Comunicatii Optice

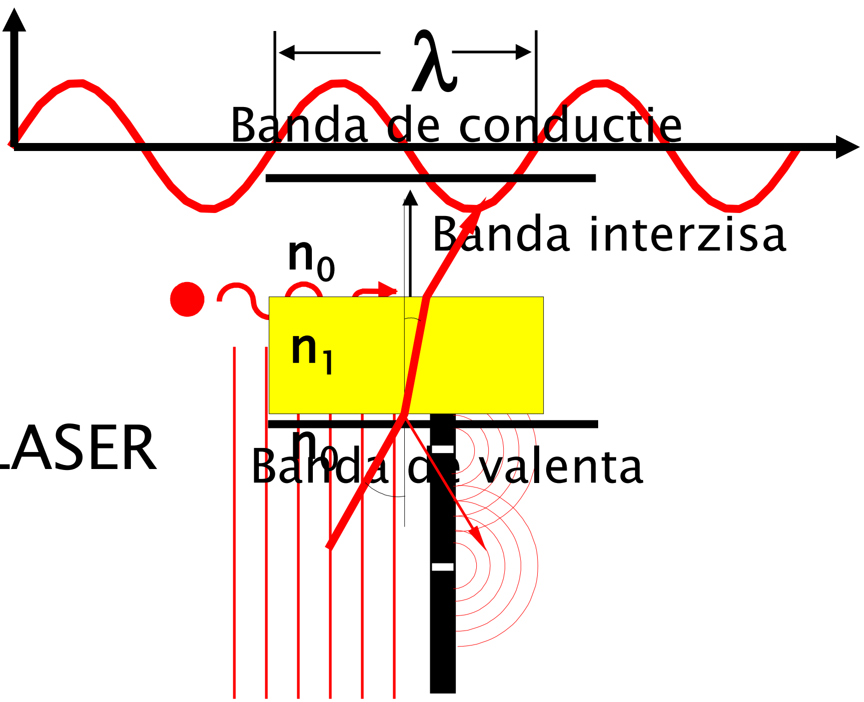
Supliment Laborator 1

2025/2026

Modelarea luminii

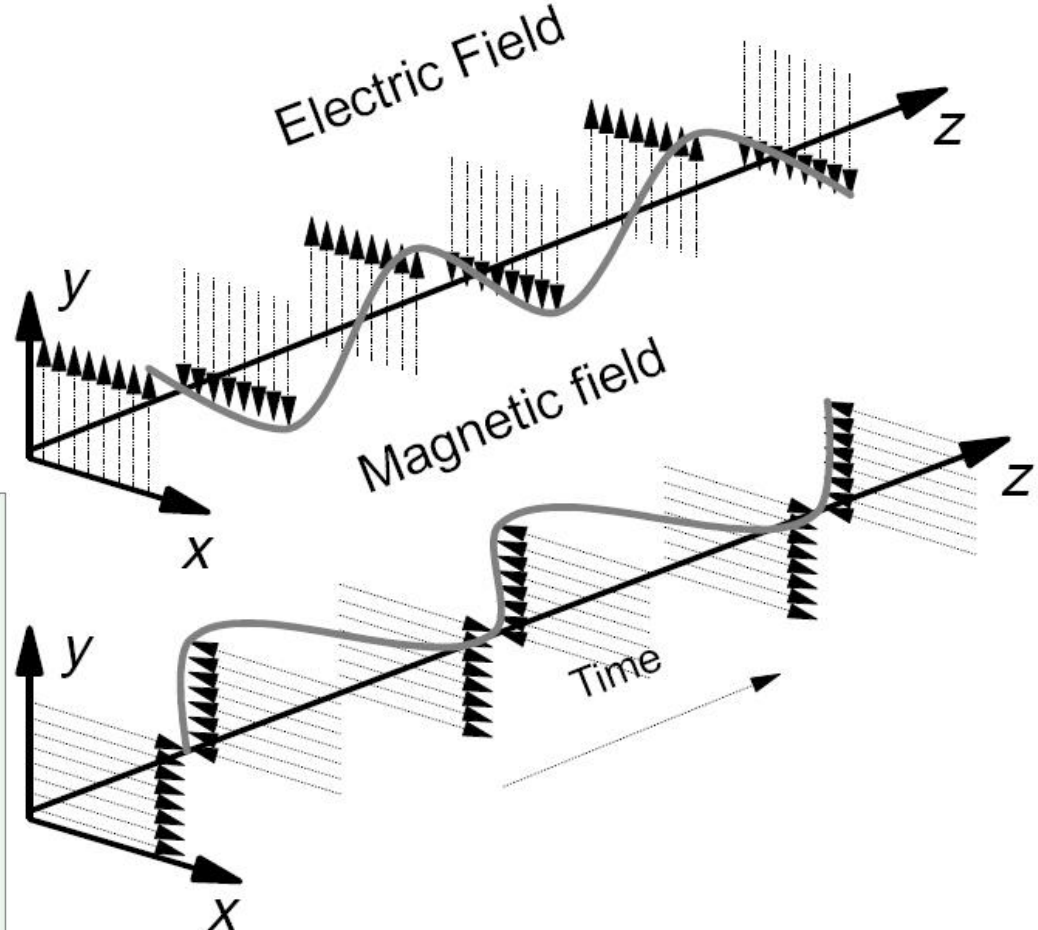
Modelarea luminii

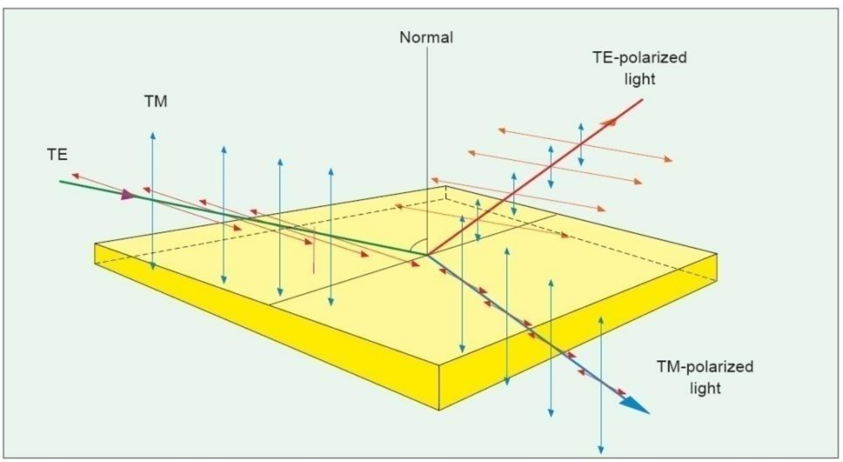
- Undă electromagnetică
  - Ecuaţiile lui Maxwell
  - λ, ε, ω, f
- Teoria cuantică
  - Benzi energetice $E = h\nu$
  - fotoni, emisie stimulată, LASER
- Optică geometrică
  - n, θ
  - raze de lumină
  - intuitivă



