

Curs 2

2022/2023

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2022/2023

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

Disciplina 2022/2023

- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
 - Miercuri/Joi, 12/14 par/impar, **II.13**
 - L – **25%** din nota
 - ADS, 4 sedinte aplicatii
 - prezenta + **rezultate personale!**
 - P – **25%** din nota
 - ADS, 3 sedinte aplicatii (-1? 21-22.12.2022)
 - tema personala

Documentatie

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

The screenshot shows the homepage of the RF-OPTO website. At the top, there is a banner featuring the RF-OPTO logo, a globe, and two satellite dishes. Below the banner, there are language links for English and Romanian, and a navigation bar with links for Start, Didactic, Master, Colectiv, Cercetare, Studenti, and several sub-links under 'Microunde' such as Comunicatii Optice, Optoelectronica, Internet, Antene, Tehnologie/Zgomote, Practica, and Soft didactic. The main content area has a light blue background and displays information about a discipline: 'Dispozitive si circuite de microunde pentru radiocomunicatii'. It includes details about the Discipline: DCMR (2021-2022), Coordinator Disciplina, Cod, Tip Disciplina, Crediti, and An de Studiu. Below this, sections for Activitati, Evaluare, Note, Prezenta, and Liste are listed.

Laboratorul de Microunde și Optică

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

RF-OPTO

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)

Coordinator Disciplina: conf. dr. Radu-Florin Damian
Cod: DOS412T
Tip Disciplina: DOS; Disciplina Optionala, Disciplina de Specialitate
Crediti: 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 \(final\)](#)

Documentatie

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

Note

■ 2017/2018

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:

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Note

[Rezultate totale](#)

Prezenta

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

Liste

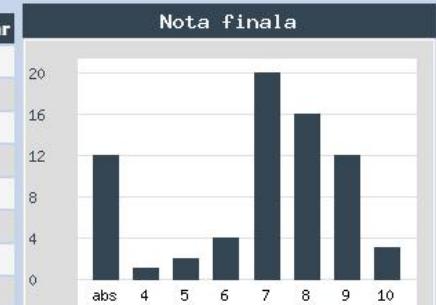
[Bonus-uri acumulate \(final\)](#)

[Studenti care nu pot intra in examen](#)

Statistici

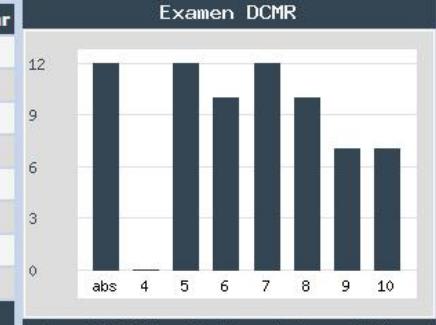
Nota. Numar

abs	12
4	1
5	2
6	4
7	20
8	16
9	12
10	3
TOTAL	70



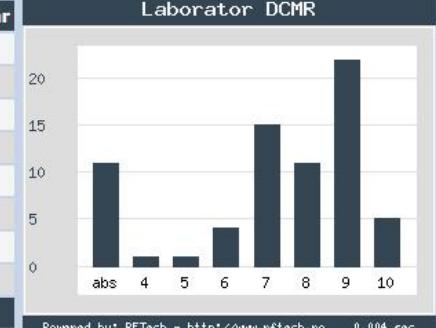
Exam. Numar

abs	12
4	0
5	12
6	10
7	12
8	10
9	7
10	7
TOTAL	70



Labo. Numar

abs	11
4	1
5	1
6	4
7	15
8	11
9	22
10	5
TOTAL	70



Prezenta, Liste

D: 15%, (Teme de casa/Lucrari de specialitate)

Note

Rezultate totale

Prezenta

Curs
Laborator

Liste

Studenti care nu pot intra in examen
Bonus-uri acumulate

Materiale

- Prezenta
- Minim 7 prezente
- Bonus
- Teme proiect
- etc.

Bonus

Grupa	Prezente curs	B. prezenta	B. activitate	B. foto	B. T1	B. T2	B. T3	Total Bonus	Obs.
5408	2	0	0	1	0.5	0	0.1	1.6	-
5408	15.5	2	1.6	1	0	0.2	0.3	5.1	-
5408	2.1	0	0	1				1	-
5408	11	1.5	0	0	0.25	0	0	1.75	-
5408	5	0.5	0	1	0.75	0.2	0	2.45	-
5408	8.875	1	0.4	1	0.85	0.1		3.35	-
5408	0	0	0	1				1	-
5408	0	0	0	1				1	-
5408	14.5	2	0.6	1	0.63	0.2	0	4.43	-
5408	6.65	1	0	1	0.13	0	0.1	2.23	-
5408	9.2	1.5	0	1	0		0	2.5	-
5408	7.8	1	0	1	0.5	0	0.2	2.7	-
5408	3	0.5	0	1			0	1.5	-
5408	1.6	0	0	1	0			1	-
5408	4.5	0.5	0	1	0.48			1.98	-
5408	8	1	0.05	1	0.38	0	0	2.43	-
5408	1	0	0	1				1	-
5408	15.5	2	0.8	1	0	0.1	0.1	4	-
5408	10.5	1.5	0	1			0	2.5	-

Istoric

Alte informatii

[Online Exam manual \(pdf, 2.56 MB, en, !\[\]\(7e49c700e4adaed94ad5398cf2e7059e_img.jpg\)](#)

[Exam Simulation \(video\) \(mp4, 41.96 MB, en, !\[\]\(5ebcf382a6ee952d6c5b8b948415801e_img.jpg\)](#)

[Important Agilent Application Notes \(rar, 2.36 MB, ro, !\[\]\(71ceb62b681518c82e95d615e7265d66_img.jpg\)](#)

Ani anterioiri

2020-2021

2019-2020

2018-2019

2017-2018

2016-2017

Mai mult...

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Calculul atenuarii/amplificării

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

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

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

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



=



-



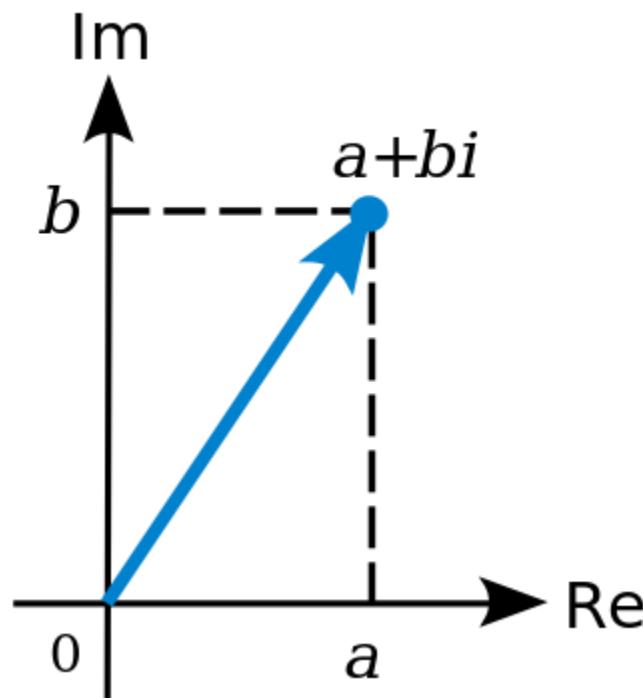
✓

Examen

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

Plan complex

- abscisa – partea reală
- ordonată – partea imaginara
- oricare poate fi negativa, intregul plan, 4 cadre



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

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

Complex Conjugat

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

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

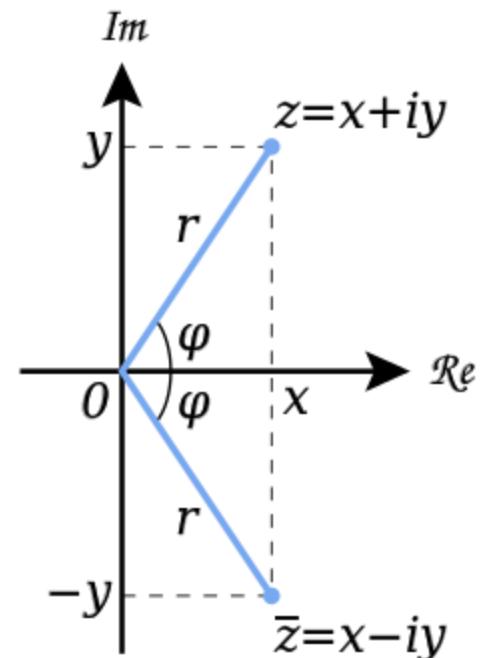
$$\operatorname{Im}(z) = b = \frac{1}{2 \cdot j} \cdot (z - z^*) = \frac{j}{2} \cdot (z^* - z)$$

