

**Curs 2**

**2018/2019**

# **Dispozitive și circuite de microunde pentru radiocomunicații**

# Disciplina 2018/2019

- 2C/1L, DCMR (CDM)
- Minim 7 prezente (curs+laborator)
- Curs - conf. Radu Damian
  - Vineri 11-13, P7
  - E – 50% din nota
  - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
    - 3pz=+0.5p
  - toate materialele permise
- Laborator – conf. Radu Damian
  - Joi 8-14 impar II.13
  - L – 25% din nota
  - P – 25% din nota

# Documentatie

■ <http://rf-opto.etti.tuiasi.ro>

Laboratorul de Microunde si Optică

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

RF-OPTO

UNIVERSITATEA TEHNICĂ "GHEORGHE ASACHI" LAZĂR

English | Romana |

Start Didactic Master Colectiv Cercetare Studenti Admin

Microunde Comunicatii Optice Optoelectronica Internet Antene Practica Retele Soft didactic

## Dispozitive si circuite de microunde pentru radiocomunicatii

### Disciplina: DCMR (2017-2018)

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

#### Activitati

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

#### Evaluare

Tip: Examen

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

#### Note

Rezultate totale

#### Prezenta

Curs  
Laborator

#### Liste

Bonus-uri acumulate (final)  
Studenti care nu pot intra in examen

# Fotografii

http://if-opto.eti.tuiasi.ro/presenza.php?act=153&nru=14&ext\_supliz=26 eti.tuiasi.ro Laboratorul de Microonde s... ro.wikipedia.org

Start Didactic Master Colectiv Cercetare Studenti Admin

Note Lista Studenti Fotografi Statistici

Grupa 5403

Nr.	Student	Prezent	Nr.	Student	Prezent	Nr.	Student	Prezent	
1	ANGHELUS IONUT-MARCUS		<input type="checkbox"/> Prezent	2	ANTIGHIN FLORIN-RAZVAN	 <b>Fotografia nu există</b>	<input type="checkbox"/> Prezent	 <b>Fotografia nu există</b>	<input type="checkbox"/> Prezent
4	APOSTOL PAVEL-MANUEL	 <b>Fotografia nu există</b>	<input type="checkbox"/> Prezent	5	BALASCA TUDIAN-PETRU	 <b>Fotografia nu există</b>	<input checked="" type="checkbox"/> Prezent	 <b>Fotografia nu există</b>	<input type="checkbox"/> Prezent
7	BOTEZAT EMANUEL		<input type="checkbox"/> Prezent	8	BUTUNOI GEORGE-MADALIN	 <b>Fotografia nu există</b>	<input type="checkbox"/> Prezent	 <b>Fotografia nu există</b>	<input type="checkbox"/> Prezent
10	CHIRITOIU ECATERINA		<input type="checkbox"/> Prezent	11	CODOC MARCUS		<input checked="" type="checkbox"/> Prezent		<input type="checkbox"/> Prezent
				12	COJOCARU ALINA-FLORINA				

Nr. Student

Prezent

2 ANTIGHIN  
FLORIN-RAZVAN

Prezent

Puncte: 0

Nota: 0

Obs:

**Fotografia nu există**

# 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

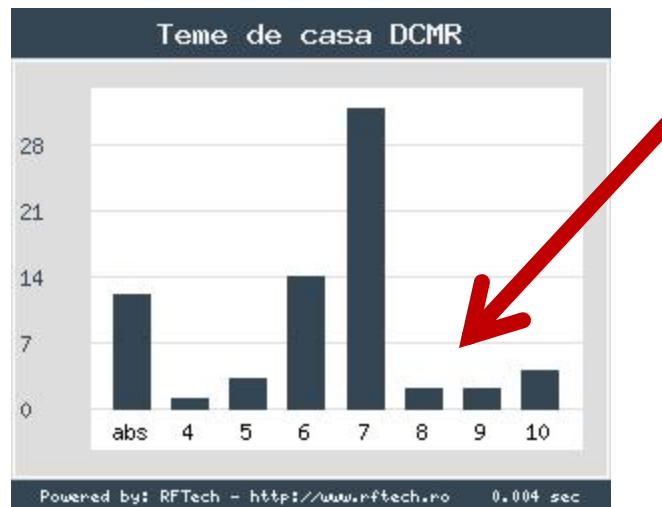
Cod de verificare

Trimite

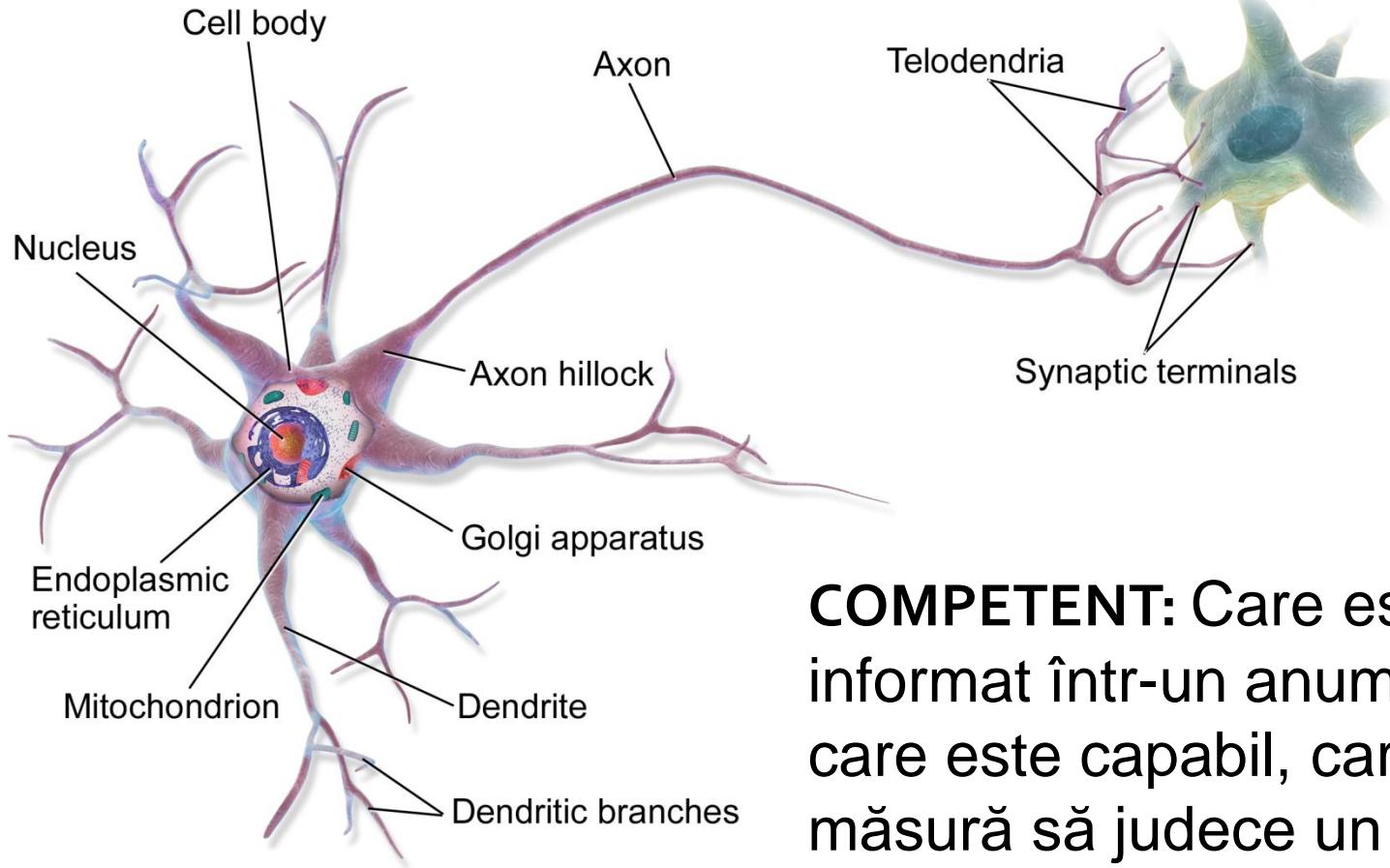
# Proiect 2018/2019

- factorul “andrei” = -2p

2017/8



# Scop curs



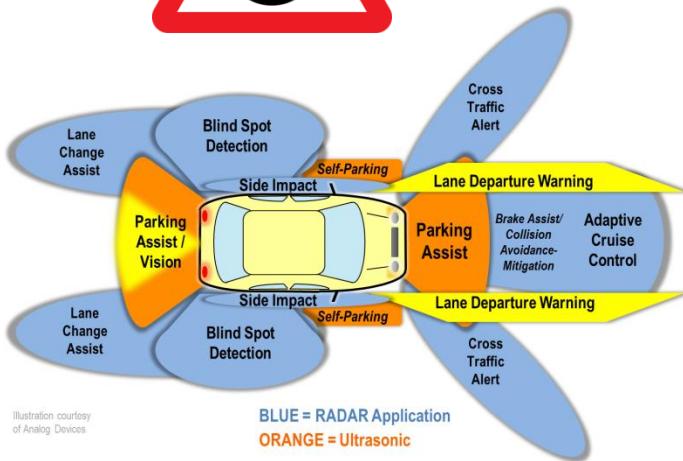
**COMPETENT:** Care este bine informat într-un anumit domeniu; care este capabil, care este în măsură să judece un anumit lucru. [DEX]

~1930



# Tehnologie

> 2010



< 1950



# Examen: Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$-20 \text{ dBm} = 1 \mu\text{W}$$

$$-30 \text{ dBm} = 1 \text{ nW}$$

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

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

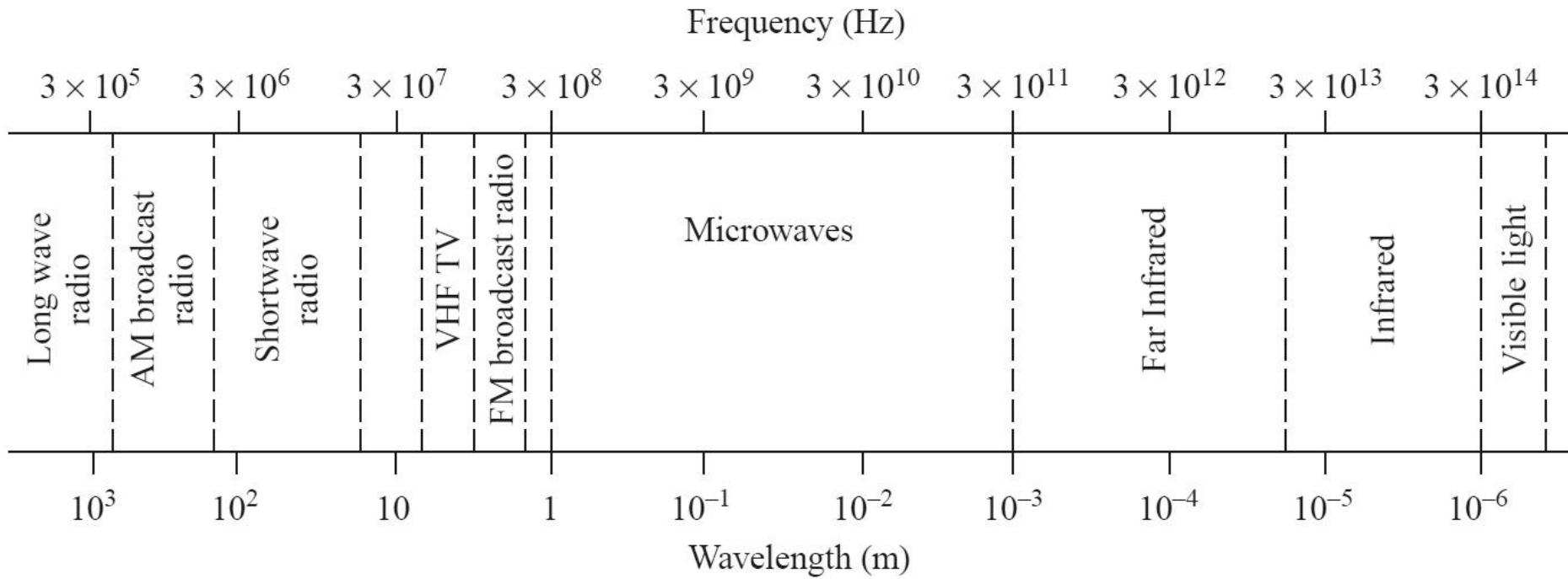
$$[x] + [\text{dB}] = [x]$$

# Examen

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

# Introducere

# Microunde



- tipic
  - $f \approx 1 \text{ GHz} - 300 \text{ GHz}$
  - $\lambda \approx 1 \text{ mm} - 10 \text{ cm}$

# ~ Microunde

- Lungimea electrică a unui circuit
  - $l$  – lungimea fizică
  - $E = \beta \cdot l$  – lungimea electrică

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

V, l variabile  
~ inutile

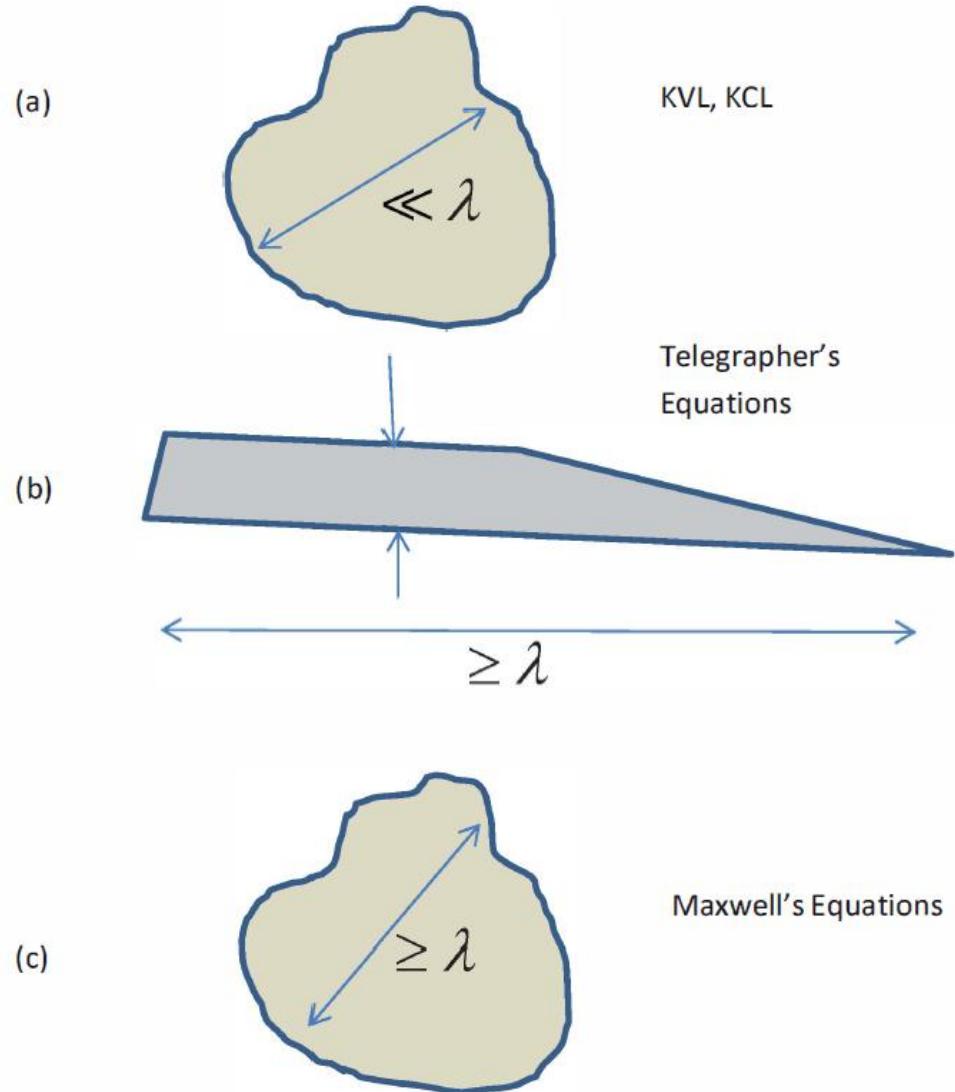
$$E = \beta \cdot l = \frac{2\pi}{c_0} \cdot \left( l \cdot f \cdot \sqrt{\epsilon_r} \right)$$