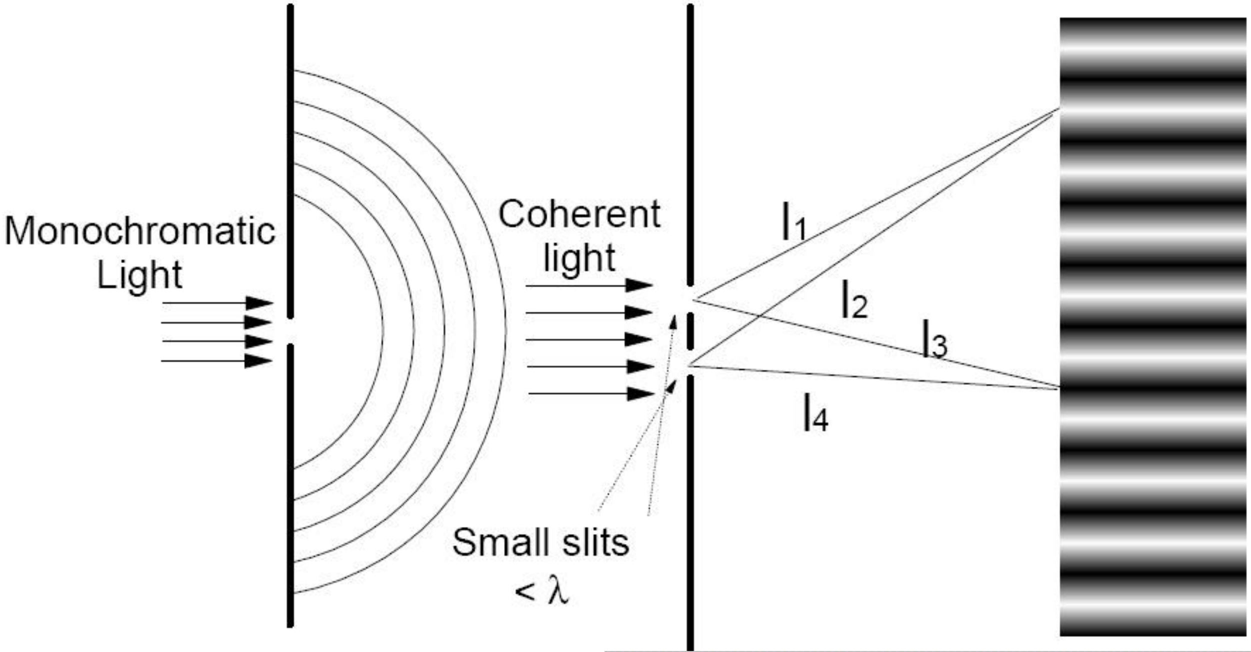
Unda electromagnetica

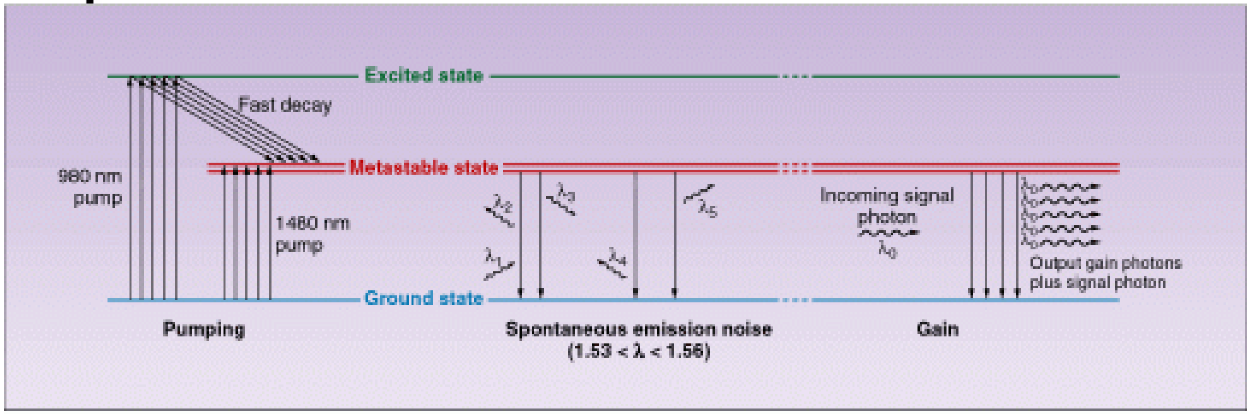
- Dispersie
- Fibre monomod
- Interferenta
- Polarizare





Fotoni/Unda

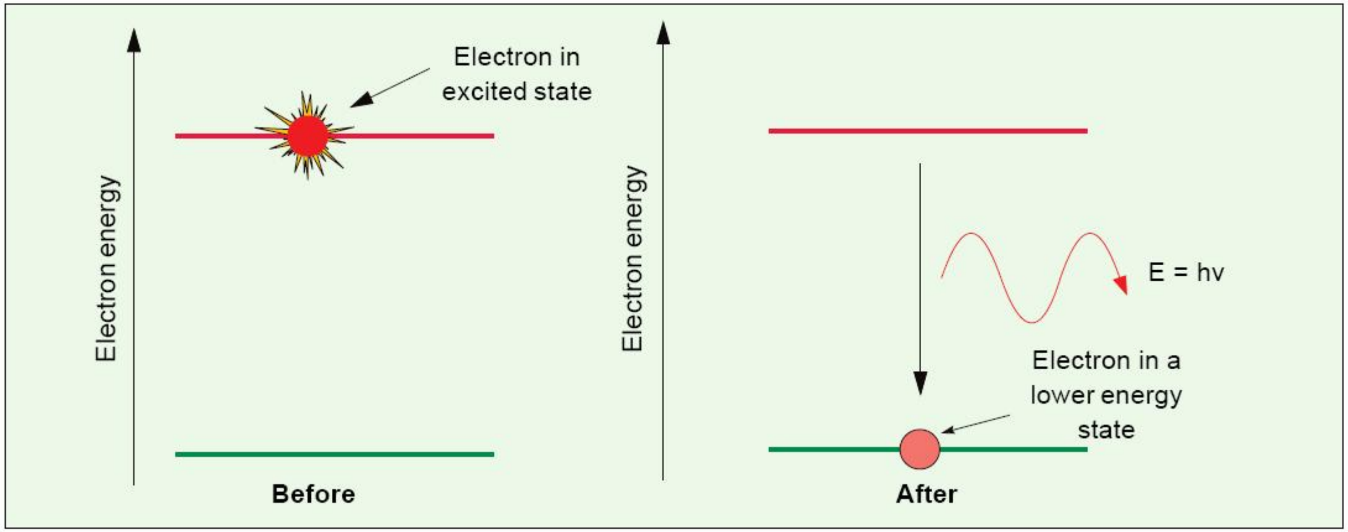




8-FEA-4 97 Fig. 2

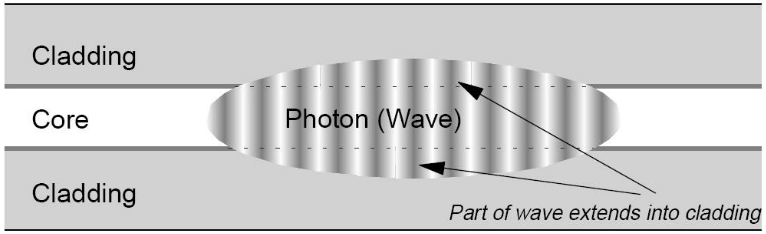
Through the Wormhole
S02E07 How Does the Universe Work

