Optoelectronică, structuri şi tehnologii

Curs 4

Fibra optică

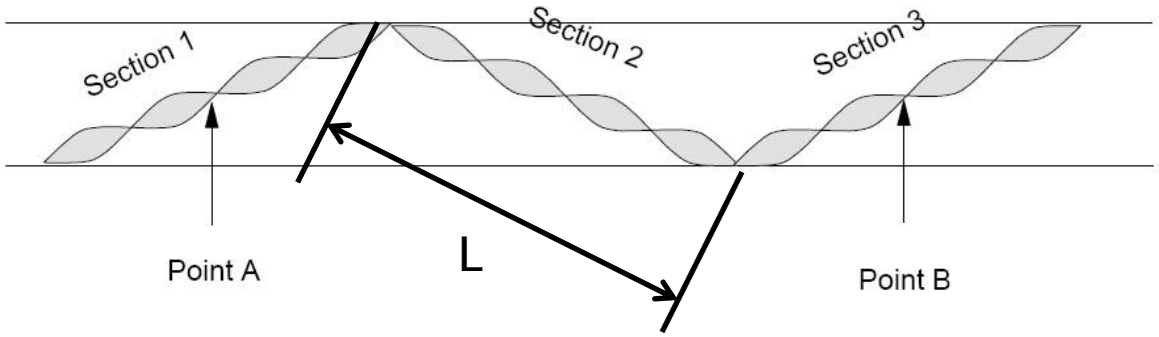
Capitolul 4

Frecventa normalizata

- Frecventa normalizata

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

- Numar de moduri



$$L = k \cdot \lambda$$

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

Frecventa normalizata

- Numar de moduri
  - Multimod cu salt de indice

$$g = 1 \quad \Rightarrow \quad N \approx \frac{V^2}{2}$$

  - 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)

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

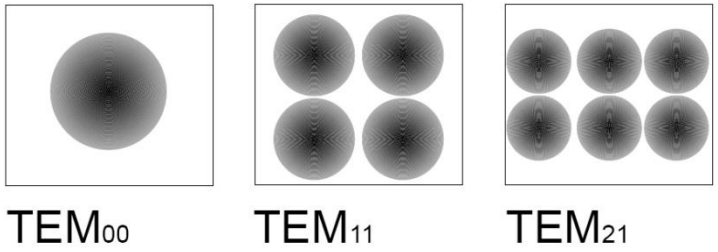
$2a = 8.5\mu m$

$NA = 0.11$

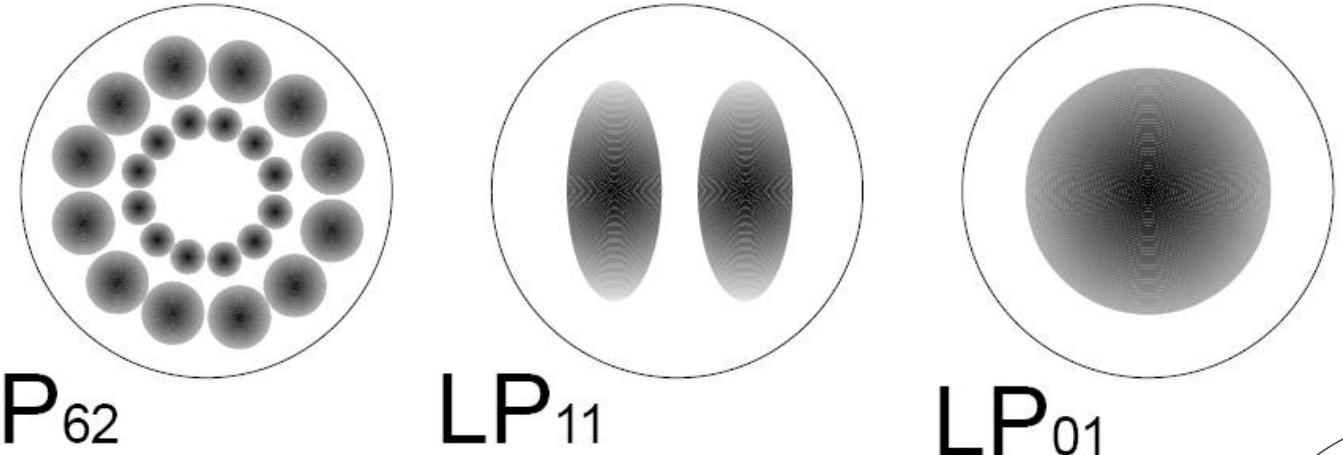
$$\lambda_C = \pi \frac{8.5}{2.405} 0.11 = 1210 nm$$

