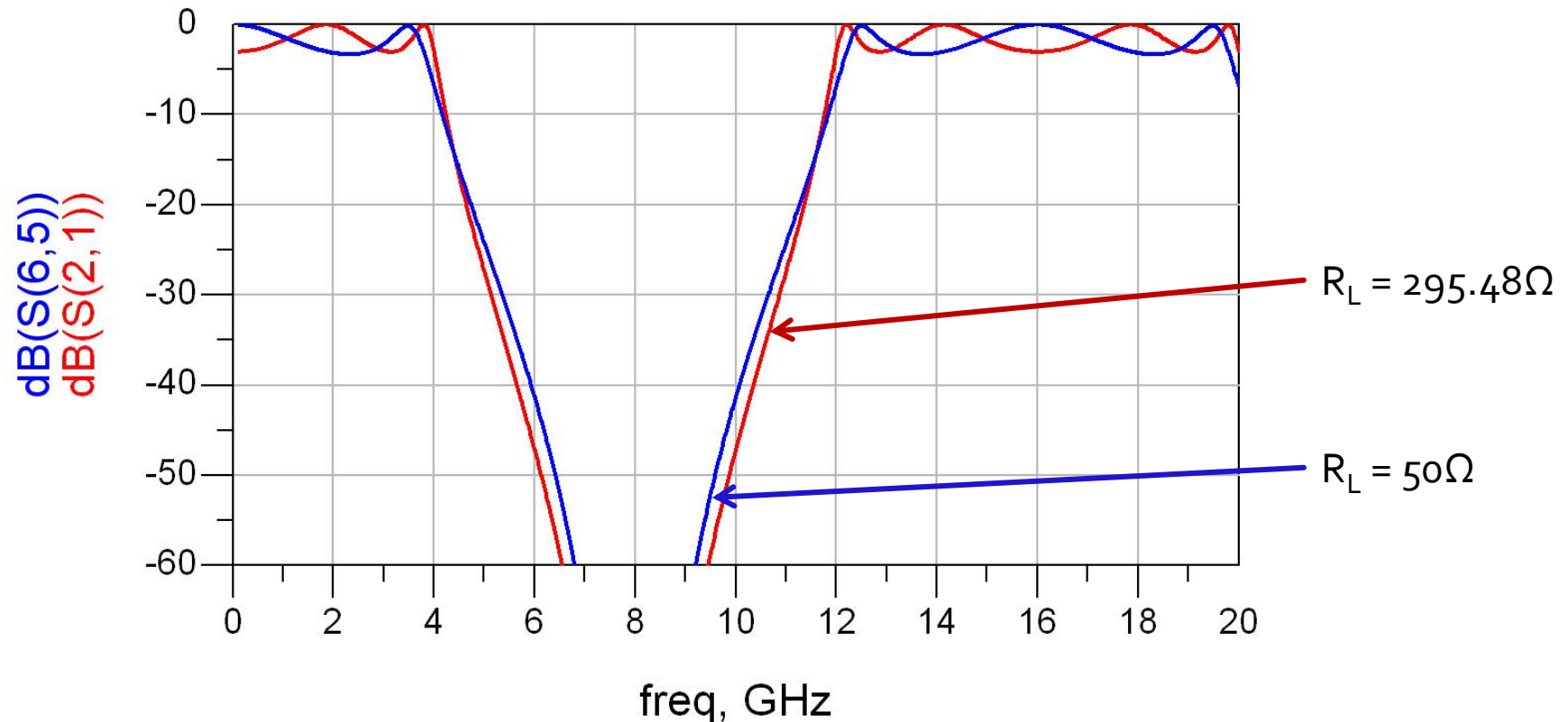
- Acelasi filtru, echiriplu 3dB
- Tabel echiriplu 3dB sau relatii de calcul:
 - $g_1 = 3.4389 = L_1$
 - $g_2 = 0.7483 = C_2$
 - $g_3 = 4.3471 = L_3$
 - $g_4 = 0.5920 = C_4$
 - $g_5 = 5.8095 = R_L$
- Impedantele liniilor
 - $Z_1 = 3.4389 \cdot 50\Omega = 171.945\Omega = \text{serie / scurt circuit}$
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

Ordin par/echiriplu – ADS



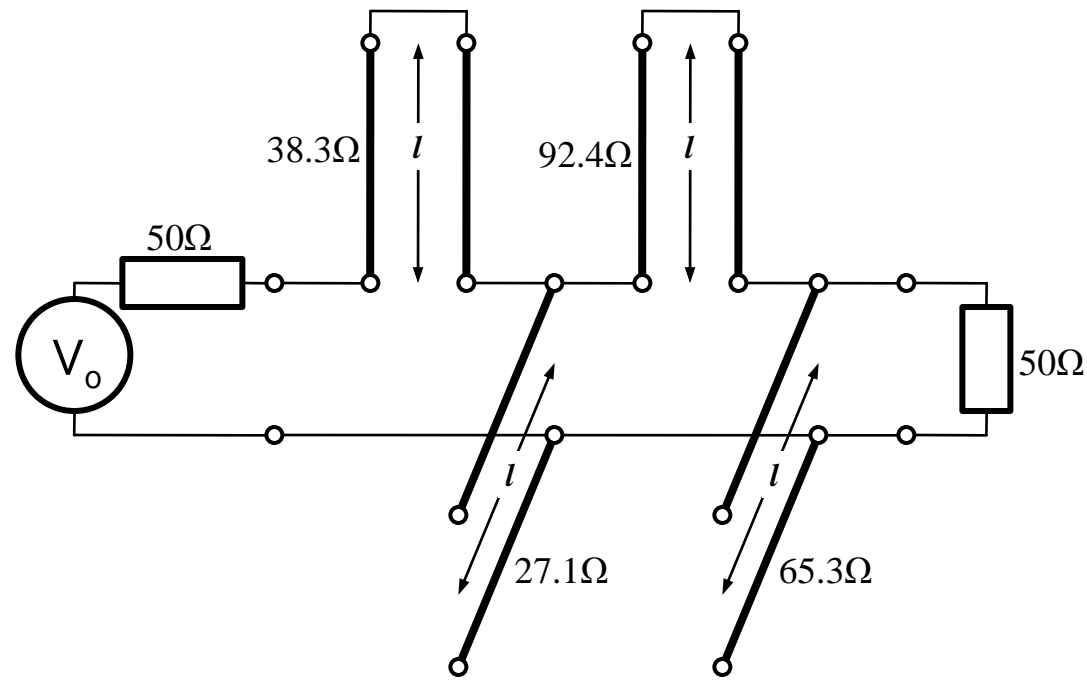
Observatie: ordin par/echiriplu

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



Identitatile Kuroda

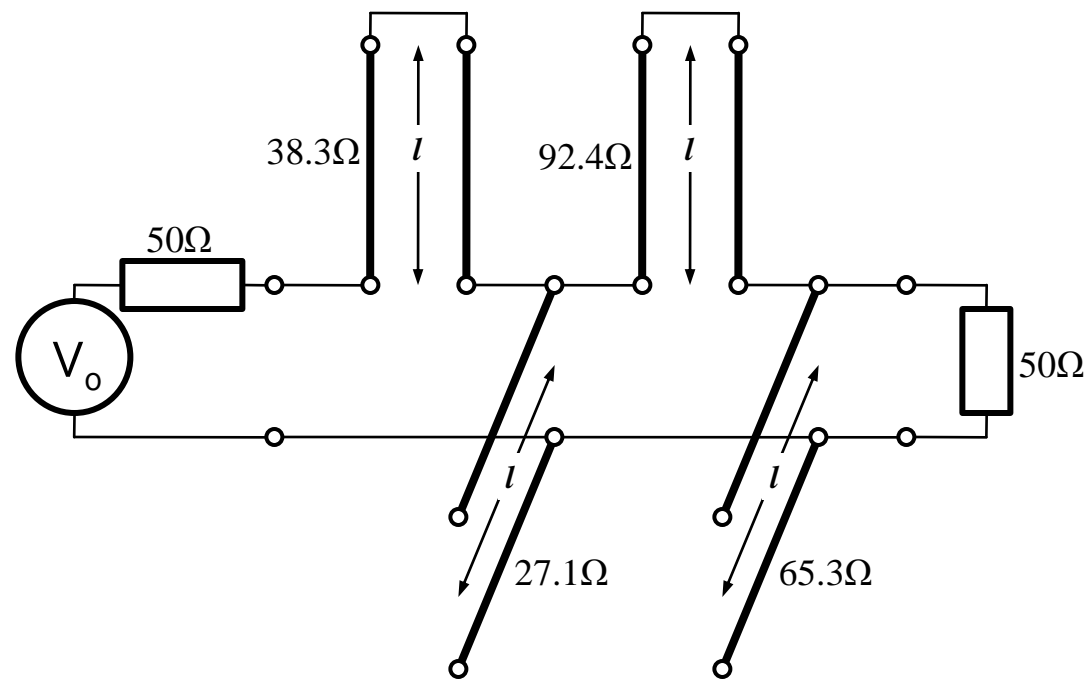
- Filtre implementate cu transformarea Richards au anumite dezavantaje in ceea ce priveste implementarea practica
- Identitatile/Transformarile Kuroda pot fi utilizate pentru a elimina o parte din aceste dezavantaje
- Se utilizeaza sectiuni de linie suplimentare pentru a obtine sisteme mai simplu de 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

