

Optoelectronică

Curs 3

2025/2026

Disciplina 2025/2026

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – conf. **Radu Damian**
 - an IV μ E
 - Marti 14:00–16:00, P7 $\rightarrow$ **P6**
 - E – 70% din nota (50%+20%)
 - **20% test (VP) la curs**, saptamana 4–6?
 - probleme + (2p prez. curs)
 - toate materialele permise
- ▶ Laborator – sl. **Catalin Iov**
 - an IV μ E
 - Marti 16–18, I.08
 - Max. 7 prezente
 - L – 30% din nota (+Caiet de laborator +Probleme)

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)
- ▶ **Emitătoare 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)

* – VP

Acces

- Personalizat (parola), Generic (email)



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

Date:

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

[Acceseaza ca acest student](#)

Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TW			Tehnologii Web			
N		17/01/2014	Nota finala	10	-	
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	-	

Login

Use the Registration no. and your

Registration no.

Email/Password

Write the code below

5dd64f9

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: 

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: 

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 Correspondents

 **Important message from RF-OPTO** ⇒ POPESCU GOPO ION

 Validation of MDCK exam from 02/05/2020 

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

Select **Important message from RF-OPTO**

To: 

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

 Laboratorul de Microunde si Optoelectronica
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Manual examen online

- ▶ Aplicatia de examen online utilizata la:
 - ~~curs (prezentat)~~
 - ~~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/fotografii)
 - ~~perioada scurta (teste: 15min, examen: 2h)~~

Start Didactic Master Colectiv Cercetare **Studenti**

Note Lista Studenti **Examine** 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

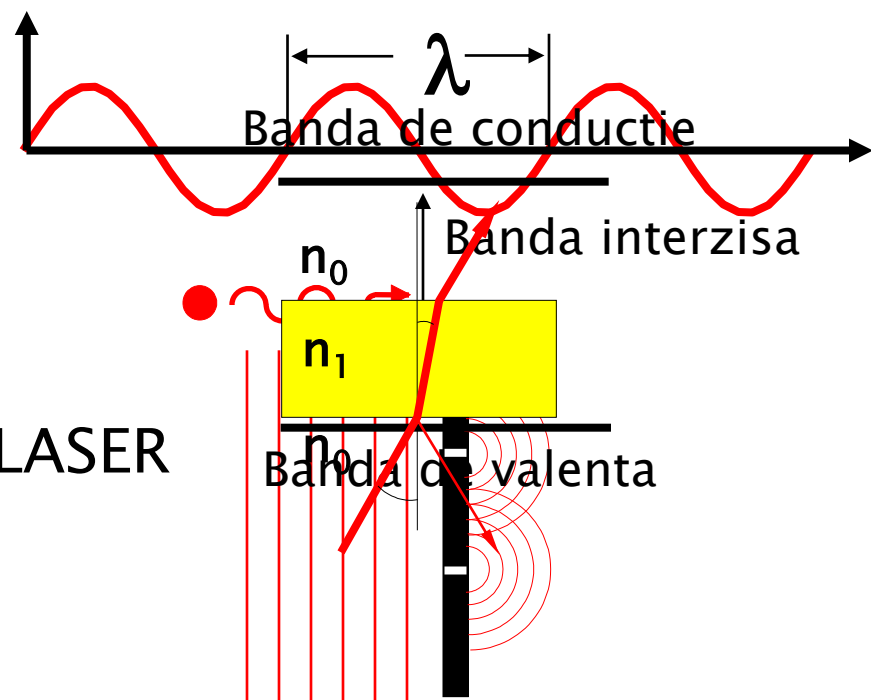
- ▶ Comunicatii
 - Infrarosu (InGaAsP)
- ▶ Vizibil
 - Spectru vizibil (GaAlAs)
- ▶ Iluminare
 - Putere ridicata, lumina alba (GaInN)
- ▶ Energie solara
 - Efect fotovoltaic (Si)

Modelarea luminii

(tot) Capitolul 1

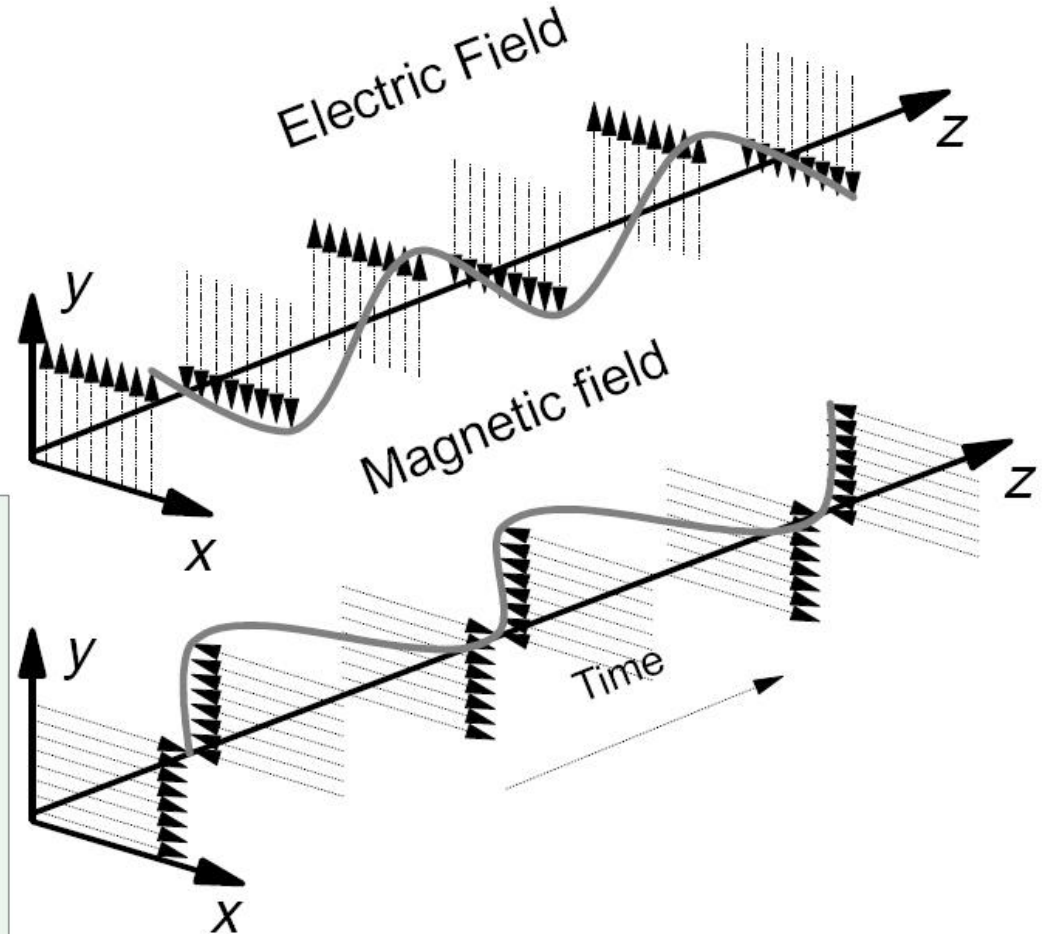
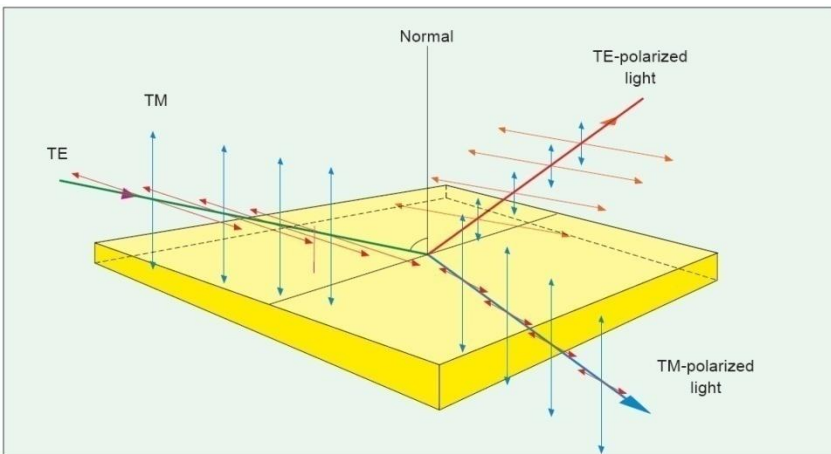
Modelarea luminii

- ▶ 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

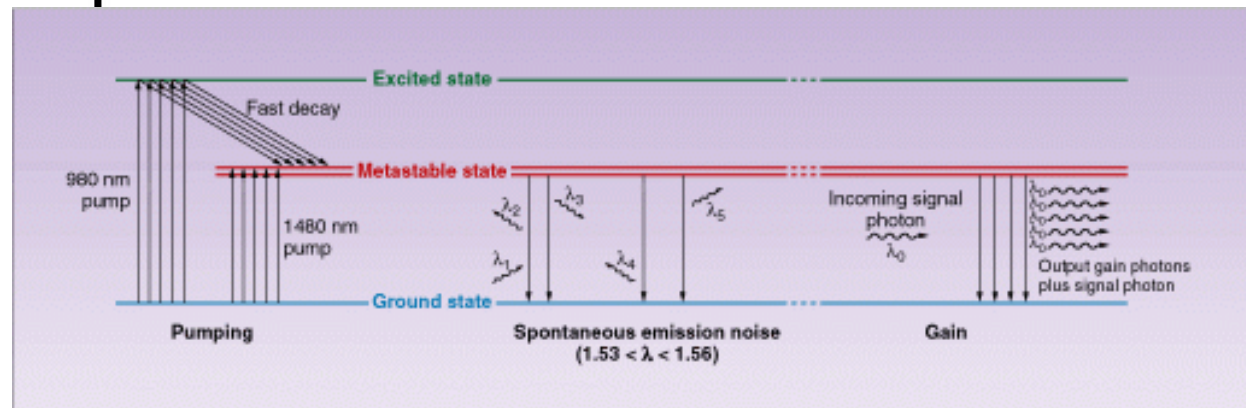
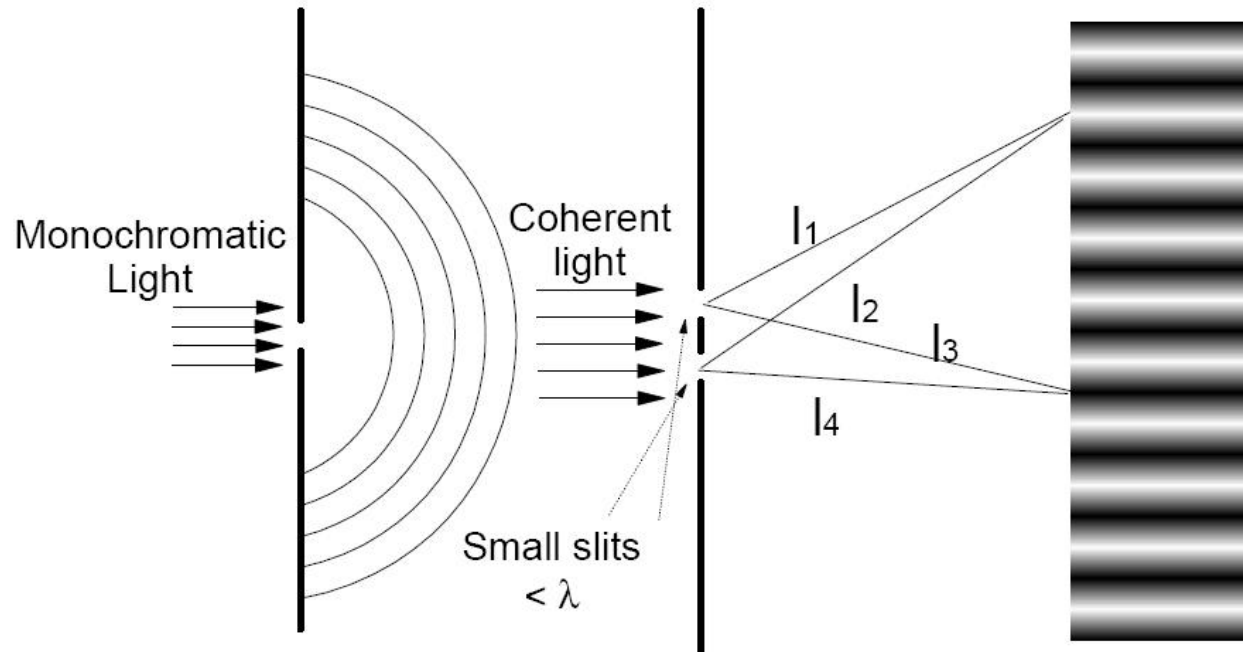


