

# Optoelectronică

Curs 2

2017/2018

# Disciplina 2017/2018

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7** prezente curs + laborator
- ▶ Curs – **sl. Radu Damian**
  - an IV  $\mu$ E
  - Vineri 8–11, P5
  - E – 70% din nota
    - **20% test la curs**, saptamana 4–5?
  - probleme + (? 1 subiect teorie) + (2p prez. curs)
  - toate materialele permise
- ▶ Laborator – **sl. Daniel Matasaru**
  - an IV  $\mu$ E, an IV Tc
    - Joi 14-16 par/impar
  - L – 15% din nota
  - C – 15% din nota

# Orar 2017/2018

## ▶ Curs

- Vineri 8–11, P5
- **2C ⇒ 3C**
  - $14 * 2/3 \approx 9.33$
  - $9 \div 10$  C

# Scop 4



**Sinapse  
“ingineresti”**



# Bibliografie

- ▶ <http://rf-opto.etti.tuiasi.ro>
- ▶ Irinel Casian-Botez, "Structuri Optoelectronice", Ed. "CANOVA", Iasi 2001, ISBN 973-96099-2-9
- ▶ Behzad Razavi - Design of Integrated Circuits for Optical Communications, Mc Graw Hill  
~~<http://rf-opto.etti.tuiasi.ro/docs/opto/>~~
- ▶ IBM - Understanding Optical Communications: on-line <http://rf-opto.etti.tuiasi.ro>
- ▶ Radu Damian, I Casian, D Matăsaru - „Comunicatii Optice” , Indrumar de laborator, 2005

# Fotografii



## Date:

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

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

## Detalii curente

<b>Finantare</b>	Buget
<b>Bursa</b>	Fara Bursa

## Observatii



## Date:

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

[Acceseaza ca acest student](#)

## Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
<b>TW</b>	<b>Tehnologii Web</b>					
	N	17/01/2014	Nota finala	10	-	
	A	17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	



## Date:

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

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

## Detalii curente

<b>Finantare</b>	Buget
<b>Bursa</b>	Bursa de Studii

## Observatii

# Fotografii

Start Didactic Master Colectiv Cercetare **Studenti** Admin

Note Lista Studenti Fotografii Statistici

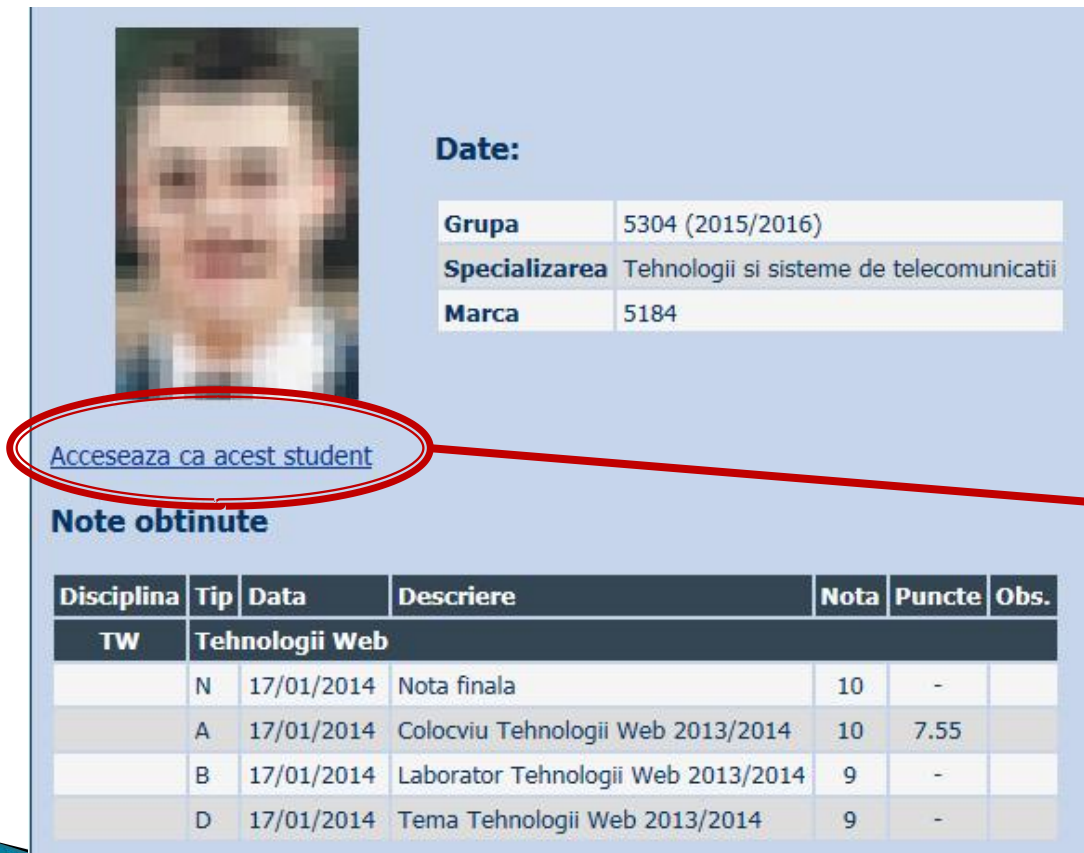
Grupa 5403

Nr. Student	Prezent	Nr. Student	Prezent	Nr. Student	Prezent
1 ANGHIELUS IONUT-MARIUS	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	2 ANTIGHIN FLORIN-RAZVAN	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	3 ANTONICA BIANCA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:
4 APOSTOL PAVEL-MANUEL	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	5 BALASCA IULIAN-PETRU	<input checked="" type="checkbox"/> Puncte: 0 Nota: 0 Obs:	6 BOSTAN ANDREI-PETRICIA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:
7 BOTEZAT EMANUEL	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	8 BUTINOI GEORGE-MADALIN	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	9 CHILEA SALUCA-MARIA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:
10 CHERITOIU ECATERINA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:	11 COJOC MARIUS	<input checked="" type="checkbox"/> Puncte: 0 Nota: 0 Obs:	12 COJOCARI AURA-FLORINA	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:

Nr. Student	Prezent
2 <u>ANTIGHIN</u> <u>FLORIN-RAZVAN</u>	<input type="checkbox"/> Puncte: 0 Nota: 0 Obs:

# Acces

## ▶ Personalizat



Student profile page showing a photo, personal details, and a table of grades. A red oval highlights the link "Acceseaza ca acest student" and an arrow points from it to the right-hand page.

**Date:**

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

[Acceseaza ca acest student](#)

**Note obtinute**

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



Login form with fields for Name, Email, and Verification Code. A red oval highlights the Email field, another red oval highlights the Verification Code field (containing the code 344bd9f), and a "Trimite" button is at the bottom.

Nume

Email

Cod de verificare

Trimite



# Examen

- ▶ subiecte **individuale**

# Examen

▶ 2015/2016

## Optoelectronica, structuri, tehnologii, circuite

### Disciplina: OSTC (2015-2016)

Coordonator Disciplina: sl. dr. Radu-Florin Damian  
Cod: DIS405M  
Tip Disciplina: DIS; Disciplina Impusa, Disciplina de Specialitate  
Credite: 4  
An de Studiu: 4, Sem. 7

### Activitati

Curs: Cadru Didactic: sl. dr. Radu-Florin Damian, 2 Ore/Saptamana, Sectie Specializare, Orar:  
Laborator: Cadru Didactic: sl. dr. Petre-Daniel Matasaru, 1 Ore/Saptamana, Semi grupa, Orar:

### Evaluare

Tip: Colocviu

A: 66%, (Examen/Colocviu)  
B: 17%, (Activitate Seminar/Laborator/Proiect)  
D: 17%, (Teme de casa/Lucrari de specialitate)

### Note

[Rezultate totale](#)

### Prezenta

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

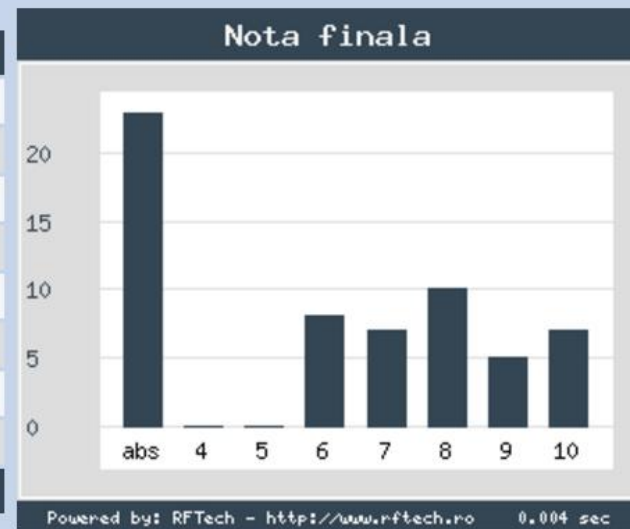
### Liste

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

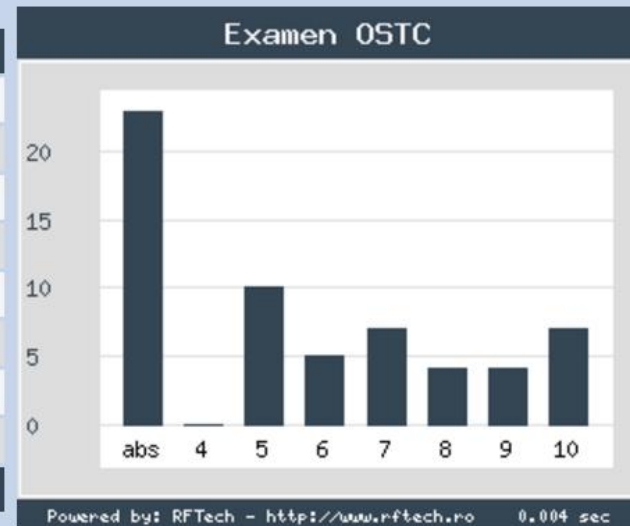
## Note

[Rezultate totale](#)

Nota.	Numar
abs	23
4	0
5	0
6	8
7	7
8	10
9	5
10	7
<b>TOTAL</b>	<b>60</b>



Exam.	Numar
abs	23
4	0
5	10
6	5
7	7
8	4
9	4
10	7
<b>TOTAL</b>	<b>60</b>



# Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

# Calculul atenuarii

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

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

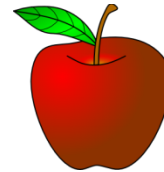
$$\text{Pierderi [dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-



$$\text{Atenuare [dB/km]} = \frac{\text{Pierderi [dB]}}{\text{lungime [km]}}$$

# Bonus

**Disciplina:** Optoelectronica, structuri, tehnologii, circuite  
**An:** 2015/2016

Bonus-uri care se aplica la nota de la teza obtinute prin:

- prezenta la curs (0.5p / 3pr)
- 3 miniteste aplicate la curs (max. 3 X 1.5p)
- contributie la site rf-opto (foto <C5=1p, >C5=0.5p)

Nr.	Student	Grupa	Prezente curs	Bonus prezenta	Bonus foto	Bonus T1	Bonus T2	Bonus T3	Total Bonus	Obs.
1	<a href="#">CIOLPAN OCTAVIAN</a>	5306	3	0.5					0.5	-
2	<a href="#">NITA COSTEL-CATALIN</a>	5307	4	0.5	1				1.5	-
3	<a href="#">BARON BOGDAN-IONUT</a>	5405	12	2	1	0.5		0.75	4.25	-

## Prezenta

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

## Liste

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

- ▶ **Minim** 7 prezente
- ▶ 0.5p/2(3)prez
- ▶ 3 teste
- ▶ foto

# Introducere

## Capitolul 1

# Aplicatii majore

## ▶ Comunicatii

- Infrarosu (InGaAsP)