- Dependenta
  - castigul antenei
  - imaginea unui obiect pe radar

# Lungimea electrică

- Comportarea (descrierea) unui circuit depinde de lungimea sa electrică la frecvențele de interes
  - $E \approx 0 \rightarrow$  Kirchhoff
  - $E > 0 \rightarrow$  propagare

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



# Ecuatiile lui Maxwell

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = \frac{\partial D}{\partial t} + J$$

$$\nabla \cdot D = \rho$$

$$\nabla \cdot B = 0$$

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t}$$

## ■ Ecuatii constitutive

$$D = \epsilon \cdot E$$

$$B = \mu \cdot H$$

$$J = \sigma \cdot E$$

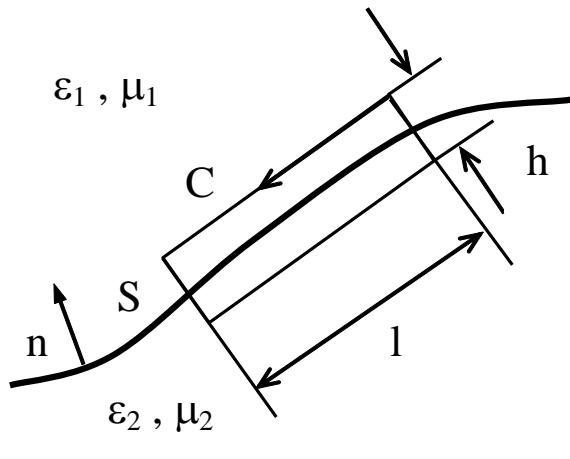
- În vid

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$$

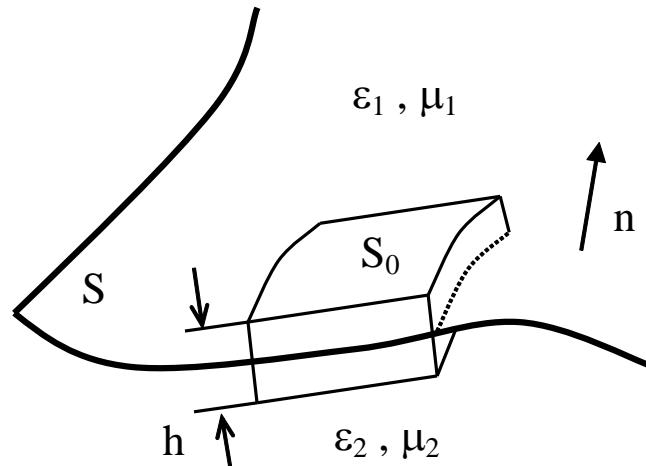
$$\epsilon_0 = 8,854 \times 10^{-12} \text{ F/m}$$

$$c_0 = \frac{1}{\sqrt{\epsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

# Condiții la limita de separație între două medii



a)



b)

$$n \times (E_1 - E_2) = 0$$

$$n \cdot (D_1 - D_2) = \rho_s$$

$$n \times (H_1 - H_2) = J_s$$

$$n \cdot (B_1 - B_2) = 0$$

- Daca un mediu este metal ideal toate campurile se anuleaza in interior

# Câmpuri electromagnetice cu variație armonică în timp

$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X$$

$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

## ■ Simplificarea ecuațiilor lui Maxwell

$$\nabla^2 E + \omega^2 \epsilon \mu E = j \omega \mu J + \frac{1}{\epsilon} \nabla \rho$$

$$\nabla^2 H + \omega^2 \epsilon \mu H = -\nabla \times J$$

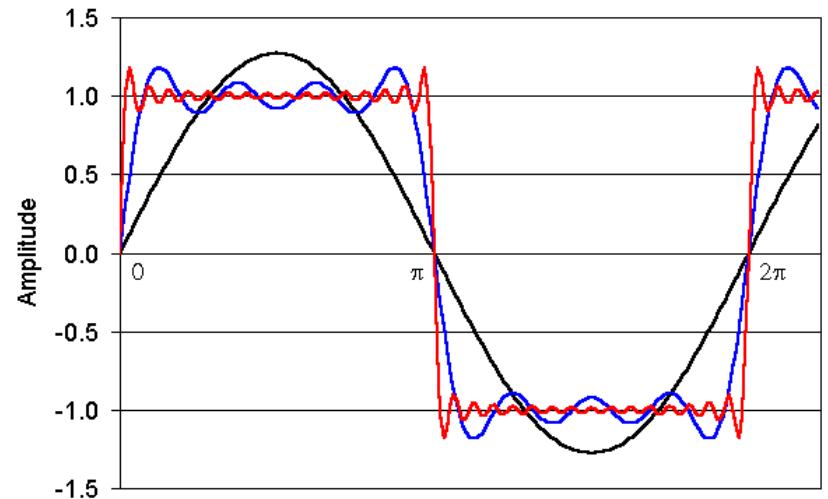
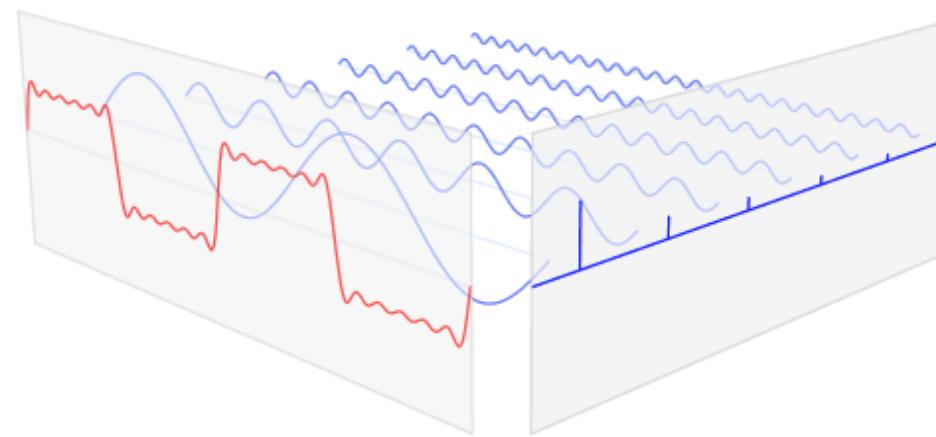
$$\nabla \cdot E = \frac{\rho}{\epsilon}$$

$$\nabla \cdot H = 0$$

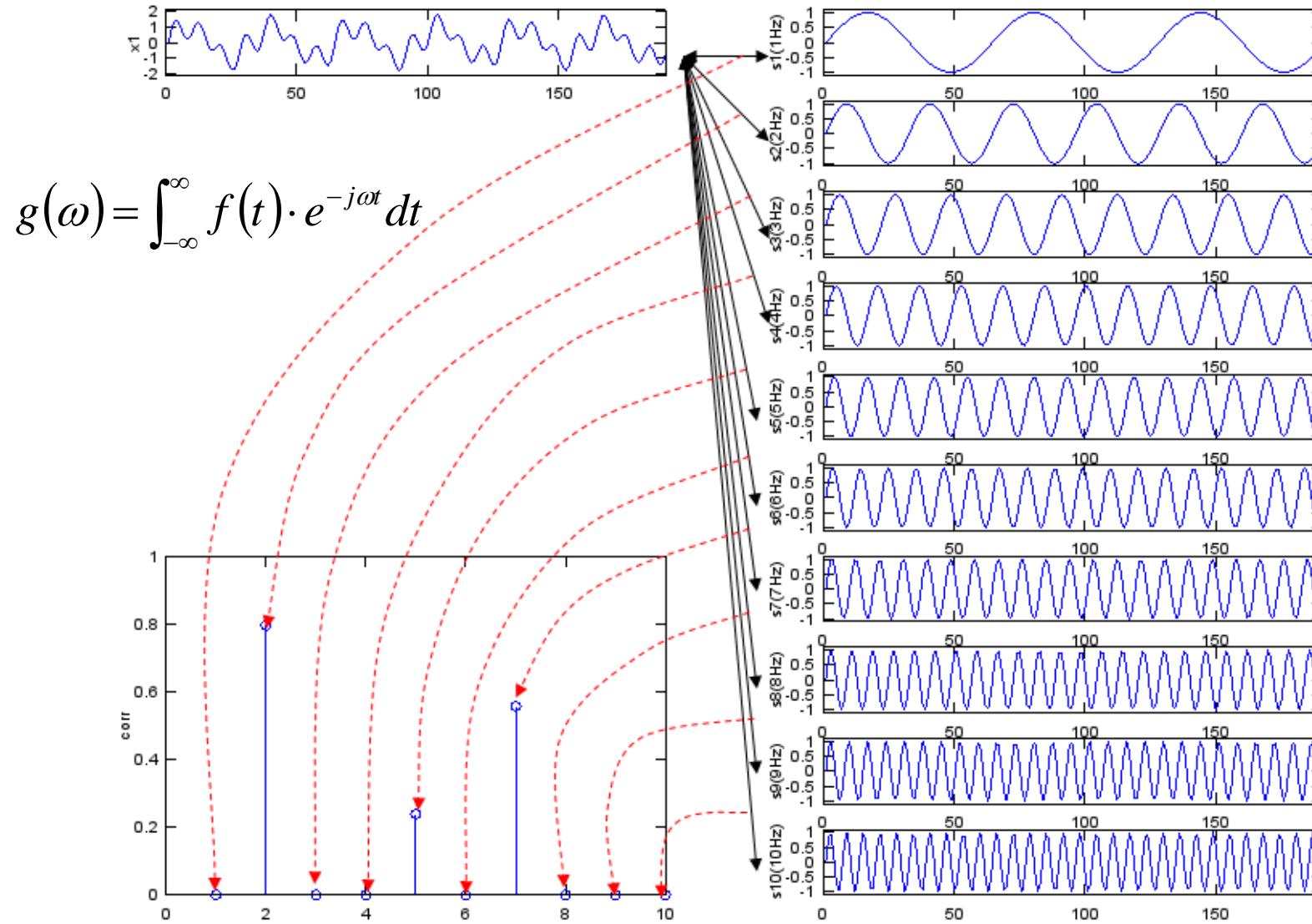
# Modele matematice

- cazuri particulare in care exista rezolvare analitica
  - semnale cu variație armonică în timp, transformata Fourier, spectru

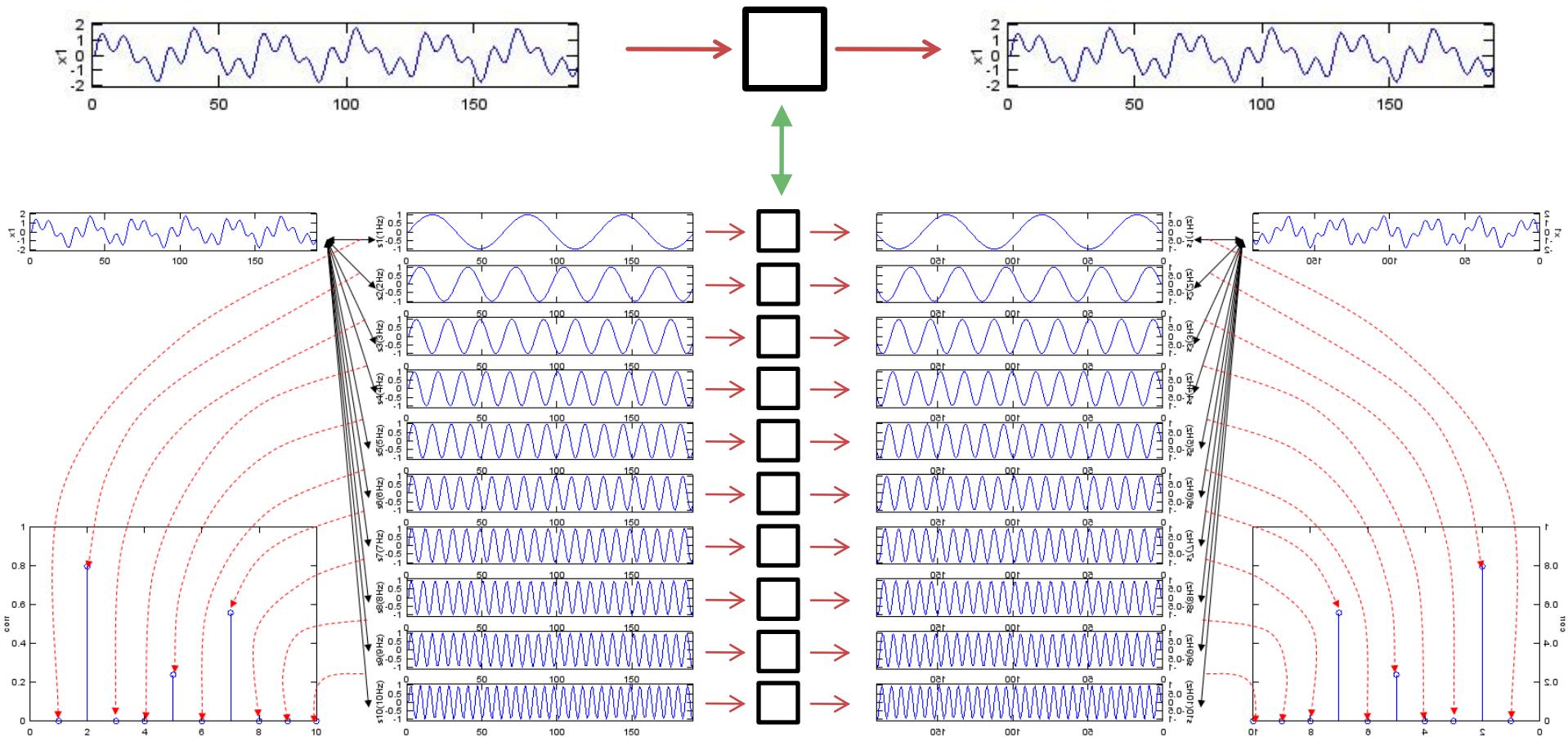
$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$



# Modele matematice



# Modele matematice



$$F(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt$$

$$G(\omega)[F(\omega)]$$

$$g(t) = \int_{-\infty}^{\infty} G(\omega) \cdot e^{j\omega t} d\omega$$

# Ecuățiile de propagare

- Ecuățiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

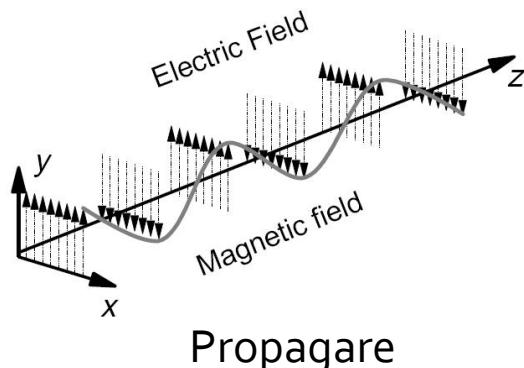
$$\nabla^2 E - \gamma^2 E = 0$$

$$\nabla^2 H - \gamma^2 H = 0$$

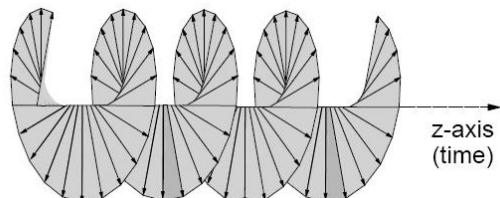
$$\gamma^2 = -\omega^2 \epsilon \mu + j \omega \mu \sigma$$