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

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

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

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



Reprezentare polara

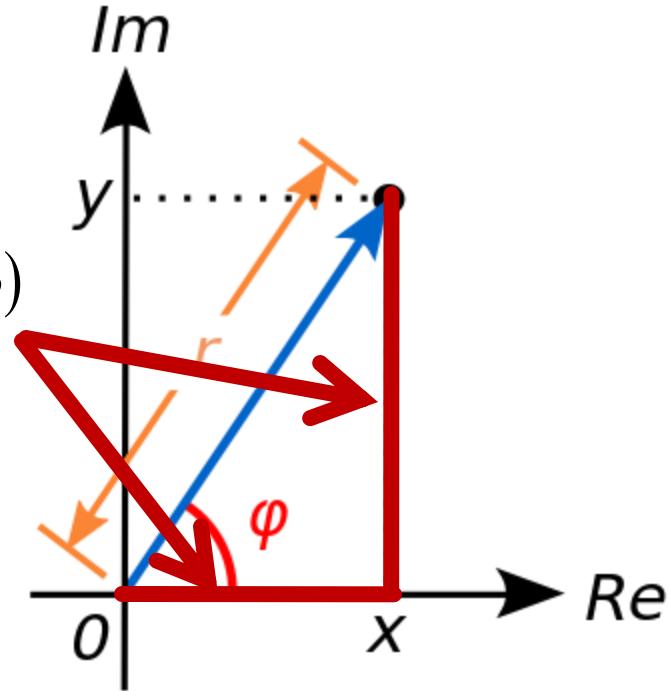
■ Reprezentare polara

- 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

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

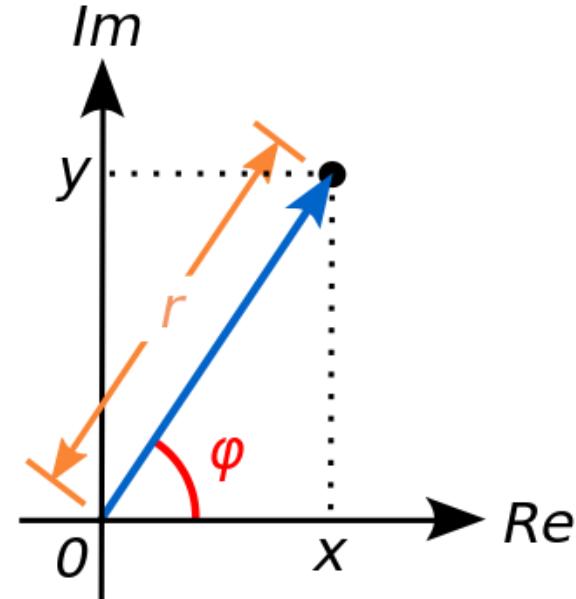
$$z = a + j \cdot b = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)$$

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

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

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

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



Reprezentare polara

■ Reprezentare polara

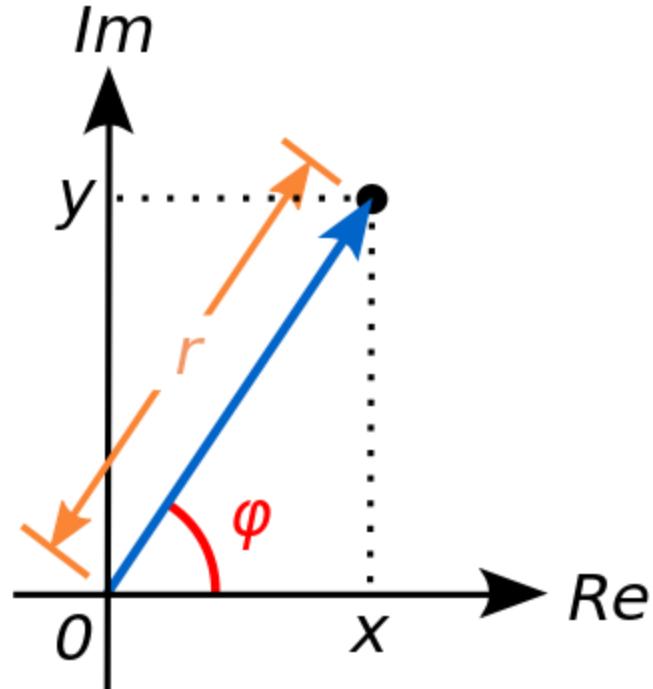
$$|z| = \sqrt{a^2 + b^2}$$

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

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

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

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

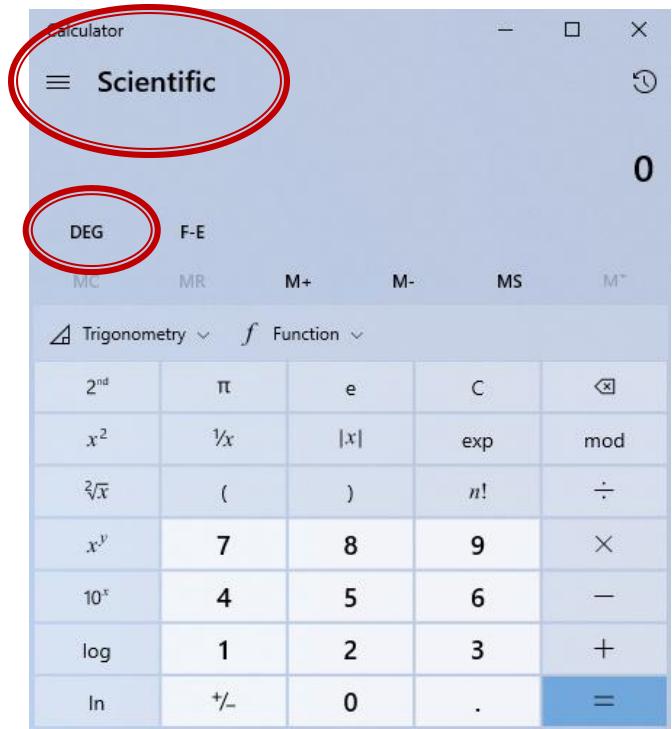


Reprezentare polara

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

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

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



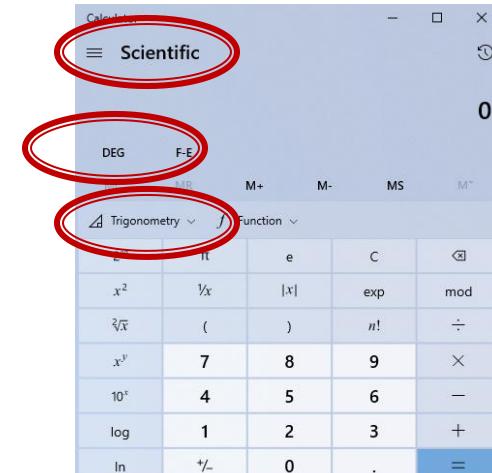
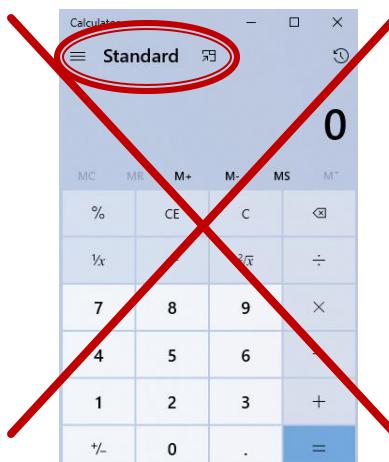
Reprezentare polară

■ 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

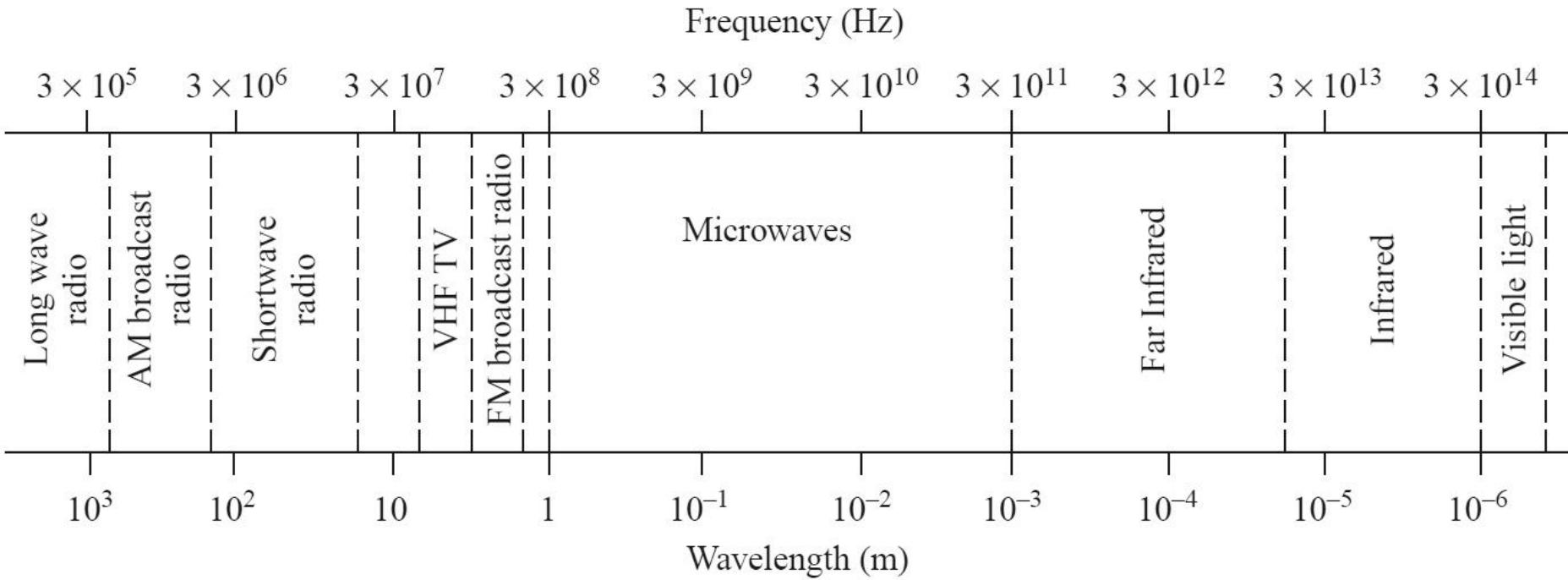
$$\varphi[\circ] = 180^\circ \cdot \frac{\varphi[\text{rad}]}{\pi}$$