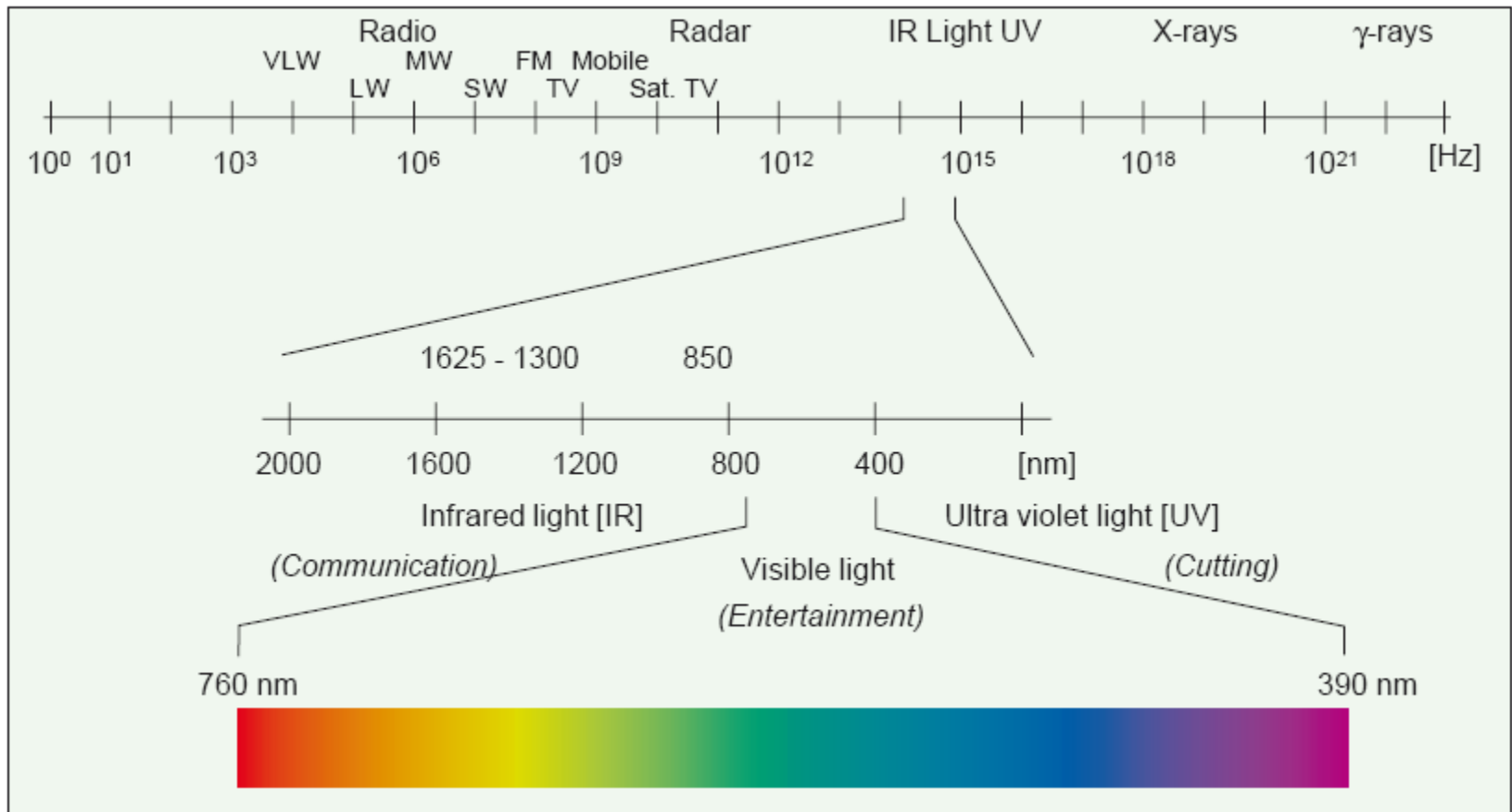
## ▶ Vizibil

- Spectru vizibil (GaAlAs)

## ▶ Iluminare

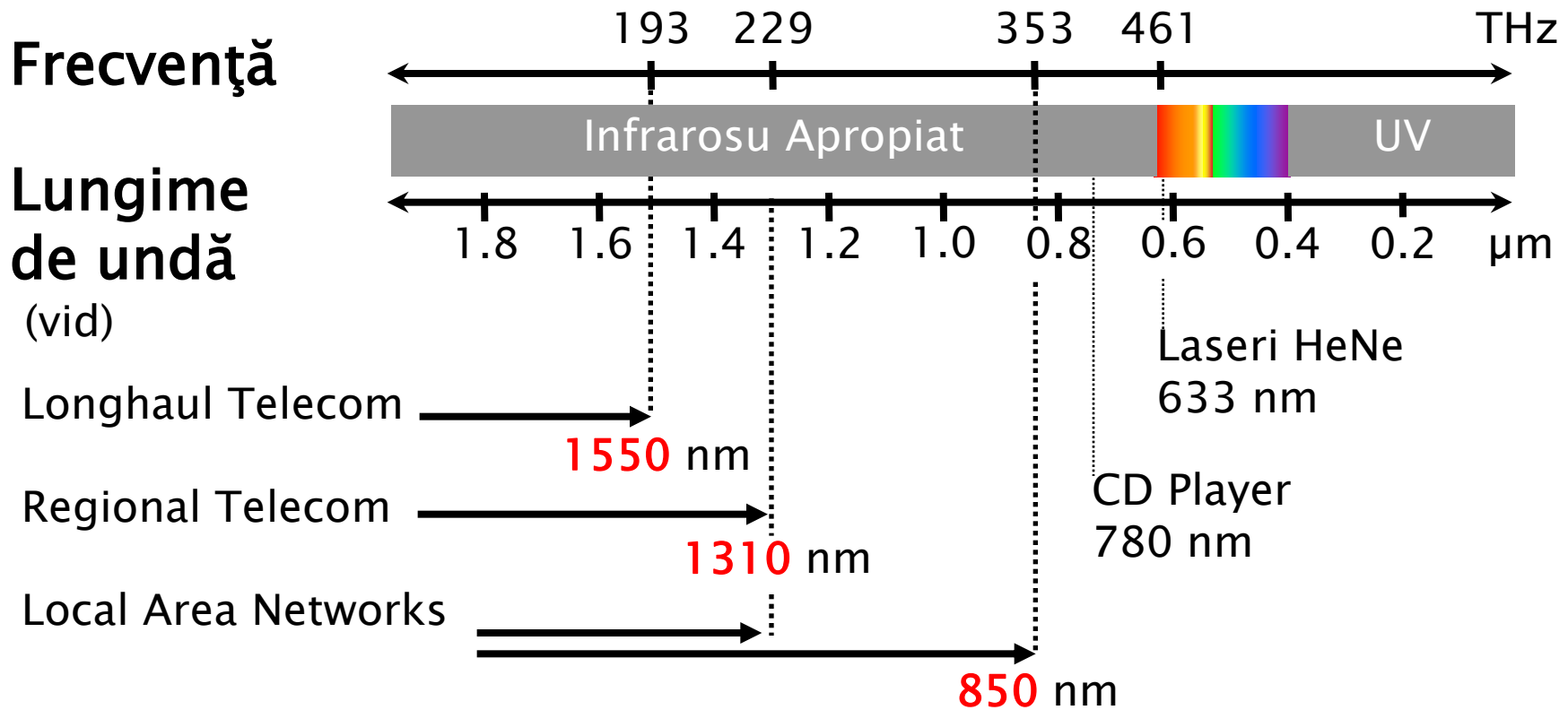
- Putere ridicata, lumina alba (GaInN)

# Spectrul electromagnetic

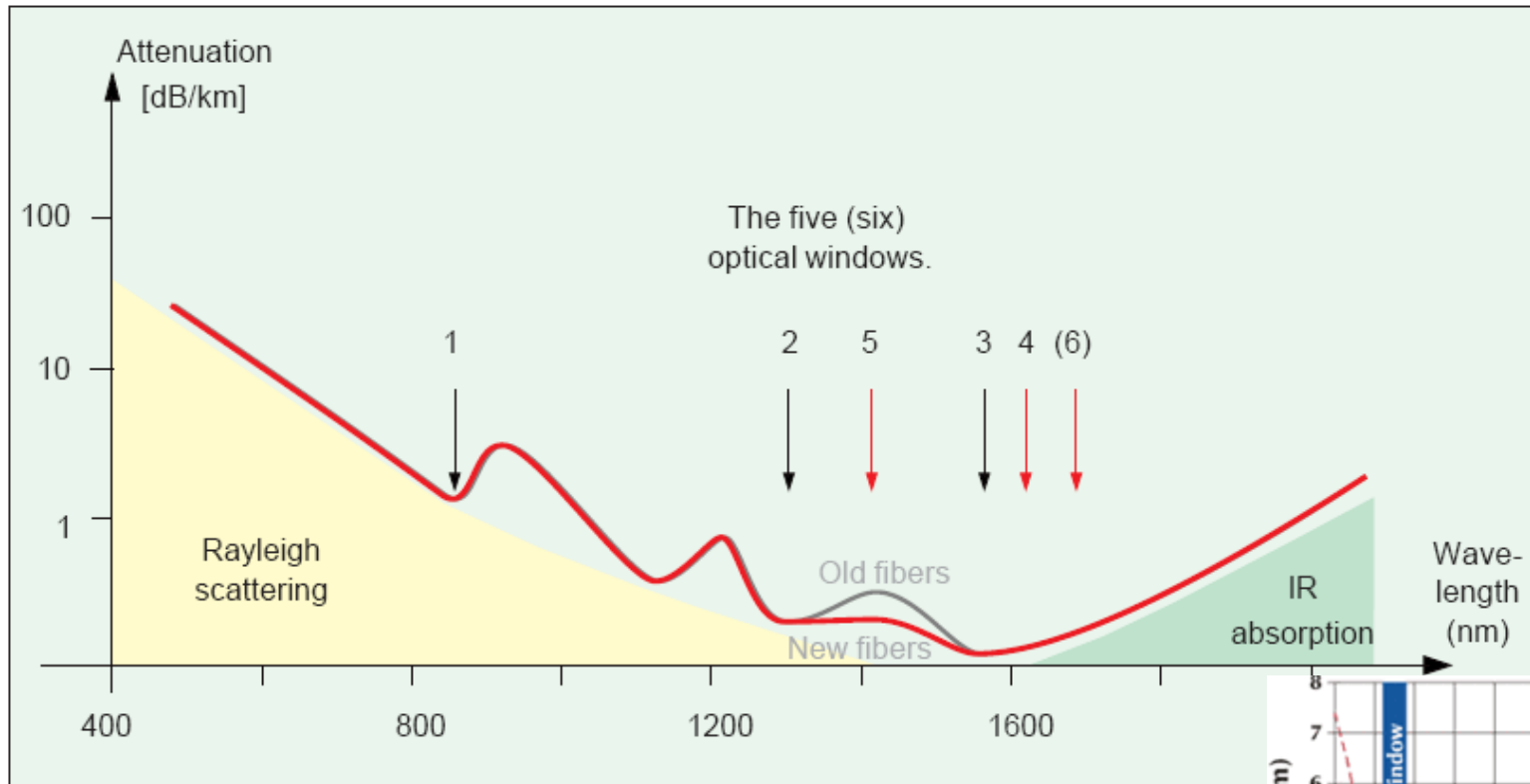




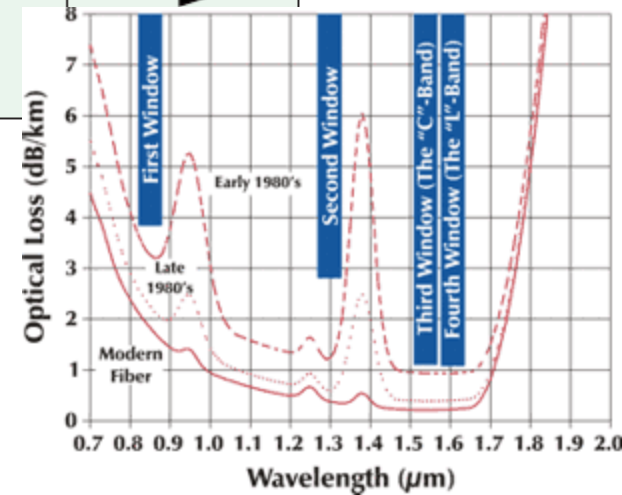
# Benzi de lucru in comunicațiile optice



# Atenuarea în fibra optică (SiO<sub>2</sub>)



**850nm, 1310nm, 1550nm**



# Aplicatii majore

- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Illuminare
  - Putere ridicata, lumina alba (GaN)

