

Optoelectronică, structuri și tehnologii

Curs 5
2012/2013

Orar

▶ Curs

- marti, 13-16, P7
- $2C \Rightarrow 3C$
 - $(14-4)*2/3 \approx 6.66$
 - $4+6.66=11-0.33$

Fotometrie și radiometrie

Capitolul 4

Fotometrie și radiometrie –

► Examen!

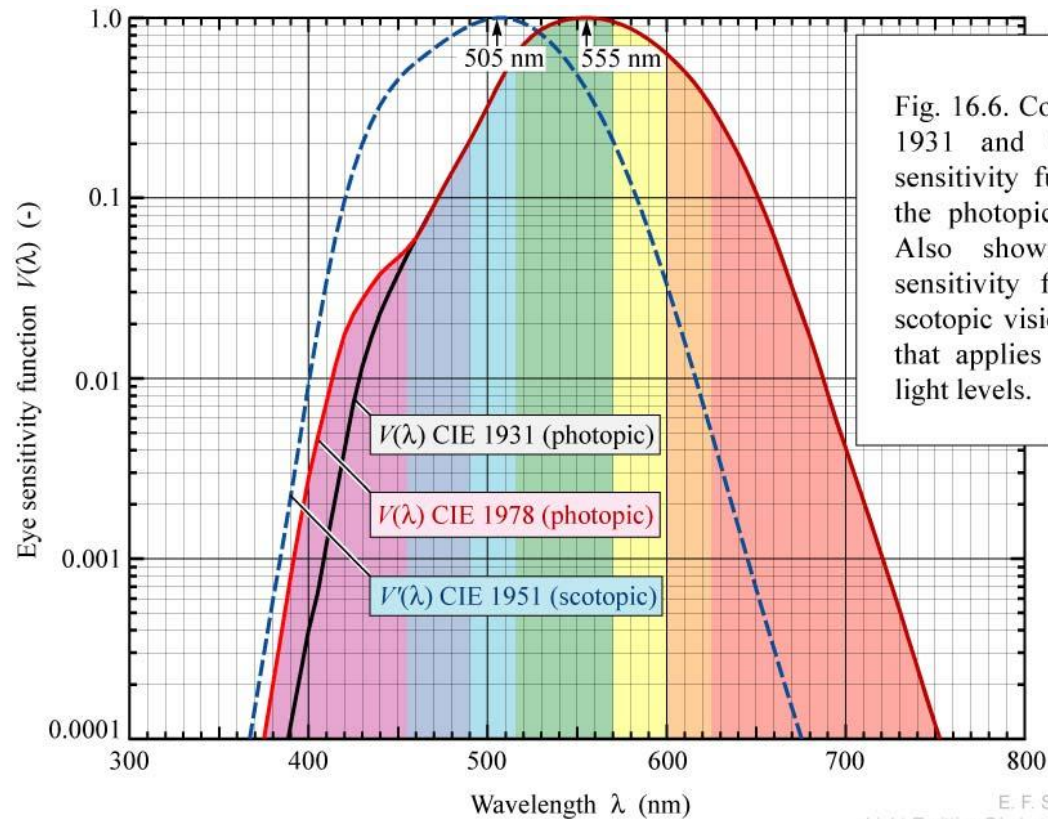


Fig. 16.6. Comparison of CIE 1931 and CIE 1978 eye sensitivity function $V(\lambda)$ for the photopic vision regime. Also shown is the eye sensitivity function for the scotopic vision regime, $V'(\lambda)$, that applies to low ambient light levels.

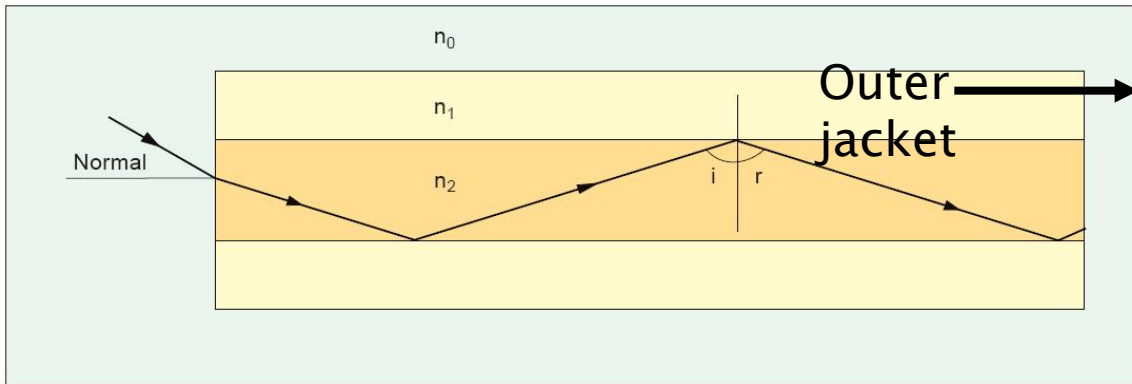
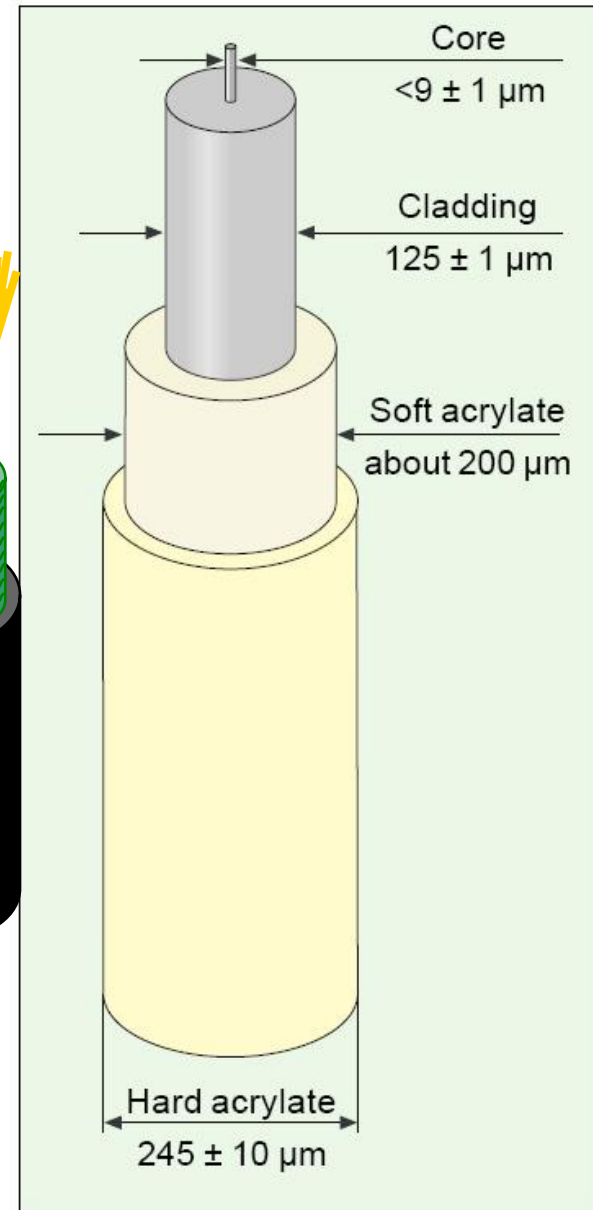
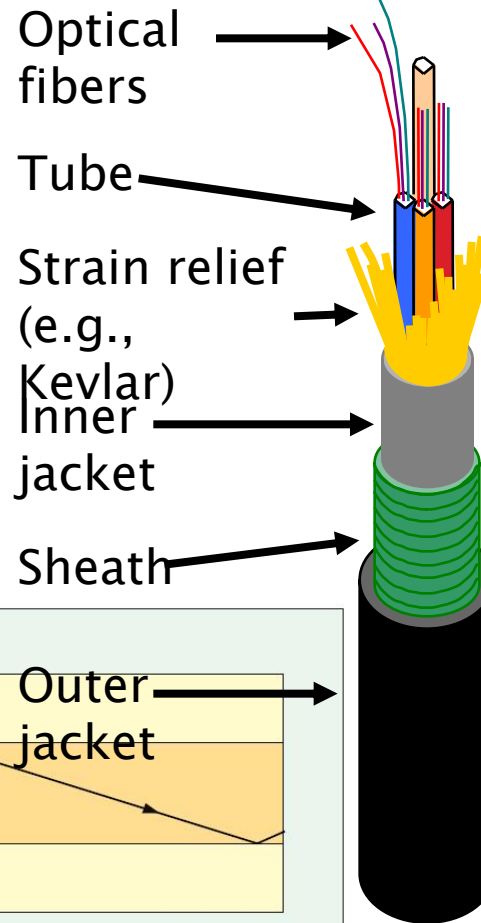
Fibra optică

