Curs 4

2022/2023

Dispozitive şi 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) ≈ +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

Documentatie

- http://rf-opto.etti.tuiasi.ro

Documentatie

- RF-OPTO
  - http://rf-opto.etti.tuiasi.ro ~~Moodle~~
- Fotografie
  - de trimis pe rf-opto
  - necesara la laborator/curs
  - bonus activitate 0.5p/1p

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)

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:

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

344bd9f

Trimite

Online

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

Online

- acces email/parola

Parola

- primita prin **email**

Important message from RF-OPTO Inbox ×

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 atentia: 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	Correspondents
Important message from RF-OPTO	POPESCU GOPO ION
Validation of MDCR exam from 02/05/2020	[redacted]
[redacted]	[redacted]

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 atentia: POPESCU GOPO ION

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Parola: [redacted]

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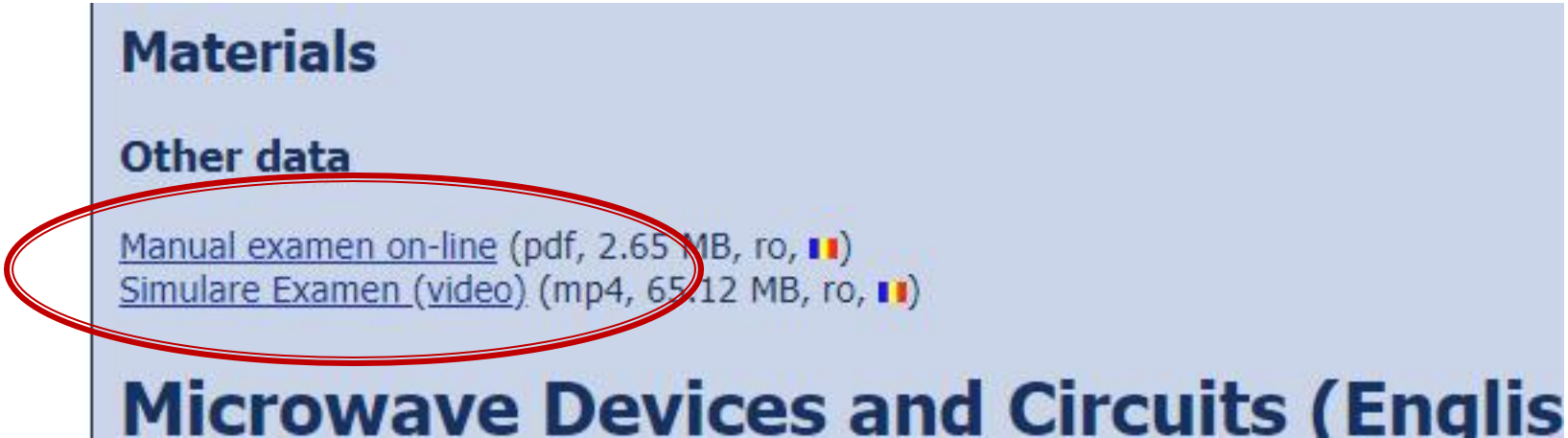
Password: [redacted]

Login to the server, with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

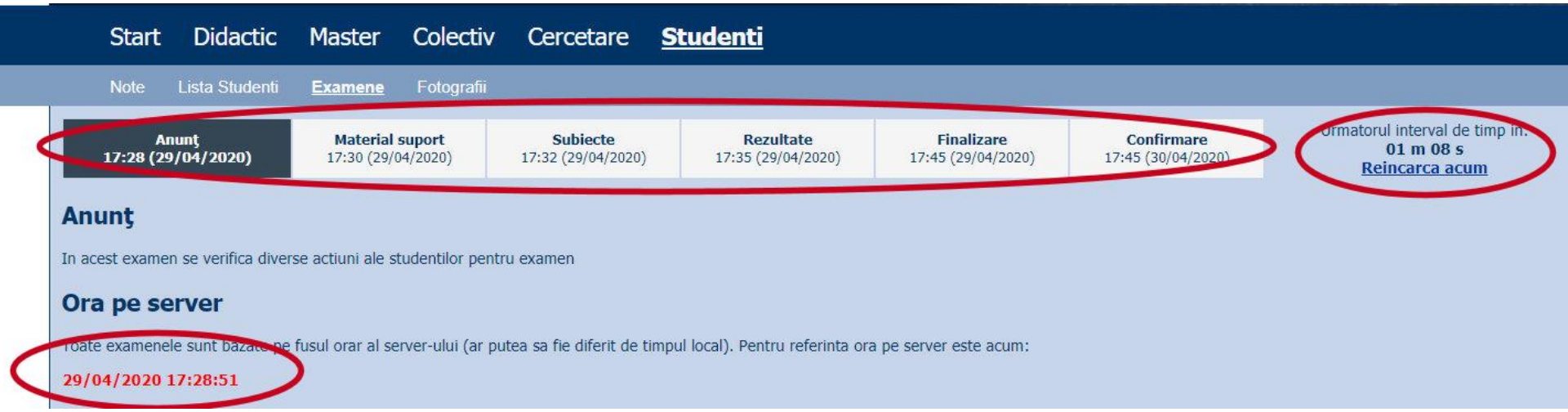
Manual examen online

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



Examen online

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



Examen online laborator 1

Examene online: 2022/2023

Disciplina: DCMR (Dispozitive si circuite de microunde pentru r

Pas 3

Nr.	Titlu	Start	Stop	Text
1	Laborator 1 (s3-5)	24/10/2022; 08:00	09/11/2022; 15:00	Temele individuale pent ...

Cuprins

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

Bibliografie

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

Examen: Reprezentare logaritmică

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

0 dB	= 1
+ 0.1 dB	= 1.023 (+2.3%)
+ 3 dB	= 2
+ 5 dB	= 3
+ 10 dB	= 10
-3 dB	= 0.5
-10 dB	= 0.1
-20 dB	= 0.01
-30 dB	= 0.001

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

0 dBm	= 1 mW
3 dBm	= 2 mW
5 dBm	= 3 mW
10 dBm	= 10 mW
20 dBm	= 100 mW
-3 dBm	= 0.5 mW
-10 dBm	= 100 μW
-30 dBm	= 1 μW
-60 dBm	= 1 nW

[dBm] + [dB] = [dBm]

[dBm/Hz] + [dB] = [dBm/Hz]

[x] + [dB] = [x]

Examen

- Operatii cu numere complexe!
- $z = a + j \cdot b$; $\mathbf{j^2 = -1}$

Linii de transmisie in mod TEM

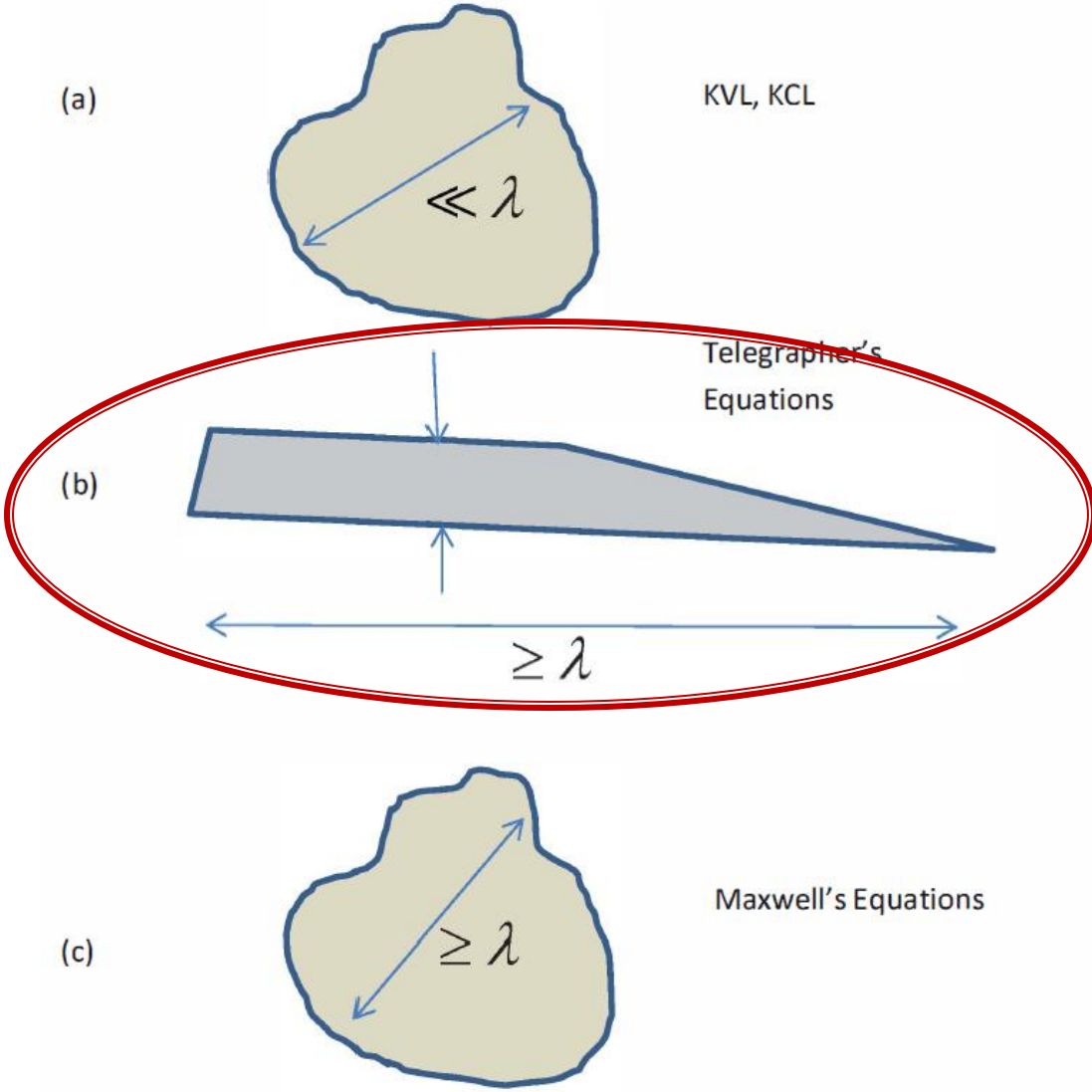
Cuprins

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

Lungime electrica

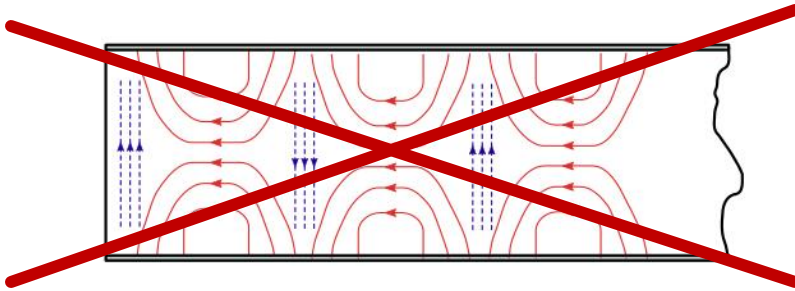
- Comportarea (descrierea) unui circuit depinde de lungimea sa electrica la frecventele de interes
  - E≈0 → Kirchhoff
  - E>0 → propagare

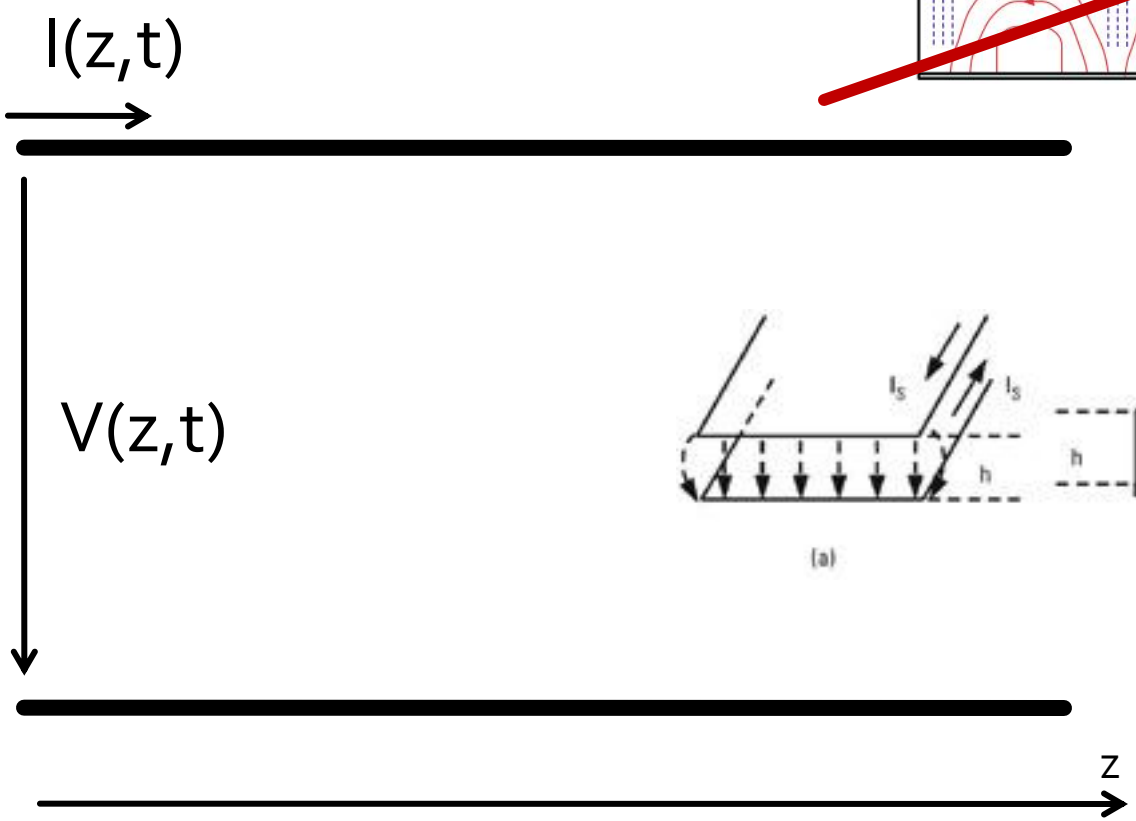
$$E = \beta \cdot l = \frac{2\pi}{\lambda} \cdot l = 2\pi \cdot \left(\frac{l}{\lambda} \right)$$

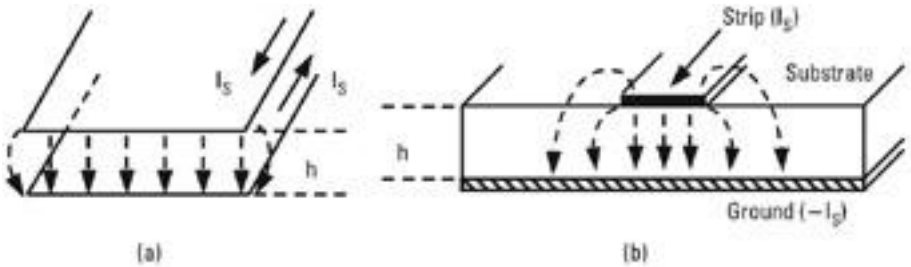


Linie de transmisie

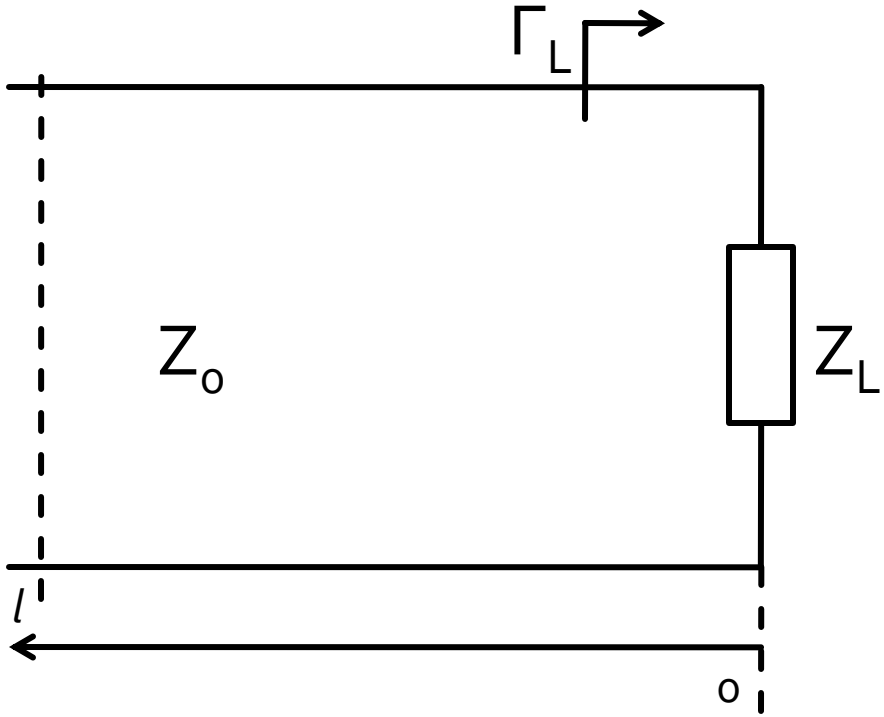
- mod TEM, doi conductori







Linie fara pierderi



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

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

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

- coeficient de reflexie in tensiune

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

- Z_o real

Linie fara pierderi

$$V(z) = V_0^+ \cdot \left(e^{-j\cdot\beta\cdot z} + \Gamma \cdot e^{j\cdot\beta\cdot z}\right) \qquad I(z) = \frac{V_0^+}{Z_0} \cdot \left(e^{-j\cdot\beta\cdot z} - \Gamma \cdot e^{j\cdot\beta\cdot z}\right)$$

- Puterea medie

$$P_{avg} = \frac{1}{2} \cdot \mathrm{Re}\left\{V(z) \cdot I(z)^*\right\} = \frac{1}{2} \cdot \frac{\left|V_0^+\right|^2}{Z_0} \cdot \mathrm{Re}\left\{1 - \Gamma^* \cdot \underbrace{e^{-2j\cdot\beta\cdot z} + \Gamma \cdot e^{2j\cdot\beta\cdot z}}_{\left(z - z^*\right) = \mathrm{Im}} - \left|\Gamma\right|^2\right\}$$

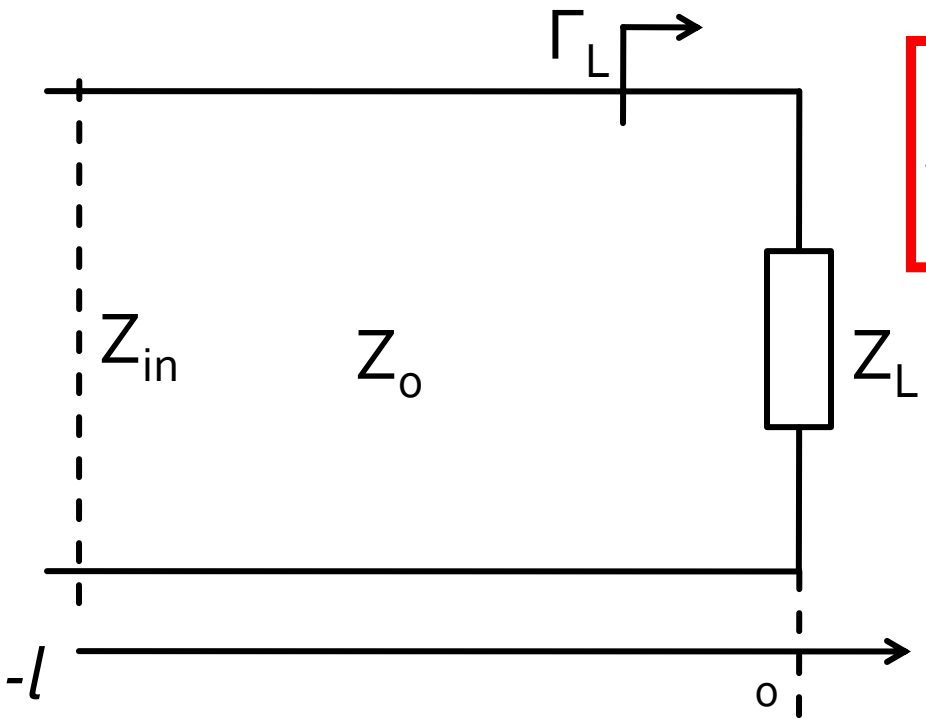
$$P_{avg} = \frac{1}{2} \cdot \frac{\left|V_0^+\right|^2}{Z_0} \cdot \left(1 - \left|\Gamma\right|^2\right)$$

- Puterea transmisa sarcinii = Puterea incidenta - Puterea "reflectata"
- Return Loss [dB]

$$\mathrm{RL} = -20 \cdot \log\left|\Gamma\right| \quad [\mathrm{dB}]$$

Linie fara pierderi

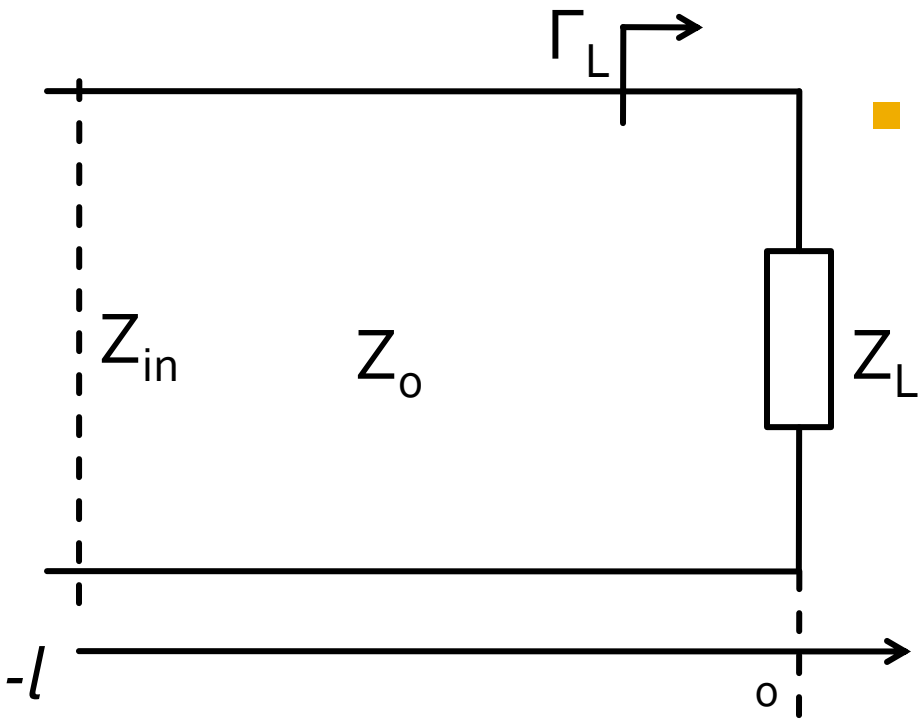
- impedanta la intrarea liniei de impedanta caracteristica Z_o, de lungime l, terminata cu impedanta Z_L



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

Linie fara pierderi, cazuri particulare

- $l = k \cdot \lambda/2$ $\quad \beta \cdot l = \frac{2\pi}{\lambda} \cdot l = k \cdot \pi \quad \tan \beta \cdot l = 0$ $\quad \boxed{Z_{in} = Z_L}$
- $l = \lambda/4 + k \cdot \lambda/2$ $\quad \tan \beta \cdot l \to \infty$ $\quad \boxed{Z_{in} = \frac{Z_0^2}{Z_L}}$



