

# Optoelectronică

Curs 8

2022/2023

# Disciplina 2022/2023

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – conf. **Radu Damian**
  - an IV  $\mu$ E
  - 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  $\mu$ E
    - Luni 18-20, Miercuri 11-15 par
    - Max. 7 prezente
  - L – 30% din nota (+Caiet de laborator)

# Cuprins

- ▶ **Lumina ca undă electromagnetică\*** (ecuațiile lui Maxwell, ecuația undelor, parametri de propagare)
- ▶ **Elemente de fotometrie și radiometrie\*** (mărimi energetice/luminoase)
- ▶ **Fibra optică** (realizare, principiu de funcționare, atenuare, dispersie, banda de frecvență)
- ▶ **Cabluri optice** (tehnologie, conectori, lipire – splice)
- ▶ **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvență, balanța puterilor)
- ▶ **Emitătoare optice** (LED și dioda laser – realizare fizică și funcționare)
- ▶ **Receptoare optice** (dioda PIN, dioda cu avalanșă – realizare fizică și funcționare)
- ▶ **Amplificatoare transimpedanță** (parametri, scheme tipice, TIA în buclă deschisă, cu reacție, diferențiale, control automat al câștigului)
- ▶ **Realizarea circuitelor pentru controlul emițătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- ▶ **Dispozitive de captare a energiei solare** (principiu de funcționare, 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:

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

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

## Detalii curente

<b>Finantare</b>	Buget
<b>Bursa</b>	Fara Bursa

## Observatii



## Date:

<b>Grupa</b>	5304 (2015/2016)
<b>Specializarea</b>	Tehnologii si sisteme de telecomunicatii
<b>Marca</b>	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	Colocenta 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		



## Date:

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

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

## Detalii curente

<b>Finantare</b>	Buget
<b>Bursa</b>	Bursa de Studii

## Observatii

# 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	<a href="#">CIOLPAN OCTAVIAN</a>	5306	3	0.5					0.5	-
2	<a href="#">NITA COSTEL-CATALIN</a>	5307	4	0.5	1				1.5	-
3	<a href="#">BARON BOGDAN-IONUT</a>	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

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

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

$$0 \text{ dB} = 1$$

$$+ 0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$+ 3 \text{ dB} = 2$$

$$+ 5 \text{ dB} = 3$$

$$+ 10 \text{ dB} = 10$$

$$-3 \text{ dB} = 0.5$$

$$-10 \text{ dB} = 0.1$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dB} = 0.001$$

$$0 \text{ dBm} = 1 \text{ mW}$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$5 \text{ dBm} = 3 \text{ mW}$$

$$10 \text{ dBm} = 10 \text{ mW}$$

$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dBm} = 100 \mu\text{W}$$

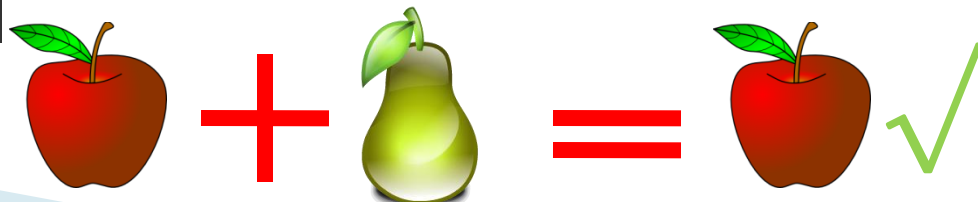
$$-30 \text{ dBm} = 1 \mu\text{W}$$

$$-60 \text{ dBm} = 1 \text{ nW}$$

$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

$$[\text{dBm/Hz}] + [\text{dB}] = [\text{dBm/Hz}]$$

$$[x] + [\text{dB}] = [x]$$



# Calculul atenuarii/amplificarii

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

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

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

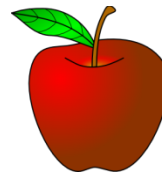
$$\text{Pierderi [dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-





# Online

- ▶ acces la **examene** necesita **parola** primita prin **email**

English | Romana |

Start Didactic Master Colectiv Cercetare Stud

Note Lista Studenti Examene Fotografii

## POPESCU GOPO ION

**Fotografia nu exista**

**Date:**

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica si telecomunicatii
Marca	7000021

Acceseaza ca acest student | [here acces la licente](#)

**Note obtinute**

Inca nu a fost notat.

Start Didactic Master Colectiv C

Note Lista Studenti Examene Fotografii

## Identificare

Introduceti numele si adresa de email utilizata la inscriere

Nume  
POPESCU GOPO

**E-mail/Parola**

Introduceti codul afisat mai jos

4db4457

Trimite

# Online

## ► acces email/parola

Start Didactic Master Colectiv

Note Lista Studenti Examene Fotografii

### POPESCU GOPO ION

Fotografia nu exista

Date:

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica
Marca	7000021

Se acceseaza site-ul [ca acest student!](#)

Start Didactic Master Colectiv

Note Lista Studenti Examene Fotografii

### POPESCU GOPO ION

Fotografia nu exista

Date:

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica s
Marca	7000021

Se acceseaza site-ul [ca acest student \(inclusiv examene\)!](#)

# Parola

## ▶ primita prin email

Important message from RF-OPTO

Inbox x



Radu-Florin Damian

to me, POPESCU

Romanian > English Translate message



Laboratorul de Microunde si Optoelectronica  
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei  
Universitatea Tehnica "Gh. Asachi" Iasi

In atentie: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul **rf-opto** este

Parola: [REDACTED]

Identificati-va pe [server](#), cu parola, cat mai rapid, pentru confirmare.

Memorati acest mesaj intr-un loc sigur, pentru utilizare ulterioara

Attention: POPESCU GOPO ION

The password to access the exams on the **rf-opto** server is

Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

Reply

Reply all

Forward

The screenshot shows an email client interface. At the top, there is a list of messages. The first message is highlighted in blue and has its subject, "Important message from RF-OPTO", circled in red. The sender is identified as "POPESCU GOPO ION". Below the list, the content of the selected email is displayed. The subject line "Important message from RF-OPTO" is also circled in red. The sender is "Me <rdamian@etti.tuiasi.ro>". The body of the email contains the same text as the main image on the left, including the laboratory logo, attention line, password information, and instructions. At the bottom of the email content, there are buttons for "Reply", "Reply all", and "Forward".

# Manual examen online

- ▶ Aplicatia de examen online utilizata intens la:
  - curs (prezenta)
  - miniteste
  - examen

## Materials

### Other data

[Manual examen on-line](#) (pdf, 2.65 MB, ro, 🇷🇴)

[Simulare Examen](#) (video) (mp4, 65.12 MB, ro, 🇷🇴)

## Microwave Devices and Circuits (Englis

# Examen online

- ▶ intotdeauna **contratimp**
  - perioada lunga (prezenta curs/rezultate laborator)
  - perioada scurta (teste: 15min, examen: 2h)

Start Didactic Master Colectiv Cercetare **Studenti**

Note Lista Studenti **Examene** Fotografii

**Anunț**  
17:28 (29/04/2020)

**Material suport**  
17:30 (29/04/2020)

**Subiecte**  
17:32 (29/04/2020)

**Rezultate**  
17:35 (29/04/2020)

**Finalizare**  
17:45 (29/04/2020)

**Confirmare**  
17:45 (30/04/2020)

urmatorul interval de timp in.  
**01 m 08 s**  
[Reincarca acum](#)

## Anunț

In acest examen se verifica diverse actiuni ale studentilor pentru examen

## Ora pe server

toate examenele sunt bazate pe fusul orar al server-ului (ar putea sa fie diferit de timpul local). Pentru referinta ora pe server este acum:

**29/04/2020 17:28:51**

# Fibra optică

## Capitolul 4

# Aplicatii majore

## ▶ Comunicatii

- Infrarosu (InGaAsP)

## ▶ Vizibil

- Spectru vizibil (GaAlAs)

## ▶ Iluminare

- Putere ridicata, lumina alba (GaInN)

## ▶ Energie solara

- Efect fotovoltaic (Si)

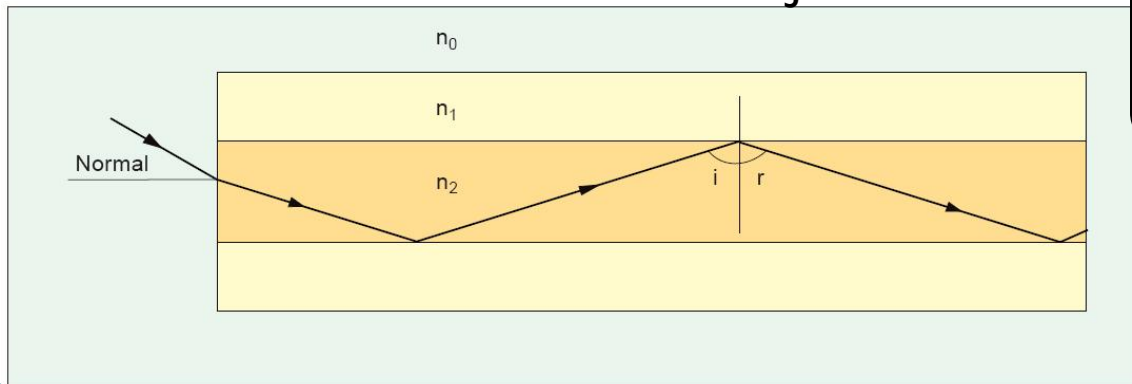
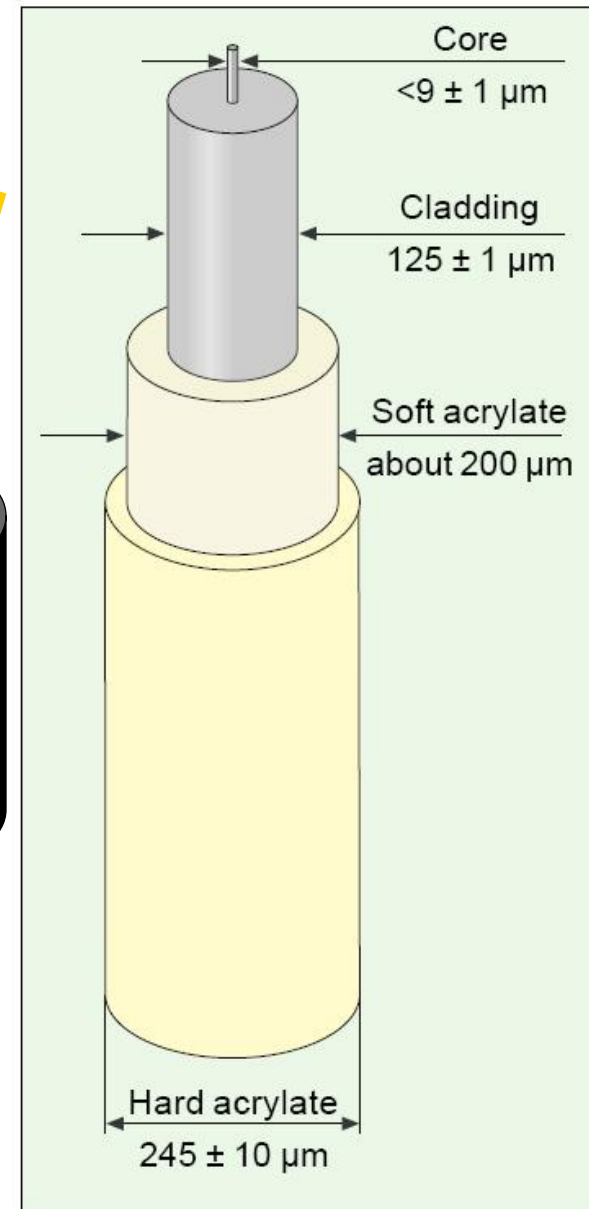
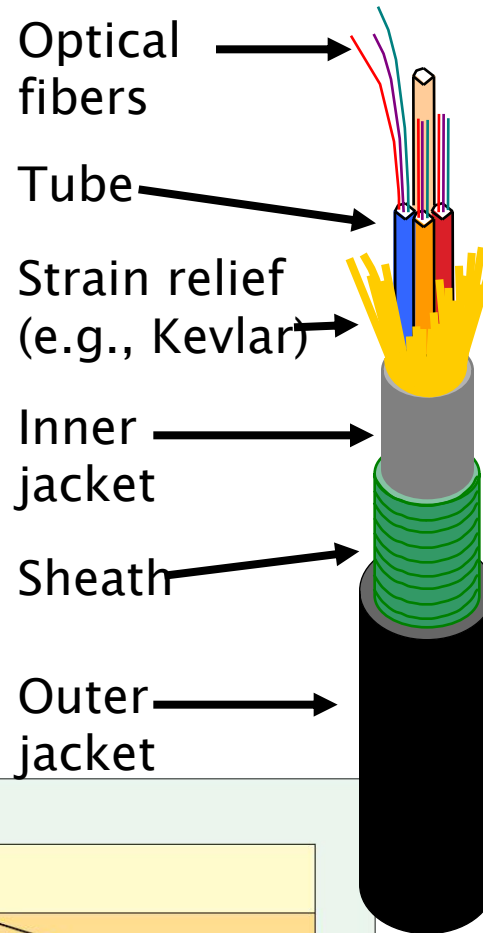
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# Fibra optica

- ▶ un ghid de unda dielectric
  - miez
  - teaca



# Unghi de acceptanta, apertura numerica

- ▶ Unghi de acceptanta

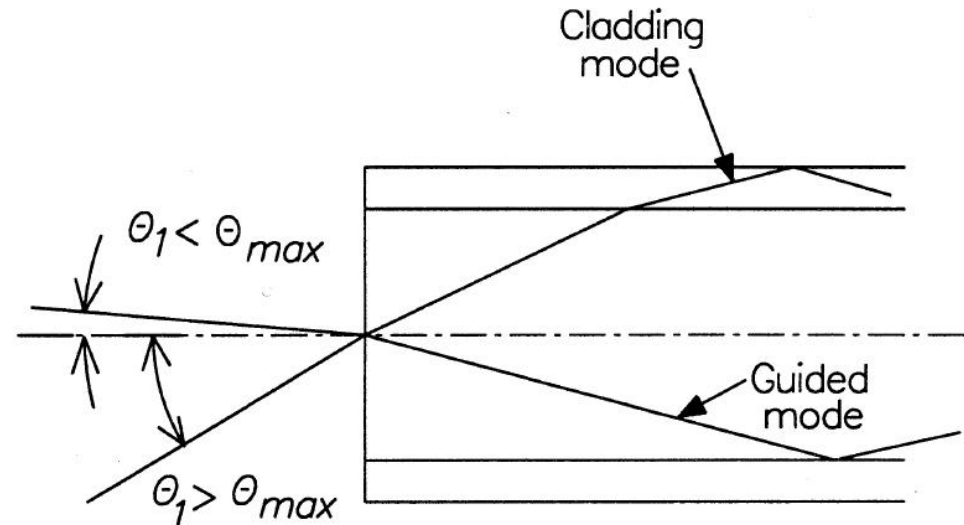
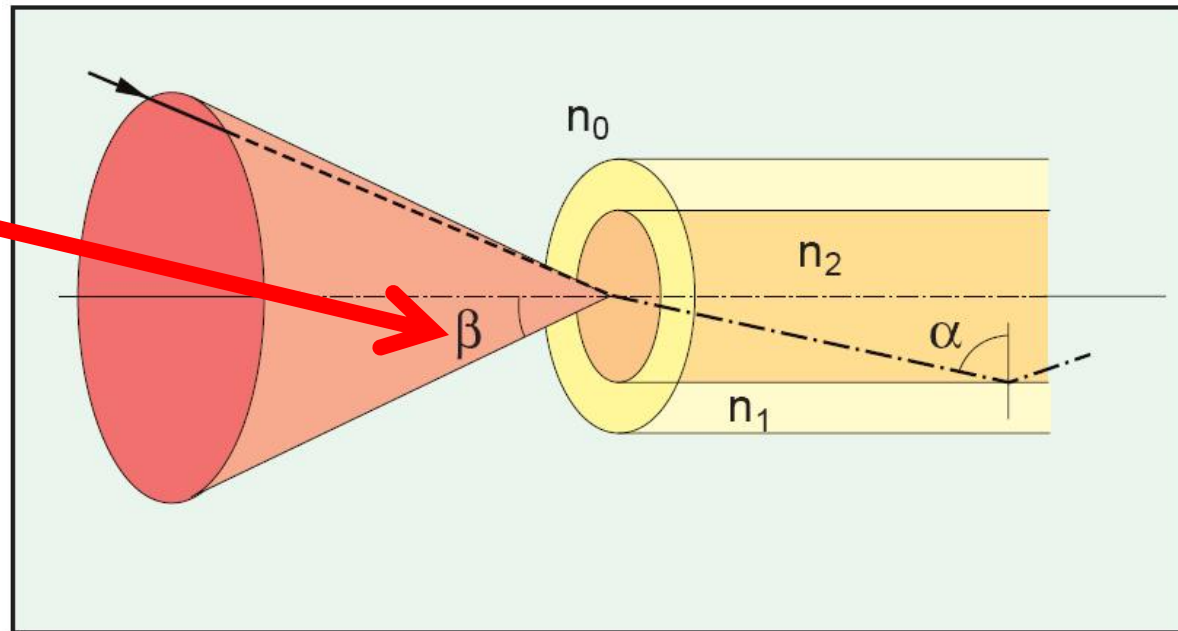
$$n_0 \cdot \sin \theta_{ACC} = n_2 \cdot \sin \phi_c$$

