Optoelectronică

Curs 3

2022/2023

Disciplina 2022/2023

- 2C/1L Optoelectronică OPTO
- **Minim 7 prezente curs + laborator**
- Curs – conf. Radu Damian
  - an IV μE
  - Joi 08(**:10**)-10:00, C1
  - E – 70% din nota (50%+20%)
    - **20% test (VP) la curs**, saptamana 4-6?
  - probleme + (2p prez. curs)
  - toate materialele permise
- Laborator – sl. Daniel Matasaru
  - an IV μE
    - Luni 18-20, Miercuri 11-15 par
    - Max. 7 prezente
  - L – 30% din nota (+Caiet de laborator)

Cuprins

- **Lumina ca undă electromagnetică*** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie*** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire - splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
- **Emiţătoare optice** (LED şi dioda laser - realizare fizică şi functionare)
- **Receptoare optice** (dioda PIN, dioda cu avalanşă - realizare fizică şi functionare)
- Amplificatoare transimpedanţă (parametri, scheme tipice, TIA în buclă deschisă, cu reacţie, diferenţiale, control automat al câştigului)
- Realizarea circuitelor pentru controlul emiţătoarelor optice **(**parametri, scheme tipice, controlul puterii, multiplexoare**)**
- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

*** – VP**

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
- John Powers - An Introduction to Fiber Optic Systems
- IBM – Understanding Optical Communications: on-line http://www.redbooks.ibm.com
- Radu Damian, I Casian, D Matăsaru – „Comunicatii Optice" , Indrumar de laborator, 2005
- MIT Course - Fundamentals of Photovoltaics, https://ocw.mit.edu

Fotografii

Date:

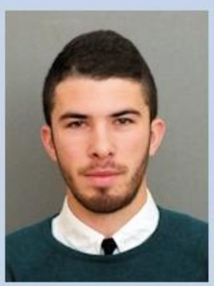
Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

Trimite email acestui student | Adauga acest student la lista (0)

Detalii curente

Observatii

Finantare	Buget
Bursa	Fara Bursa



Date:

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

Trimite email acestui student | Adauga acest student la lista (0)

Detalii curente

Observatii

Finantare	Buget
Bursa	Bursa de Studii

Date:

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

Acceseaza ca acest student

Note obtinute

Disciplina	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		

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	CIOLPAN OCTAVIAN	5306	3	0.5					0.5	-
2	NITA COSTEL-CATALIN	5307	4	0.5	1				1.5	-
3	BARON BOGDAN-IONUT	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/3(2)prez
- 3 teste
- foto <C3/<C5

Reprezentare logaritmică

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

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

0 dB	= 1
+ 0.1 dB	= 1.023 (+2.3%)
+ 3 dB	= 2
+ 5 dB	= 3
+ 10 dB	= 10
−3 dB	= 0.5
−10 dB	= 0.1
−20 dB	= 0.01
−30 dB	= 0.001

0 dBm	= 1 mW
3 dBm	= 2 mW
5 dBm	= 3 mW
10 dBm	= 10 mW
20 dBm	= 100 mW
−3 dBm	= 0.5 mW
−10 dBm	= 100 μW
−30 dBm	= 1 μW
−60 dBm	= 1 nW

[dBm] + [dB] = [dBm]

[dBm/Hz] + [dB] = [dBm/Hz]

[x] + [dB] = [x]

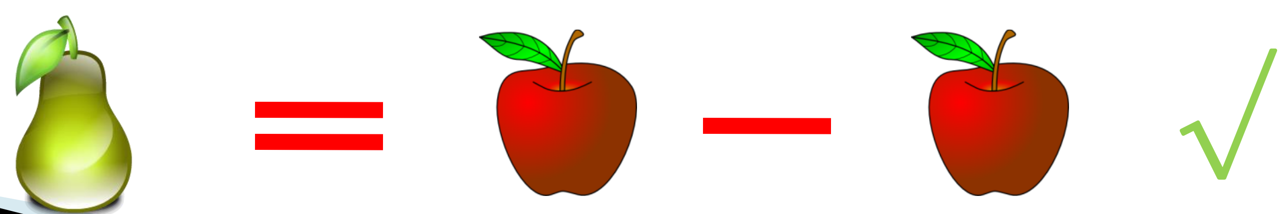
Calculul atenuarii/amplificarii

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

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

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

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

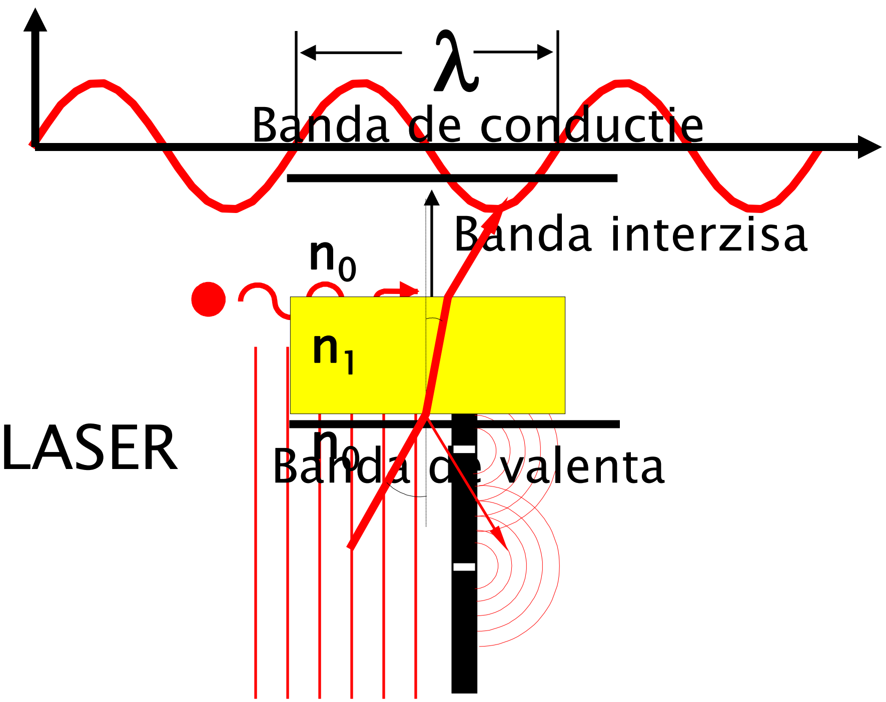


Modelarea luminii

(tot) Capitolul 1

Modelarea luminii

- Undă electromagnetică
  - Ecuaţiile 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

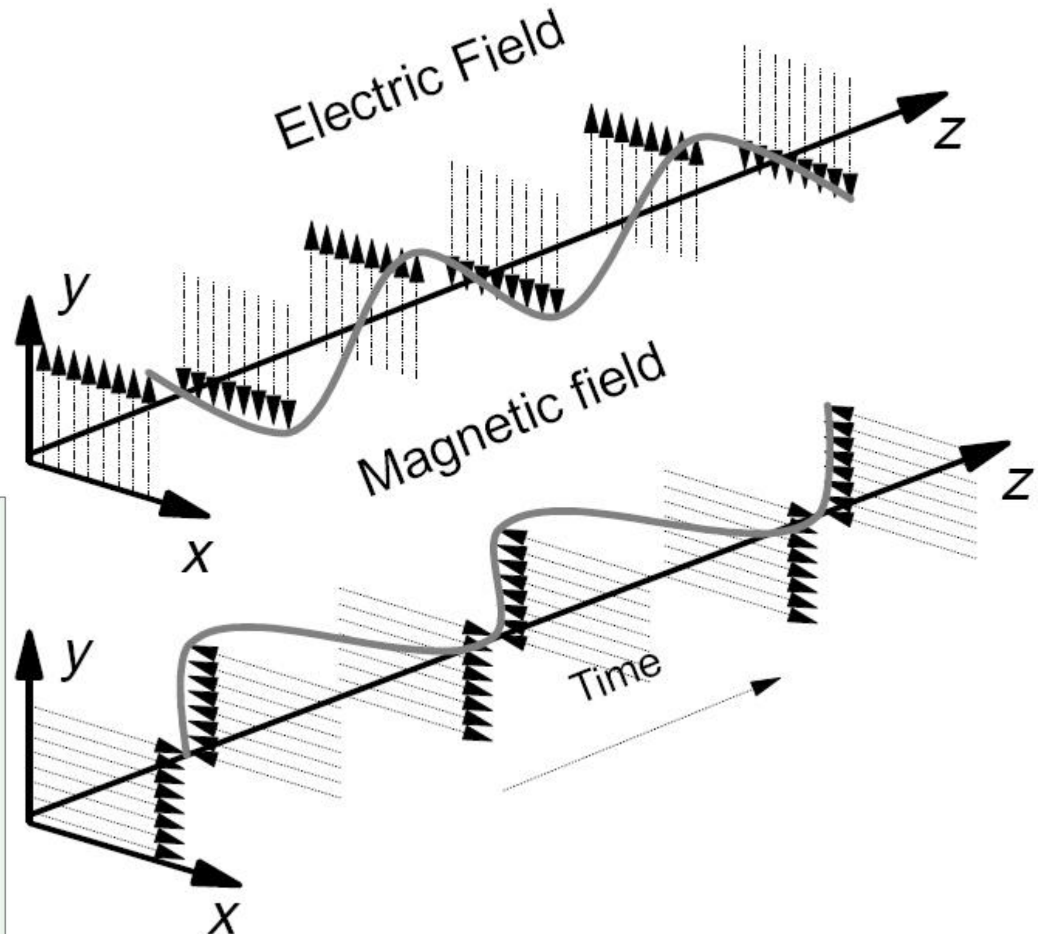


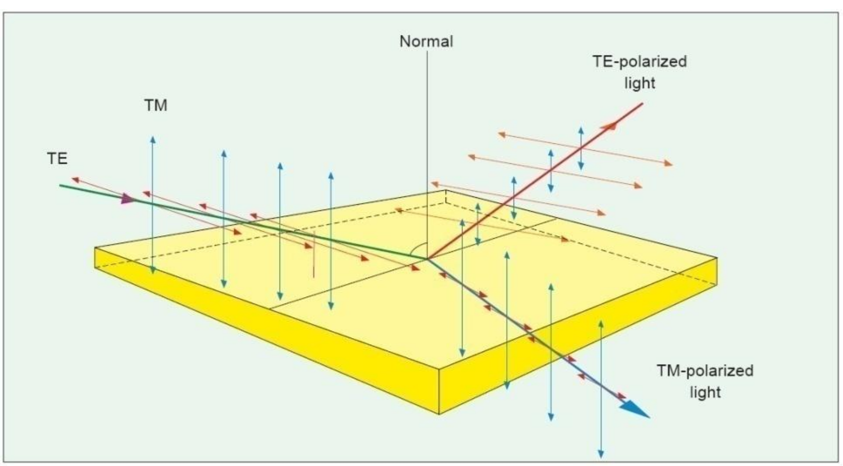
Through the Wormhole
S02E07 How Does the Universe Work