Moduri in fibra

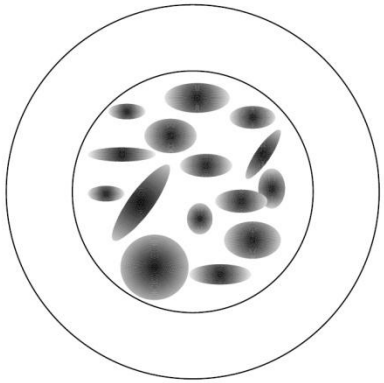
- Moduri in ghid rectangular



- Moduri linear polarizate in fibra



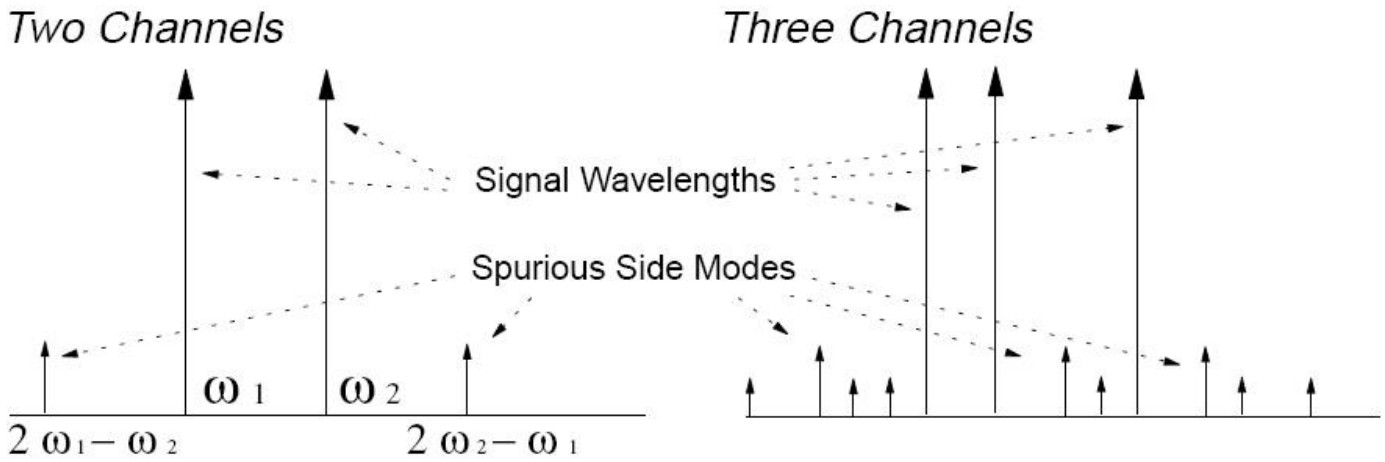
"Sparkle" pattern



Efecte neliniare in fibra

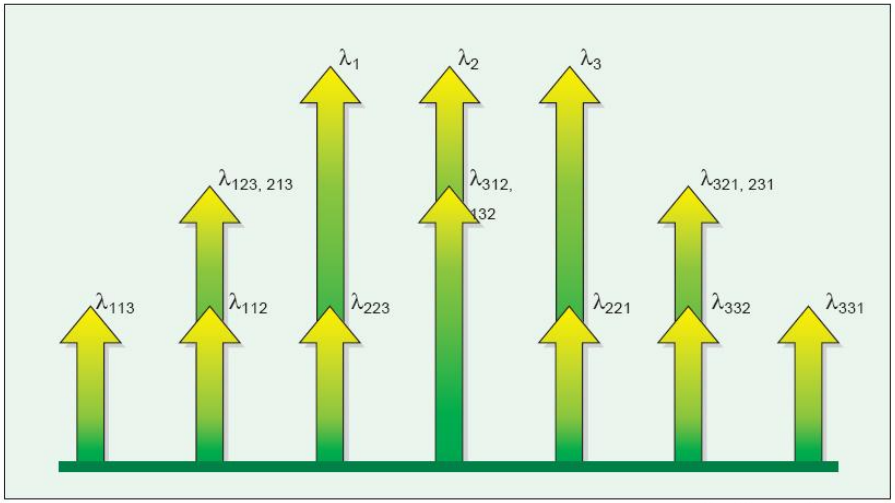
- Stimulated Brillouin Scattering, SBC
  - difractia luminii inspre emitator datorita undelor mecano-acustice generate in fibra
  - 6-10 dBm
- Stimulated Raman Scattering, SRS
  - interactiunea luminii cu vibratiile moleculare
  - 27 dBm (~1W)
- Self Phase Modulation, SPM
  - Frontiera impulsului implica 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



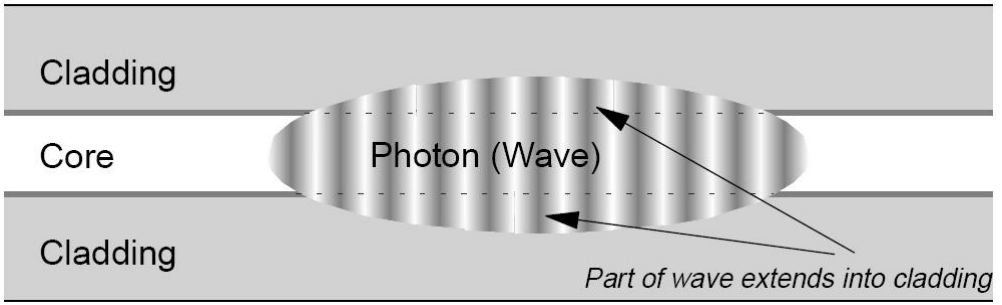
$$NL = \frac{1}{2}\left(N^3 - N^2\right)$$