- ▶ **Apertura numerica**

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

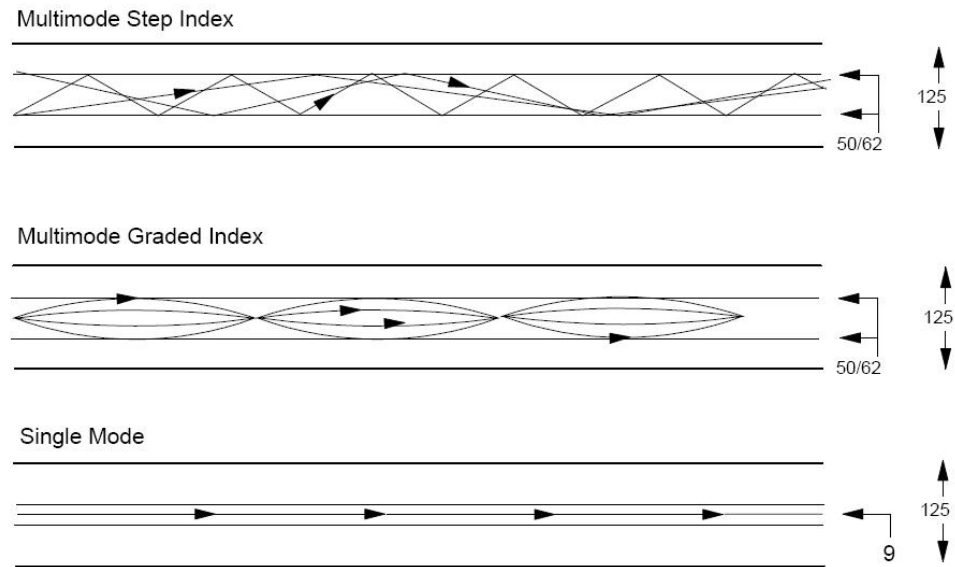
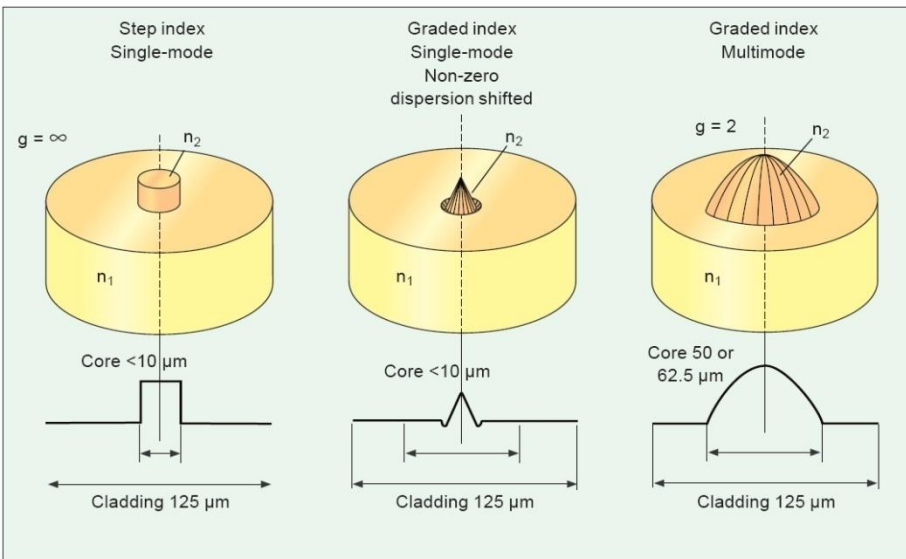
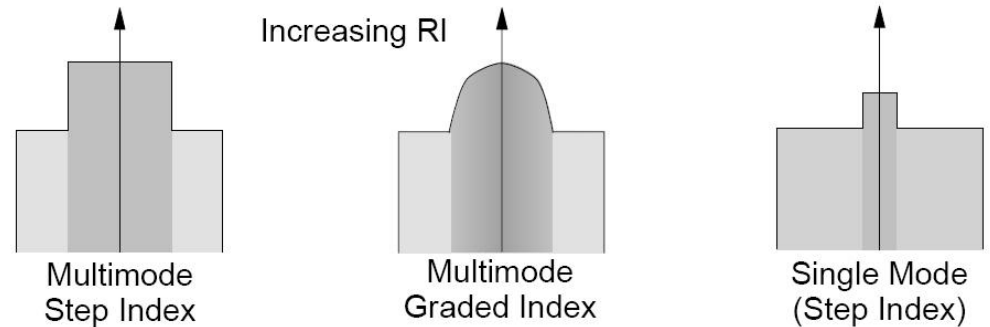
$$NA = n_2 \sqrt{\frac{n_2^2 - n_1^2}{n_2^2}} = \sqrt{n_2^2 - n_1^2}$$

$n_2$  - miez  
 $n_1$  - teaca  
 **$n_2 > n_1$  !!**



# Tipuri de fibra

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



# Fenomene de interes

- ▶ Cat de departe pot transmite semnalul luminos pe fibra
  - **atenuare**
- ▶ Cat de rapid pot transmite informația
  - dispersie

# Reprezentare logaritmică

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

$$P[\text{dBm}] = 10 \cdot \log_{10} \left( \frac{P}{P_0} \right) = 10 \cdot \log_{10} \left( \frac{P}{1 \text{ mW}} \right)$$

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

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

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$$0 \text{ dBm} = 1 \text{ mW}$$

$$+ 0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$+ 3 \text{ dB} = 2$$

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$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dB} = 0.5$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dB} = 0.1$$

$$-10 \text{ dBm} = 100 \text{ } \mu\text{W}$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dBm} = 1 \text{ } \mu\text{W}$$

$$-30 \text{ dB} = 0.001$$

$$-60 \text{ dBm} = 1 \text{ nW}$$

$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

$$[\text{dBm/Hz}] + [\text{dB}] = [\text{dBm/Hz}]$$

$$[x] + [\text{dB}] = [x]$$

# Calculul atenuarii

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

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

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

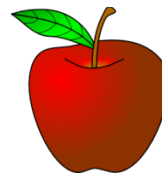
$$\text{Pierderi [dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-

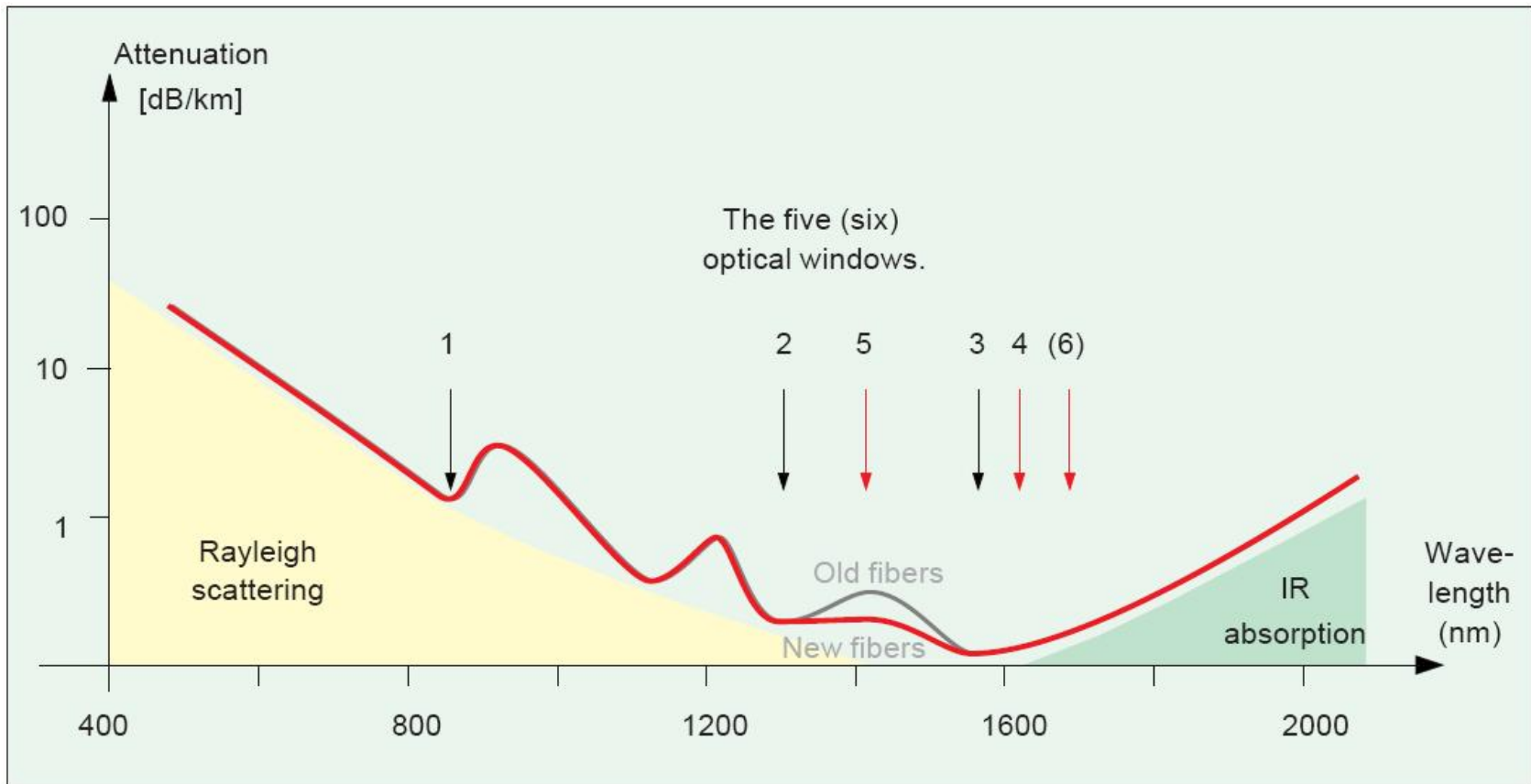


$$\text{Atenuare [dB/km]} = \frac{\text{Pierderi [dB]}}{\text{lungime [km]}}$$

# Atenuare

- ▶ Macrocurburi
  - utilizator, **localizat**, dB
- ▶ Discontinuitate in fibra
  - utilizator, **localizat**, dB
- ▶ Microcurburi
  - **distribuit**, tehnologie, dB/km
- ▶ Imprastiere
  - **distribuit**, tehnologie, dB/km
- ▶ Absorbție
  - **distribuit**, material, dB/km

# Absorbtie

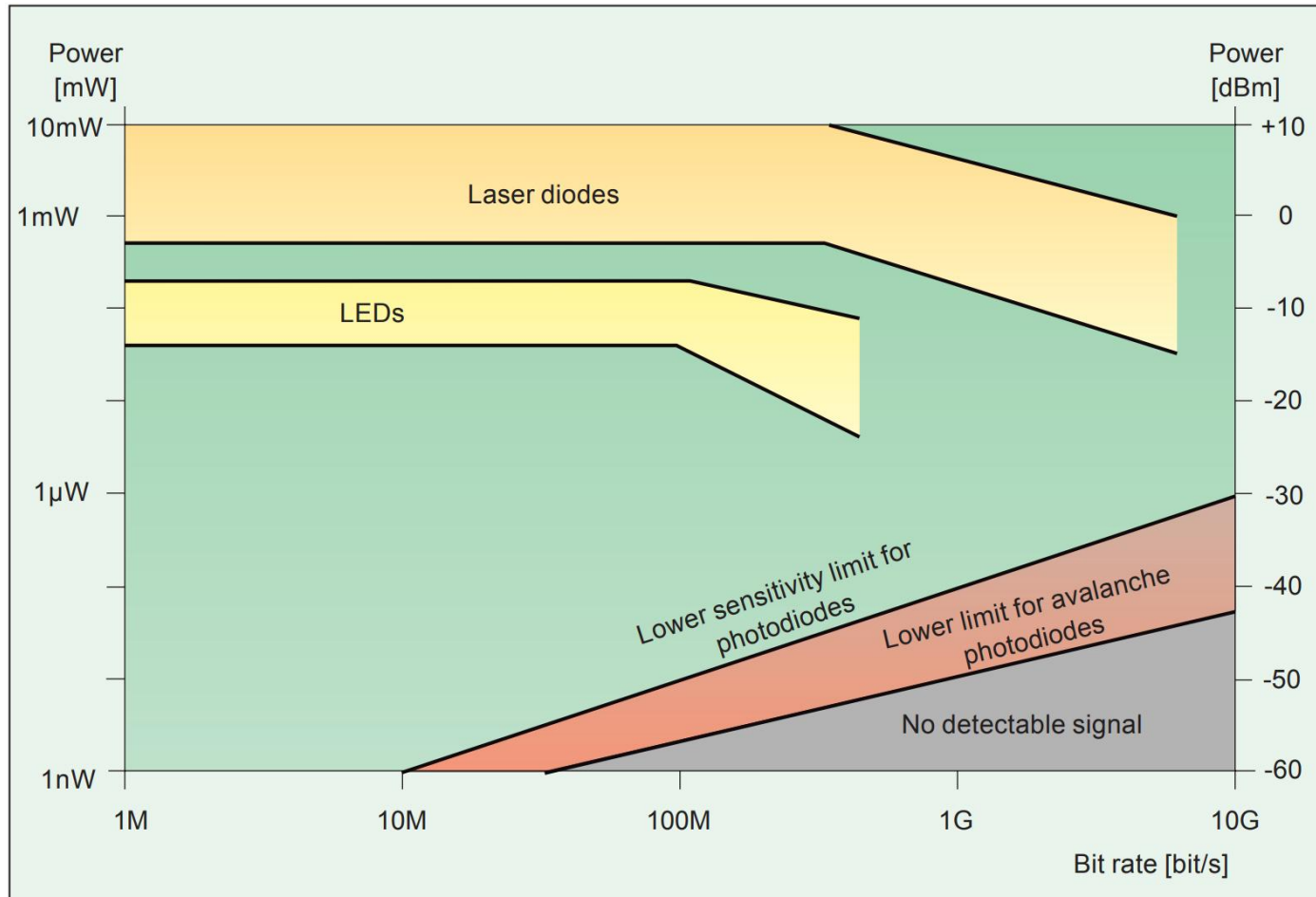


**distribuit, material, dB/km**

$$A[dB] = A_i[dB / km] \cdot L[km]$$



# Limite putere/bandă a dispozitivelor optoelectronice

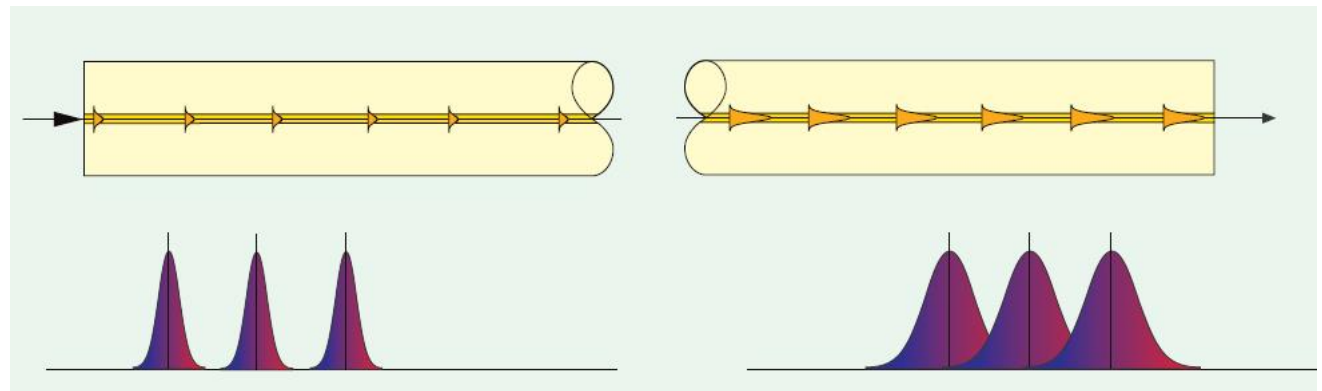


# Fenomene de interes

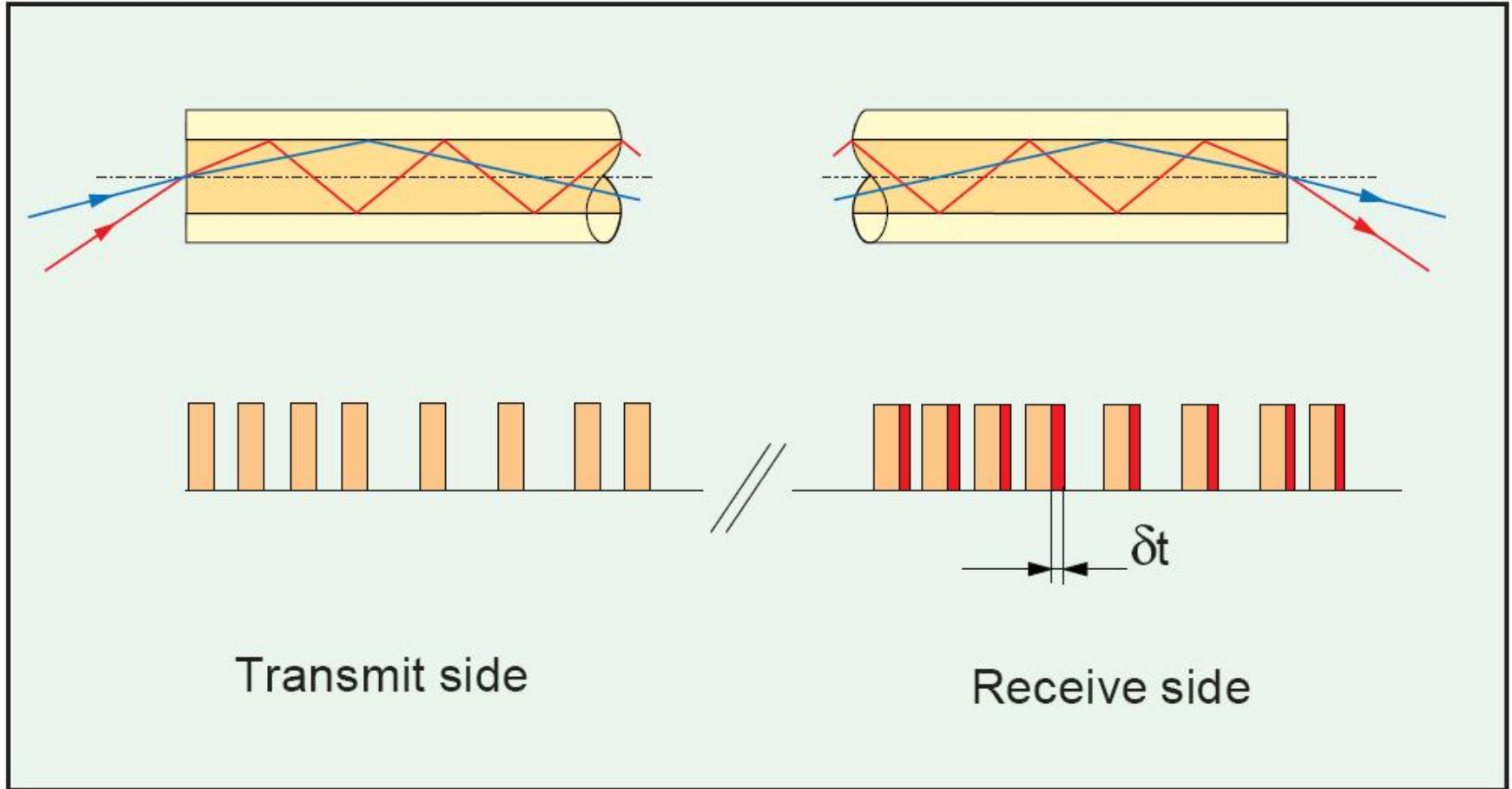
- ▶ Cat de departe pot transmite semnalul luminos pe fibra
  - atenuare
- ▶ Cat de rapid pot transmite informația
  - **dispersie**

