

Curs 2

2023/2024

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2023/2024

- 2C/1L (+1), **DCMR (CDM)**
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
 - Miercuri 08(:15)-17, ~~Online~~/**Video (istoric)**, P5
 - E – **50%** din nota
 - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
 - primul test L1: 04.10.2023 (t2 si t3 neanuntate la **curs**)
 - 3pz (C) \approx +0.5p (**2p** max)
 - toate materialele permise

Disciplina 2023/2024

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

Laboratorul de Microunde si Opti x +

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



English | Romana

Start **Didactic** Master Colectiv Cercetare Studenti

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

Dispozitive si circuite de microunde pentru radiocomunicatii

Disciplina: DCMR (2021-2022)

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

Activitati

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

Evaluare

Tip: Examen

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

Note

[Rezultate totale](#)

Prezenta

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


Liste


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

Istoric

Alte informatii

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

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

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

Ani anteriori

2020-2021

2019-2020

2018-2019

2017-2018

2016-2017

Mai mult...

Dispozitive si circuite de microunde pentru radiocomunicatii

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

Adrese email

- Sefii de grupa
 - lista cu adrese de email **utilizate** de toti studentii
 - poate fi @student.etti.tuiasi.ro (@gmail @yahoo etc.)
 - **rdamian@etti.tuiasi.ro**

Fotografii



Date:

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

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

Detalii curente

Observatii

Finantare	Buget
Bursa	Fara Bursa



Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5244

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

Detalii curente

Observatii

Finantare	Buget
Bursa	Bursa de Studii



Date:

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


[Acceseaza ca acest student](#)

Note obtinute

Disciplina	Tin	Data	Descriere	Nota	Puncte	Obs.
TW			Tehnologii Web			
	N	17/01/2014	Nota Finala	10	-	
	A	17/01/2014	Coloana Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	B	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	

Acces

- Personalizat (parola), Generic (email)



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	-	
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	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	

Identificare

Introduceti numele si adresa de email

Nume

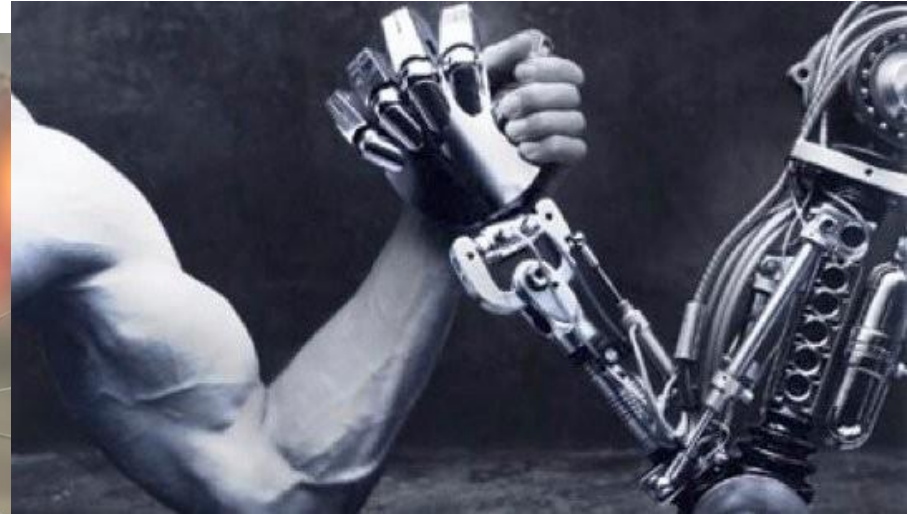
E-mail/Parola

Introduceti codul afisat mai jos

ff769c3

Trimite

Scop curs 4



**Sinapse
"înginerești"**



Cuprins

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

Bibliografie

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

Examen: Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Calculul atenuarii/amplificarii

$$\text{Pierderi/Castig} = \frac{P_{out}}{P_{in}}$$

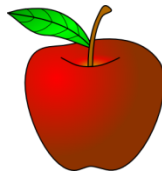
$$\text{Pierderi[dB]} = [-] 10 \cdot \log_{10} \left(\frac{P_{out}}{P_{in}} \right)$$

$$\text{Pierderi[dB]} = [-] 10 \cdot \log_{10} \left(\frac{P_{out}}{P_0} \cdot \frac{P_0}{P_{in}} \right) = [-] 10 \cdot \left[\log_{10} \left(\frac{P_{out}}{P_0} \right) - \log_{10} \left(\frac{P_{in}}{P_0} \right) \right]$$

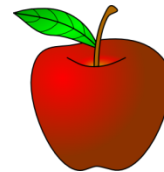
$$\text{Pierderi[dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-

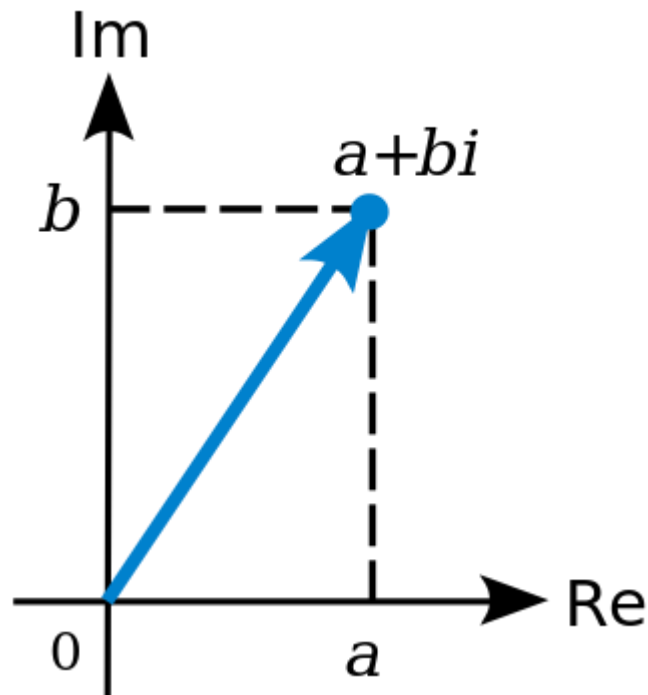


Examen

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

Plan complex

- abscisa – partea reala
- ordonata – partea imaginara
- oricare poate fi negativa, intregul plan, 4 cadrane



Operatii

- Adunare

$$z + w = (a + j \cdot b) + (c + j \cdot d) = (a + c) + j \cdot (b + d)$$

- Scadere

$$z - w = (a + j \cdot b) - (c + j \cdot d) = (a - c) + j \cdot (b - d)$$

- Inmultire

$$z \cdot w = (a + j \cdot b) \cdot (c + j \cdot d) = (a \cdot c - b \cdot d) + j \cdot (b \cdot c + a \cdot d)$$

- Impartire

$$z / w = \frac{a + j \cdot b}{c + j \cdot d} \stackrel{(c - j \cdot d)}{=} \frac{(a + j \cdot b) \cdot (c - j \cdot d)}{(c + j \cdot d) \cdot (c - j \cdot d)} = \left(\frac{a \cdot c + b \cdot d}{c^2 + d^2} \right) + j \cdot \left(\frac{b \cdot c - a \cdot d}{c^2 + d^2} \right)$$

Complex Conjugat

- $z = a + j \cdot b$
- $z^* = a - j \cdot b$
- Simetric fata de axa **reala**

$$\operatorname{Re}(z) = a = \frac{1}{2} \cdot (z + z^*)$$

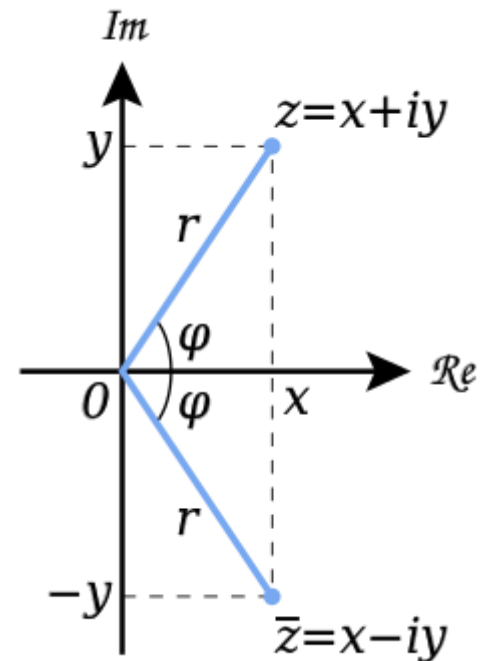
$$\operatorname{Im}(z) = b = \frac{1}{2 \cdot j} \cdot (z - z^*) = \frac{j}{2} \cdot (z^* - z)$$

$$(z + w)^* = z^* + w^*$$

$$(z - w)^* = z^* - w^*$$

$$(z \cdot w)^* = z^* \cdot w^*$$

$$(z / w)^* = z^* / w^*$$



Reprezentare polara

■ Reprezentare polara

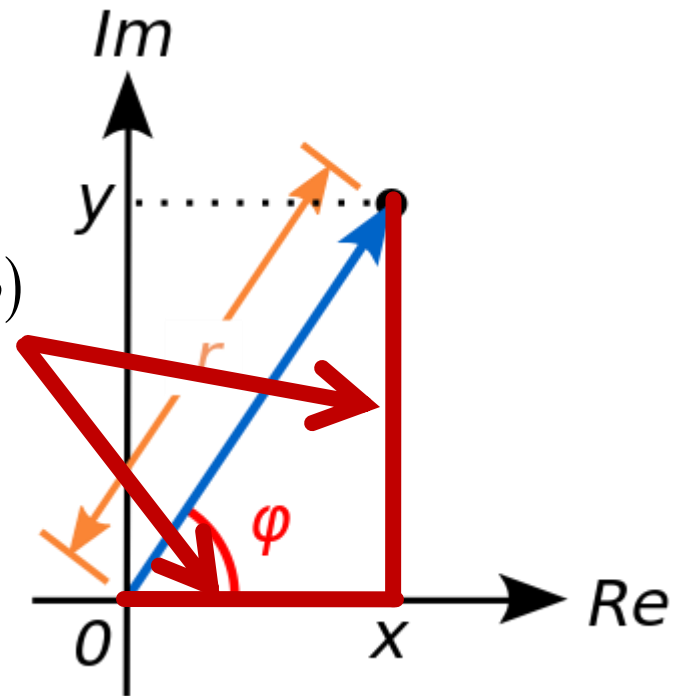
■ modul

■ faza

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

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

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



Reprezentare polara

- Formula lui Euler

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

- Reprezentare polara

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

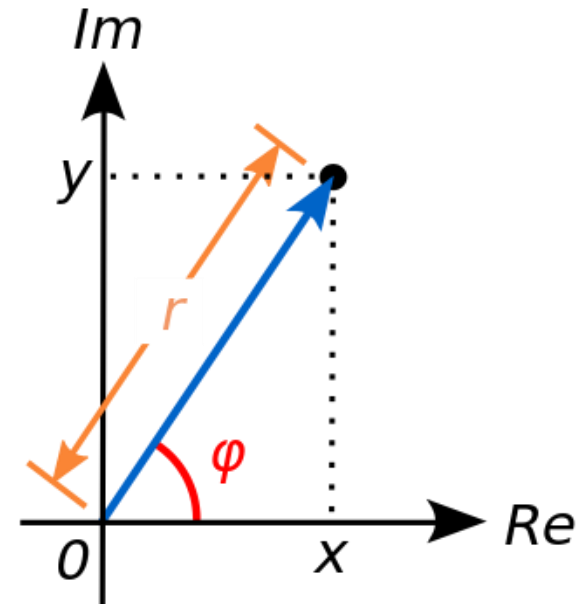
$$z = a + j \cdot b = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)$$

