

Optoelectronică

Curs 3

2020/2021

Disciplina 2020/2021

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – conf. **Radu Damian**
 - an IV μE
 - Miercuri 11–14, online, Microsoft Teams
 - E – 70% din nota (50+20), online, rf-opto
 - **20% test la curs**, saptamana 4–5?
 - probleme + (? 1 subiect teorie) + (2p prez. curs)
 - toate materialele permise
- ▶ Laborator – **sl. Daniel Matasaru**
 - an IV μE
 - Marti 10-14 impar/par
 - L – 30% din nota (+Caiet de laborator)

Orar 2020/2021

▶ Curs

- Miercuri 11–14, online
- **2C ⇒ 3C**
 - $14 * 2/3 \approx 9.33$
 - $9 \div 10 C \approx 9C + E$

Online

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

English | Romana |

Start Didactic Master Colectiv Cercetare Stud

Note Lista Studenti Examene Fotografii

POPESCU GOPO ION

Fotografia nu exista

Date:

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

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

Note obtinute

Inca nu a fost notat.

Start Didactic Master Colectiv C

Note Lista Studenti Examene Fotografii

Identificare

Introduceti numele si adresa de email utilizata la inscriere

Nume
POPESCU GOPO

E-mail/Parola

Introduceti codul afisat mai jos

4db4457

Trimite

Online

► acces email/parola

Start Didactic Master Colectiv

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POPESCU GOPO ION

Fotografia nu exista

Date:

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

Se acceseaza site-ul [ca acest student!](#)

Start Didactic Master Colectiv

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Fotografia nu exista

Date:

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

Se acceseaza site-ul [ca acest student \(inclusiv examene\)!](#)

Parola

▶ primita prin email

Important message from RF-OPTO

Inbox x



Radu-Florin Damian

to me, POPESCU

Romanian > English Translate message



Laboratorul de Microunde si Optoelectronica
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei
Universitatea Tehnica "Gh. Asachi" Iasi

In atentie: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul **rf-opto** este

Parola: [REDACTED]

Identificati-va pe [server](#), cu parola, cat mai rapid, pentru confirmare.

Memorati acest mesaj intr-un loc sigur, pentru utilizare ulterioara

Attention: POPESCU GOPO ION

The password to access the exams on the **rf-opto** server is

Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

Reply

Reply all

Forward

Subject: Important message from RF-OPTO

Correspondents: POPESCU GOPO ION

Validation of MIDCR exam from 02/05/2020

From: Me <rdamian@etti.tuiasi.ro>

Subject: Important message from RF-OPTO

To: [REDACTED]

Cc: Me <rdamian@etti.tuiasi.ro>

Laboratorul de Microunde si Optoelectronica
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei
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Save this message in a safe place for later use

Manual examen online

- ▶ Aplicatia de examen online utilizata intens la:
 - curs (prezenta)
 - miniteste
 - examen

Materials

Other data

[Manual examen on-line](#) (pdf, 2.65 MB, ro, 🇷🇴)

[Simulare Examen](#) (video) (mp4, 65.12 MB, ro, 🇷🇴)

Microwave Devices and Circuits (Englis

Examen online

- ▶ intotdeauna **contratimp**
 - perioada lunga (prezenta curs/rezultate laborator)
 - perioada scurta (teste: 15min, examen: 2h)

Start Didactic Master Colectiv Cercetare **Studenti**

Note Lista Studenti **Examene** Fotografii

Anunț
17:28 (29/04/2020)

Material suport
17:30 (29/04/2020)

Subiecte
17:32 (29/04/2020)

Rezultate
17:35 (29/04/2020)

Finalizare
17:45 (29/04/2020)

Confirmare
17:45 (30/04/2020)

Urmatorul interval de timp in:
01 m 08 s
[Reincarca acum](#)

Anunț

In acest examen se verifica diverse actiuni ale studentilor pentru examen

Ora pe server

Toate examenele sunt bazate pe fusul orar al server-ului (ar putea sa fie diferit de timpul local). Pentru referinta ora pe server este acum:

29/04/2020 17:28:51

Introducere

Capitolul 1

Aplicatii majore

- ▶ Comunicatii

- Infrarosu (InGaAsP)

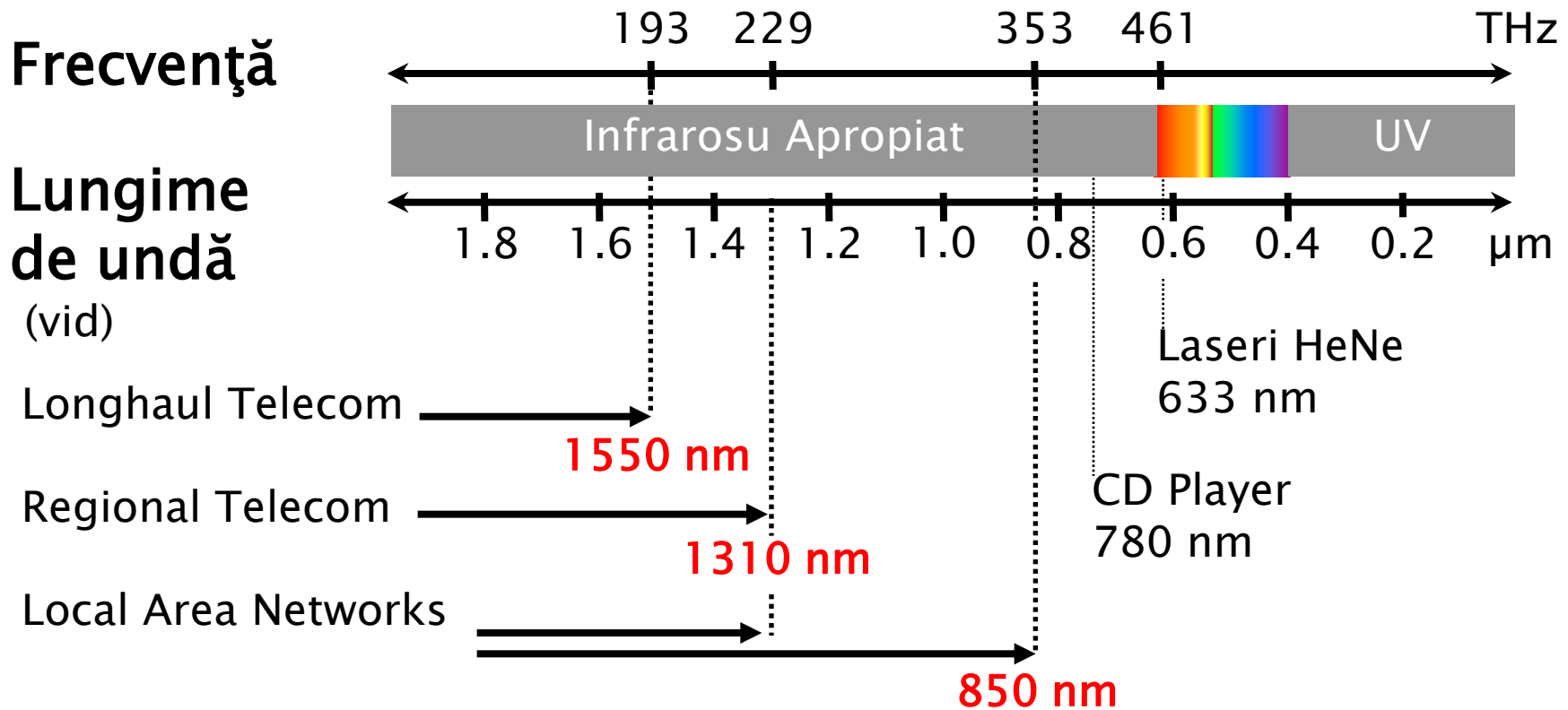
- ▶ Vizibil

- Spectru vizibil (GaAlAs)

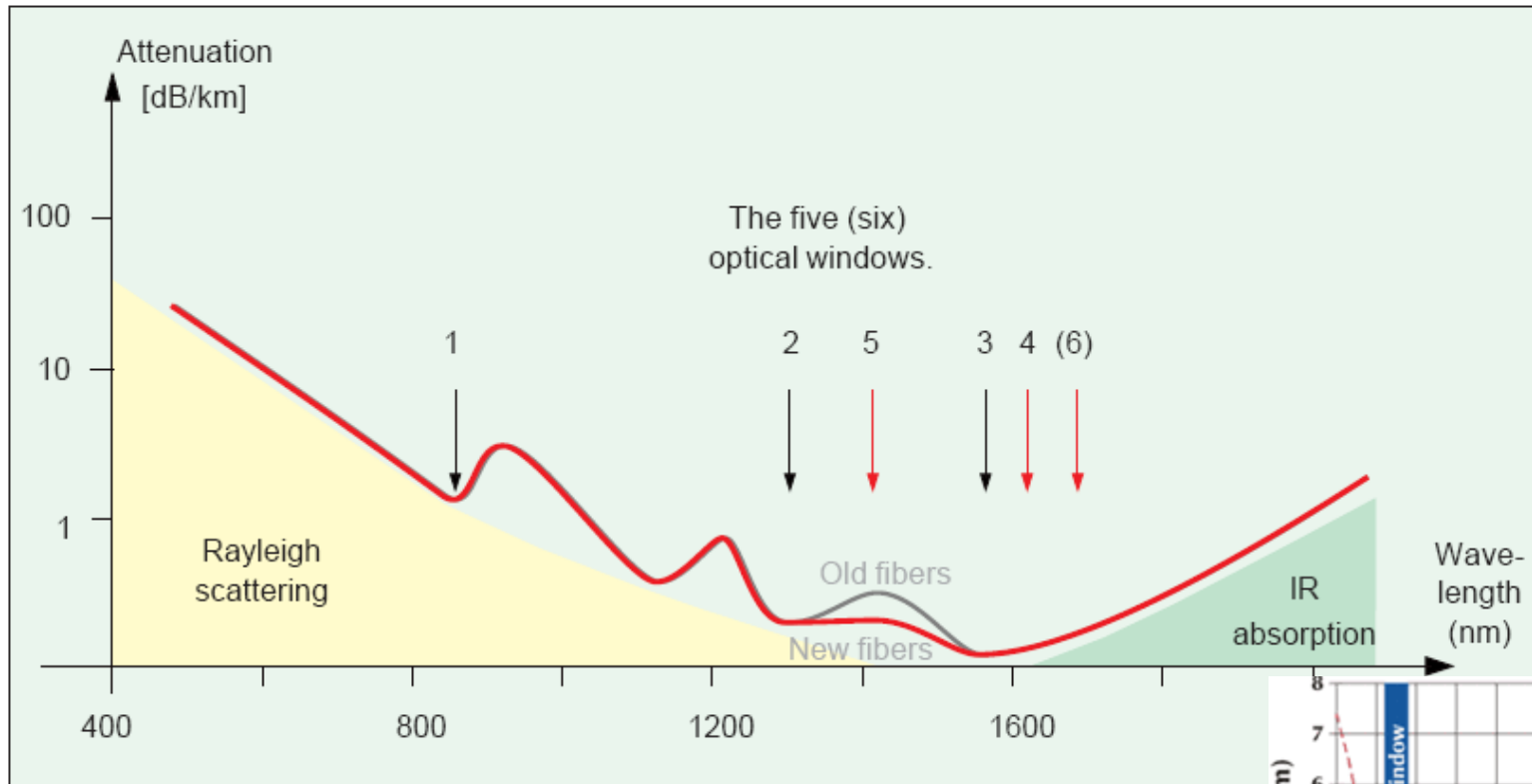
- ▶ Iluminare

- Putere ridicata, lumina alba (GaInN)

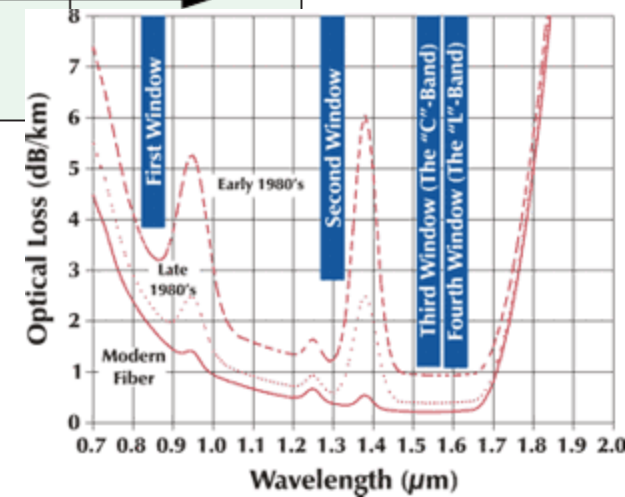
Benzi de lucru in comunicațiile optice



Atenuarea în fibra optică (SiO₂)



850nm, 1310nm, 1550nm



Aplicatii majore

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

Premiul Nobel, Fizica, 2014

Physics



The Nobel Prize in Physics 2014

Summary



The Nobel Prize in Physics 2014

Isamu Akasaki
Hiroshi Amano
Shuji Nakamura

Share this



The Nobel Prize in Physics 2014



© Nobel Media AB. Photo: A. Mahmoud

Isamu Akasaki

Prize share: 1/3



© Nobel Media AB. Photo: A. Mahmoud

Hiroshi Amano

Prize share: 1/3



© Nobel Media AB. Photo: A. Mahmoud

Shuji Nakamura

Prize share: 1/3

The Nobel Prize in Physics 2014 was awarded jointly to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura "for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources."

To cite this section

MLA style: The Nobel Prize in Physics 2014, NobelPrize.org, Nobel Media AB 2021. Tue, 2 Mar 2021.

Aplicatii majore

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

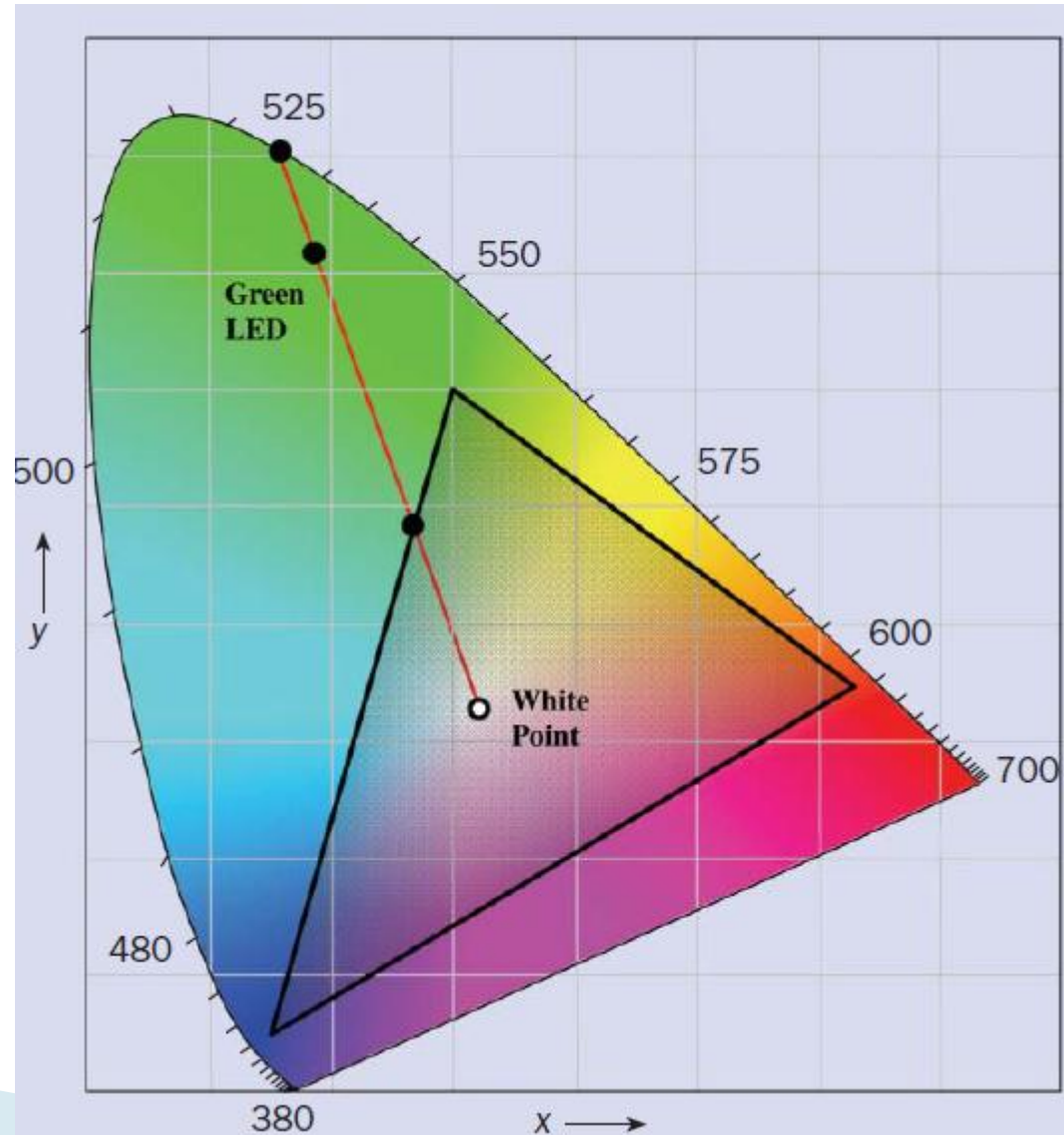
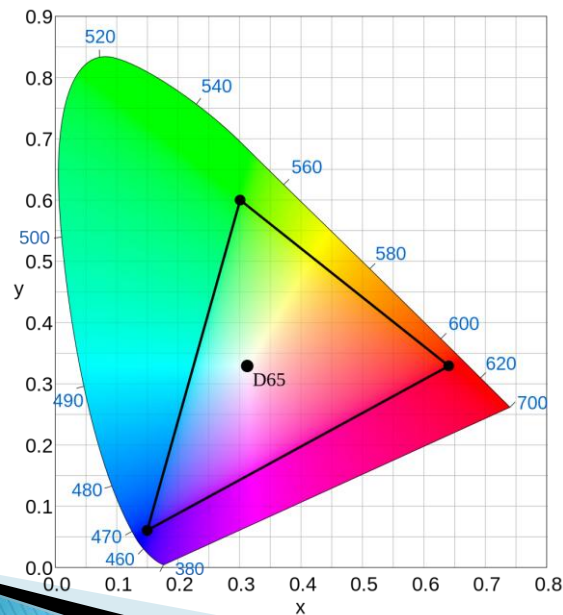
ITU-R BT.709



ITU-R BT.709 phosphor properties

Phosphor	x	y
Red	0.640	0.330
Green	0.300	0.600
Blue	0.150	0.060

Data refers to xy chromaticity co-ordinates of ITU-R BT.709 phosphors which are used in most CRT displays [1].