# Dispersia

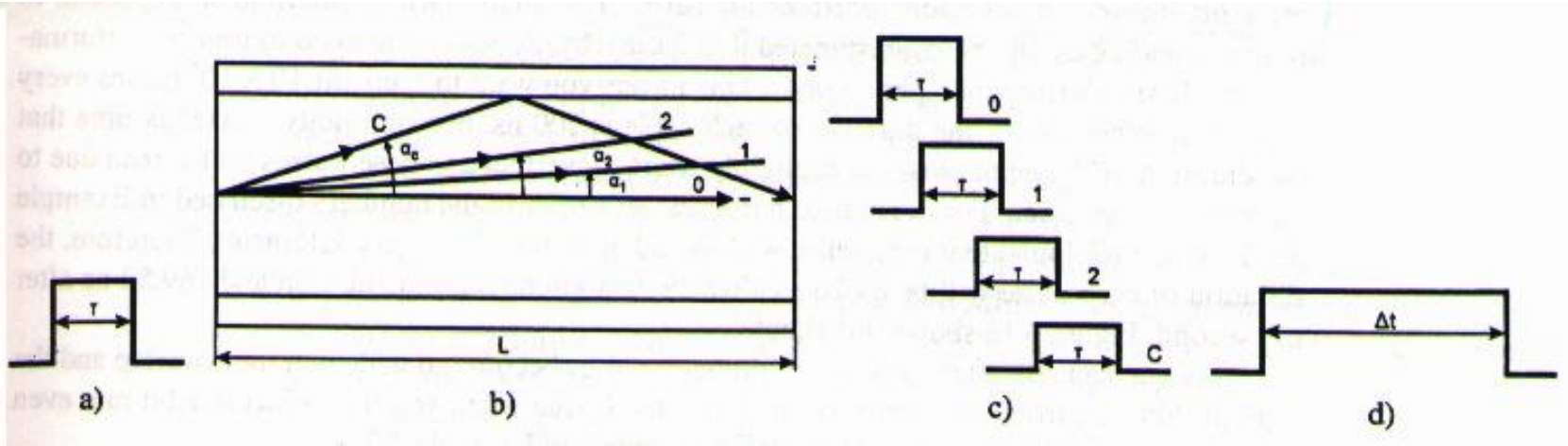
- ▶ Propagarea cu viteze diferite a radiatiilor cu trasee/lungimi de unda diferite
  - intermodala (**modala** – depinde de prezenta modurilor)
  - intramodala (**cromatica** – depinde de lungimea de unda)
    - de material
    - de ghid



# Dispersia modala



# Dispersia modala



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

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

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

$$\cos \alpha_C = NA$$

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

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

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

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

$$\Delta t_{SI} \rightarrow dt$$

# 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

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

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

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

## ▶ indice gradat

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

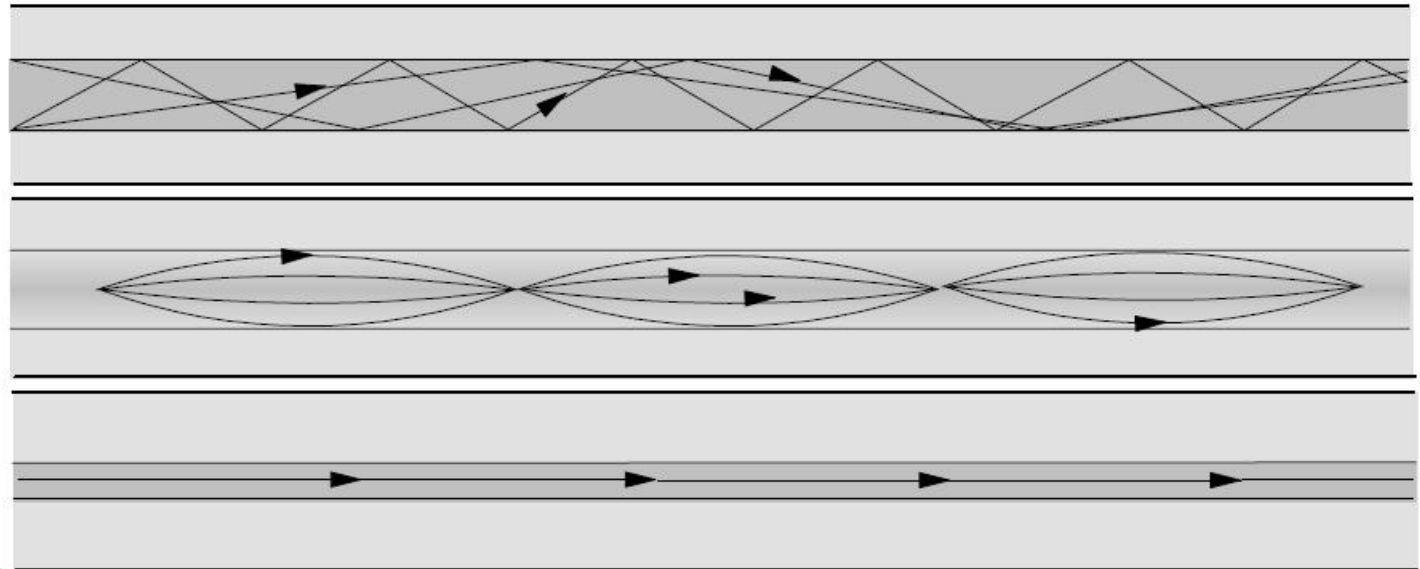
$$\Delta \tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta^2}{4\sqrt{3} \cdot c}$$

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

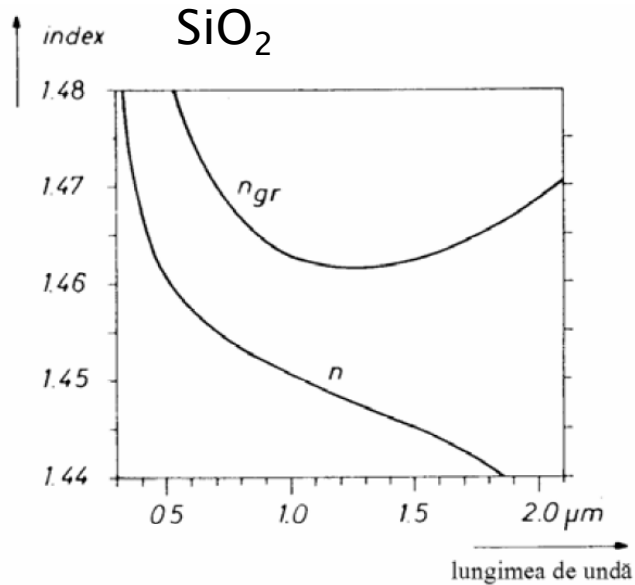
$n_2$  - miez  
 $n_1$  - teaca  
 $n_2 > n_1$  !!

# Dispersia modala

- ▶ Mai mare la fibre multimod cu salt de indice
- ▶ Mai mica la fibre multimod cu indice gradat
  - traseele mai lungi trec prin zone cu indice mai mic
- ▶ Inexistenta la fibrele monomod

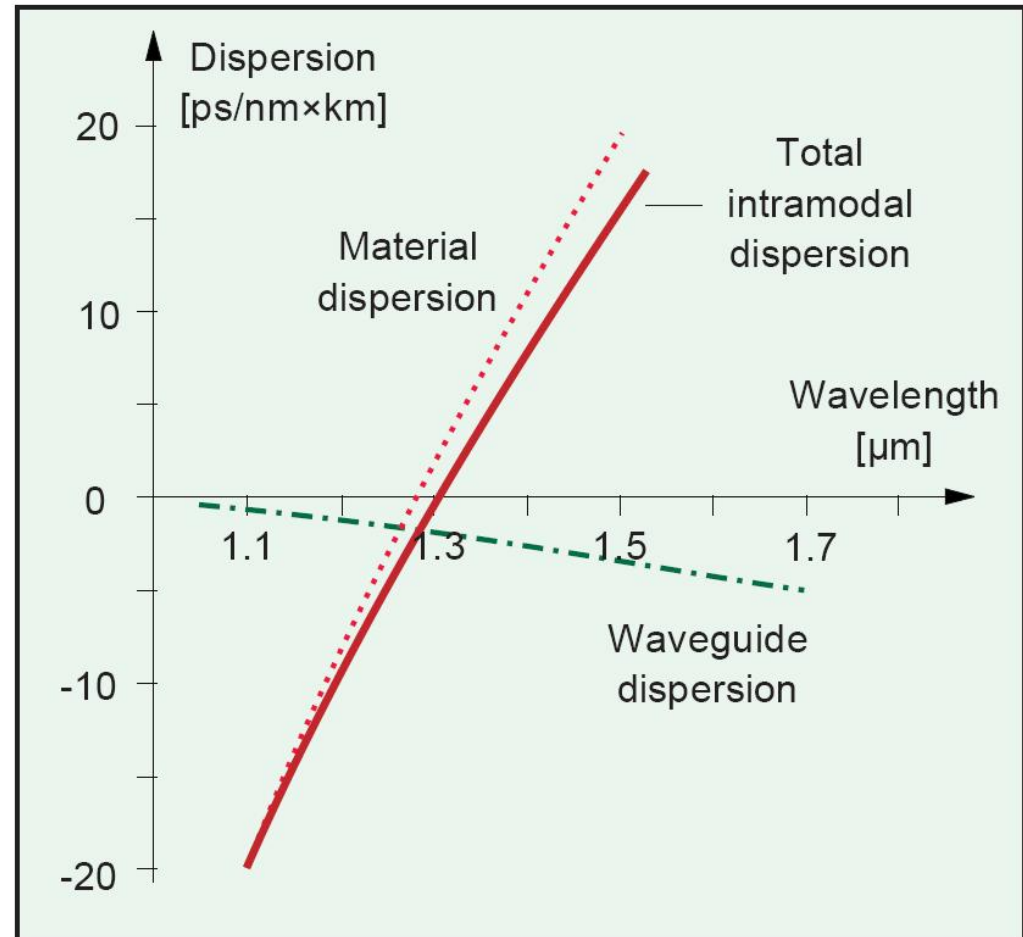


# Dispersia de material



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

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



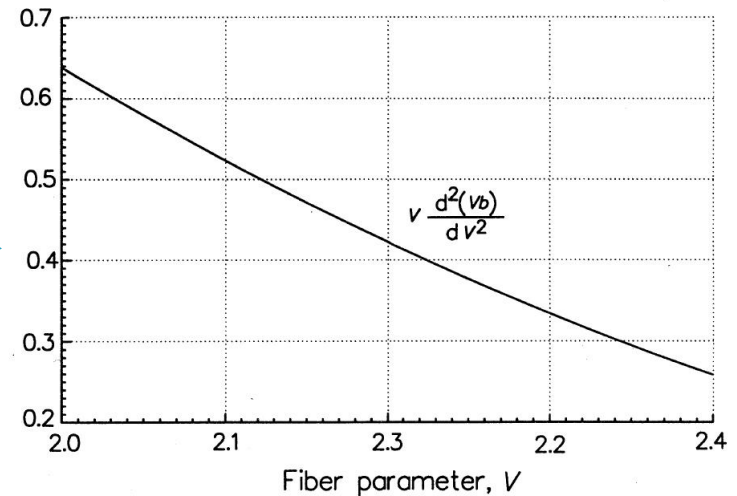
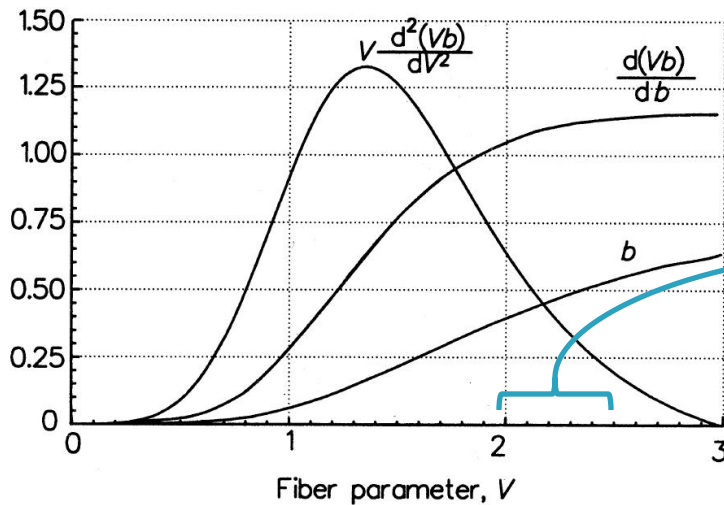


# Dispersia de ghid

- ▶ Neglijabila in fibrele multimod fata de dispersia modala

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

b - constanta de propagare normalizata

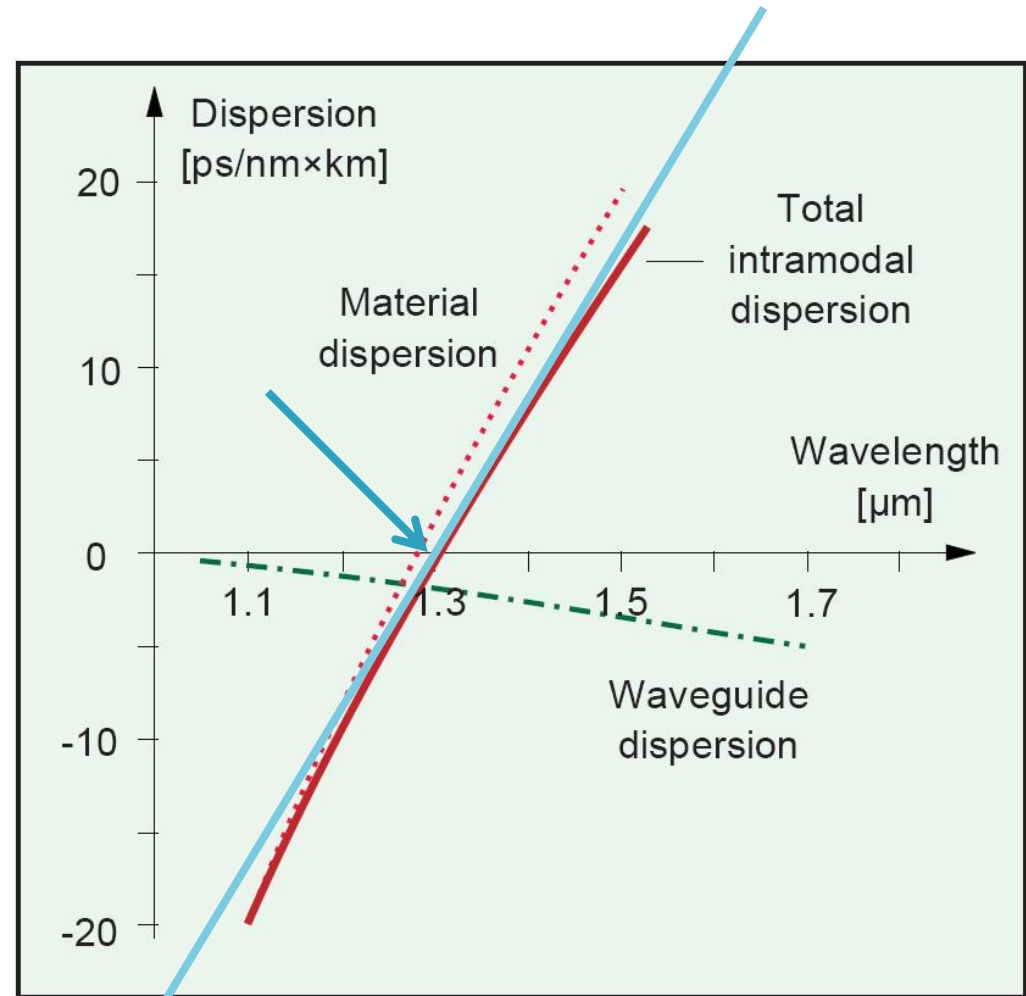


$$V \leq V_c = 2.405$$

# Dispersia cromatica (gh+mat)

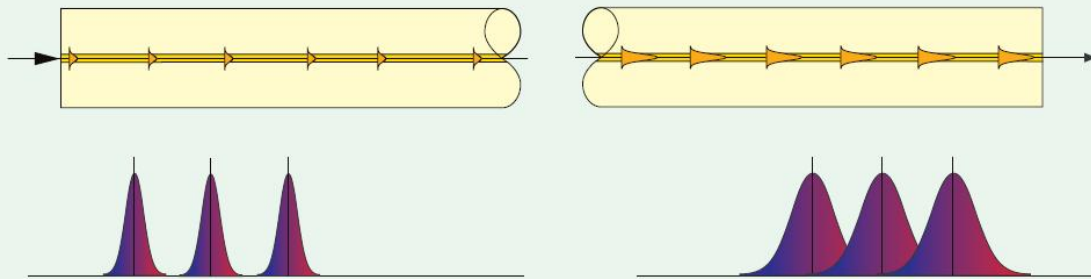
- ▶ Variatie aproximativ liniara
- ▶ Caracterizata de panta si punctul de trecere prin 0

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



# Dispersia cromatica (gh+mat)

> 50 km Single-mode step index  
 < 10 km Multimode graded index  
 < 1 km Multimode step index



Transmission:  
 Well-defined pulses but not absolutely monochromatic.  
 Typical spectral 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.