# Premiul Nobel, Fizica, 2014

Nobelpriset i fysik 2014

The Nobel Prize in Physics 2014

 Nobelpriset i fysik 2014

 KUNGL. VETENSKAPS AKADEMIEN  
THE ROYAL SWEDISH ACADEMY OF SCIENCES

  
**Isamu Akasaki**  
Meijo University, Nagoya, Japan  
Nagoya University, Japan

  
**Hiroshi Amano**  
Nagoya University, Japan

  
**Shuji Nakamura**  
University of California,  
Santa Barbara, CA, USA

*"För uppfinningen av effektiva blå lysdioder vilka möjliggjort ljusstarka och energisnåla vita ljuskällor"*

*"For the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"*

2014-10-07

© Kungl. Vetenskapsakademien

# Aplicatii majore

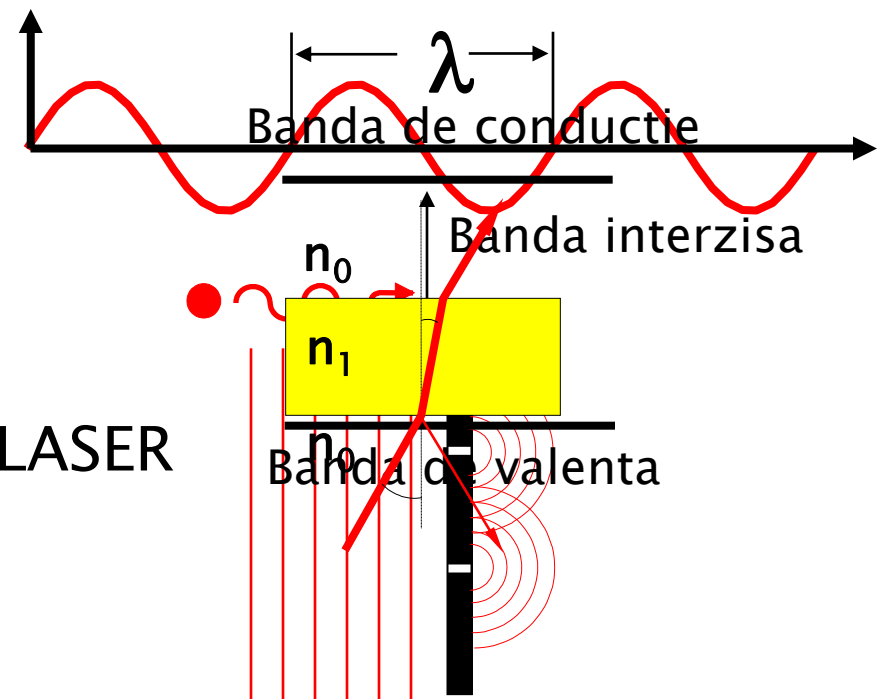
- ▶ Comunicatii
  - Infrarosu (InGaAsP)
- ▶ Vizibil
  - Spectru vizibil (GaAlAs)
- ▶ Iluminare
  - Putere ridicata, lumina alba (GaInN)

# Modelarea luminii

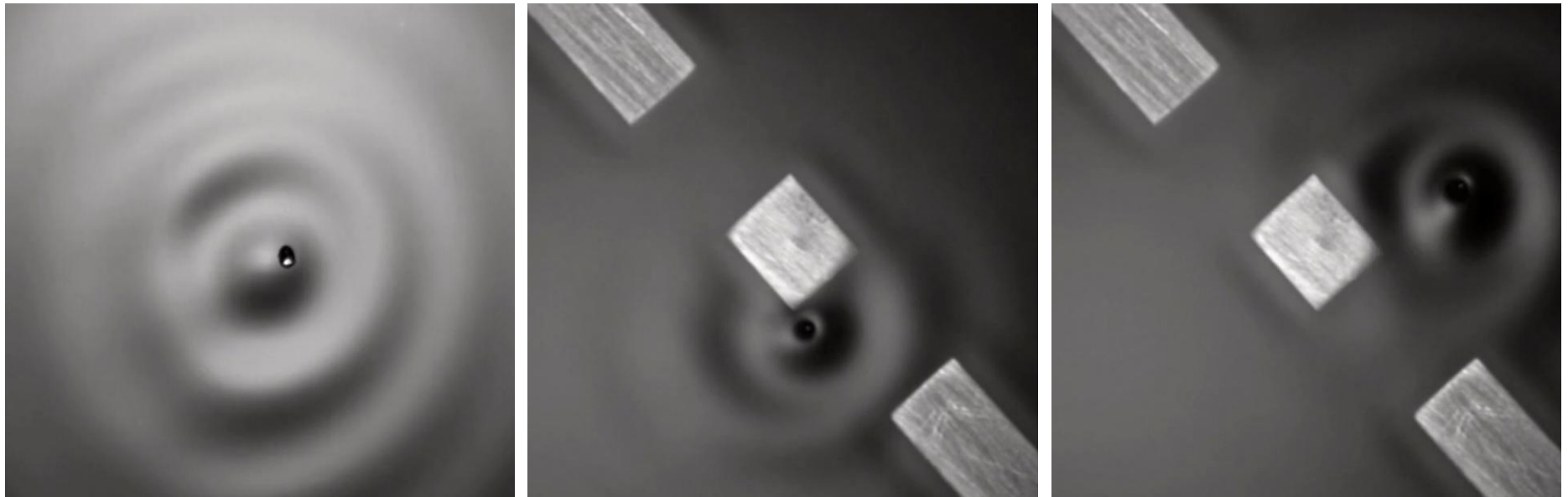
(tot) Capitolul 1

# Modelarea luminii

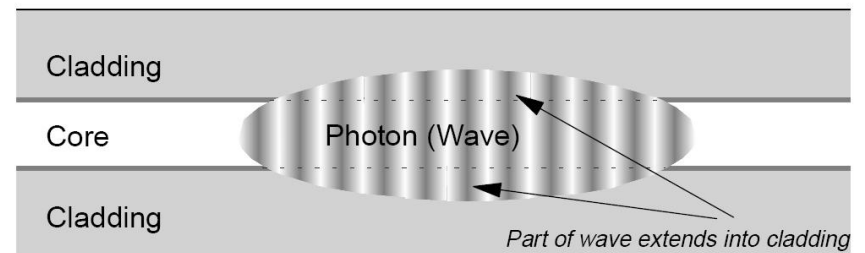
- ▶ Undă electromagnetică
  - Ecuațiile lui Maxwell
  - $\lambda$ ,  $\epsilon$ ,  $\omega$ ,  $f$
- ▶ Teoria cuantică
  - Benzi energetice  $E = h \nu$
  - fotoni, emisie stimulată, LASER
- ▶ Optică geometrică
  - $n$ ,  $\theta$
  - raze de lumină
  - intuitivă



# Modelare



Through the Wormhole  
S02E07 How Does the Universe Work





# Lumina ca undă electromagnetică

Capitolul 2

# 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

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

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

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

# Câmpuri electromagnetice cu variație armonică în timp

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

## ► Simplificarea ecuațiilor lui Maxwell

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

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

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

$$\nabla \cdot H = 0$$

## ► Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

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

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

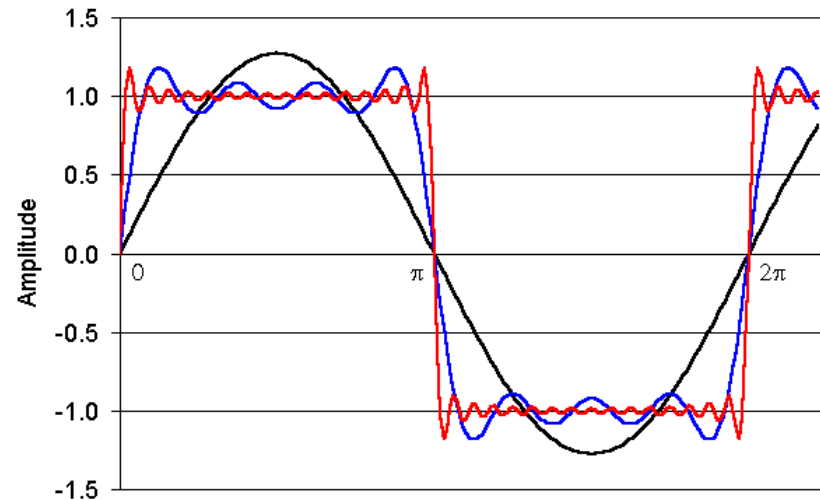
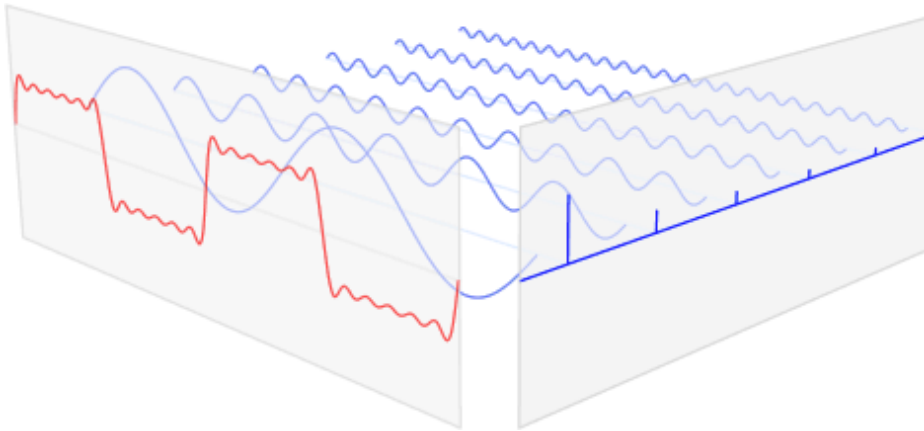
$$\gamma^2 = -\omega^2 \epsilon \mu + j\omega \mu \sigma$$

$\gamma$  – Constanta de propagare

# Modele matematice

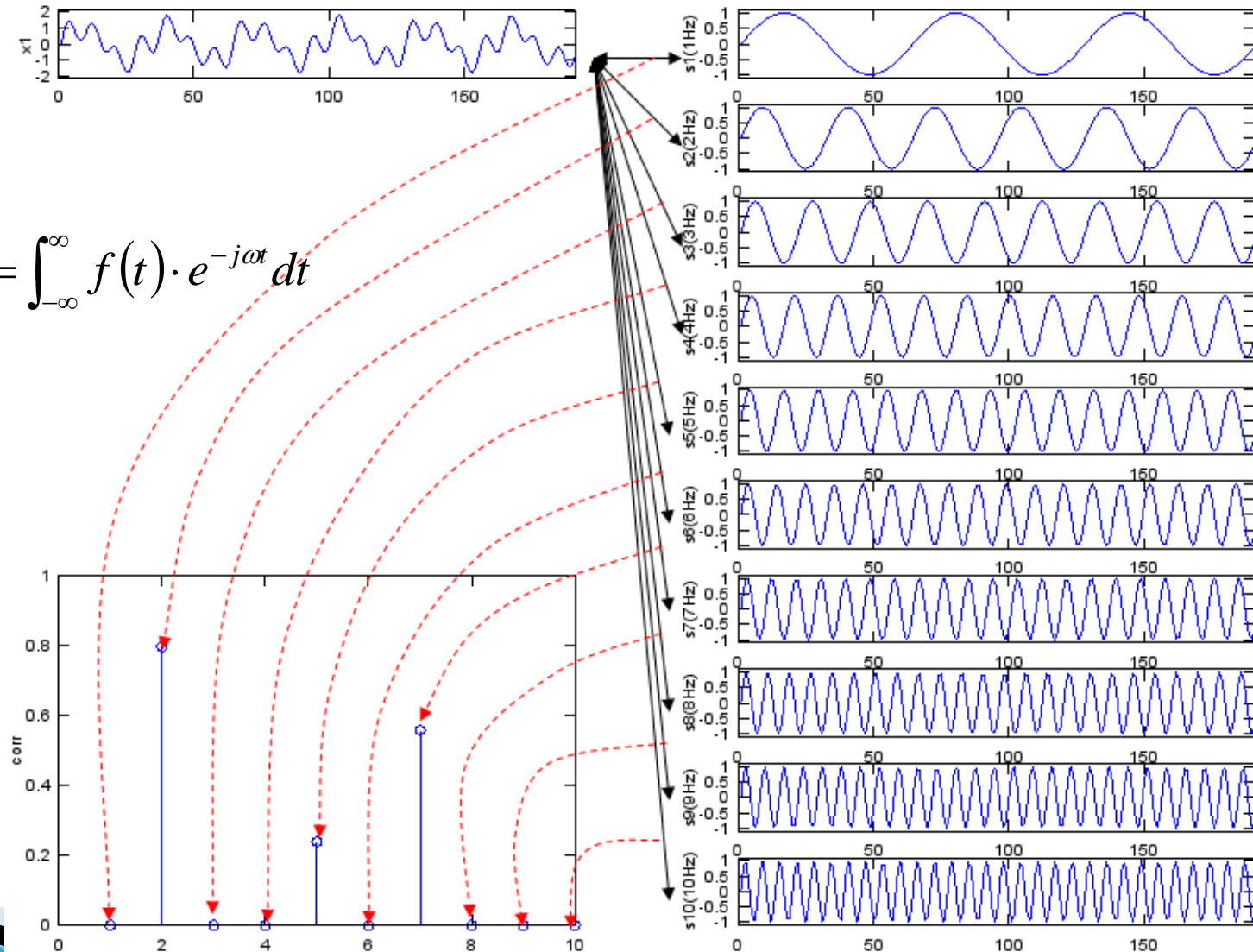
- ▶ cazuri particulare in care exista rezolvare analitica
  - semnale cu variație armonică în timp, transformata Fourier, spectru