$\gamma$  – Constanta de propagare

# Solutia ecuatiilor de propagare



Propagare



Polarizare circulara

Camp electric dupa directia Oy,  $\leftarrow$  prin alegerea judicioasa  
propagare dupa directia Oz  $\leftarrow$  a sistemului de referinta

$$E_y = E_+ e^{-\gamma \cdot z} + E_- e^{\gamma \cdot z}$$

$$\gamma = \sqrt{-\omega^2 \epsilon \mu + j \omega \mu \sigma} = \alpha + j \cdot \beta$$

Exista numai unda progresiva  $E_+ \Rightarrow A$

$$E_y = A e^{-(\alpha + j \cdot \beta) \cdot z}$$

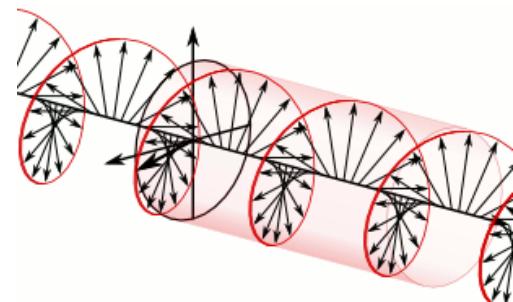
Camp armonic

$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$$

Amplitudine

Atenuare

Propagare  
(variatie in timp si spatiu)



# Atenuare

$$E_y(z_1) = Ct \cdot e^{-\alpha \cdot z_1} \cdot e^{j(\omega t - \beta \cdot z_1)}$$

$$E_y(z_2) = Ct \cdot e^{-\alpha \cdot z_2} \cdot e^{j(\omega t - \beta \cdot z_2)}$$

$$W, P \sim \int E^2$$

$$A = \frac{P_2}{P_1} = \frac{Ct^2 \cdot e^{-2\alpha \cdot z_2}}{Ct^2 \cdot e^{-2\alpha \cdot z_1}} = e^{-2\alpha \cdot (z_2 - z_1)}$$

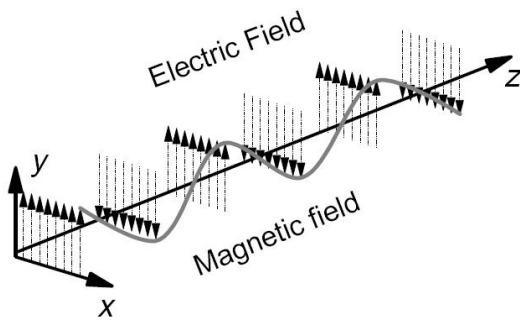
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} [e^{-2\alpha \cdot (z_2 - z_1)}]$$

$$A[dB] = -20 \cdot \alpha \cdot (z_2 - z_1) \log_{10} e = -8.686 \cdot \alpha \cdot (z_2 - z_1)$$

$$A / L[dB / km] = -8.686 \cdot \alpha < 0$$

- ▶ Atenuarea se exprima de obicei in **dB/km**
  - ▶ de obicei valori pozitive
  - ▶ semnul = **implicit**

# Parametri de propagare



$$\nabla \times E = -j\omega\mu \cdot H$$

$$H_x = \frac{j\gamma \cdot E_y}{\omega\mu}$$

Mediu fara pierderi,  $\sigma = 0$

$$\gamma = j\omega \cdot \sqrt{\epsilon\mu}$$

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\epsilon}} \quad \text{Impedanta intrinseca a mediului}$$

$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)} \quad \text{punctele de faza constante:} \quad (\omega \cdot t - \beta \cdot z) = \text{const}$$

Viteza de faza

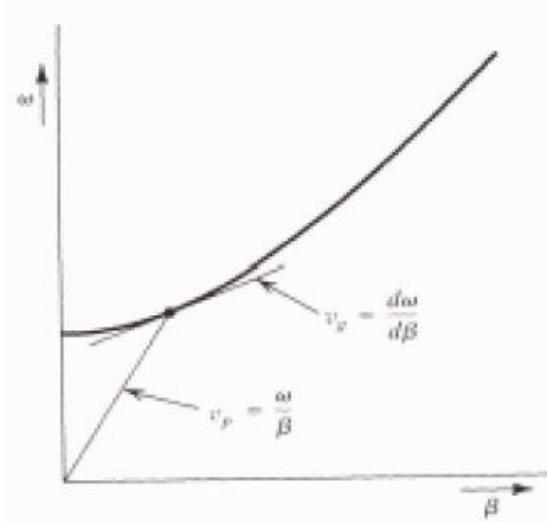
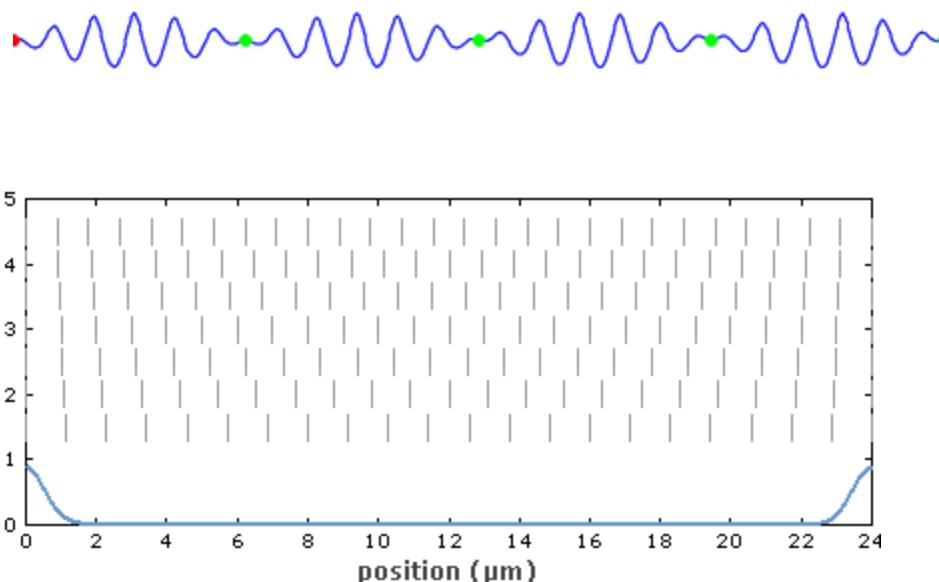
$$v = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{\epsilon\mu}}$$

Viteza de grup

$$v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta} \quad \text{in medii dispersive unde } \beta = \beta(\omega)$$

# Viteze de grup și fază

- Viteza de fază – viteza virtuală cu care circula punctul cu o anumita fază
- Viteza de grup – viteza cu care circula informația (energia)



# Parametri de propagare

## ■ În vid

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega \quad v = v_g = c_0 \quad c_0 = \frac{1}{\sqrt{\epsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f}$$

Periodicitate în spațiu

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

Periodicitate în timp

## ■ În mediu nedispersiv $\epsilon_r$

$$c = \frac{1}{\sqrt{\epsilon \cdot \mu_0}} = \frac{1}{\sqrt{\epsilon_0 \epsilon_r \cdot \mu_0}} = \frac{c_0}{\sqrt{\epsilon_r}}$$

$$n = \sqrt{\epsilon_r} \quad \text{Indice de refractie al mediului}$$

$$c = \frac{c_0}{n}$$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda = \frac{2\pi}{\beta} = \frac{c}{f}$$

$$\lambda = \frac{c_0}{\sqrt{\epsilon_r \cdot f}} = \frac{\lambda_0}{\sqrt{\epsilon_r}}$$



# Solutia ecuatiilor de propagare

$E_y = E^+ e^{-\gamma \cdot z} + E^- e^{\gamma \cdot z}$  Camp electric dupa directia Oy,  $\leftarrow$  prin alegerea judicioasa propagare dupa directia Oz  $\leftarrow$  a sistemului de referinta

$$\gamma = \sqrt{-\omega^2 \epsilon \mu + j\omega \mu \sigma} = \alpha + j \cdot \beta$$

## ■ unda

- incidenta
- reflectata

$$E_y = E^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$$

$$(\omega \cdot t - \beta \cdot z) = \text{const}$$

## ■ unda

- directa
- inversa

$$E_y = E^- \cdot e^{\alpha \cdot z} \cdot e^{j(\omega \cdot t + \beta \cdot z)}$$

$$(\omega \cdot t + \beta \cdot z) = \text{const}$$

punctele  
de faza  
constanta:

# Solutia ecuatiilor de propagare

## ■ unda

- incidenta
- reflectata

$$E_y = E^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)} + E^- \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t + \beta \cdot z)}$$

$$H_z = H^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)} + H^- \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t + \beta \cdot z)}$$

## ■ unda

- directa
- inversa

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

$$I(z) = I^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)} + I^- \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t + \beta \cdot z)}$$

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

# Moduri in medii delimitate

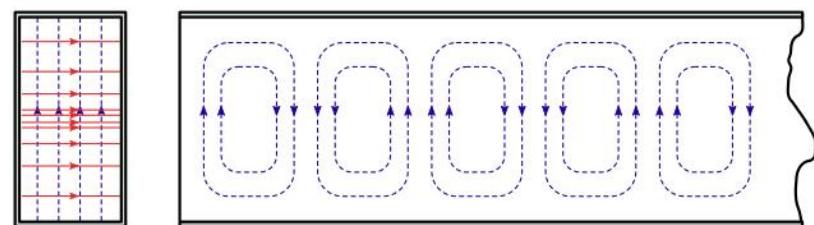
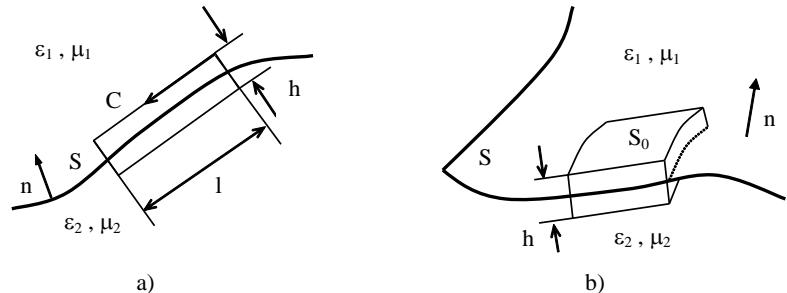
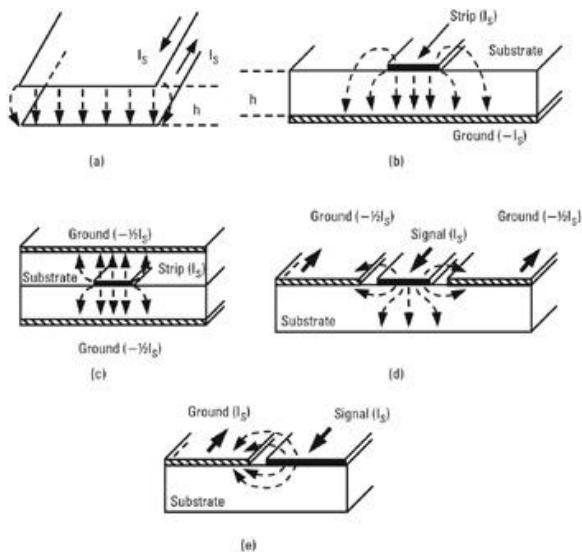
- Câmpuri electromagnetice cu variație armonică în timp
  - simplificarea ecuațiilor lui Maxwell

$$X = X_0 e^{j\omega t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

- În medii delimitate soluțiile ecuațiilor lui Maxwell trebuie să verifice condițiile la limită
  - soluțiile trebuie să respecte anumite condiții suplimentare

# Moduri in medii delimitate

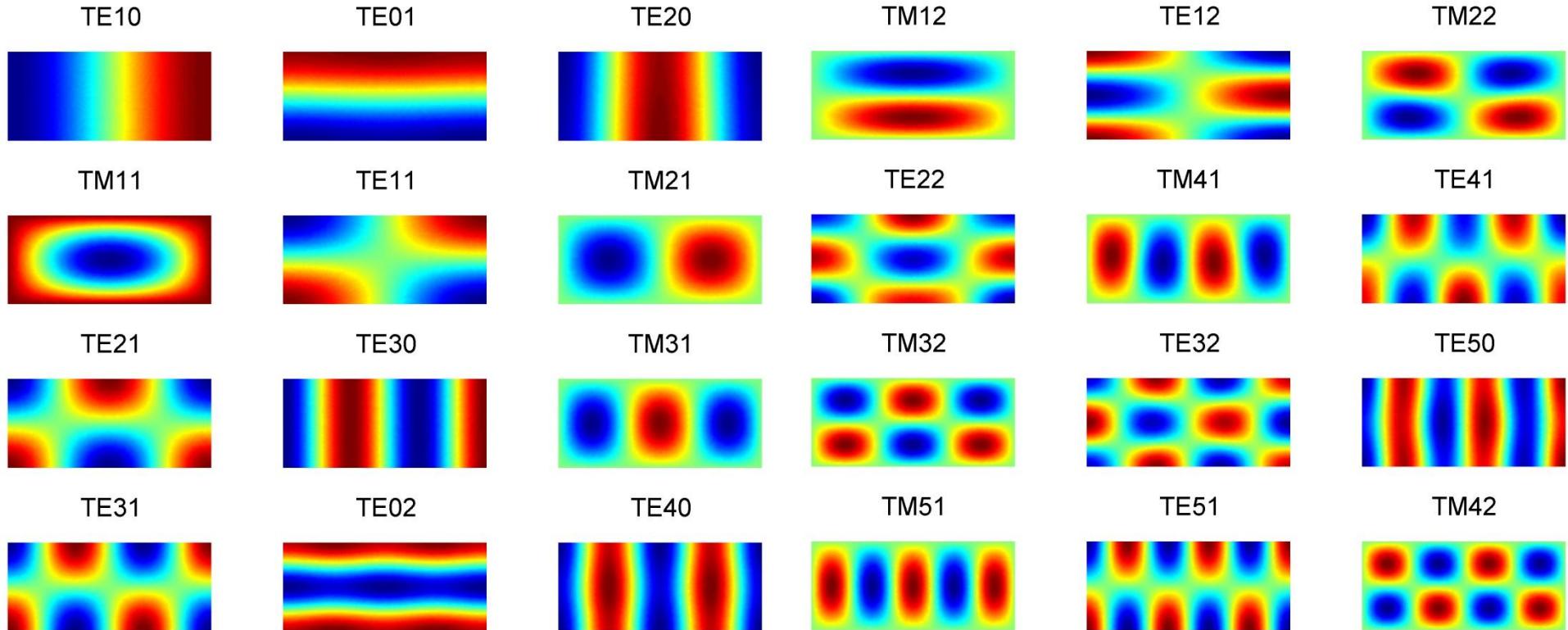
- Campul electric **trebuie** sa fie perpendicular pe un perete metalic sau nul
- Campul magnetic **trebuie** sa fie tangent la un perete metalic sau nul