Spectru vizibil



ITU-R BT.709



RGB values for Luxeon LEDs

LED color	Dominant wavelength λ_D (nm)	RGB values
Royal blue	455	0.05, 0.00, 0.95
Blue	470	0.00, 0.11, 0.89
Cyan	505	0.00, 0.63, 0.37
Green	530	0.00, 0.77, 0.23
Amber	590	0.70, 0.30, 0.00
Red-orange	615	0.97, 0.00, 0.03
Red	625	0.92, 0.00, 0.08

Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

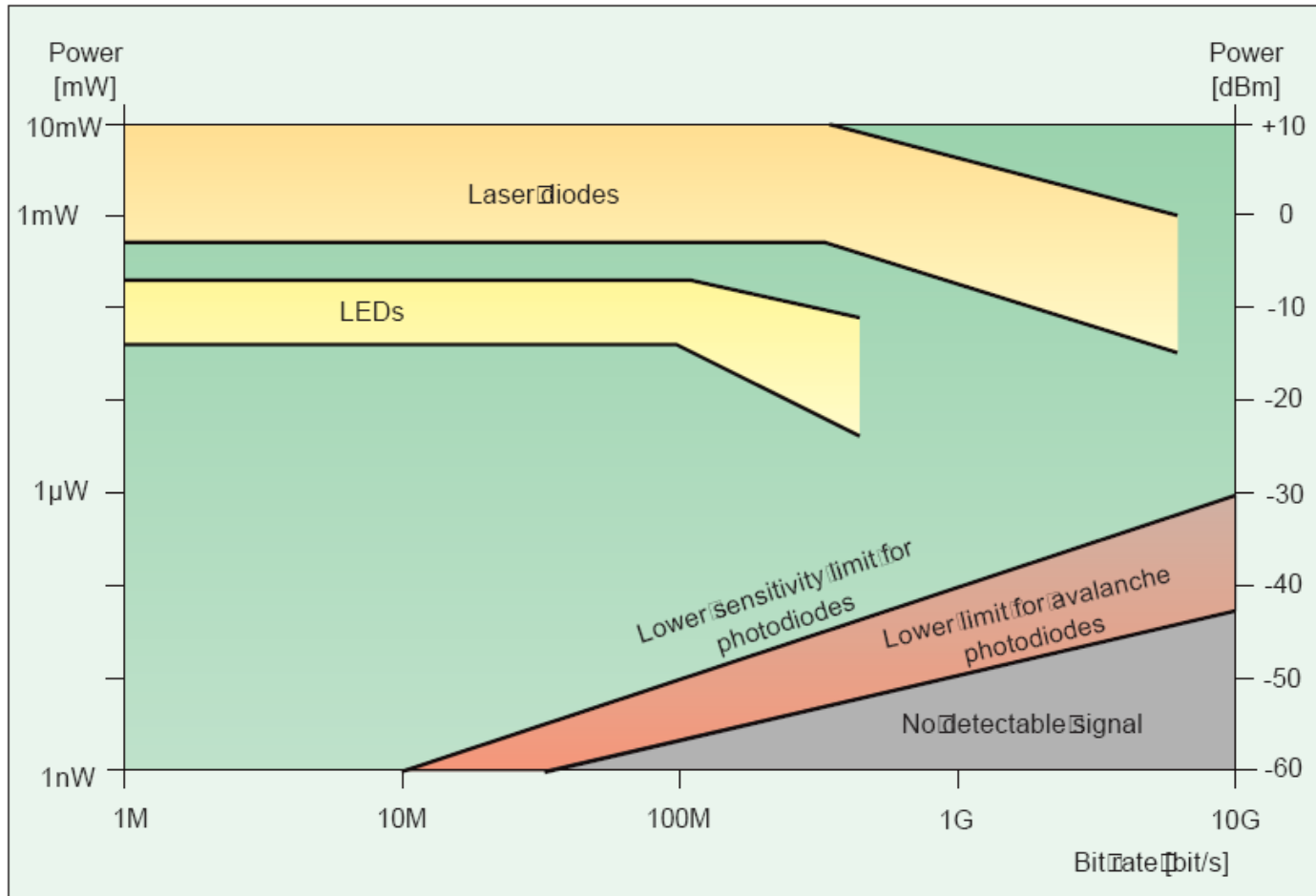
$$-60 \text{ dBm} = 1 \text{ nW}$$

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

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

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

Limite putere/bandă a dispozitivelor optoelectronice

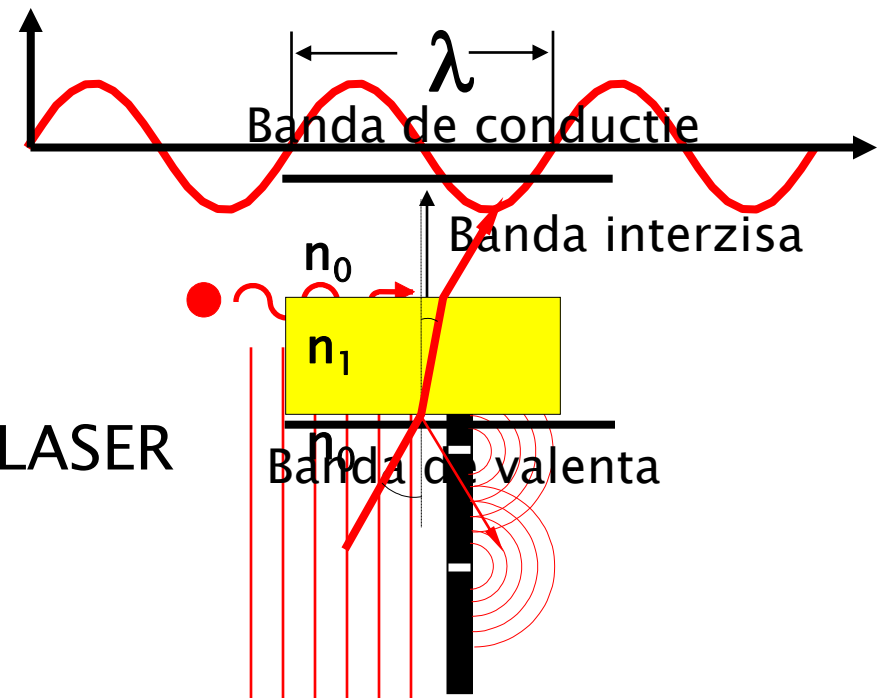


Modelarea luminii

(tot) Capitolul 1

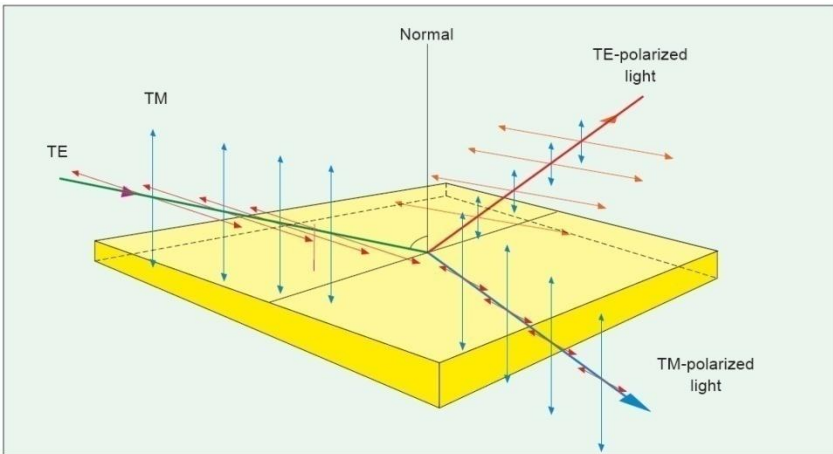
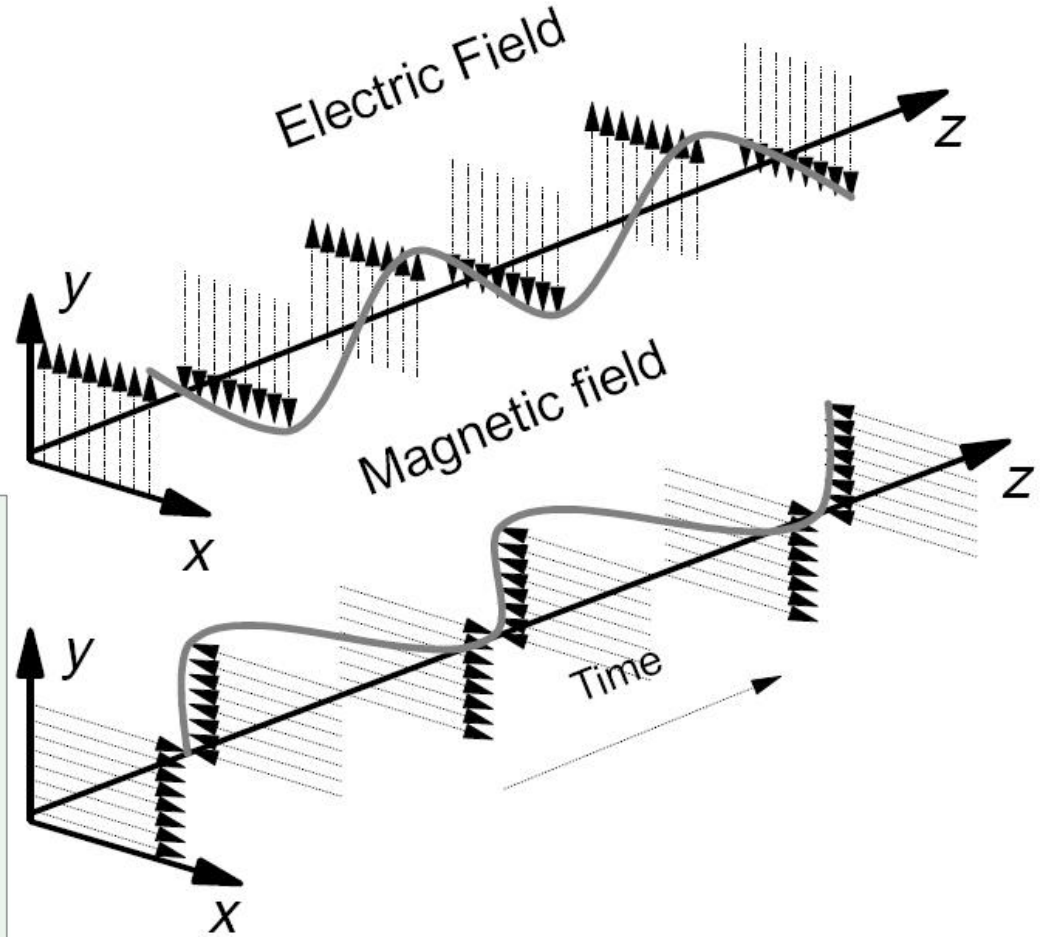
Modelarea luminii

- ▶ Undă electromagnetică
 - Ecuațiile lui Maxwell
 - λ , ϵ , ω , f
- ▶ Teoria cuantică
 - Benzi energetice $E = h \nu$
 - fotoni, emisie stimulată, LASER
- ▶ Optică geometrică
 - n , θ
 - raze de lumină
 - intuitivă

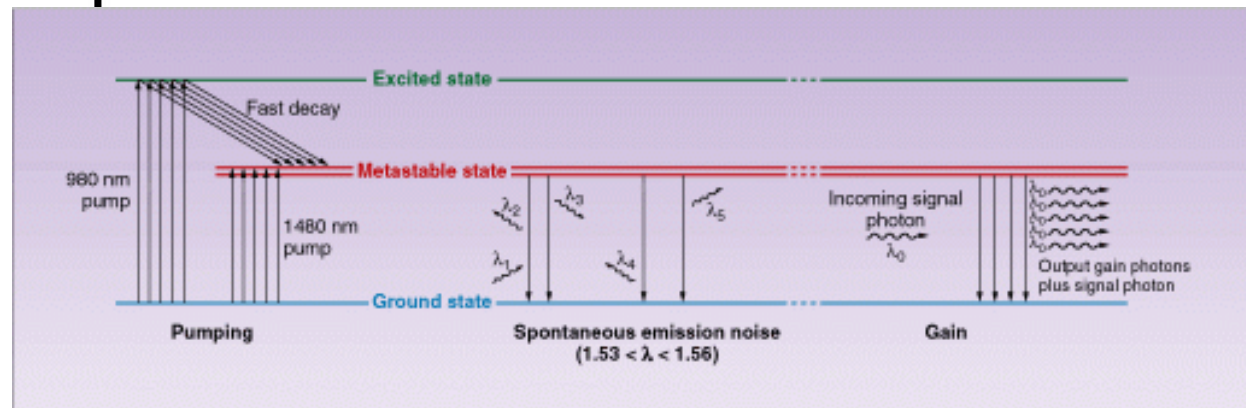
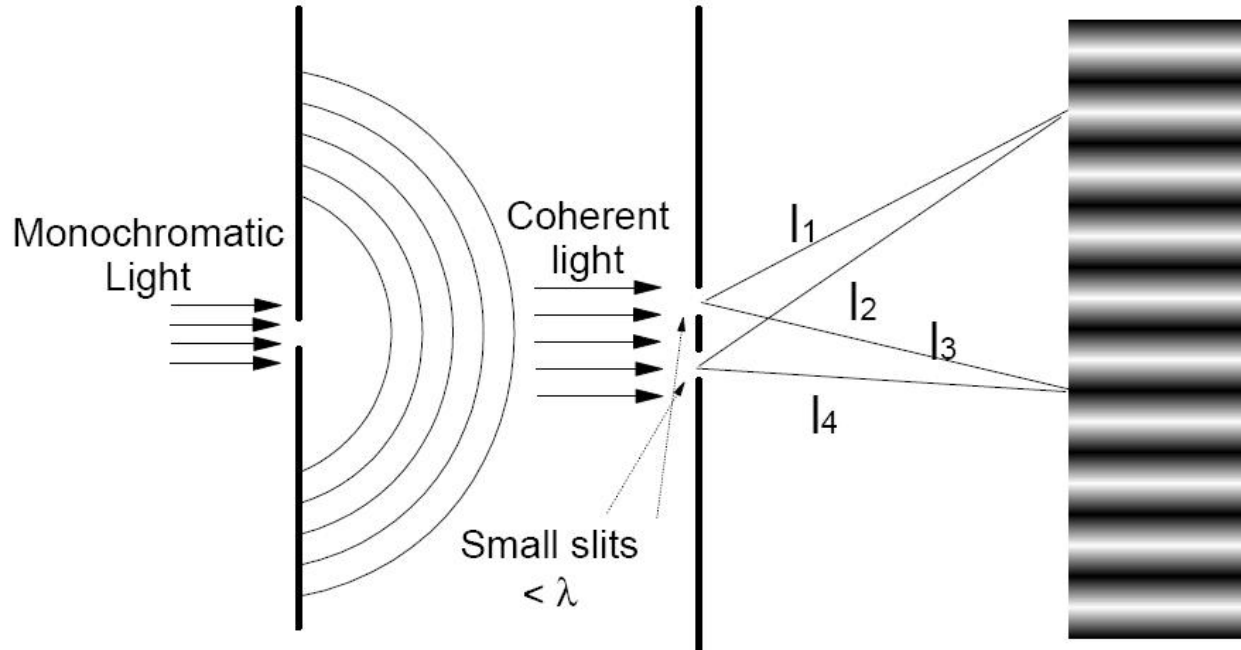


