

Curs 12-13

2022/2023

# Dispozitive și circuite de microunde pentru radiocomunicații

# Disciplina 2022/2023

- 2C/1L, **DCMR (CDM)**
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
  - Marti 15-17, ~~Online~~/**Video (istoric)**, P2
  - E – **50%** din nota
  - **probleme** + (2p prez. curs) + (3 teste) + (bonus activitate)
    - primul test L1: 05.10.2022 (t2 si t3 neanuntate la **curs**)
    - 3pz (C)  $\approx$  +0.5p (**2p** max)
  - **toate materialele permise**

# Disciplina 2022/2023

- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
  - Miercuri/Joi, 12/14 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

# Laborator

- 5409 – 21.12.2022, 12-14
- online
  - **fara** prezenta (proiect)
  - prezenta necesara (**minim 7**)
    - curs
    - alta grupa



# Documentatie

## ■ <http://rf-opto.etti.tuiasi.ro>

Laboratorul de Microunde si Opti x +

← → ↻ ⚠ Not secure | rf-opto.etti.tuiasi.ro/microwave\_cd.php?chg\_lang=1



English | Romana

Start **Didactic** Master Colectiv Cercetare Studenti

Microunde Comunicatii Optice Optoelectronica Internet Antene Tehnologie/Zgomote Practica Soft didactic

### Dispozitive si circuite de microunde pentru radiocomunicatii

#### Disciplina: DCMR (2021-2022)

**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


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

# Istoric

## Alte informatii

[Online Exam manual](#) (pdf, 2.56 MB, en, )

[Exam Simulation \(video\)](#) (mp4, 41.96 MB, en, )

[Important Agilent Application Notes](#) (rar, 2.36 MB, ro, )

## Ani anteriori

2020-2021

2019-2020

2018-2019

2017-2018

2016-2017

Mai mult...

## Dispozitive si circuite de microunde pentru radiocomunicatii

### Disciplina: DCMR (2020-2021)

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

# Acces

## ■ Personalizat



### Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

[Acceseaza ca acest student](#)

### Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TW	Tehnologii Web					
	N	17/01/2014	Nota finala	10	-	
	A	17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	

Nume

Email

Cod de verificare

Trimite

# Online

- acces la **examene** necesita **parola** primita prin email

English | Romana |

Start Didactic Master Colectiv Cercetare Studii

Note Lista Studenti Examene Fotografii

**POPESCU GOPO ION**

Fotografia nu exista

Date:

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica si telecomunicatii
Marca	7000021

Acceseaza ca acest student | [Iere acces la licente](#)

**Note obtinute**

Inca nu a fost notat.

Start Didactic Master Colectiv C

Note Lista Studenti Examene Fotografii

**Identificare**

Introduceti numele si adresa de email utilizata la inscriere

Nume  
POPESCU GOPO

**E-mail/Parola**

Introduceti codul afisat mai jos

**4db4457**

Trimite

# Online

- acces email/parola

[Start](#) [Didactic](#) [Master](#) [Colectiv](#)

[Note](#) [Lista Studenti](#) [Examene](#) [Fotografii](#)

**POPESCU GOPO ION**

Fotografia  
nu exista

**Date:**

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica
Marca	7000021

Se acceseaza site-ul **ca acest student!**

[Start](#) [Didactic](#) [Master](#) [Colectiv](#) [C](#)

[Note](#) [Lista Studenti](#) [Examene](#) [Fotografii](#)

**POPESCU GOPO ION**

Fotografia  
nu exista

**Date:**

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica s
Marca	7000021

Se acceseaza site-ul **ca acest student (inclusiv examene)!**



# Parola

## ■ primita prin email

Important message from RF-OPTO

Inbox x



Radu-Florin Damian

to me, POPESCU



Romanian

> English

[Translate message](#)



Laboratorul de Microunde si Optoelectronica  
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei  
Universitatea Tehnica "Gh. Asachi" Iasi

In atentie: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul **rf-opto** este

Parola: [REDACTED]

Identificati-va pe [server](#), cu parola, cat mai rapid, pentru confirmare.

**Memorati** acest mesaj intr-un loc sigur, pentru utilizare ulterioara

Attention: POPESCU GOPO ION

The password to access the exams on the **rf-opto** server is

Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

**Save** this message in a safe place for later use

Reply

Reply all

Forward

Subject: Important message from RF-OPTO

Correspondents: POPESCU GOPO ION

Validation of MDCK exam from 02/05/2020

From: Me <rdamian@etti.tuiasi.ro>

Subject: Important message from RF-OPTO

To: [REDACTED]

Cc: Me <rdamian@etti.tuiasi.ro>

Laboratorul de Microunde si Optoelectronica  
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei  
Universitatea Tehnica "Gh. Asachi" Iasi

In atentie: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul **rf-opto** este

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Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

**Save** this message in a safe place for later use


# Manual examen online

- Aplicatia de examen online utilizata intens la:
  - ~~curs (prezentat)~~
  - **laborator (rezultate)**
  - **proiect (predare)**
  - ~~examen~~

## Materials

### Other data

[Manual examen on-line](#) (pdf, 2.65 MB, ro, )

[Simulare Examen](#) (video) (mp4, 65.12 MB, ro, )

## Microwave Devices and Circuits (Englis

# Examen online

- intotdeauna **contratimp**
  - **perioada lunga** (rezultate laborator)
  - perioada scurta (teste: 15min, examen: 2h)

Start Didactic Master Colectiv Cercetare **Studenti**

Note Lista Studenti **Examene** Fotografii

**Anunț**  
17:28 (29/04/2020)

**Material suport**  
17:30 (29/04/2020)

**Subiecte**  
17:32 (29/04/2020)

**Rezultate**  
17:35 (29/04/2020)

**Finalizare**  
17:45 (29/04/2020)

**Confirmare**  
17:45 (30/04/2020)

urmatorul interval de timp in:  
**01 m 08 s**  
[Reincarca acum](#)

## Anunț

In acest examen se verifica diverse actiuni ale studentilor pentru examen

## Ora pe server

Toate examenele sunt bazate pe fusul orar al server-ului (ar putea sa fie diferit de timpul local). Pentru referinta ora pe server este acum:

**29/04/2020 17:28:51**



# Cuprins

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

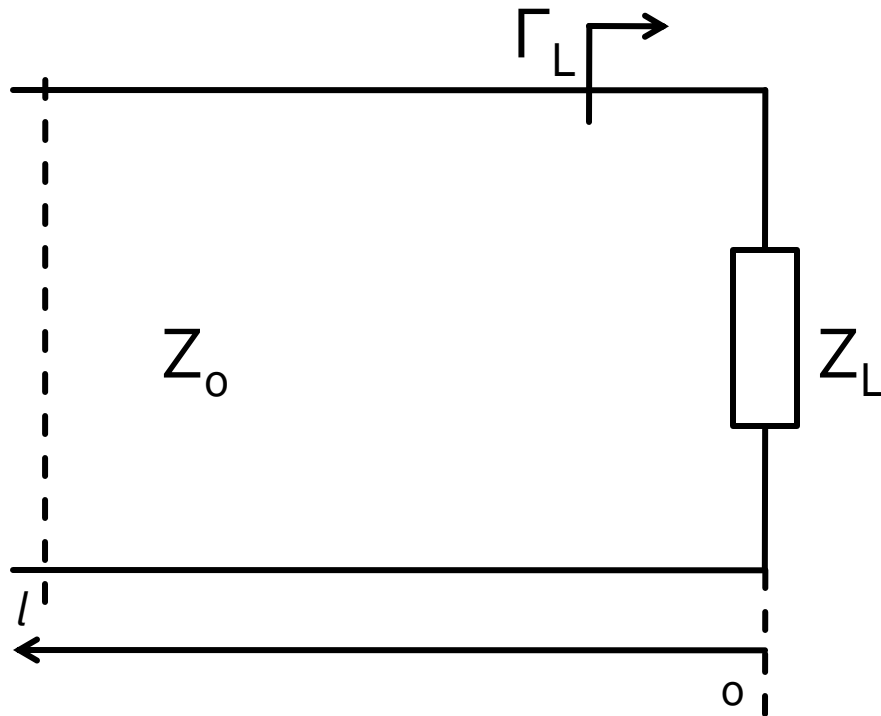
# Bibliografie

- <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)**

# Cuprins

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

# Linie fara pierderi



$$V(z) = V_0^+ e^{-j\beta \cdot z} + V_0^- e^{j\beta \cdot z}$$

$$I(z) = \frac{V_0^+}{Z_0} e^{-j\beta \cdot z} - \frac{V_0^-}{Z_0} e^{j\beta \cdot z}$$

$$Z_L = \frac{V(0)}{I(0)} \quad Z_L = \frac{V_0^+ + V_0^-}{V_0^+ - V_0^-} \cdot Z_0$$

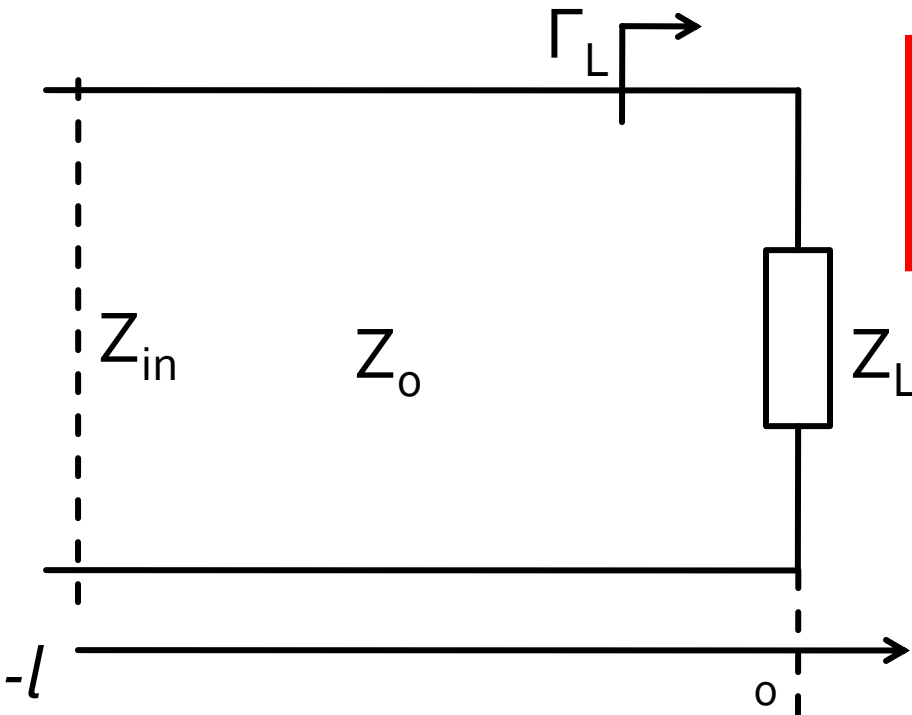
- coeficient de reflexie in tensiune

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

- $Z_0$  real

# Linie fara pierderi

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



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

# Cuprins

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

# Adaptare dpdv al puterii

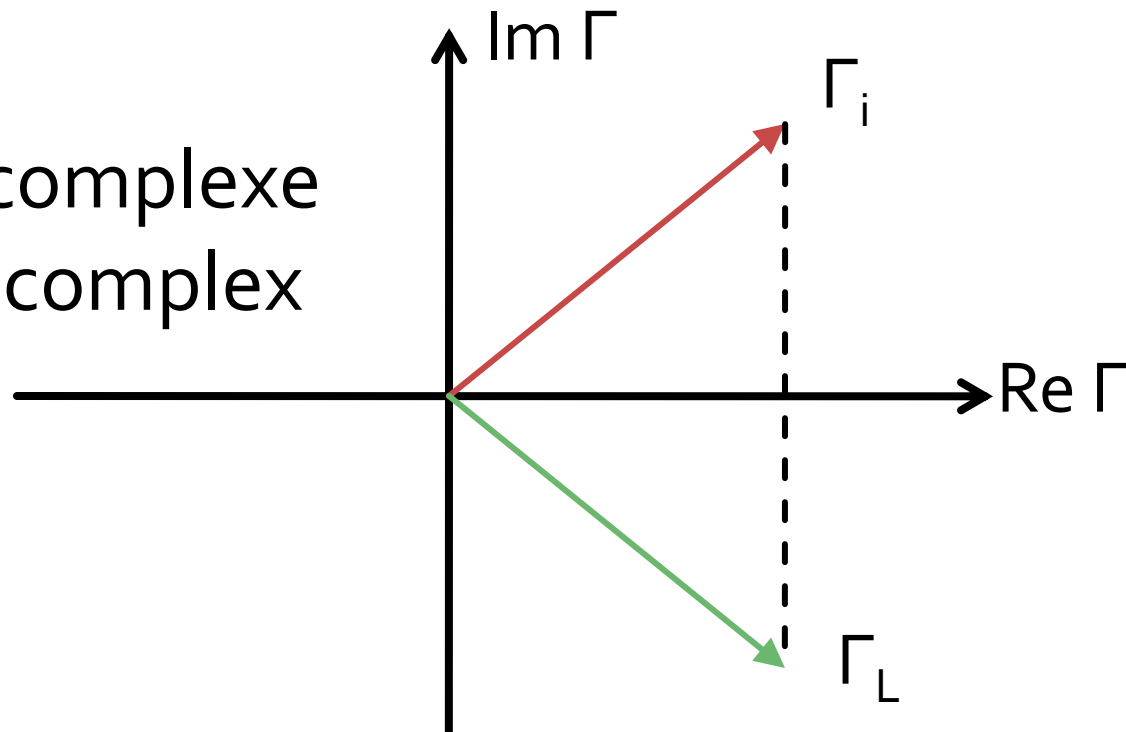
Daca se alege un  $Z_0$  real

$$Z_L = Z_i^*$$

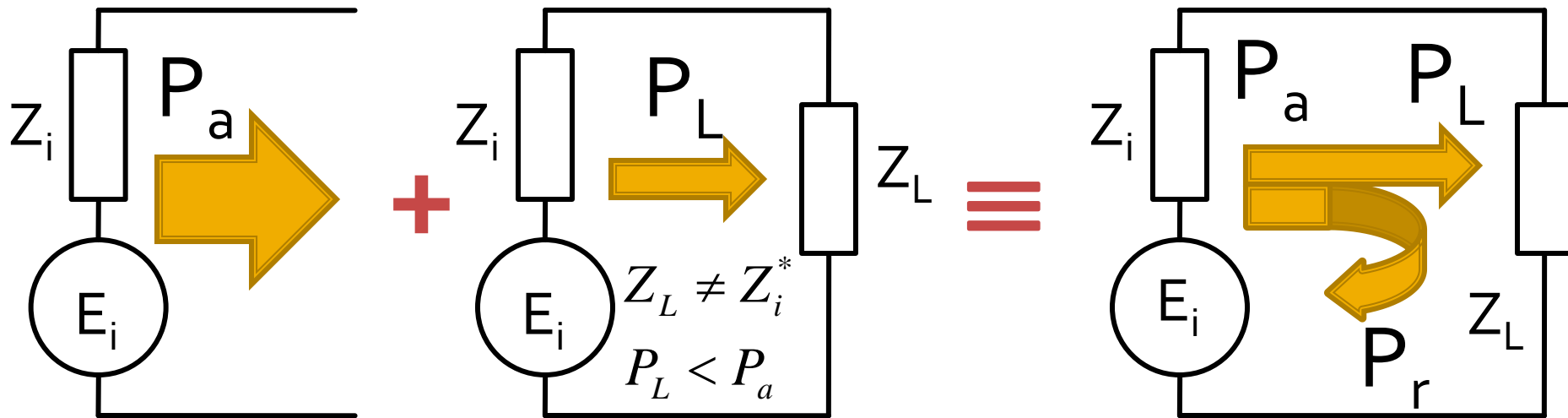
$$\Gamma = \frac{Z - Z_0}{Z + Z_0}$$

$$\Gamma_L = \Gamma_i^*$$

- numere complexe
- in planul complex



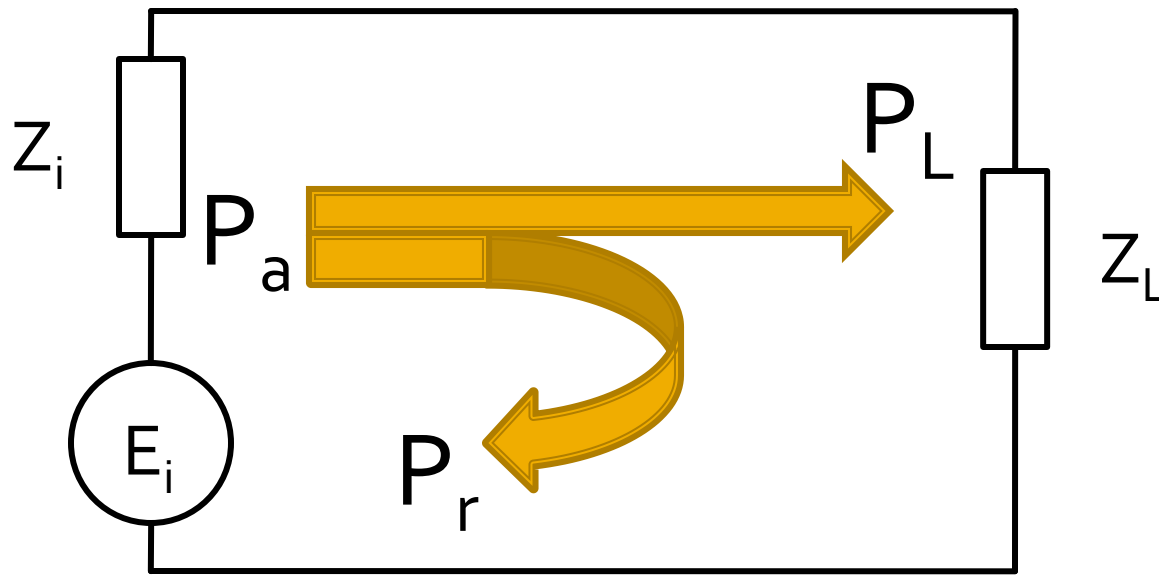
# Reflexie de putere / Model



- 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!**



# Reflexie de putere / Model



$$P_a = \frac{|E_i|^2}{4R_i}$$

$$P_L = \frac{R_L \cdot |E_i|^2}{(R_i + R_L)^2 + (X_i + X_L)^2}$$

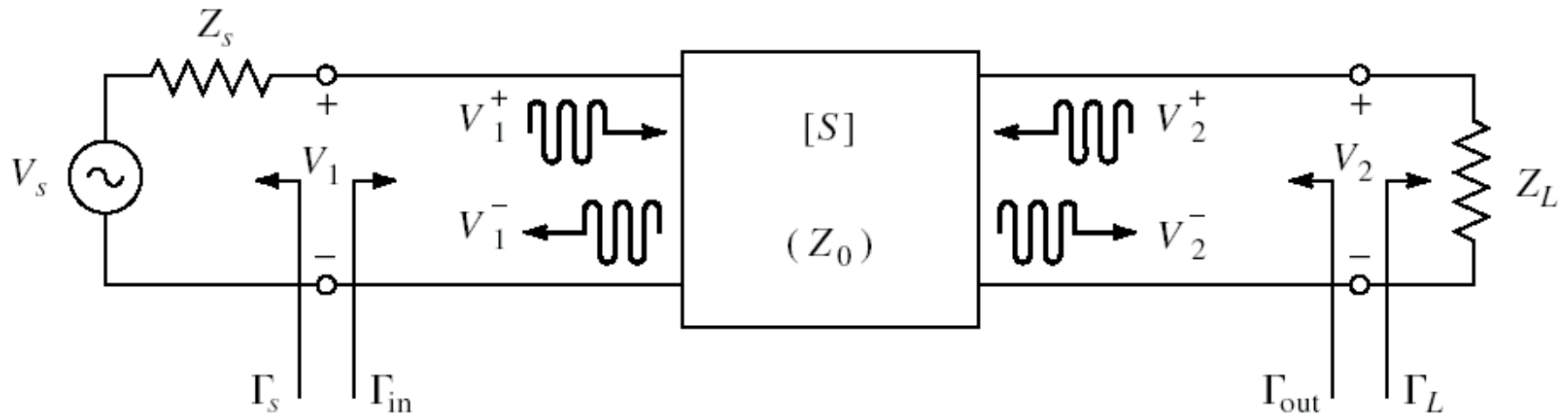
$$P_r = P_a - P_L = \frac{|E_i|^2}{4R_i} - \frac{R_L \cdot |E_i|^2}{(R_i + R_L)^2 + (X_i + X_L)^2} = \frac{|E_i|^2}{4R_i} \cdot \left[ 1 - \frac{4R_L \cdot R_i}{(R_i + R_L)^2 + (X_i + X_L)^2} \right]$$

$$P_r = \frac{|E_i|^2}{4R_i} \cdot \left[ \frac{(R_i - R_L)^2 + (X_i + X_L)^2}{(R_i + R_L)^2 + (X_i + X_L)^2} \right] = P_a \cdot |\Gamma|^2$$

- $|\Gamma|^2$  **este** un coeficient de reflexie in putere

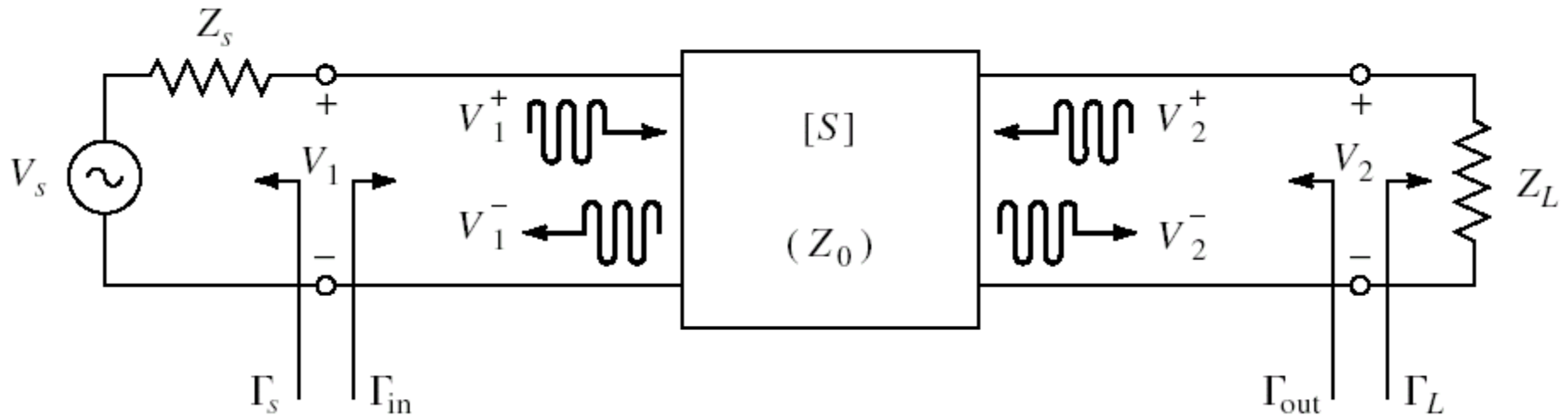
# Amplificatoare de microunde

# Cuadripol Amplificator (diport)



- Caracterizare cu parametri S
- Normalizati la  $Z_0$  (implicit  $50\Omega$ )
- Cataloage: parametri S pentru anumite polarizari

# Diport amplificador

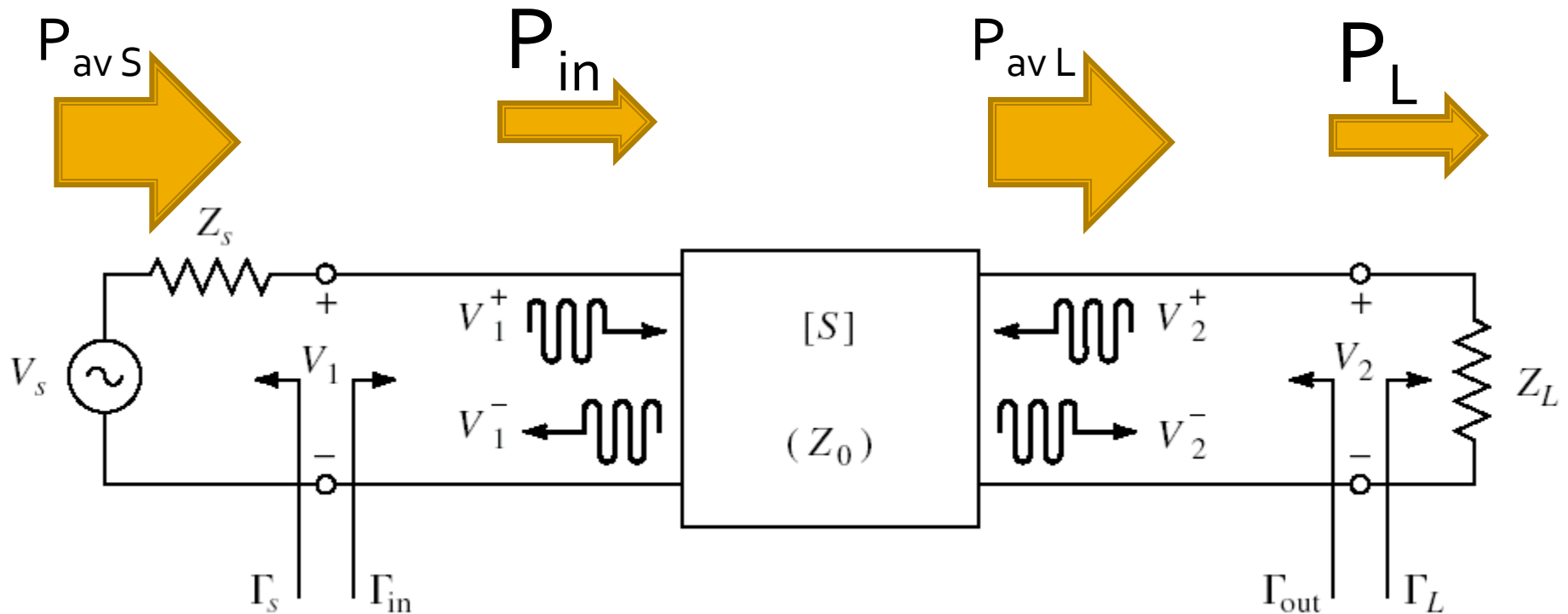


$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

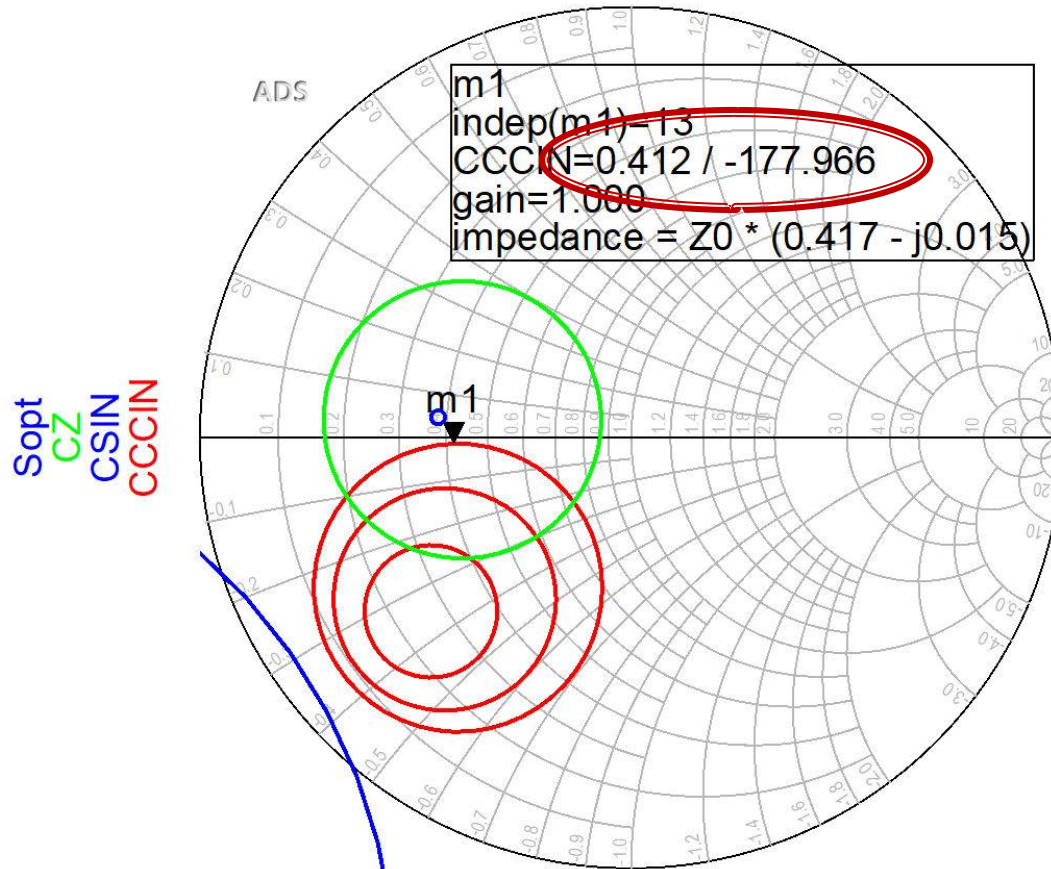
$$\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_s}{1 - S_{11} \cdot \Gamma_s}$$

# Puteri / Adaptare

- Doua porturi in care adaptarea influenteaza transferul de putere

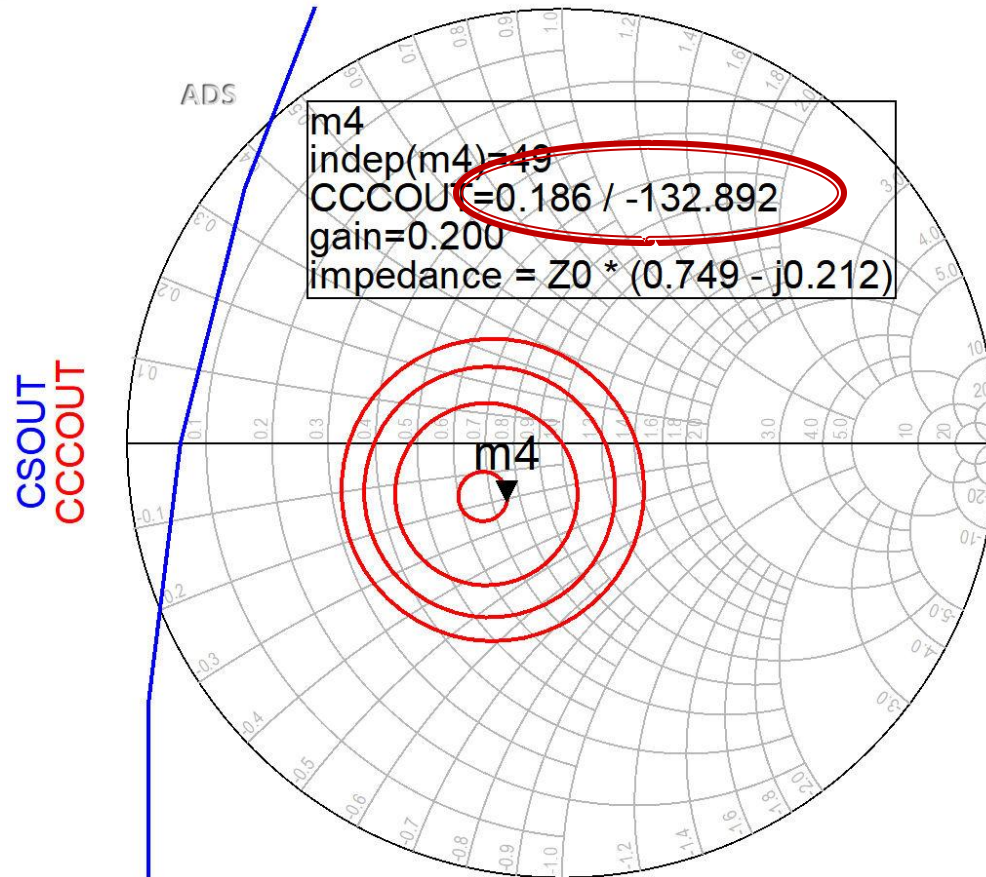


# Adaptare la intrare



- Daca se sacrifica 1.2dB castig la intrare pentru conditii convenabile F,Q ( $G_s = 1$  dB)
- Se prefera obtinerea unui zgomot mai mic

# Adaptare la iesire



- CCCOUT: -0.4dB, -0.2dB, 0dB, +0.2dB
- Lipsa conditiilor privitoare la zgomot ofera posibilitatea obtinerii unui castig mai mare (spre maxim)

# 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  $\omega$

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

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

- 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

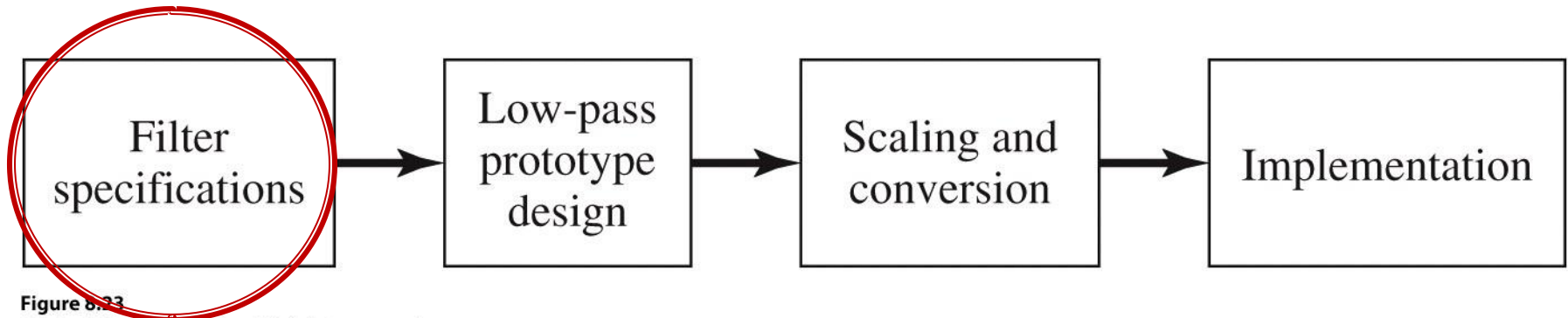


Figure 8.23  
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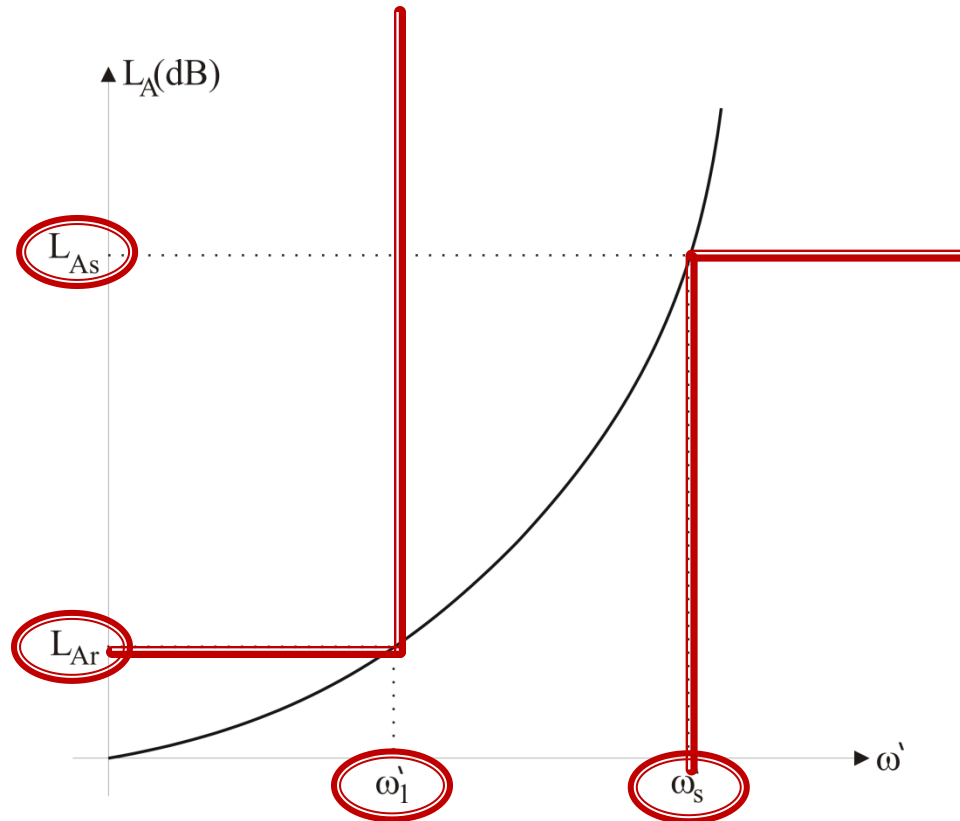
# Date de proiectare

## ■ 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  $\omega_1'$  ( $\omega_c$ : cutoff) 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

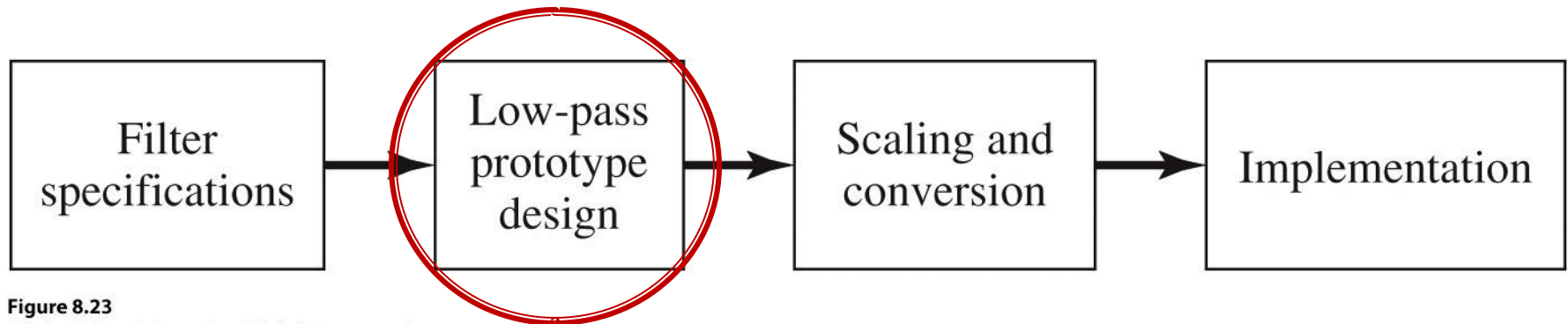


Figure 8.23

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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