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



Introducere

Microunde



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

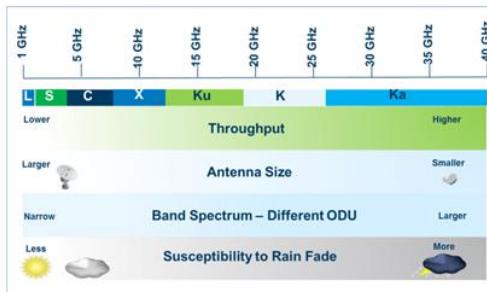
Microunde

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

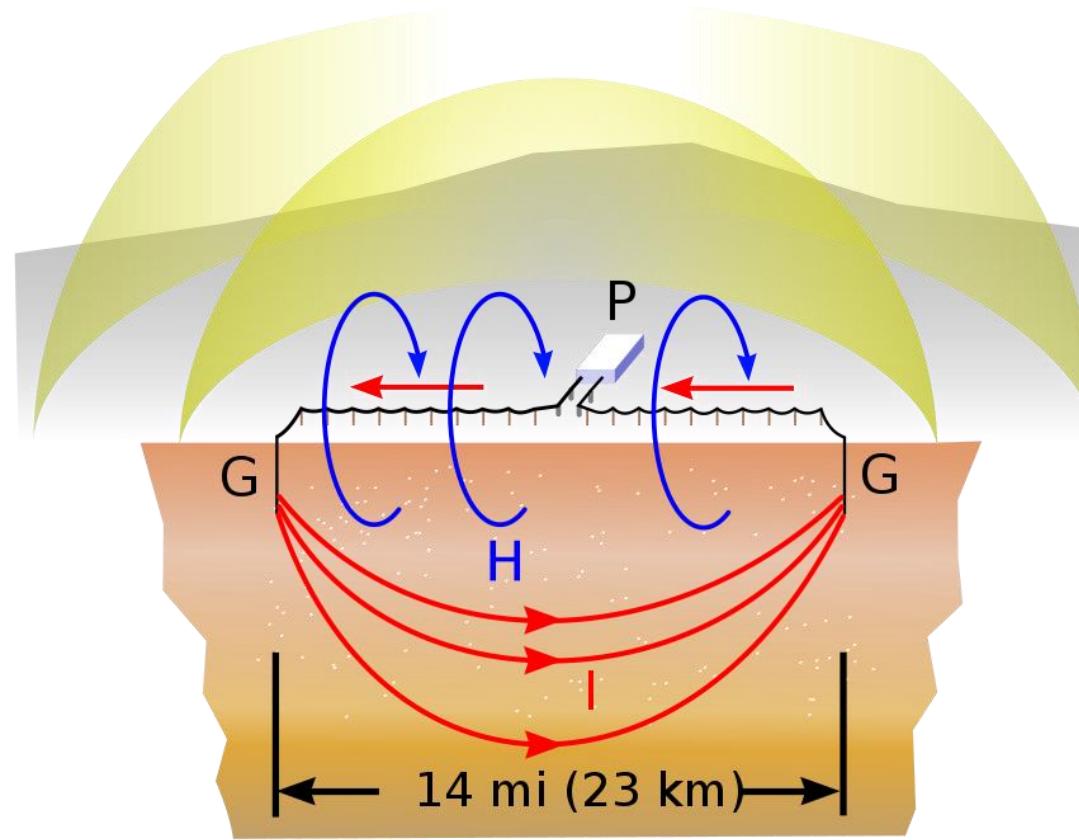
Approximate Band Designations

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 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

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

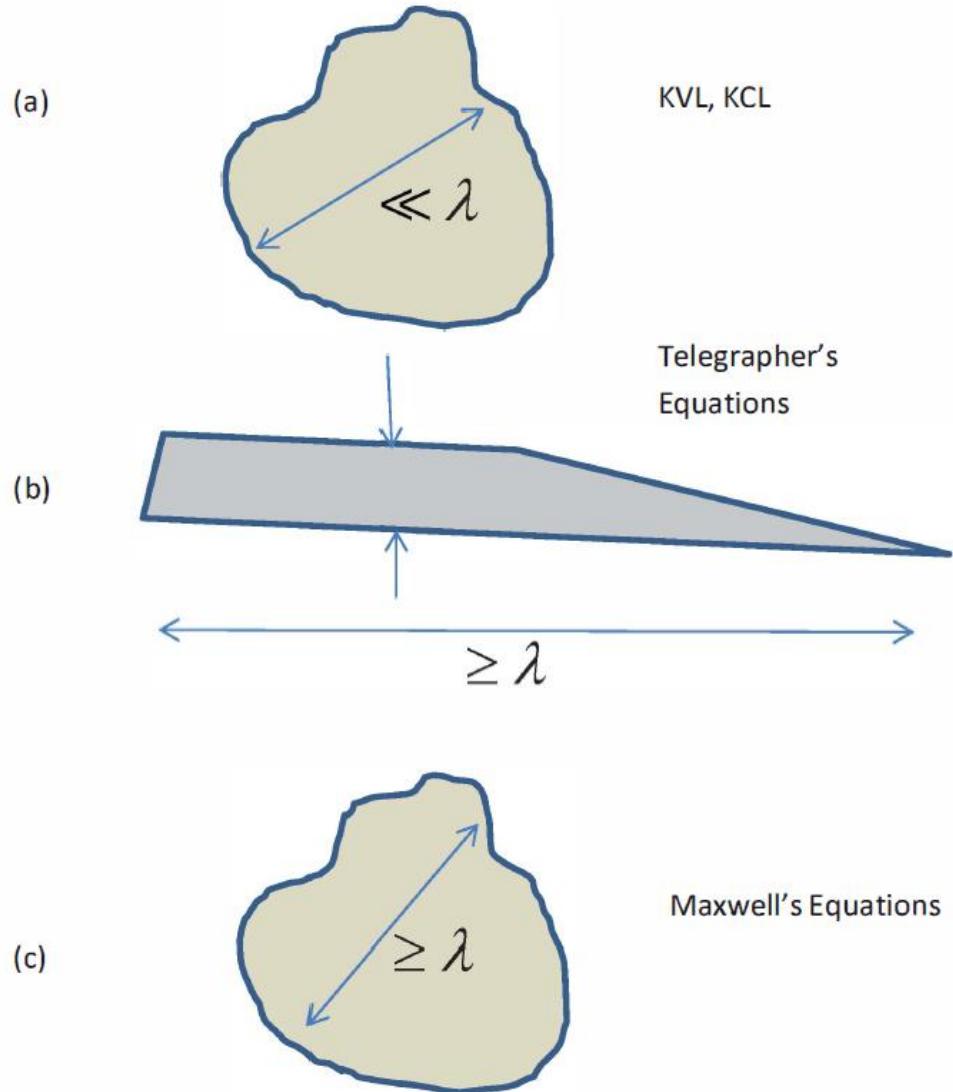
- Dependenta
 - castigul antenei
 - imaginea unui obiect pe radar

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

$$D = \varepsilon \cdot E$$

$$B = \mu \cdot H$$

$$J = \sigma \cdot E$$

- În vid

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

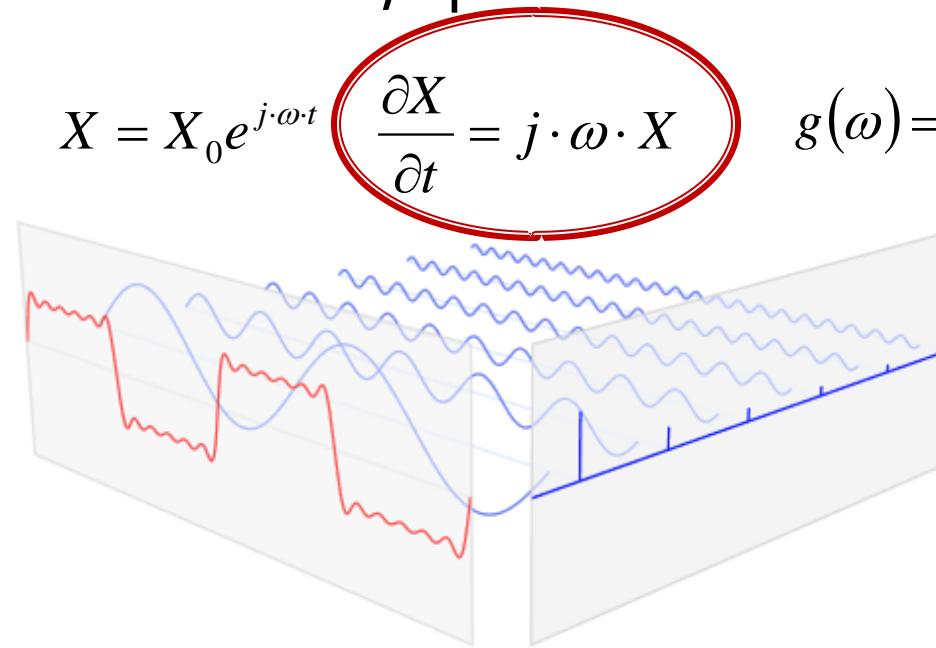
$$\varepsilon_0 = 8,854 \times 10^{-12} \text{ F/m}$$