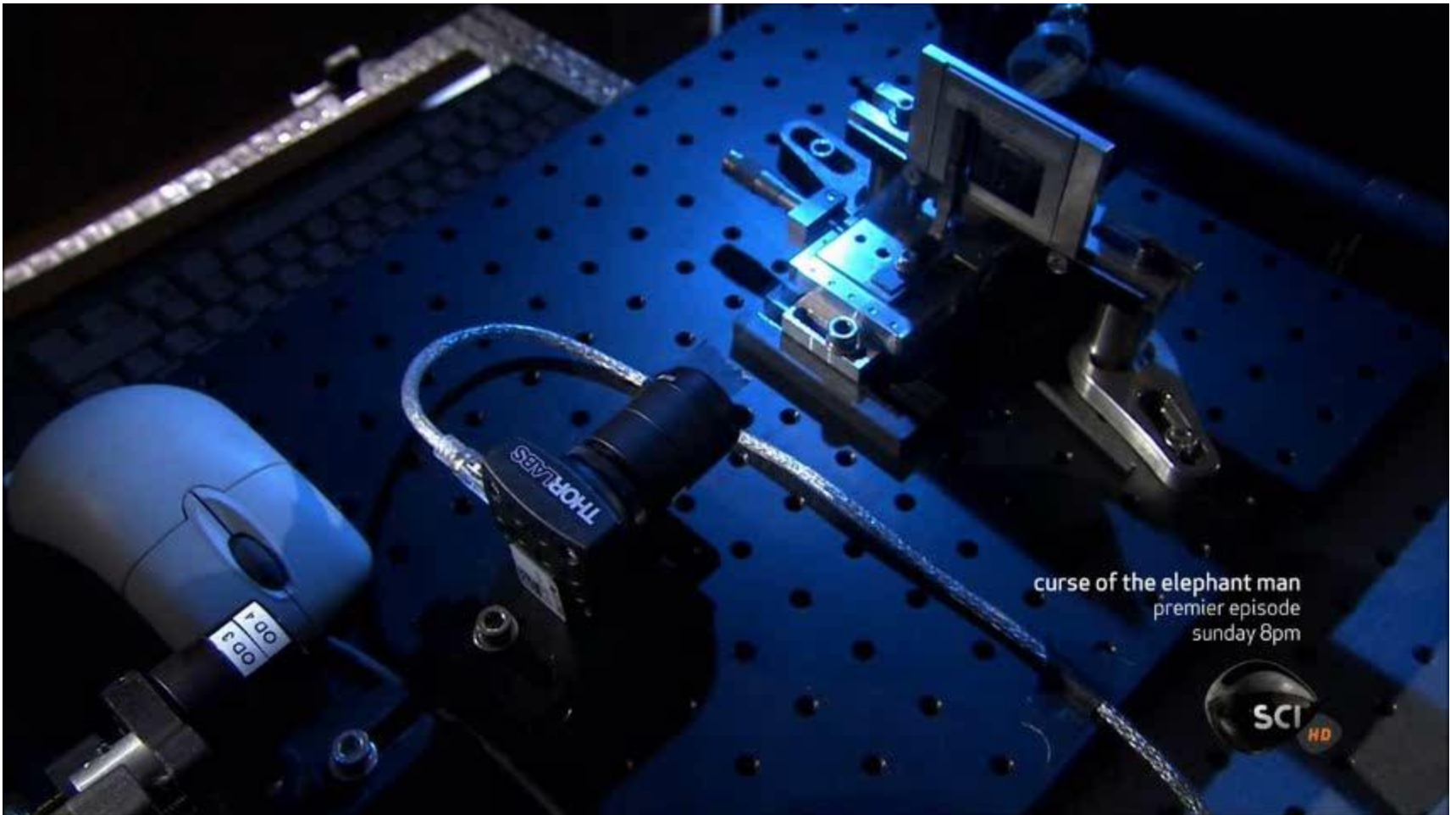
Unda electromagnetica

- ▶ Dispersie
- ▶ Fibre monomod
- ▶ Interferenta
- ▶ Polarizare



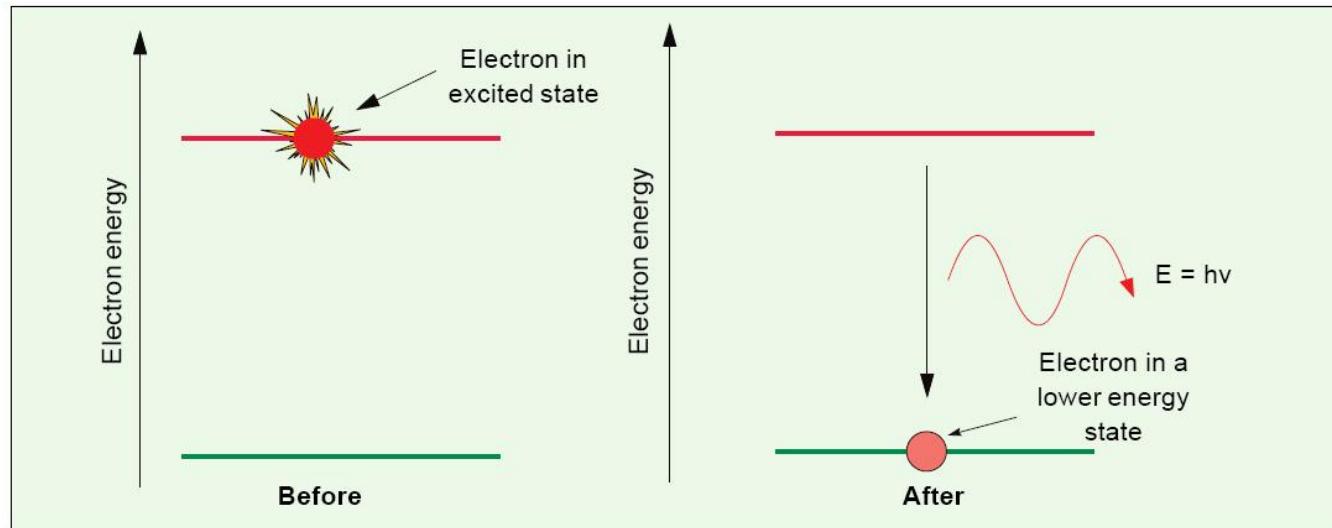
Fotoni/Unda





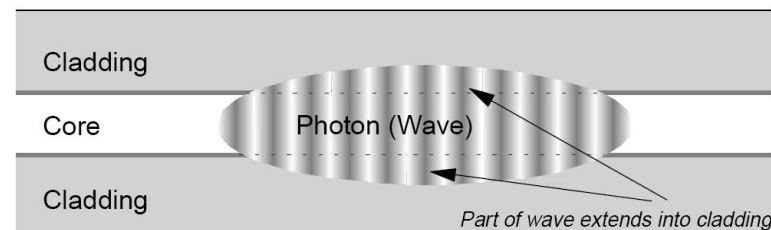
Through the Wormhole S02E07 How Does the Universe Work

Model cuantic – foton



$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}; \quad \lambda[\mu\text{m}] = \frac{1.240}{E_g[\text{eV}]}$$

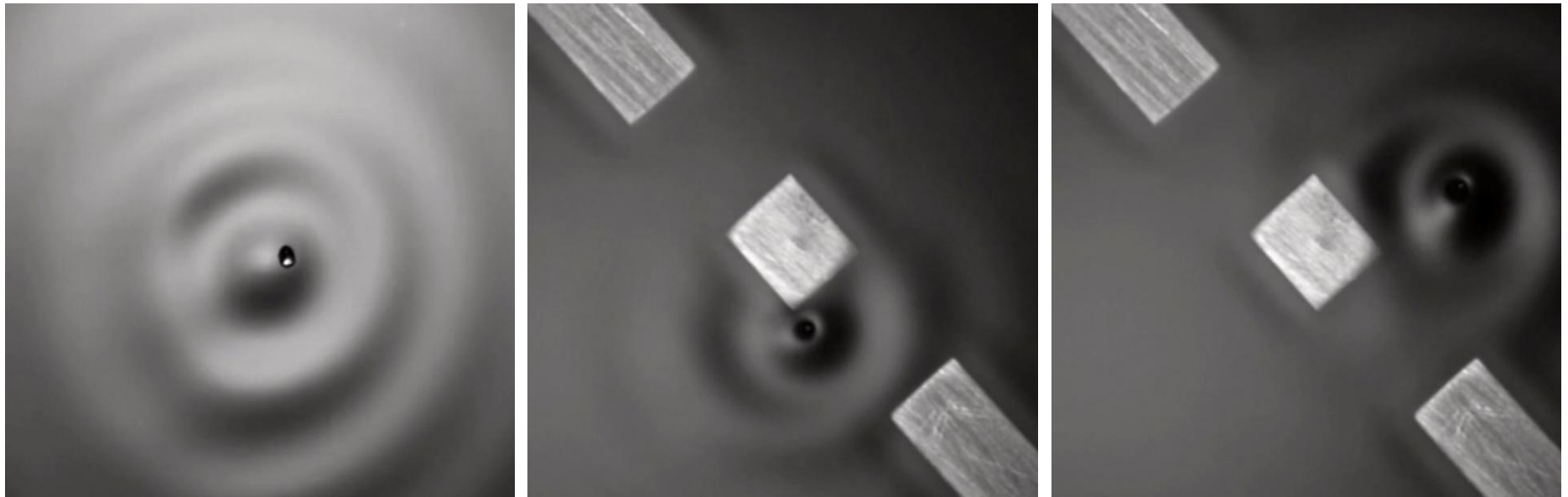
- ▶ h constanta lui Plank
 $6.62 \cdot 10^{-32} \text{ Ws}^2$
- ▶ c viteza luminii **in vid**
 $2.998 \cdot 10^8 \text{ m/s}$



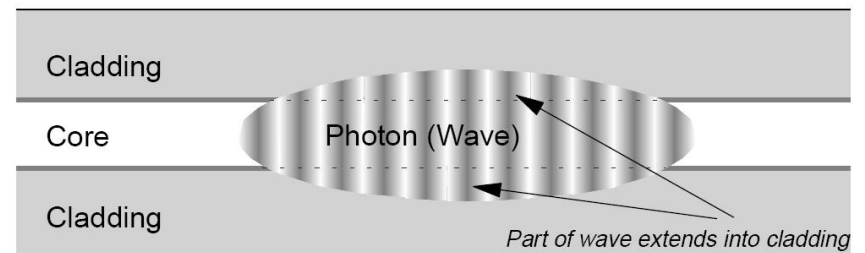


Through the Wormhole
S02E07 How Does the Universe Work

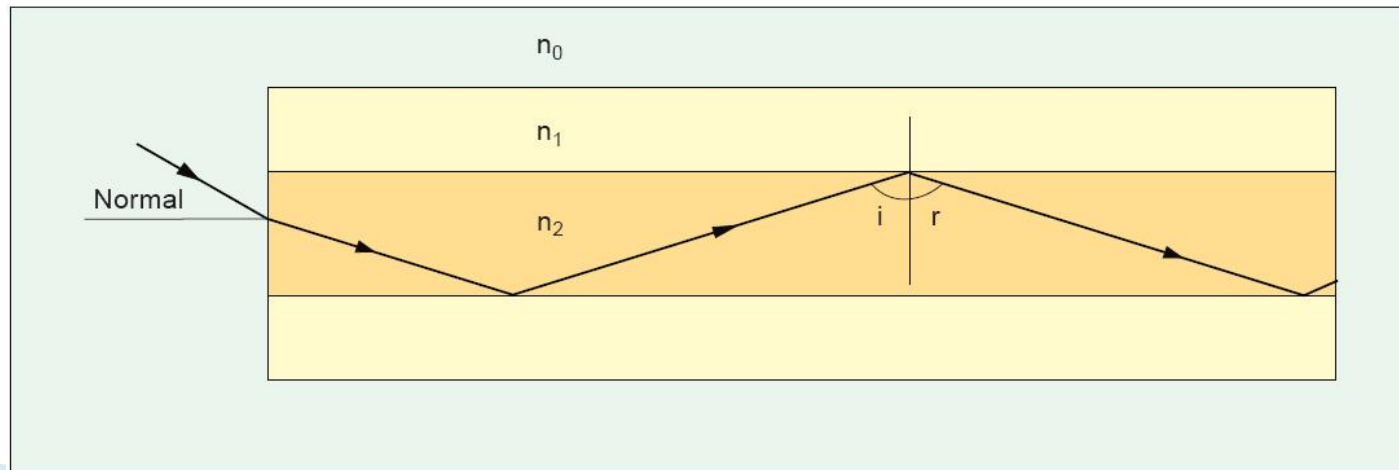
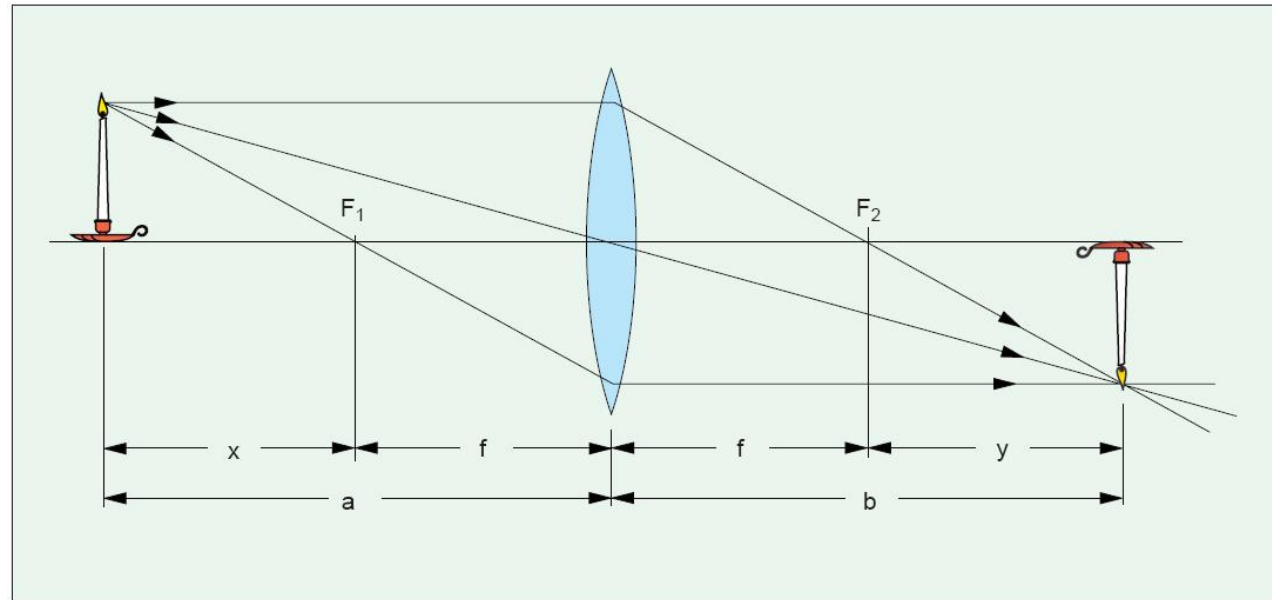
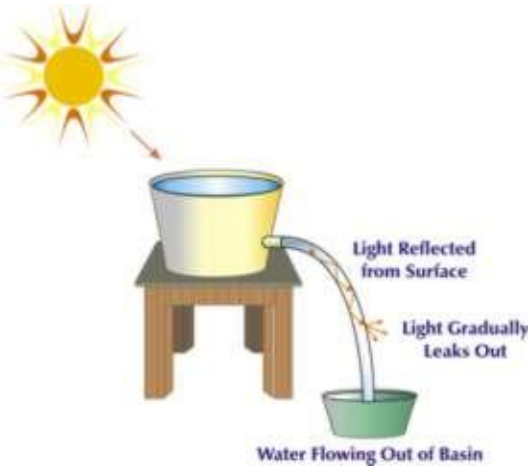
Modelare