N = 2, NL = 4
N = 3, NL = 9
N = 16, NL = 1920

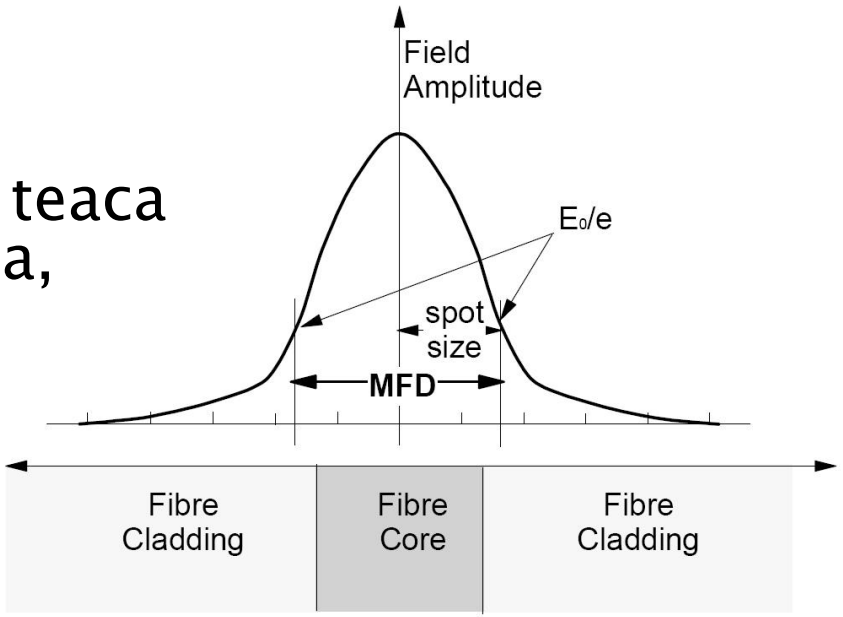


Propagarea in fibra monomod

- Propagarea luminii poate fi explicata doar prin teoria electromagnetica

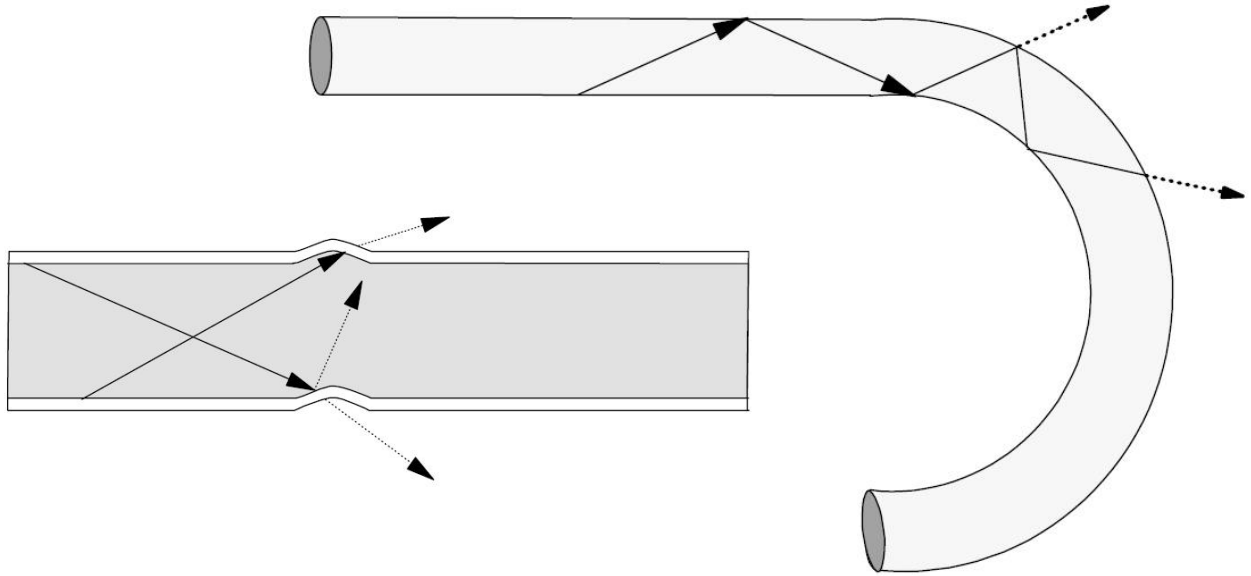


- Energia campului se extinde in teaca (diametrul efectiv al spotului luminos – MFD, Mode Field Diameter)
- MFD > 2a
- Adancimea de patrundere in teaca depinde de lungimea de unda, generand dispersia de ghid