Model cuantic – foton



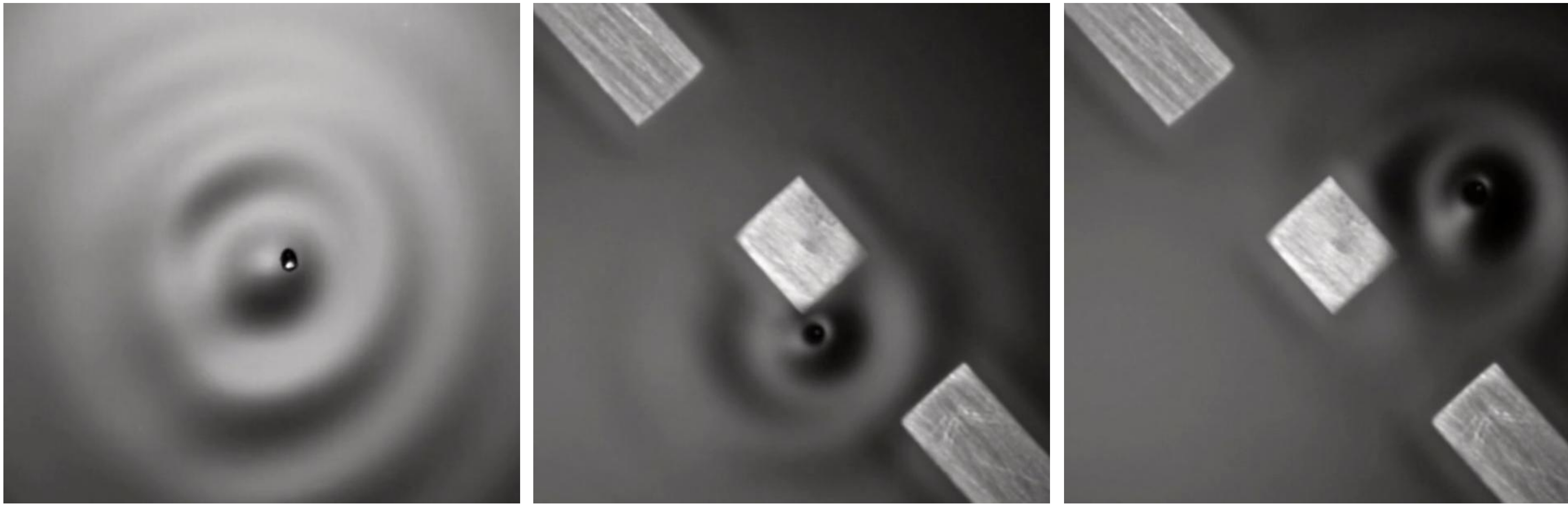
$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}; \quad \lambda[\mu\text{m}] = \frac{1.240}{E_g[\text{eV}]}$$