Through the Wormhole
S02E07 How Does the Universe Work

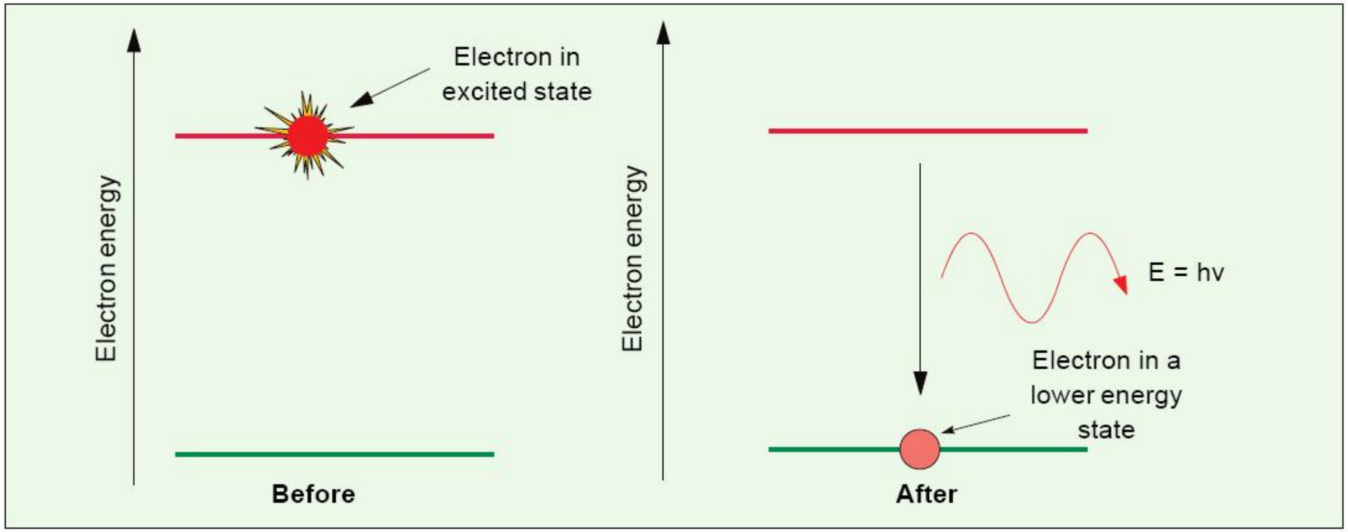
Unda electromagnetica

- Dispersie
- Fibre monomod
- Interferenta
- Polarizare



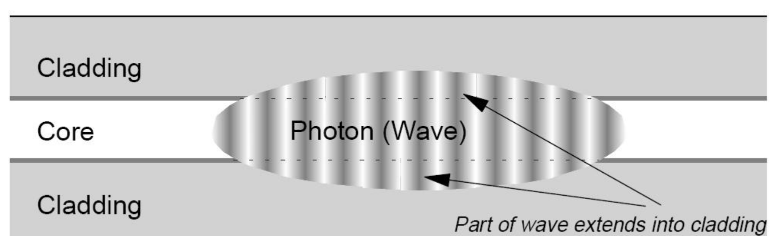


Model cuantic – foton

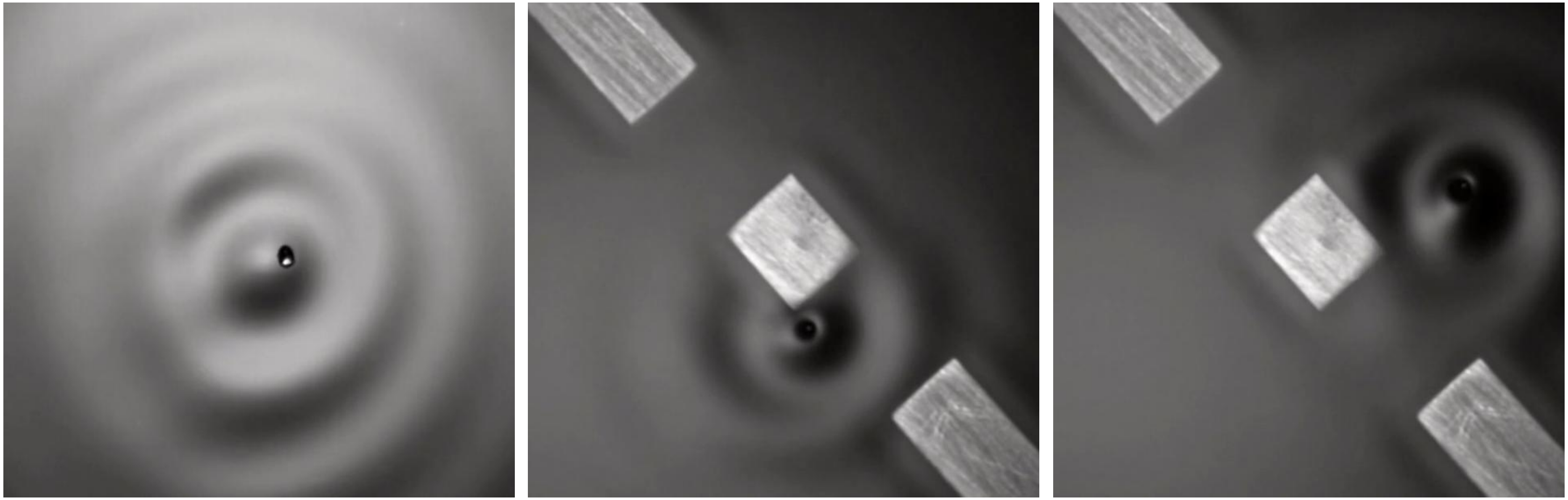


$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}; \quad \lambda[\mu m] = \frac{1.240}{E_g[eV]}$$

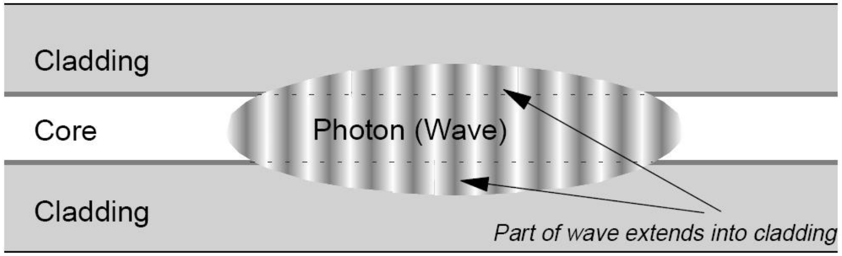
- h constanta lui Plank $6.62 \cdot 10^{-32}\ Ws^2$
- c viteza luminii in vid $2.998 \cdot 10^8 m/s$