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

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

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

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



Reprezentare polara

■ Reprezentare polara

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

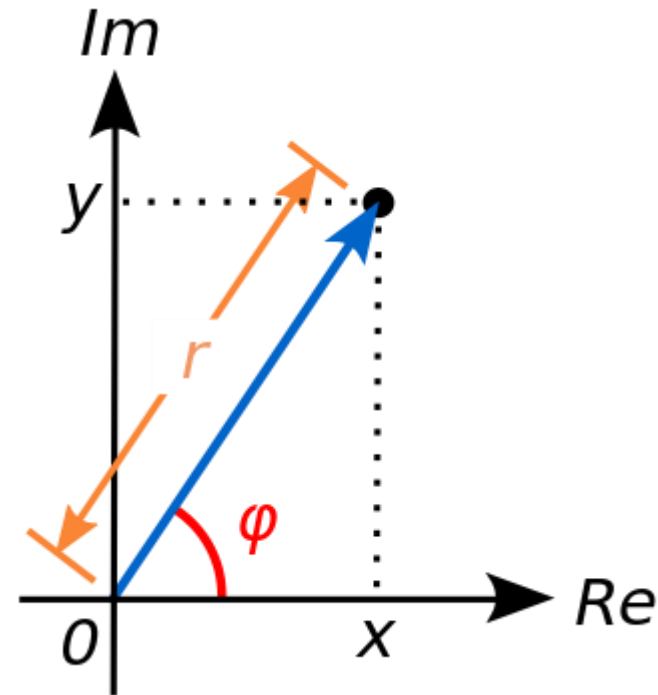
$$|z|^2 = z \cdot z^*$$

⇒

$$|e^{j \cdot x}| = |\cos x + j \cdot \sin x| = \sqrt{\cos^2 x + \sin^2 x} = 1$$

$$|e^{j \cdot x}| = 1; \quad \forall x \in R$$

$$\begin{aligned} z^* &= (|z| \cdot e^{j \cdot \varphi})^* = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)^* = |z| \cdot (\cos \varphi - j \cdot \sin \varphi) = \\ &= |z| \cdot [\cos(-\varphi) + j \cdot \sin(-\varphi)] = |z| \cdot e^{-j \cdot \varphi} \end{aligned}$$

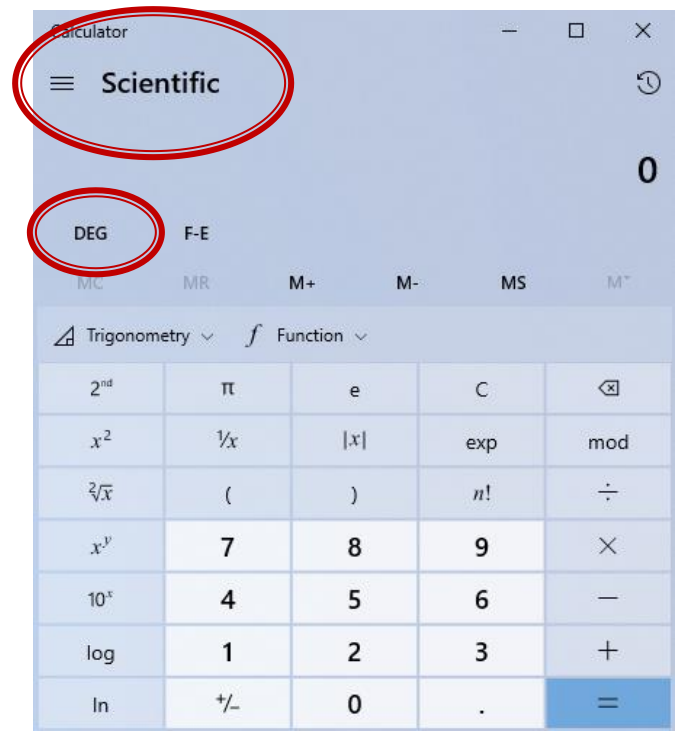


Reprezentare polara

- unitate de masura standard – radiani
- unitate de masura traditionala in microunde – **grade format zecimal** (55.89°)

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

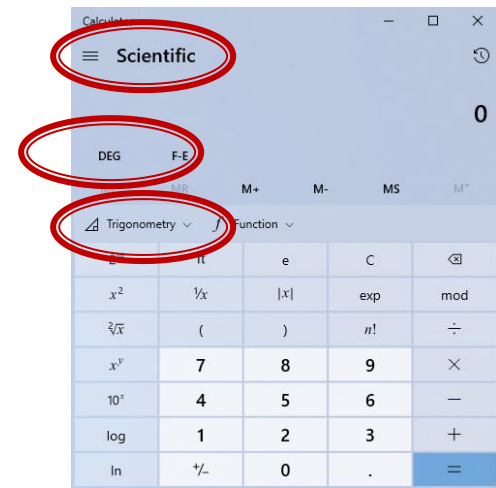
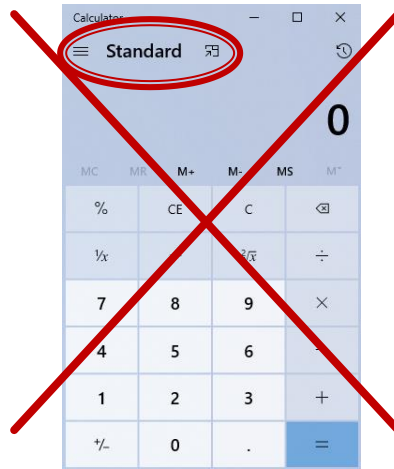
$$\varphi[^\circ] = 180^\circ \cdot \frac{\varphi[\text{rad}]}{\pi} \qquad \varphi[\text{rad}] = \pi \cdot \frac{\varphi[^\circ]}{180^\circ}$$



Reprezentare polara

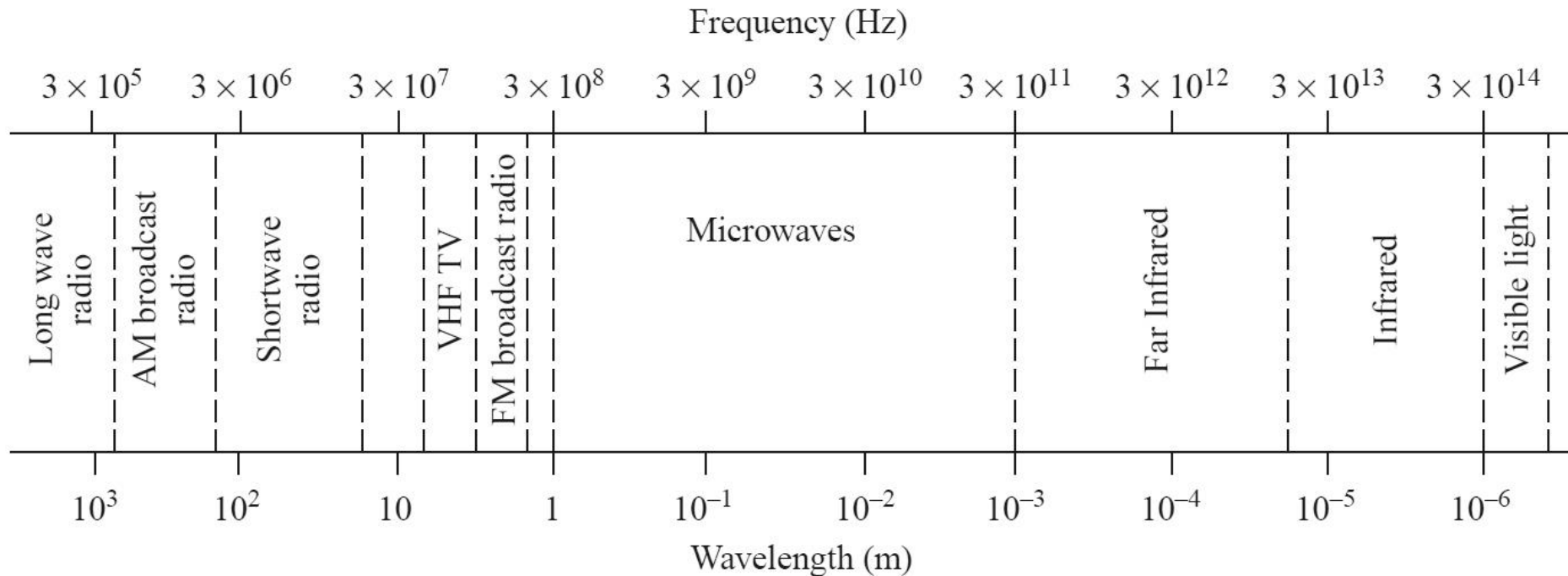
- **Atentie la reprezentarea unghiurilor!!**
 - programele matematice – lucreaza standard in radiani
 - e necesara o **conversie** inainte si una dupa aplicarea unei functii trigonometrice
 - calculatoarele (stiintifice) au posibilitatea (de obicei) de a stabili unitatea de masura pentru unghiuri
 - e necesara **verificarea** unitatii de masura curente

$$\varphi[^\circ] = 180^\circ \cdot \frac{\varphi[rad]}{\pi}$$
$$\varphi[rad] = \pi \cdot \frac{\varphi[^\circ]}{180^\circ}$$



Introdurre

Microunde



- tipic
 - $f \approx 1 \div 3 \text{GHz} - 300 \text{GHz}$
 - $\lambda \approx 1 \text{mm} - 10 \text{cm}$

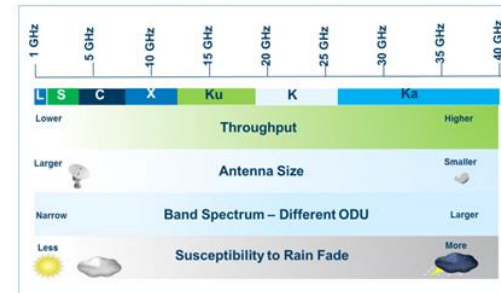
Microunde

Typical Frequencies

AM broadcast band	535–1605 kHz
Short wave radio band	3–30 MHz
FM broadcast band	88–108 MHz
VHF TV (2–4)	54–72 MHz
VHF TV (5–6)	76–88 MHz
UHF TV (7–13)	174–216 MHz
UHF TV (14–83)	470–890 MHz
US cellular telephone	824–849 MHz 869–894 MHz
European GSM cellular	880–915 MHz 925–960 MHz
GPS	1575.42 MHz 1227.60 MHz
Microwave ovens	2.45 GHz
US DBS	11.7–12.5 GHz
US ISM bands	902–928 MHz 2.400–2.484 GHz 5.725–5.850 GHz
US UWB radio	3.1–10.6 GHz

