Comunicatii Optice

Supliment Laborator 4
2025/2026

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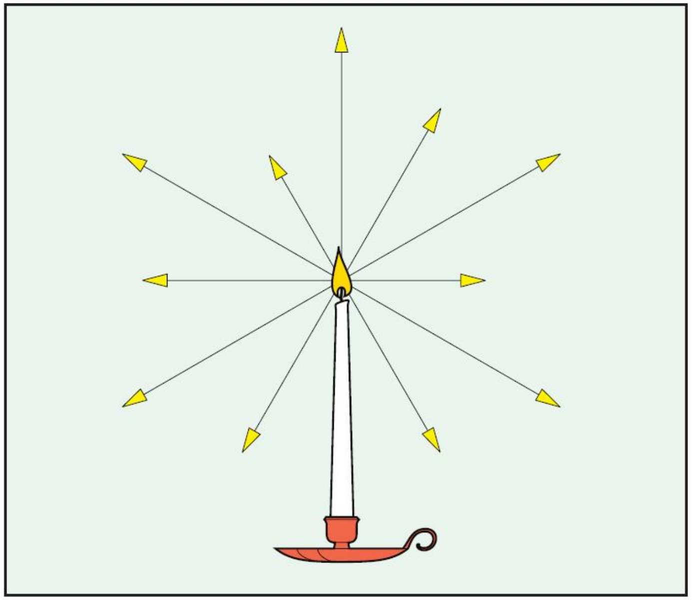
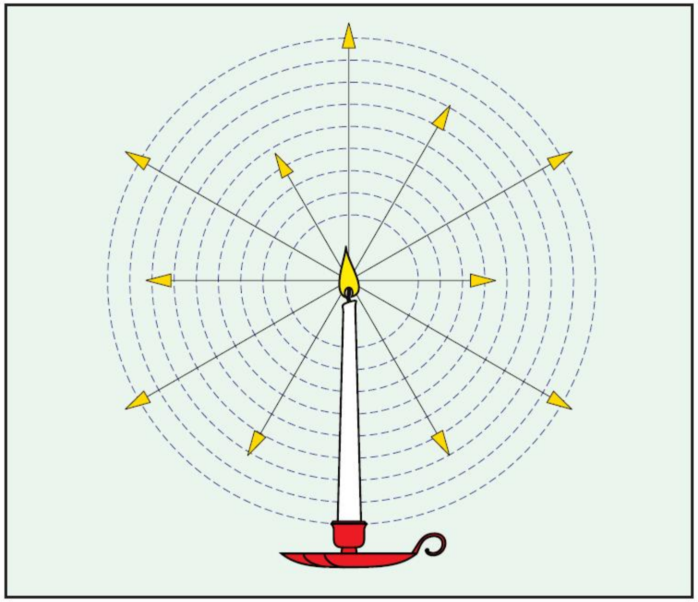
Optică geometrică

Raze de lumina

- Lumina este constituita din raze care se propaga in linie dreapta in medii omogene
- Sursa omnidirecționala: 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)



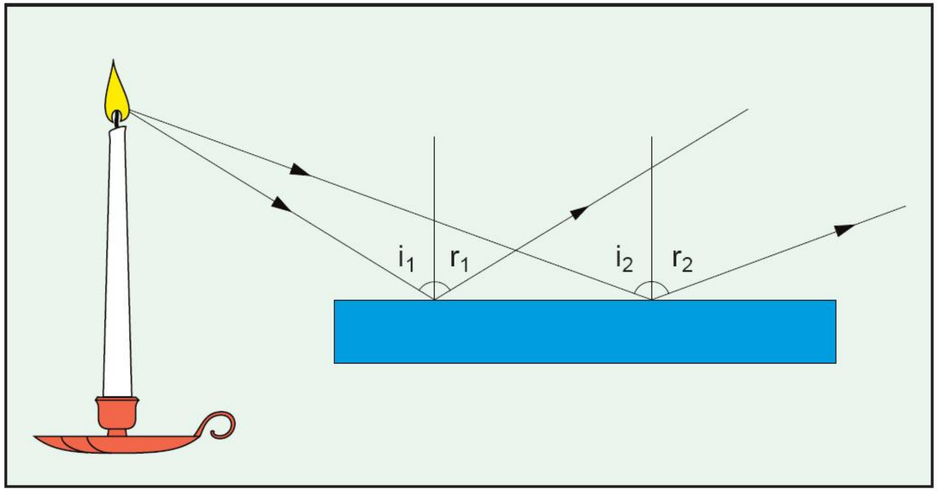
$$P = \frac{P_0}{r^2}$$

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**

$$\phi_i = \phi_r$$

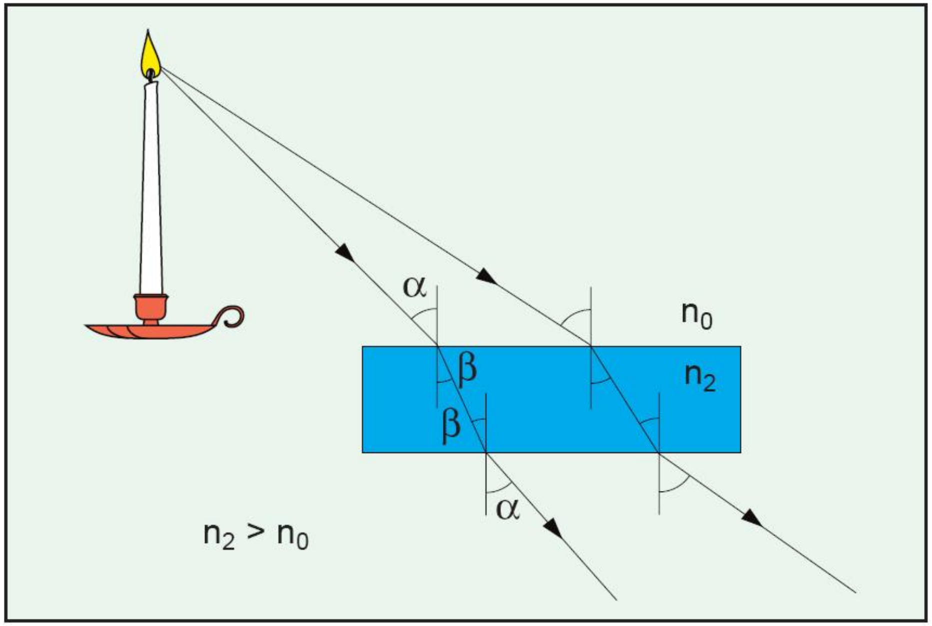


Refractia luminii

- 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)



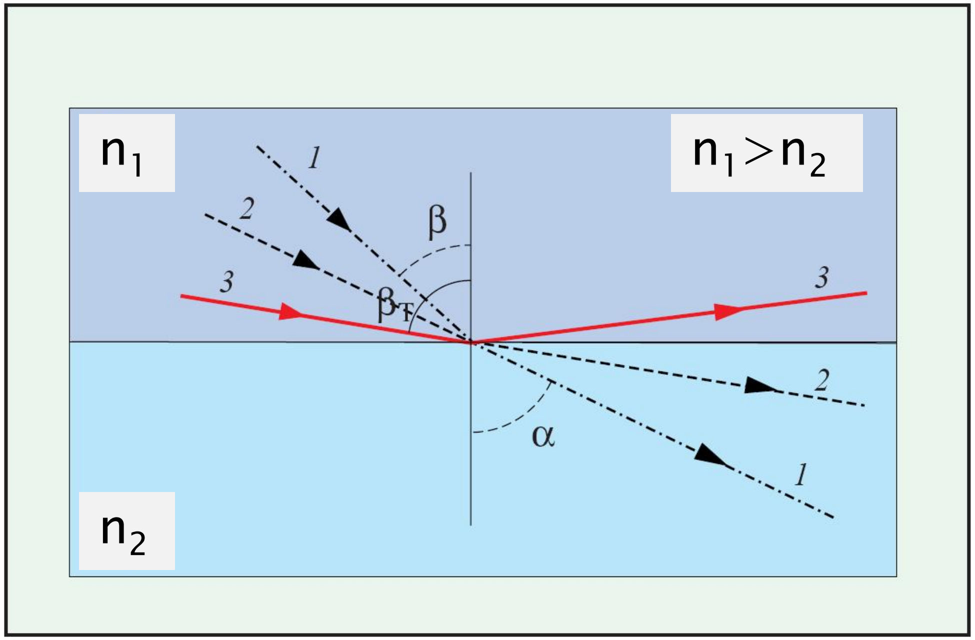
Reflexia totala

- Apare **numai când** lumina se propaga dintr-un mediu mai dens optic intr-un mediu mai puțin dens
- La intersecția luminii cu suprafața de separație a doua medii se întâlnesc in general raze reflectate **si** raze refractate
- Pentru un unghi de incidenta numit **unghi critic**, raza refractata se obține in lungul suprafeței de separație
- Pentru orice unghi mai mare decât unghiul critic exista numai raza reflectata