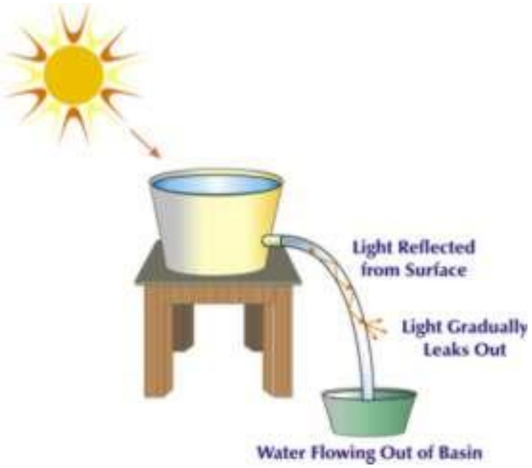
Modelare

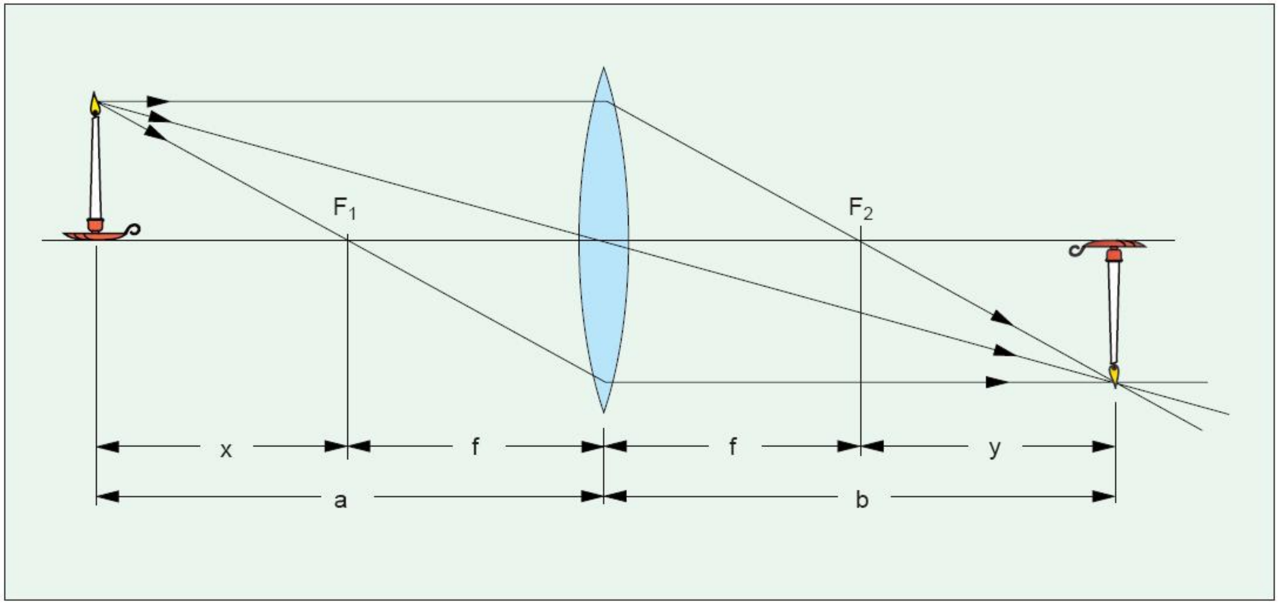


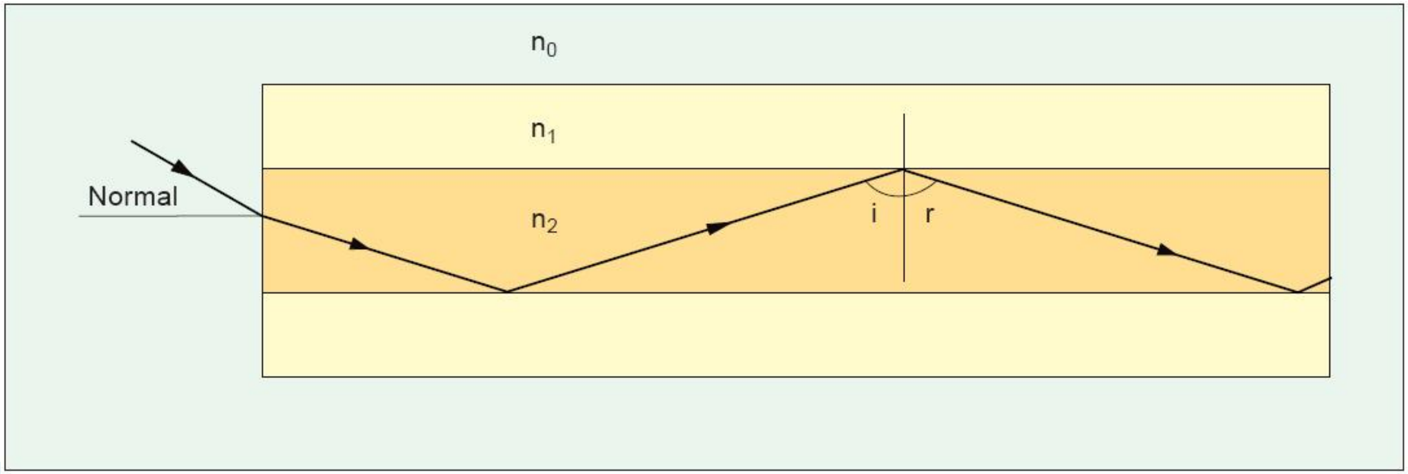
Through the Wormhole
S02E07 How Does the Universe Work



Optica geometrica







Lumina ca undă electromagnetică

Capitolul 2

Cuprins

- Lumina ca undă electromagnetică (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
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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

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

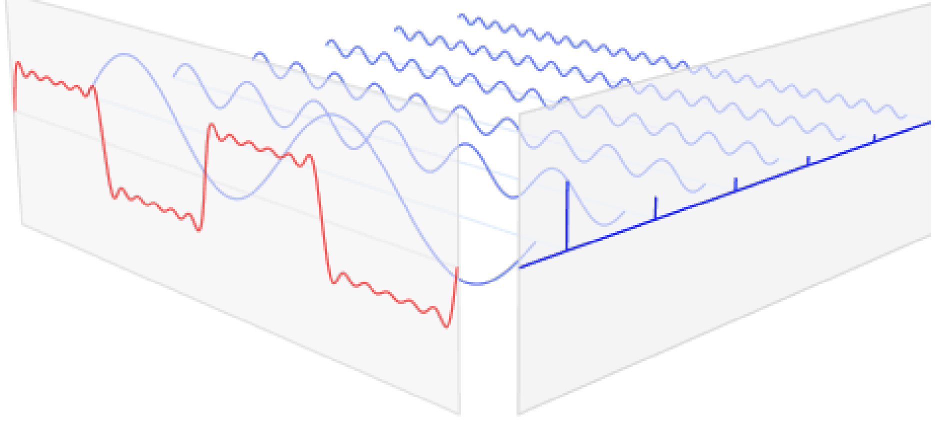
$$\varepsilon_0 = 8{,}854 \times 10^{-12}\ F/m$$

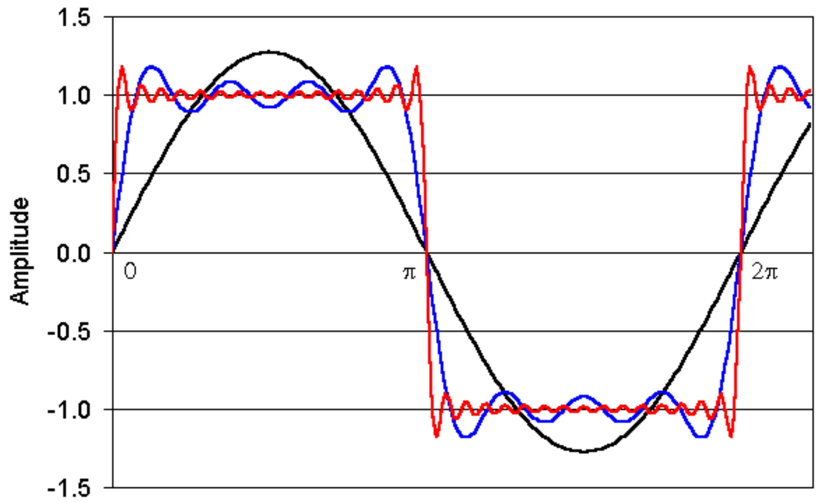
$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^{8}\ m/s$$

Modele matematice

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

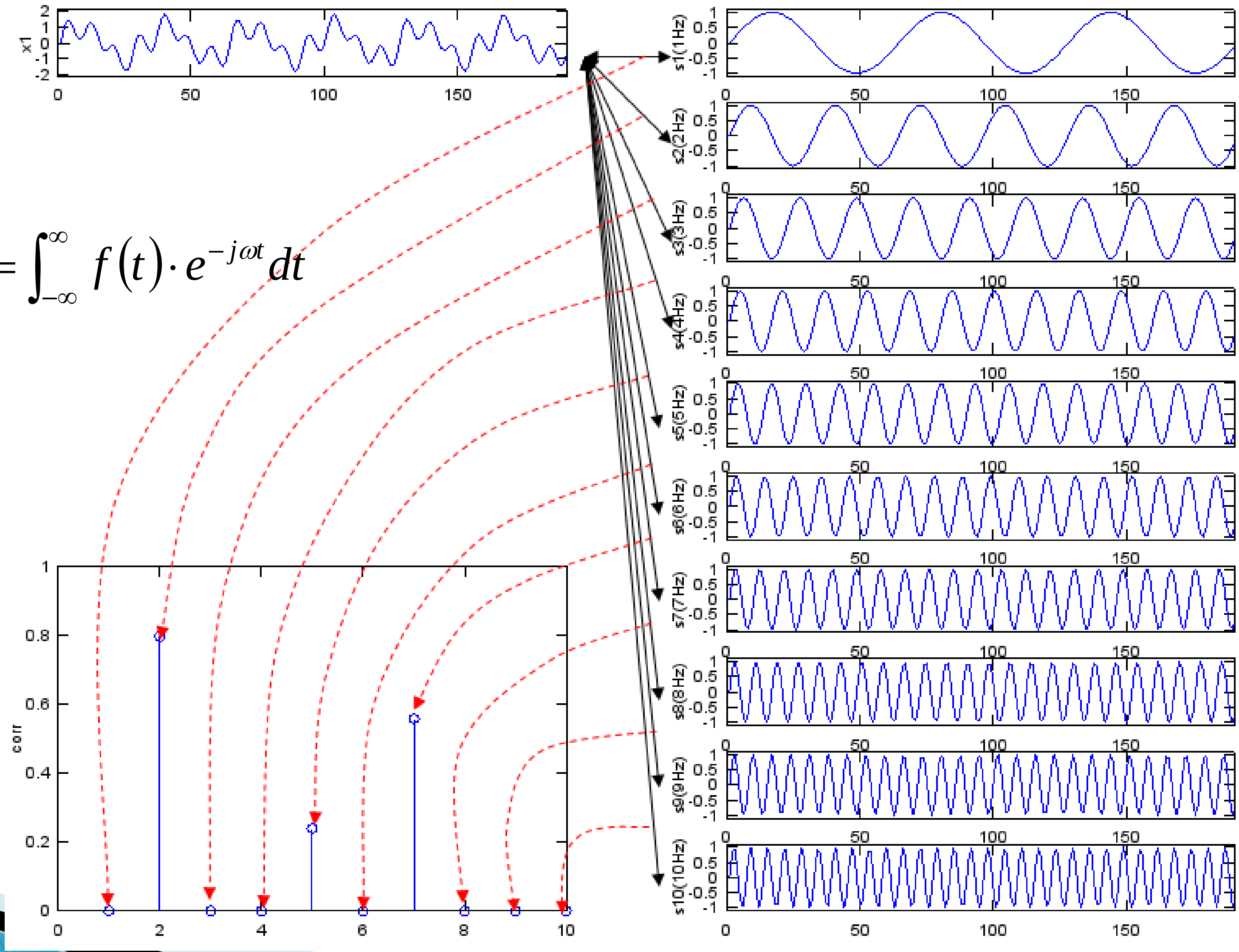
$$X = X_0 e^{j\cdot\omega\cdot t} \qquad \frac{\partial X}{\partial t} = j\cdot\omega\cdot X \qquad g(\omega) = \int_{-\infty}^{\infty} f(t)\cdot e^{-j\omega t}dt \qquad f(t) = \int_{-\infty}^{\infty} g(\omega)\cdot e^{j\omega t}d\omega$$