**TE<sub>10</sub>**

**TM<sub>11</sub>**

# Moduri in mediile delimitate



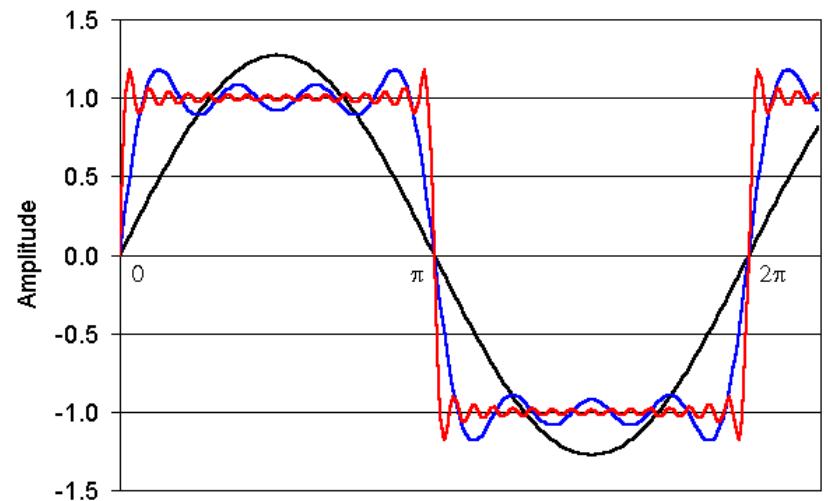
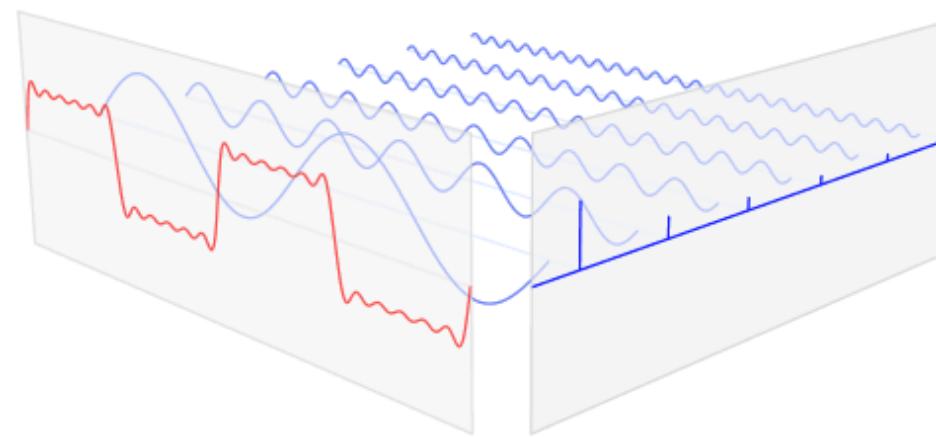
- Similar cu transformata Fourier 
$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

$$E^+, E^- = \sum_1^{\infty} A_i \cdot Mod_i \quad A_i = \langle E, Mod_i \rangle$$

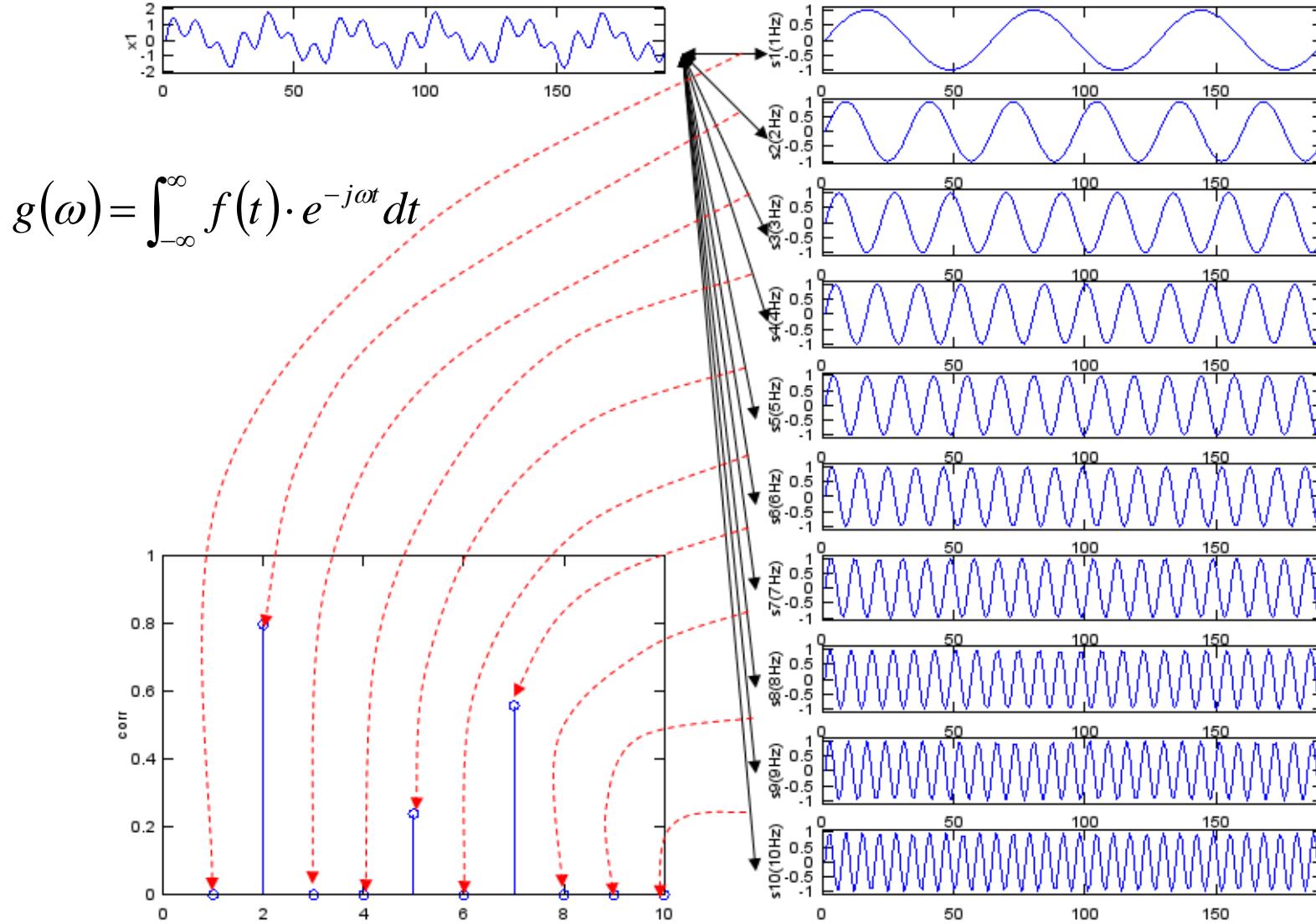
# Modele matematice

- cazuri particulare in care exista rezolvare analitica
  - semnale cu variație armonică în timp, transformata Fourier, spectru

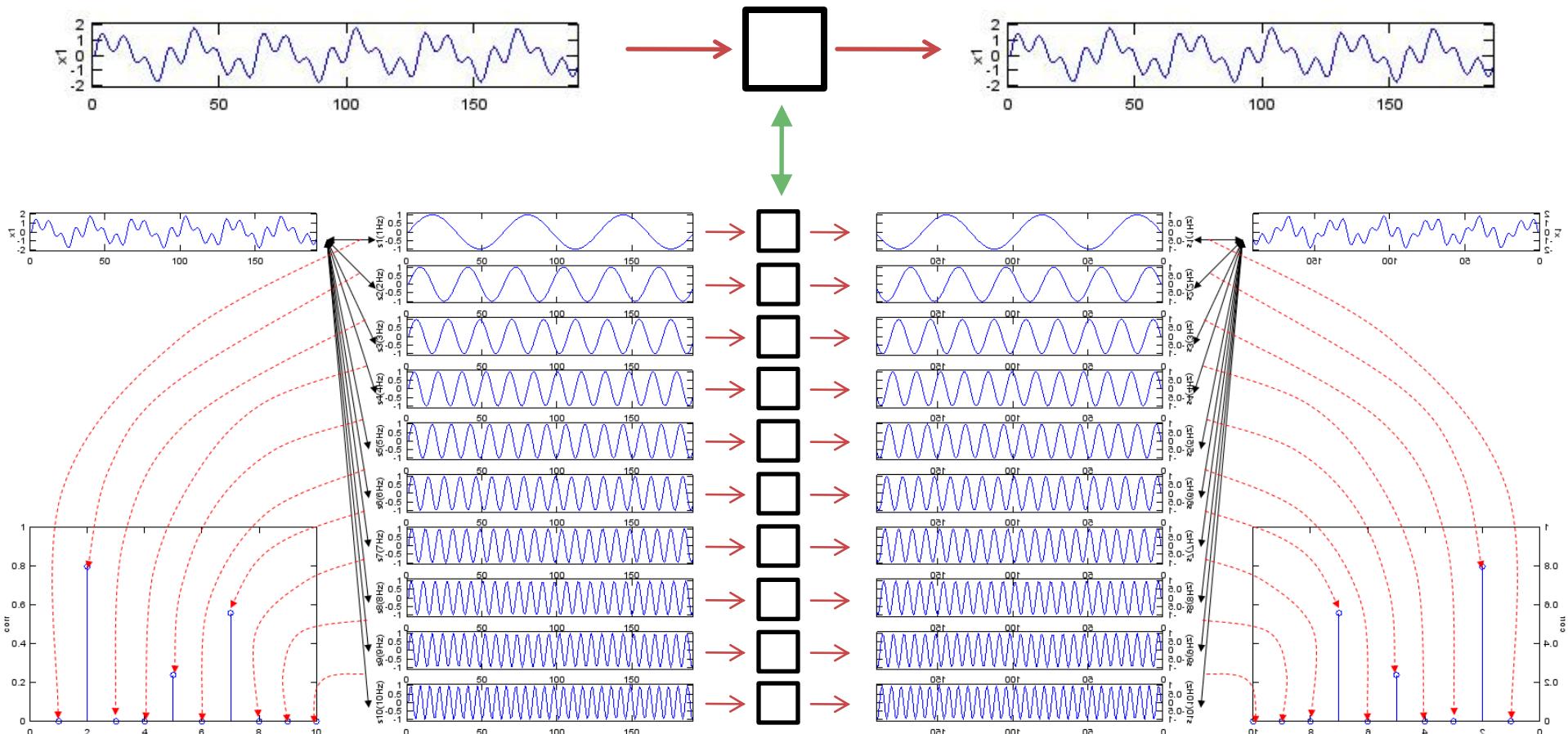
$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$



# Modele matematice



# Modele matematice



$$F(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt$$

$$G(\omega)[F(\omega)]$$

$$g(t) = \int_{-\infty}^{\infty} G(\omega) \cdot e^{j\omega t} d\omega$$

# Modele matematice

## ■ cazuri particulare in care exista rezolvare analitica

- Exista unda in o singura directie  $E^+ (E^+), E^- (E^-)$

### ■ unda

- incidenta

$$E_y = E^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)} + E^- \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t + \beta \cdot z)}$$

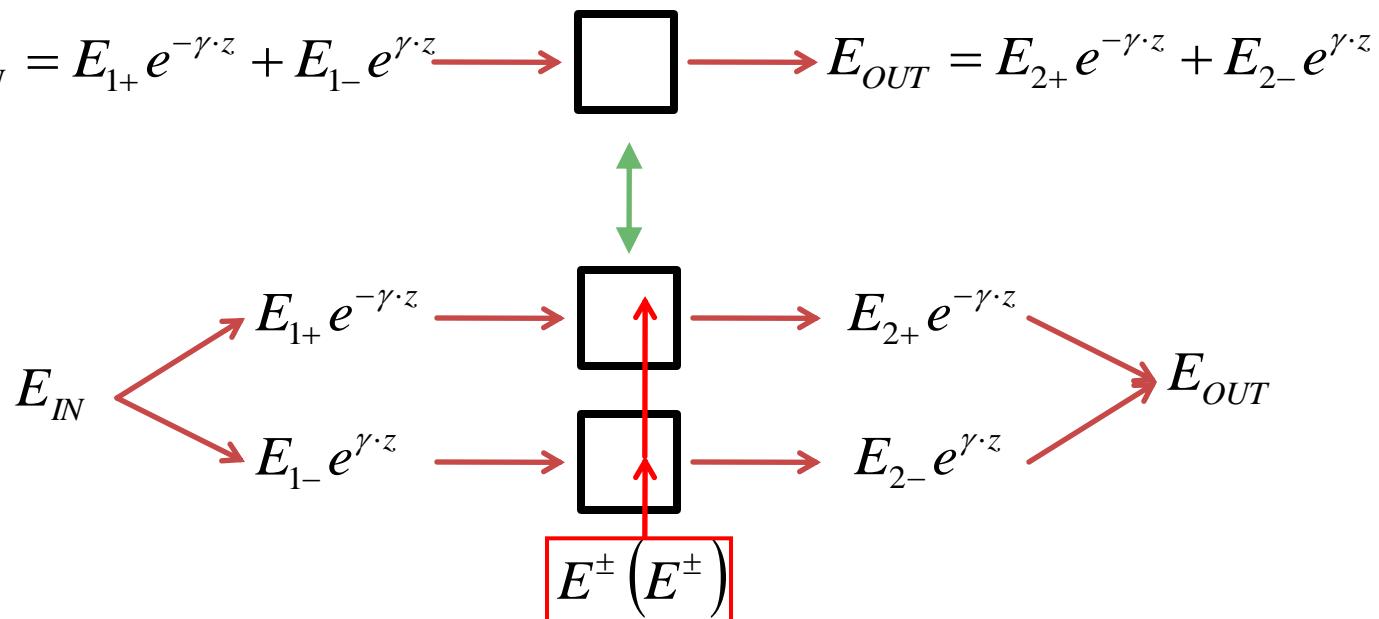
- reflectata

$$E_{IN} = E_{1+} e^{-\gamma \cdot z} + E_{1-} e^{\gamma \cdot z} \rightarrow \boxed{\text{ }} \rightarrow E_{OUT} = E_{2+} e^{-\gamma \cdot z} + E_{2-} e^{\gamma \cdot z}$$

### ■ unda

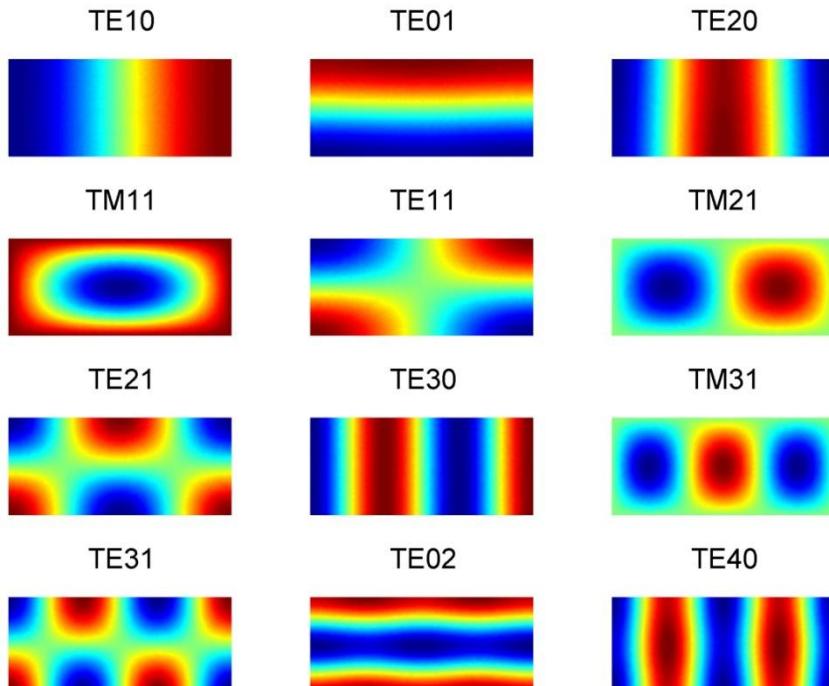
- directa

- inversa

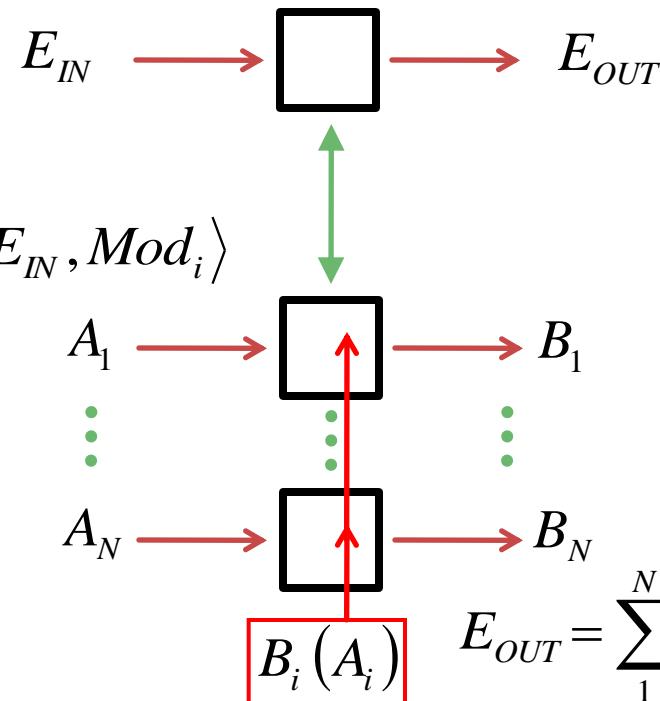


# Modele matematice

- cazuri particolare in care exista rezolvare analitica
  - moduri in medii delimitate  $B_i(A_i)$