Through the Wormhole
S02E07 How Does the Universe Work



Optica geometrica



Lumina ca undă electromagnetică

Capitolul 2

Cuprins

- ▶ **Lumina ca undă electromagnetică** (ecuațiile lui Maxwell, ecuația undelor, parametri de propagare)
- ▶ **Elemente de fotometrie și radiometrie** (mărimi energetice/luminoase)
- ▶ **Fibra optică** (realizare, principiu de funcționare, atenuare, dispersie, banda de frecvență)
- ▶ **Cabluri optice** (tehnologie, conectori, lipire – splice)
- ▶ **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvență, balanța puterilor)
- ▶ **Emițătoare optice** (LED și dioda laser – realizare fizică și funcționare)
- ▶ **Receptoare optice** (dioda PIN, dioda cu avalanșă – realizare fizică și funcționare)
- ▶ **Amplificatoare transimpedanță** (parametri, scheme tipice, TIA în buclă deschisă, cu reacție, diferențiale, control automat al câștigului)
- ▶ **Realizarea circuitelor pentru controlul emițătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- ▶ **Dispozitive de captare a energiei solare** (principiu de funcționare, utilizare, proiectare)

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

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

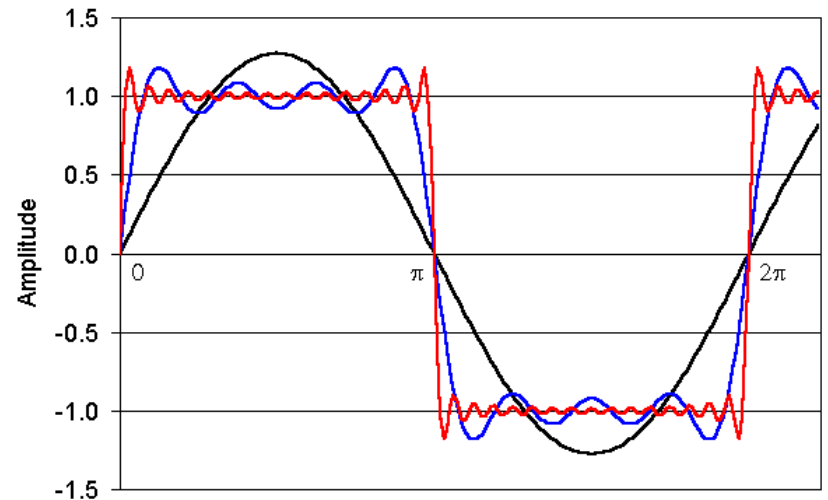
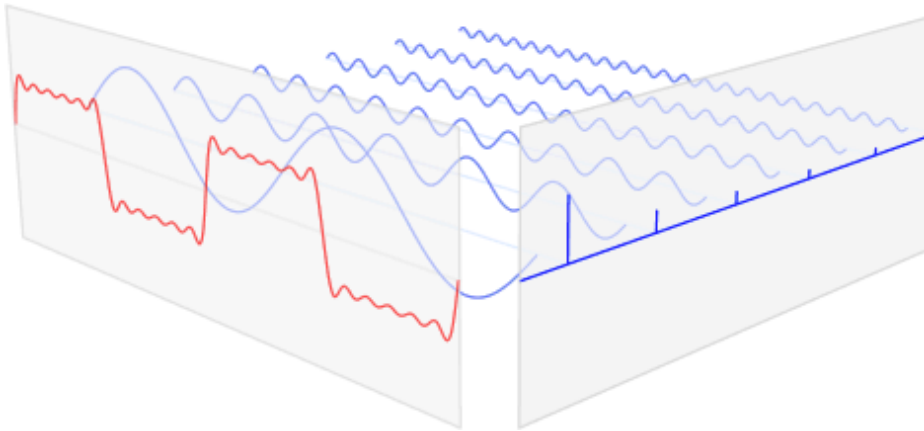
$$\varepsilon_0 = 8,854 \times 10^{-12} \text{ F/m}$$

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

Modele matematice

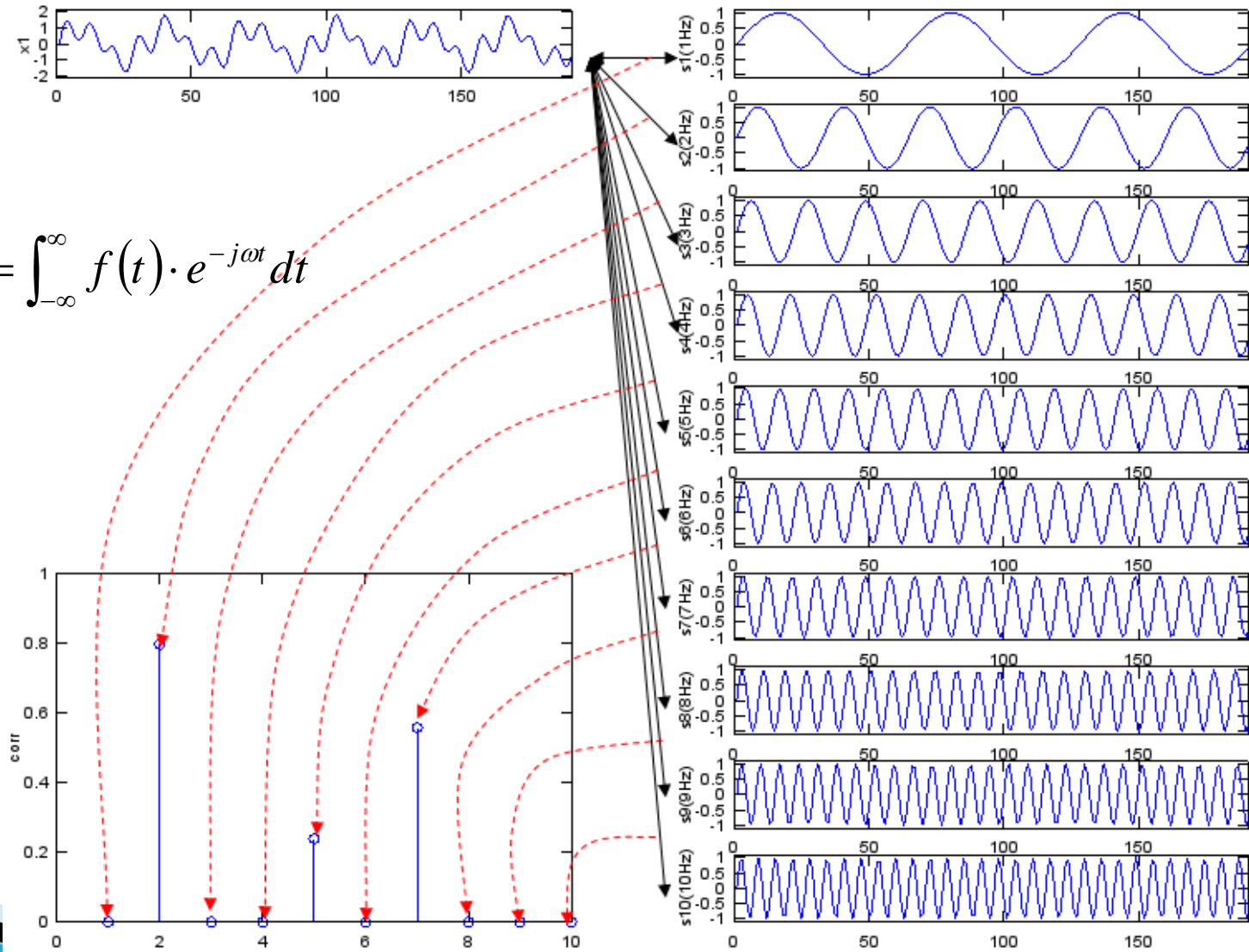
- ▶ cazuri particulare in care exista rezolvare analitica
 - semnale cu variație armonică în timp, transformata Fourier, spectru

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

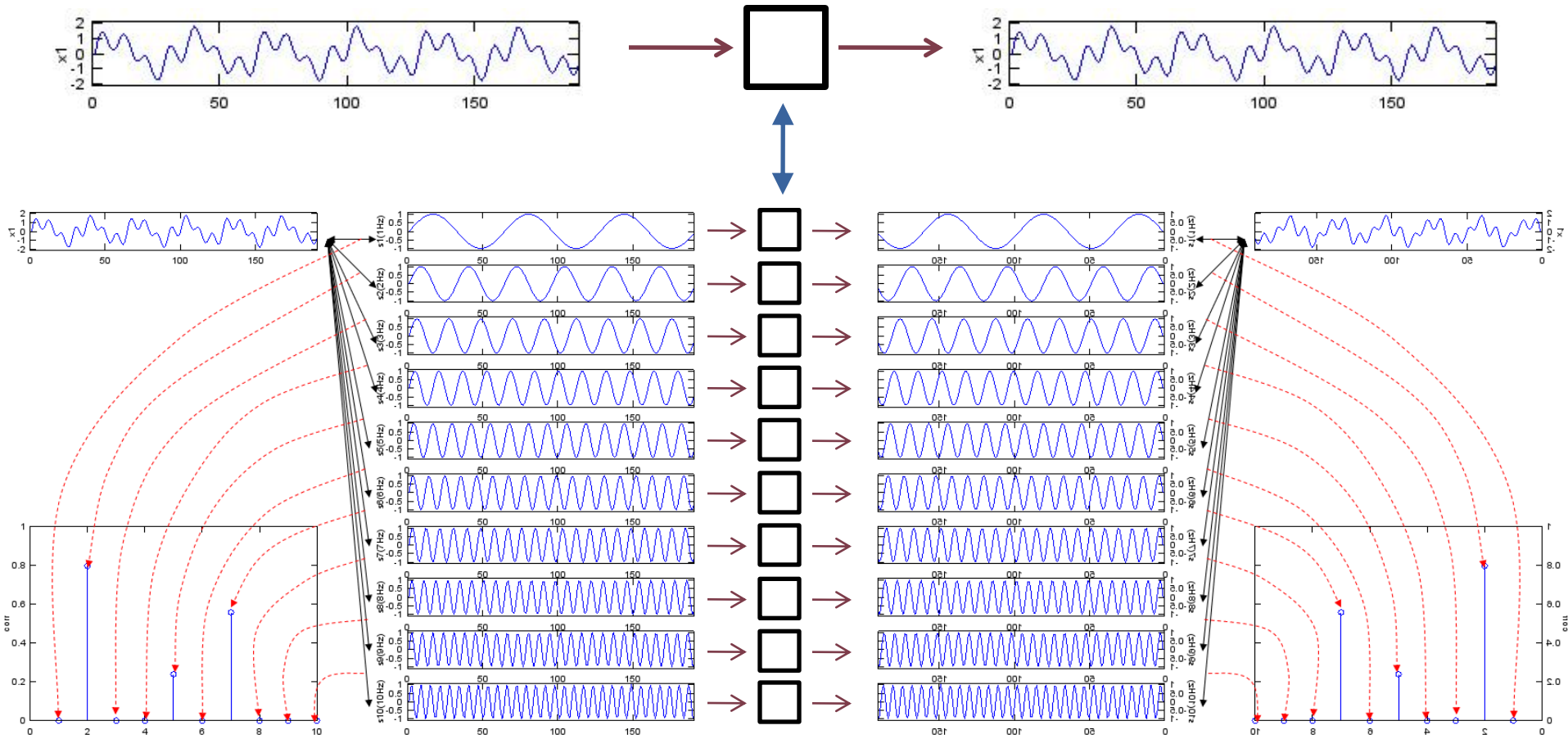


Modelle matematiche

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



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

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

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

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

$$\nabla \cdot H = 0$$

▶ Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

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

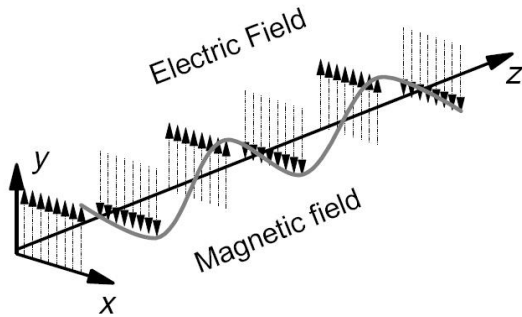
$$\nabla^2 H - \gamma^2 H = 0$$

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

γ – Constanta de propagare

Solutia ecuatiilor de propagare

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



Propagare

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

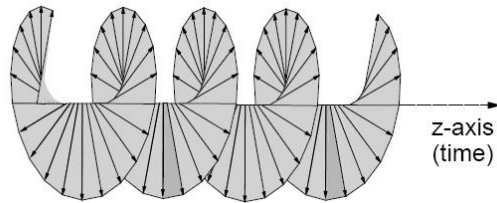
$$\gamma = \sqrt{-\omega^2 \epsilon \mu + j \omega \mu \sigma} = \alpha + j \cdot \beta$$

Exista numai unda progresiva $E_+ \Rightarrow A$

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

Camp armonic

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



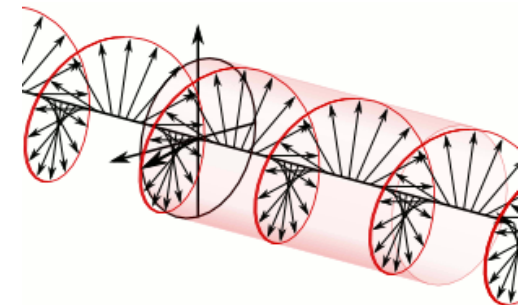
Polarizare circulara

Amplitudine

Atenuare

Propagare

(variatie in timp si spatiu)

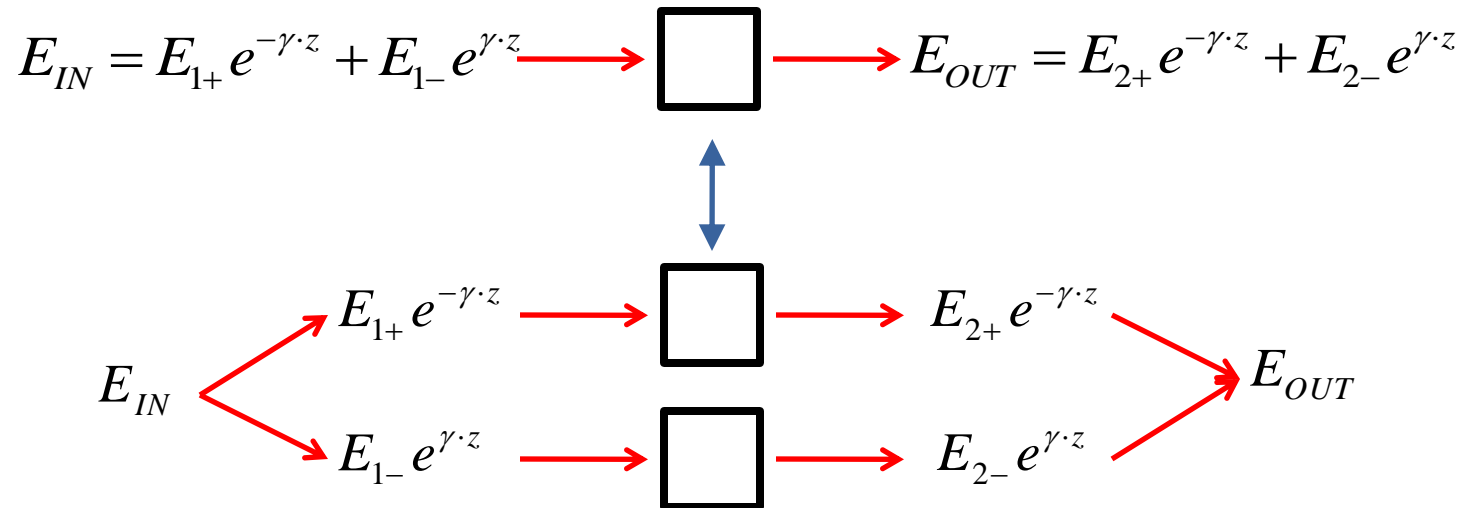


Modele matematice

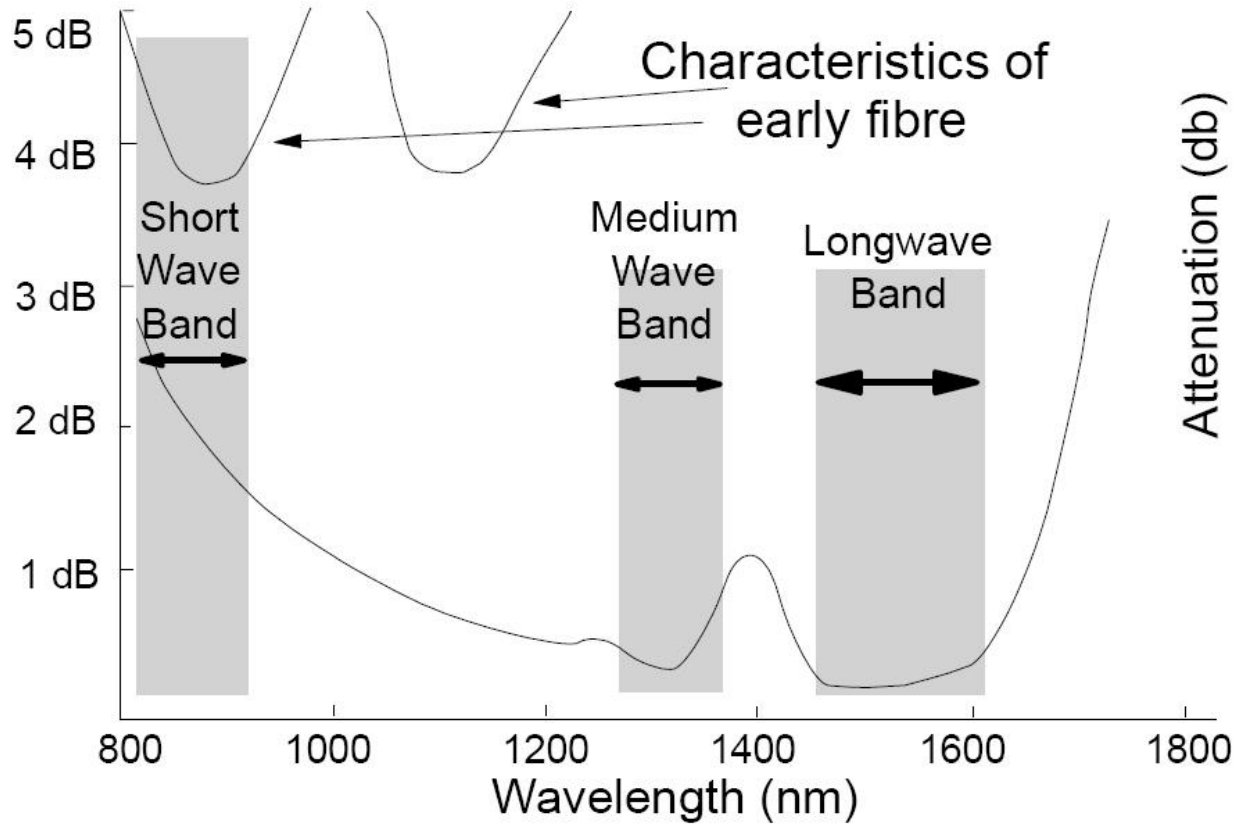
► cazuri particulare in care exista rezolvare analitica