Capitolul 5

Recapitulare

Fibra optica

- ▶ un ghid de unda dielectric
 - miez
 - teaca



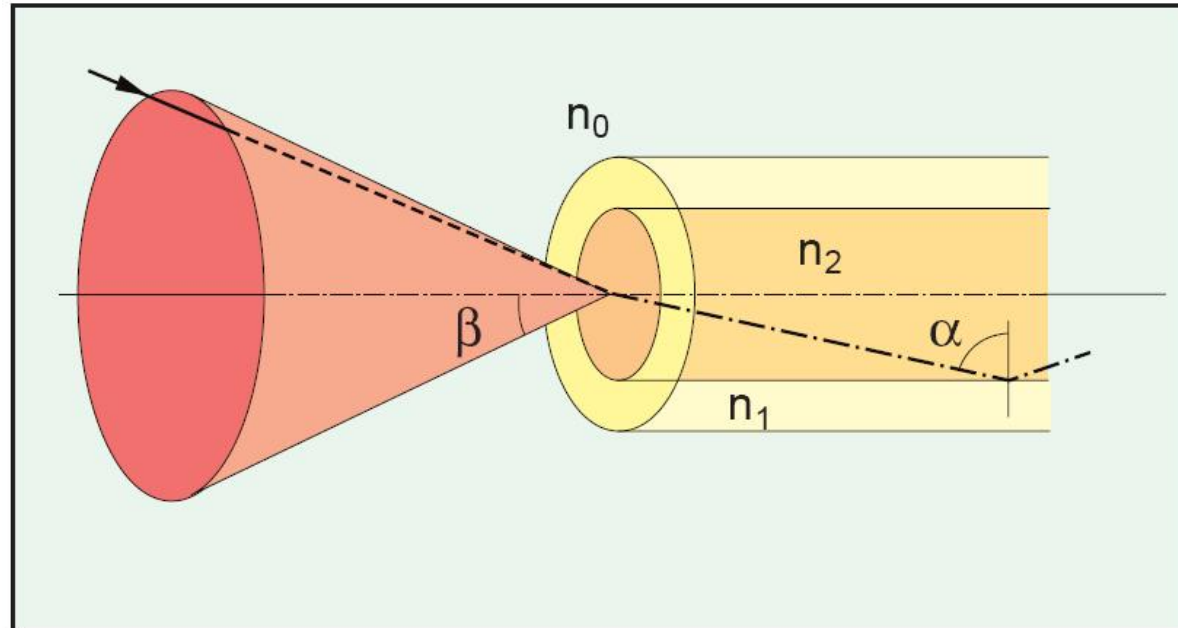
Unghi de acceptanta, apertura numerica

- ▶ Unghi de acceptanta

$$n_0 \cdot \sin \theta_{ACC} = n_1 \cdot \sin \phi_c$$

- ▶ Apertura numerica

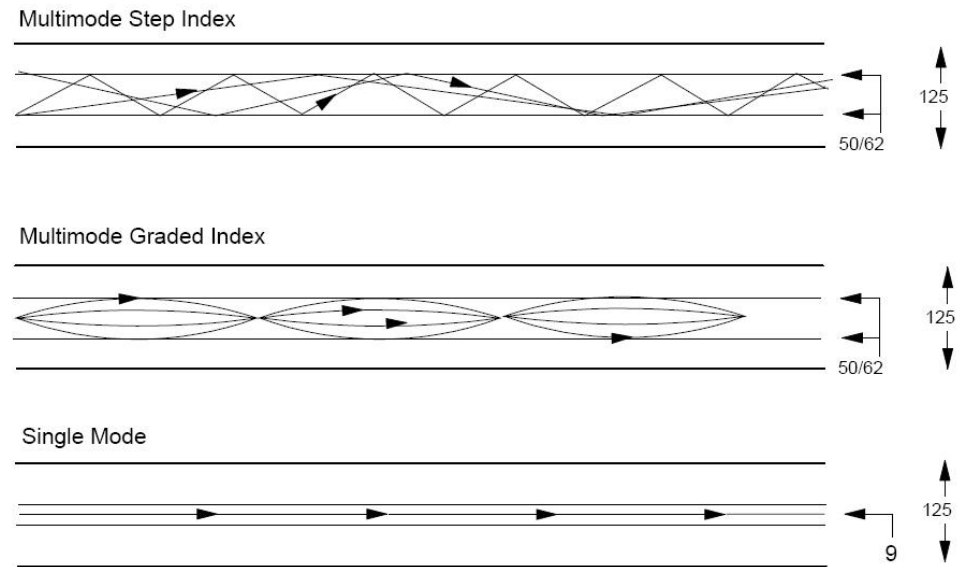
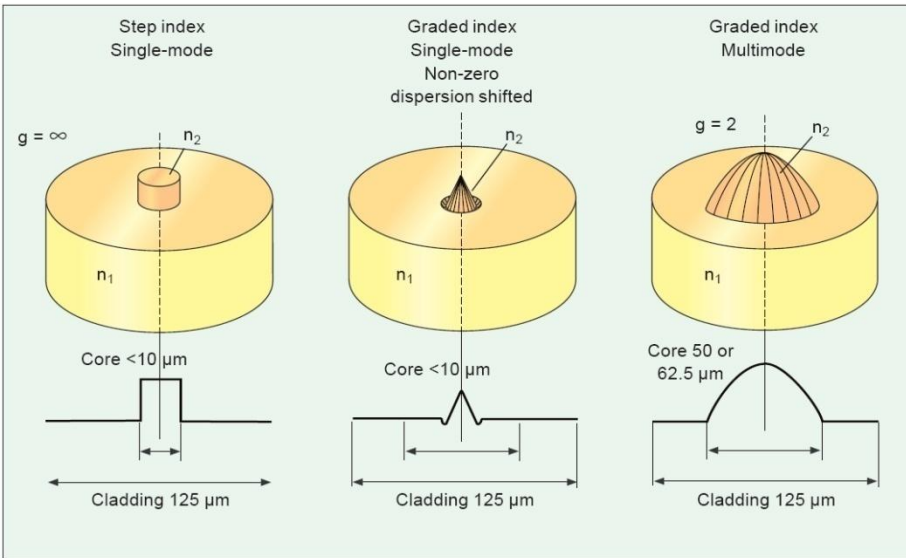
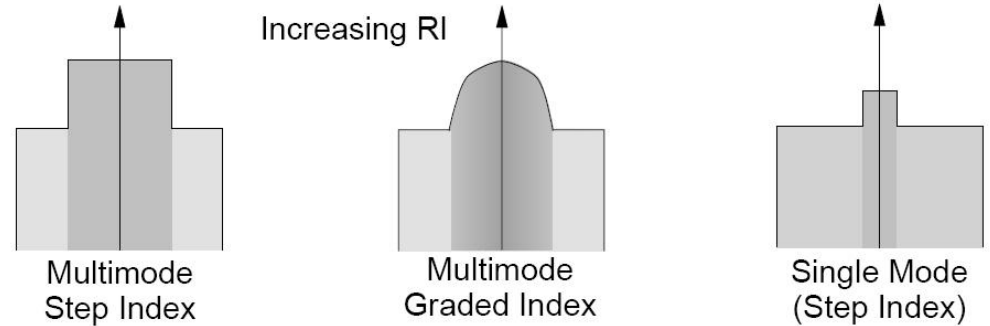
$$NA = n_0 \cdot \sin \theta_{ACC}$$



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

Tipuri de fibra

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



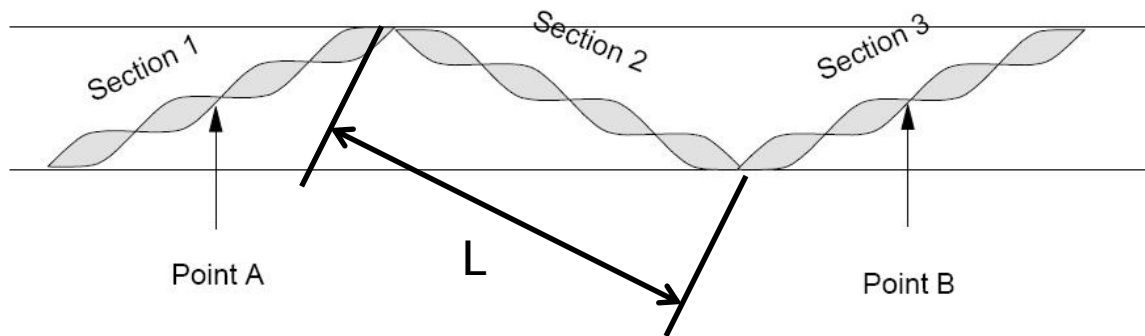
Frecventa normalizata

► Frecventa normalizata

$$V = 2\pi \frac{a}{\lambda} NA = k \cdot a \cdot NA \quad a - \text{raza miezului}$$

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

► Numar de moduri

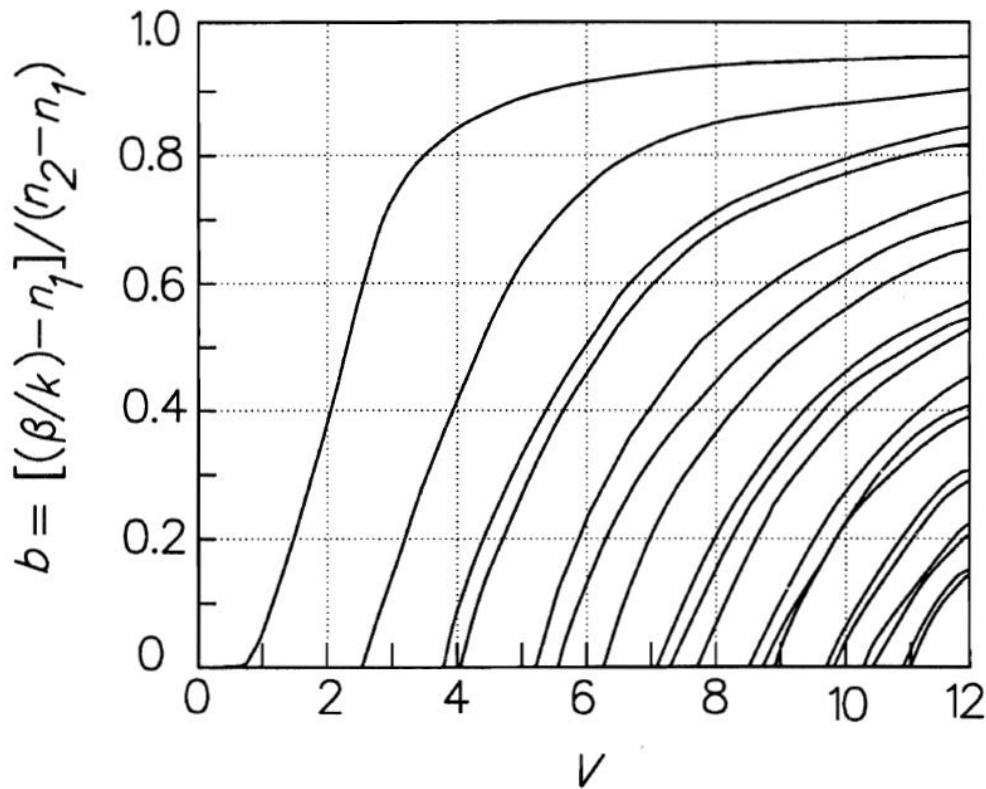


$$L = m \cdot \lambda$$

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

Frecventa normalizata – monomod

► Fibre monomod



b – coeficient de propagare modal relativ

$$V \leq V_c = 2.405$$

exista un singur mod (solutii fc. Bessel)

$$\lambda \geq \lambda_c = \pi \frac{2a}{V_c} NA = \pi \frac{2a}{2.405} NA$$

Exemplu:

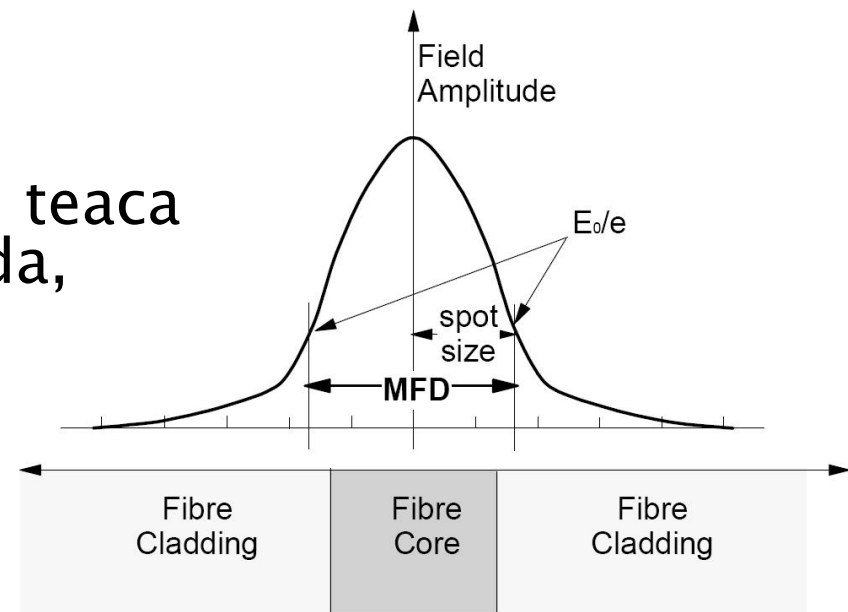
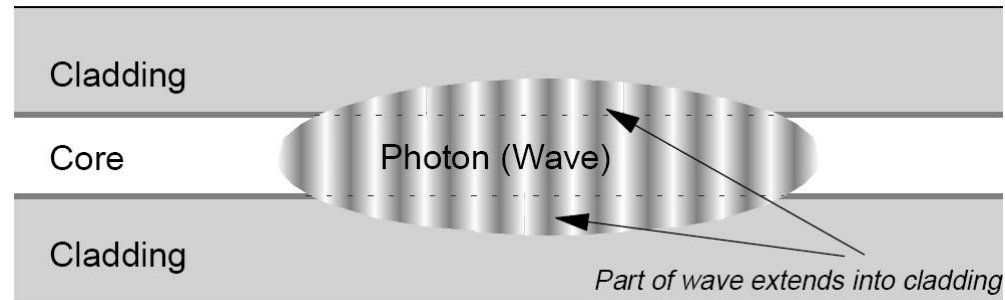
$$2a = 8.5 \mu\text{m}$$