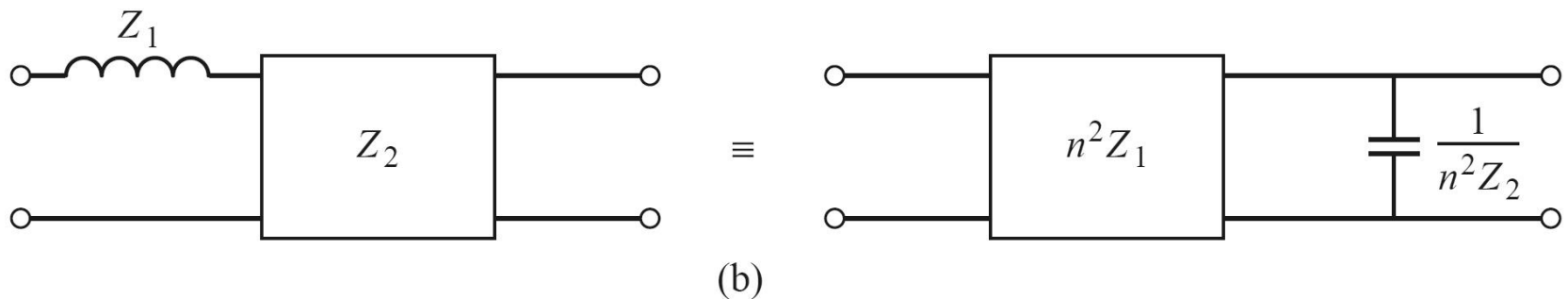
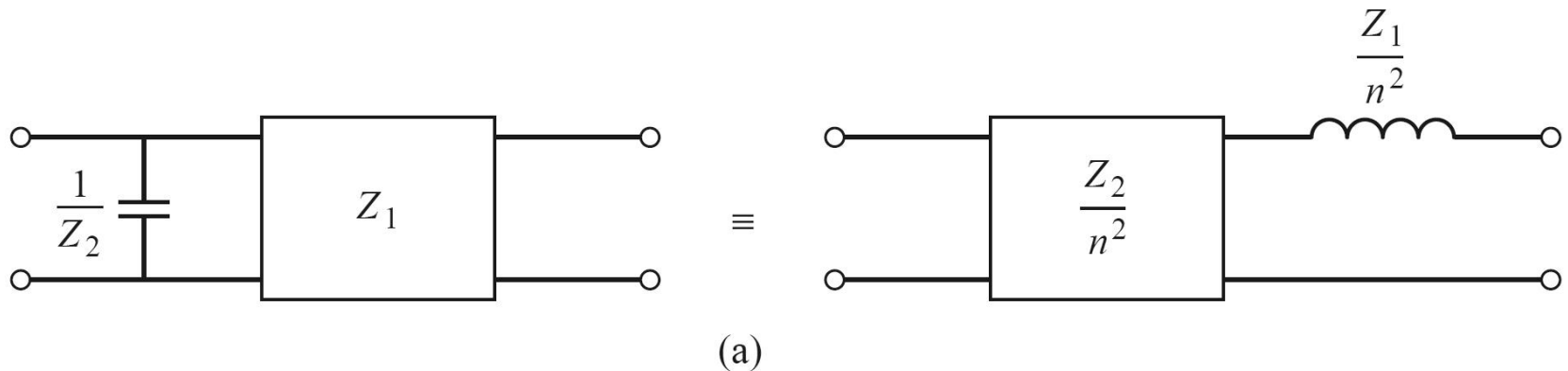
- Identitatile Kuroda pot fi utilizate pentru a realiza urmatoarele operatii:

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



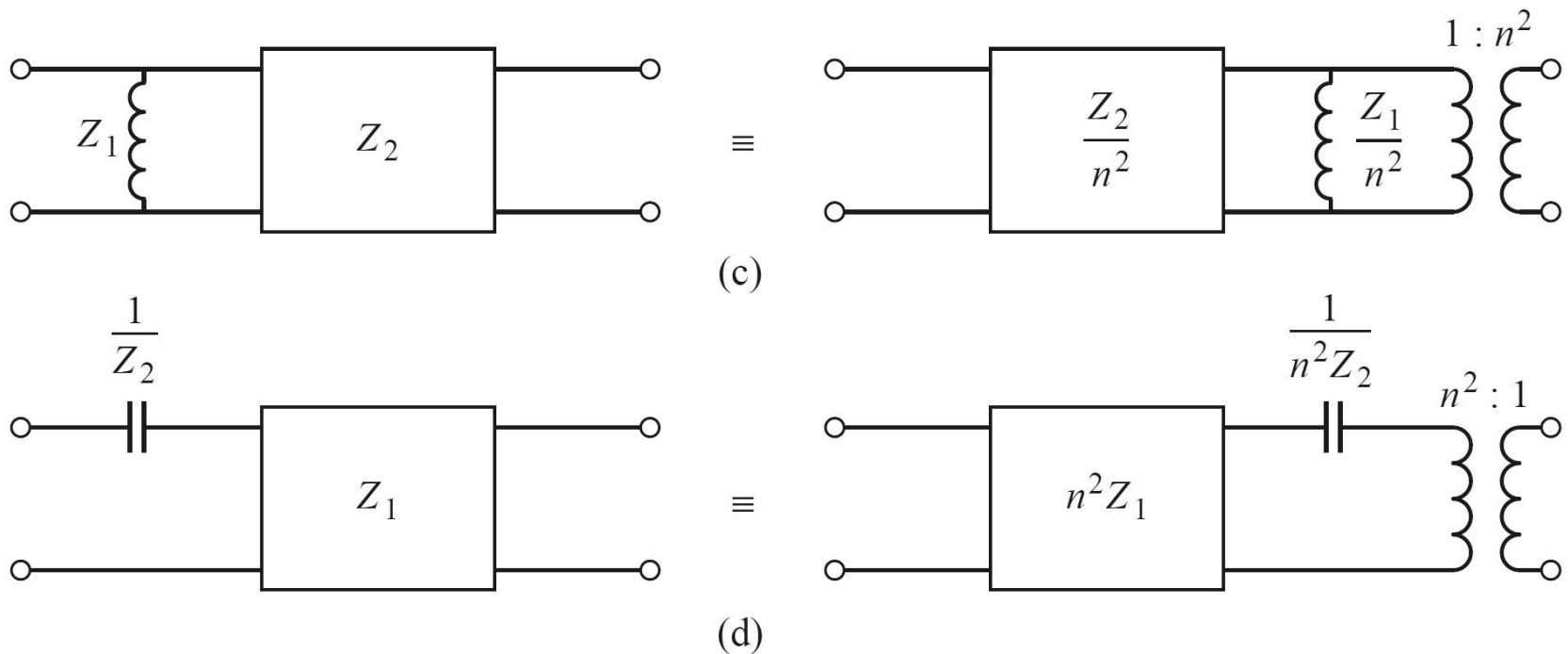
Identitățile Kuroda

- 4 echivalente de circuit



Identitatile Kuroda

- 4 echivalente de circuit



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

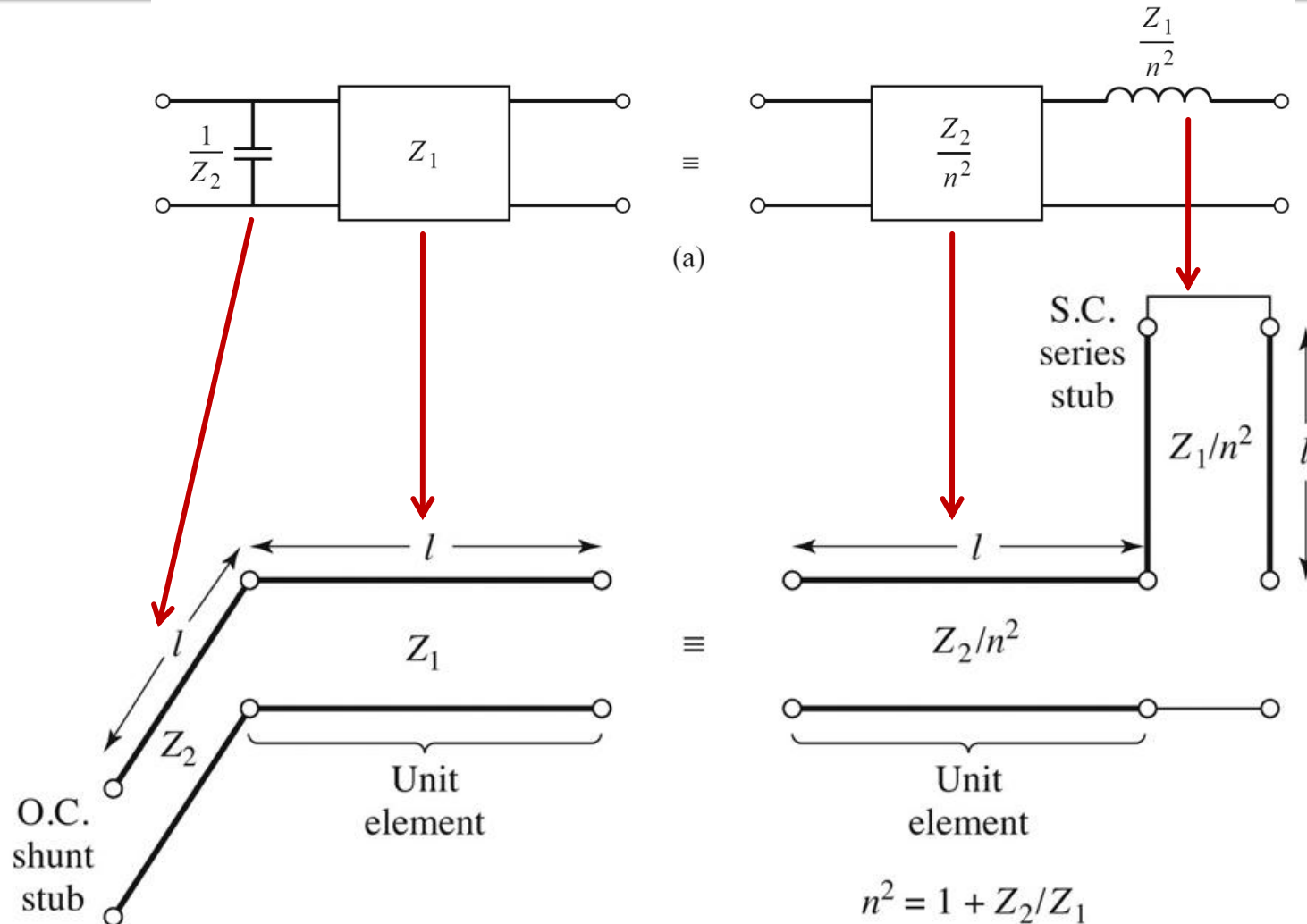
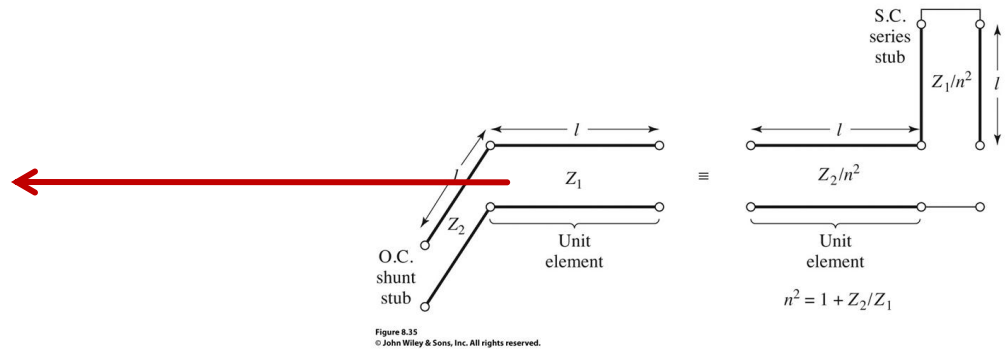
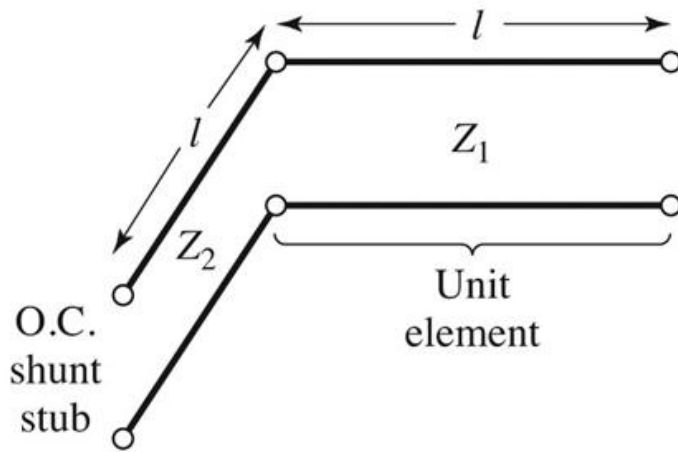
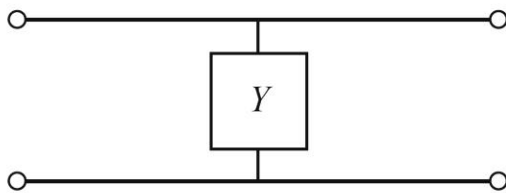