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

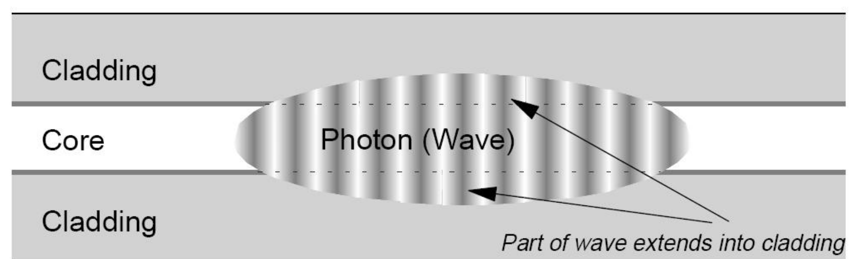


Through the Wormhole
S02E07 How Does the Universe Work

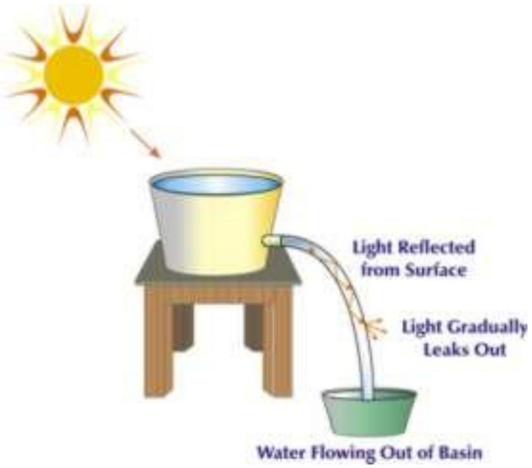
Modelare

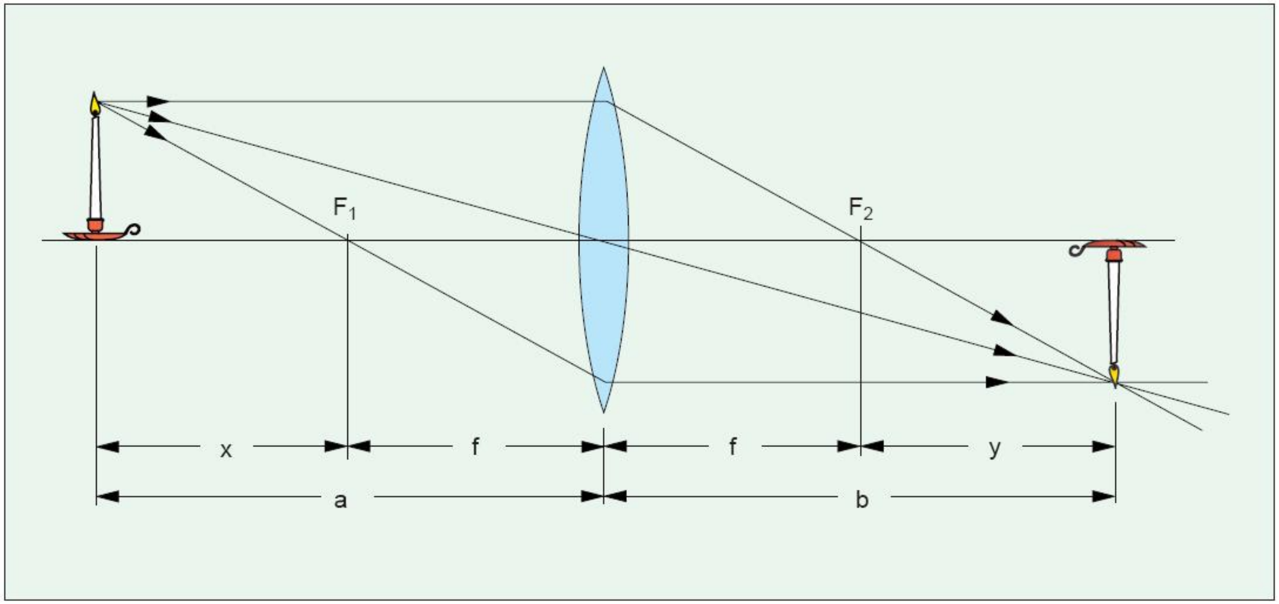


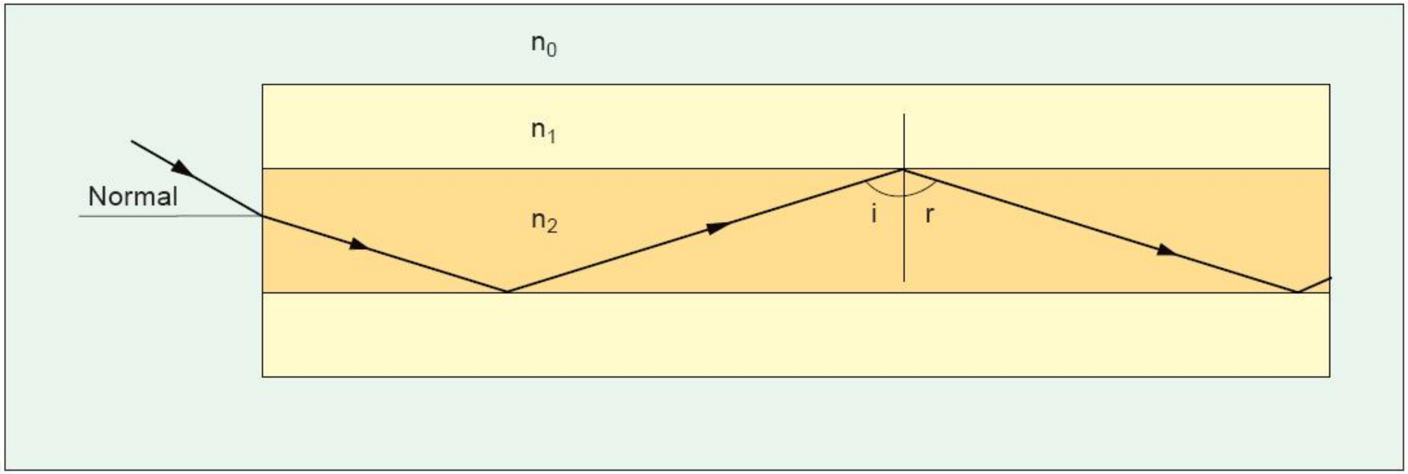
Through the Wormhole
S02E07 How Does the Universe Work



Optica geometrica







Lumina ca undă electromagnetică

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

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

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

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

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

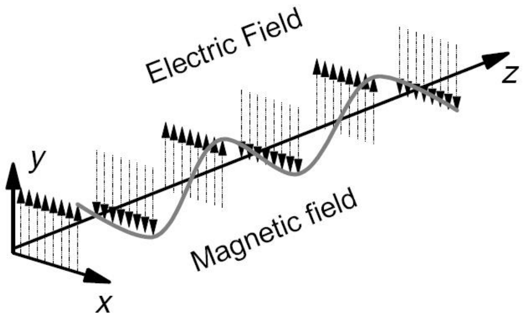
$$\nabla^2 E - \gamma^2 E = 0$$

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

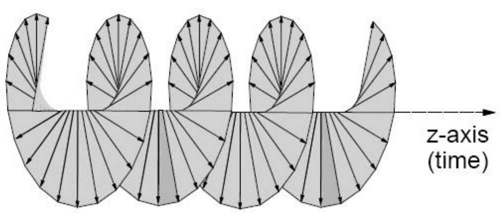
$$\gamma^2 = -\omega^2\varepsilon\mu + j\omega\mu\sigma$$

