

Curs 3

2020/2021

Dispozitive și circuite de microunde pentru radiocomunicații

Cuprins

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

Disciplina 2020/2021

- 2C/1L, **DCMR (CDM)**
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
 - Vineri 8-10, Online/Video, Microsoft Teams
 - E – **50%** din nota
 - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
 - primul test C2: 16.10.2020 (t₂ si t₃ neanuntate ~ **C₇, C₁₂**)
 - 3pz (C) ≈ +0.5p (**2p** max)
 - toate materialele permise

Online

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

English | Romana |

Start Didactic Master Colectiv Cercetare **Studenti**

Note Lista Studenti Examene Fotografii

POPESCU GOPO ION

Fotografia nu exista

Date:

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

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

Note obtinute

Inca nu a fost notat.

Start Didactic Master Colectiv C

Note **Lista Studenti** Examene Fotografii

Identificare

Introduceti numele si adresa de email utilizata la inscriere

Nume
POPESCU GOPO

E-mail/Parola

Introduceti codul afisat mai jos

4db4457

Trimite

Cuprins

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

Bibliografie

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

Examen: Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Examen

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

Reprezentare polara

■ Formula lui Euler

$$e^{j \cdot x} = \cos x + j \cdot \sin x; \forall x \in R$$

■ Reprezentare polara

$$z = a + j \cdot b = |z| \cdot e^{j \cdot \varphi}$$

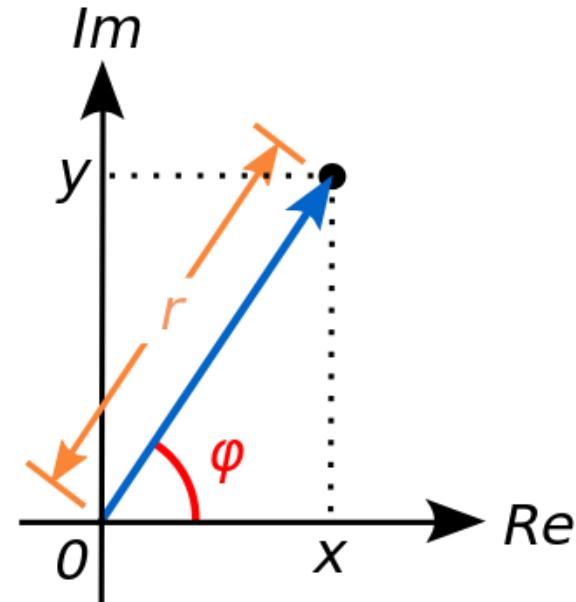
$$z = a + j \cdot b = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)$$

$$z^n = (|z| \cdot e^{j \cdot \varphi})^n = |z|^n \cdot e^{j \cdot n \cdot \varphi} = |z|^n \cdot [\cos(n \cdot \varphi) + j \cdot \sin(n \cdot \varphi)]$$

$$\sqrt{z} = (|z| \cdot e^{j \cdot \varphi})^{1/2} = \sqrt{|z|} \cdot e^{j \cdot \frac{\varphi}{2}} = \sqrt{|z|} \cdot \left(\cos \frac{\varphi}{2} + j \cdot \sin \frac{\varphi}{2} \right)$$

$$z \cdot w = |z| \cdot e^{j \cdot \varphi} \cdot |w| \cdot e^{j \cdot \theta} = |z| \cdot |w| \cdot e^{j \cdot (\varphi + \theta)} = |z| \cdot |w| \cdot [\cos(\varphi + \theta) + j \cdot \sin(\varphi + \theta)]$$

$$z/w = \frac{|z| \cdot e^{j \cdot \varphi}}{|w| \cdot e^{j \cdot \theta}} = \frac{|z|}{|w|} \cdot e^{j \cdot \varphi} \cdot e^{-j \cdot \theta} = \frac{|z|}{|w|} \cdot e^{j \cdot (\varphi - \theta)} = \frac{|z|}{|w|} \cdot [\cos(\varphi - \theta) + j \cdot \sin(\varphi - \theta)]$$



Introducere

~ Microunde

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

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

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

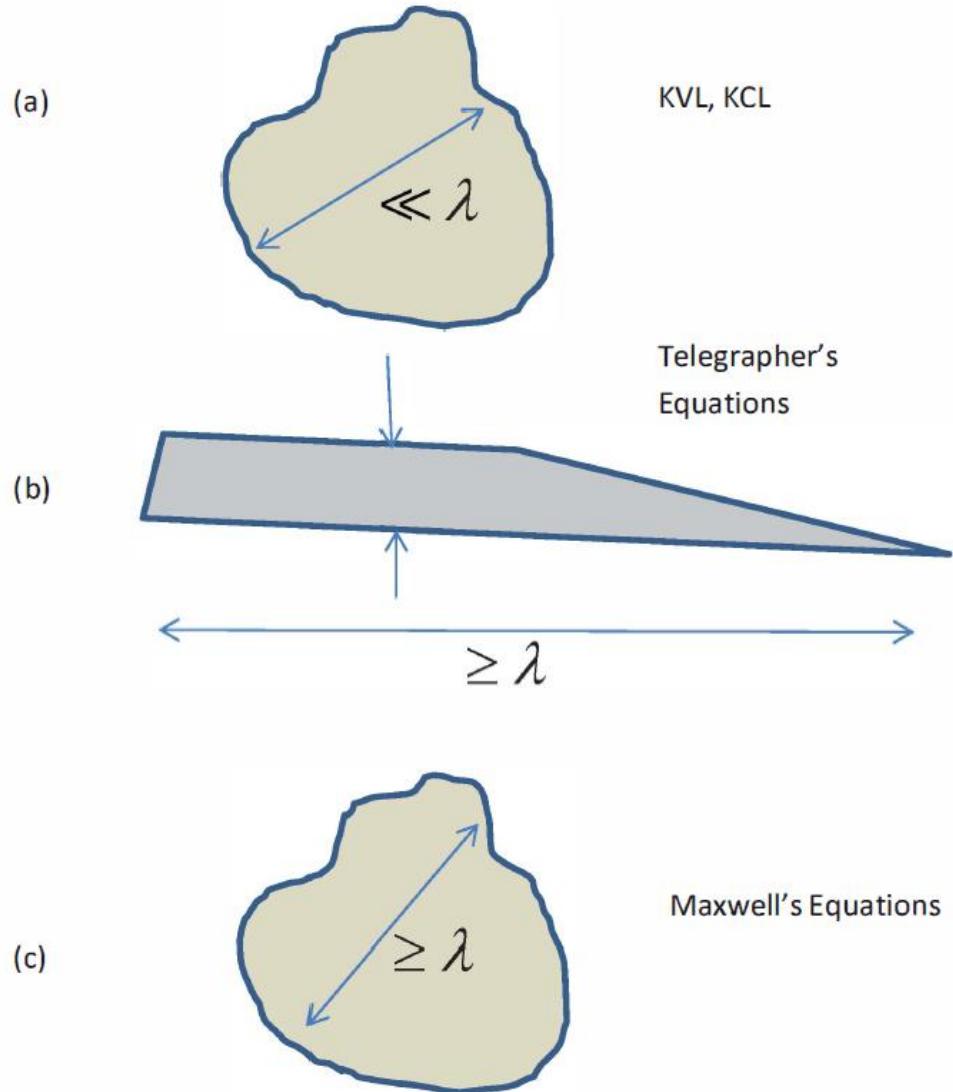
- Dependenta
 - castigul antenei
 - imaginea unui obiect pe radar

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

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

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

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

Ecuățiile de propagare

- Ecuățiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

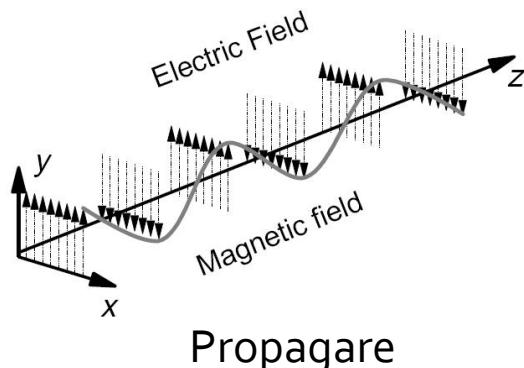
$$\nabla^2 E - \gamma^2 E = 0$$

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

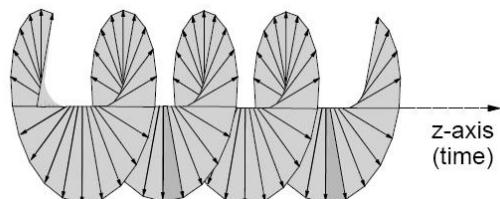
$$\gamma^2 = -\omega^2 \epsilon \mu + j \omega \mu \sigma$$

γ – 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 $E_+ \Rightarrow A$

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

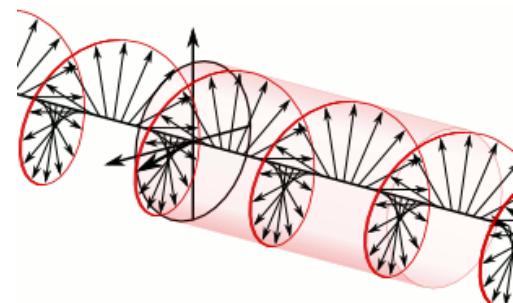
Camp armonic

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

Amplitudine

Atenuare

Propagare
(variatie in timp si spatiu)



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

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

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

■ unda

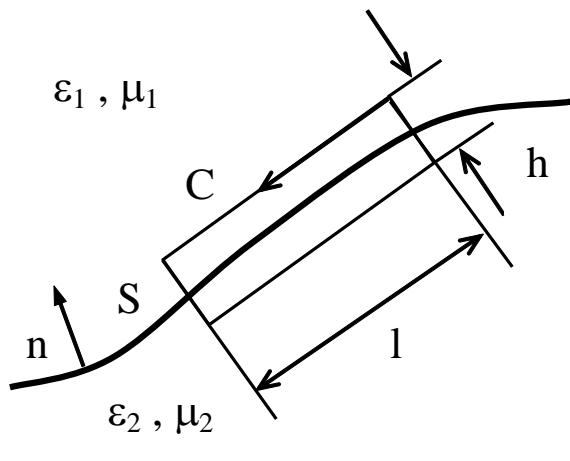
- directa
- inversa

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

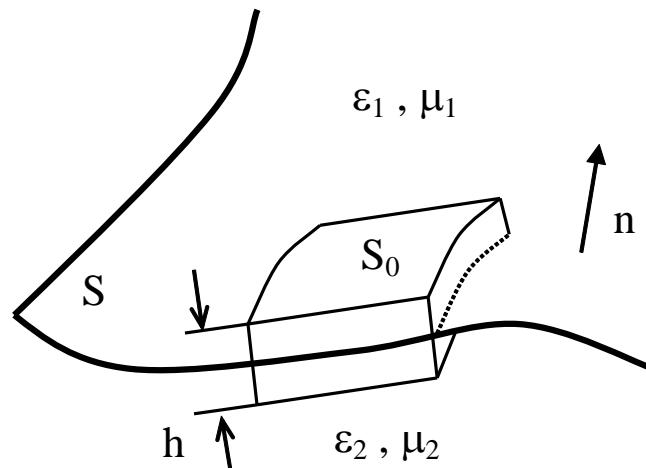
$$I(z) = I^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t - \beta \cdot z)} + I^- \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t + \beta \cdot z)}$$