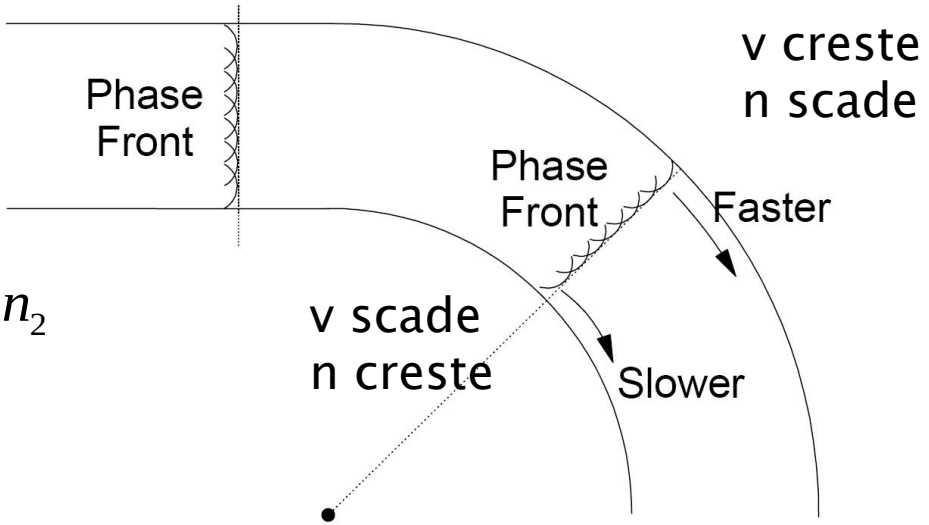


Efectul curburilor

- Multimod



- Monomod

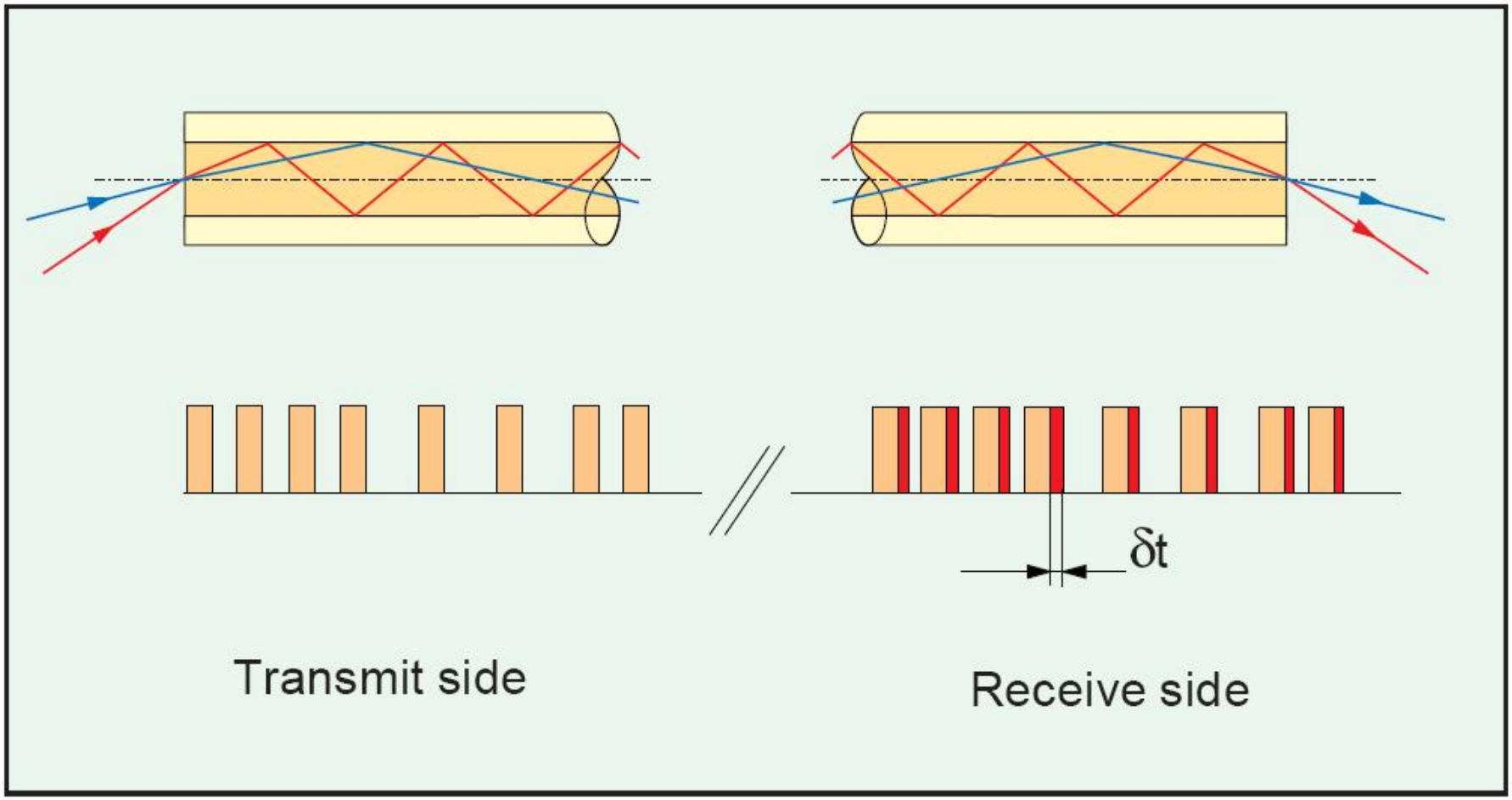


$$R > R_C \quad \Rightarrow \quad n_{1,ext} > n_2$$

Dispersia

- intermodala (modala – depinde de prezenta modurilor)
- intramodala (cromatica – depinde de lungimea de unda)
  - de material
  - de ghid

Dispersia modala



Dispersia modala

- salt de indice

$$dt = \frac{L \cdot n_2^2}{c \cdot n_1}\left(\frac{n_2 - n_1}{n_2}\right) \approx \frac{L \cdot NA^2}{2 \cdot c \cdot n_2}$$

intarzierea intre moduri cand $\Delta = \frac{n_2 - n_1}{n_1} << 1$

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

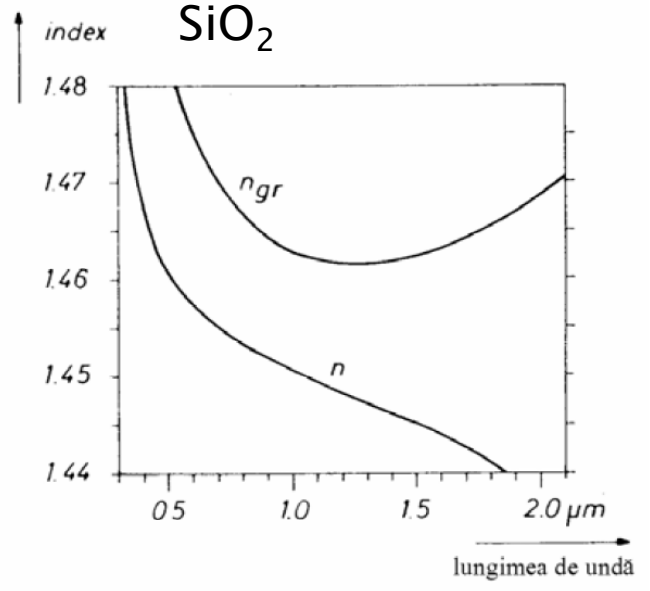
$$\Delta\tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta}{2\sqrt{3} \cdot c} \approx \frac{L \cdot NA^2}{4\sqrt{3} \cdot c \cdot n_2}$$