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

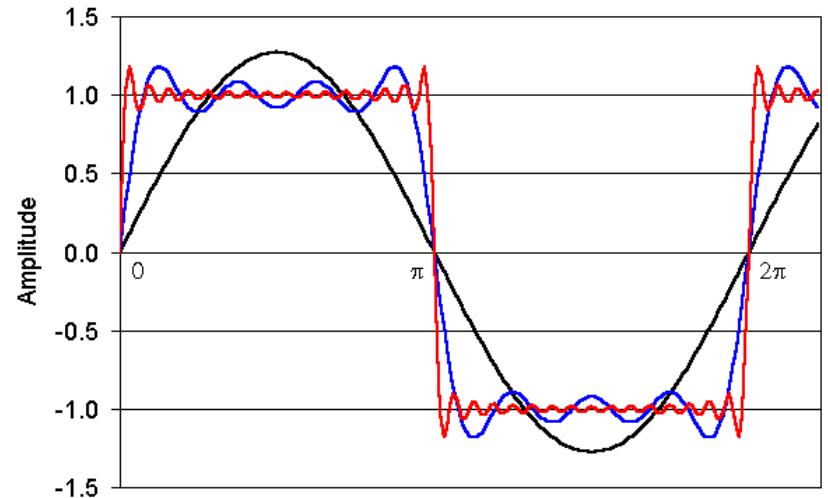
Modele matematice

- cazuri particulare în care există rezolvare analitică
 - semnale cu variație armonică în timp, transformata Fourier, spectru

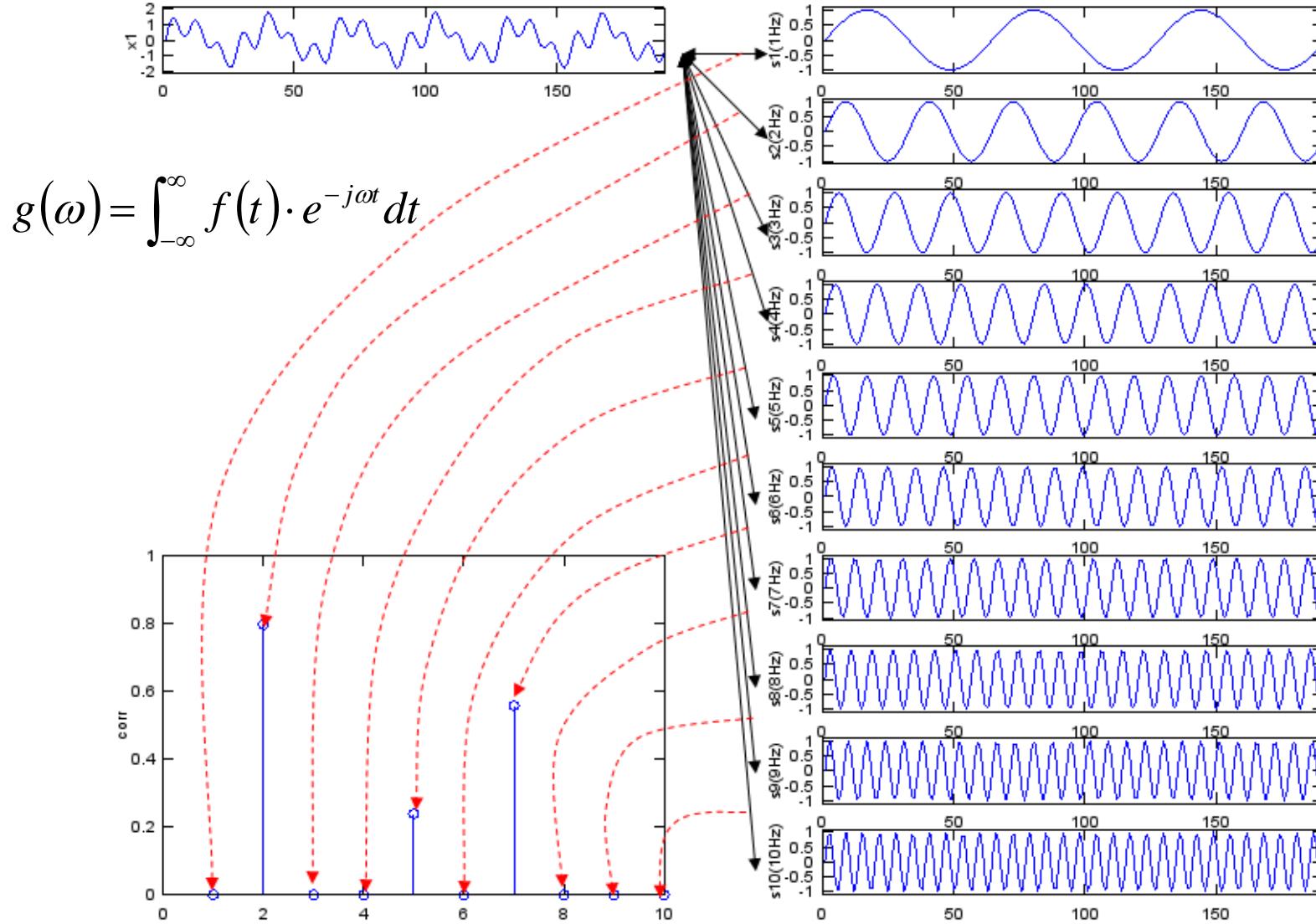
$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X$$



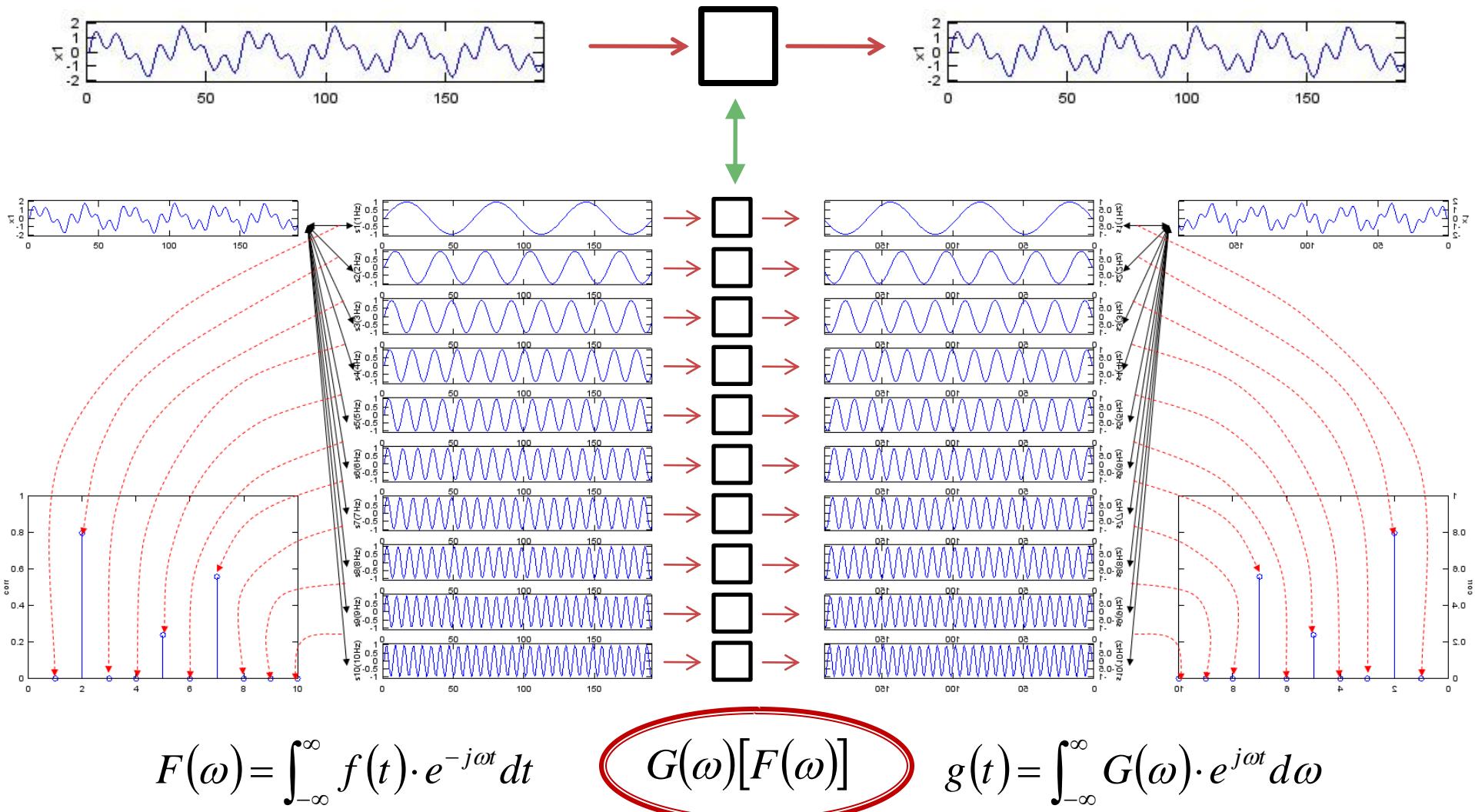
$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$