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

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

Moduri in medii delimitate

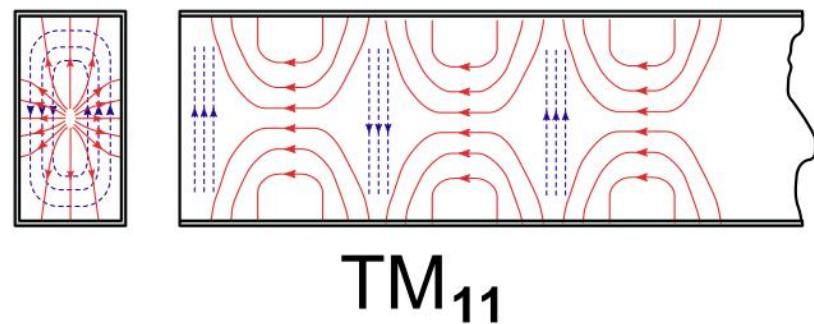
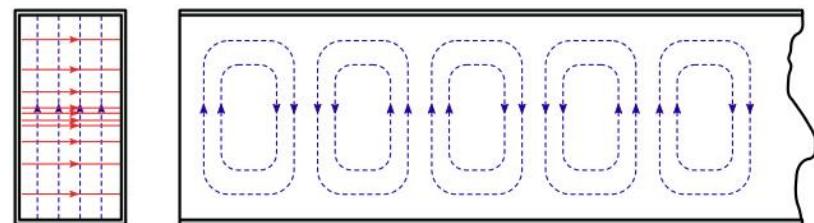
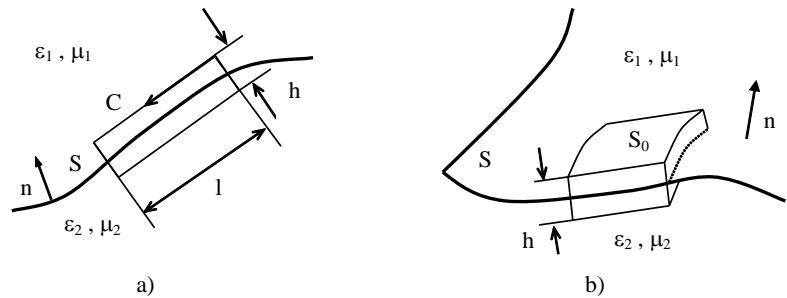
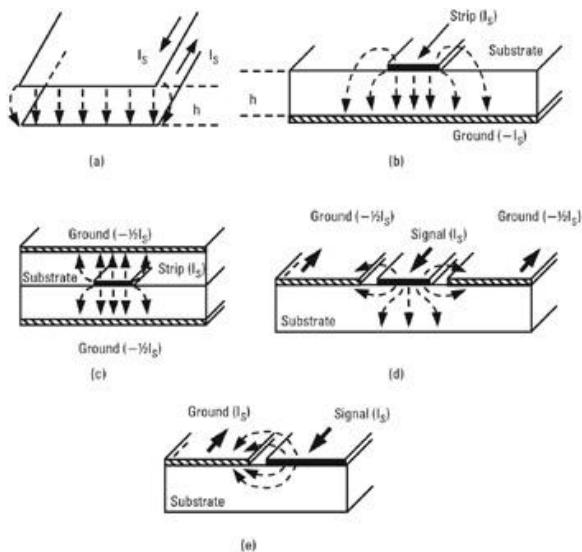
- Câmpuri electromagnetice cu variație armonică în timp
 - simplificarea ecuațiilor lui Maxwell

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

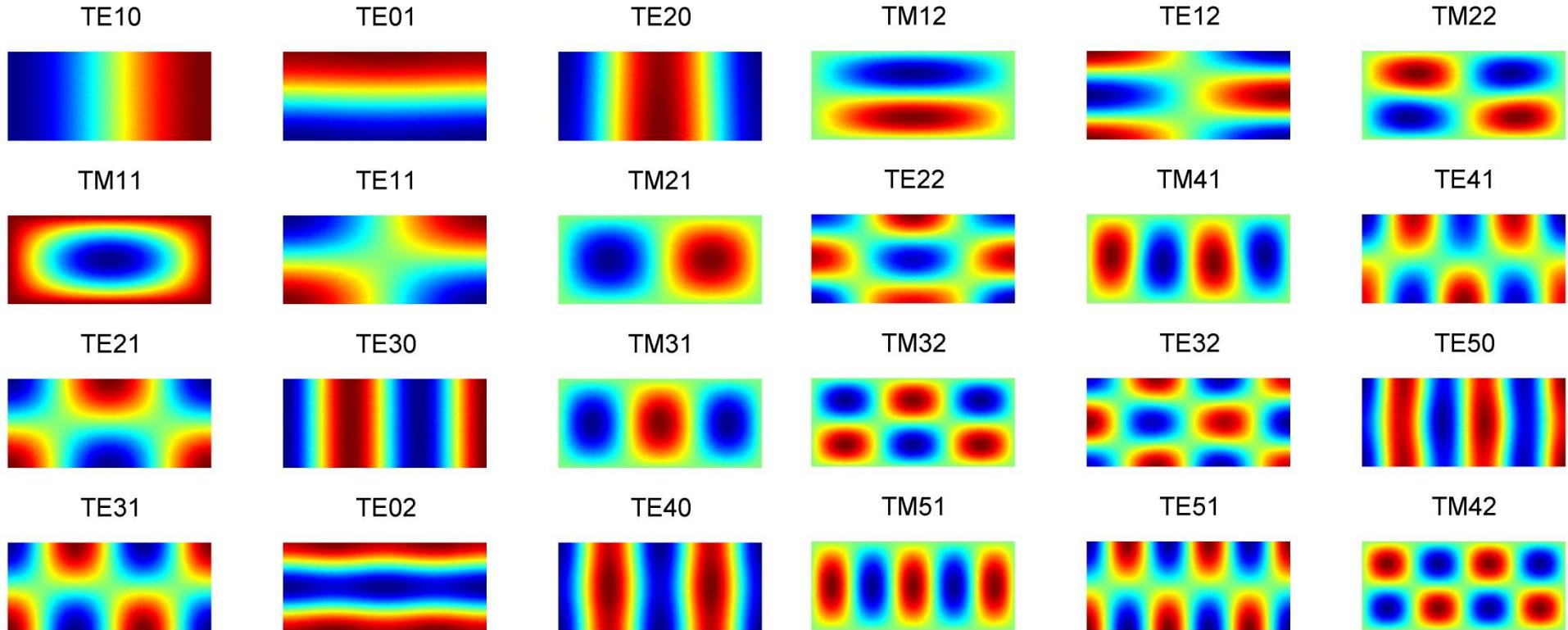
- În medii delimitate soluțiile ecuațiilor lui Maxwell trebuie să verifice condițiile la limită
 - soluțiile trebuie să respecte anumite condiții suplimentare

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



Moduri in mediile delimitate



■ Similar cu transformata Fourier

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

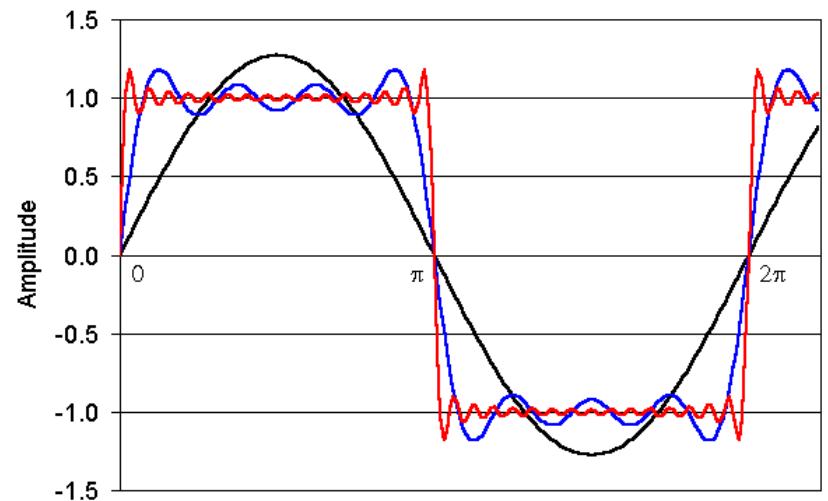
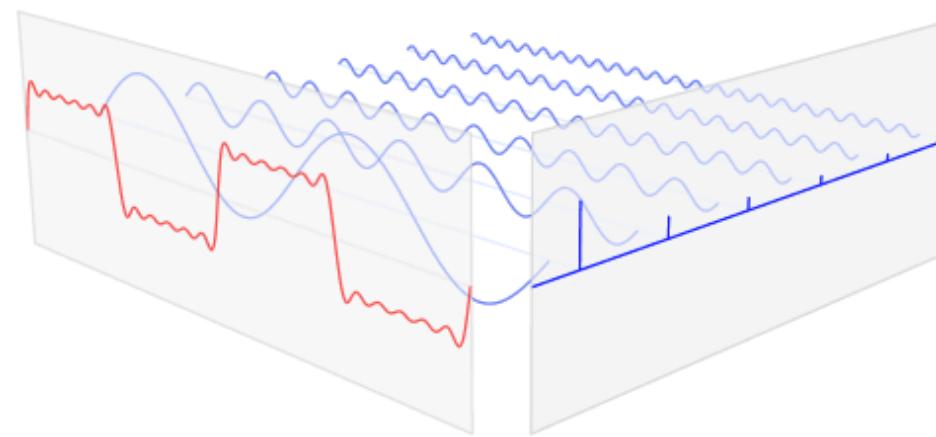
$$E^+, E^- = \sum_1^{\infty} A_i \cdot Mod_i$$