$$n_1 > n_2; \quad \phi_R = 90°$$

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

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

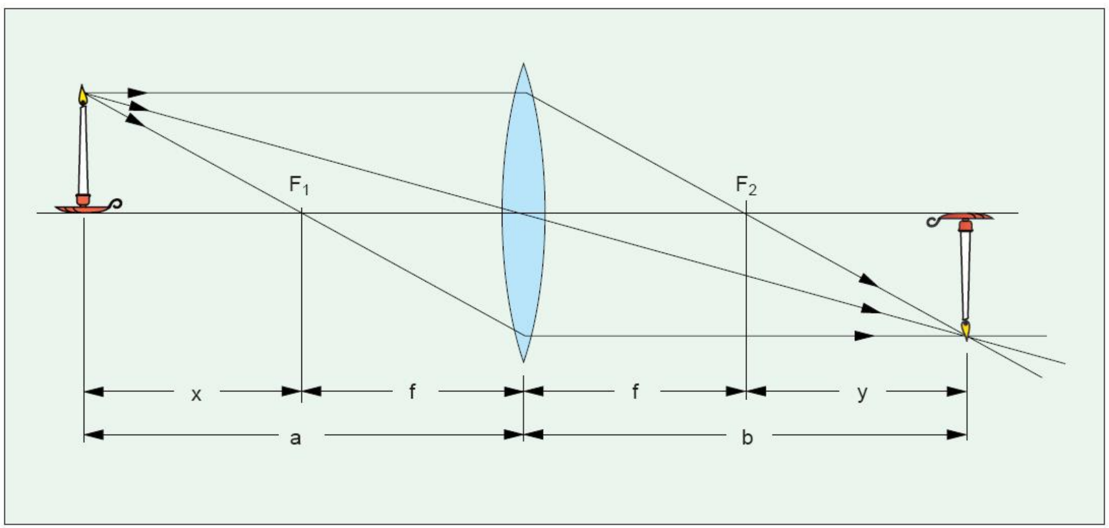


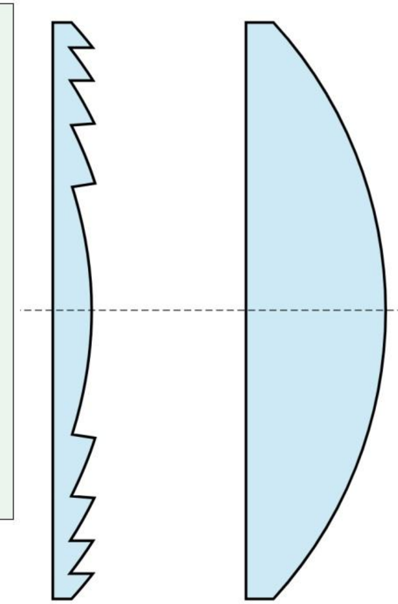
Lentile

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

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

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





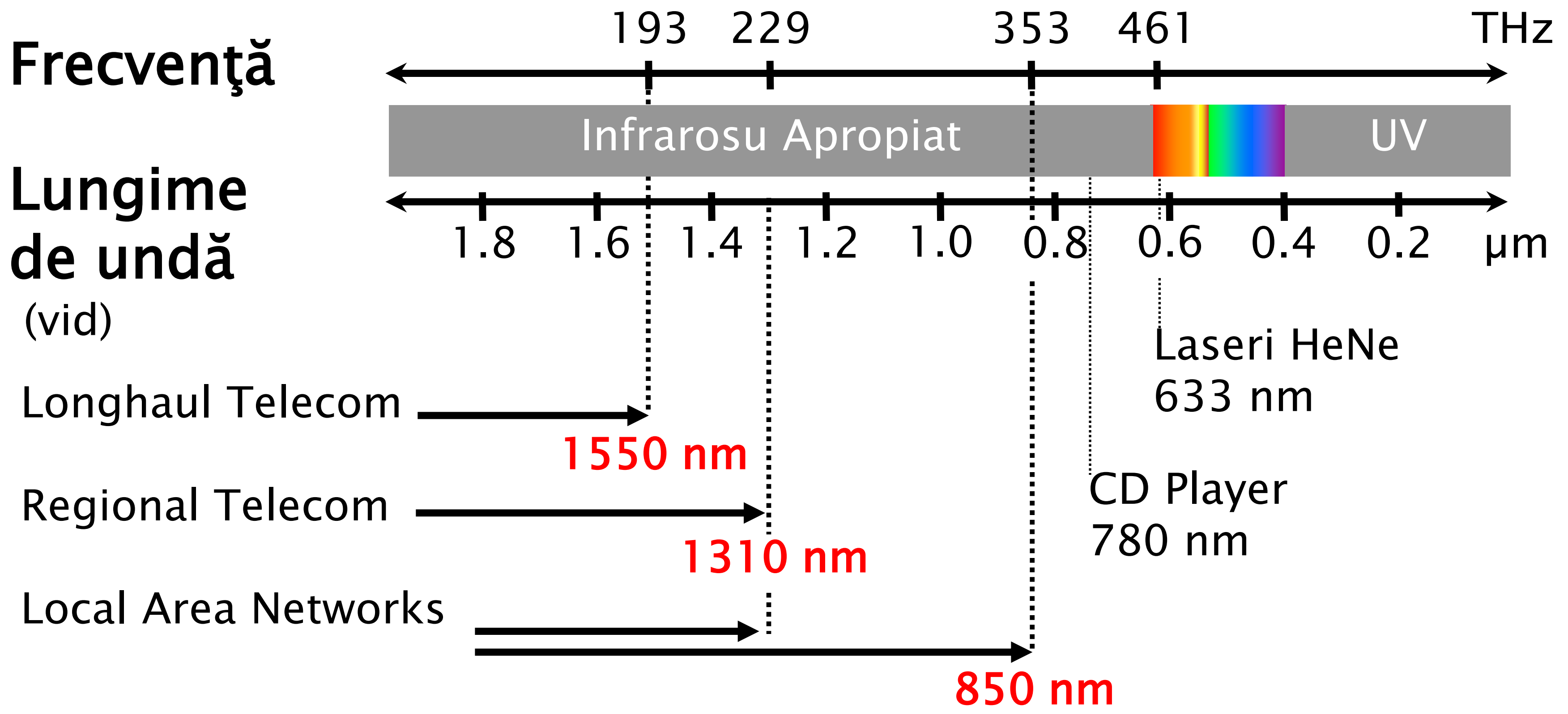
1 2

Fibra optică

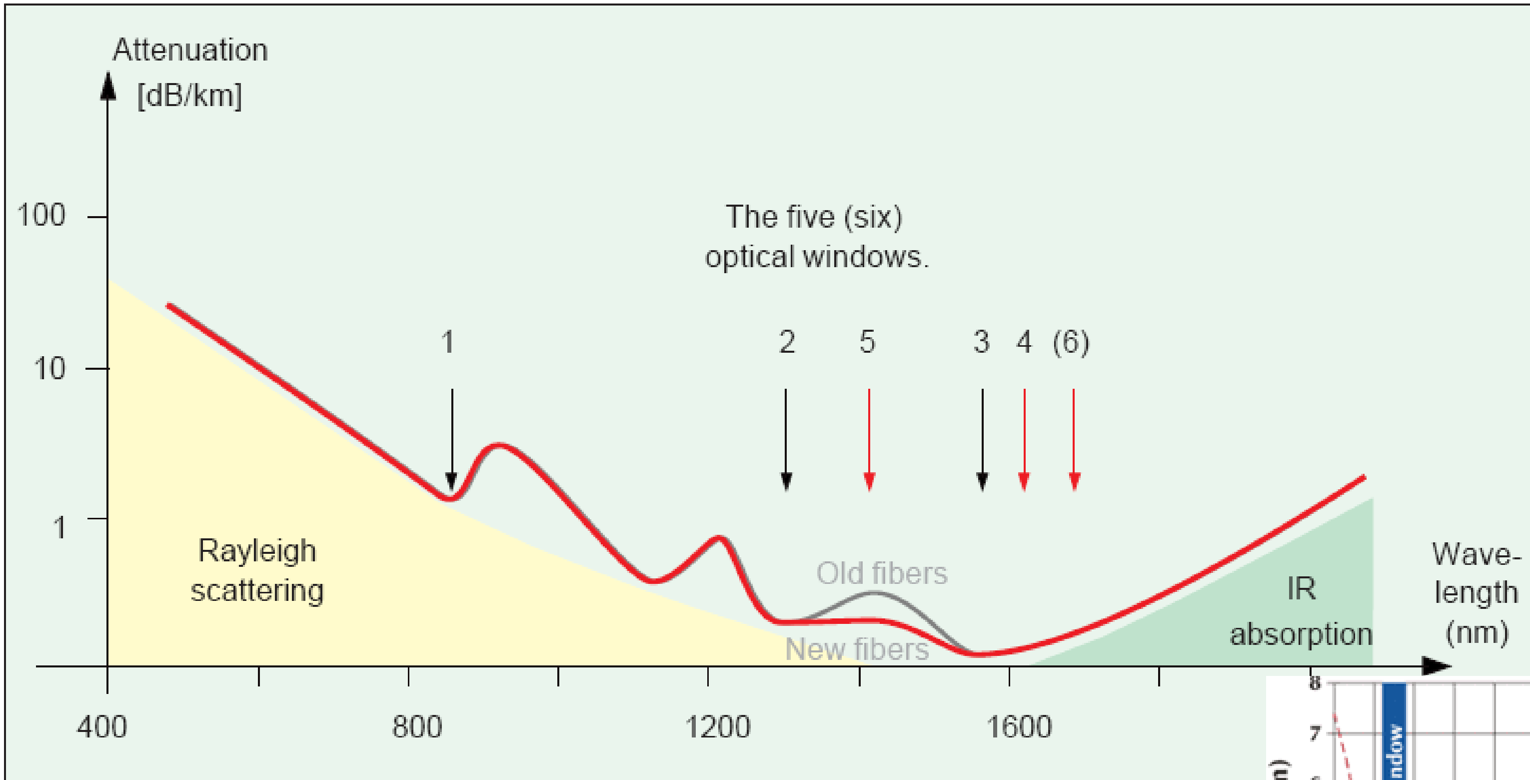
Aplicatii majore

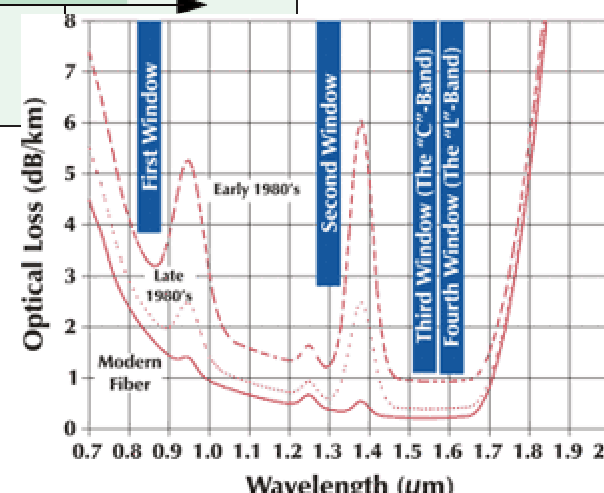
- Comunicatii
  - Infrarosu (InGaAsP)
- Vizibil
  - Spectru vizibil (GaAlAs)
- Iluminare
  - Putere ridicata, lumina alba (GaInN)
- Energie solara
  - Efect fotovoltaic (Si)

Benzi de lucru in comunicaţiile optice



Atenuarea în fibra optică (SiO_2)