$$NA = 0.11$$

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

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

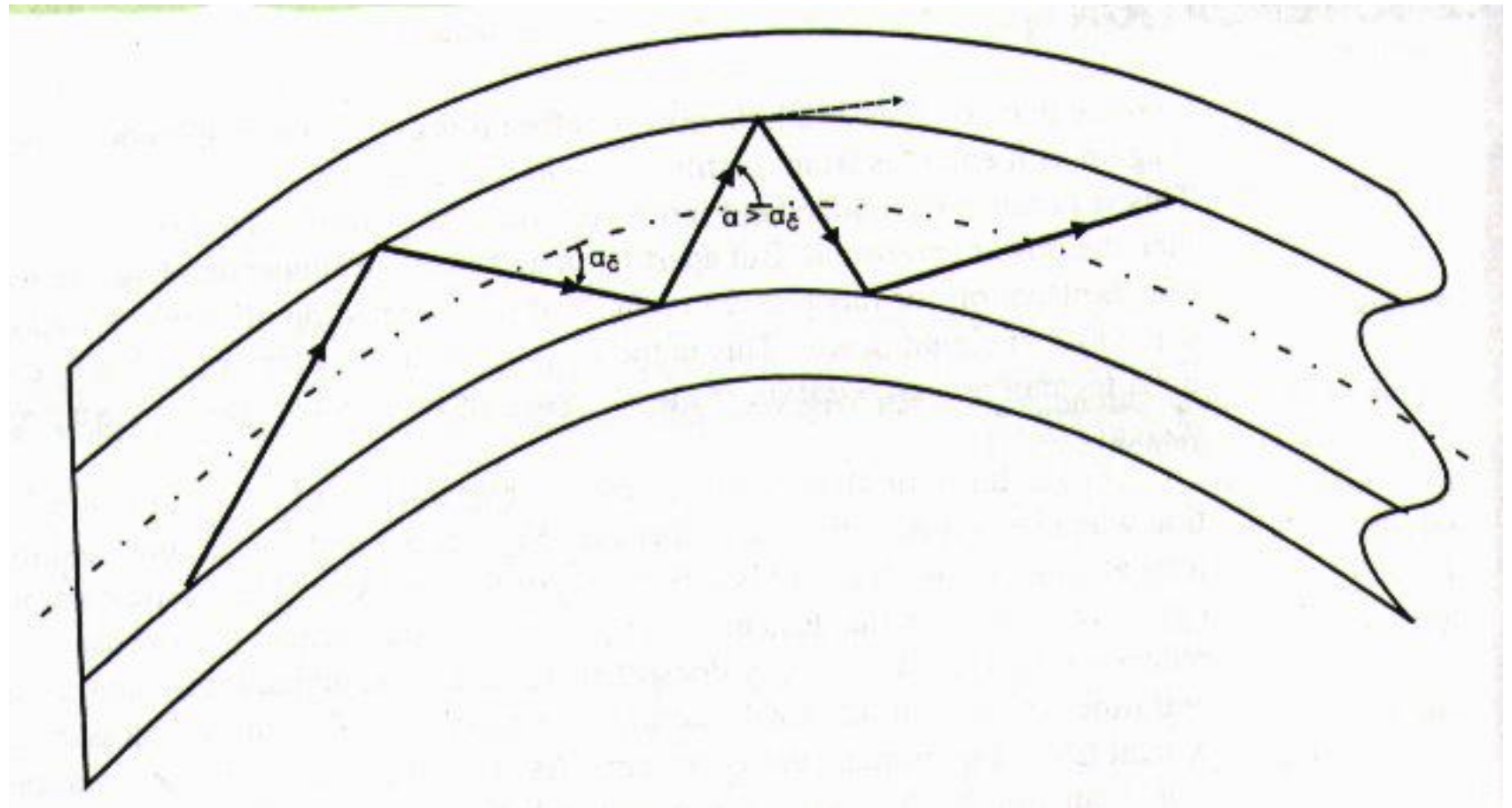


Continuare

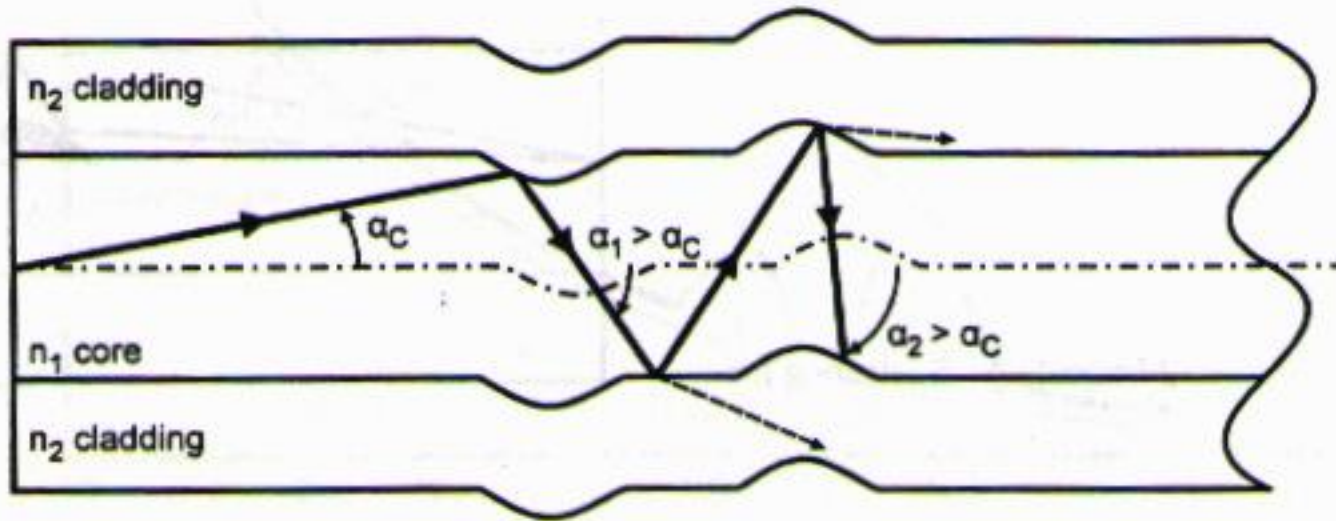
ATENUAREA

- ▶ Macrocurburi
- ▶ Microcurburi
- ▶ Imprastiere
- ▶ Absorbție

Macrocurburi

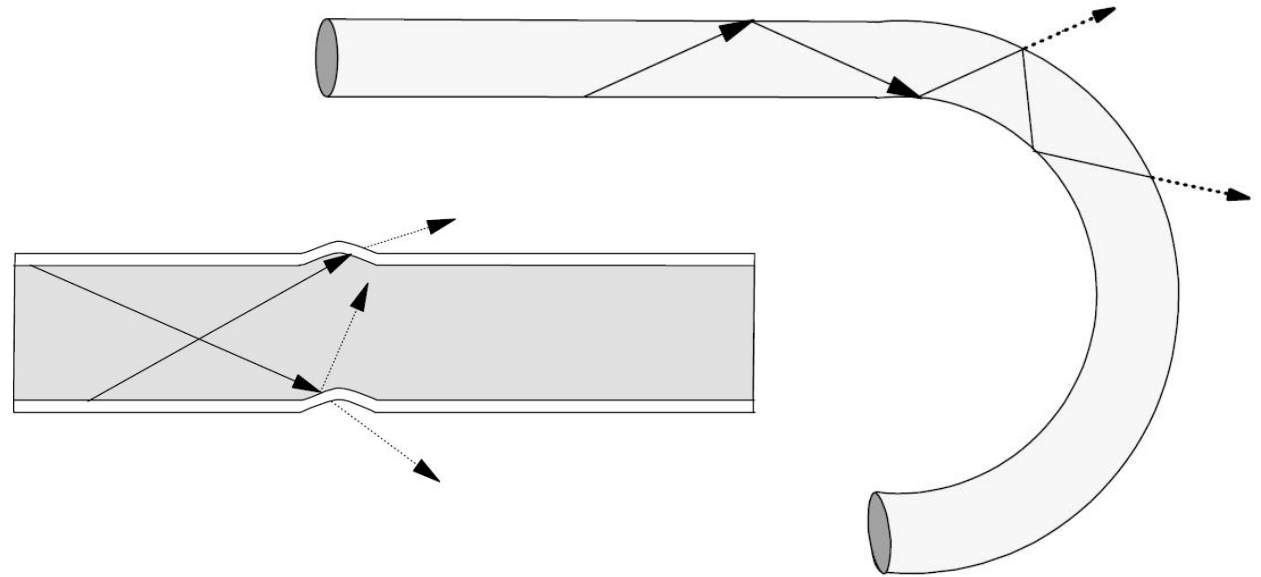


Microcurburi



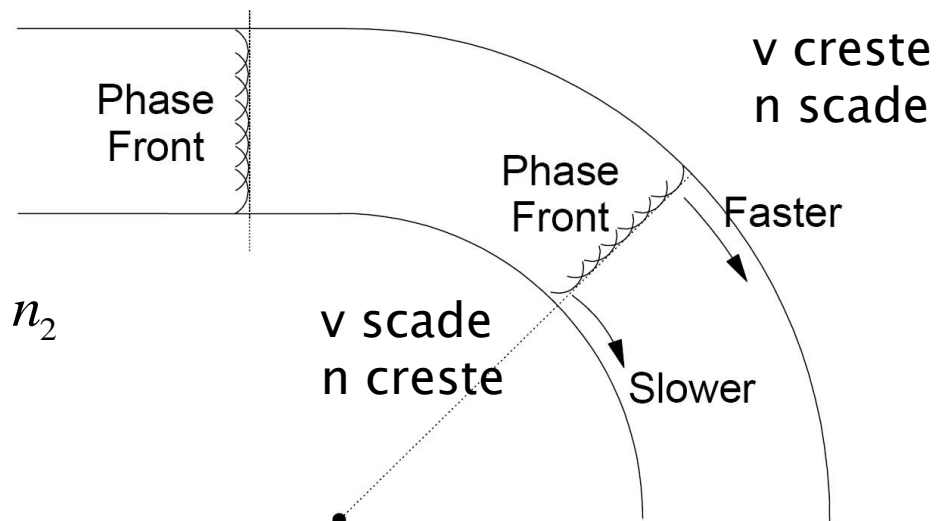
Efectul curburilor

▶ Multimod

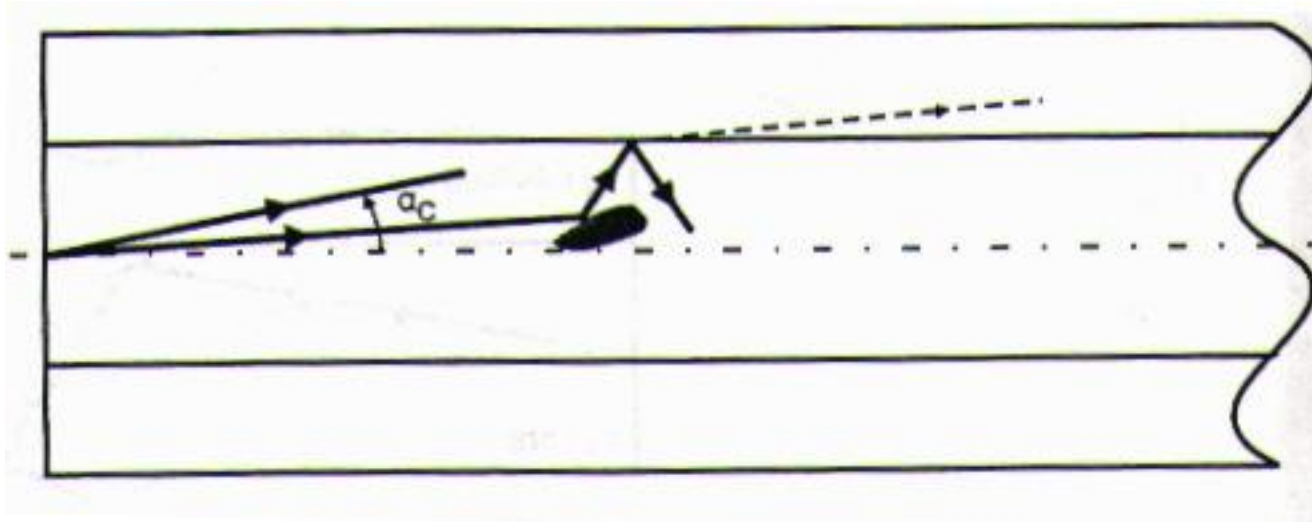


▶ Monomod

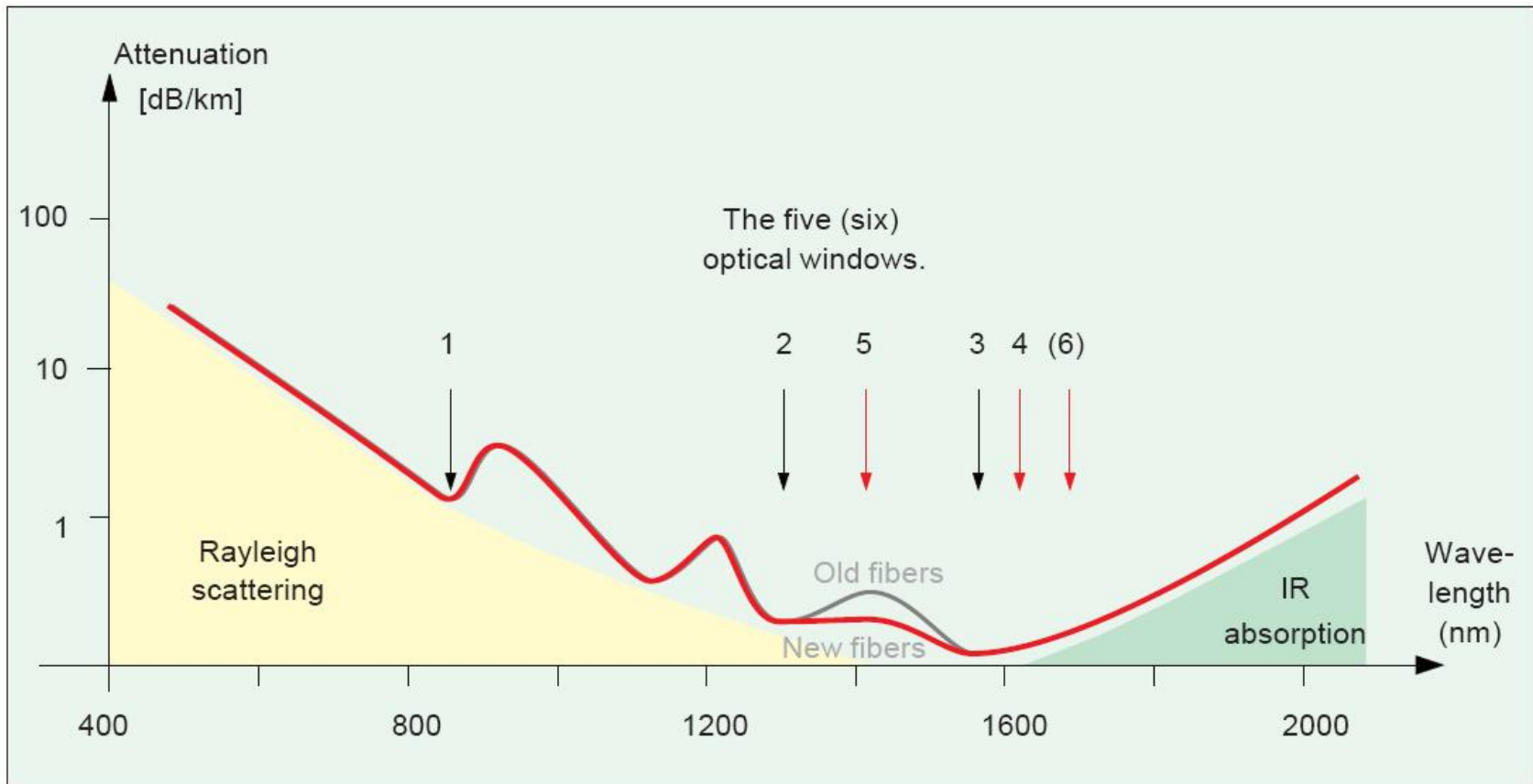
$$R > R_C \Rightarrow n_{1,ext} > n_2$$



Imprastiere

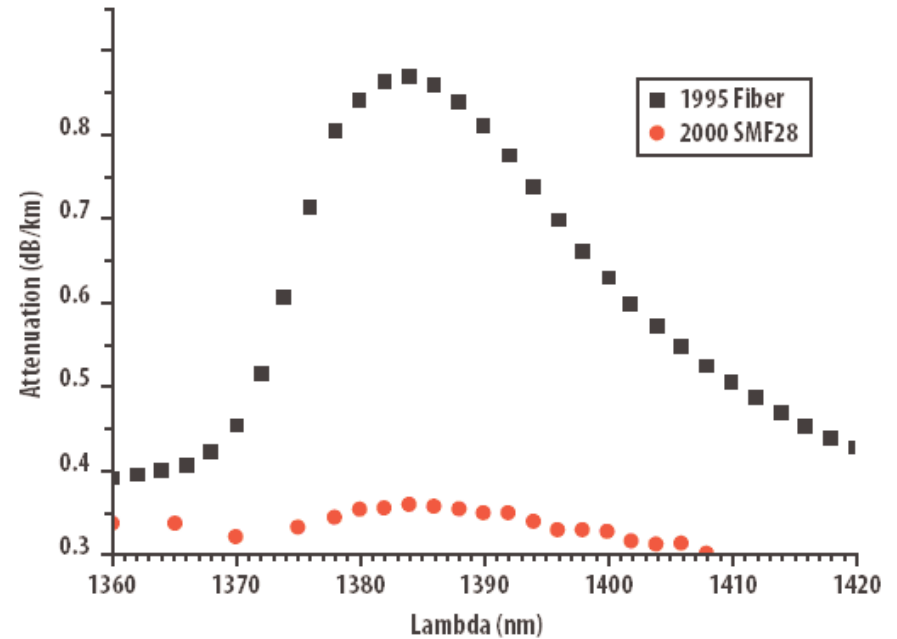
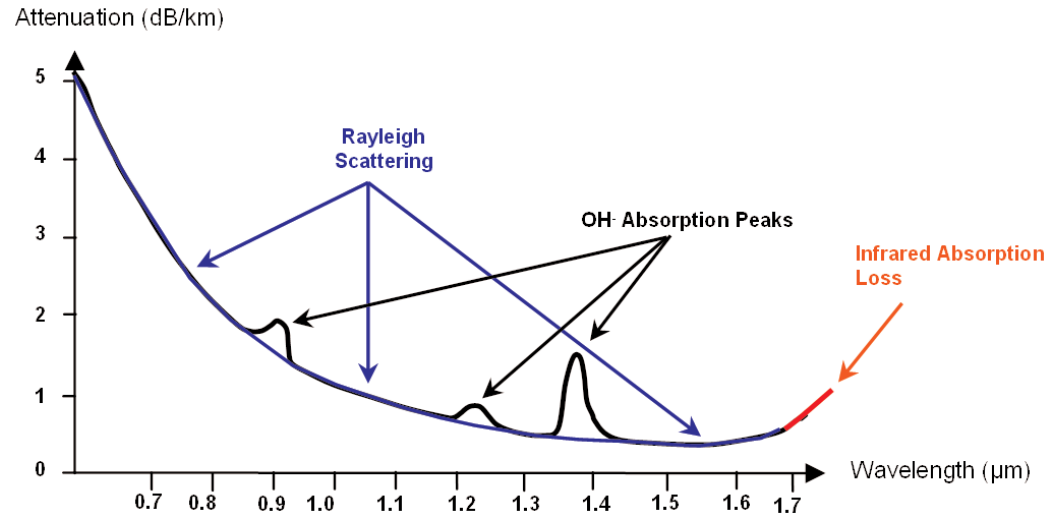


Absorbctie



Absorbentie OH

- ▶ Absorbentie
 - 950nm
 - 1244nm
 - 1383nm
- ▶ Apa!



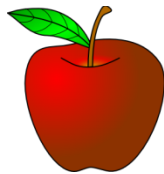
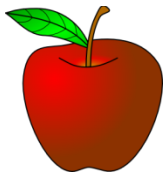