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

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

$S_0$  panta dispersiei -  
 ps/nm<sup>2</sup>/km

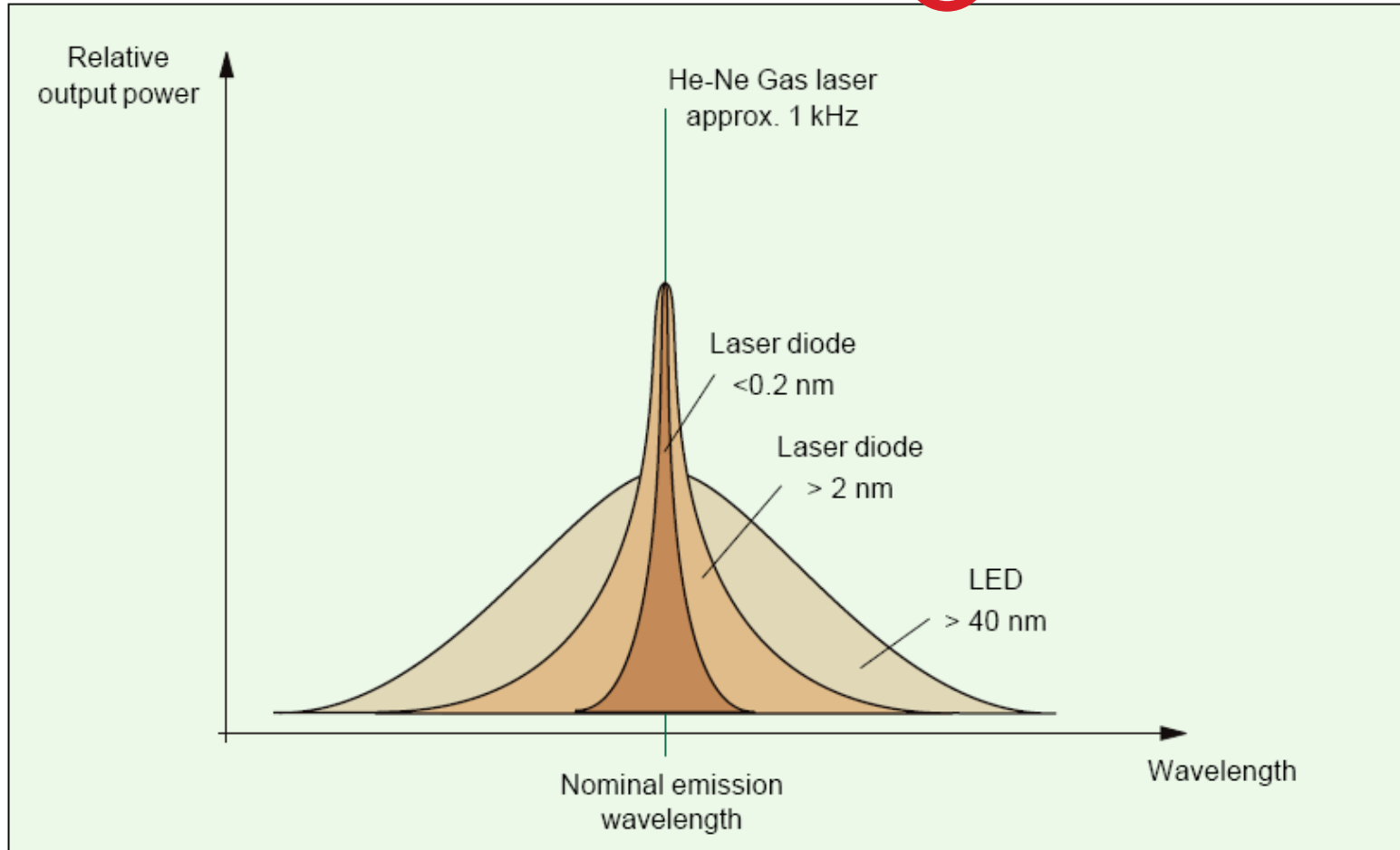
$$D(\lambda_0) = 0$$

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

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

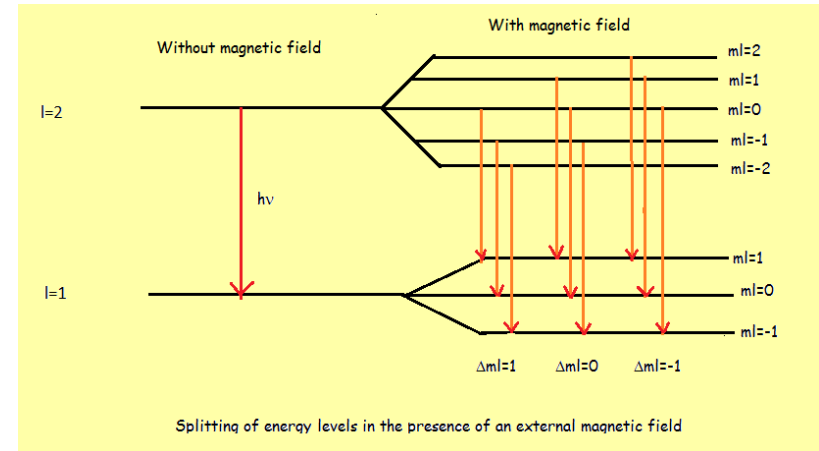
# Calitatea spectrală a emițătorilor optici

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

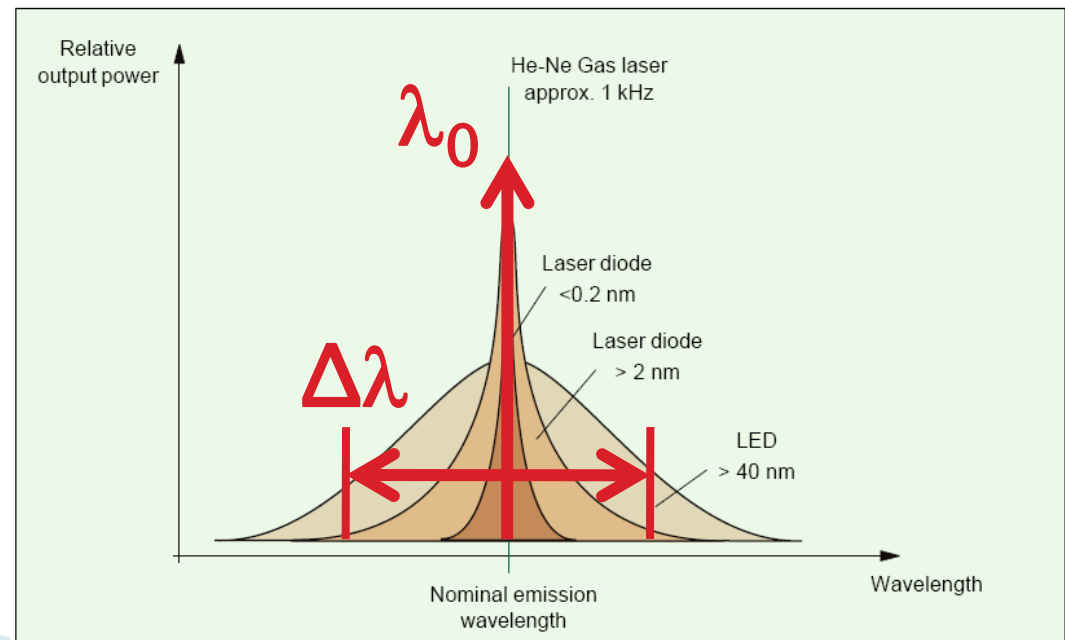


# Calitatea spectrală a emițătorilor optici

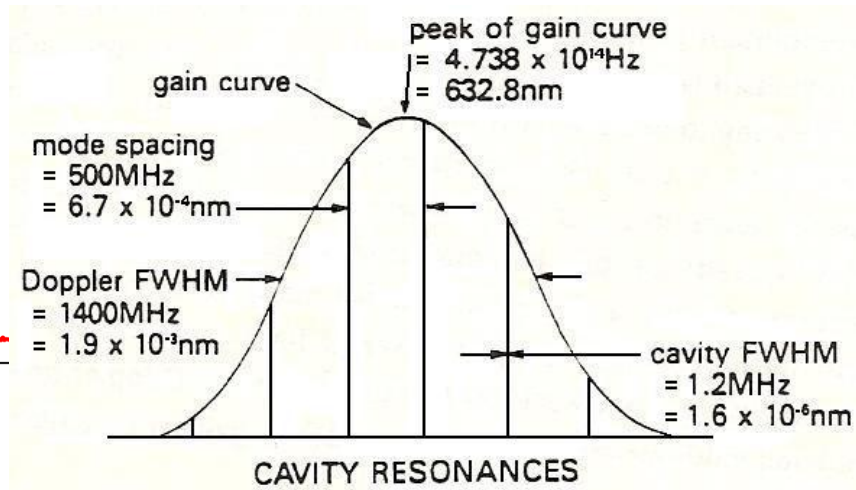
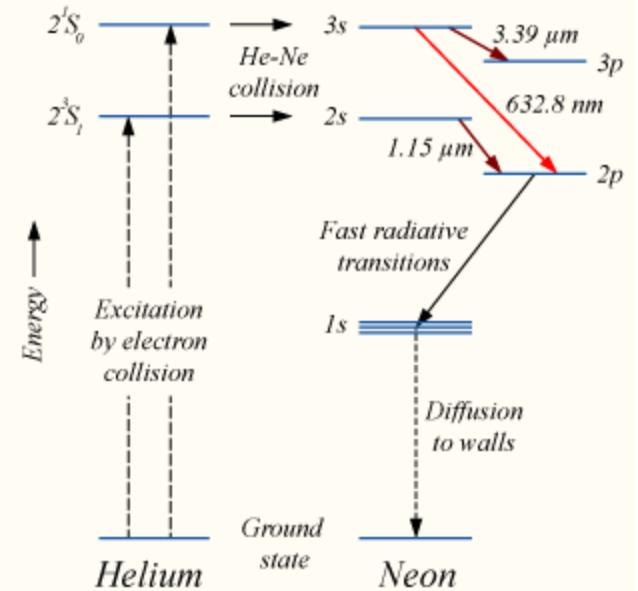
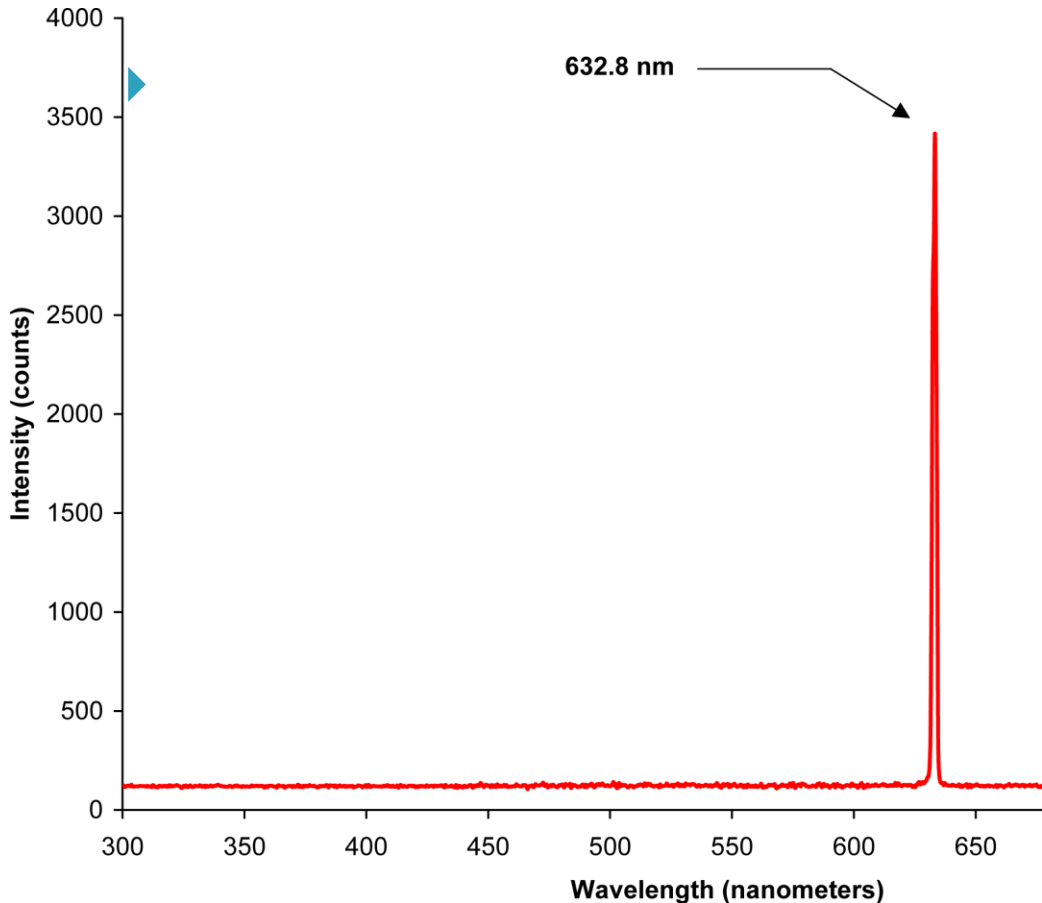
- ▶ degenerarea nivelelor energetice duce la aparitia benzilor energetice
- ▶ Multitudinea de tranzitii posibile intre cate doua nivele situate in benzi energetice diferite duce la largirea caracteristicii spectrale a surselor



$$\lambda_0 \rightarrow \left[ \lambda_0 - \frac{\Delta\lambda}{2}, \lambda_0 + \frac{\Delta\lambda}{2} \right]$$

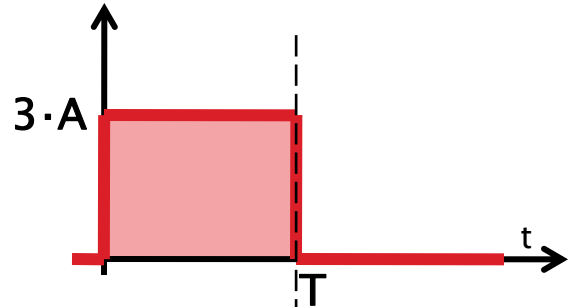


# He-Ne Laser

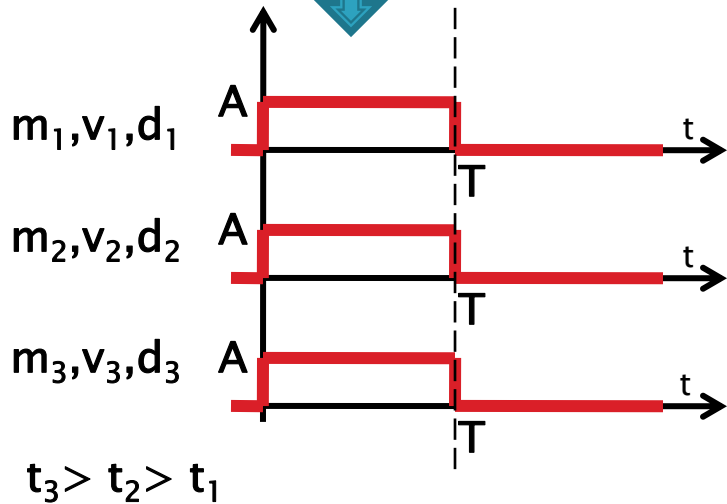


$$\Delta\lambda = 0.002 \text{ nm}$$

# Dispersia modala

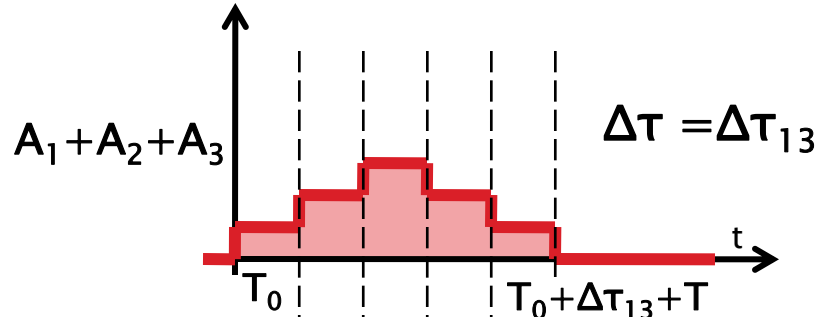


Impartire energie pe moduri

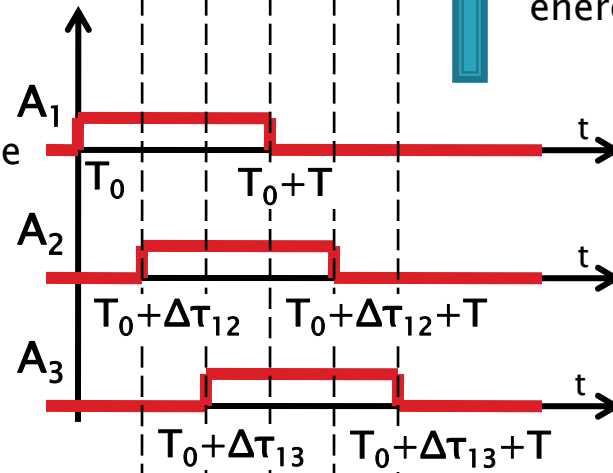


Transmisie cu viteze, distante diferite

$t_3 > t_2 > t_1$

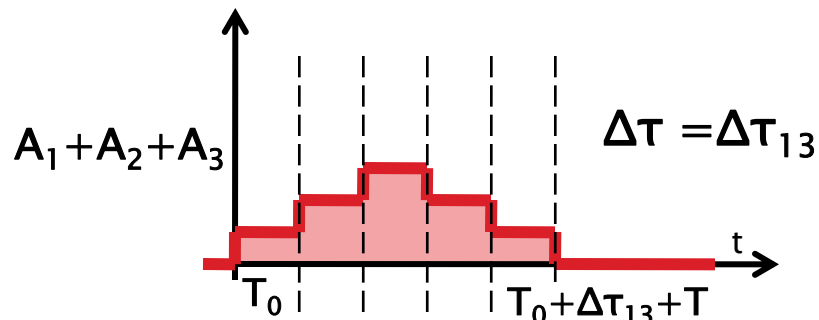
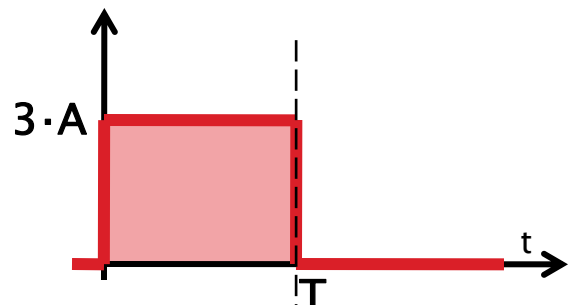