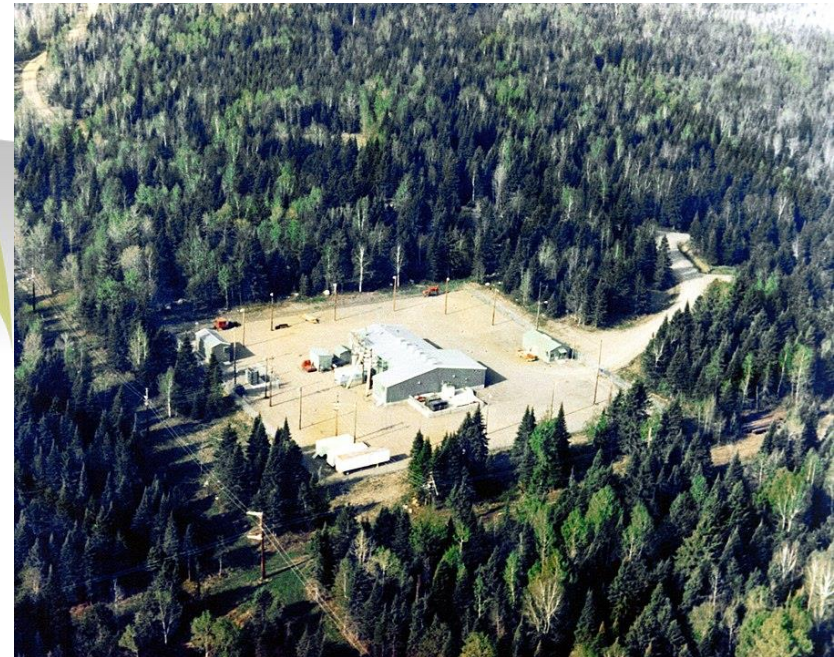
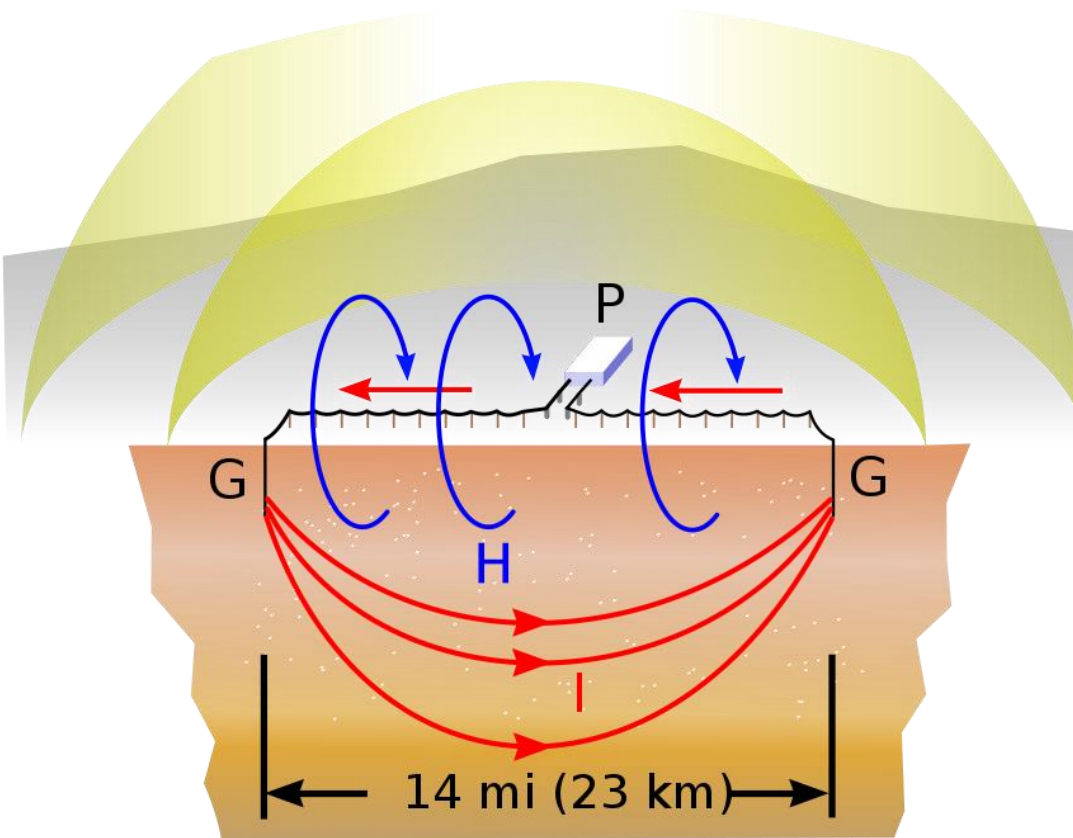
Approximate Band Designations

Medium frequency	300 kHz–3 MHz
High frequency (HF)	3 MHz–30 MHz
Very high frequency (VHF)	30 MHz–300 MHz
Ultra high frequency (UHF)	300 MHz–3 GHz
L band	1–2 GHz
S band	2–4 GHz
C band	4–8 GHz
X band	8–12 GHz
Ku band	12–18 GHz
K band	18–26 GHz
Ka band	26–40 GHz
U band	40–60 GHz
V band	50–75 GHz
E band	60–90 GHz
W band	75–110 GHz
F band	90–140 GHz



ELF, VLF

- Extremely low frequency, 3 - 30 Hz
- Very low frequency, 3 - 30 kHz



~ Microunde

- Lungimea electrica a unui circuit
 - l – lungimea fizica
 - $E = \beta \cdot l$ – lungimea electrica

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

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

V, I variabile
~ inutile

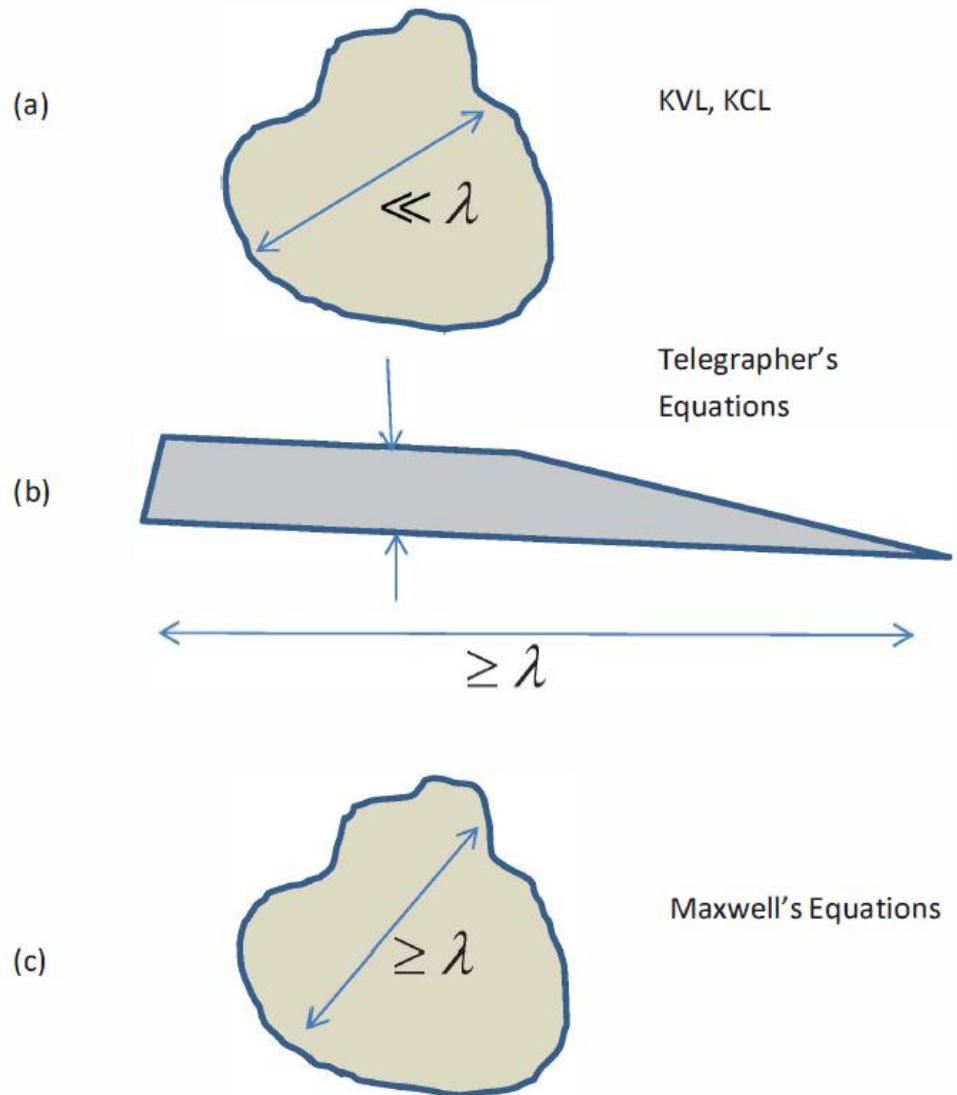
- Dependenta
 - castigul antenei
 - imaginea unui obiect pe radar

Lungime electrica

- Comportarea (descrierea) unui circuit depinde de lungimea sa electrica la frecventele 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

$$D = \varepsilon \cdot E$$

$$B = \mu \cdot H$$

$$J = \sigma \cdot E$$

• In vid

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

$$\varepsilon_0 = 8,854 \times 10^{-12} \text{ F/m}$$

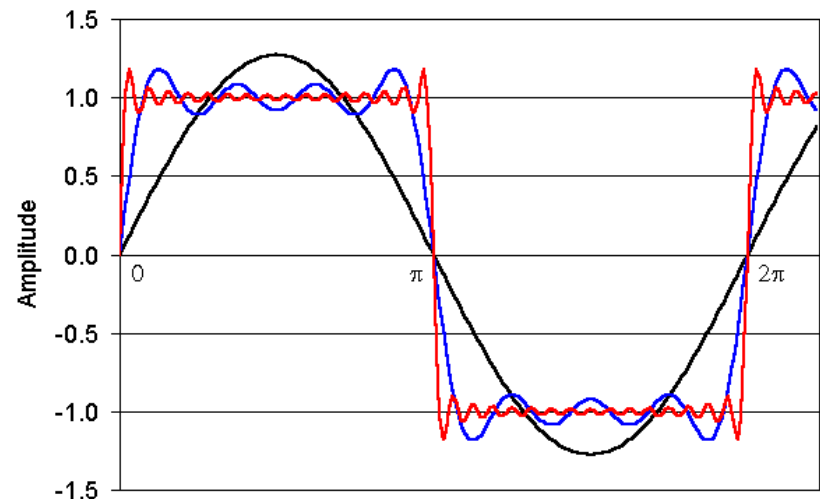
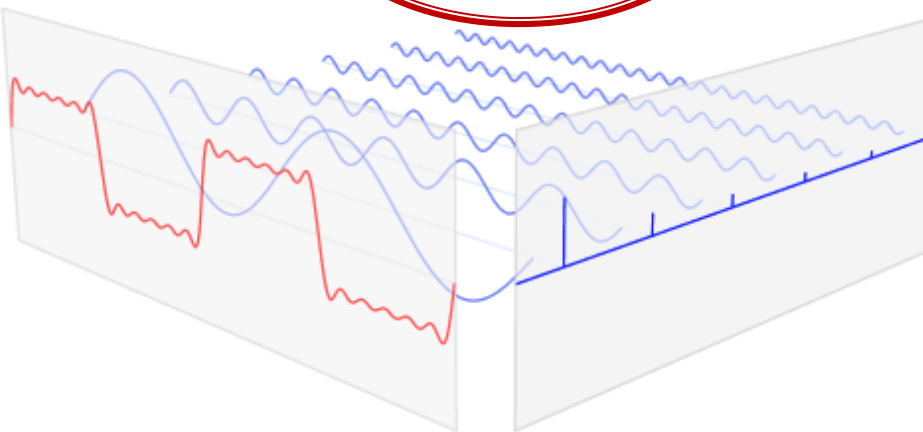
$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