- Transformatorul in sfert de lungime de unda

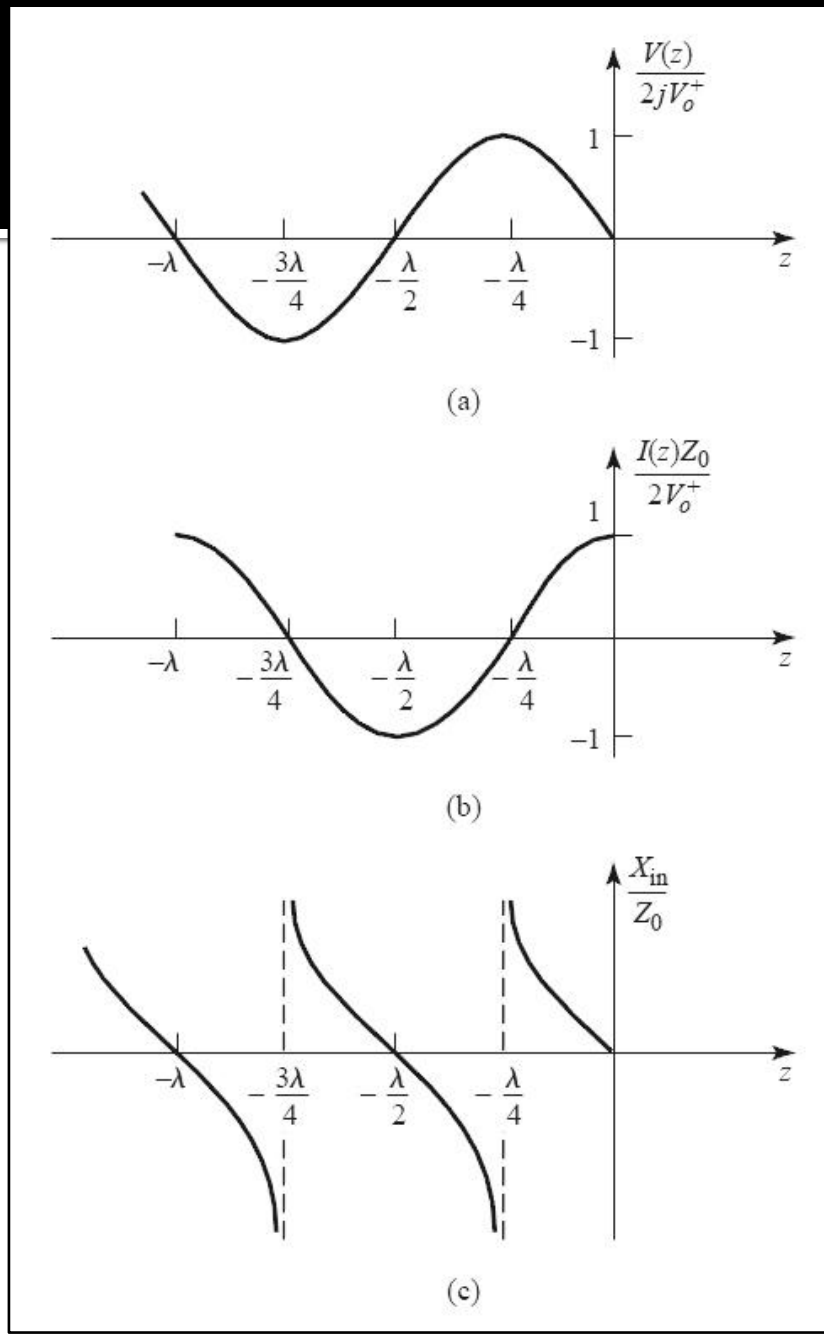
$$\boxed{Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}}$$

Linie in scurtcircuit

- $Z_L = 0$
- reactanța pură
  - +/- → in funcție de *l*

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

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

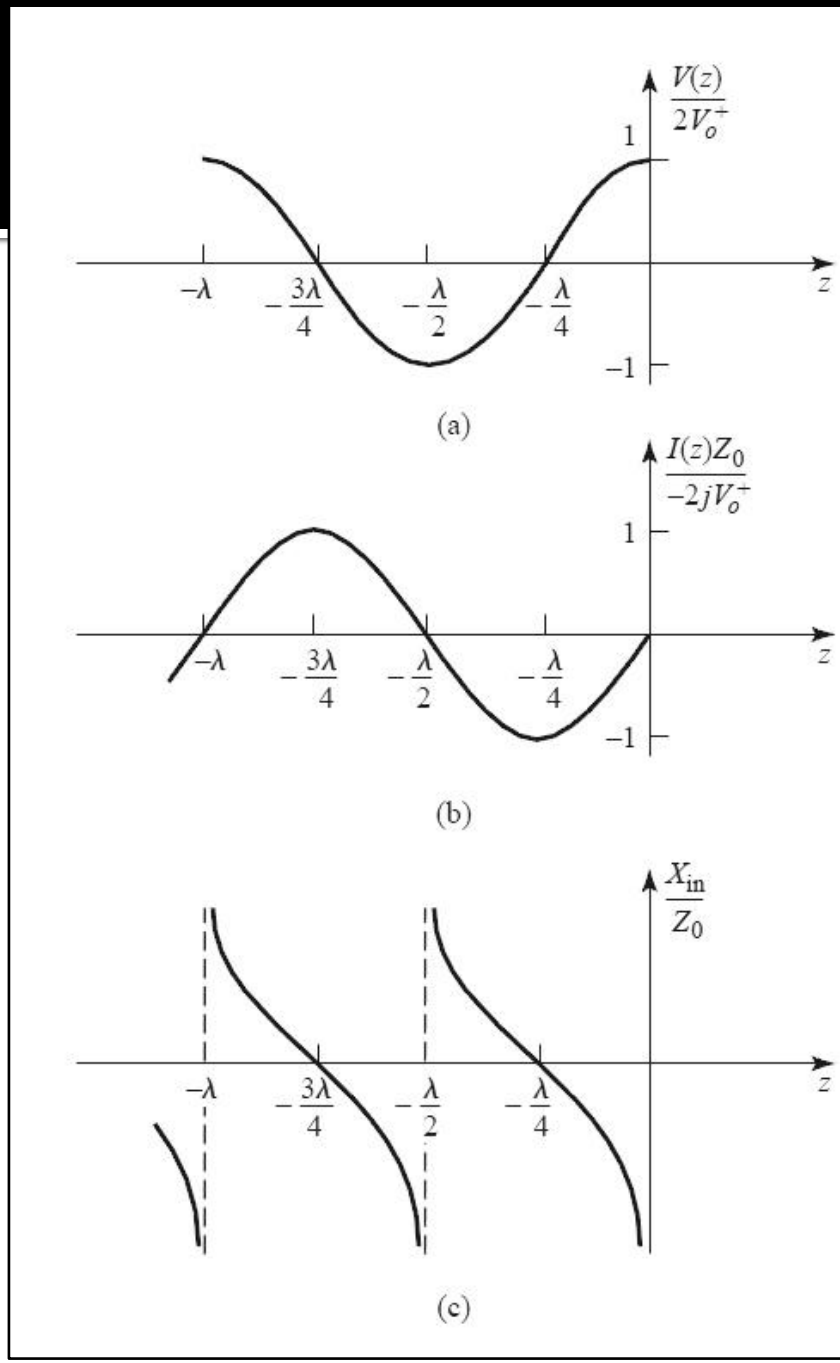


Linie in gol

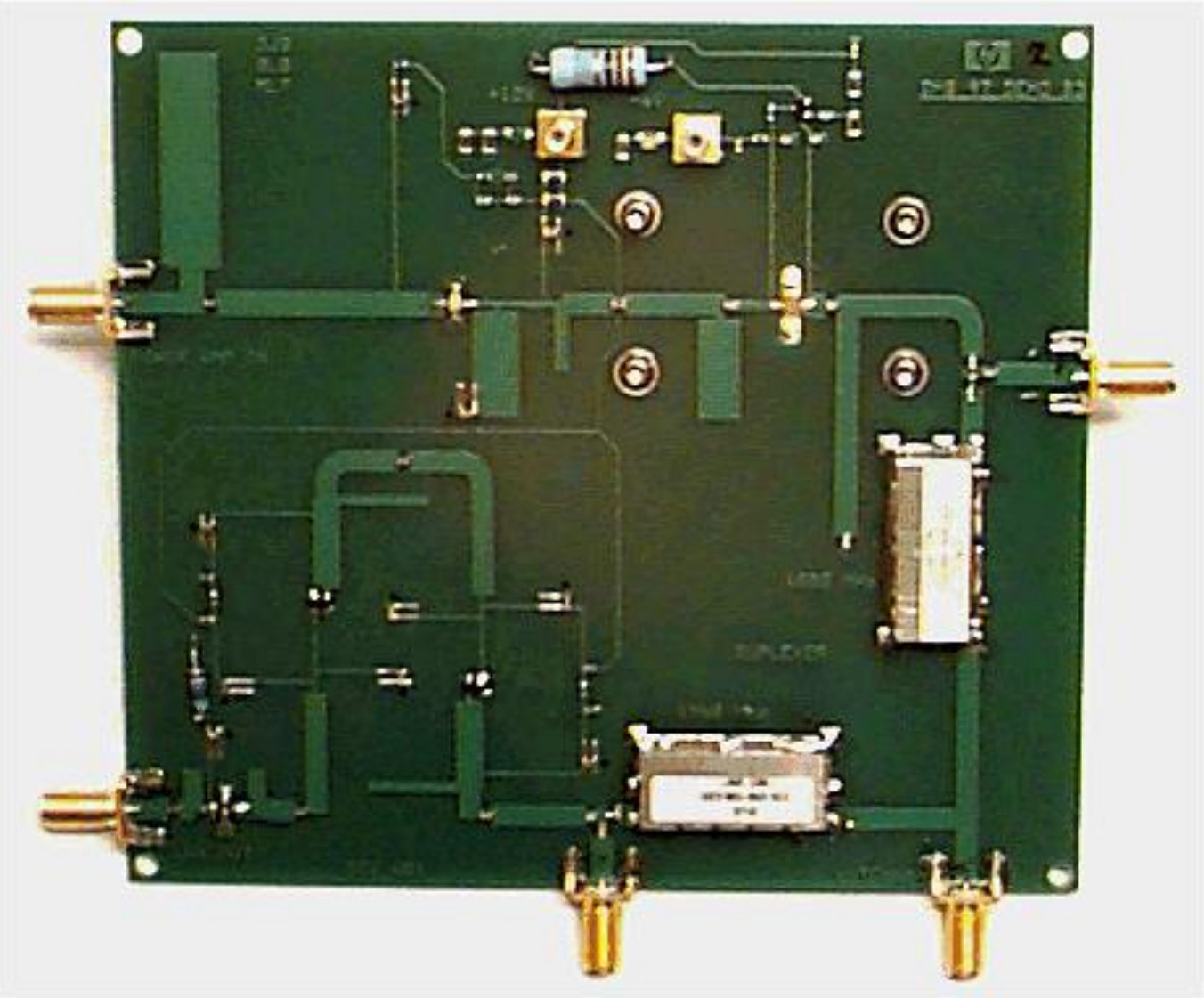
- $Z_L = \infty \longrightarrow 1 / Z_L = 0$
- reactanța pură
  - +/- → in funcție de *l*

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

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



Exemple



Factor de unda stationara

$$V(z) = V_0^+ \cdot \left(e^{-j\cdot\beta\cdot z} + \Gamma \cdot e^{j\cdot\beta\cdot z}\right) \qquad |V(z)| = |V_0^+| \cdot |e^{-j\cdot\beta\cdot z}| \cdot |1 + \Gamma \cdot e^{2j\cdot\beta\cdot z}| \qquad \Gamma = |\Gamma| \cdot e^{j\theta}$$

$$|V(z)| = |V_0^+| \cdot |1 + |\Gamma| \cdot e^{\theta + 2j\cdot\beta\cdot z}|$$

amplitudine maxima pentru $e^{\theta+2j\cdot\beta\cdot z} = 1$ $\qquad V_{\max} = |V_0^+| \cdot (1 + |\Gamma|)$

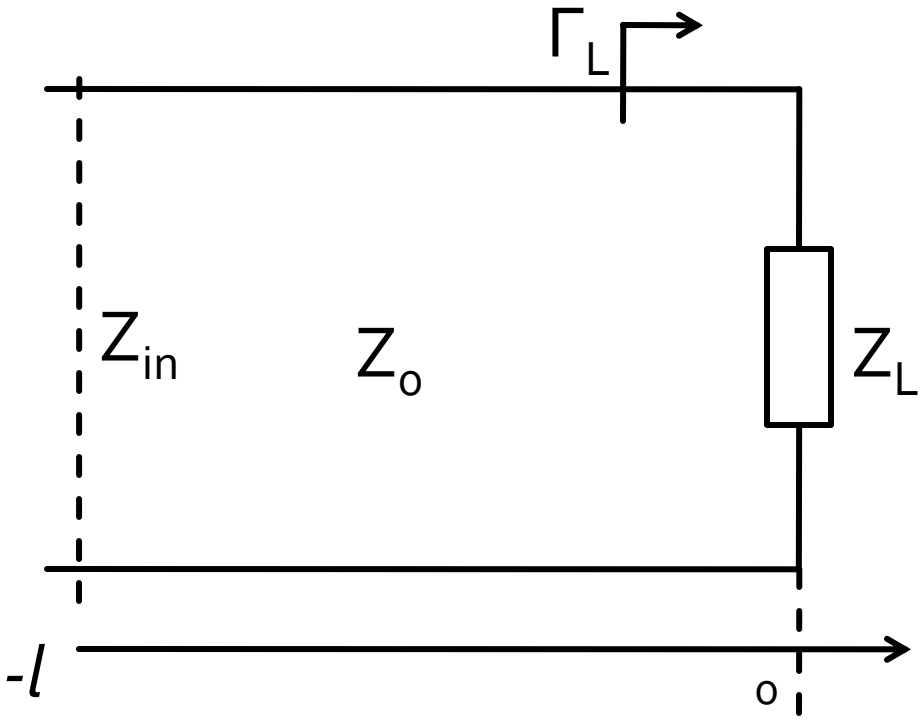
amplitudine minima pentru $e^{\theta+2j\cdot\beta\cdot z} = -1$ $\qquad V_{\min} = |V_0^+| \cdot (1 - |\Gamma|)$

- se defineste factorul de unda stationara
  - (Voltage) Standing Wave Ratio

$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

  - numar real $1 \le VSWR < \infty$
  - o masura a dezadaptarii (SWR = 1 semnifica adaptare)

Linie fara pierderi +/-



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

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

$$I(z) = I_0^+ e^{-\gamma \cdot z} + I_0^- e^{\gamma \cdot z}$$

$$\Gamma(-l) = \Gamma(0) \cdot e^{-2j \cdot \beta \cdot l}$$

$$\Gamma_{in} = \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}$$

Transfer de putere

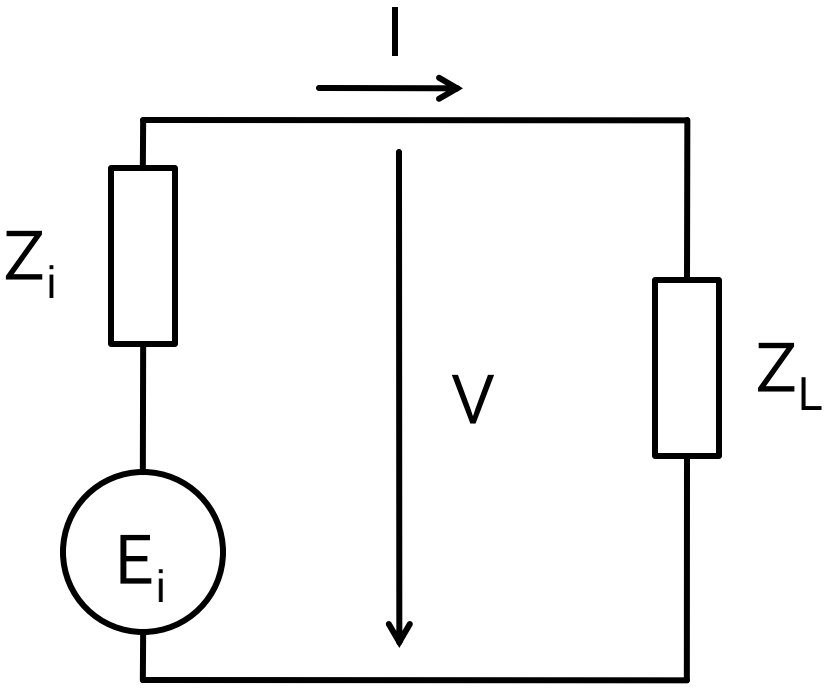
Adaptarea de impedanța

Cuprins

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

Adaptare

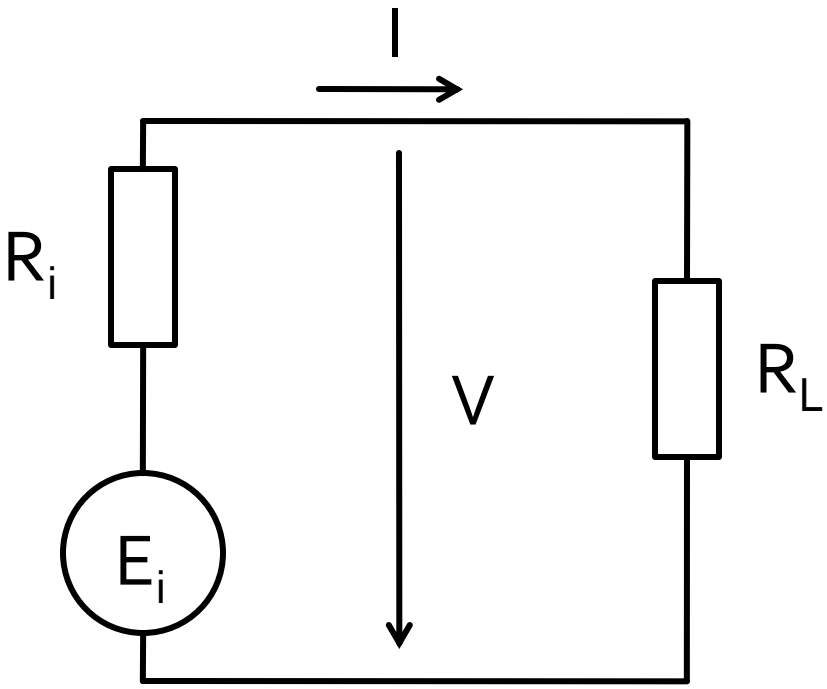
- Generator **adaptat** la sarcina ?



- valori impedanta ?
- reflexii ?

Adaptare, impedante reale

- Generator adaptat la sarcina



$$I = \frac{E_i}{R_i + R_L}$$

$$V = \frac{E_i \cdot R_L}{R_i + R_L}$$

$$P_L = R_L \cdot I^2$$

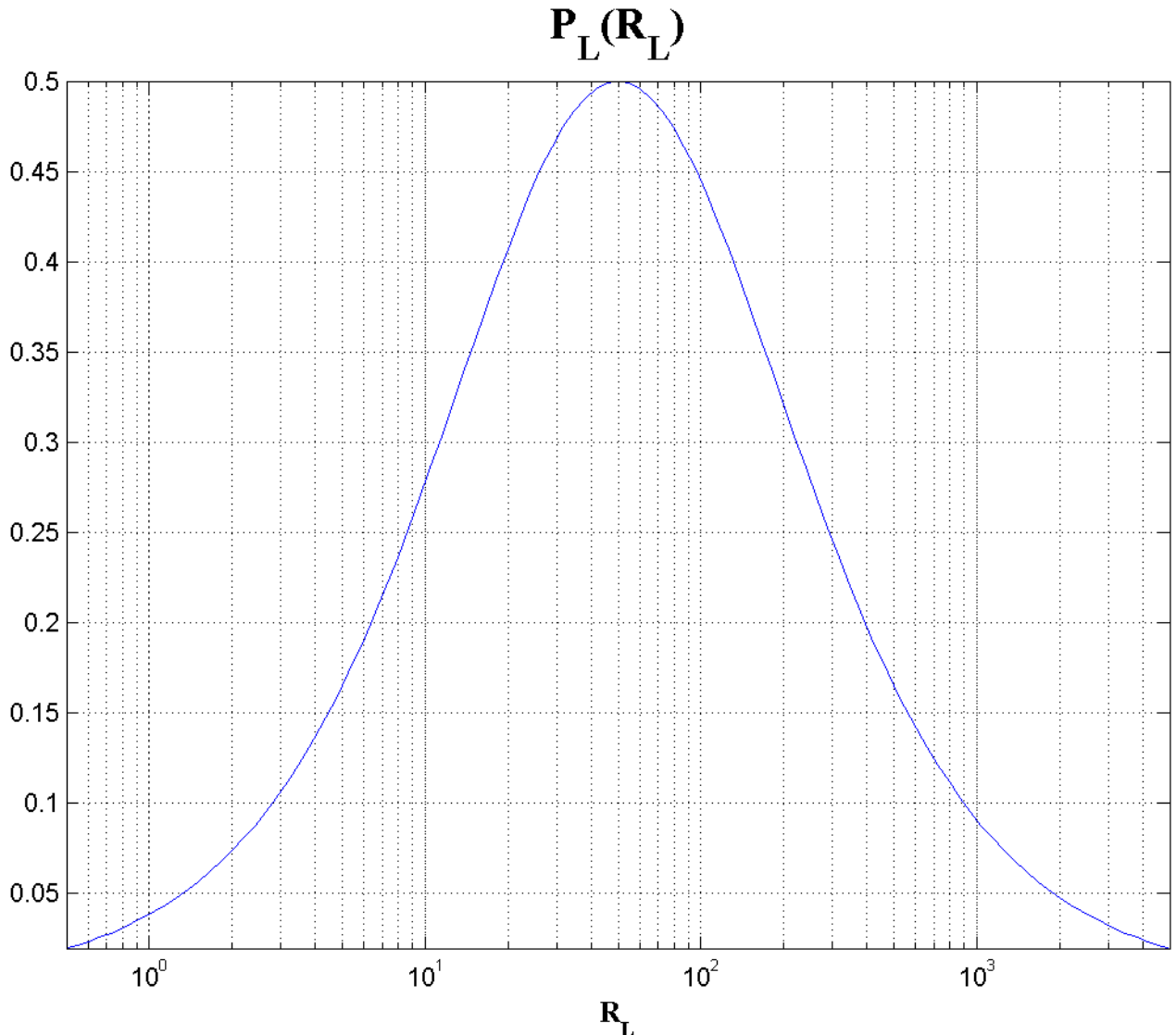
$$P_L = \frac{R_L \cdot E_i^2}{(R_i + R_L)^2}$$

Adaptare , impedante reale

$$P_L = R_L \cdot I^2 \qquad P_L = \frac{R_L \cdot E_i^2}{(R_i + R_L)^2}$$

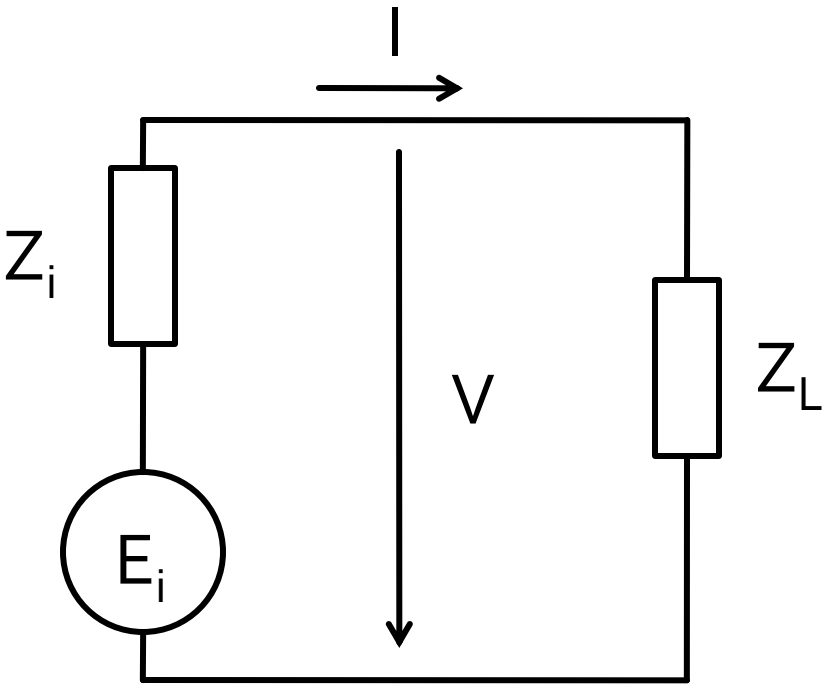
- Putere pe sarcina
  - $R_i = 50\Omega$
  - $R_L = 0 \rightarrow P_L = 0$
  - $R_L = \infty \rightarrow P_L = 0$

Adaptare , impedante reale



Adaptare, impedante complexe

- Generator adaptat la sarcina



$$I = \frac{E_i}{Z_i + Z_L}$$

$$V = \frac{E_i \cdot Z_L}{Z_i + Z_L}$$

$$P_L = \operatorname{Re} Z_L \cdot |I|^2$$

$$P_L = \operatorname{Re} Z_L \cdot \left| \frac{E_i}{Z_i + Z_L} \right|^2$$

Adaptare

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

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

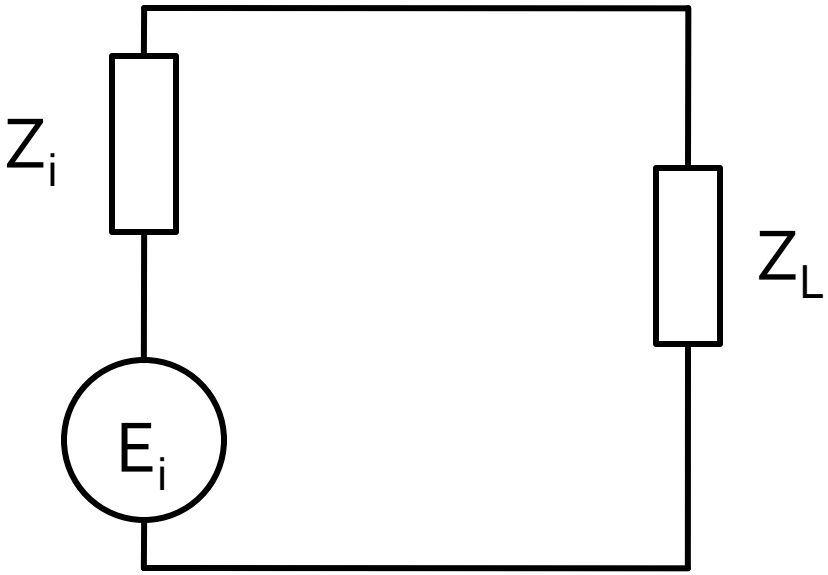
$$P_L = \frac{R_L \cdot |E_i|^2}{(R_i + R_L)^2 + (X_i + X_L)^2}$$

- Adaptare
  - putere maxima transmisa sarcinii
  - conditie?