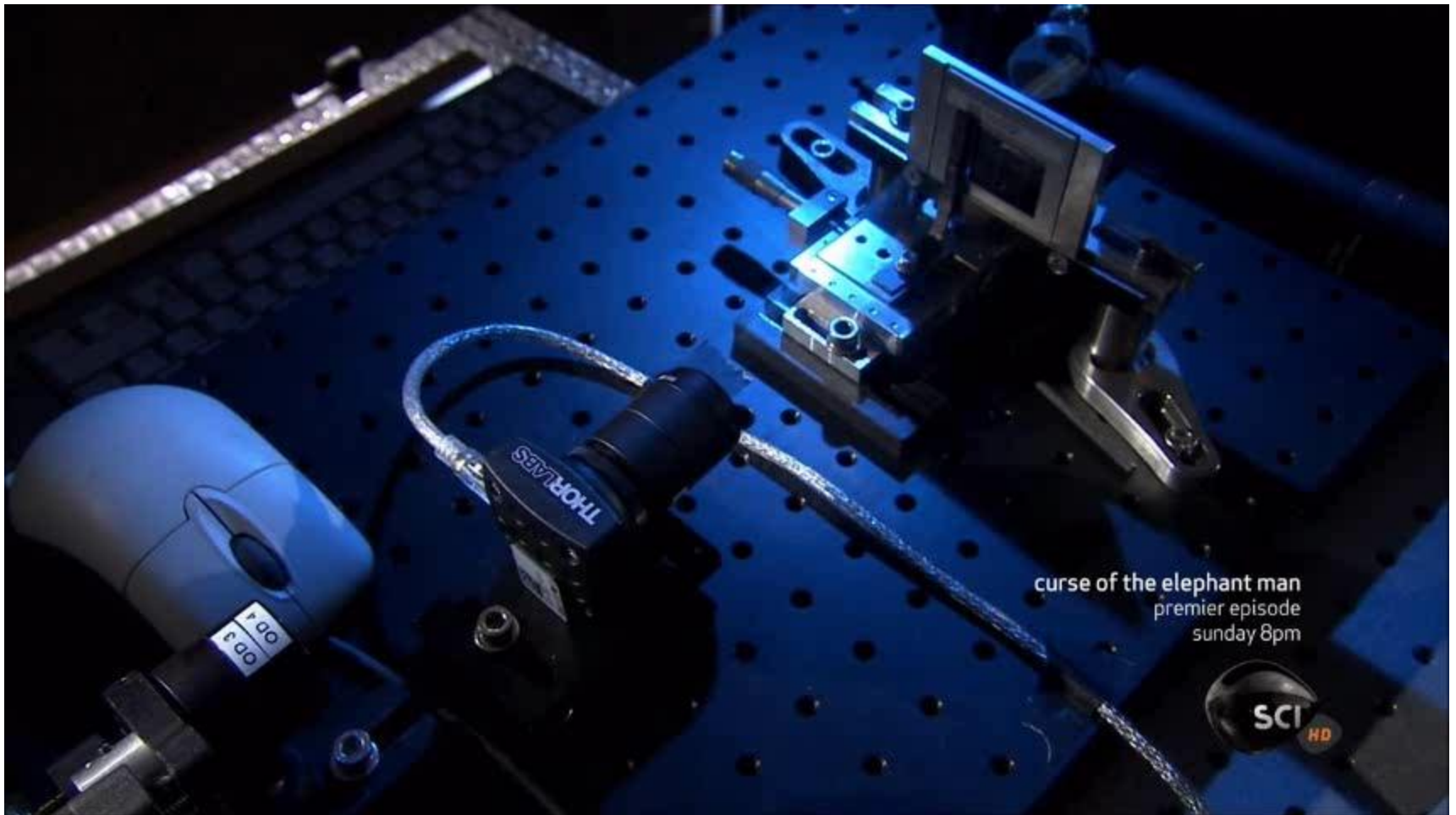
Unda electromagnetica

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



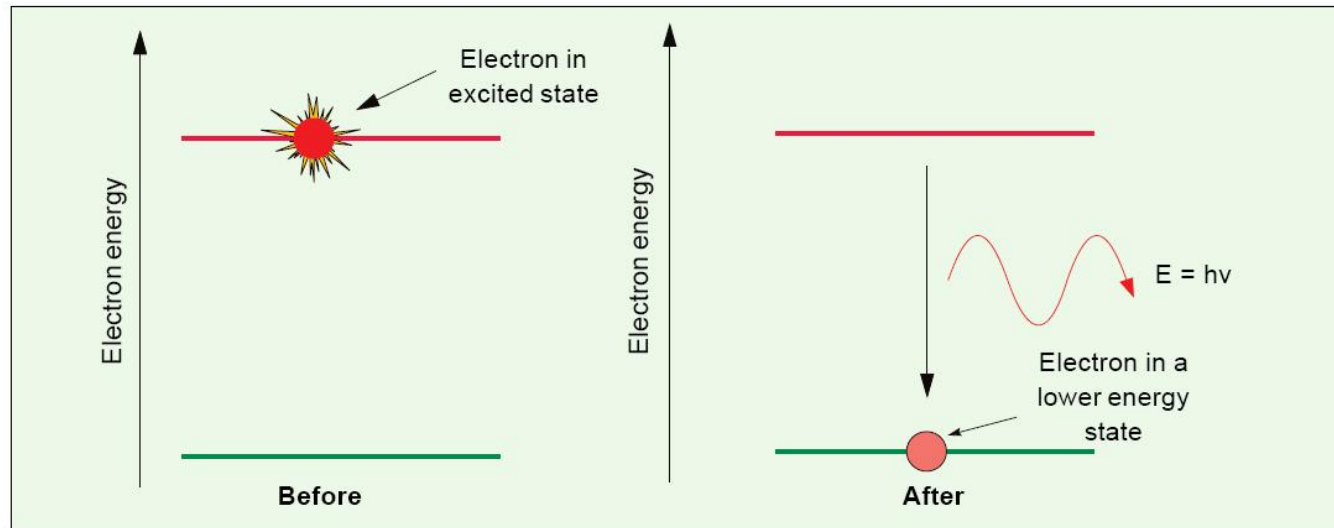
Fotoni/Unda





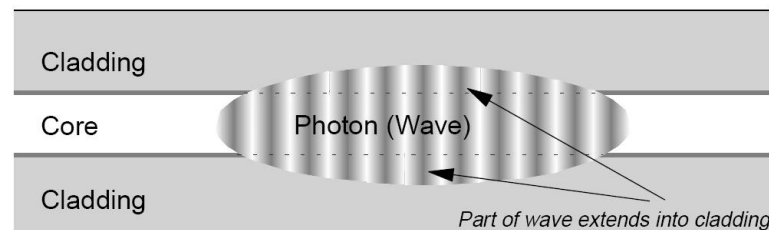
Through the Wormhole S02E07 How Does the Universe Work

Model cuantic – foton



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

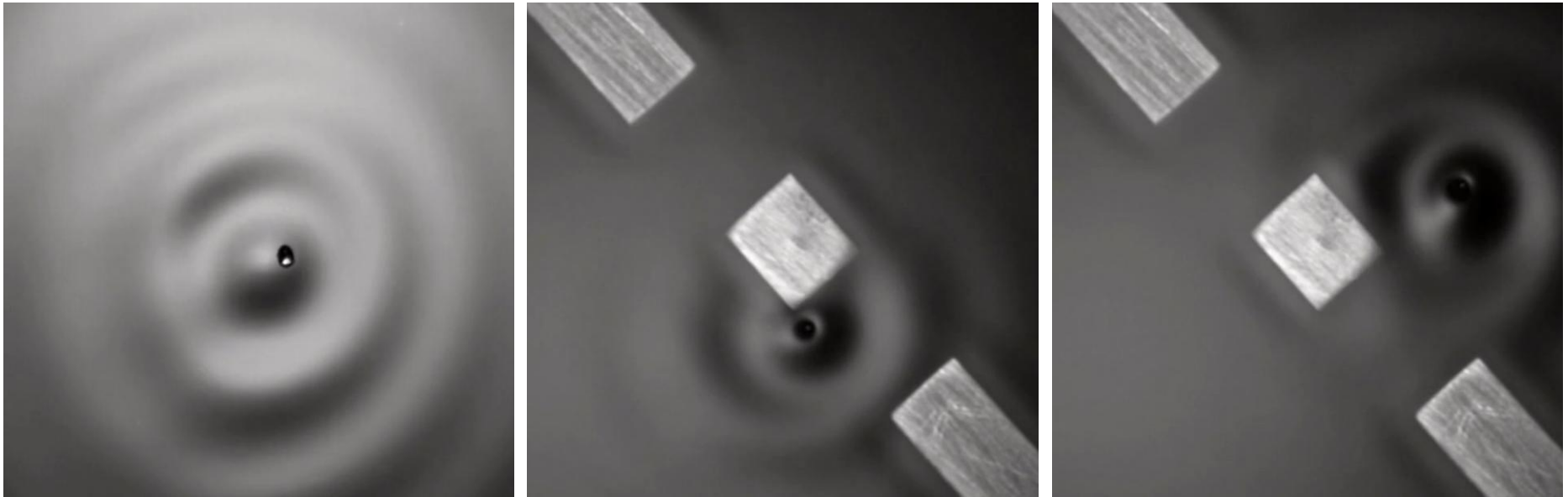
- ▶ h constanta lui Plank
 $6.62 \cdot 10^{-32} \text{ Ws}^2$
- ▶ c viteza luminii **in vid**
 $2.998 \cdot 10^8 \text{ m/s}$