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

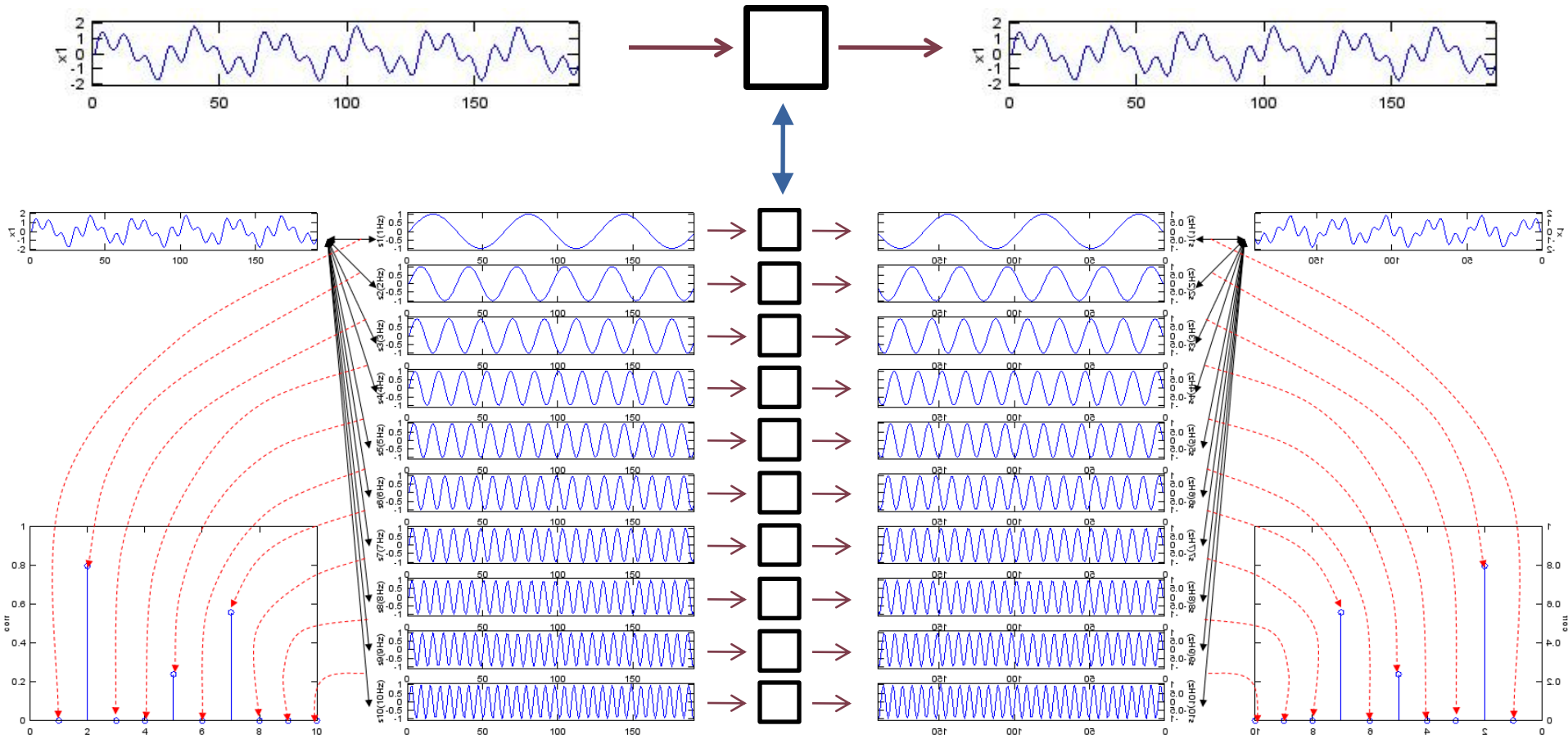


# Modelle matematiche

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



# Modelle matematiche



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

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

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

# Câmpuri electromagnetice cu variație armonică în timp

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

## ▶ Simplificarea ecuațiilor lui Maxwell

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

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

$$\nabla \cdot H = 0$$

## ▶ Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

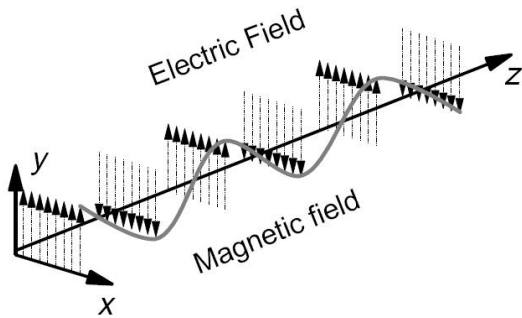
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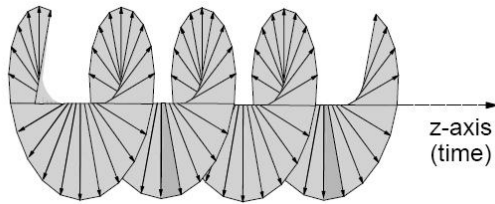
$$\gamma^2 = -\omega^2 \epsilon \mu + j \omega \mu \sigma$$

$\gamma$  – Constanta de propagare

# Solutia ecuatiilor de propagare



Propagare



Polarizare circulara

Camp electric dupa directia Oy,  
propagare dupa directia Oz

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

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

Exista numai unda progresiva  $E_+ \Rightarrow A$

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

Camp armonic

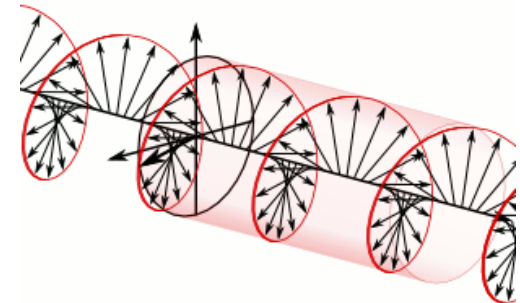
$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t - \beta \cdot z)}$$

Amplitudine

Atenuare

Propagare

(variatie in timp si spatiu)



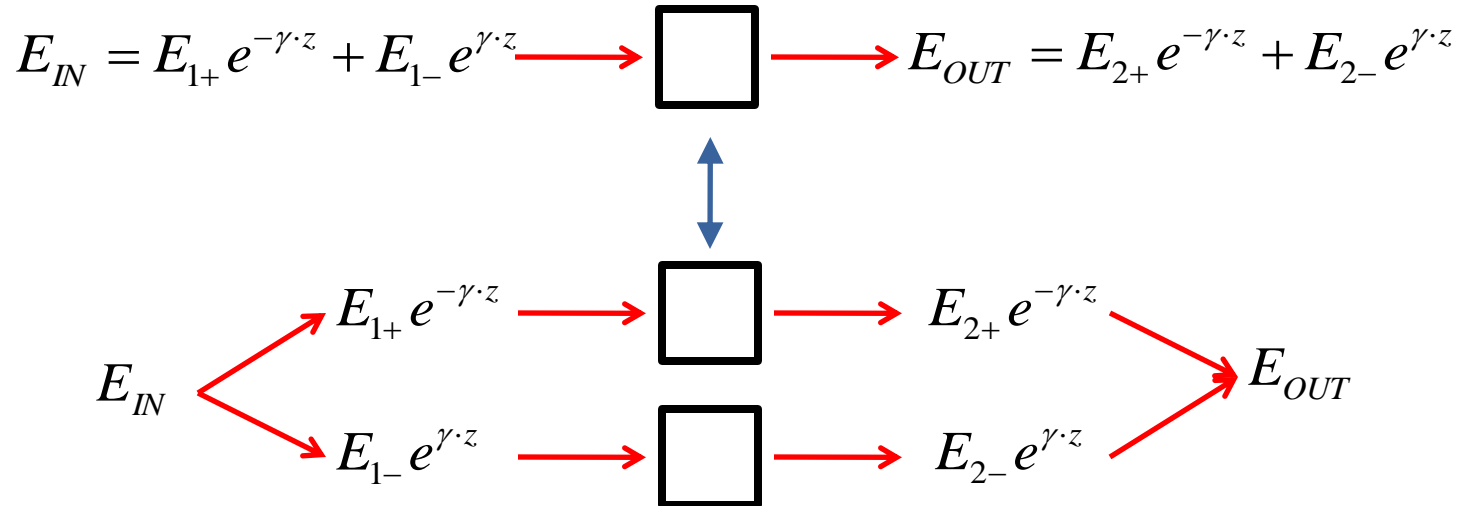


# Modele matematice

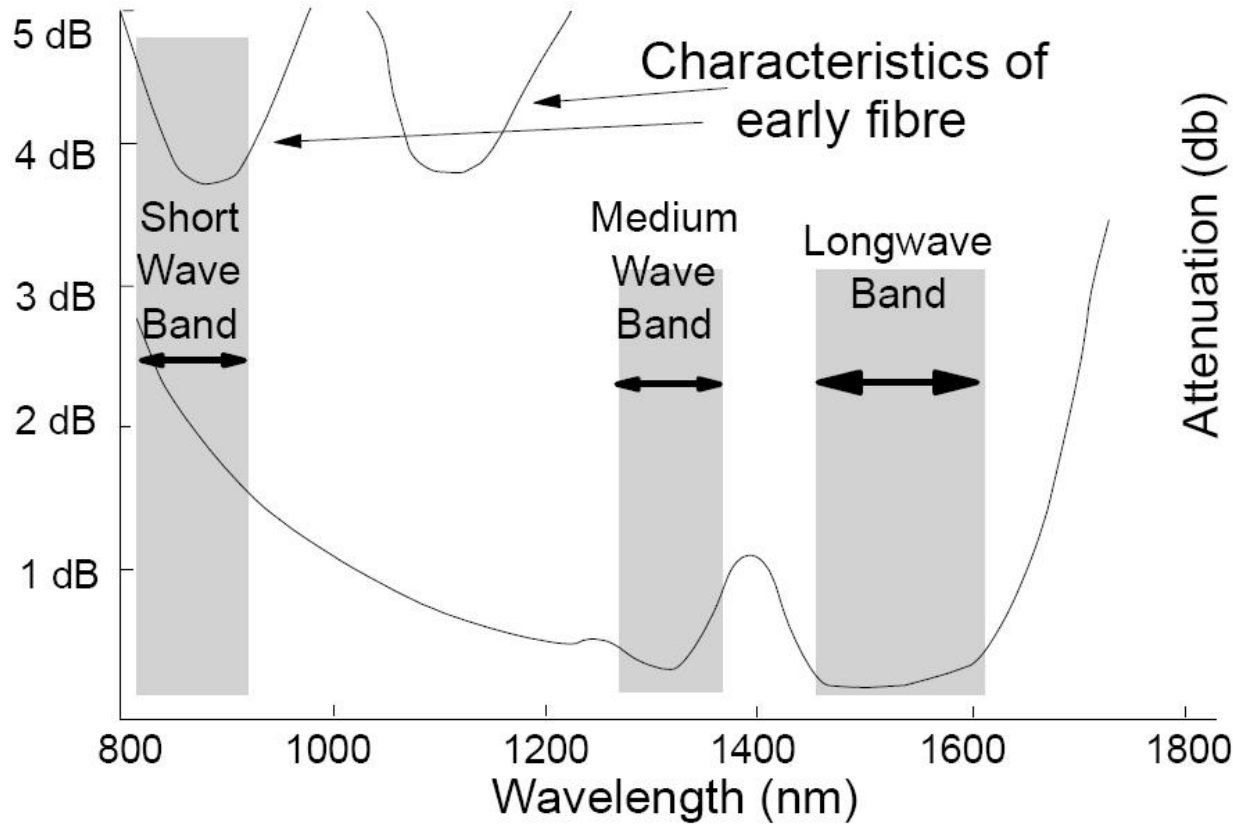
► cazuri particulare in care exista rezolvare analitica