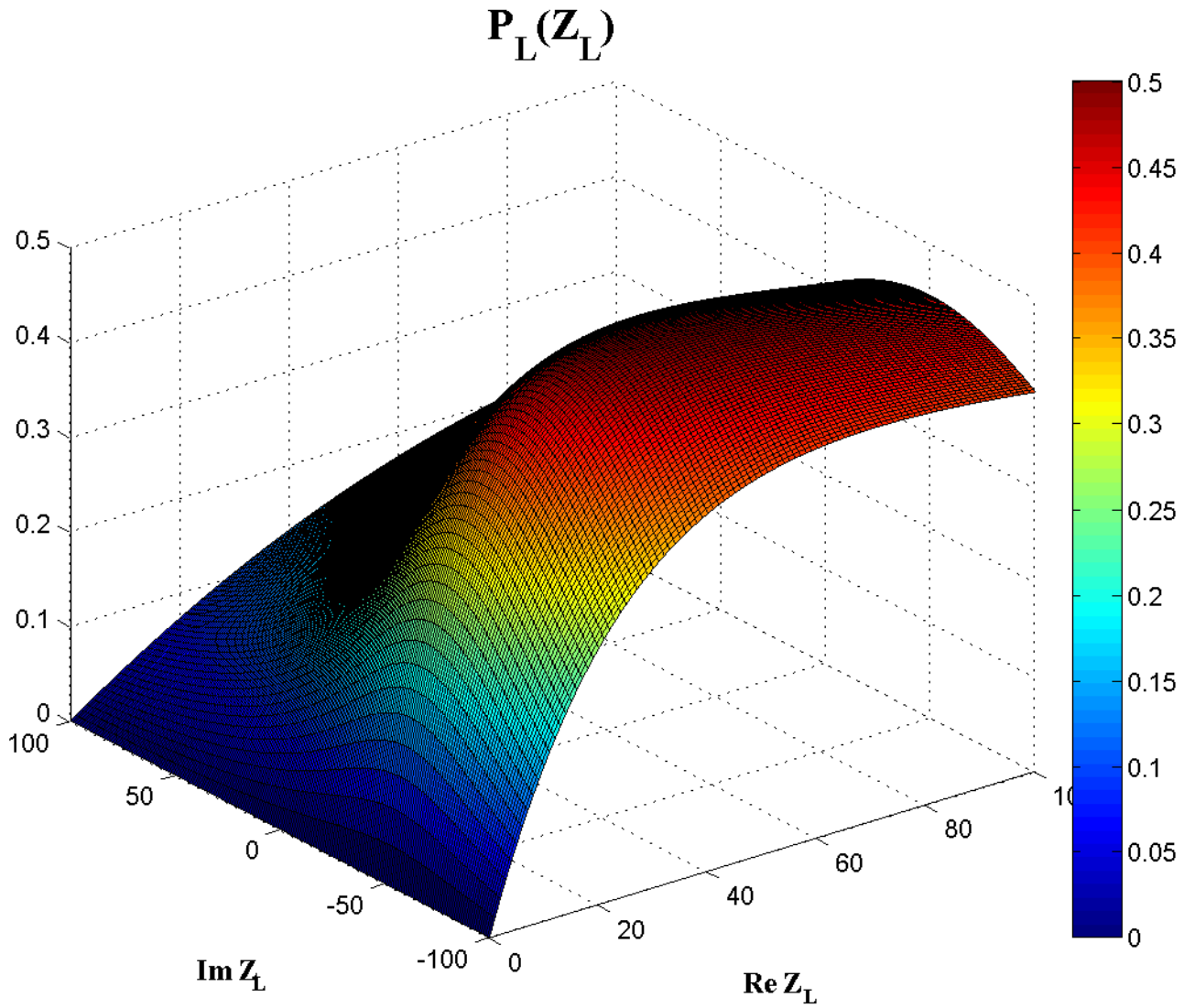
Adaptare, exemplu

- $E = 10V$
- $Z_i = 50\,\Omega + j \cdot 50\Omega$
- $P_L(Z_L)$?

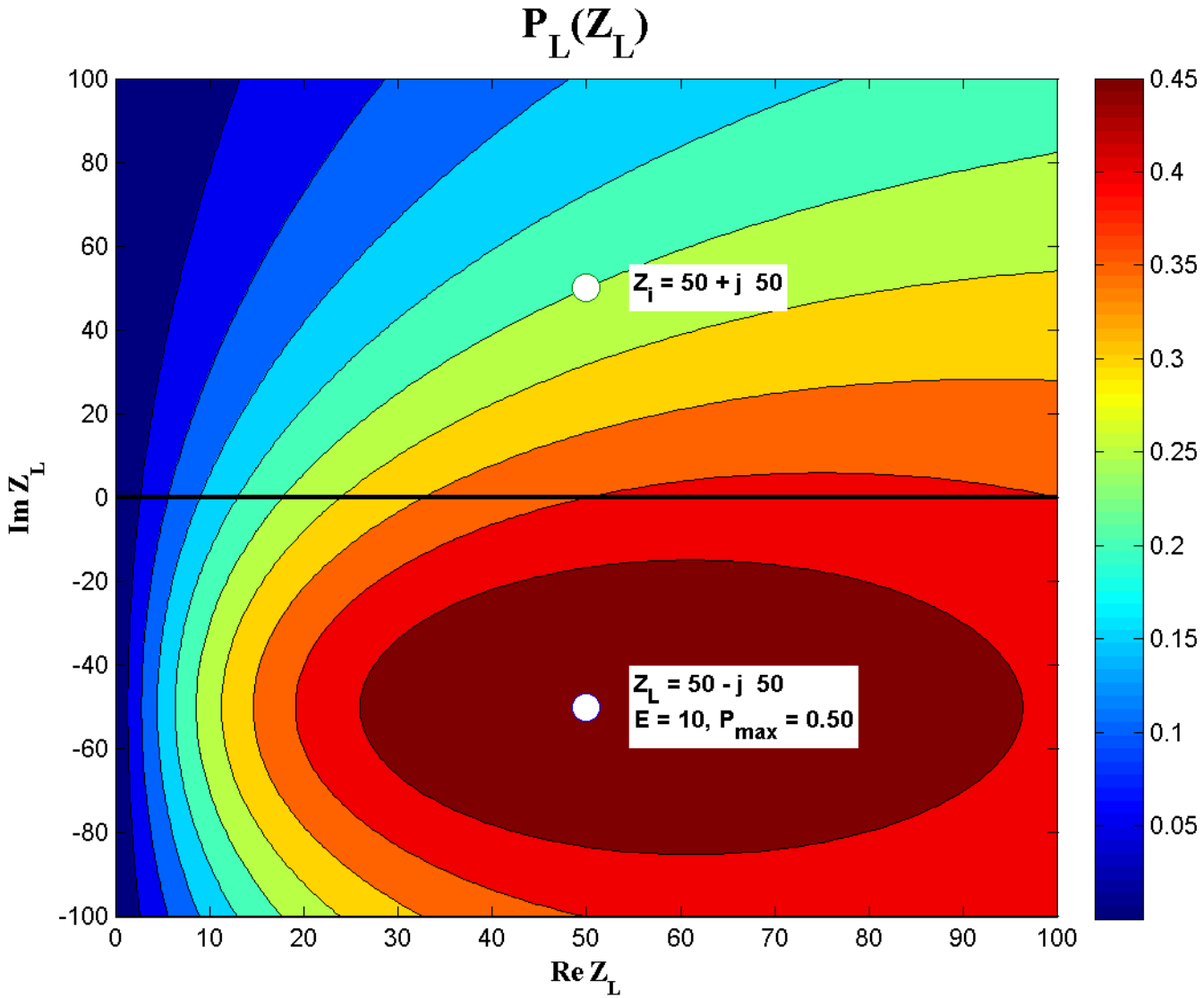
$$P_L = \frac{R_L \cdot |E_i|^2}{(R_i + R_L)^2 + (X_i + X_L)^2}$$



Adaptare, exemplu



Adaptare, exemplu



Adaptare dpdv al puterii

$$R_i > 0,\ R_L > 0$$

$$P_L = \frac{|E_i|^2}{4R_i + \frac{(R_i - R_L)^2}{R_L} + \frac{(X_i + X_L)^2}{R_L}}$$

$$P_{L\max} = \frac{|E_i|^2}{4R_i} \equiv P_a$$

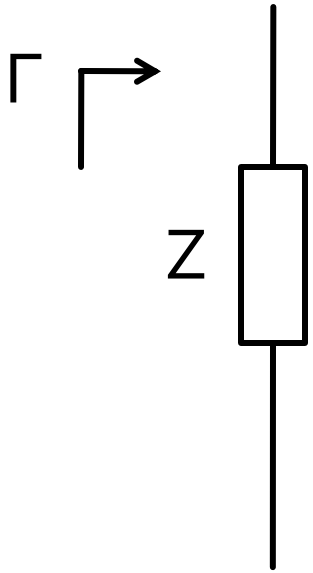
$$R_L = R_i,\ X_L = -X_i$$

- P_a : Puterea disponibila (available)

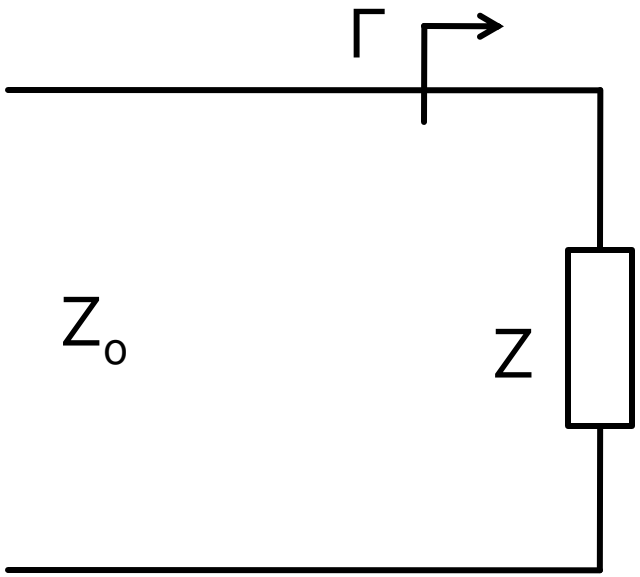
$$Z_L = Z_i^*$$

Coeficient de reflexie

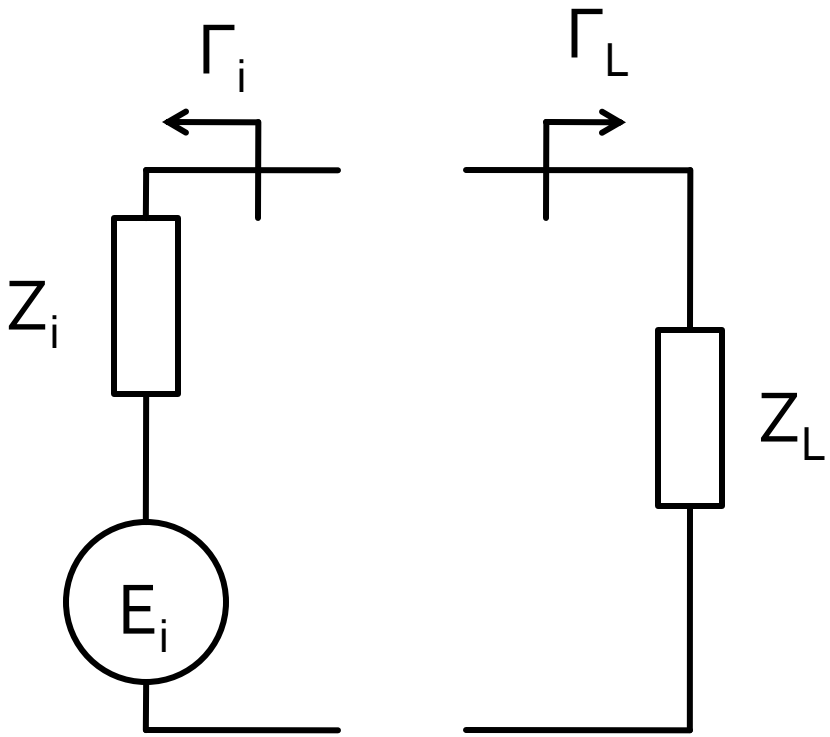
- Un Z_o oarecare ales ca referinta



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



Adaptare dpdv al puterii



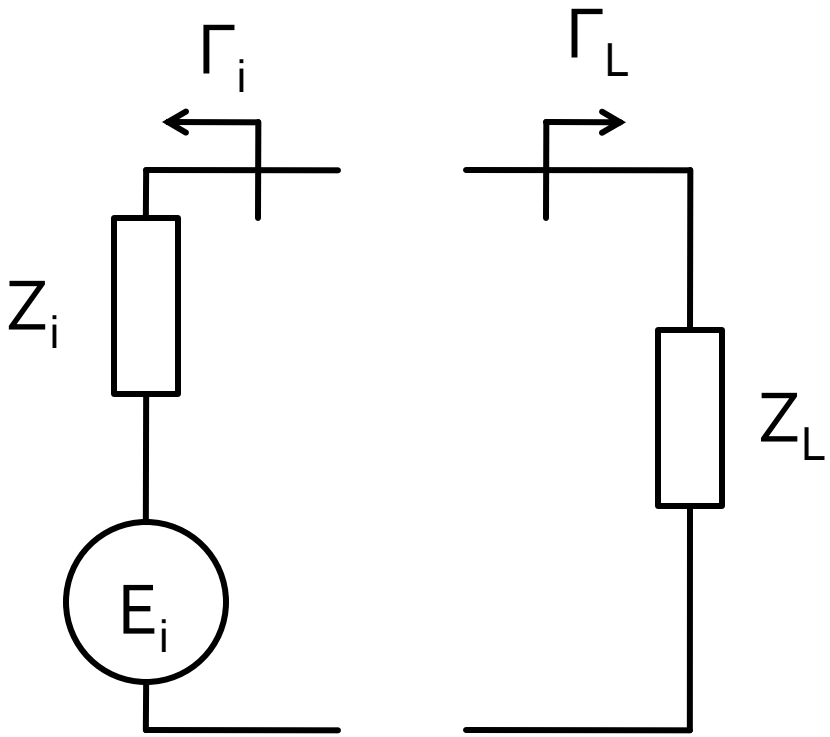
$$\Gamma_i = \frac{Z_i - Z_0^*}{Z_i + Z_0}$$

$$\Gamma_i = \frac{(R_i - R_0) + j \cdot (X_i + X_0)}{(R_i + R_0) + j \cdot (X_i + X_0)}$$

$$\Gamma_L = \frac{Z_L - Z_0^*}{Z_L + Z_0}$$

$$\Gamma_L = \frac{(R_L - R_0) + j \cdot (X_L + X_0)}{(R_L + R_0) + j \cdot (X_L + X_0)}$$

Adaptare dpdv al puterii



$$\Gamma_i = \frac{Z_i - Z_0^*}{Z_i + Z_0} = 1 - \frac{Z_0 + Z_0^*}{Z_i + Z_0}$$

$$\Gamma_L = \frac{Z_L - Z_0^*}{Z_L + Z_0} = 1 - \frac{Z_0 + Z_0^*}{Z_L + Z_0}$$

$$\Gamma_i^* = 1 - \frac{Z_0^* + Z_0}{Z_i^* + Z_0^*} = 1 - \frac{Z_0^* + Z_0}{Z_L + Z_0^*}$$