Recombinarea energiei modurilor

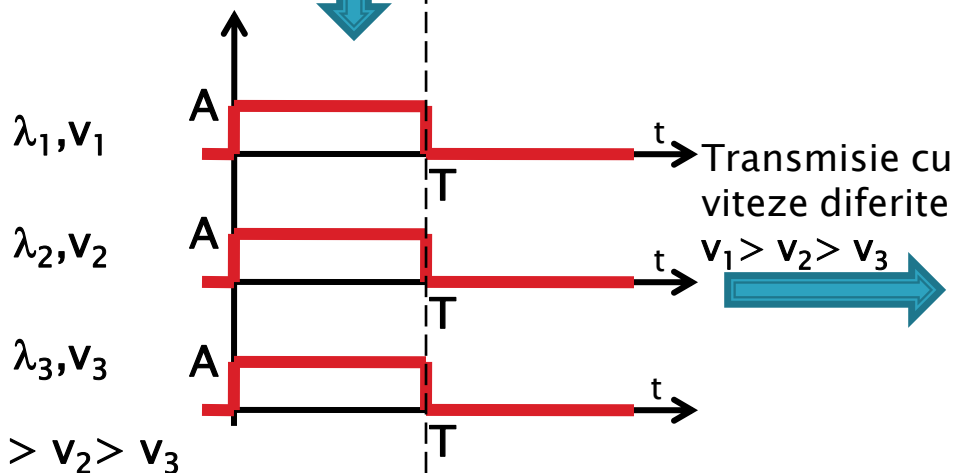


Conceptual  $\rightarrow f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$

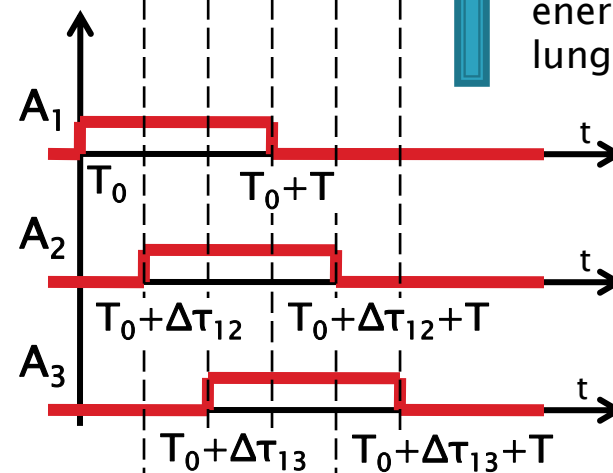
# Dispersia cromatica (gh+mat)



Impartire energie pe lungimi de unda



Recombinarea energiei la diferite lungimi de unda

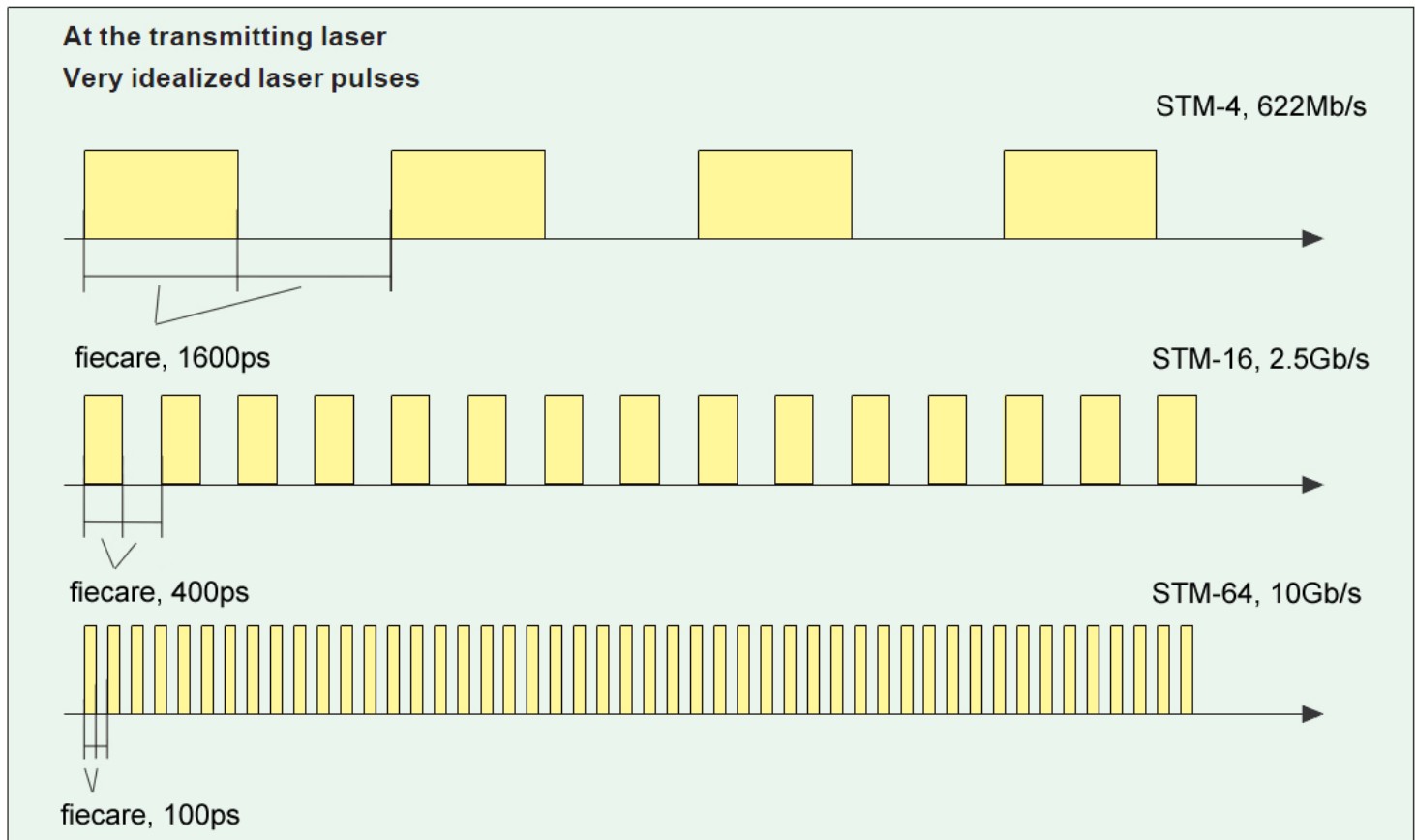


Efectiv  $\rightarrow f(t) = \int_{-\infty}^{\infty} g(\omega) \cdot e^{j\omega t} d\omega$



# Dispersie exemplu - 1

- ▶ transmisii cu viteze diferite



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

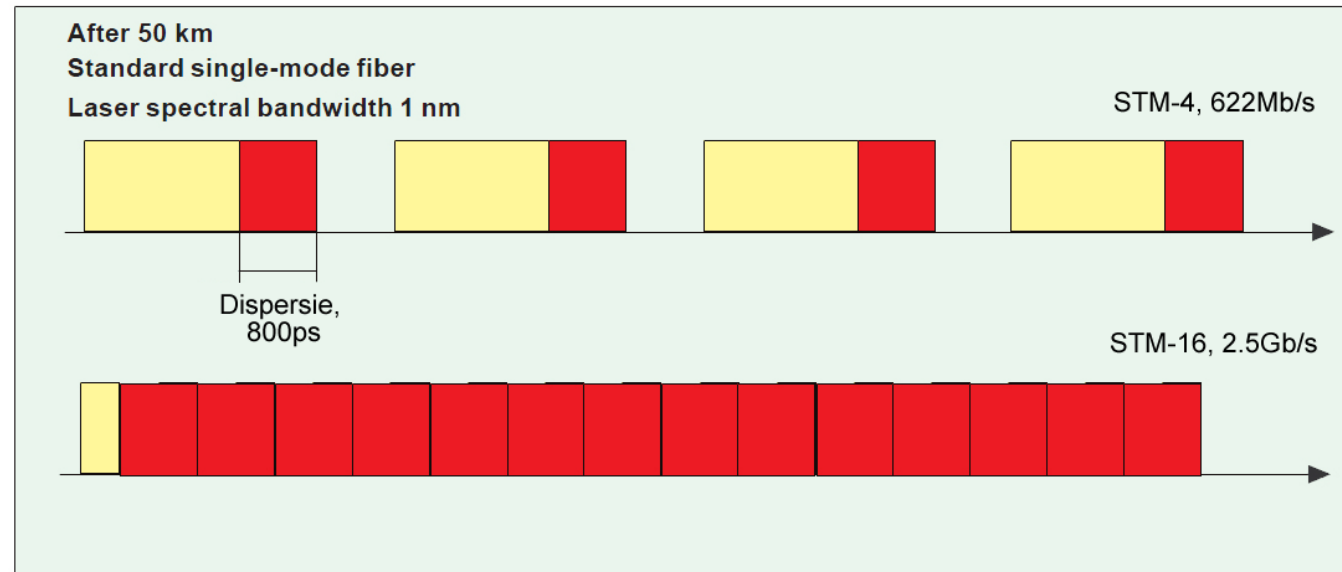
# Dispersie exemplu - 2

▶ 1550nm

▶ Efectul sursei

- fibra monomod cu dispersia 16ps/nm/km@1550
- latimea spectrala a sursei  $\Delta\lambda=1$  nm
- 50km

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



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

$$\Delta\tau_{cr} = 16 \cdot 1 \cdot 50 \text{ ps} = 800 \text{ ps}$$

$$[\Delta\tau_{cr}] = \frac{\text{ps}}{\text{nm} \cdot \text{km}} \cdot \text{nm} \cdot \text{km} = \text{ps}$$

$$100 < 400 < 800 < 1600$$

# Dispersie exemplu – 3

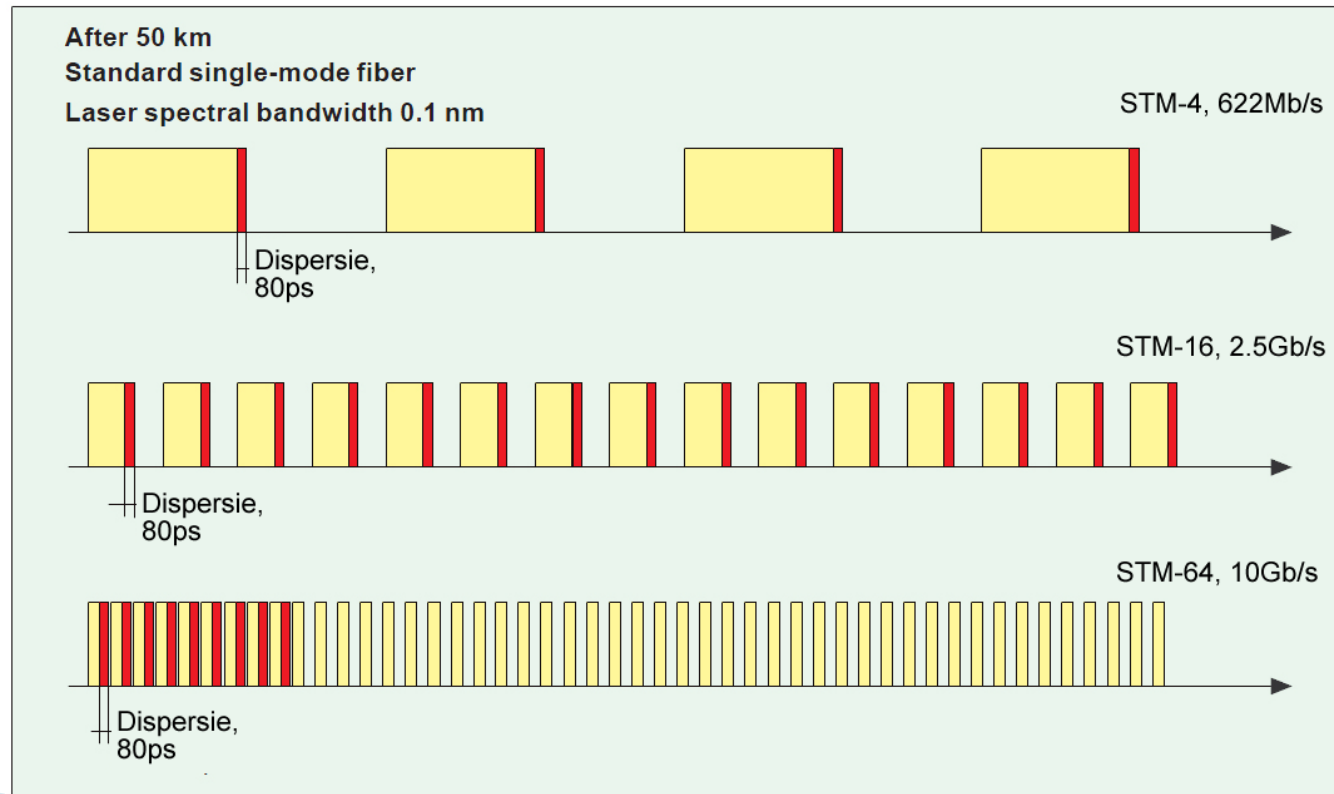
- ▶ 1550nm
- ▶ Efectul sursei
  - fibra monomod cu dispersia 16ps/nm/km@1550
  - latimea spectrala a sursei  $\Delta\lambda=0.1\text{ nm}$
  - 50km

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

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

$$\Delta\tau_{cr} = 16 \cdot 0.1 \cdot 50 \text{ ps} = 80 \text{ ps}$$

$$[\Delta\tau_{cr}] = \frac{\text{ps}}{\text{nm} \cdot \text{km}} \cdot \text{nm} \cdot \text{km} = \text{ps}$$



$$100 \approx 80 < 400 < 1600$$

# Dispersie exemplu - 4

## ▶ Efectul fibrei

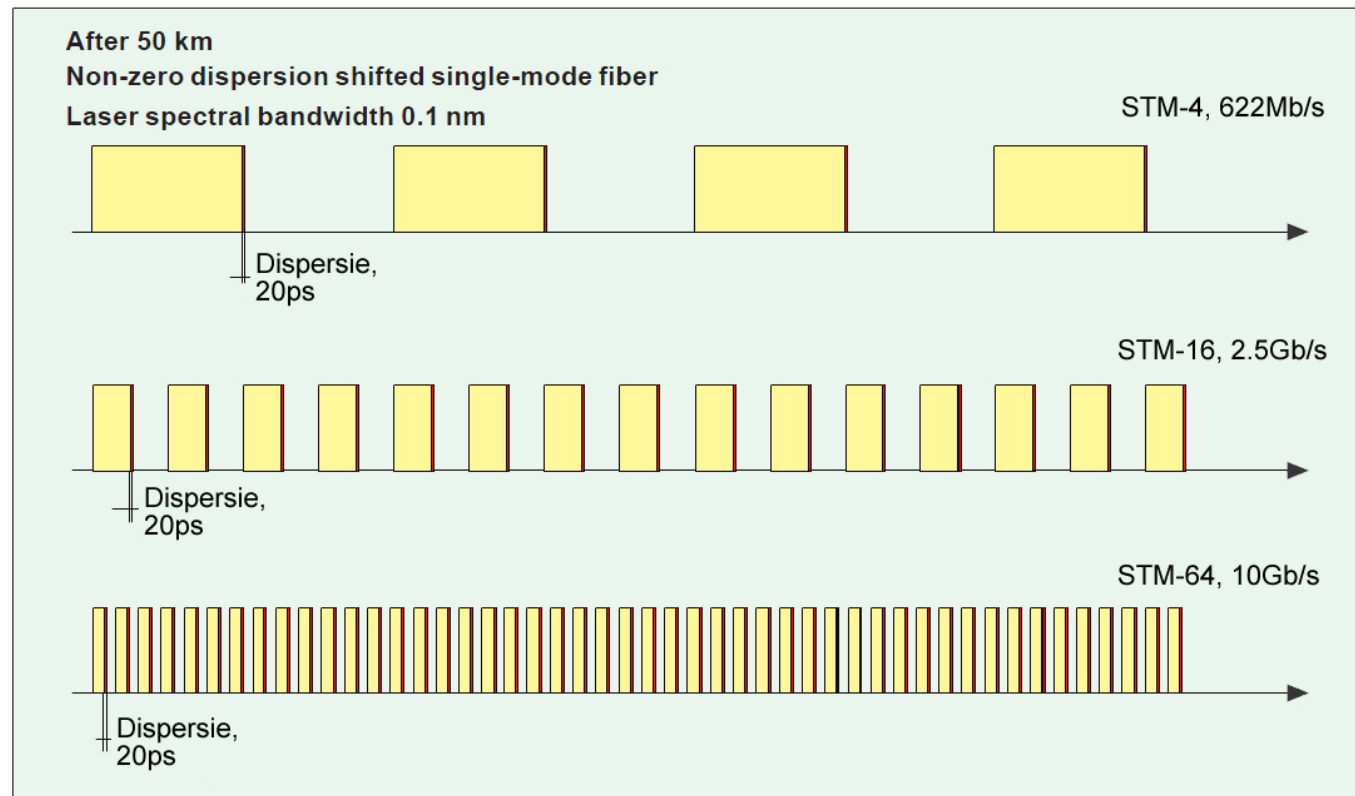
- fibra cu dispersie deplasata: **4ps/nm/km@1550**
- latimea spectrala a sursei  $\Delta\lambda=0.1\text{ nm}$
- 50km