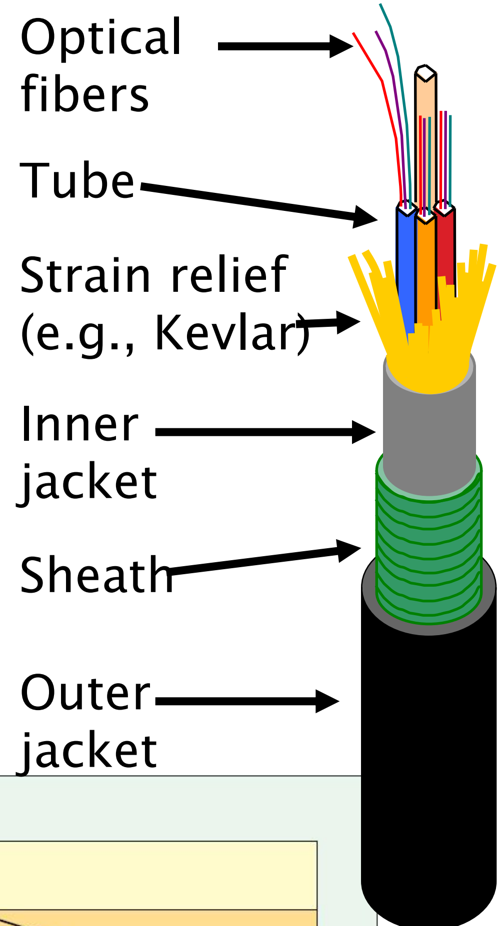


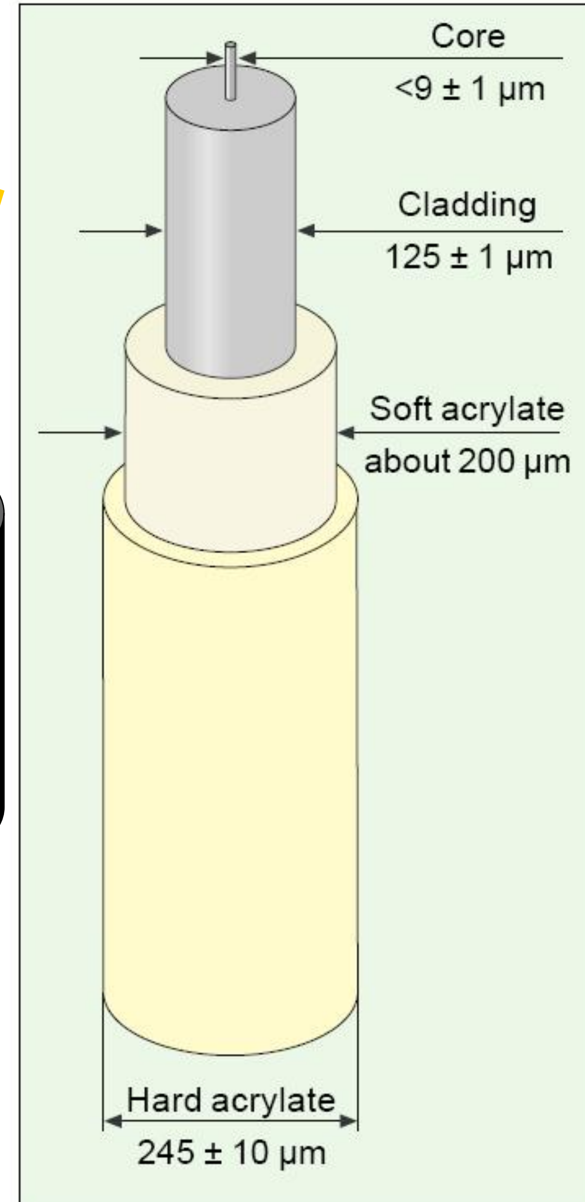


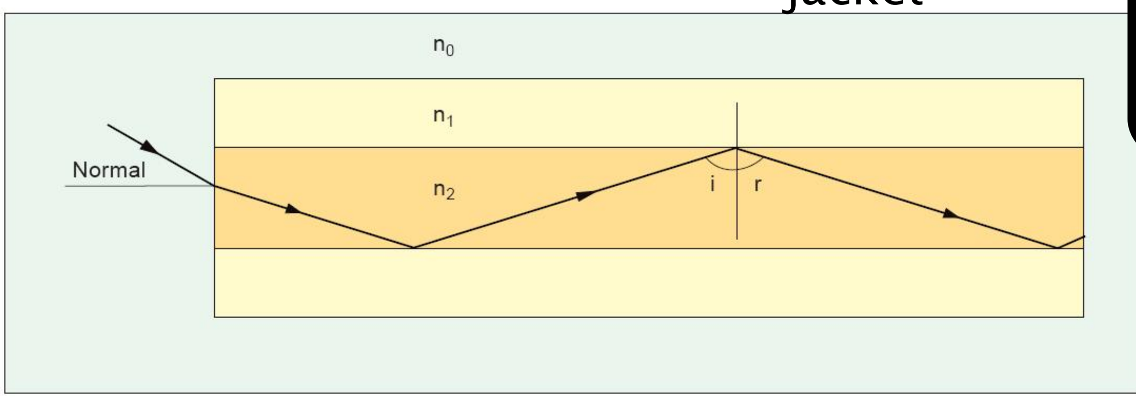
850nm, 1310nm, 1550nm

Fibra optica

- un ghid de unda dielectric
  - miez
  - teaca





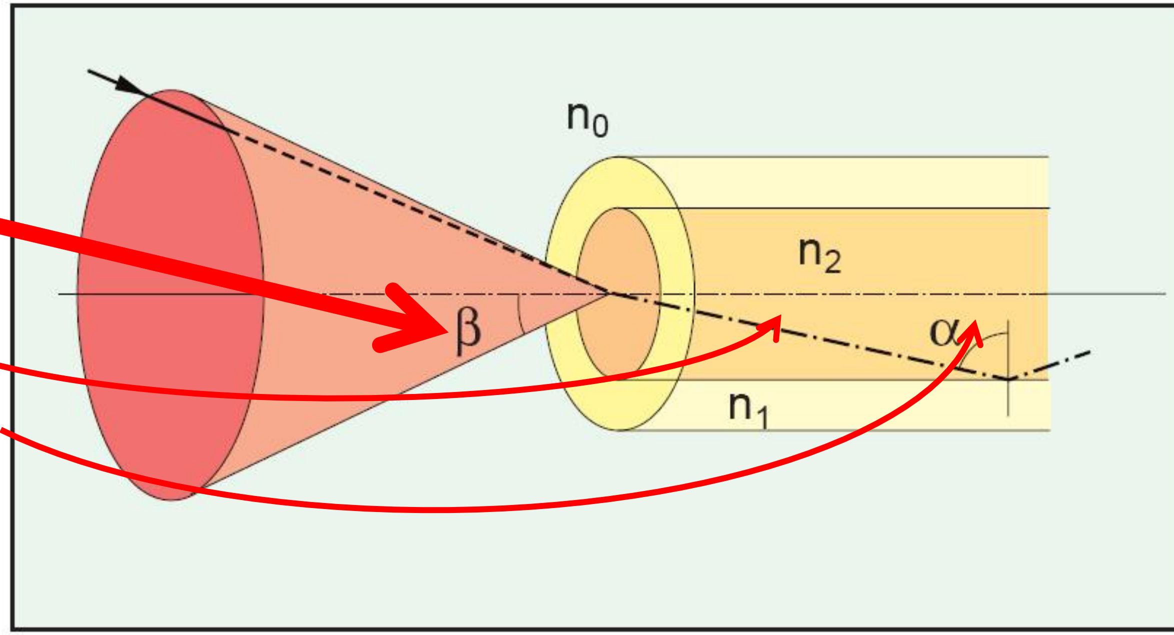


Unghi de acceptanta, apertura numerica

- Unghi de acceptanta

$$n_0 \cdot \sin\theta_{ACC} = n_2 \cdot \sin\phi_2$$