Modele matematice



Modele matematice



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

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

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

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

$$\nabla \cdot H = 0$$

Ecuățiile de propagare

- Ecuățiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

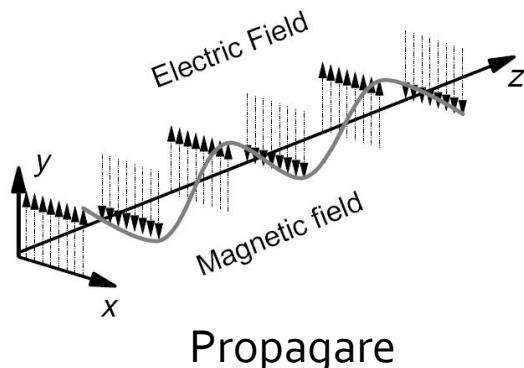
$$\nabla^2 E - \gamma^2 E = 0$$

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

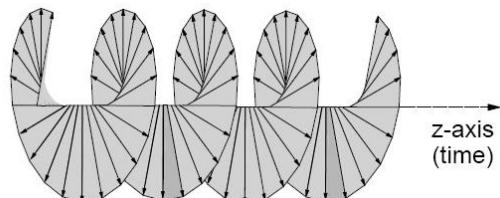
$$\gamma^2 = -\omega^2 \epsilon \mu + j \omega \mu \sigma$$

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 $E_+ \Rightarrow A$

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

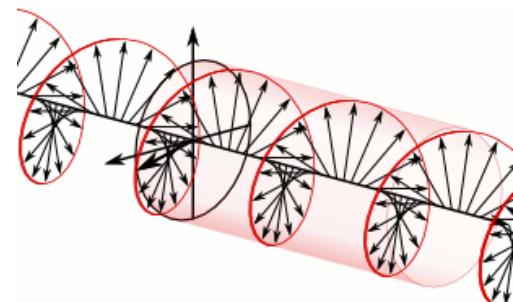
Camp armonic

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

Amplitudine

Atenuare

Propagare
(variatie in timp si spatiu)



Atenuare

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

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

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

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

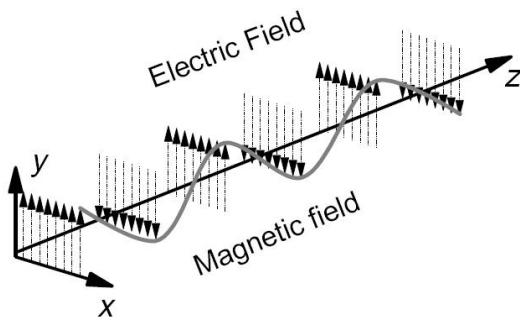
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} [e^{-2\alpha \cdot (z_2 - z_1)}]$$

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

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

- ▶ 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

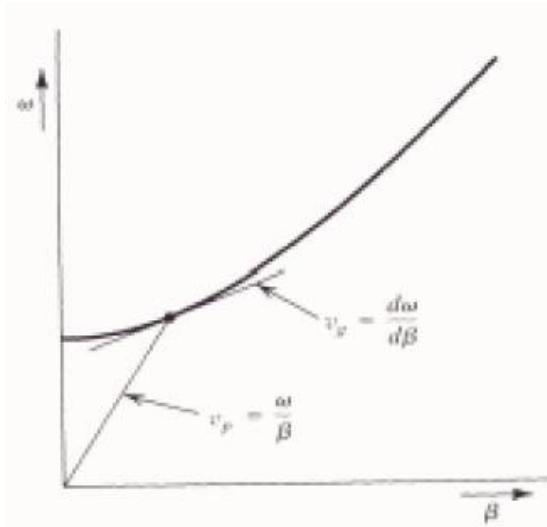
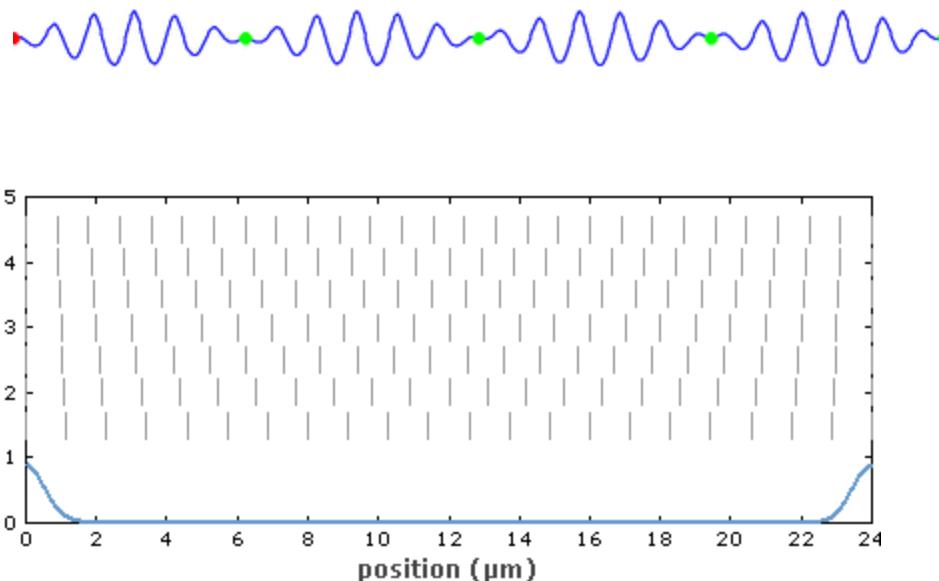
$$v = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{\epsilon\mu}}$$

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

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

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

Periodicitate în spațiu

Periodicitate în timp

■ În mediu nedispersiv ϵ_r

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

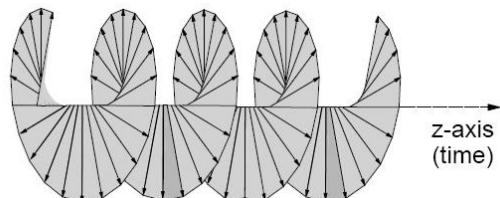
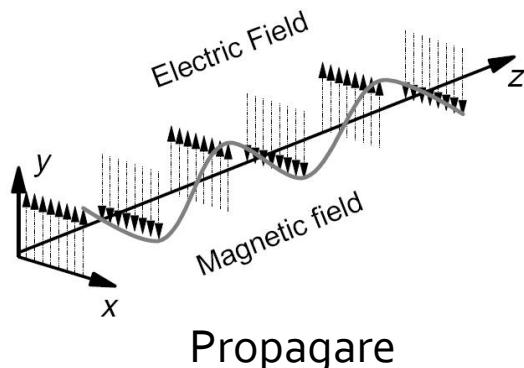
$$n = \sqrt{\epsilon_r} \quad \text{Indice de refractie al mediului}$$

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

$$T = \frac{2\pi}{\omega} = \frac{1}{f} \quad \lambda = \frac{2\pi}{\beta} = \frac{c}{f} \quad \lambda = \frac{c_0}{\sqrt{\epsilon_r \cdot f}} = \frac{\lambda_0}{\sqrt{\epsilon_r}}$$



Solutia ecuatiilor de 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 $E_+ \Rightarrow A$