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

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

$$\Delta\tau_{cr} = 4 \cdot 0.1 \cdot 50 \text{ ps} = 20 \text{ ps}$$

$$[\Delta\tau_{cr}] = \frac{\text{ps}}{\text{nm} \cdot \text{km}} \cdot \text{nm} \cdot \text{km} = \text{ps}$$



20 < 100 < 400 < 1600

# Dispersie exemplu - 5

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

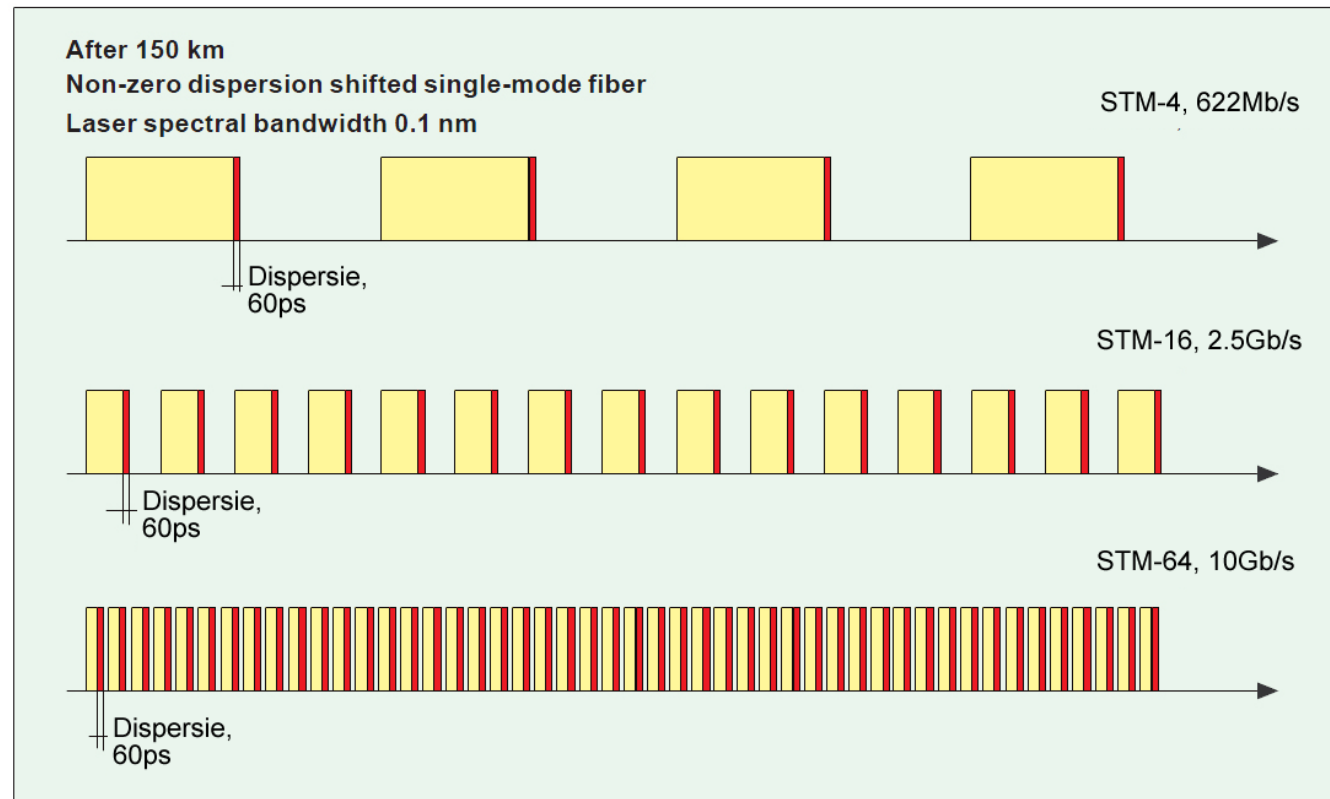
## ► Efectul fibrei

- fibra cu dispersie deplasata: 4ps/nm/km@1550
- latimea spectrala a sursei  $\Delta\lambda=0.1$  nm
- **150km**

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

$$\Delta\tau_{cr} = 4 \cdot 0.1 \cdot 150 \text{ ps} = 60 \text{ ps}$$

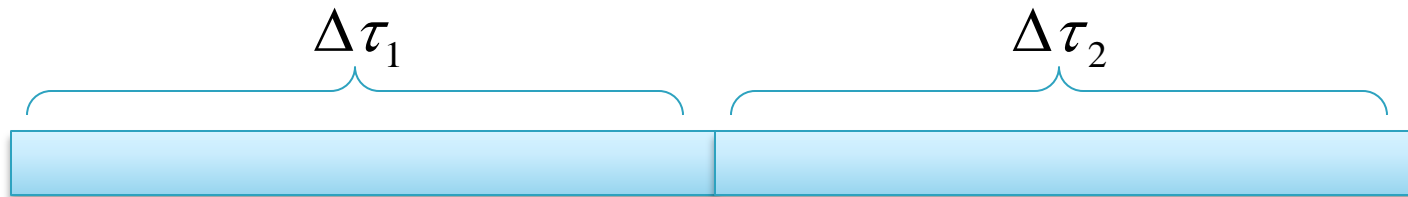
$$[\Delta\tau_{cr}] = \frac{\text{ps}}{\text{nm} \cdot \text{km}} \cdot \text{nm} \cdot \text{km} = \text{ps}$$



60 < 100 < 400 < 1600

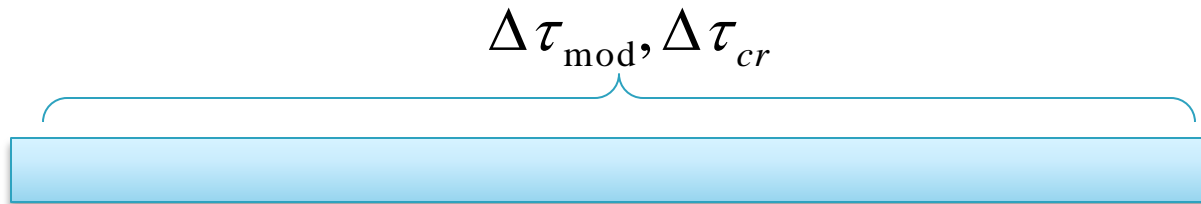
# Sumarea efectelor

- ▶ efecte **succesive** se adună liniar



$$\Delta\tau_{tot} = \Delta\tau_1 + \Delta\tau_2$$

- ▶ efecte **simultane** se adună pătratic



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

# Dispersia

## ▶ Dispersia modala

### ▶ salt de indice

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

### ▶ indice gradat

$$\Delta\tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta^2}{4\sqrt{3} \cdot c} \cong \frac{L \cdot NA^4}{16\sqrt{3} \cdot c \cdot n_2^3}$$

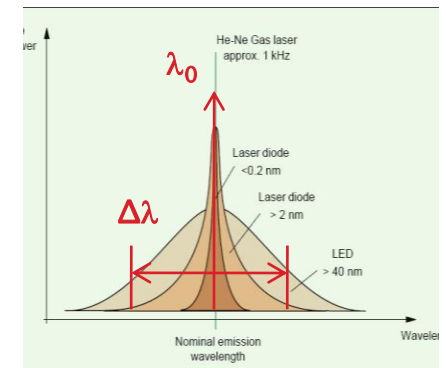
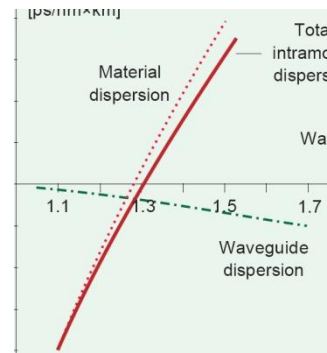
$$\Delta = 0.01 \div 0.02 \ll 1$$

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

## ▶ Dispersia cromatica

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

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



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

# Banda

- ▶ Dispersia totala

$$\Delta\tau_{tot} = \sqrt{\Delta\tau_{cr}^2 + \Delta\tau_{mod}^2} \quad \text{sau} \quad \Delta\tau_{tot} = \Delta\tau_1 + \Delta\tau_2$$

- ▶ Banda

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

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

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

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

- ▶ Viteza legaturii

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



# Produs Banda · Distanta

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

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

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

$$\Delta\tau_{\text{tot}} = \text{const} \cdot L$$

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

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

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

$$V [\text{Gb/s}] \cong \frac{\text{const}}{L}$$

$$V [\text{Gb/s}] \cdot L [\text{km}] \cong \text{const}$$

# Produs Banda · Distanta

$$\Delta\tau_{\text{mod}} \sim L$$

$$\Delta\tau_{\text{cr}} \sim L$$

$$\Delta\tau_{\text{tot}} \sim L$$

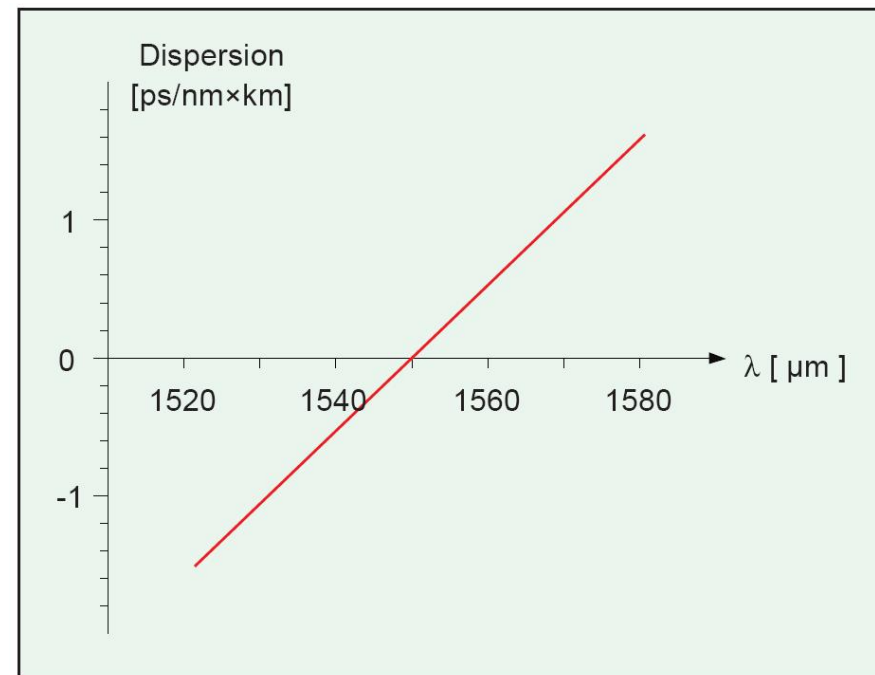
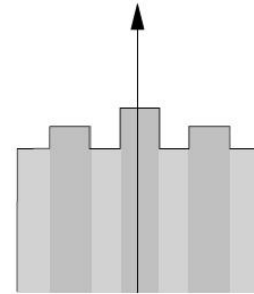
$$V[\text{Gb/s}] \sim B_{\text{el}}[\text{GHz}] \sim \frac{1}{\Delta\tau_{\text{tot}}} \sim \frac{1}{L[\text{km}]}$$

$$V[\text{Gb/s}] \times L[\text{km}] = \text{ct.}$$

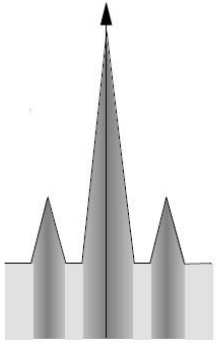
$$B_{\text{el}}[\text{MHz}] \times L[\text{km}] = \text{ct.}$$

# Dispersion shifted fibers

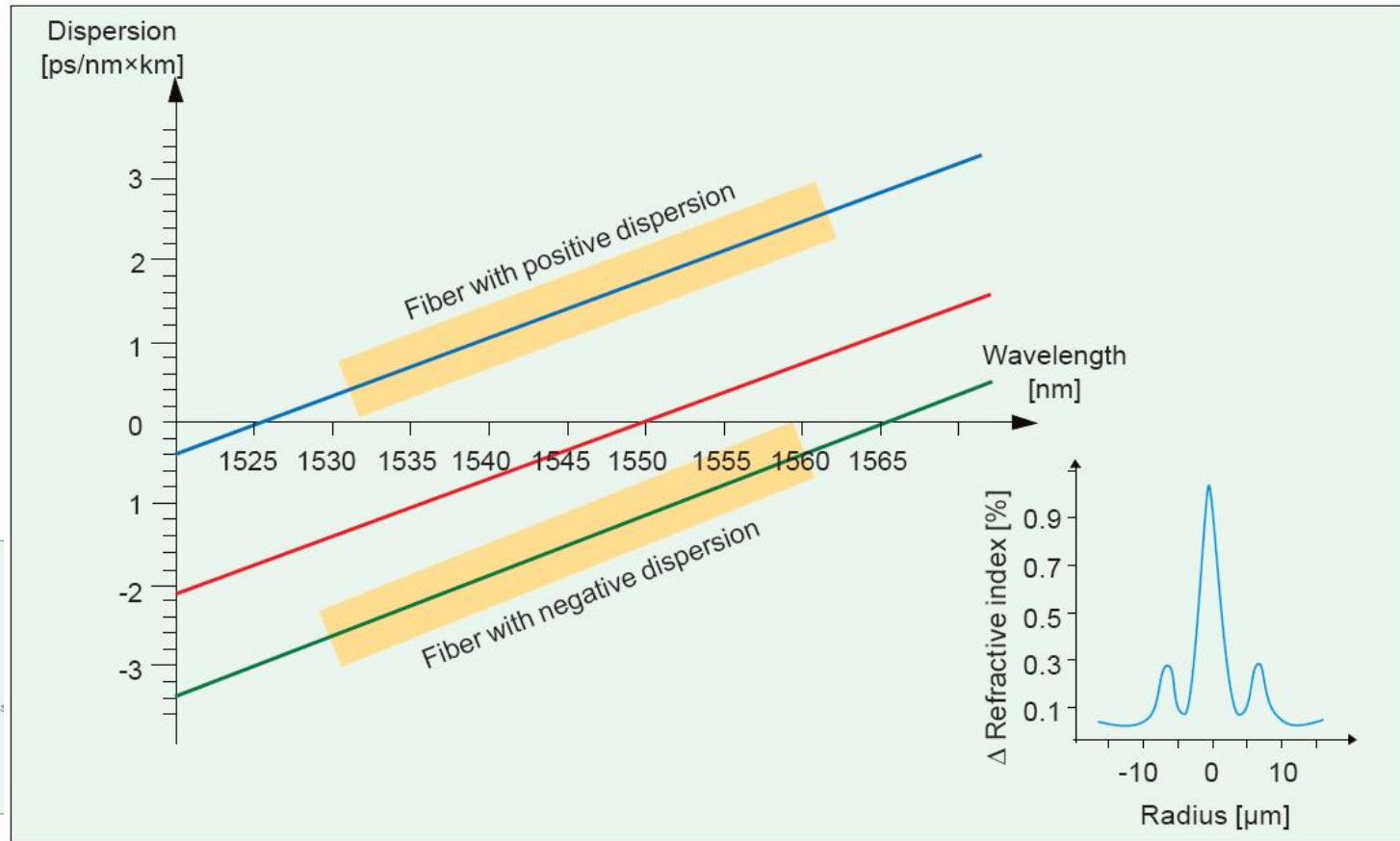
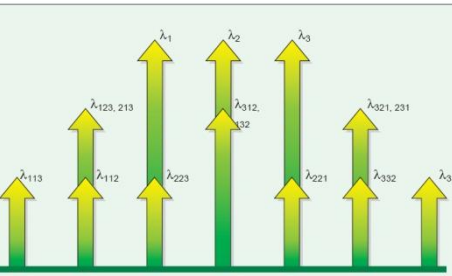
- ▶ Sticla are (nativ) dispersie cromatica 0 la 1310nm
- ▶ Atenuarea e mai mica la 1550 nm
- ▶ EDFA (Erbium doped fibre amplifiers) opereaza in banda 1550nm
- ▶ Sistemele WDM (Wavelength division Multiplexing) necesita banda larga amplificata