Fiber Attenuation Comparison

Calculul atenuarii

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

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

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



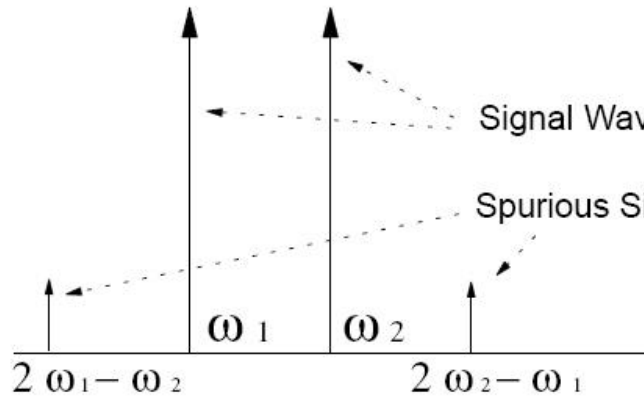
$$\text{Atenuare [dB/km]} = \frac{\text{Pierderi [dB]}}{\text{lungime [km]}}$$

Efecte neliniare in fibra

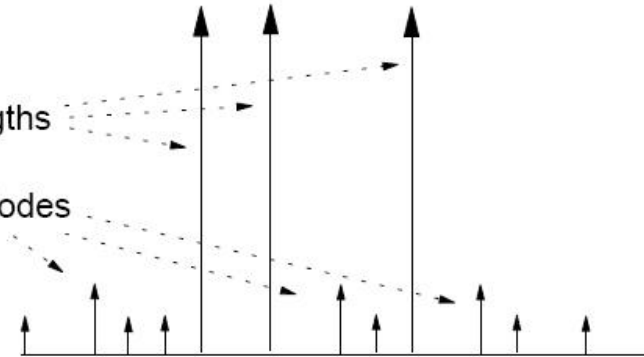
- ▶ **Stimulated Brillouin Scattering, SBC**
 - difractia luminii inspre emitator datorita undelor mecano-acustice generate in fibra
 - 6–10 dBm
- ▶ **Stimulated Raman Scattering, SRS**
 - interactiunea luminii cu vibratiile moleculare
 - 27 dBm (~1W)
- ▶ **Self Phase Modulation, SPM**
 - Frontiera impulsului implica indice de refractie variabil in timp moduland faza impulsului
 - 5 dBm
 - Cross Phase Modulation, CPM
- ▶ **Four-Wave Mixing, FWM**
 - 0 dBm