- indice gradat

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

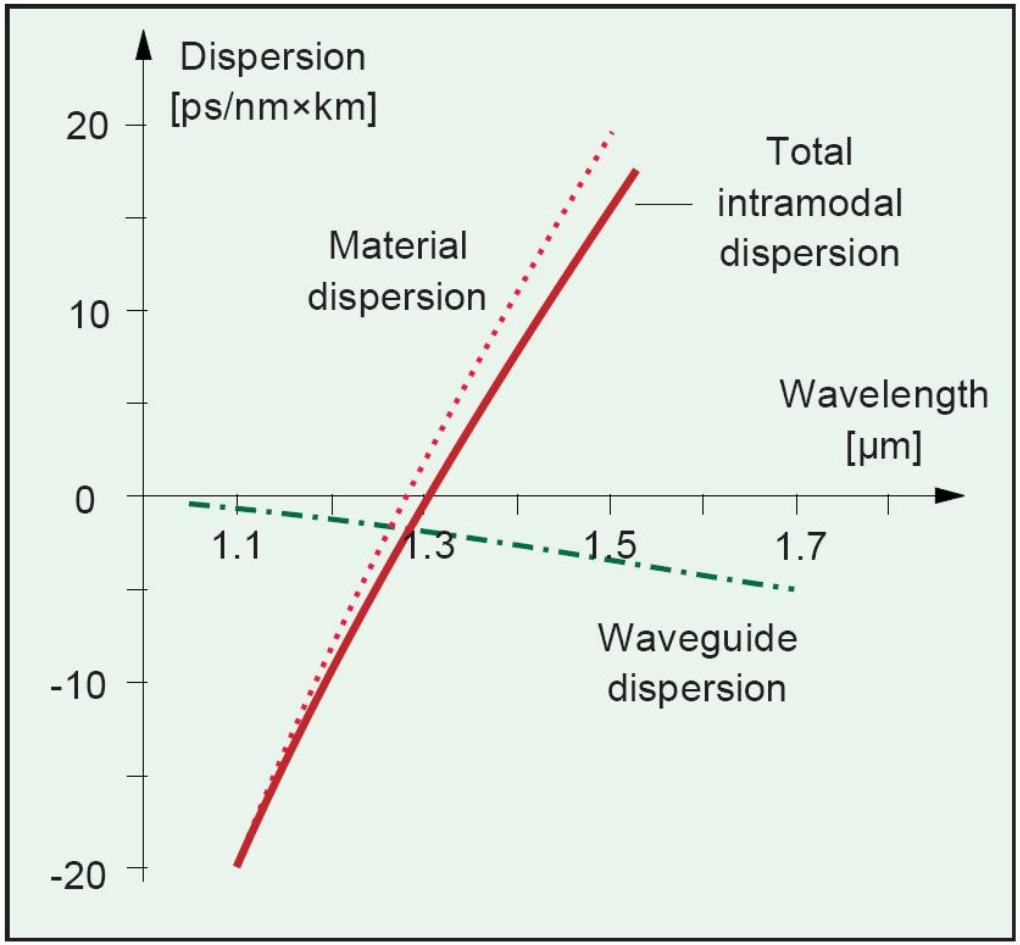
$$\Delta\tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta^2}{4\sqrt{3} \cdot c}$$