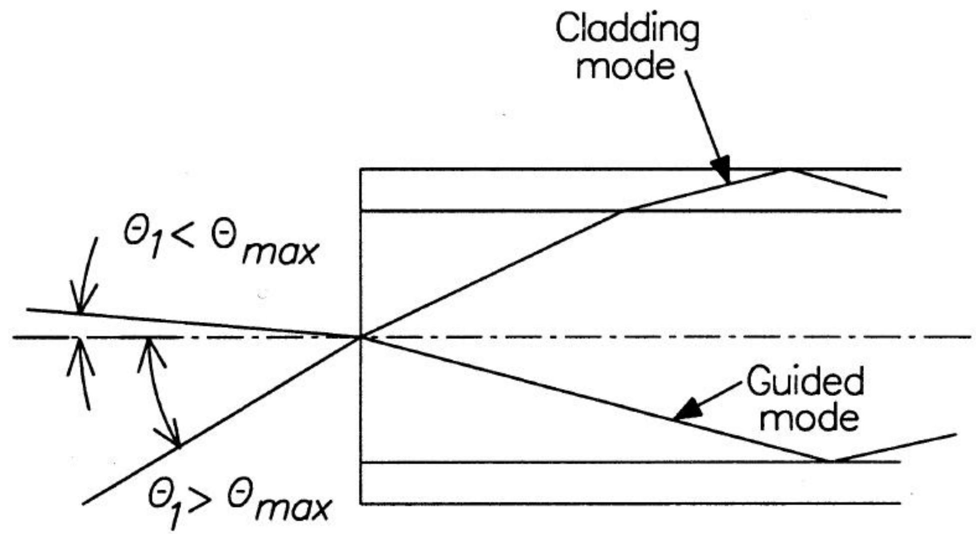
$$n_0 \cdot \sin\theta_{ACC} = n_2 \cdot \cos\phi_c$$



- **Apertura numerica**

$$NA = n_0 \cdot \sin\theta_{ACC}$$

$$NA = n_2\sqrt{\frac{n_2^2 - n_1^2}{n_2^2}} = \sqrt{n_2^2 - n_1^2}$$



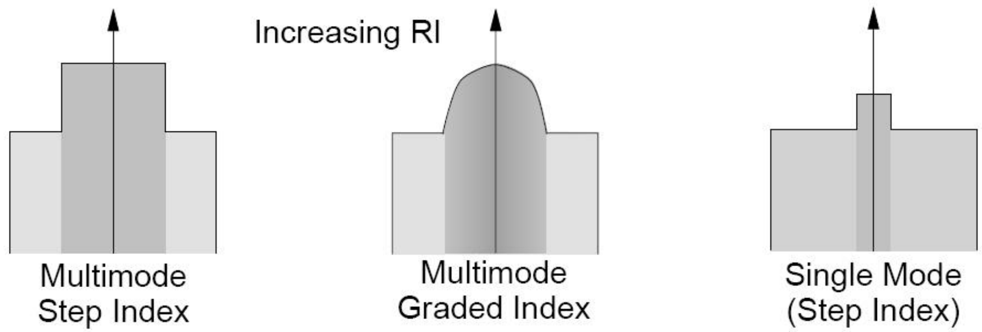
n_2 – miez

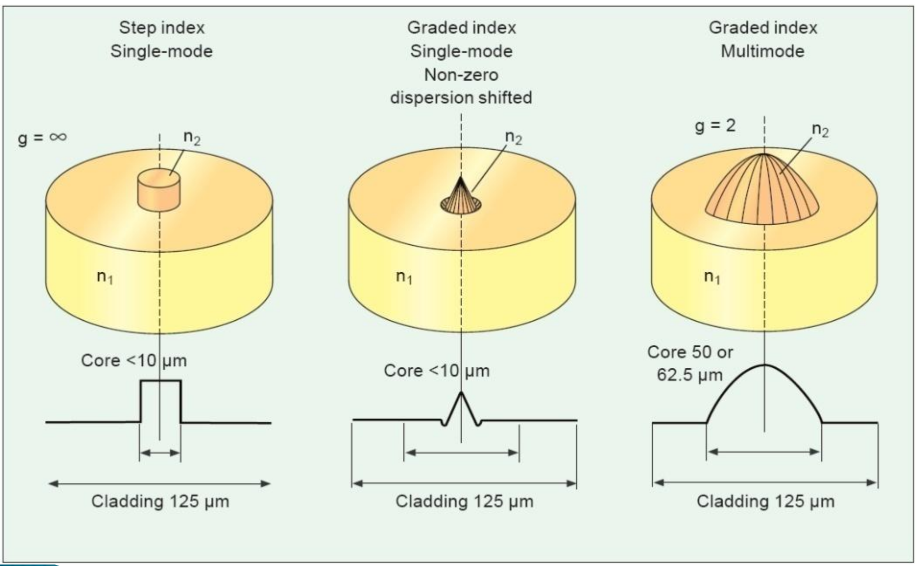
n_1 – teaca

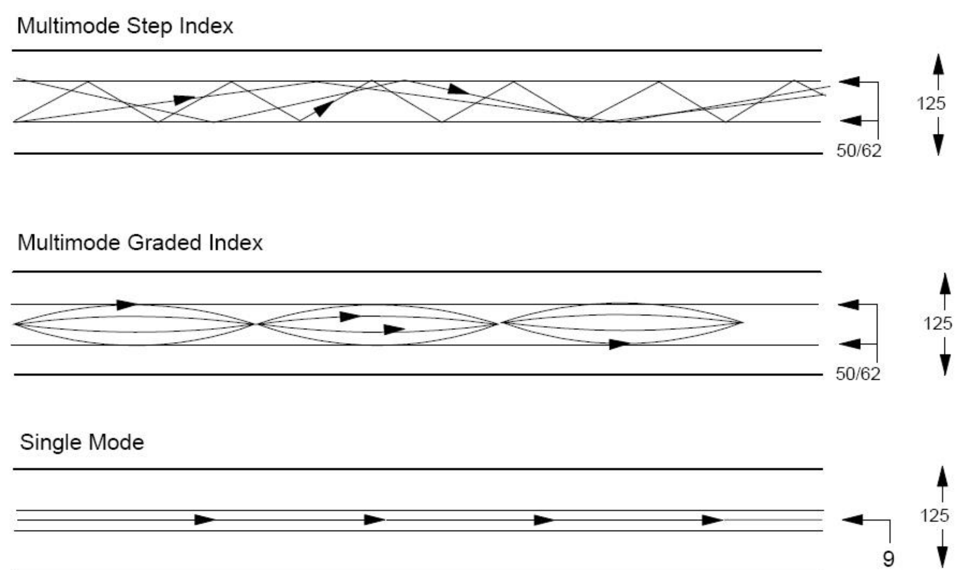
$n_2 > n_1$!!