Adaptare dpdv al puterii

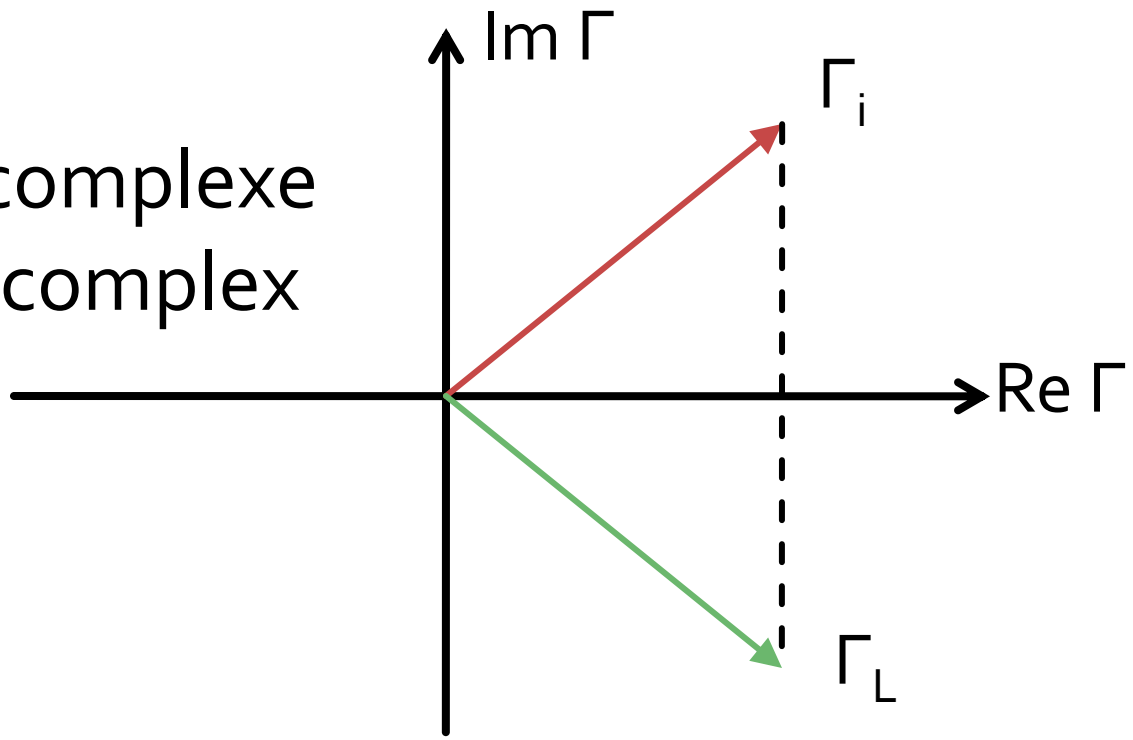
$$Z_L = Z_i^*$$

Daca se alege un Zo real

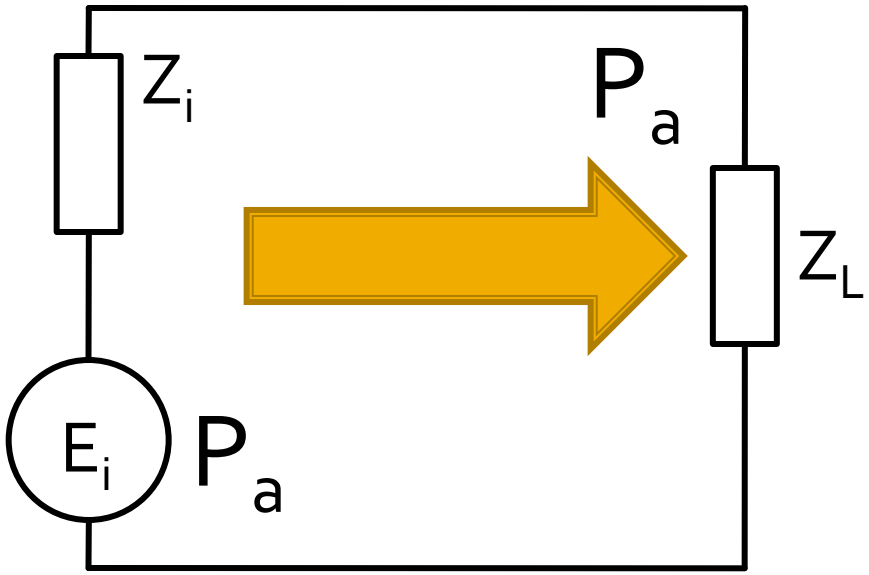
$$\Gamma = \frac{Z - Z_0}{Z + Z_0}$$

$$\Gamma_L = \Gamma_i^*$$

- numere complexe
- in planul complex

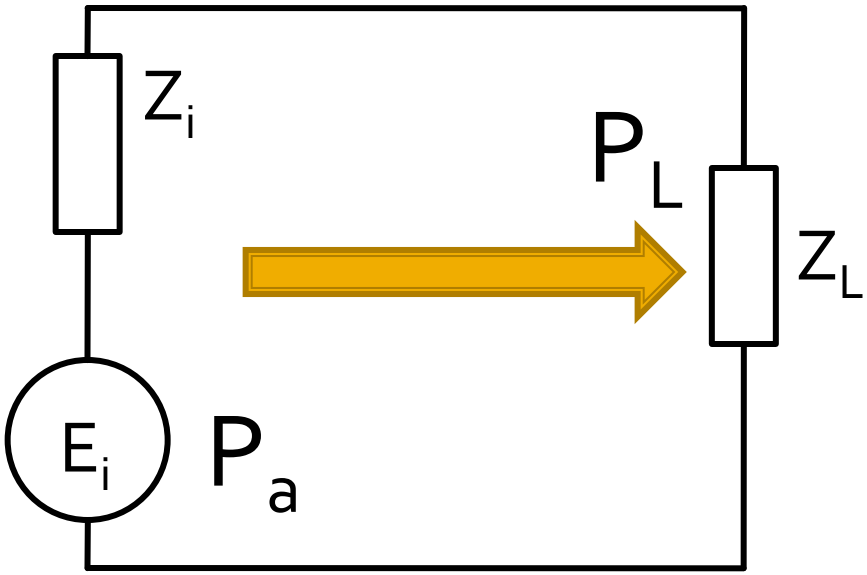


Reflexie de putere / Model



$$Z_L = Z_i^*$$

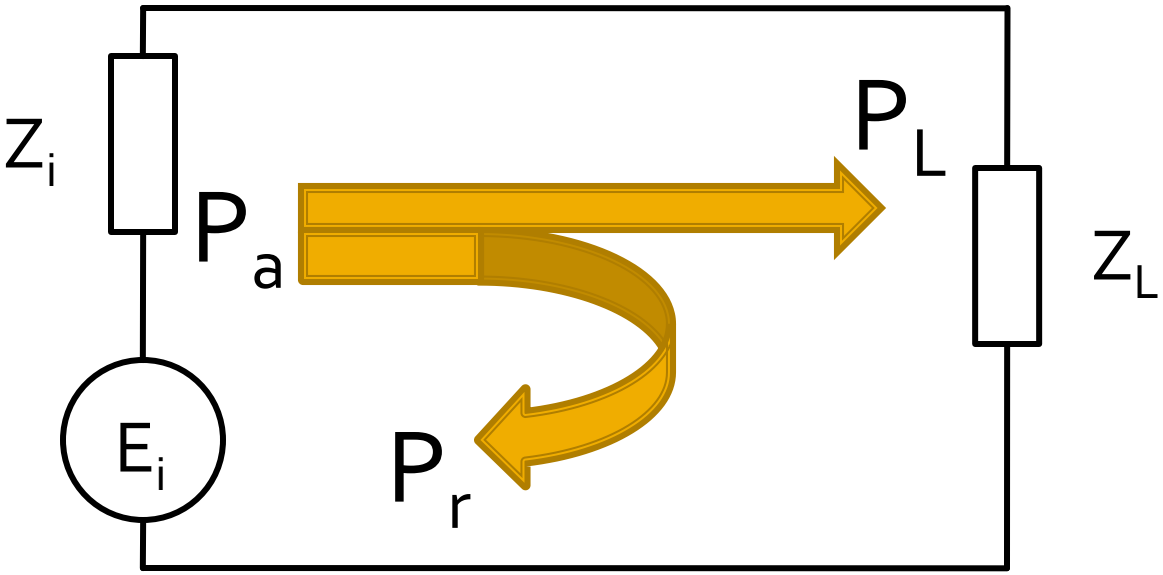
$$P_L = P_a$$



$$Z_L \neq Z_i^*$$

$$P_L < P_a$$

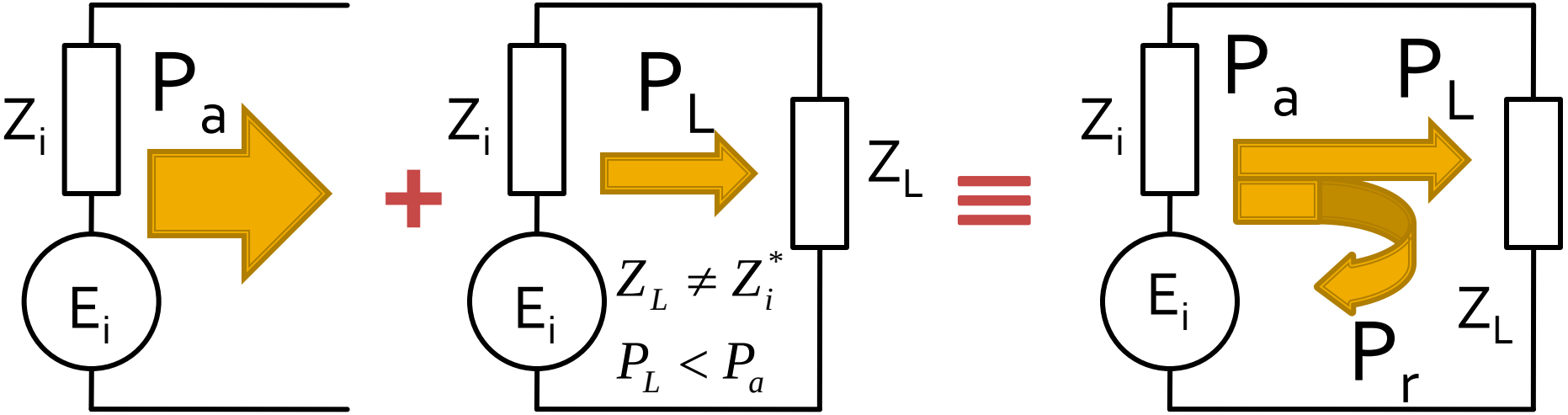
Reflexie de putere / Model



$$Z_L \neq Z_i^*$$

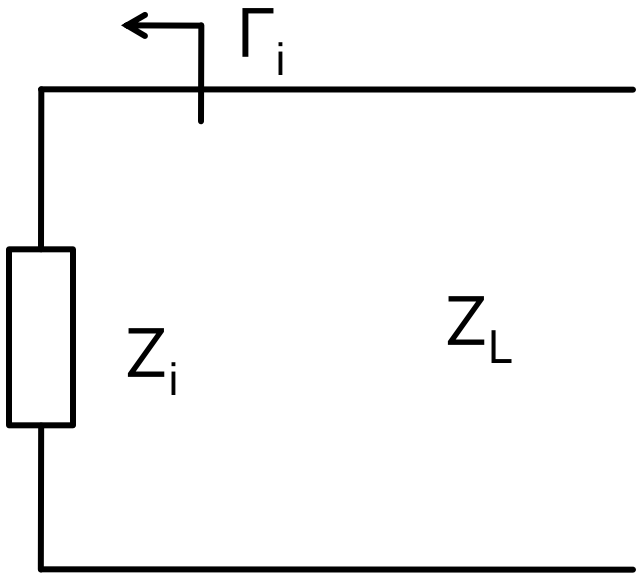
- ~~Putere reflectata~~
- Putere a undei reflectate

Reflexie de putere / Model

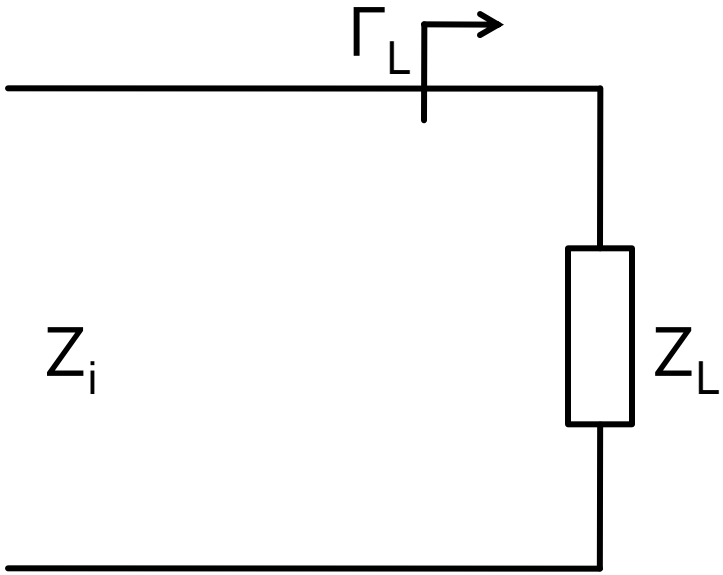


- Generatorul are posibilitatea de a oferi o anumita putere maxima de semnal P_a
- Pentru o sarcina oarecare, acesteia i se ofera o putere de semnal mai mica $P_L < P_a$
- Se intampla **"ca si cum"** (model) o parte din putere se reflecta $P_r = P_a - P_L$
- Puterea este o marime **scalara!**

Coeficienti de reflexie



$$\Gamma_i = \frac{Z_i - Z_L^*}{Z_i + Z_L}$$



$$\Gamma_L = \frac{Z_L - Z_i^*}{Z_L + Z_i}$$

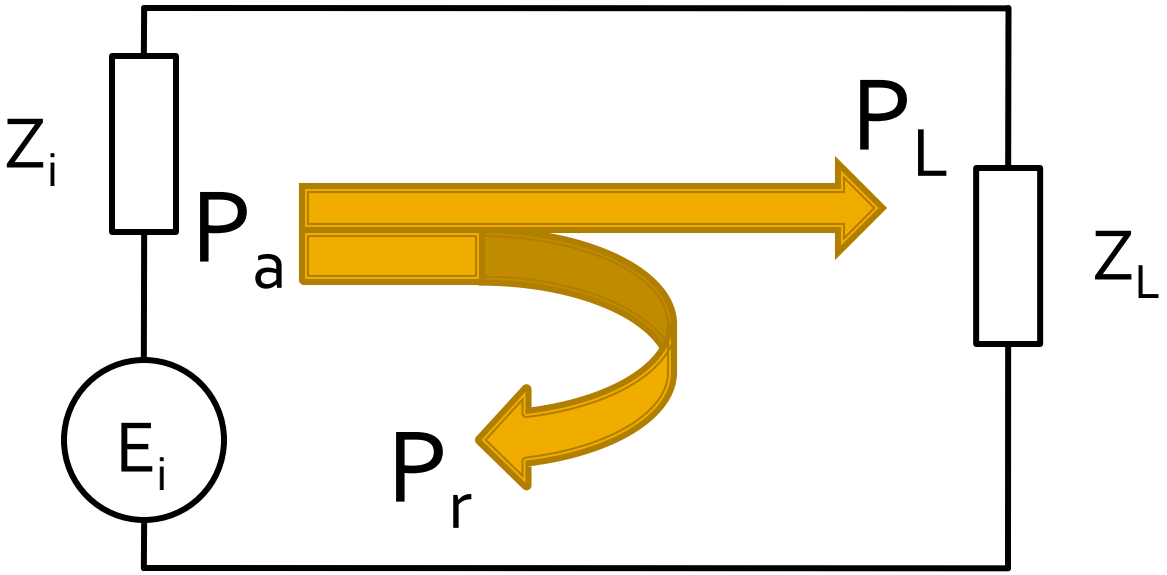
Coeficienti de reflexie

$$\Gamma_i = \frac{(R_i - R_L) + j \cdot (X_i + X_L)}{(R_i + R_L) + j \cdot (X_i + X_L)} \qquad \Gamma_L = \frac{(R_L - R_i) + j \cdot (X_L + X_i)}{(R_L + R_i) + j \cdot (X_L + X_i)}$$

$$|\Gamma_i| = \frac{|(R_i - R_L) + j \cdot (X_i + X_L)|}{|(R_i + R_L) + j \cdot (X_i + X_L)|} = \frac{\sqrt{(R_i - R_L)^2 + (X_i + X_L)^2}}{\sqrt{(R_i + R_L)^2 + (X_i + X_L)^2}} = |\Gamma_L|$$

$$|\Gamma_i| = |\Gamma_L| \equiv |\Gamma|$$

Reflexie de putere / Model



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

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

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

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

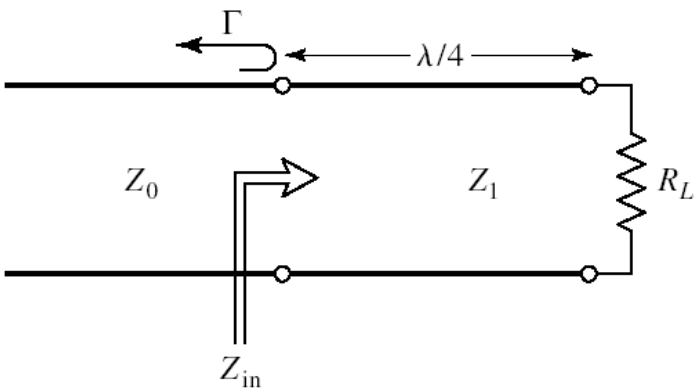
- $|\Gamma|^2$ **este** un coeficient de reflexie in putere

Transformatorul in sfert de lungime de unda

Adaptarea de impedanța

Transformatorul in sfert de lungime de unda

- Feed line – linie de intrare cu impedanta caracteristica Z_o
- Sarcina cu impedanta (**rezistiva!**) R_L
- Dorim adaptarea sarcinei la fider cu o linie de lungime $\lambda/4$ si impedanta caracteristica Z_1

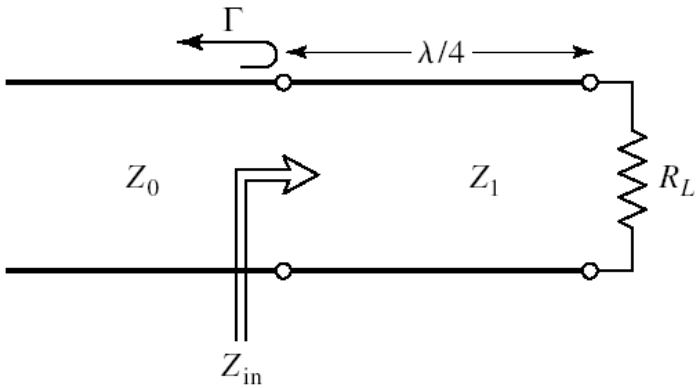


$$Z_{in} = Z_1 \frac{1+\Gamma e^{-2j\beta l}}{1-\Gamma e^{-2j\beta l}}$$

$$\Gamma_O = \frac{V_0^-}{V_0^+} = \frac{R_L - Z_1}{R_L + Z_1}$$

$$Z_{in} = Z_1 \frac{R_L + jZ_1 \tan(\beta l)}{Z_1 + jR_L \tan(\beta l)}$$

Transformatorul in sfert de lungime de unda



$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

$$\beta \cdot l = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4} = \frac{\pi}{2} \qquad Z_{in} = \frac{Z_1^2}{R_L}$$

$$\Gamma_{in} = \frac{Z_1^2 - Z_0 \cdot R_L}{Z_1^2 + Z_0 \cdot R_L} \qquad \Gamma_{in} = 0 \quad \Rightarrow \quad Z_1 = \sqrt{Z_0 R_L}$$

- Pe fider (Z_o) avem doar unda progresiva
- Pe linia in sfert de lungime de unda (Z_1) avem unda stationara

Transformatorul in sfert de lungime de unda

- Punct de vedere fizic

$$\Gamma = \Gamma_1 - T_1 T_2 \Gamma_3 + T_1 T_2 \Gamma_2 \Gamma_3^2 - T_1 T_2 \Gamma_2^2 \Gamma_3^3 + \cdots$$

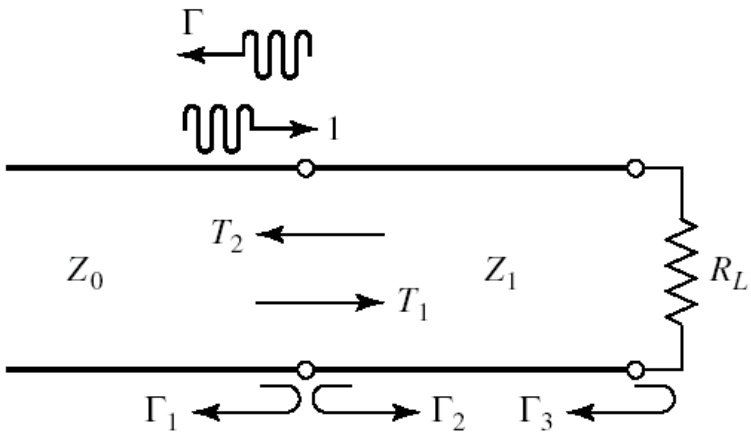
$$= \Gamma_1 - T_1 T_2 \Gamma_3 \sum_{n=0}^{\infty} (-\Gamma_2 \Gamma_3)^n.$$

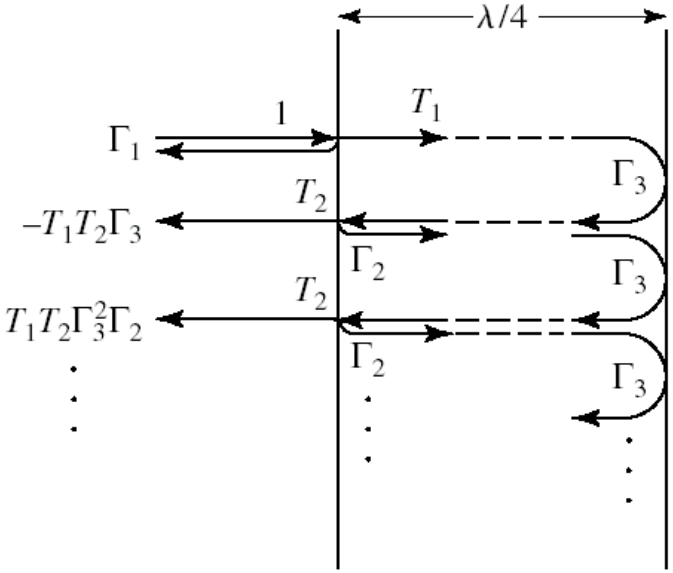
$$\Gamma_1 = \frac{Z_1 - Z_0}{Z_1 + Z_0},$$

$$\Gamma_2 = \frac{Z_0 - Z_1}{Z_0 + Z_1} = -\Gamma_1,$$

$$\Gamma_3 = \frac{R_L - Z_1}{R_L + Z_1},$$

$$\left.\begin{aligned} T_1 &= \frac{2Z_1}{Z_1 + Z_0}, \\ T_2 &= \frac{2Z_0}{Z_1 + Z_0}. \end{aligned}\right\} \quad T = 1 - \Gamma$$





Transformatorul in sfert de lungime de unda

- Punct de vedere fizic

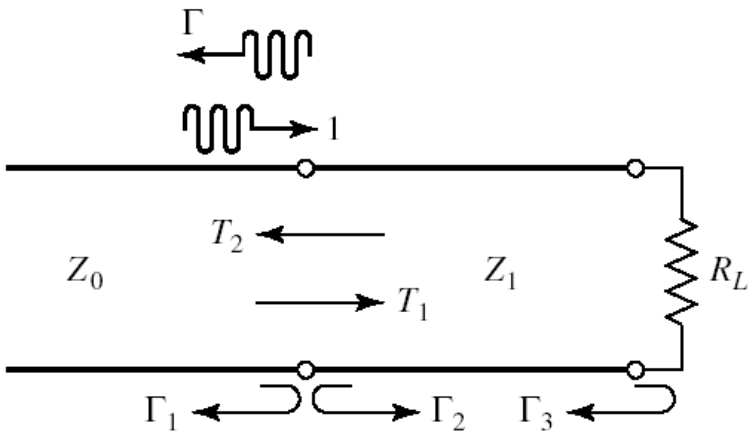
$$\sum_{n=0}^{\infty} x^n = \frac{1}{1-x}, \qquad \text{for } |x| < 1,$$

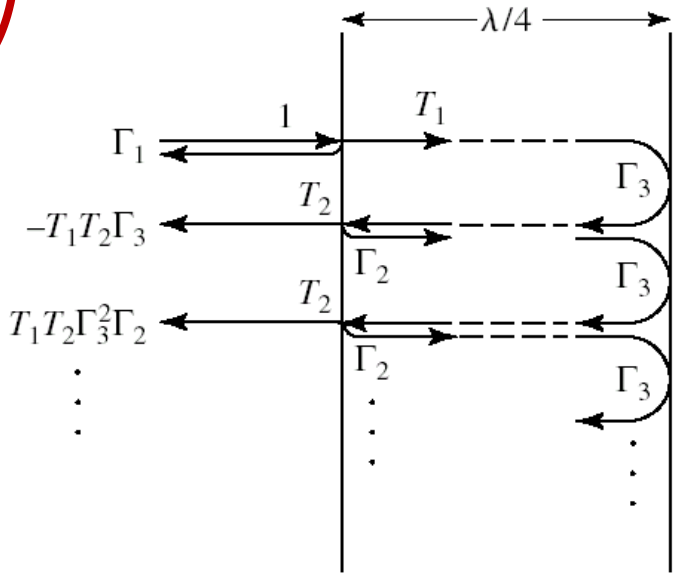
$$\Gamma = \Gamma_1 - \frac{T_1 T_2 \Gamma_3}{1+\Gamma_2\Gamma_3} = \frac{\Gamma_1 + \Gamma_1\Gamma_2\Gamma_3 - T_1 T_2 \Gamma_3}{1+\Gamma_2\Gamma_3}.$$

$$\Gamma_1 - \Gamma_3\left(\Gamma_1^2 + T_1 T_2\right) = \frac{2\left(Z_1^2 - Z_0 R_L\right)}{(Z_1+Z_0)(R_L+Z_1)},$$

$$\Gamma_1^2 + T_1 T_2 = \frac{(Z_1 - Z_0)^2}{(Z_1+Z_0)^2} + \frac{4 Z_1 Z_0}{(Z_1+Z_0)^2} = 1$$

$$\Gamma = 0 \quad \Leftrightarrow \quad Z_1^2 - Z_0 \cdot R_L = 0$$





Caracteristica de frecventa

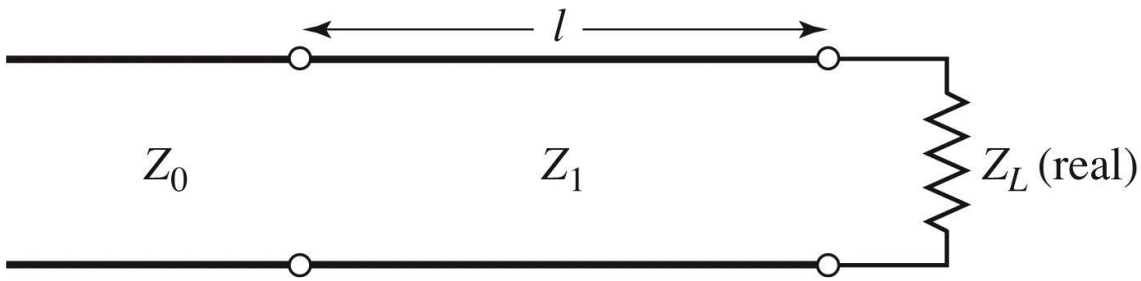


Figure 5.10
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$$Z_1 = \sqrt{Z_0 \cdot Z_L}$$

- (**doar**) la frecventa f_o

$$l = \frac{\lambda_0}{4} \qquad \beta_0 \cdot l = \frac{2\pi}{\lambda_0} \cdot \frac{\lambda_0}{4} = \frac{\pi}{2}$$

$$Z_{in} = Z_1 \cdot \frac{Z_L + j \cdot Z_1 \cdot \tan(\beta \cdot l)}{Z_1 + j \cdot Z_L \cdot \tan(\beta \cdot l)} \qquad \theta \overset{not}{=} \beta \cdot l \qquad t \overset{not}{=} \tan(\beta \cdot l)$$

$$Z_{in} = Z_1 \cdot \frac{Z_L + j \cdot Z_1 \cdot t}{Z_1 + j \cdot Z_L \cdot t}$$

$$\Gamma = \frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0} = \frac{Z_1(Z_L - Z_0) + jt\left(Z_1^2 - Z_0 Z_L\right)}{Z_1(Z_L + Z_0) + jt\left(Z_1^2 + Z_0 Z_L\right)}. \qquad Z_1^2 = Z_0 \cdot Z_L$$