Dispersia de material



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

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

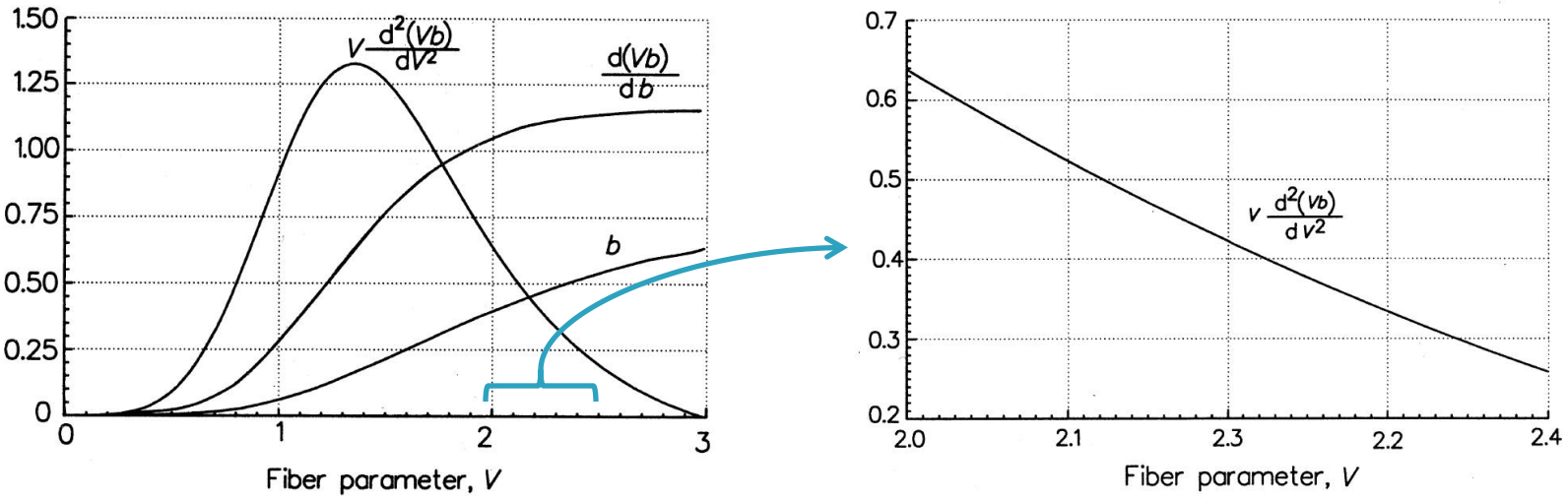


Dispersia de ghid

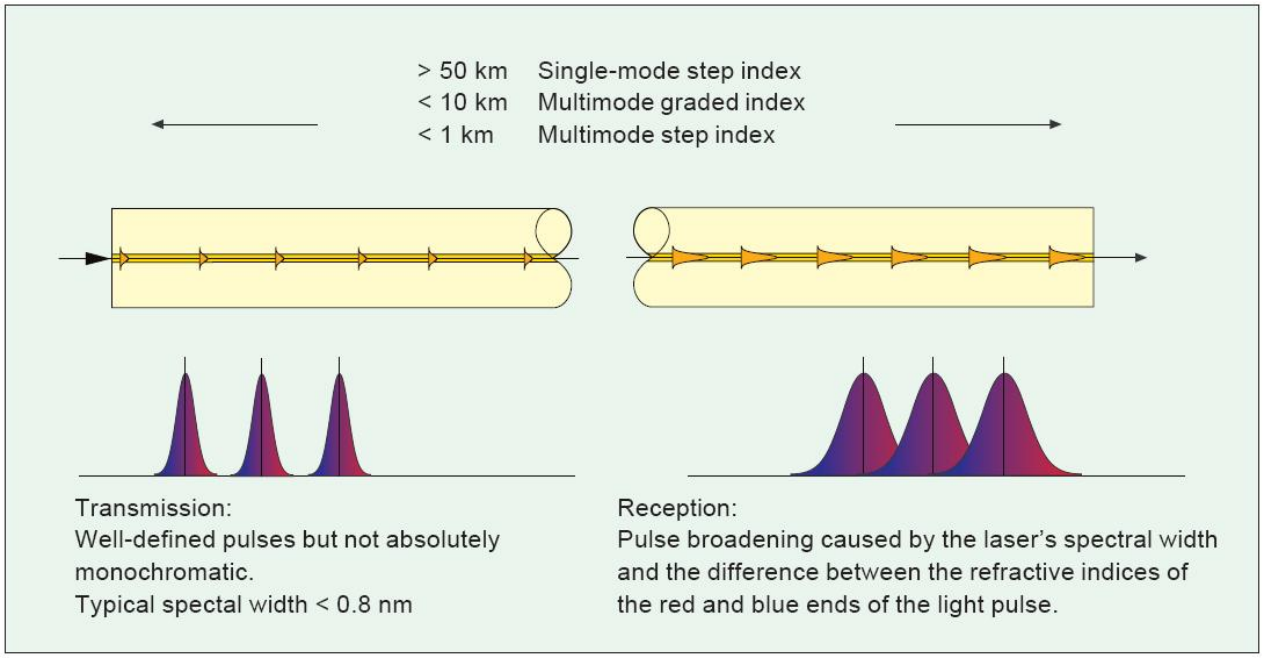
- Neglijabila in fibrele multimod fata de dispersia modala

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

b – constanta de propagare normalizata



Dispersia cromatica



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

- $D(\lambda) \approx 100 + 0.4\,(850 - \lambda)$ [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

Banda

- Dispersia totala

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

- Banda

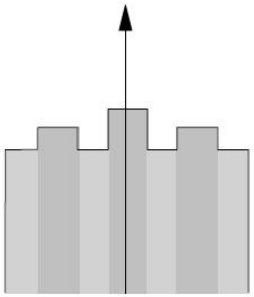
$$B_{opt} = \frac{0.44}{\Delta\tau_{tot}[ns]} \quad [GHz] \qquad\qquad B_{opt} = \sqrt{2}B_{el}$$

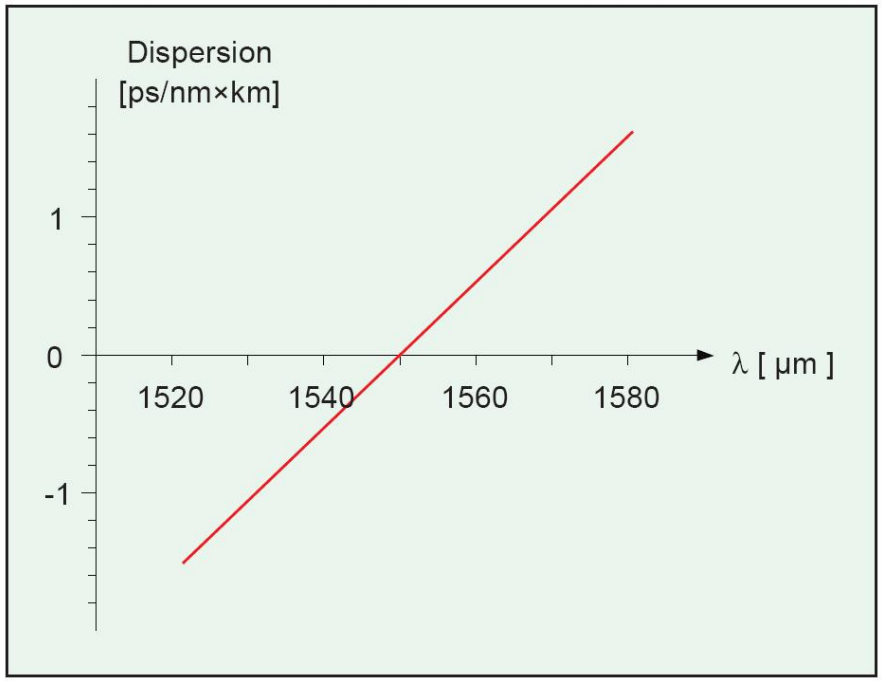
- Banda optica la 3 dB corespunde unei benzi electrice la 6 dB
  - $P_{opt} \sim I; \quad P_{el} \sim I^2$
- Viteza legaturii