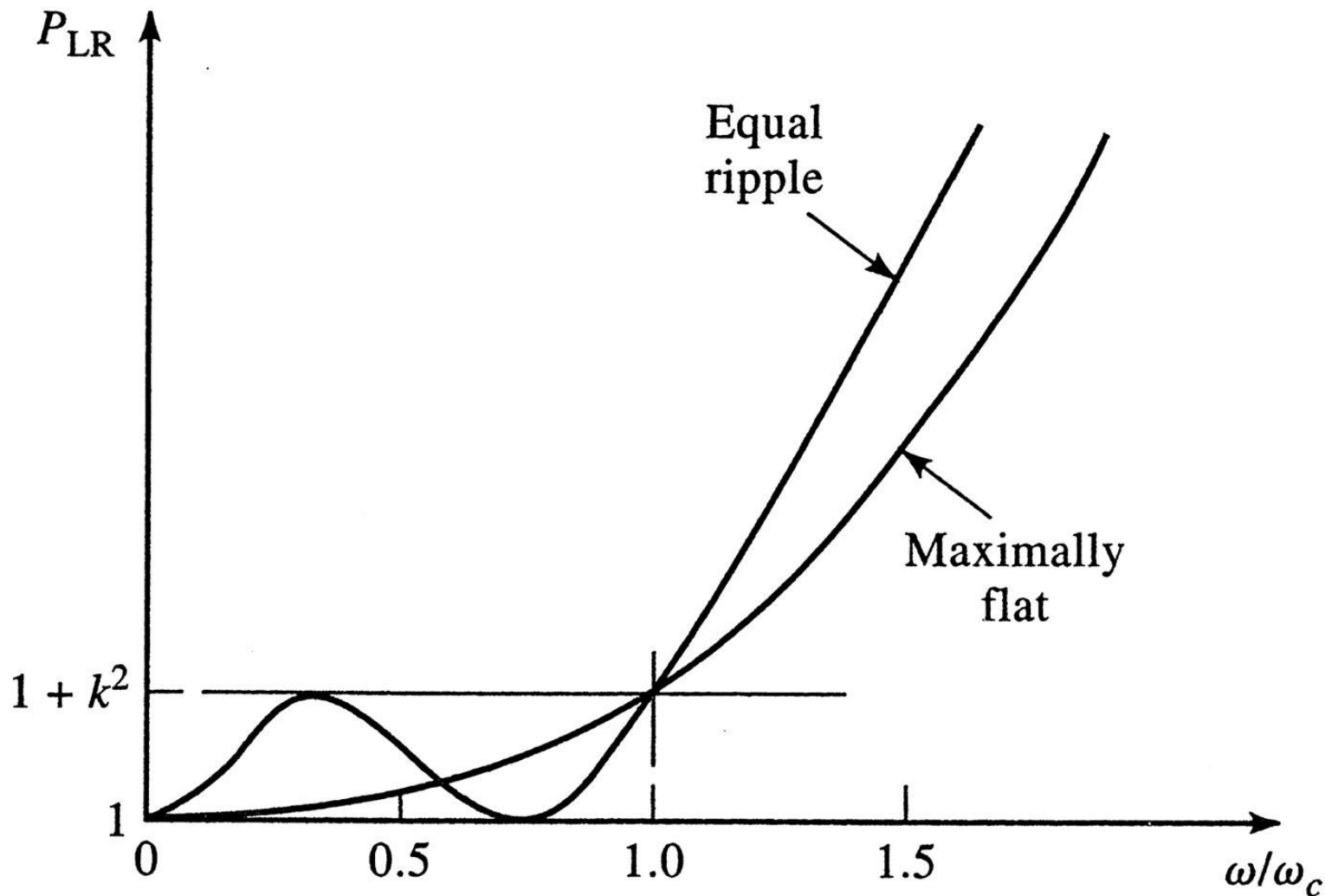


Figure 8.21  
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# FTJ elliptic prototip

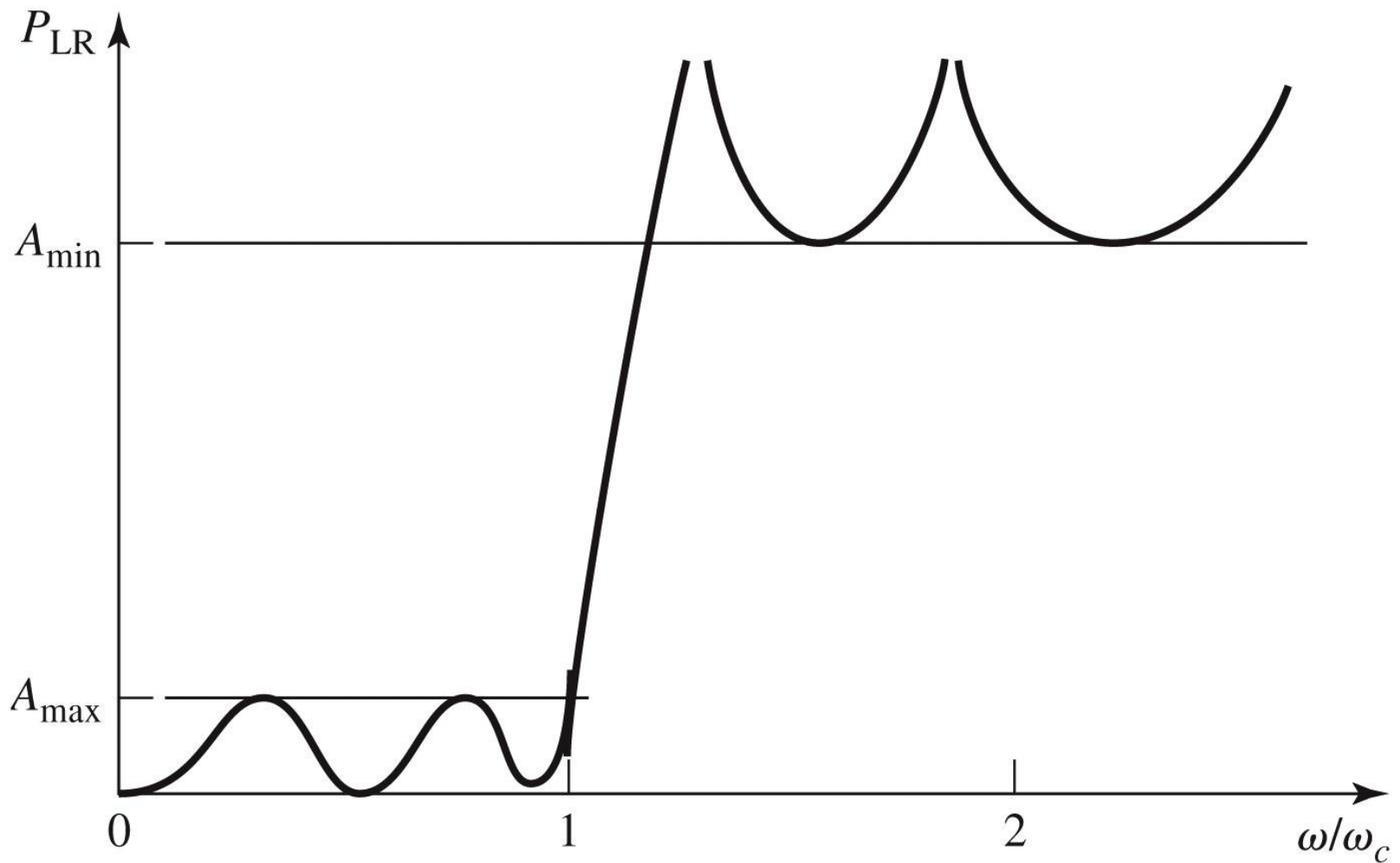


Figure 8.22  
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# FTJ de tip maxim plat

- Polinomul

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

- pentru  $\omega \gg \omega_c$

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

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

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

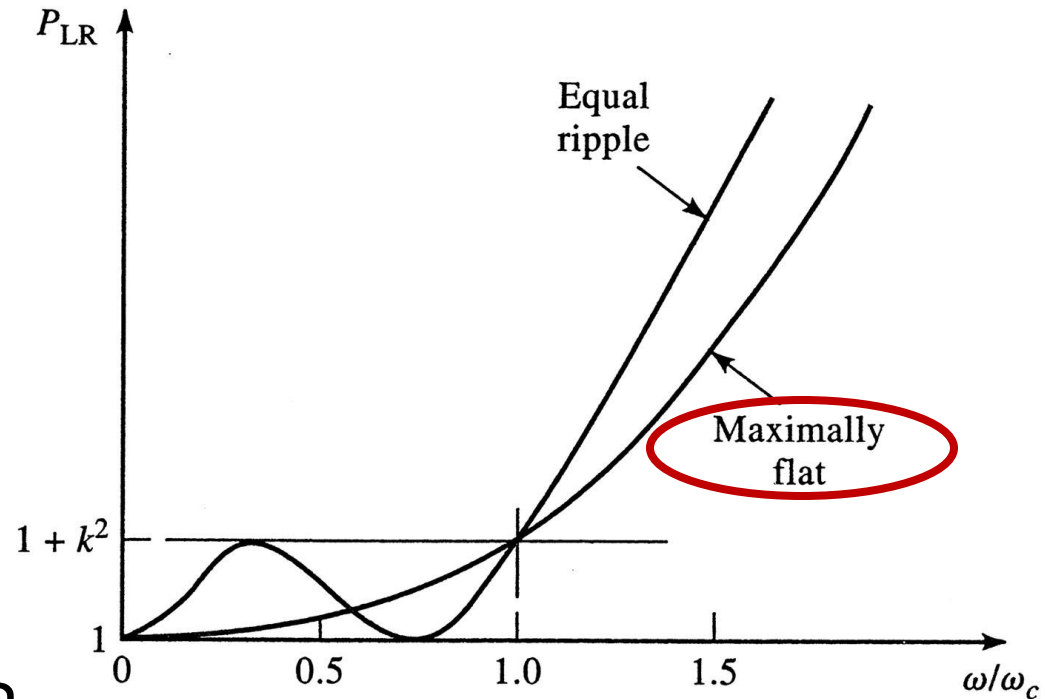


Figure 8.21  
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# FTJ de tip echiriplu

- Polinomul

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

- pentru  $\omega \gg \omega_c$

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

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

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

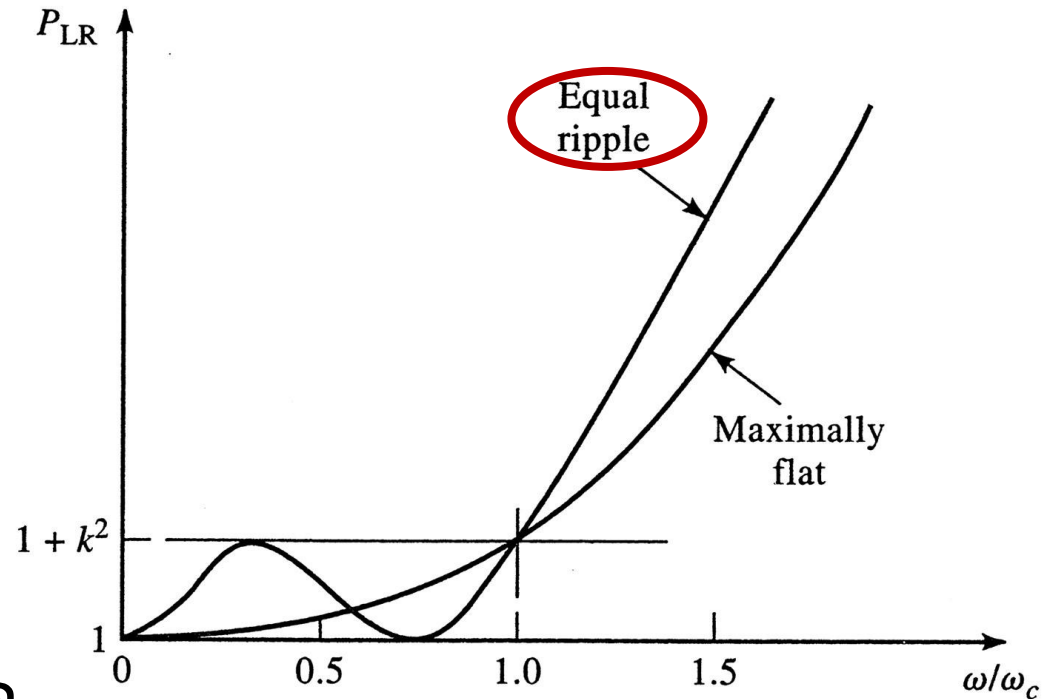
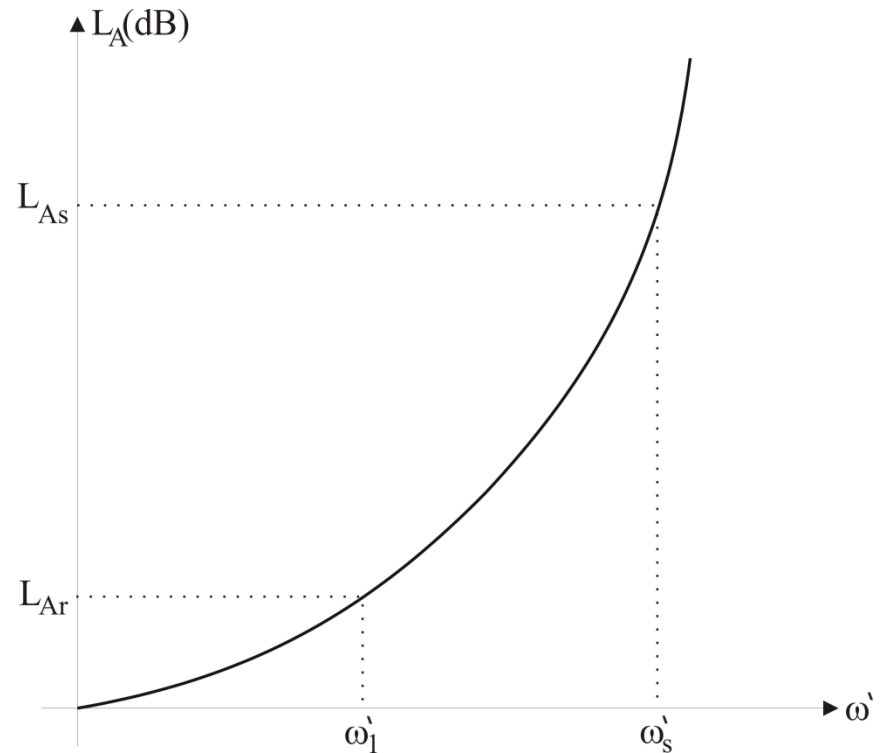


Figure 8.21  
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# Calculul ordinului filtrului maxim plat

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

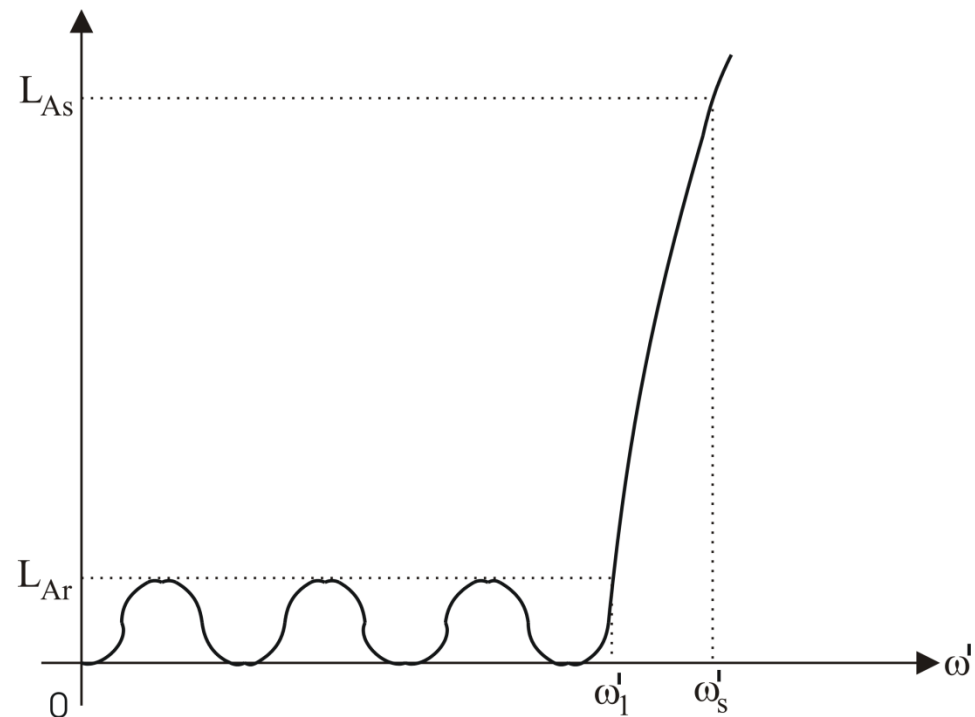
- cu atenuările in **dB**



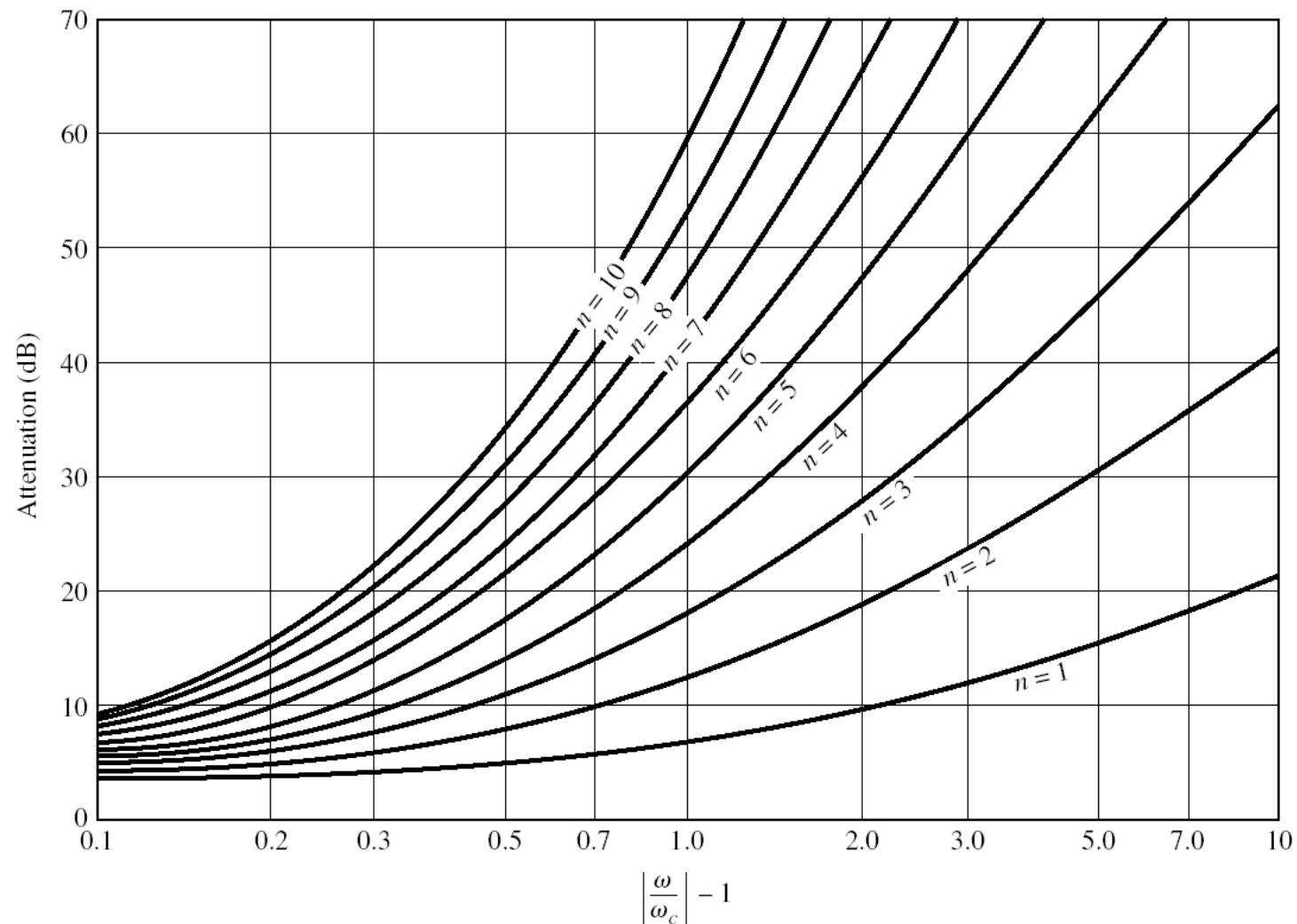
# Calculul ordinului filtrului echiriplu

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

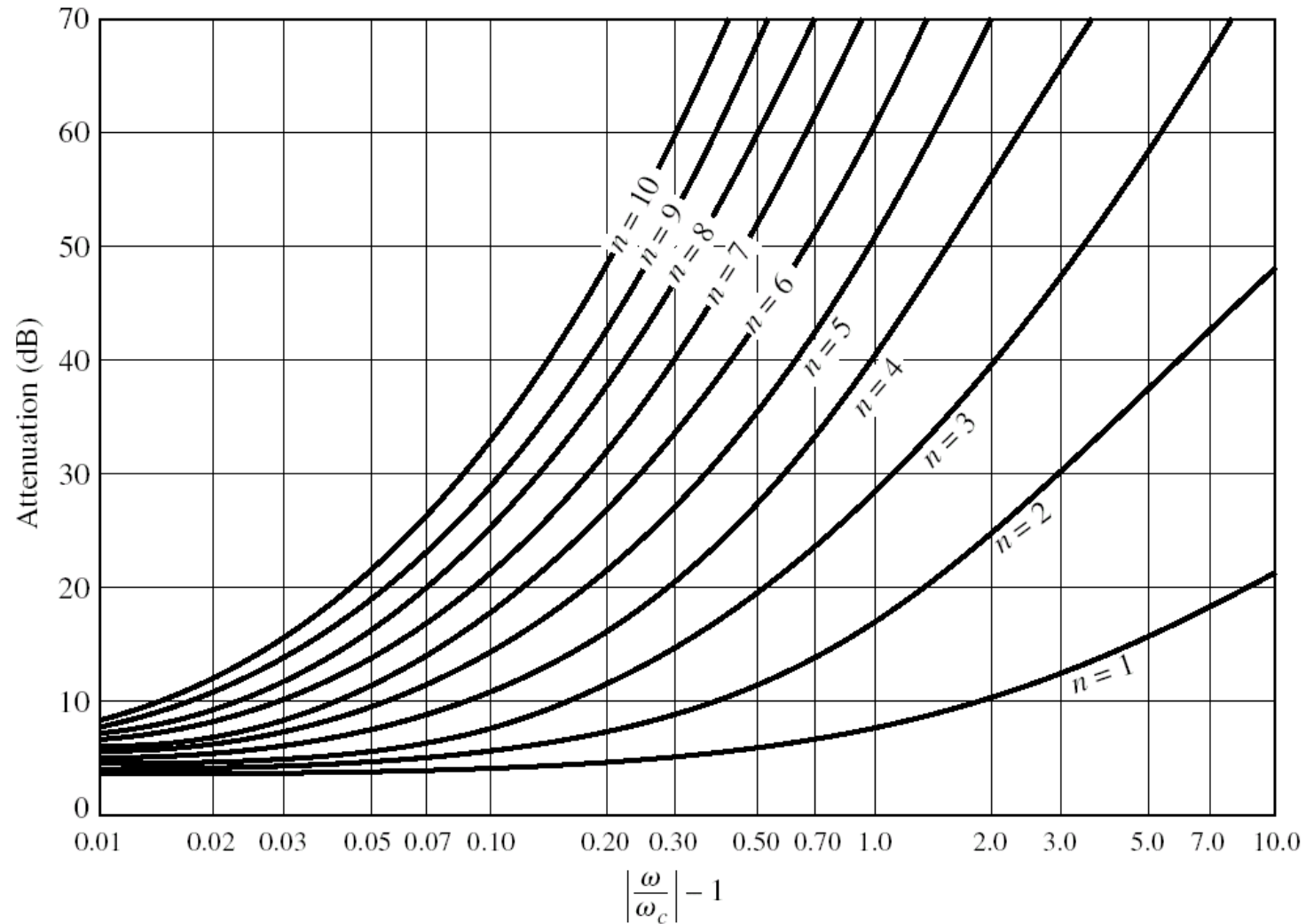
■ cu atenuările in **dB**



# Raspunsul filtrului maxim plat

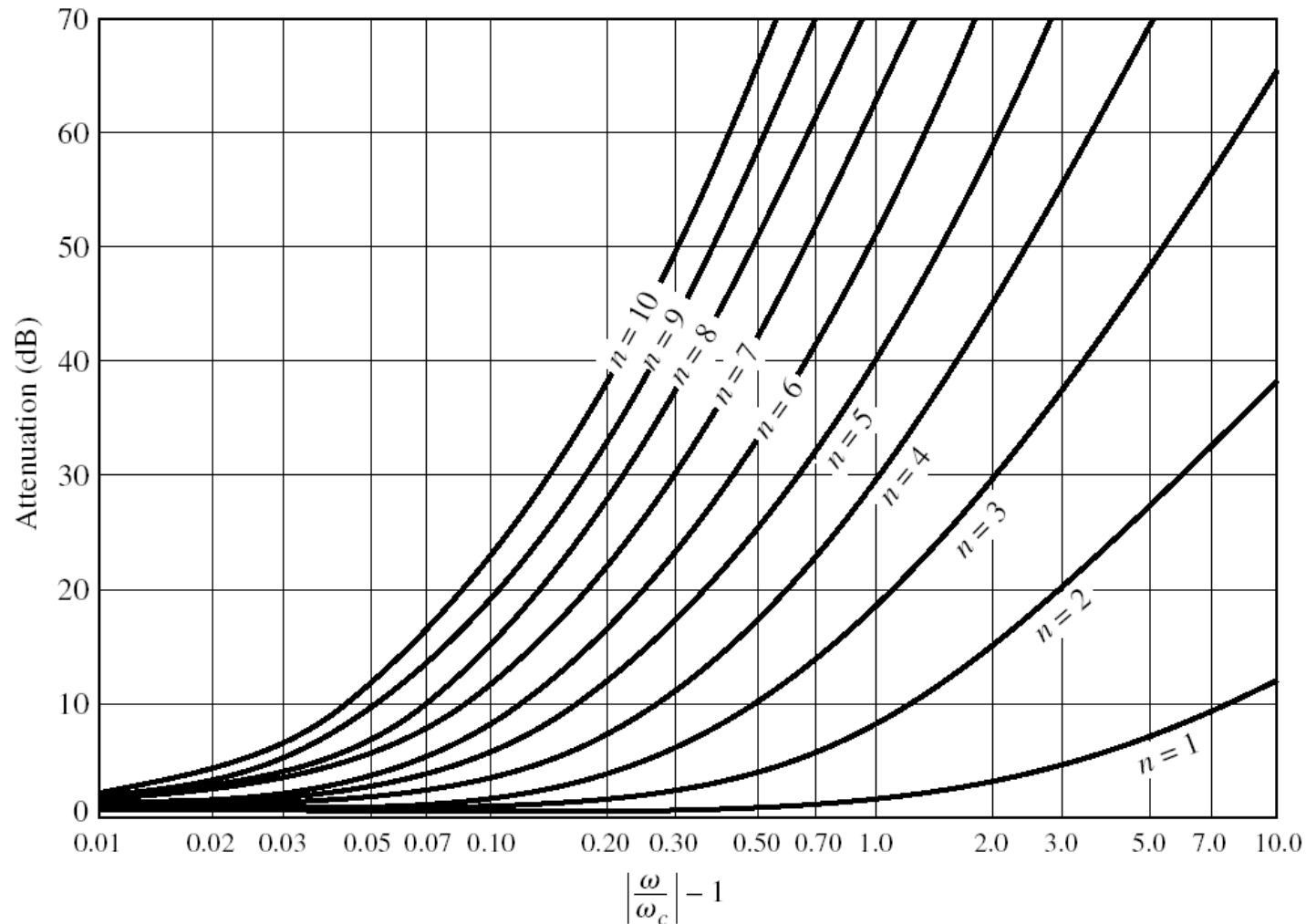


# Raspunsul filtrului echiriplu 3 dB



(b)

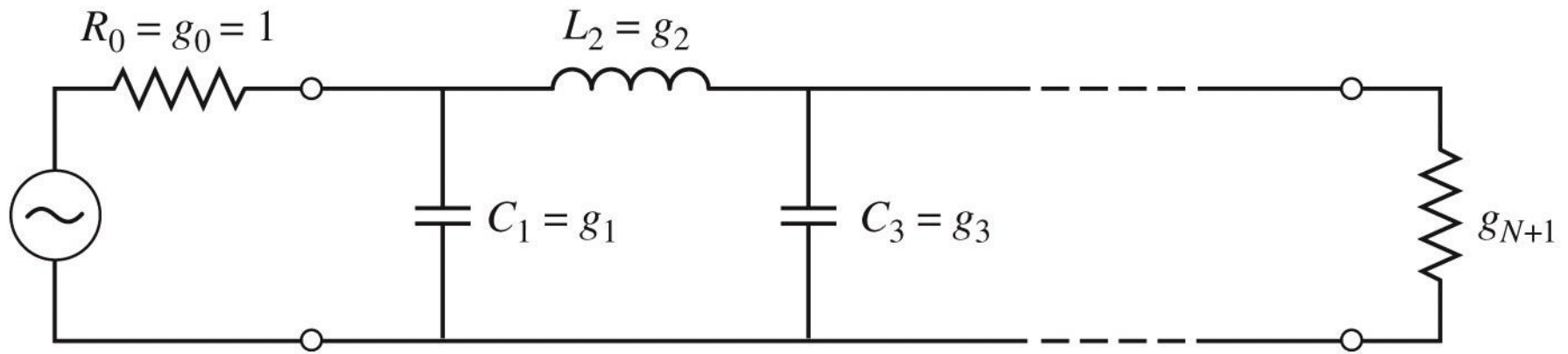
# Raspunsul filtrului echiriplu 0.5 dB



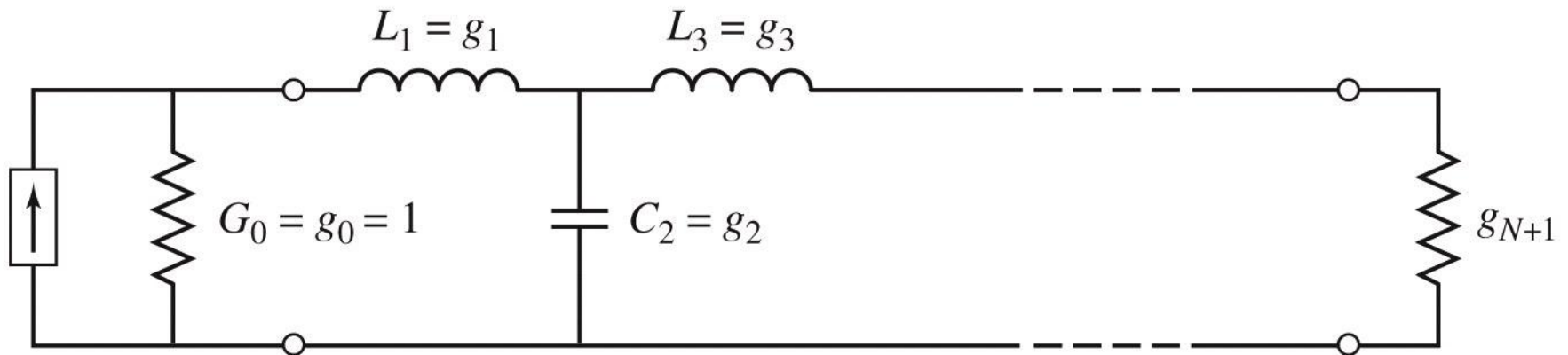
(a)



# 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

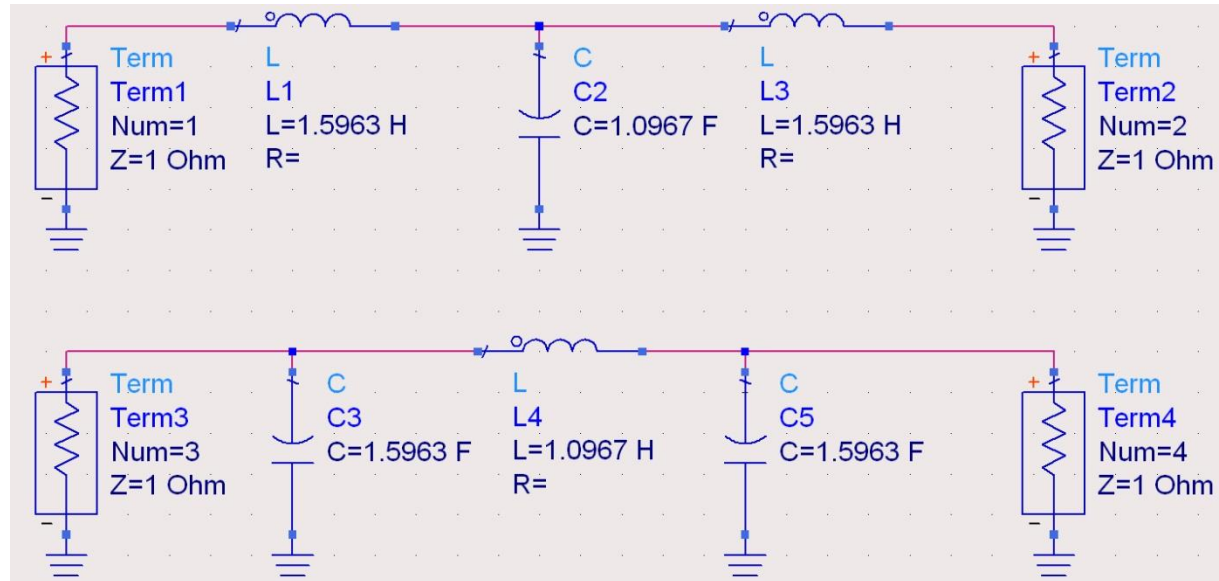
- Să se proiecteze un filtru ~~trece-bandă~~ **de ordinul 3**, având **riplurile** în bandă **de 0.5 dB**.  
~~Frecvența centrală a filtrului să fie de 1 GHz.~~  
~~Banda să fie de 10%, și impedanța de 50  $\Omega$ .~~



# Filtru prototip

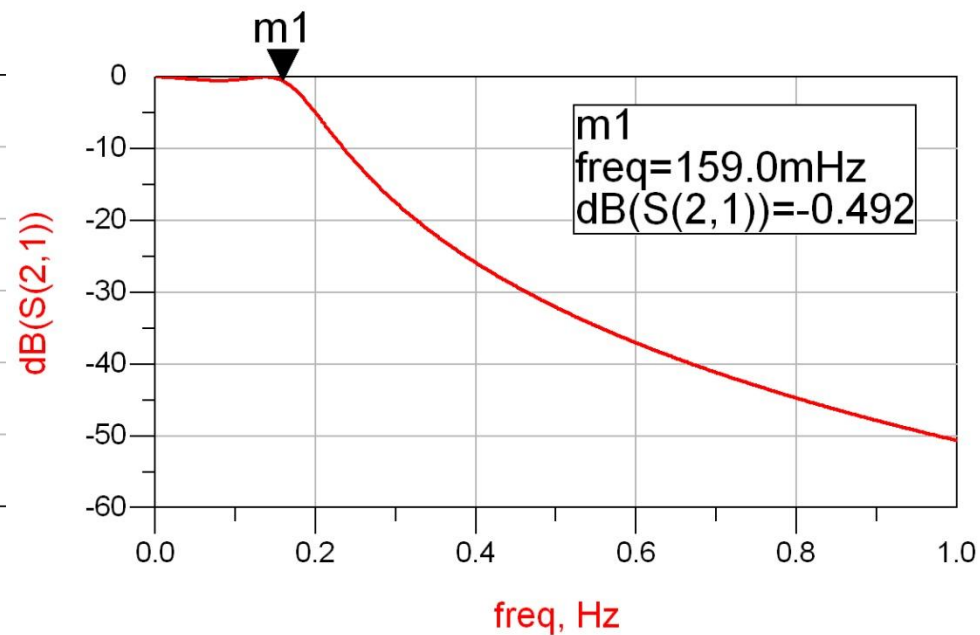
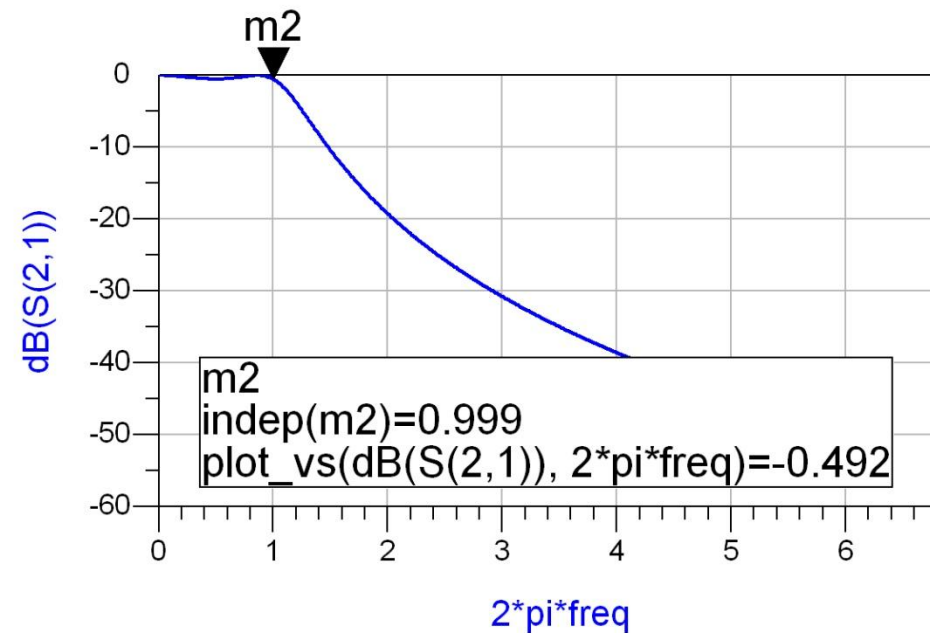
- Tabel echiriplu 0.5dB sau relatii de calcul:

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



# 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  $R = 1$

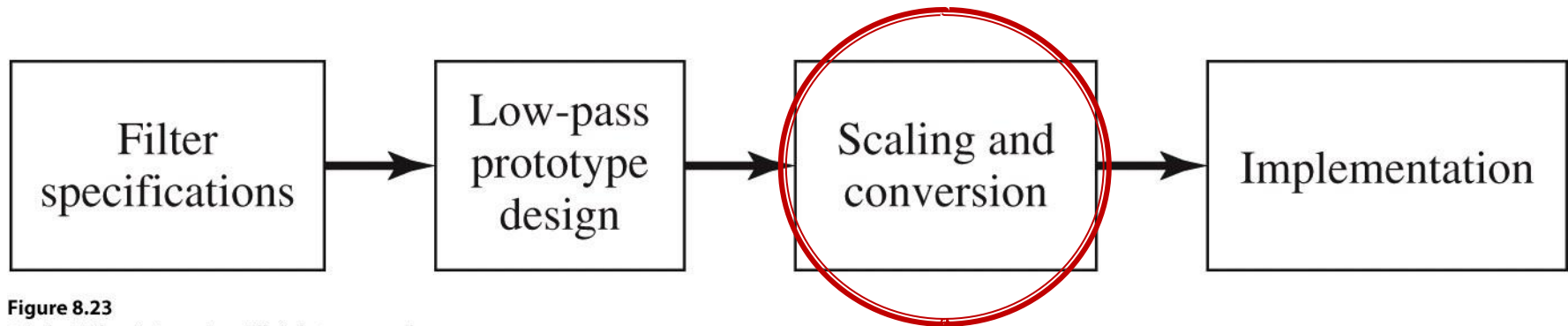


Figure 8.23

# 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)

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

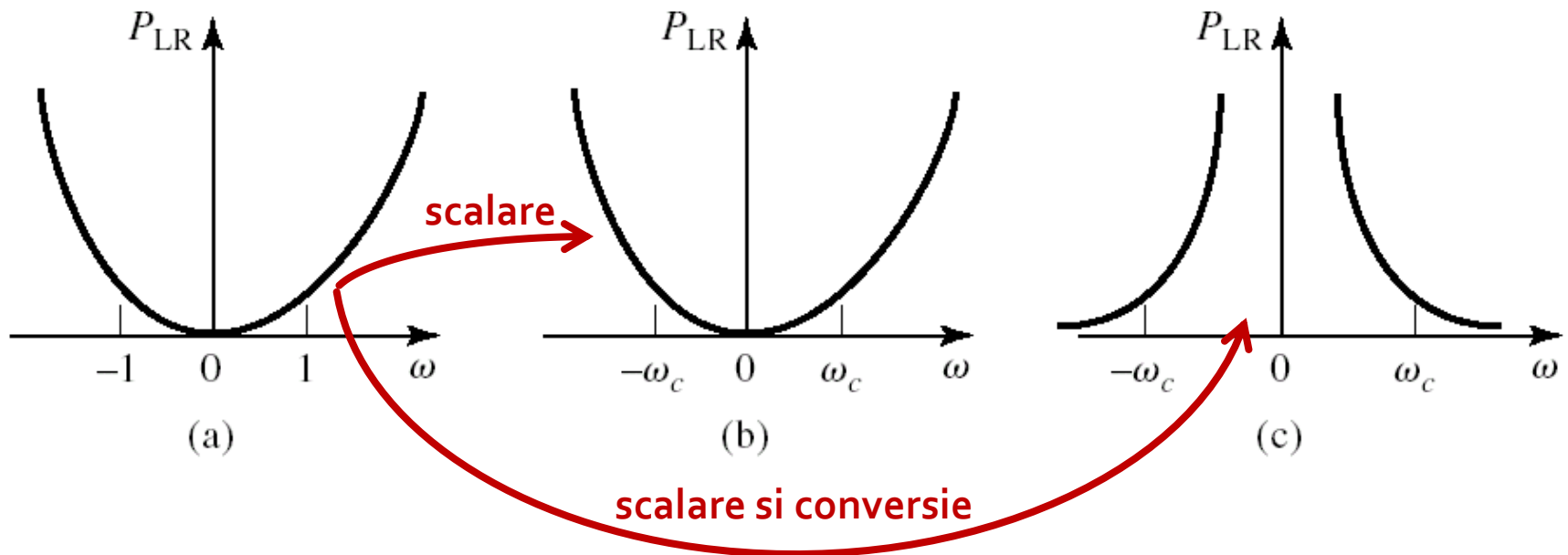
$$R'_L = R_0 \cdot R_L$$

$$L' = R_0 \cdot L$$

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

# Scalarea in frecventa

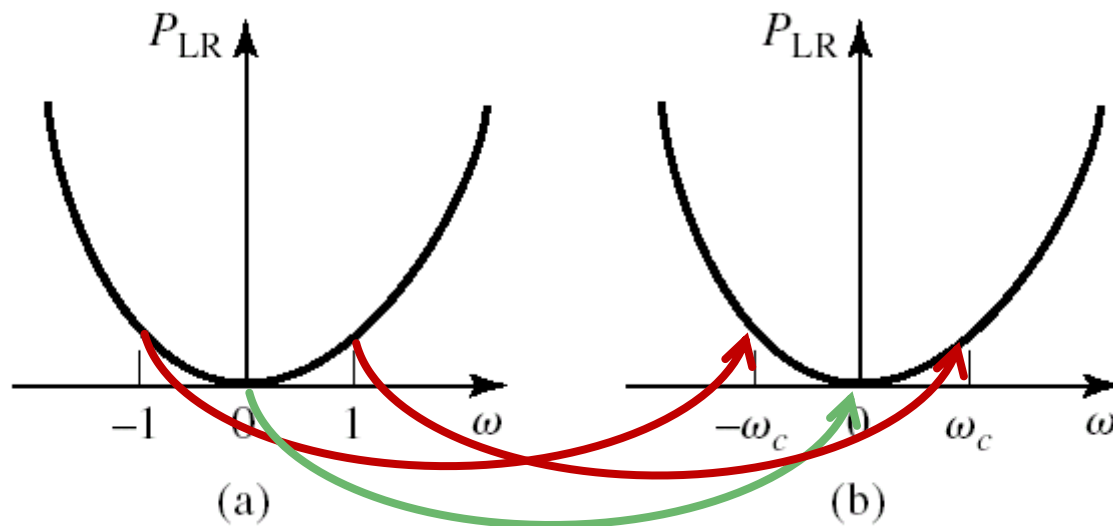
- modificarea frecventei de taiere – (fig. b)
- modificarea caracteristicii de atenuare (de exemplu FTJ  $\rightarrow$  FTS – fig. c)



# 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

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

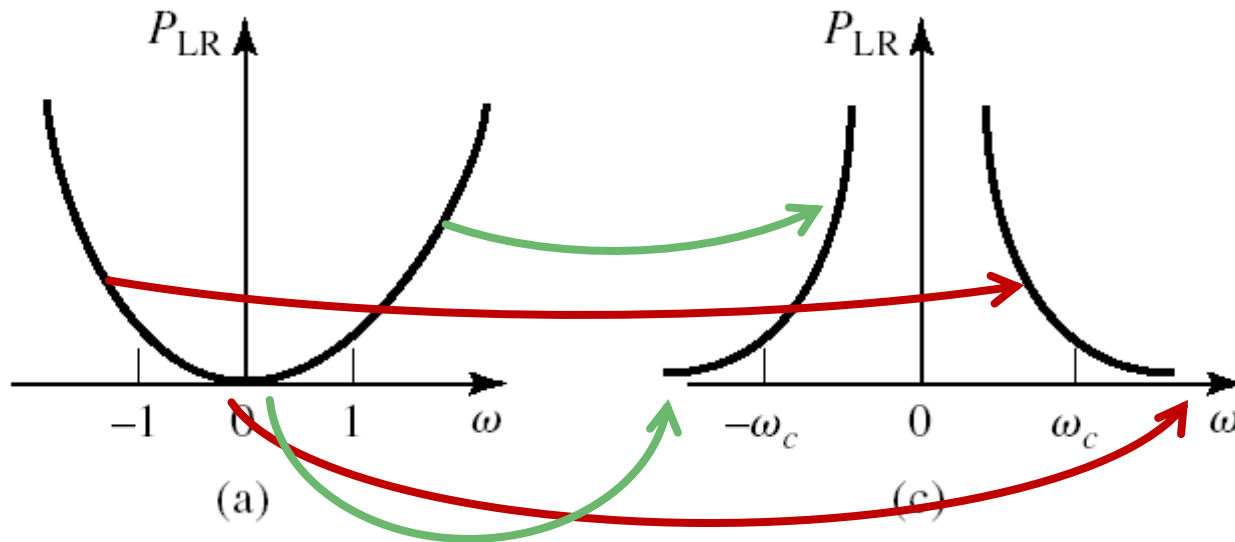
- Daca se aplica simultan si scalarea in impedanta

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

# 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 → FTB

- Se face schimbarea de variabila:

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

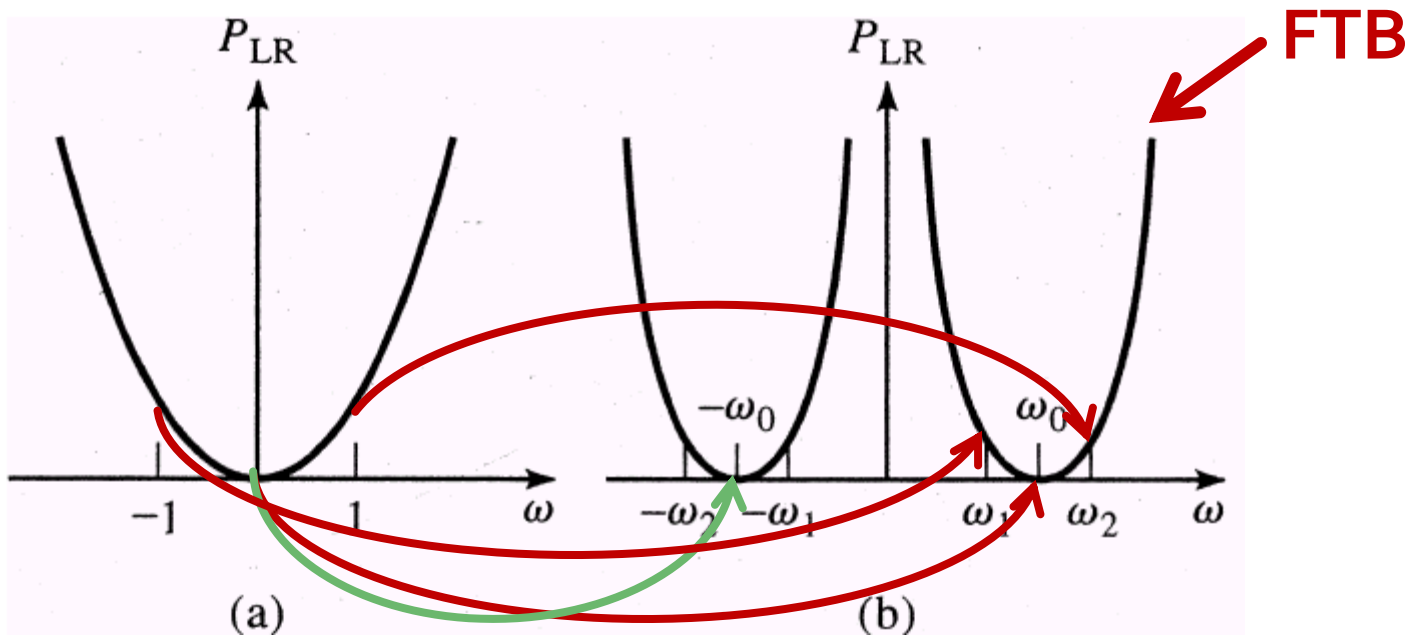
- unde intervin banda fractionara si frecventa centrala

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

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

# 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**

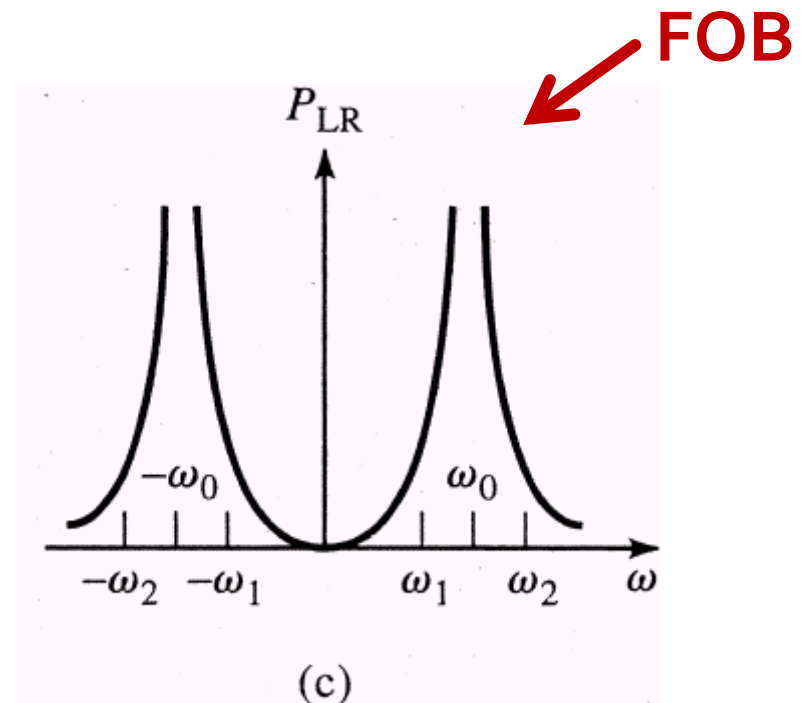
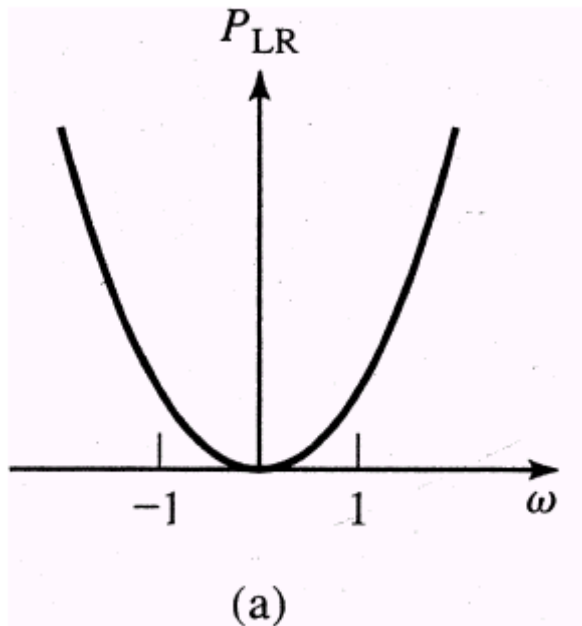
$$L'_k = \frac{L_k}{\Delta \cdot \omega_0} \quad C'_k = \frac{\Delta}{\omega_0 \cdot L_k}$$

- 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


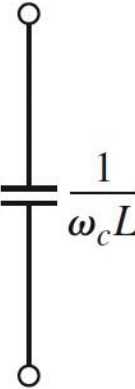
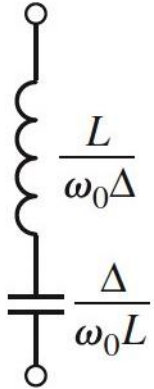
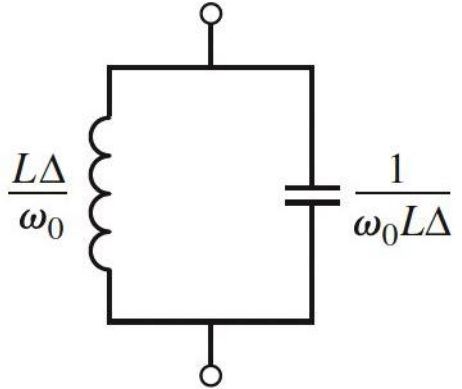
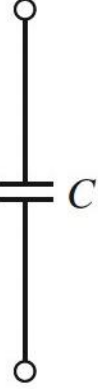
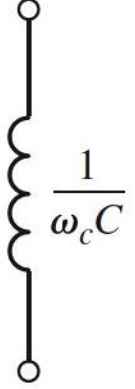
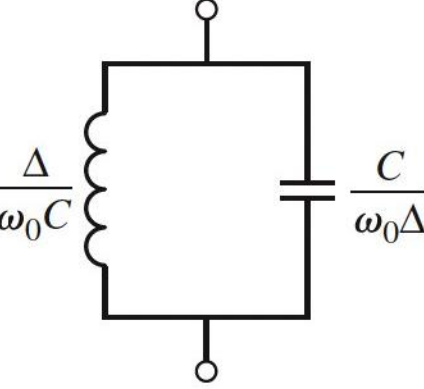
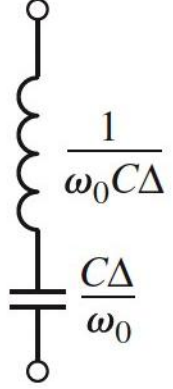
Low-pass	High-pass	Bandpass	Bandstop
			
			

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  $\Omega$ .

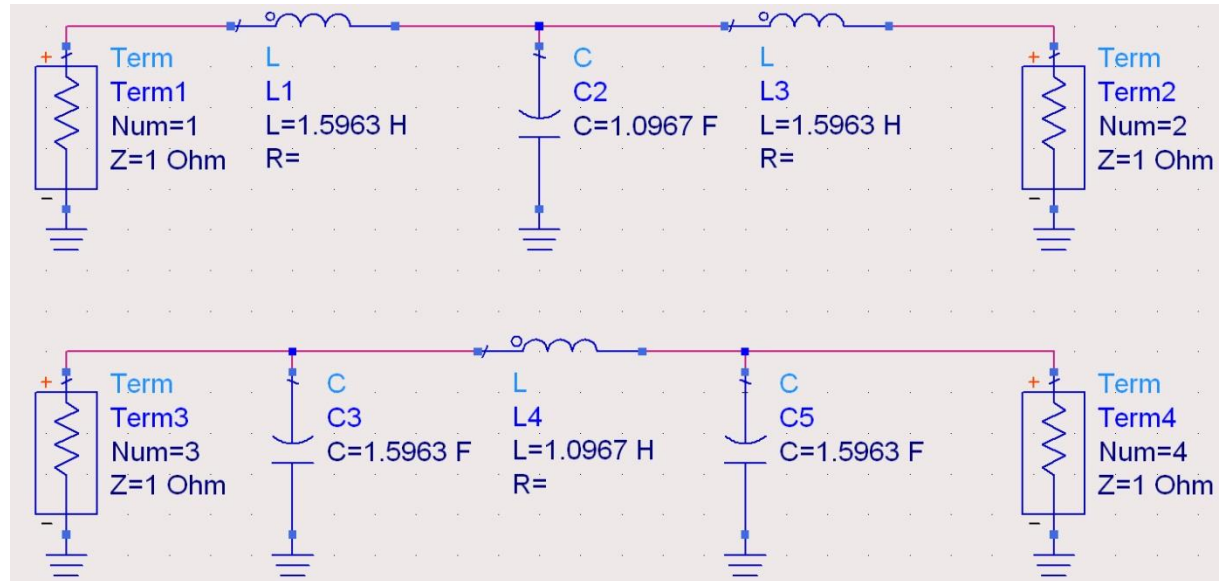
$$\omega_0 = 2 \cdot \pi \cdot 1 \text{ GHz} = 6.283 \cdot 10^9 \text{ rad} / \text{s}$$

$$\Delta = 0.1$$

# Filtru prototip

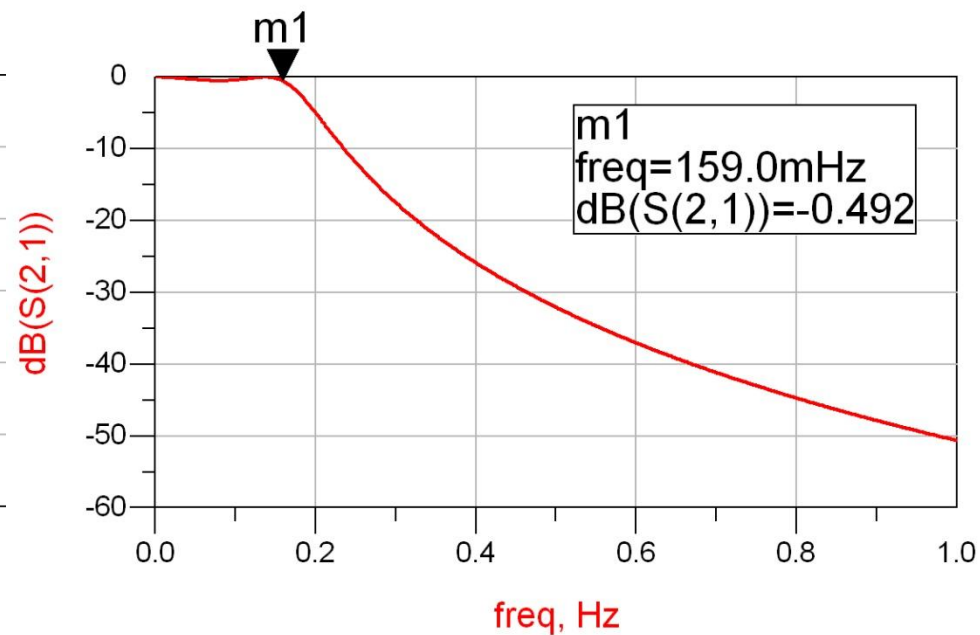
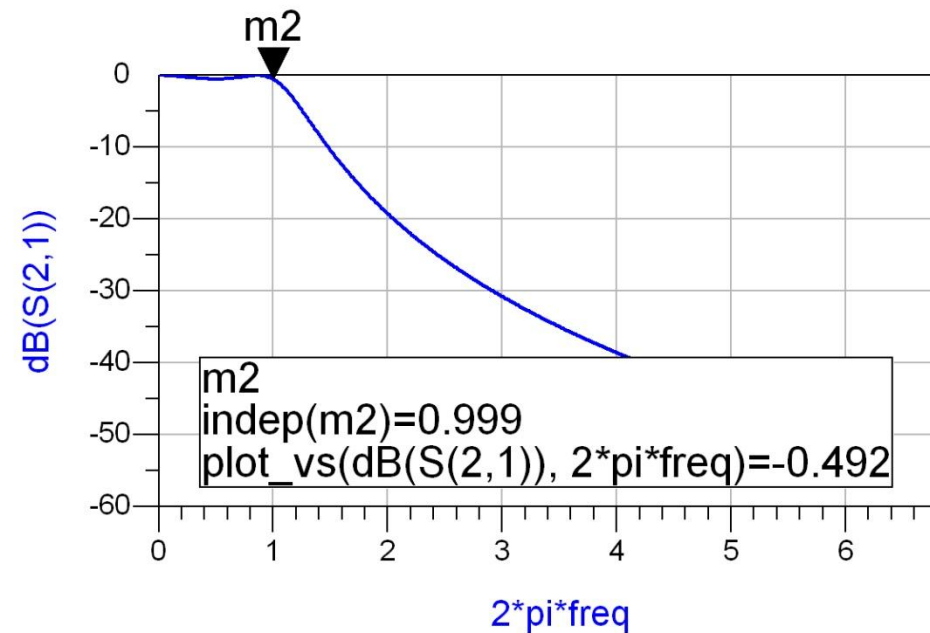
- Tabel echiriplu 0.5dB sau relatii de calcul:

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



# Filtru prototip

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



# Scalare frecventa / FTB

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

$$g_1 = 1.5963 = L_1,$$

$$g_2 = 1.0967 = C_2,$$

$$g_3 = 1.5963 = L_3,$$

$$g_4 = 1.000 = R_L$$

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

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

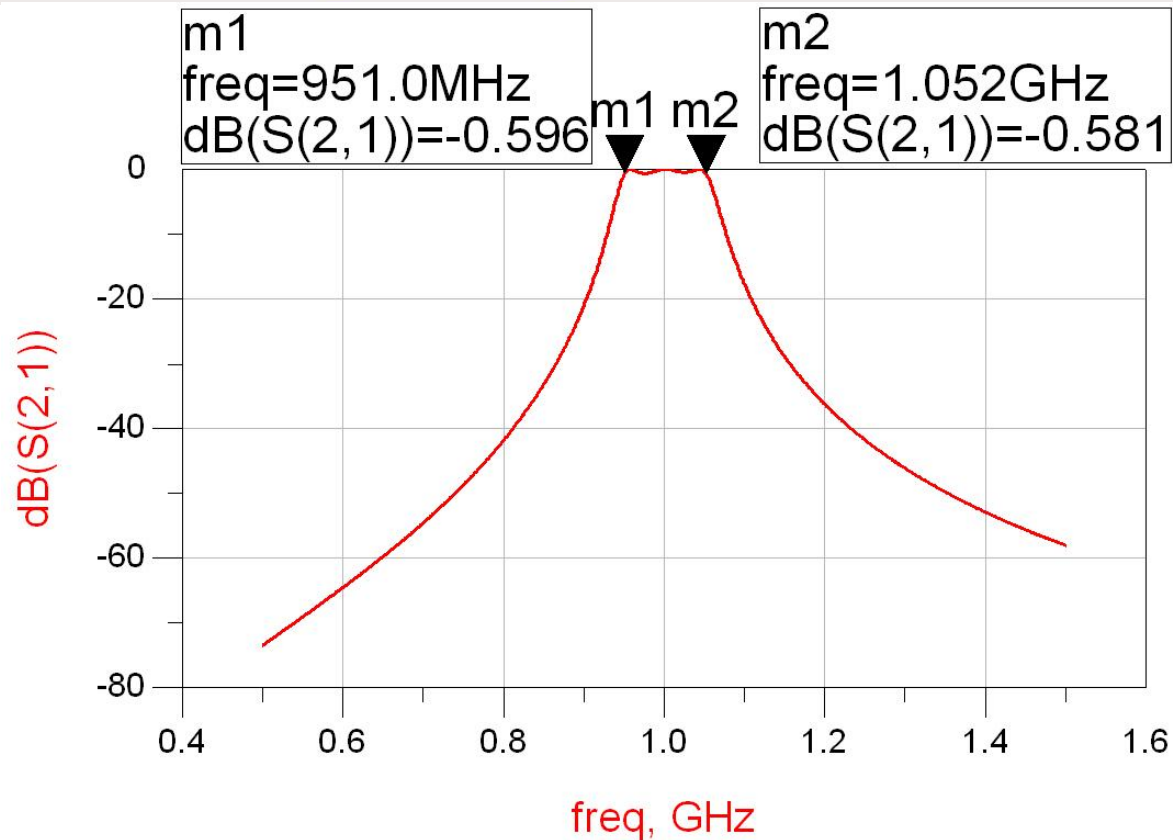
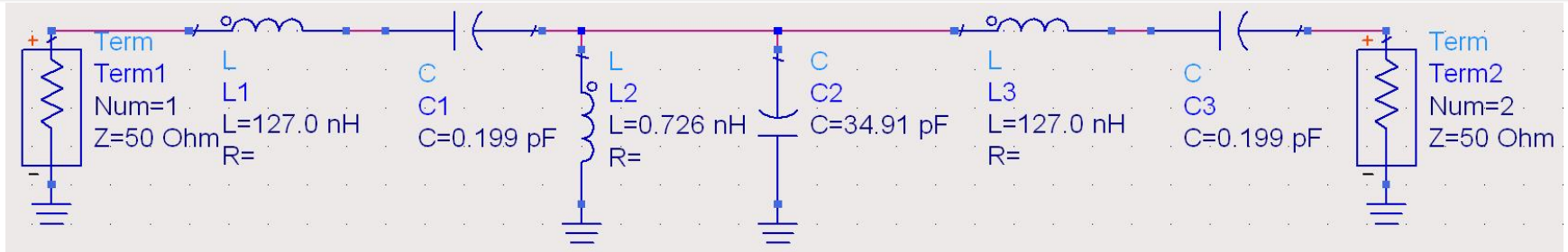
$$L'_2 = \frac{\Delta \cdot R_0}{\omega_0 \cdot C_2} = 0.726 \text{ nH}$$

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

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

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

# 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

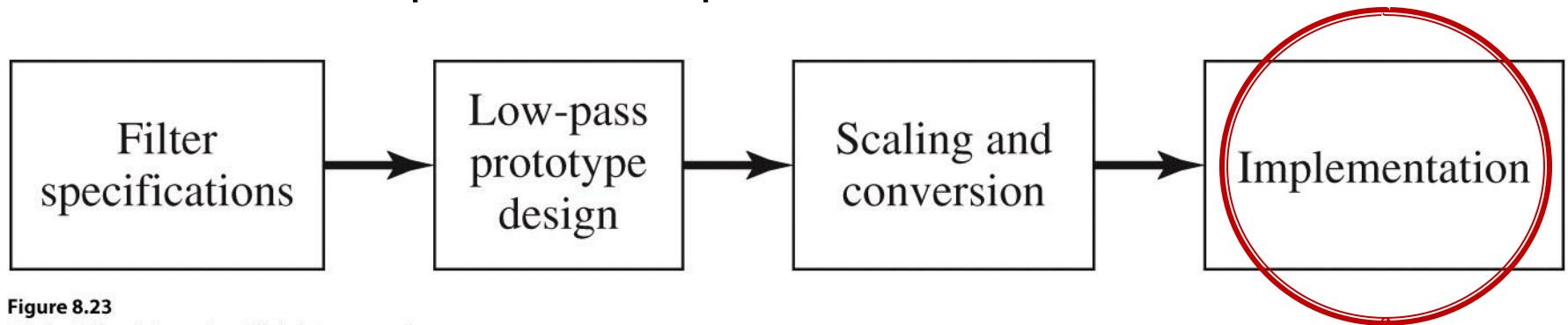


Figure 8.23



# 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  $\Omega$  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 ( $\omega_c$ ) si impedantele caracteristice corespunzatoare ( $L/C$ ) vom obtine foarte precis la frecvente in jurul lui  $\omega_c$  o comportare similara cu a filtrului prototip
  - La frecvente departate de  $\omega_c$  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  $4 \cdot \omega_c$

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

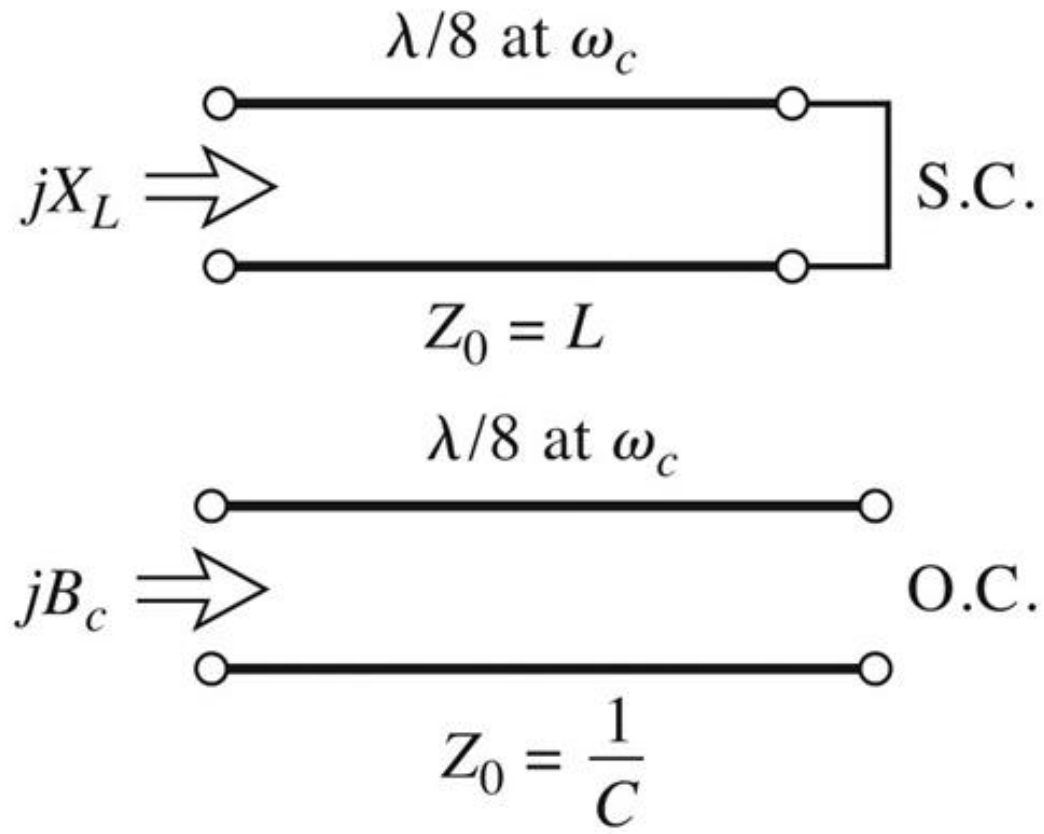
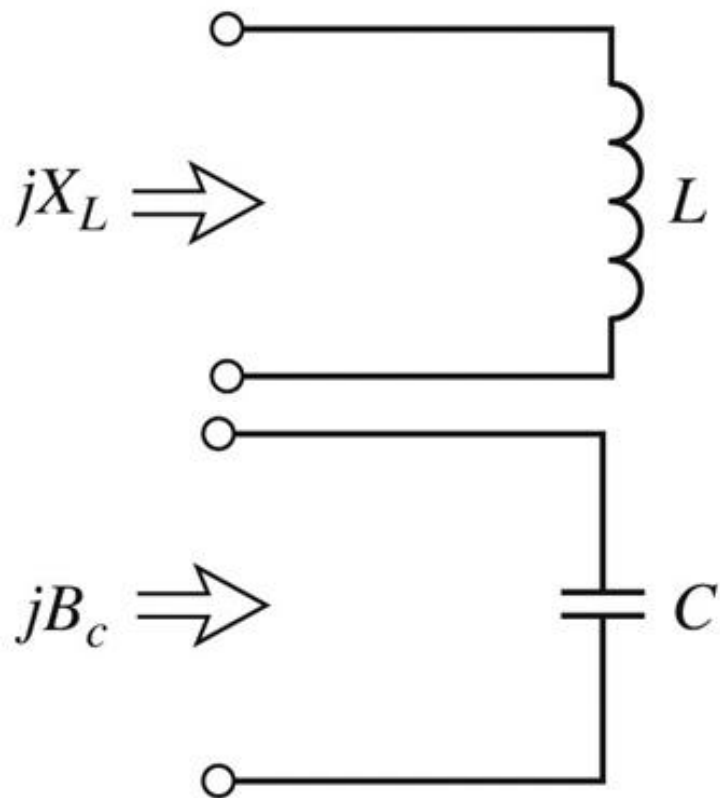
$$\beta \cdot l \Big|_{\omega=\omega_c} = \frac{\pi}{4} \Rightarrow \frac{\omega_c \cdot l}{v_p} = \frac{\pi}{4} \Rightarrow \pi = \frac{(4 \cdot \omega_c) \cdot l}{v_p}$$