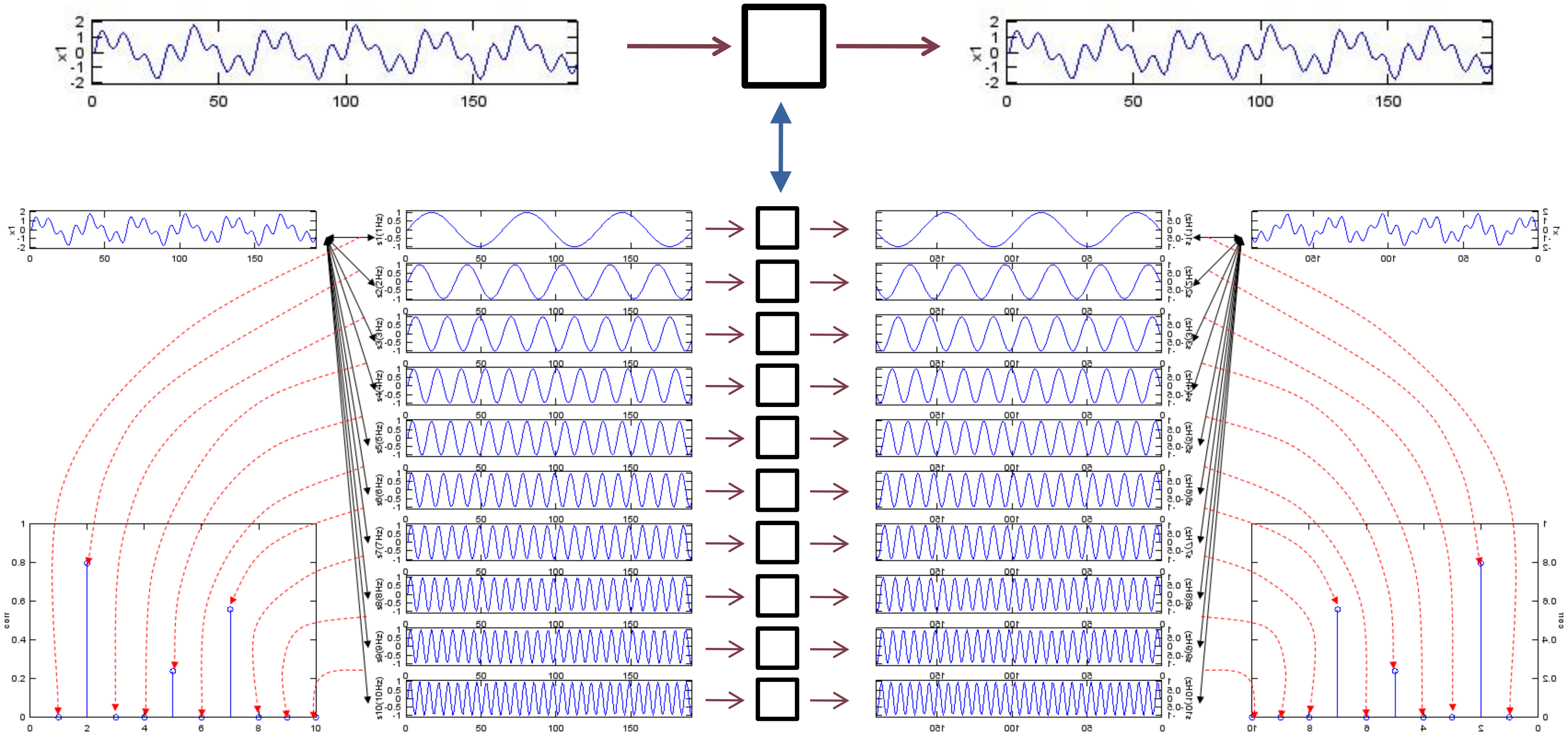


Modele matematice

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



Modele matematice



$$F(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt \qquad G(\omega)[F(\omega)] \qquad g(t) = \int_{-\infty}^{\infty} G(\omega) \cdot e^{j\omega t} d\omega$$

Câmpuri electromagnetic cu variaţie armonică în timp

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

- Simplificarea ecuatiilor lui Maxwell

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

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

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

$$\nabla\cdot H = 0$$

- Ecuaţiile Helmoltz sau ecuaţiile de propagare

Mediu lipsit de sarcini electrice

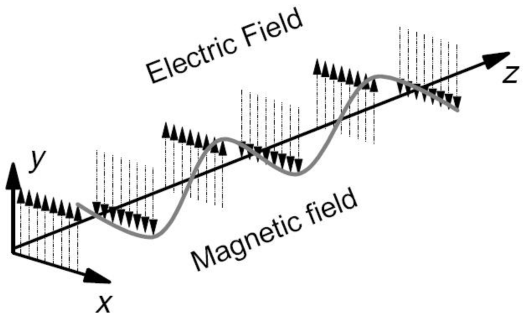
$$\nabla^2 E - \gamma^2 E = 0$$

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

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

γ – Constanta de propagare

Solutia ecuatiilor de propagare



Propagare

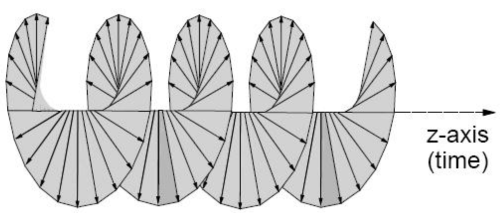
Camp electric dupa directia Oy, ← **prin alegerea judicioasa**
propagare dupa directia Oz ← **a sistemului de referinta**

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

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

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

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



Polarizare circulara

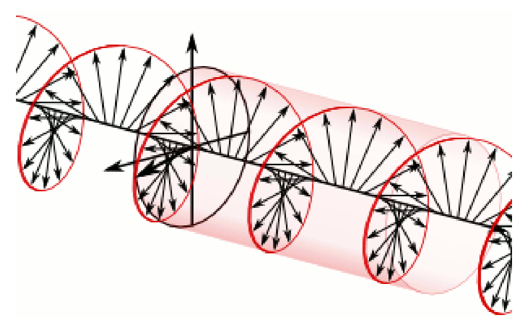
Camp armonic

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

Amplitudine

Atenuare

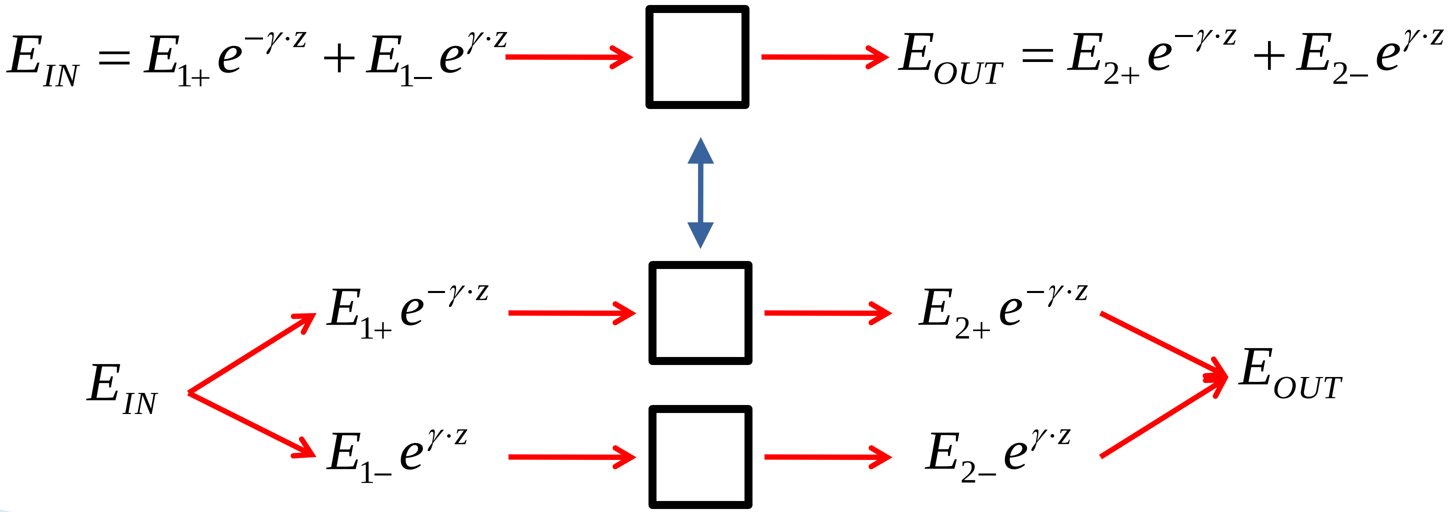
Propagare
(variatie in timp si spatiu)



Modele matematice

- cazuri particulare in care exista rezolvare analitica
  - unda
    - incidenta
    - reflectata
  - unda
    - directa
    - inversa

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



Atenuare

$$E_y(z_1) = Ct \cdot e^{-\alpha \cdot z_1} \cdot e^{j(\omega t - \beta \cdot z_1)} \qquad E_y(z_2) = Ct \cdot e^{-\alpha \cdot z_2} \cdot e^{j(\omega t - \beta \cdot z_2)}$$

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

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

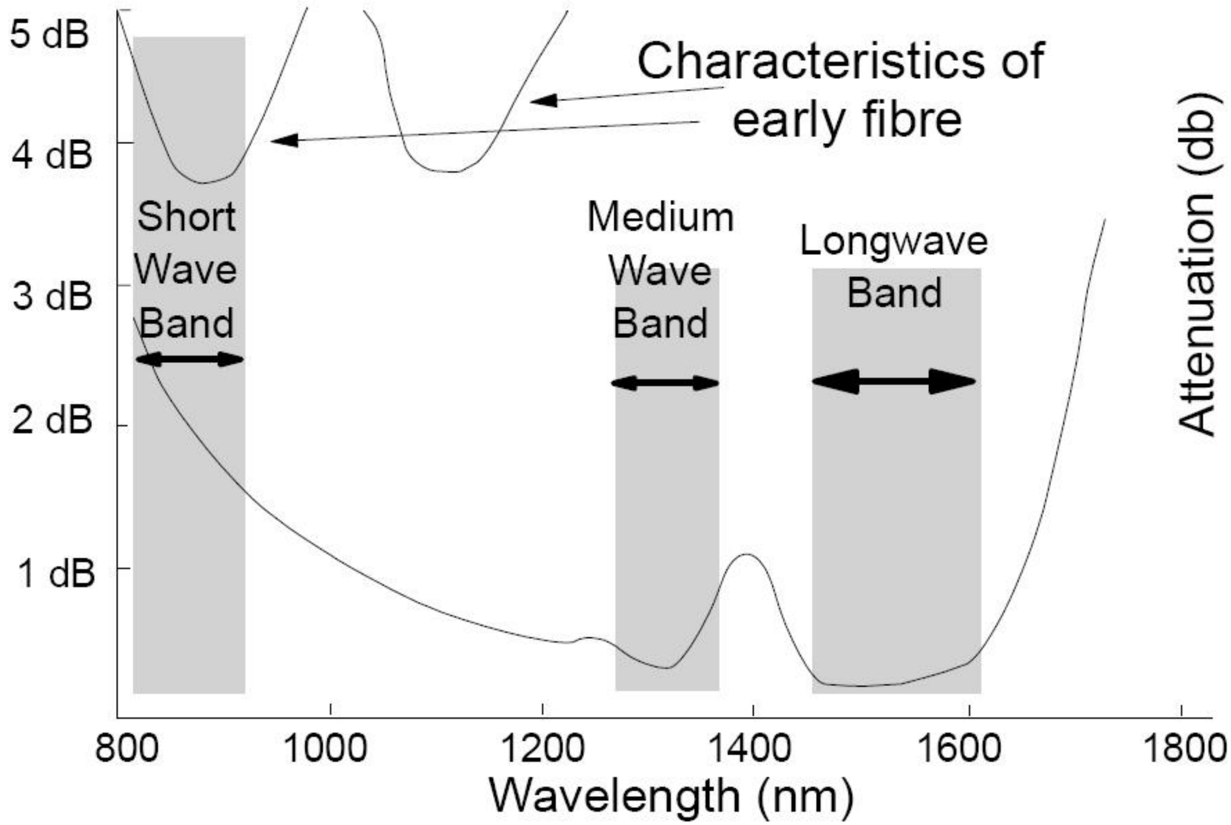
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