$$A_i = \langle E, Mod_i \rangle$$

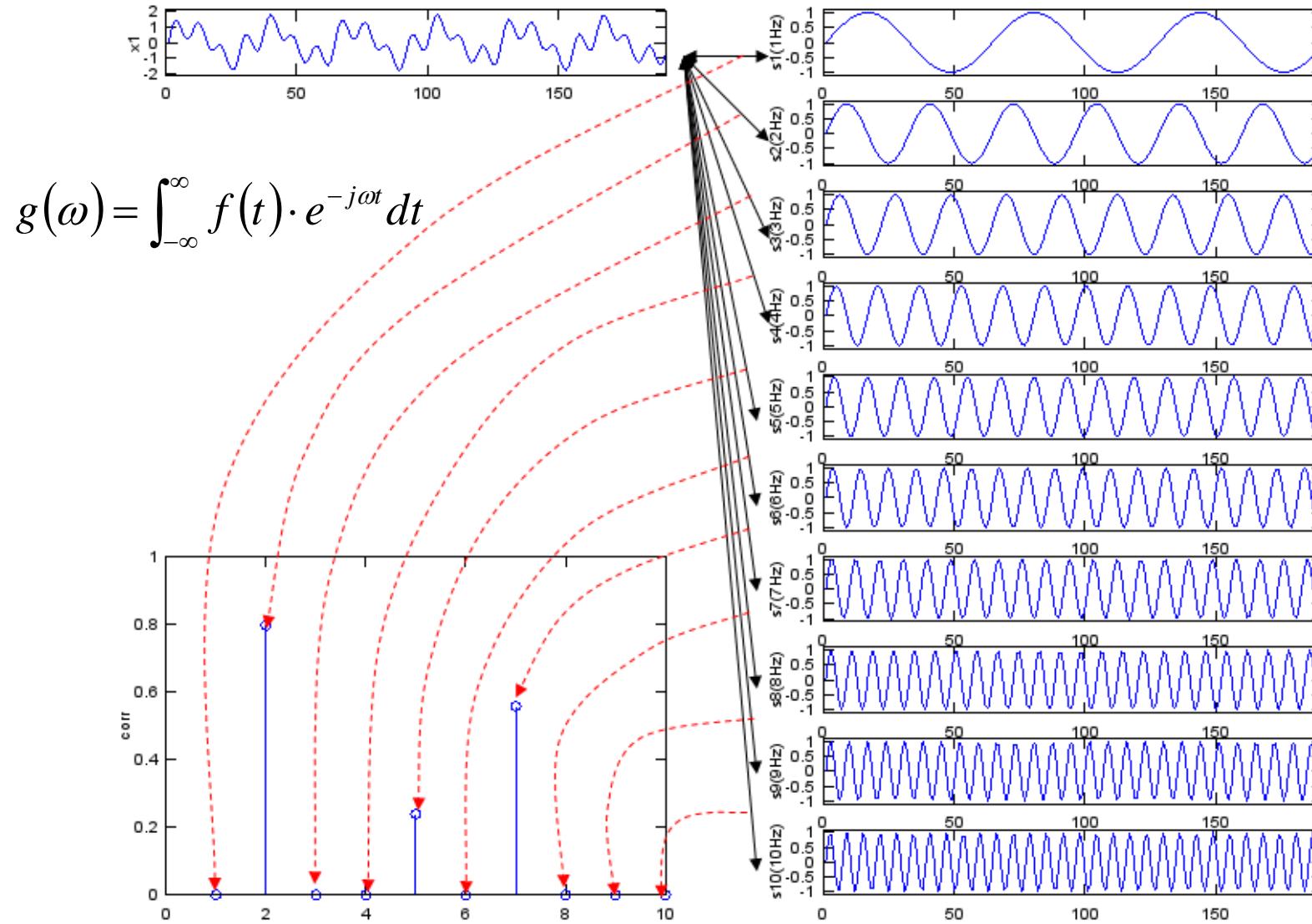
Modele matematice

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

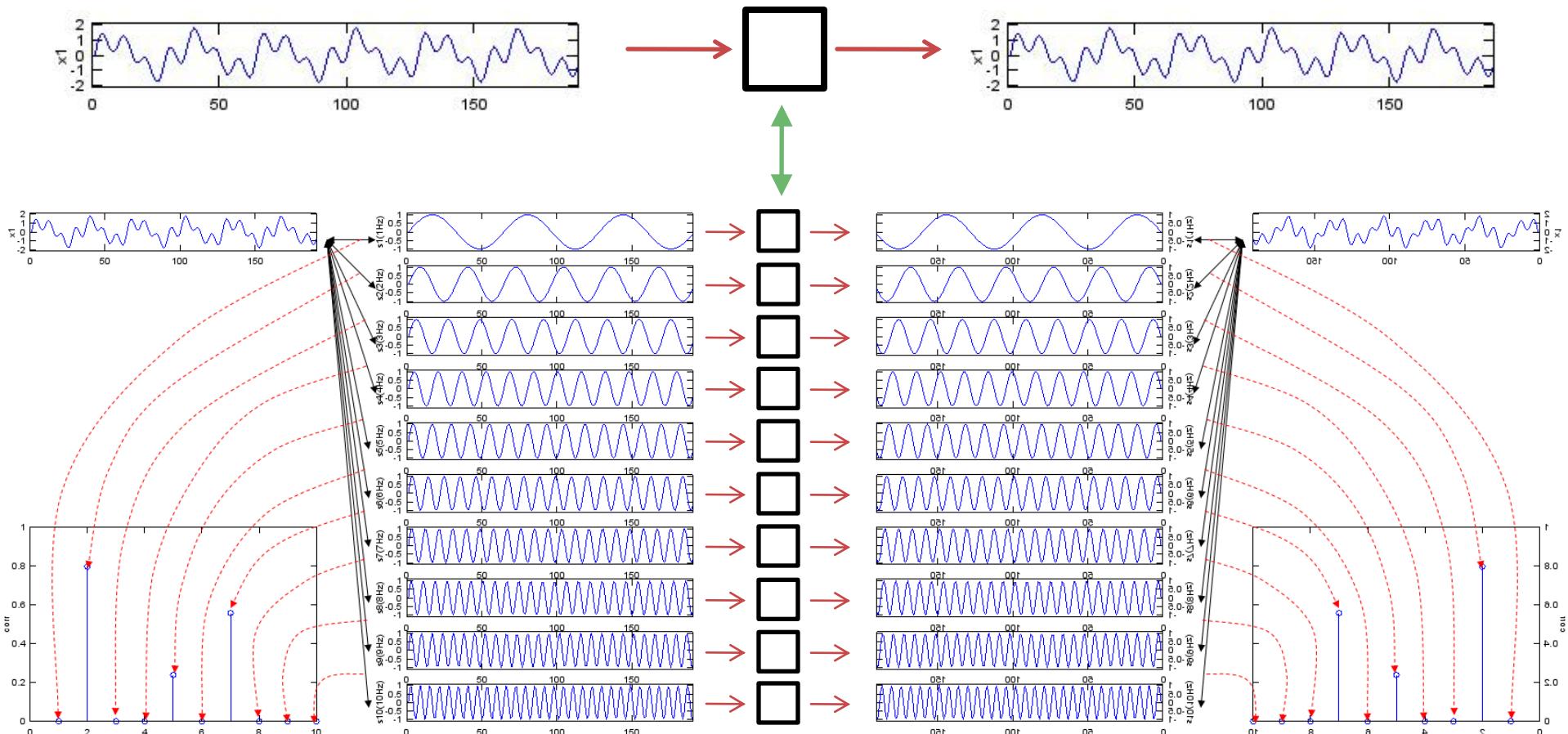
$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$



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

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

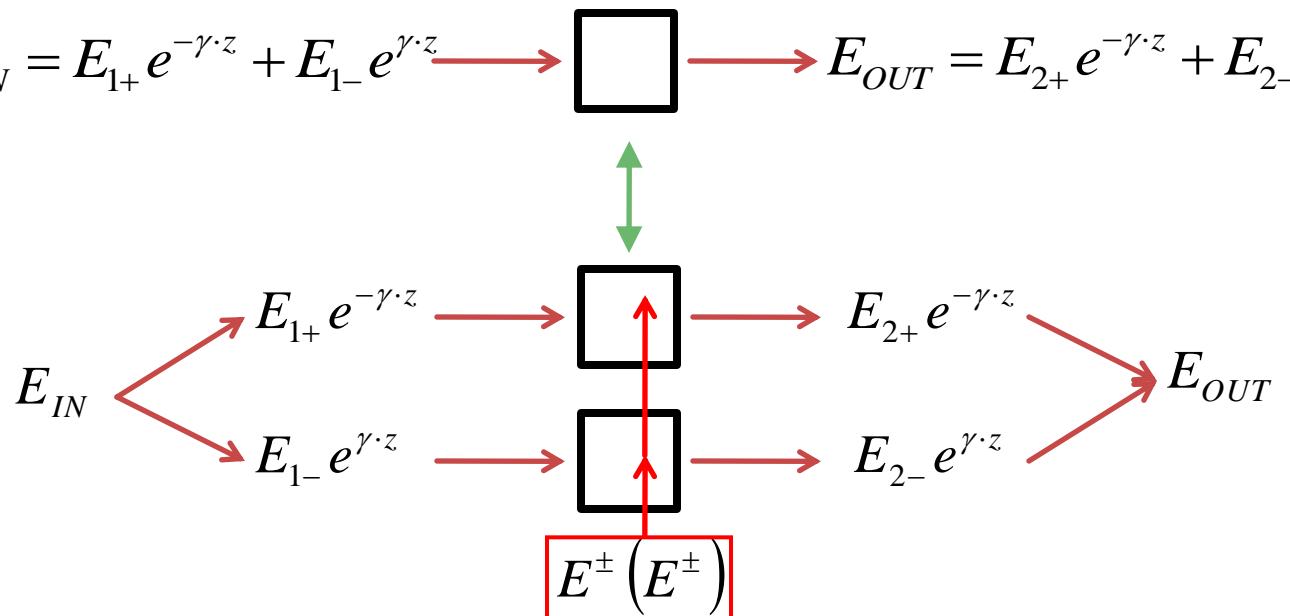
- reflectata

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

■ unda

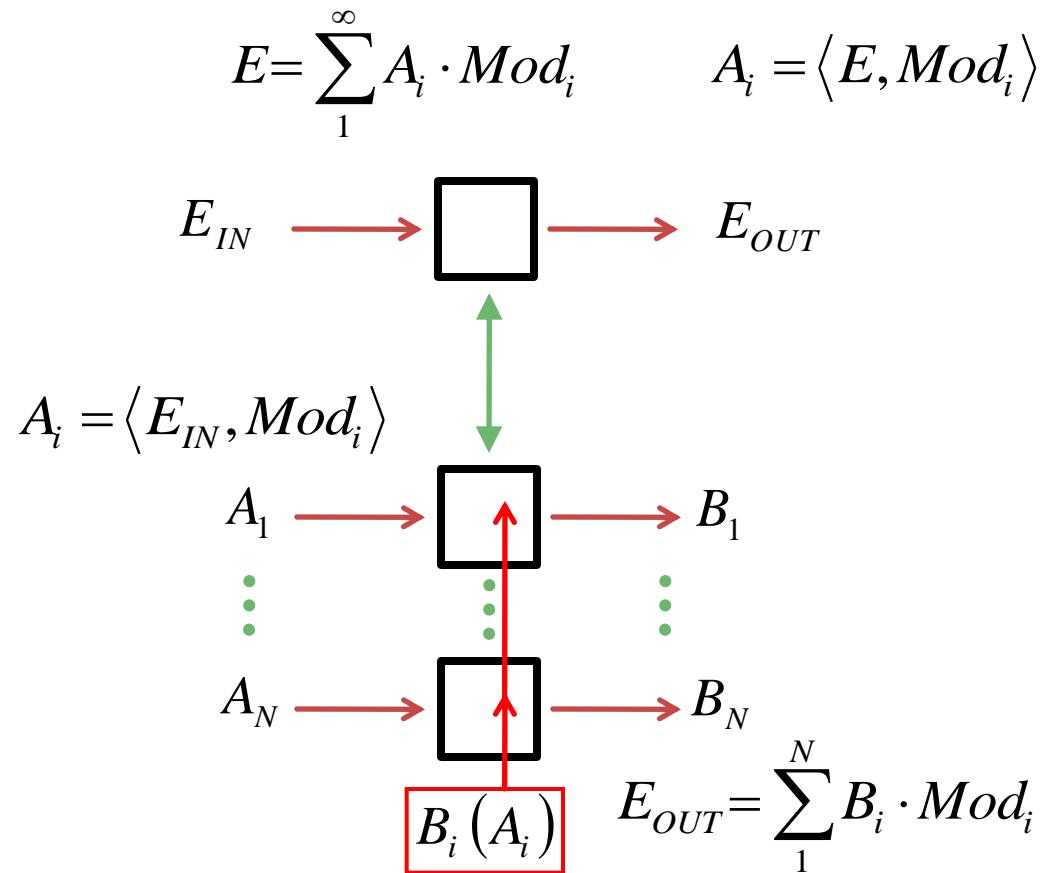
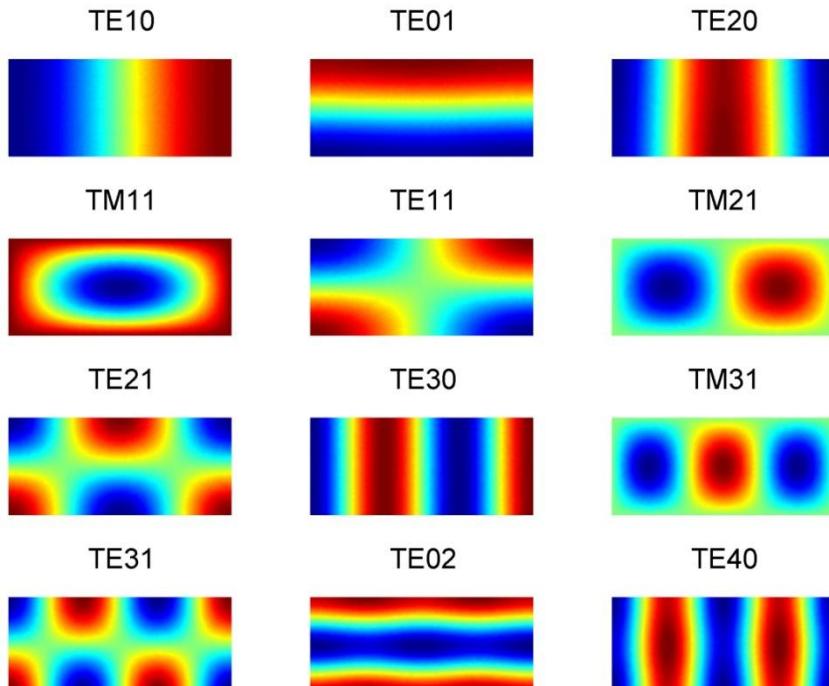
- directa