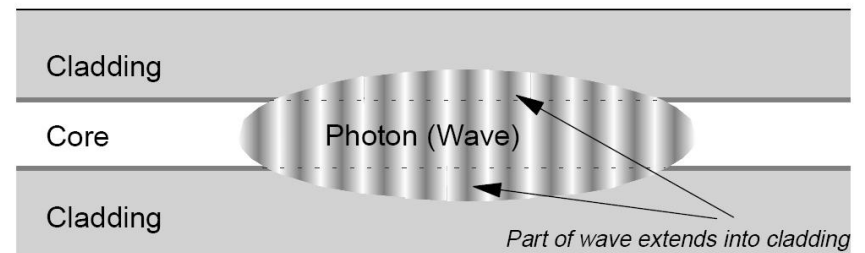


Through the Wormhole S02E07 How Does the Universe Work

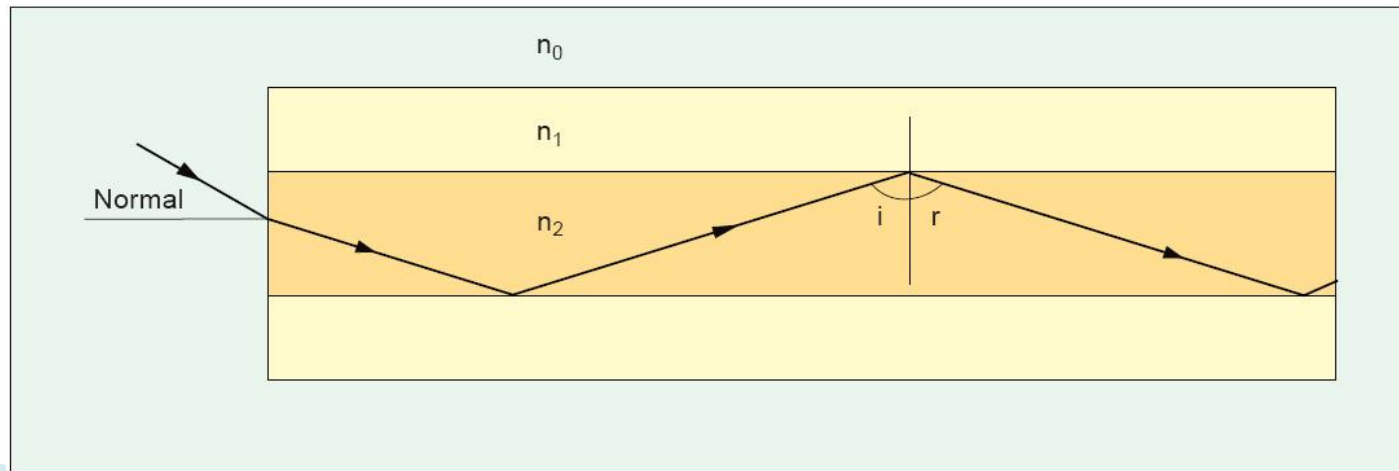
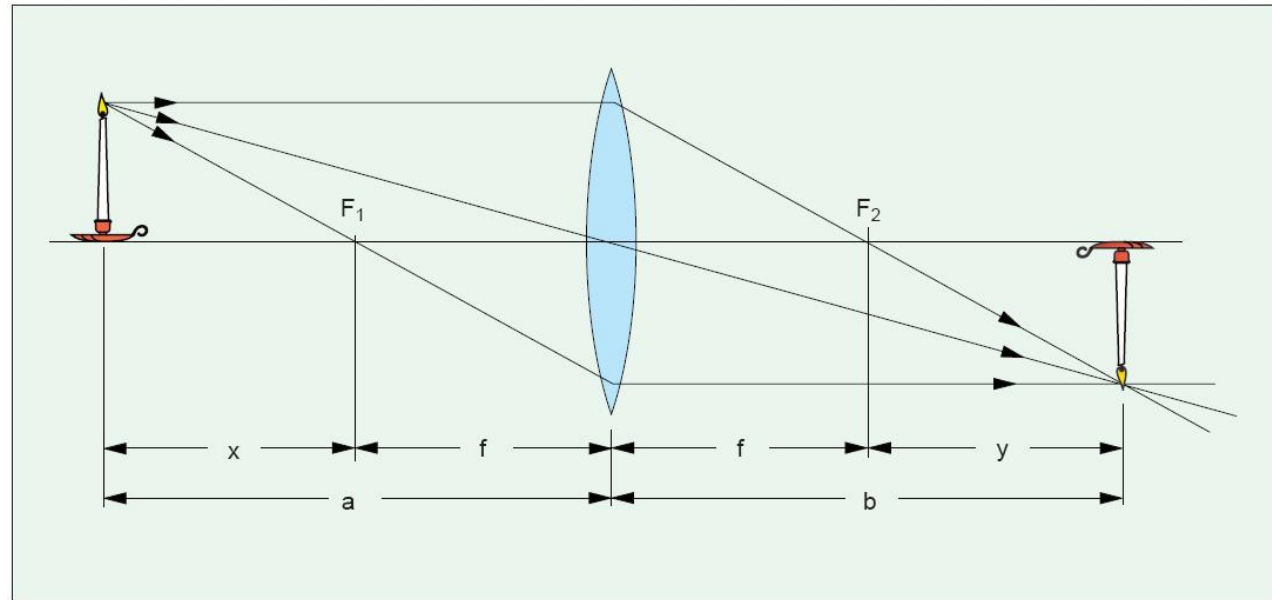
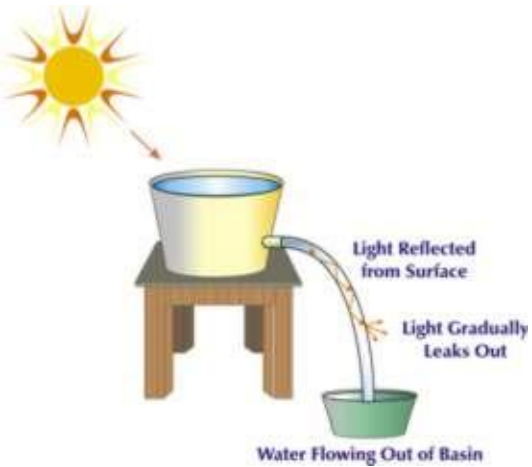
Modelare



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)
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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

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

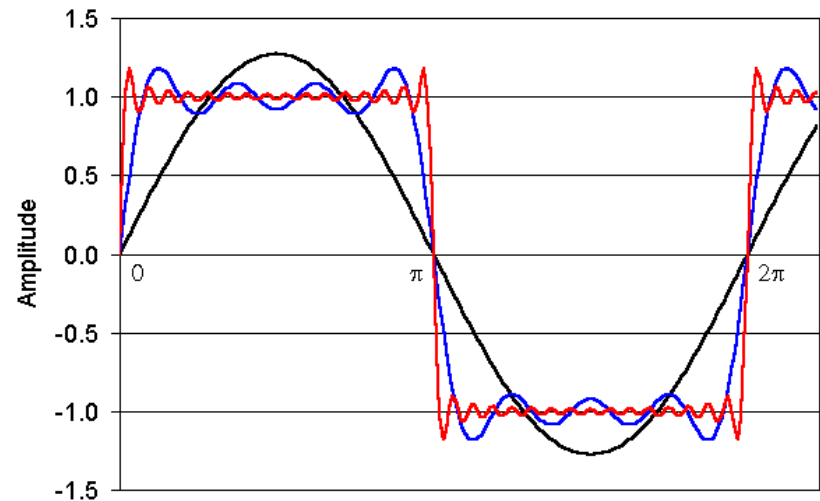
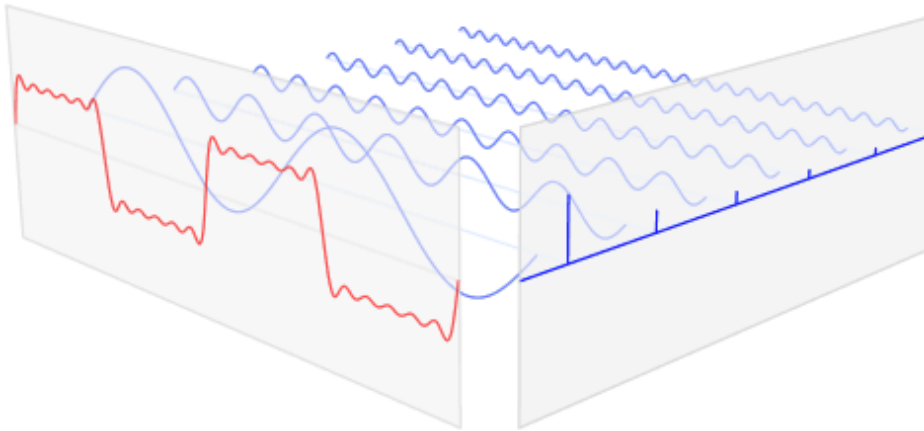
$$\varepsilon_0 = 8,854 \times 10^{-12} \text{ F/m}$$

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

Modele matematice

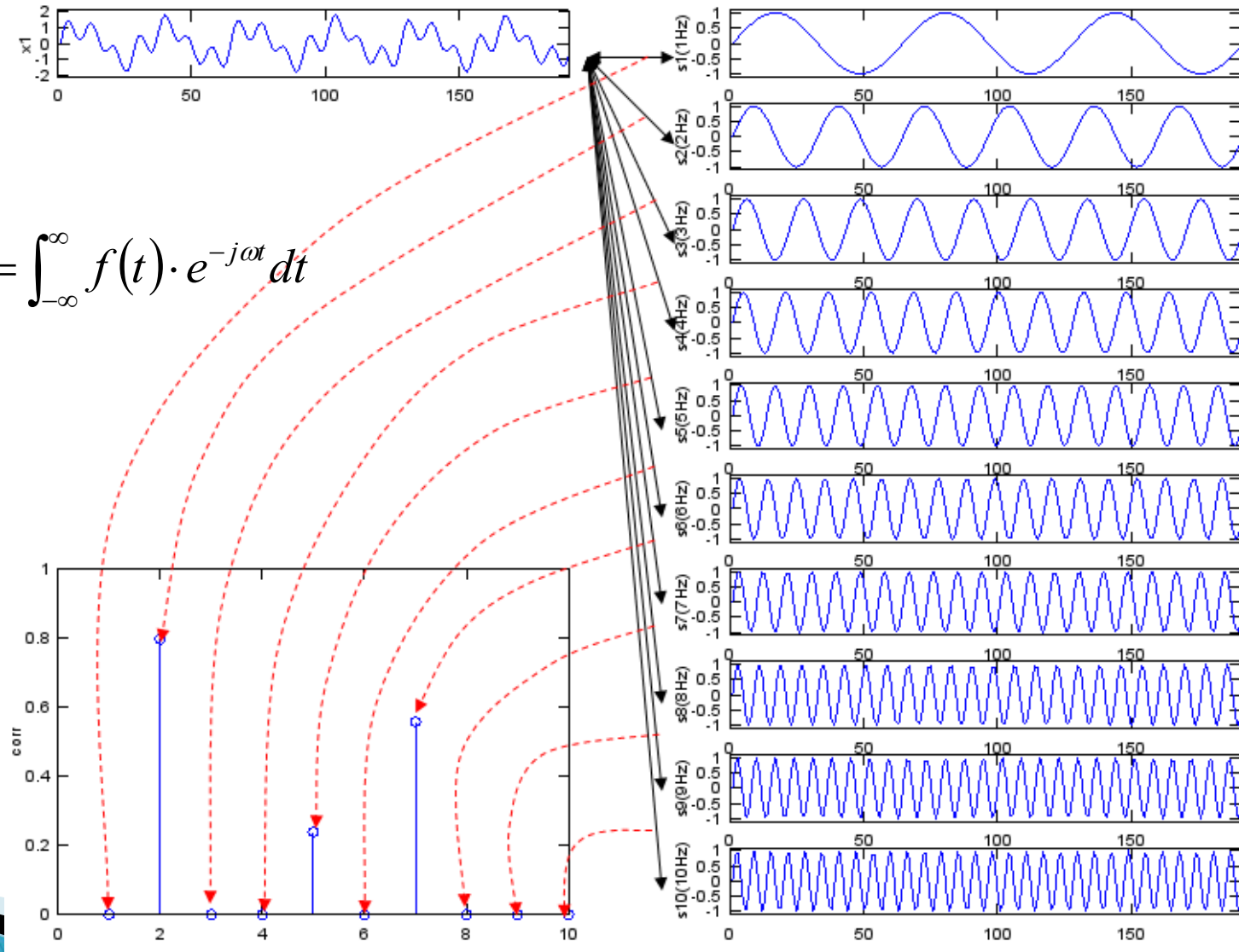
- ▶ cazuri particulare in care exista rezolvare analitica
 - semnale cu variație armonică în timp, transformata Fourier, spectru