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

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

- Atenuarea se exprima de obicei in **dB/km**
  - de obicei valori pozitive
  - semnul = **implicit**

Atenuarea pe 1 km in SiO_2



Reprezentare logaritmică

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

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

0 dB	= 1	0 dBm	= 1 mW
+ 0.1 dB	= 1.023 (+2.3%)	3 dBm	= 2 mW
+ 3 dB	= 2	5 dBm	= 3 mW
+ 5 dB	= 3	10 dBm	= 10 mW
+ 10 dB	= 10	20 dBm	= 100 mW
−3 dB	= 0.5	−3 dBm	= 0.5 mW
−10 dB	= 0.1	−10 dBm	= 100 μW
−20 dB	= 0.01	−30 dBm	= 1 μW
−30 dB	= 0.001	−60 dBm	= 1 nW

[dBm] + [dB] = [dBm]

[dBm/Hz] + [dB] = [dBm/Hz]

[x] + [dB] = [x]

Calculul atenuarii

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

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

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

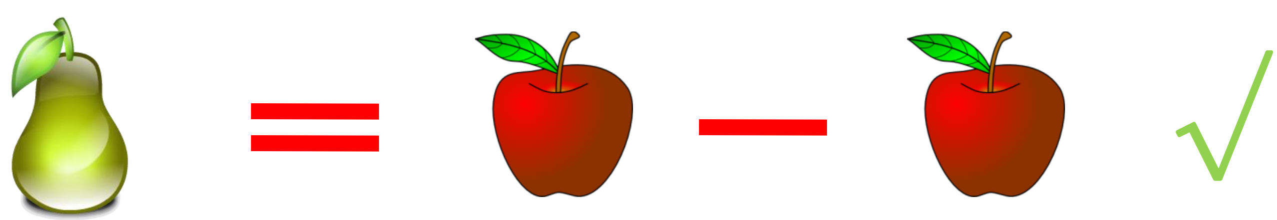
$$\text{Atenuare}[\text{dB/km}] = \frac{\text{Pierderi}[\text{dB}]}{\text{lungime}[\text{km}]}$$

Calculul atenuarii

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

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

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



Calculul atenuarii

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

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

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

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

Reprezentare logaritmică

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

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

0 dB	= 1	0 dBm	= 1 mW
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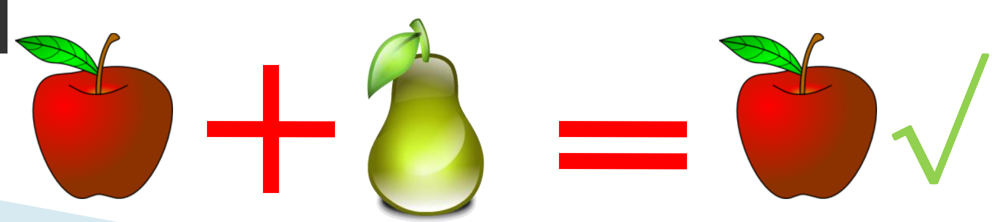
+ 3 dB	= 2	5 dBm	= 3 mW
+ 5 dB	= 3	10 dBm	= 10 mW
+ 10 dB	= 10	20 dBm	= 100 mW
–3 dB	= 0.5	–3 dBm	= 0.5 mW
–10 dB	= 0.1	–10 dBm	= 100 μW
–20 dB	= 0.01	–30 dBm	= 1 μW
–30 dB	= 0.001	–60 dBm	= 1 nW

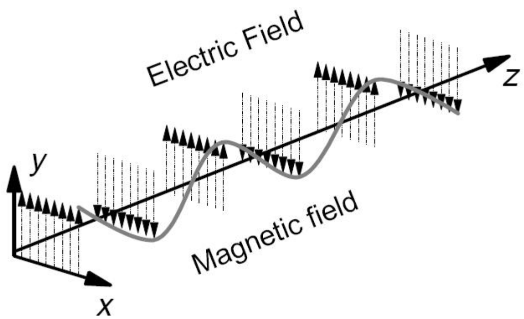
[dBm] + [dB] = [dBm]

[dBm/Hz] + [dB] = [dBm/Hz]

[x] + [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, $\sigma = 0$ $\quad \gamma = j\omega \cdot \sqrt{\varepsilon\mu}$

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\varepsilon}}$$ $[\Omega]$ 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 $\quad v = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{\varepsilon\mu}}$

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

Parametri de propagare

- In vid

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

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

Periodicitate in spatiu — Periodicitate in timp

- In mediu nedispersiv ε_r

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

$n = \sqrt{\varepsilon_r}$ Indice de refractie al mediului $c = \dfrac{c_0}{n}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f} \qquad \lambda = \frac{2\pi}{\beta} = \frac{c}{f} \qquad \lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

Parametri, dependenta de mediu

$n = 1$

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

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

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

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

$n = \sqrt{\varepsilon_r}$

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

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

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

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

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

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

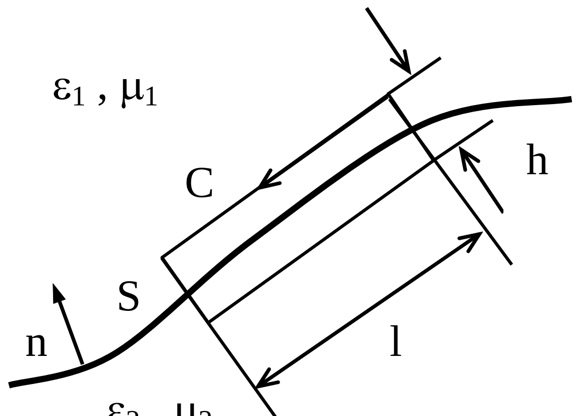
ITU G.692

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

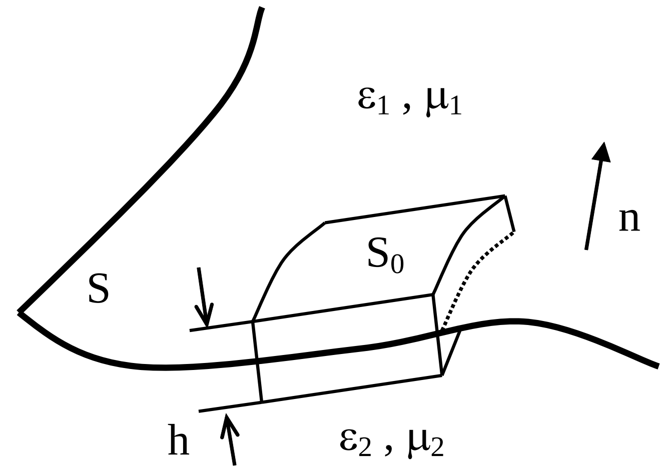
SI

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

Condiţii la limita de separaţie între două medii



a)



b)

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

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

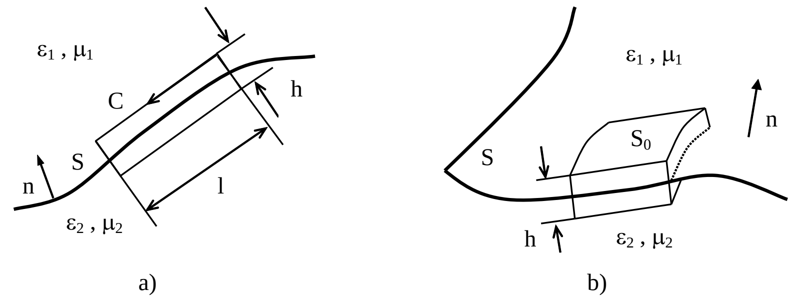
$$n\cdot\left(D_1-D_2\right)=\rho_S$$

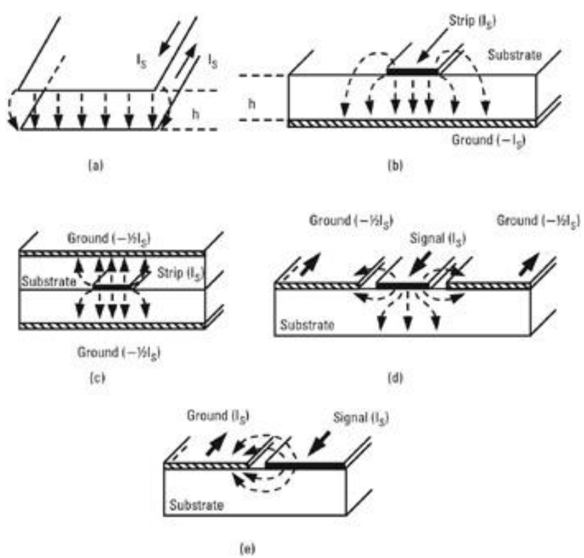
$$n\cdot\left(B_1-B_2\right)=0$$

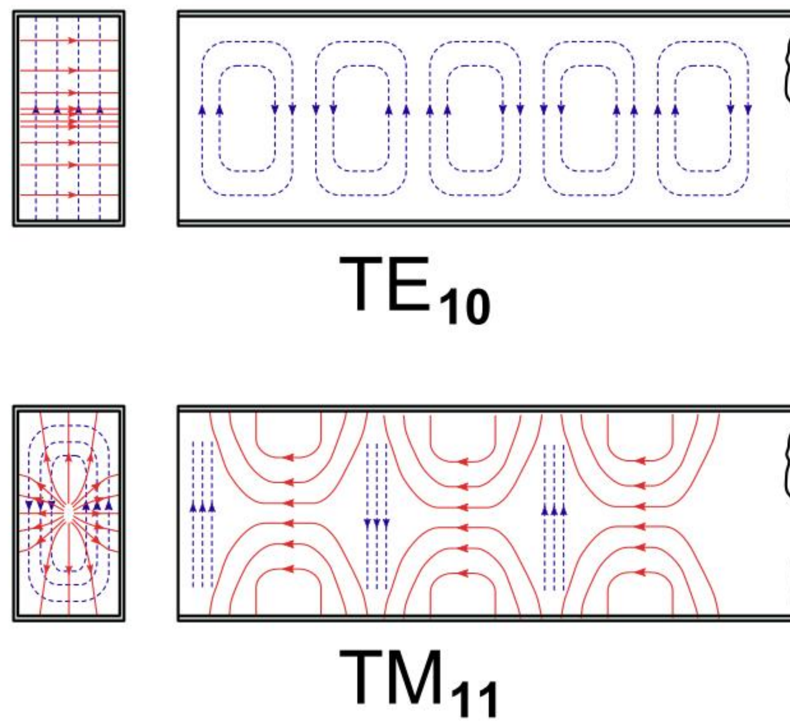
- Daca un mediu este metal ideal toate campurile se anuleaza in interior