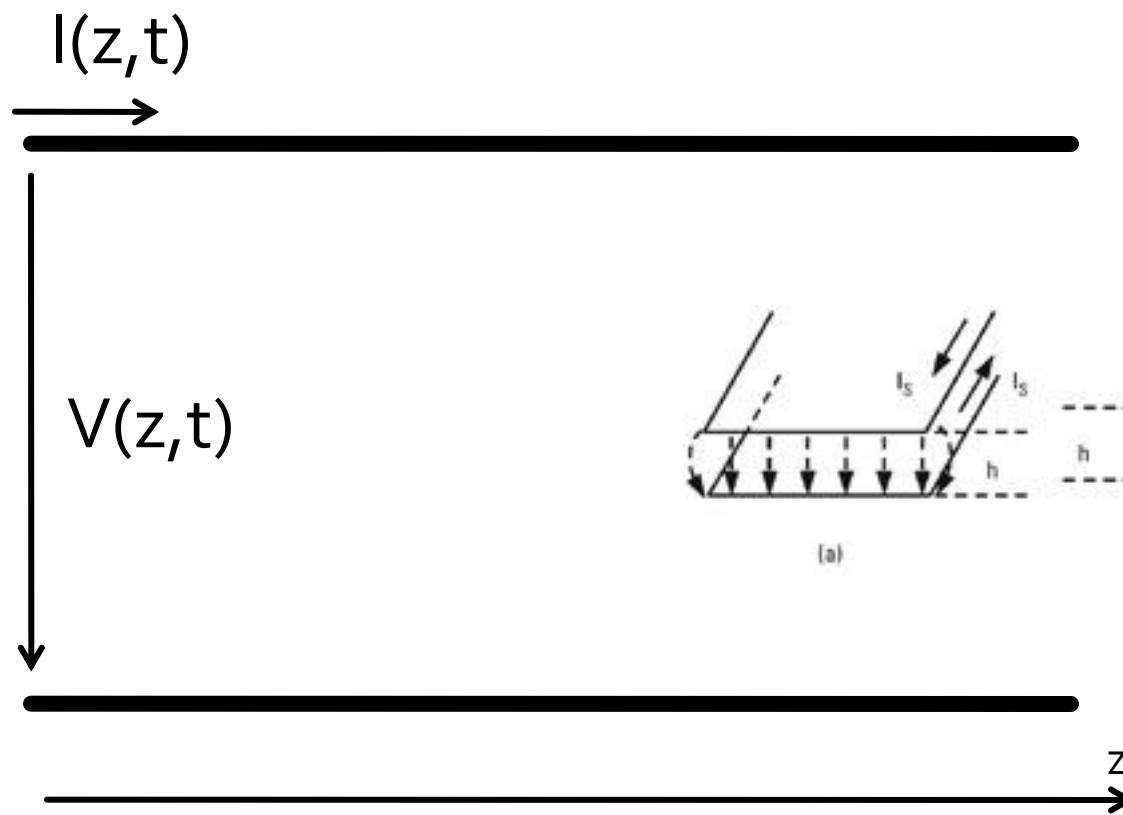
$$E = \sum_{i=1}^{\infty} A_i \cdot Mod_i \quad A_i = \langle E, Mod_i \rangle$$



# **Linii de transmisie in mod TEM**

# Linie de transmisie

- mod TEM, doi conductori

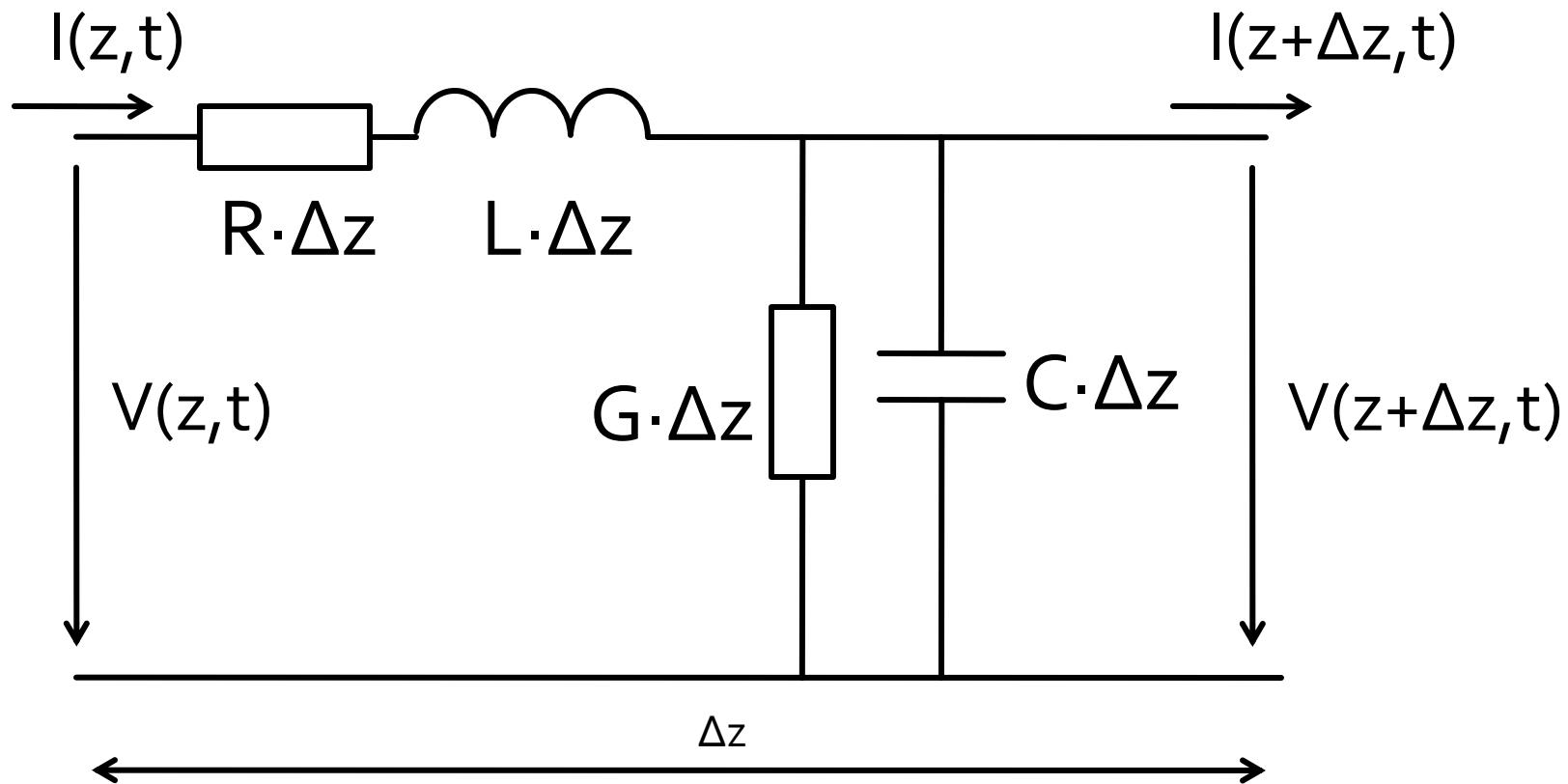


(a)

(b)

# Linie de transmisie model echivalent

- mod TEM, doi conductori



# Ecuatiile telegrafistilor

## ■ domeniu timp

$$\frac{\partial v(z,t)}{\partial z} = -R \cdot i(z,t) - L \cdot \frac{\partial i(z,t)}{\partial t} \quad KII$$

$$\frac{\partial i(z,t)}{\partial z} = -G \cdot v(z,t) - C \cdot \frac{\partial v(z,t)}{\partial t} \quad KI$$

## ■ semnale sinusoidale

$$\frac{dV(z)}{dz} = -(R + j \cdot \omega \cdot L) \cdot I(z) \quad \left/ \frac{d}{dz} (\dots) \right.$$

$$\frac{dI(z)}{dz} = -(G + j \cdot \omega \cdot C) \cdot V(z)$$

# Rezolvare

$$\frac{d^2V(z)}{dz^2} - \gamma^2 \cdot V(z) = 0$$

$$\frac{d^2I(z)}{dz^2} - \gamma^2 \cdot I(z) = 0$$



$$\nabla^2 E - \gamma^2 E = 0$$

$$\nabla^2 H - \gamma^2 H = 0$$

$$\gamma^2 = -\omega^2 \epsilon u + j \omega \mu \sigma$$

$$\gamma = \alpha + j \cdot \beta = \sqrt{(R + j \cdot \omega \cdot L) \cdot (G + j \cdot \omega \cdot C)}$$

# Solutiile

$$\begin{cases} V(z) = V_0^+ e^{-\gamma \cdot z} + V_0^- e^{\gamma \cdot z} \\ I(z) = I_0^+ e^{-\gamma \cdot z} + I_0^- e^{\gamma \cdot z} \end{cases}$$

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

$$\frac{dV(z)}{dz} = -(R + j \cdot \omega \cdot L) \cdot I(z)$$

$$Z_0 \equiv \frac{R + j \cdot \omega \cdot L}{\gamma} = \sqrt{\frac{R + j \cdot \omega \cdot L}{G + j \cdot \omega \cdot C}}$$

$$\gamma = \alpha + j \cdot \beta = \sqrt{(R + j \cdot \omega \cdot L) \cdot (G + j \cdot \omega \cdot C)}$$

$$I(z) = \frac{\gamma}{R + j \cdot \omega \cdot L} (V_0^+ e^{-\gamma \cdot z} - V_0^- e^{\gamma \cdot z})$$

- Impedanta caracteristica a liniei

$$\frac{V_0^+}{I_0^+} = Z_0 = -\frac{V_0^-}{I_0^-}$$

$$\lambda = \frac{2\pi}{\beta} \quad v_f = \frac{\omega}{\beta} = \lambda \cdot f$$

# Linie fara pierderi

- R=G=0

$$\gamma = \alpha + j \cdot \beta = \sqrt{(R + j \cdot \omega \cdot L) \cdot (G + j \cdot \omega \cdot C)} = j \cdot \omega \cdot \sqrt{L \cdot C}$$

$$\alpha = 0 \quad ; \quad \beta = \omega \cdot \sqrt{L \cdot C}$$

$$Z_0 = \sqrt{\frac{R + j \cdot \omega \cdot L}{G + j \cdot \omega \cdot C}} = \sqrt{\frac{L}{C}}$$

- Z<sub>o</sub> real

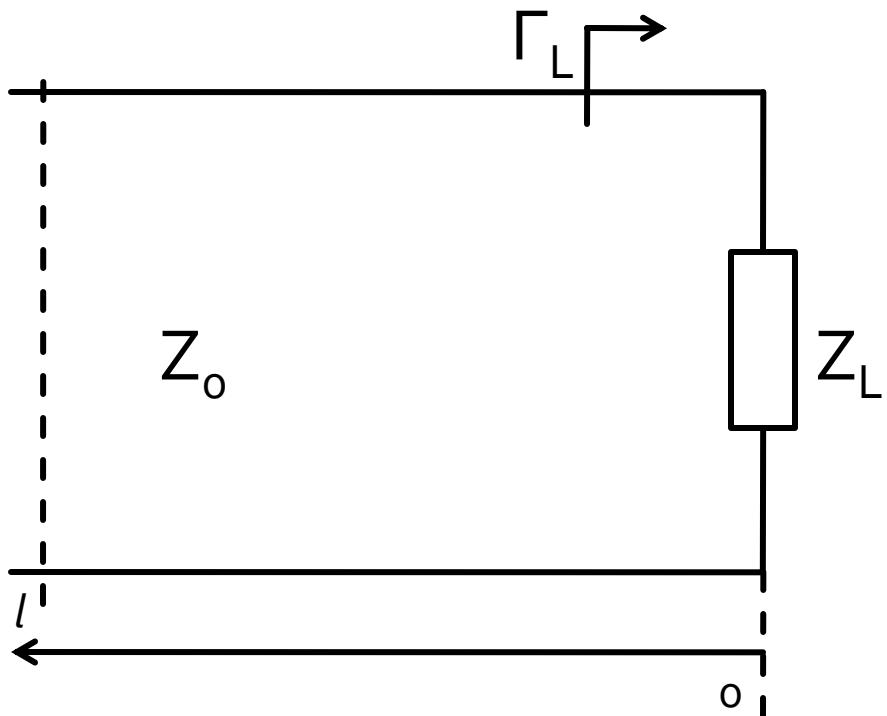
$$V(z) = V_0^+ e^{-j \cdot \beta \cdot z} + V_0^- e^{j \cdot \beta \cdot z}$$

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

$$\lambda = \frac{2\pi}{\omega \cdot \sqrt{LC}}$$

$$v_f = \frac{1}{\sqrt{LC}}$$

# Linie fara pierderi



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

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

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

- coeficient de reflexie in tensiune

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

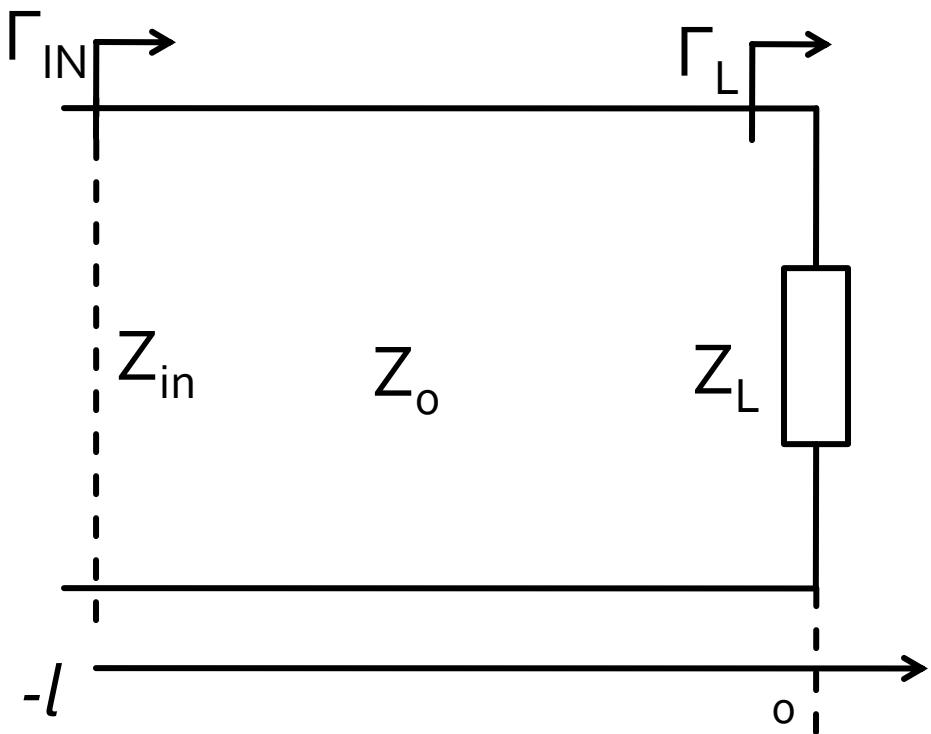
- $Z_0$  real

# Linie fara pierderi

- coeficientul de reflexie la intrarea liniei

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

$$\Gamma = \Gamma(z) = \frac{V_0^-(z)}{V_0^+(z)}$$



$$V(0) = V_0^+ + V_0^-$$

$$\Gamma(0) = \Gamma_L = \frac{V_0^-}{V_0^+}$$

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

$$\Gamma(-l) = \Gamma_{IN} = \frac{V_0^- \cdot e^{-j\beta l}}{V_0^+ \cdot e^{j\beta l}} = \Gamma(0) \cdot e^{-2j\beta l}$$