Modele matematice

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

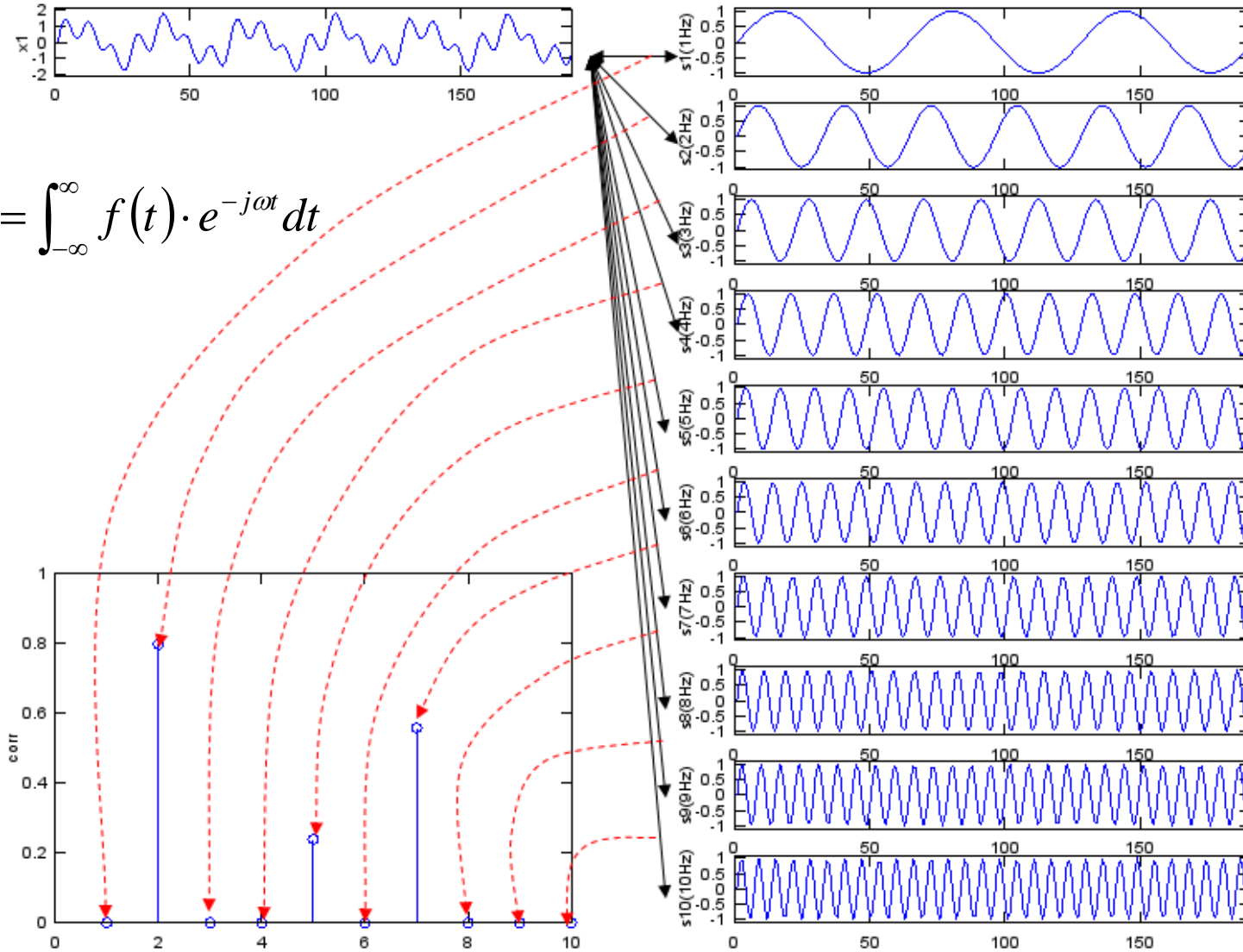
$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X$$

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

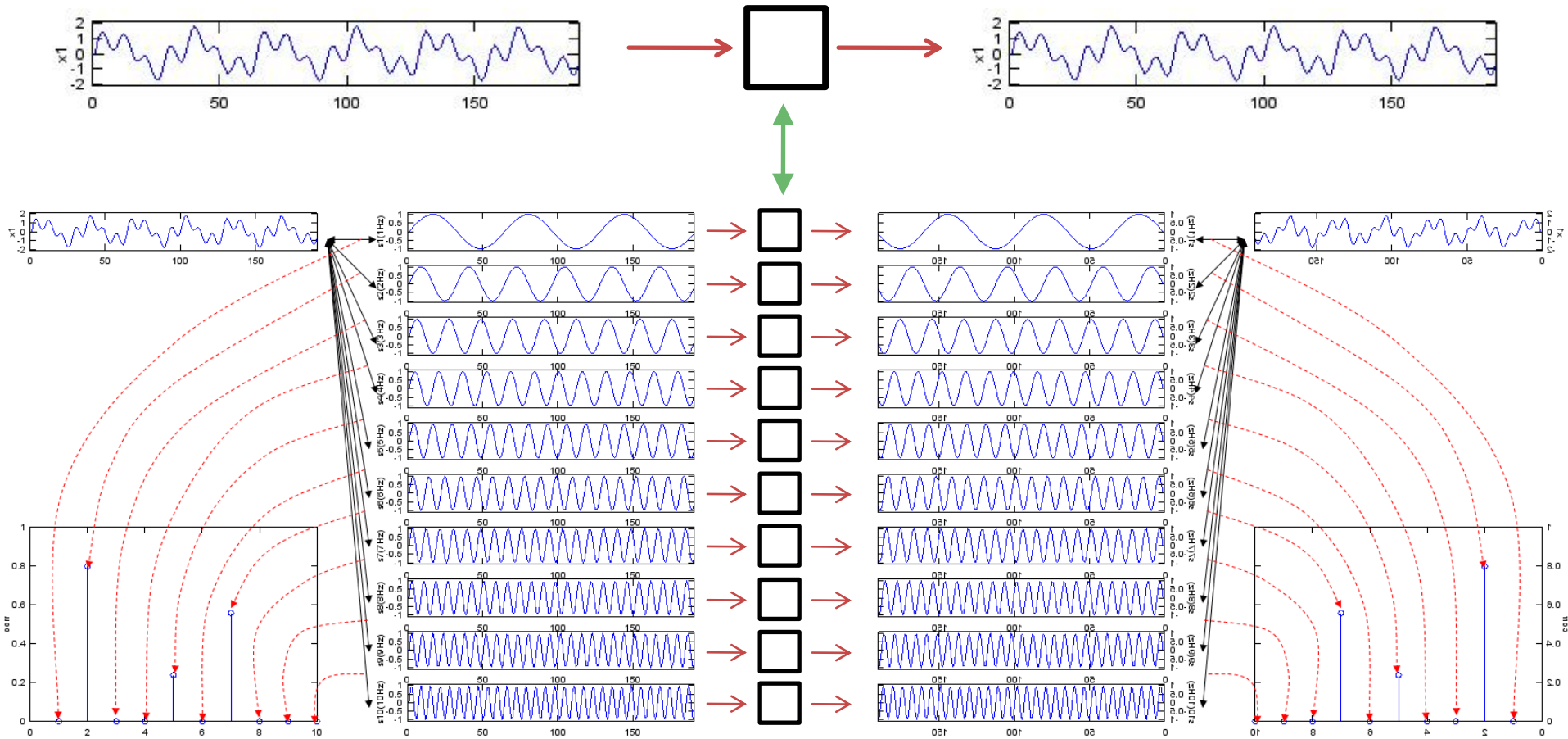


Modelle matematiche

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



Modele matematic



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

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

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

Câmpuri electromagnetice cu variație armonică în timp

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

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

■ Simplificarea ecuațiilor lui Maxwell

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

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

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

$$\nabla \cdot H = 0$$

Ecuațiile de propagare

- Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

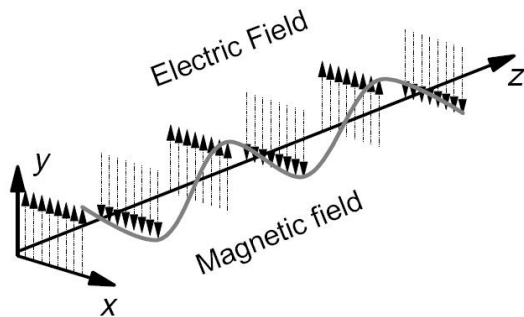
$$\nabla^2 E - \gamma^2 E = 0$$

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

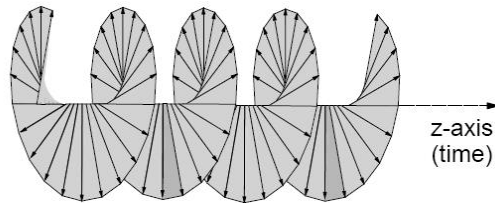
$$\gamma^2 = -\omega^2 \epsilon \mu + j\omega \mu \sigma$$

γ – Constanta de propagare

Solutia ecuatiilor de propagare



Propagare



Polarizare circulara

Camp electric dupa directia Oy, **← prin alegerea judicioasa**
propagare dupa directia Oz **← 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 $E_+ \Rightarrow A$

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

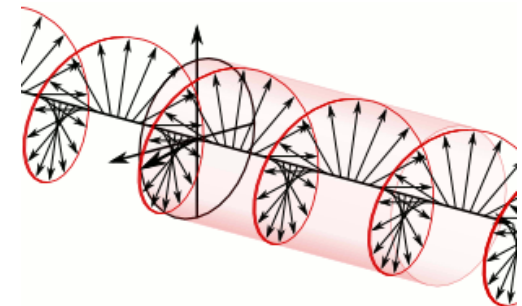
Camp armonic

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

Amplitudine

Atenuare

Propagare
(variatie in timp si spatiu)



Atenuare

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

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

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

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

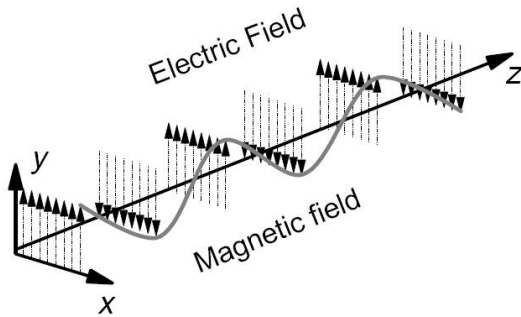
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} [e^{-2\alpha \cdot (z_2 - z_1)}]$$

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

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

- ▶ 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, $\sigma = 0$

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

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\epsilon}}$$

Impedanta intrinseca a mediului

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

punctele de faza constanta:

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

Viteza de faza

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

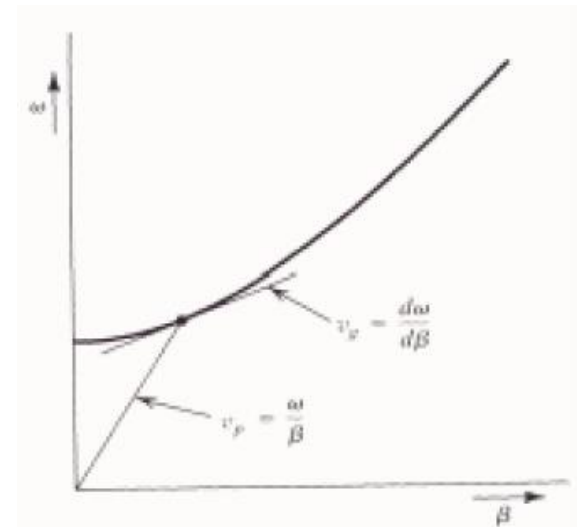
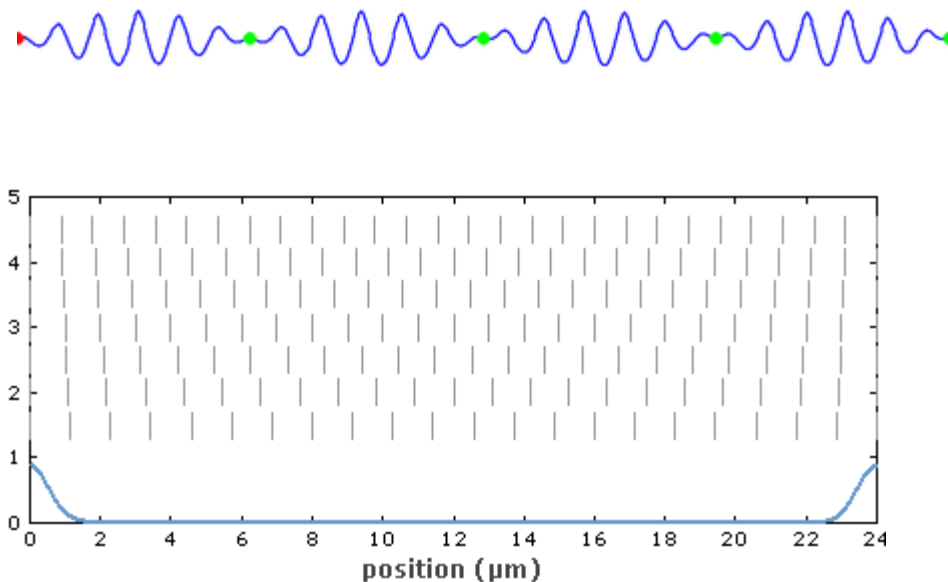
Viteza de grup

$$v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta}$$

in medii dispersive unde $\beta = \beta(\omega)$

Viteze de grup si faza

- Viteza de faza – viteza virtuala cu care circula punctul cu o anumita faza
- Viteza de grup – viteza cu care circula informatia (energia)