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

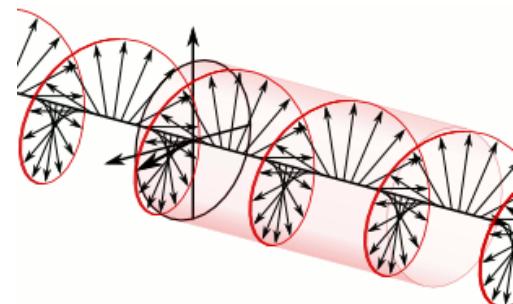
Camp armonic

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

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

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

■ 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

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

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

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

Modele matematice

■ cazuri particulare in care exista rezolvare analitica

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

■ unda

- incidenta

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

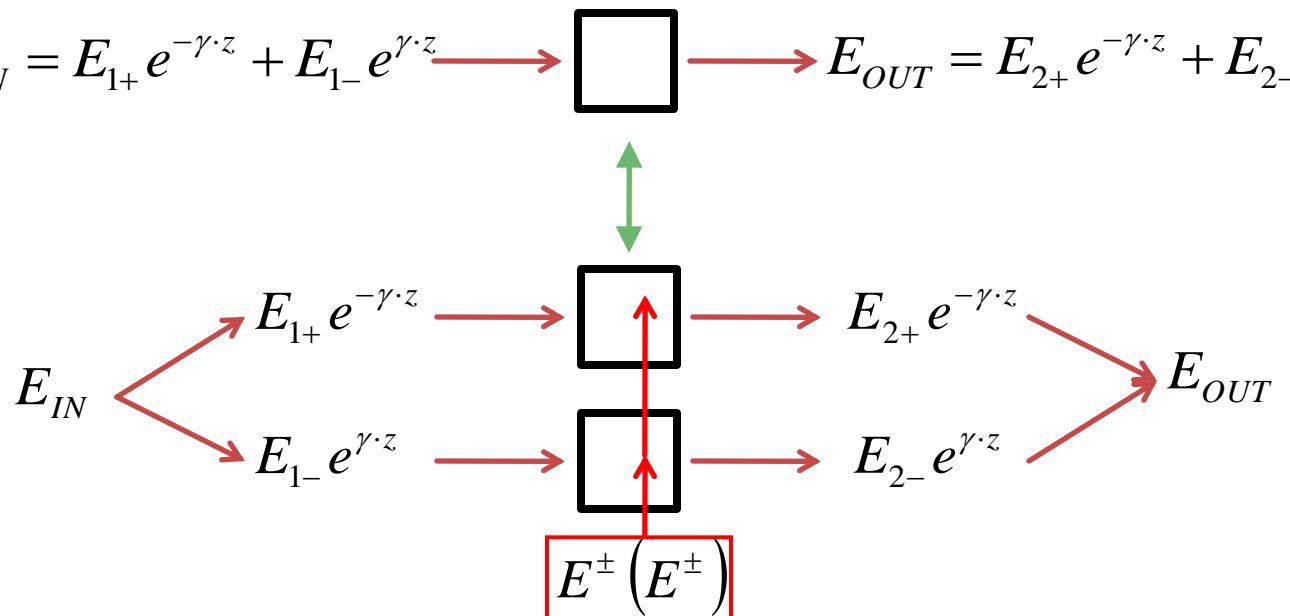
- reflectata

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

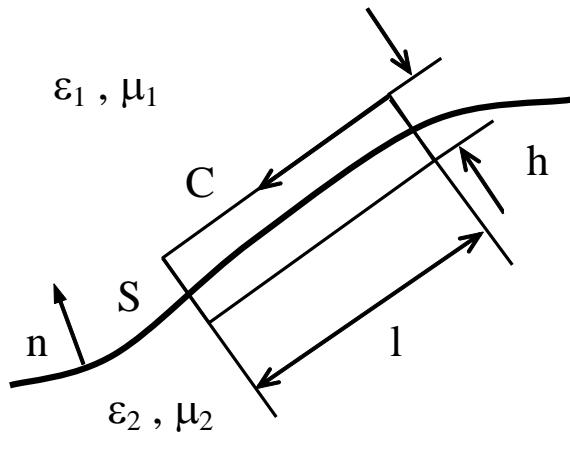
■ unda

- directa

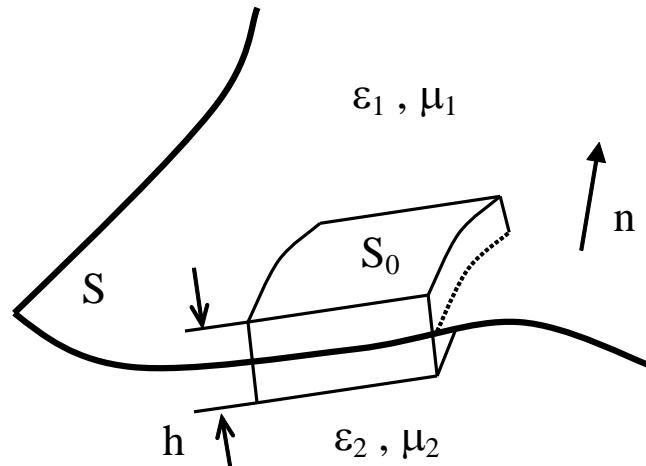
- inversa



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

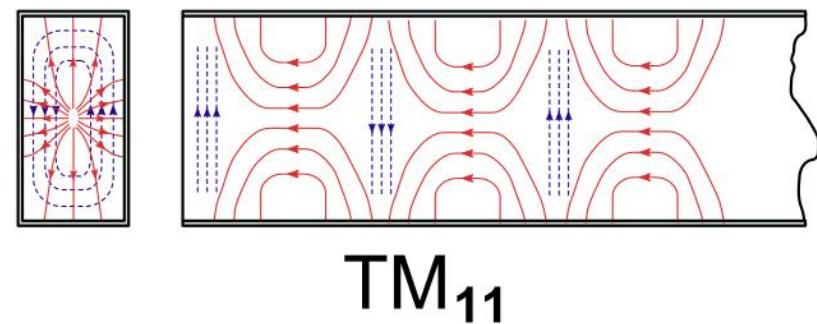
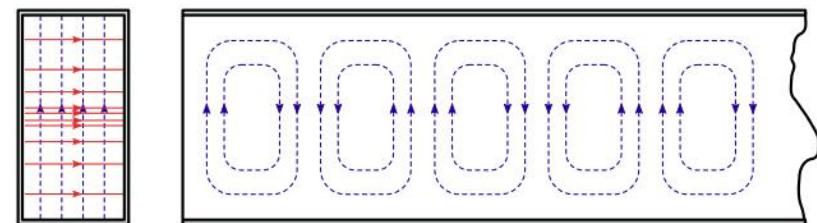
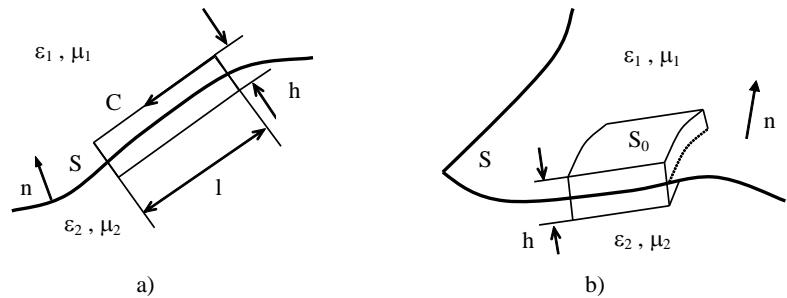
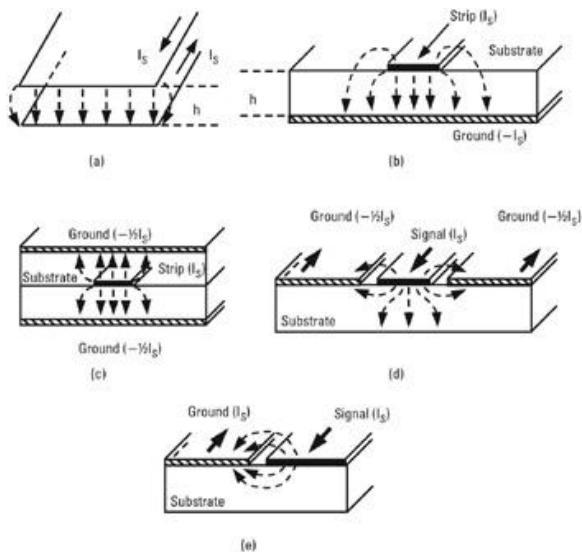
- Câmpuri electromagnetice cu variație armonică în timp
 - simplificarea ecuațiilor lui Maxwell

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

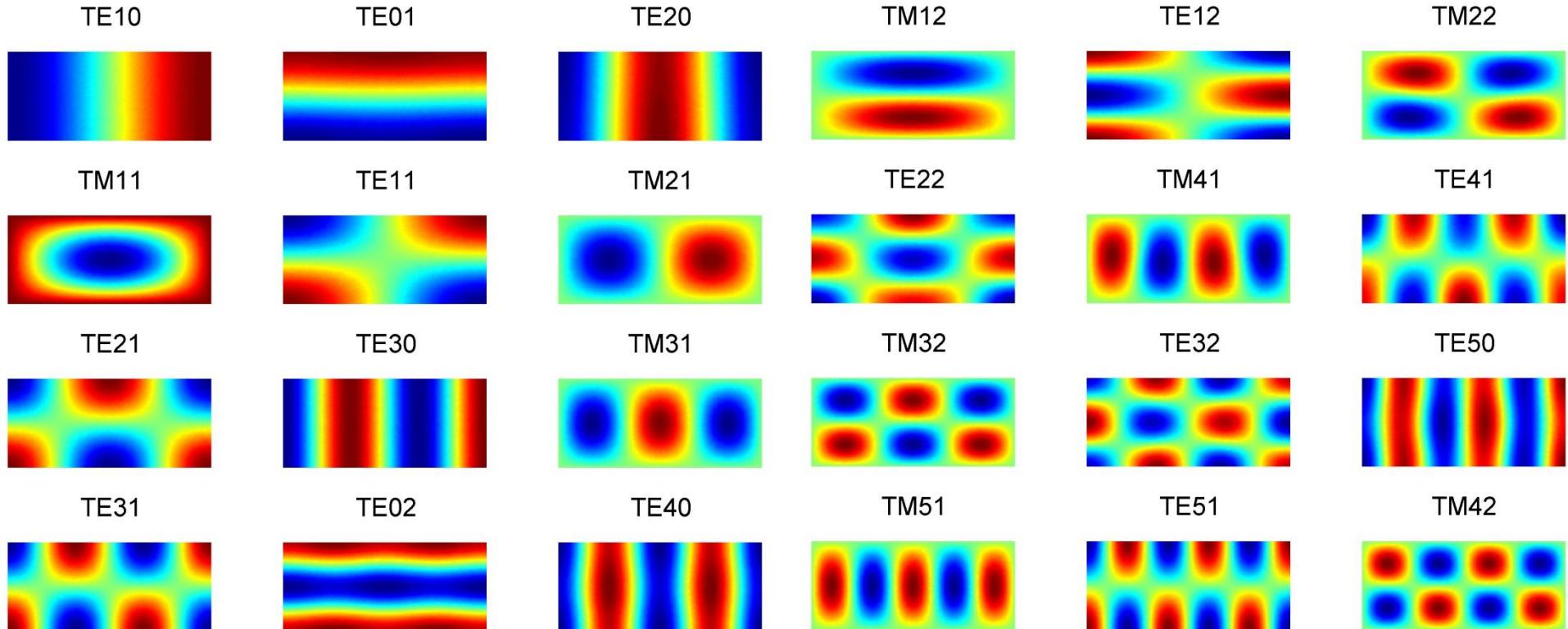
- În medii delimitate soluțiile ecuațiilor lui Maxwell trebuie să verifice condițiile la limită
 - soluțiile trebuie să respecte anumite condiții suplimentare