- inversa



Modele matematice

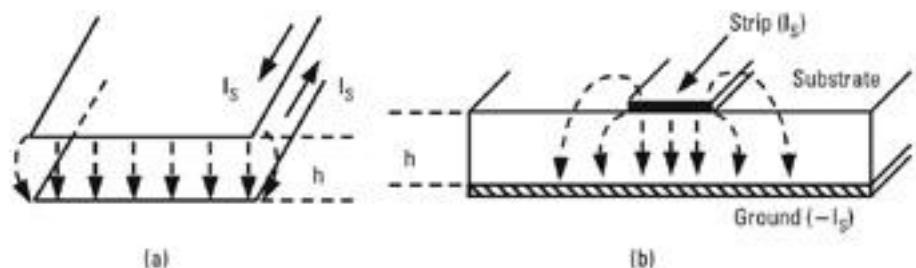
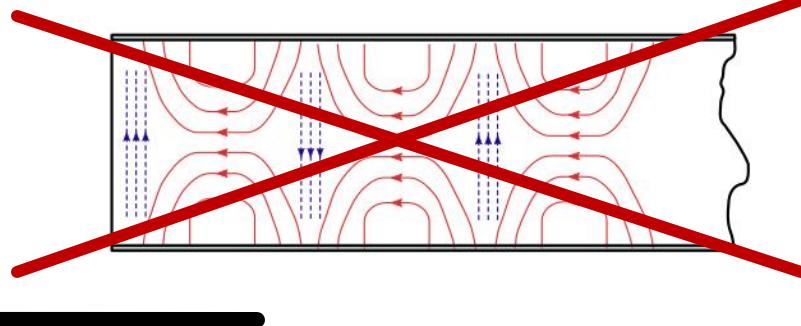
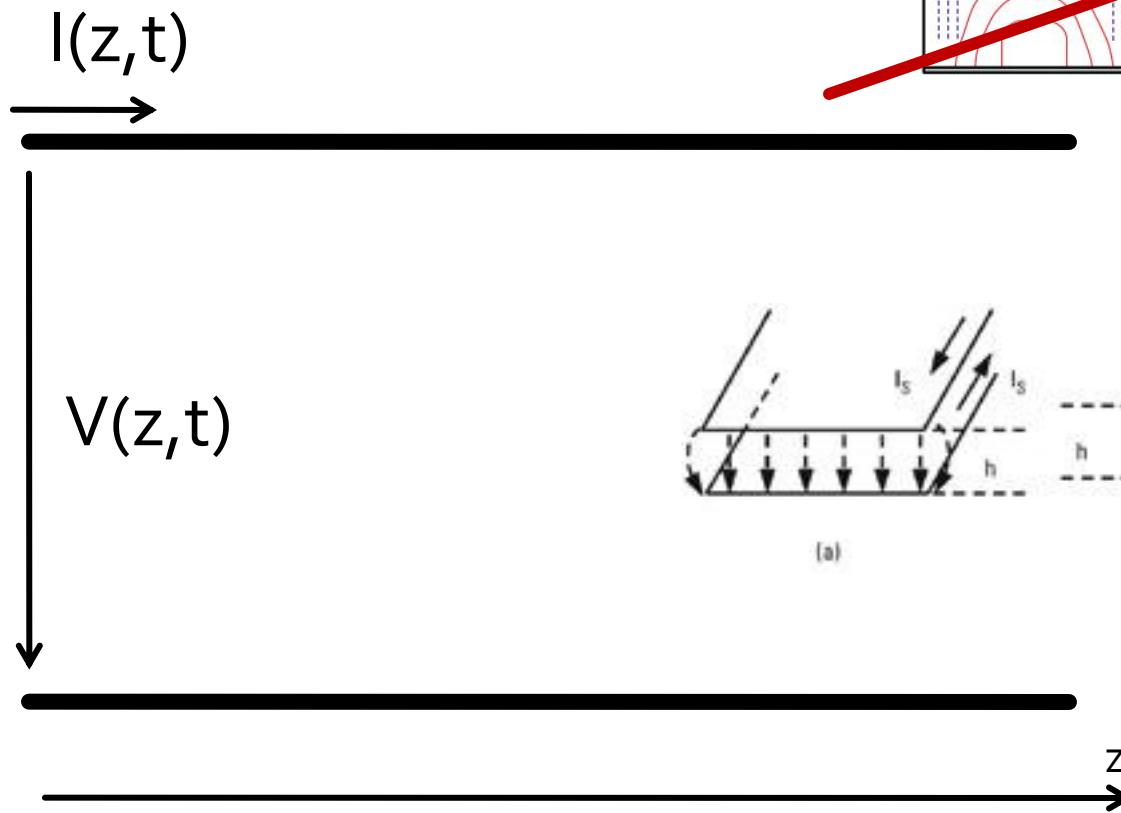
- cazuri particolare in care exista rezolvare analitica
 - moduri in medii delimitate $B_i(A_i)$



Linii de transmisie in mod TEM

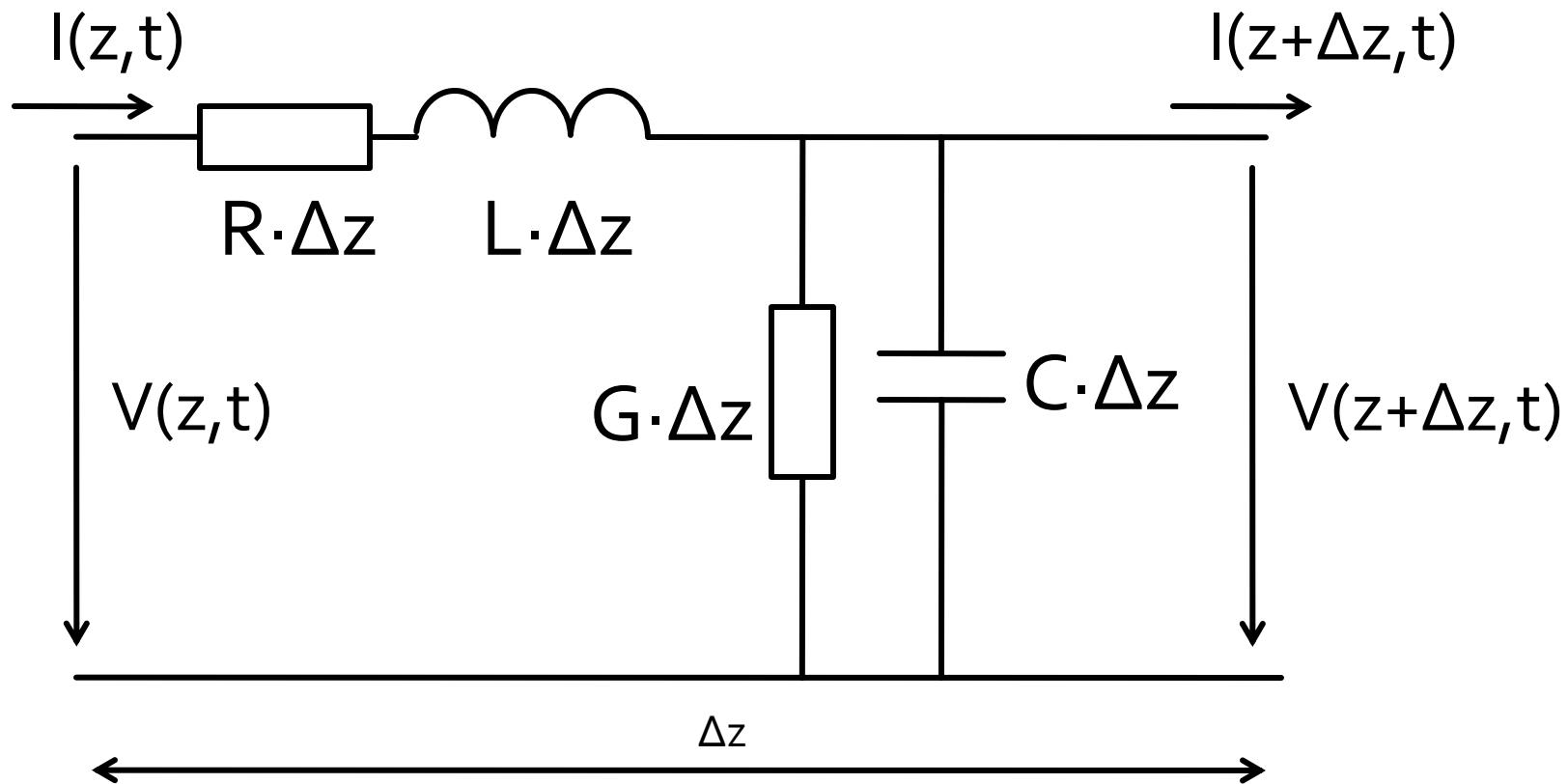
Linie de transmisie

- mod TEM, doi conductori



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

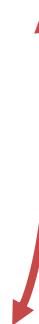
$$\frac{dV(z)}{dz} = -(R + j \cdot \omega \cdot L) \cdot I(z) \quad \left/ \frac{d}{dz} (\dots) \right.$$

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

Rezolvare

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

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



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

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

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

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

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

Solutiile

$$\left\{ \begin{array}{l} V(z) = V_0^+ e^{-\gamma \cdot z} + V_0^- e^{\gamma \cdot z} \\ I(z) = I_0^+ e^{-\gamma \cdot z} + I_0^- e^{\gamma \cdot z} \end{array} \right.$$