Tipuri de fibra

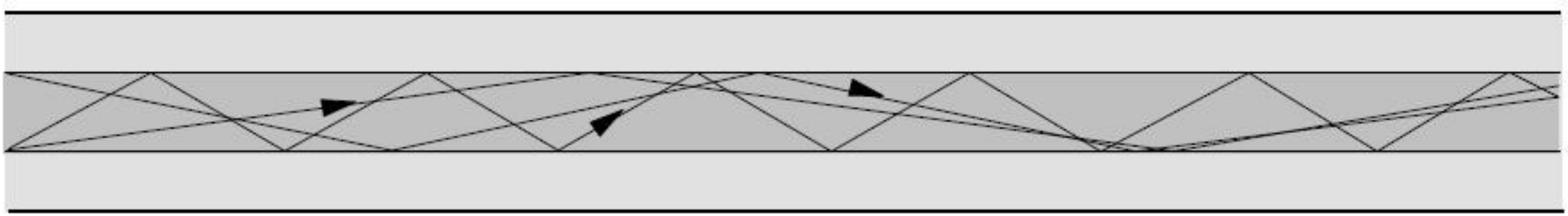
- Monomod
- Multimod
  - cu salt de indice
  - cu indice gradat



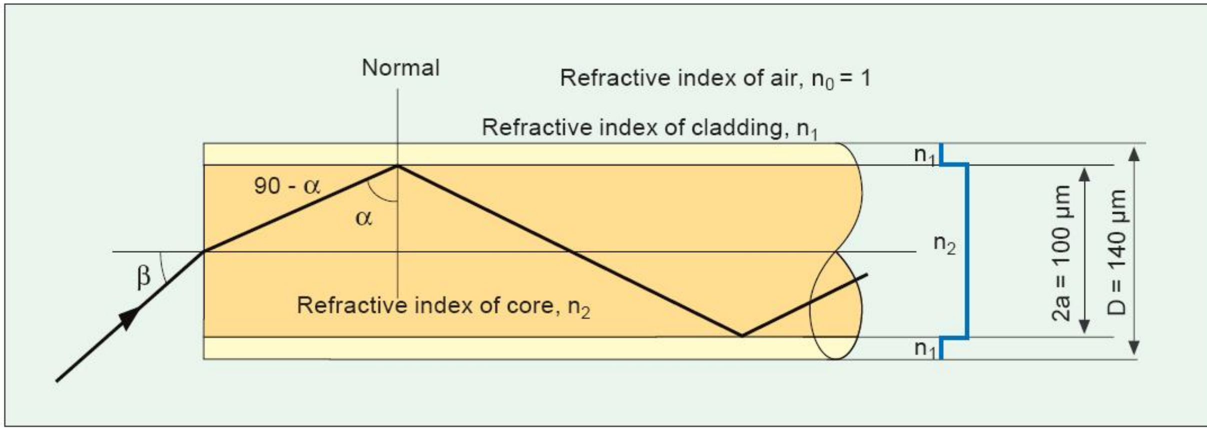


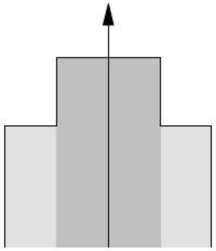


Fibre multimod cu salt de indice



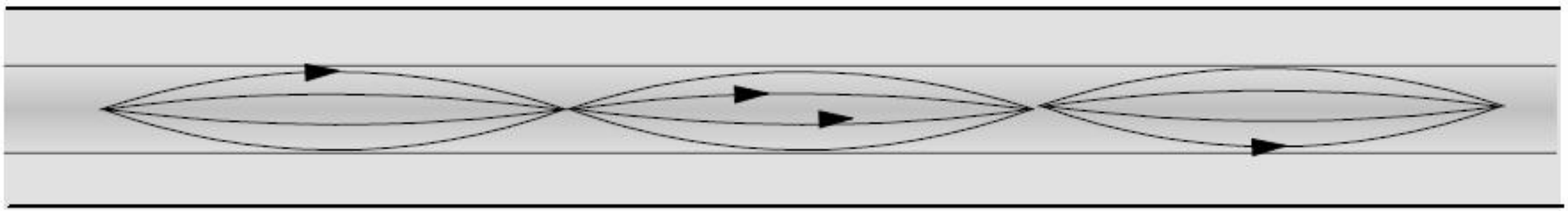
- 50/125 sau 62.5/125 (μm)
- 15–50 MHz · km



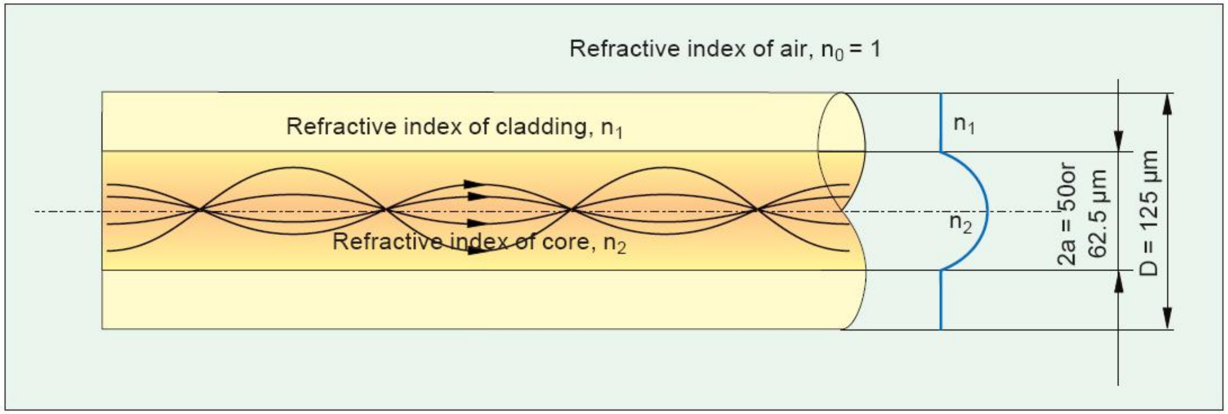


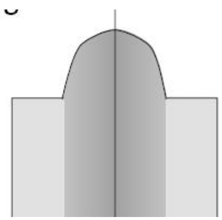
	glass	plastic
core diameter 2a	62.5 ~~100~~ μm	980 μm
cladding diameter D	125 ~~140~~ μm	1000 μm
core refractive index n_2	1.48	
cladding refractive index n_1	1.45	

Fibre multimod cu indice gradat



- 50/125 sau 62.5/125 (µm)
- 700-1200 MHz·km

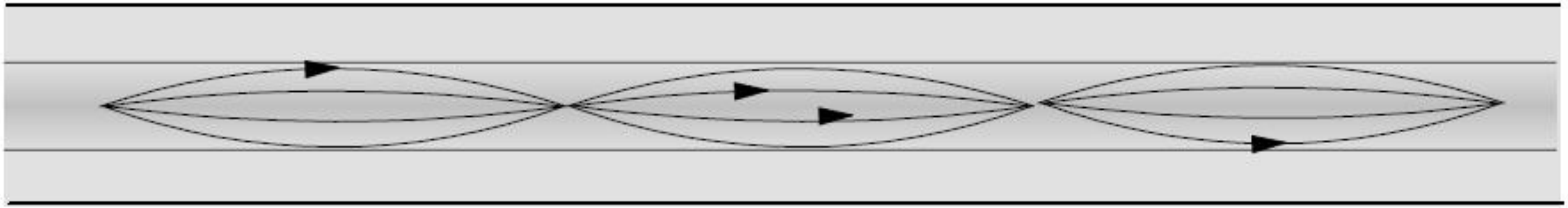




Core diameter 2a	50 or 62.5 µm
Cladding diameter D	125 µm
Maximum refractive index, core	1.46
Relative differential refractive index	0.010