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

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

# Transformarea Richards

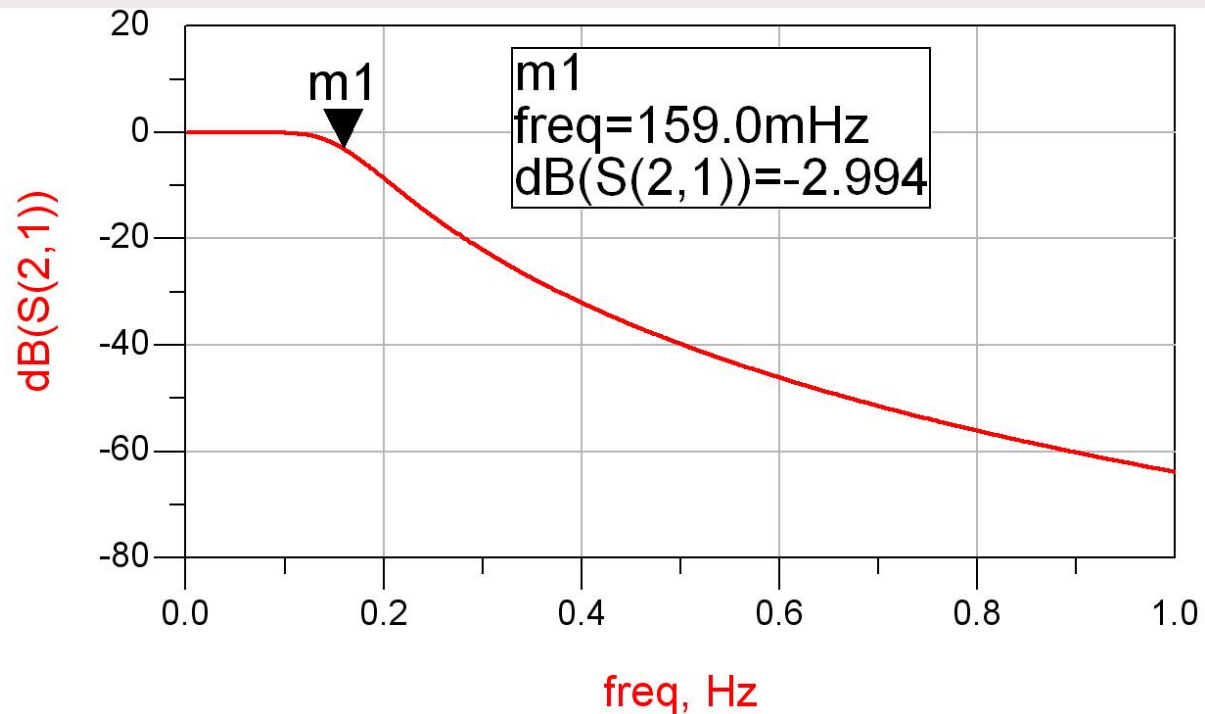
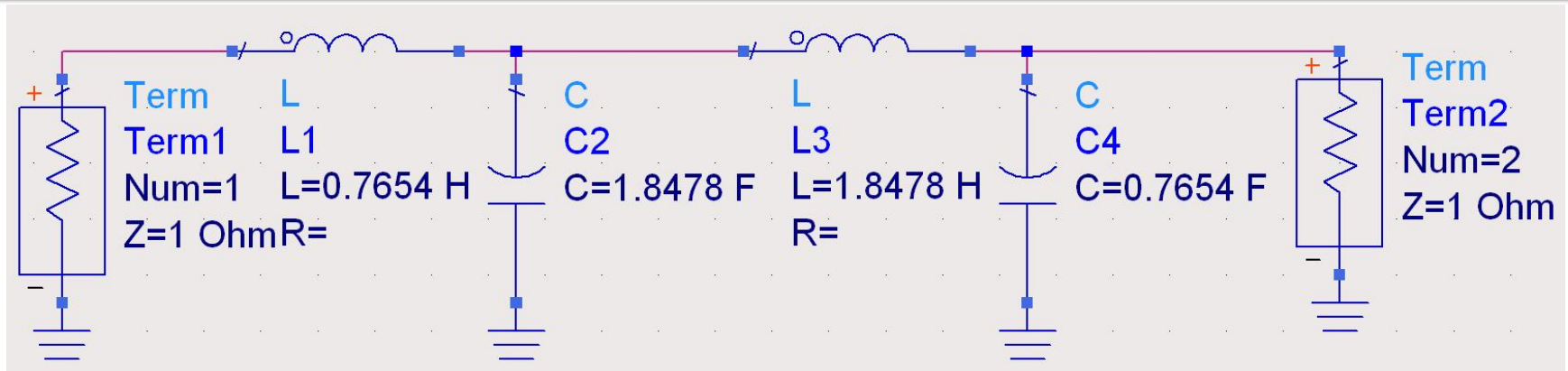
- permite obtinerea cu sectiuni de linii a inductantelor si capacitatilor **dupa** scalarea prototipului pentru functia corespunzatoare (FTJ/FTS/FTB /FOB)



# Exemplu

- Filtru trece jos de ordinul 4, cu frecventa de taiere de 4 GHz, de tip maxim plat (care sa functioneze pe  $50\Omega$  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

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

$$g_1 = 0.7654 = L_1,$$

$$g_2 = 1.8478 = C_2,$$

$$g_3 = 1.8478 = L_3,$$

$$g_4 = 0.7654 = C_4,$$

$$g_5 = 1 = RL$$

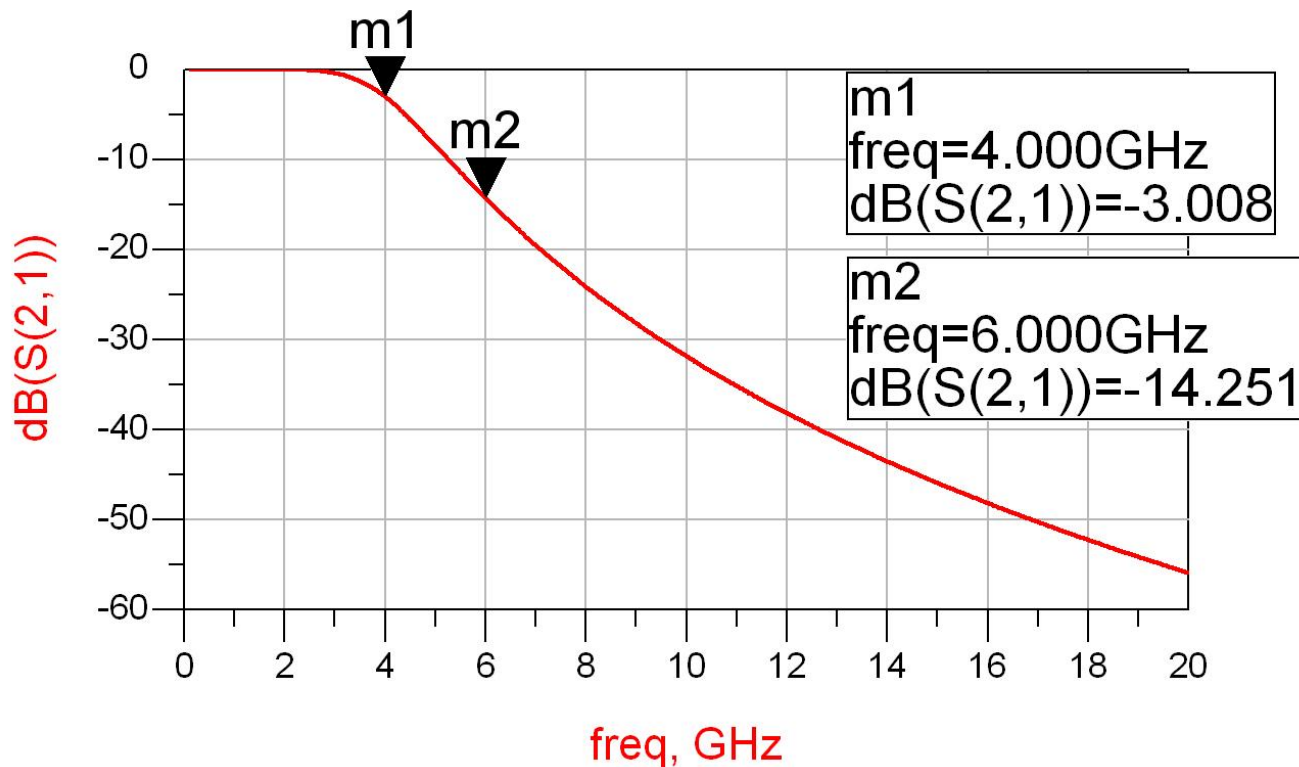
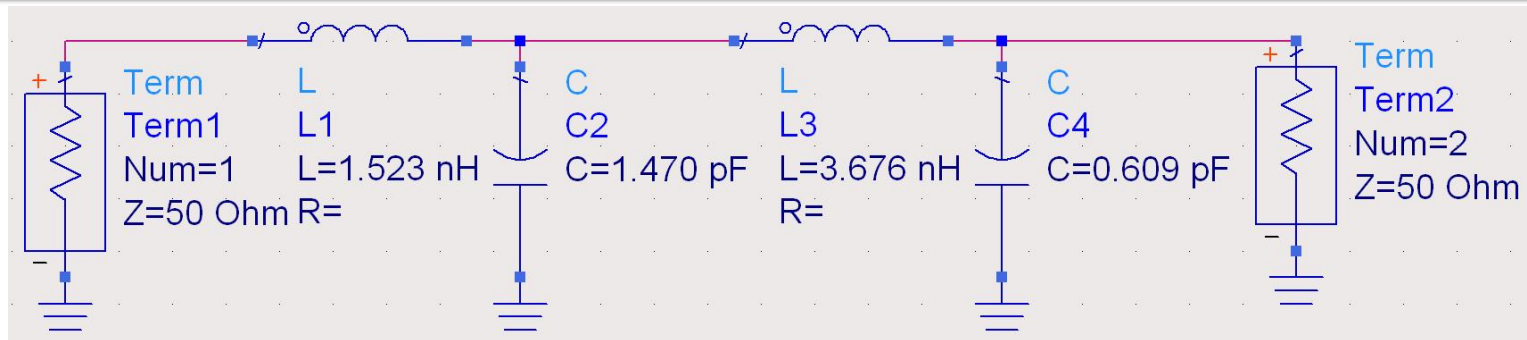
$$L'_1 = \frac{R_0 \cdot L_1}{\omega_c} = 1.523 \text{ nH}$$

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

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

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

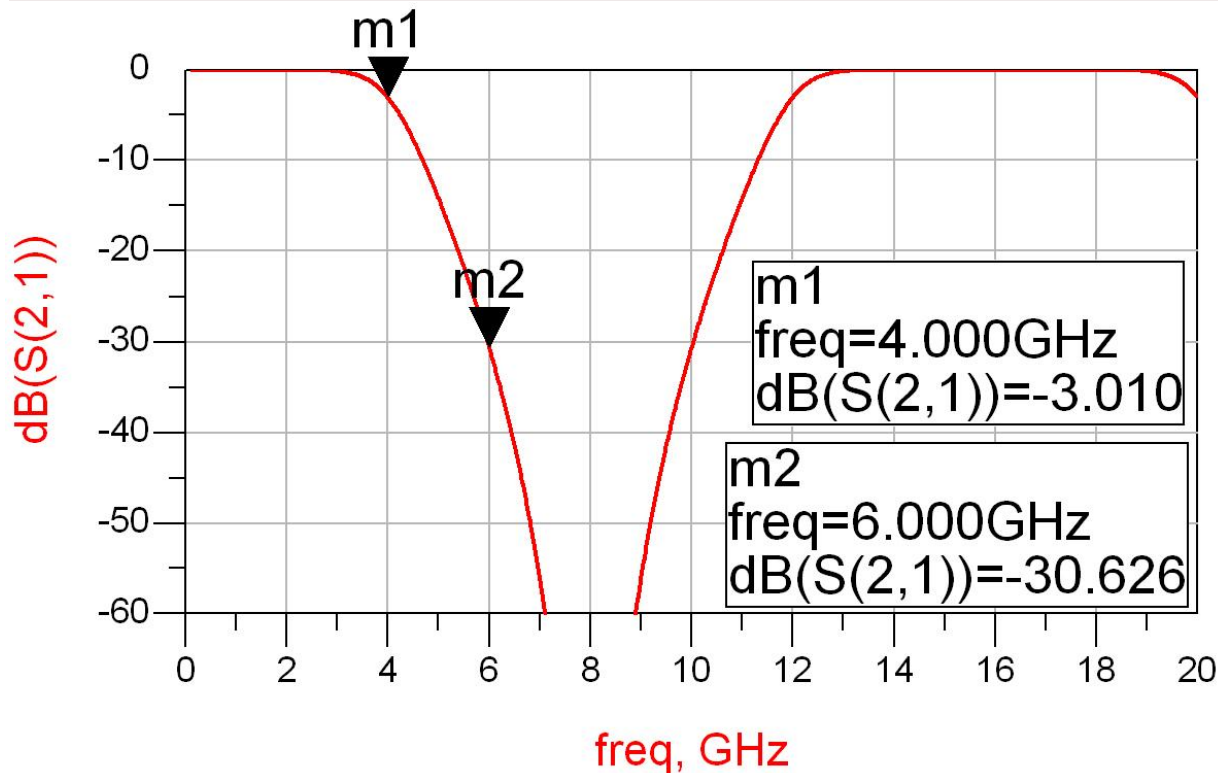
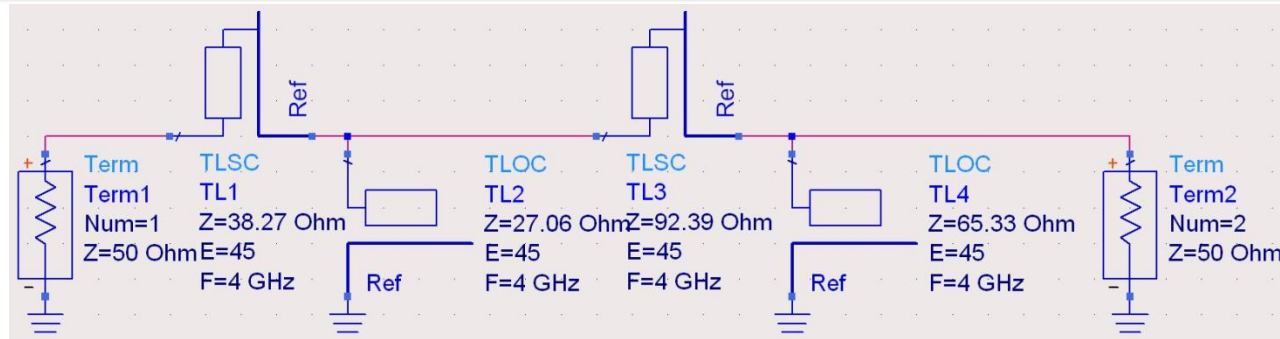
# Elemente concentrate – ADS



# Transformarea Richards

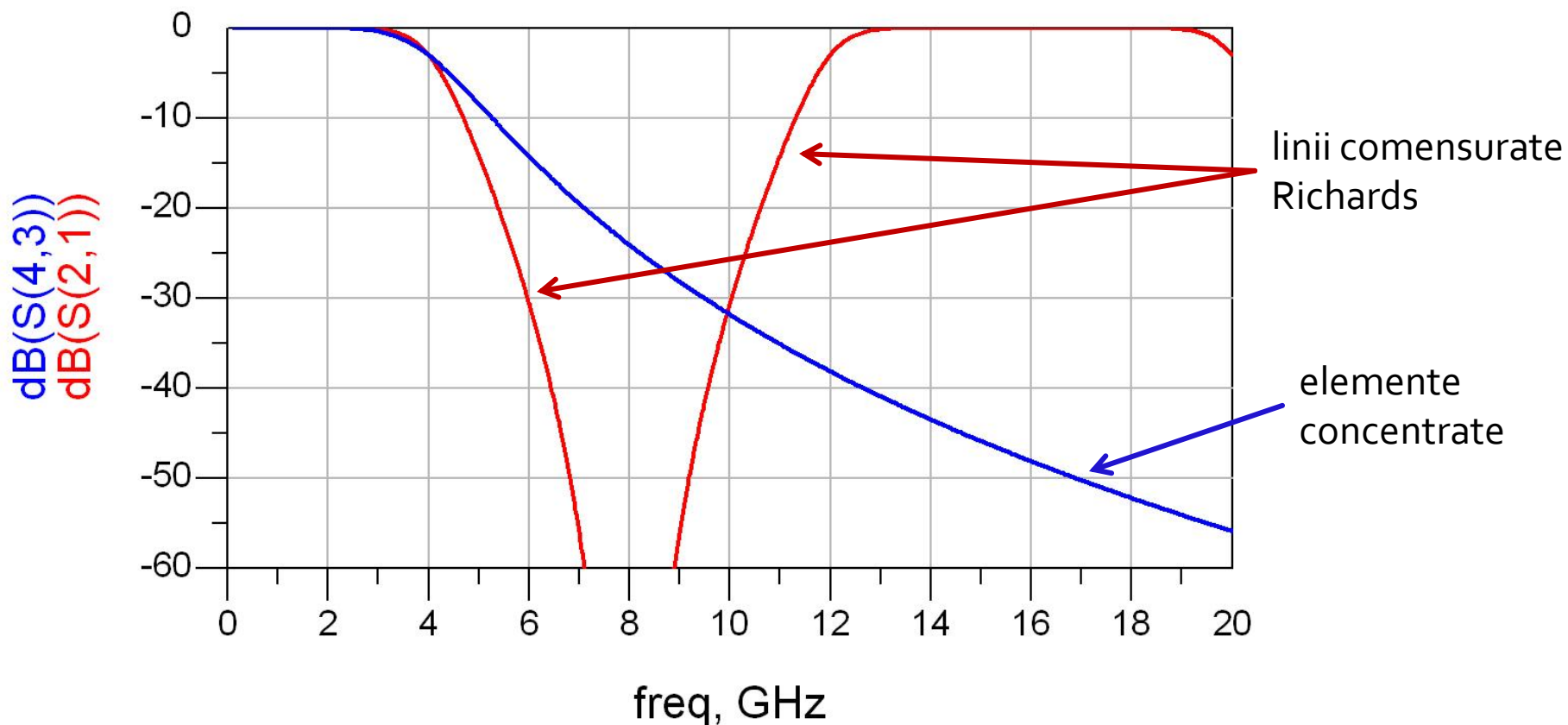
- Parametrii filtrului prototip:
  - $g_1 = 0.7654 = L_1$
  - $g_2 = 1.8478 = C_2$
  - $g_3 = 1.8478 = L_3$
  - $g_4 = 0.7654 = C_4$
- Impedantele raportate ale liniilor
  - $z_1 = 0.7654 = \text{serie / scurt circuit}$
  - $z_2 = 1 / 1.8478 = 0.5412 = \text{paralel / gol}$
  - $z_3 = 1.8478 = \text{serie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

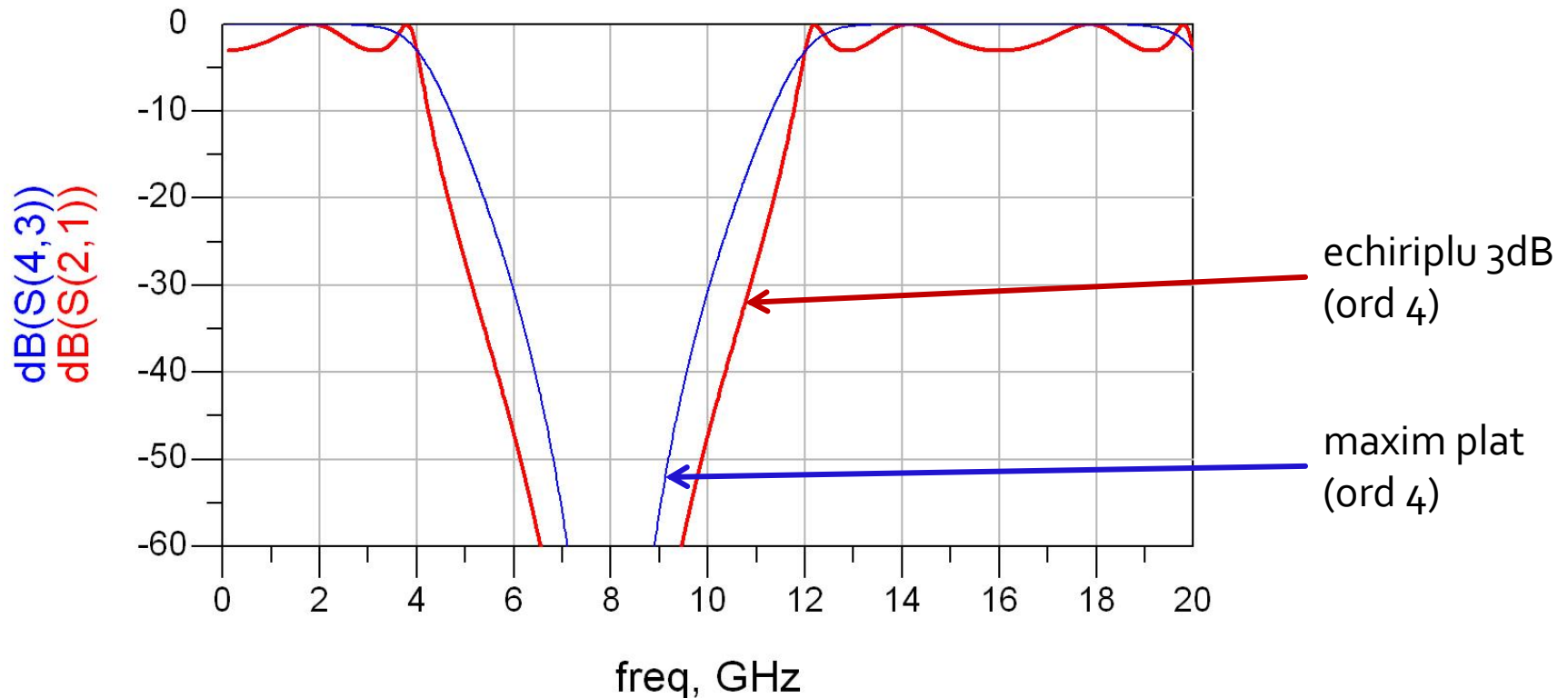
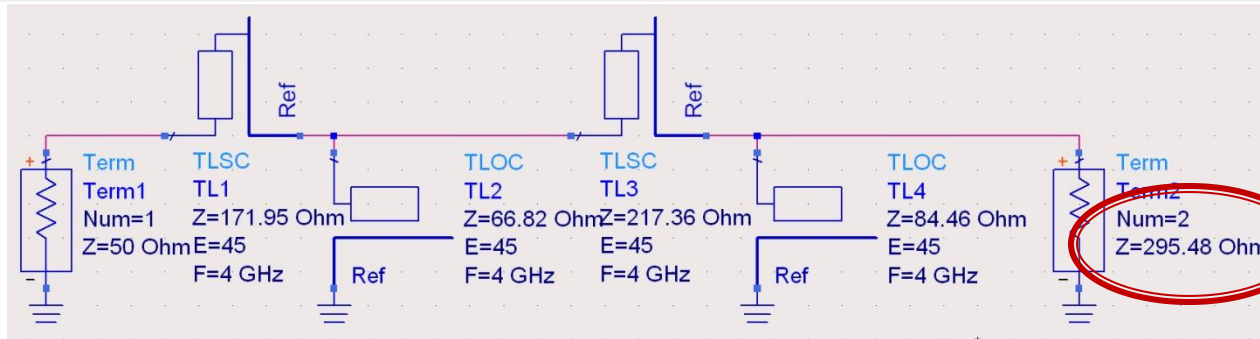
- Pentru ordin par al filtrului ( $N = 2, 4, 6, 8 \dots$ ) filtrele echiriplu **trebuie** sa fie inchise pe o impedanta de terminatie diferita de cea standard
- Daca aplicatia nu suporta aceasta comportare, e necesara introducerea unei adaptari de impedanta suplimentare (transformator in sfert de lungime 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
  - $Z_1 = 3.4389 \cdot 50\Omega = 171.945\Omega = \text{serie / scurt circuit}$
  - $Z_2 = 50\Omega / 0.7483 = 66.818\Omega = \text{paralel / gol}$
  - $Z_3 = 4.3471 \cdot 50\Omega = 217.355\Omega = \text{serie / scurt circuit}$
  - $Z_4 = 50\Omega / 0.5920 = 84.459\Omega = \text{paralel / gol}$
  - $R_L = 5.8095 \cdot 50\Omega = 295.475\Omega = \text{sarcina}$

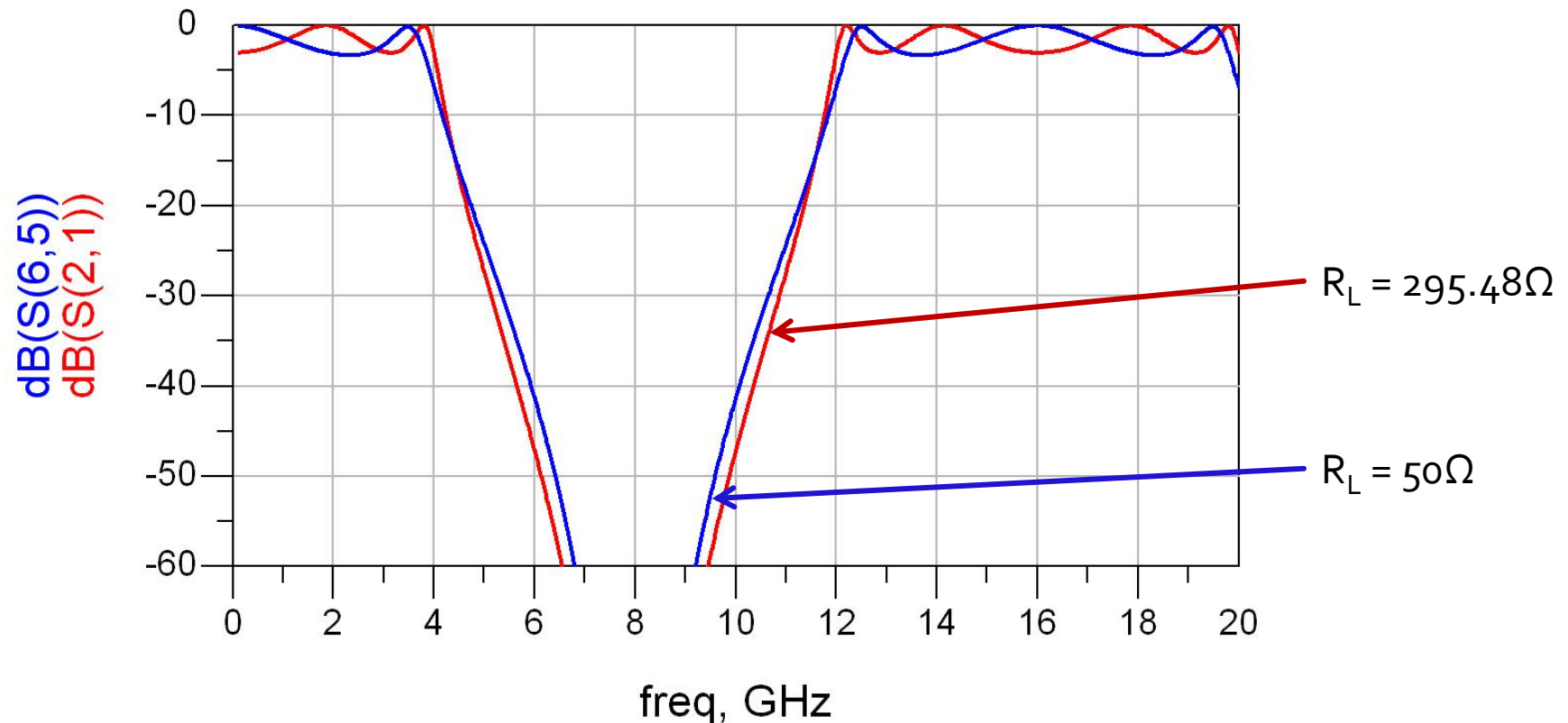
# Ordin par/echiriplu – ADS





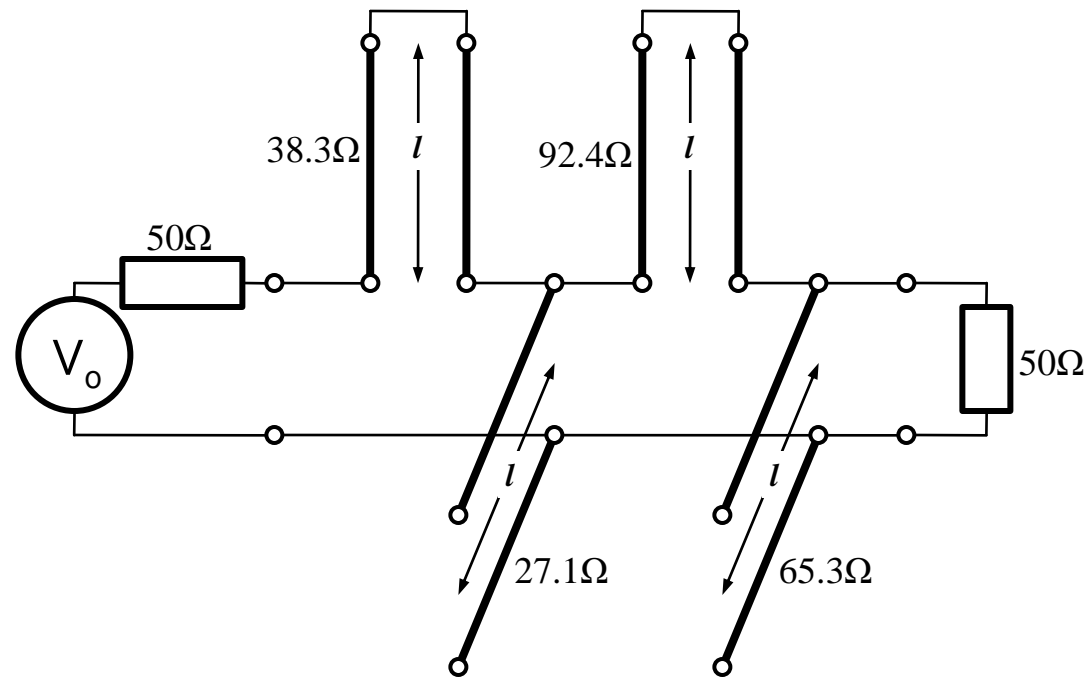
# Observatie: ordin par/echiriplu

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



# Identitatile Kuroda

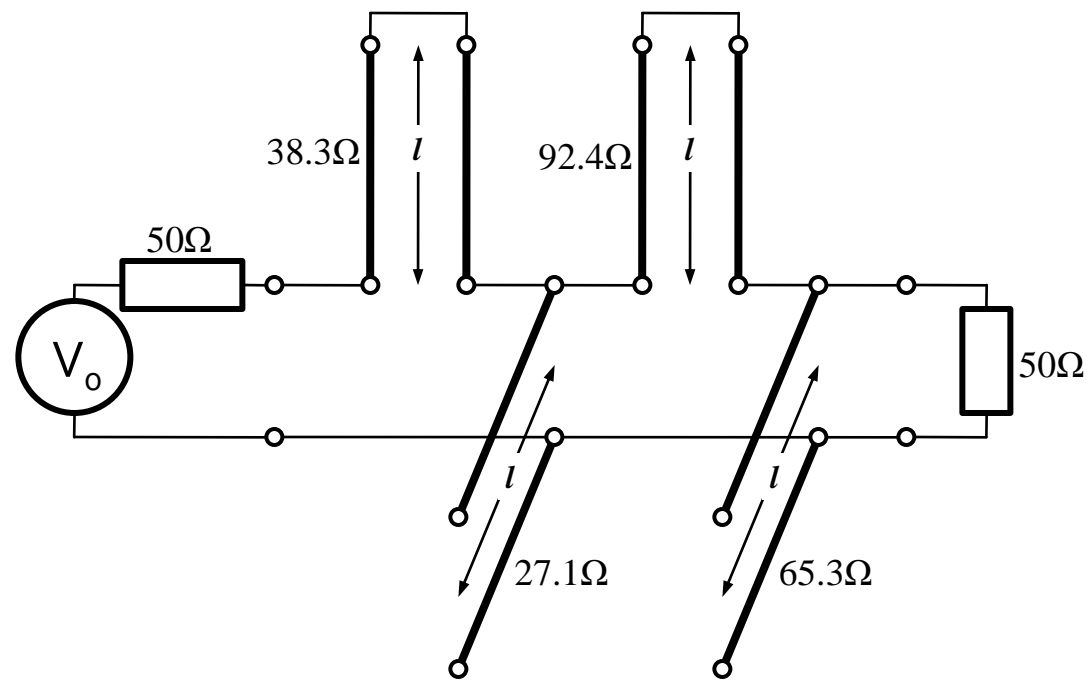
- Filtre implementate cu transformarea Richards au anumite dezavantaje in ceea ce priveste implementarea practica
- Identitatile/Transformarile Kuroda pot fi utilizate pentru a elimina o parte din aceste dezavantaje
- Se utilizeaza sectiuni de linie suplimentare pentru a obtine sisteme mai simplu de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



# Identitatile Kuroda

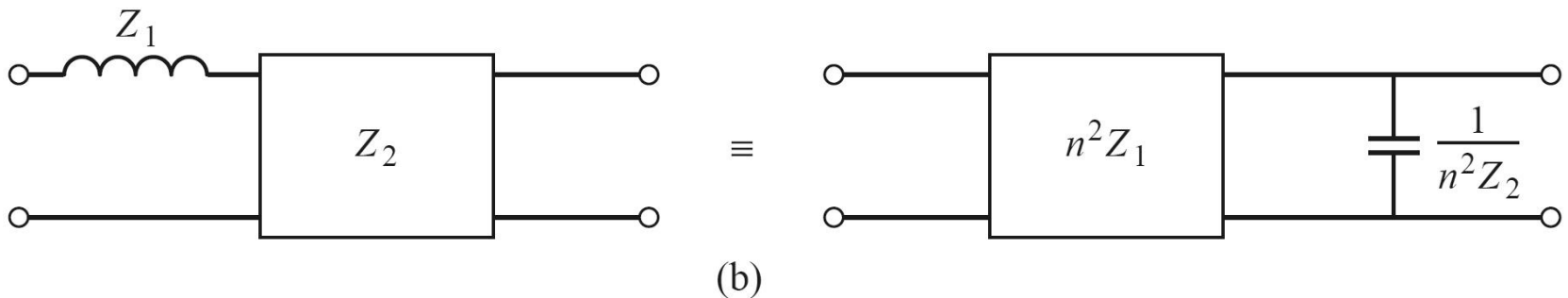
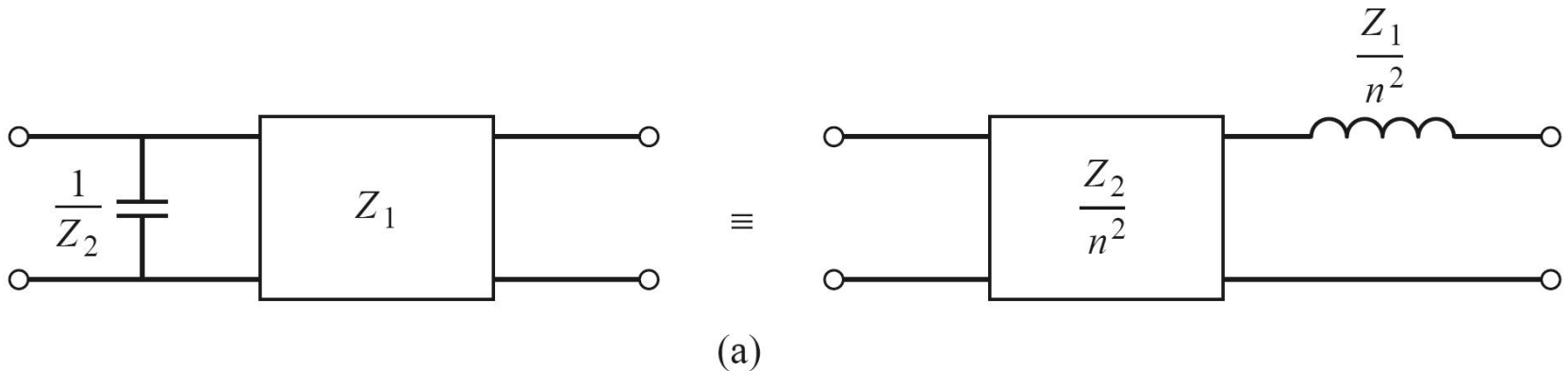
- Identitatile Kuroda pot fi utilizate pentru a realiza urmatoarele operatii:

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



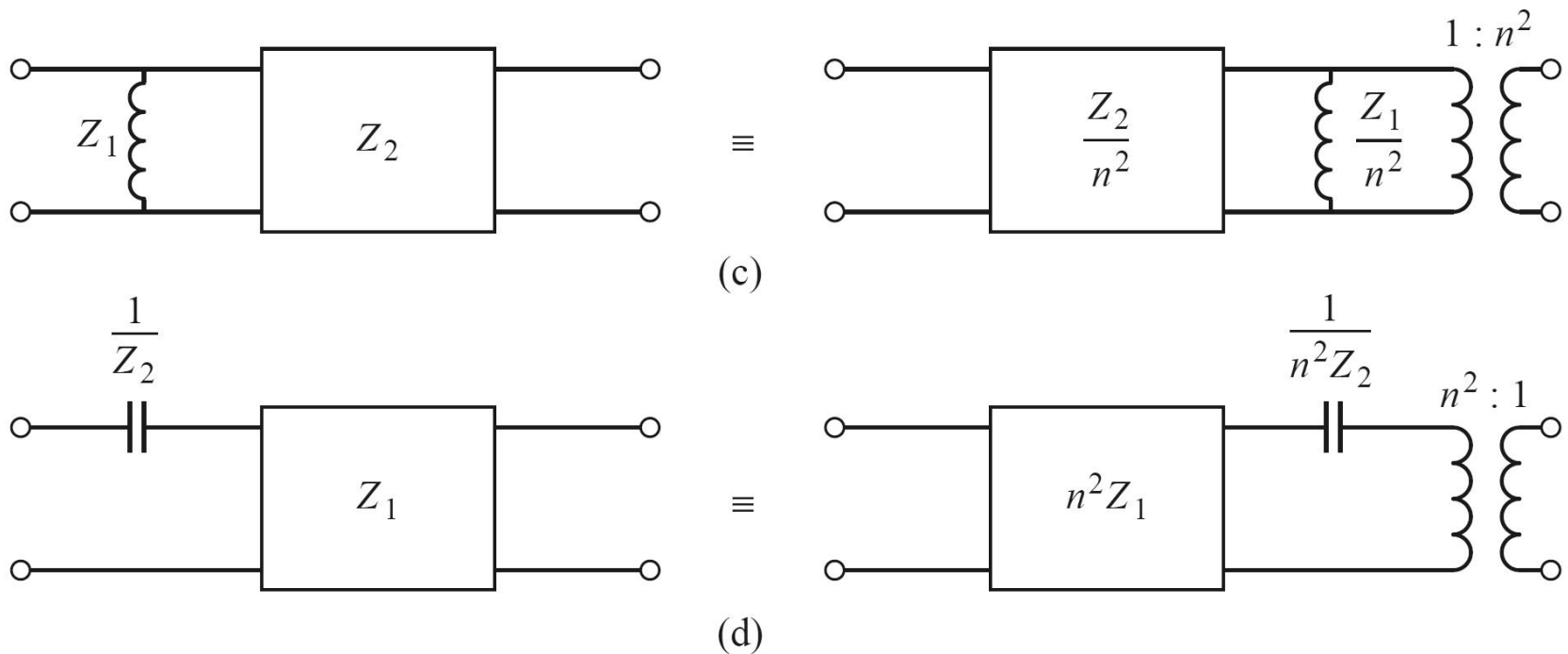
# Identitatile Kuroda

- 4 echivalente de circuit (a,b)