$$V[Gb/s] \cong \frac{1}{2} B_{el}$$

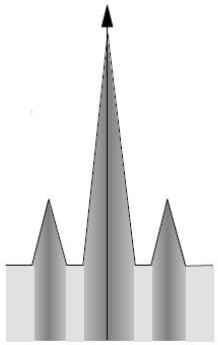
Dispersion shifted fibers

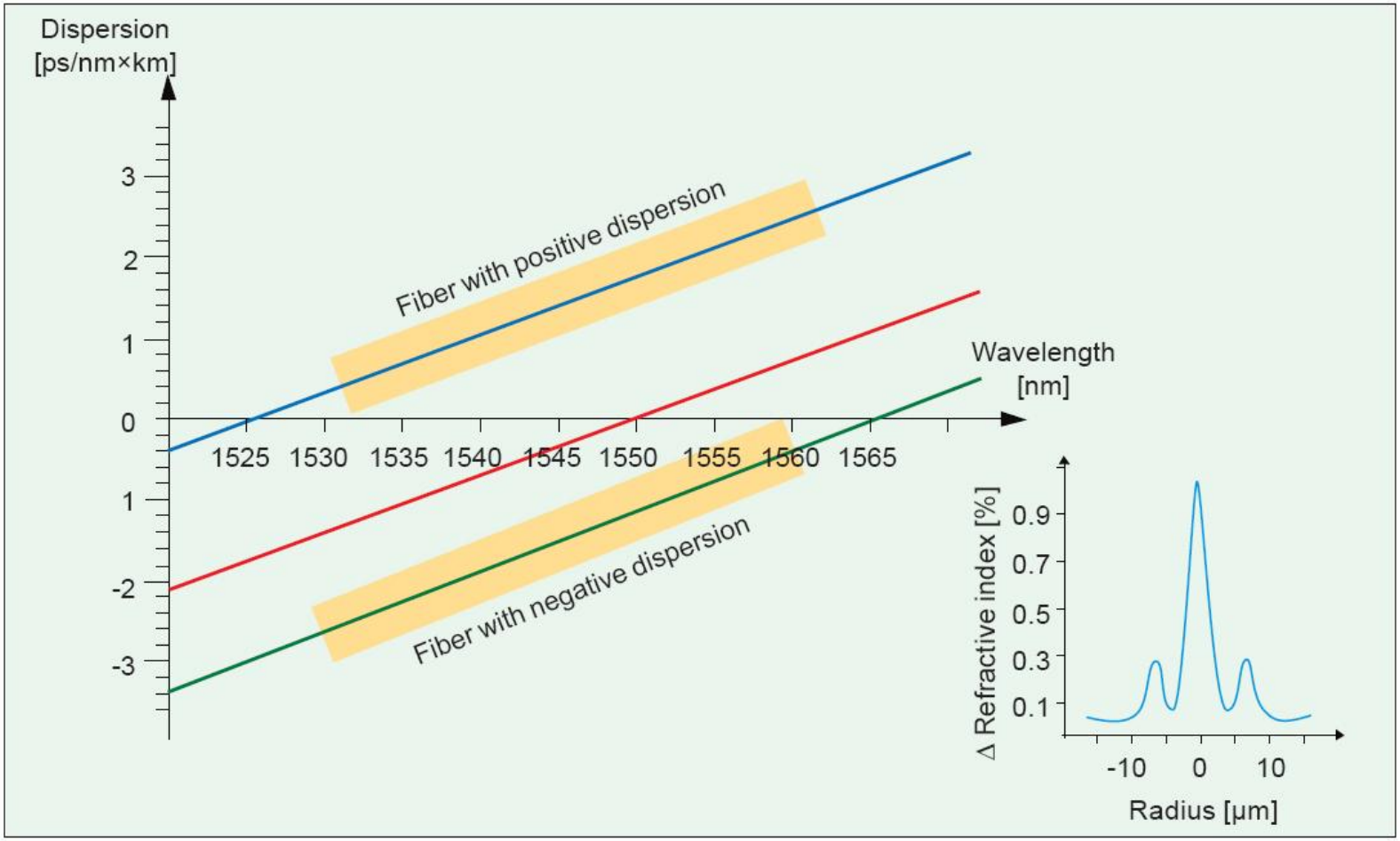
- Atenuarea e mai mica la 1550 nm
- EDFA (Erbium doped fibre amplifiers) opereaza in banda aceasta
- Sistemele WDM (Wavelength division Multiplexing) necestia banda larga amplificata