Figure 8.35
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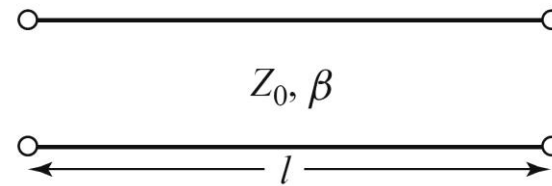
Prima Identitate Kuroda – Demonstratie



■ Matrici ABCD, C₄



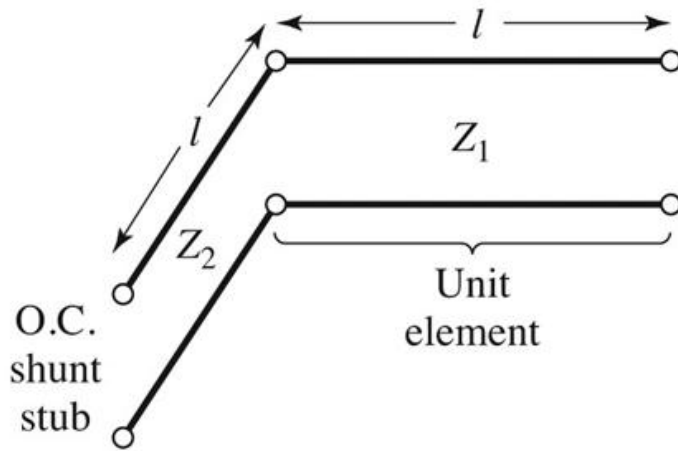
+



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

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

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

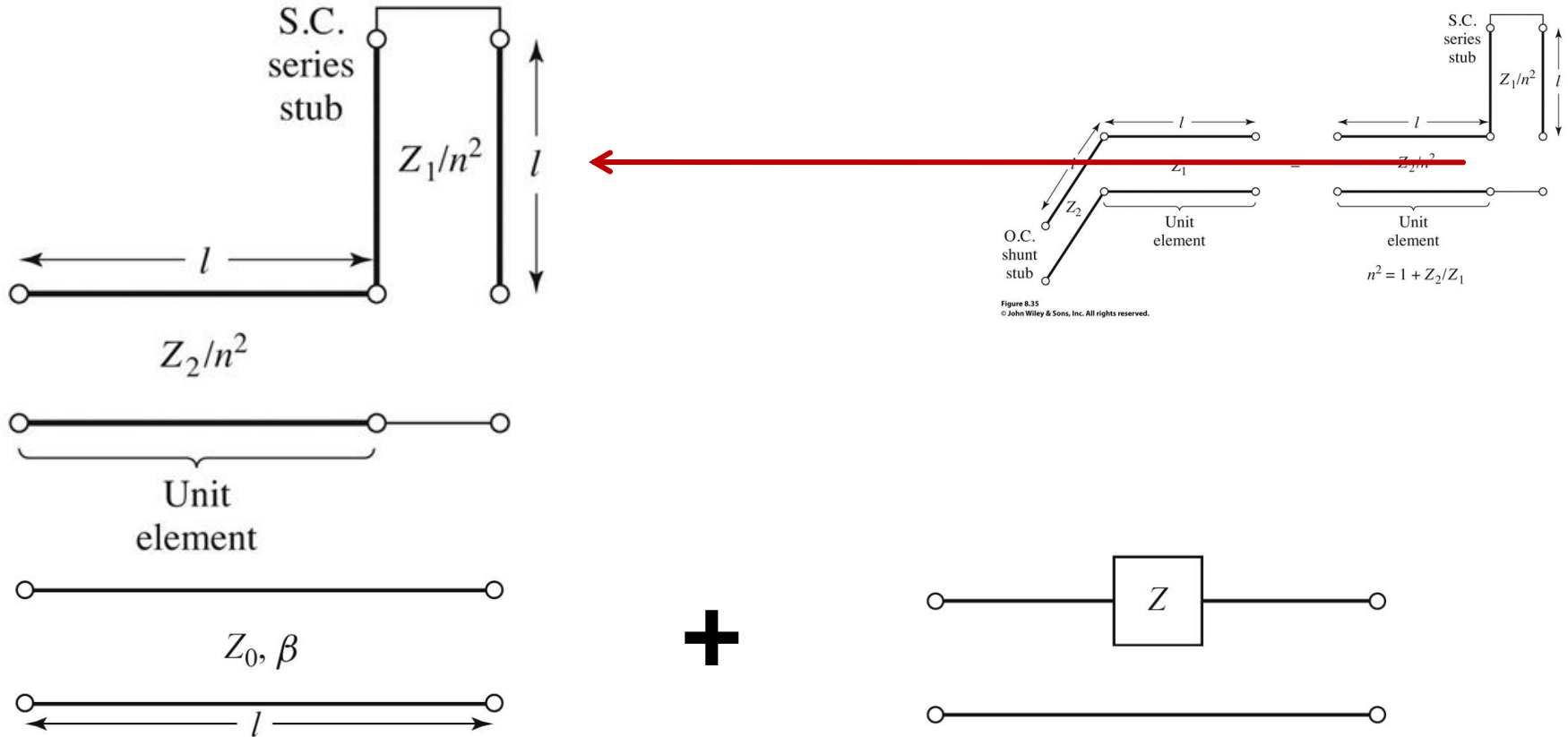
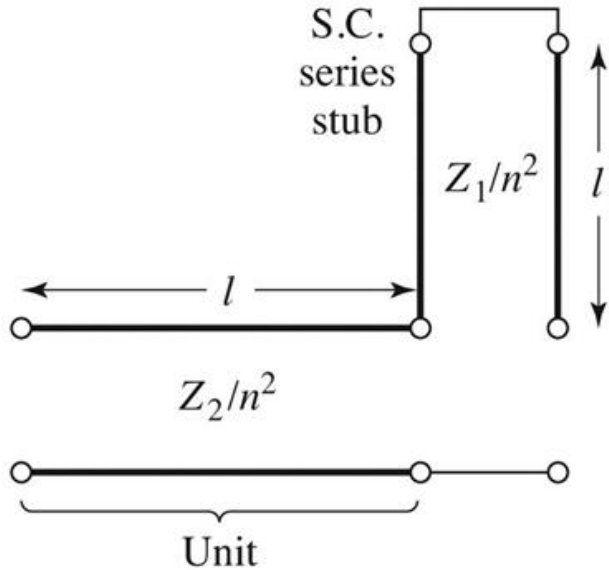


Figure 8.35
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$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos \beta \cdot l & j \cdot Z_0 \cdot \sin \beta \cdot l \\ j \cdot Y_0 \cdot \sin \beta \cdot l & \cos \beta \cdot l \end{bmatrix}$$

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

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

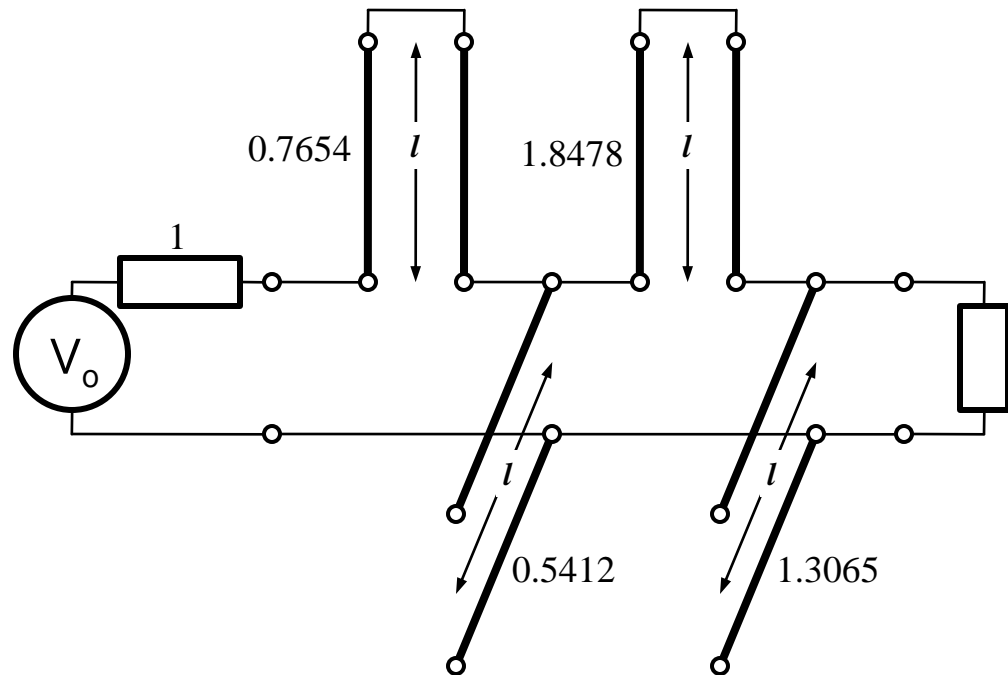
- Filtru trece jos de ordinul 4, cu frecventa de taiere de 4 GHz, de tip maxim plat (care sa functioneze pe 50Ω la intrare si iesire)
- Tabel maxim plat sau relatii de calcul:
 - $g_1 = 0.7654 = L_1$
 - $g_2 = 1.8478 = C_2$
 - $g_3 = 1.8478 = L_3$
 - $g_4 = 0.7654 = C_4$
 - $g_5 = 1$ (**nu** are nevoie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