γ – Constanta de propagare

Solutia ecuatiilor de propagare



Propagare



Polarizare circulara

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 $E_+ \Rightarrow A$

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

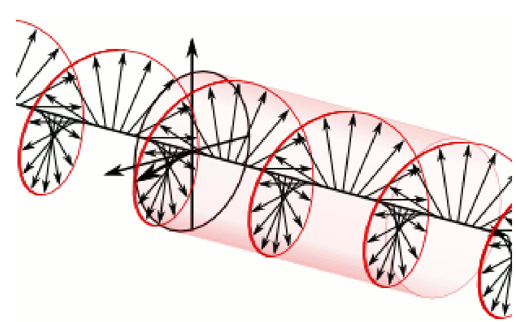
Camp armonic

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

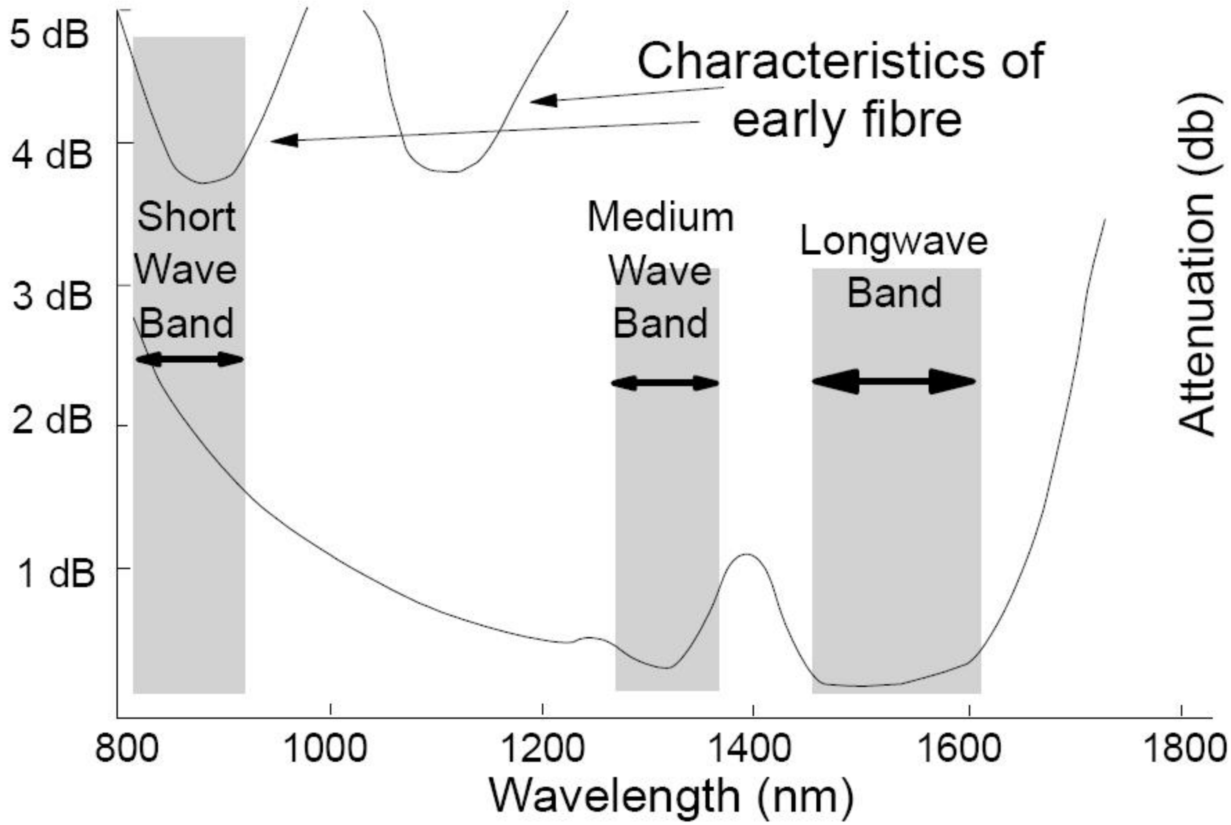
Amplitudine

Atenuare

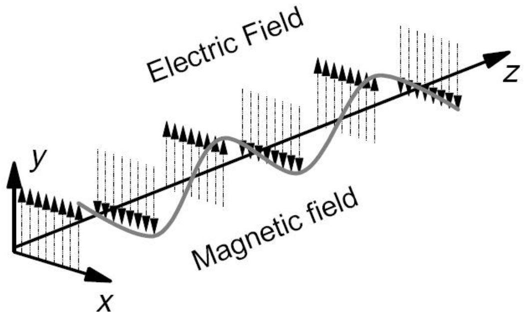
Propagare
(variatie in timp si spatiu)



Atenuarea pe 1 km in SiO_2



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

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

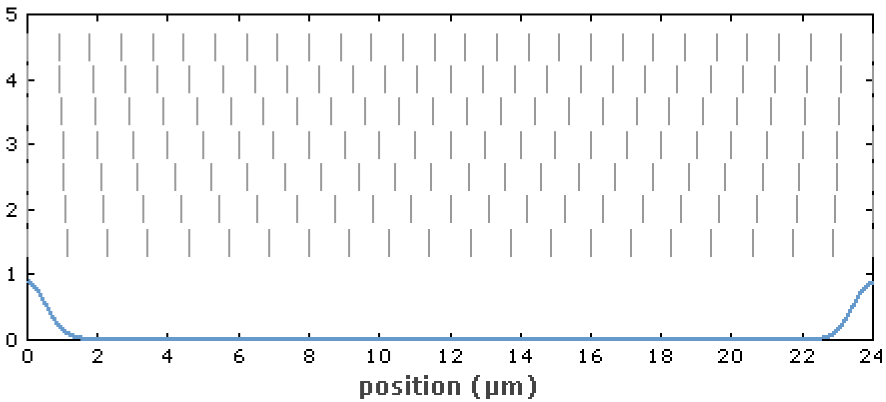
$$E_y = A\cdot e^{-\alpha\cdot z}\cdot e^{j(\omega\cdot t-\beta\cdot z)}$$ punctele de faza constanta: $(\omega\cdot t-\beta\cdot z) = \text{const}$

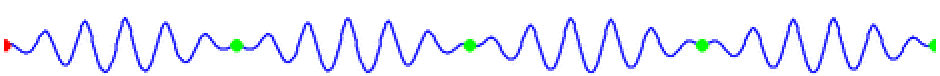
Viteza de faza $\quad v = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{\varepsilon\mu}}$

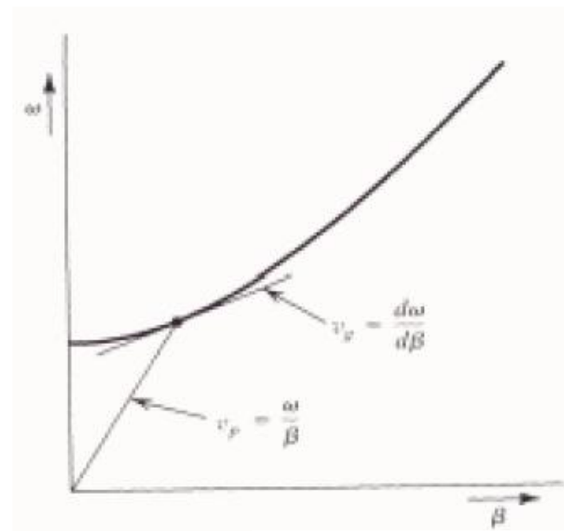
Viteza de grup $\quad v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta}$ $\quad$ in medii dispersive unde $\beta = \beta(\omega)$

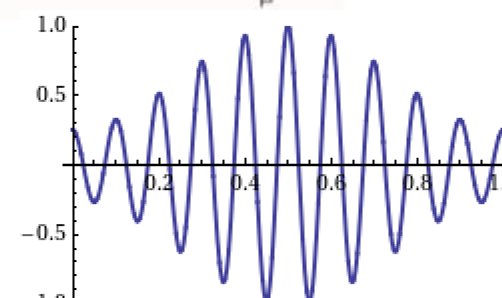
Viteze de grup si faza

- 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

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

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

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

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \qquad c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8 \ m/s$$

$n = 1$

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

$$\eta = \frac{\eta_0}{n} \qquad c = \frac{c_0}{n}$$

$n = \sqrt{\varepsilon_r}$

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

$$\boxed{\begin{aligned} \lambda &= \lambda(n) \\ f &= \text{indep.} \end{aligned}}$$