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

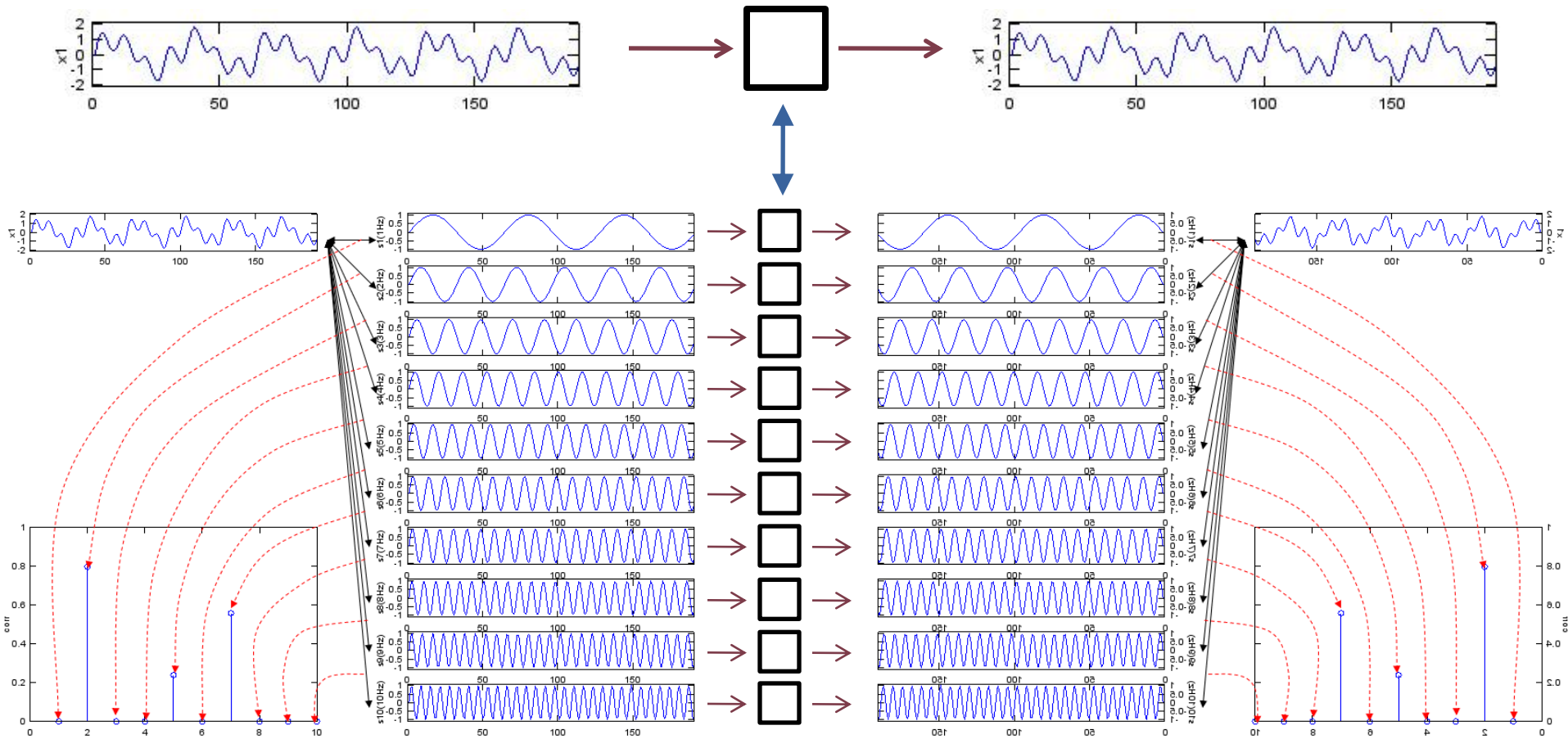


Modelle matematiche

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



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

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

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

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

$$\nabla \cdot H = 0$$

► Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

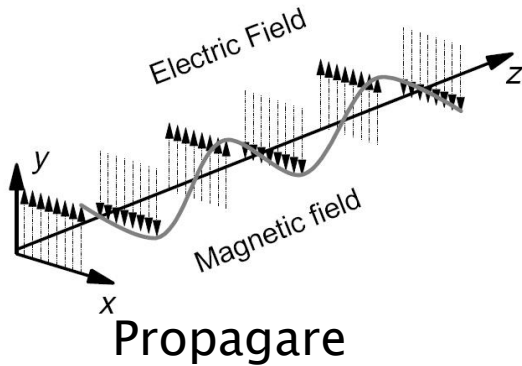
$$\nabla^2 E - \gamma^2 E = 0$$

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

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

γ – Constanta de propagare

Solutia ecuatiilor de propagare



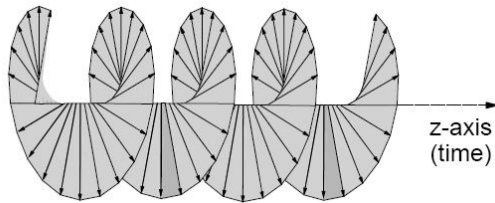
Camp electric dupa directia Oy, ← prin alegerea judicioasa
 propagare dupa directia Oz ← a sistemului de referinta

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

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

Exista **numai** unda progresiva $E_+ \Rightarrow A$

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



Polarizare circulara

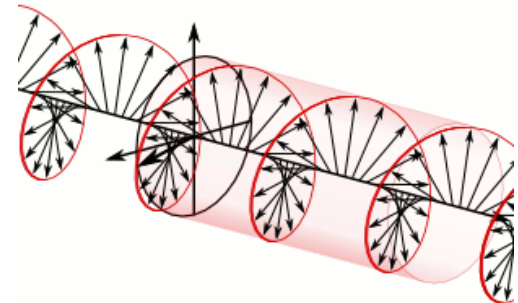
Camp armonic

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

Amplitudine

Atenuare

Propagare
(variatie in timp si spatiu)



Modele matematice

► cazuri particulare in care exista rezolvare analitica

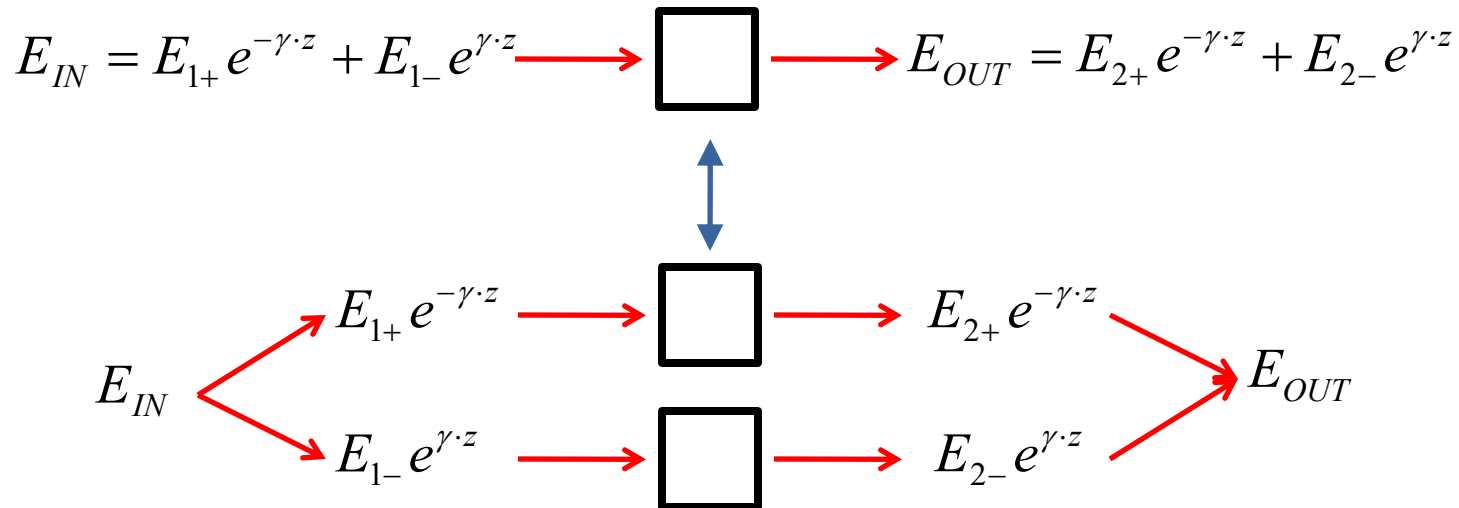
◦ unda

- incidenta
- reflectata

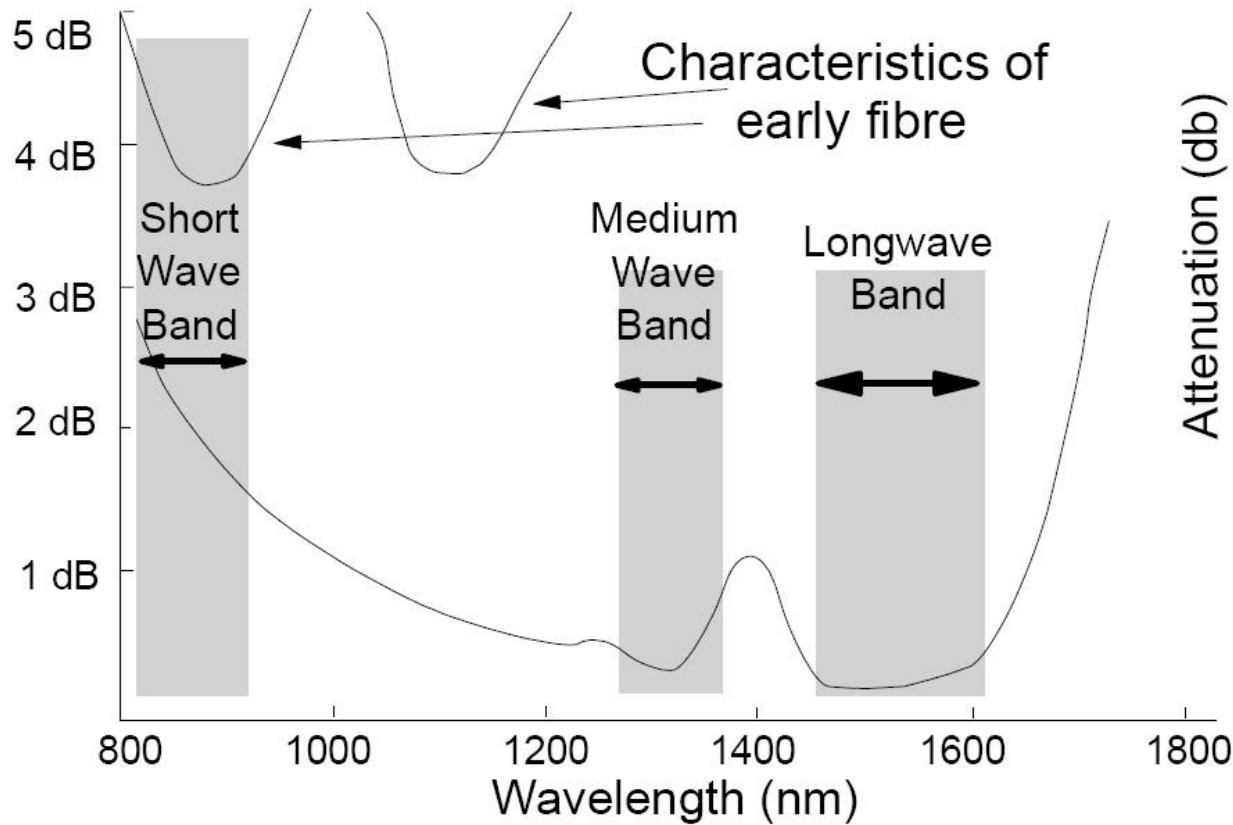
◦ unda

- 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/amplificarii

$$\text{Atenuare/Amplificare} = \frac{P_{out}}{P_{in}}$$

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

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

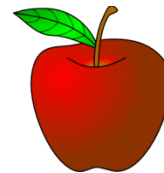
$$\text{Pierderi[dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=

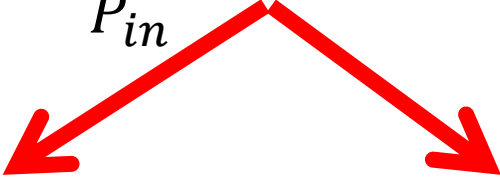


-



Calculul atenuarii/amplificarii

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


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

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

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

Calculul atenuarii/amplificarii

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

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


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

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


Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

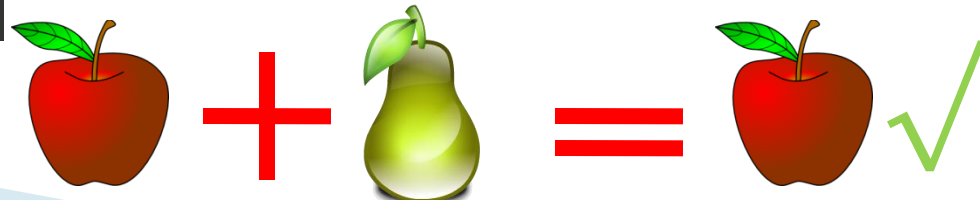
$$-30 \text{ dBm} = 1 \mu\text{W}$$

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

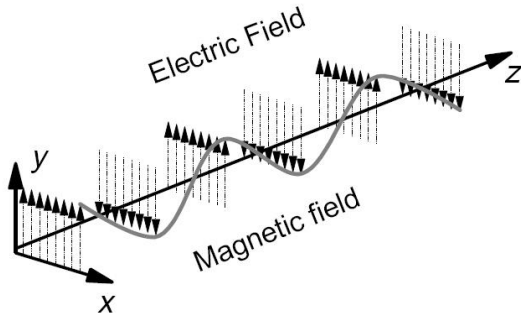
$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