Parametri de propagare

■ In vid

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \quad v = v_g = c_0 \quad c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f} \quad T = \frac{2\pi}{\omega} = \frac{1}{f}$$

Periodicitate in spatiu

Periodicitate in timp

■ In mediu nedispersiv ε_r


$$c = \frac{1}{\sqrt{\varepsilon \cdot \mu_0}} = \frac{1}{\sqrt{\varepsilon_0 \varepsilon_r \cdot \mu_0}} = \frac{c_0}{\sqrt{\varepsilon_r}}$$

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

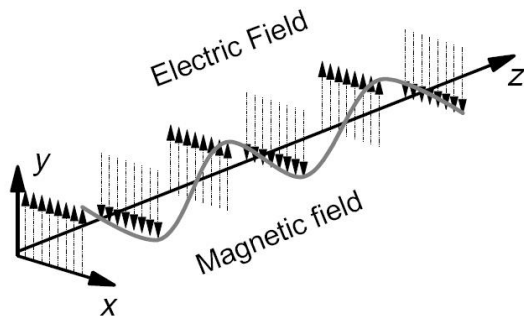
$$c = \frac{c_0}{n}$$

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

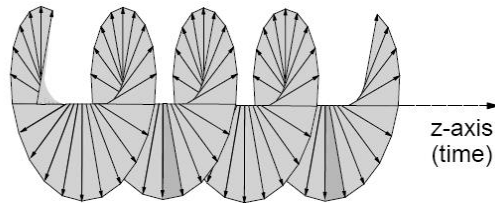
$$\lambda = \frac{2\pi}{\beta} = \frac{c}{f}$$

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


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 $E_+ \Rightarrow A$

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

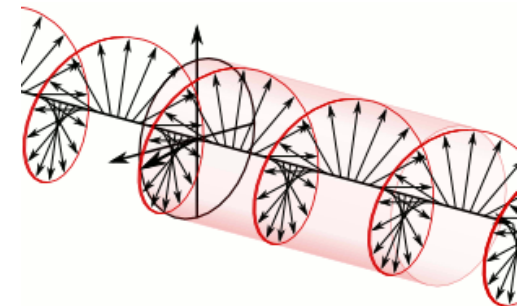
Camp armonic

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

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, ← prin alegerea judicioasa
propagare dupa directia Oz ← a sistemului de referinta

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

- unda
 - incidenta
 - reflectata
- unda
 - directa
 - inversa

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

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

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

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

punctele
de faza
constanta:

Solutia ecuatiilor de propagare

- unda
 - incidenta
 - reflectata
- unda
 - directa
 - inversa

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

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

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

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

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

Modele matematice

- cazuri particulare in care exista rezolvare analitica

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

- unda

- incidenta

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

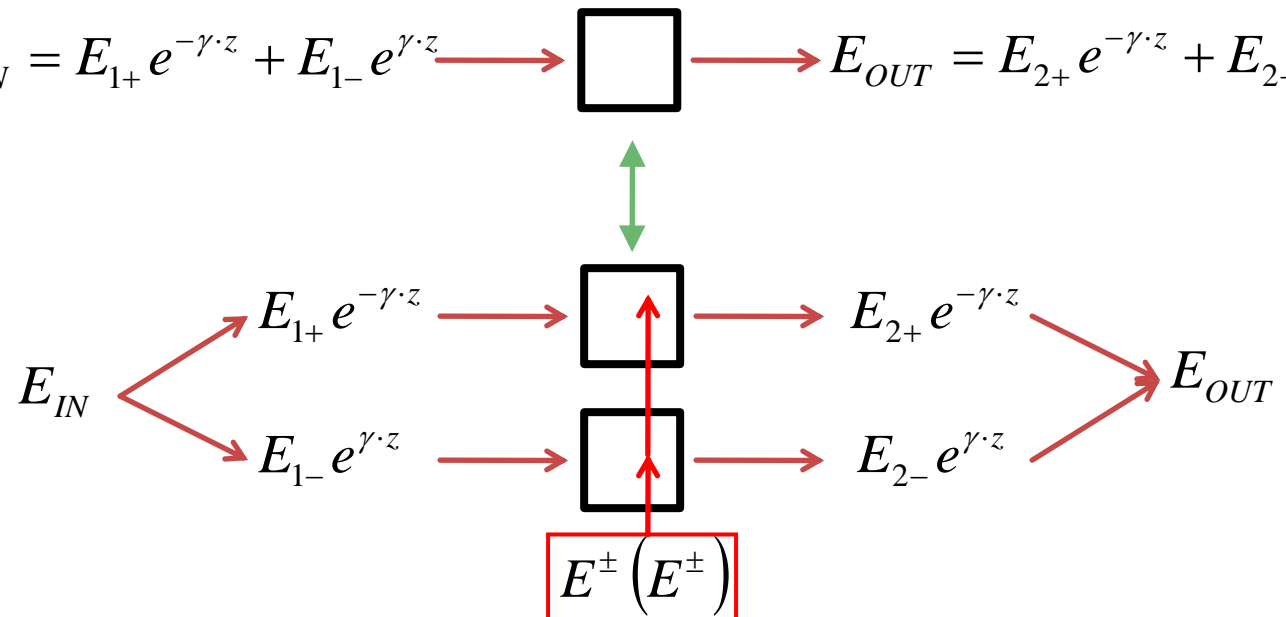
- reflectata

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

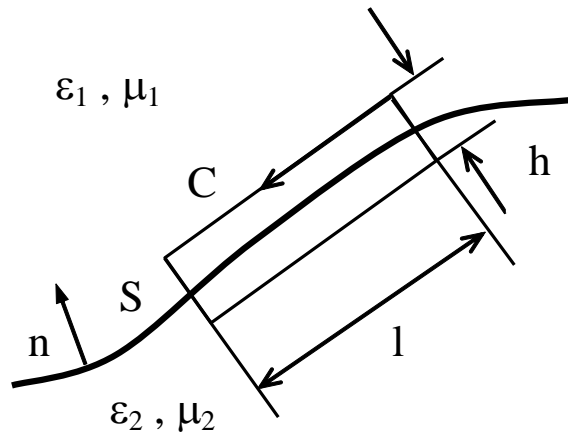
- unda

- directa

- inversa



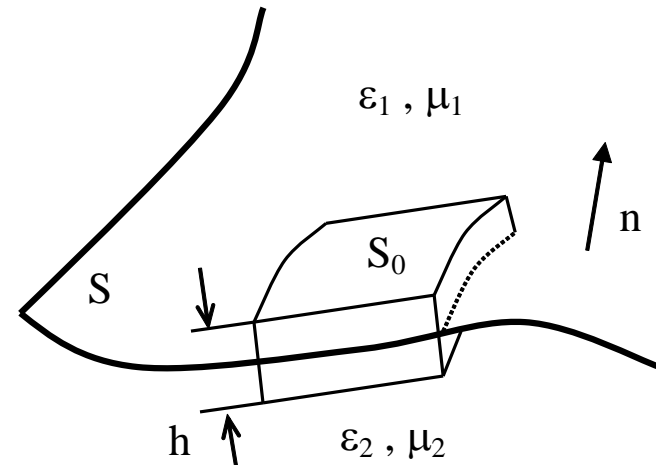
Condiții la limita de separație între două medii



a)

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

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



b)

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

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

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

Moduri in medii delimitate

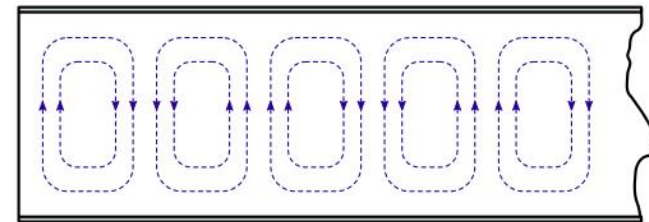
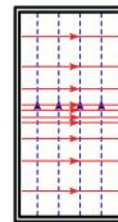
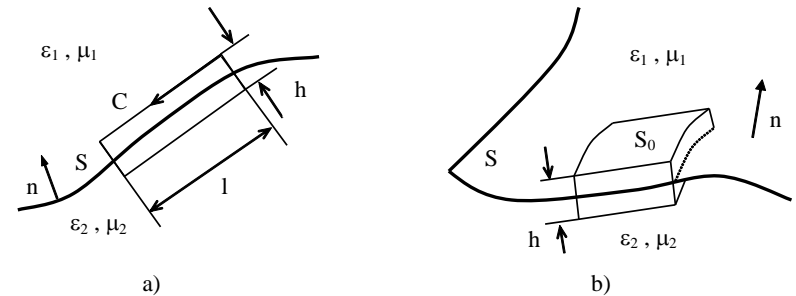
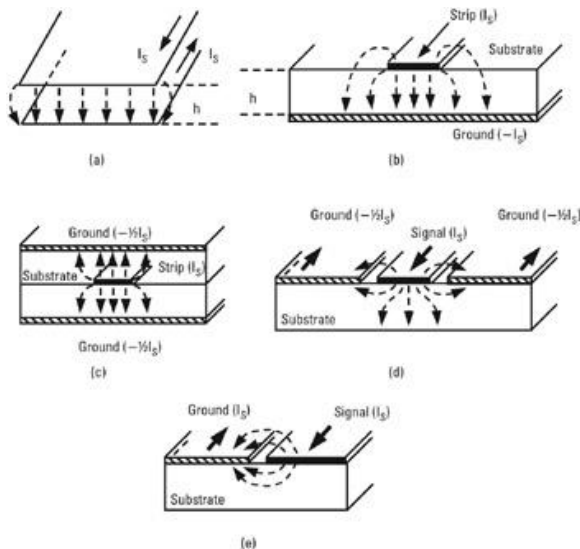
- Câmpuri electromagnetice cu variație armonică în timp
 - simplificarea ecuatiilor lui Maxwell

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

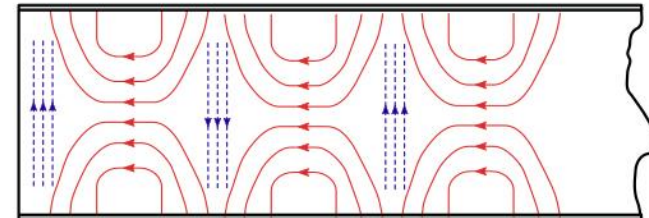
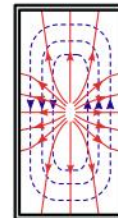
- In medii delimitate solutiile ecuatiilor lui Maxwell trebuie sa verifice conditiile la limita
 - solutiile trebuie sa respecte anumite conditii suplimentare