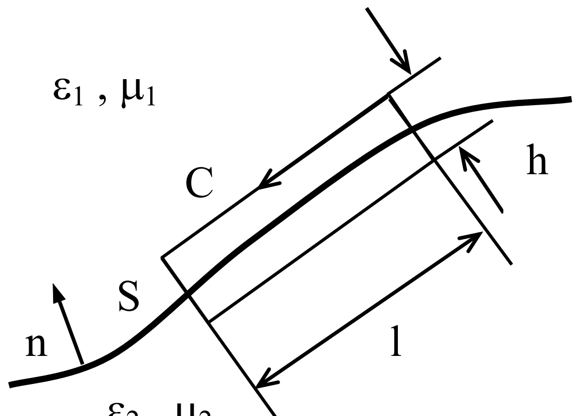
ITU G.692

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

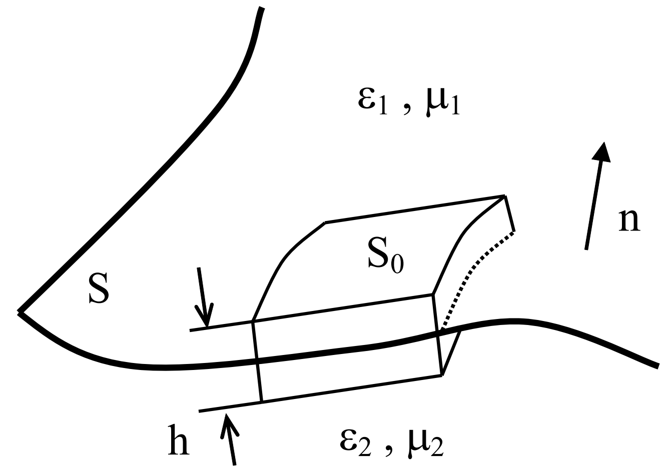
SI

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

Condiţii la limita de separaţie între două medii



a)



b)

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

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

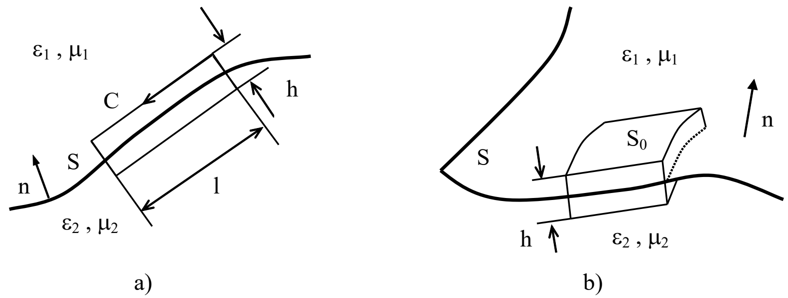
$$n \cdot (D_1 - D_2) = \rho_S$$

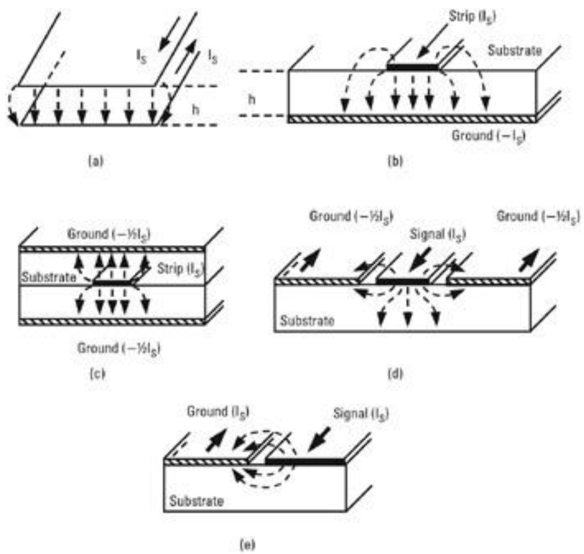
$$n \cdot (B_1 - B_2) = 0$$

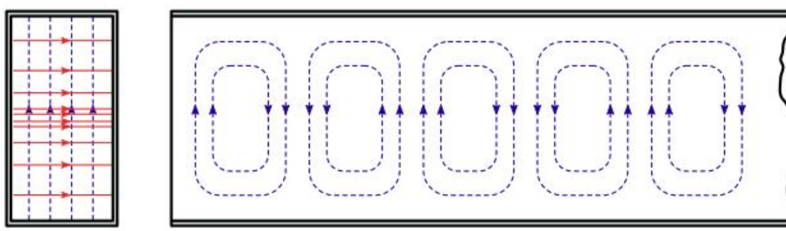
- Daca un mediu este metal ideal toate campurile se anuleaza in interior

Moduri in medii delimitate

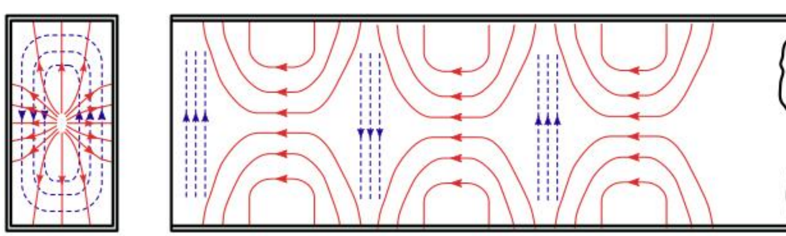
- Campul electric **trebuie** sa fie perpendicular pe un perete metalic sau nul
- Campul magnetic **trebuie** sa fie tangent la un perete metalic sau nul