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

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



Parametri de propagare



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

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

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

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

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

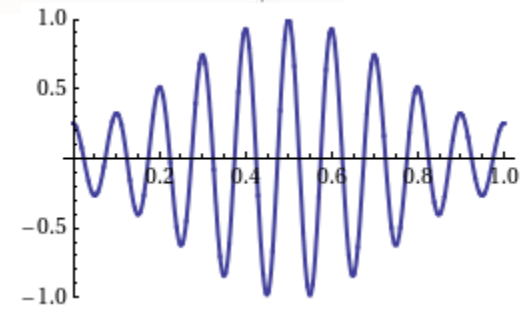
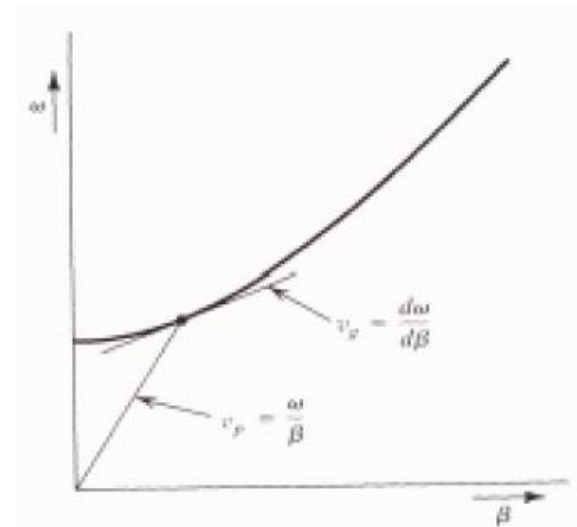
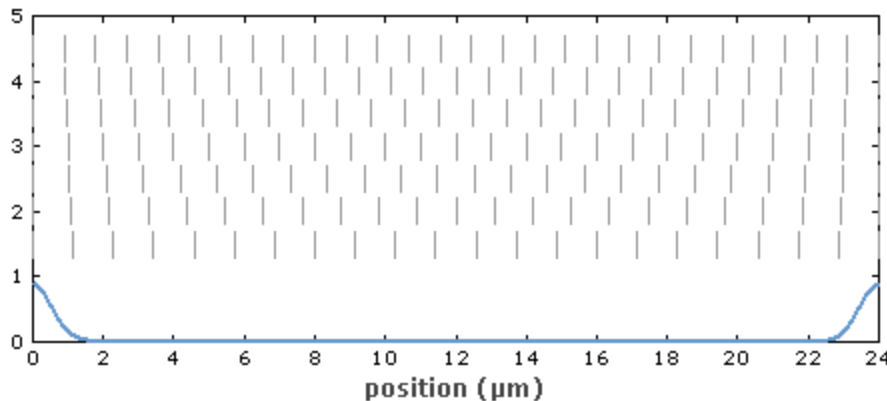
$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)} \quad \text{punctele de faza constanta: } (\omega \cdot t - \beta \cdot z) = \text{const}$$

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

Viteza de grup $v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta}$ in medii dispersive unde $\beta = \beta(\omega)$

Viteze de grup si faza

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



Parametri de propagare

► In vid

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \quad v = v_g = c_0 \quad c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99792 \cdot 10^8 \text{ m/s}$$

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

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

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

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

$n = 1$

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

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

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

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

$n = \sqrt{\varepsilon_r}$

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

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

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

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

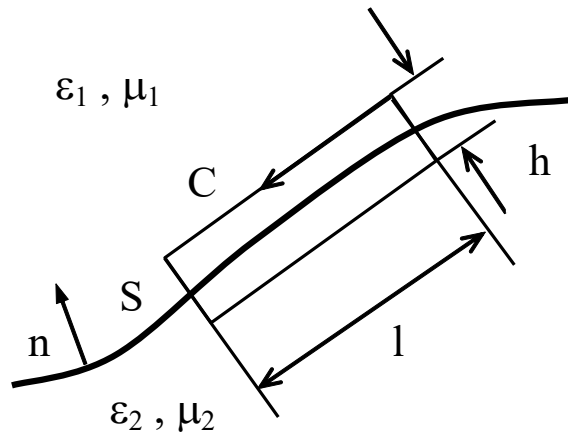
ITU G.692

"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 $540 \cdot 10^{12} \text{ Hz}$ "

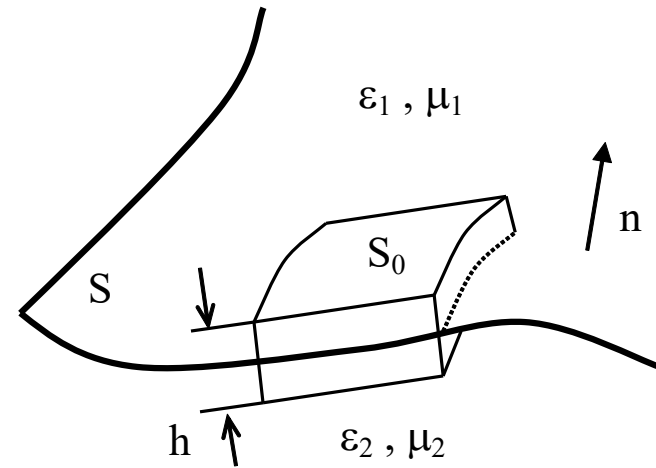
Condiții la limita de separație între două medii



a)

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

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



b)

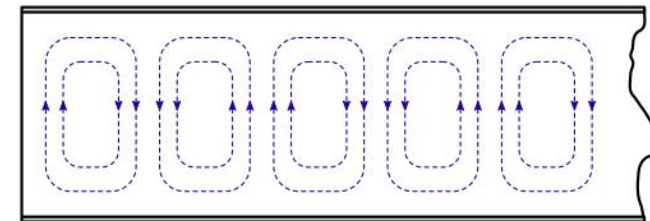
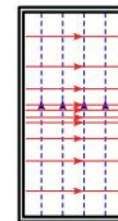
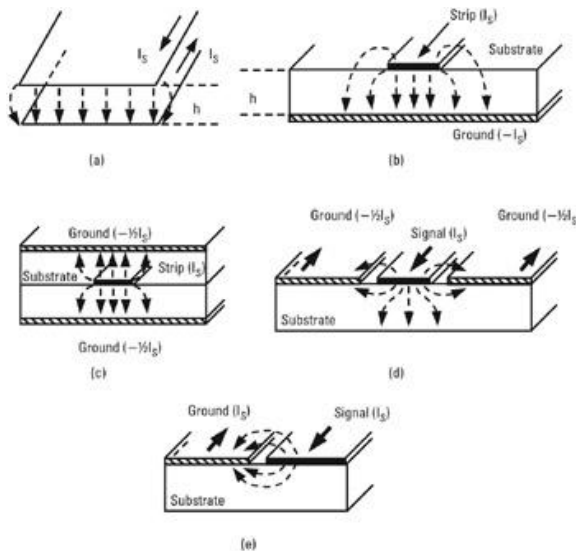
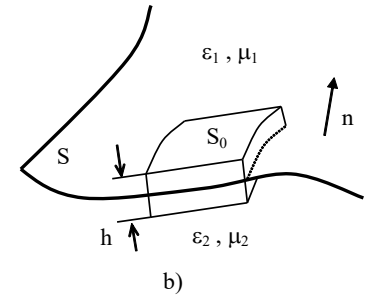
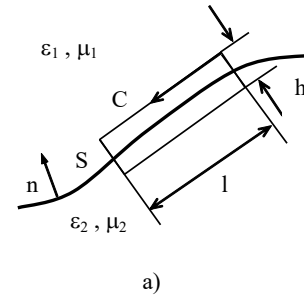
$$n \cdot (D_1 - D_2) = \rho_S$$

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

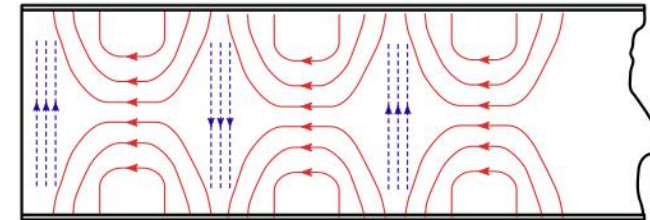
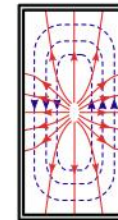
- ▶ Dacă un mediu este metal ideal toate campurile se anuleaza in interior

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

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

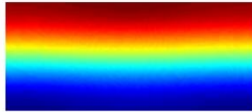
- ▶ In medii delimitate solutiile ecuatiilor lui Maxwell trebuie sa verifice conditiile la limita
 - solutiile trebuie sa respecte anumite conditii suplimentare