# Identitățile 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

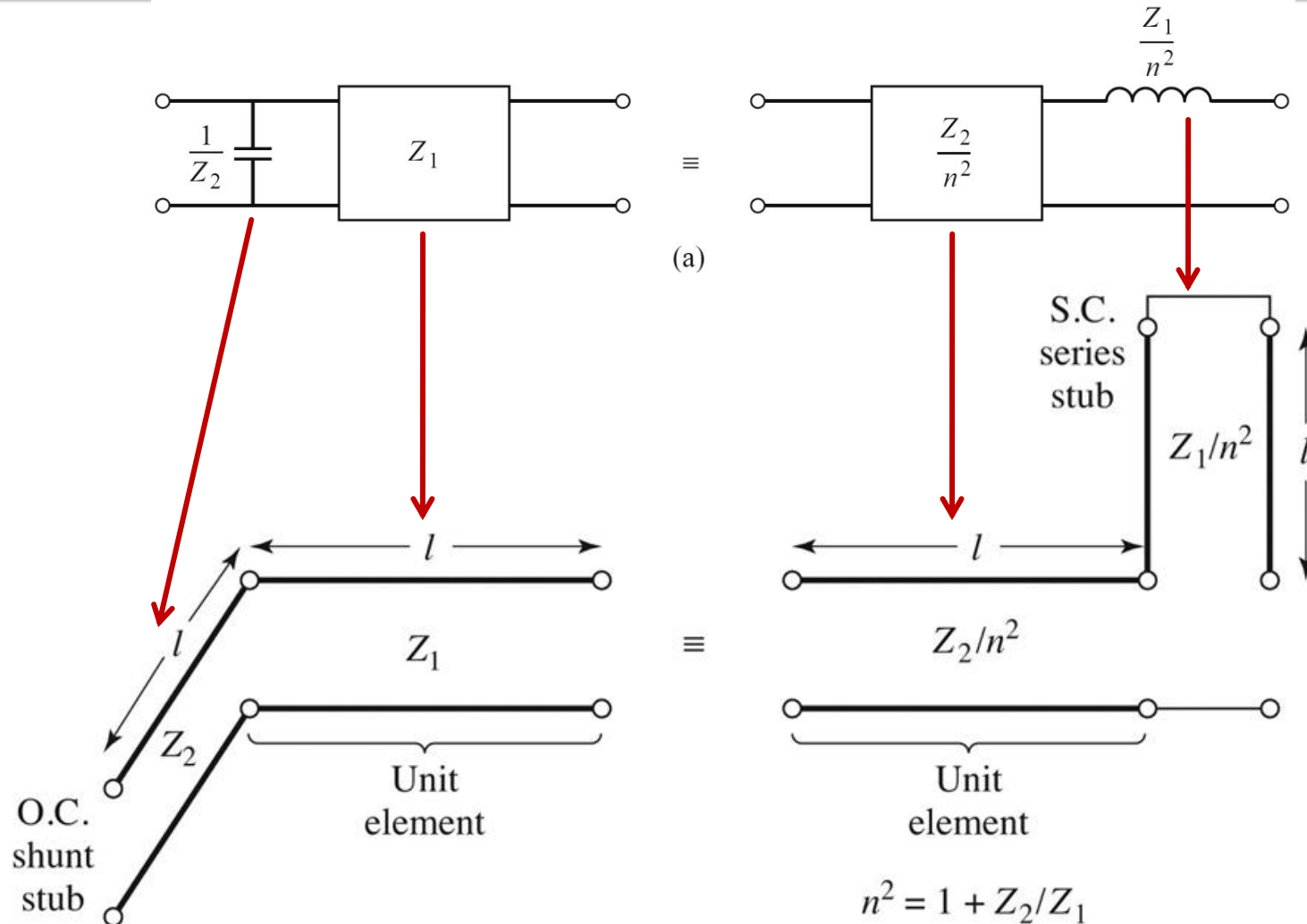
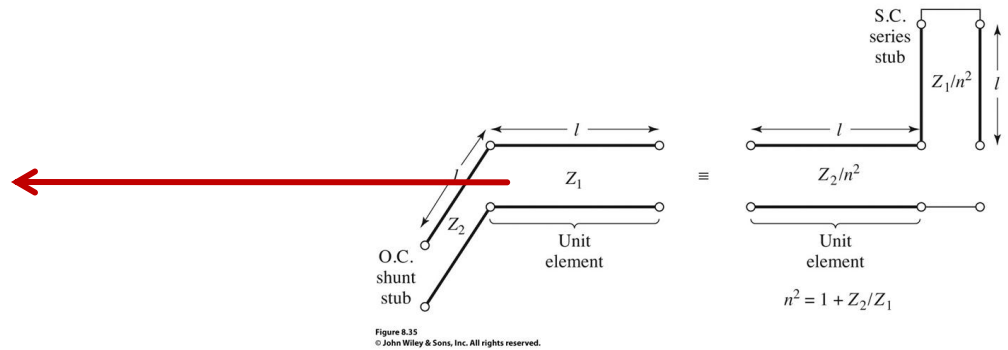
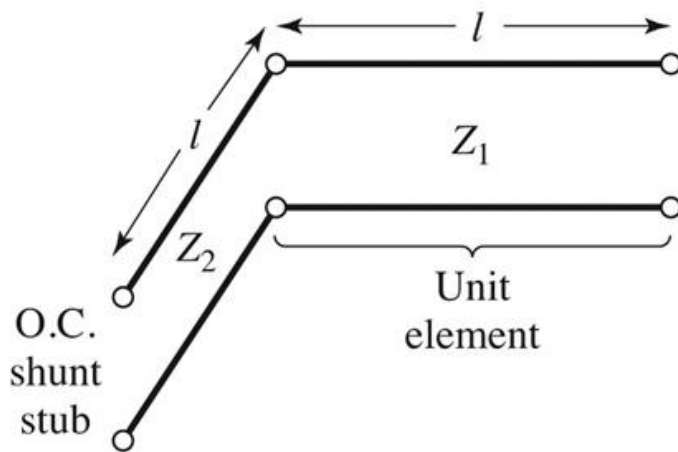
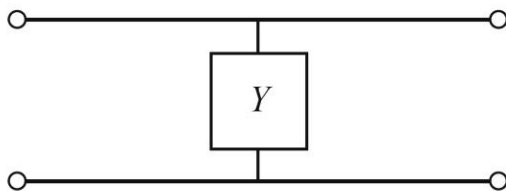


Figure 8.35  
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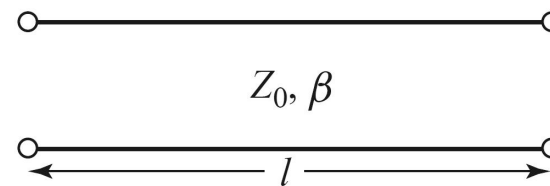
# Prima Identitate Kuroda – Demonstratie



## ■ Matrici ABCD, C5



+

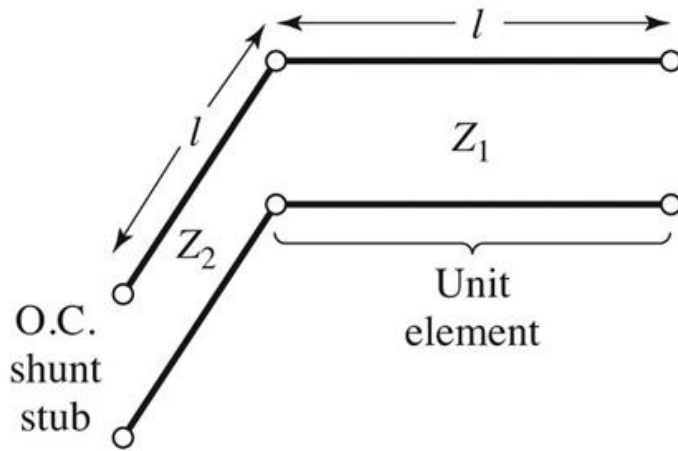


$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

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



# 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

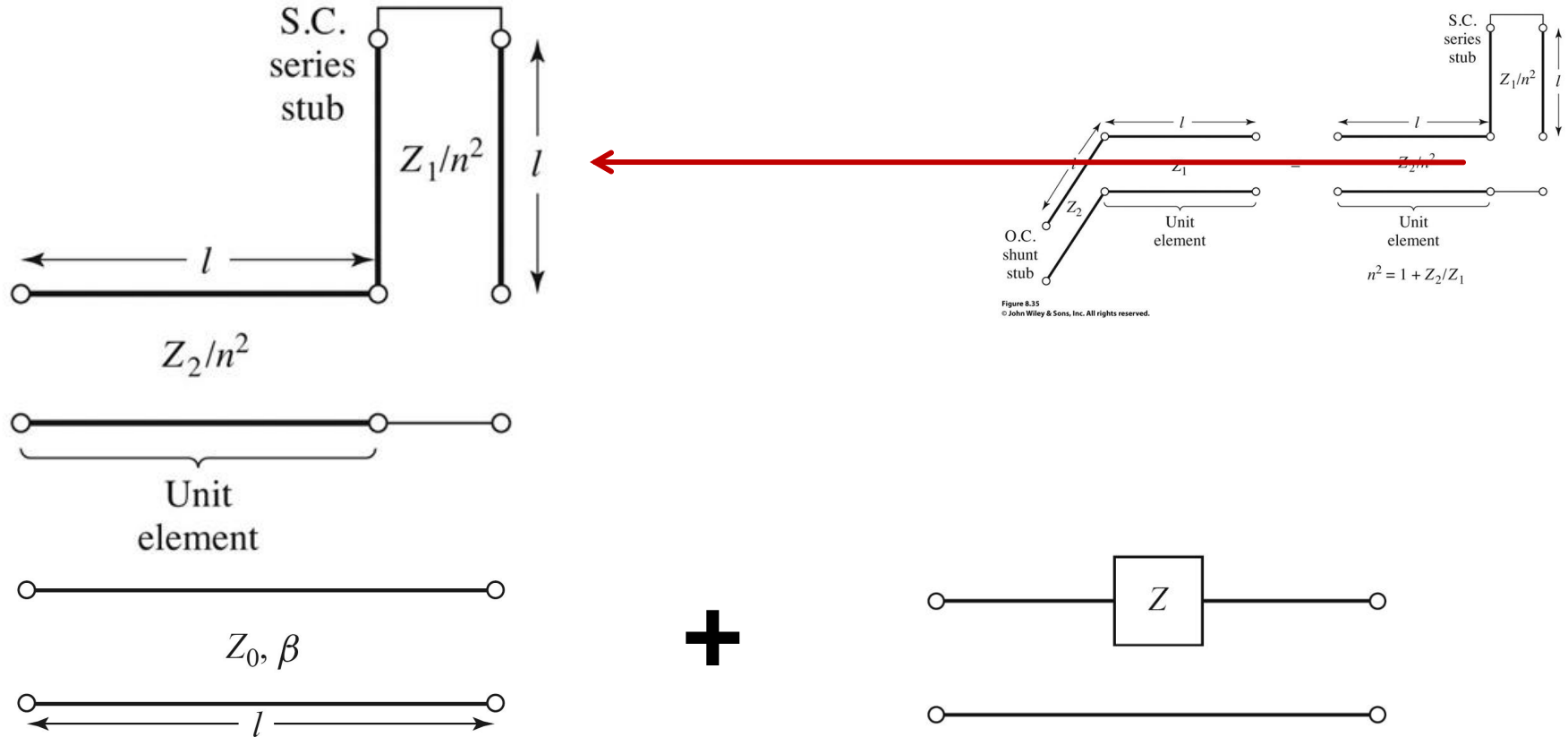
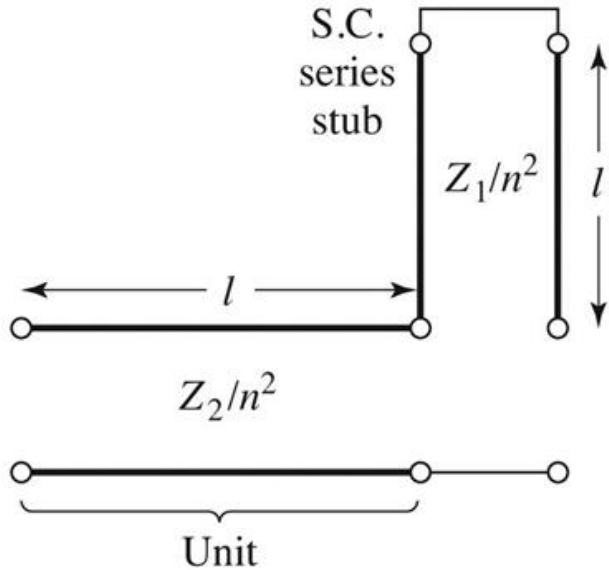


Figure 8.35  
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$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos \beta \cdot l & j \cdot Z_0 \cdot \sin \beta \cdot l \\ j \cdot Y_0 \cdot \sin \beta \cdot l & \cos \beta \cdot l \end{bmatrix}$$

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

# 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

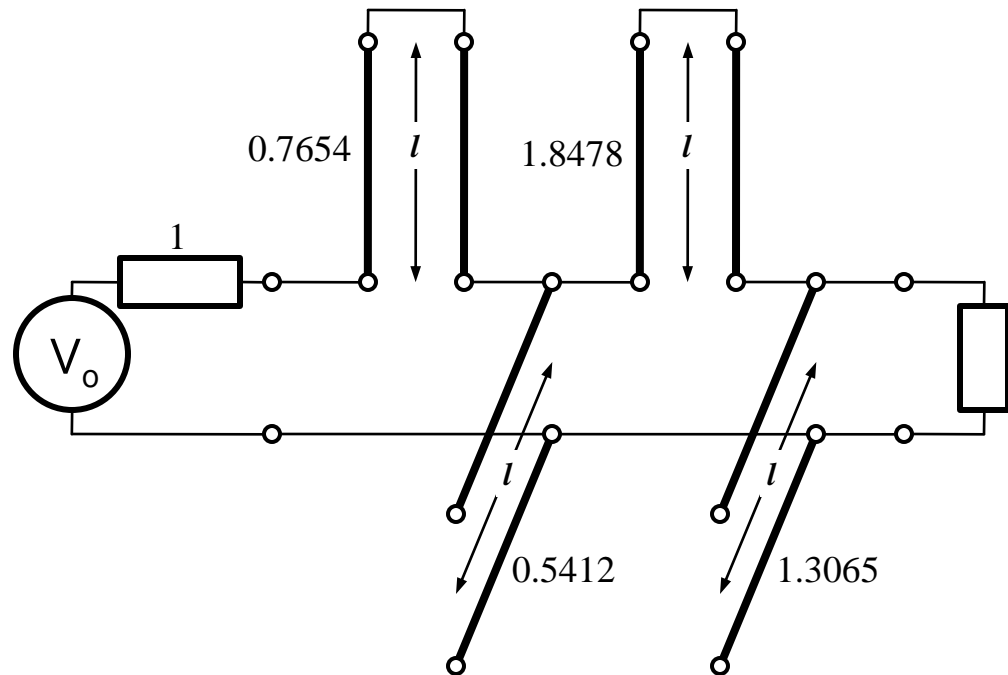
- Filtru trece jos de ordinul 4, cu frecventa de taiere de 4 GHz, de tip maxim plat (care sa functioneze pe  $50\Omega$  la intrare si iesire)
- Tabel maxim plat sau relatii de calcul:
  - $g_1 = 0.7654 = L_1$
  - $g_2 = 1.8478 = C_2$
  - $g_3 = 1.8478 = L_3$
  - $g_4 = 0.7654 = C_4$
  - $g_5 = 1$  (**nu**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

# Exemplu

## ■ Se aplica transformarea Richards

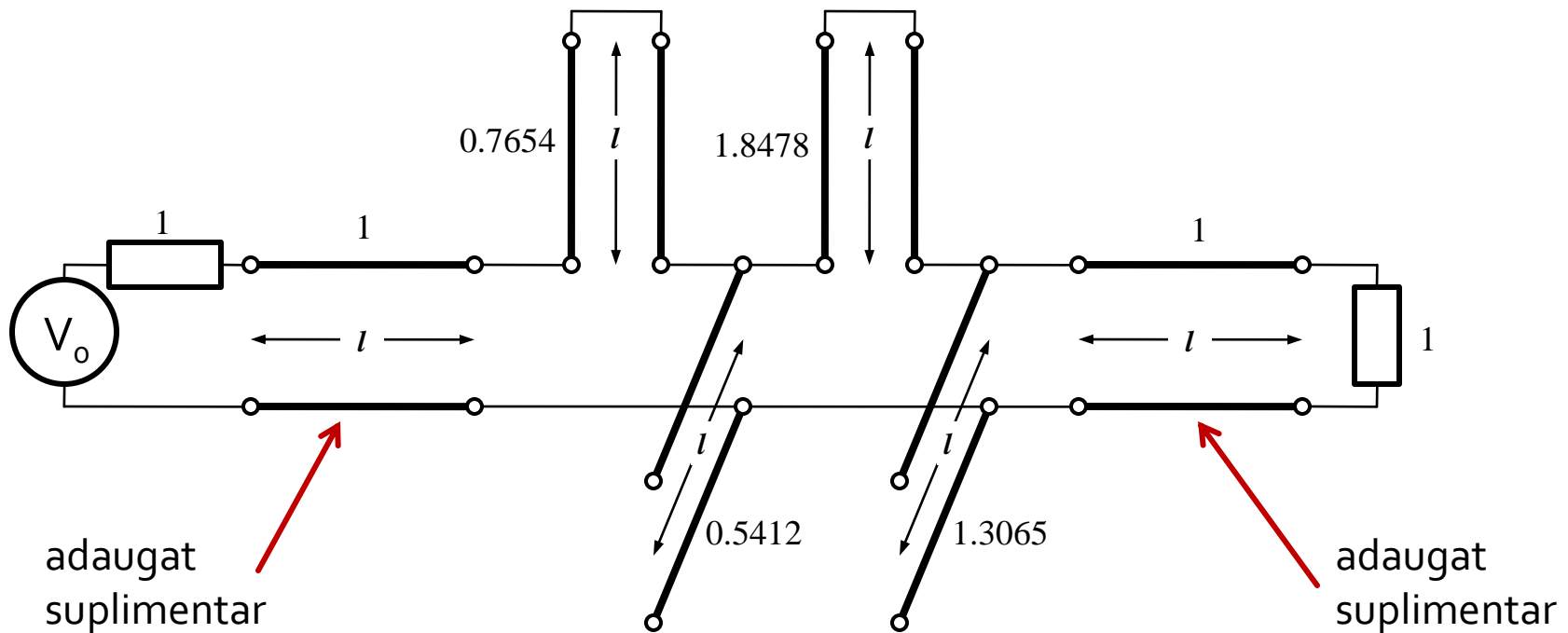
### ■ Probleme:

- 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  $50\Omega$



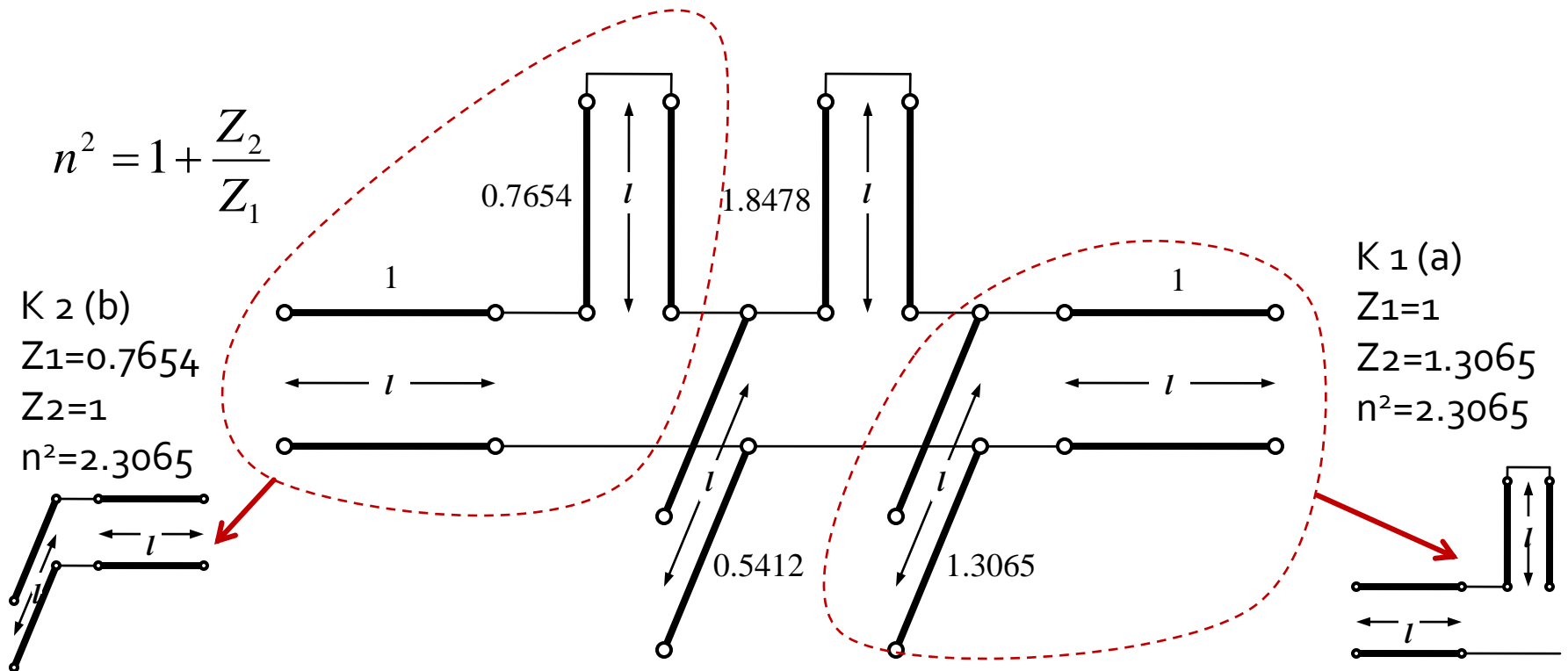
# Exemplu

- 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

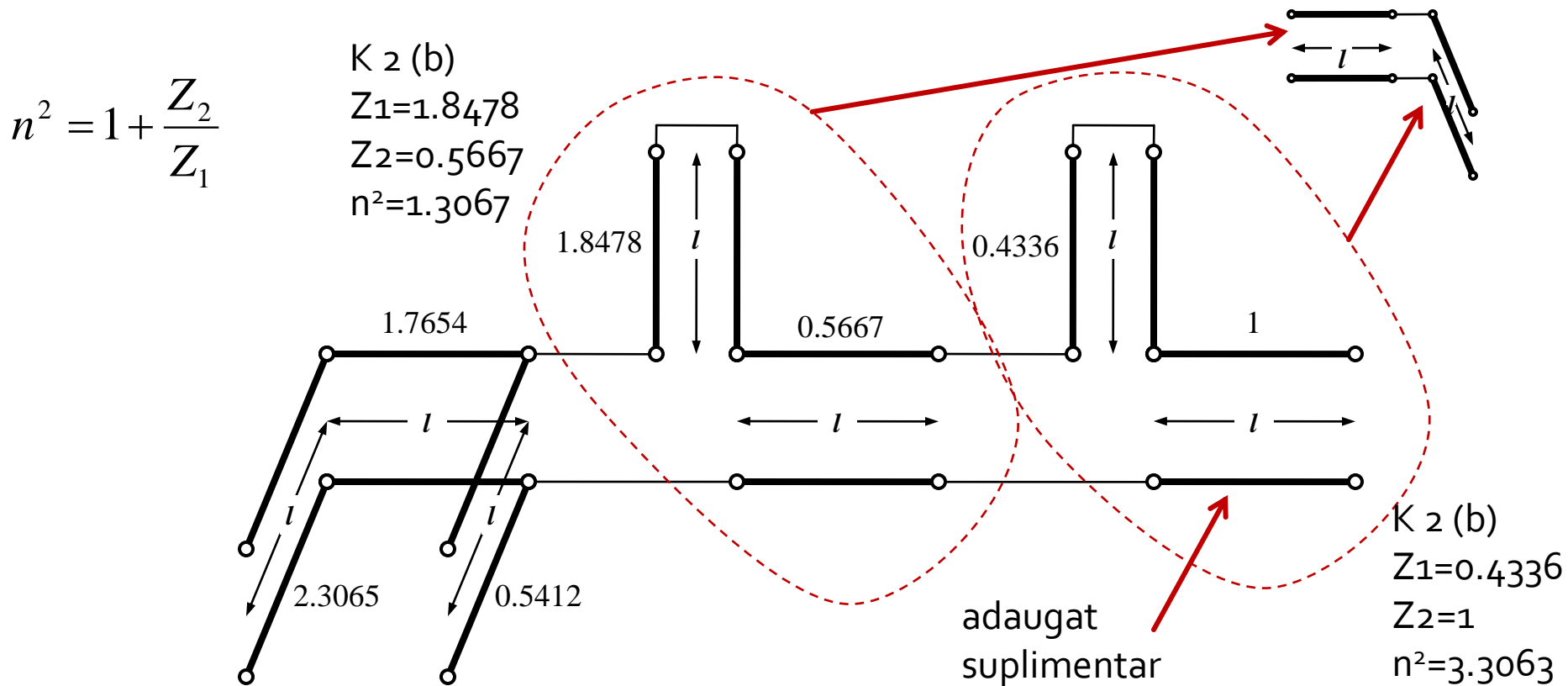
- Se aplica :
  - Kuroda 2 ( $L, Z$  cunoscut  $\rightarrow C, Z$ ) in partea stanga
  - Kuroda 1 ( $C, Z$  cunoscut  $\rightarrow L, Z$ ) in partea dreapta



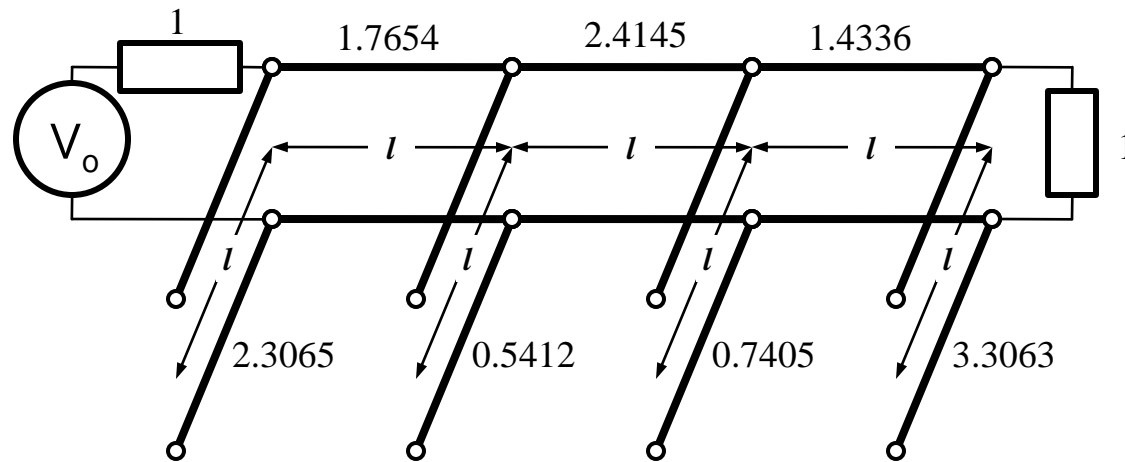


# Exemplu

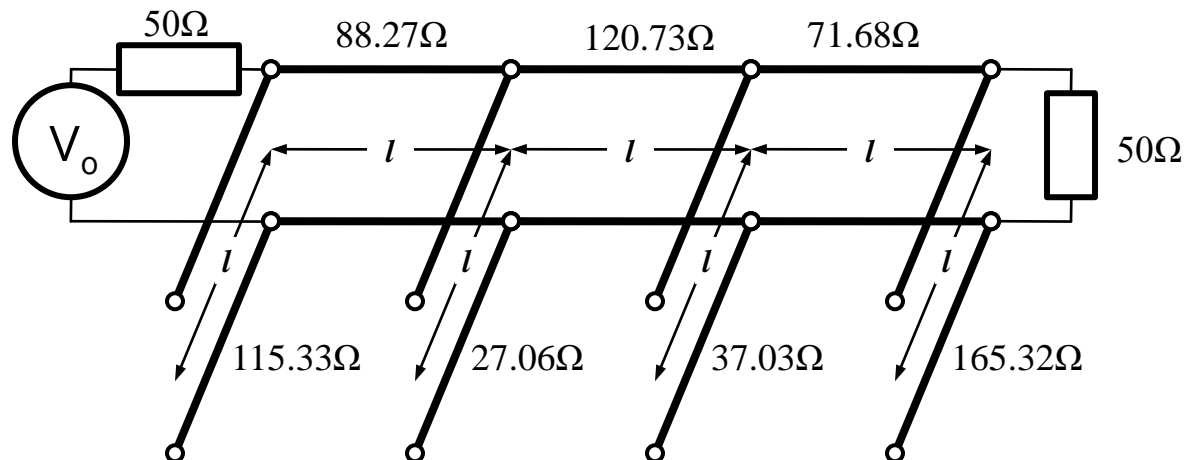
- Se mai adauga un element unitar in partea dreapta si se aplica Kuroda 2 de doua ori



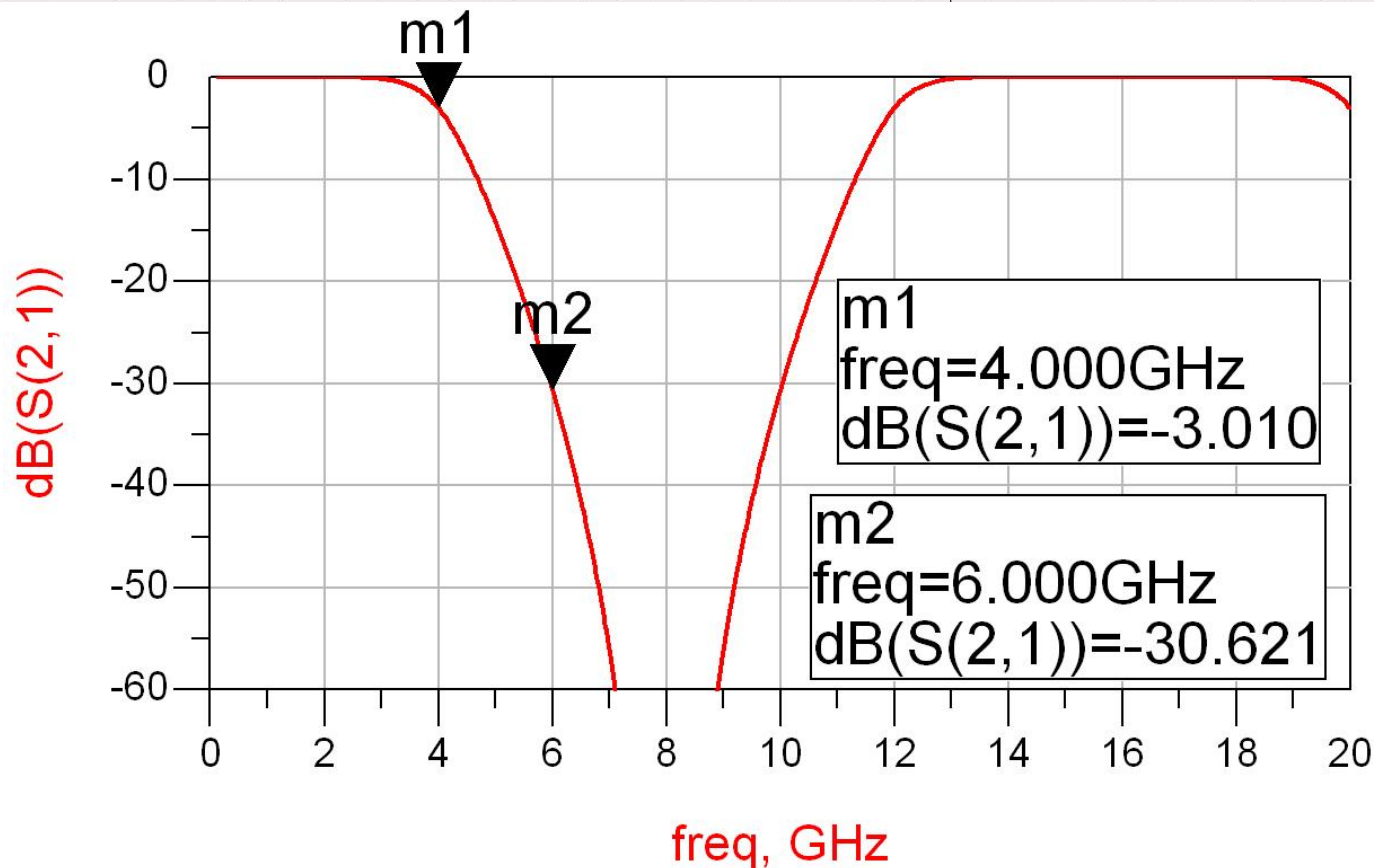
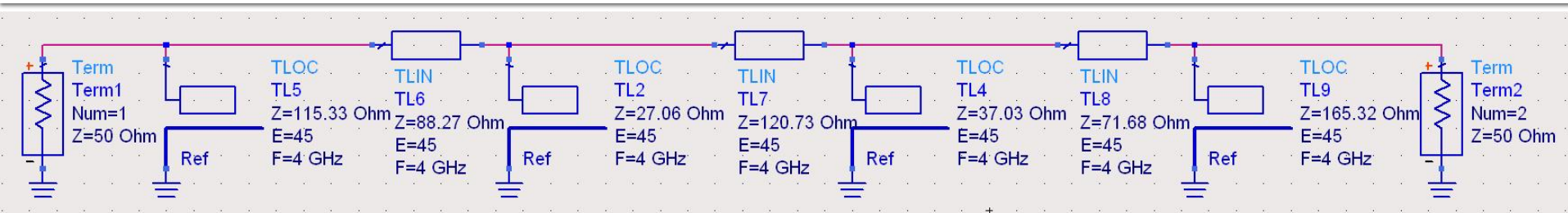
# Exemplu



- Scalare la  $50\Omega$



# Identitatile Kuroda – ADS



# Example

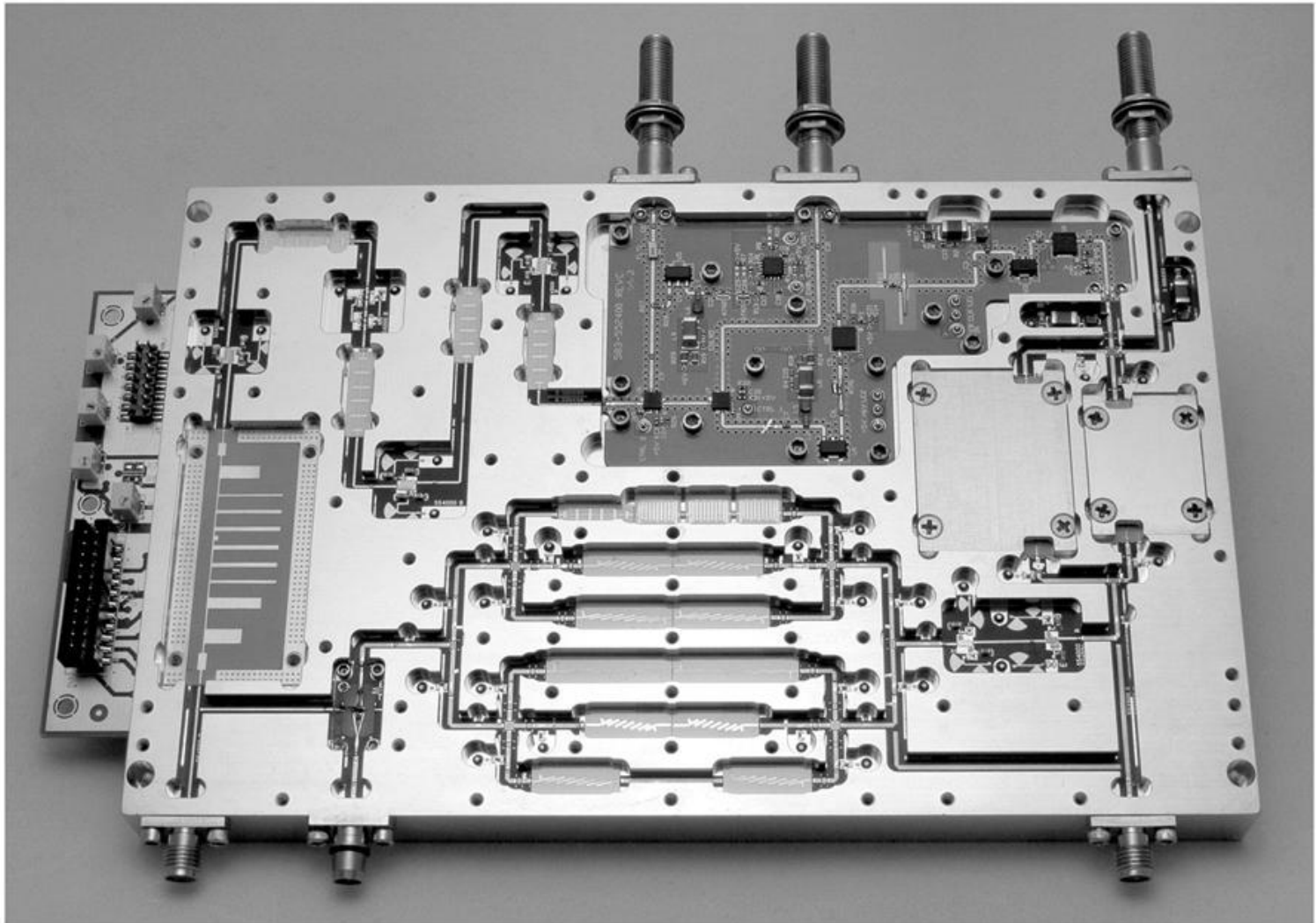


Figure 8.55  
Courtesy of LNX Corporation, Salem, N.H.