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

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



# Atenuarea pe 1 km in $\text{SiO}_2$



# Atenuare

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

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

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

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

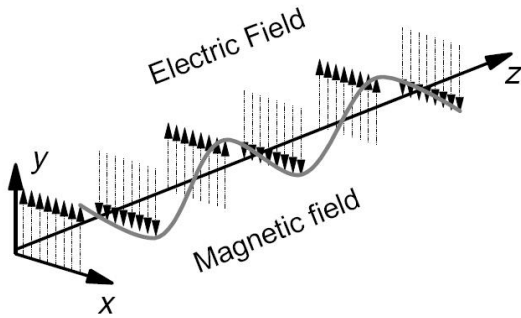
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[ e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

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

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

- ▶ 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,  $\sigma = 0$        $\gamma = j\omega \cdot \sqrt{\epsilon\mu}$

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

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

# 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 $\varepsilon_r$

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

$$n = \sqrt{\varepsilon_r} \quad \text{Indice de refractie al mediului} \quad c = \frac{c_0}{n}$$

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

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

$$\lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$



# Parametri, dependenta de mediu

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega$$

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

$n = 1$

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

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

$$\eta = \frac{\eta_0}{n}$$

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

$n = \sqrt{\varepsilon_r}$

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

$$\lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

$$\lambda = \lambda(n)$$

$$f = \text{indep.}$$

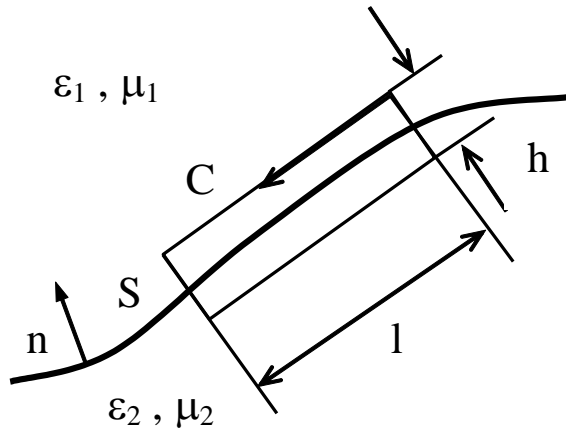
ITU G.692

"the allowed channel frequencies are based on a 50 GHz grid with the reference frequency at 193.10 THz"

SI

"a source that emits monochromatic radiation of frequency  $540 \cdot 10^{12}$  Hz"

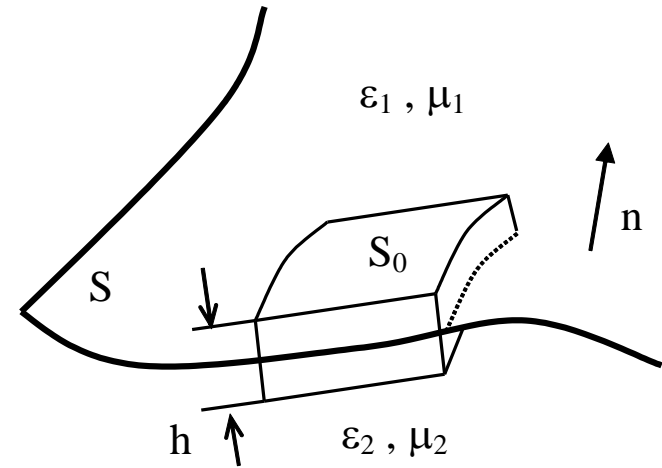
# Condiții la limita de separație între două medii



a)

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

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



b)

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

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

# Moduri in medii delimitate

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

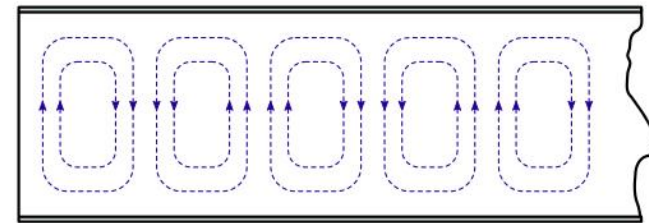
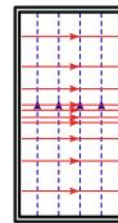
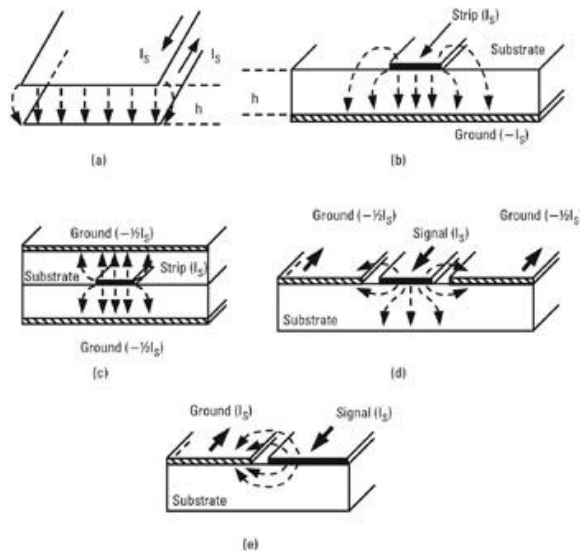
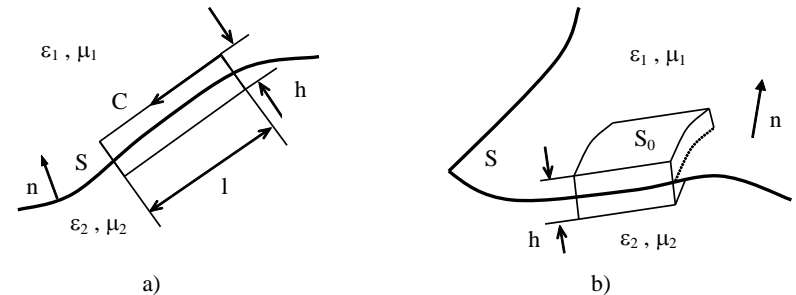
$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

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

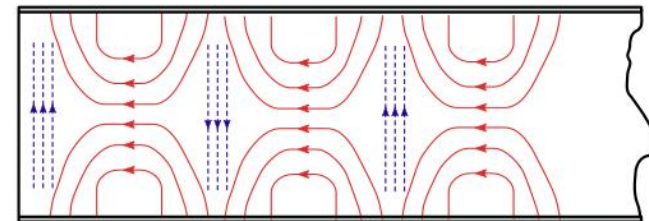
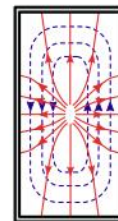


# Moduri in medii delimitate

- ▶ Câmpul electric trebuie sa fie perpendicular pe un perete metalic sau nul
- ▶ Câmpul magnetic trebuie sa fie tangent la un perete metalic sau nul



TE<sub>10</sub>



TM<sub>11</sub>

# Moduri in medii delimitate

TE10

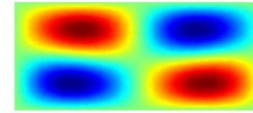
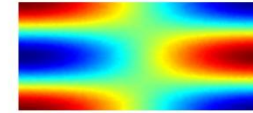
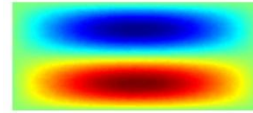
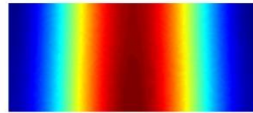
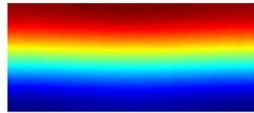
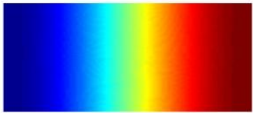
TE01

TE20

TM12

TE12

TM22



TM11

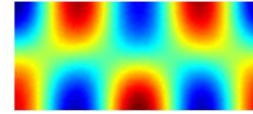
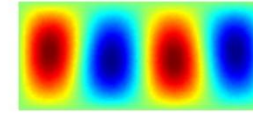
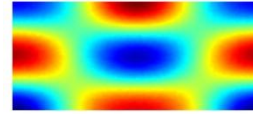
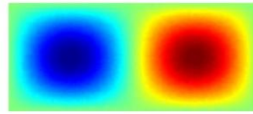
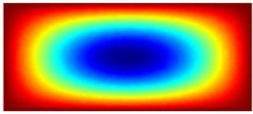
TE11

TM21

TE22

TM41

TE41



TE21

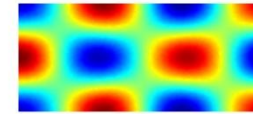
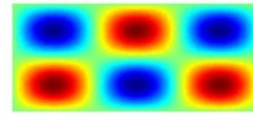
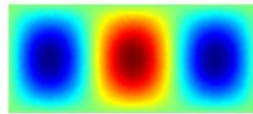
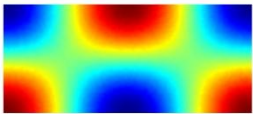
TE30

TM31

TM32

TE32

TE50



TE31

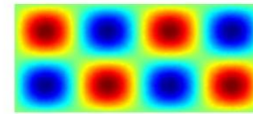
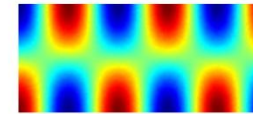
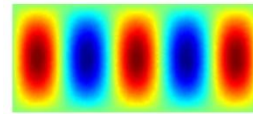
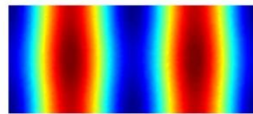
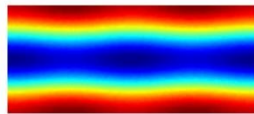
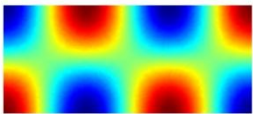
TE02

TE40

TM51

TE51

TM42



► Similar cu transformata Fourier

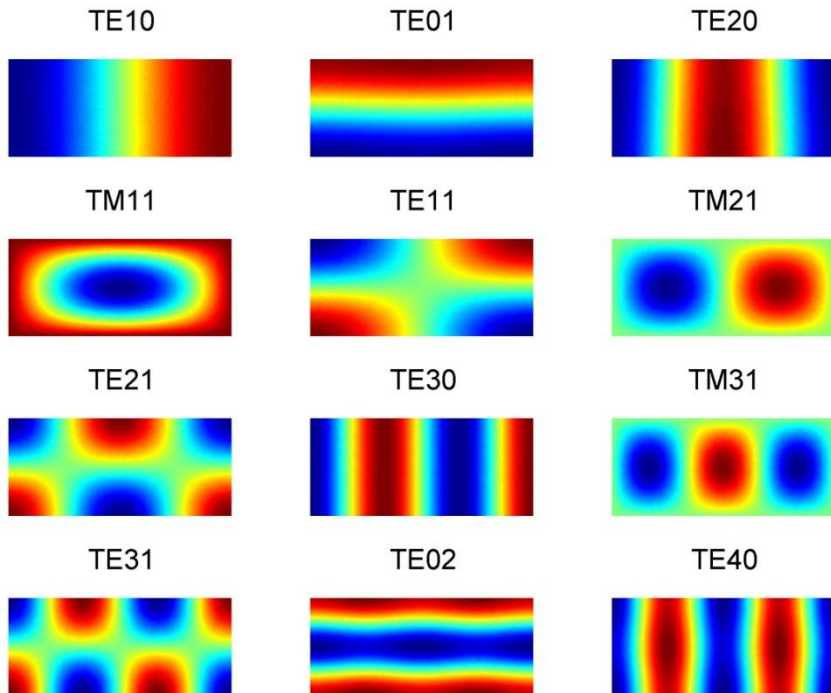
$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