Fata Morgana

Fibre multimod cu indice gradat

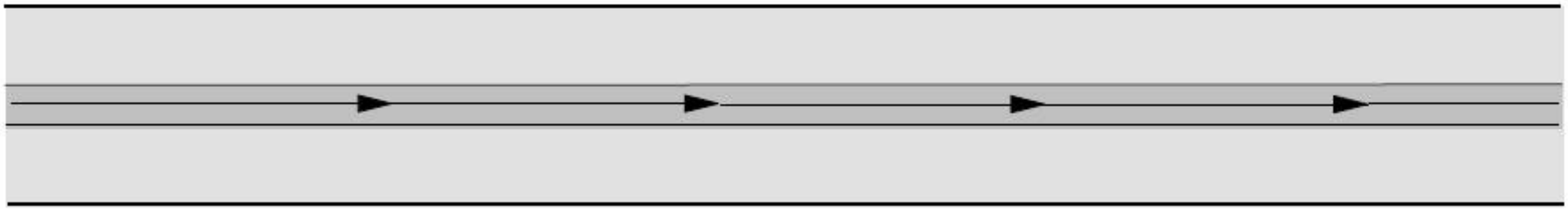


$$n(r) = n_2\left[1 - \Delta\left(\frac{r}{a}\right)^g\right]$$

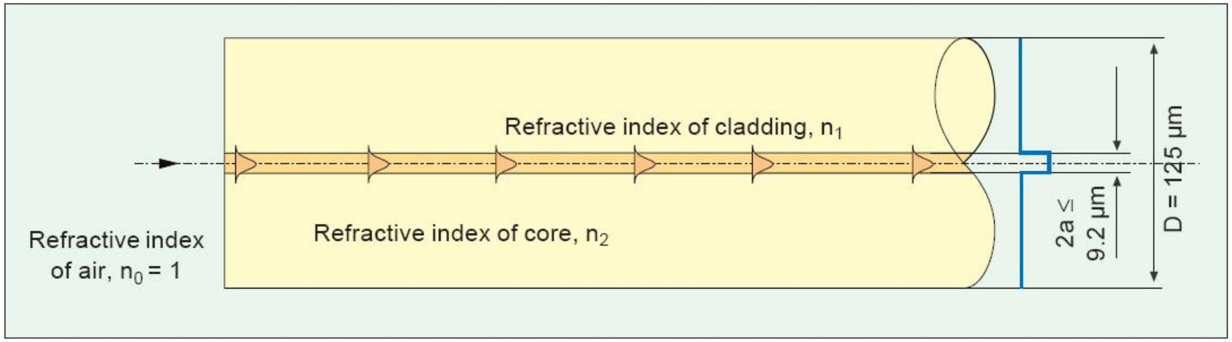
$$\Delta = \frac{NA^2}{2n_2^2} = \frac{n_2^2 - n_1^2}{2n_2^2} \approx \frac{n_2 - n_1}{n_2} \approx \frac{\Delta n}{n} \quad \text{for } \Delta << 1$$

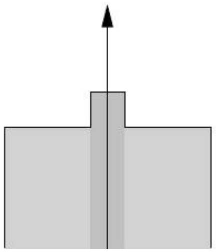
- g = 1 – indice gradat triunghiular
- g = 2 – indice gradat parabolic
- g = ∞ – salt de indice

Fibre monomod



- 6–8/125 (μm)
- MHz·km nerelevant
- MFD – Mode Field Diameter





Cladding diameter D	125 μm
Core refractive index n_2	1.4485
Cladding refractive index n_1	1.4440
Refractive index differential	0.003 = 0.3%

Ghid cilindric dielectric

- Ecuatiile 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)

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

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

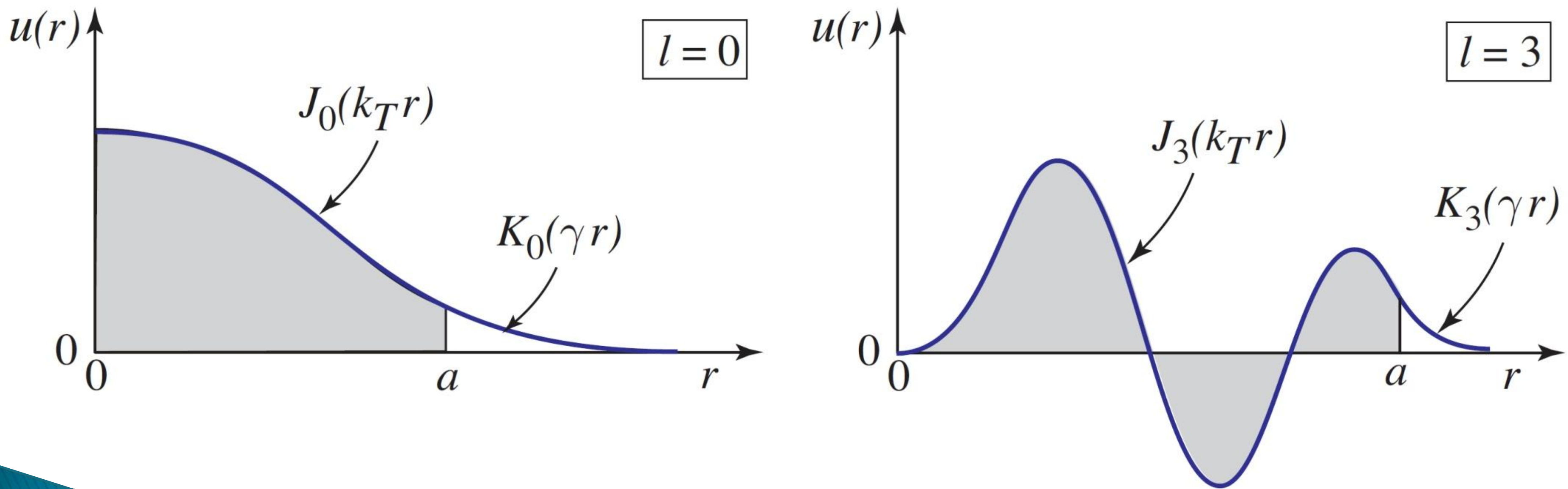
$$\frac{d^2 u}{dr^2} + \frac{1}{r}\frac{du}{dr} + \left(k_T^2 - \frac{l^2}{r^2}\right)u = 0, \qquad r < a$$

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

Ghid cilindric dielectric

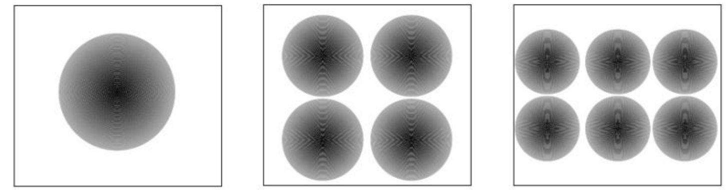
- solutii proportionale cu functii Bessel