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

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

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

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

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

- 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

- **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_o real**

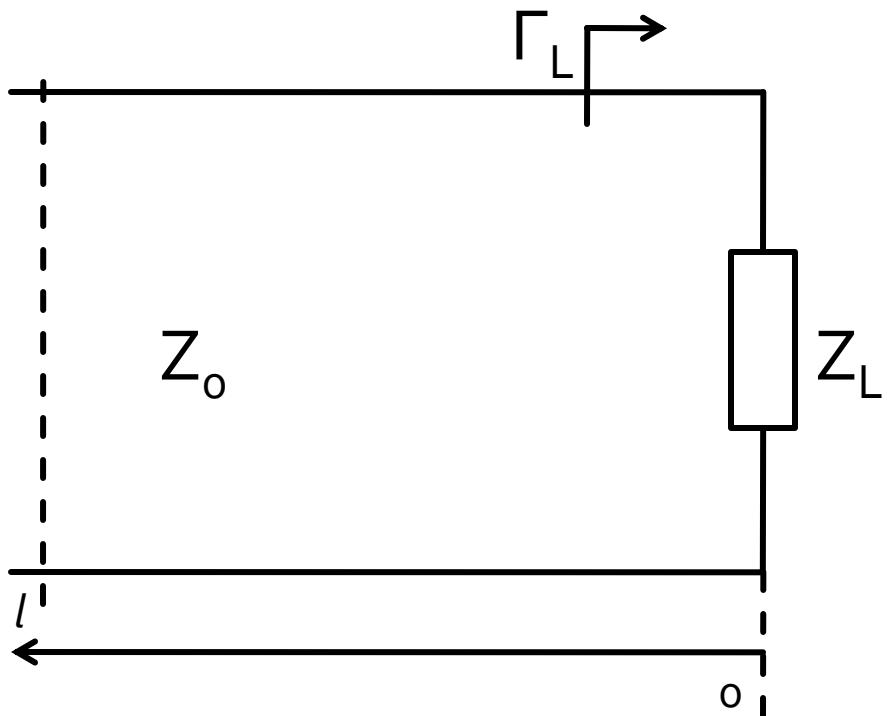
$$V(z) = V_0^+ e^{-j \cdot \beta \cdot z} + V_0^- e^{j \cdot \beta \cdot z}$$

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

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

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

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

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

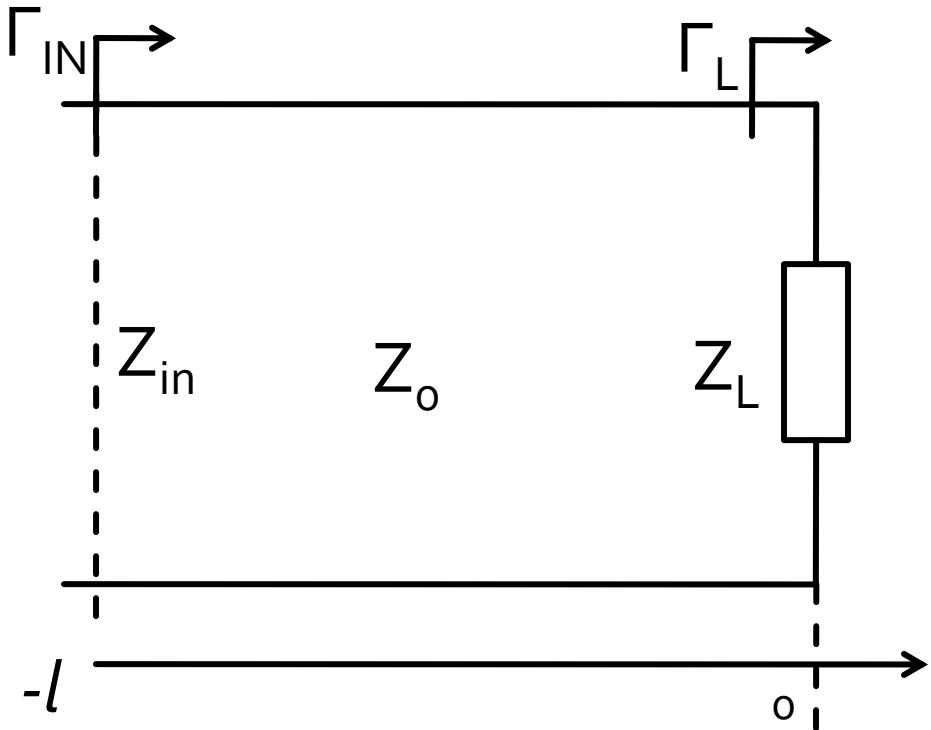
- Z_0 real

Linie fara pierderi

- coeficientul de reflexie la intrarea liniei

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

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



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

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

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

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

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

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

$$\boxed{|\Gamma_{IN}| = |\Gamma_L|}$$

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

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

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

$$(z - z^*) = \text{Im}$$

■ Puterea transmisa sarcinii = Puterea incidenta - Puterea "reflectata"

■ Return Loss [dB]

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

Reprezentare polara

■ Formula lui Euler

$$e^{j \cdot x} = \cos x + j \cdot \sin x; \forall x \in R$$

■ Reprezentare polara

$$z = a + j \cdot b = |z| \cdot e^{j \cdot \varphi}$$

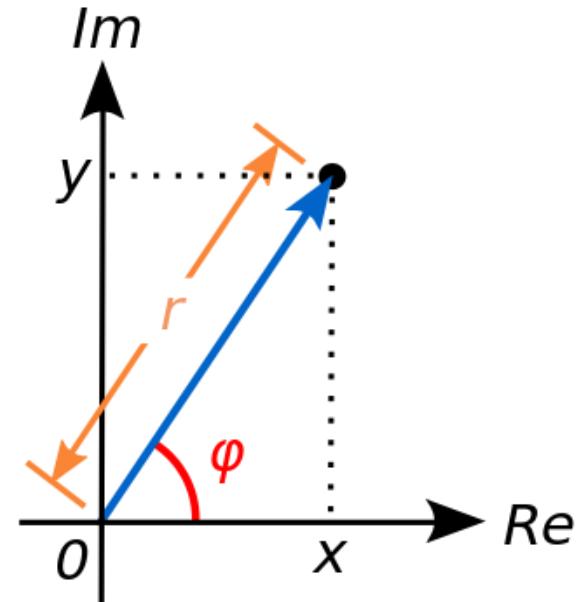
$$z = a + j \cdot b = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)$$

$$z^n = (|z| \cdot e^{j \cdot \varphi})^n = |z|^n \cdot e^{j \cdot n \cdot \varphi} = |z|^n \cdot [\cos(n \cdot \varphi) + j \cdot \sin(n \cdot \varphi)]$$

$$\rightarrow \sqrt{z} = (|z| \cdot e^{j \cdot \varphi})^{1/2} = \sqrt{|z|} \cdot e^{j \cdot \frac{\varphi}{2}} = \sqrt{|z|} \cdot \left(\cos \frac{\varphi}{2} + j \cdot \sin \frac{\varphi}{2} \right)$$

$$z \cdot w = |z| \cdot e^{j \cdot \varphi} \cdot |w| \cdot e^{j \cdot \theta} = |z| \cdot |w| \cdot e^{j \cdot (\varphi + \theta)} = |z| \cdot |w| \cdot [\cos(\varphi + \theta) + j \cdot \sin(\varphi + \theta)]$$

$$z/w = \frac{|z| \cdot e^{j \cdot \varphi}}{|w| \cdot e^{j \cdot \theta}} = \frac{|z|}{|w|} \cdot e^{j \cdot \varphi} \cdot e^{-j \cdot \theta} = \frac{|z|}{|w|} \cdot e^{j \cdot (\varphi - \theta)} = \frac{|z|}{|w|} \cdot [\cos(\varphi - \theta) + j \cdot \sin(\varphi - \theta)]$$



Reprezentare polara

■ Formula lui Euler

$$e^{j \cdot x} = \cos x + j \cdot \sin x; \forall x \in R$$

$$e^{j \cdot x} + e^{-j \cdot x} = \cos x + j \cdot \sin x + \cos(-x) + j \cdot \sin(-x)$$

$$e^{j \cdot x} + e^{-j \cdot x} = \cos x + j \cdot \sin x + \cos x - j \cdot \sin x = 2 \cdot \cos x$$

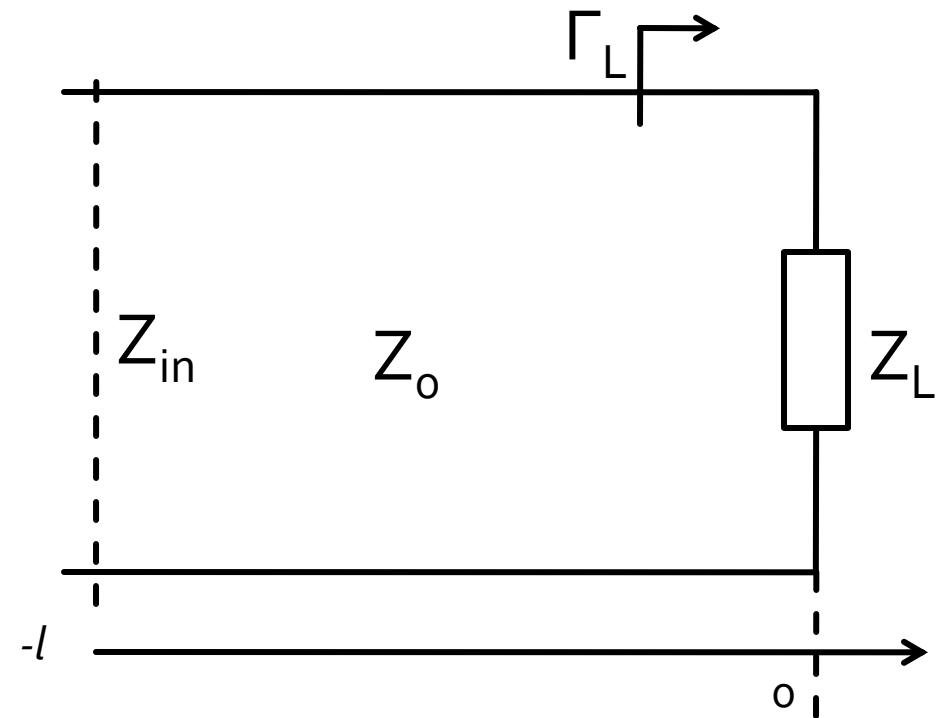

$$\cos x = \frac{e^{j \cdot x} + e^{-j \cdot x}}{2}$$

$$e^{j \cdot x} - e^{-j \cdot x} = \cos x + j \cdot \sin x - \cos(-x) - j \cdot \sin(-x)$$

$$e^{j \cdot x} - e^{-j \cdot x} = \cos x + j \cdot \sin x - \cos x + j \cdot \sin x = 2j \cdot \sin x$$