- 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 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**

Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

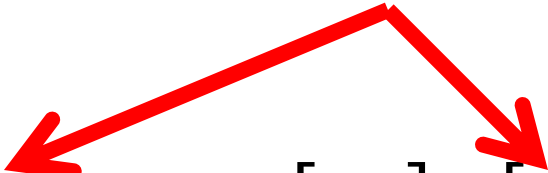
$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

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

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

Calculul atenuarii

$$\text{Pierderi} = \frac{P_{out}}{P_{in}} < 1 \quad \text{Pierderi[dB]} = 10 \cdot \log_{10} \left(\frac{P_{out}}{P_{in}} \right) < 0$$


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

$$\text{Castig} = \frac{P_{out}}{P_{in}} > 1 \quad \text{Castig[dB]} = 10 \cdot \log_{10} \left(\frac{P_{out}}{P_{in}} \right) > 0$$

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

Calculul atenuarii

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

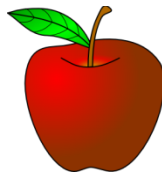
$$\text{Pierderi[dB]} = [-] 10 \cdot \log_{10} \left(\frac{P_{out}}{P_{in}} \right)$$

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

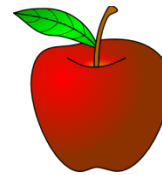
$$\text{Pierderi [dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-



Calculul atenuarii

Pierderi/A tenuare $\rightarrow P_{out} < P_{in} \rightarrow P_{out} [\text{dBm}] < P_{in} [\text{dBm}]$

$$P_{out} [\text{dBm}] = P_{in} [\text{dBm}] - \text{Pierderi/A tenuare} [\text{dB}]$$



Castig/Amp lificare $\rightarrow P_{out} > P_{in} \rightarrow P_{out} [\text{dBm}] > P_{in} [\text{dBm}]$

$$P_{out} [\text{dBm}] = P_{in} [\text{dBm}] + \text{Castig/Amp lificare} [\text{dB}]$$



Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

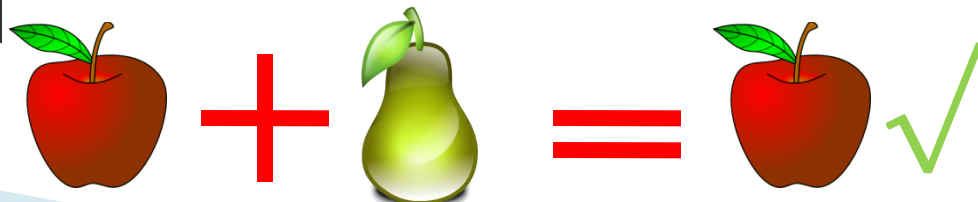
$$-30 \text{ dBm} = 1 \mu\text{W}$$

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

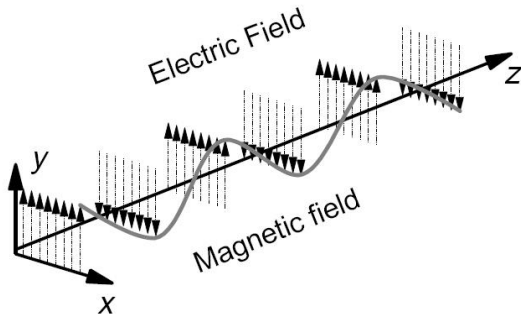
$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

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

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



Parametri de propagare



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

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

Mediu fara pierderi, $\sigma = 0$ $\gamma = j\omega \cdot \sqrt{\epsilon\mu}$

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

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

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

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

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

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

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


Parametri, dependenta de mediu

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega$$

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

$n=1$

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

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

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

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

$n = \sqrt{\epsilon_r}$

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

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

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

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

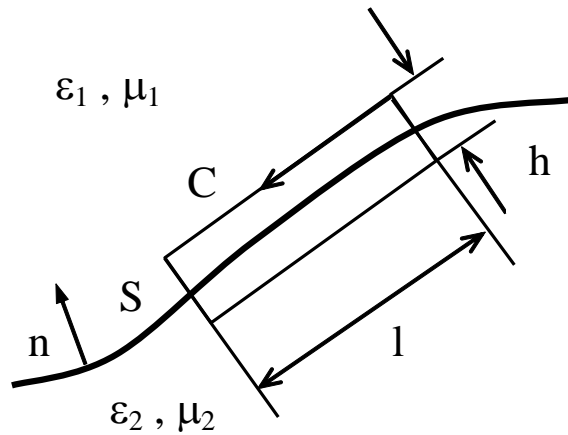
ITU G.692

"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"

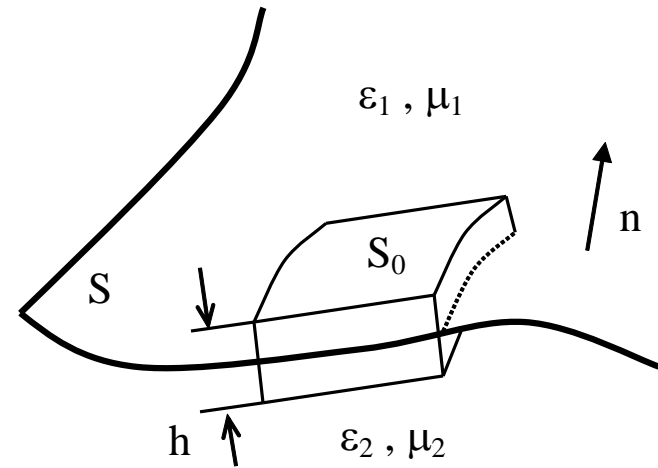
Condiții la limita de separație între două medii



a)

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

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



b)

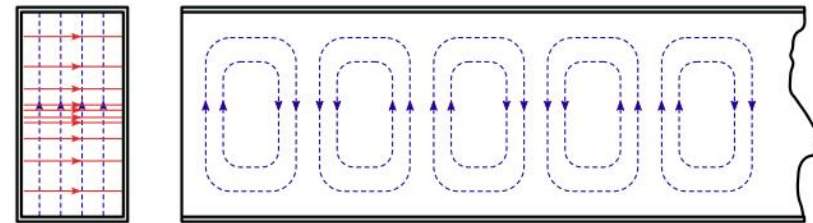
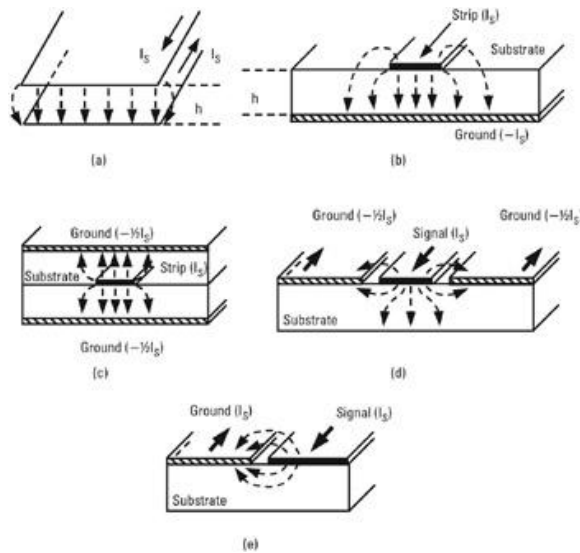
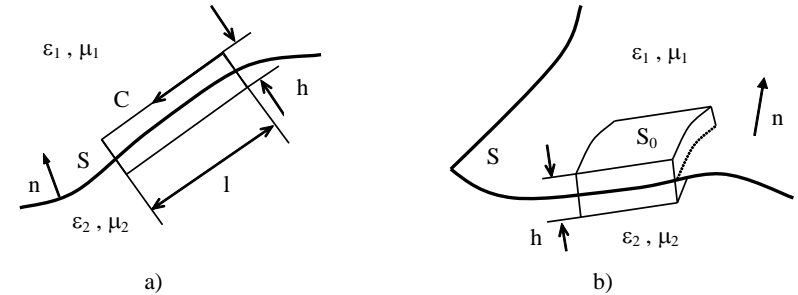
$$n \cdot (D_1 - D_2) = \rho_S$$

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

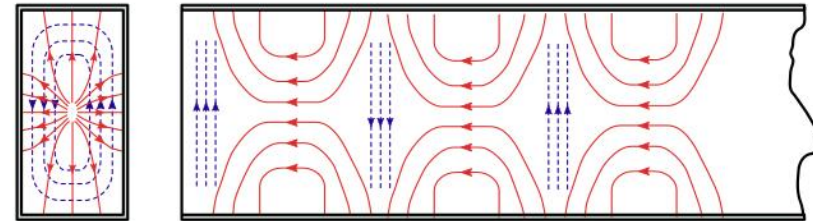
- ▶ Dacă un mediu este metal ideal toate campurile se anuleaza in interior

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

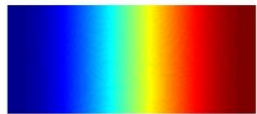
- ▶ Câmpuri electromagnetice cu variație armonică în timp
 - simplificarea ecuatiilor lui Maxwell

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

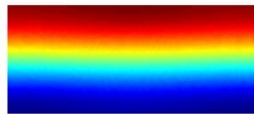
- ▶ In medii delimitate solutiile ecuatiilor lui Maxwell trebuie sa verifice conditiile la limita
 - solutiile trebuie sa respecte anumite conditii suplimentare

Moduri in medii delimitate

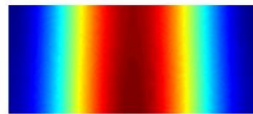
TE10



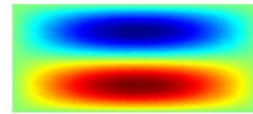
TE01



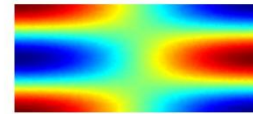
TE20



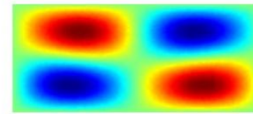
TM12



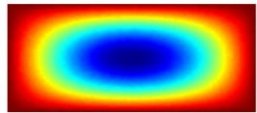
TE12



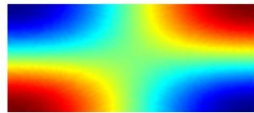
TM22



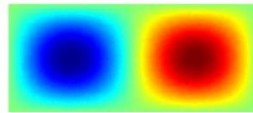
TM11



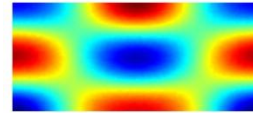
TE11



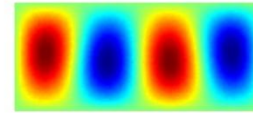
TM21



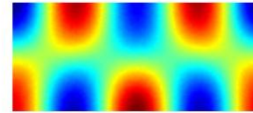
TE22



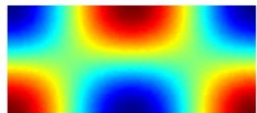
TM41



TE41



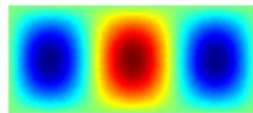
TE21



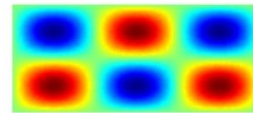
TE30



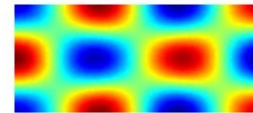
TM31



TM32



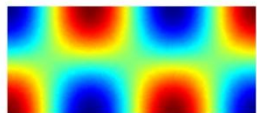
TE32



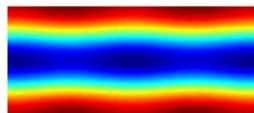
TE50



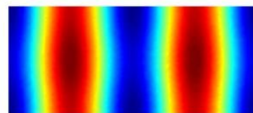
TE31



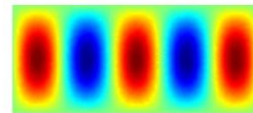
TE02



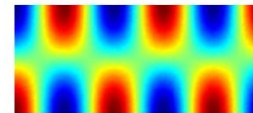
TE40



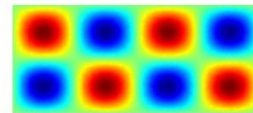
TM51



TE51



TM42



- ▶ Similar cu transformata Fourier

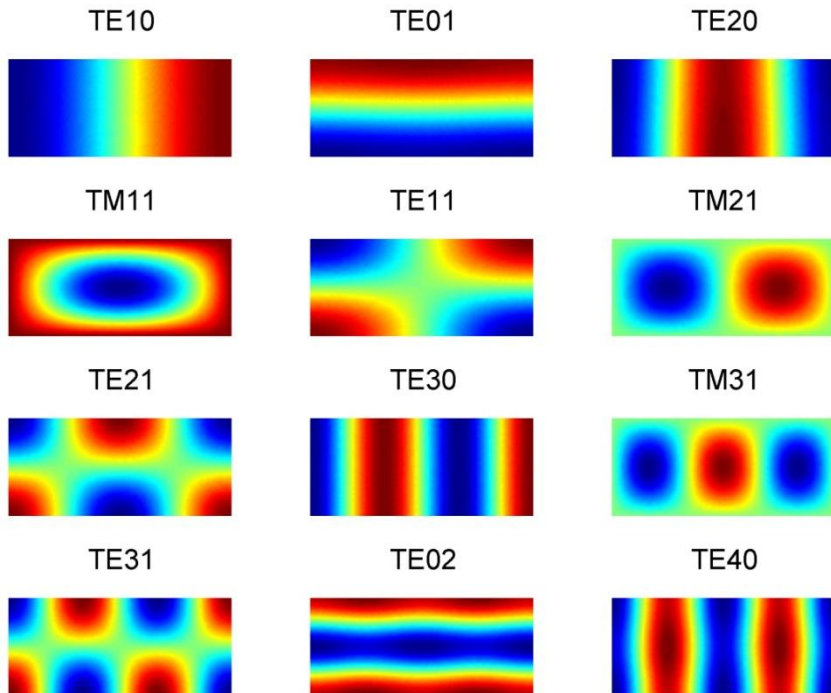
$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

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

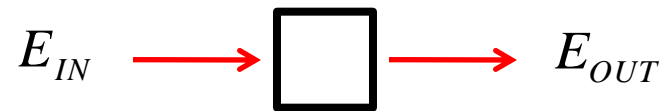
$$A_i = \langle E, Mod_i \rangle$$

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)