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

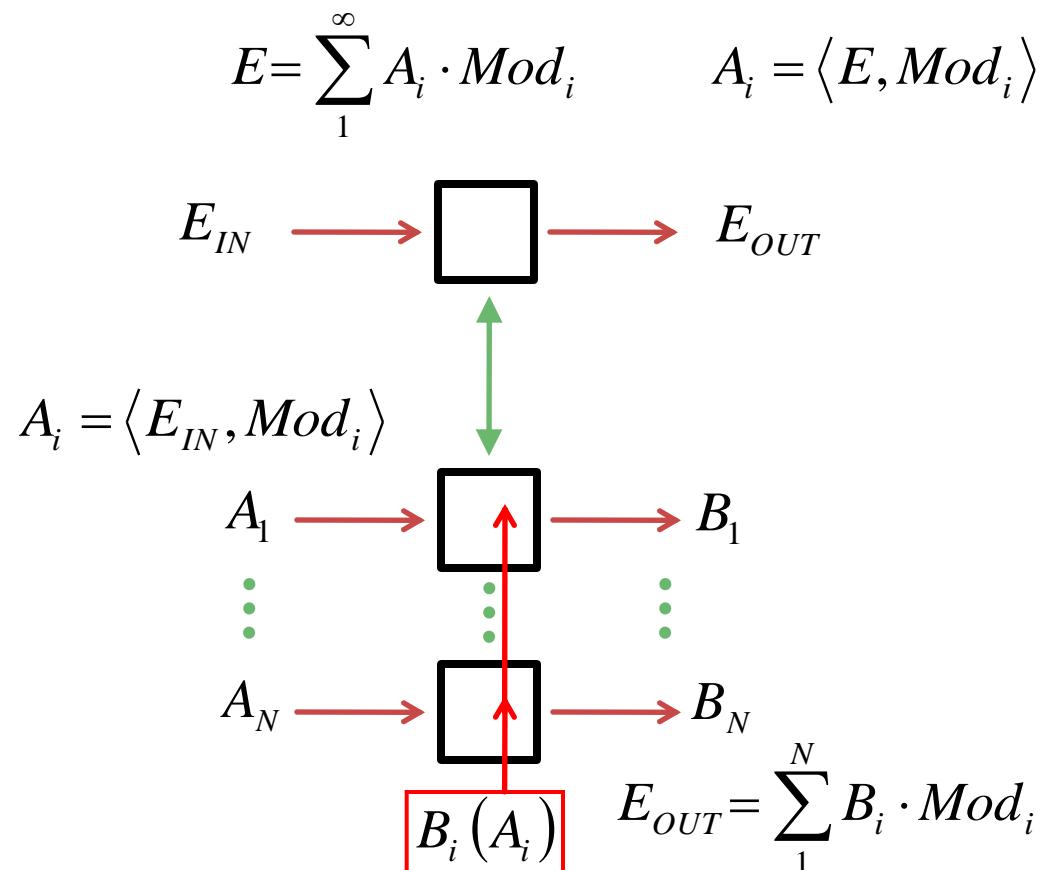
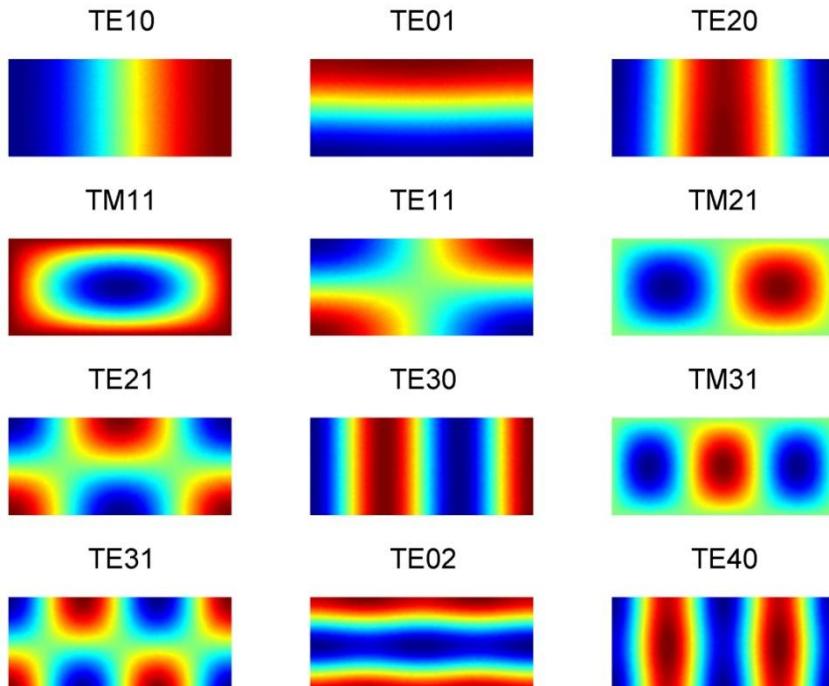


- Similar cu transformata Fourier
$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

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

Modele matematice

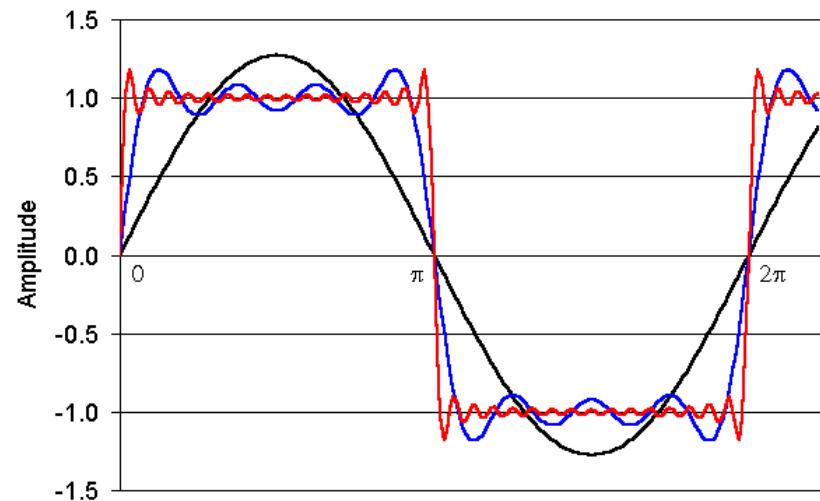
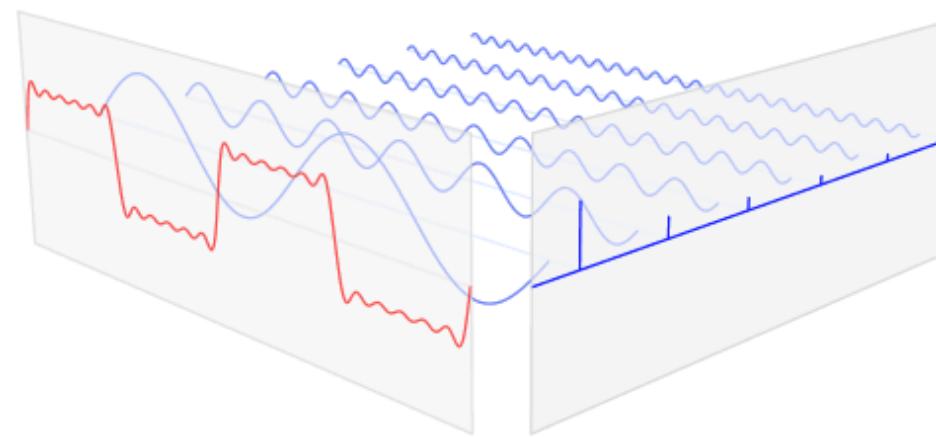
- cazuri particolare in care exista rezolvare analitica
 - moduri in medii delimitate $B_i(A_i)$