TE_{10}



TM_{11}

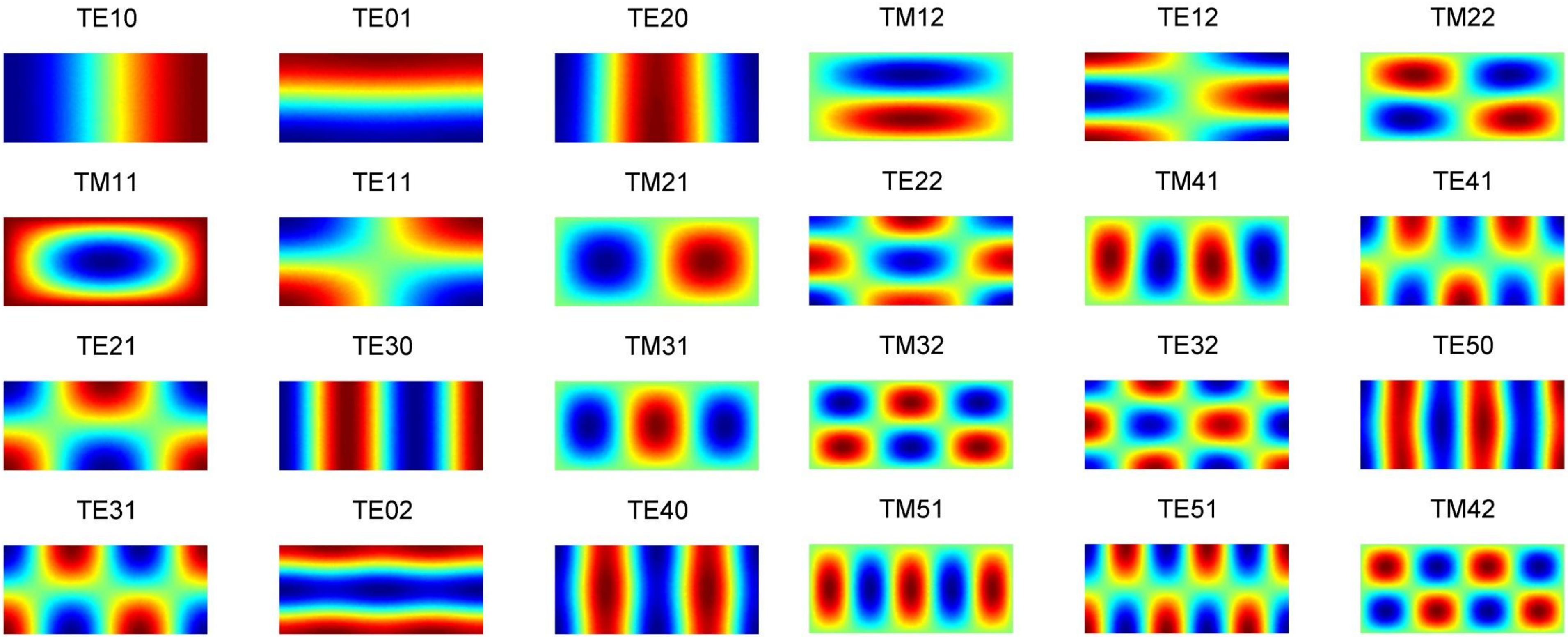
Moduri in medii delimitate

- 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



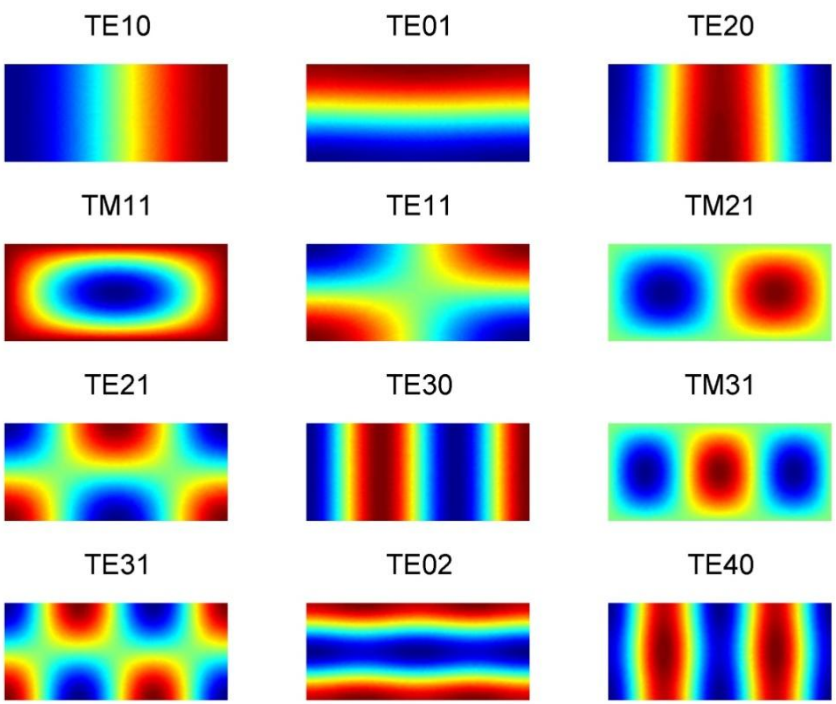
- Similar cu transformata Fourier

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

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

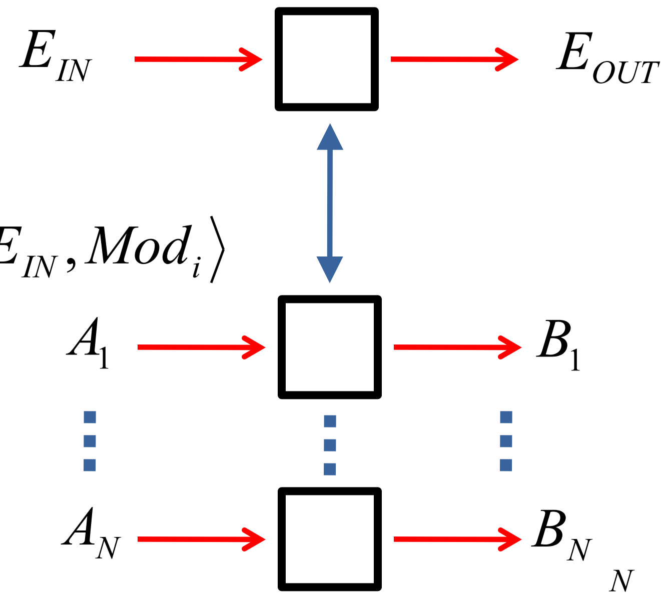
Modele matematice

- 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)

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

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

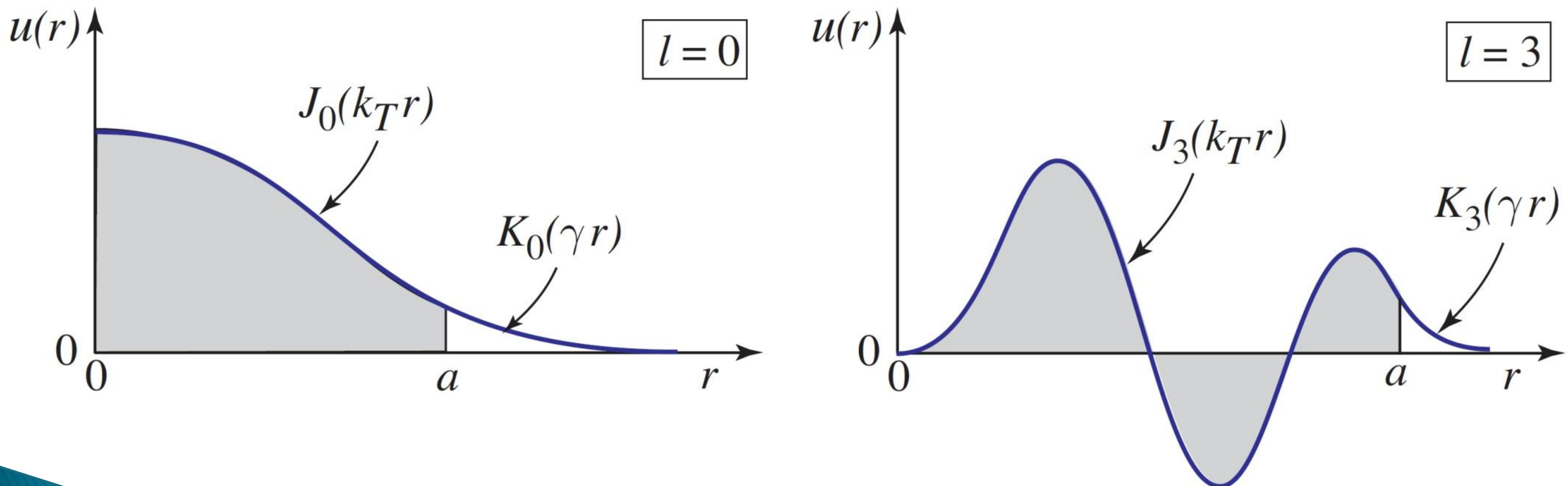
$$\frac{d^2 u}{dr^2} + \frac{1}{r}\frac{du}{dr} + \left(k_T^2 - \frac{l^2}{r^2}\right)u = 0, \qquad r < a$$