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

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

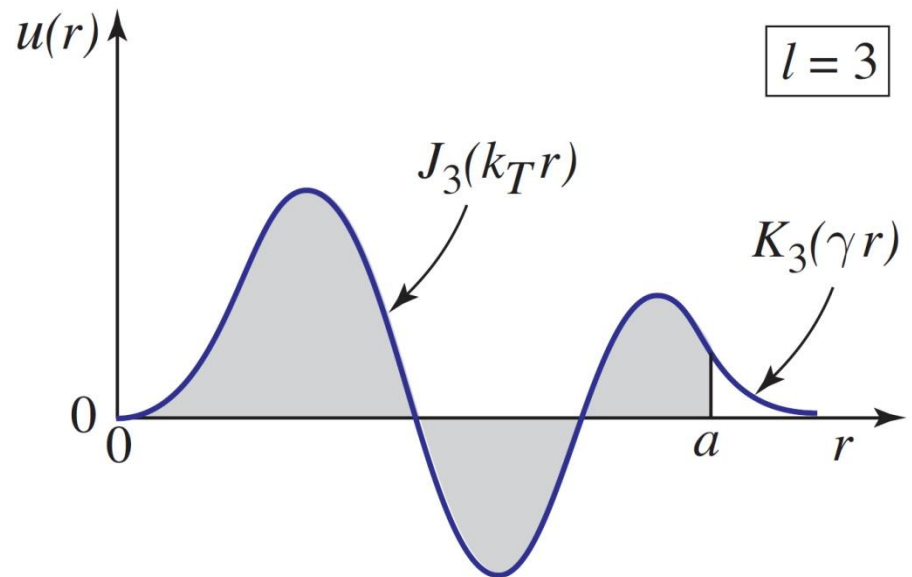
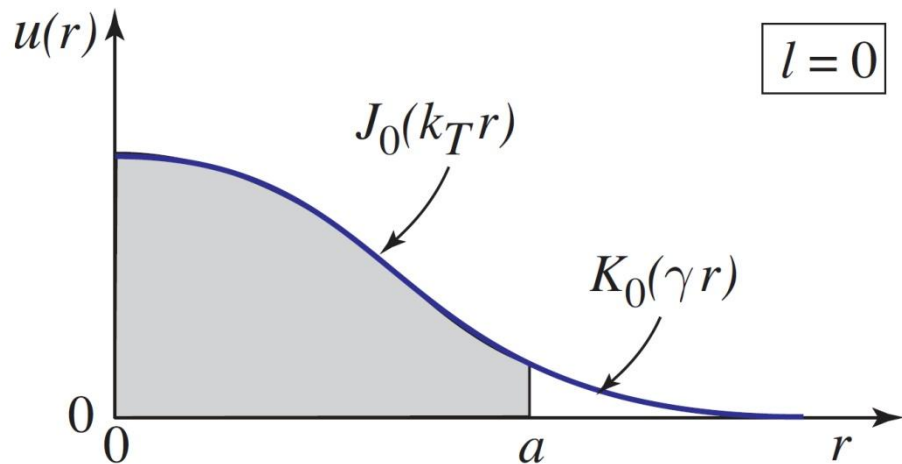
$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} + \left(k_T^2 - \frac{l^2}{r^2} \right) u = 0, \quad r < a$$

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

Ghid cilindric dielectric

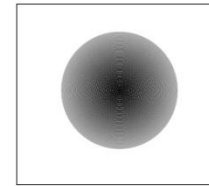
- ▶ soluții proporționale cu funcții Bessel

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

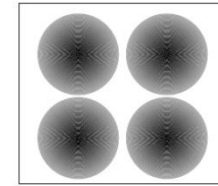


Moduri in fibra

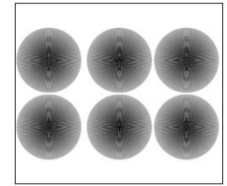
- ▶ Moduri in ghid rectangular



TEM₀₀

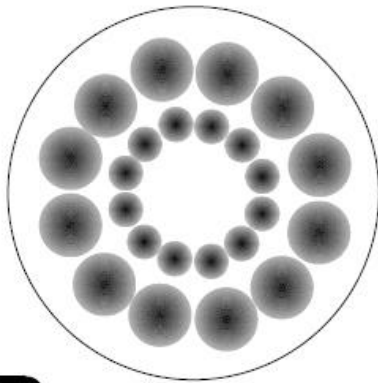


TEM₁₁

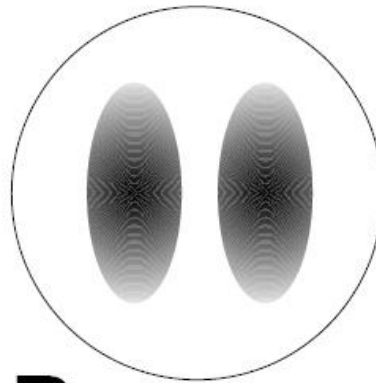


TEM₂₁

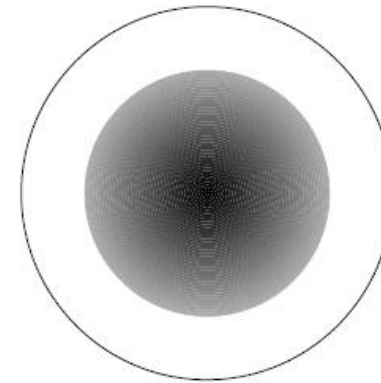
- ▶ Moduri linear polarizate in fibra



LP₆₂

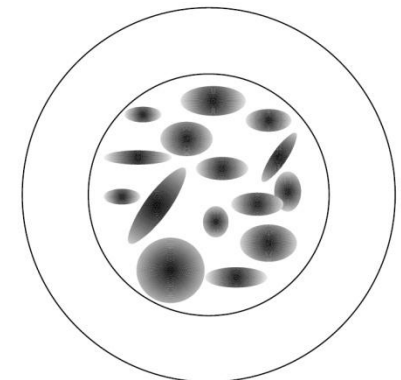


LP₁₁



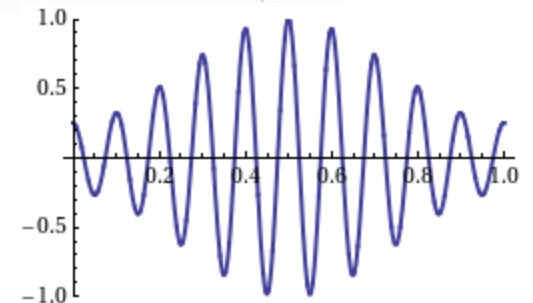
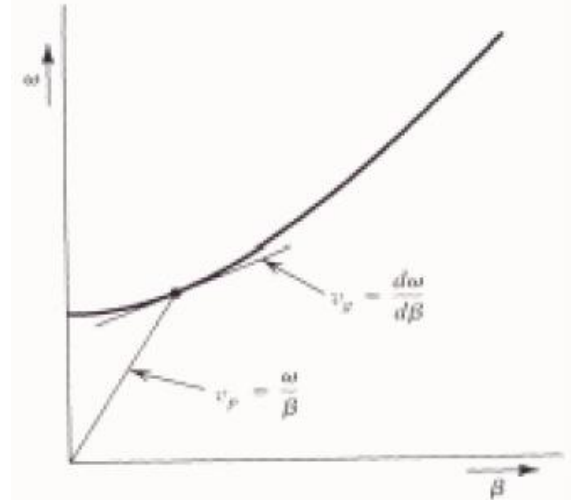
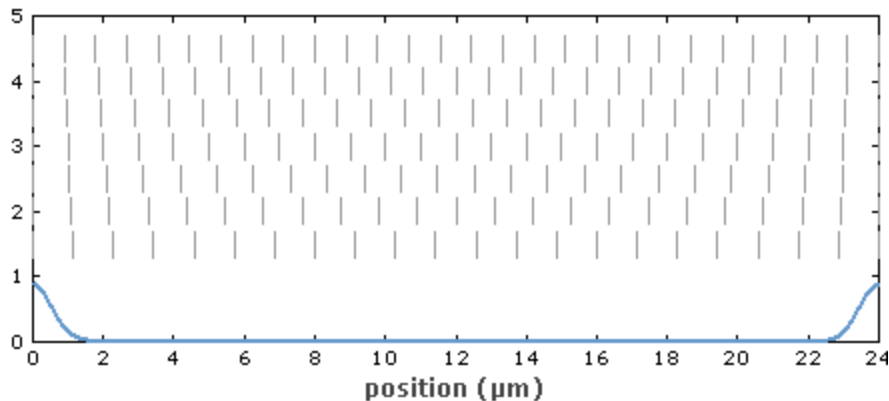
LP₀₁

“Sparkle” pattern



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



Dispersia

- ▶ In medii dispersive $\beta = \beta(\omega)$, $n = n(\omega)$, $v_g = \frac{d\omega}{d\beta} = \frac{1}{\left(\frac{d\beta}{d\omega}\right)}$
- ▶ Timpul in care o radiatie ajunge la distanta L

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

- ▶ Se prefera exprimarea in functie de lungimea de unda

$$\lambda = \frac{c}{f} = \frac{2\pi \cdot c}{\omega} \rightarrow \frac{d\lambda}{d\omega} = -\frac{2\pi \cdot c}{\omega^2} = -\frac{\lambda}{\omega} \rightarrow d\omega = -\frac{\omega}{\lambda} \cdot d\lambda$$

$$\tau = \frac{L}{c} \left(n + \omega \frac{dn}{-\frac{\omega}{\lambda} \cdot d\lambda} \right) = \frac{L}{c} \left(n - \lambda \cdot \frac{dn}{d\lambda} \right)$$

Dispersia

▶ $n = n(\omega)$ $\tau = \frac{L}{c} \left(n - \lambda \cdot \frac{dn}{d\lambda} \right)$

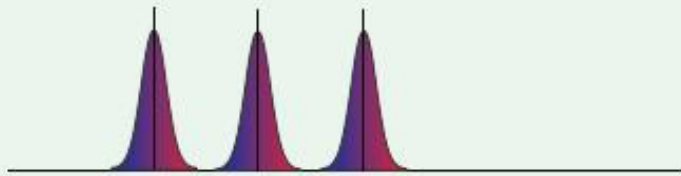
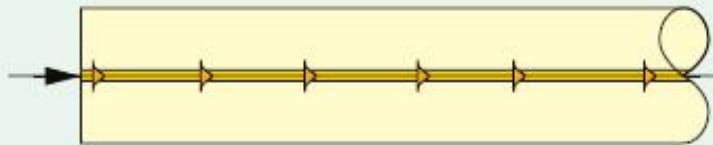
$$\frac{d\tau}{d\lambda} = \frac{L}{c} \left(\frac{dn}{d\lambda} - \lambda \frac{d^2n}{d\lambda^2} - \frac{dn}{d\lambda} \right) = -\frac{L}{c} \cdot \lambda \cdot \frac{d^2n}{d\lambda^2} \qquad D = -\frac{\lambda}{c} \cdot \frac{d^2n}{d\lambda^2} \quad (s/m^2)$$

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

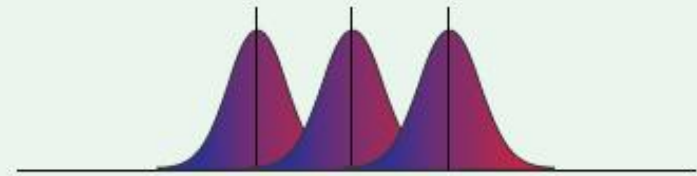
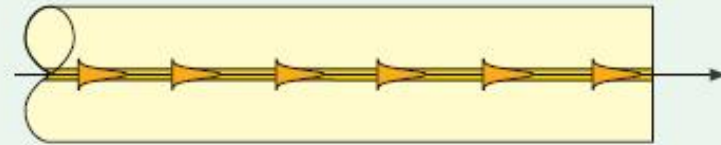
$$\Delta\tau = D \cdot \Delta\lambda \cdot L$$

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



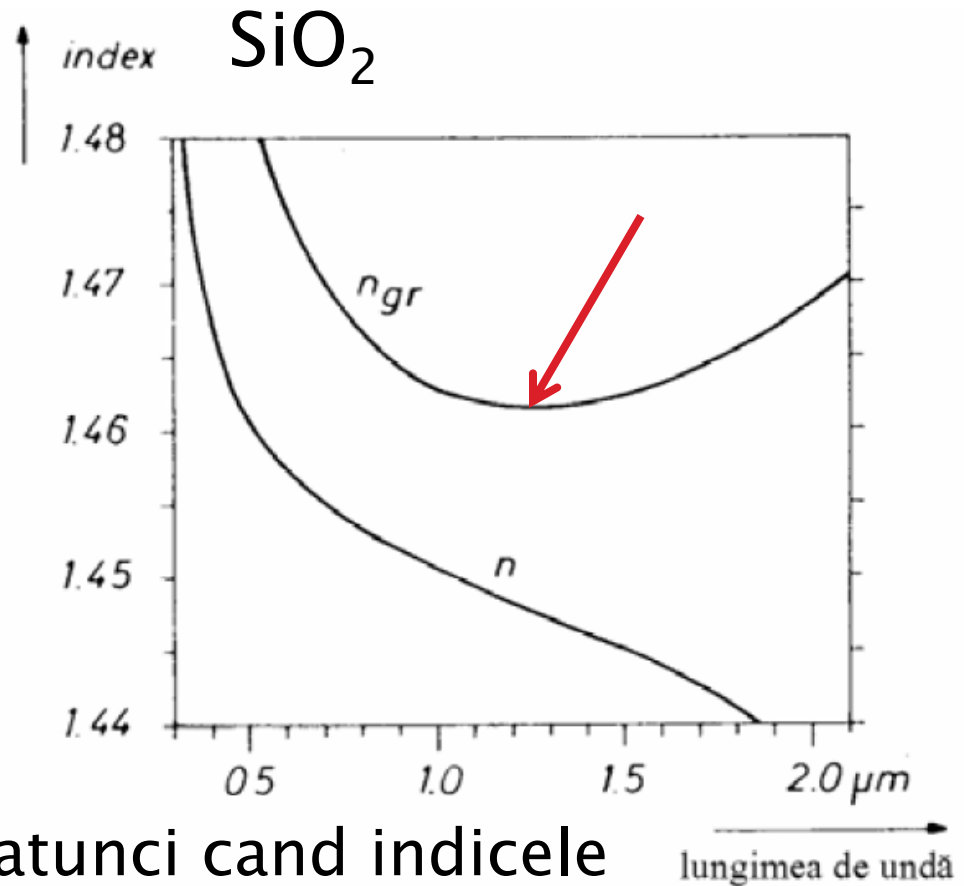
Reception:
Pulse broadening caused by the laser's spectral width and the difference between the refractive indices of the red and blue ends of the light pulse.

Dispersie normala

$$\tau = \frac{L}{v_g} = \frac{L}{c} \left(n - \lambda \cdot \frac{dn}{d\lambda} \right)$$

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

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

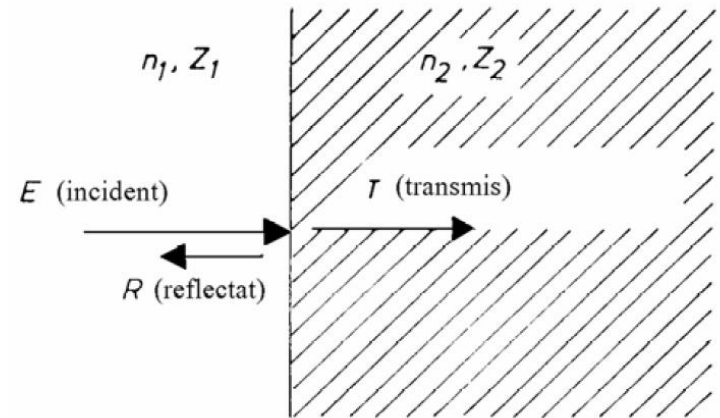


- ▶ Dispersia este **0** atunci cand indicele de refractie de grup este minim
- ▶ Pentru sticla $\lambda_0 \sim 1310 \text{ nm}$

Transmisia puterii intre medii

- ▶ incidenta normala
- ▶ reflexia in amplitudine

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



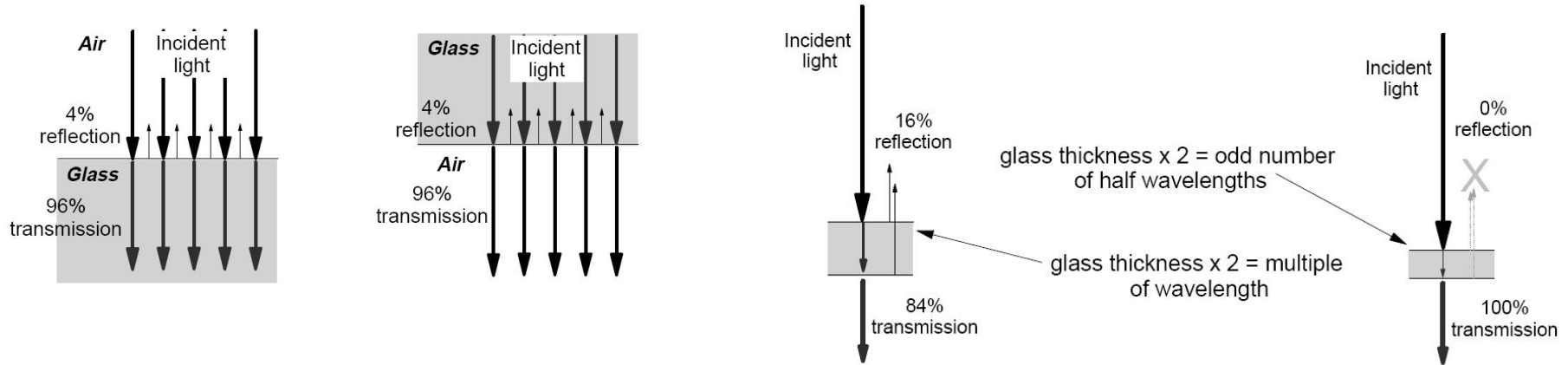
- ▶ densitatea de putere proportionala cu patratul amplitudinii câmpului