Exemplu

■ Se aplica transformarea Richards

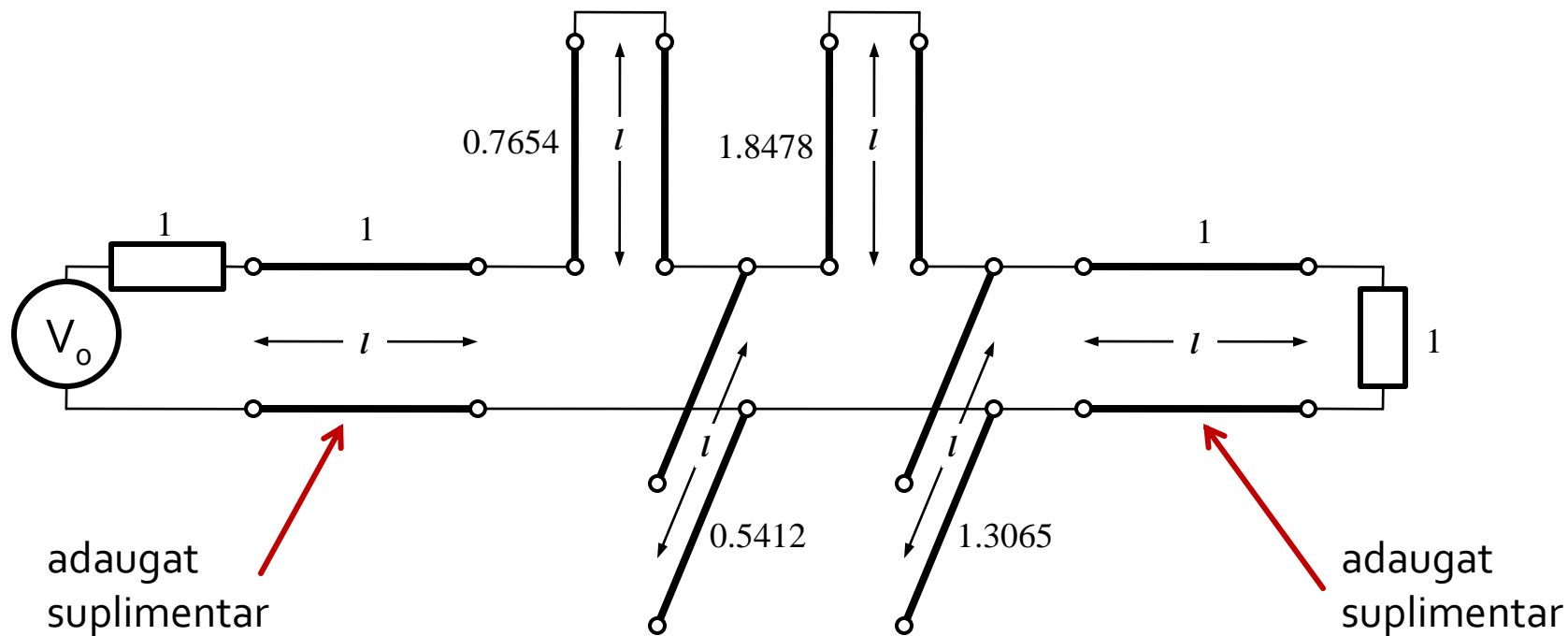
■ Probleme:

- 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



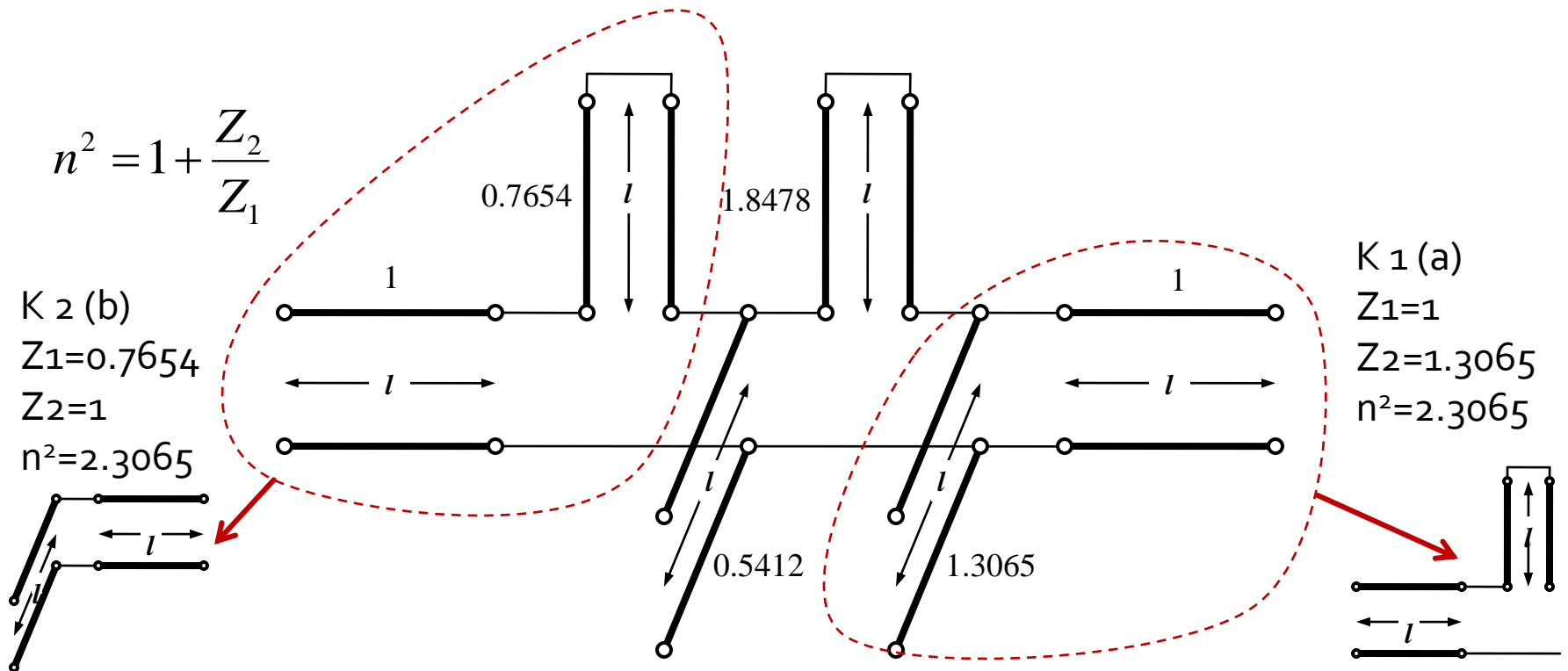
Exemplu

- 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 **aplica** una din identitățile Kuroda la fiecare capăt și se **continua**
 - un indicator al **opririi** procedurii este apariția unei secțiuni de linie între toate stub-urile obținute cu transformarea Richards



Exemplu

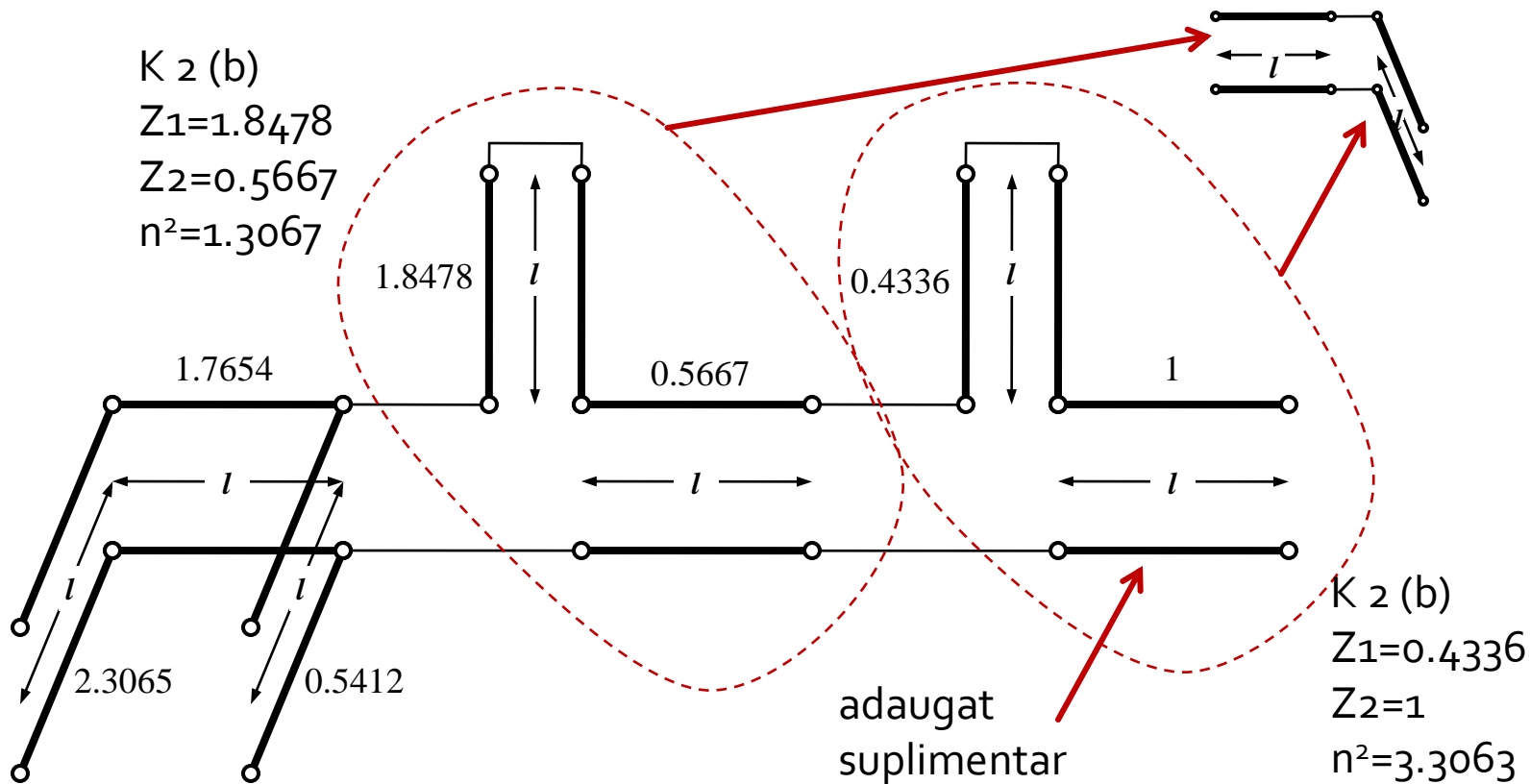
- Se aplica :
 - Kuroda 2 (L,Z cunoscut \rightarrow C,Z) in partea stanga
 - Kuroda 1 (C,Z cunoscut \rightarrow L,Z) in partea dreapta