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0 + j2t\sqrt{Z_0 Z_L}}.$$

Caracteristica de frecventa

- calitatea adaptarii ≡coeficient de reflexie in putere

$$|\Gamma| = \frac{|Z_L - Z_0|}{\left[(Z_L + Z_0)^2 + 4t^2 Z_0 Z_L\right]^{1/2}}$$

$$= \frac{1}{\left\{(Z_L + Z_0)^2/(Z_L - Z_0)^2 + [4t^2 Z_0 Z_L/(Z_L - Z_0)^2]\right\}^{1/2}}$$

$$= \frac{1}{\left\{1 + [4Z_0 Z_L/(Z_L - Z_0)^2] + [4Z_0 Z_L t^2/(Z_L - Z_0)^2]\right\}^{1/2}}$$

$$= \frac{1}{\left\{1 + [4Z_0 Z_L/(Z_L - Z_0)^2]\ \sec^2\theta\right\}^{1/2}},$$

$$\sec\theta = \frac{1}{\cos\theta} \rightarrow$$

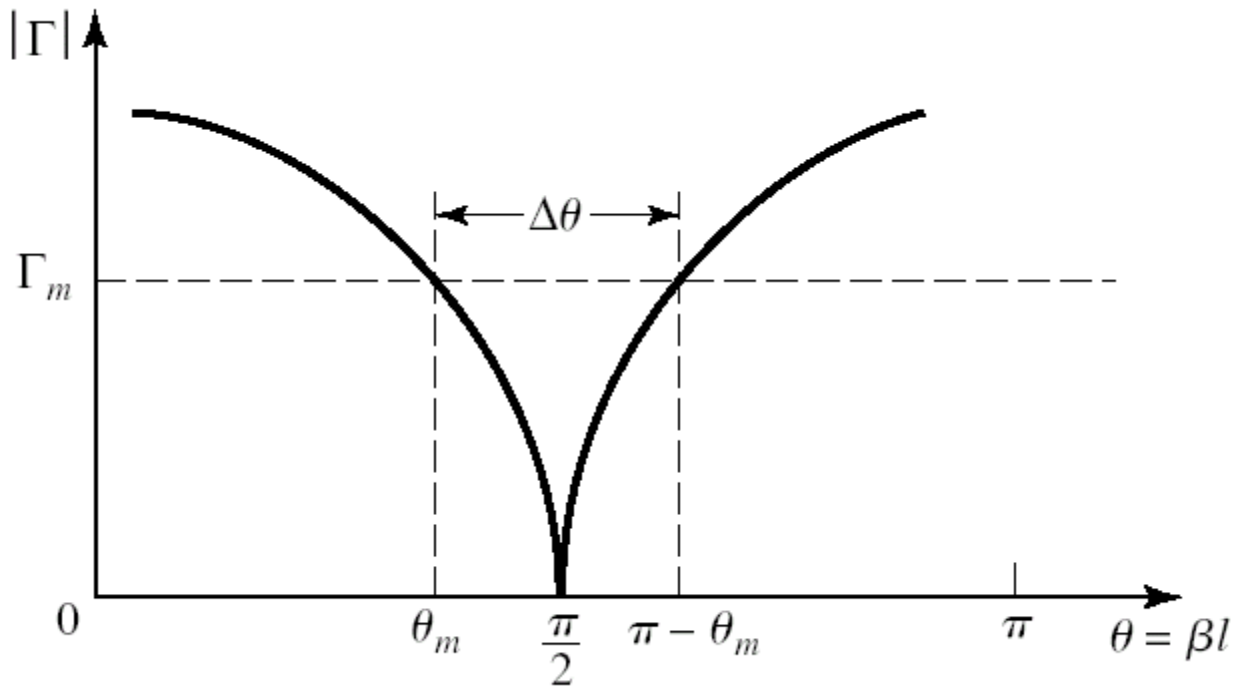
$$\sec^2\theta = 1 + \tan^2\theta = 1 + t^2$$

Caracteristica de frecventa

- ne intereseaza frecventa in jurul frecventei la care facem adaptarea (banda ingusta)

$$f \approx f_0 \qquad l \approx \frac{\lambda_0}{4} \qquad \theta \approx \frac{\pi}{2} \qquad \sec^2\theta = 1 + \tan^2\theta >> 1$$

$$|\Gamma| \cong \frac{|Z_L - Z_0|}{2 \cdot \sqrt{Z_0 \cdot Z_L}} \cdot |\cos\theta|$$



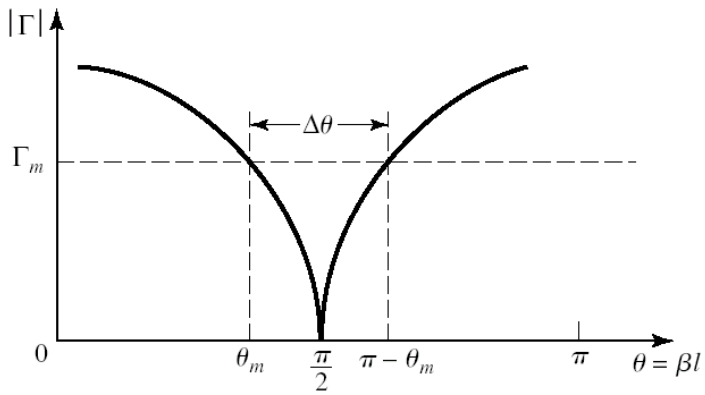
Caracteristica de frecventa

- Definim un maxim acceptat pentru coeficientul de reflexie Γ_m care va defini banda adaptarii, θ_m

$$\frac{1}{\Gamma_m^2} = 1 + \left(\frac{2\sqrt{Z_0 Z_L}}{Z_L - Z_0}\sec\theta_m\right)^2,$$

$$\cos\theta_m = \frac{\Gamma_m}{\sqrt{1-\Gamma_m^2}}\frac{2\sqrt{Z_0 Z_L}}{|Z_L - Z_0|}.$$

$$\Delta\theta = 2\left(\frac{\pi}{2} - \theta_m\right)$$



- in linii TEM

$$\theta = \beta \cdot l = \beta \cdot \frac{\lambda_0}{4} = \frac{2\pi \cdot f}{v_f} \cdot \frac{1}{4} \cdot \frac{v_f}{f_0} = \frac{\pi \cdot f}{2 f_0}$$

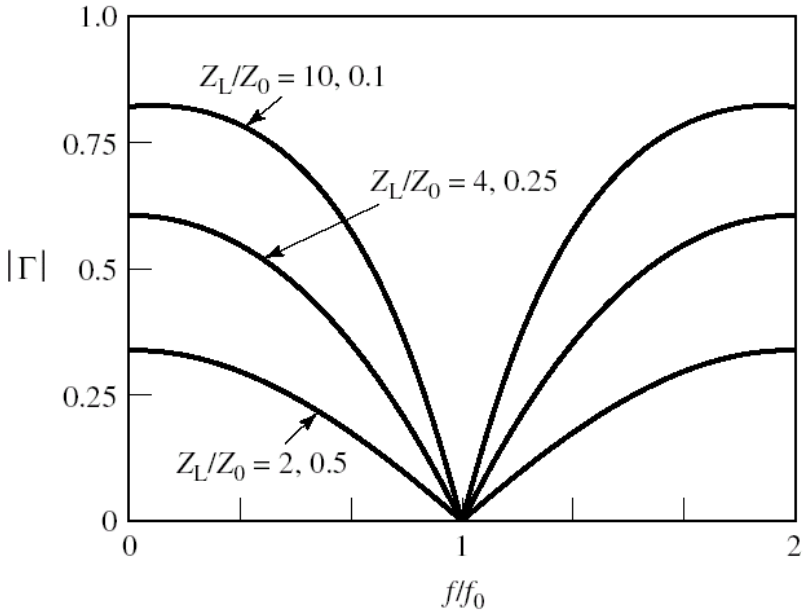
$$f_m = \frac{2 \cdot \theta_m \cdot f_0}{\pi}$$

$$\frac{\Delta f}{f_0} = \frac{2 \cdot (f_0 - f_m)}{f_0} = 2 - \frac{4 \cdot \theta_m}{\pi} = 2 - \frac{4}{\pi} \cdot \cos^{-1}\left[\frac{\Gamma_m}{\sqrt{1-\Gamma_m^2}} \cdot \frac{2\sqrt{Z_0 \cdot Z_L}}{|Z_L - Z_0|}\right]$$

Caracteristica de frecventa

- Pentru linii non TEM constanta de propagare nu depinde liniar de frecventa, dar in practica influenta este minora in banda ingusta
- Sunt neglijate reactantele introduse de discontinuitati (Z_0 -> Z_1). Compensarea se face printr-o mica modificare a lungimii liniei
- Banda depinde de dezadaptarea initiala

cu cat dezadaptarea este mai mica
cu atat banda se obtine mai larga



Exemplu

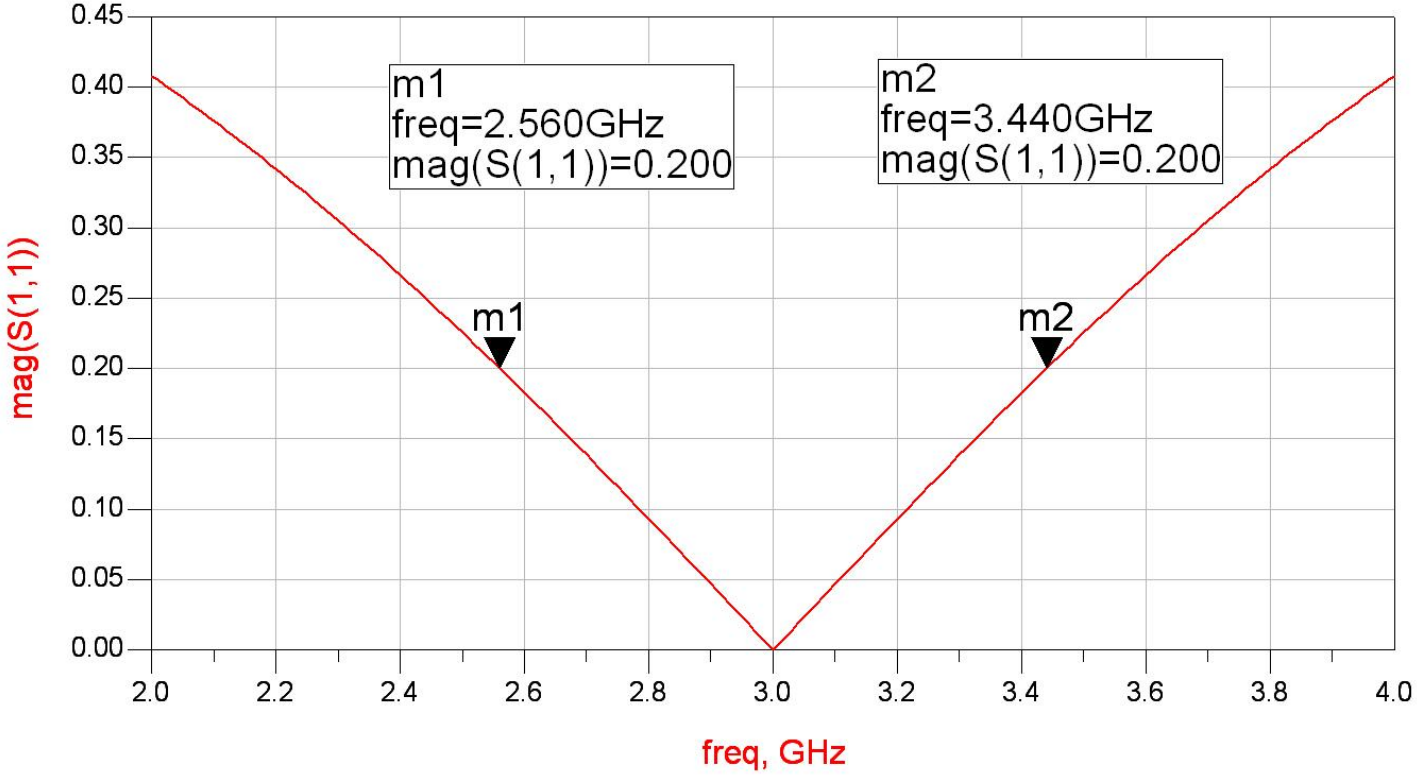
- Transformator de adaptare cu o singura sectiune (λ/4) pentru a adapta o sarcina de 10Ω la o linie de 50 Ω la frecventa f_o=3GHz
  - banda pentru SWR<1.5

$$Z_1 = \sqrt{Z_0 Z_L} = \sqrt{(50)(10)} = 22.36\ \Omega, \qquad \Gamma_m = \frac{\mathrm{SWR}-1}{\mathrm{SWR}+1} = \frac{1.5-1}{1.5+1} = 0.2.$$

$$\begin{aligned}\frac{\Delta f}{f_0} &= 2 - \frac{4}{\pi}\cos^{-1}\left[\frac{\Gamma_m}{\sqrt{1-\Gamma_m^2}}\frac{2\sqrt{Z_0 Z_L}}{|Z_L - Z_0|}\right] \\ &= 2 - \frac{4}{\pi}\cos^{-1}\left[\frac{0.2}{\sqrt{1-(0.2)^2}}\frac{2\sqrt{(50)(10)}}{|10-50|}\right] \\ &= 0.29, \text{ or } 29\%.\end{aligned}$$

Simulare

- simulare ADS

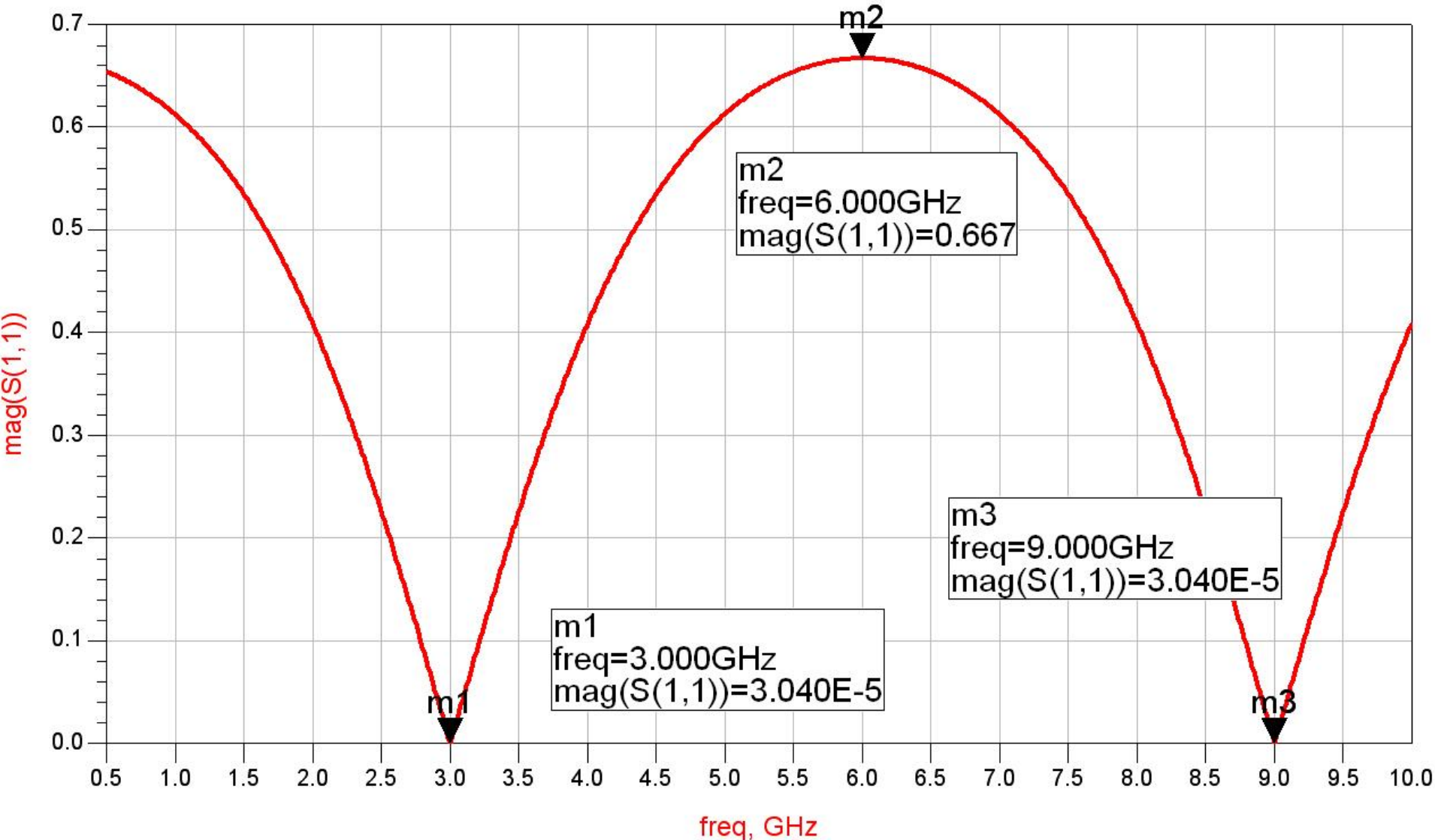


$$\Delta f = 0.88GHz$$

$$\left|\Gamma(3GHz)\right| = 3\cdot 10^{-5}$$

$$\frac{\Delta f}{f_0} = \frac{0.88}{3} = 0.2933$$

Simulare banda larga



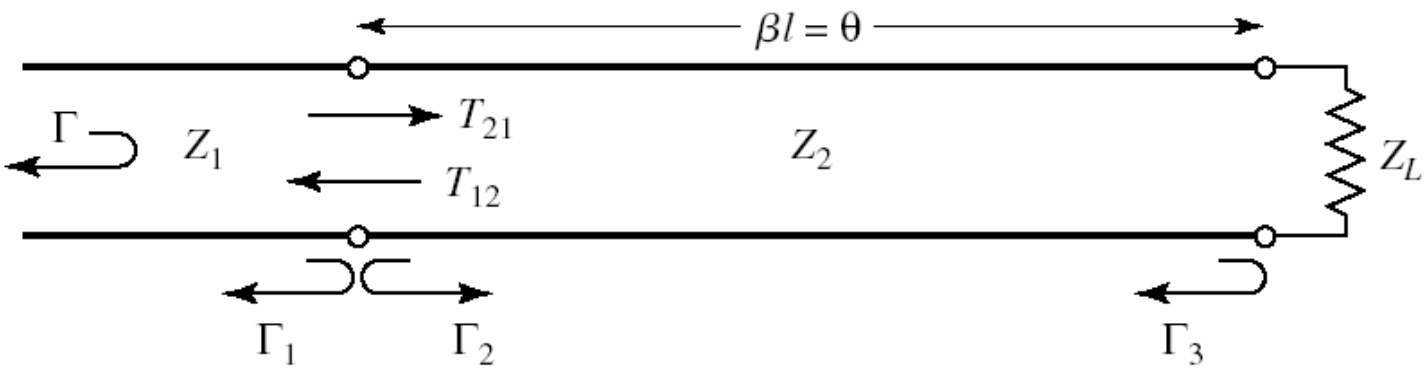
Adaptarea cu transformatoare de impedanta (Lab. 1)

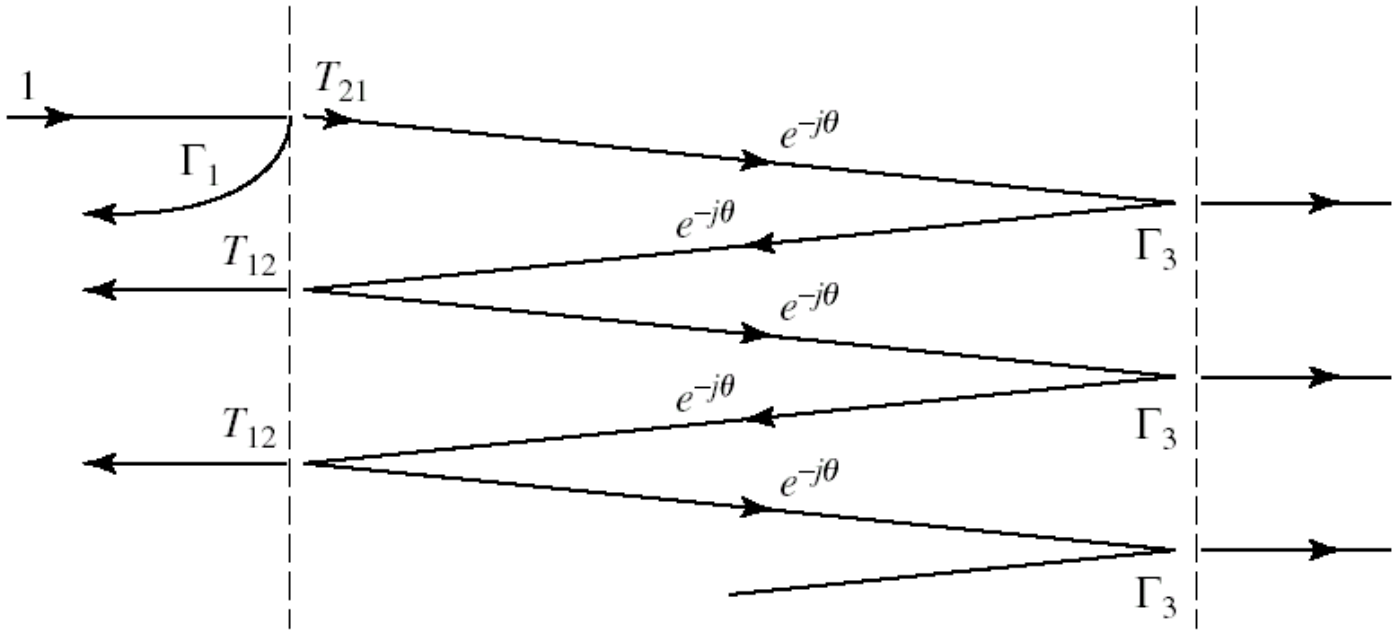
Adaptarea de impedanța

Transformatoare de impedanta multisectiune

- Transformatorul in sfert de lungime de unda permite adaptarea oricarei impedante reale cu orice impedanta a fiderului (liniei).
- Daca banda necesara este mai mare decat cea oferita de transformatorul in sfert de lungime de unda se folosesc transformatoare multisectiune
  - caracteristica binomiala
  - tip Cebîşev

Teoria reflexiilor mici





Teoria reflexiilor mici

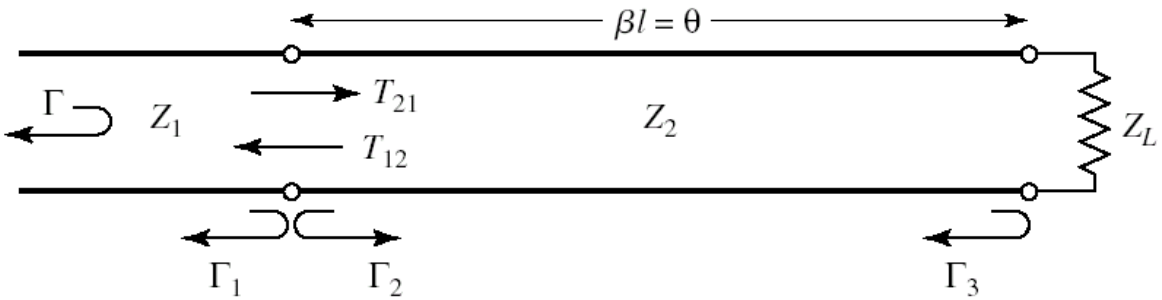
$$\Gamma_1 = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