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

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

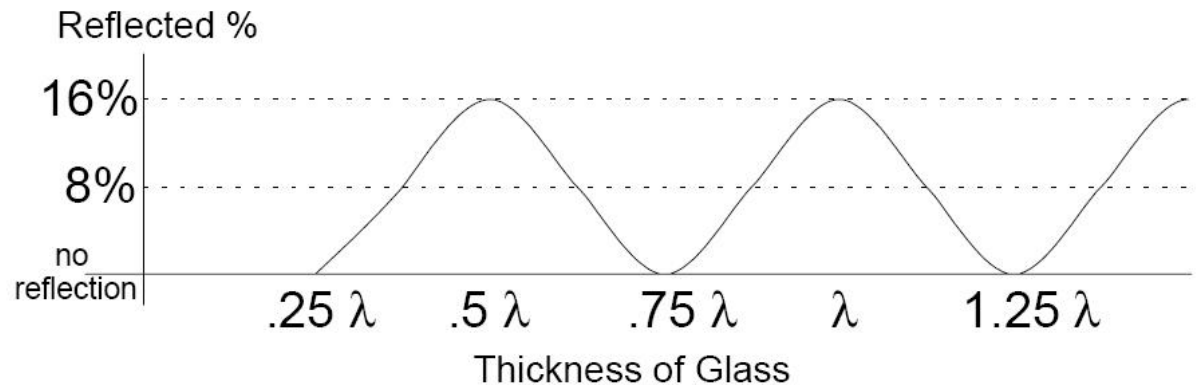
$$\Gamma = \frac{1.5 - 1}{1.5 + 1} = 0.2; \quad r = \Gamma^2 = 0.04 = 4\%$$

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



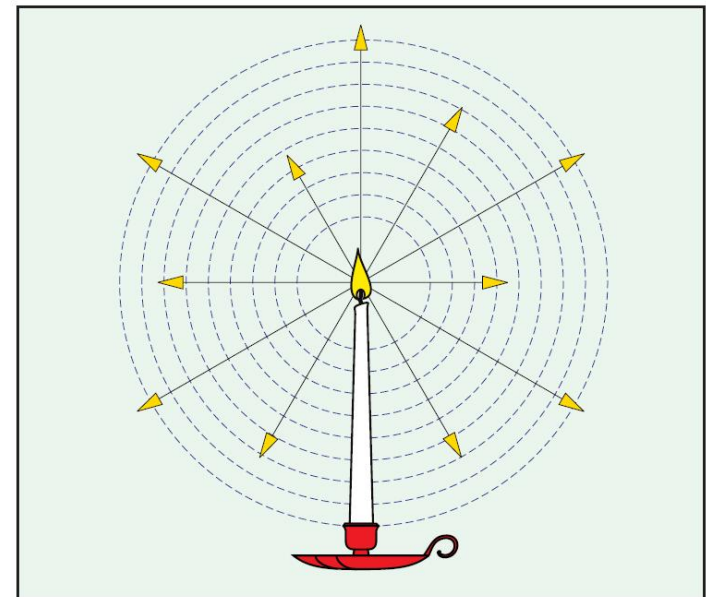
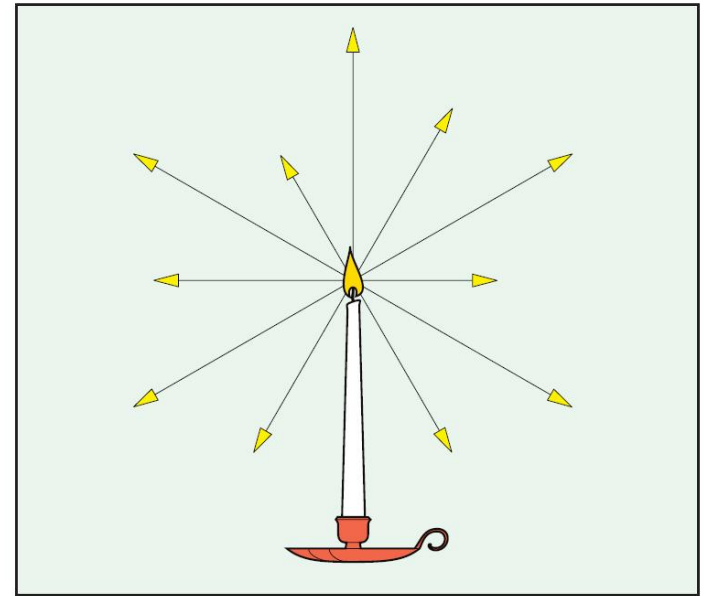
Optică geometrică

(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)

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

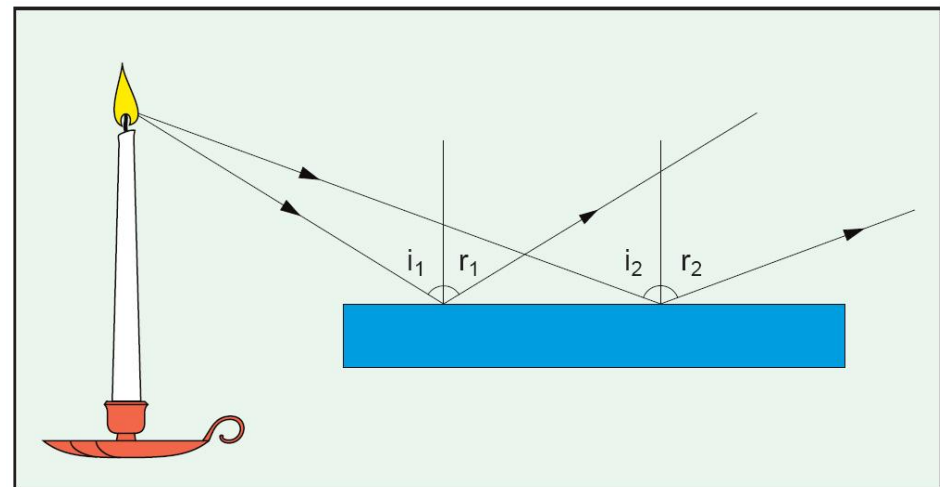


Reflexia luminii

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

▶ Legea reflexiei

$$\phi_i = \phi_r$$



Refractia luminii

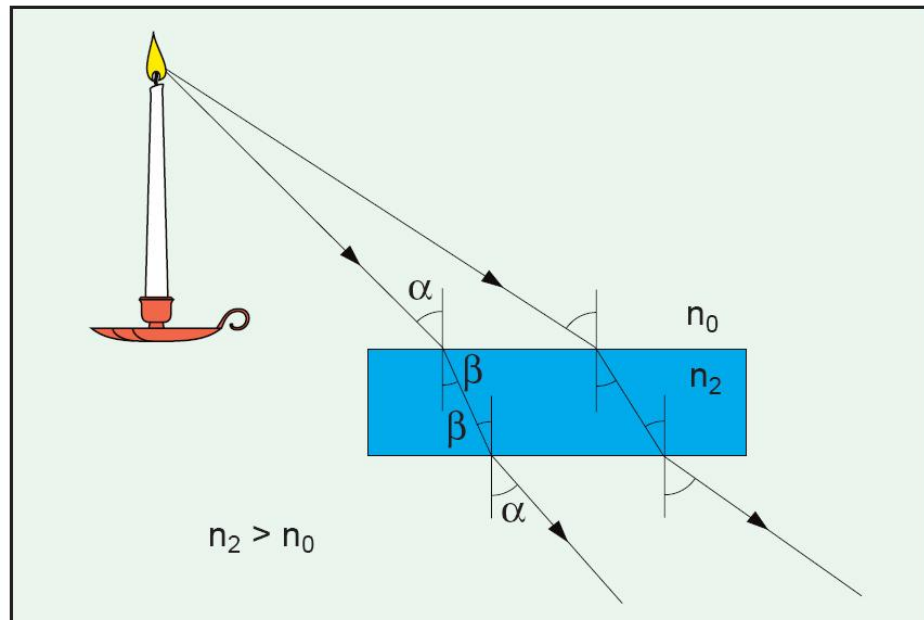
- ▶ la suprafața de separație dintre doua medii, (o parte din) lumina se (poate) propaga in mediul de transmisie sub un unghi diferit de unghiul incident
- ▶ la trecerea in medii mai “dense” (optic) lumina se apropie de normala
- ▶ la trecerea in medii mai “puțin dense” (optic) lumina se depărtează de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

▶ Legea lui Snell (a refracției)

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

ϕ_i - unghi incident (in n_1)

ϕ_R - unghi de refracție (in n_2)



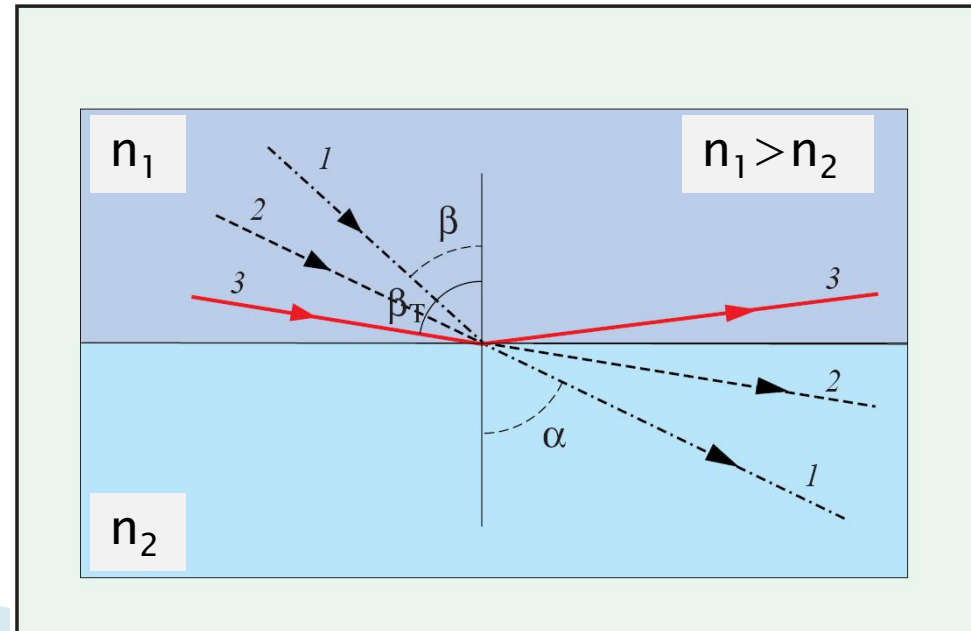
Reflexia totala

- ▶ 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

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

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

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

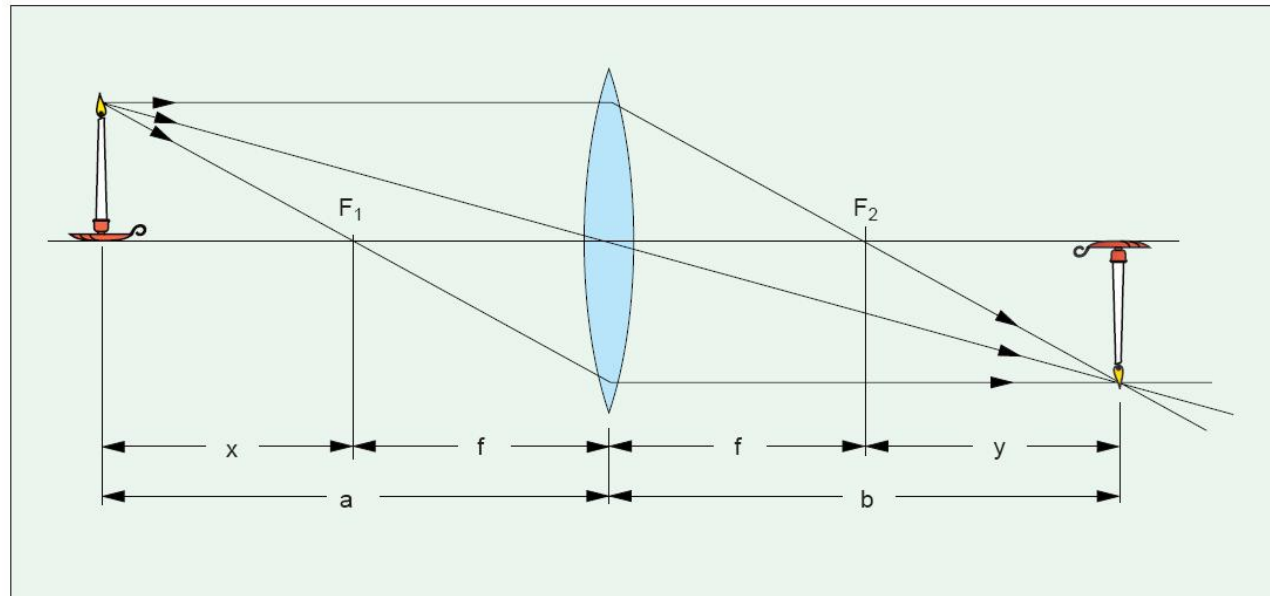


Lentile

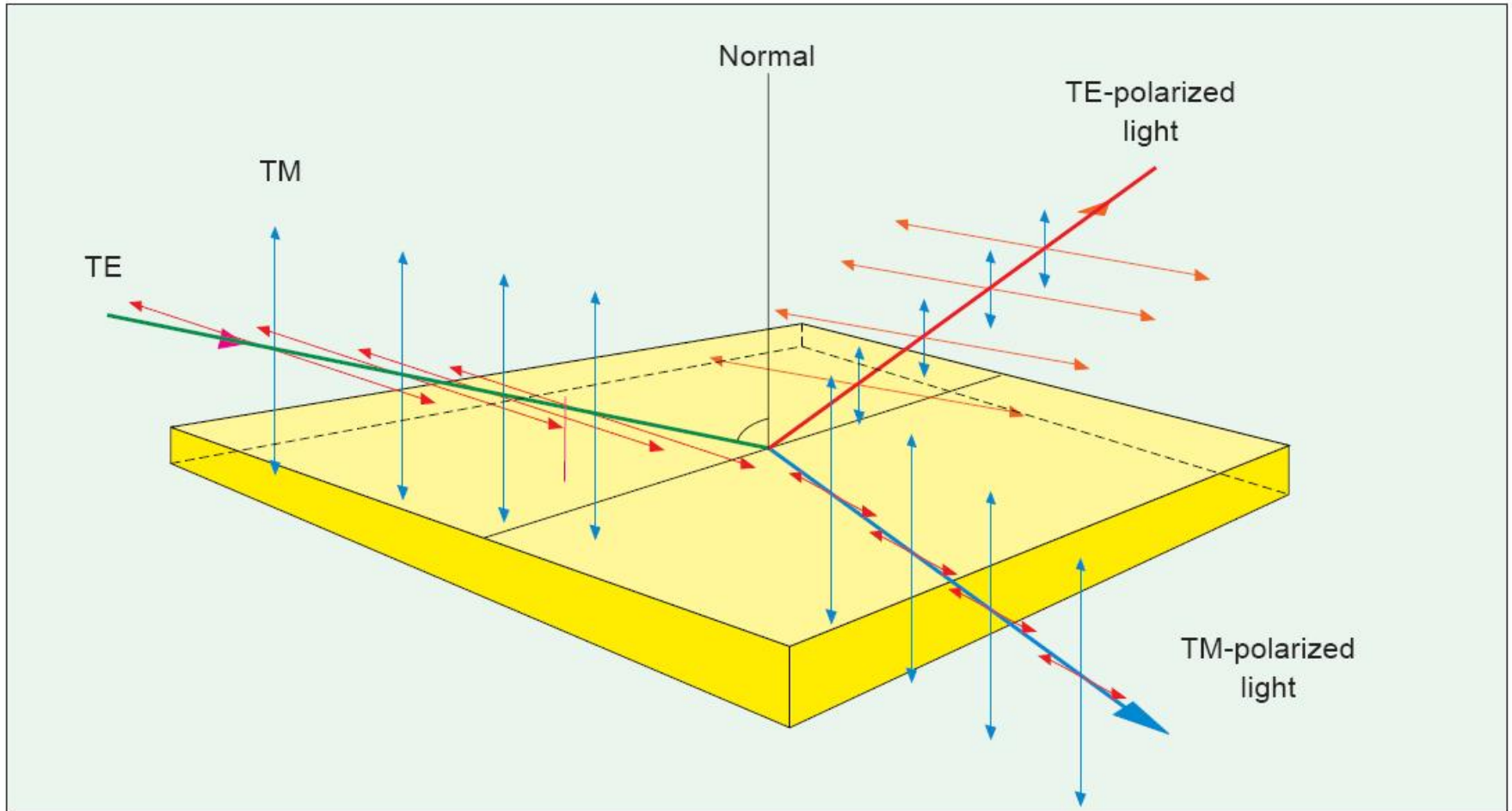
- ▶ Razele de lumina paralele sunt concentrate intr-un punct numit focar, aflat la **distanța focala** de planul lentilei
- ▶ O sursa omnidirectională poziționată în focar va permite obținerea unui fascicul paralel