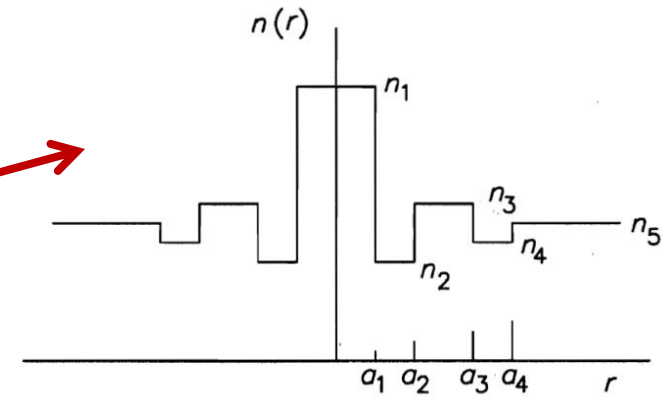
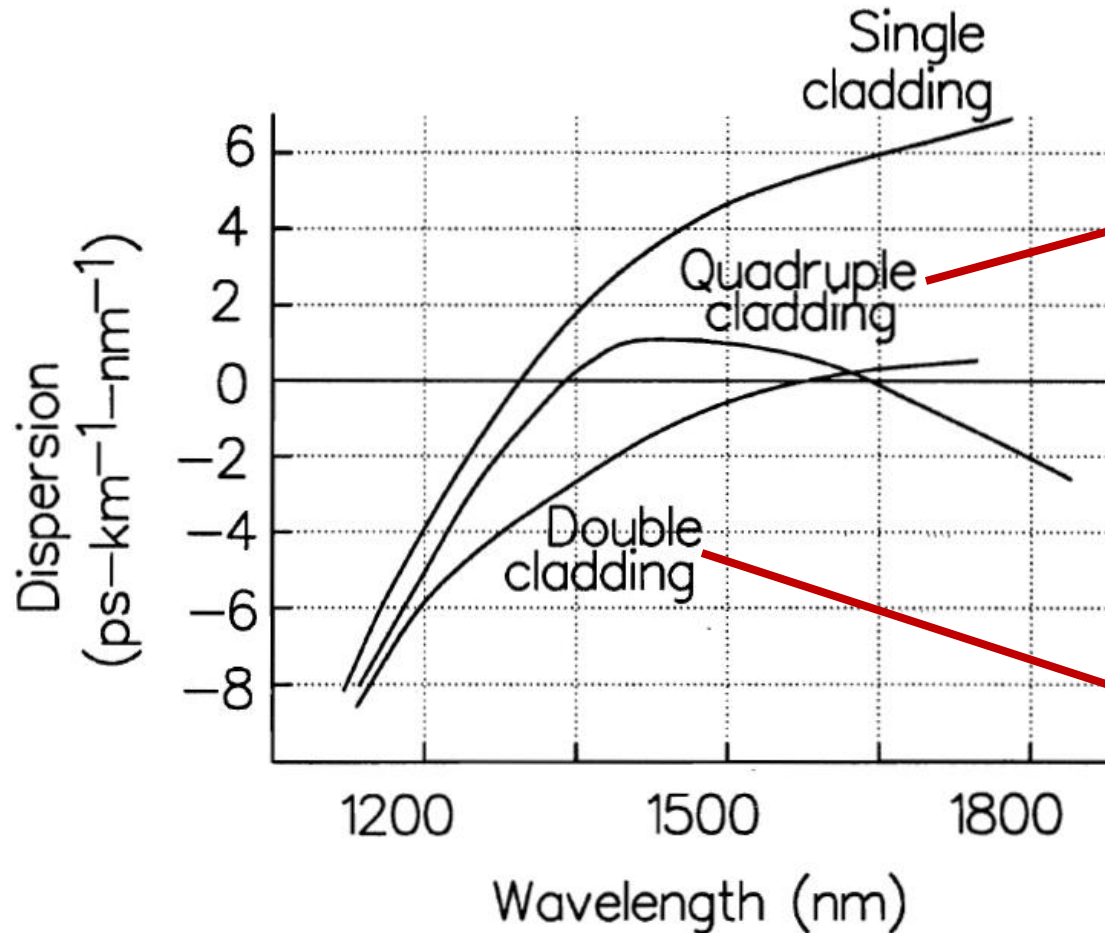
# Non-zero Dispersion shifted fibers



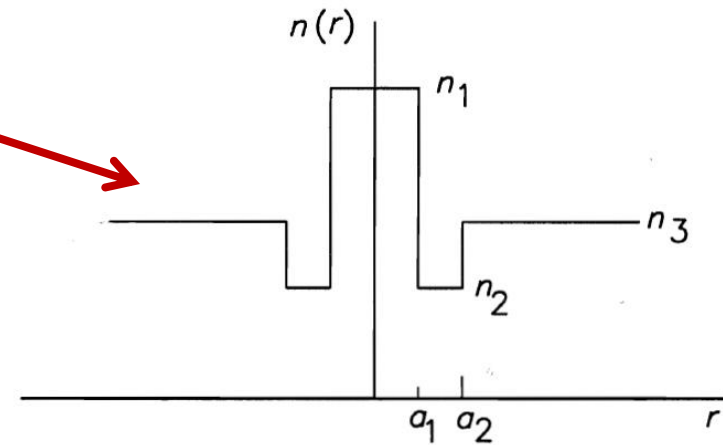
FWM



# Dispersion shifted fibers

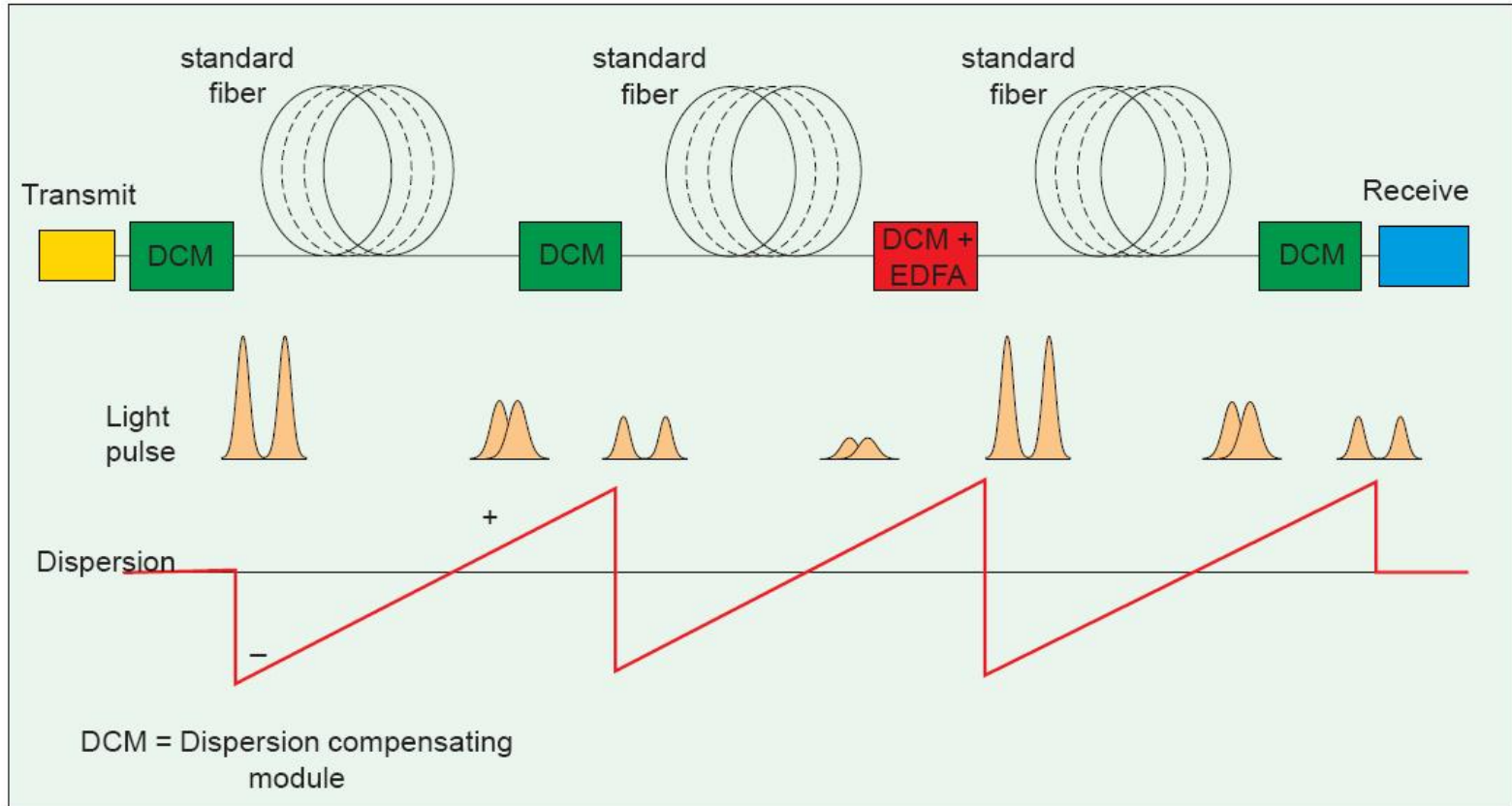


(b)



(a)

# Fibra pentru compensarea dispersiei



- ▶ Dispersie:  $-100 \text{ ps/nm/km}$
- ▶ Atenuare  $0.5 \text{ dB/km}$

# Catalog – monomod

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

## Mechanical Specifications

### Proof Test

The entire fiber length is subjected to a tensile stress  $\approx 100$  kpsi (0.7 GPa)\*.  
\*Higher proof test levels available.

### Length

Fiber lengths available up to 50.4\* km/spool.  
\*Longer optical lengths available.

## Performance Characterizations

Characterized parameters are typical values.

Core Diameter	8.2 $\mu$ m
Numerical Aperture	0.14 <i>NA is measured as the one percent power level of a one-dimensional intensity profile at 1310 nm.</i>
Zero Dispersion Wavelength ( $\lambda_0$ )	1317 nm
Zero Dispersion Slope ( $S_0$ )	0.088 ps/(nm <sup>2</sup> ·km)
Effective Group Index at Wavelength ( $N_e$ )	1310 nm: 1.4670 1550 nm: 1.4675
Fatigue Resistance Parameter ( $N_f$ )	20
Coating Strip Force	Dry: 0.6 lbs. (3N) Wet, 14-day room temperature: 0.6 lbs. (3N)
Rayleigh Backscatter Coefficient (for 1m Pulse Width)	1310 nm: -77 dB 1550 nm: -82 dB
Stimulated Brillouin Scattering Threshold	20 dBm <sup>0</sup>

Notes:  
(1) When characterized with a transmitter specifying 17 dBm SBS threshold over standard single-mode fiber. While absolute SBS threshold is a function of distance and signal format, NextCore fiber offers a 3 dB improvement over standard single-mode fiber independent of these variables.

## Formulas

### Dispersion

$$\text{Dispersion} = D(\lambda) = \frac{S_0}{4} \cdot \left[ \lambda - \frac{\lambda_0^4}{\lambda^3} \right] \text{ ps/(nm}^2\text{·km)}$$

for 1200 nm  $\leq$   $\lambda$   $\leq$  1625 nm  
 $\lambda$  = Operating Wavelength

### Cladding Non-Circularity

$$\text{Non-Circularity} = \left[ \frac{\text{Min. Cladding Diameter}}{\text{Max. Cladding Diameter}} \right] \times 100$$

### How to Order

Contact your sales representative, or call the Optical Fiber Customer Service Department.  
Ph: 607-248-2000 (U.S. and Canada)  
+44-1244-287-437 (Europe)  
Email: opticalfibers@corning.com  
Please specify the fiber type, attenuation and quantity when ordering.

Corning Incorporated  
www.corning.com/opticalfiber  
One Riverfront Plaza  
Corning, NY 14831  
U.S.A.  
Ph: 800-525-5724 (U.S. and Canada)  
607-786-8125 (International)  
Fax: 800-539-3632 (U.S. and Canada)  
607-786-8344 (International)  
Email: corning.com

Europe  
Ph: 00 800 6620 6621 (U.K., Ireland, France, Germany, The Netherlands, Spain and Sweden)  
+1 607 248 2000 (All Other Countries)  
Fax: 00 44 1244 287 437  
Tel: 00 44 1244 287 437

Asia Pacific  
Australia  
Ph: 1-800-148-690  
Fax: 1-800-148-568

Indonesia  
Ph: 001-800-015-721-1261  
Fax: 001-800-015-721-1262

Malaysia  
Ph: 1-800-80-3156  
Fax: 1-800-80-3155

Philippines  
Ph: 1-800-1-116-0338  
Fax: 1-800-1-116-0339

Singapore  
Ph: 800-1300-955  
Fax: 800-1300-956

Thailand  
Ph: 001-800-1-1-721-1261  
Fax: 001-800-1-1-721-1264

Latin America  
Brazil  
Ph: 000817-762-4732  
Fax: 000817-762-4996

Mexico  
Ph: 001-800-235-1719  
Fax: 001-800-339-1472

Venezuela  
Ph: 800-1-4418  
Fax: 800-1-4419

Greater China  
Email: CCCofic@corning.com

Beijing  
Ph: (86) 10-6505-5066  
Fax: (86) 10-6505-5077

Hong Kong  
Ph: (852) 2807-2723  
Fax: (852) 2807-2152

Shanghai  
Ph: (86) 21-3222-4608  
Fax: (86) 21-6288-1575

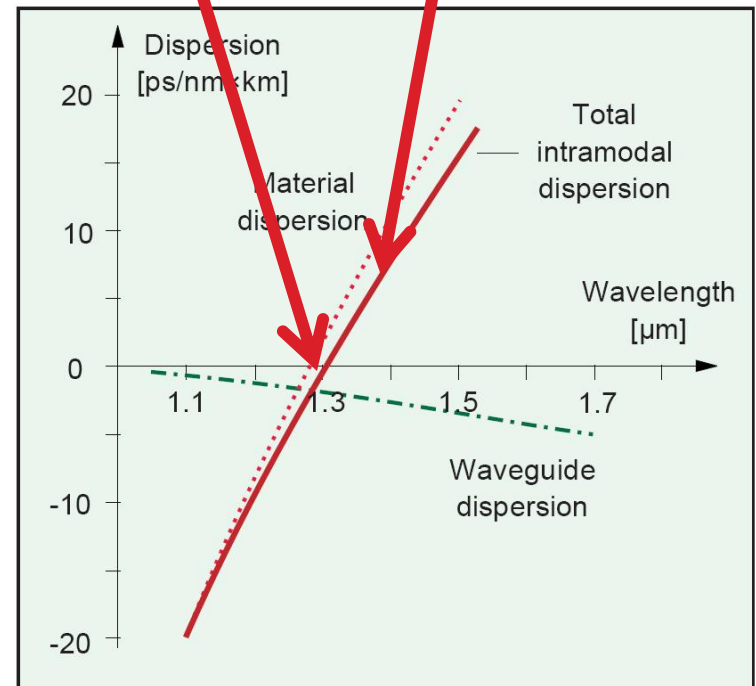
Taiwan  
Ph: (886) 2-2716-0338  
Fax: (886) 2-2716-0339

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jar-jveia scan at 1510 nm

Zero Dispersion Wavelength ( $\lambda_0$ )	1317 nm
Zero Dispersion Slope ( $S_0$ )	0.088 ps/(nm <sup>2</sup> ·km)
Effective Group Index at Wavelength ( $N_e$ )	1310 nm: 1.4670 1550 nm: 1.4675



# Catalog – multimod

## *Bandwidth*

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

+

Standard Bandwidth Cells	
850/1300 nm (MHz•km)	
	400/400
	400/600
	400/1200
	500/500
	600/600
	600/1000

*Other bandwidth cells available upon request.*



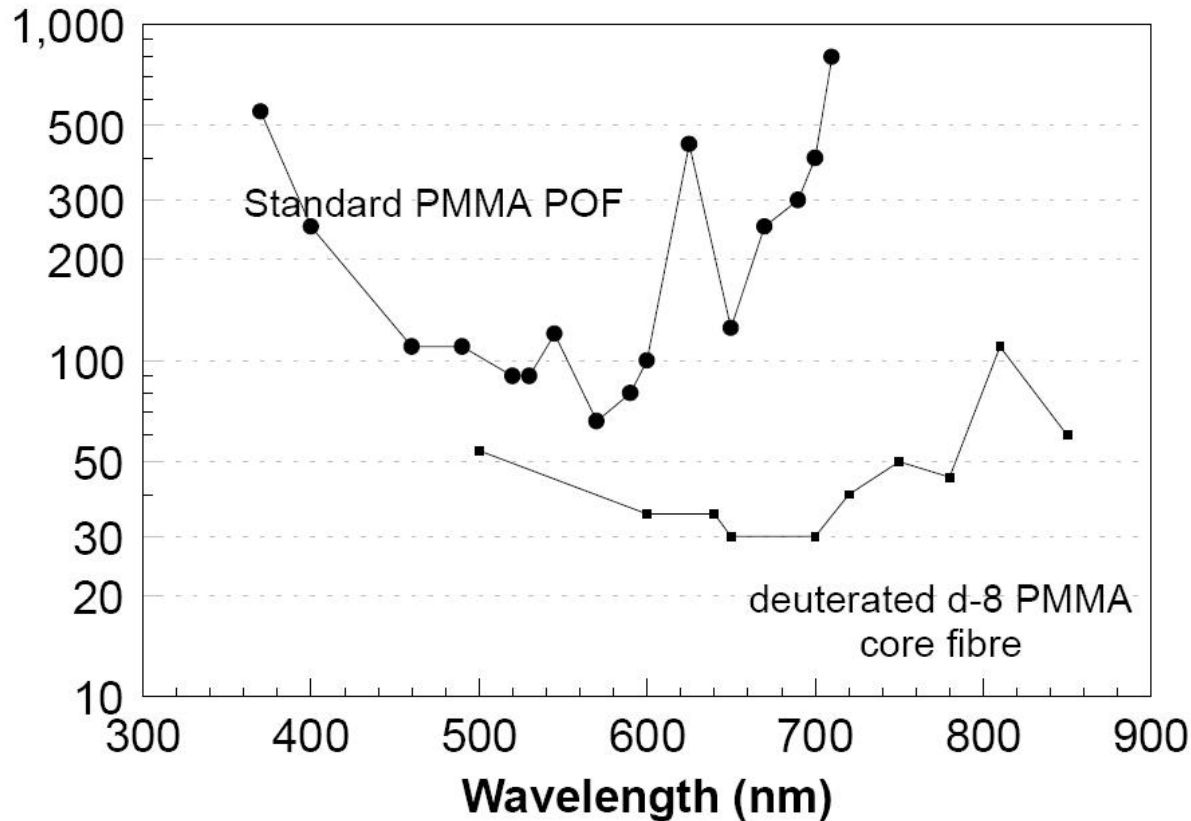
# Fibra standard ITU G.652

- ▶ Diametru teaca = 125  $\mu\text{m}$
- ▶ MFD = 9÷10  $\mu\text{m}$  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/nm<sup>2</sup>/km