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

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

# Linie fara pierderi

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

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

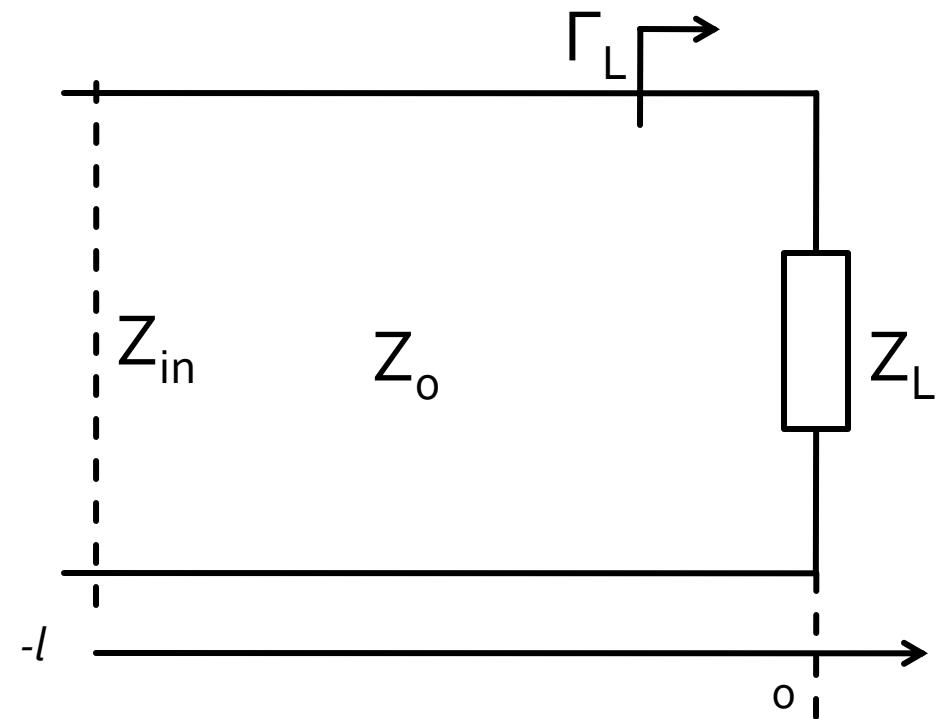
## ■ Puterea medie

$$P_{\text{avg}} = \frac{1}{2} \operatorname{Re}\{V(z)I(z)^*\} = \frac{1}{2} \frac{|V_o^+|^2}{Z_0} \operatorname{Re}\{1 - \Gamma^* e^{-2j\beta z} + \Gamma e^{2j\beta z} - |\Gamma|^2\}$$

$$P_{\text{avg}} = \frac{1}{2} \frac{|V_o^+|^2}{Z_0} (1 - |\Gamma|^2)$$

- Puterea transmisa sarcinii = Puterea incidenta - Puterea "reflectata"
- Return Loss [dB] 
$$\text{RL} = -20 \log |\Gamma| \text{ dB},$$

# Linie fara pierderi



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

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

$$Z_{in} = \frac{V(-l)}{I(-l)} \quad Z_{in} = Z_0 \cdot \frac{1 + \Gamma \cdot e^{-2j \cdot \beta \cdot l}}{1 - \Gamma \cdot e^{-2j \cdot \beta \cdot l}}$$

- **impedanta la intrarea liniei**

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

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

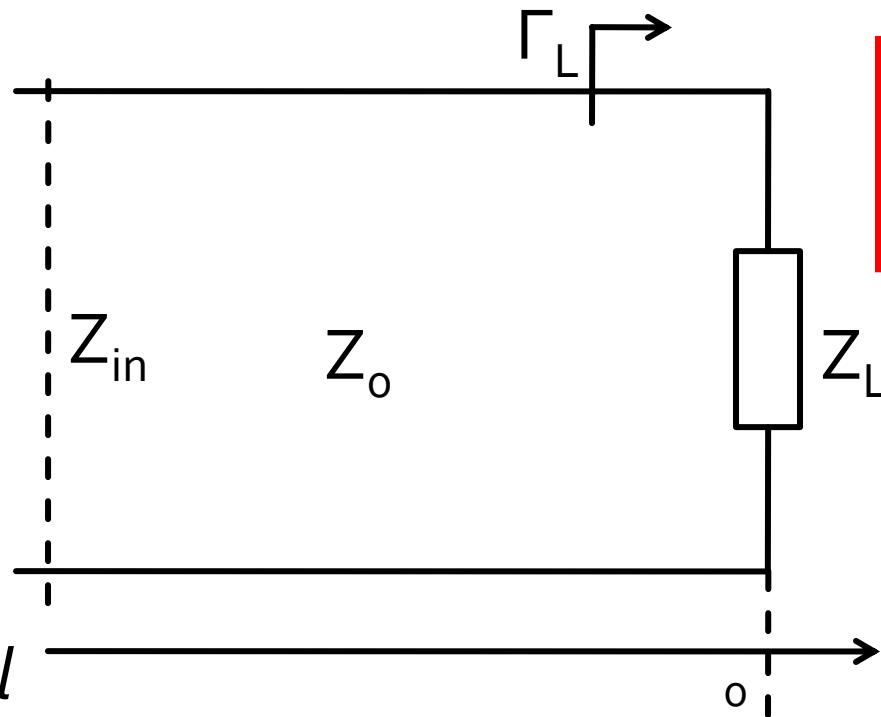
# Linie fara pierderi

- impedanta la intrarea liniei

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

# Linie fara pierderi

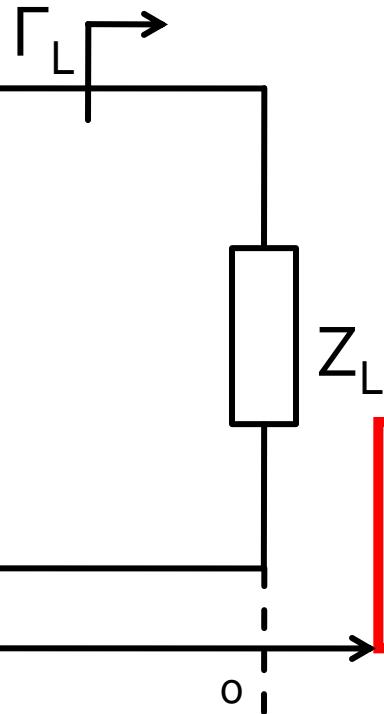
- impedanta la intrarea liniei de impedanta caracteristica  $Z_0$ , de lungime  $l$ , terminata cu impedanta  $Z_L$



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

# Linie fara pierderi

- relatia este **dependenta de frecventa** prin valoarea  $\beta \cdot l$



$$v_f = \frac{\omega}{\beta} = \lambda \cdot f \quad \lambda = \frac{2\pi}{\beta}$$

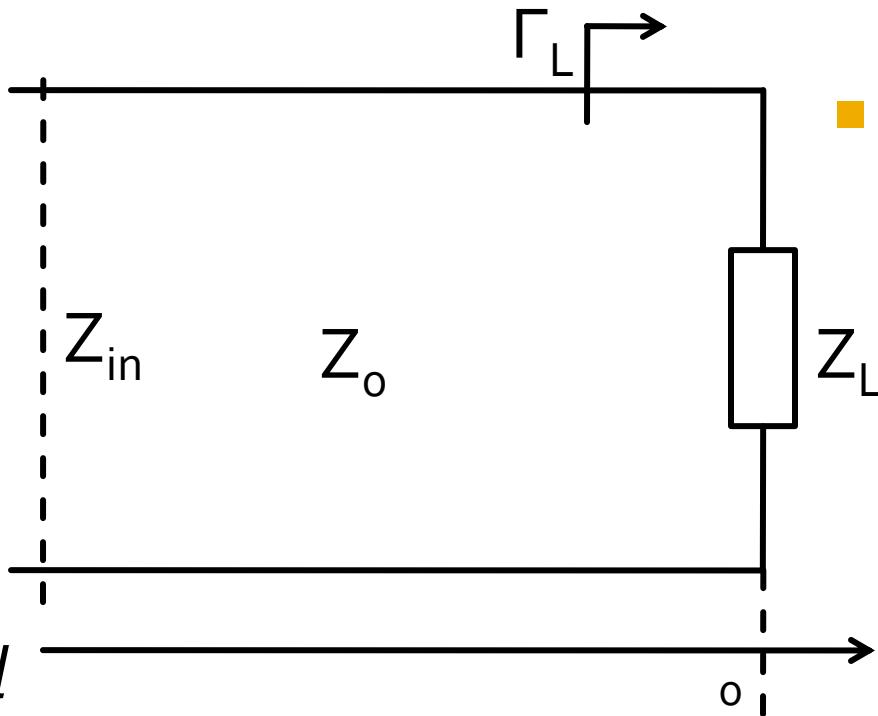
$$\beta \cdot l = \frac{2\pi}{\lambda} \cdot l = \frac{2\pi \cdot f}{v_f} \cdot l = \frac{2\pi \cdot l}{v_f} \cdot f$$

dependenta de frecventa este **periodica**, impusa de functia tangenta

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

# Linie fara pierderi, cazuri particulare

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



- Transformatorul în sfert de lungime de undă

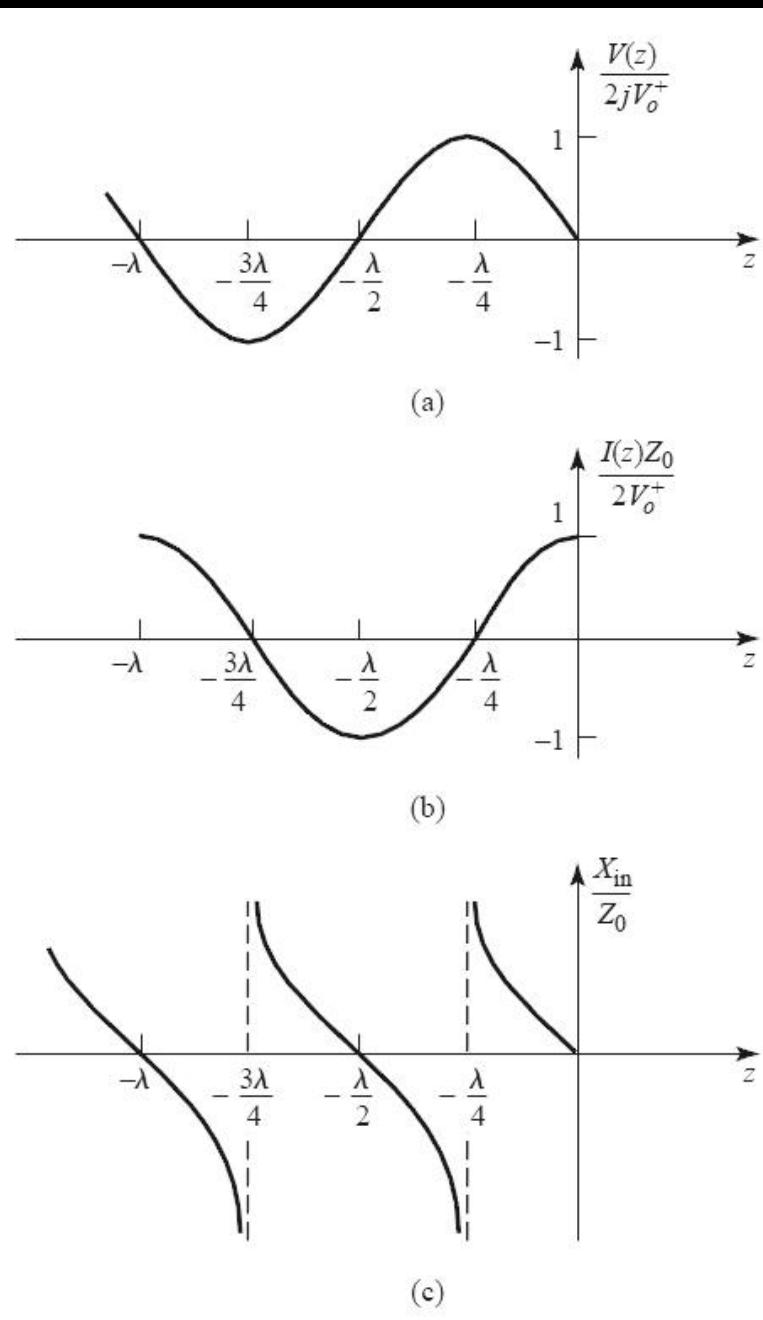
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

# Linie în scurtcircuit

- $Z_L = 0$
- reactanță pură
  - $+/- \rightarrow$  în funcție de  $l$

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

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

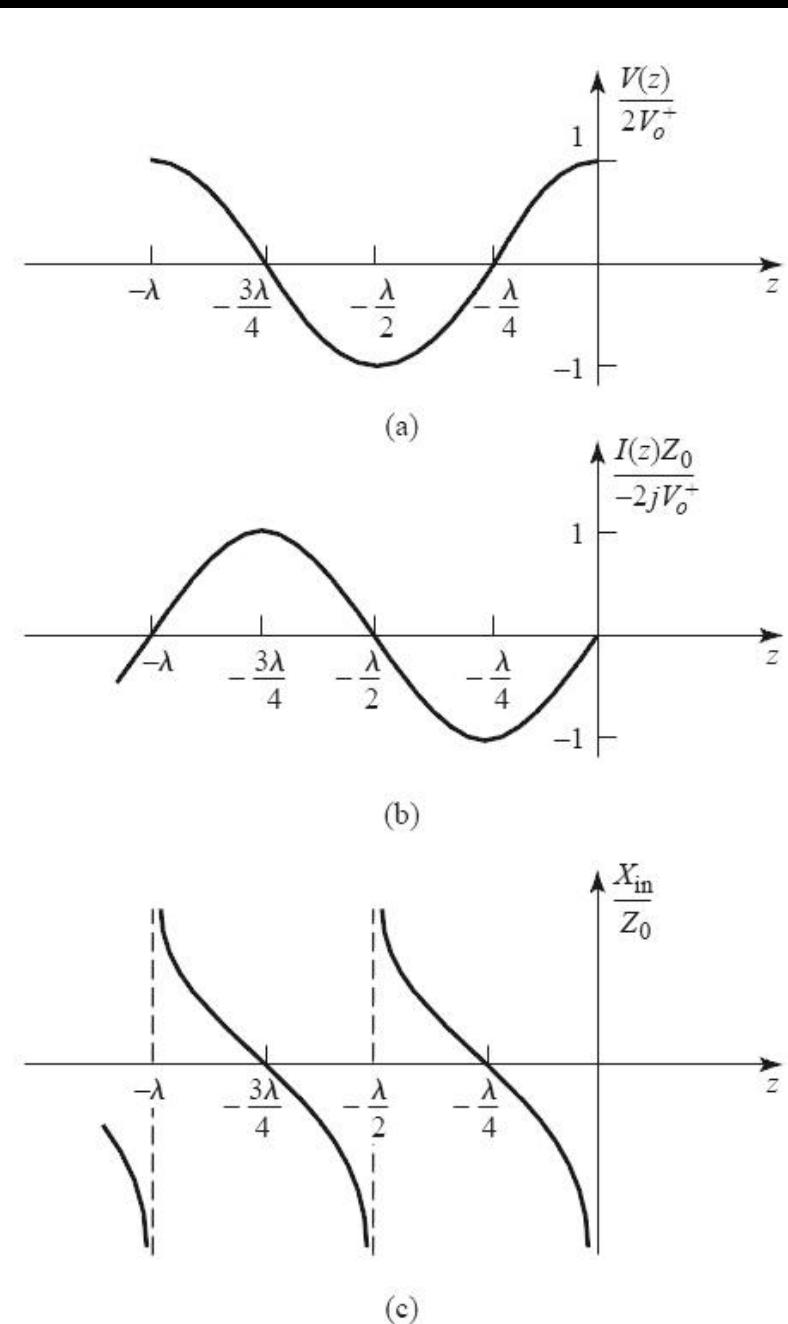


# Linie în gol

- $Z_L = \infty \rightarrow 1/Z_L = 0$
- reactanță pură
  - $+/- \rightarrow$  în funcție de  $l$