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

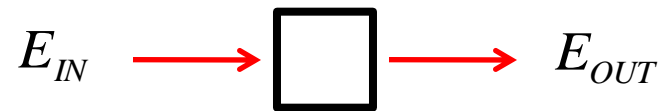
$$A_i = \langle E, Mod_i \rangle$$

# Modele matematice

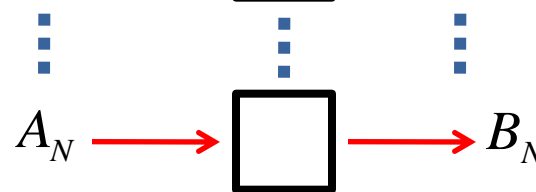
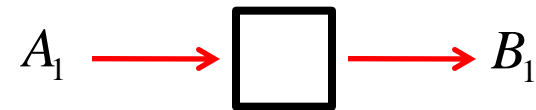
- ▶ cazuri particulare in care exista rezolvare analitica
  - moduri in medii delimitate



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



$$A_i = \langle E_{IN}, Mod_i \rangle$$



$$E_{OUT} = \sum_1^N B_i \cdot Mod_i$$

# Ghid cilindric dielectric

- ▶ Ecuațiile lui Maxwell in coordonate cilindrice

$$\frac{\partial^2 U}{\partial r^2} + \frac{1}{r} \frac{\partial U}{\partial r} + \frac{1}{r^2} \frac{\partial^2 U}{\partial \phi^2} + \frac{\partial^2 U}{\partial z^2} + n^2 k_o^2 U = 0$$

a – raza miezului  
U – E(r) sau H(r)

$$U(r, \phi, z) = u(r) e^{-jl\phi} e^{-j\beta z}, \quad l = 0, \pm 1, \pm 2, \dots$$

$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} + \left( n^2(r) k_o^2 - \beta^2 - \frac{l^2}{r^2} \right) u = 0$$

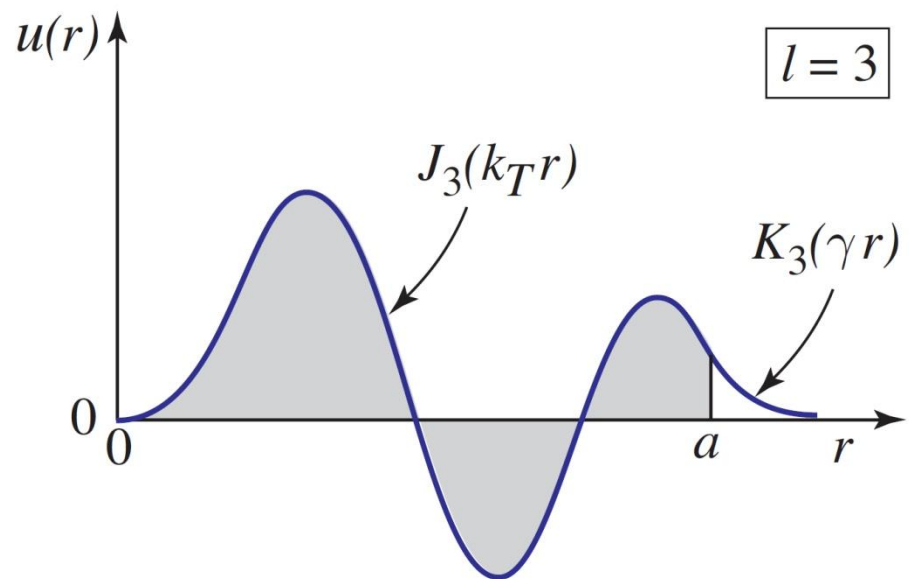
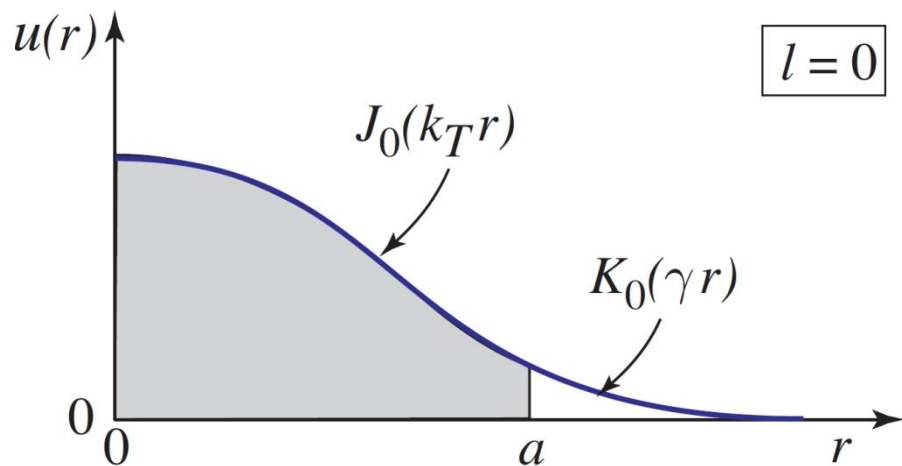
$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} + \left( k_T^2 - \frac{l^2}{r^2} \right) u = 0, \quad r < a$$

$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} - \left( \gamma^2 + \frac{l^2}{r^2} \right) u = 0, \quad r > a$$

# Ghid cilindric dielectric

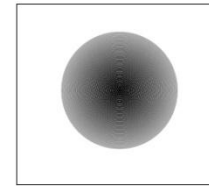
- ▶ soluții proporționale cu funcții Bessel

$$u(r) \propto \begin{cases} J_l(k_T r), & r < a \quad (\text{core}) \\ K_l(\gamma r), & r > a \quad (\text{cladding}) \end{cases}$$

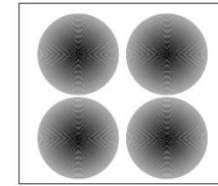


# Moduri in fibra

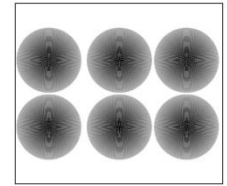
- ▶ Moduri in ghid rectangular



TEM<sub>00</sub>

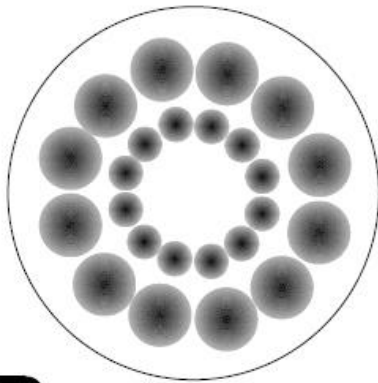


TEM<sub>11</sub>

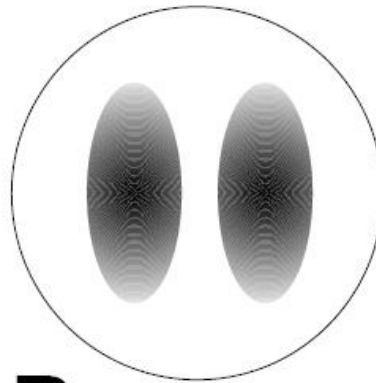


TEM<sub>21</sub>

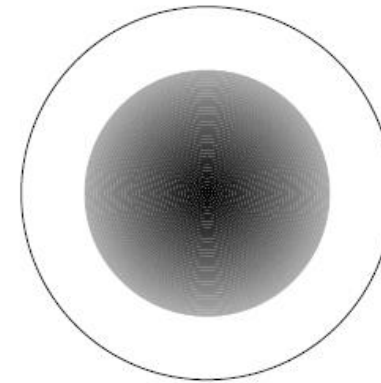
- ▶ Moduri linear polarizate in fibra



LP<sub>62</sub>

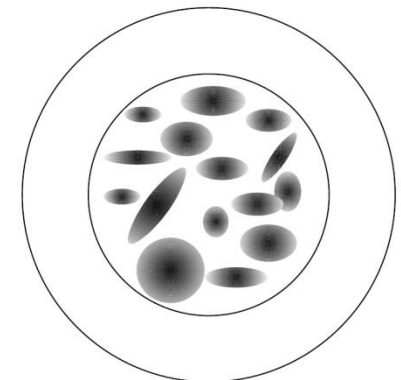


LP<sub>11</sub>



LP<sub>01</sub>

“Sparkle” pattern



# Dispersia

- ▶ In medii dispersive  $\beta = \beta(\omega)$ ,  $n = n(\omega)$

$$\frac{d\beta}{d\omega} = \frac{d}{d\omega} \left( \frac{\omega \cdot n}{c} \right) = \frac{1}{c} \left( n + \omega \frac{dn}{d\omega} \right)$$

$$\frac{d\beta}{d\omega} = -\frac{\lambda}{\omega} \cdot \frac{d\beta}{d\lambda} = \frac{1}{c} \left( n - \lambda \frac{dn}{d\lambda} \right) = \tau \quad (s/m)$$

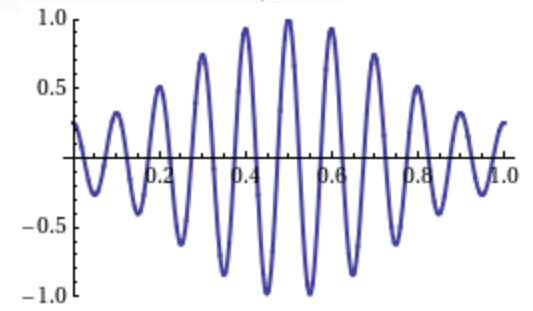
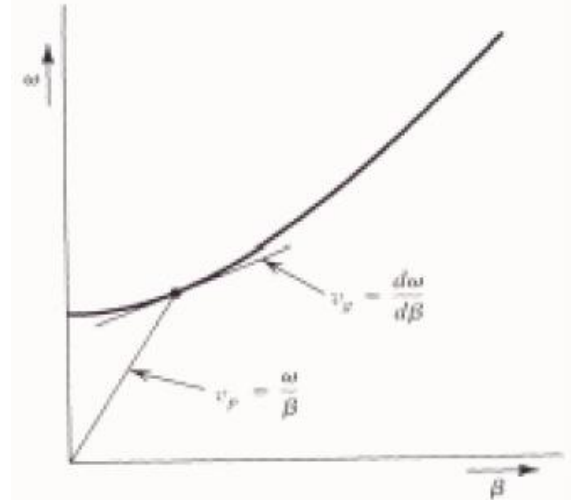
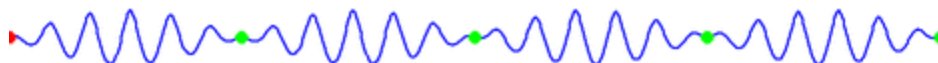
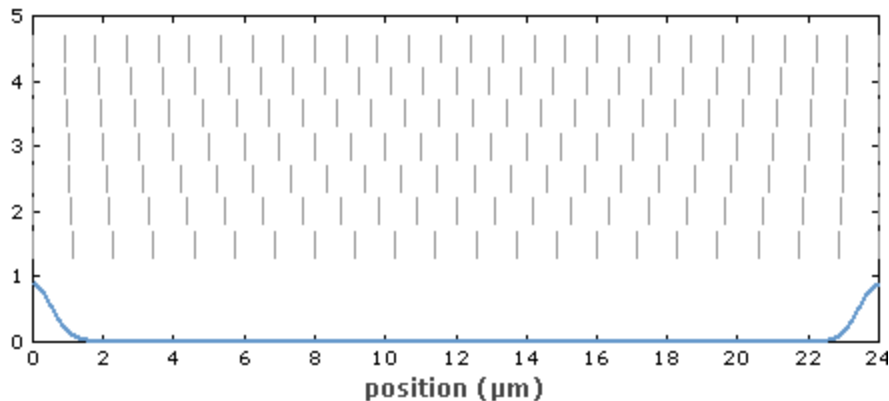
$$D = \frac{d\tau}{d\lambda} = \frac{1}{c} \left( \frac{dn}{d\lambda} - \lambda \frac{d^2n}{d\lambda^2} - \frac{dn}{d\lambda} \right) = -\frac{\lambda}{c} \frac{d^2n}{d\lambda^2} \quad (s/m^2)$$