Four-Wave Mixing, FWM

Two Channels



Three Channels

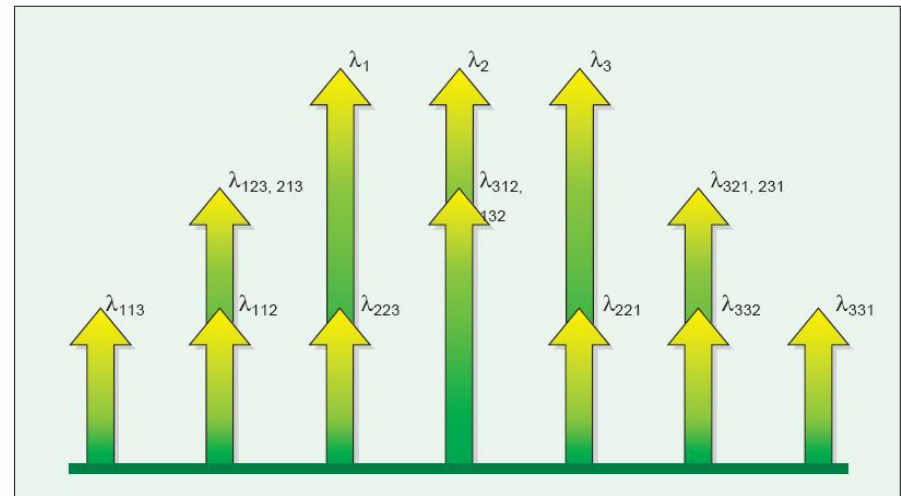


$$NL = \frac{1}{2}(N^3 - N^2)$$

$$N = 2, NL = 4$$

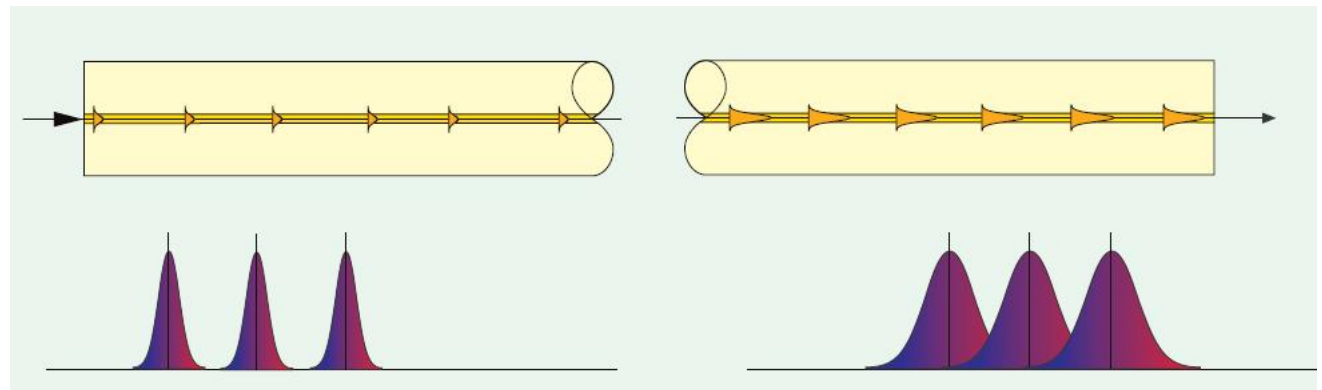
$$N = 3, NL = 9$$

$$N = 16, NL = 1920$$

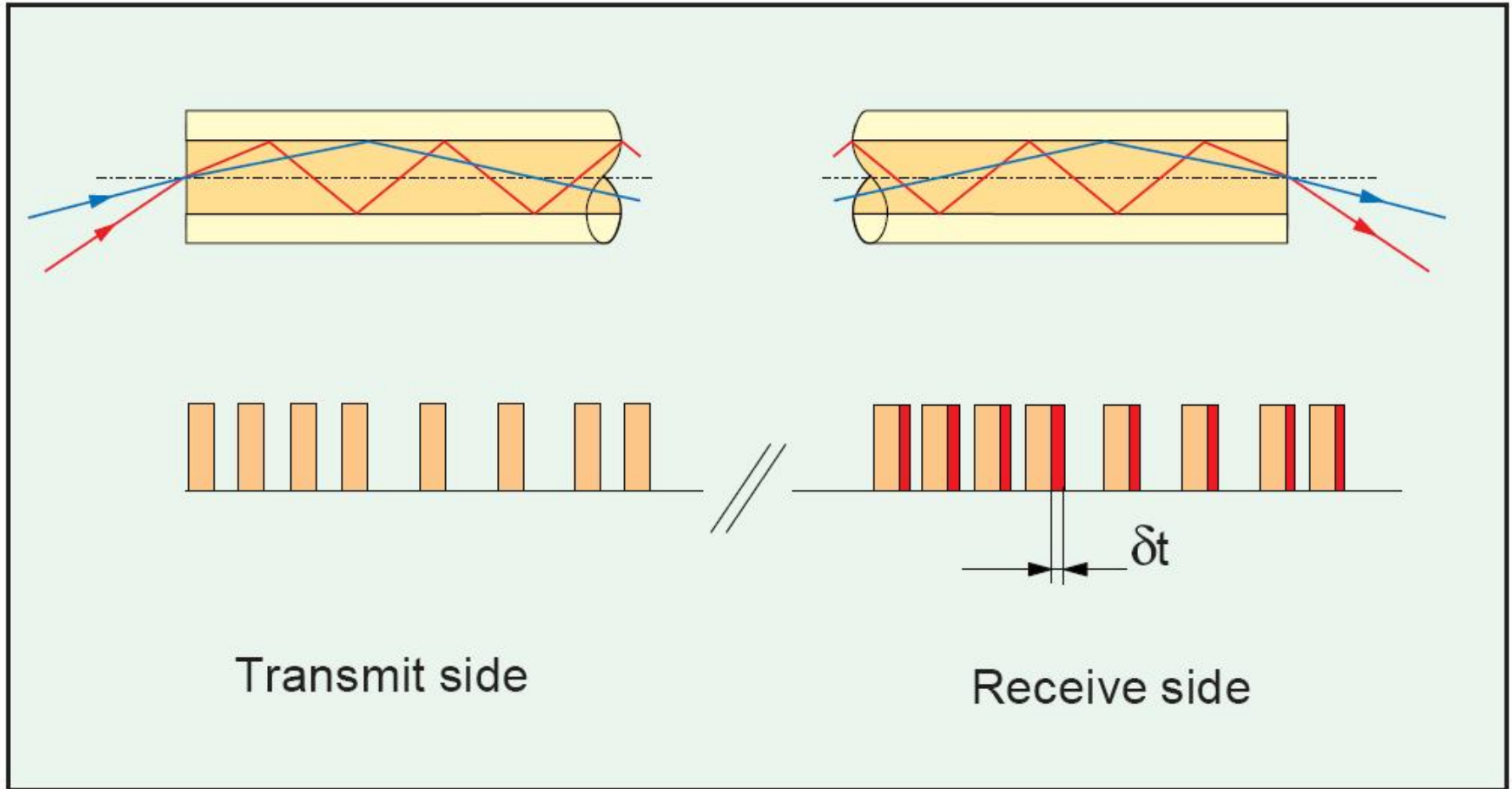


Dispersia

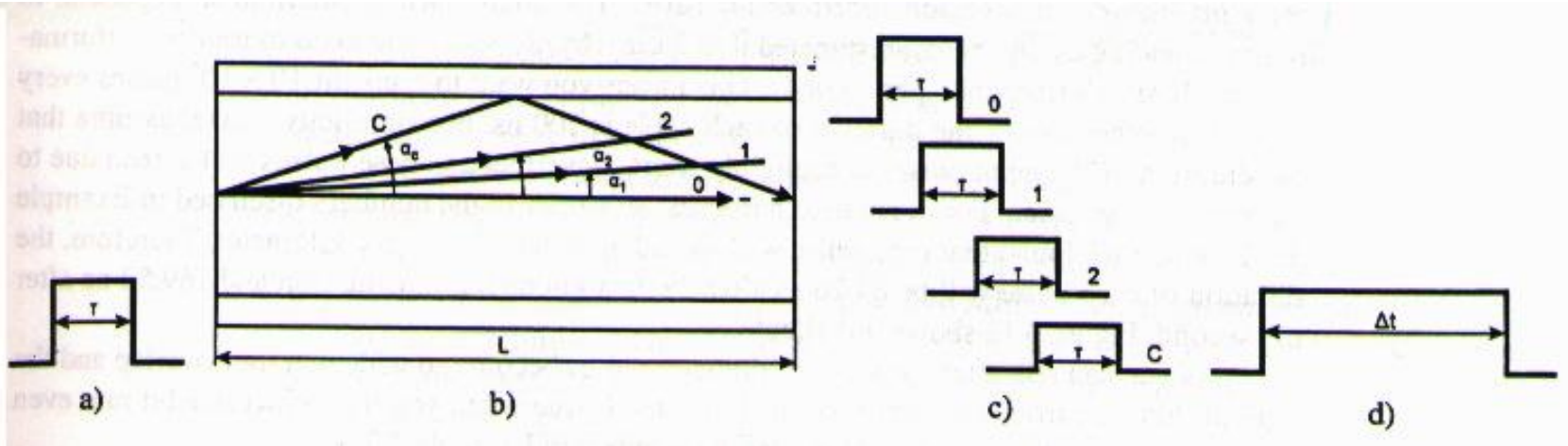
- ▶ Propagarea cu viteze diferite a radiatiilor cu lungimi de unda diferite
 - intermodala (modala – depinde de prezenta modurilor)
 - intramodala (cromatica – depinde de lungimea de unda)
 - de material
 - de ghid



Dispersia modala



Dispersia modala



$$t_0 = \frac{L}{v}$$

$$t_C = \frac{L}{v \cdot \cos \alpha_C}$$

$$v = \frac{c}{n_2}$$

$$\cos \alpha_C = NA$$

$$\Delta t_{SI} = t_C - t_0 = \frac{L \cdot n_2}{c} \cdot \left(\frac{n_2 - n_1}{n_2} \right)$$

$$\Delta t_{SI} = t_C - t_0 = \frac{L \cdot n_2}{c} \cdot \Delta$$

$$\Delta = \frac{n_2 - n_1}{n_1} \lll 1$$

$$\Delta t_{SI} = t_C - t_0 \approx \frac{L}{2 \cdot c \cdot n_2} \cdot (NA)^2$$

Dispersia modala

▶ salt de indice

$$dt = \frac{L \cdot n_2^2}{c \cdot n_1} \left(\frac{n_2 - n_1}{n_2} \right) \approx \frac{L \cdot NA^2}{2 \cdot c \cdot n_2} \quad \text{intarzierea intre moduri cand} \quad \Delta = \frac{n_2 - n_1}{n_1} \ll 1$$

$$\Delta \tau_{\text{mod}}^2 = \frac{1}{3} \left(\frac{dt}{2} \right)^2$$

$$\Delta \tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta}{2\sqrt{3} \cdot c} \approx \frac{L \cdot NA^2}{4\sqrt{3} \cdot c \cdot n_2}$$

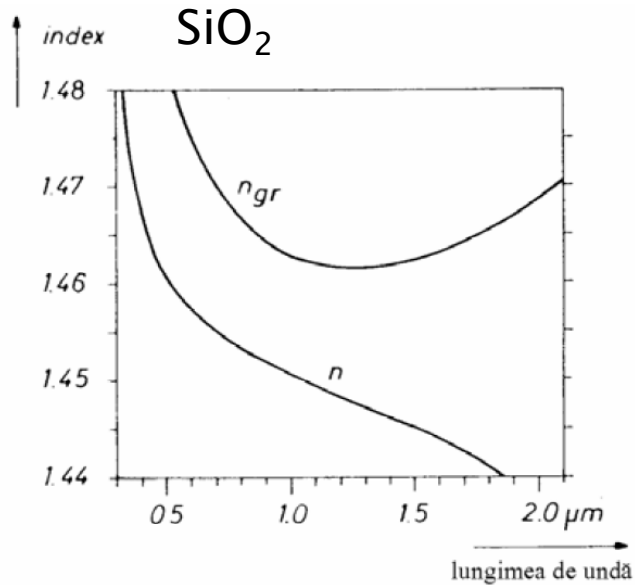
▶ indice gradat

$$dt = \frac{L \cdot n_2 \cdot \Delta^2}{2c} \approx \frac{L \cdot NA^4}{8 \cdot c \cdot n_2^3}$$

$$\Delta \tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta^2}{4\sqrt{3} \cdot c}$$