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



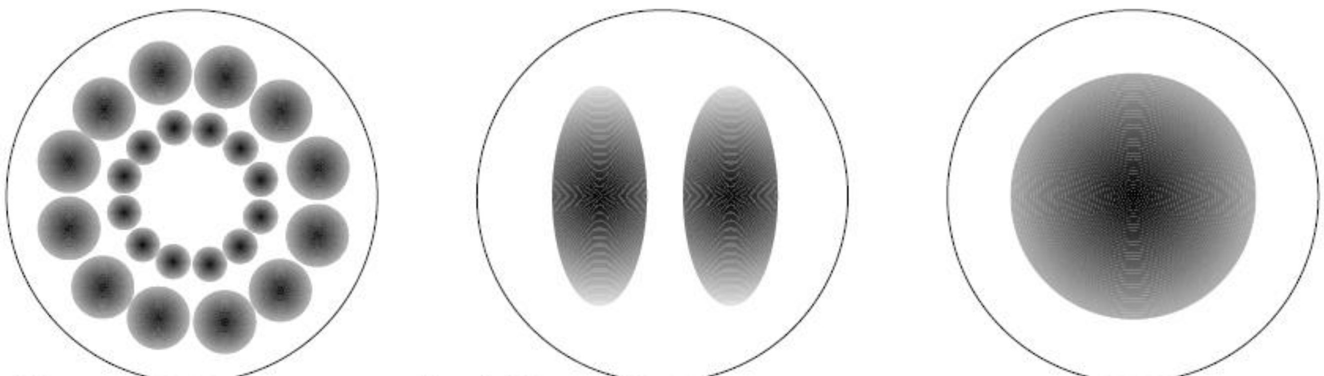
Moduri in fibra

- Moduri in ghid rectangular

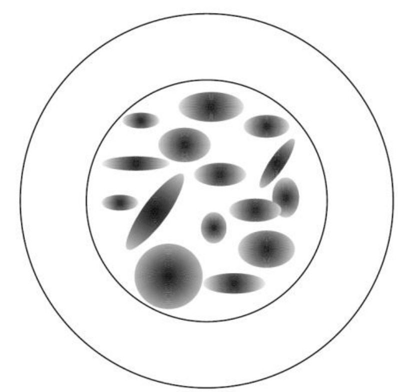


TEM_{00} TEM_{11} TEM_{21}

- Moduri linear polarizate in fibra



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



"Sparkle" pattern

Frecventa normalizata

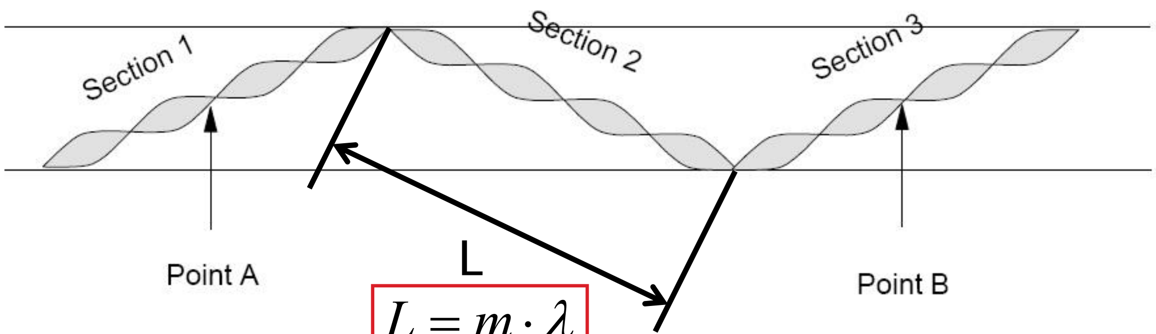
- Frecventa normalizata

$$V = 2\pi \frac{a}{\lambda} NA = k \cdot a \cdot NA$$

a – **raza** miezului

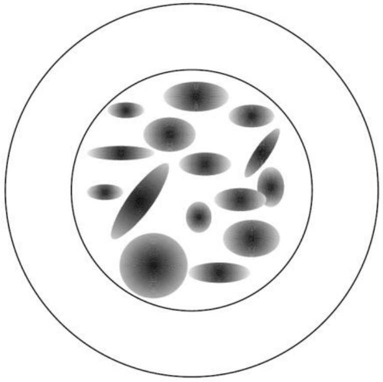
$$k = \frac{2\pi}{\lambda}$$

- Numar de moduri



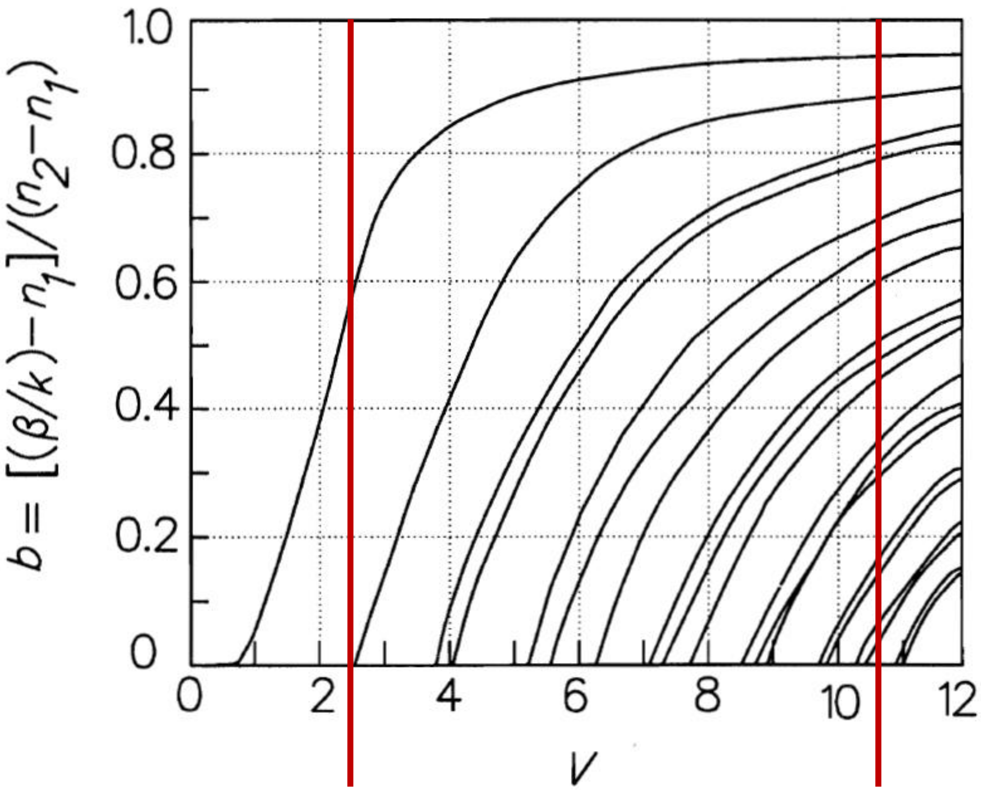
$$\boxed{L = m \cdot \lambda}$$

$$N \approx \frac{V^2}{2} \cdot \frac{g}{g+2}$$



Frecventa normalizata – monomod

- Fibre monomod



b – coeficient de propagare modal relativ

$$V \le V_C = 2.405$$

exista un **singur** mod (solutii fc. Bessel)

$$V = 2\pi \frac{a}{\lambda} NA = k \cdot a \cdot NA$$

$$\lambda \ge \lambda_C = \pi \frac{2a}{V_C} NA = \pi \frac{2a}{2.405} NA$$

Exemplu:
2a = 8.5μm
NA = 0.11

$$\lambda_C = \pi \frac{8.5}{2.405} 0.11 = 1210\text{nm}$$

Frecventa normalizata

- Numar de moduri
  - Multimod cu salt de indice

$$g = \infty \quad \Rightarrow \quad N \approx \frac{V^2}{2}$$

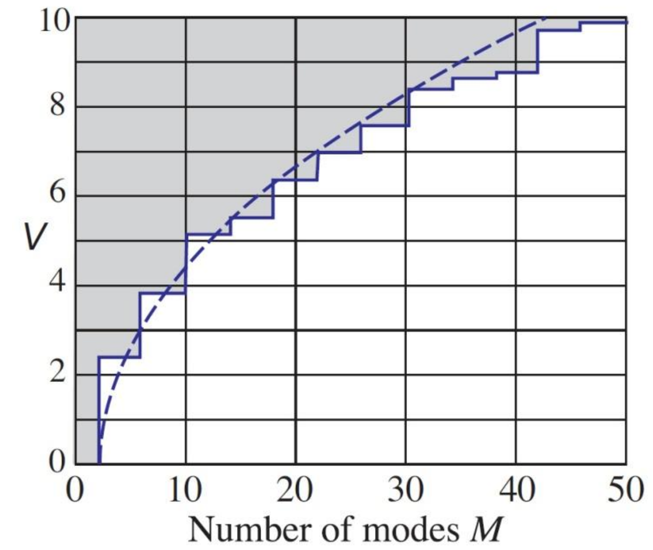
  - Multimod cu indice gradat

$$g = 2 \quad \Rightarrow \quad N \approx \frac{V^2}{4}$$

  - Monomod

$$V \le V_C = 2.405$$ exista un singur mod (solutii fc. Bessel)

$$N \approx \frac{V^2}{2} \cdot \frac{g}{g+2}$$

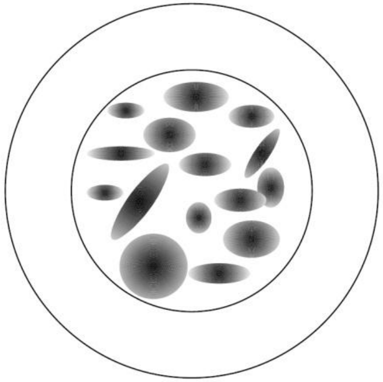


Exemplu

- fibra tipica multimod
  - g=2
  - 2a = 50μm -> a = 25μm
  - NA = 0.2 la λ = 1μm