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

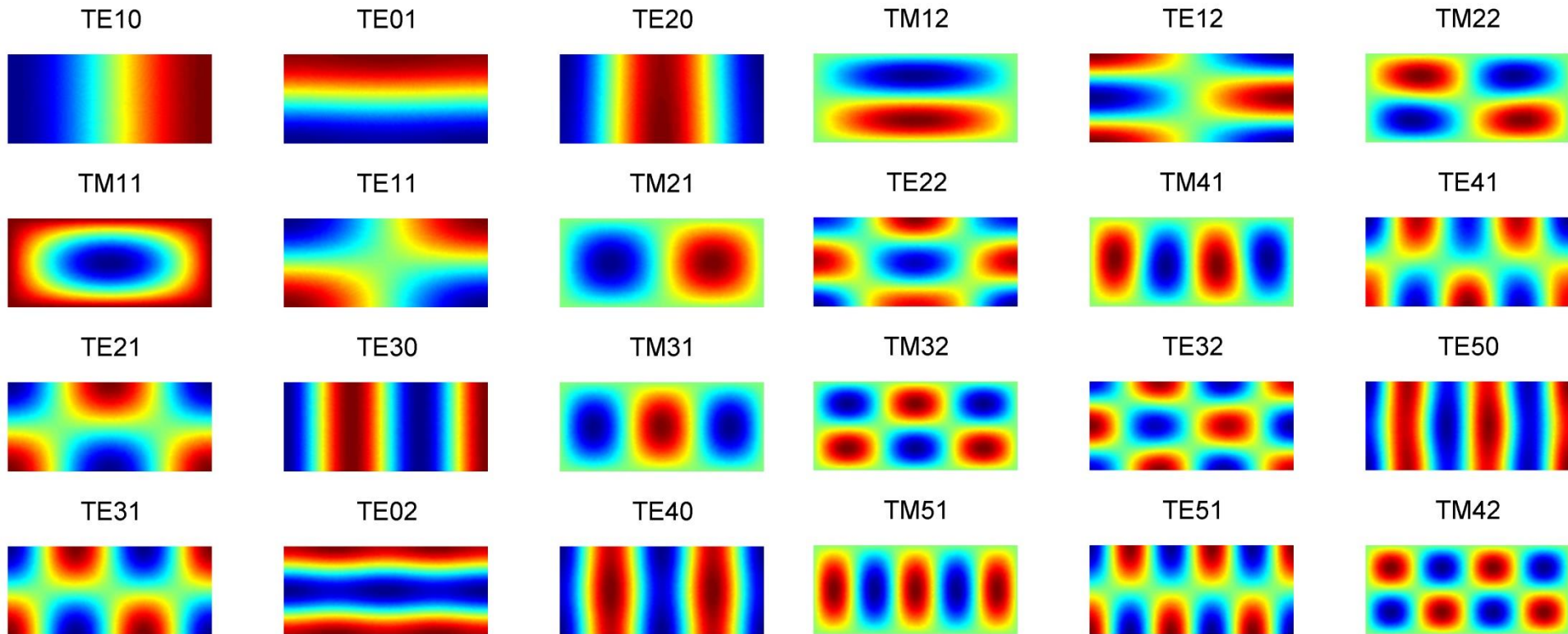


TE₁₀



TM₁₁

Moduri in medii delimitate

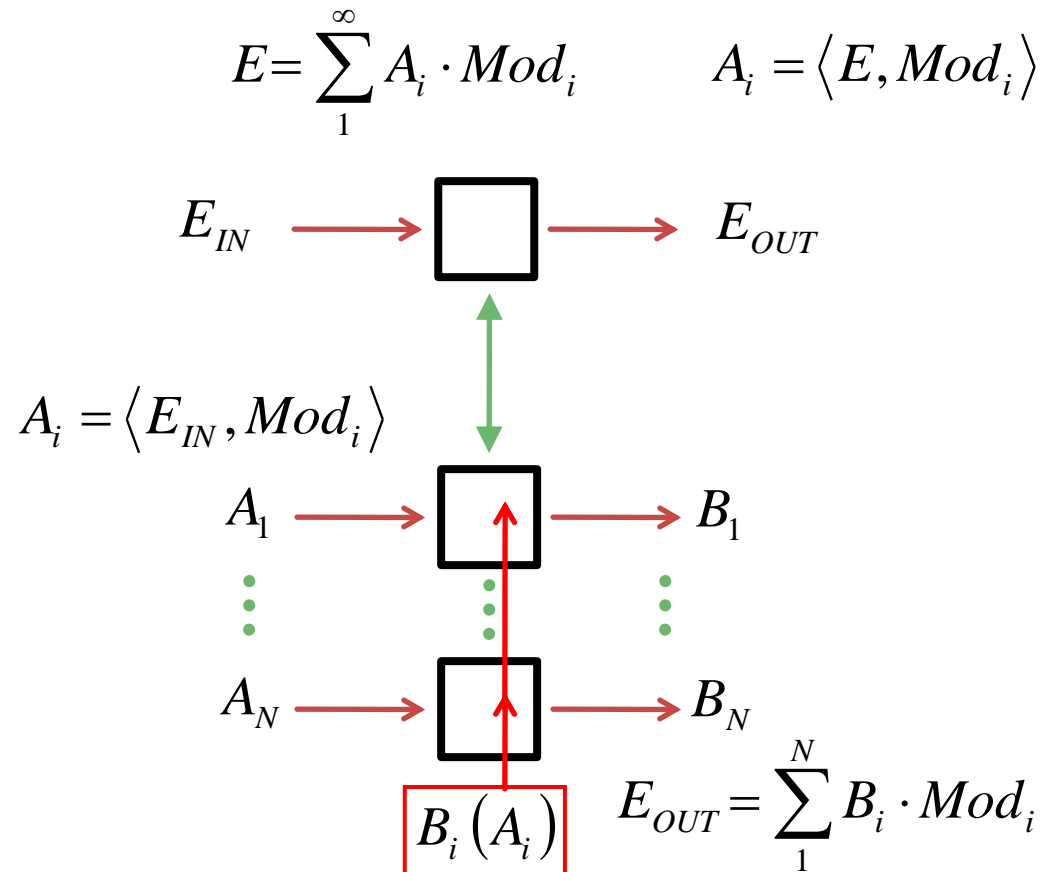
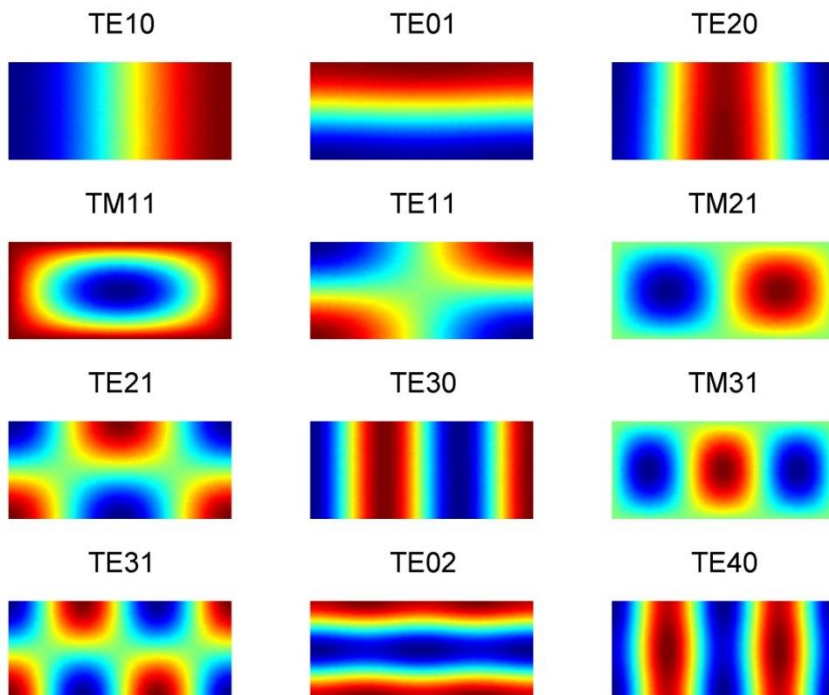


- Similar cu transformata Fourier $g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt$ $f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$

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

Modele matematice

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

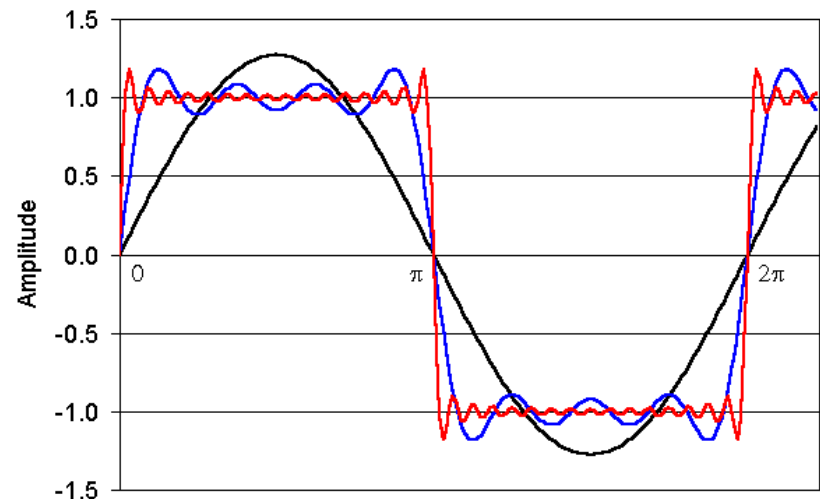
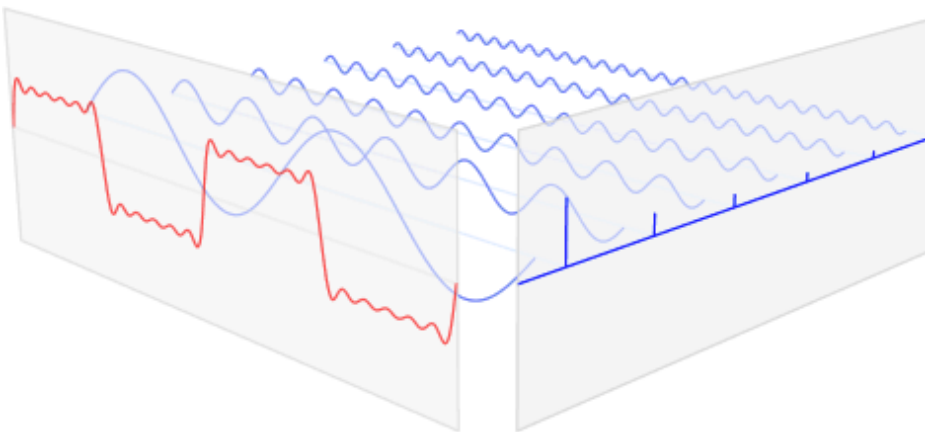