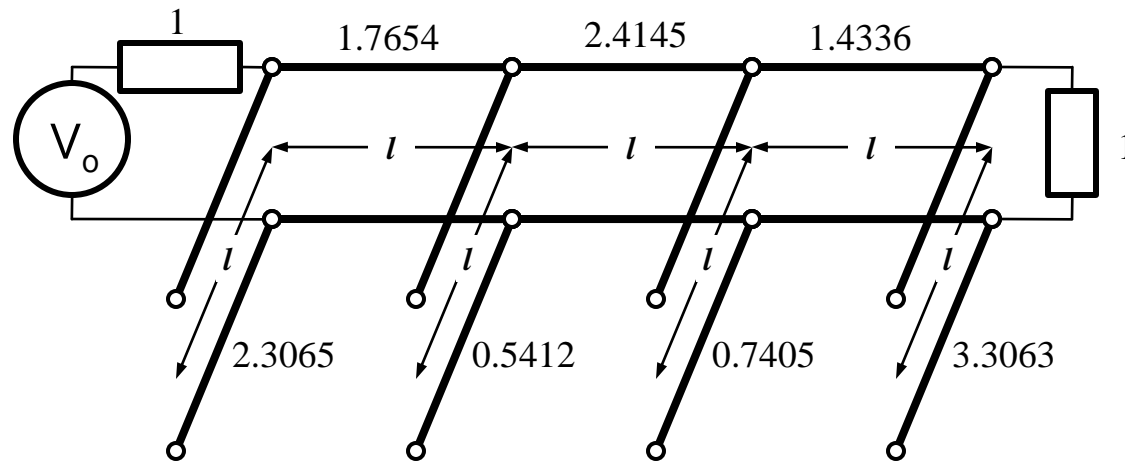
Exemplu

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

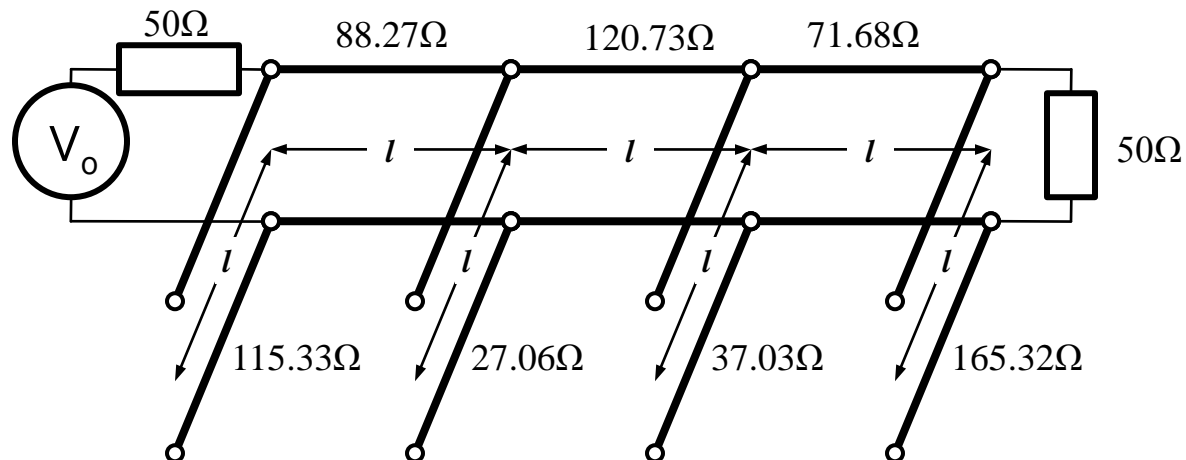
$$n^2 = 1 + \frac{Z_2}{Z_1}$$



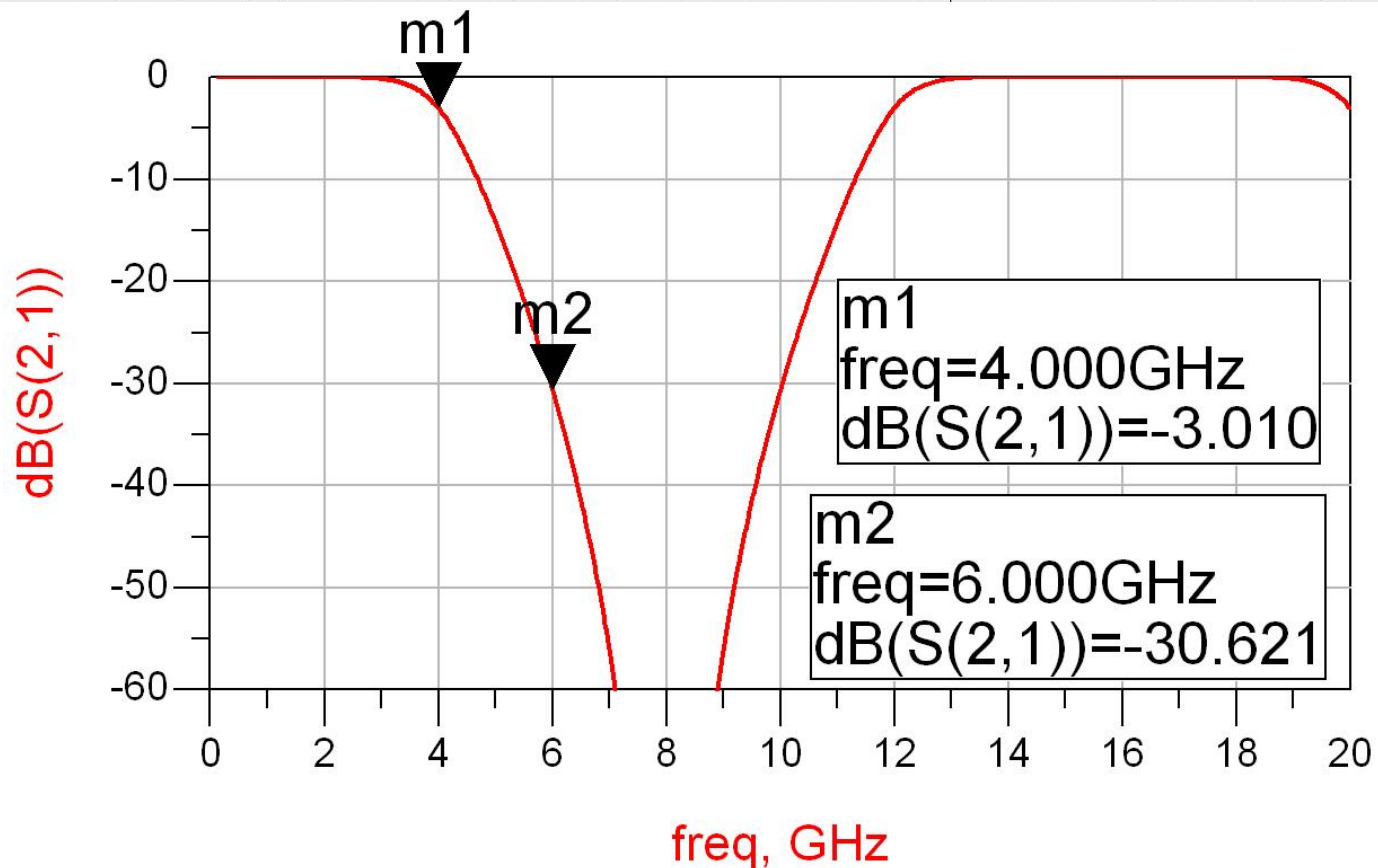
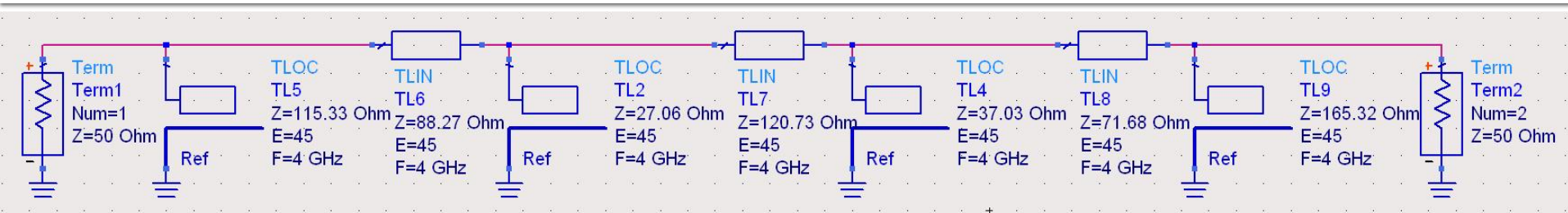
Exemplu



- Scalare la 50Ω



Identitatile Kuroda – ADS



Example

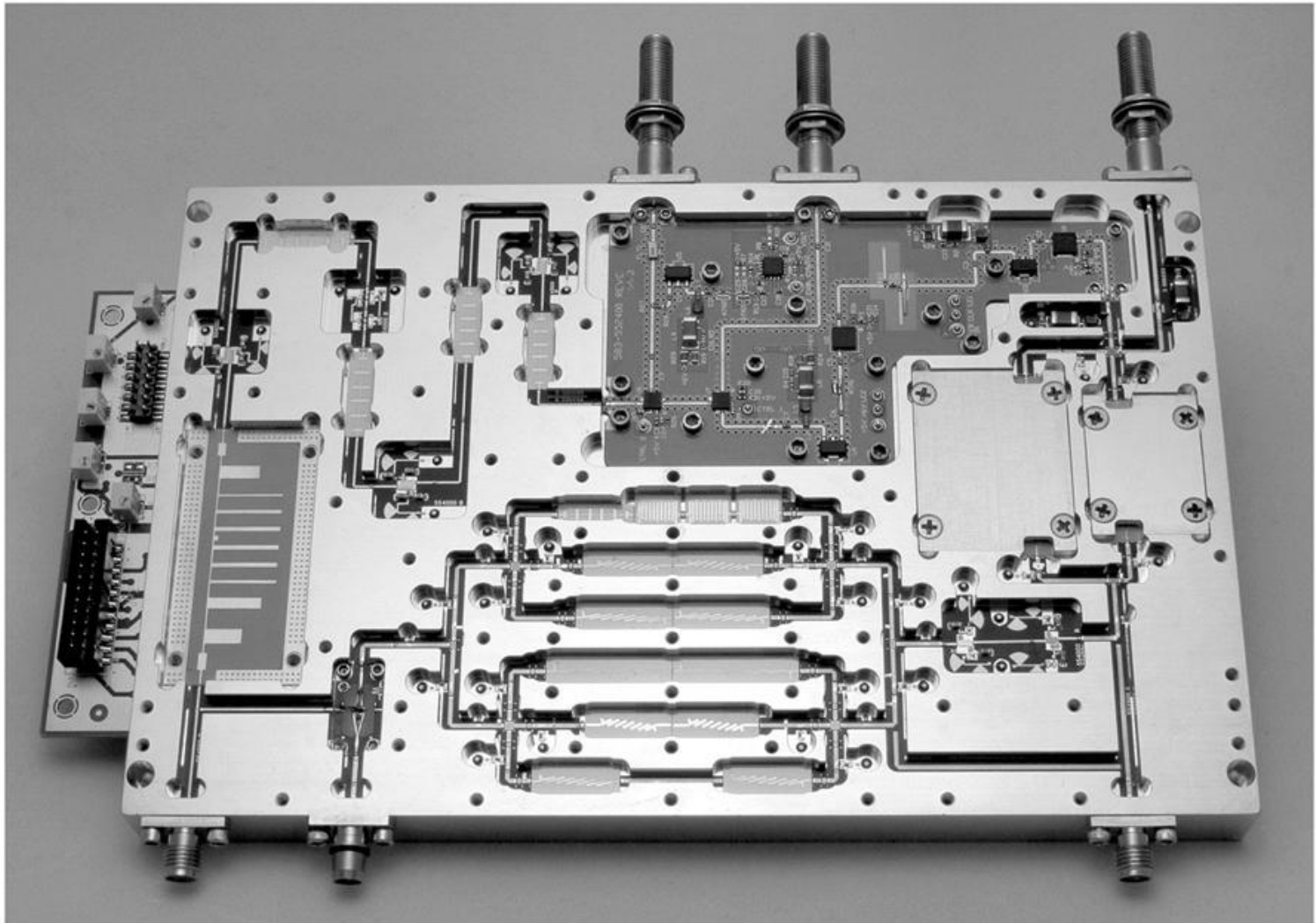


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.