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







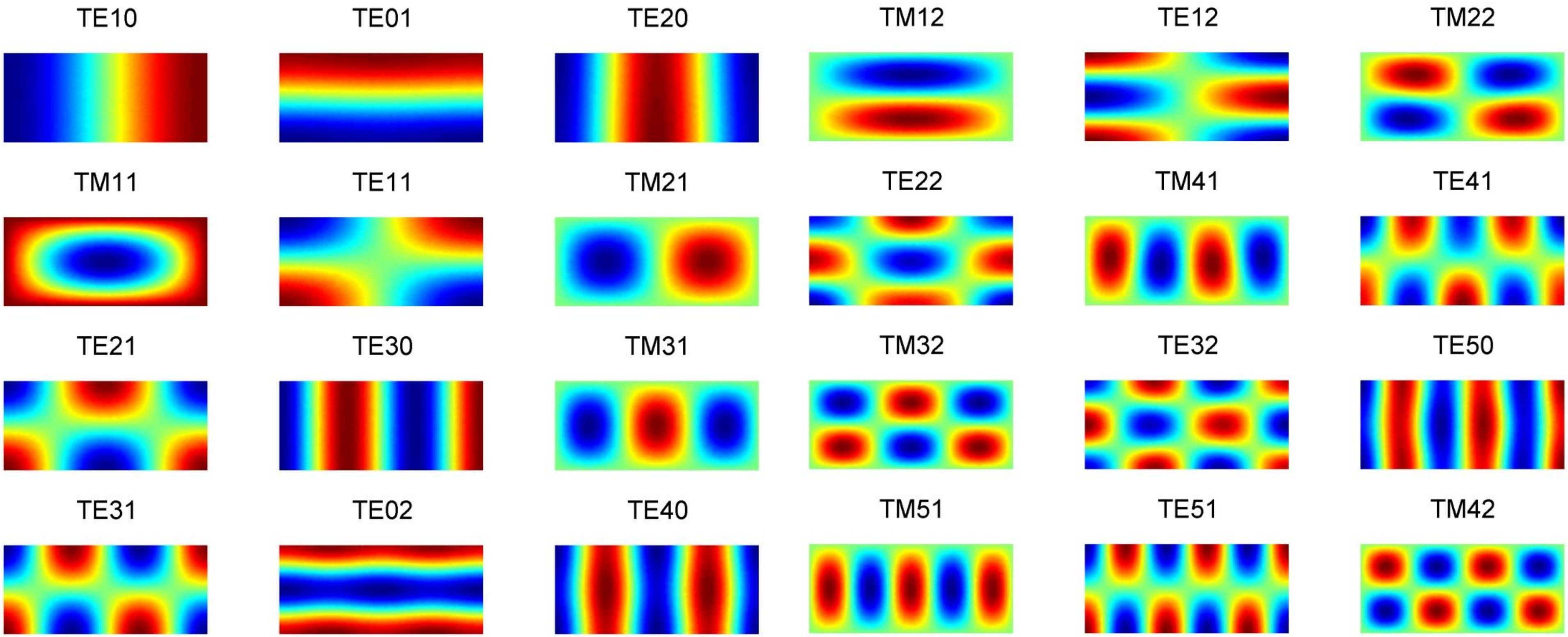
Moduri in medii delimitate

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

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

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

Moduri in medii delimitate



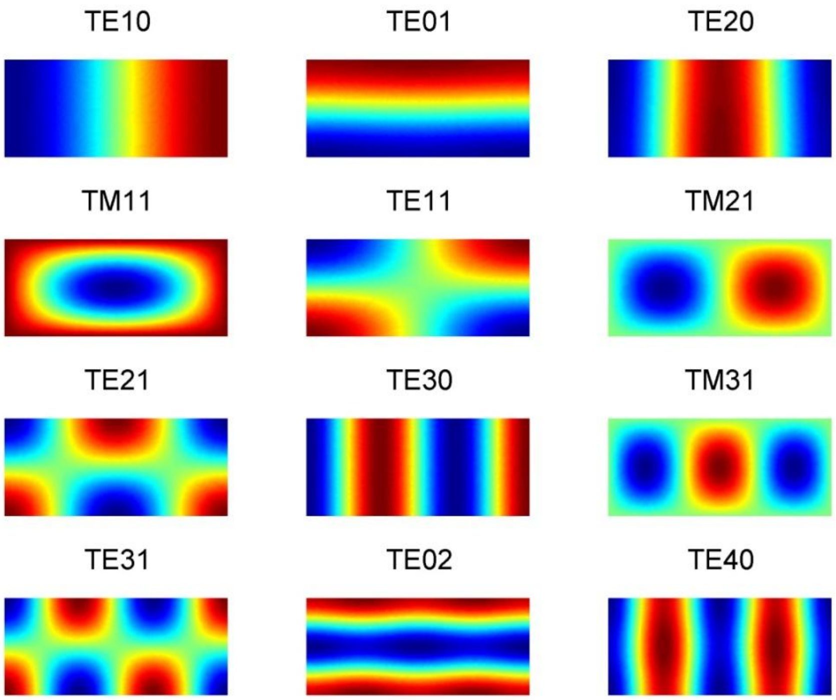
- Similar cu transformata Fourier

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

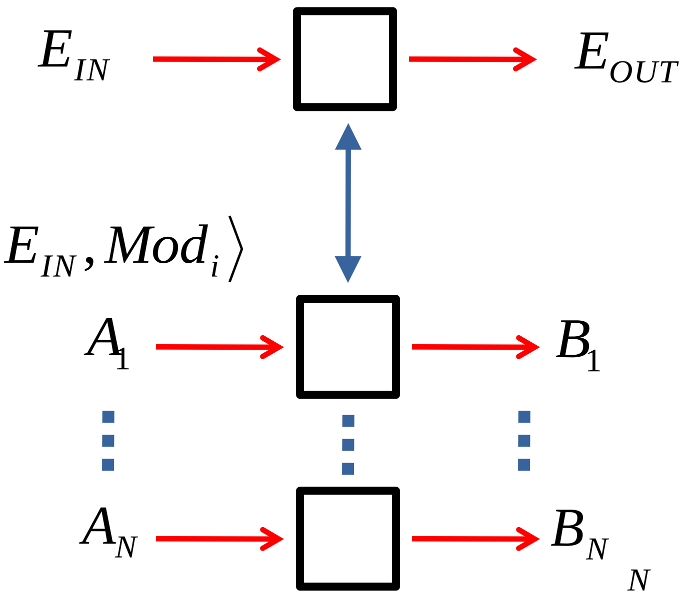
$$E^{+},E^{-}=\sum_{1}^{\infty} A_i \cdot Mod_i \qquad A_i=\langle E, Mod_i\rangle$$

Modele matematice

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



$$E = \sum_{1}^{\infty} A_i \cdot Mod_i \qquad A_i = \langle E, Mod_i \rangle$$



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

$$E_{OUT} = \sum_{1}^{N} B_i \cdot Mod_i$$

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)

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

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

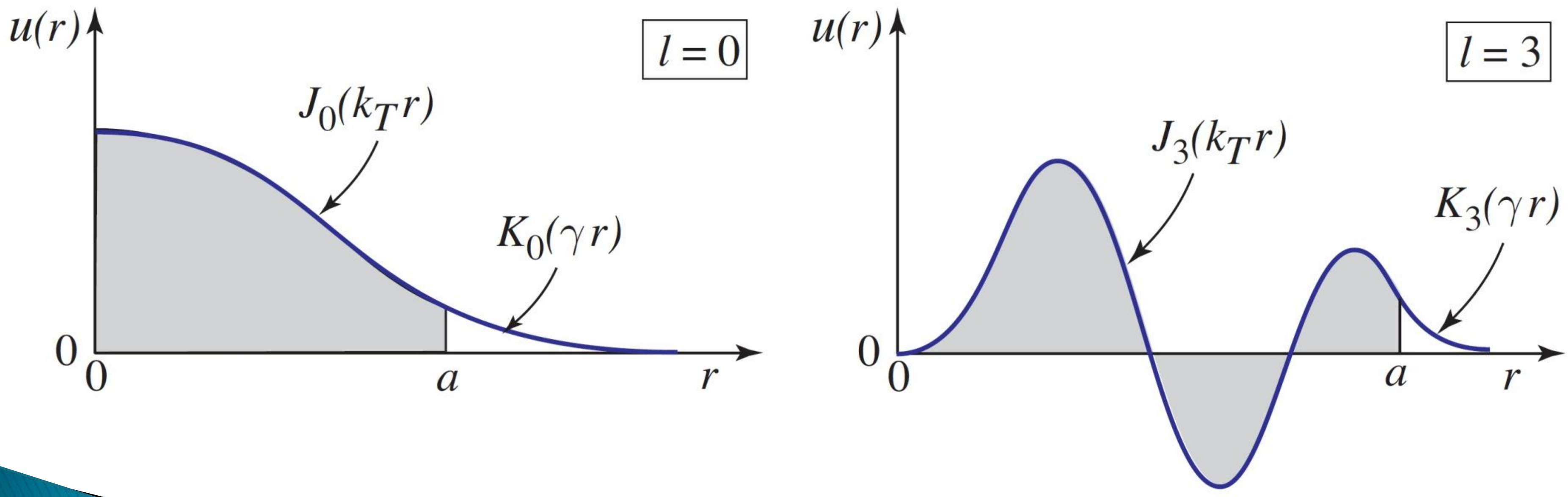
$$\frac{d^2 u}{dr^2} + \frac{1}{r}\frac{du}{dr} + \left(k_T^2 - \frac{l^2}{r^2}\right) u = 0, \qquad r < a$$