- ▶ Dispersia se exprima de obicei in **ps/nm/km** si permite aflarea intarzierilor aparute intre "moduri" (latirea impulsurilor) pentru o anumita latime spectrala si o anumita distanta parcursa

$$\Delta\tau = D \cdot \Delta\lambda \cdot L$$

# Viteze de grup si faza

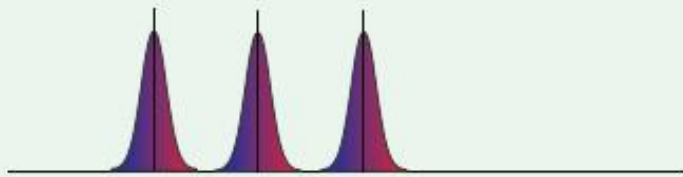
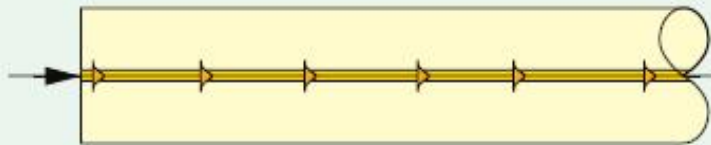
- ▶ Viteza de faza – viteza virtuala cu care circula punctul cu o anumita faza
- ▶ Viteza de grup – viteza cu care circula informatia (energia) – in medii cu dispersie normala



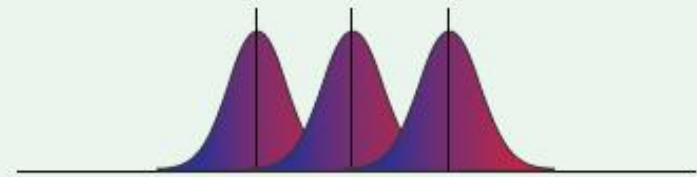
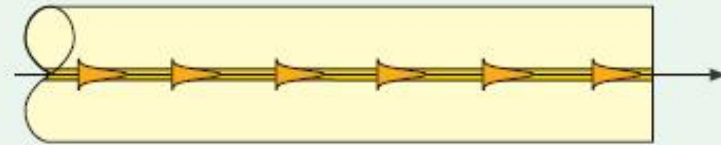


# Dispersie

> 50 km Single-mode step index  
< 10 km Multimode graded index  
< 1 km Multimode step index



Transmission:  
Well-defined pulses but not absolutely monochromatic.  
Typical spectral width < 0.8 nm

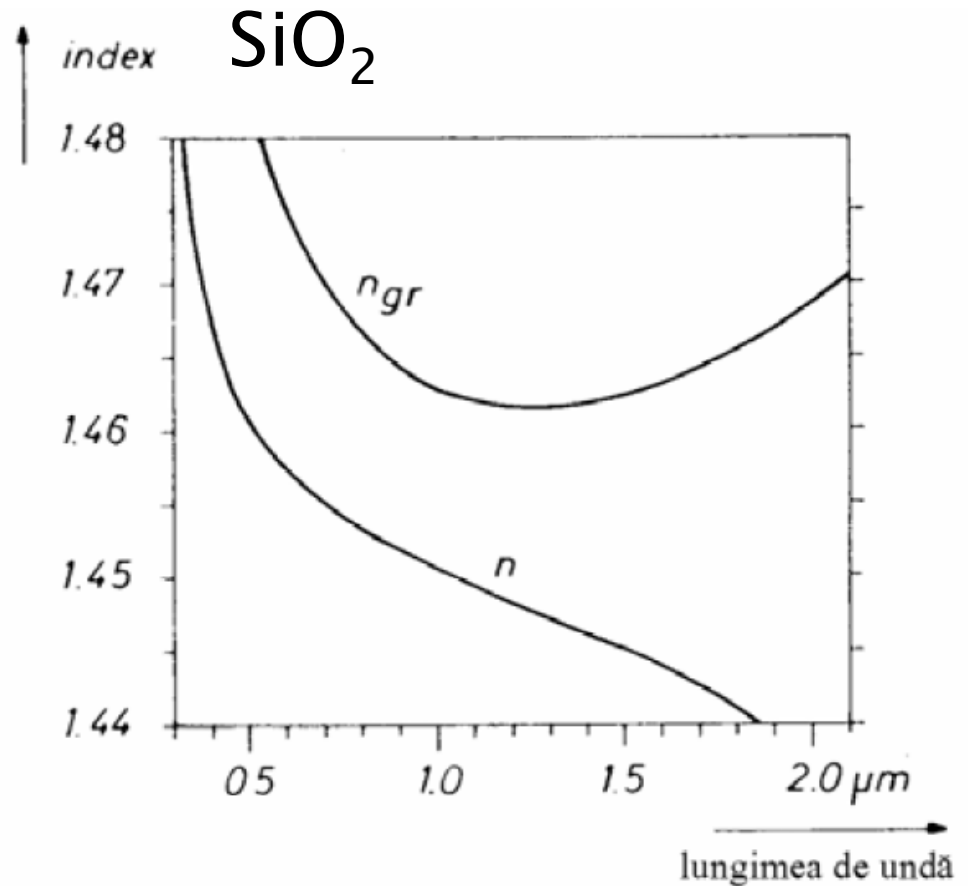


Reception:  
Pulse broadening caused by the laser's spectral width and the difference between the refractive indices of the red and blue ends of the light pulse.

# Dispersie normala

$$n_{gr} = n - \lambda \frac{dn}{d\lambda}$$

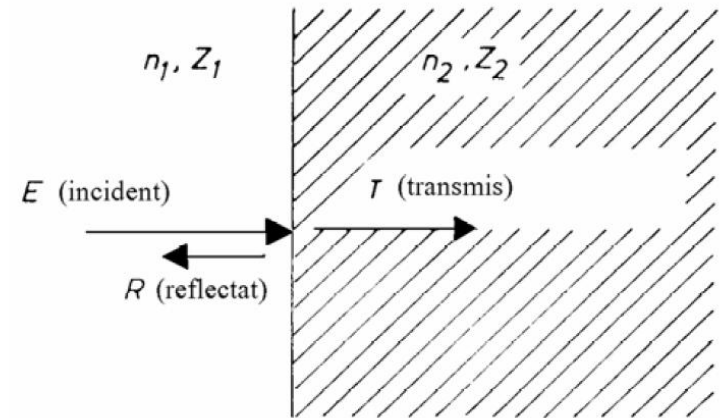
$$D = \frac{d\tau}{d\lambda} = \frac{1}{c} \cdot \frac{dn_{gr}}{d\lambda}$$



# Transmisia puterii între medii

- ▶ incidenta normala
- ▶ reflexia in amplitudine

$$Z = \frac{Z_0}{n} \quad \Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{n_1 - n_2}{n_1 + n_2}$$



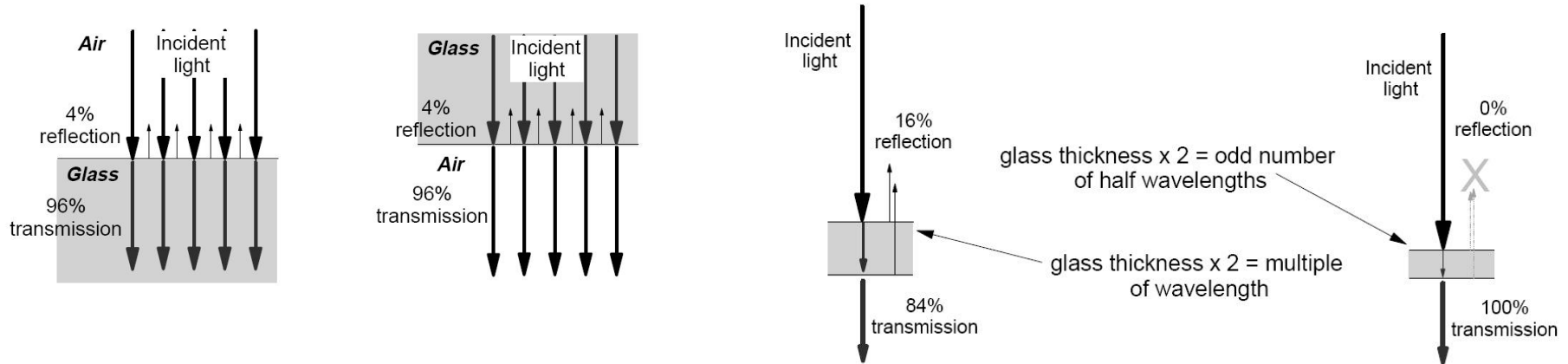
- ▶ densitatea de putere proportionala cu patratul amplitudinii câmpului

$$r = \left( \frac{n_1 - n_2}{n_1 + n_2} \right)^2 \quad t = \left( \frac{2n_1}{n_1 + n_2} \right)^2$$

- ▶ interfata aer–sticla ( $n_1 = 1$ ,  $n_2 = 1.5$ )

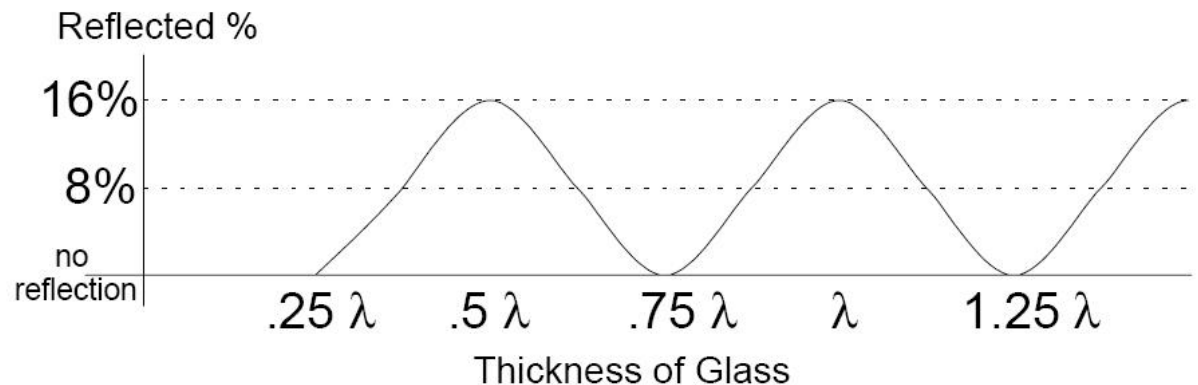
$$r = 0.04 = 4\%$$

# Transmisia printr-o lamela



$$\Gamma = \frac{1.5 - 1}{1.5 + 1} = 0.2; \quad r = \Gamma^2 = 0.04 = 4\% \quad \Gamma_{\max} = 0.2 + 0.2; \quad r_{\max} = \Gamma_{\max}^2 = 0.16 = 16\%$$

- ▶ apare interferența între diversele unde reflectate
- ▶ se adună câmpurile nu puterile
- ▶ lamele antireflexive