# Example

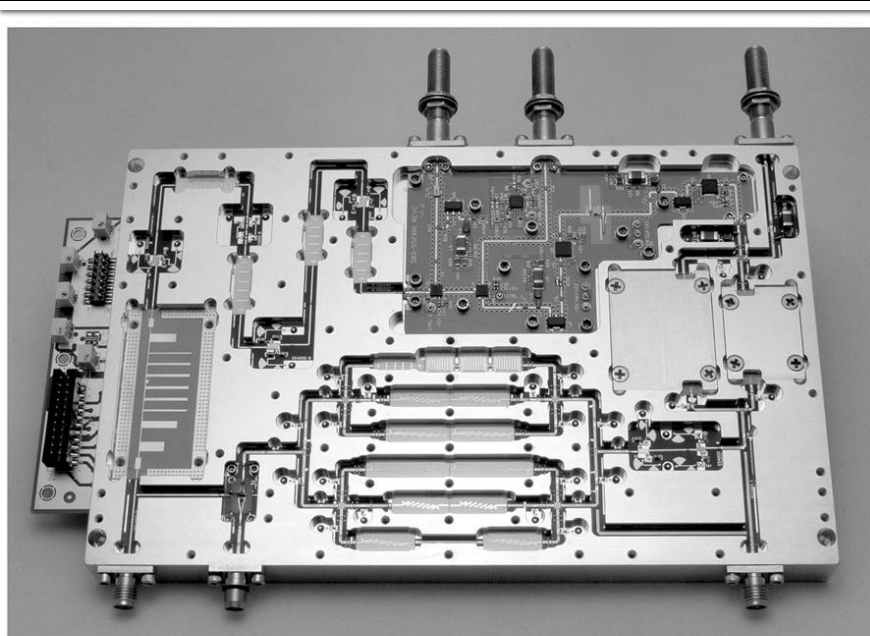
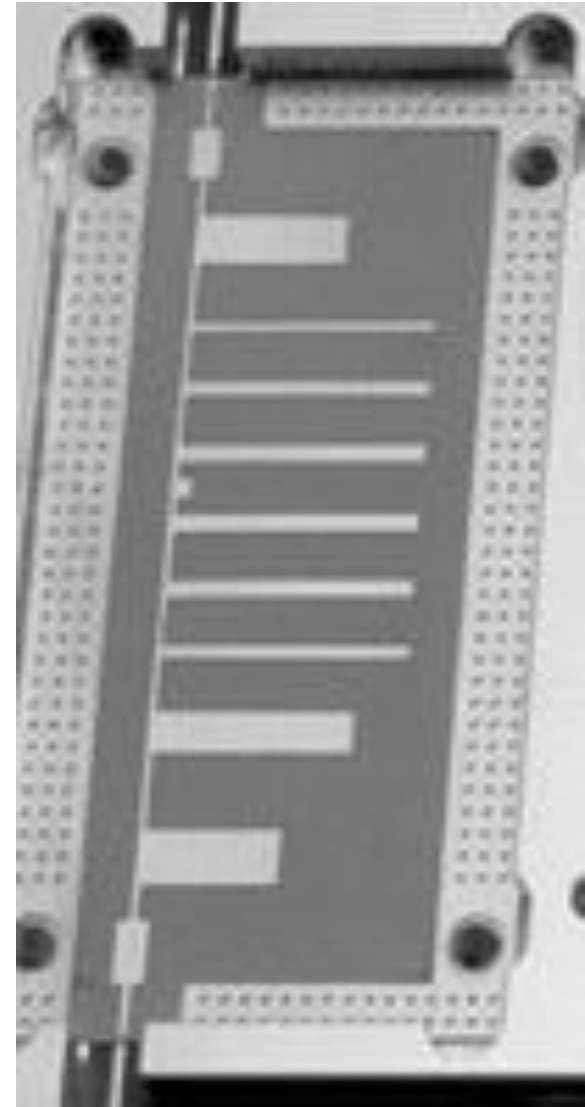
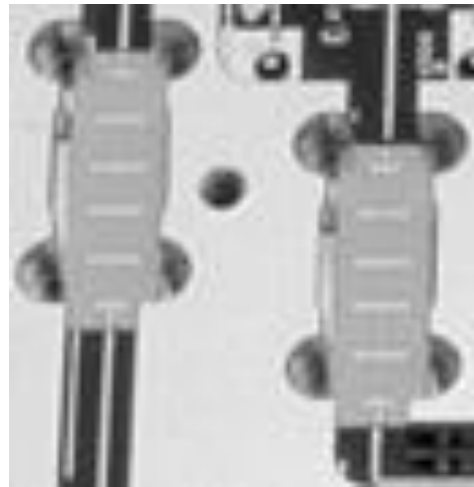
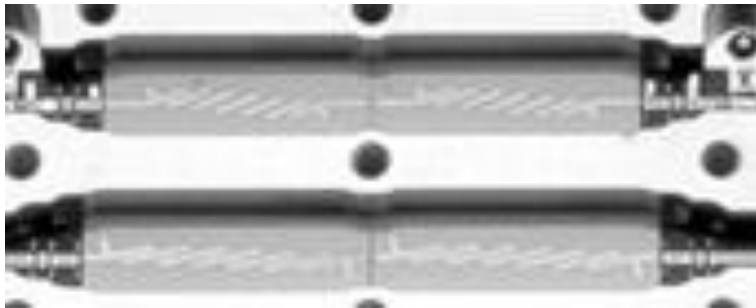


Figure 8.55  
Courtesy of LNX Corporation, Salem, N.H.



# 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

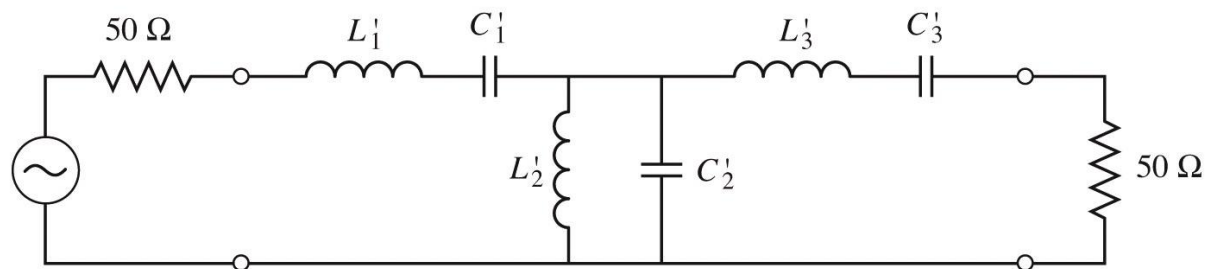


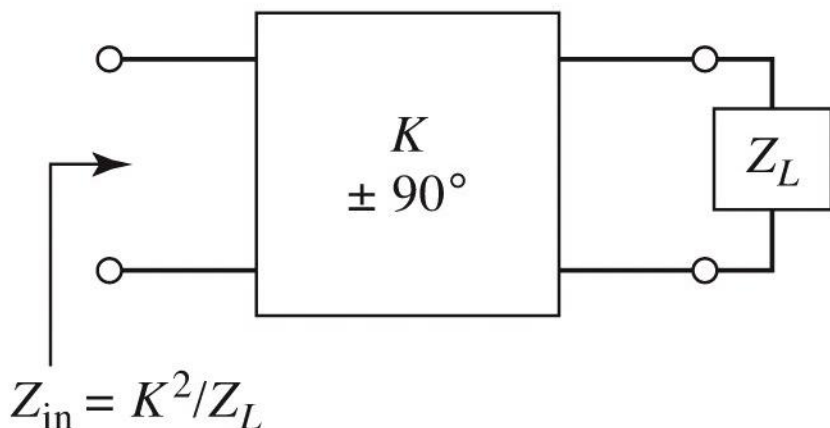
Figure 8.32  
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# Inversoare de impedanta si admitanta

- 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

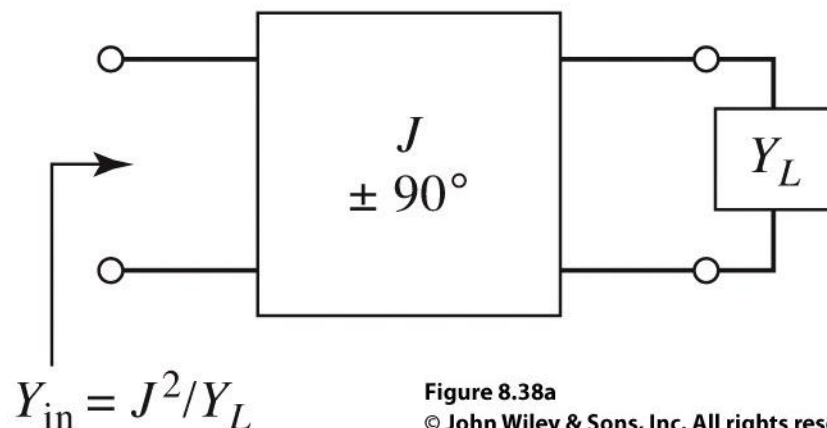


Figure 8.38a

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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)

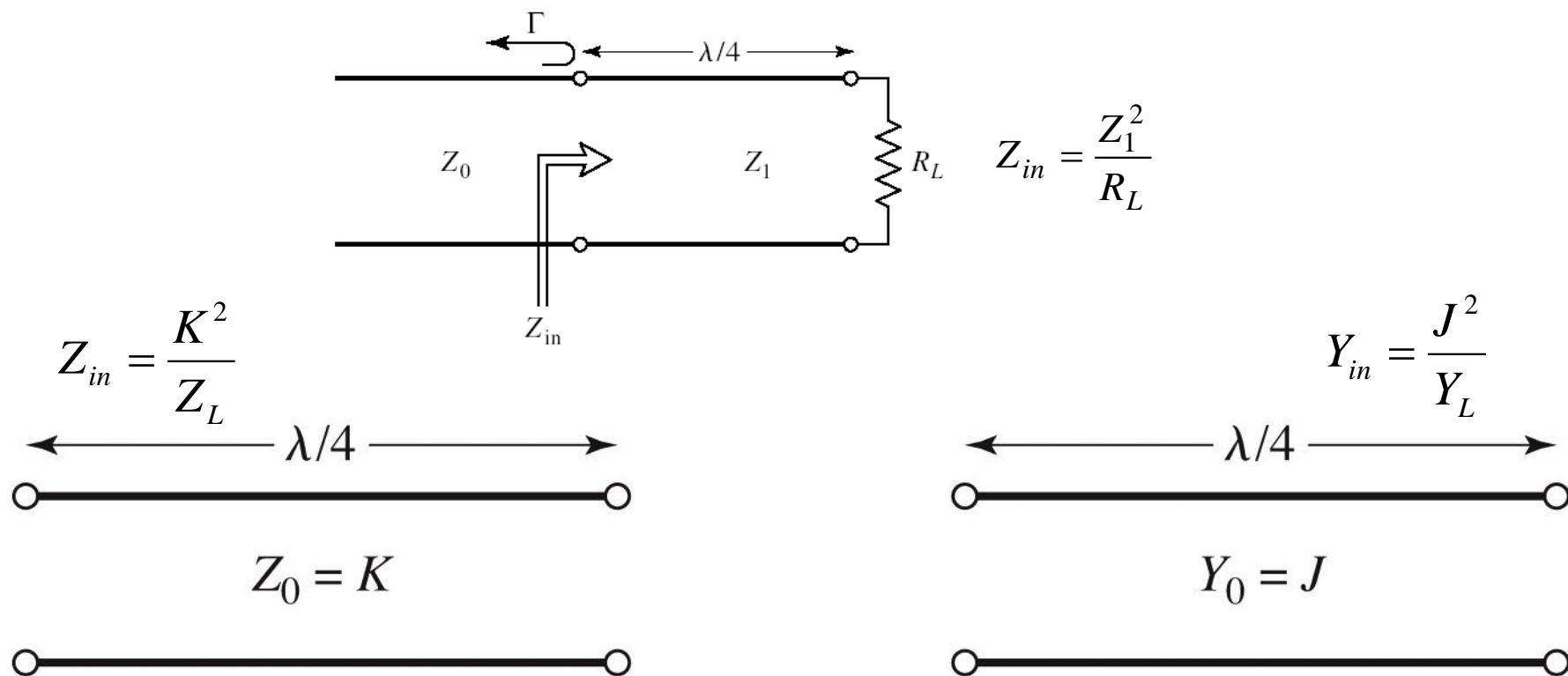
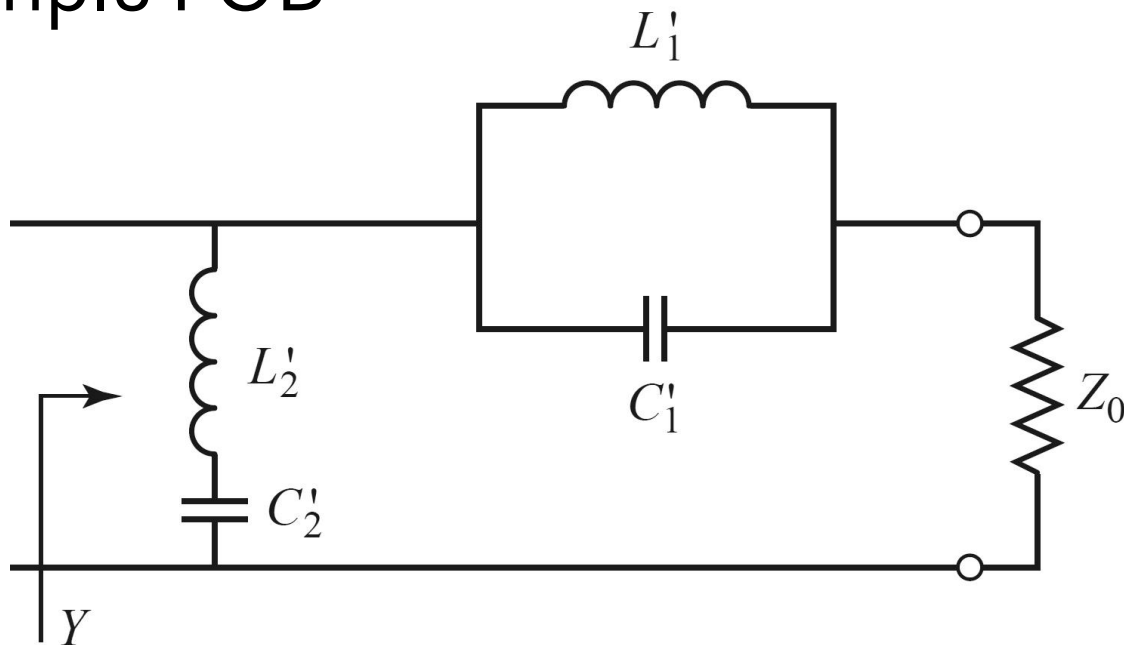


Figure 8.38b



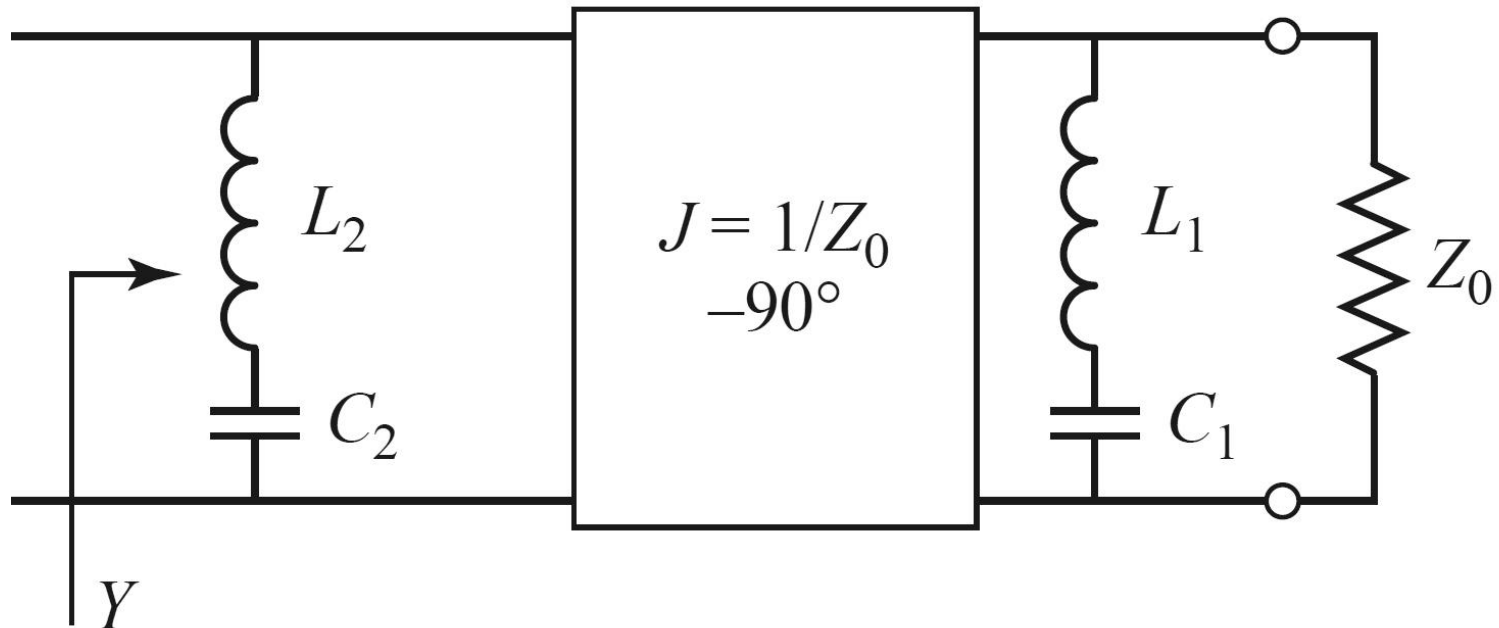
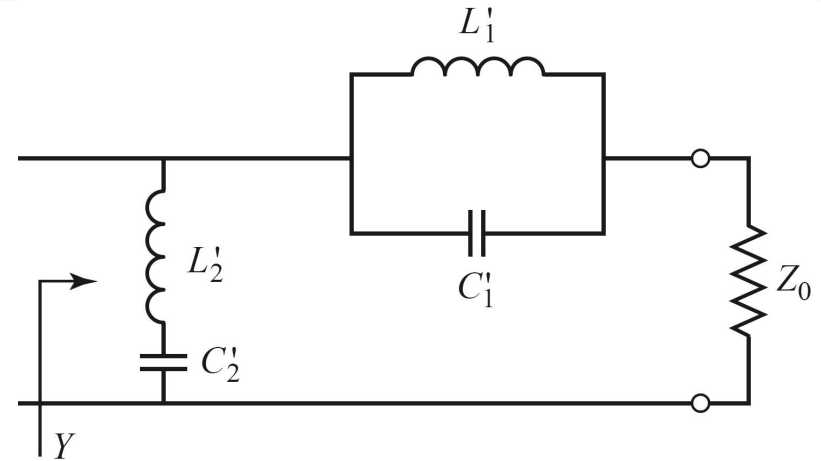
# Inversoare de impedanta si admitanta

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



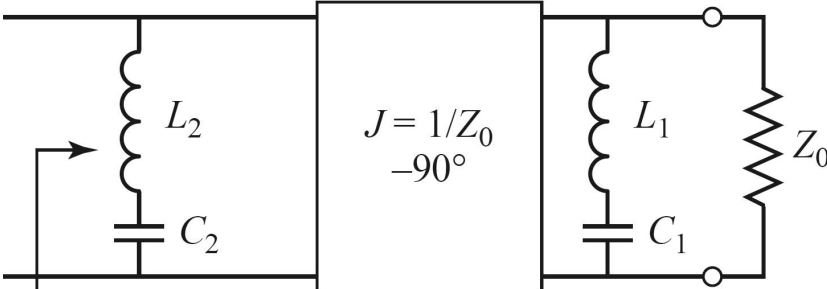
# Inversoare de impedanta si admitanta

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



# Inversoare de impedanta si admitanta

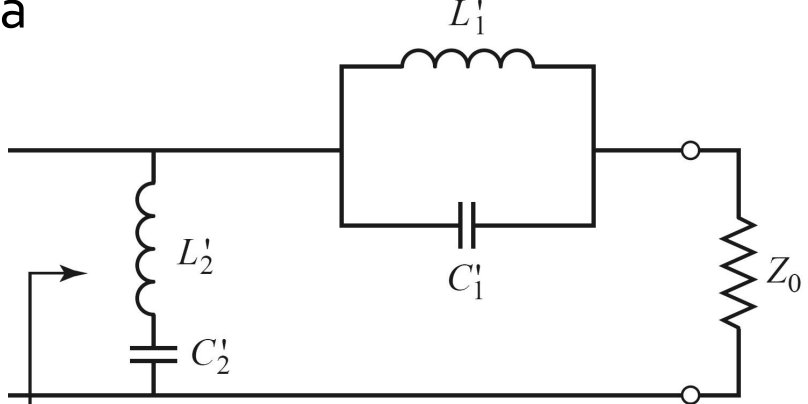
- Echivalenta celor doua scheme se demonstreaza prin obtinerea aceleiasi admitante de intrare
- Echivalenta completa se obtine prin incadrarea grupului simulat intre doua inversoare de admitanta



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

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

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

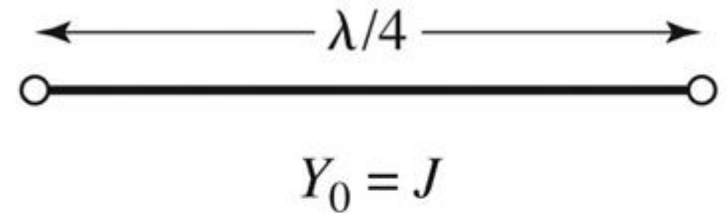
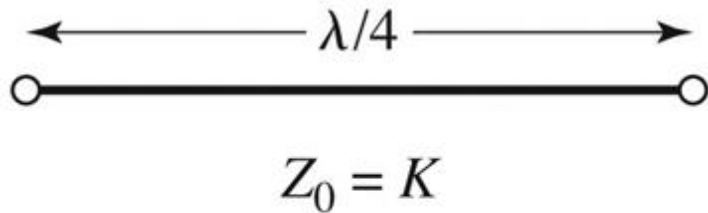


$$Y' = \frac{1}{j \cdot \omega \cdot L'_2 + \frac{1}{j \cdot \omega \cdot C'_2}} + \left( \frac{1}{j \cdot \omega \cdot C'_1 + \frac{1}{j \cdot \omega \cdot L'_1}} + Z_0 \right)^{-1}$$

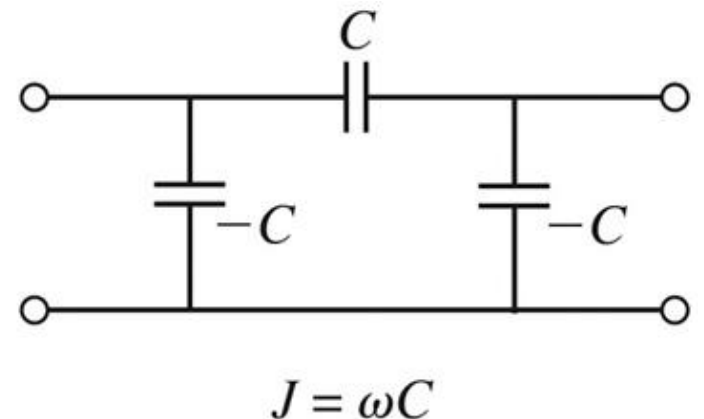
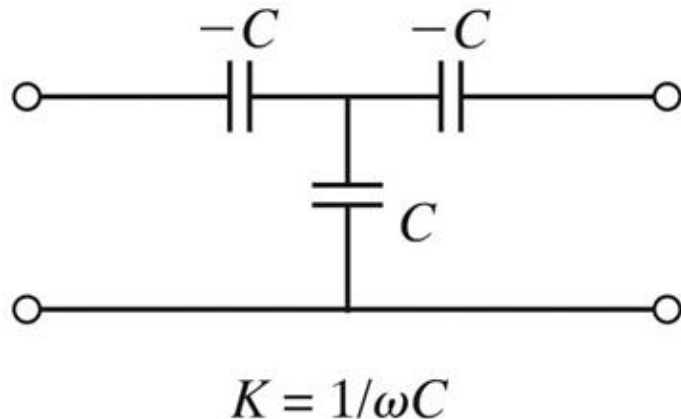
- Rezultat similar se obtine si pentru filtrul trece banda
- Un grup **LC serie** introdus in serie se poate inlocui cu un grup **LC paralel** introdus in paralel incadrat de doua inversoare de admitanta

# Realizari practice de inversoare de impedanta/admitanta

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

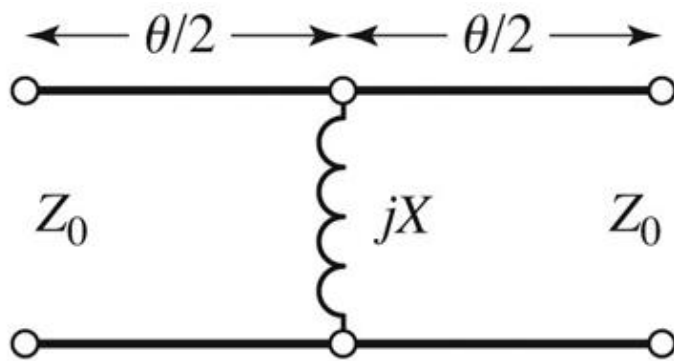


- Realizare cu elemente concentrate



# Realizari practice de inversoare de impedanta/admitanta

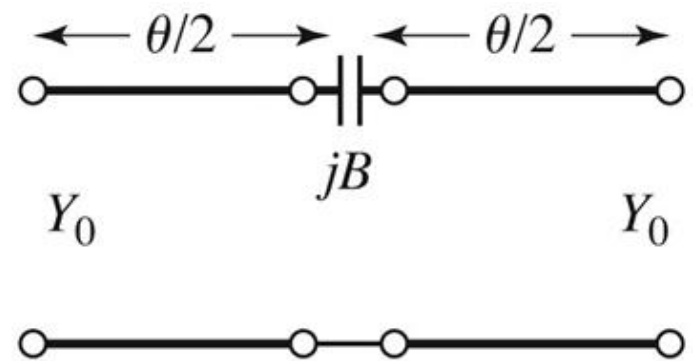
## ■ Realizare cu linii



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

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

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



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

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

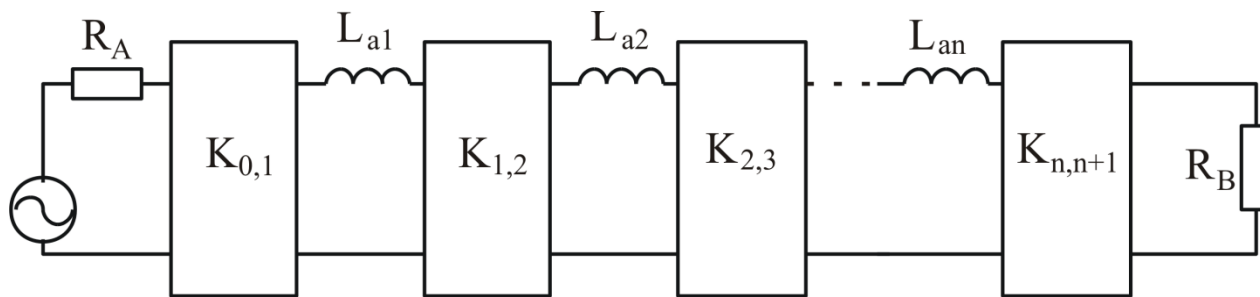
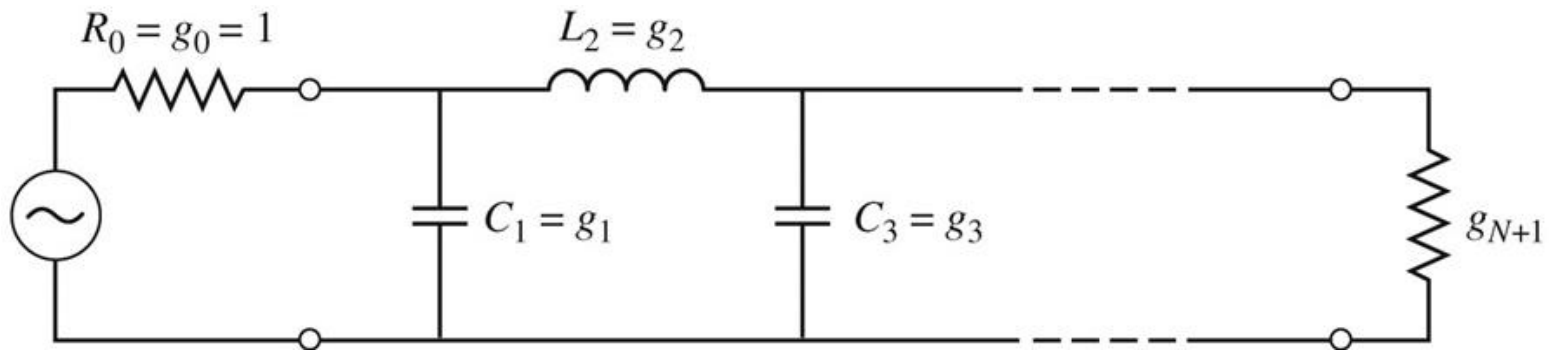
$$\theta = -\tan^{-1} \frac{2 \cdot B}{Y_0}$$

Two red arrows point from the equations above to the expression  $\theta < 0$ .

$$\theta < 0$$

# Filtre prototip cu inversoare

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



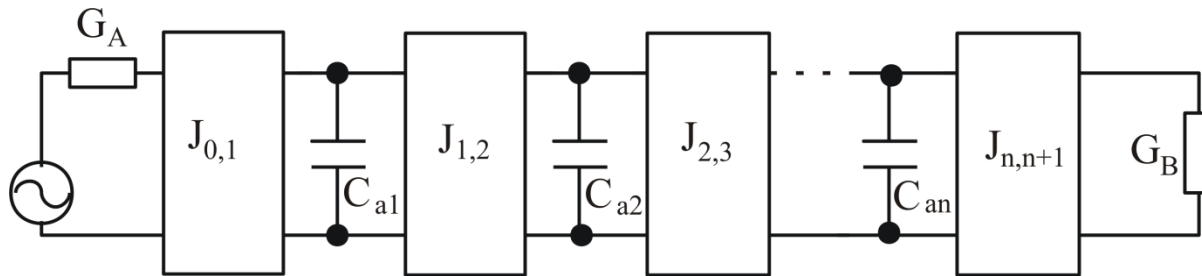
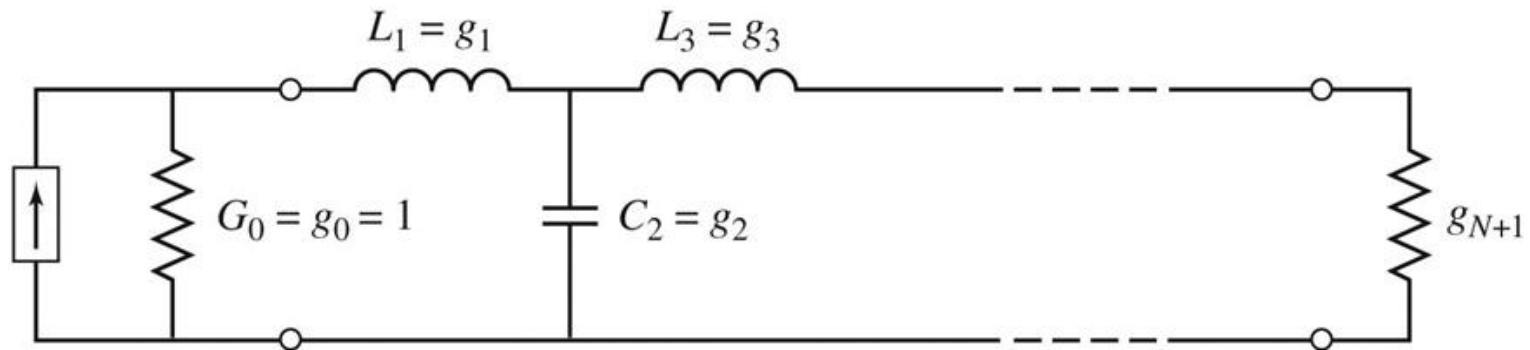
$$K_{0,1} = \sqrt{\frac{R_A \cdot L_{a,1}}{g_0 \cdot g_1}}$$

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

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

# 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  $\omega_0$ ) 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

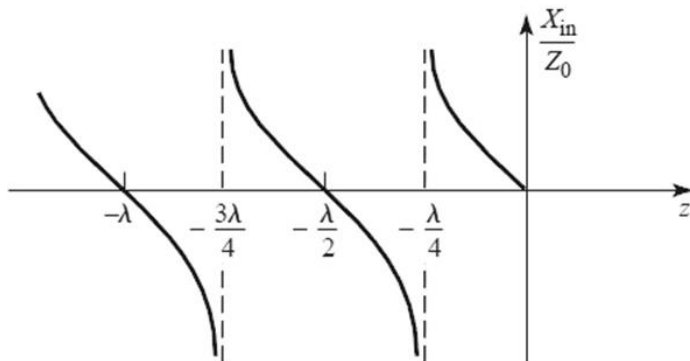


# Linii ca rezonatoare

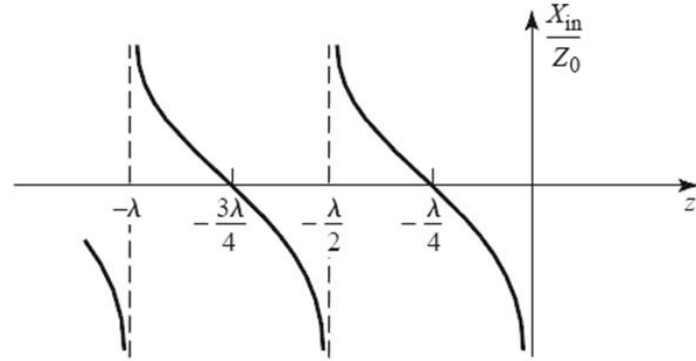
- Impedanta de intrare intr-o linie (stub) scurtcircuitata sau lasata in gol la capat manifesta comportament rezonant care poate fi utilizat pentru implementarea rezonatoarelor

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

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

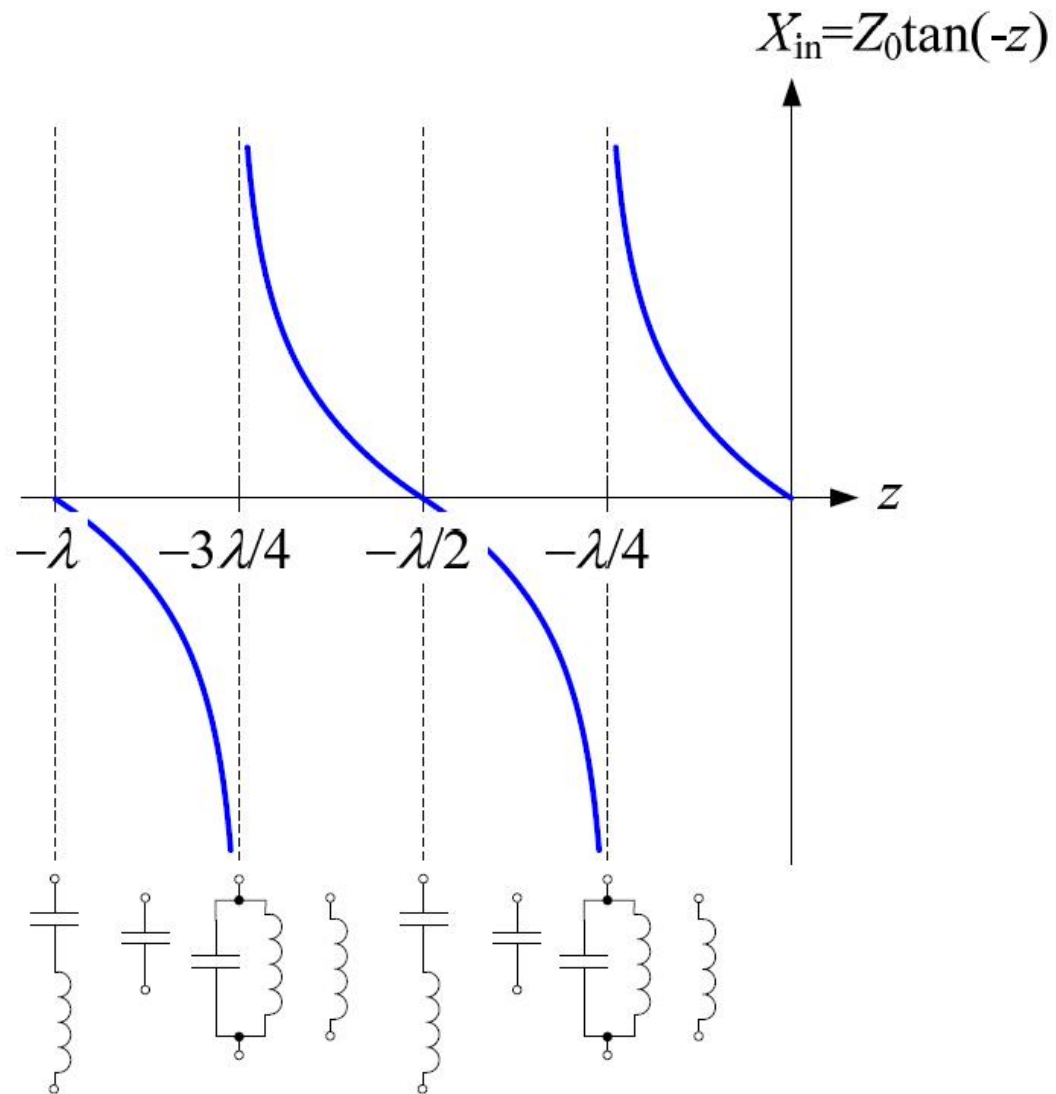


$$Z_{in,g} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$



# Linii ca rezonatoare

- Linie in scurtcircuit
- Pentru frecventa ( $\omega_0$ ) la care  $l = \lambda/4$  se obtine un circuit rezonant LC paralel
  - linia are comportament capacitiv pentru frecvente mai mici ( $l > \lambda/4$ )
  - linia are comportament inductiv pentru frecvente mai mari ( $l < \lambda/4$ )
- Discutie similara pentru linia in gol (LC serie la frecventa 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  $l = \lambda/4$