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

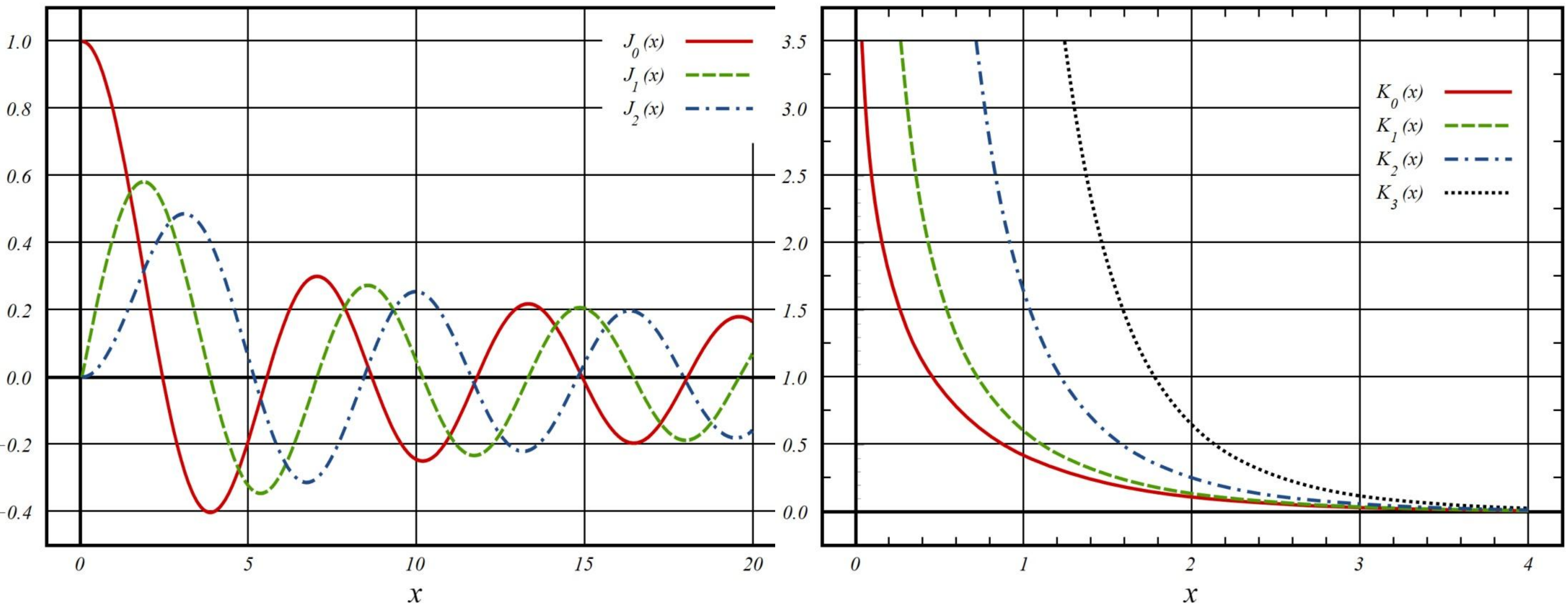
Ghid cilindric dielectric

- soluții proporționale cu funcții Bessel

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

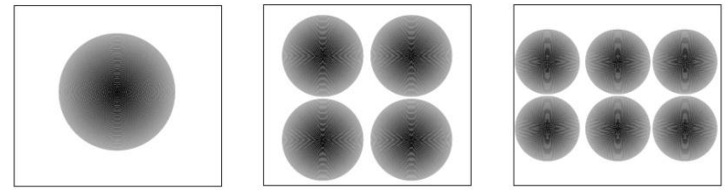


Funcții Bessel



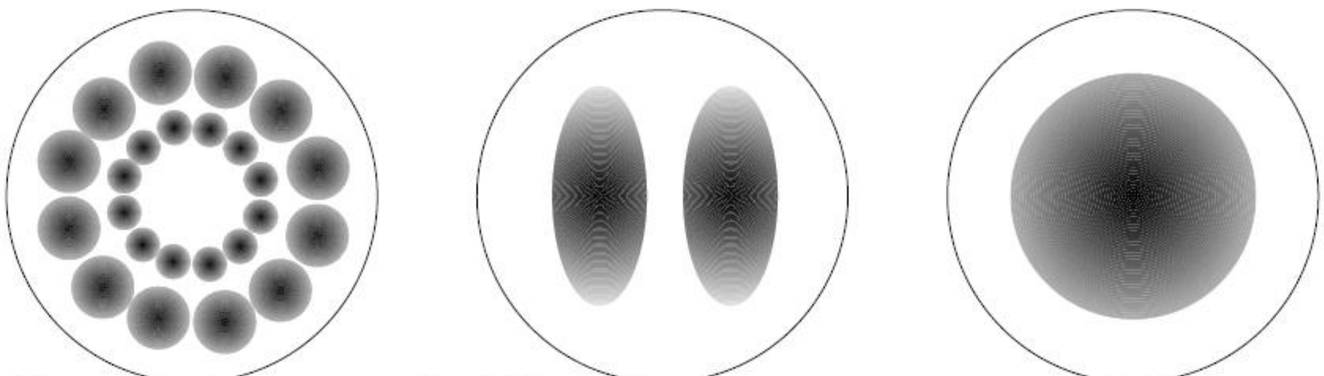
Moduri in fibra

- Moduri in ghid rectangular

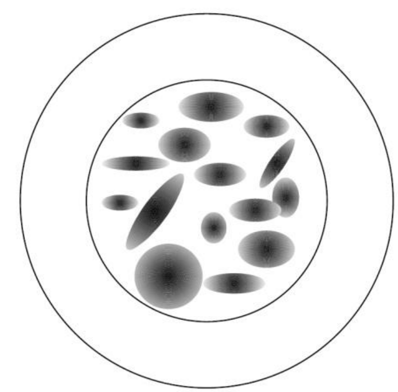


TEM_{00} TEM_{11} TEM_{21}

- Moduri linear polarizate in fibra



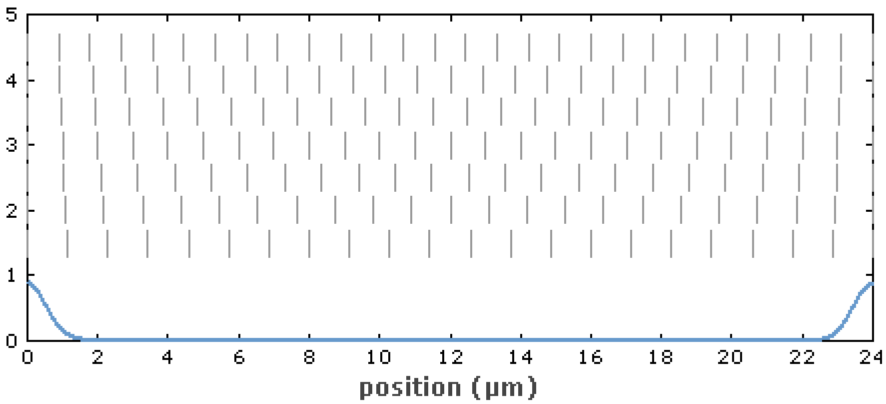
LP_{62} LP_{11} LP_{01}

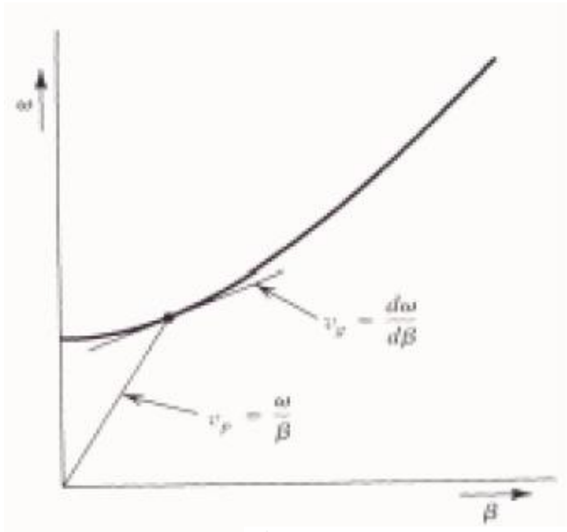


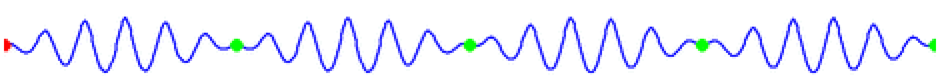
“Sparkle” pattern

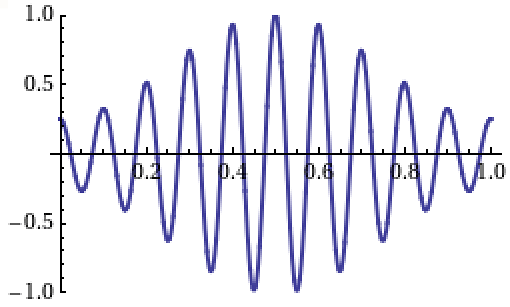
Viteze de grup si faza

- 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 β = β(ω), n = n(ω), $v_g = \frac{d\omega}{d\beta} = \frac{1}{\left(\frac{d\beta}{d\omega}\right)}$
- 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(ω)