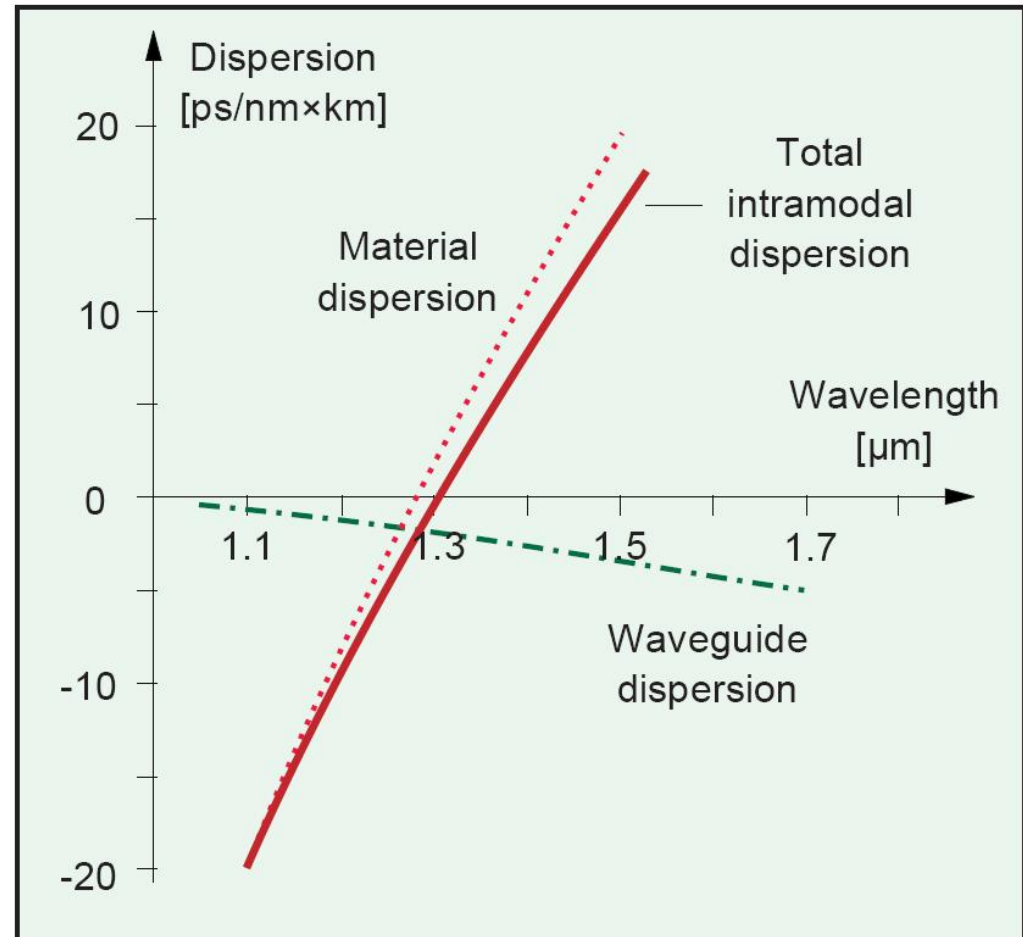
$$NA = 0.1 \div 0.2 < 1$$

Dispersia de material



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

$$\Delta\tau_{mat} = \frac{L \cdot \lambda \cdot \Delta\lambda}{c} \cdot \frac{d^2n}{d\lambda^2}$$

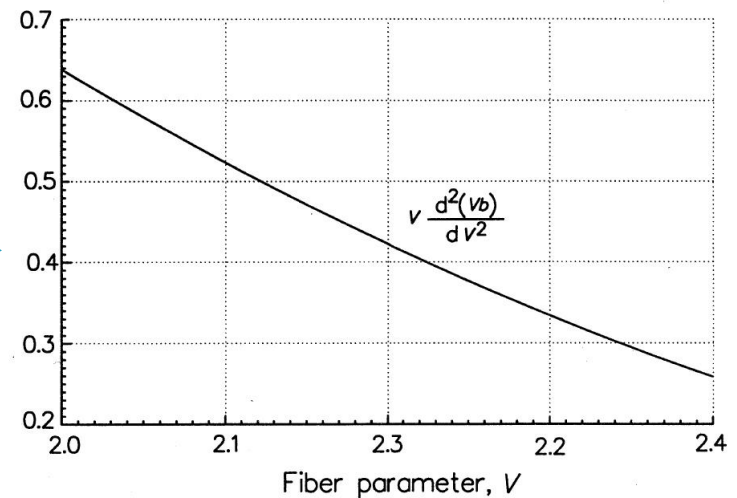
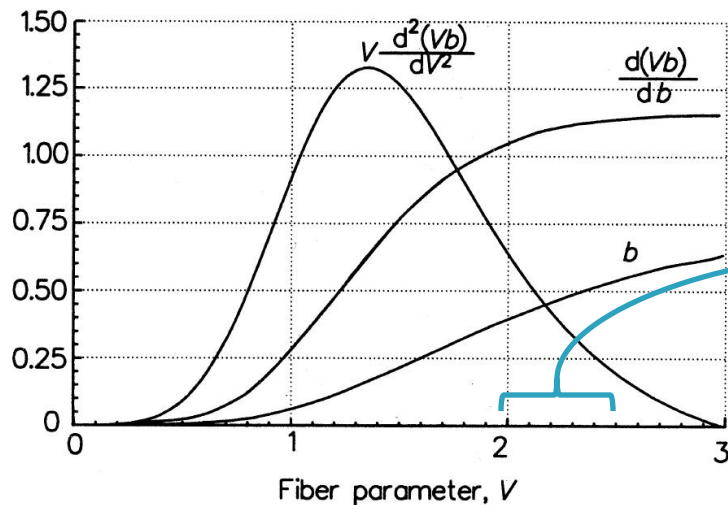


Dispersia de ghid

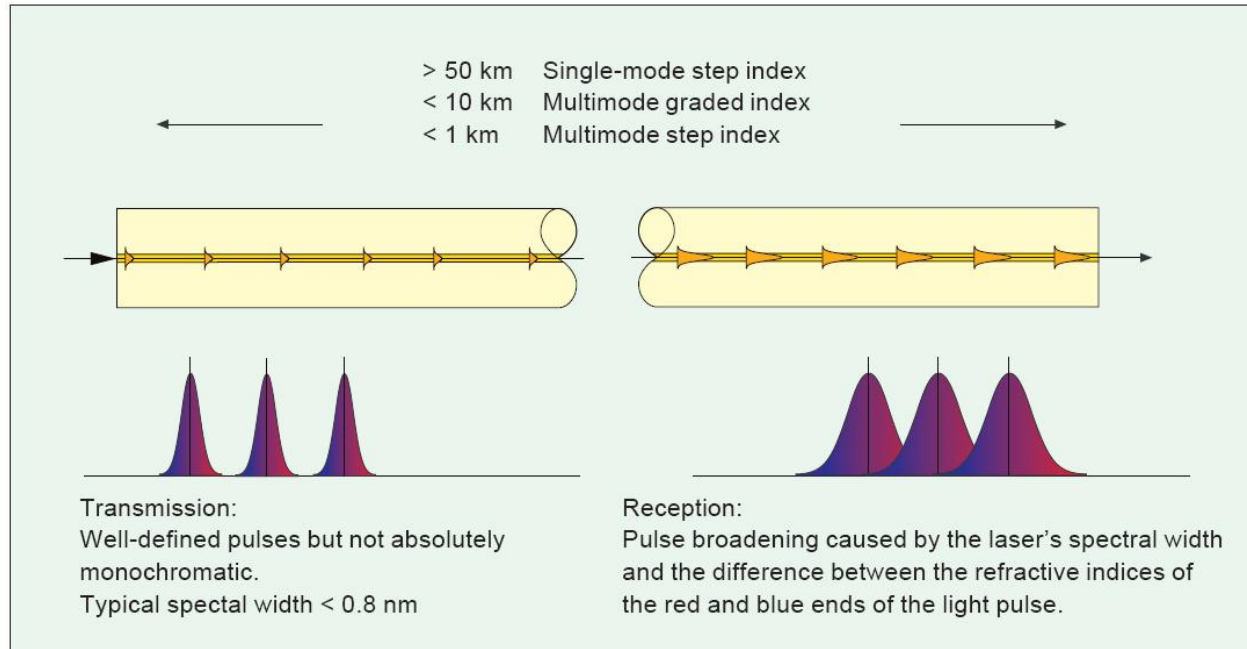
- ▶ Neglijabila in fibrele multimod fata de dispersia modala

$$\Delta\tau_{mat} = \frac{n \cdot L \cdot \Delta}{c} \cdot \frac{\Delta\lambda}{\lambda} \cdot \left(V \frac{d^2(Vb)}{dV^2} \right)$$

b – constanta de propagare normalizata



Dispersia cromatica



$$\Delta\tau_{cr} = D(\lambda) \cdot \Delta\lambda \cdot L$$

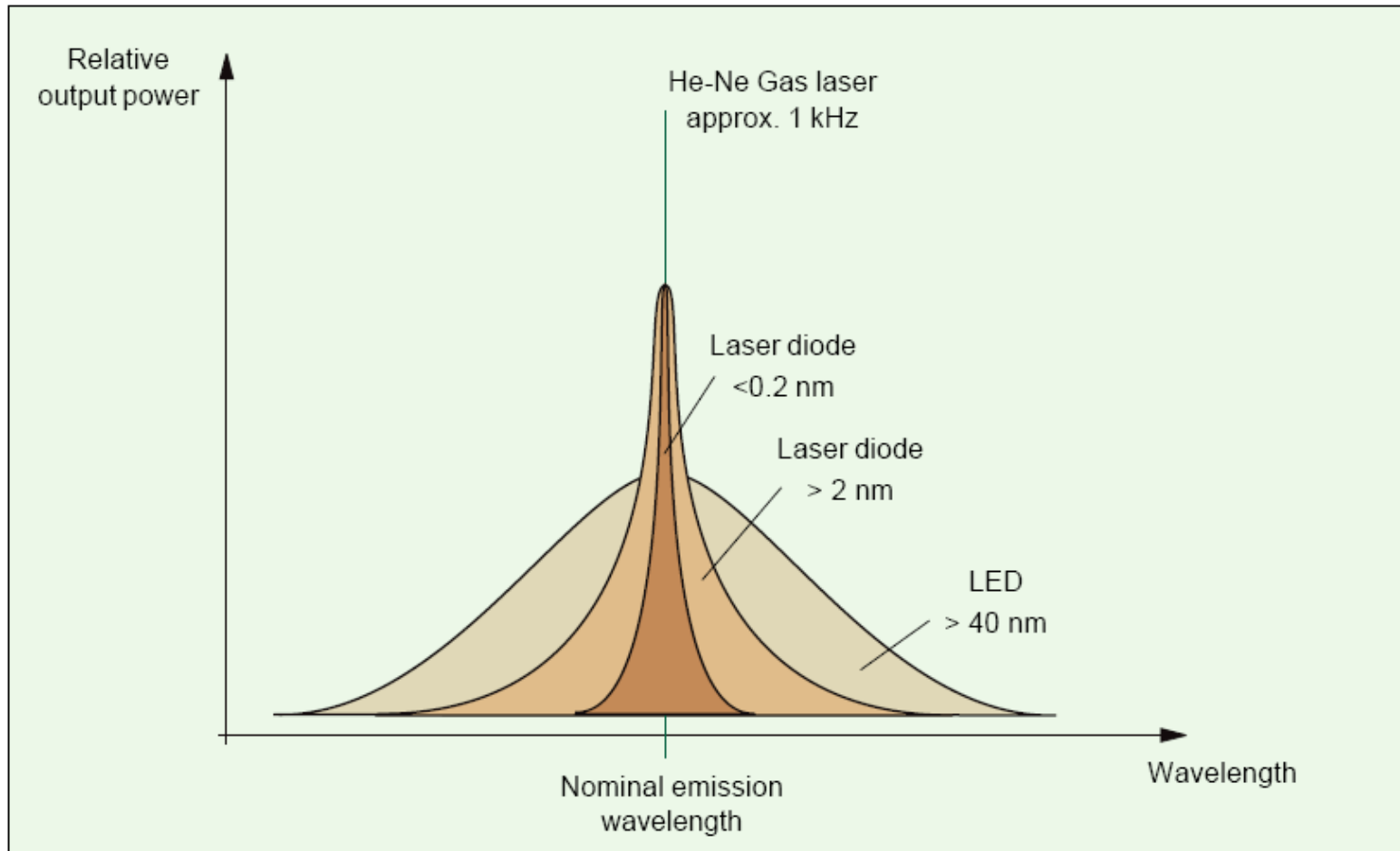
$$D(\lambda) = \frac{S_0}{4} \cdot \left(\lambda - \frac{\lambda_0^4}{\lambda^3} \right)$$