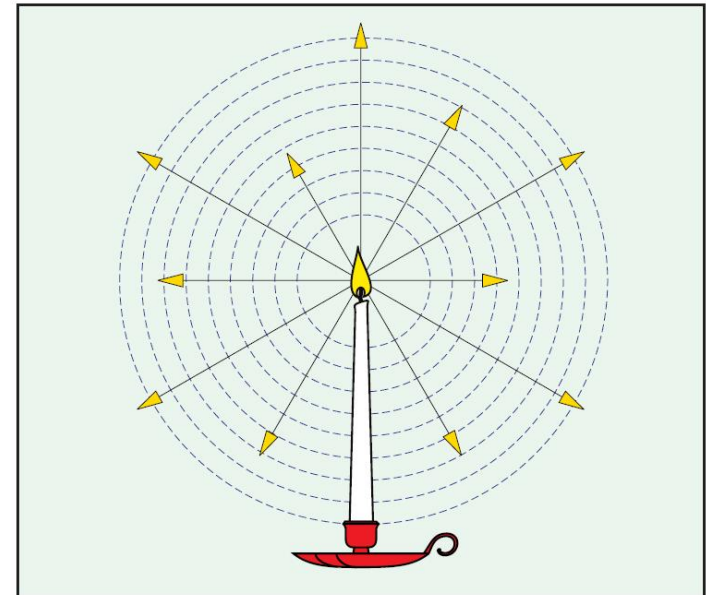
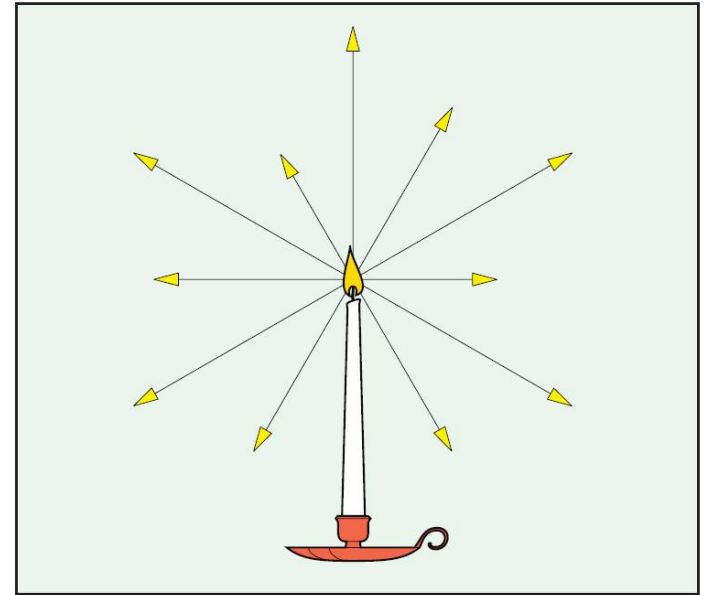


# Optică geometrică

(tot) Capitolul 2

# Raze de lumina

- ▶ Lumina este constituita din raze care se propaga in linie dreapta in medii omogene
- ▶ Sursa omnidirecțională: emite similar in toate direcțiile
- ▶ Densitatea de energie luminoasa descrește invers proporțional cu pătratul distantei fata de sursa (energia se împarte uniform pe suprafața întregii sfere)



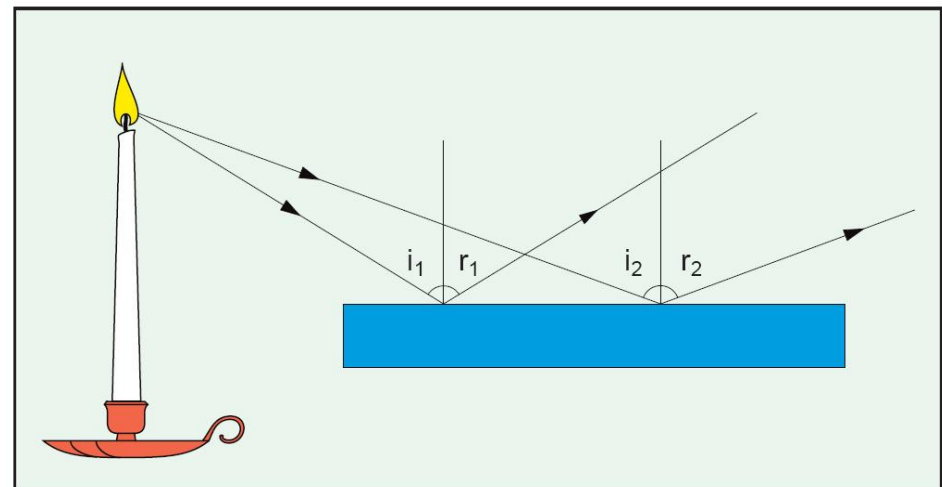
$$P = \frac{P_0}{r^2}$$

# Reflexia luminii

- ▶ la suprafata de separatie dintre doua medii, (o parte din) lumina se intoarce in mediul de incidenta
- ▶ unghiul dintre raza incidenta si normala ( $\phi_i$ ) este egal cu unghiul dintre raza reflectata si normala ( $\phi_r$ )

## ▶ Legea reflexiei

$$\phi_i = \phi_r$$



# Refractia luminii

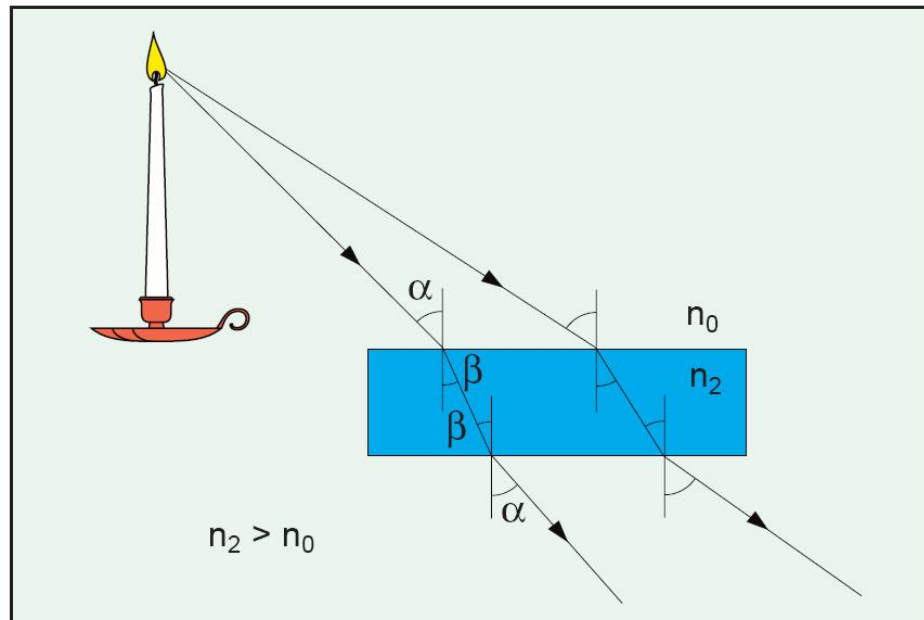
- ▶ la suprafața de separație dintre doua medii, (o parte din) lumina se (poate) propaga in mediul de transmisie sub un unghi diferit de unghiul incident
- ▶ la trecerea in medii mai “dense” (optic) lumina se apropie de normala
- ▶ la trecerea in medii mai “puțin dense” (optic) lumina se depărtează de normala

## ▶ Legea lui Snell (a refracției)

$$n_1 \cdot \sin \phi_i = n_2 \cdot \sin \phi_R$$

$\phi_i$  - unghi incident (in  $n_1$ )

$\phi_R$  - unghi de refracție (in  $n_2$ )





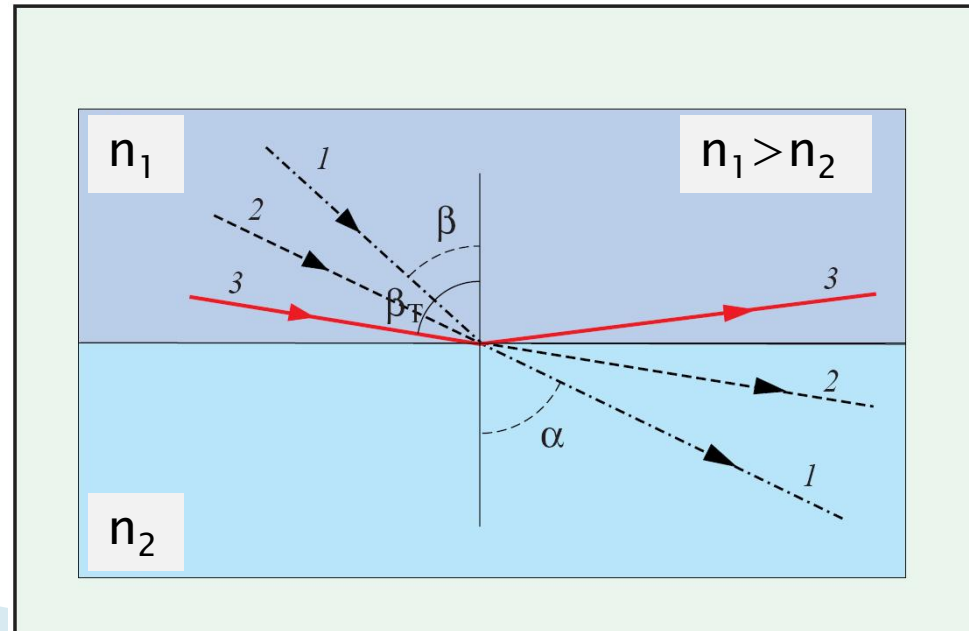
# Reflexia totala

- ▶ Apare **numai când** lumina se propaga dintr-un mediu mai dens optic într-un mediu mai puțin dens
- ▶ La intersecția luminii cu suprafața de separație a doua medii se întâlnesc în general raze reflectate **și** raze refractate
- ▶ Pentru un unghi de incidență numit **unghi critic**, raza refractată se obține în lungul suprafeței de separație
- ▶ Pentru orice unghi mai mare decât unghiul critic există numai raza reflectată

$$n_1 > n_2; \quad \phi_R = 90^\circ$$

$$n_1 \cdot \sin \phi_C = n_2$$

$$\phi_C = \arcsin\left(\frac{n_2}{n_1}\right)$$

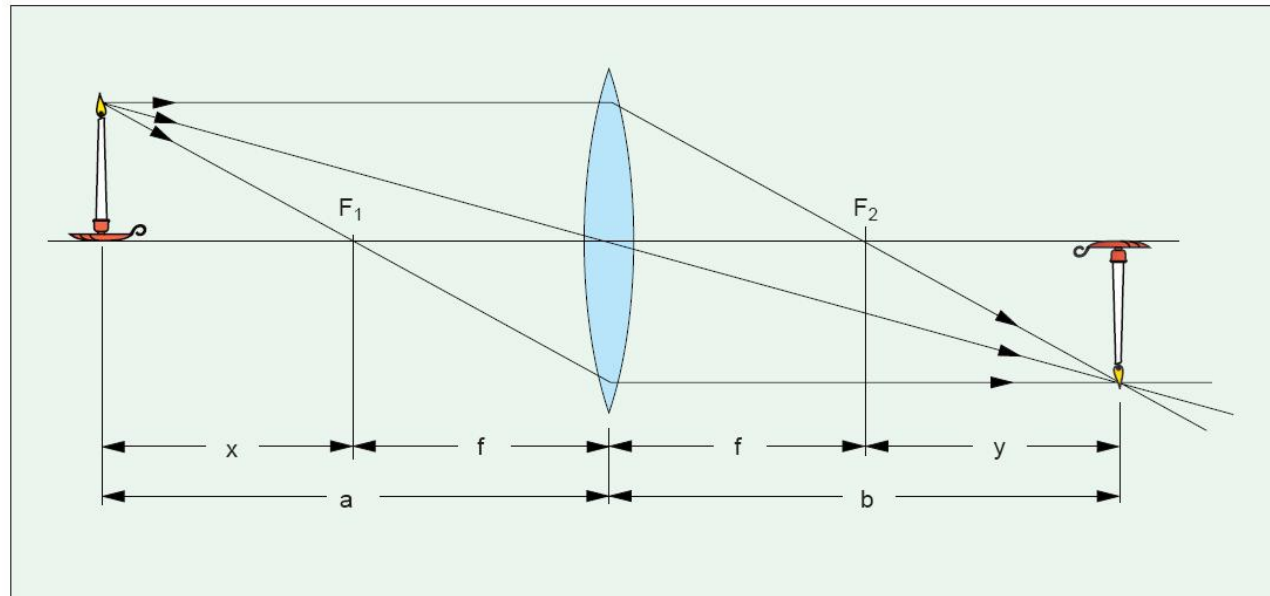


# Lentile

- ▶ Razele de lumina paralele sunt concentrate intr-un punct numit focar, aflat la **distanta focala** de planul lentilei
- ▶ O sursa omnidirectionala positionata in focar va permite obtinerea unui fascicul paralel

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

$$x \cdot y = f^2$$



# Contact

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