Example

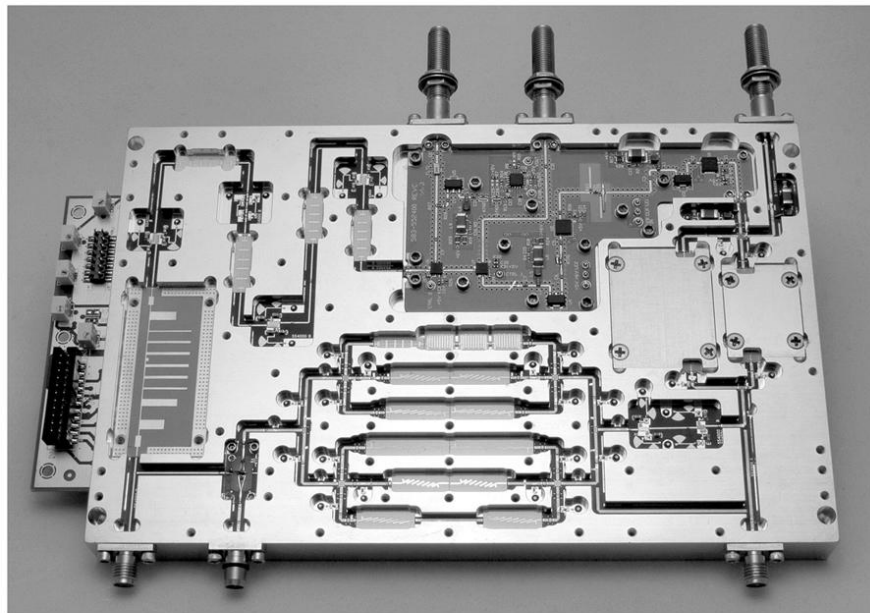
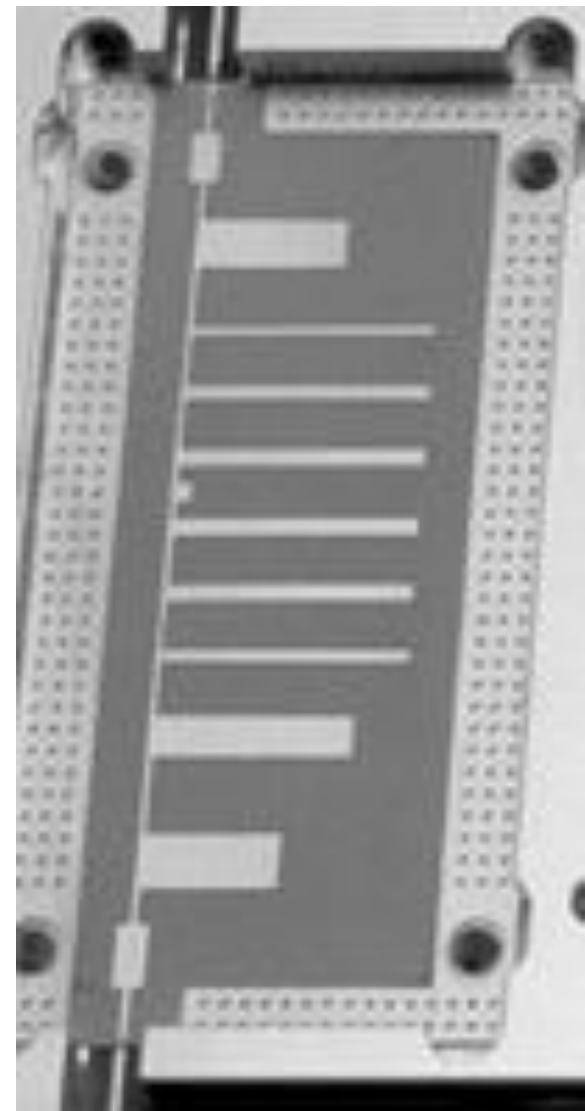
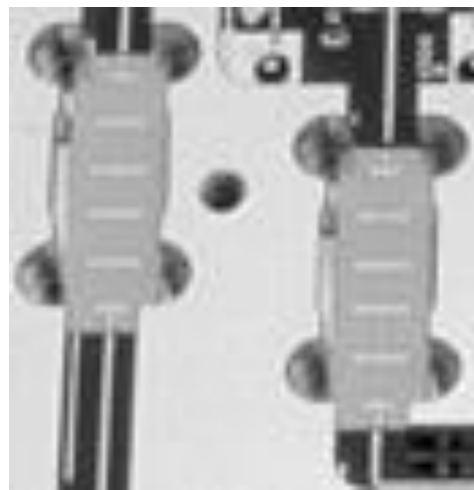
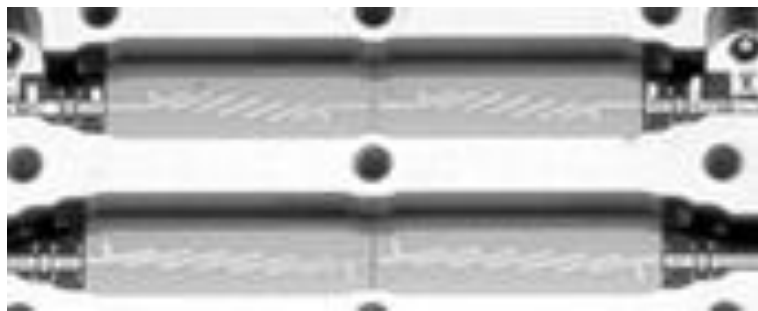


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.



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

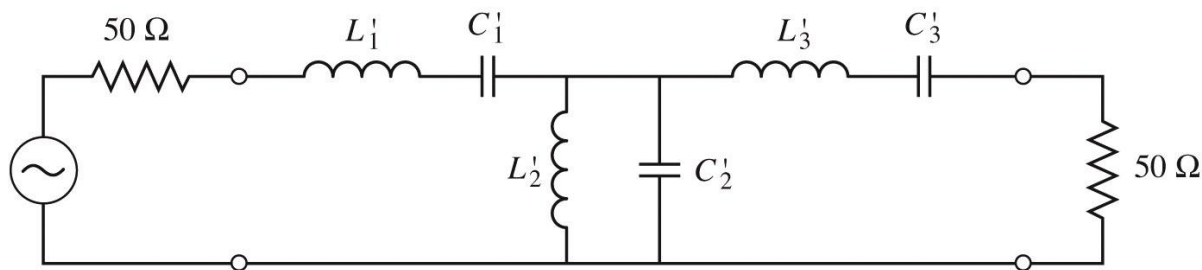


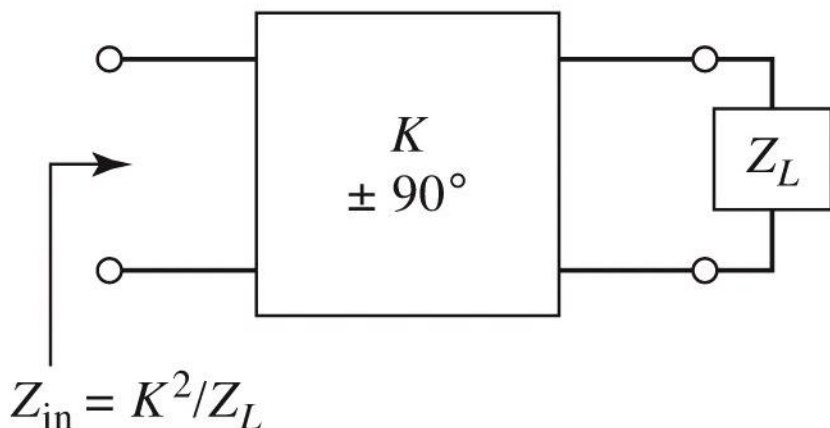
Figure 8.32
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Inversoare de impedanta si admitanta

- 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

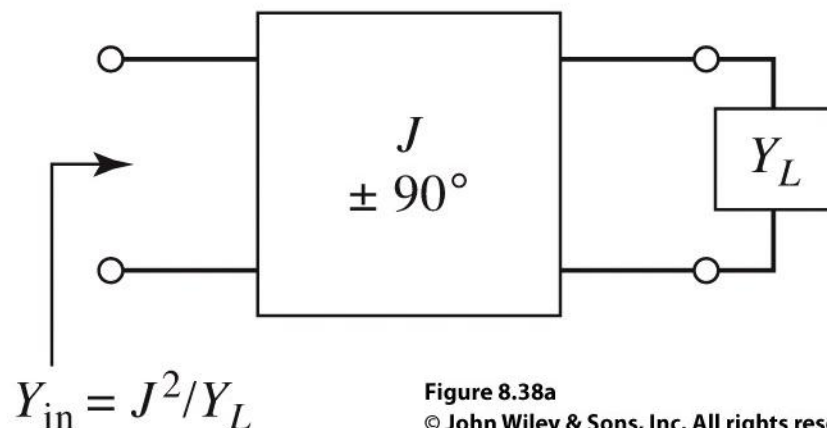


Figure 8.38a

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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 (C2)**