Modele matematice

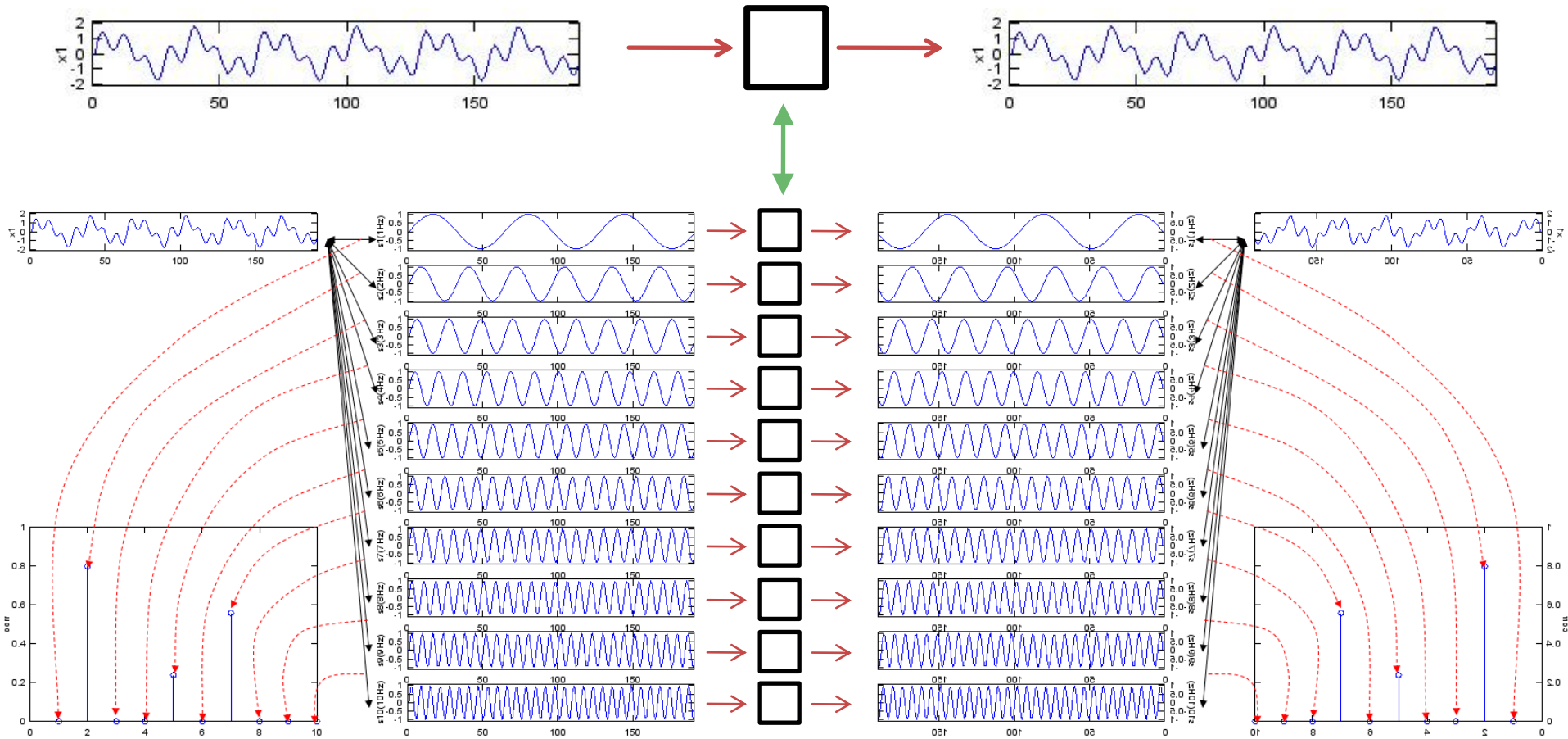
- cazuri particulare in care exista rezolvare analitica
 - semnale cu variație armonică în timp, transformata Fourier, spectru

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

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



Modele matematiche



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

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

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

Modele matematice

- cazuri particulare in care exista rezolvare analitica

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

- unda

- incidenta

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

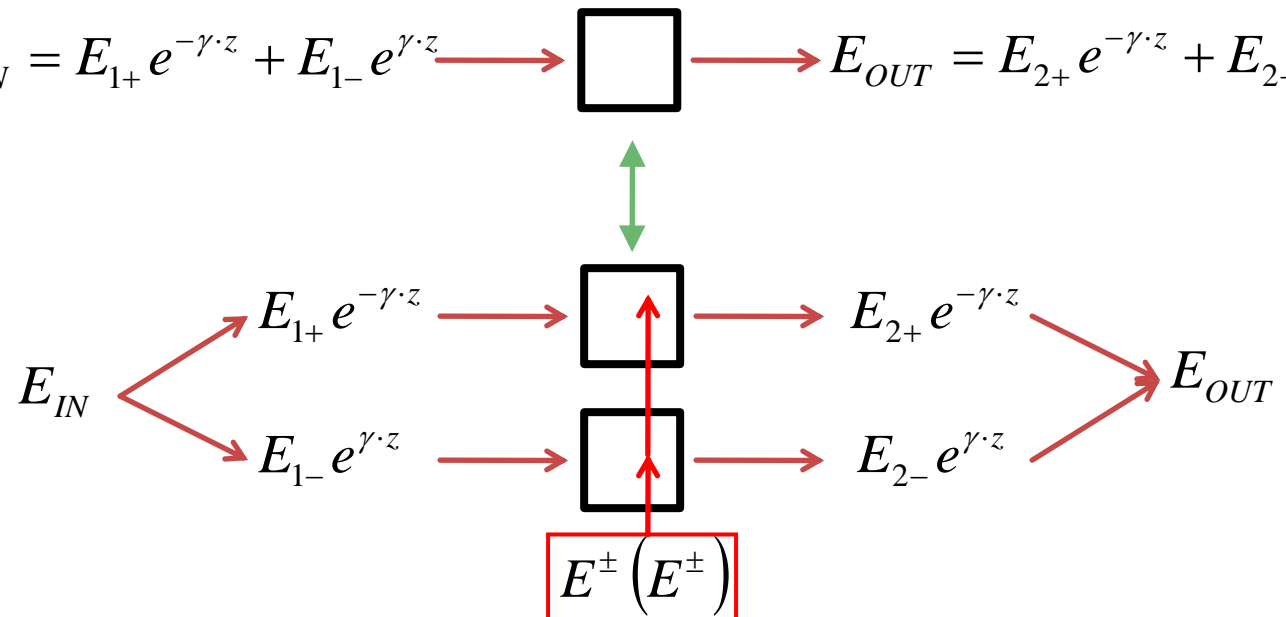
- reflectata

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

- unda

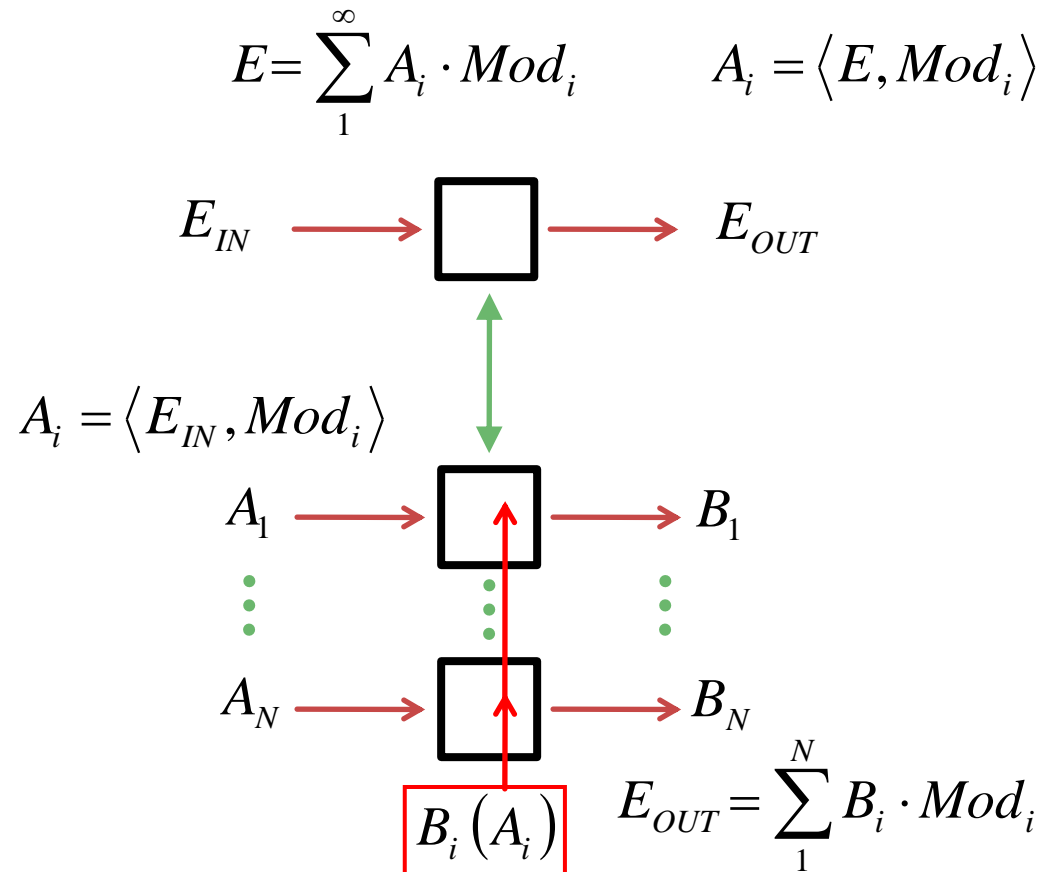
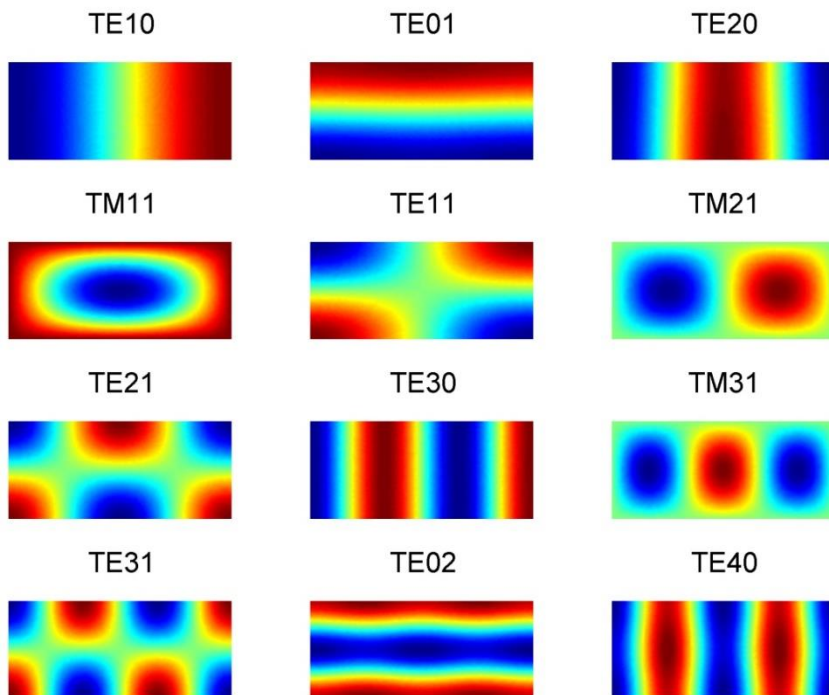
- directa