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

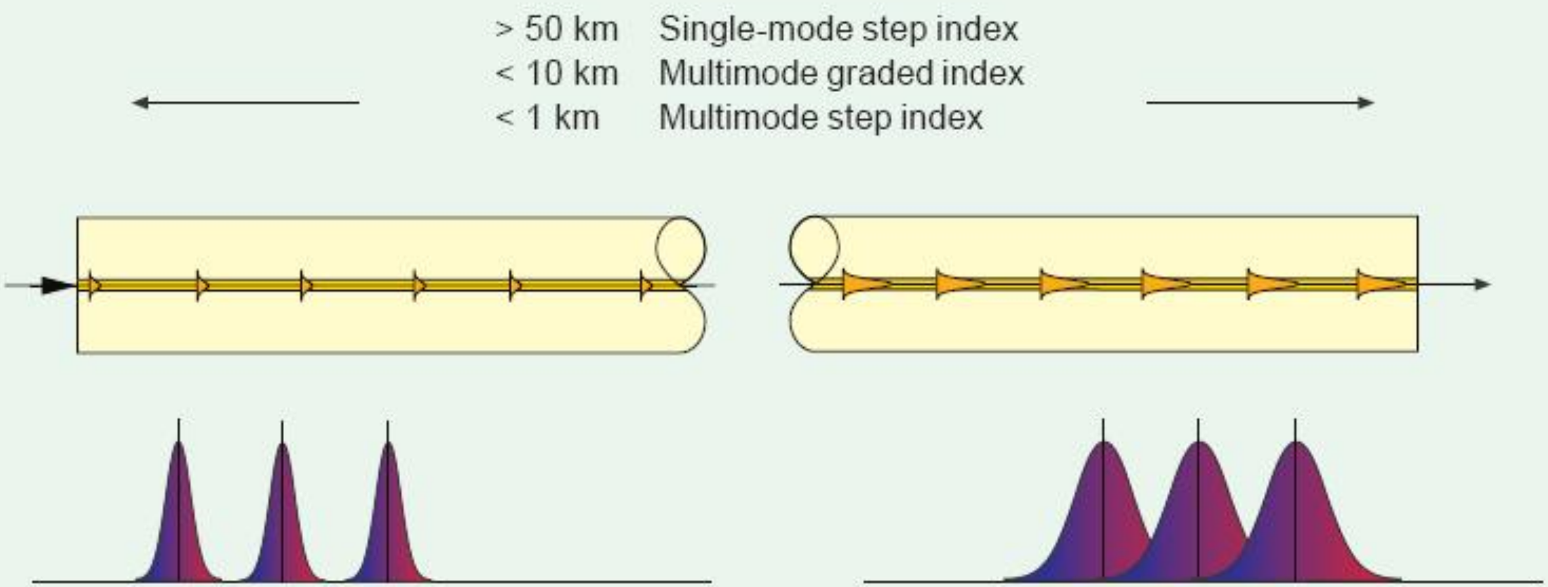
$$\frac{d\tau}{d\lambda} = \frac{L}{c}\left(\frac{dn}{d\lambda} - \lambda\frac{d^2n}{d\lambda^2} - \frac{dn}{d\lambda}\right) = -\frac{L}{c} \cdot \lambda \cdot \frac{d^2n}{d\lambda^2}$$

$$D \overset{not}{=} -\frac{\lambda}{c} \cdot \frac{d^2n}{d\lambda^2} \quad (s/m^2)$$

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

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

Dispersie



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

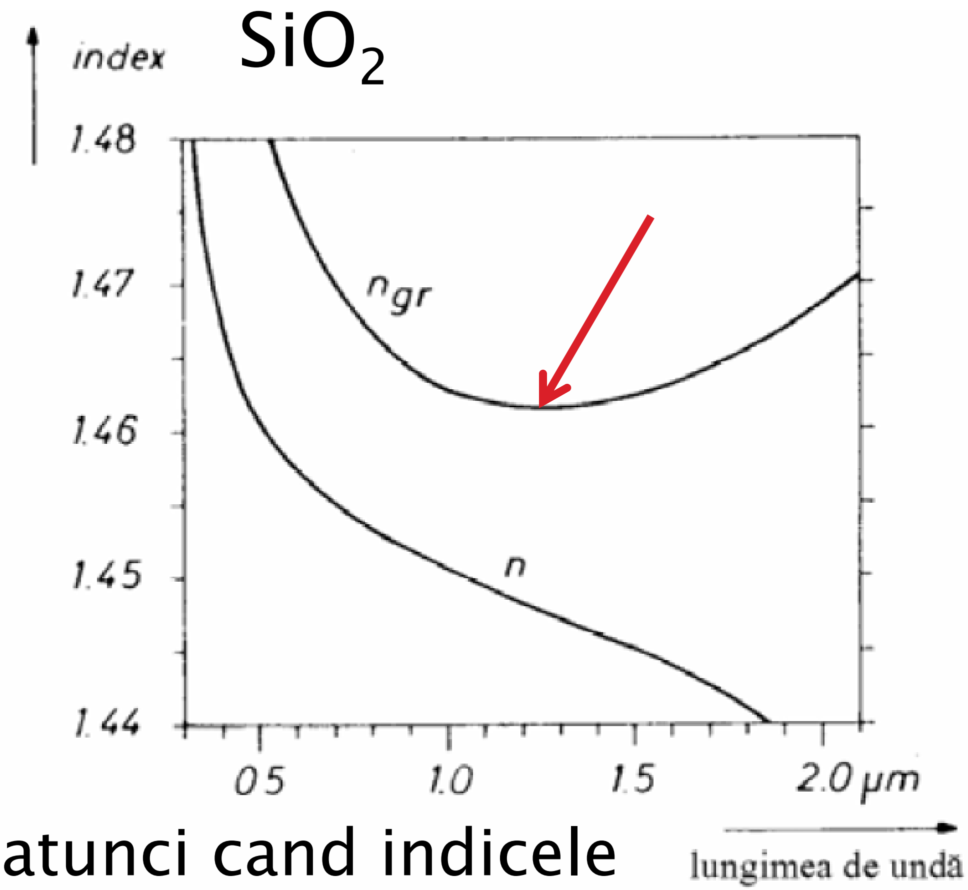
Reception:
Pulse broadening caused by the laser's spectral width and the difference between the refractive indices of the red and blue ends of the light pulse.

Dispersie normala

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

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

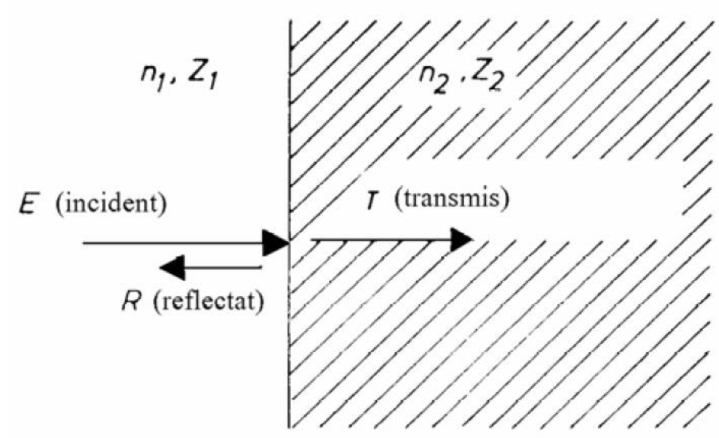
$$D = \frac{1}{L} \cdot \frac{d\tau}{d\lambda} = \frac{1}{c} \cdot \frac{dn_{gr}}{d\lambda}$$



- Dispersia este 0 atunci cand indicele de refractie de grup este minim
- Pentru sticla λ_0~1310 nm

Transmisia puterii intre medii

- incidenta normala
- reflexia in amplitudine



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

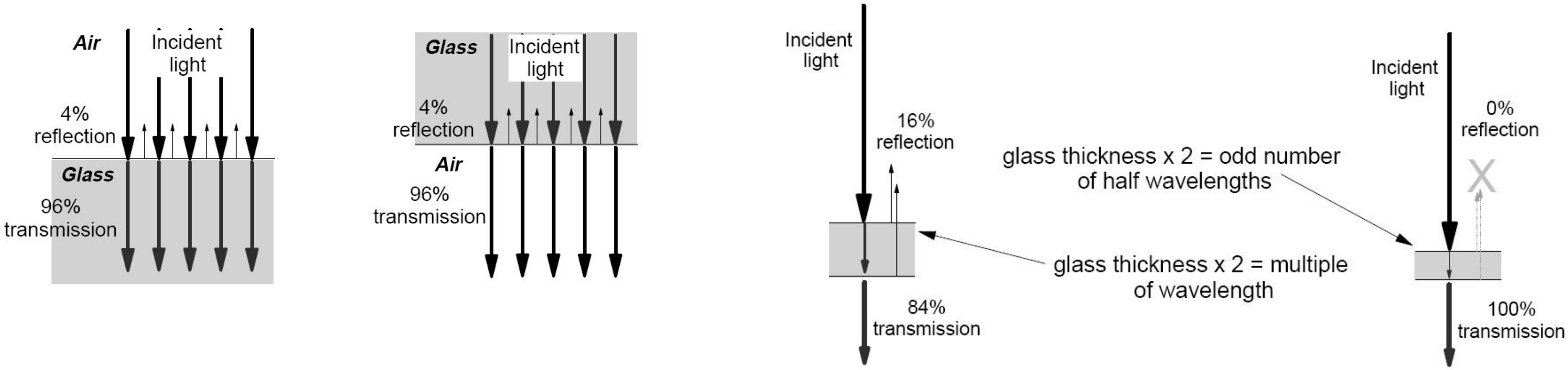
- densitatea de putere proportionala cu patratul amplitudinii câmpului

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

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

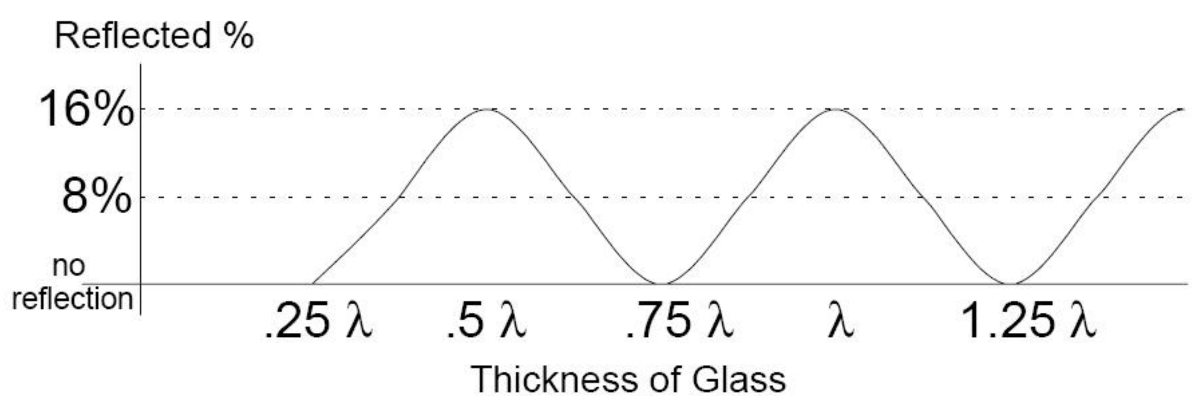
$$\Gamma = \frac{1.5 - 1}{1.5 + 1} = 0.2; \quad r = \Gamma^2 = 0.04 = 4\%$$

Transmisia printr-o lamela



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

- apare interferenta intre diversele unde reflectate
- se aduna câmpurile nu puterile
- lamele antireflexive



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