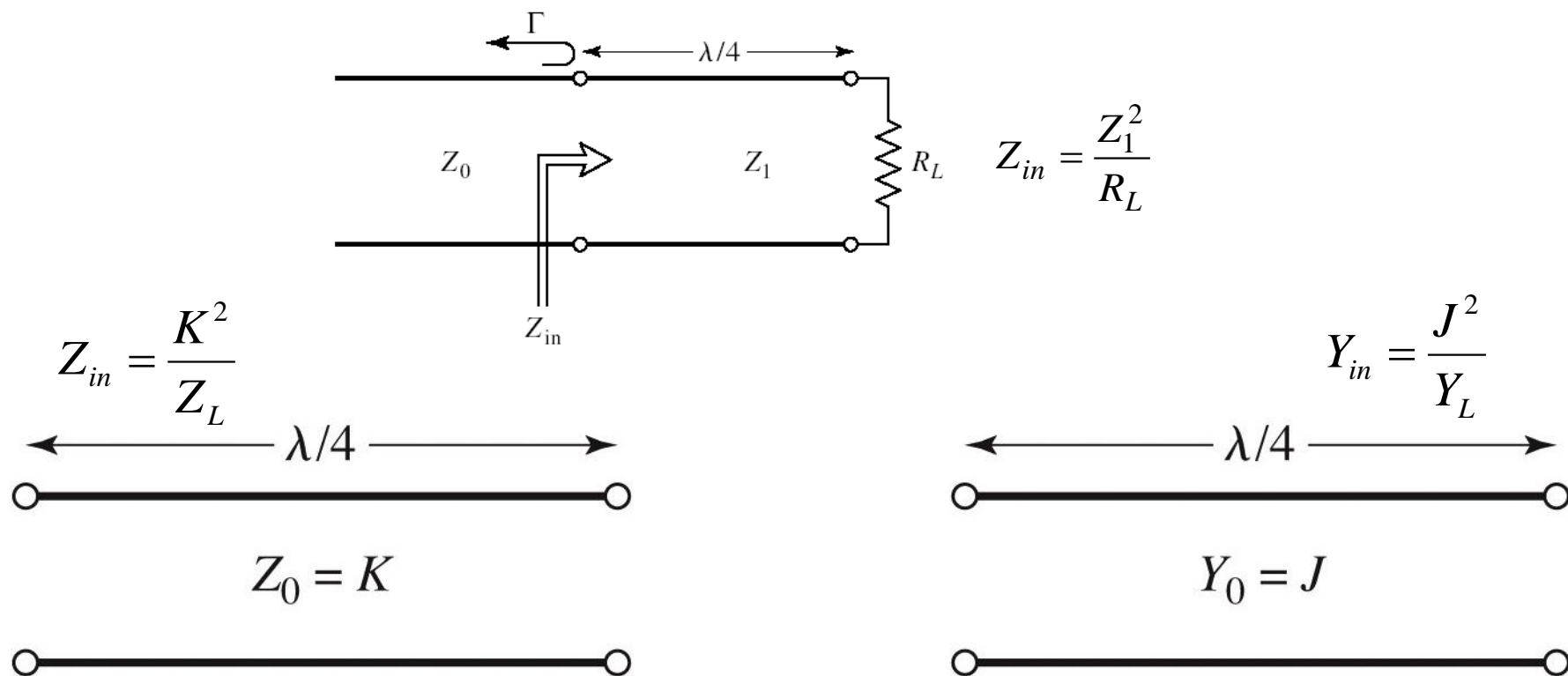
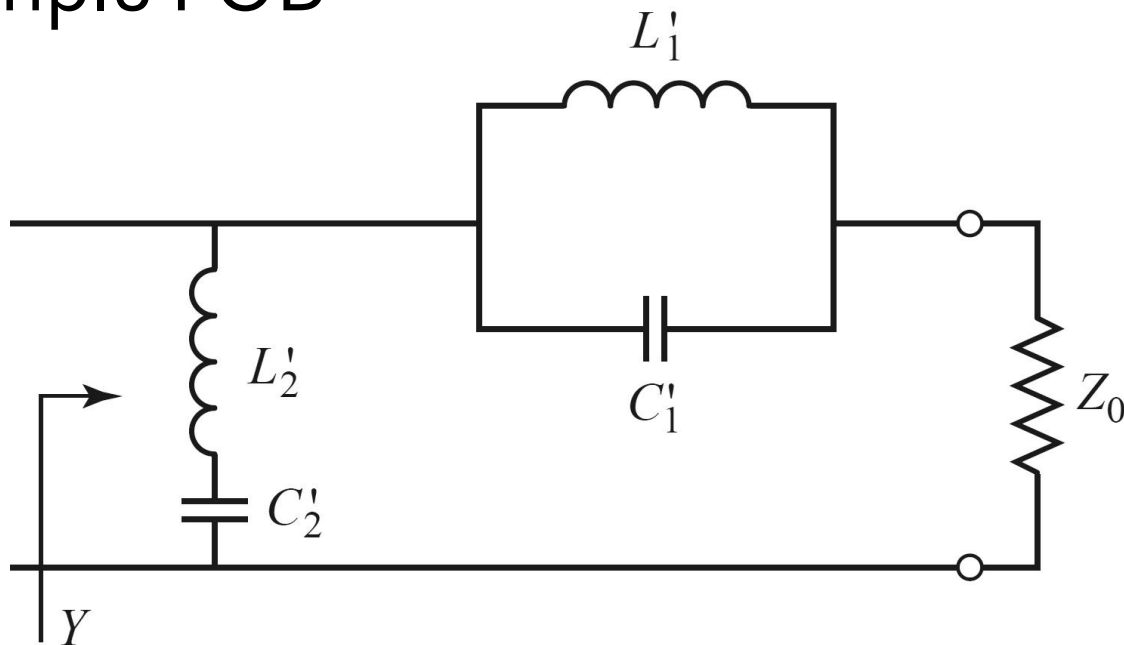


Figure 8.38b

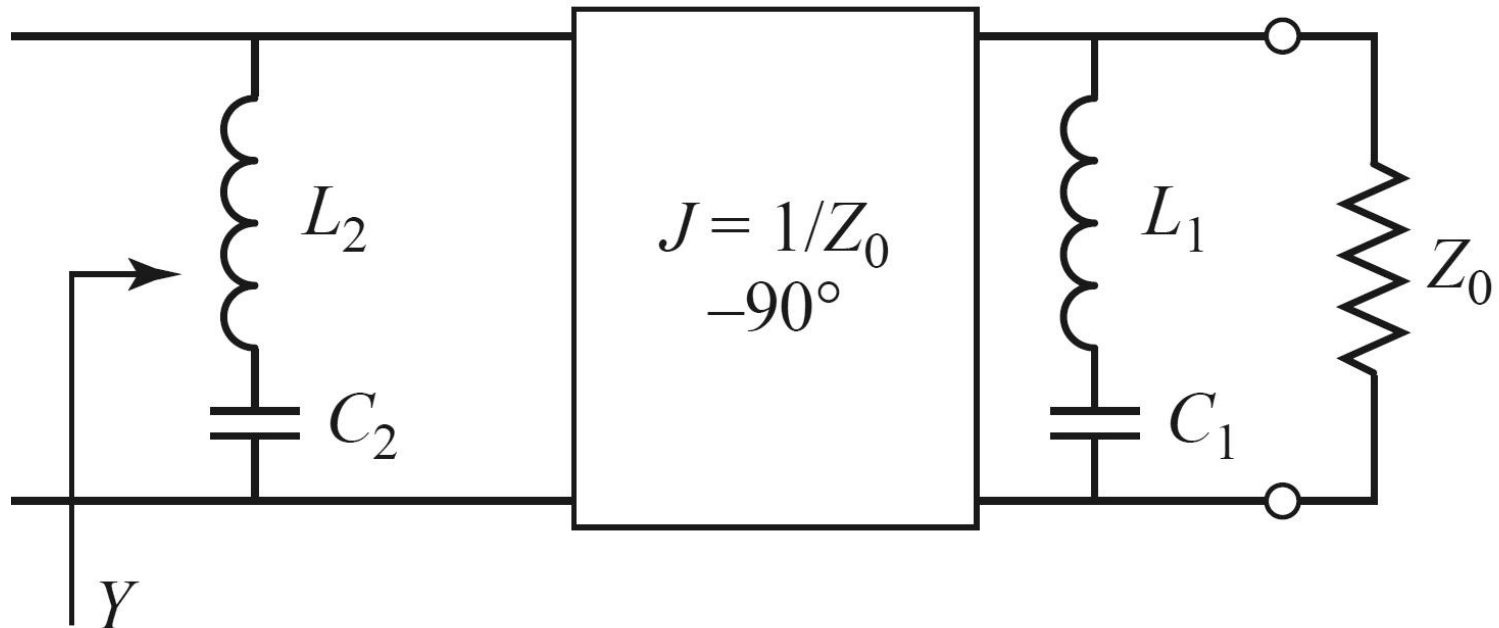
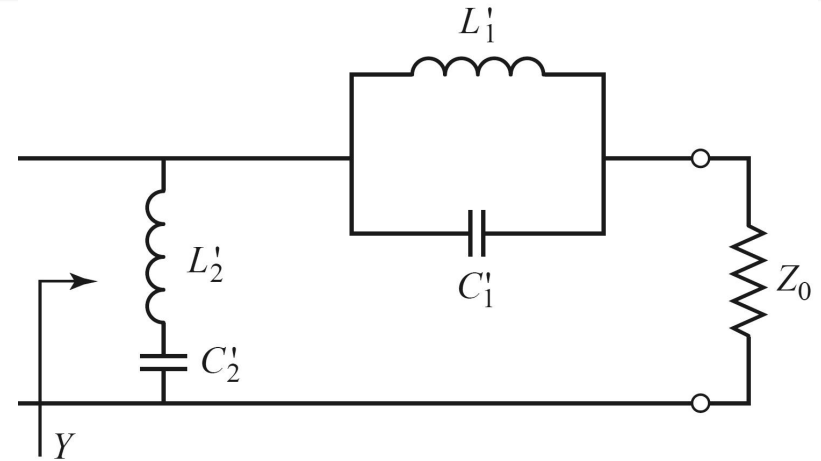
Inversoare de impedanta si admitanta

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



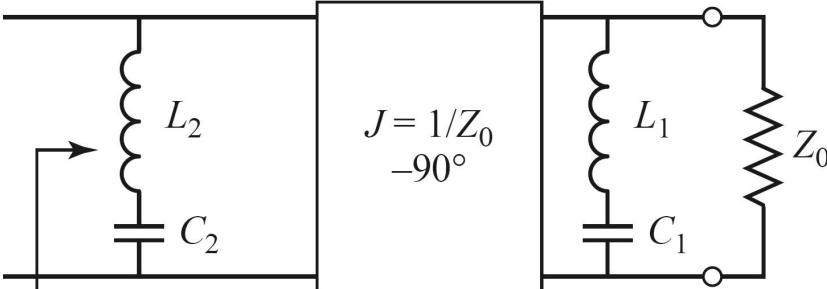
Inversoare de impedanta si admitanta

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



Inversoare de impedanta si admitanta

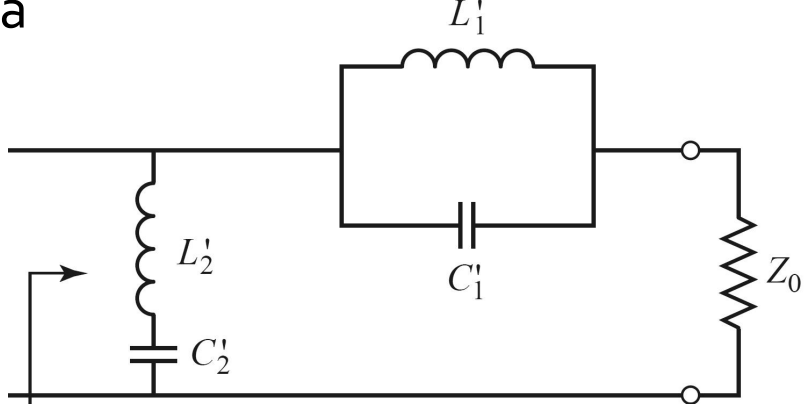
- Echivalenta celor doua scheme se demonstreaza prin obtinerea aceleiasi admitante de intrare
- Echivalenta completa se obtine prin incadrarea grupului simulat intre doua invertoare de admitanta