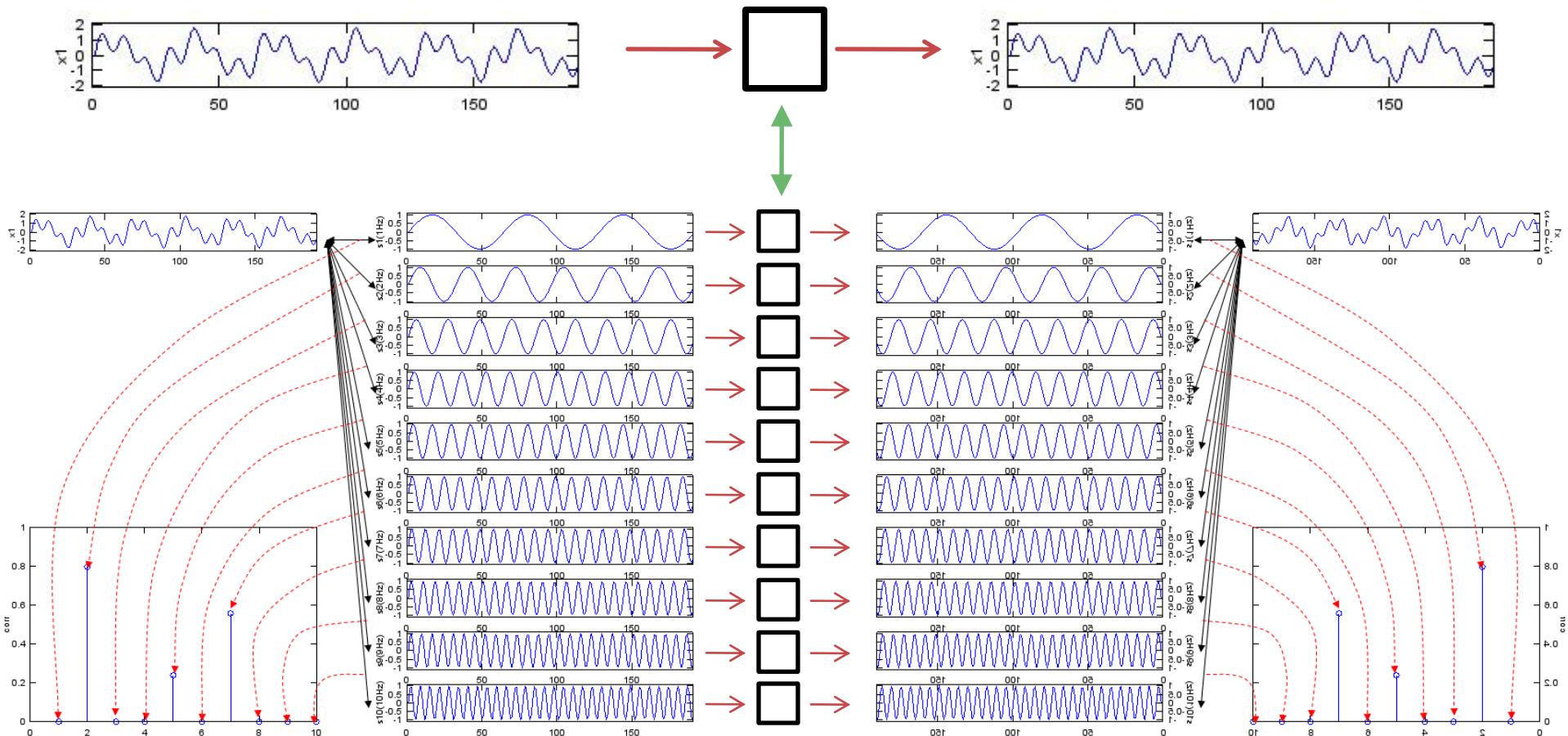
Modele matematice

- cazuri particulare în care există rezolvare analitică
 - 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



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

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

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

Modele matematice

■ cazuri particulare in care exista rezolvare analitica

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

■ unda

- incidenta

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

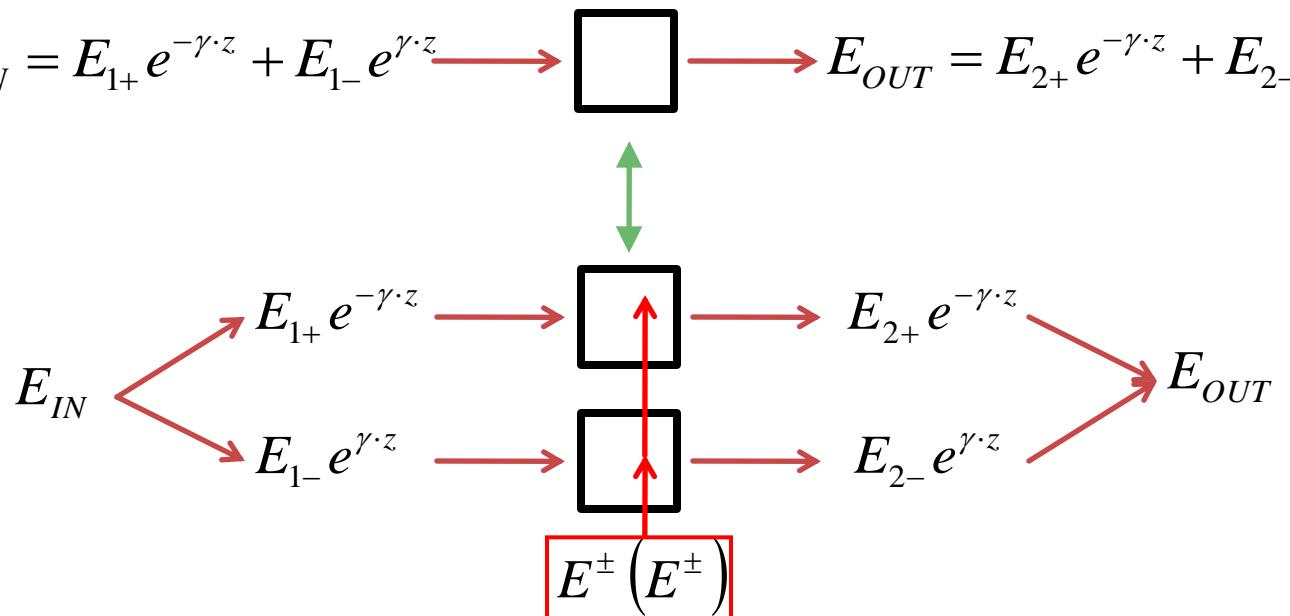
- reflectata

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

■ unda

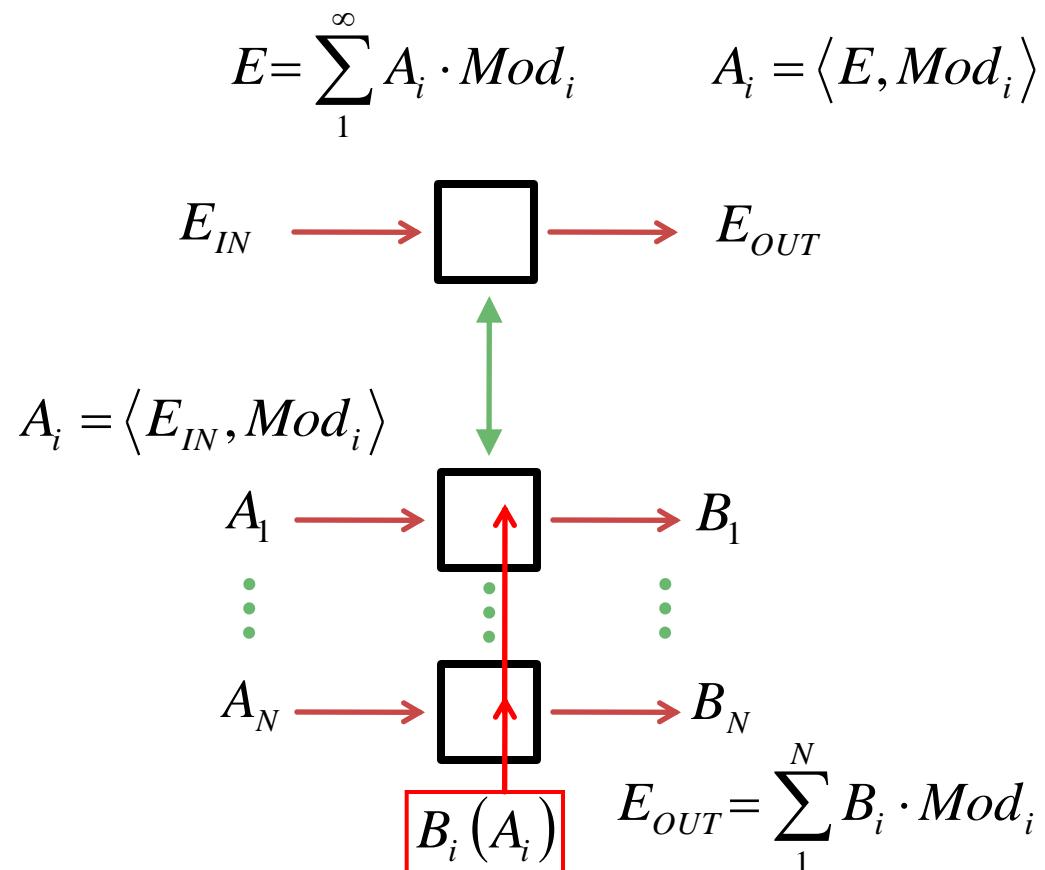
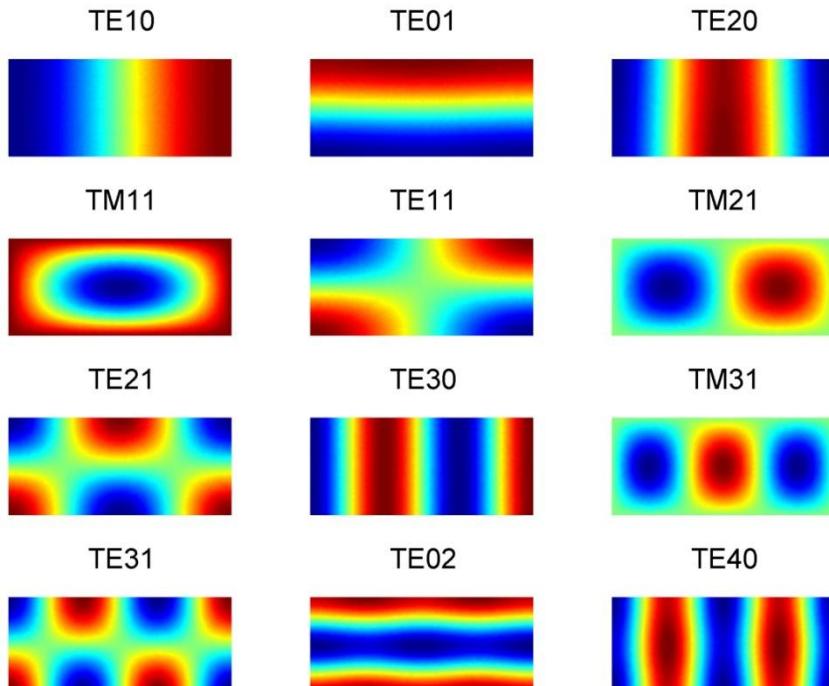
- directa

- inversa



Modele matematice

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



Contact

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