- inversa



Modele matematice

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



Linii de transmisie in mod TEM

Cuprins

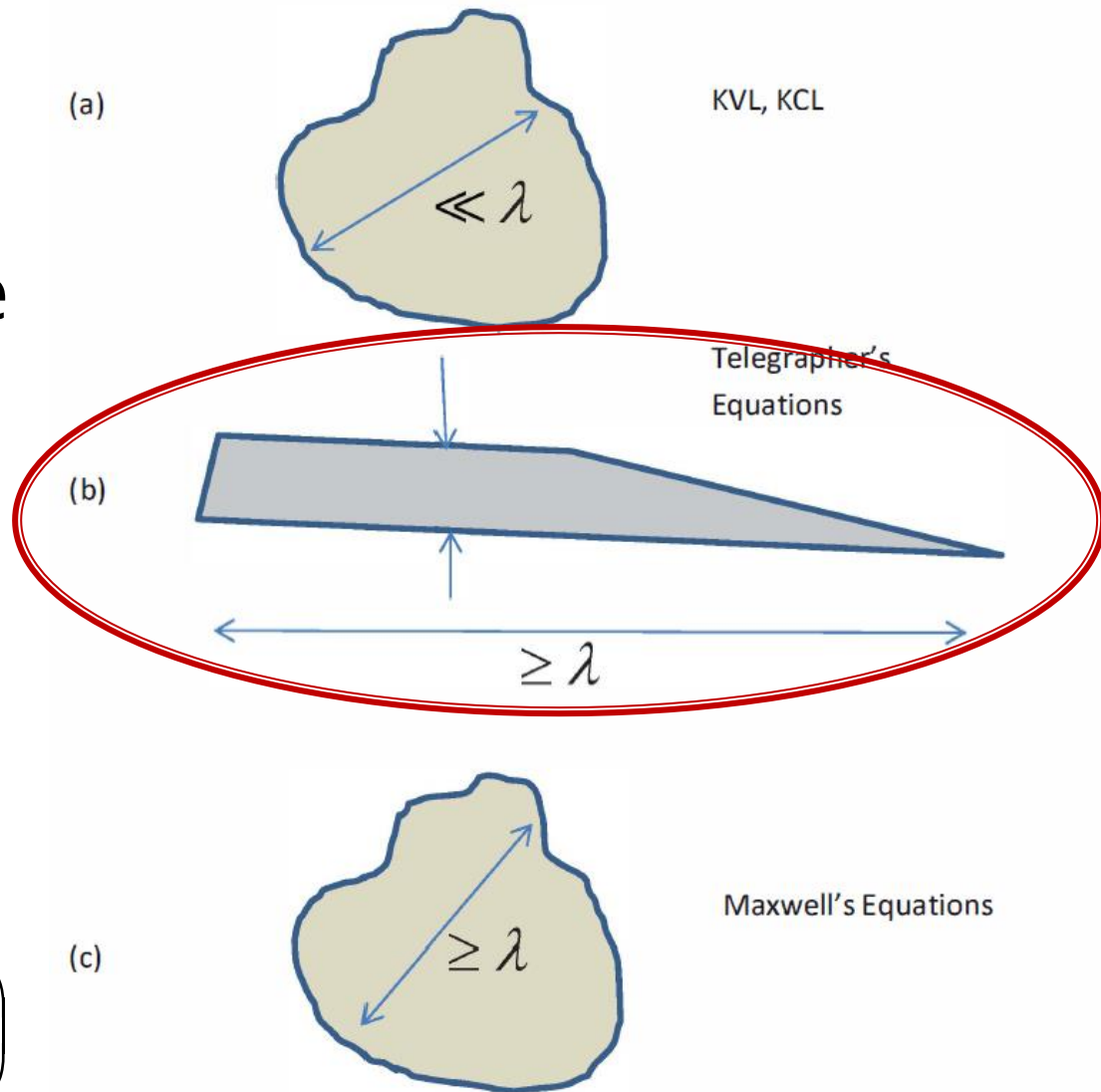
- **Linii de transmisie**
- **Adaptarea de impedanță**
- **Cuploare direcționale**
- **Divizoare de putere**
- **Amplificatoare de microunde**
- **Filtre de microunde**
- **Oscilatoare de microunde ?**

Lungime electrica

- Comportarea (descrierea) unui circuit depinde de lungimea sa electrica la frecventele de interes

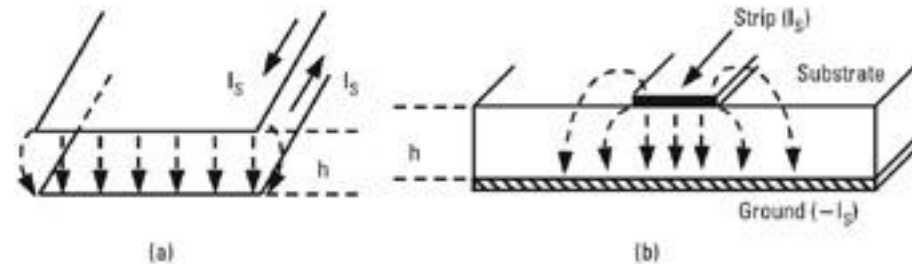
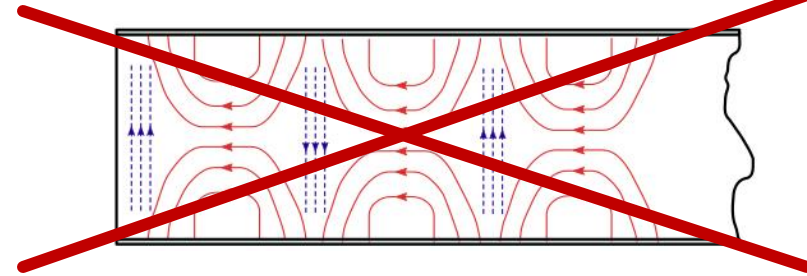
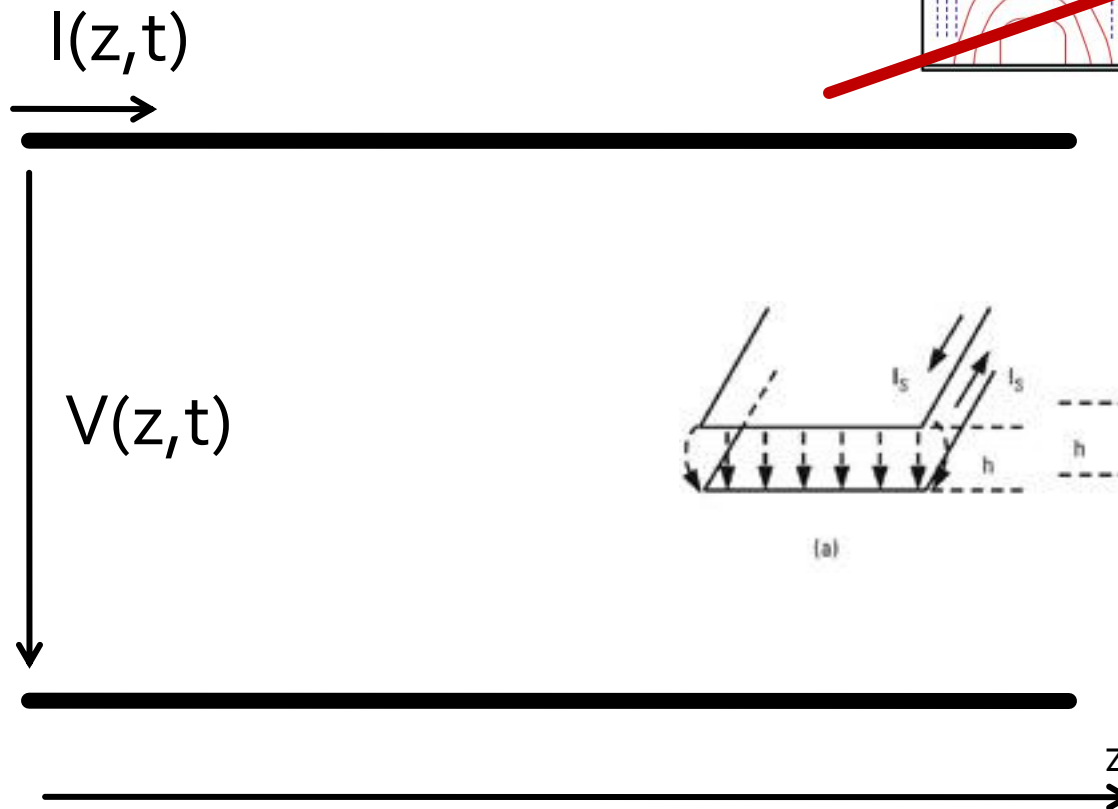
- $E \approx 0 \rightarrow$ Kirchhoff
- $E > 0 \rightarrow$ propagare

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



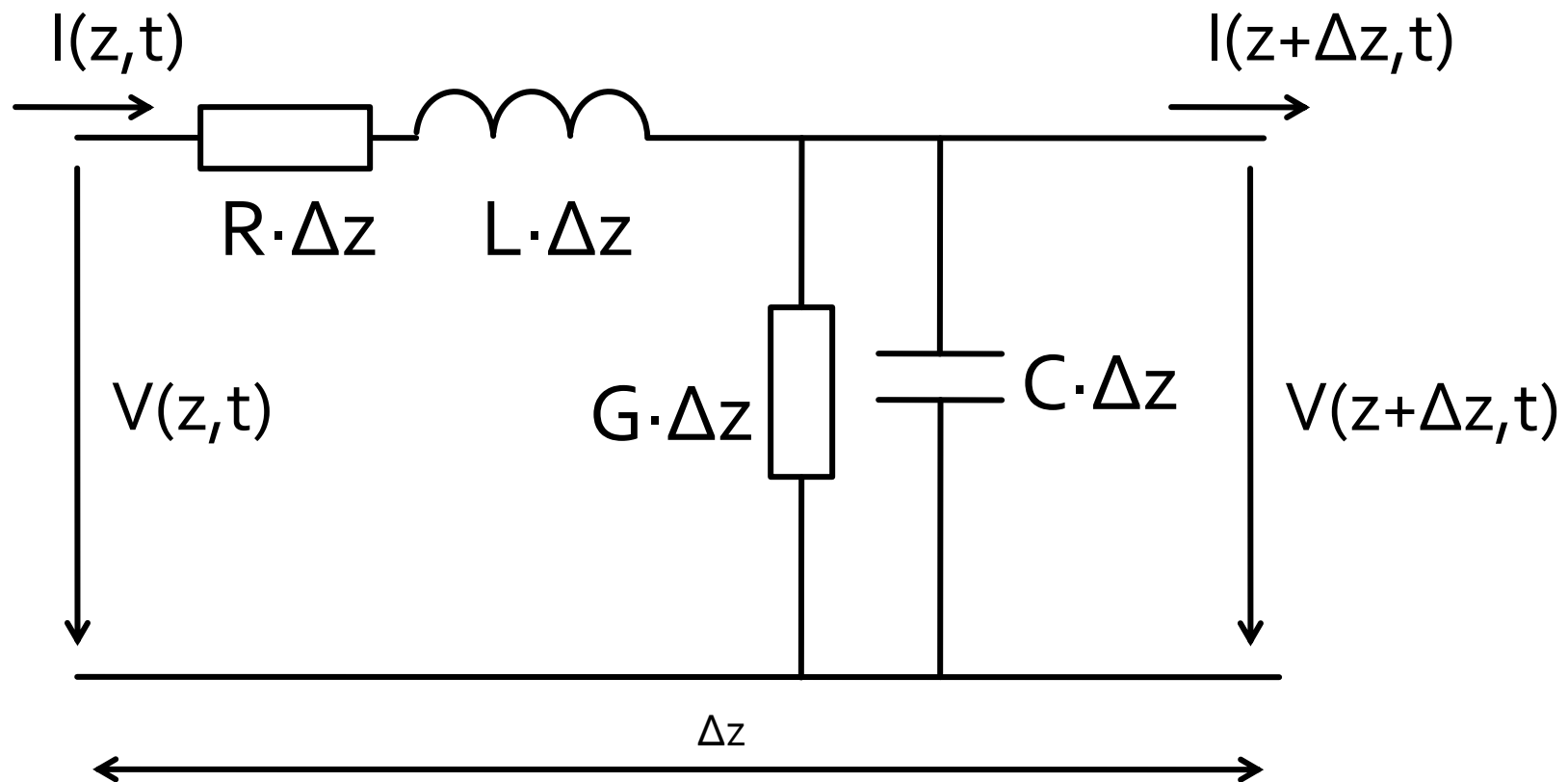
Linie de transmisie

- mod TEM, doi conductori



Linie de transmisie model echivalent

- mod TEM, doi conductor, parametri **lineici**



- parametri **lineici, distribuiti** R, L, G, C ($\Omega/\text{m}, \text{H}/\text{m} \dots$)

Contact

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- rdamian@etti.tuiasi.ro