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

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



# Factor de unda stationara

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

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

amplitudine maxima pentru  $e^{\theta + 2j\beta z} = 1$

$$V_{\max} = |V_0^+| \cdot (1 + |\Gamma|)$$

amplitudine minima pentru  $e^{\theta + 2j\beta z} = -1$

$$V_{\min} = |V_0^+| \cdot (1 - |\Gamma|)$$

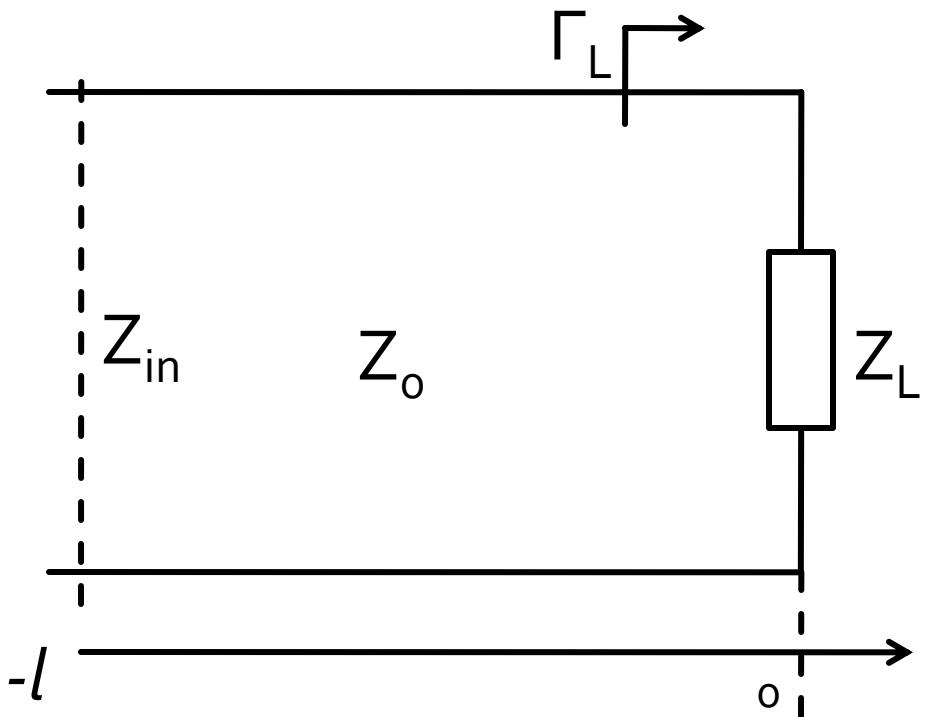
■ se defineste factorul de unda stationara

- (Voltage) Standing Wave Ratio

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

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

# Linie fara pierderi +/-



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

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

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

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

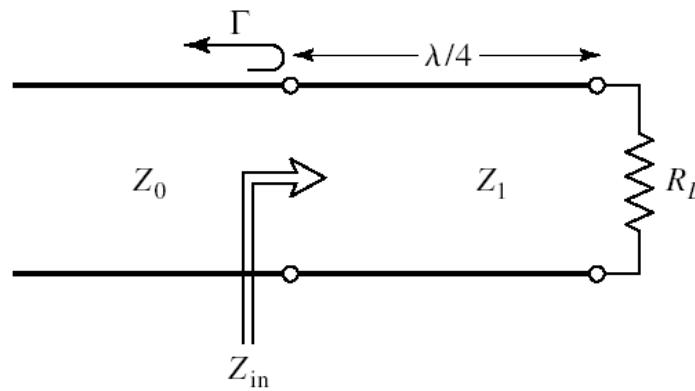
$$\Gamma_{in} = \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}$$

Adaptarea de impedanță

# **Laborator 1**

# Transformatorul in sfert de lungime de unda

- Feed line – linie de intrare cu impedanta caracteristica  $Z_0$
- Sarcina cu impedanta  $R_L$
- Dorim adaptarea sarcinei la fider cu o linie de lungime  $\lambda/4$  si impedanta caracteristica  $Z_1$

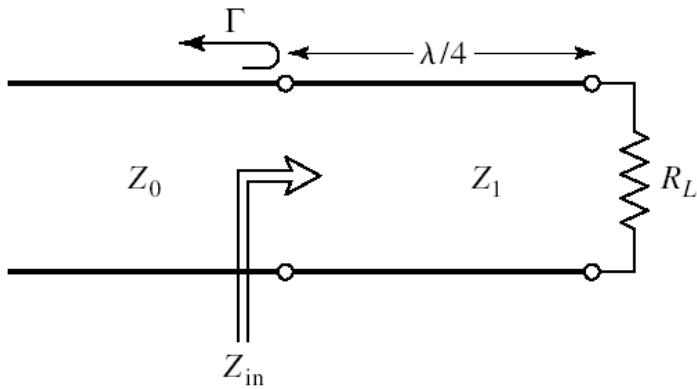


$$Z_{in} = Z_1 \frac{1 + \Gamma e^{-2j\beta l}}{1 - \Gamma e^{-2j\beta l}}$$

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

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

# Transformatorul in sfert de lungime de unda



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

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

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

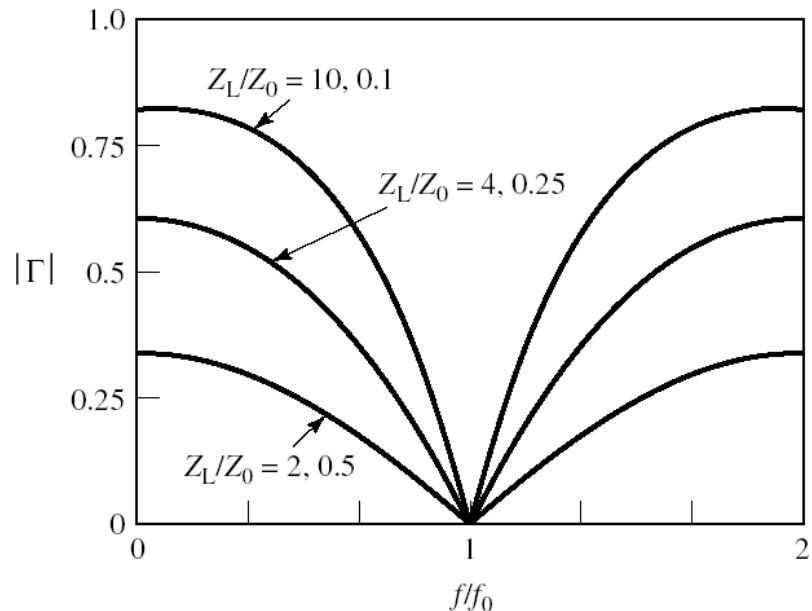
$$\Gamma_{in} = \frac{Z_1^2 - Z_0 \cdot R_L}{Z_1^2 + Z_0 \cdot R_L} \quad \Gamma_{in} = 0 \quad Z_1 = \sqrt{Z_0 R_L}$$

- Pe fider ( $Z_0$ ) avem doar unda progresiva
- Pe linia in sfert de lungime de unda ( $Z_1$ ) avem unda stationara

# Caracteristica de frecventa

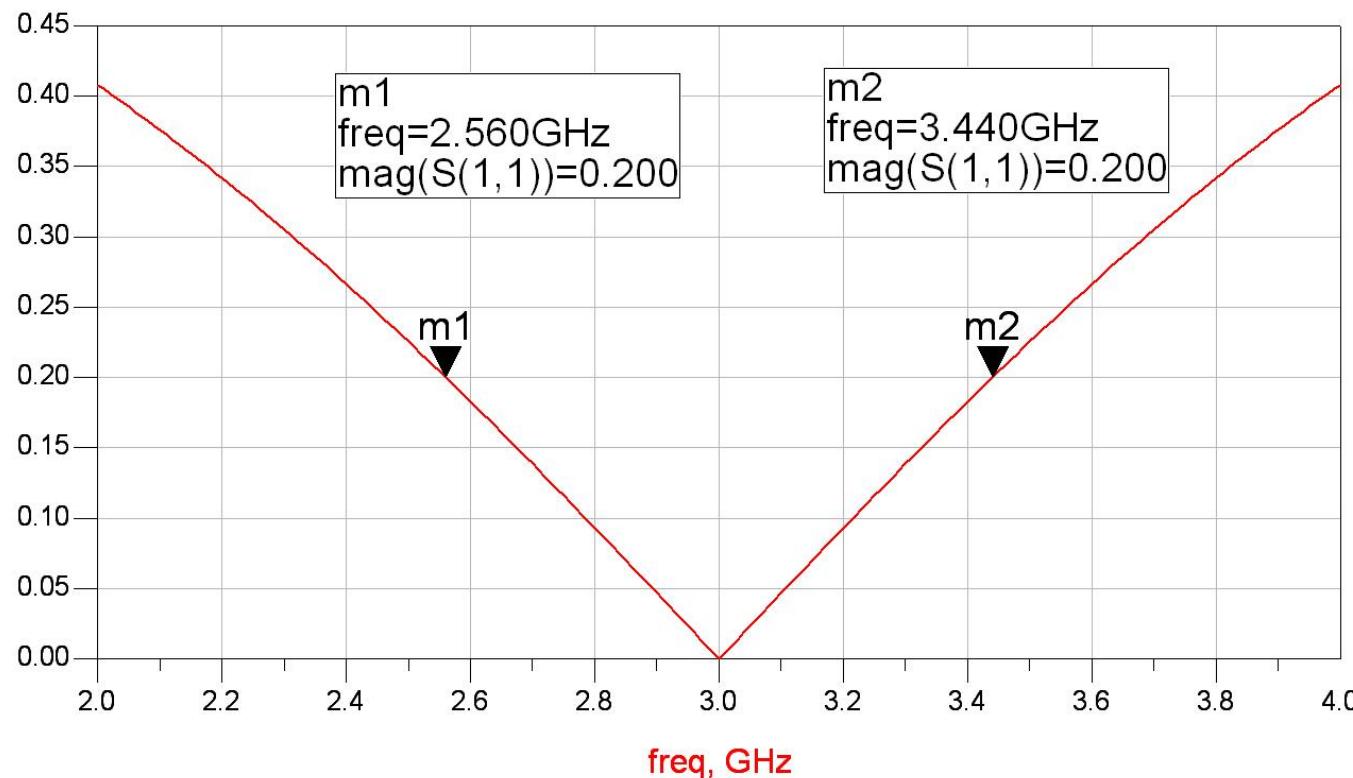
- Pentru linii non TEM constanta de propagare nu depinde liniar de frecventa, dar in practica influenta este minora in banda ingusta
- Sunt neglijate reactantele introduse de discontinuitati ( $Z_0 \rightarrow Z_1$ ). Compensarea se face printr-o mica modificare a lungimii liniei
- Banda depinde de dezadaptarea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

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



# Simulare

## ■ simulare ADS

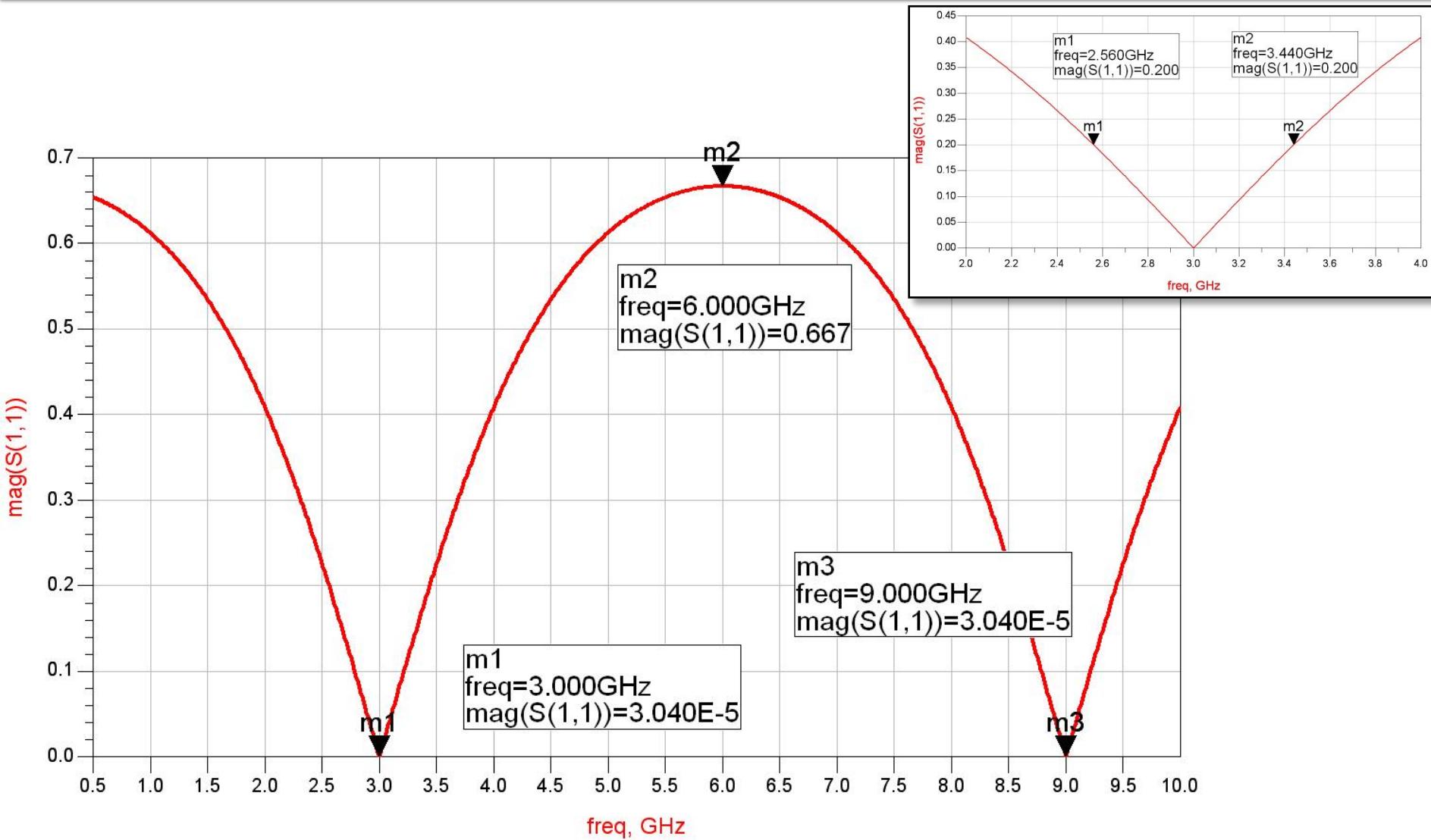


$$\Delta f = 0.88\text{GHz}$$

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

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

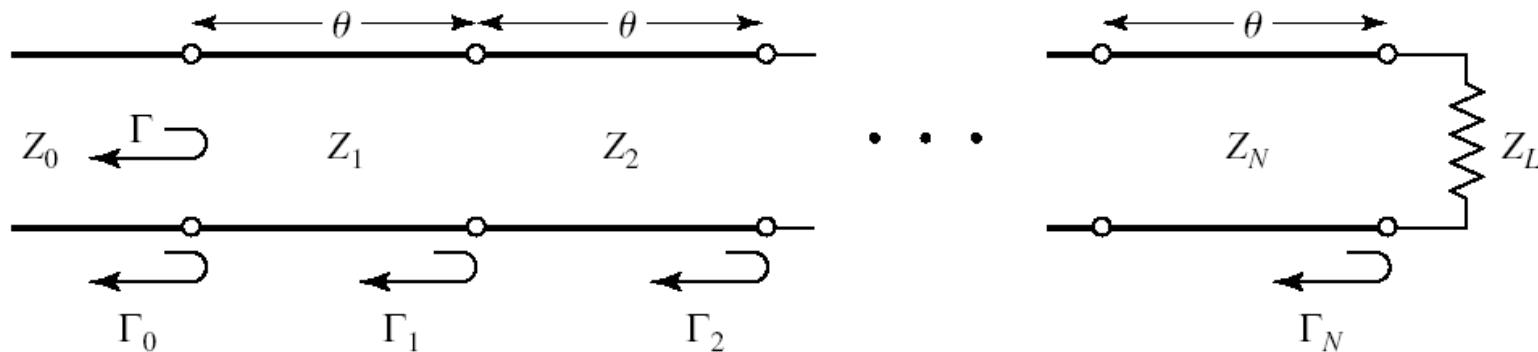
# Simulare banda larga



# 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

# Transformatoare cu mai multe sectiuni



- Presupunem ca toate impedantele **cresc sau descresc uniform**
- Toti coeficientii de reflexie vor fi reali si de acelasi semn
- Anterior  $\Gamma \cong \Gamma_1 + \Gamma_3 \cdot e^{-2j\theta} \Rightarrow$   
$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \dots + \Gamma_N \cdot e^{-2jN\theta}$$