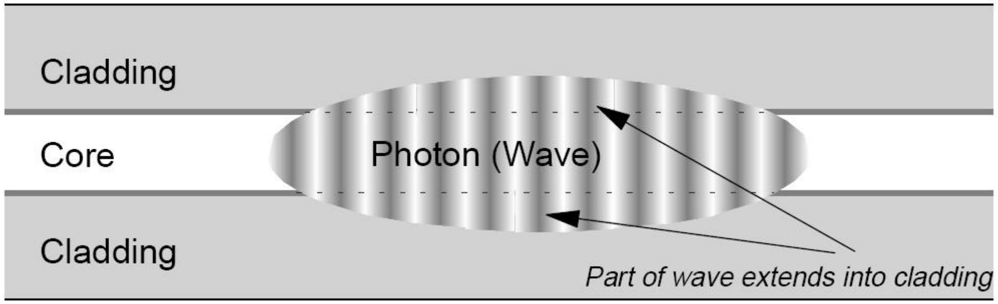
$$V = 2\pi \frac{a}{\lambda} NA = 2\pi \frac{25}{1} 0.2 = 2 \cdot \pi \cdot 5 \approx 31.4$$

$$g = 2 \quad \Rightarrow \quad N = \frac{V^2}{4} = \frac{31.4^2}{4} = 247$$

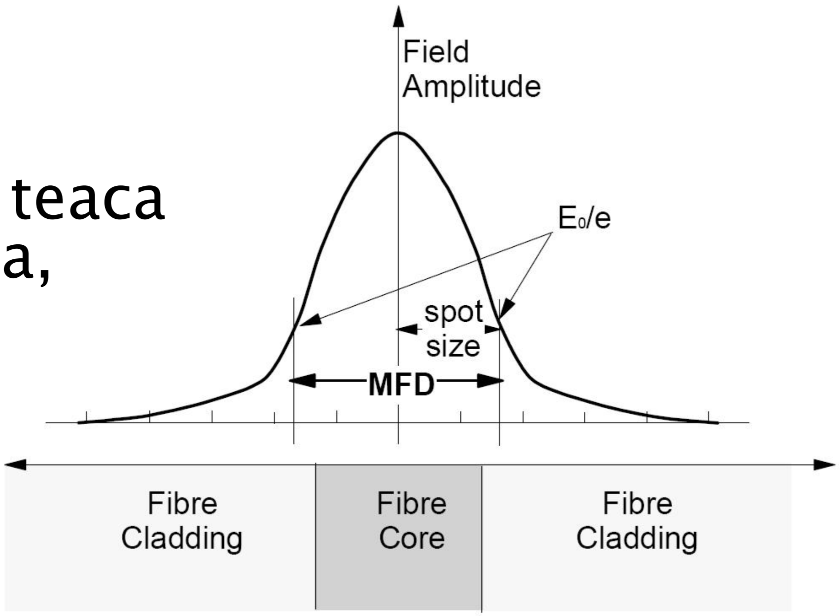


Propagarea in fibra monomod

- Propagarea luminii poate fi explicata doar prin teoria electromagnetica



- Energia campului se extinde in teaca (diametrul efectiv al spotului luminos – MFD, Mode Field Diameter)
- MFD > 2a
- Adancimea de patrundere in teaca depinde de lungimea de unda, generand dispersia de ghid



Cod culoare cablu optic

Fiber Color Code

lightoptics

Fiber Type	Color Code		
Multimode & Single mode	**Non-military Applications**	**Military Applications**	**Suggested Print Nomenclature**
OM1 62.5/125µm Multimode	Orange	Slate	62.5/125
OM2 50/125µm Multimode	Orange	Orange	50/125
OM3 50/125µm Multimode	Aqua	Undefined	850 LO 50/125
OM4 50/125µm Multimode	Aqua Meganta	Undefined	850 LO 50/125
OM5 50/125µm Multimode	Lime Green	Undefined	850 LO 50/125
100/140µm Multimode	Orange	Green	100/140
OS1/OS2 Single Mode	Yellow	Yellow	SM/NZDS, SM
Polarization Maintaining Single Mode	Blue	Undefined	Undefined

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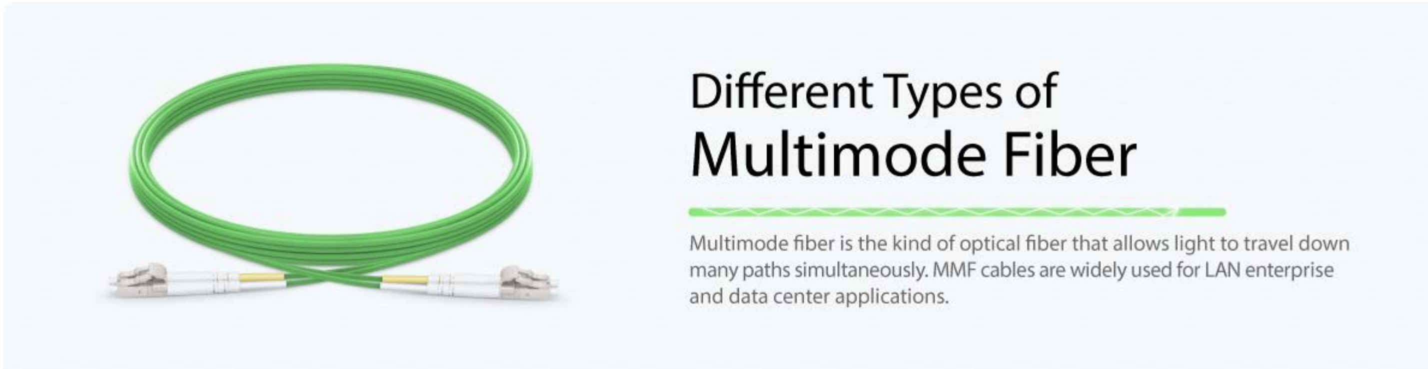

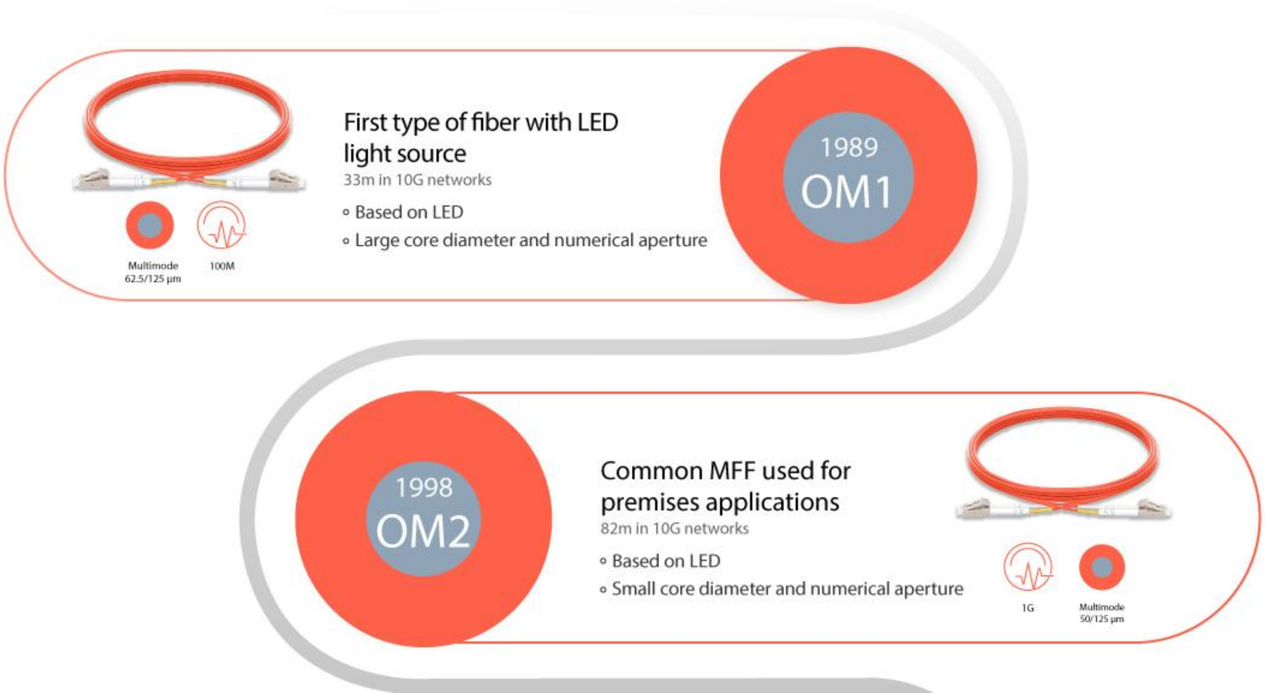

Cod culoare cablu optic

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