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

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

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

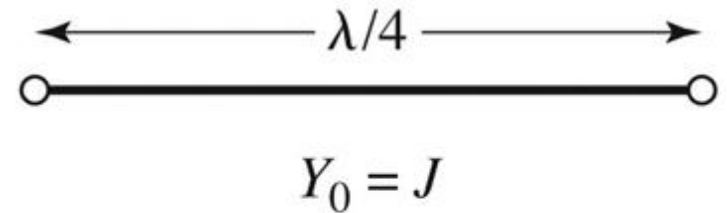
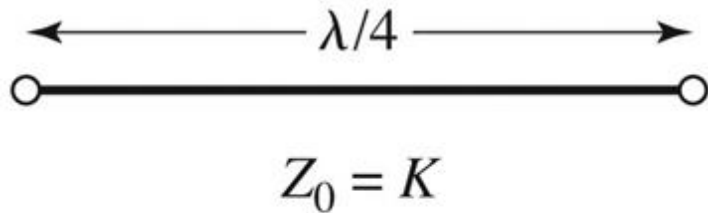


$$Y' = \frac{1}{j \cdot \omega \cdot L'_2 + \frac{1}{j \cdot \omega \cdot C'_2}} + \left(\frac{1}{j \cdot \omega \cdot C'_1 + \frac{1}{j \cdot \omega \cdot L'_1}} + Z_0 \right)^{-1}$$

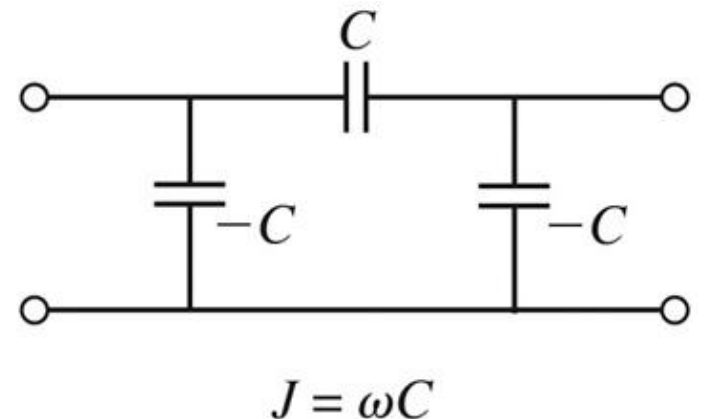
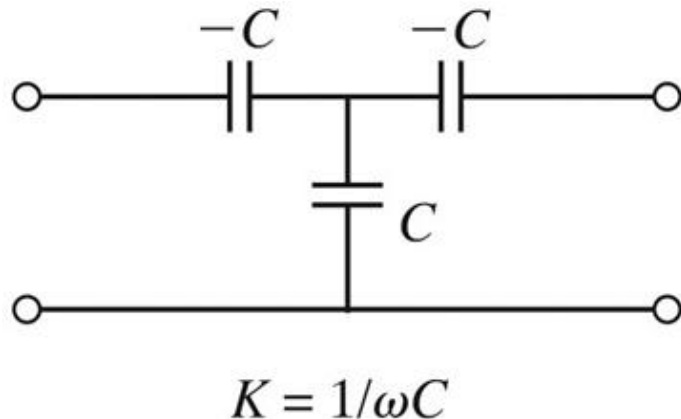
- Rezultat similar se obtine si pentru filtrul trece banda
- Un grup **LC serie** introdus in serie se poate inlocui cu un grup **LC paralel** introdus in paralel incadrat de doua invertoare de admitanta

Realizari practice de inversoare de impedanta/admitanta

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

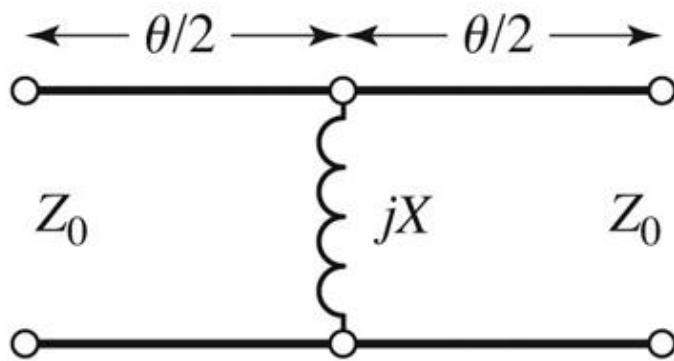


- Realizare cu elemente concentrate

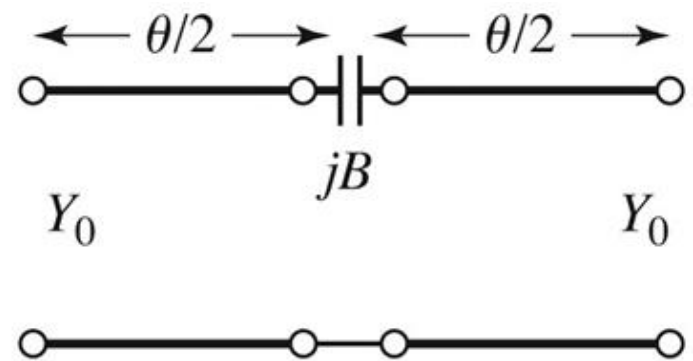


Realizari practice de inversoare de impedanta/admitanta

■ Realizare cu linii



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



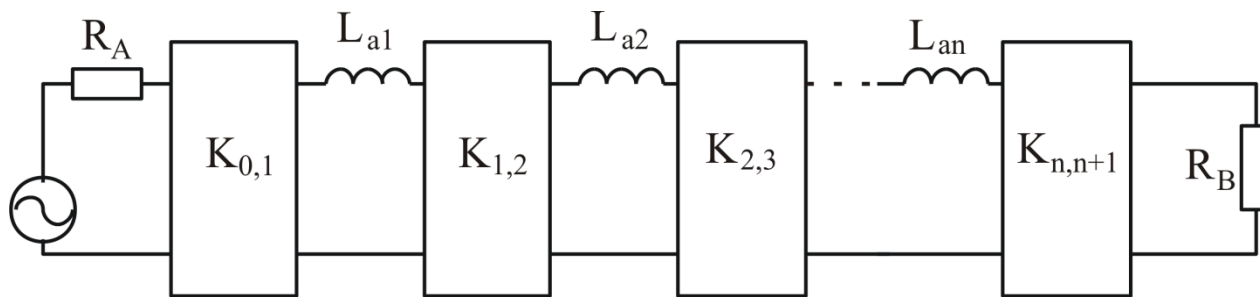
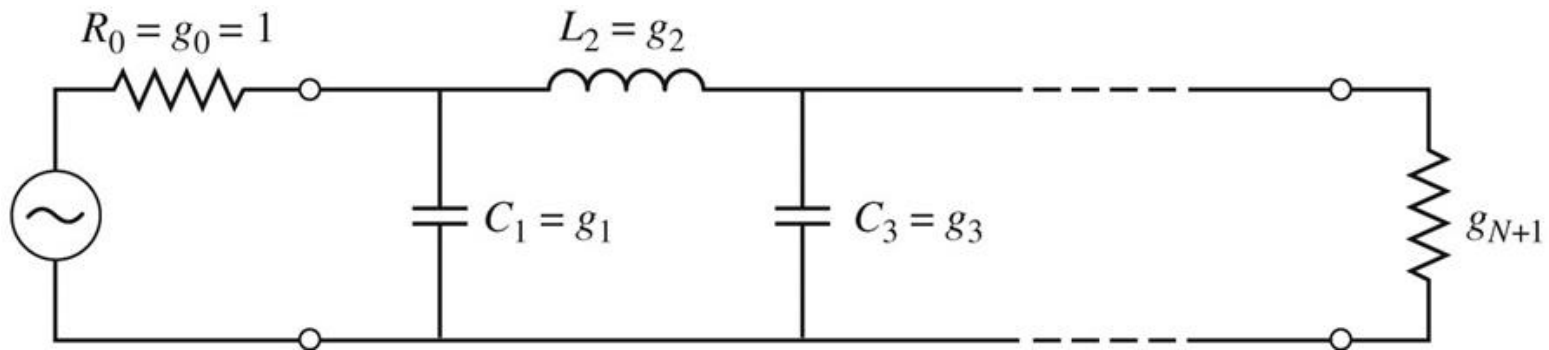
$$J = Y_0 \cdot \tan \left| \frac{\theta}{2} \right|$$
$$B = \frac{J}{1 - \left(\frac{J}{Y_0} \right)^2}$$
$$\theta = -\tan^{-1} \frac{2 \cdot B}{Y_0}$$

Red arrows point from the inductor and capacitor diagrams to this equation:

$$\theta < 0$$

Filtre prototip cu inversoare

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



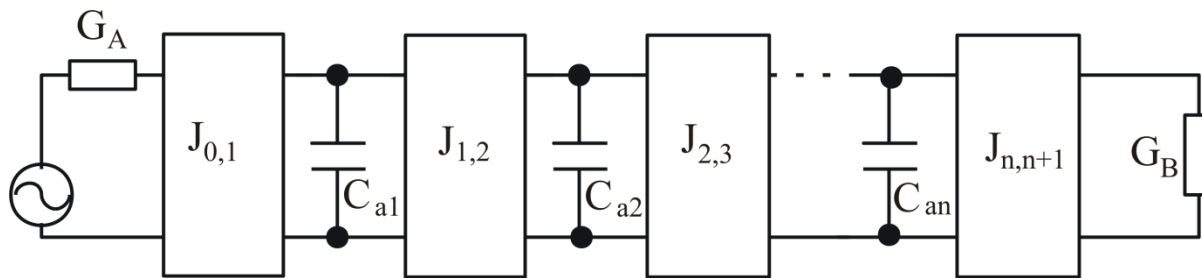
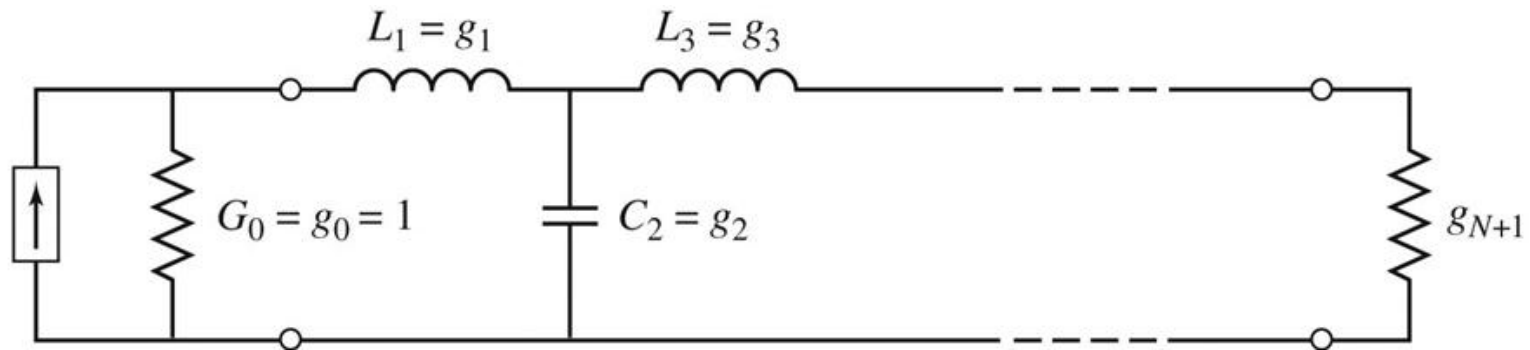
$$K_{0,1} = \sqrt{\frac{R_A \cdot L_{a,1}}{g_0 \cdot g_1}}$$

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

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

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

Contact

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