S_0 panta dispersiei -
ps/nm²/km

- ▶ $D(\lambda) \approx 100 + 0.4 (850 - \lambda)$ [ps/nm/km]
pentru $800 < \lambda < 900$ nm
- ▶ $D(\lambda) \leq 3,5$ ps/nm/km
pentru $1285 < \lambda < 1330$ nm
- ▶ $D(\lambda) \leq 17$ ps/nm/km
pentru $1525 < \lambda < 1575$ nm

$$D(\lambda) = \frac{S_0}{4} \cdot \left(\lambda - \frac{\lambda_0^4}{\lambda^3} \right)$$

Calitatea spectrală a emițătorilor optici



Banda

- ▶ Dispersia totala

$$\Delta\tau_{tot} = \sqrt{\Delta\tau_{cr}^2 + \Delta\tau_{mod}^2}$$

- ▶ Banda

$$B_{opt} = \frac{0.44}{\Delta\tau_{tot} [ns]} [GHz]$$

$$B_{opt} = \sqrt{2} B_{el}$$

- ▶ Banda optica la 3 dB corespunde unei benzi electrice la 6 dB

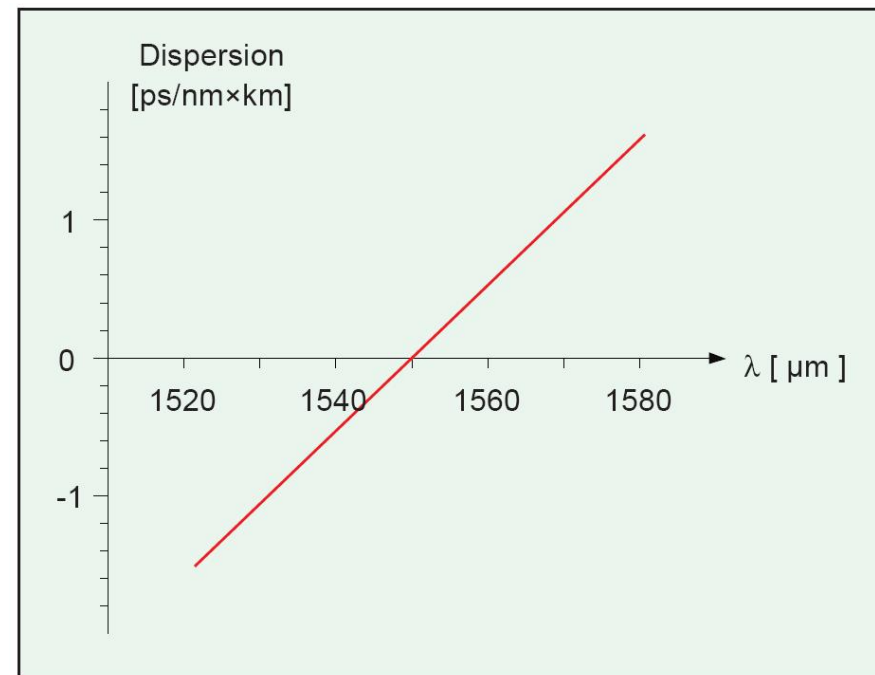
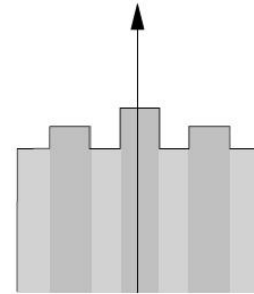
- $P_{opt} \sim I$; $P_{el} \sim I^2$

- ▶ Viteza legaturii

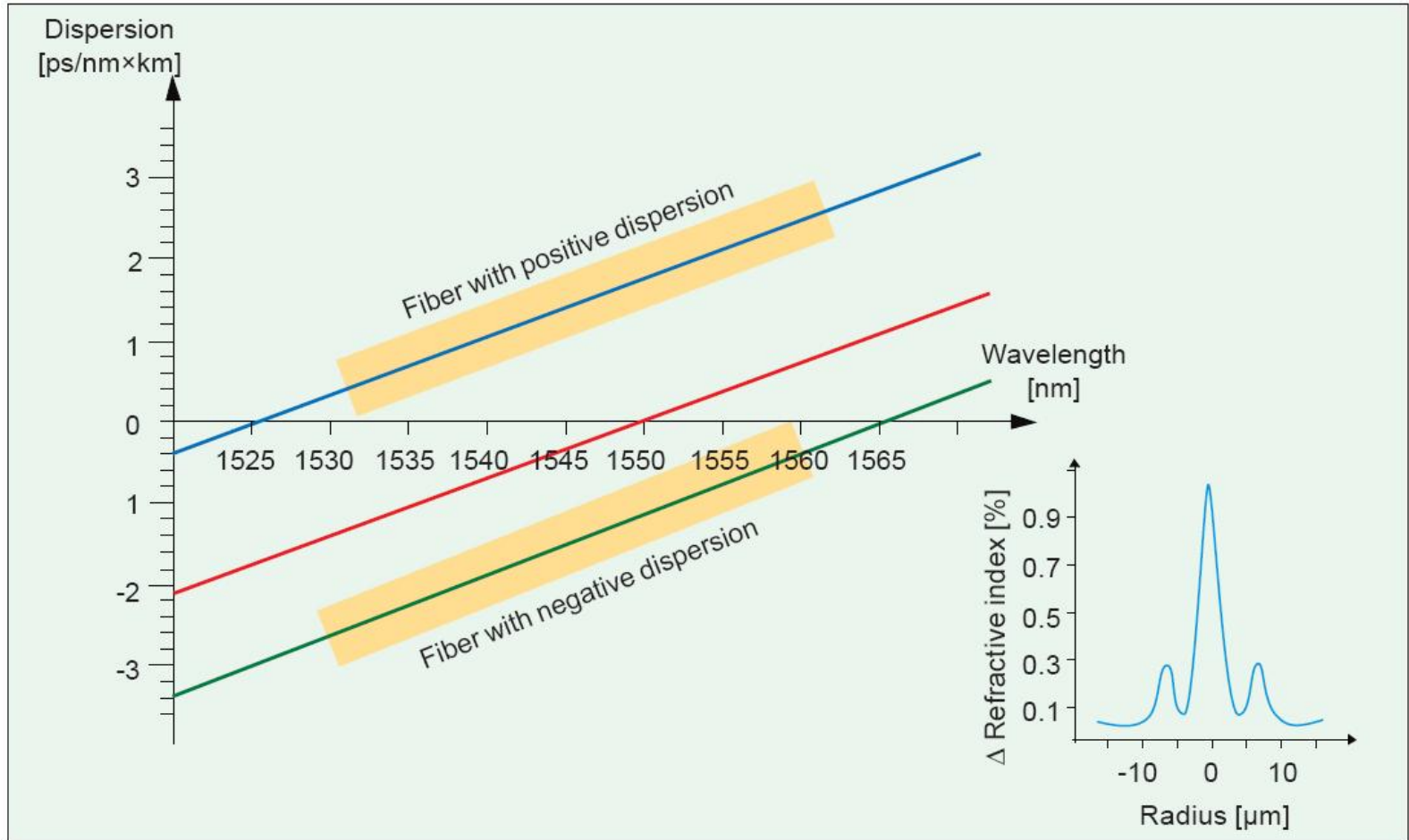
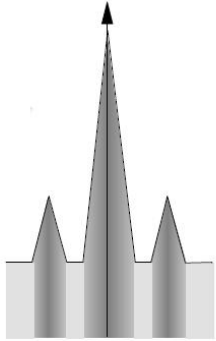
$$V [Gb/s] \cong 2 \cdot B_{el} [GHz]$$