Moduri in medii delimitate

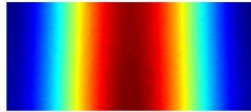
TE10



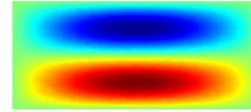
TE01



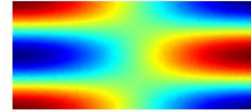
TE20



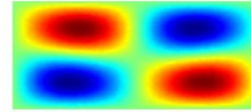
TM12



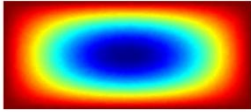
TE12



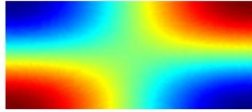
TM22



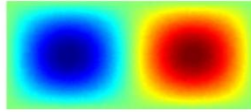
TM11



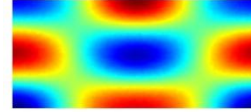
TE11



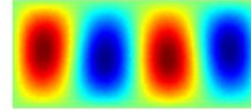
TM21



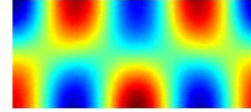
TE22



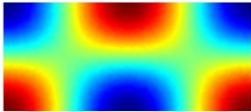
TM41



TE41



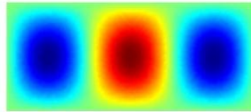
TE21



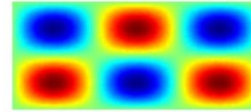
TE30



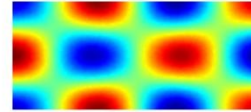
TM31



TM32



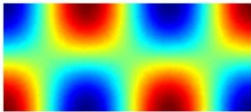
TE32



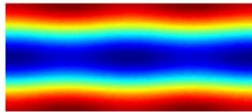
TE50



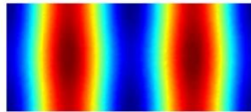
TE31



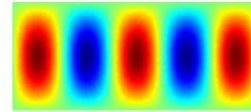
TE02



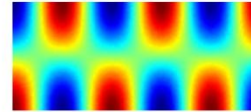
TE40



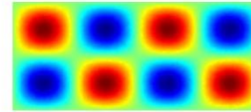
TM51



TE51



TM42



- Similar cu transformata Fourier

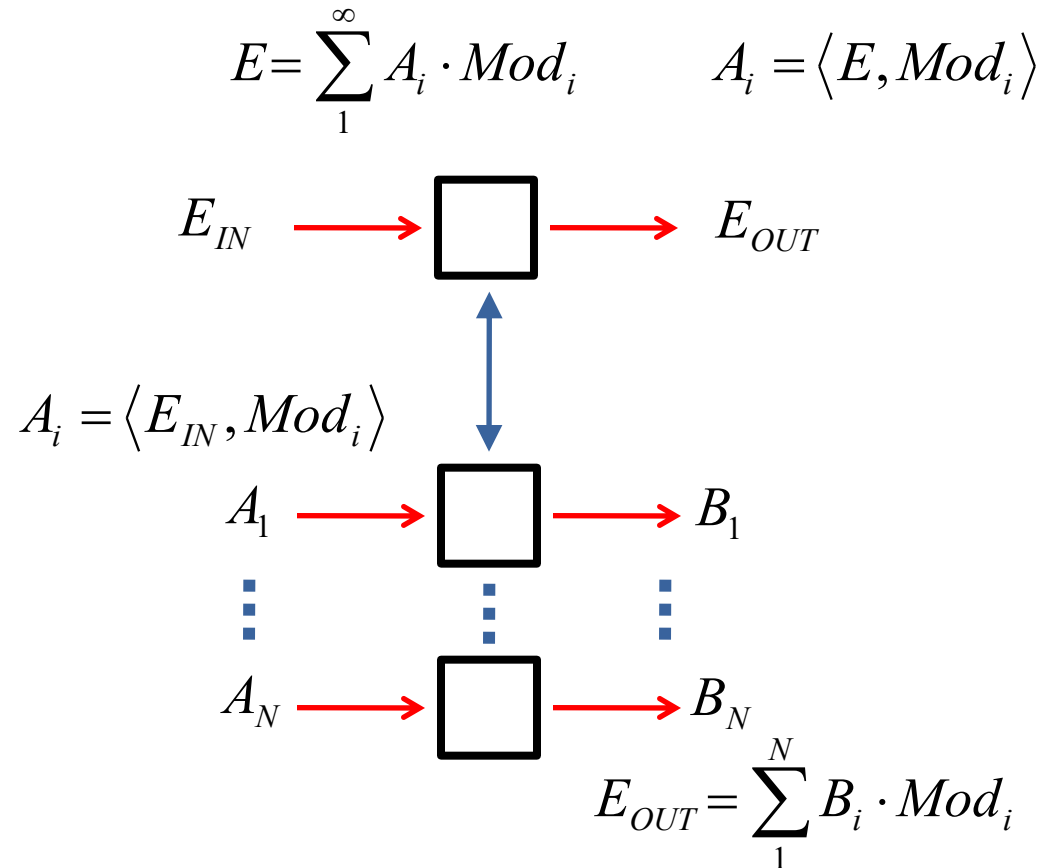
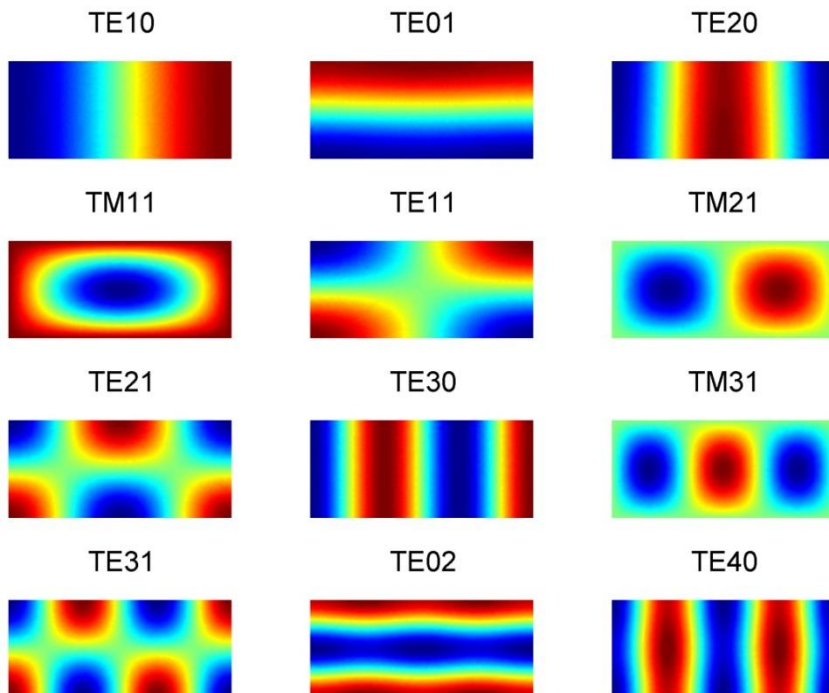
$$g(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$$

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

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

Modele matematice

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



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)

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

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

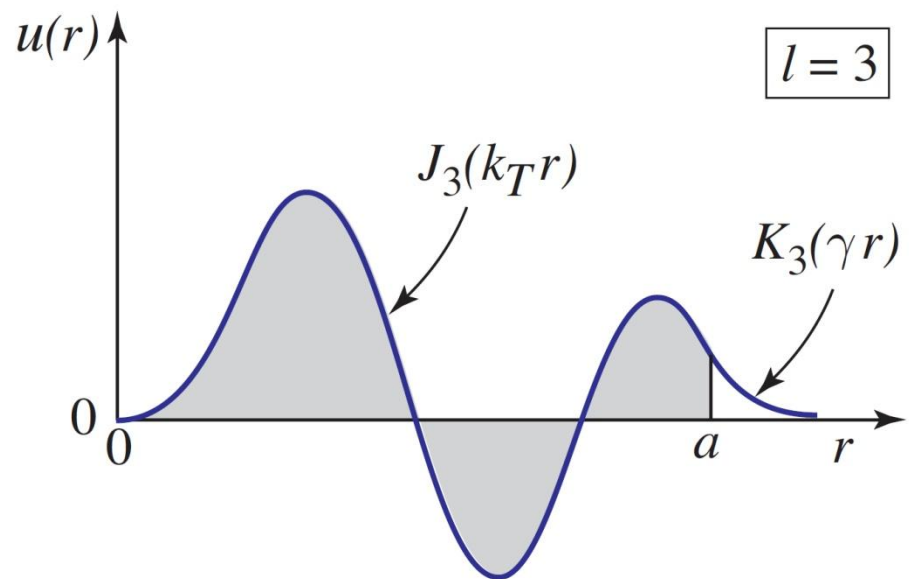
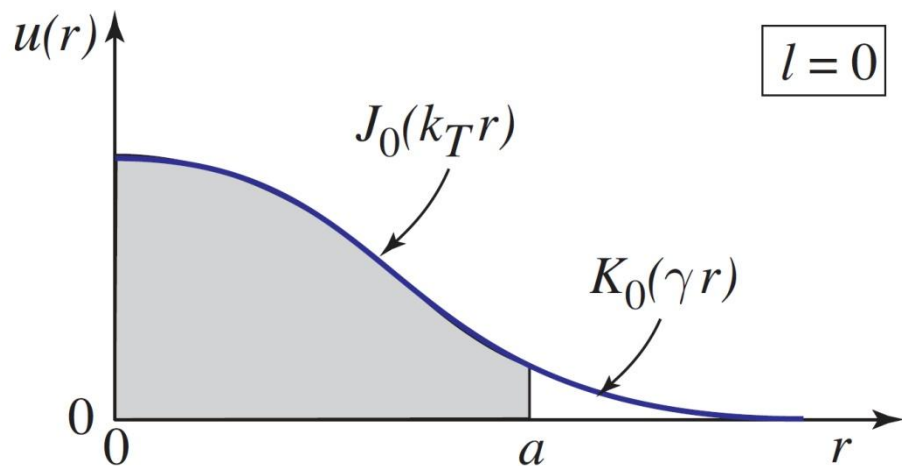
$$\frac{d^2 u}{dr^2} + \frac{1}{r} \frac{du}{dr} + \left(k_T^2 - \frac{l^2}{r^2} \right) u = 0, \quad r < a$$

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

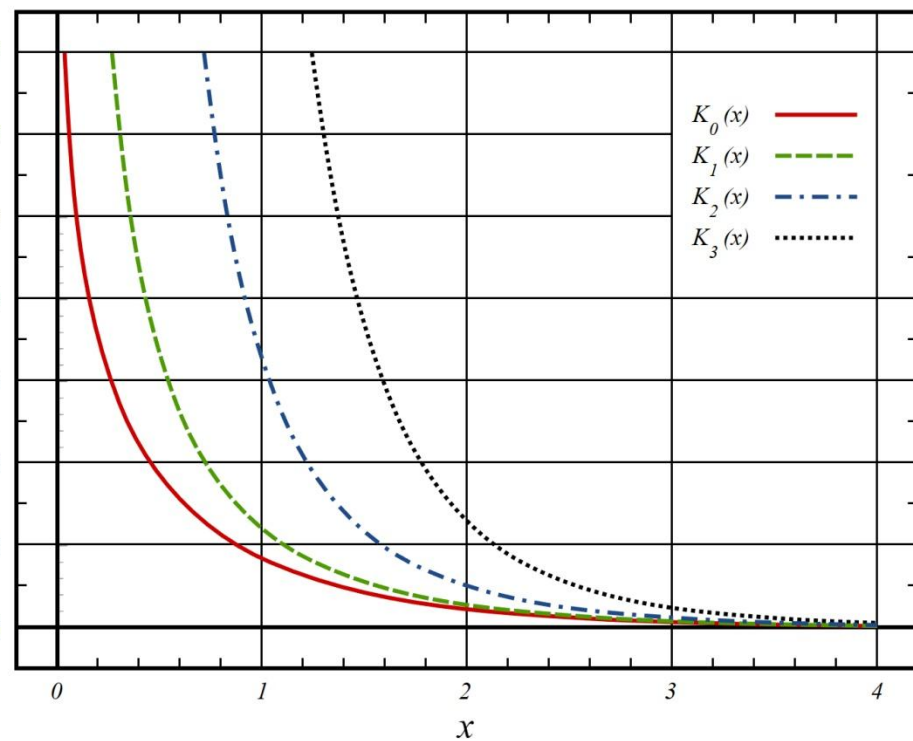
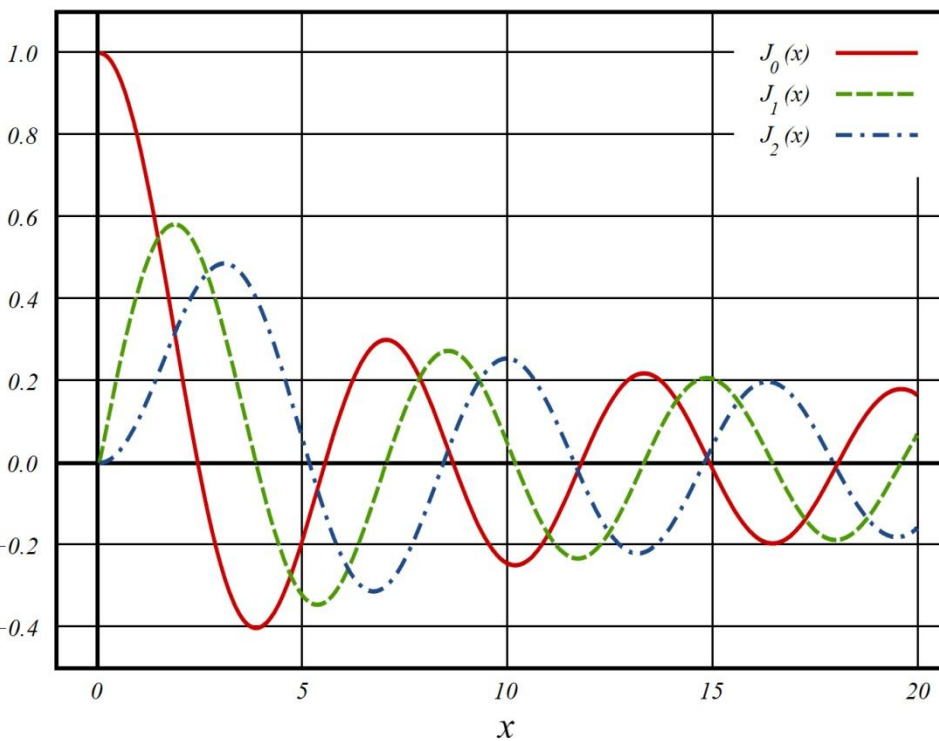
Ghid cilindric dielectric