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

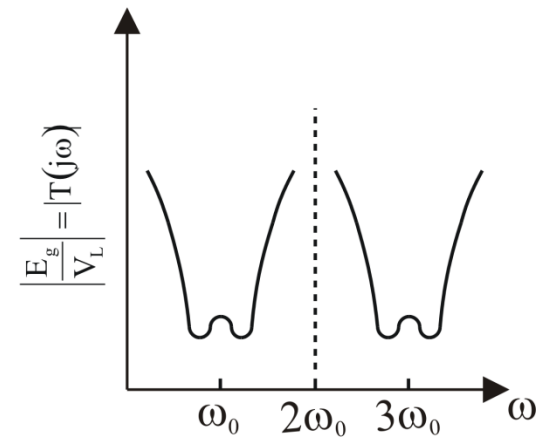
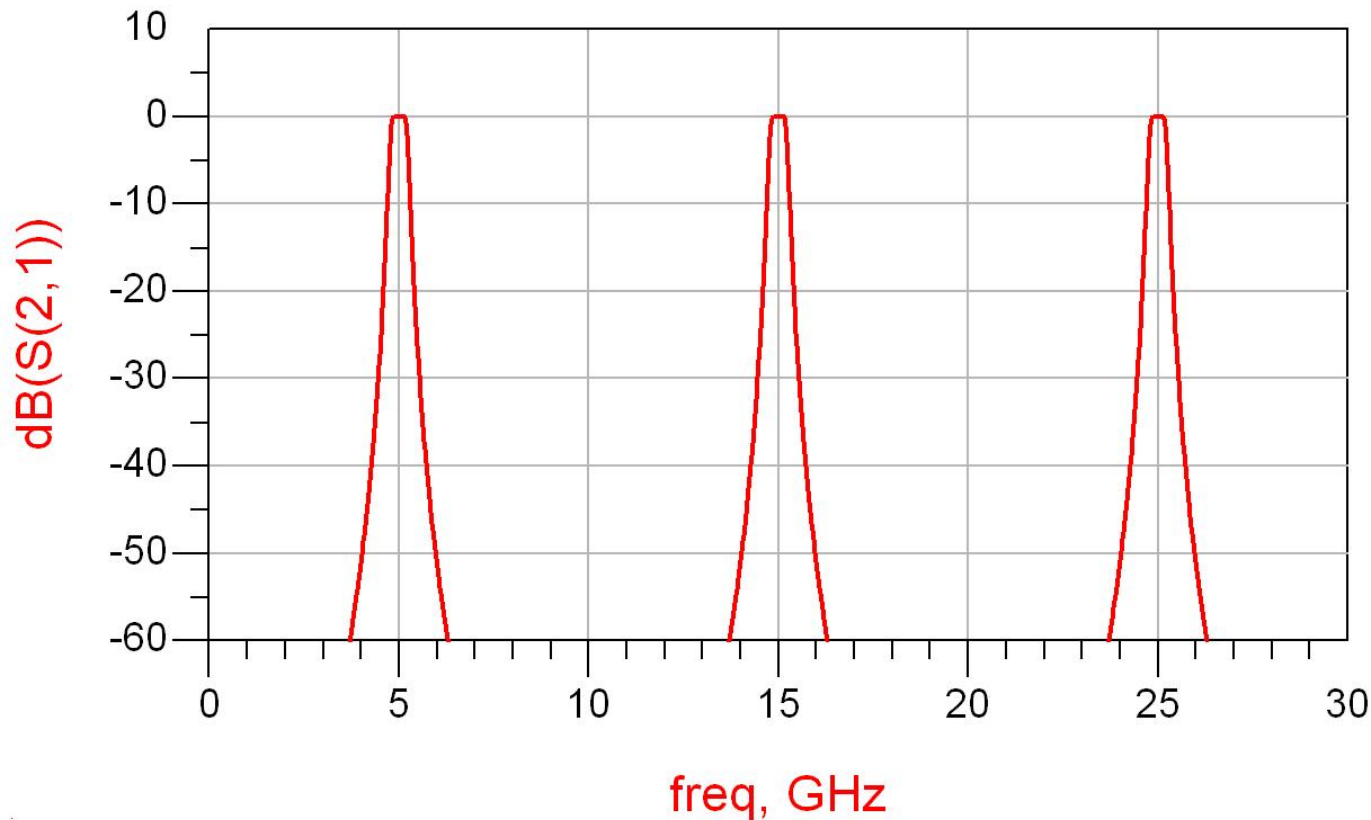
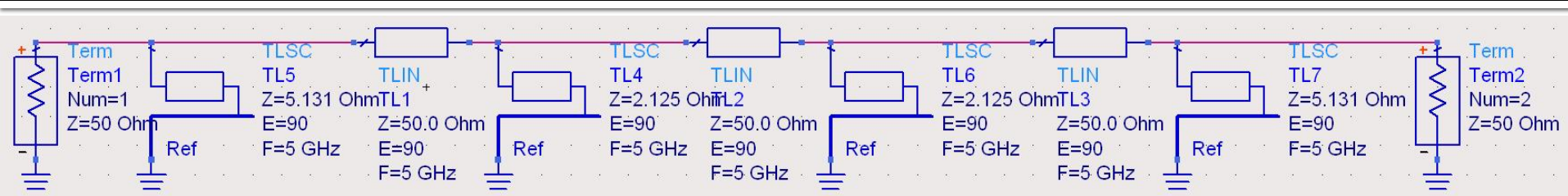
# Exemplu

- 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:

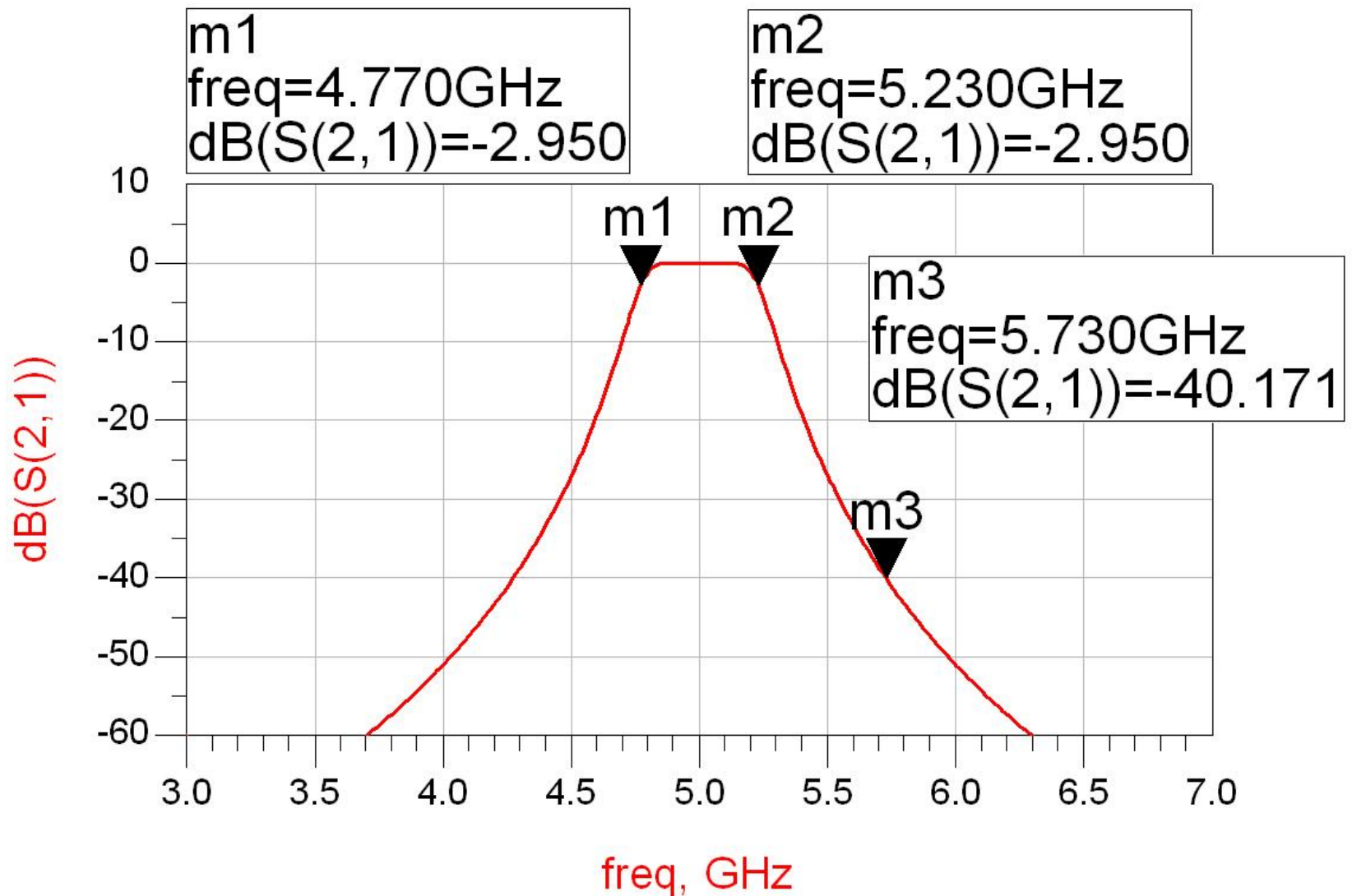
n	$g_n$	$Z_{on}(\Omega)$
1	0.7654	5.131
2	1.8478	2.125
3	1.8478	2.125
4	0.7654	5.131

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

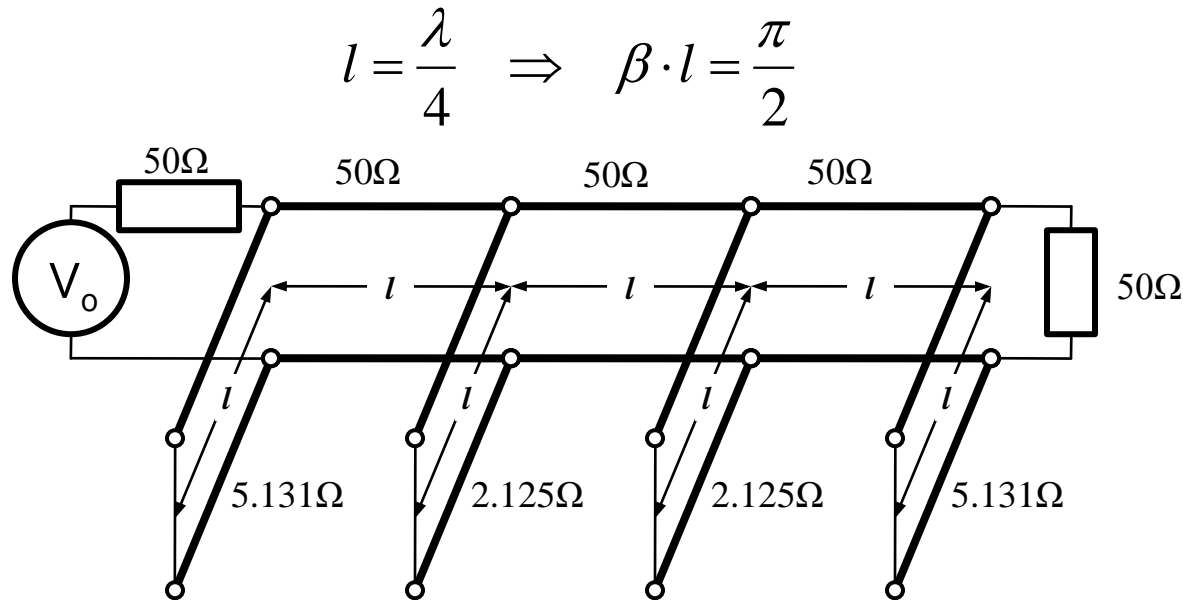
# ADS – FTB



# ADS – FTB



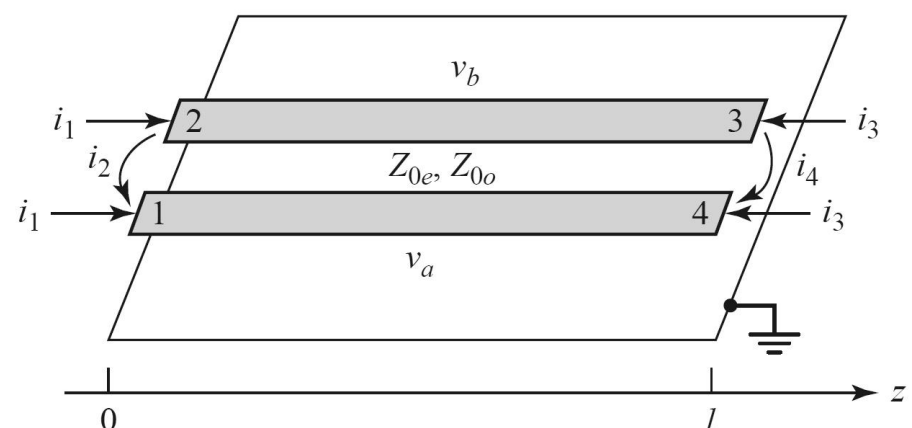
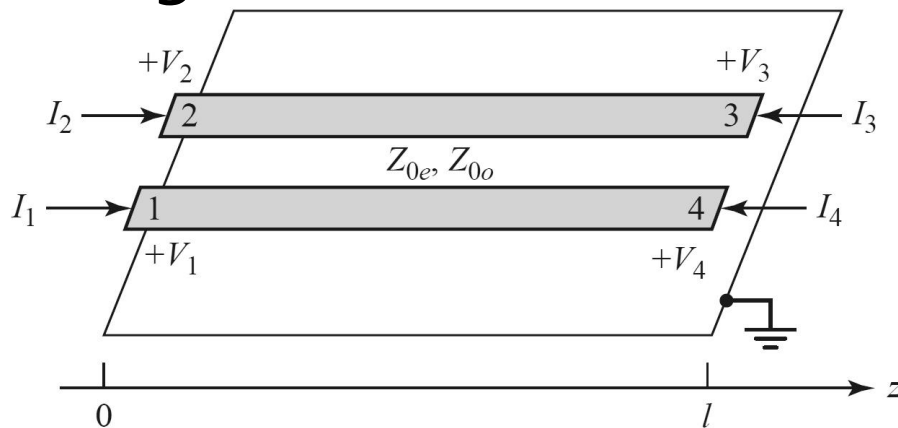
# Exemplu



- 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

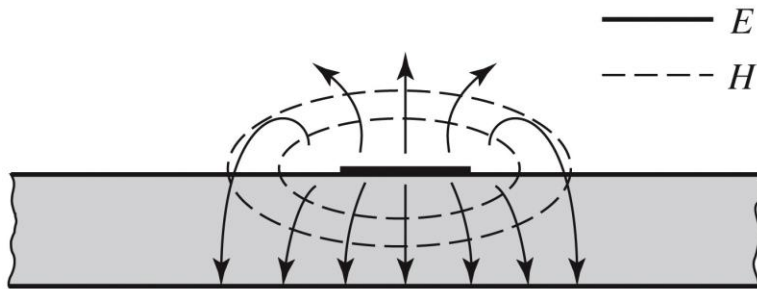
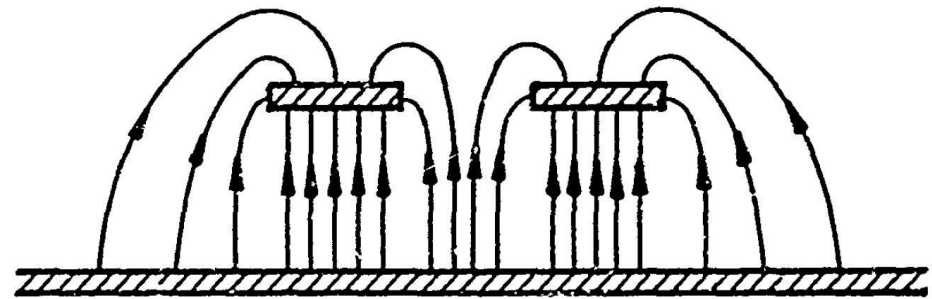
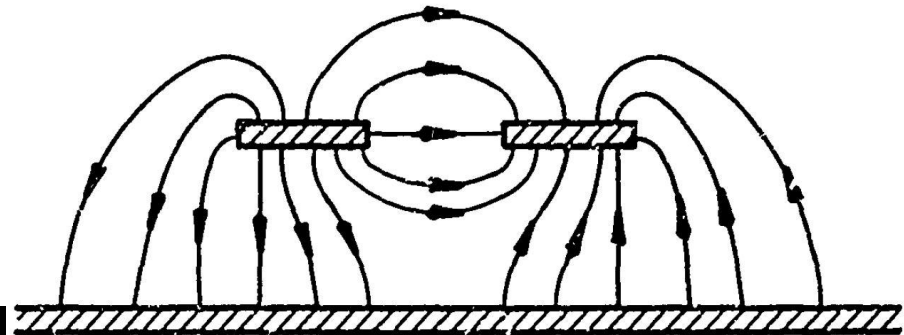


Figure 3.25b  
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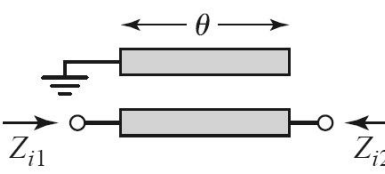
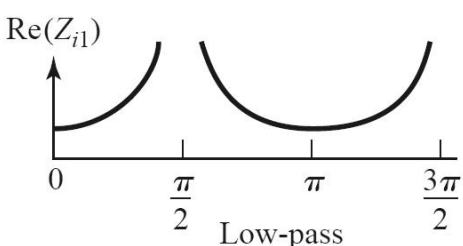
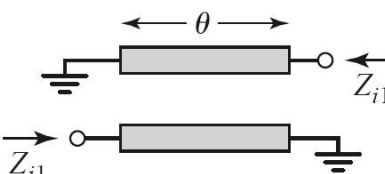
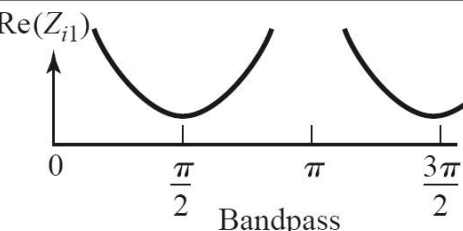
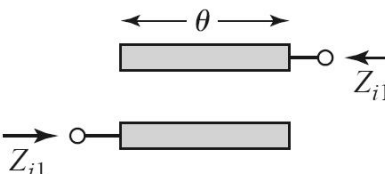
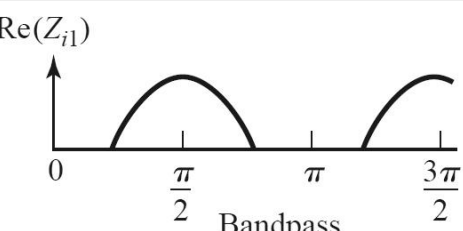
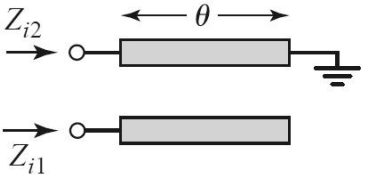
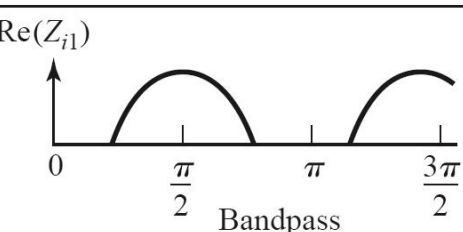
b) EVEN MODE ELECTRIC FIELD PATTERN (SCHEMATIC)



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  $\theta = \pi/2$  ( $l = \lambda/4$ )

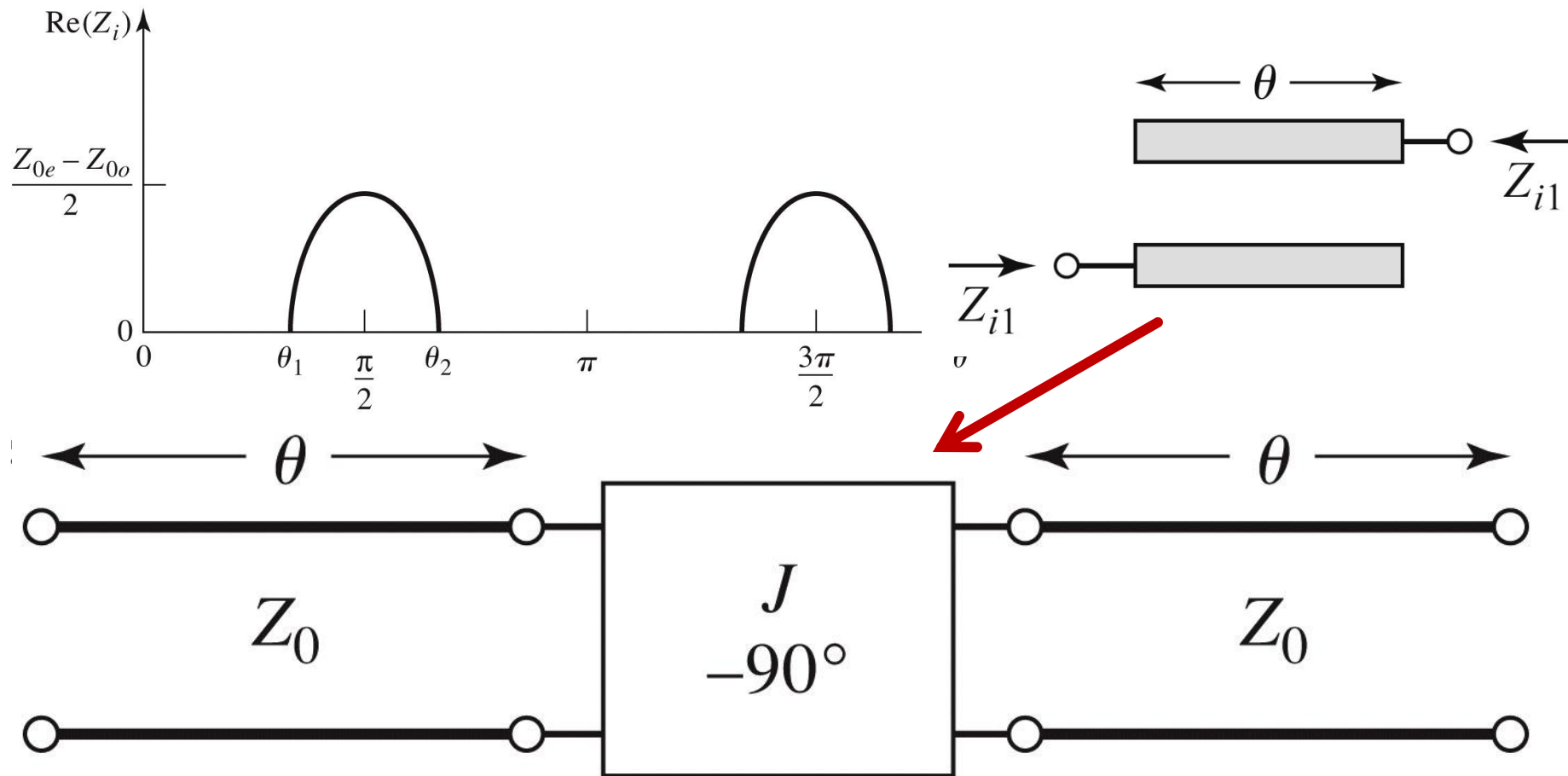
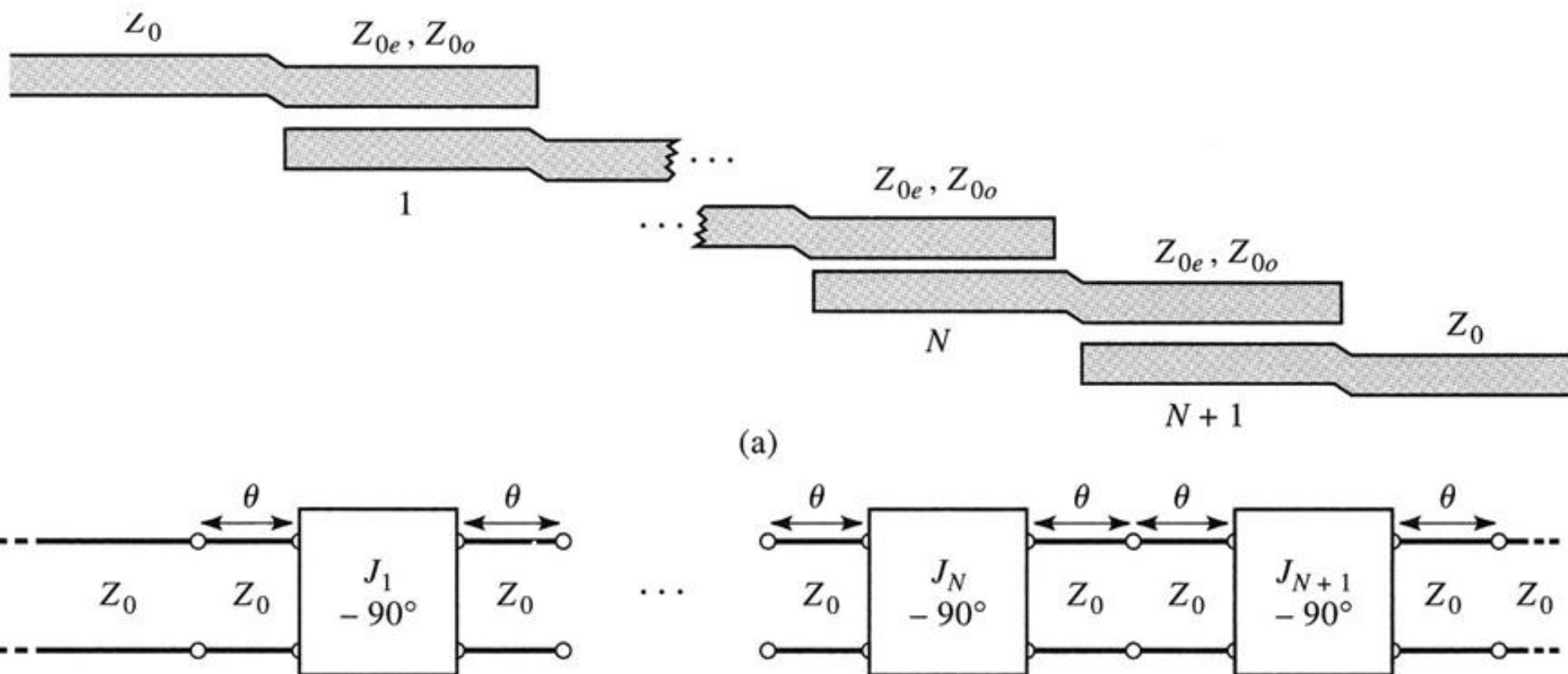


Figure 8.44

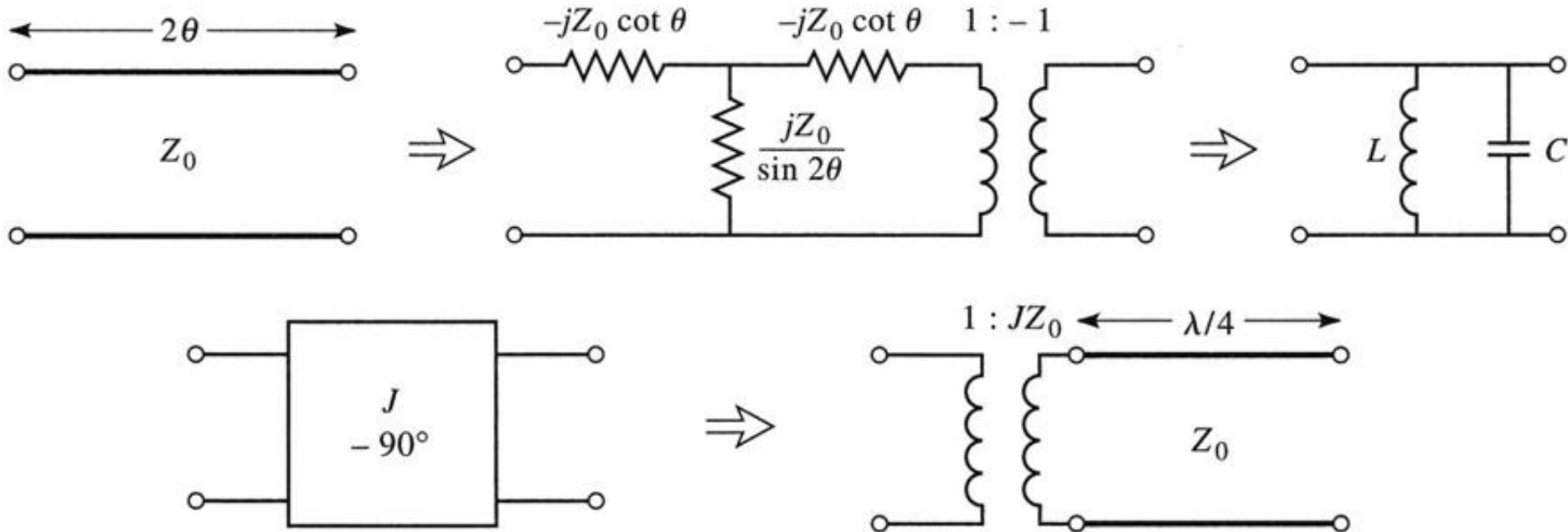
# Filtre cu linii cuplate

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



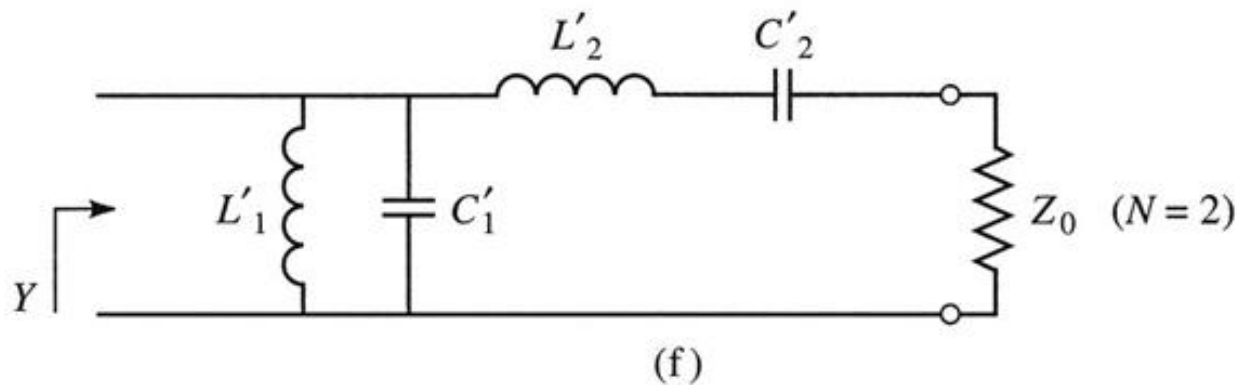
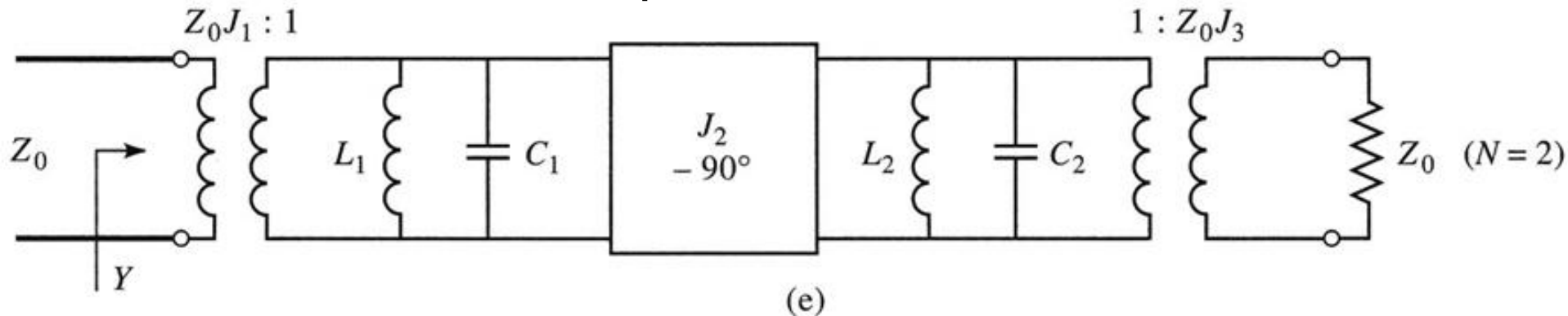
# Filtre cu linii cuplate

- 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  $l = \lambda/4$ )

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

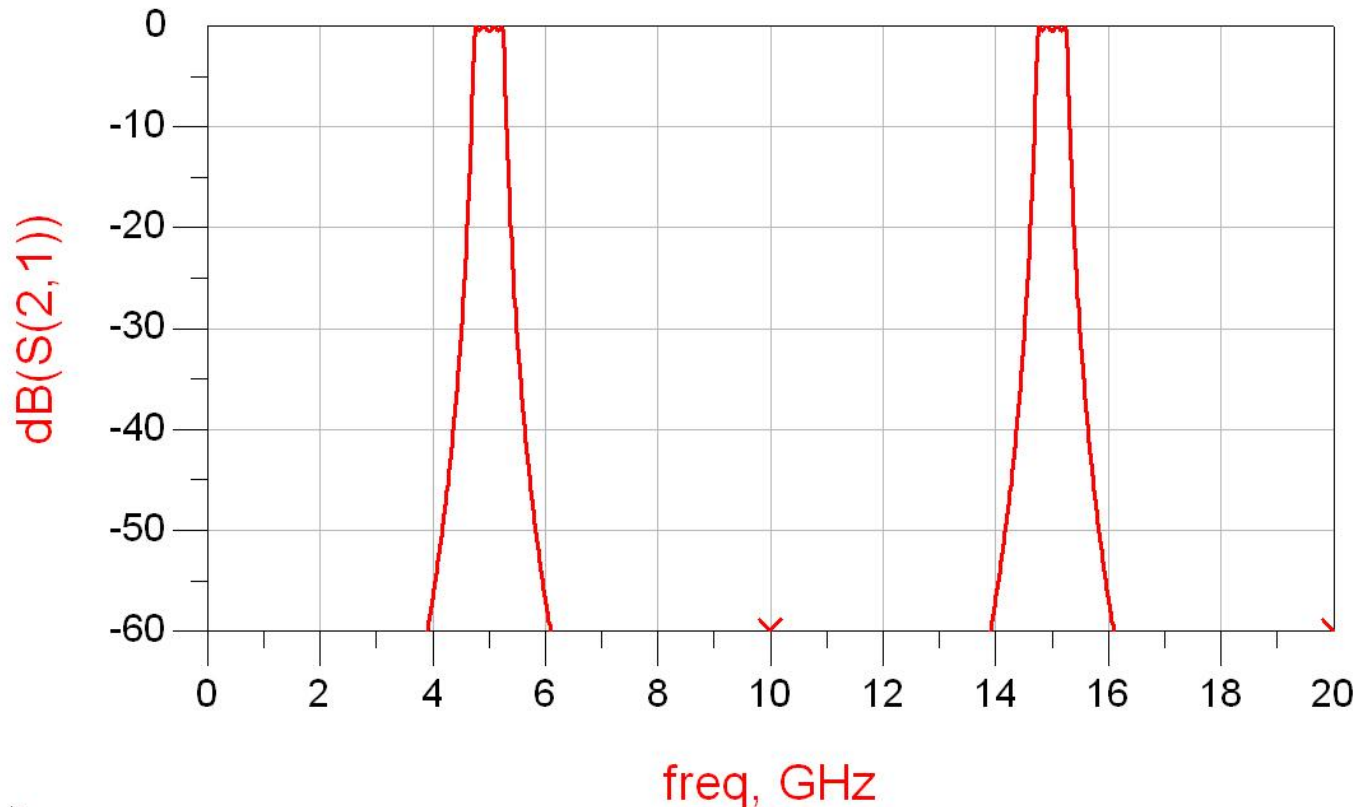
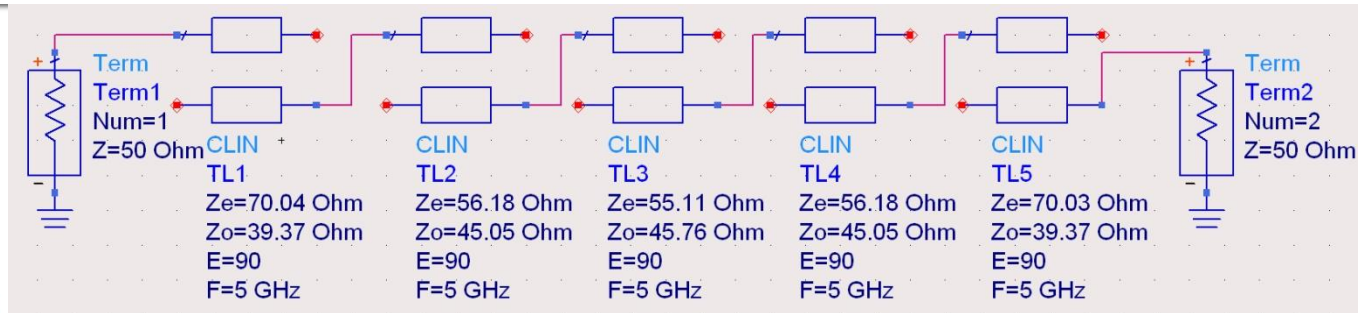
# Exemplu

- 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:

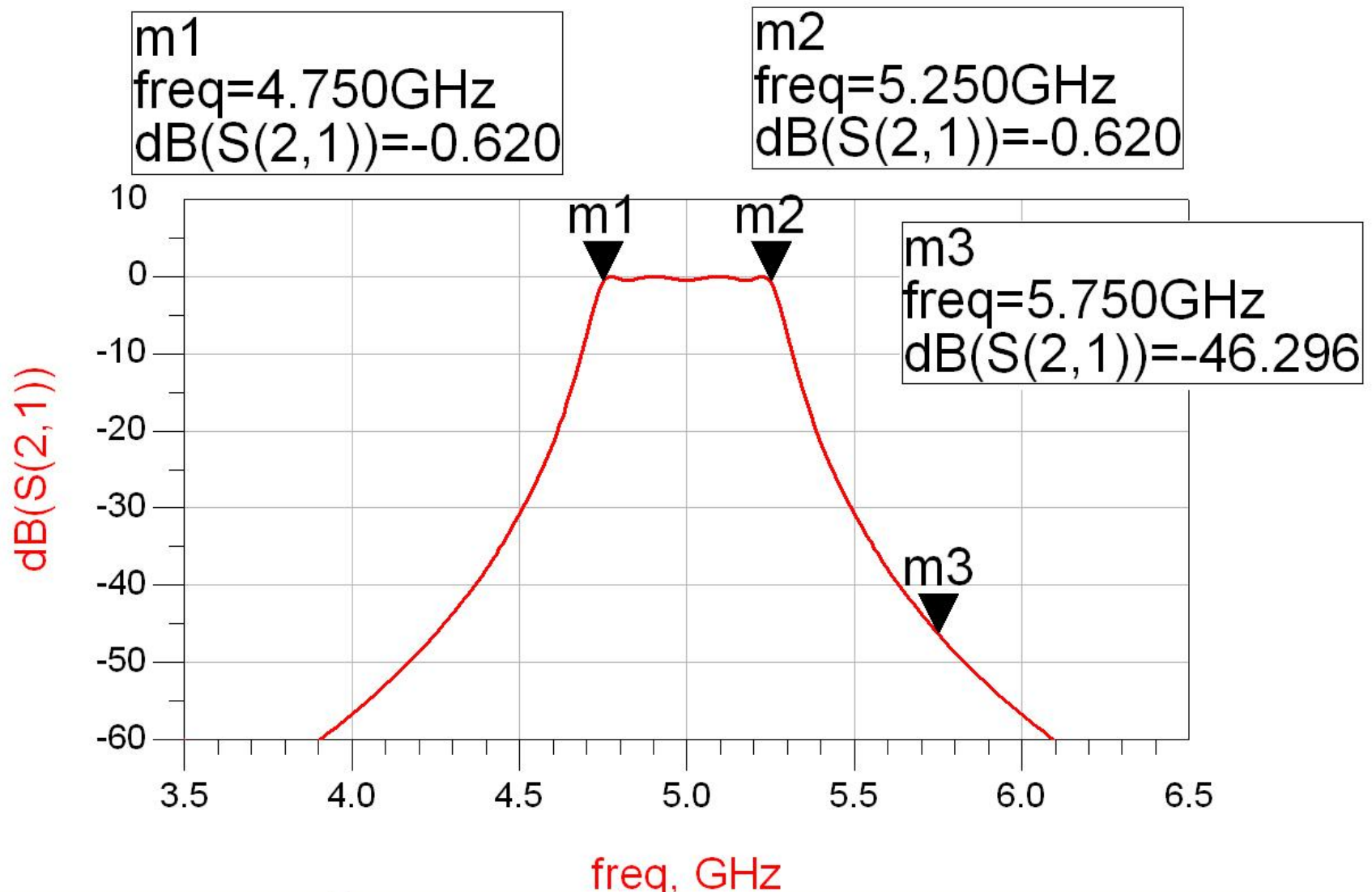
n	g	$Z_0 J_n$	$Z_{0e}$	$Z_{0o}$
1	1.6703	0.306664	70.04	39.37
2	1.1926	0.111295	56.18	45.05
3	2.3661	0.09351	55.11	45.76
4	0.8419	0.111294	56.18	45.05
5	1.9841	0.306653	70.03	39.37



# ADS – FTB coupled line



# ADS – FTB coupled line



# Example

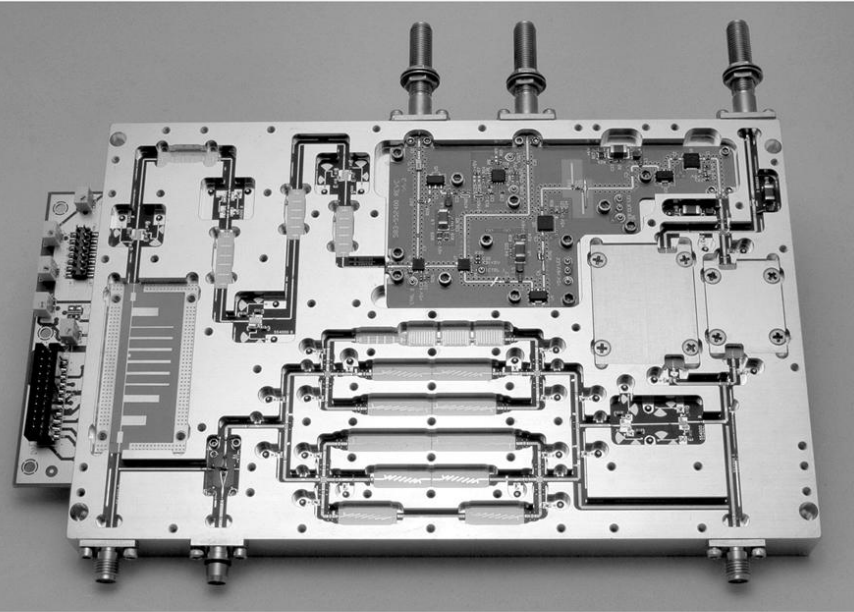
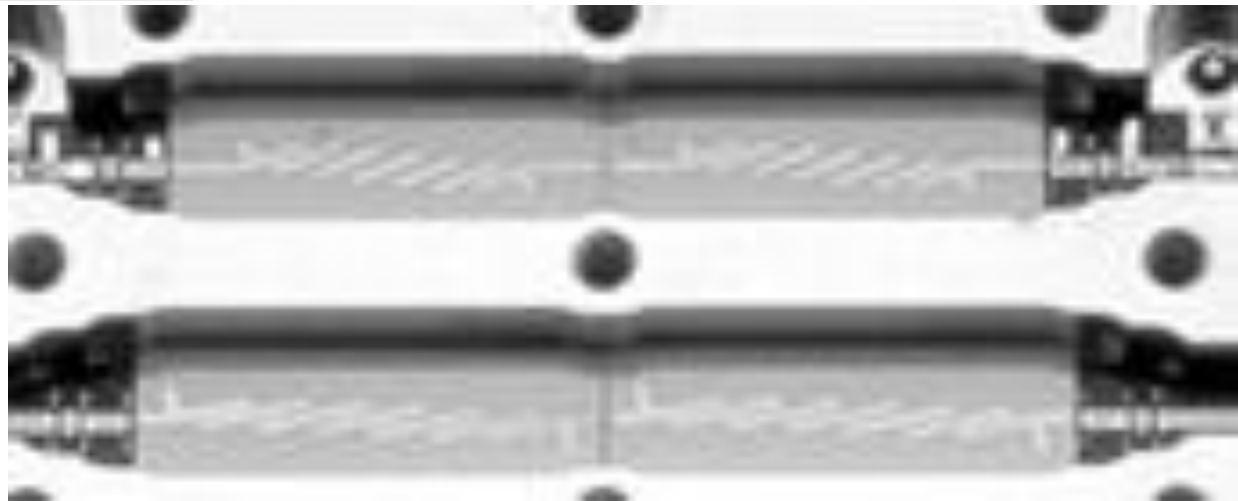
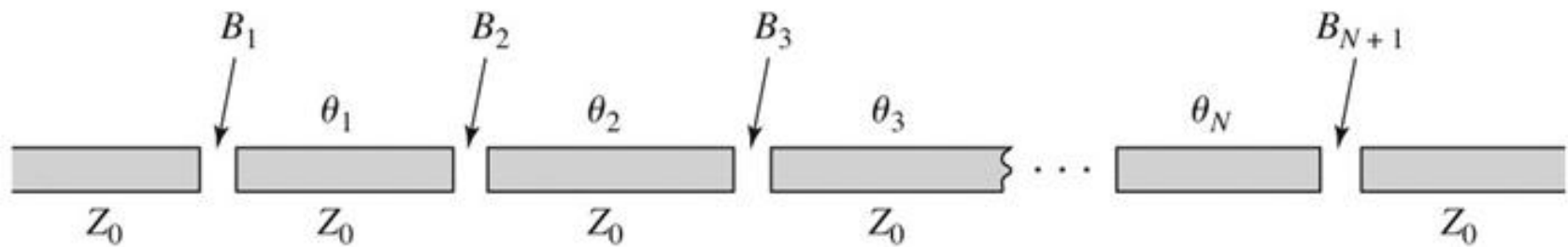


Figure 8.55  
Courtesy of LNX Corporation, Salem, N.H.

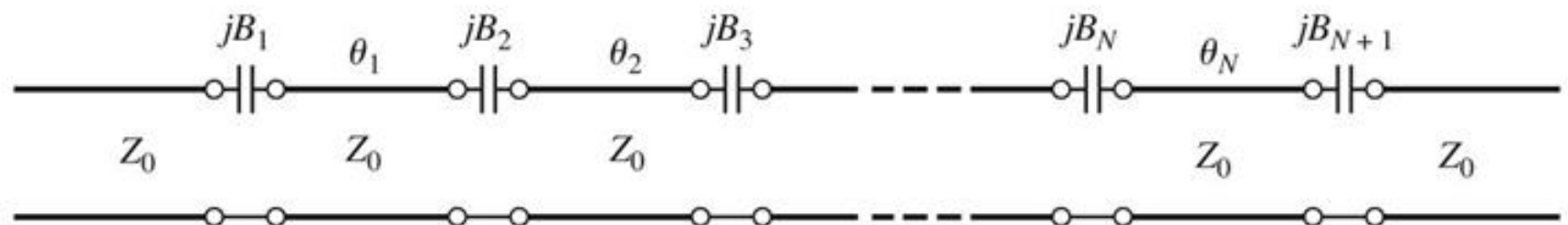


# Filtru cu rezonatoare serie cuplate capacitiv

- 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  $\phi = \pi$ ,  $l = \lambda/2$ )

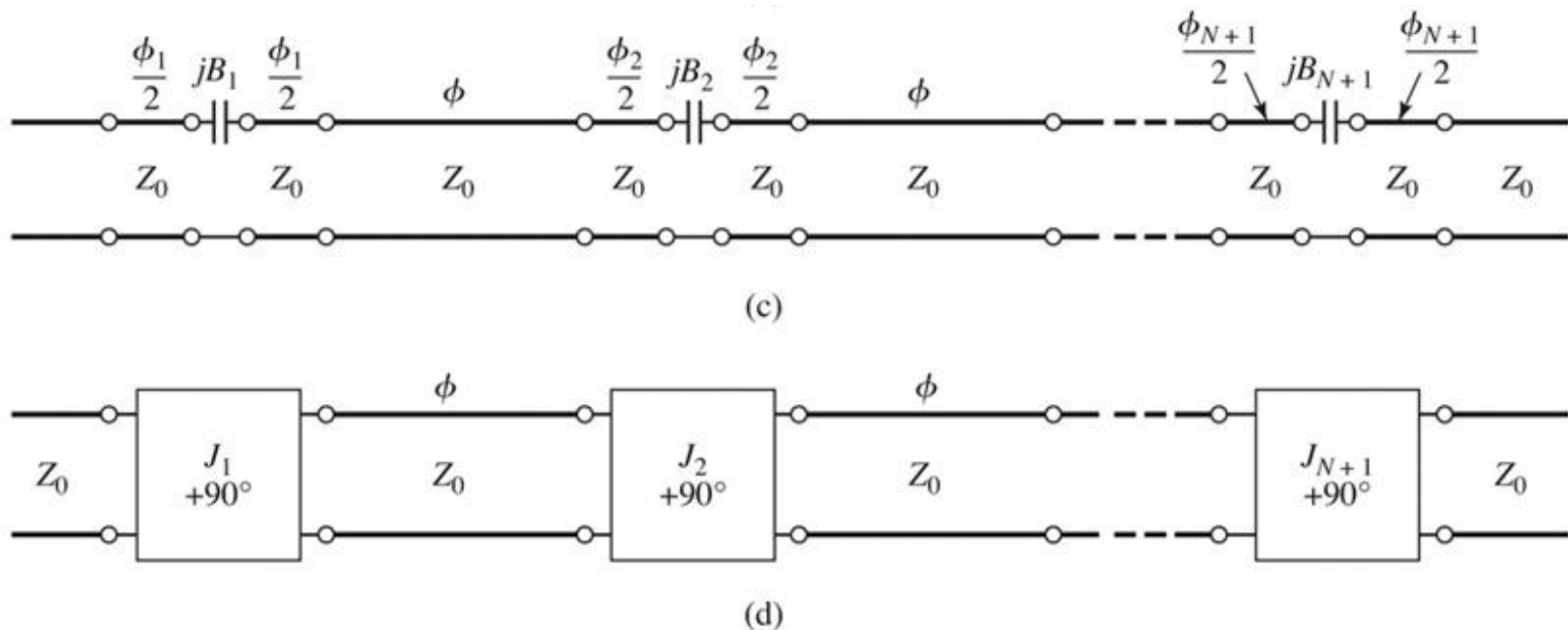


Figure 8.50

# 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

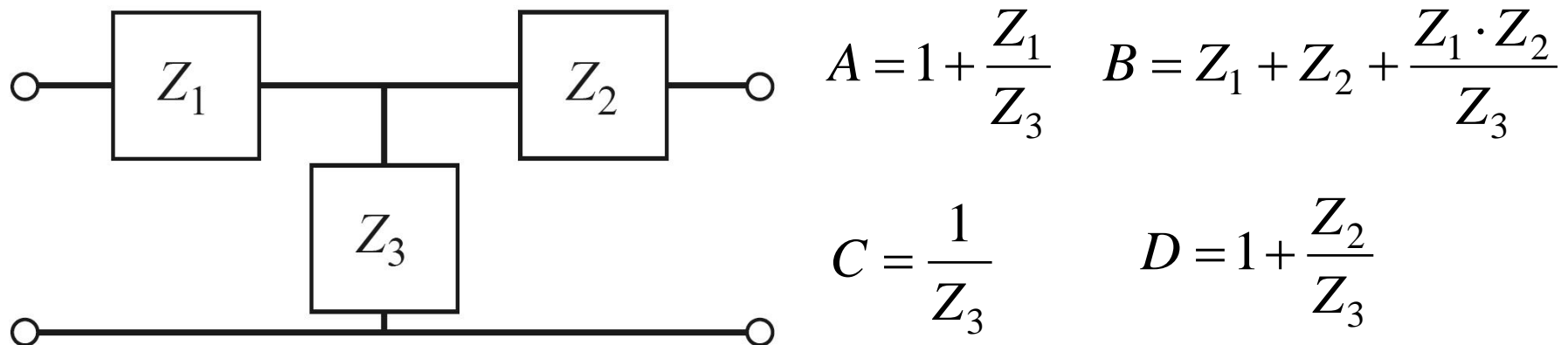
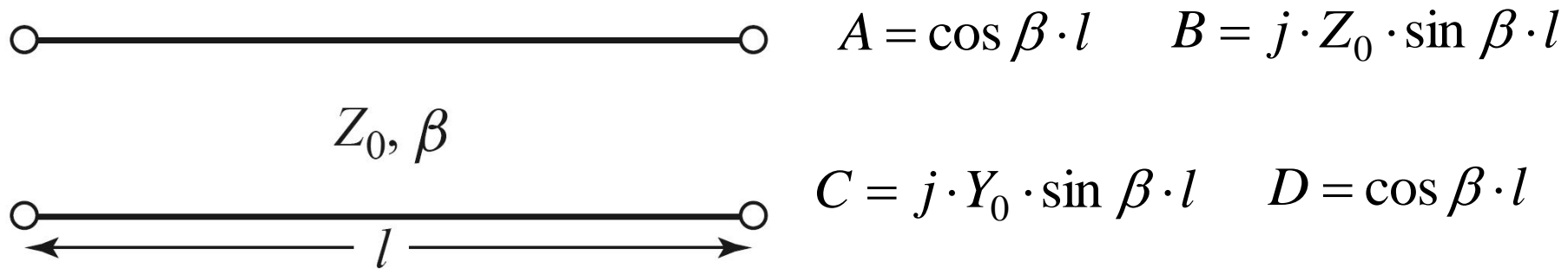
$$\phi_n = -\tan^{-1}(2 \cdot Z_0 \cdot B_n), n = \overline{1, N+1} \quad \phi_n < 0, n = \overline{1, N+1}$$

- 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

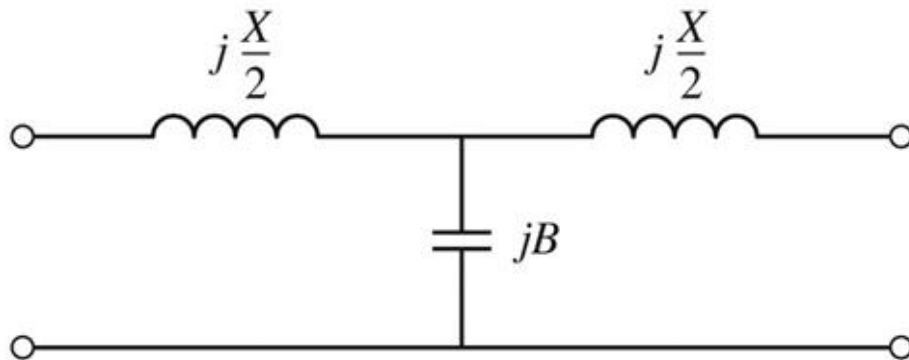
$$Z_3 = \frac{1}{j \cdot Y_0 \cdot \sin \beta \cdot l}$$

- 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



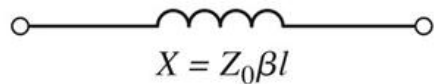
$$\frac{X}{2} = Z_0 \cdot \tan \frac{\beta \cdot l}{2}$$
$$B = \frac{1}{Z_0} \cdot \sin \beta \cdot l$$



# Circuite echivalente pentru sectiuni scurte de linii

- In functie de valoarea impedantei caracteristice

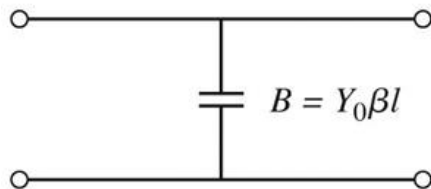
- impedanta ridicata  $Z_0 \gg$



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



- 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

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

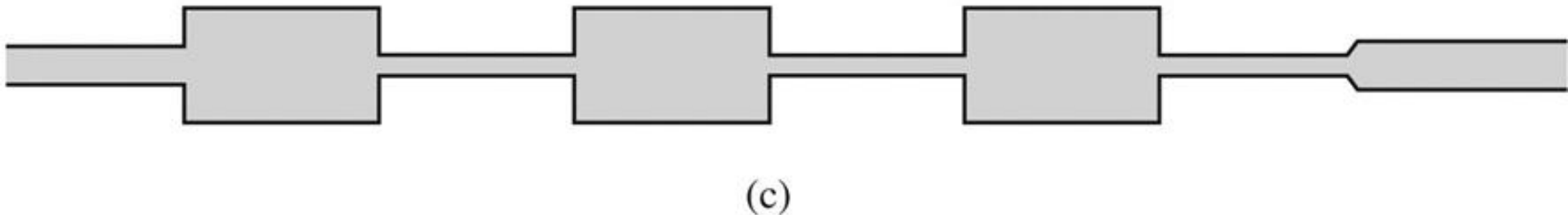
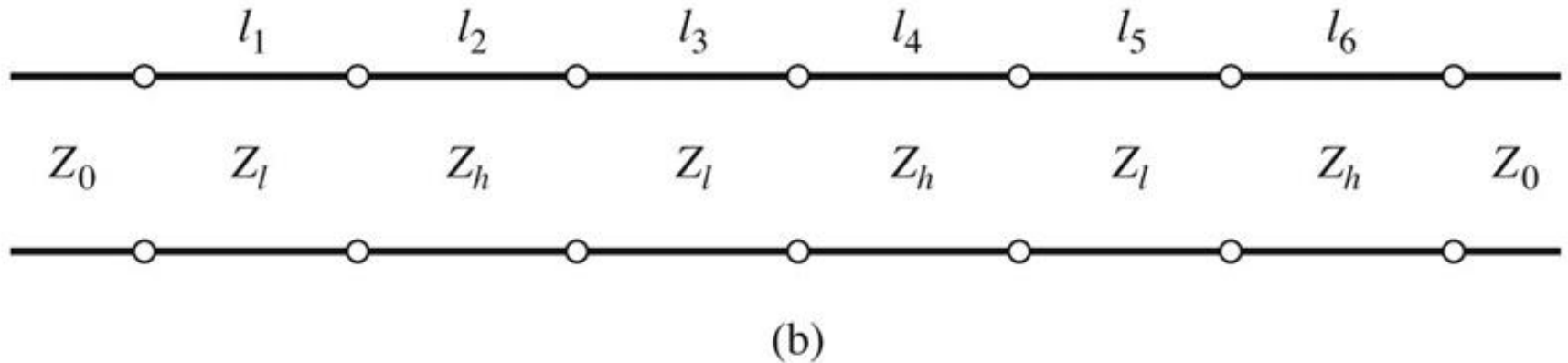
- linii cu impedanta caracteristica mica pentru a implementa o capacitate

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

- 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

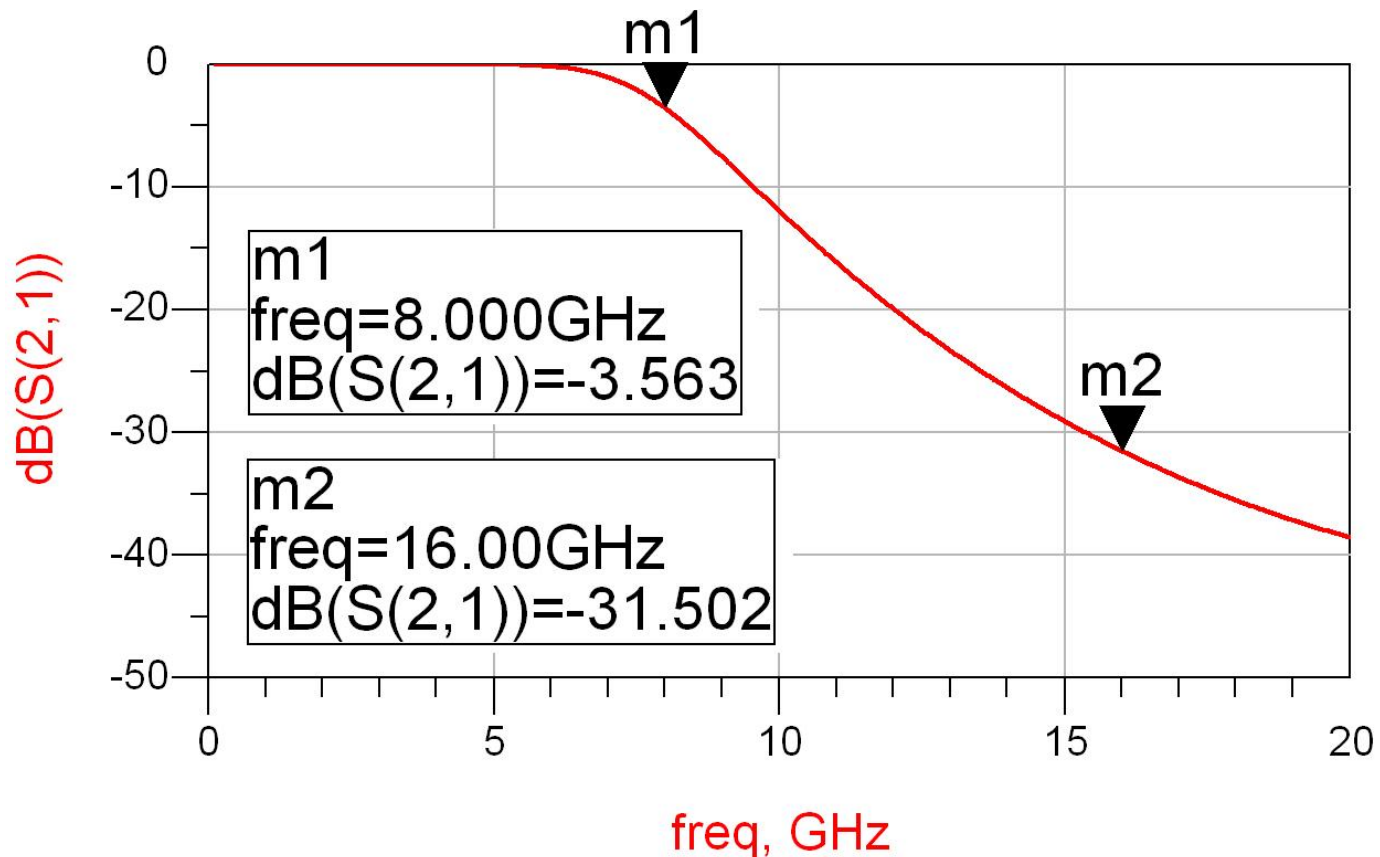
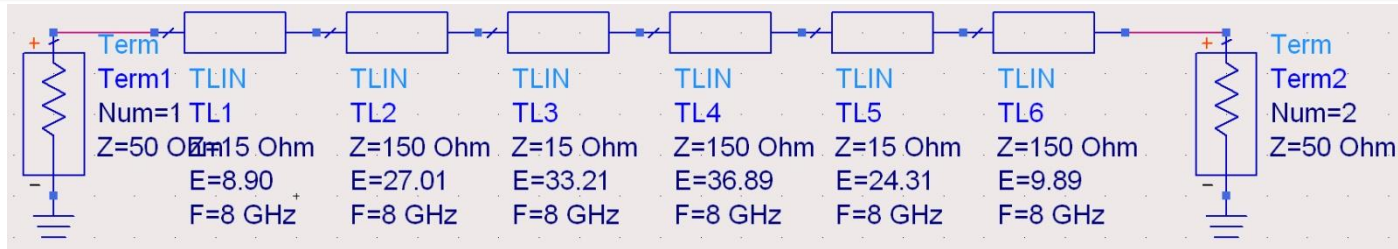


# Exemplu

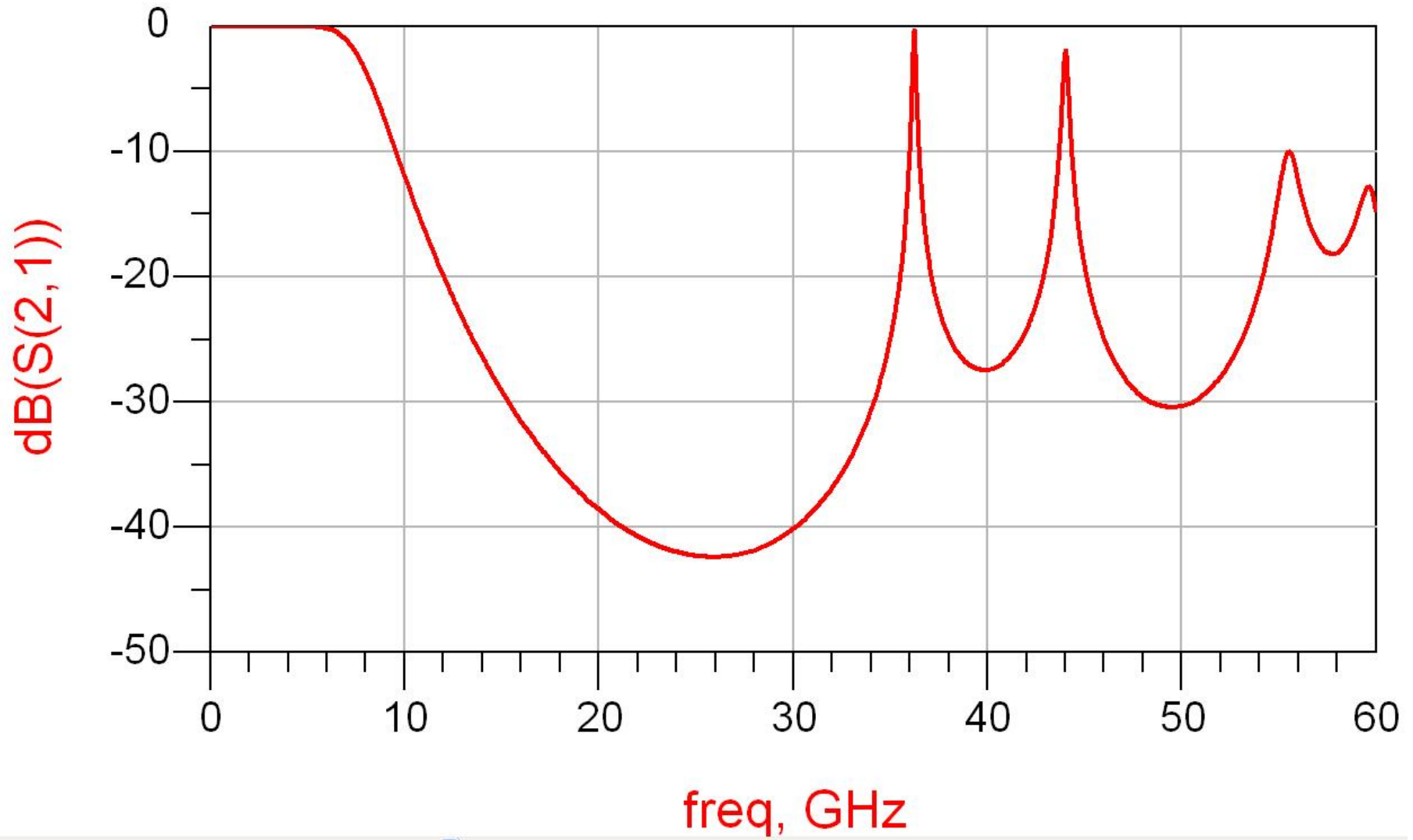
- FTJ cu frecventa de taiere 8GHz, de ordinul 6. Impedanta maxima realizabila este  $150\Omega$  iar cea minima  $15\Omega$ .

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

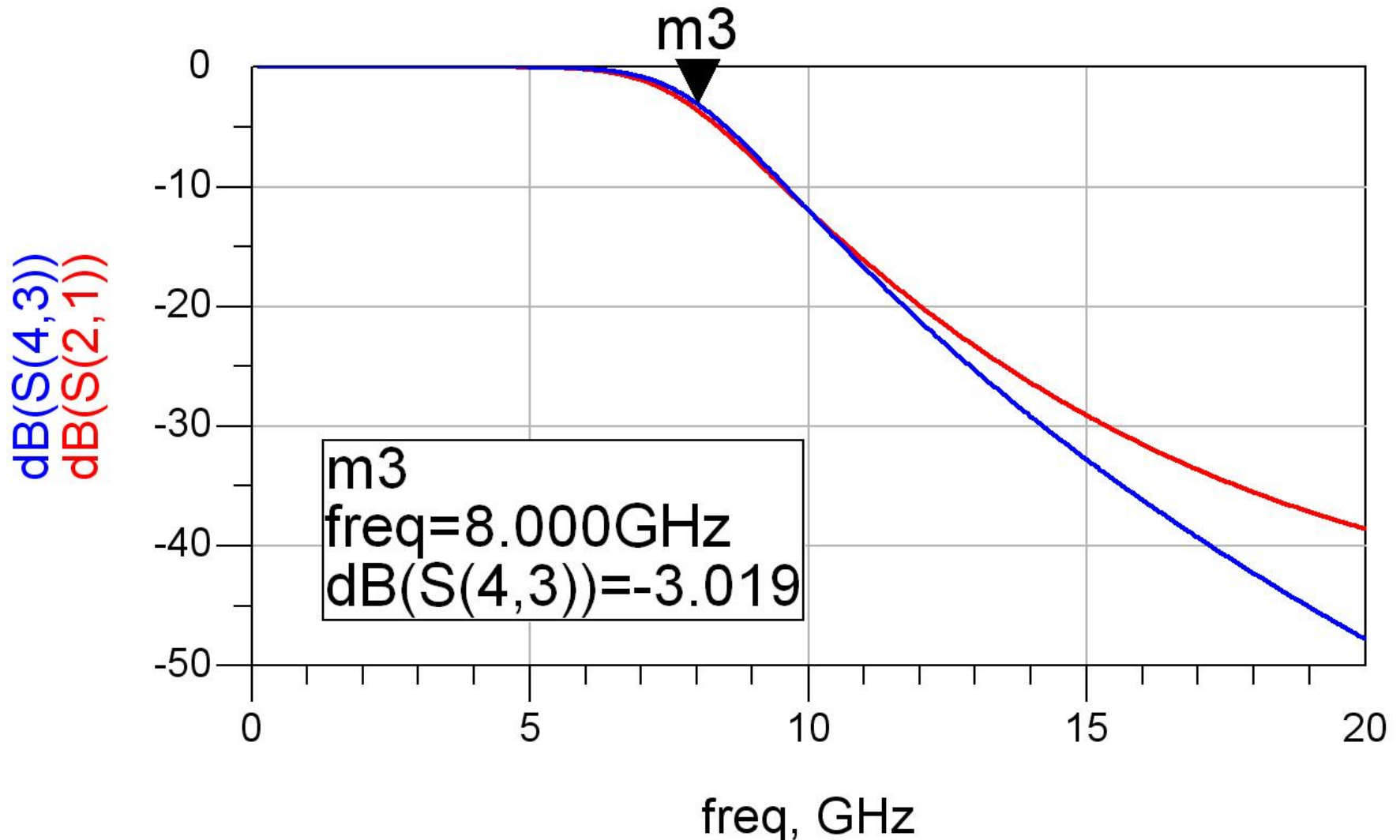
# ADS – FTJ stepped impedance



# ADS – FTJ stepped impedance



# ADS – FTJ comparatie cu elemente concentrate



# Example

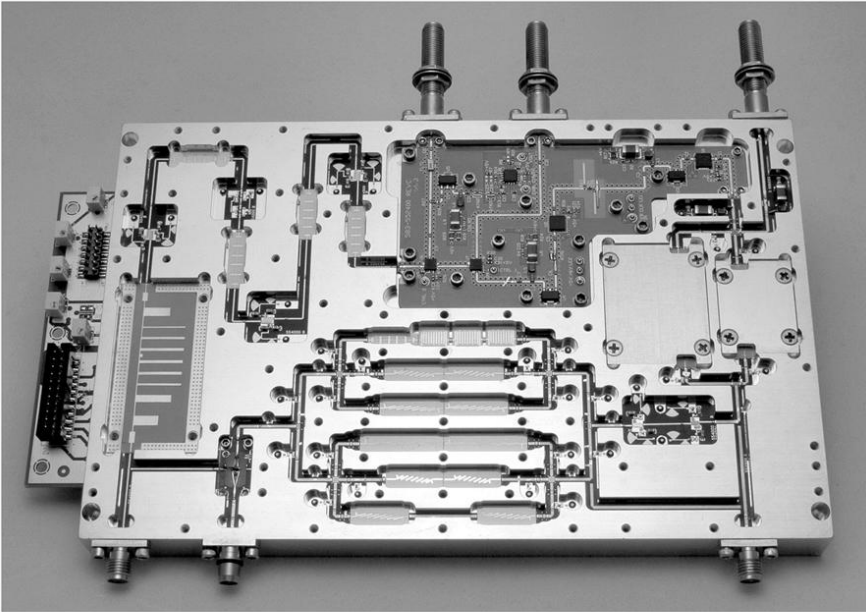
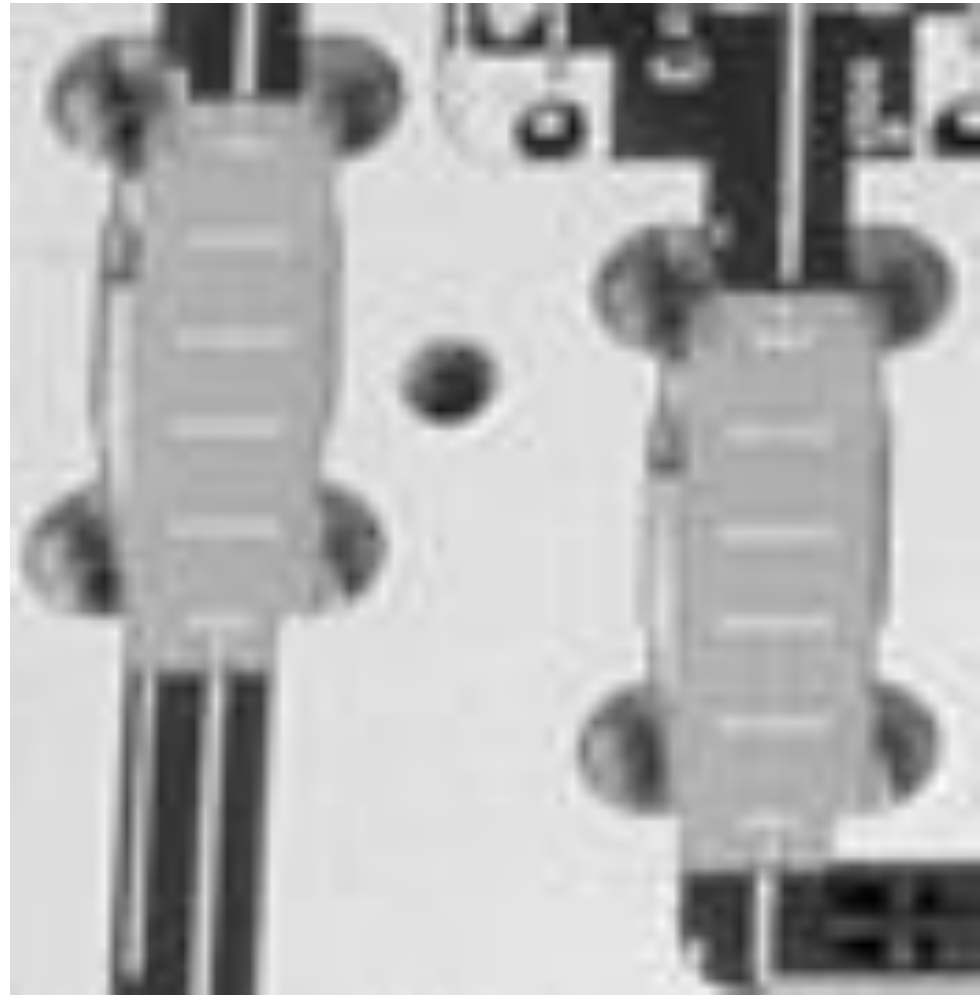


Figure 8.55  
Courtesy of LNX Corporation, Salem, N.H.





# Contact

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