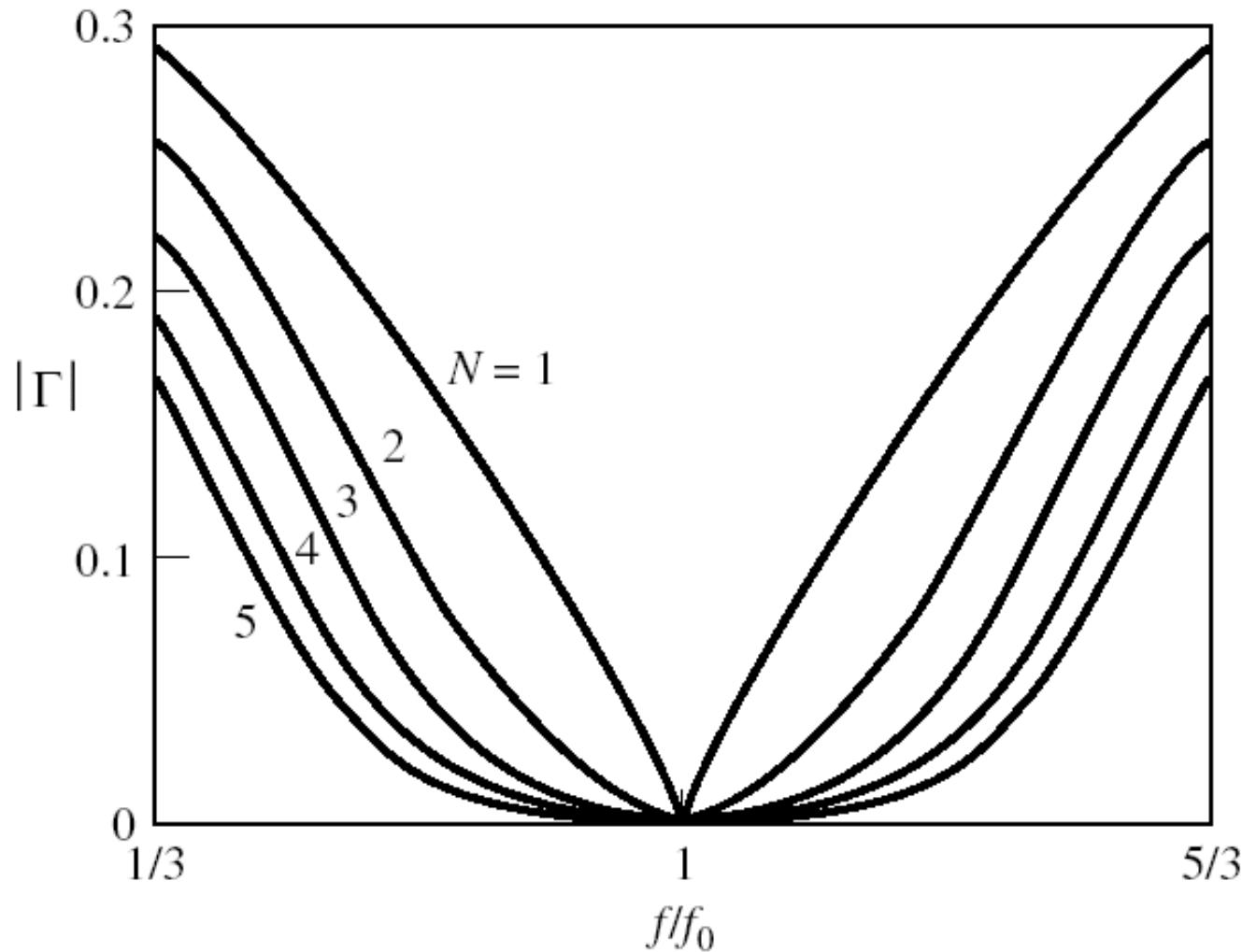
$$\Gamma_1 = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

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

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

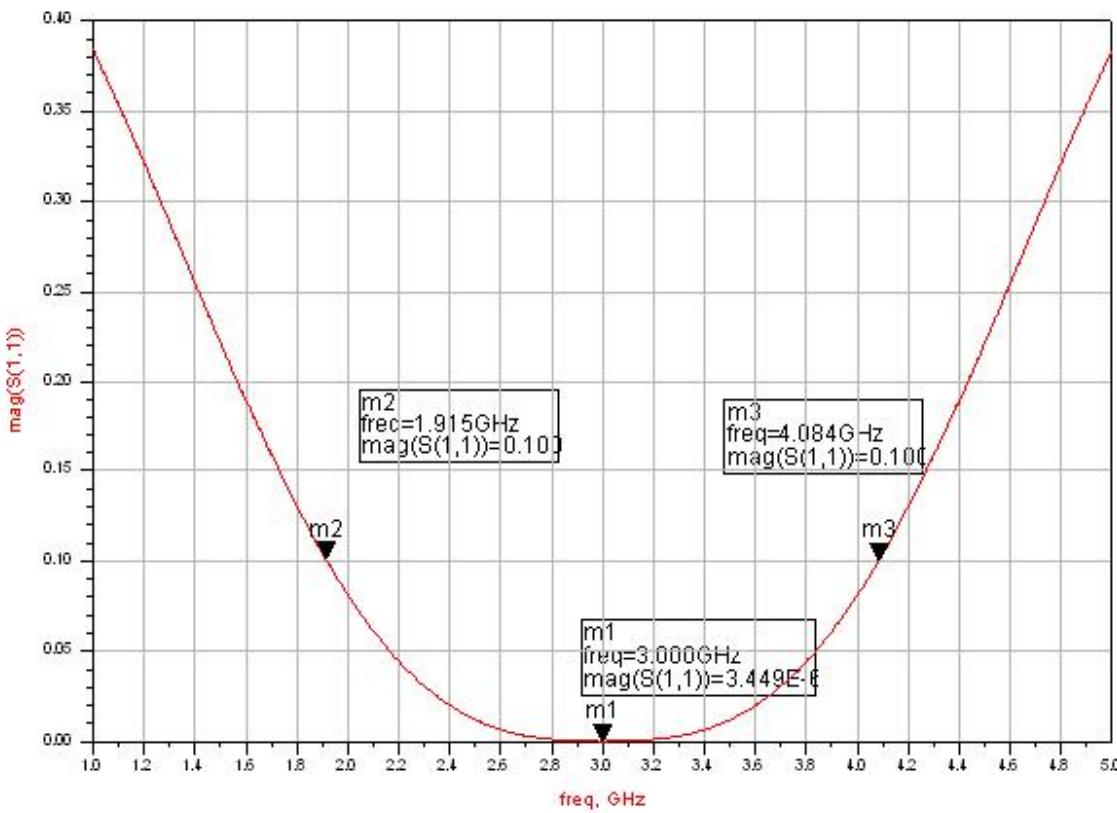
$$\Gamma_N = \frac{Z_L - Z_N}{Z_L + Z_N}$$

# Transformatoare cu mai multe sectiuni cu caracteristica binomiala



# Simulare

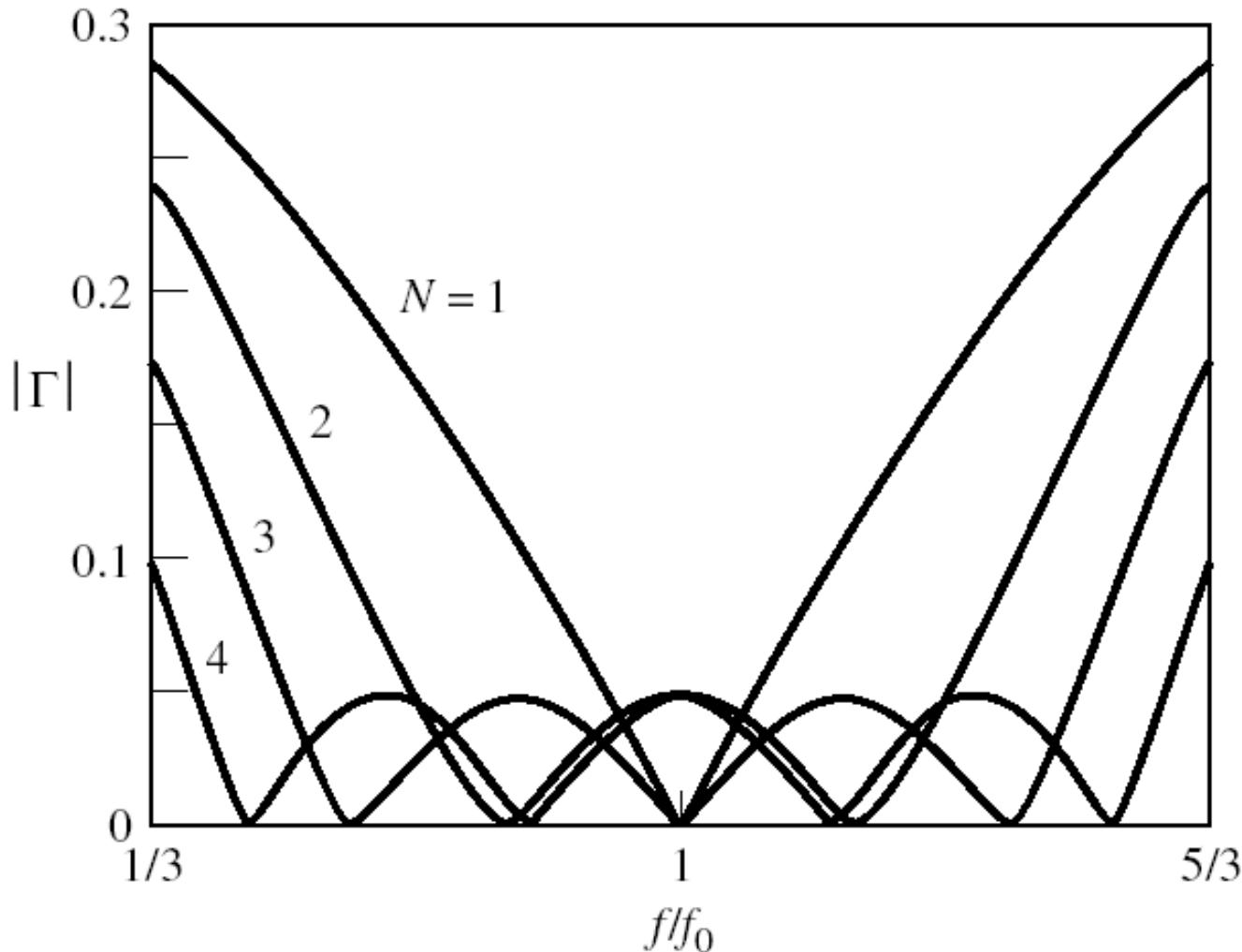
## ■ Similar Lab. 1



$$\Delta f = 2.169 \text{ GHz}$$

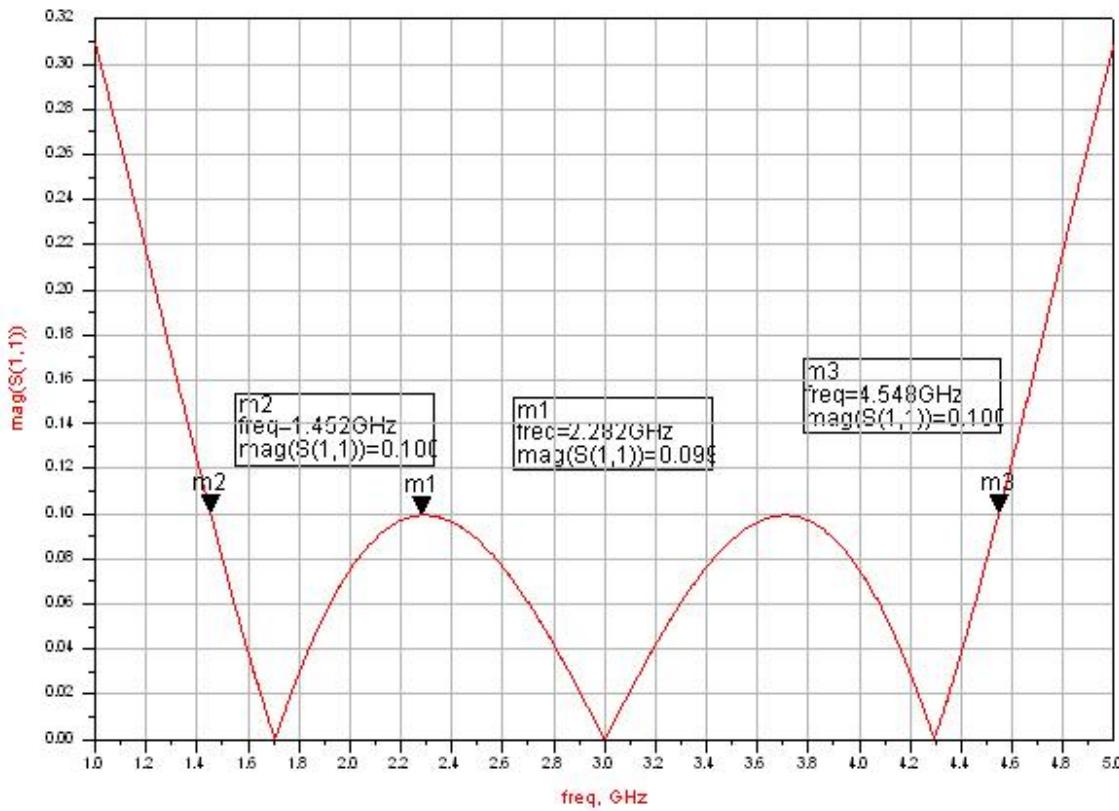
$$|\Gamma(3 \text{ GHz})| = 3.5 \cdot 10^{-6}$$

# Transformatoare cu mai multe sectiuni de tip Cebîșev



# Simulare

## ■ Similar Lab. 1



$$\Delta f = 3.096 \text{ GHz}$$

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

$$|\Gamma(2.282 \text{ GHz})| = 0.09925$$

# Contact

- Laboratorul de microunde si optoelectronica
- <http://rf-opto.etti.tuiasi.ro>
- [rdamian@etti.tuiasi.ro](mailto:rdamian@etti.tuiasi.ro)