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

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



Polarizarea luminii



Polarizarea luminii

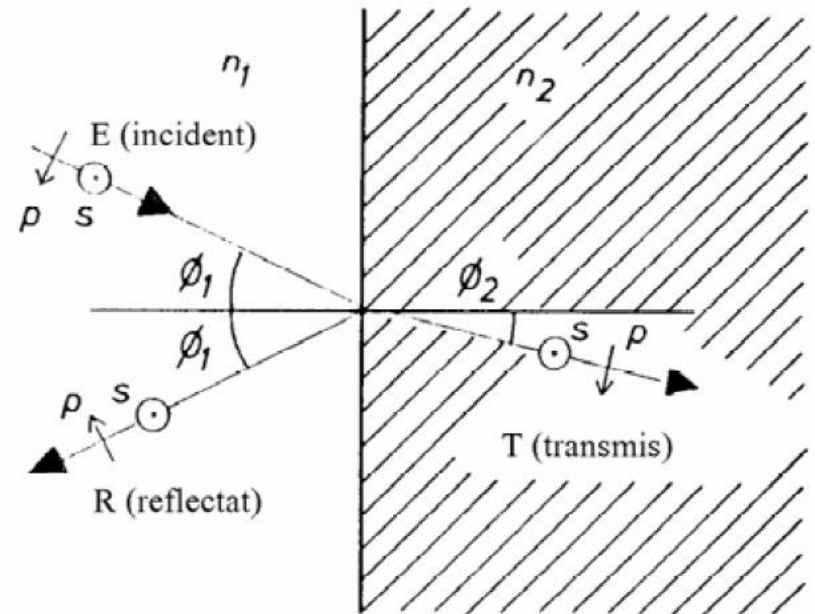
- ▶ incidenta oblica
- ▶ reflexiile in amplitudine a campului:

$$r_s = -\frac{\sin(\phi_1 - \phi_2)}{\sin(\phi_1 + \phi_2)}$$

$$r_p = \frac{\tan(\phi_1 - \phi_2)}{\tan(\phi_1 + \phi_2)}$$

$$t_s = \frac{2 \sin \phi_2 \cos \phi_1}{\sin(\phi_1 + \phi_2)}$$

$$t_p = \frac{2 \sin \phi_2 \cos \phi_1}{\sin(\phi_1 + \phi_2) \cos(\phi_1 - \phi_2)}$$



Unghi Brewster

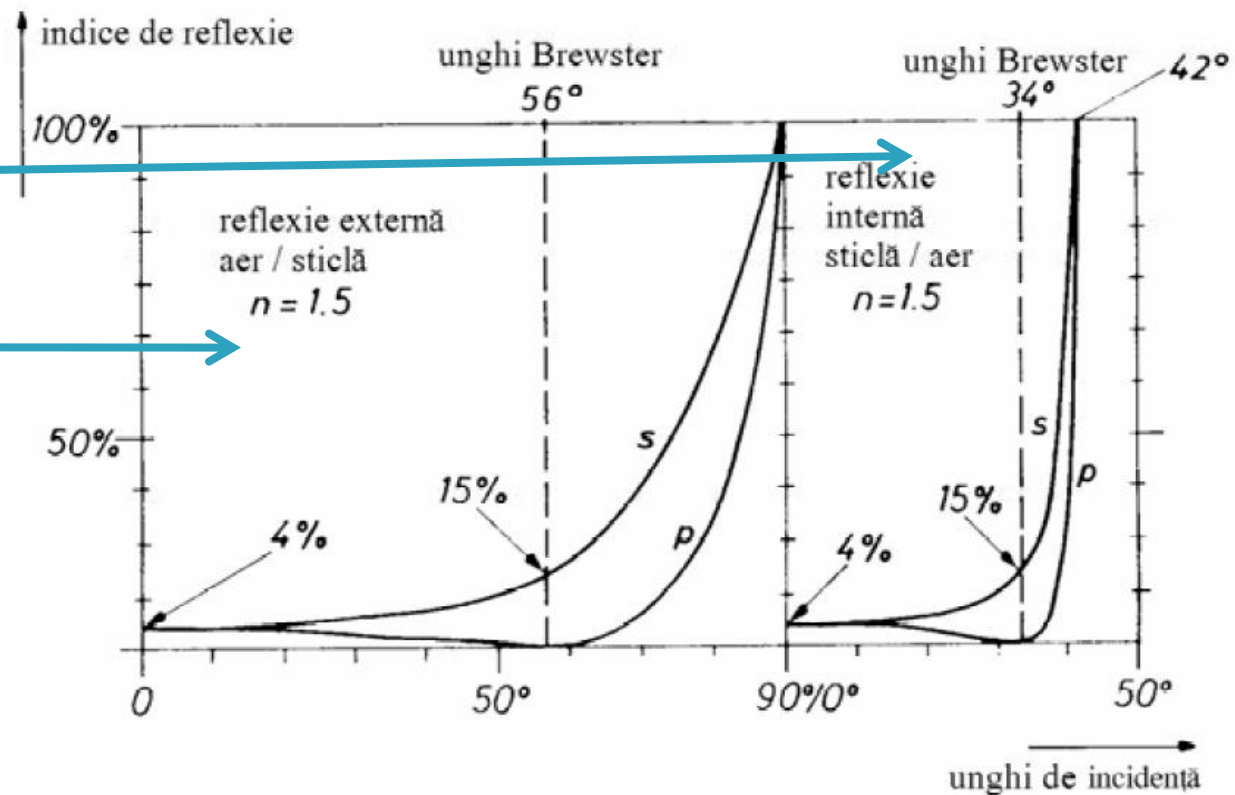
$$r_p = 0 \Rightarrow \tan(\phi_1 + \phi_2) \rightarrow \infty \Rightarrow \phi_1 + \phi_2 = \frac{\pi}{2}$$

$$n_1 \cdot \sin \phi_1 = n_2 \cdot \sin \phi_2 = n_2 \cdot \cos \phi_1$$

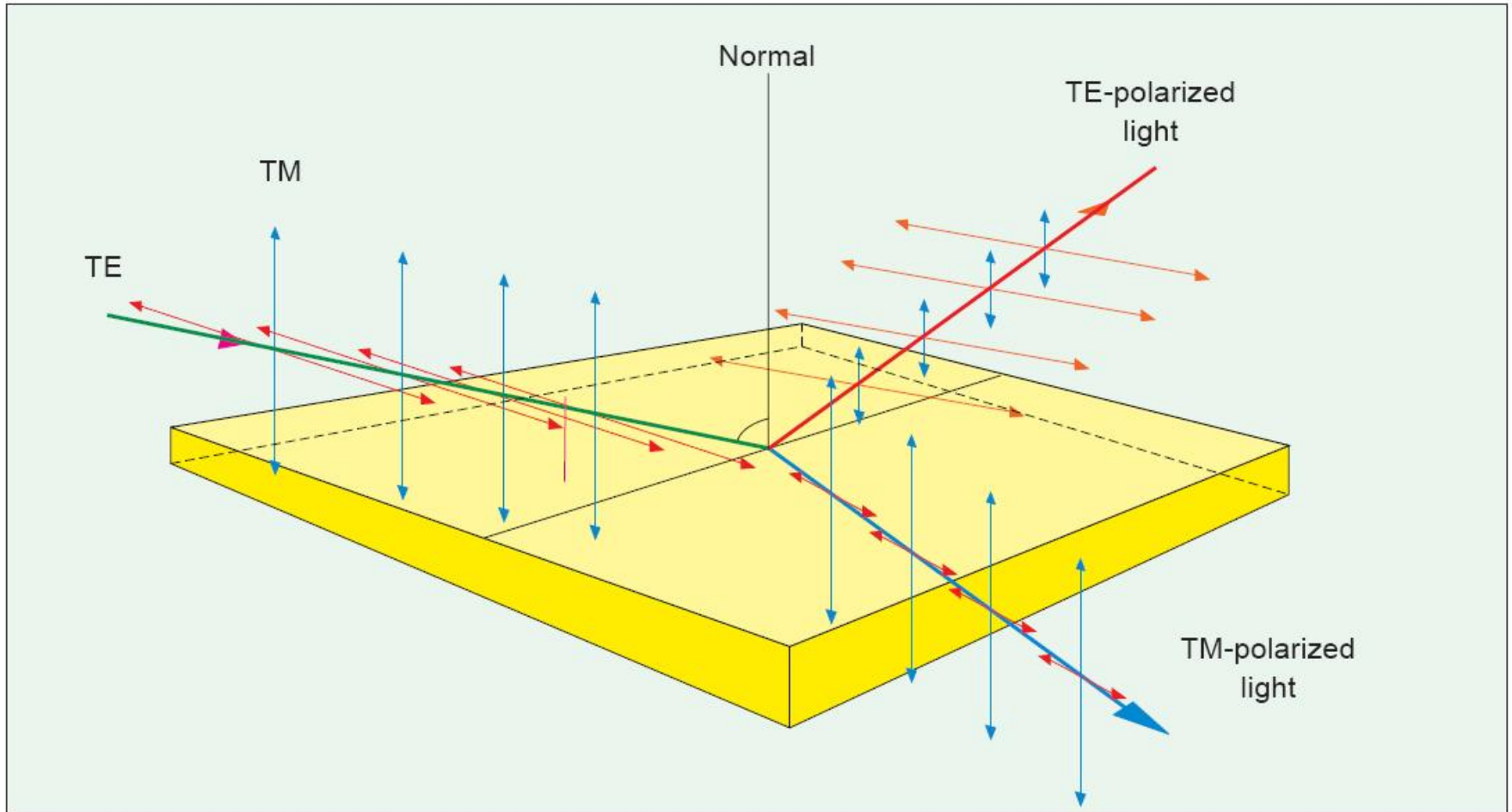
$$\phi_B = \arctan\left(\frac{n_2}{n_1}\right)$$

$$\phi_B = 34^\circ$$

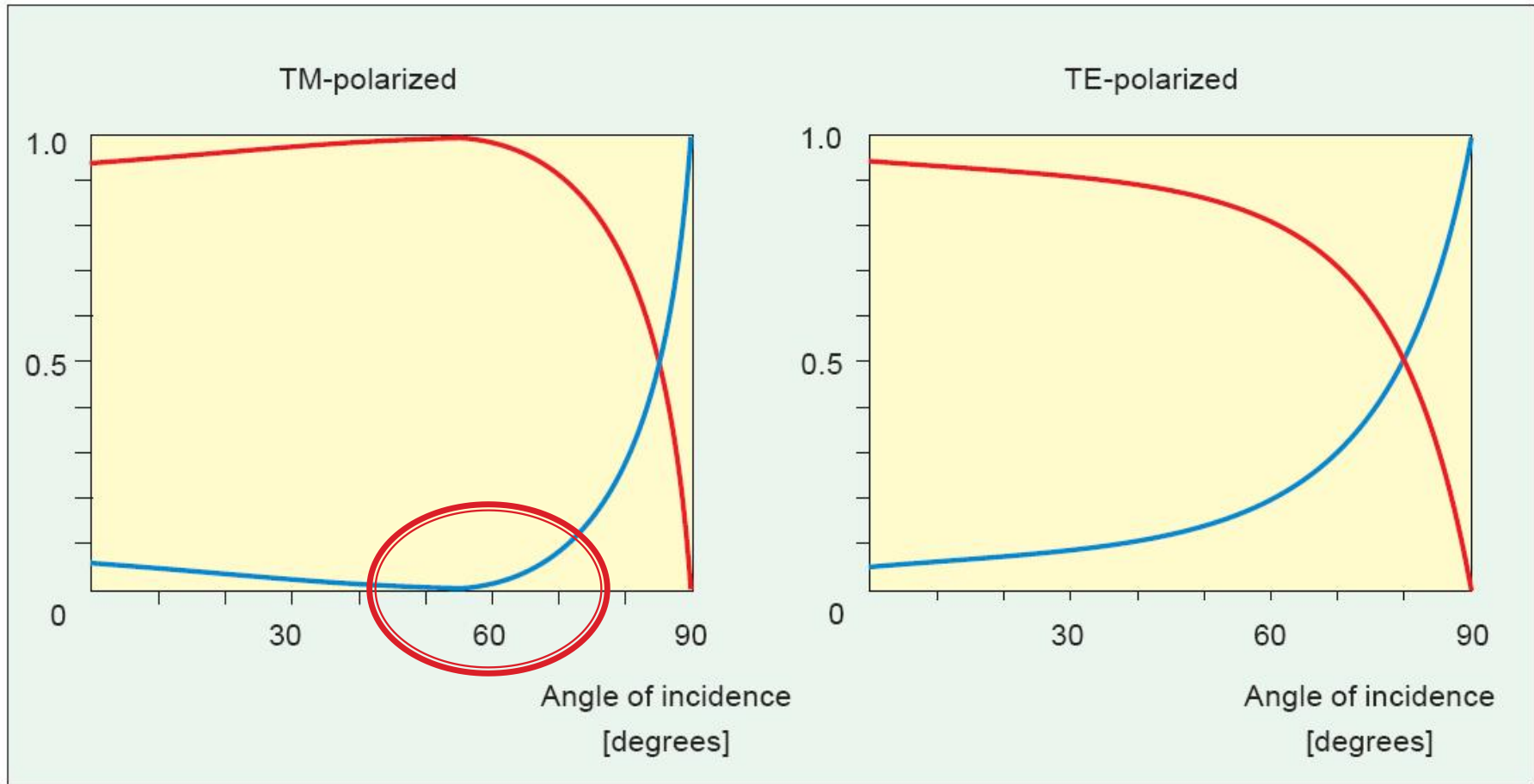
$$\phi_B = 56^\circ$$



Polarizarea luminii



Polarizarea luminii



Probleme

- ▶ Într-un LASER Fabry-Perrot, coerența luminii este obținută prin reflexii succesive ale luminii între două oglinzi paralele, separate de o distanță egală cu un multiplu a jumătate de lungime de undă ce se dorește emisă. Interferența constructivă și coerența dintre lumina incidentă și reflectată asigură amplificarea numai a luminii care îndeplinește această condiție. Se dorește realizarea unei diode LASER cu lungimea de undă $\lambda_0 = 1305\text{nm}$ utilizând un material cu $\epsilon_{r1} = 10.80$.

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

Probleme

- ▶ Care trebuie să fie distanța între oglinzi dacă se alege în așa fel încât să corespundă la 380 jumătăți de lungime de undă? (1 p)
- ▶ Dacă oglinda este realizată prin inserarea în material a unei lamele dintr-un dielectric cu $n_2 = 2.23$, ce procent din lumină incidentă părăsește zonă activă dintre cele două oglinzi la fiecare reflexie? (1 p)
- ▶ Dacă în total se emit 3 linii spectrale corespunzătoare selectării luminii la care distanța dintre oglinzi calculată la a) este egală cu $(380 - 1)$, (380) , $(380 + 1)$ jumătăți de lungime de undă, care este lățimea spectrală în domeniul frecvență a diodei? Valoarea trebuie exprimată în GHz. (2p)
- ▶ Care este unghiul Brewster de obținere a luminii liniar polarizate pentru trecerea din materialul cu $\epsilon_{r1} = 10.80$ în aer. (1 p)
- ▶ Rezolvări: <http://rf-opto.etti.tuiasi.ro>

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

unghi Brewster

lamela dielectrica

Probleme

- ▶ Într-un material cu indicele de refracție $n_1 = 3.75$ se interpune un strat de material (2) cu $\epsilon_{r2} = 5.20$ pentru a realiza o oglindă parțial reflectantă la realizarea unui LASER cu $\lambda_0 = 950\text{nm}$. Înălțimea stratului (2) este aleasă pentru reflectivitate maximă la incidență normală.
 - Care este înălțimea cea mai mică a stratului (2) pentru a obține acest efect? (2p)
 - Ce procent din puterea incidentă este întoarsă în materialul (1)? (1p)
 - O radiație care sosește cu înclinația de 41.2° față de normala la suprafața de separație, va trece din mediul (1) în mediul (2)? (1p)
- ▶ Rezolvări: <http://rf-opto.etti.tuiasi.ro>

lamela dielectrica

unghi critic

Contact

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