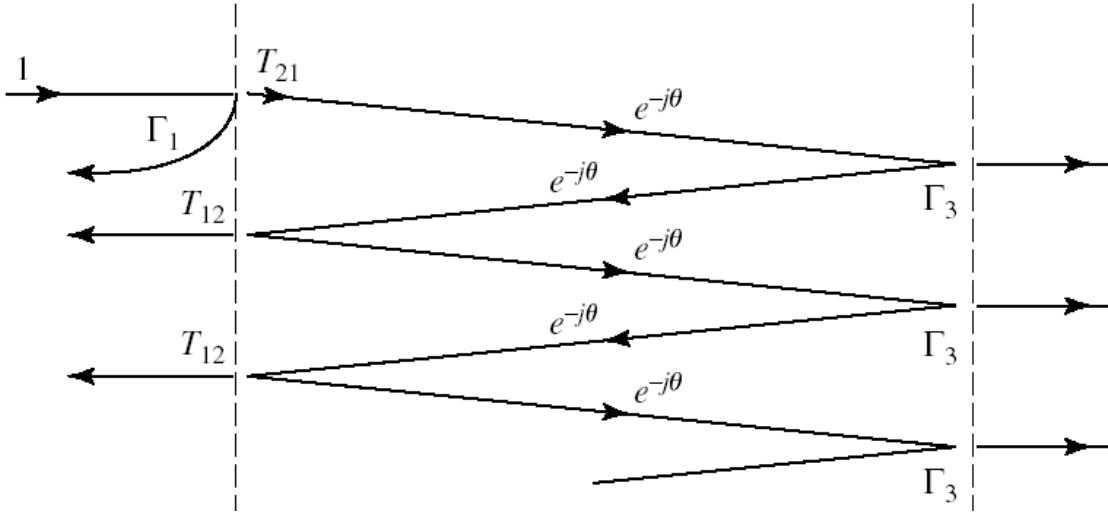
$$\Gamma_2 = -\Gamma_1$$

$$\Gamma_3 = \frac{Z_L - Z_2}{Z_L + Z_2}$$

$$T_{21} = 1 + \Gamma_1 = \frac{2 \cdot Z_2}{Z_1 + Z_2}$$

$$T_{12} = 1 + \Gamma_2 = \frac{2 \cdot Z_1}{Z_1 + Z_2}$$





$$\Gamma = \Gamma_1 + T_{12} \cdot T_{21} \cdot \Gamma_3 \cdot e^{-2j\theta} + T_{12} \cdot T_{21} \cdot \Gamma_3^2 \cdot \Gamma_2 \cdot e^{-4j\theta} + T_{12} \cdot T_{21} \cdot \Gamma_3^3 \cdot \Gamma_2^2 \cdot e^{-6j\theta} + \cdots$$

$$\Gamma = \Gamma_1 + T_{12} \cdot T_{21} \cdot \Gamma_3 \cdot e^{-2j\theta} \sum_{n=0}^{\infty} \Gamma_3^n \cdot \Gamma_2^n \cdot e^{-2jn\theta}$$

Teoria reflexiilor mici

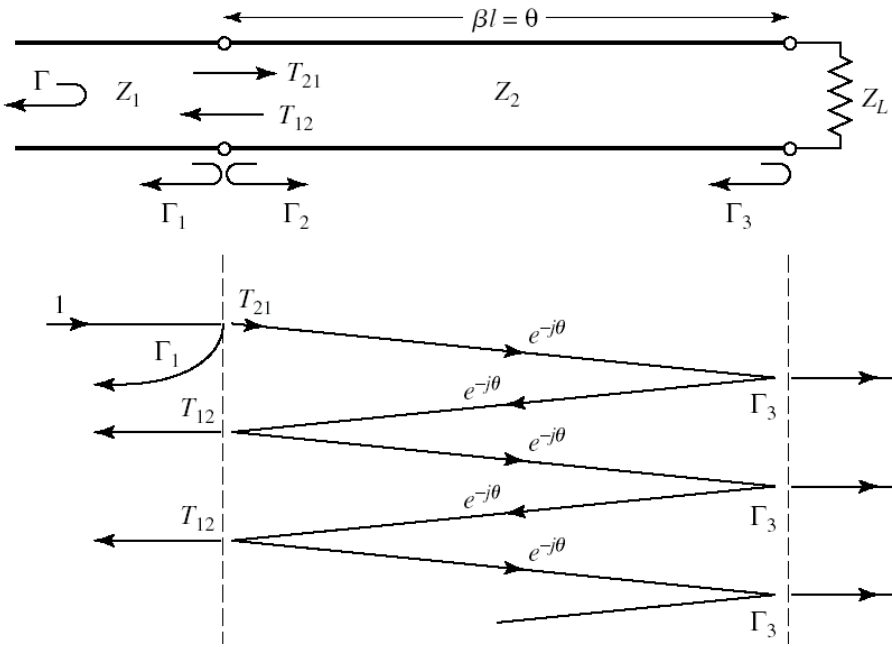
$$\Gamma = \Gamma_1 + T_{12} \cdot T_{21} \cdot \Gamma_3 \cdot e^{-2j\theta} \sum_{n=0}^{\infty} \Gamma_3^n \cdot \Gamma_2^n \cdot e^{-2jn\theta}$$

$$\sum_{n=0}^{\infty} x^n = \frac{1}{1-x} \qquad |x| < 1$$

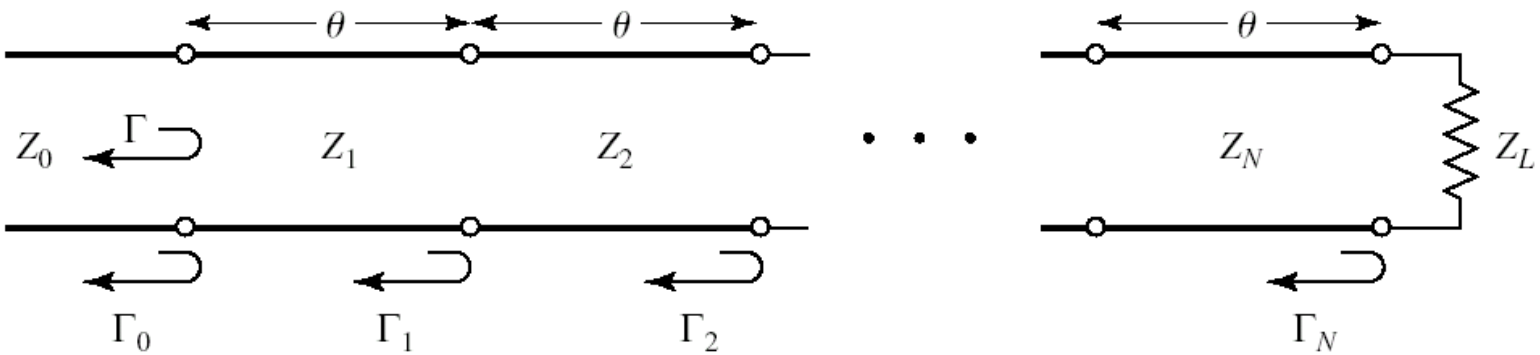
$$\Gamma = \frac{\Gamma_1 + \Gamma_3 \cdot e^{-2j\theta}}{1 + \Gamma_1 \cdot \Gamma_3 \cdot e^{-2j\theta}}$$

- Daca diferentele intre $Z_1 \div Z_2$ si $Z_2 \div Z_L$ sunt mici putem aproxima:

$$\Gamma \cong \Gamma_1 + \Gamma_3 \cdot e^{-2j\theta}$$



Transformatoare cu mai multe sectiuni



$$\Gamma_1 = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

$$\Gamma_n = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n}$$

$$n = \overline{1, N-1}$$

$$\Gamma_N = \frac{Z_L - Z_N}{Z_L + Z_N}$$

- Presupunem ca toate impedantele **cresc sau descresc uniform**
- Toti coeficientii de reflexie vor fi reali si de acelasi semn
- Anterior $\Gamma \cong \Gamma_1 + \Gamma_3 \cdot e^{-2j\theta} \Rightarrow$

$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \cdots + \Gamma_N \cdot e^{-2jN\theta}$$

Transformatoare cu mai multe sectiuni

- Realizez transformatorul **simetric**

$$\Gamma_0 = \Gamma_N, \Gamma_1 = \Gamma_{N-1}, \Gamma_2 = \Gamma_{N-2} \cdots$$

- Aceasta **nu** implica faptul ca impedantele sunt egale

$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \cdots + \Gamma_N \cdot e^{-2jN\theta}$$

$$\Gamma(\theta) = e^{-jN\theta} \cdot \left[\Gamma_0 \cdot \left(e^{jN\theta} + e^{-jN\theta}\right) + \Gamma_1 \cdot \left(e^{j(N-2)\theta} + e^{-j(N-2)\theta}\right) + \Gamma_2 \cdot \left(e^{j(N-4)\theta} + e^{-j(N-4)\theta}\right) + \cdots\right]$$

$$\Gamma(\theta) = 2e^{-jN\theta} \cdot \left[\Gamma_0 \cdot \cos N\theta + \Gamma_1 \cdot \cos(N-2)\theta + \cdots \Gamma_n \cdot \cos(N-2n)\theta + \cdots\right]$$

ultimul termen:

$$\cdots \frac{1}{2} \cdot \Gamma_{N/2} \quad n \text{ par}$$

$$\cdots \Gamma_{(N-1)/2} \cdot \cos\theta \quad n \text{ impar}$$

Transformatoare cu mai multe sectiuni

- Coeficient de reflexie

$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \cdots + \Gamma_N \cdot e^{-2jN\theta}$$

$$e^{-2j\theta} \equiv x$$

$$f(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + \cdots + a_N \cdot x^N$$

- aleg coeficientii astfel incat sa obtin o variatie dorita (a polinomului)

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

- Raspunsul acestui transformator este de tip maxim plat in jurul frecventei de adaptare
- Pentru N sectiuni se anuleaza primele N-1 derivate ale functiei |Γ(θ)|

$$f(x) = A \cdot (1 + x)^N$$

$$\Gamma(\theta) = A \cdot \left(1 + e^{-2j\theta}\right)^N$$

$$|\Gamma(\theta)| = |A| \cdot \left|e^{-j\theta}\right|^N \cdot \left|e^{j\theta} + e^{-j\theta}\right|^N = 2^N \cdot |A| \cdot |\cos\theta|^N$$

$$l = \frac{\lambda}{4} \Rightarrow \theta = \beta \cdot l = \frac{\pi}{2} \qquad \left|\Gamma\left(\frac{\pi}{2}\right)\right| = 0; \quad \frac{d^n}{d\theta^n}|\Gamma(\theta)|\Big|_{\theta=\frac{\pi}{2}} = 0 \qquad n = \overline{1, N-1}$$

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

- A, θ →o , liniile de lungime o, dispar

$$\Gamma(0) = 2^N \cdot A = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad \boxed{A = 2^{-N} \cdot \frac{Z_L - Z_0}{Z_L + Z_0}}$$

- dezvoltarea binomului

$$f(x) = (1+x)^N = C_N^0 + C_N^1 \cdot x + \cdots + C_N^n \cdot x^n + \cdots + C_N^N \cdot x^N$$

$$C_N^n = \frac{N!}{(N-n)!\,n!}$$

- Coeficientii de reflexie

$$\Gamma(\theta) = A \cdot \left(1 + e^{-2j\theta}\right)^N \qquad \Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \cdots + \Gamma_N \cdot e^{-2jN\theta}$$

$$\boxed{\Gamma_n = A \cdot C_N^n}$$

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

- Proiectare, solutii aproximative

$$\boxed{A = 2^{-N} \cdot \frac{Z_L - Z_0}{Z_L + Z_0}} \qquad \boxed{\Gamma_n = A \cdot C_N^n}$$

$$\Gamma_n = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n} \cong \frac{1}{2} \ln \frac{Z_{n+1}}{Z_n} \qquad \ln x \cong 2 \cdot \frac{x-1}{x+1} \quad x \cong 1$$

$$\ln \frac{Z_{n+1}}{Z_n} \cong 2 \cdot \Gamma_n = 2 \cdot A \cdot C_N^n = 2 \cdot 2^{-N} \cdot \frac{Z_L - Z_0}{Z_L + Z_0} \cdot C_N^n \cong 2^{-N} \cdot C_N^n \cdot \ln \frac{Z_L}{Z_0}$$

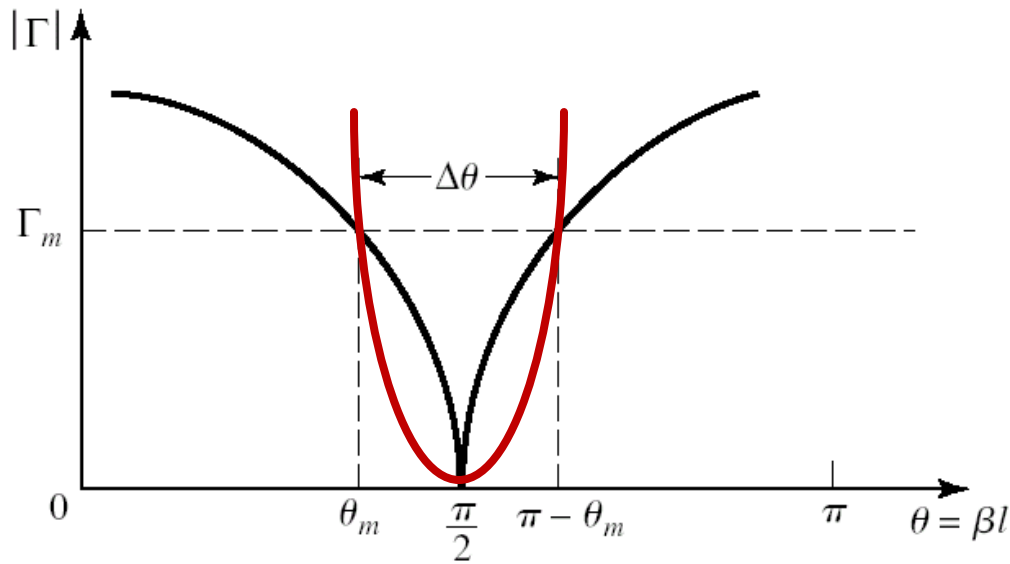
$$\ln Z_{n+1} \cong \ln Z_n + 2^{-N} \cdot C_N^n \cdot \ln \frac{Z_L}{Z_0}$$

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

- Banda, Γ_m maxim tolerat

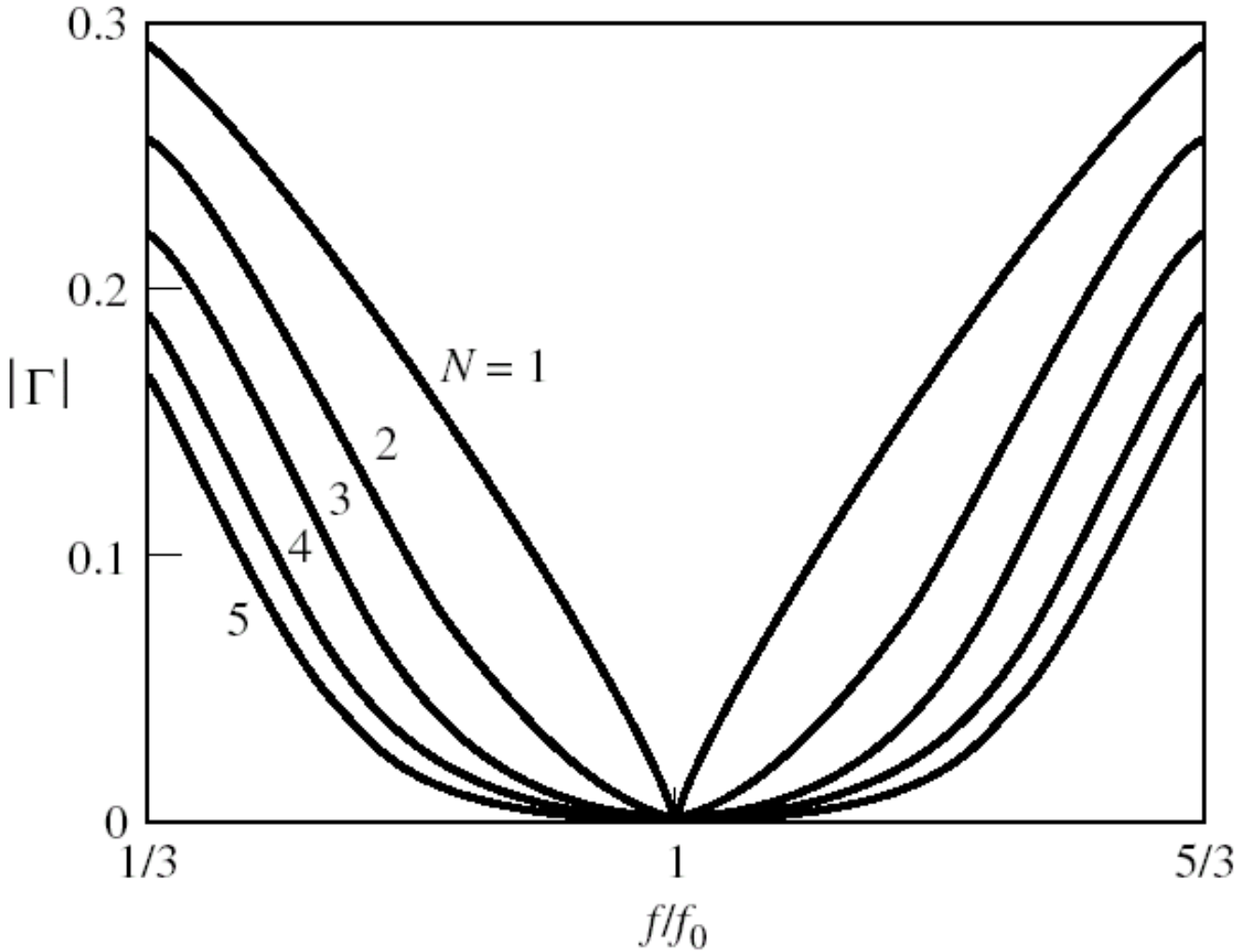
$$\Gamma_m = |\Gamma(\theta_m)| = 2^N \cdot |A| \cdot |\cos\theta_m|^N$$

$$\theta_m = \cos^{-1}\left[\frac{1}{2}\left(\frac{\Gamma_m}{|A|}\right)^{\frac{1}{N}}\right]$$



$$\frac{\Delta f}{f_0} = \frac{2(f_0 - f_m)}{f_0} = 2 - \frac{4\theta_m}{\pi} = 2 - \frac{4}{\pi} \cdot \cos^{-1}\left[\frac{1}{2}\left(\frac{\Gamma_m}{|A|}\right)^{\frac{1}{N}}\right]$$

Banda



Transformatoare cu mai multe sectiuni cu caracteristica binomiala, rezultate exacte

	$N=2$		$N=3$			$N=4$			
Z_L/Z_0	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.1067	1.3554	1.0520	1.2247	1.4259	1.0257	1.1351	1.3215	1.4624
2.0	1.1892	1.6818	1.0907	1.4142	1.8337	1.0444	1.2421	1.6102	1.9150
3.0	1.3161	2.2795	1.1479	1.7321	2.6135	1.0718	1.4105	2.1269	2.7990
4.0	1.4142	2.8285	1.1907	2.0000	3.3594	1.0919	1.5442	2.5903	3.6633
6.0	1.5651	3.8336	1.2544	2.4495	4.7832	1.1215	1.7553	3.4182	5.3500
8.0	1.6818	4.7568	1.3022	2.8284	6.1434	1.1436	1.9232	4.1597	6.9955
10.0	1.7783	5.6233	1.3409	3.1623	7.4577	1.1613	2.0651	4.8424	8.6110

	$N=5$					$N=6$					
Z_L/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_5/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_5/Z_0	Z_6/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.0128	1.0790	1.2247	1.3902	1.4810	1.0064	1.0454	1.1496	1.3048	1.4349	1.4905
2.0	1.0220	1.1391	1.4142	1.7558	1.9569	1.0110	1.0790	1.2693	1.5757	1.8536	1.9782
3.0	1.0354	1.2300	1.7321	2.4390	2.8974	1.0176	1.1288	1.4599	2.0549	2.6577	2.9481
4.0	1.0452	1.2995	2.0000	3.0781	3.8270	1.0225	1.1661	1.6129	2.4800	3.4302	3.9120
6.0	1.0596	1.4055	2.4495	4.2689	5.6625	1.0296	1.2219	1.8573	3.2305	4.9104	5.8275
8.0	1.0703	1.4870	2.8284	5.3800	7.4745	1.0349	1.2640	2.0539	3.8950	6.3291	7.7302
10.0	1.0789	1.5541	3.1623	6.4346	9.2687	1.0392	1.2982	2.2215	4.5015	7.7030	9.6228

Exemplu

- Transformator de adaptare cu 3 sectiuni pentru a adapta o sarcina de 30Ω la o linie de 100 Ω la frecventa f_o=3GHz, Γ_m=0.1
  - N = 3

$$Z_L = 30\Omega \qquad Z_0 = 100\,\Omega$$

$$A = 2^{-N}\frac{Z_L - Z_0}{Z_L + Z_0} \approx \frac{1}{2^{N+1}}\ln\frac{Z_L}{Z_0} = -0.07525$$

$$C_3^0 = \frac{3!}{3!\cdot 0!} = 1 \qquad C_3^1 = \frac{3!}{2!\cdot 1!} = 3 \qquad C_3^2 = \frac{3!}{1!\cdot 2!} = 3$$