- ▶ soluții proporționale cu funcții Bessel

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

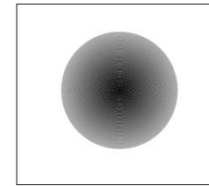


Funcții Bessel

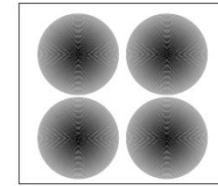


Moduri in fibra

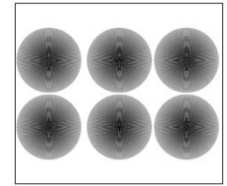
- ▶ Moduri in ghid rectangular



TEM₀₀

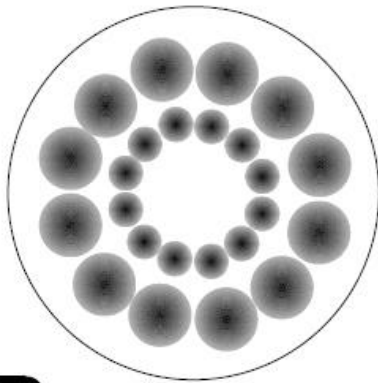


TEM₁₁

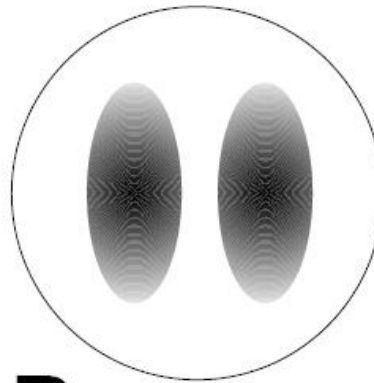


TEM₂₁

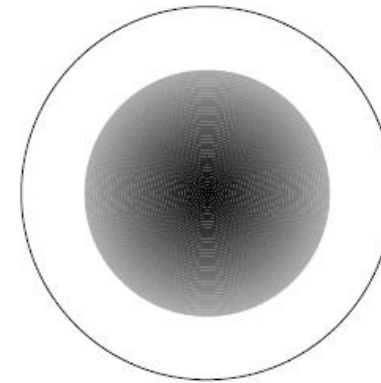
- ▶ Moduri linear polarizate in fibra



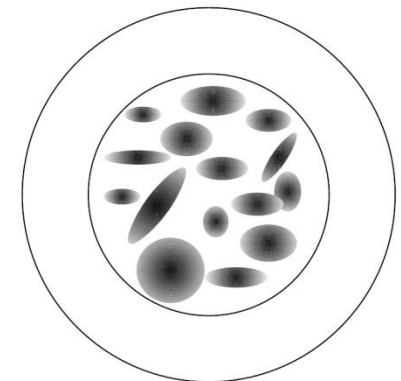
LP₆₂



LP₁₁



LP₀₁



“Sparkle” pattern

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

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

$$\frac{d\tau}{d\lambda} = \frac{L}{c} \left(\frac{dn}{d\lambda} - \lambda \frac{d^2n}{d\lambda^2} - \frac{dn}{d\lambda} \right) = -\frac{L}{c} \cdot \lambda \cdot \frac{d^2n}{d\lambda^2} \qquad D \stackrel{not}{=} -\frac{\lambda}{c} \cdot \frac{d^2n}{d\lambda^2} \quad (s/m^2)$$

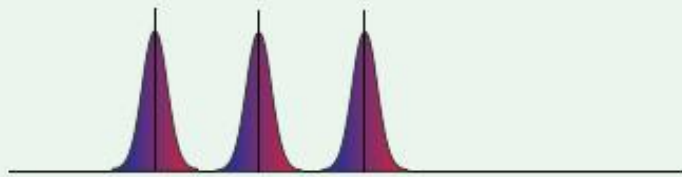
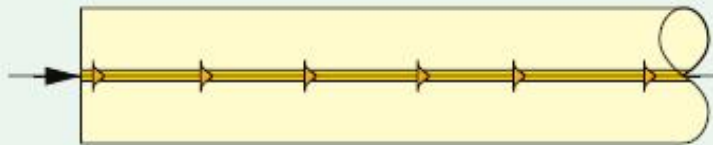
- Dispersia **D** se exprima de obicei in **ps/nm/km** si permite aflarea intarzierilor aparute intre "moduri" (latirea impulsurilor) pentru o anumita latime spectrala $\Delta\lambda$ si o anumita distanta parcursa L

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

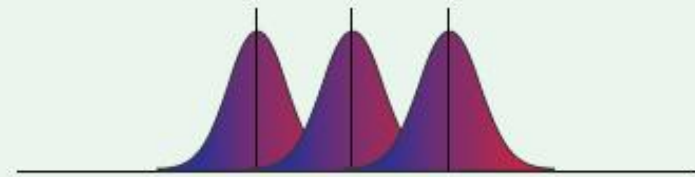
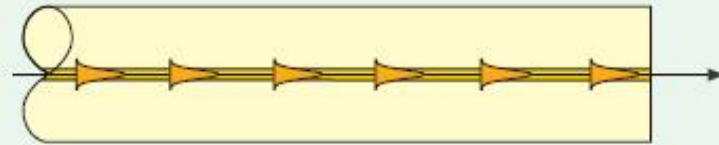
Dispersie

← →

> 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



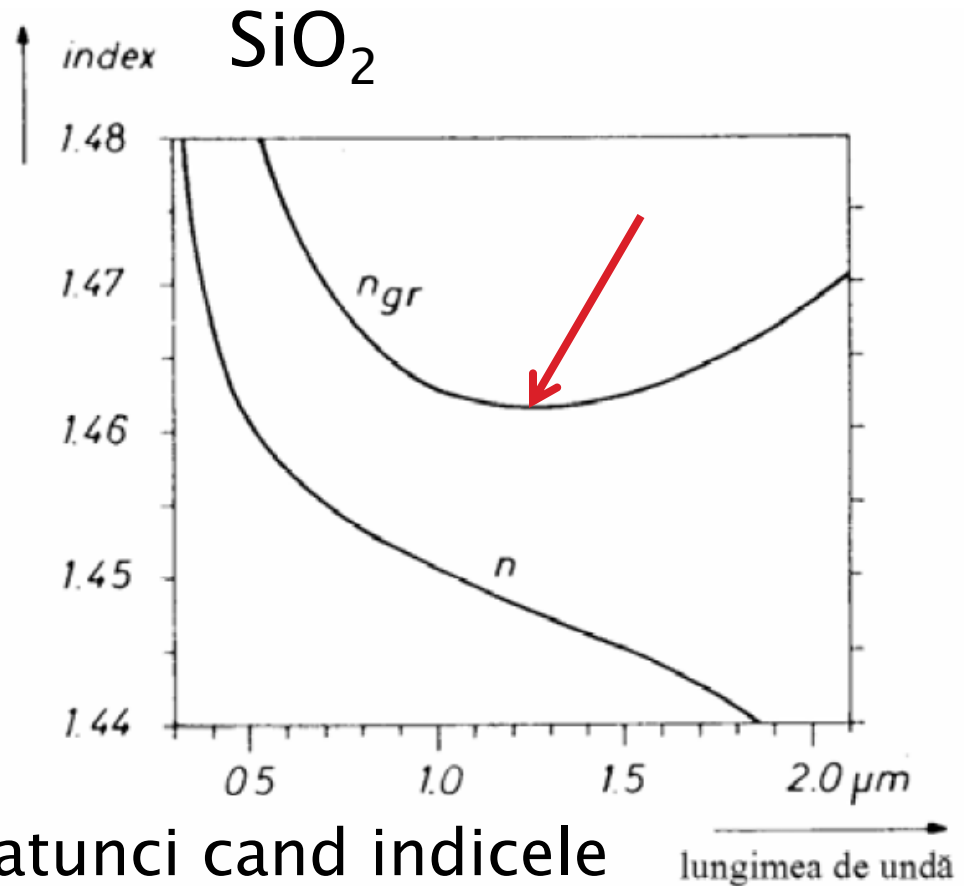
Reception:
Pulse broadening caused by the laser's spectral width and the difference between the refractive indices of the red and blue ends of the light pulse.

Dispersie normala

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

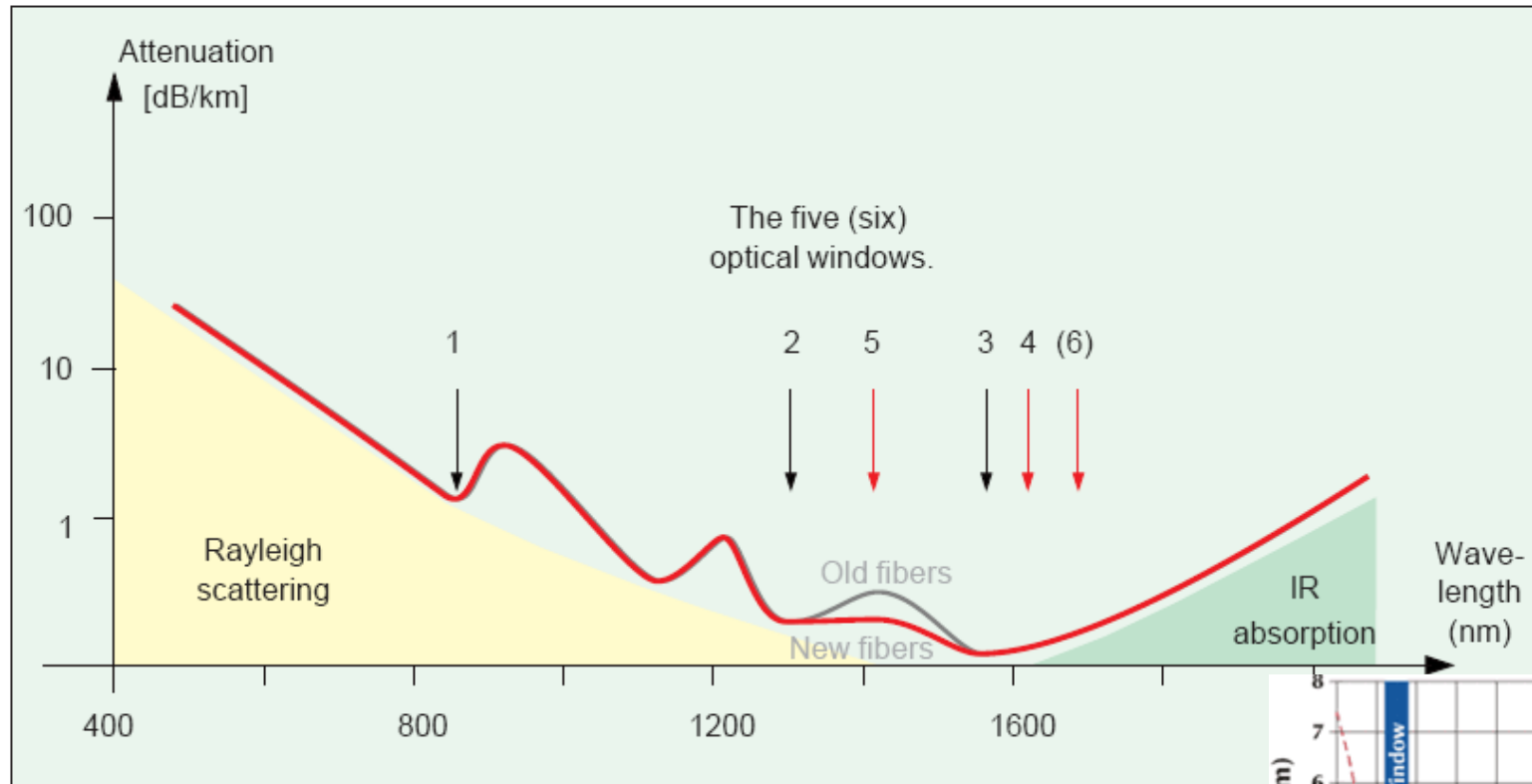
$$v_g = \frac{c}{n_{gr}} \quad n_{gr} = n - \lambda \frac{dn}{d\lambda}$$

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

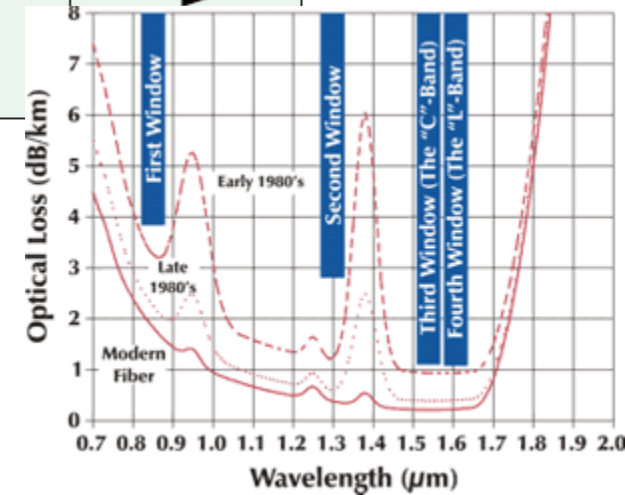


- ▶ Dispersia este **0** atunci cand indicele de refractie de grup este minim
- ▶ Pentru sticla $\lambda_0 \sim 1310 \text{ nm}$

Atenuarea în fibra optică (SiO_2)