$$\sin x = \frac{e^{j \cdot x} - e^{-j \cdot x}}{2j}$$

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**

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

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

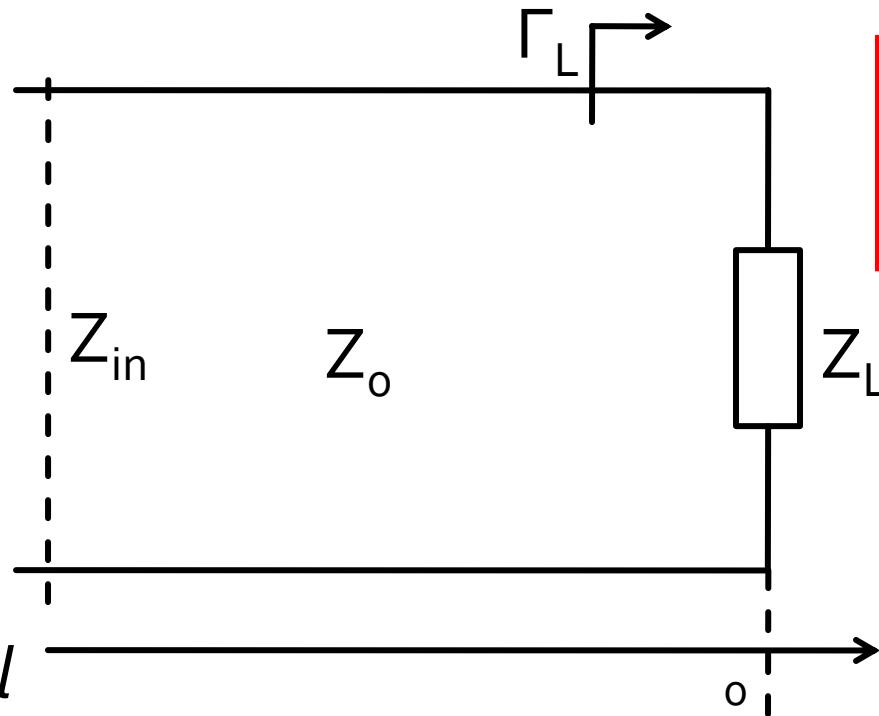
Linie fara pierderi

- 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

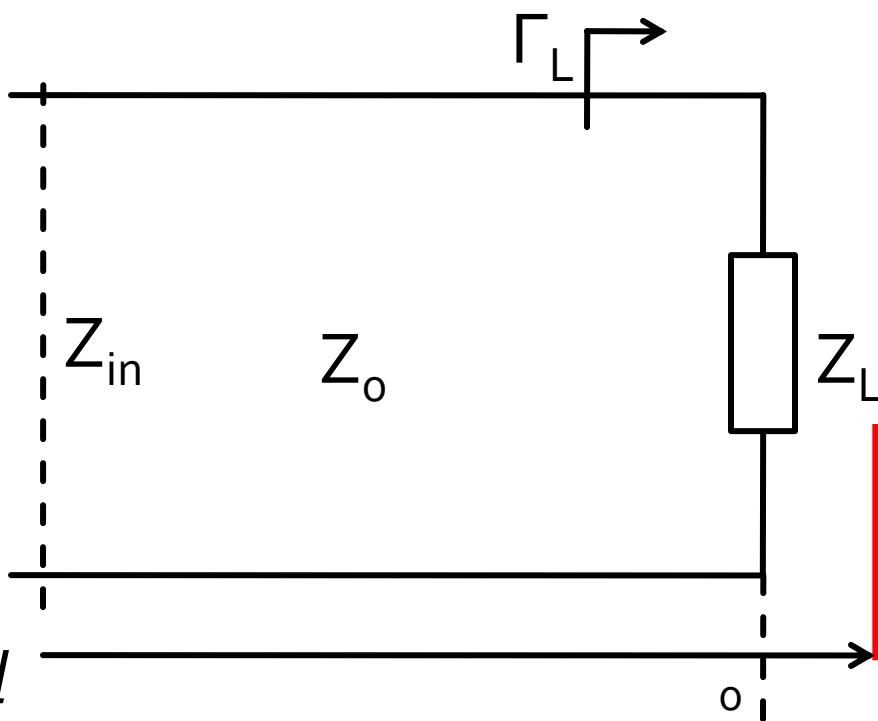
- impedanta la intrarea liniei de impedanta caracteristica Z_0 , de lungime l , terminata cu impedanta Z_L



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

Linie fara pierderi

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



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

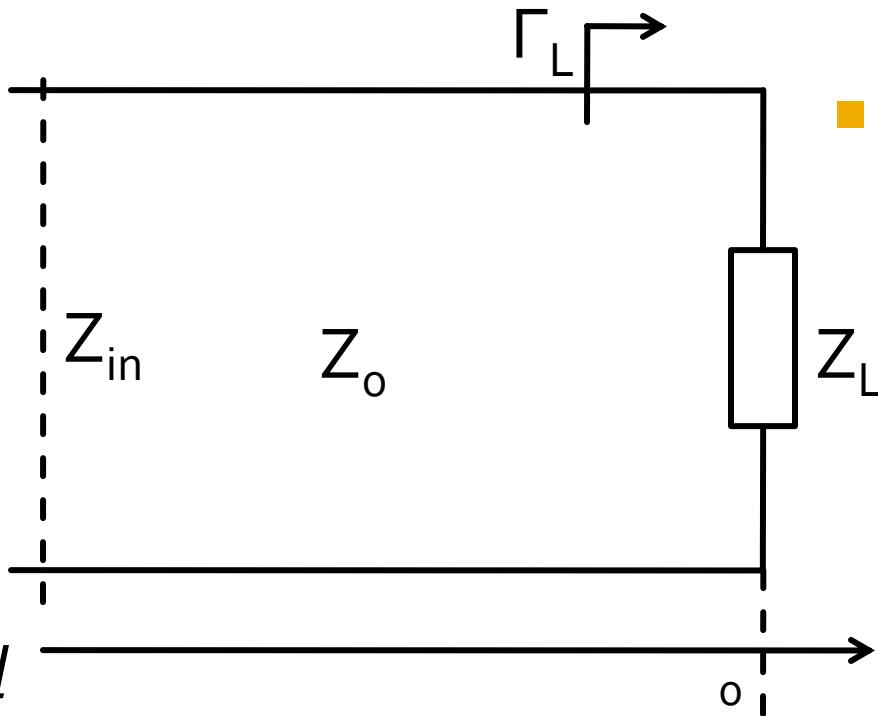
$$\beta \cdot l = \frac{2\pi}{\lambda} \cdot l = \frac{2\pi \cdot f}{v_f} \cdot l = \frac{2\pi \cdot l}{v_f} \cdot f$$

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

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



- Transformatorul în sfert de lungime de undă

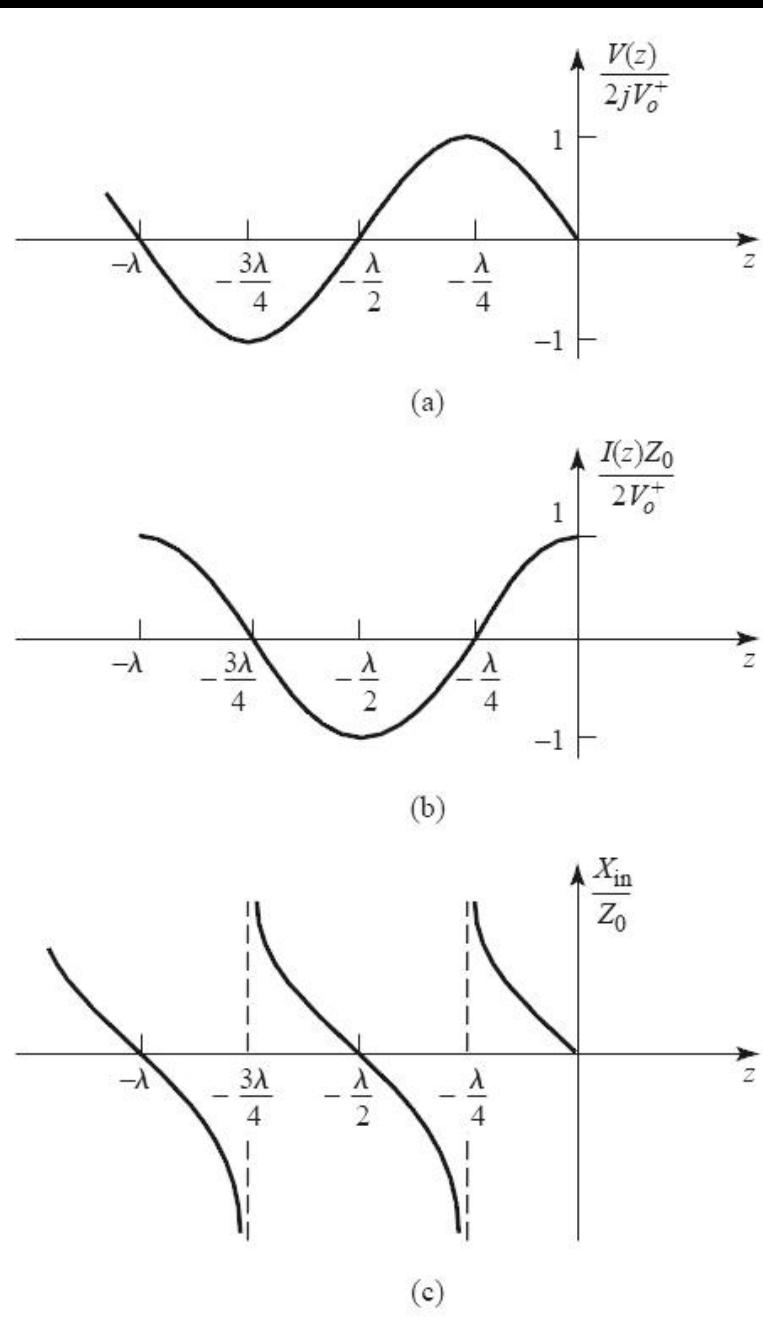
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Linie în scurtcircuit