Exemplu

$n = 0$

$$\ln Z_1 = \ln Z_0 + 2^{-N} C_3^0 \ln \frac{Z_L}{Z_0} = \ln 100 + 2^{-3} \cdot 1 \cdot \ln \frac{30}{100} = 4.455$$

$$Z_1 = 86.03\Omega$$

$n = 1$

$$\ln Z_2 = \ln Z_1 + 2^{-N} C_3^1 \ln \frac{Z_L}{Z_0} = \ln 86.03 + 2^{-3} \cdot 3 \cdot \ln \frac{30}{100} = 4.003$$

$$Z_2 = 54.77\Omega$$

$n = 2$

$$\ln Z_3 = \ln Z_2 + 2^{-N} C_3^2 \ln \frac{Z_L}{Z_0} = \ln 54.77 + 2^{-3} \cdot 3 \cdot \ln \frac{30}{100} = 3.552$$

$$Z_3 = 34.87\Omega$$

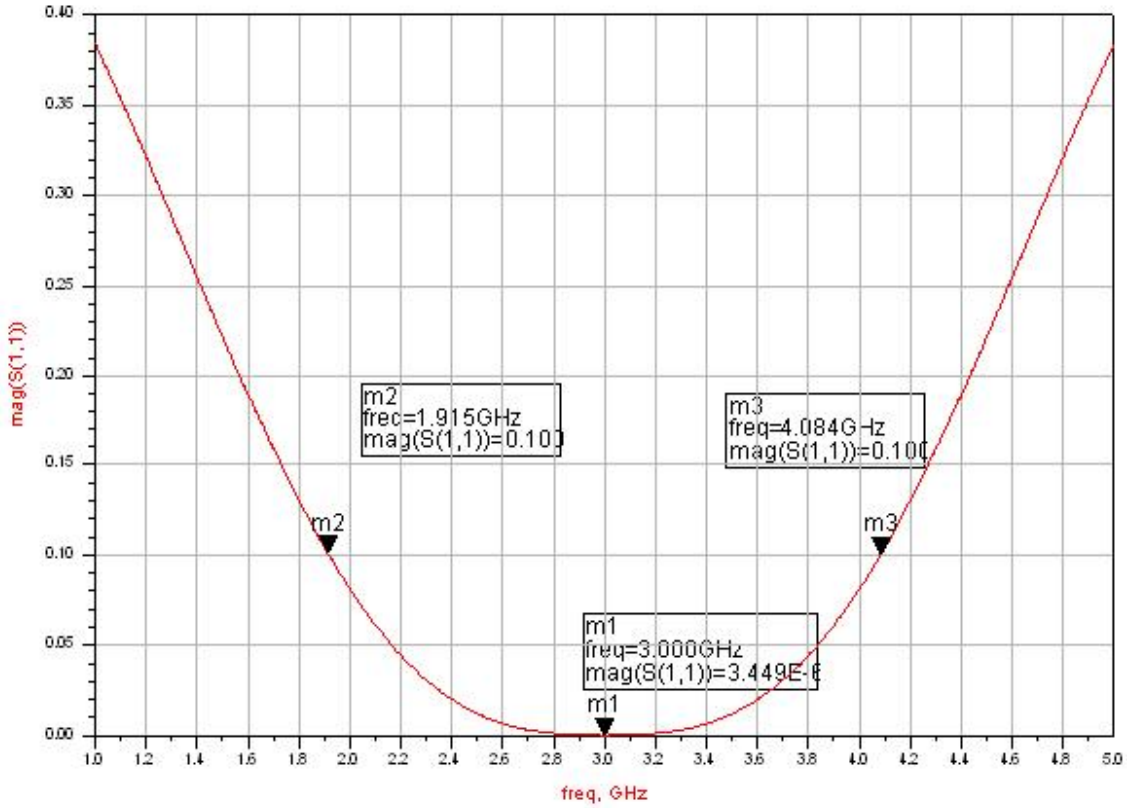
Exemplu

$$\frac{\Delta f}{f_0} = 2 - \frac{4}{\pi}\arccos\left[\frac{1}{2}\left(\frac{\Gamma_m}{|A|}\right)^{1/N}\right] = 2 - \frac{4}{\pi}\arccos\left[\frac{1}{2}\left(\frac{0.1}{0.07525}\right)^{1/3}\right] = 0.74$$

$$\Delta f = 2.22GHz$$

Simulare

- Similar Lab. 1



$$\Delta f = 2.169GHz$$

$$\left|\Gamma\left(3GHz\right)\right| = 3.5 \cdot 10^{-6}$$

Transformatoare cu mai multe sectiuni de tip Cebîşev

- Raspunsul acestui transformator este de tip echiriplu in jurul frecventei de adaptare
- mareste banda in detrimentul riplului (variatiilor) in banda de adaptare
- Se egaleaza functia $\Gamma(\theta)$ cu un polinom Cebîşev

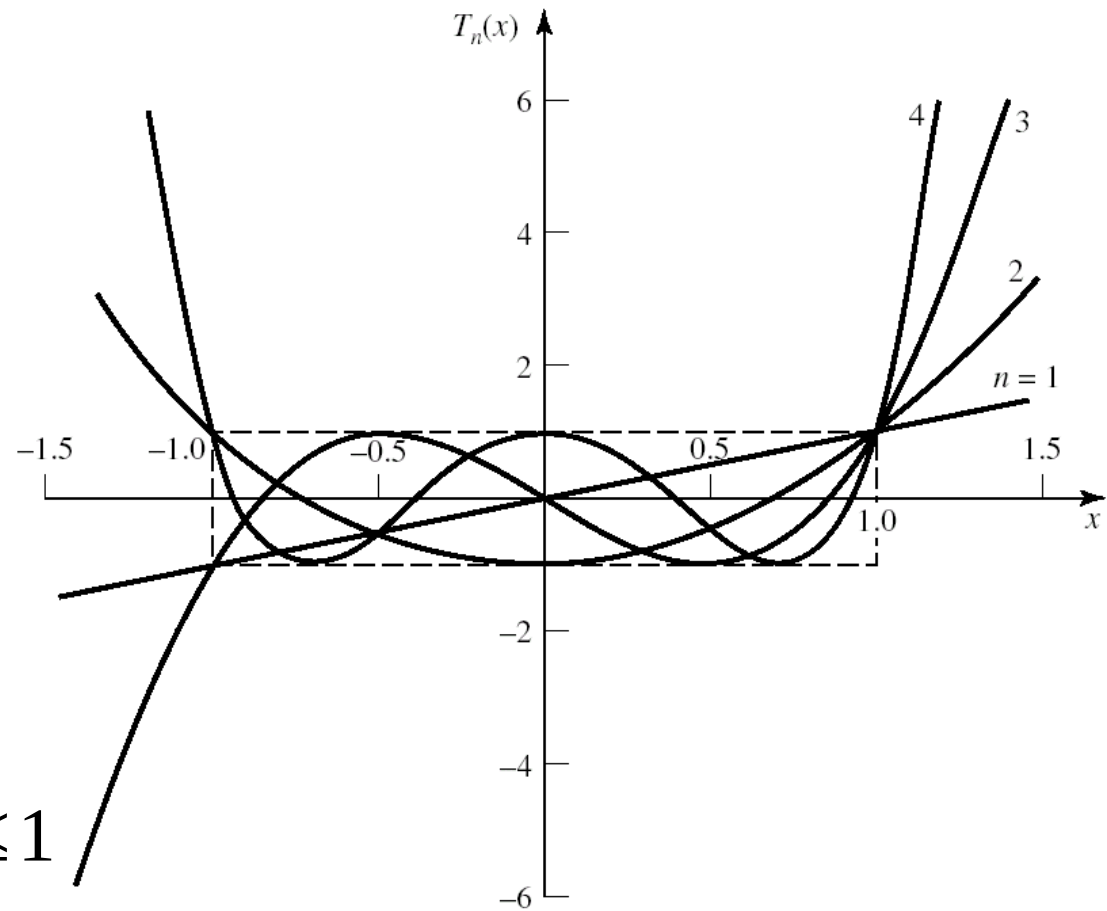
Polinoame Cebîşev

$$T_1(x) = x$$

$$T_2(x) = 2x^2 - 1$$

$$T_3(x) = 4x^3 - 3x$$

$$T_4(x) = 8x^4 - 8x^2 + 1$$



- **Echiriplu**

$$-1 \le x \le 1 \quad \Rightarrow \quad |T_n(x)| \le 1$$

$$T_n(x) = 2xT_{n-1}(x) - T_{n-2}(x)$$

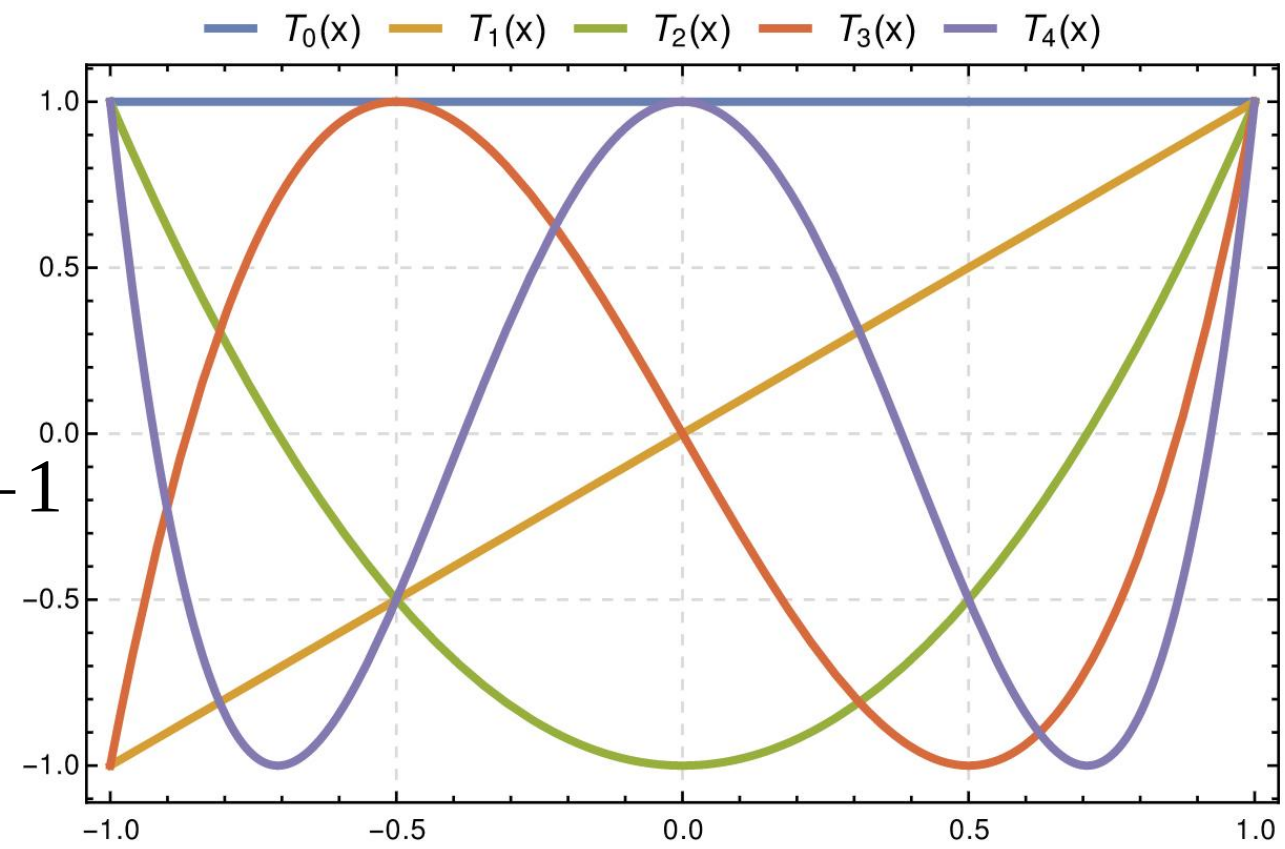
Polinoame Cebîşev

$$T_1(x) = x$$

$$T_2(x) = 2x^2 - 1$$

$$T_3(x) = 4x^3 - 3x$$

$$T_4(x) = 8x^4 - 8x^2 + 1$$



- **Echiriplu**

$$-1 \le x \le 1 \quad \Rightarrow \quad |T_n(x)| \le 1$$

Polinoame Cebîşev

$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \cdots + \Gamma_N \cdot e^{-2jN\theta}$$

$$e^{-2j\theta} \equiv x$$

$$f(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + \cdots + a_N \cdot x^N$$

$$\Gamma(\theta) = 2e^{-jN\theta} \cdot \left[\Gamma_0 \cdot \cos N\theta + \Gamma_1 \cdot \cos(N-2)\theta + \cdots \Gamma_n \cdot \cos(N-2n)\theta + \cdots\right]$$

ultimul termen:

$$\cdots \frac{1}{2} \cdot \Gamma_{N/2} \quad n \text{ par}$$

$$\cdots \Gamma_{(N-1)/2} \cdot \cos\theta \quad n \text{ impar}$$

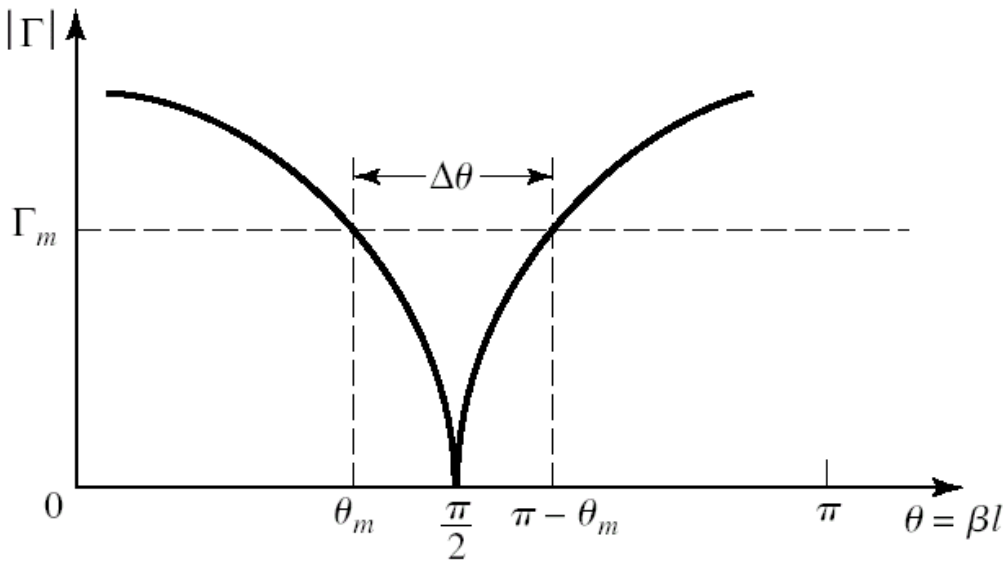
$$x = \cos\theta \qquad |x| < 1$$

- Se poate arata ca: $T_n(\cos\theta) = \cos(n\theta)$

$$T_n(x) = \cos(n \arccos(x)) \quad |x| < 1 \qquad T_n(x) = \cosh\left(n \cosh^{-1}(x)\right) \quad |x| > 1$$

Transformatoare cu mai multe sectiuni de tip Cebîşev

- Schimbare de variabila
  - banda de interes -> [-1,1]



$$\theta = \theta_m \rightarrow x = 1 \qquad \theta = \pi - \theta_m \rightarrow x = -1$$

$$\boxed{x \equiv \frac{\cos\theta}{\cos\theta_m}}$$

$$\sec\theta = \frac{1}{\cos\theta} \qquad x = \sec\theta_m \cos\theta$$

Transformatoare cu mai multe sectiuni de tip Cebîşev

- Cautam coeficientii pentru a obtine un polinom Cebîşev

$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \cdots + \Gamma_N \cdot e^{-2jN\theta}$$

$$\Gamma(\theta) = e^{-jN\theta} \cdot \left[\Gamma_0 \cdot \left(e^{jN\theta} + e^{-jN\theta}\right) + \Gamma_1 \cdot \left(e^{j(N-2)\theta} + e^{-j(N-2)\theta}\right) + \Gamma_2 \cdot \left(e^{j(N-4)\theta} + e^{-j(N-4)\theta}\right) + \cdots\right]$$

$$\Gamma(\theta) = 2e^{-jN\theta} \cdot \left[\Gamma_0 \cdot \cos N\theta + \Gamma_1 \cdot \cos(N-2)\theta + \cdots \Gamma_n \cdot \cos(N-2n)\theta + \cdots\right]$$

ultimul termen:

$$\cdots \frac{1}{2} \cdot \Gamma_{N/2} \quad n \text{ par}$$

$$\cdots \Gamma_{(N-1)/2} \cdot \cos\theta \quad n \text{ impar}$$

$$\Gamma(\theta) = A \cdot e^{-jN\theta} \cdot T_N\left(\sec\theta_m \cos\theta\right)$$

Polinoame Cebîşev

$$\cancel{(\cos\theta)}^k \Leftrightarrow \cos k\theta$$

$$T_1(x) = x \qquad \boxed{T_1(\sec\theta_m \cos\theta) = \sec\theta_m \cos\theta}$$

$$T_2(x) = 2x^2 - 1 \qquad T_2(\sec\theta_m \cos\theta) = 2\sec^2\theta_m \cos^2\theta - 1$$

$$\cos 2\theta = \cos^2\theta - \sin^2\theta = 2\cos^2\theta - 1$$

$$\boxed{T_2(\sec\theta_m \cos\theta) = \sec^2\theta_m (1 + \cos 2\theta) - 1}$$

$$T_3(x) = 4x^3 - 3x \qquad T_3(\sec\theta_m \cos\theta) = 4\sec^3\theta_m \cos^3\theta - 3\sec\theta_m \cos\theta$$

$$\cos 3\theta = \cos(2\theta + \theta) = \cos 2\theta \cos\theta - \sin 2\theta \sin\theta$$

$$\cos 3\theta = (2\cos^2\theta - 1)\cos\theta - 2(1 - \cos^2\theta)\cos\theta$$

$$\cos 3\theta = 4\cos^3\theta - 3\cos\theta$$

$$\boxed{T_3(\sec\theta_m \cos\theta) = \sec^3\theta_m (\cos 3\theta + 3\cos\theta) - 3\sec\theta_m \cos\theta}$$

Transformatoare cu mai multe sectiuni de tip Cebîşev

$$T_1(\sec\theta_m \cos\theta) = \sec\theta_m \cos\theta$$

$$T_2(\sec\theta_m \cos\theta) = \sec^2\theta_m (1+\cos 2\theta) - 1$$

$$T_3(\sec\theta_m \cos\theta) = \sec^3\theta_m (\cos 3\theta + 3\cos\theta) - 3\sec\theta_m \cos\theta$$

$$T_4(\sec\theta_m \cos\theta) = \sec^4\theta_m (\cos 4\theta + 4\cos 2\theta + 3) - 4\sec^2\theta_m (\cos 2\theta + 1) + 1$$

- Cautam coeficientii pentru a obtine un polinom Cebîşev

$$\Gamma(\theta) = 2e^{-jN\theta} \cdot [\Gamma_0 \cdot \cos N\theta + \Gamma_1 \cdot \cos(N-2)\theta + \cdots \Gamma_n \cdot \cos(N-2n)\theta + \cdots]$$

$$\Gamma(\theta) = A \cdot e^{-jN\theta} \cdot T_N(\sec\theta_m \cos\theta)$$

ultimul termen:

$$\cdots \frac{1}{2} \cdot \Gamma_{N/2} \quad n \text{ par}$$

$$\cdots \Gamma_{(N-1)/2} \cdot \cos\theta \quad n \text{ impar}$$

Transformatoare cu mai multe sectiuni de tip Cebîşev

- A, θ →o , liniile de lungime o, dispar

$$\Gamma(0)=\frac{Z_L-Z_0}{Z_L+Z_0}=A\cdot T_N(\sec\theta_m) \qquad A=\frac{Z_L-Z_0}{Z_L+Z_0}\cdot\frac{1}{T_N(\sec\theta_m)} \qquad \boxed{\Gamma_m=|A|}$$

$$T_N(\sec\theta_m)=\frac{1}{\Gamma_m}\left|\frac{Z_L-Z_0}{Z_L+Z_0}\right|\cong\frac{1}{2\Gamma_m}\left|\ln\frac{Z_L}{Z_0}\right|$$

$$T_n(x)=\cosh\left(n\cosh^{-1}(x)\right)$$

$$\sec\theta_m=\cosh\left[\frac{1}{N}\cosh^{-1}\left(\frac{1}{\Gamma_m}\left|\frac{Z_L-Z_0}{Z_L+Z_0}\right|\right)\right]\cong\cosh\left[\frac{1}{N}\cosh^{-1}\left(\left|\frac{\ln(Z_L/Z_0)}{2\Gamma_m}\right|\right)\right]$$

- se poate calcula θ_m pentru Γ_m maxim tolerat (riplu) deci banda

$$\frac{\Delta f}{f_0}=\frac{2(f_0-f_m)}{f_0}=2-\frac{4\theta_m}{\pi}$$

Transformatoare cu mai multe sectiuni de tip Cebîşev

- Proiectare, solutii aproximative

$$\boxed{\Gamma_m = |A|}$$

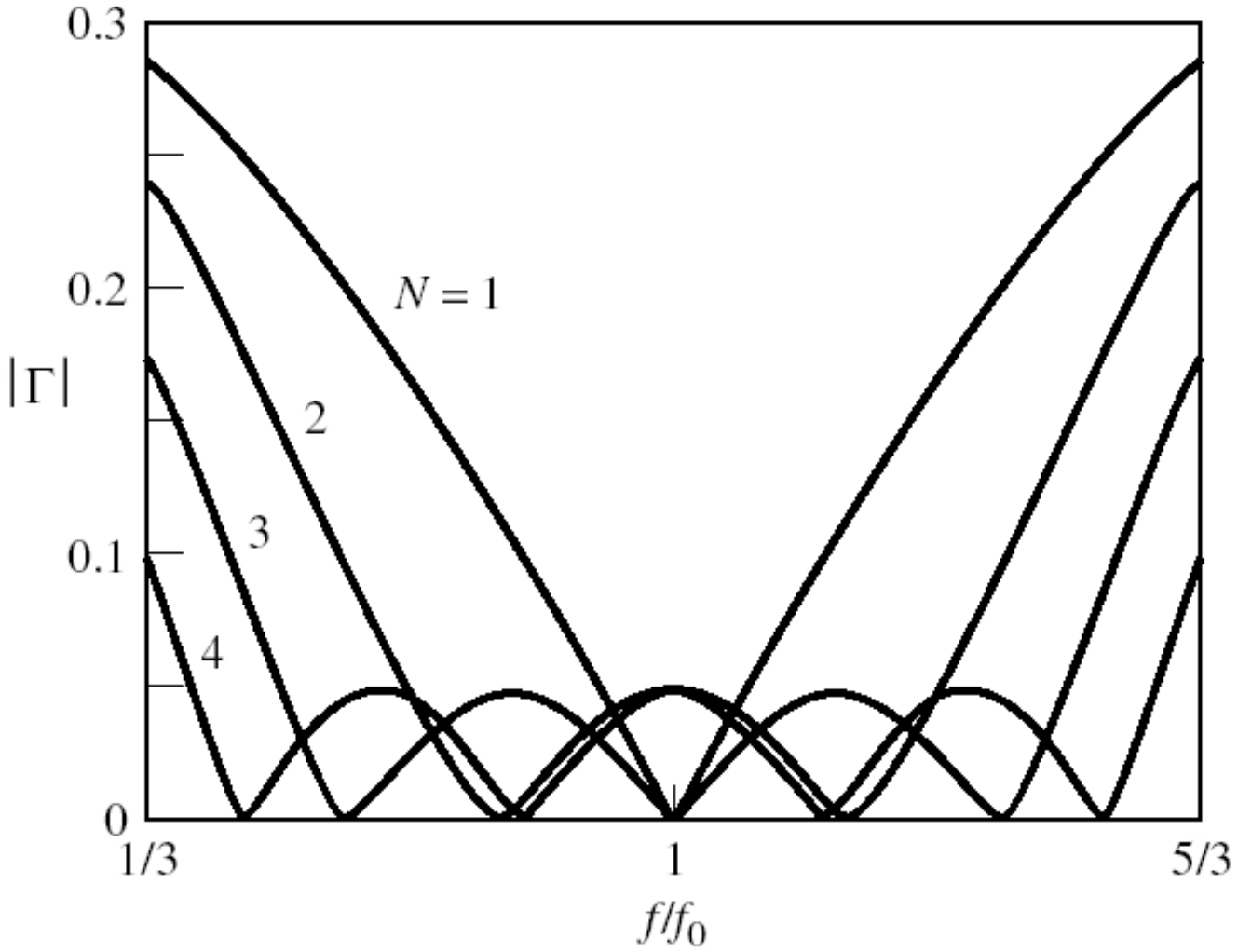
$$A = \frac{Z_L - Z_0}{Z_L + Z_0} \cdot \frac{1}{T_N(\sec\theta_m)}$$

- Semnul lui A depinde de Z_L <> Z_o
- Se calculeaza sec θ_m
- Se reprezinta polinomul Cebîşev de ordin ales si se identifica coeficientii pentru cos kθ

$$\Gamma(\theta) = 2e^{-jN\theta} \cdot [\Gamma_0 \cdot \cos N\theta + \Gamma_1 \cdot \cos(N-2)\theta + \cdots \Gamma_n \cdot \cos(N-2n)\theta + \cdots]$$

$$\ln \frac{Z_{n+1}}{Z_n} \cong 2 \cdot \Gamma_n \qquad \ln Z_{n+1} \cong \ln Z_n + 2 \cdot \Gamma_n$$