Dispersion shifted fibers

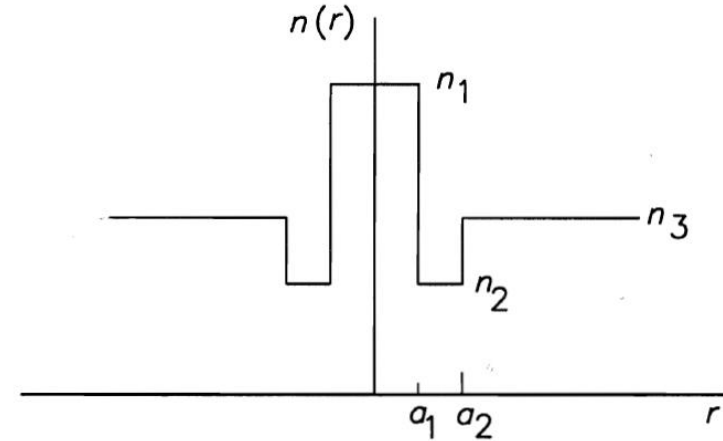
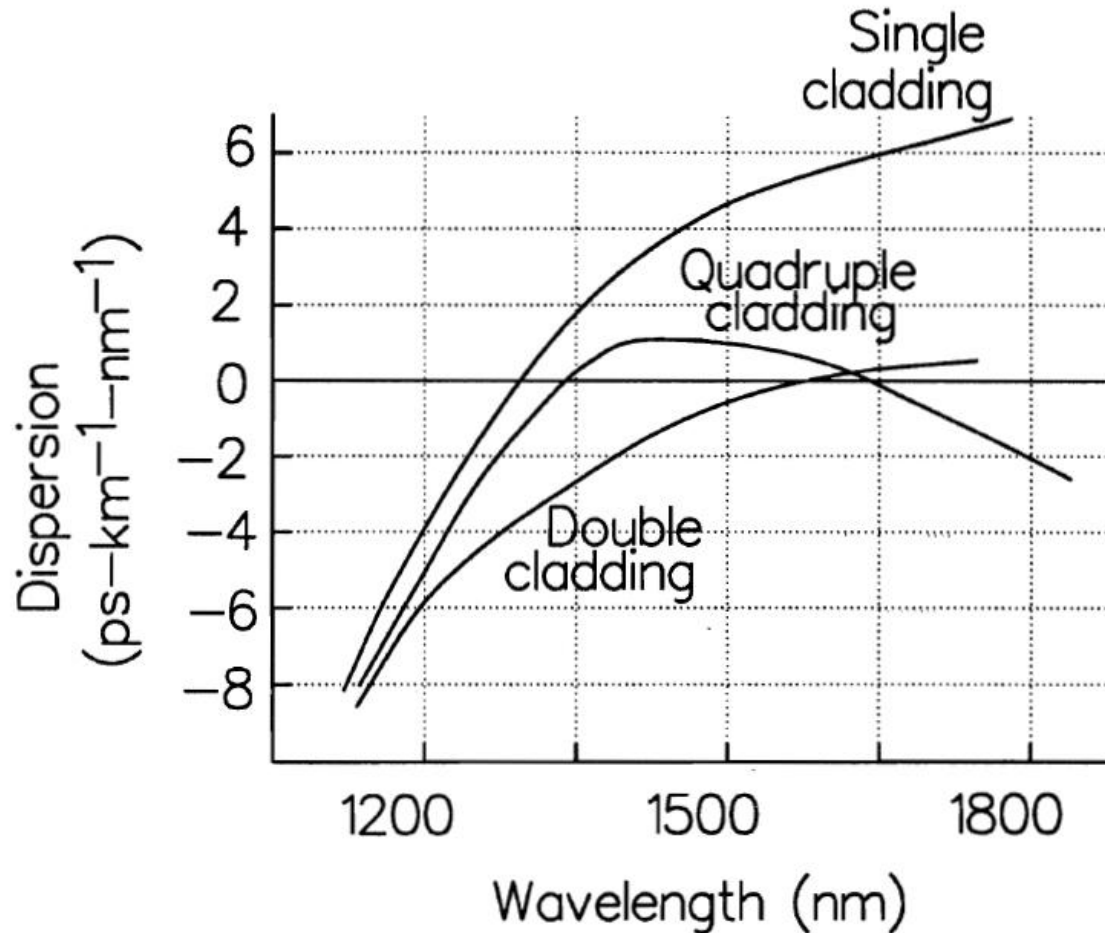
- ▶ Atenuarea e mai mica la 1550 nm
- ▶ EDFA (Erbium doped fibre amplifiers) opereaza in banda aceasta
- ▶ Sistemele WDM (Wavelength division Multiplexing) necesita banda larga amplificata



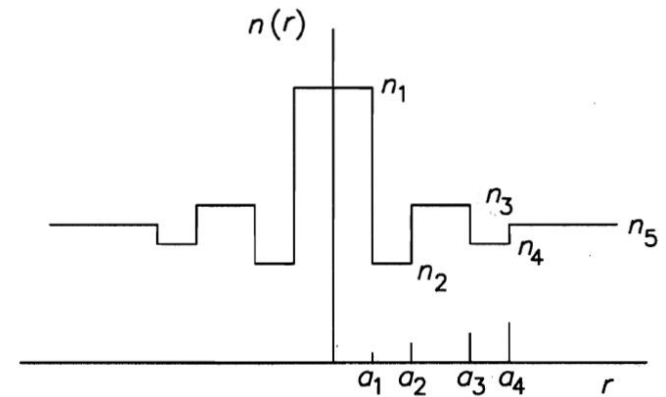
Non-zero Dispersion shifted fibers



Dispersion shifted fibers

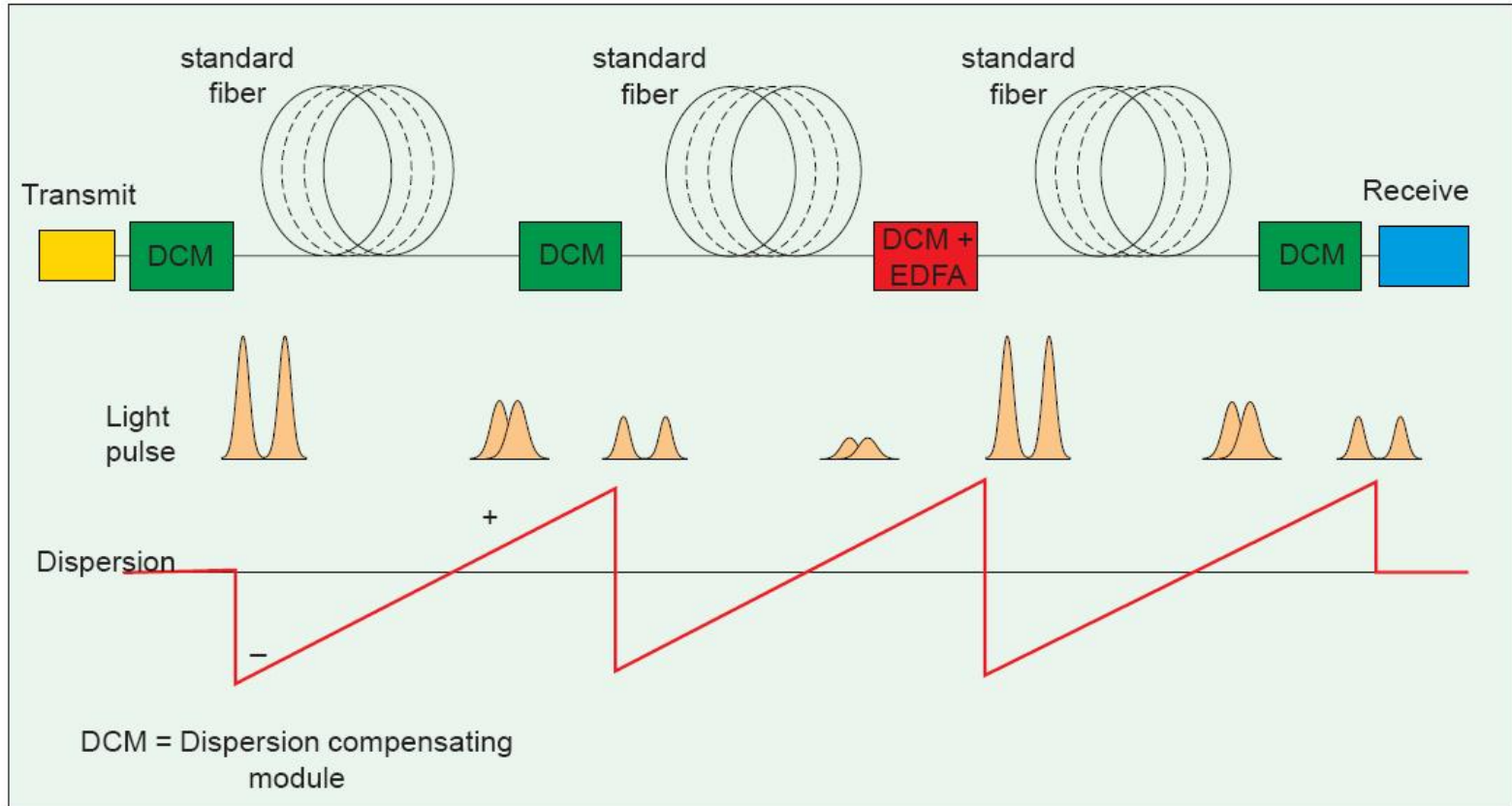


(a)



(b)

Fibra pentru compensarea dispersiei



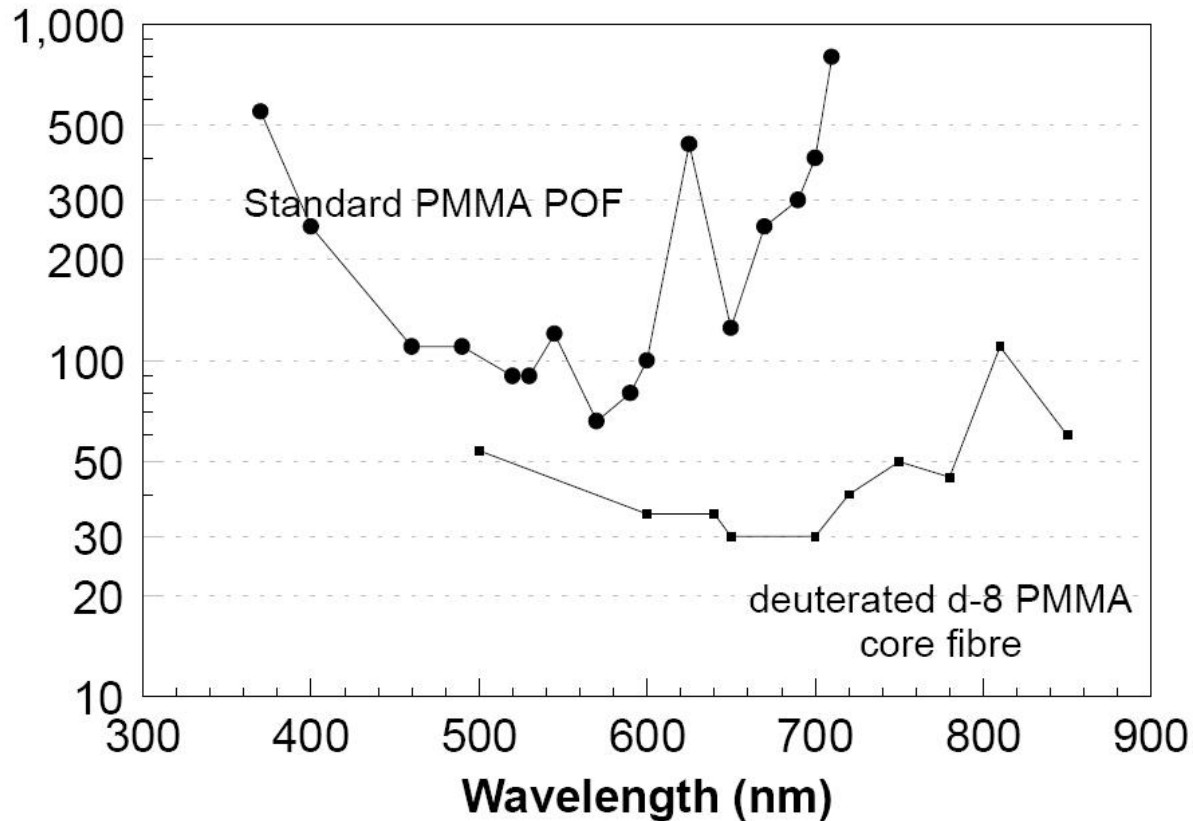
- ▶ Dispersie -100 ps/nm/km
- ▶ Atenuare 0.5 dB/km

Fibra standard ITU G.652

- ▶ Diametru teaca = 125 μm
- ▶ MFD = 9÷10 μm la 1300 nm
- ▶ $\lambda_c = 1100\div 1280$ nm
- ▶ Pierderi de curbura (la 1550 nm) mai mici de 1 dB pentru 100 spire de fibra rulata pe un mosor cu 7.5 cm diametru
- ▶ Dispersia in banda 1300 nm (1285–1330 nm) mai mica de 3.5 ps/nm/km. La 1550 nm dispersia trebuie sa fie mai mica de 20 ps/nm/km
- ▶ Viteza de variatie a dispersiei (panta dispersiei S_0) mai mica de 0.095 ps/nm²/km

Fibra optica din plastic (POF)

Attenuation dB/Km



- ▶ Atenuare 180 dB/km
- ▶ $NA = 0.3$
- ▶ Diametru 1 mm
- ▶ Banda 125MHz (100m)

Contact

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- ▶ rdamian@etti.tuiasi.ro