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

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

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

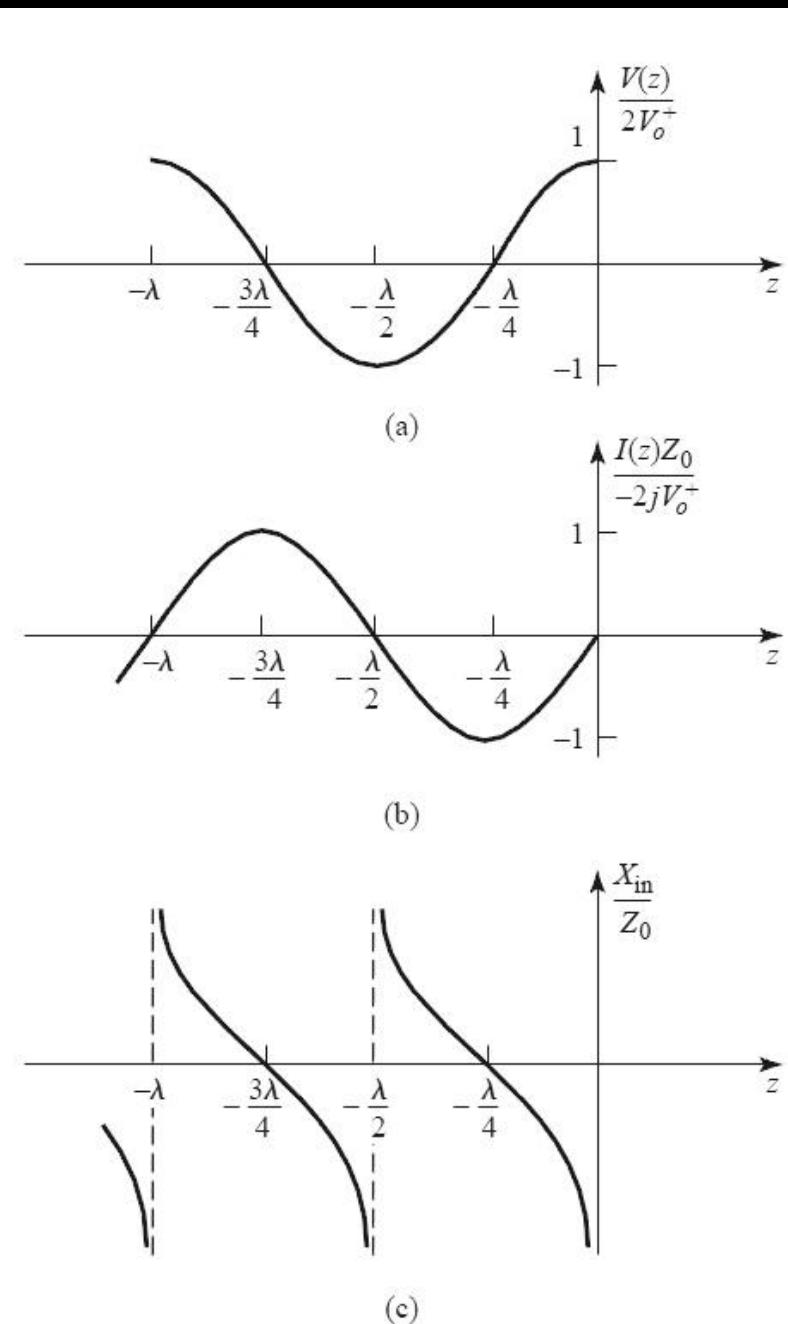


Linie în gol

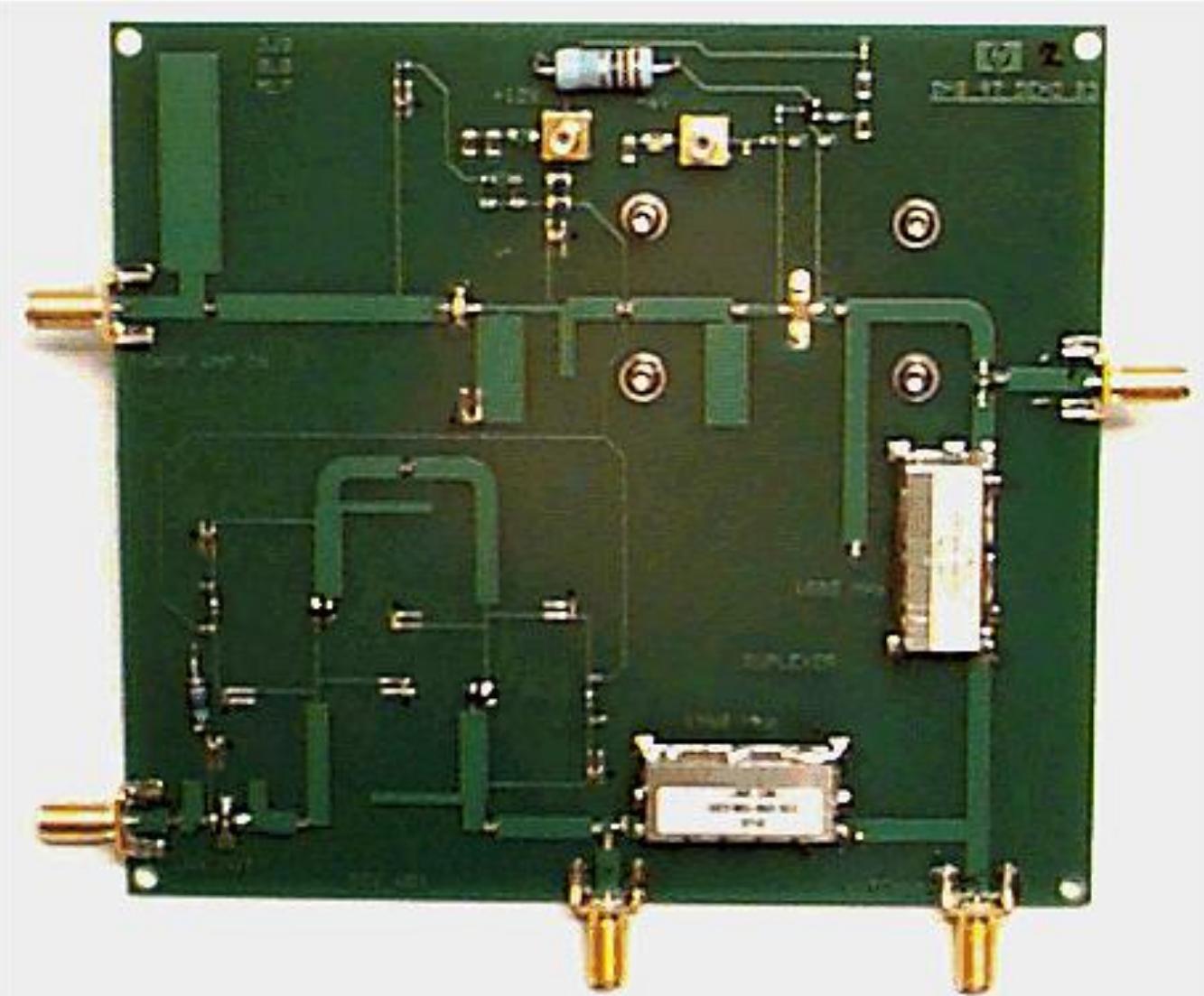
- $Z_L = \infty \rightarrow 1/Z_L = 0$
- reactanță pură
 - $+/- \rightarrow$ în funcție de l

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

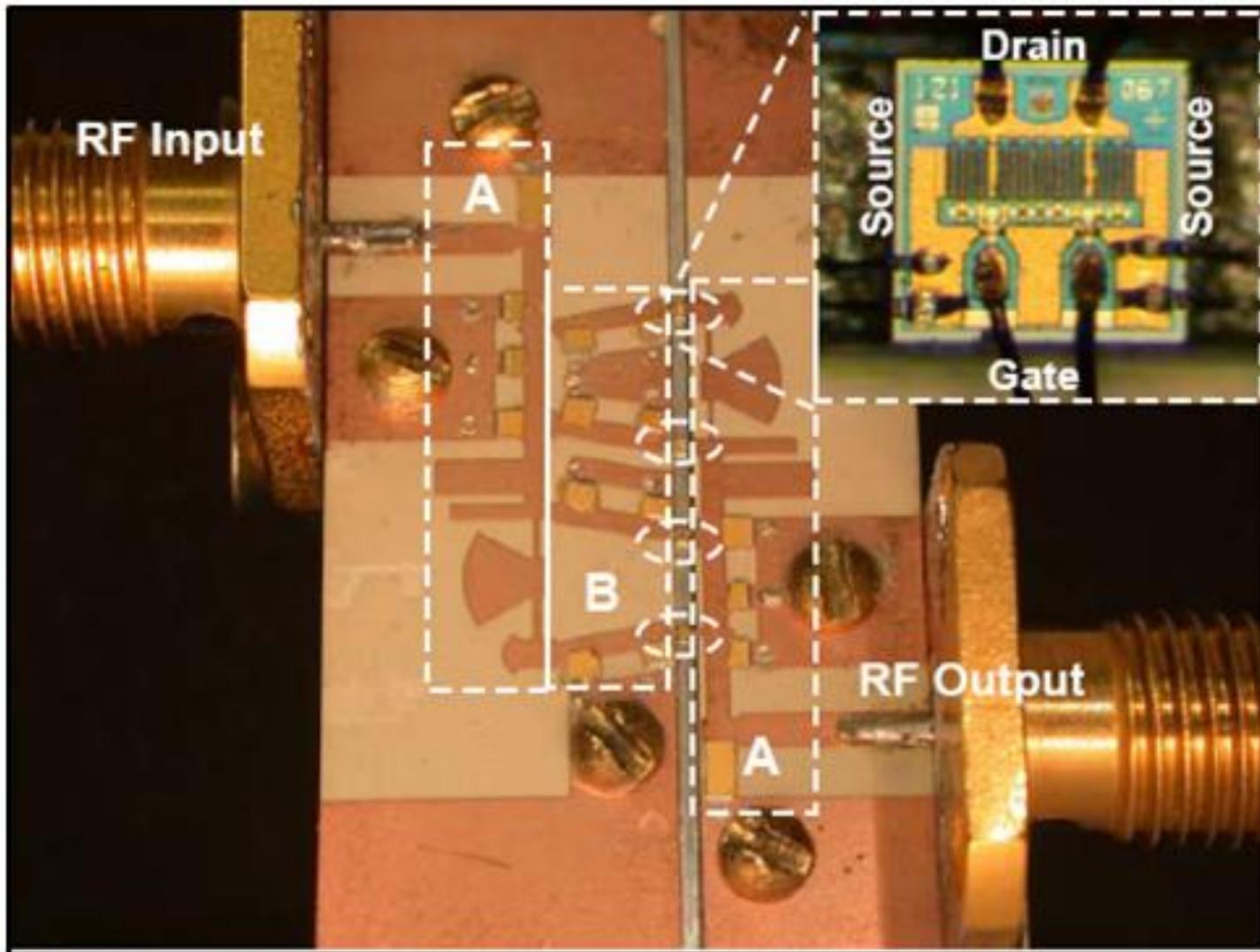
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan(\beta \cdot l)}{Z_0 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$