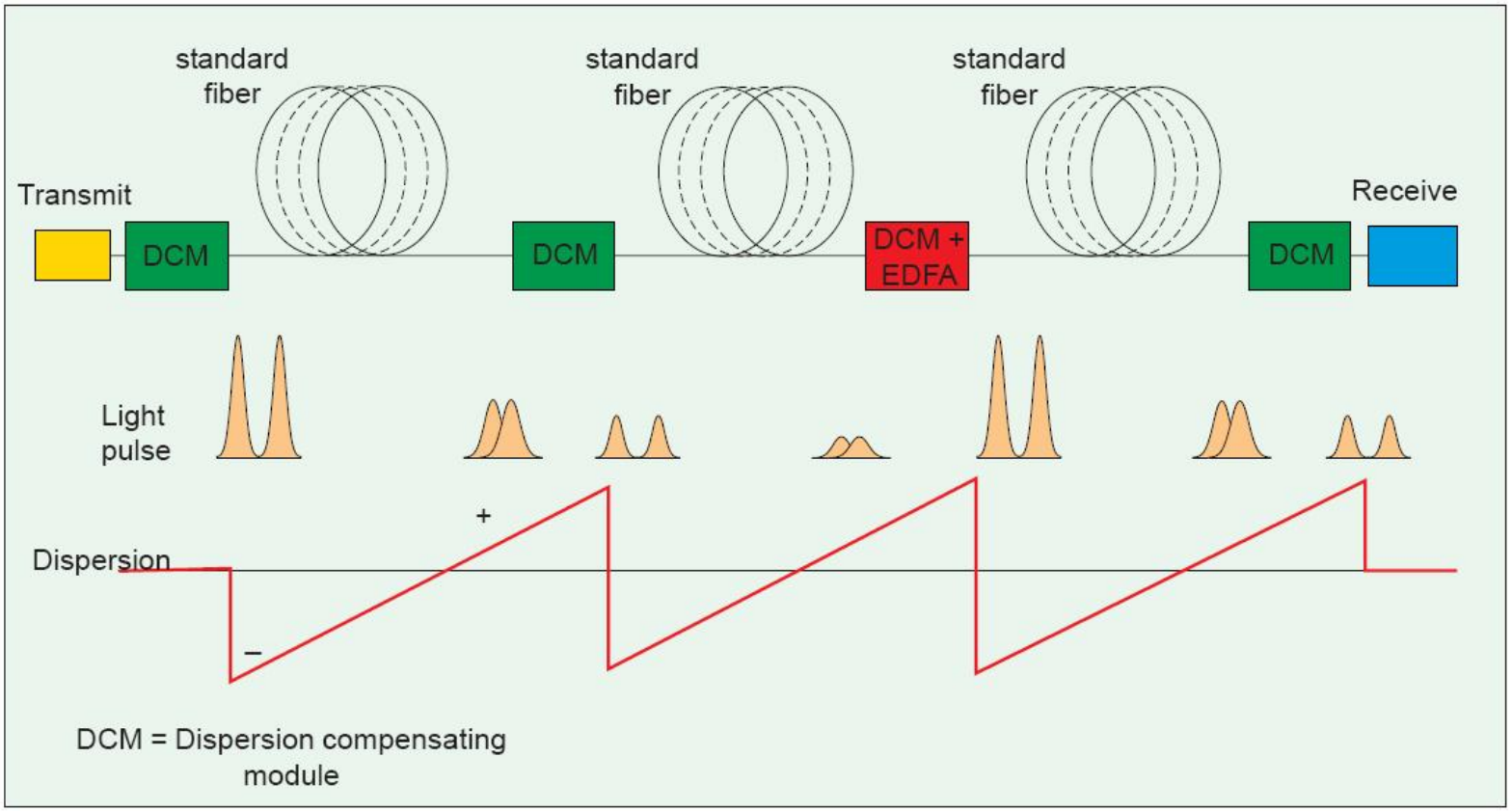


Non-zero Dispersion shifted fibers





Fibra pentru compensarea dispersiei

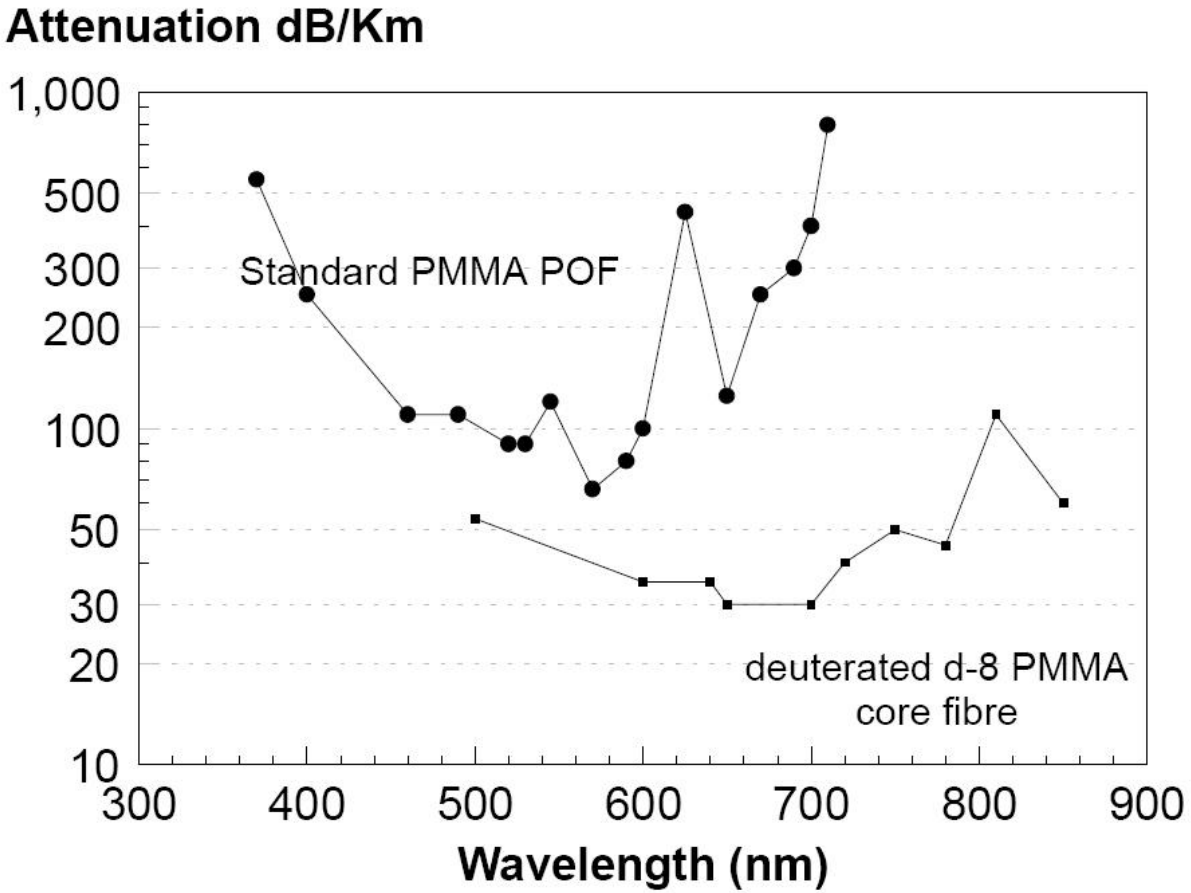


- Dispersie -100 ps/nm/km
- Atenuare 0.5 dB/km

Fibra standard ITU G.652

- Diametru teaca = 125 µm
- MFD = 9÷10 µm la 1300 nm
- λ_C = 1100÷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) mai mica de 0.095 ps/nm^2/km

Fibra optica din plastic (POF)



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