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

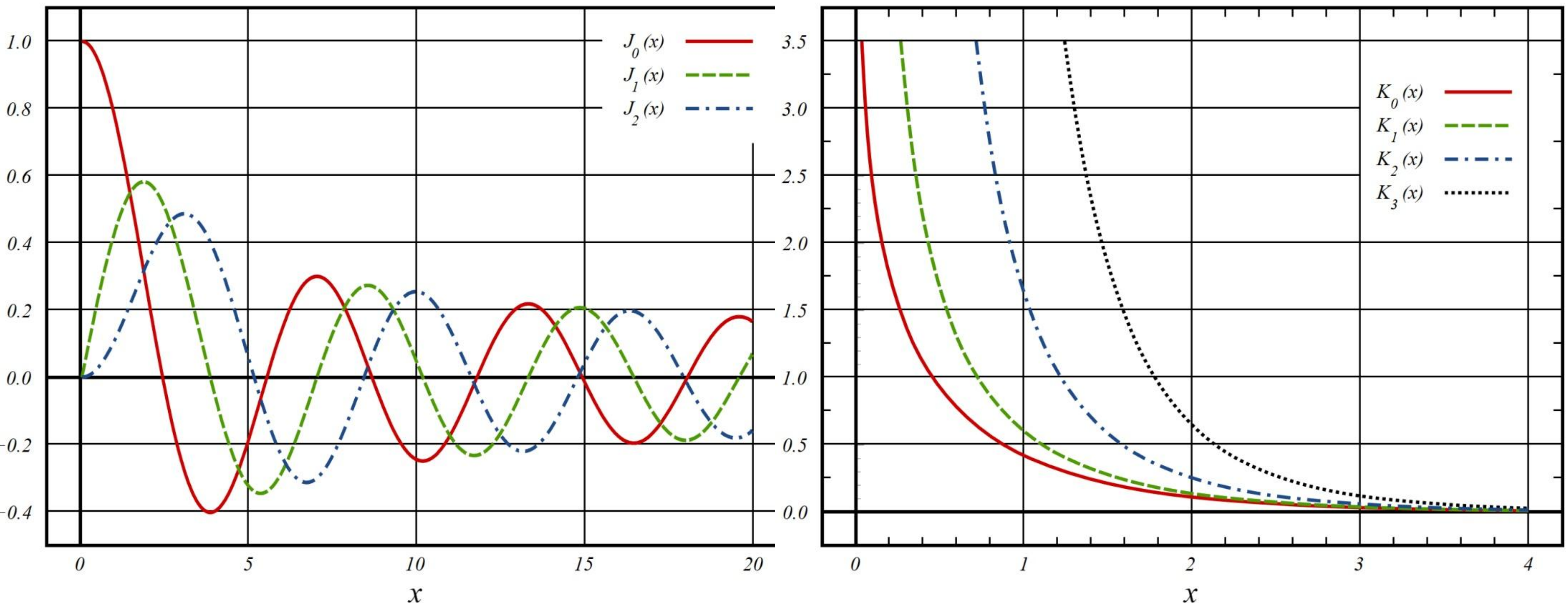
Ghid cilindric dielectric

- soluții proporționale cu funcții Bessel

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

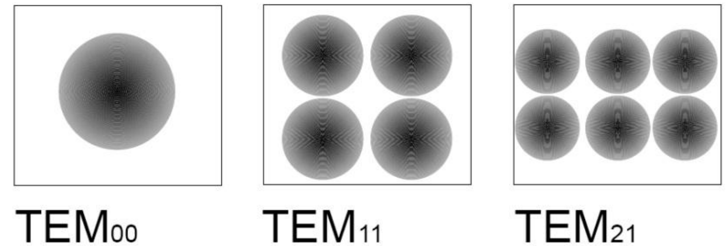


Funcții Bessel

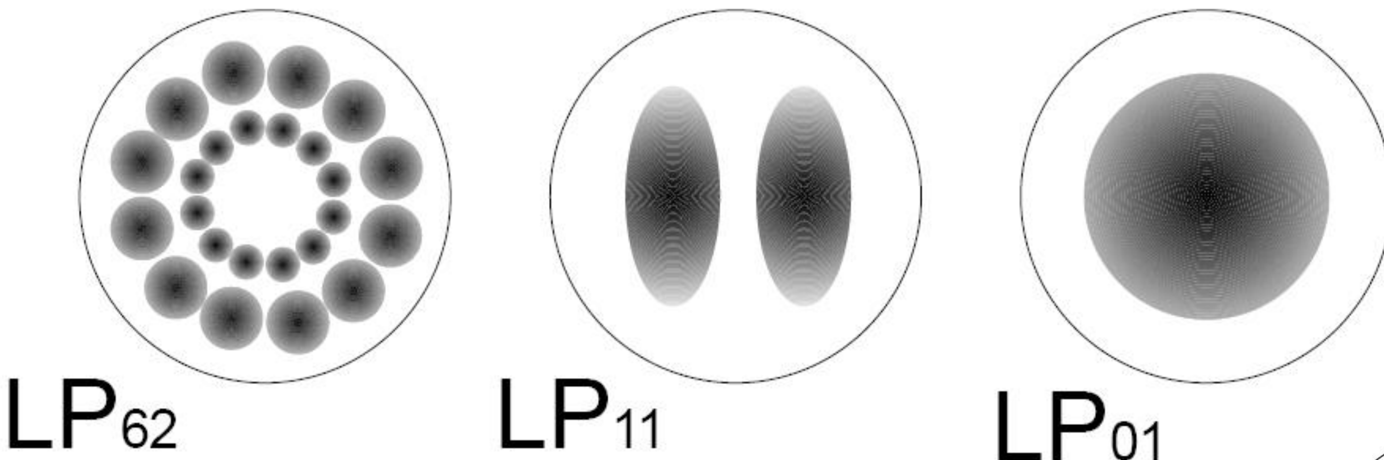


Moduri in fibra

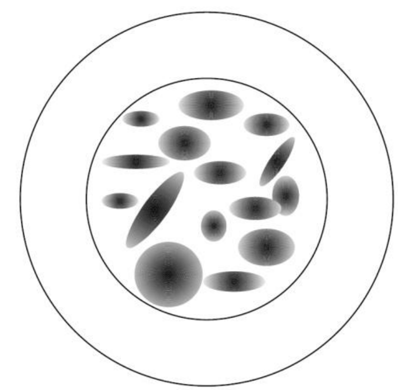
- Moduri in ghid rectangular



- Moduri linear polarizate in fibra



"Sparkle" pattern



Contact

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