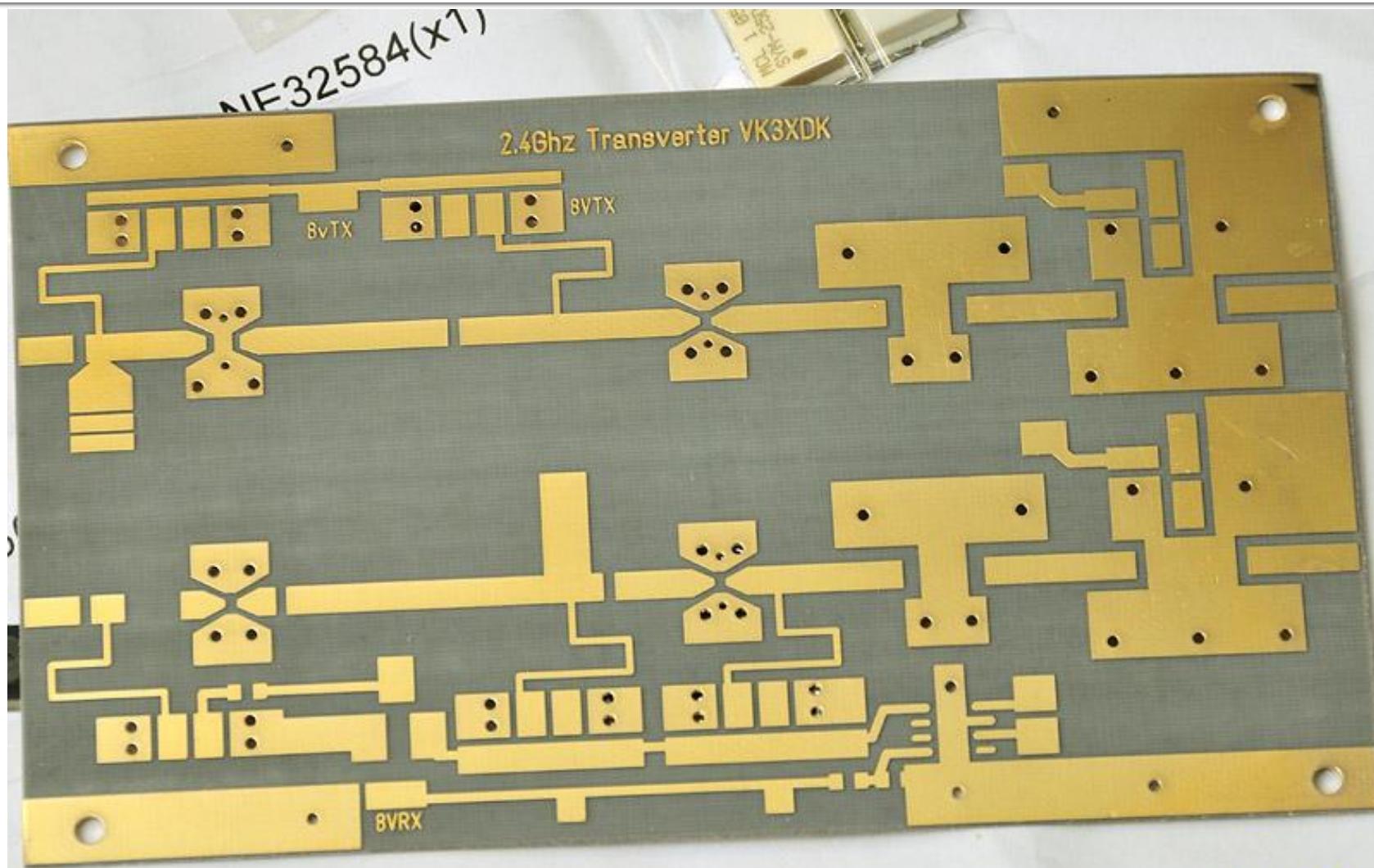
Exemple



Exemple

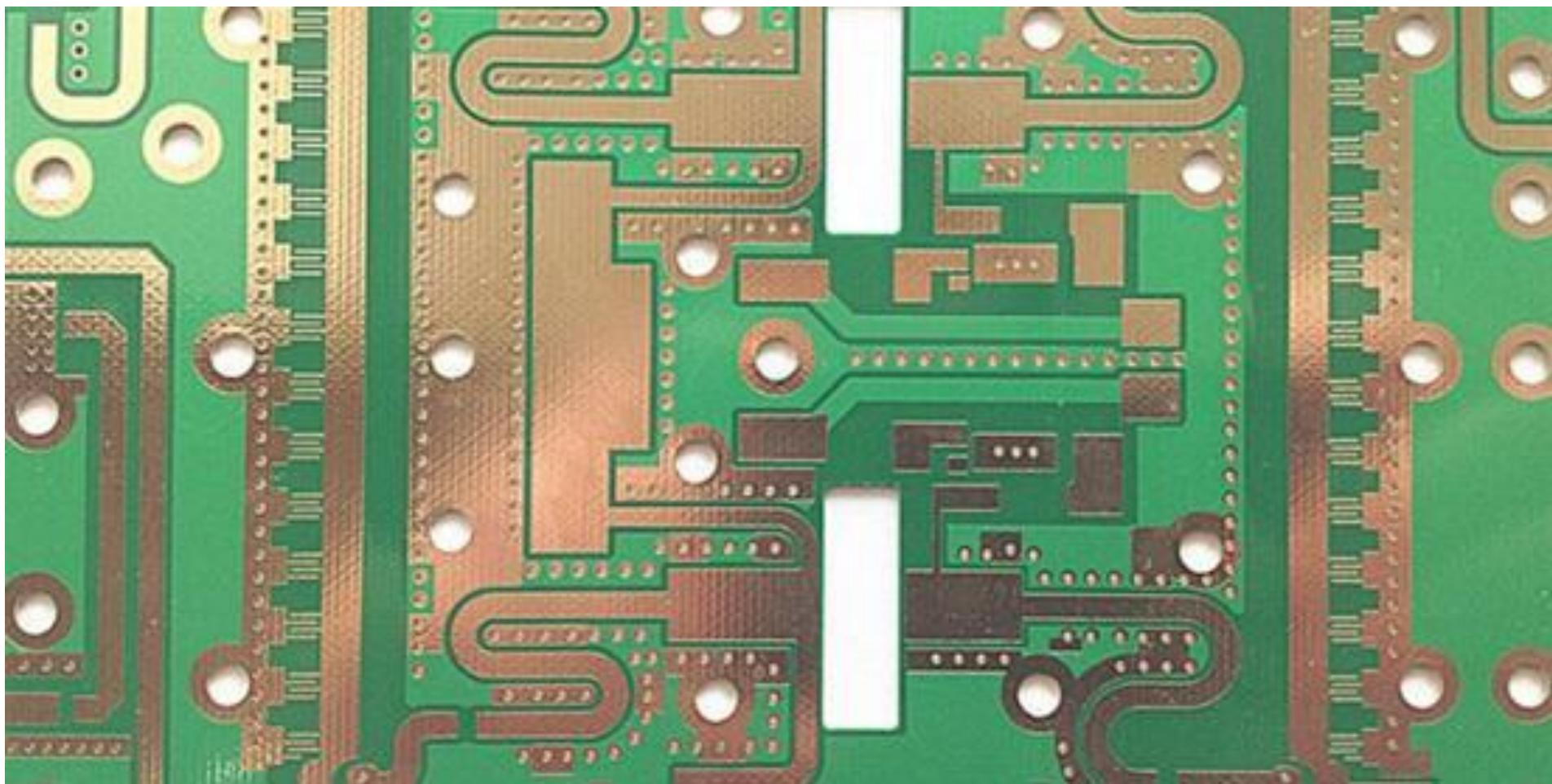


Exemple

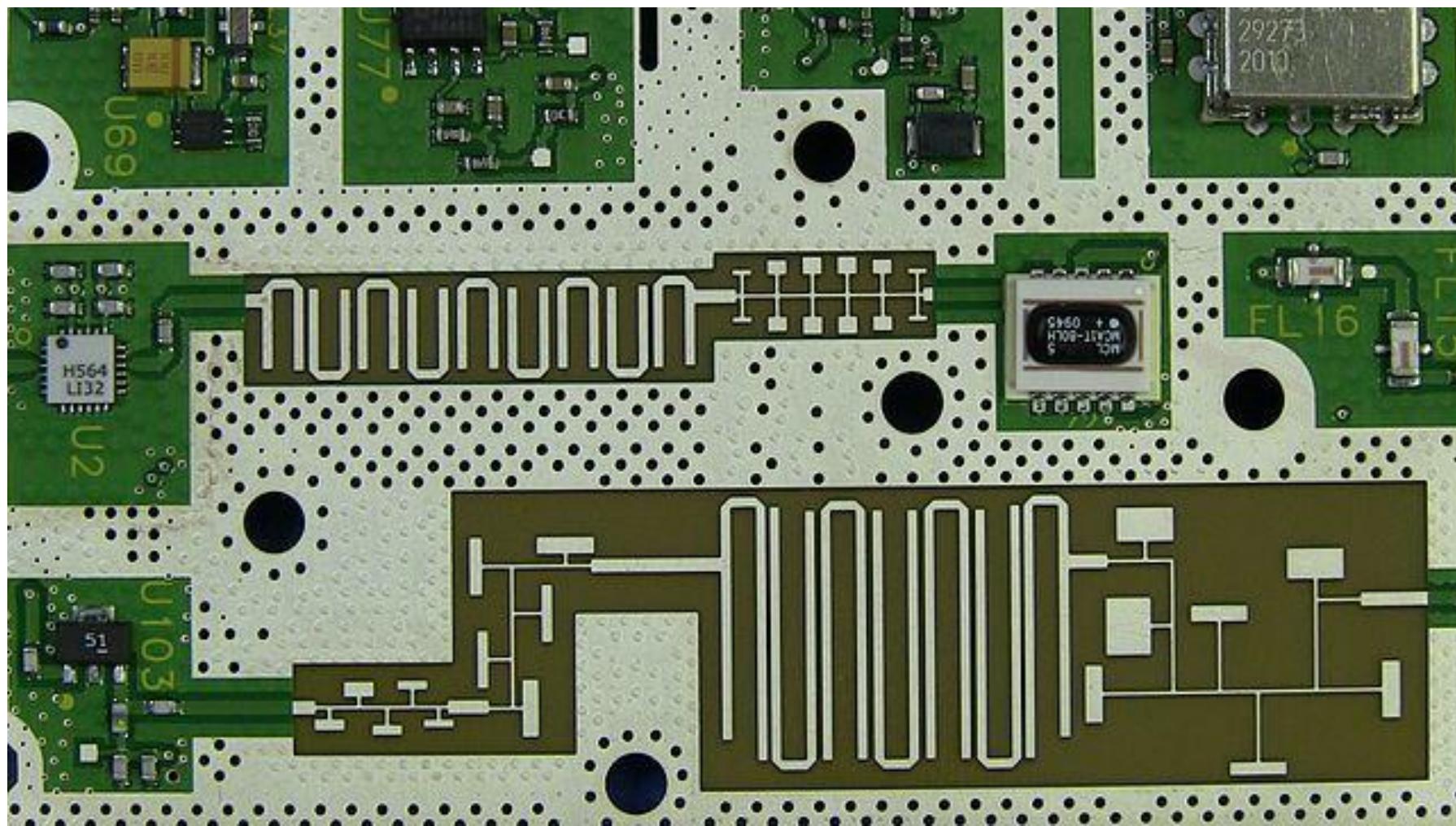


VK4CP

Exemple



Exemple



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

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

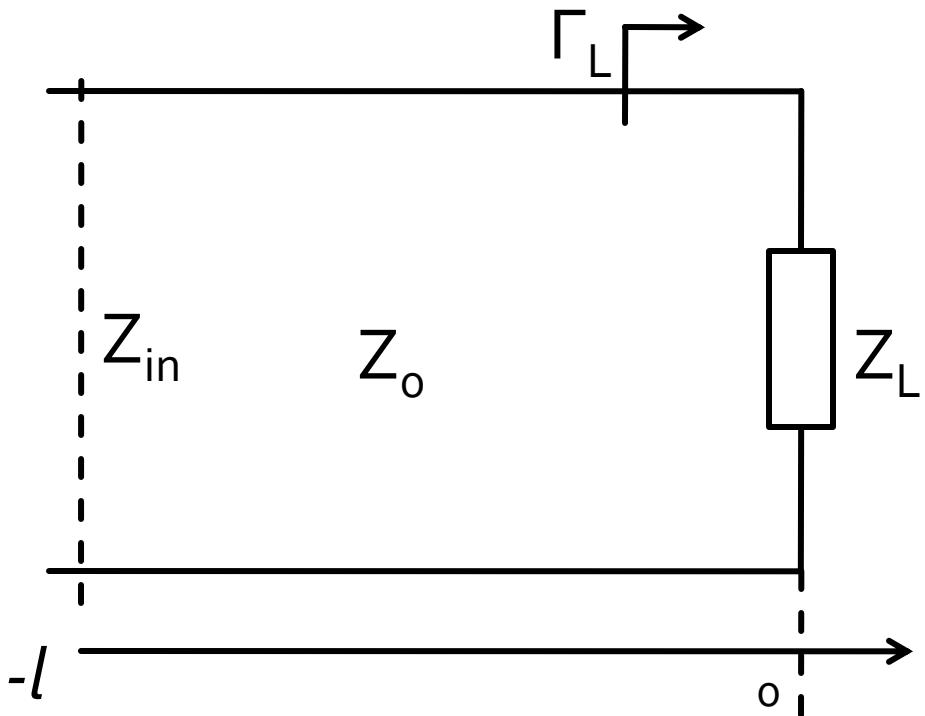
■ se defineste factorul de unda stationara

- (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 +/-



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

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

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

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

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

Contact

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