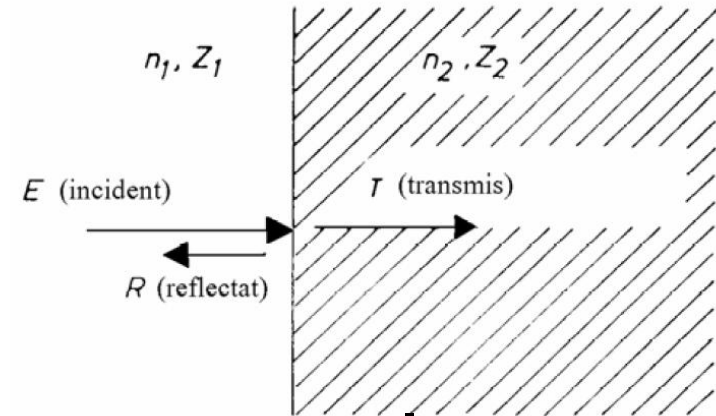
850nm, 1310nm, 1550nm



Transmisia puterii între medii

- ▶ incidenta normala
- ▶ reflexia in amplitudine

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



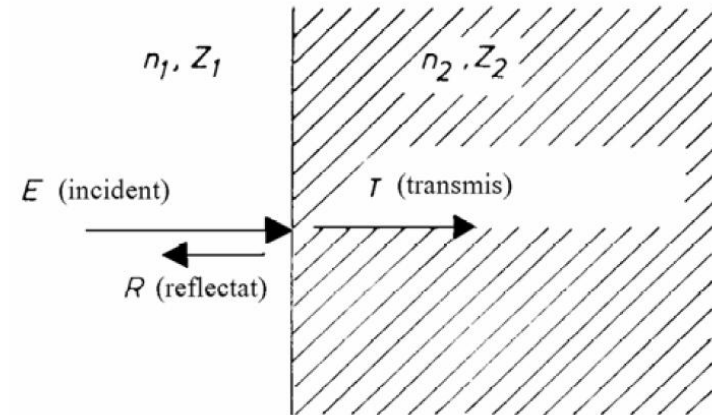
- ▶ densitatea de putere proportionala cu patraturul amplitudinii câmpului

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

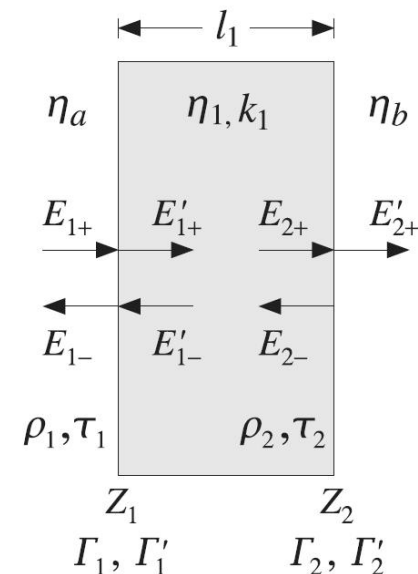
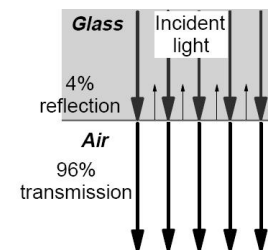
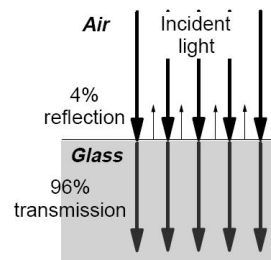
Transmisia puterii intre medii

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

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

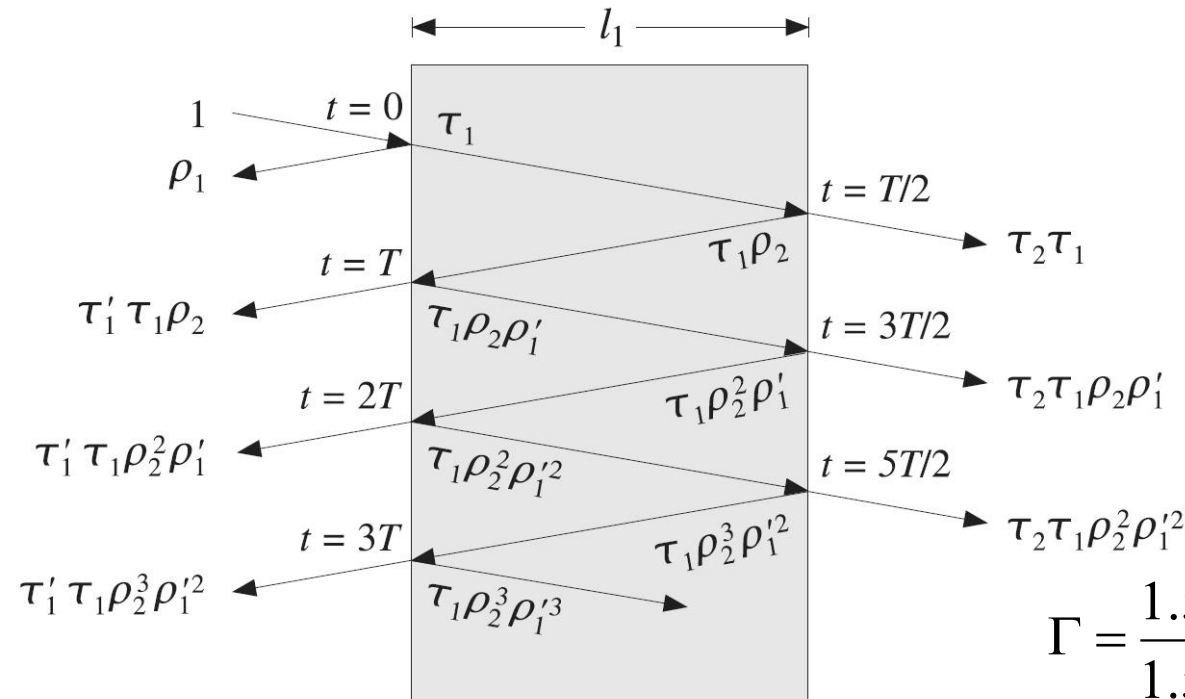


- ▶ reflexia de putere 4%, transmisia de putere 96%
- ▶ lamela dielectrica
- ▶ trecere intr–un mediu diferit, urmat de intoarcerea in mediul initial



Transmisia printr-o lamela

- apare interferenta intre multiplele unde reflectate/transmise

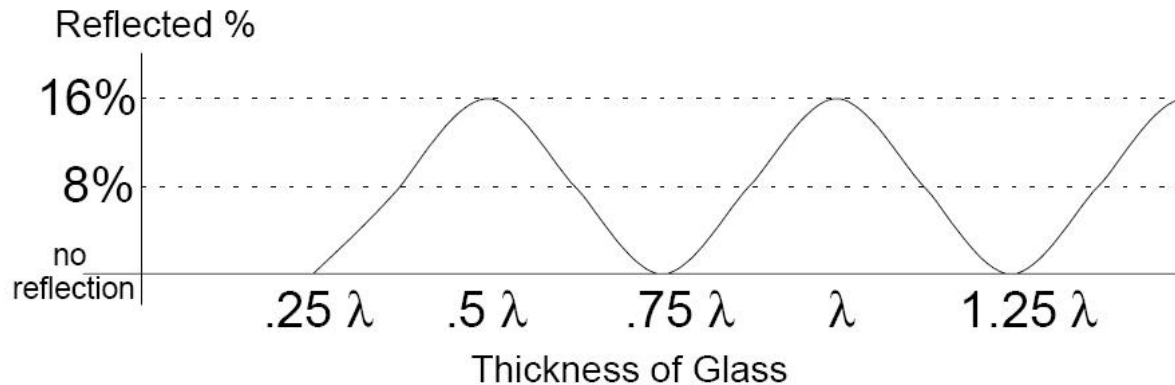


- se aduna câmpurile nu puterile

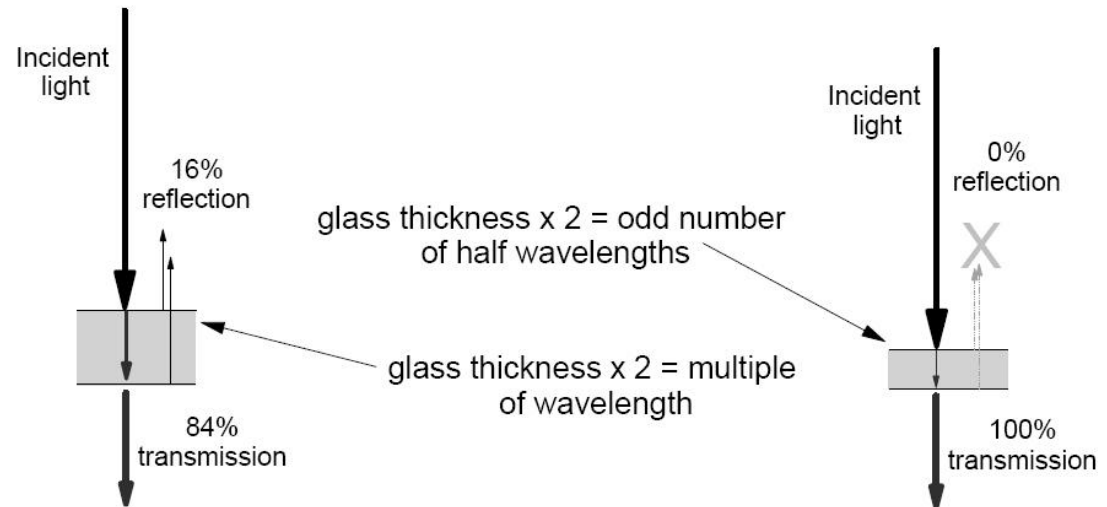
$$\Gamma = \frac{1.5 - 1}{1.5 + 1} = 0.2; \quad r = \Gamma^2 = 0.04 = 4\%$$

$$\Gamma_{\max} = 0.2 + 0.2; \quad r_{\max} = \Gamma_{\max}^2 = 0.16 = 16\%$$

Transmisia printr-o lamela



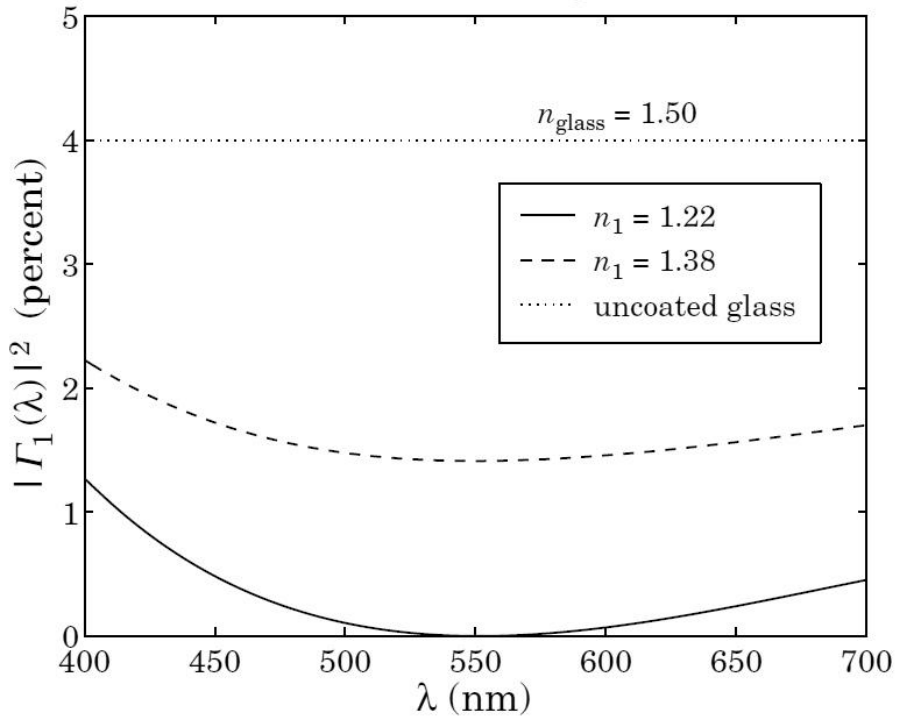
- ▶ lamele antireflexive



Transmisia printr-o lamela

▶ lamele antireflexive

Antireflection Coating on Glass



Contact

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