Transformatoare cu mai multe sectiuni de tip Cebîşev



Transformatoare cu mai multe sectiuni de tip Cebîşev, rezultate exacte

	$N=2$				$N=3$					
	$\Gamma_m = 0.05$		$\Gamma_m = 0.20$		$\Gamma_m = 0.05$			$\Gamma_m = 0.20$		
Z_L/Z_0	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.1347	1.3219	1.2247	1.2247	1.1029	1.2247	1.3601	1.2247	1.2247	1.2247
2.0	1.2193	1.6402	1.3161	1.5197	1.1475	1.4142	1.7429	1.2855	1.4142	1.5558
3.0	1.3494	2.2232	1.4565	2.0598	1.2171	1.7321	2.4649	1.3743	1.7321	2.1829
4.0	1.4500	2.7585	1.5651	2.5558	1.2662	2.0000	3.1591	1.4333	2.0000	2.7908
6.0	1.6047	3.7389	1.7321	3.4641	1.3383	2.4495	4.4833	1.5193	2.4495	3.9492
8.0	1.7244	4.6393	1.8612	4.2983	1.3944	2.8284	5.7372	1.5766	2.8284	5.0742
10.0	1.8233	5.4845	1.9680	5.0813	1.4385	3.1623	6.9517	1.6415	3.1623	6.0920

$N=4$

	$\Gamma_m = 0.05$				$\Gamma_m = 0.20$			
Z_L/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.0892	1.1742	1.2775	1.3772	1.2247	1.2247	1.2247	1.2247
2.0	1.1201	1.2979	1.5409	1.7855	1.2727	1.3634	1.4669	1.5715
3.0	1.1586	1.4876	2.0167	2.5893	1.4879	1.5819	1.8965	2.0163
4.0	1.1906	1.6414	2.4369	3.3597	1.3692	1.7490	2.2870	2.9214
6.0	1.2290	1.8773	3.1961	4.8820	1.4415	2.0231	2.9657	4.1623
8.0	1.2583	2.0657	3.8728	6.3578	1.4914	2.2428	3.5670	5.3641
10.0	1.2832	2.2268	4.4907	7.7930	1.5163	2.4210	4.1305	6.5950

Exemplu

- Transformator de adaptare cu 3 sectiuni pentru a adapta o sarcina de 30Ω la o linie de 100 Ω la frecventa f_o=3GHz, Γ_m=0.1
  - N = 3 $\quad Z_L = 30\Omega \quad Z_0 = 100\,\Omega$

$$\Gamma(\theta) = 2e^{-j3\theta}\left[\Gamma_0 \cos 3\theta + \Gamma_1 \cos\theta\right] = Ae^{-j3\theta}T_3\left(\sec\theta_m \cos\theta\right)$$

$$|A| = \Gamma_m = 0.1 \qquad A = \frac{Z_L - Z_0}{Z_L + Z_0}\cdot\frac{1}{T_N\left(\sec\theta_m\right)} \qquad Z_L < Z_0 \rightarrow A < 0 \qquad A = -0.1$$

$$\sec\theta_m = \cosh\left[\frac{1}{N}\cdot\cosh^{-1}\left(\left|\frac{\ln Z_L/Z_0}{2\Gamma_m}\right|\right)\right] = \cosh\left[\frac{1}{3}\cdot\cosh^{-1}\left(\left|\frac{\ln(30/100)}{2\cdot 0.1}\right|\right)\right] = 1.362$$

$$\theta_m = \arccos\left(\frac{1}{\sec\theta_m}\right) = 0.746\,rad = 42.76^\circ$$

Exemplu

$$2\left[\Gamma_0 \cos 3\theta + \Gamma_1 \cos\theta\right] = A\sec^3\theta_m\left(\cos 3\theta + 3\cos\theta\right) - 3A\sec\theta_m \cos\theta$$

$\cos 3\theta$ $\qquad 2\Gamma_0 = A\sec^3\theta_m$ $\qquad \Gamma_0 = -0.1263$

$\cos\theta$ $\qquad 2\Gamma_1 = 3A\left(\sec^3\theta_m - \sec\theta_m\right)$ $\qquad \Gamma_1 = -0.1747$

simetrie: $\quad \Gamma_3 = \Gamma_0; \quad \Gamma_2 = \Gamma_1$

Exemplu

$n = 0$

$$\ln Z_1 = \ln Z_0 + 2 \cdot \Gamma_0 = \ln 100 - 2 \cdot 0.1263 = 4.353$$

$$\Gamma_0 = -0.1263$$

$$Z_1 = 77.68\Omega$$

$$\Gamma_1 = -0.1747$$

$n = 1$

$$\ln Z_2 = \ln Z_1 + 2 \cdot \Gamma_1 = \ln 77.68 - 2 \cdot 0.1747 = 4.003$$

$$Z_2 = 54.77\Omega$$

$n = 2$

$$\ln Z_3 = \ln Z_2 + 2 \cdot \Gamma_2 = \ln 54.77 - 2 \cdot 0.1747 = 3.654$$

$$Z_3 = 38.62\Omega$$

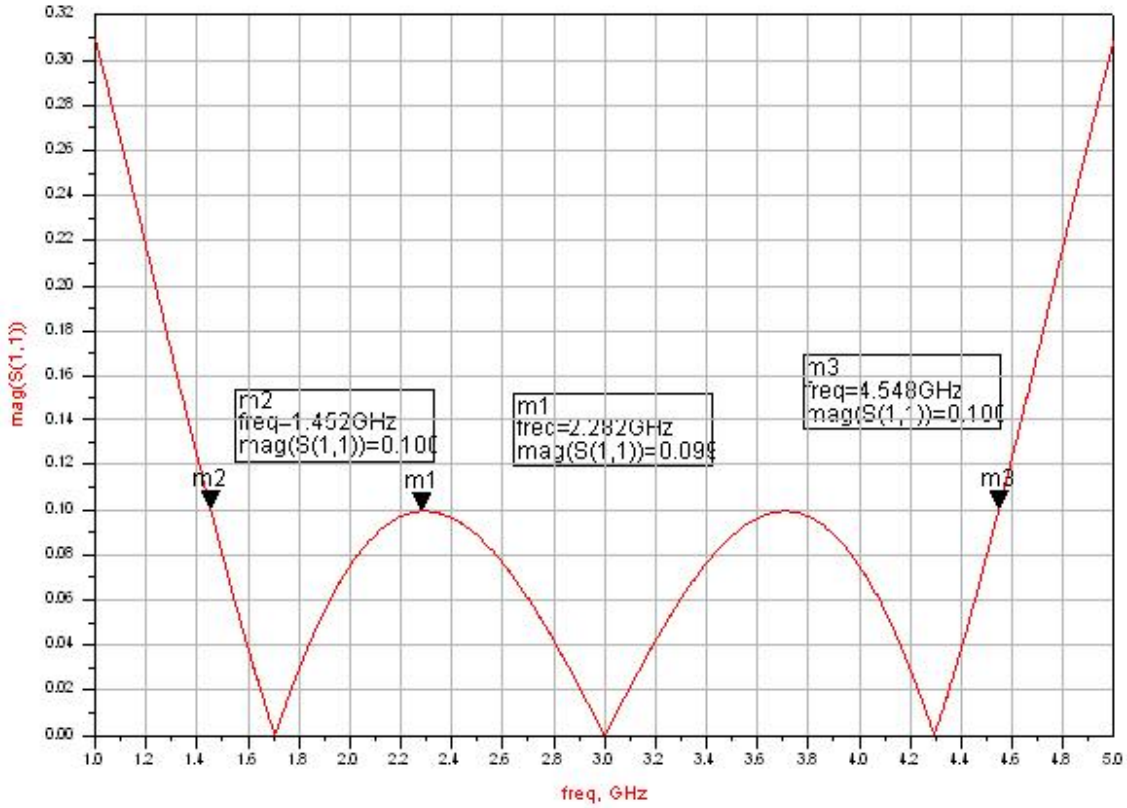
Exemplu

$$\frac{\Delta f}{f_0} = \frac{2\left(f_0 - f_m\right)}{f_0} = 2 - \frac{4\theta_m}{\pi} = 2 - \frac{4 \cdot 42.76°}{180°} = 1.045$$

$$\Delta f = 3.15 GHz$$

Simulare

- Similar Lab. 1



$$\Delta f = 3.096GHz$$

$$\left|\Gamma(3GHz)\right| = 4.17 \cdot 10^{-5}$$

$$\left|\Gamma(2.282GHz)\right| = 0.09925$$

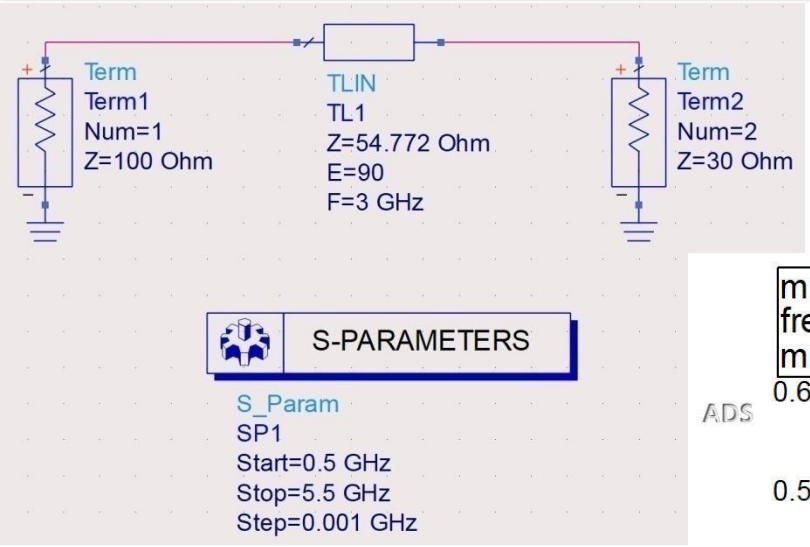
Solutii exacte

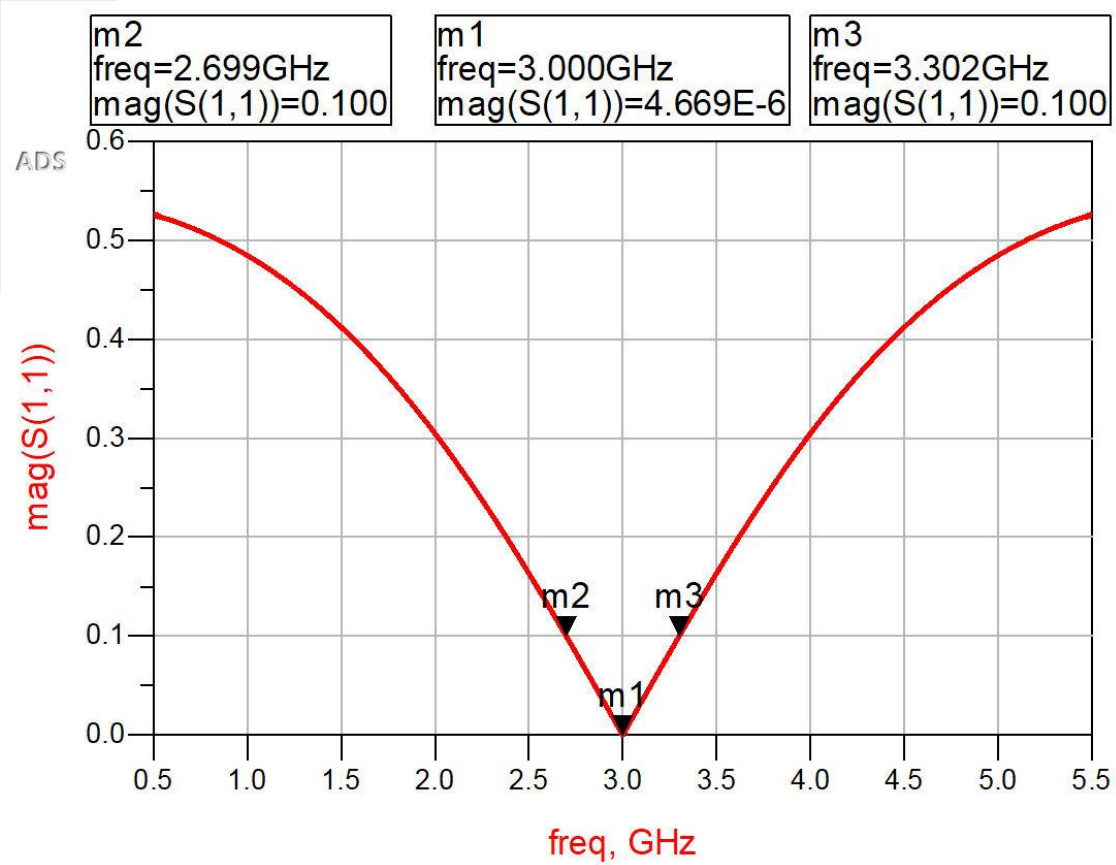
- G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks,and Coupling Structures, Artech House Books, Dedham, Mass. 1980*

Lab. 1

Adaptarea de impedanța

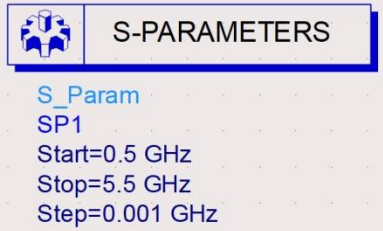
Sfert de lungime de unda

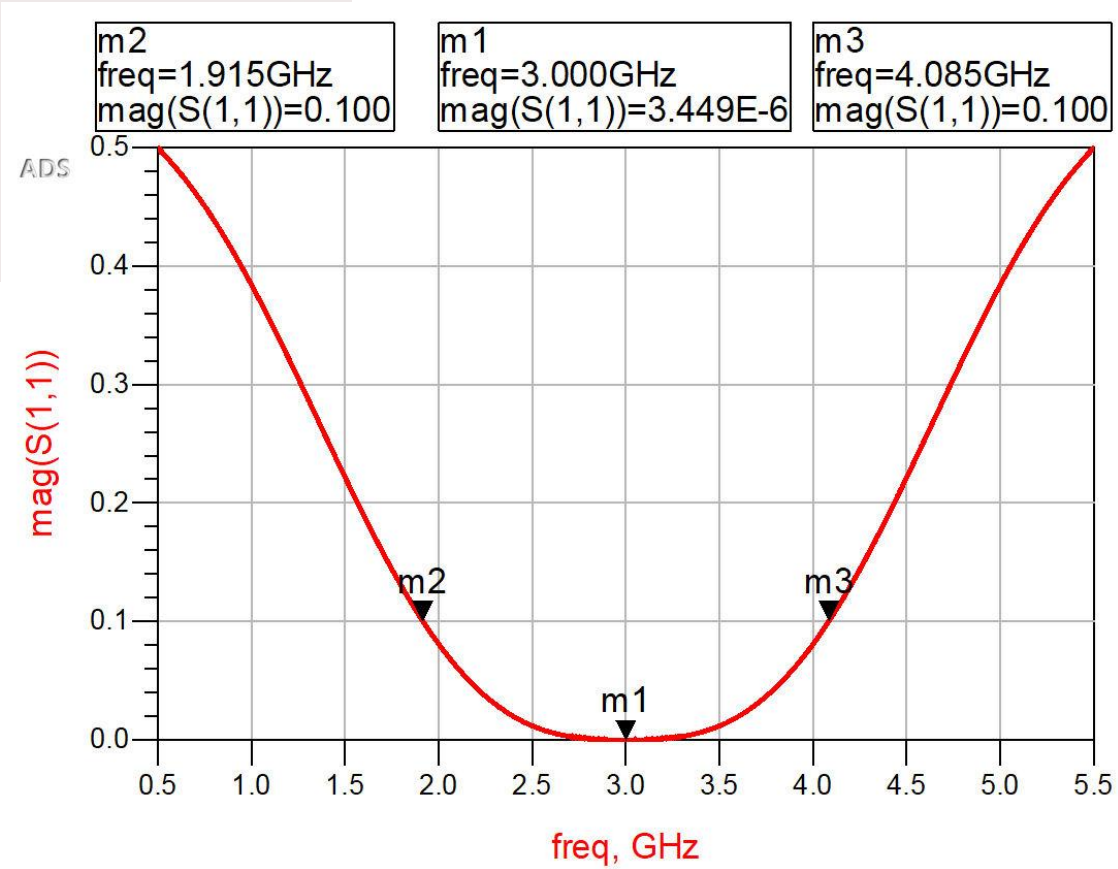




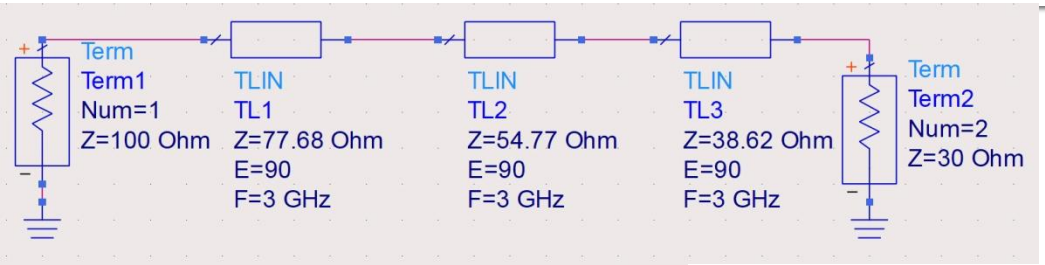
Binomial

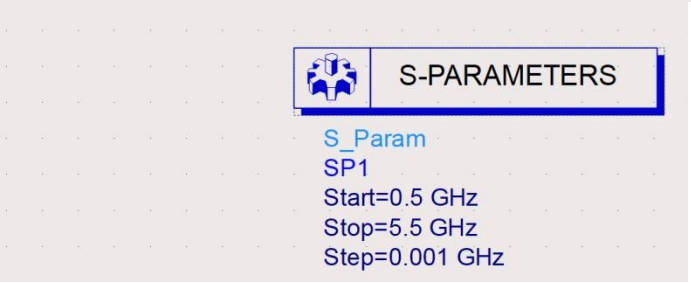
Term
Term1
Num=1
Z=100 Ohm
TLIN
TL1
Z=86.03 Ohm
E=90
F=3 GHz
TLIN
TL2
Z=54.77 Ohm
E=90
F=3 GHz
TLIN
TL3
Z=34.87 Ohm
E=90
F=3 GHz
Term
Term2
Num=2
Z=30 Ohm

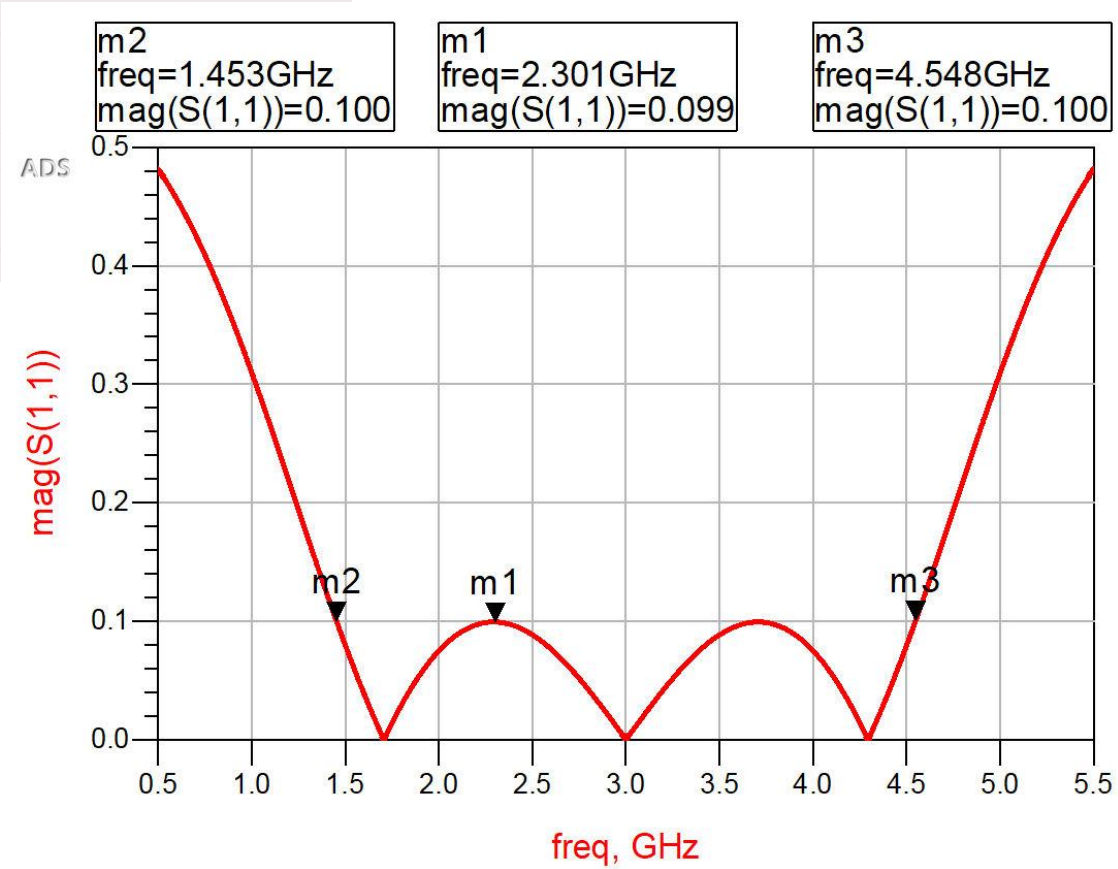

S-PARAMETERS
S_Param
SP1
Start=0.5 GHz
Stop=5.5 GHz
Step=0.001 GHz


m2
freq=1.915GHz
mag(S(1,1))=0.100
m1
freq=3.000GHz
mag(S(1,1))=3.449E-6
m3
freq=4.085GHz
mag(S(1,1))=0.100
ADS
mag(S(1,1))
freq, GHz
0.0
0.1
0.2
0.3
0.4
0.5
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
m2
m1
m3

Cebâşev


Term
Term1
Num=1
Z=100 Ohm
TLIN
TL1
Z=77.68 Ohm
E=90
F=3 GHz
TLIN
TL2
Z=54.77 Ohm
E=90
F=3 GHz
TLIN
TL3
Z=38.62 Ohm
E=90
F=3 GHz
Term
Term2
Num=2
Z=30 Ohm


S-PARAMETERS
S_Param
SP1
Start=0.5 GHz
Stop=5.5 GHz
Step=0.001 GHz


m2
freq=1.453GHz
mag(S(1,1))=0.100
m1
freq=2.301GHz
mag(S(1,1))=0.099
m3
freq=4.548GHz
mag(S(1,1))=0.100
ADS
mag(S(1,1))
0.0
0.1
0.2
0.3
0.4
0.5
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
freq, GHz

Puncte suplimentare

Tema

Tema

- Scrieti pe o foaie de hartie (si scanati/foto) relatiile pentru:
  - determinarea conditiei de maxim de putere utilizand derivate partiale

$$\frac{\partial P_L}{\partial R_L} = 0 \qquad \frac{\partial P_L}{\partial X_L} = 0$$

  - determinarea expresiei pentru polinomul Cebîşev de ordinul 4

$$T_4(\sec\theta_m \cos\theta) = \sec^4\theta_m(\cos 4\theta + 4\cos 2\theta + 3) - 4\sec^2\theta_m(\cos 2\theta + 1) + 1$$

Contact

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