ITU (International Telecommunication Union) is the United Nations specialized agency for information and communication technologies - ICTs

# Fibra optica din plastic (POF)

Attenuation dB/Km



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

# Fibra optică – Tehnologie

Capitolul 5

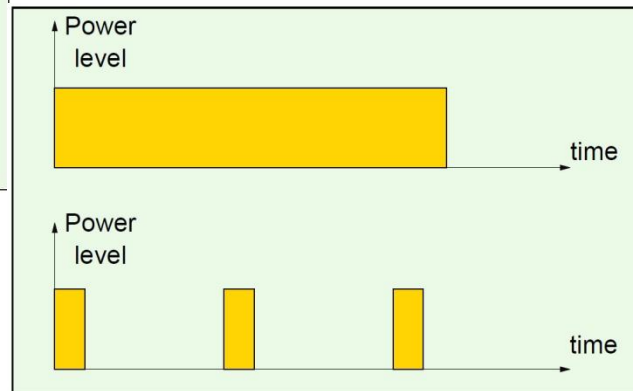
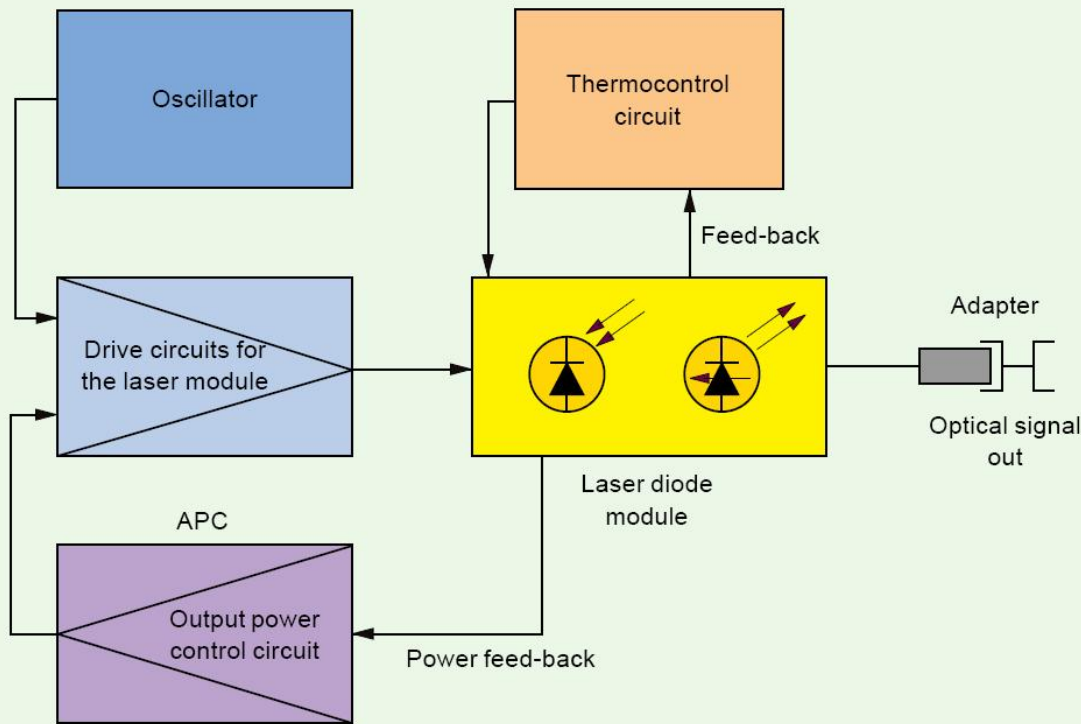
# Cuprins

- ▶ **Lumina ca undă electromagnetică** (ecuațiile lui Maxwell, ecuația undelor, parametri de propagare)
- ▶ **Elemente de fotometrie și radiometrie** (mărimi energetice/luminoase)
- ▶ **Fibra optică** (realizare, principiu de funcționare, atenuare, dispersie, banda de frecvență)
- ▶ **Cabluri optice** (tehnologie, conectori, lipire – splice)
- ▶ **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvență, balanța puterilor)
- ▶ **Emițătoare optice** (LED și dioda laser – realizare fizică și funcționare)
- ▶ **Receptoare optice** (dioda PIN, dioda cu avalanșă – realizare fizică și funcționare)
- ▶ **Amplificatoare transimpedanță** (parametri, scheme tipice, TIA în buclă deschisă, cu reacție, diferențiale, control automat al câștigului)
- ▶ **Realizarea circuitelor pentru controlul emițătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- ▶ **Dispozitive de captare a energiei solare** (principiu de funcționare, utilizare, proiectare )

# Stabilized light source

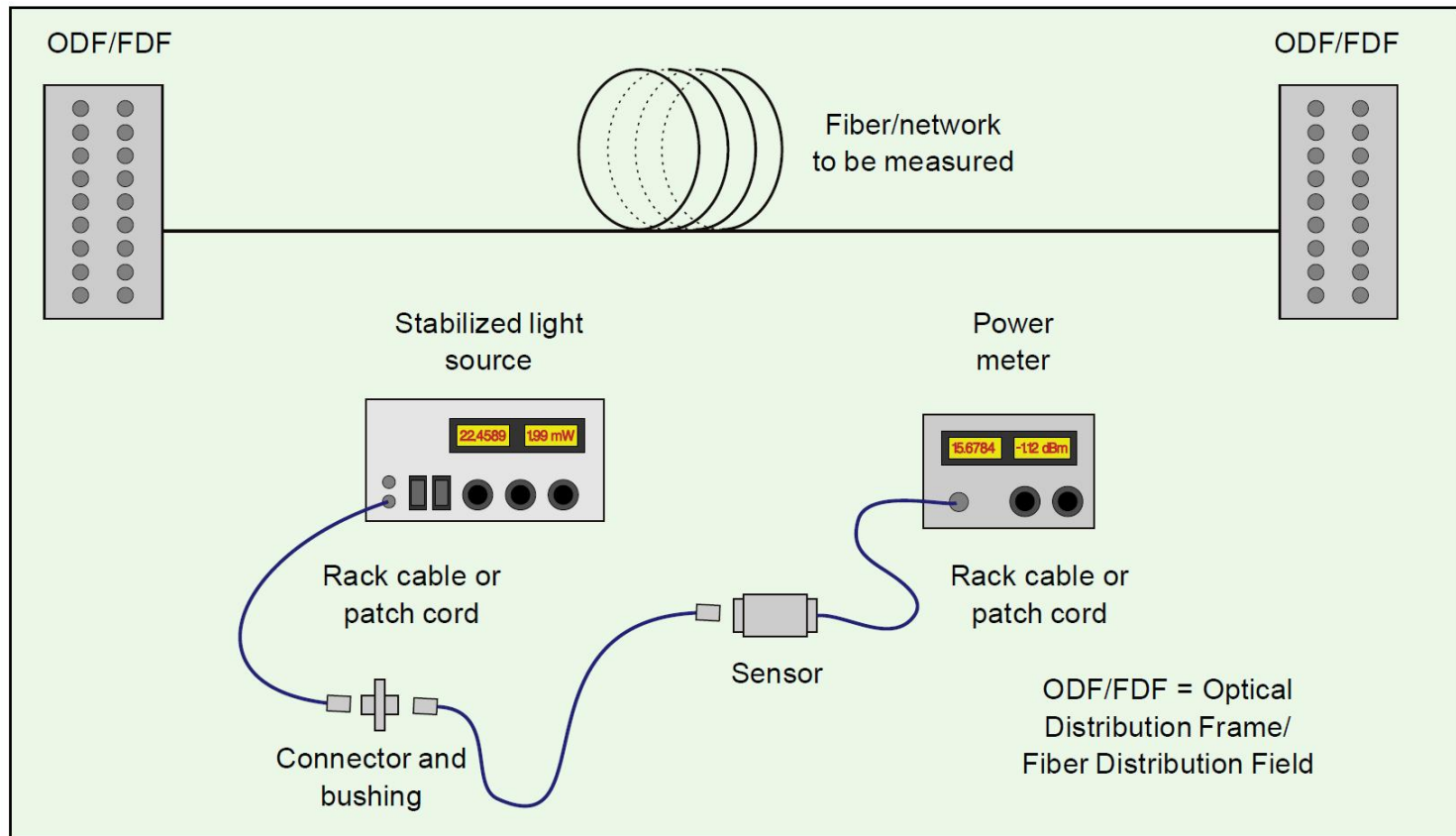
## Optical power meter

### ► Masurarea puterii si atenuarii



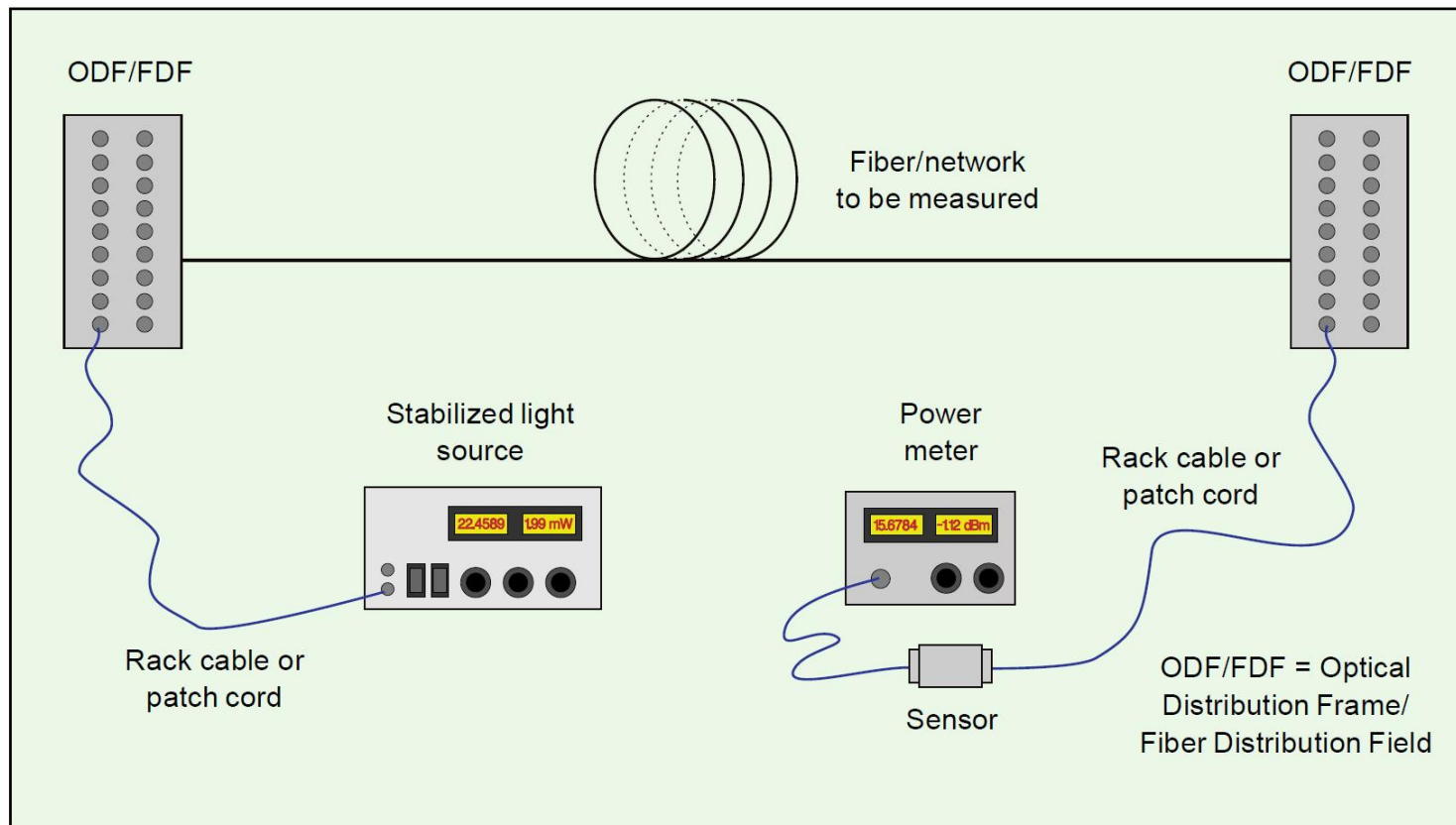
# Masurarea puterii si atenuarii

## ► Masuratoare referinta



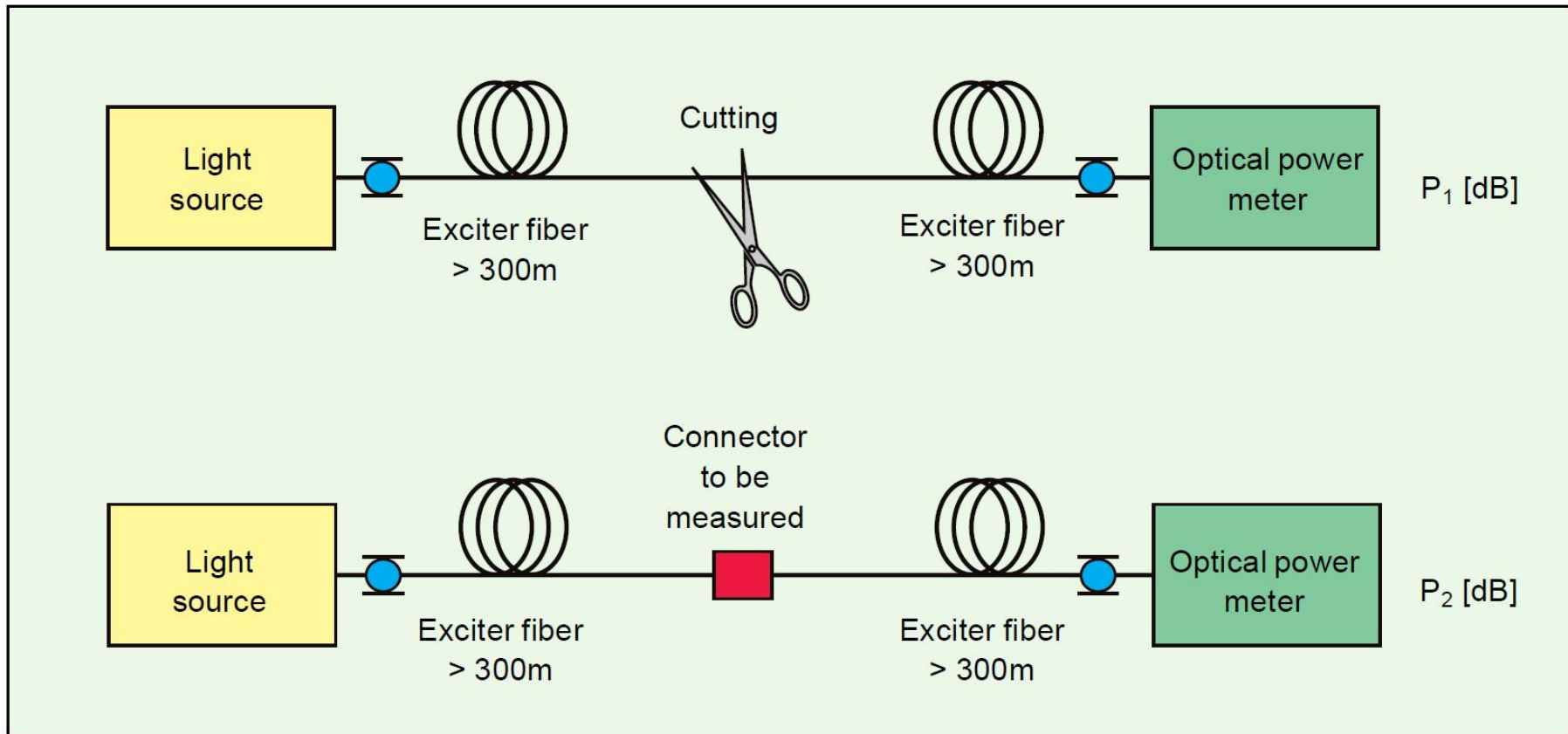
# Masurarea puterii si atenuarii

## ► Masuratoare instalatie



# Masurare conectori si splice

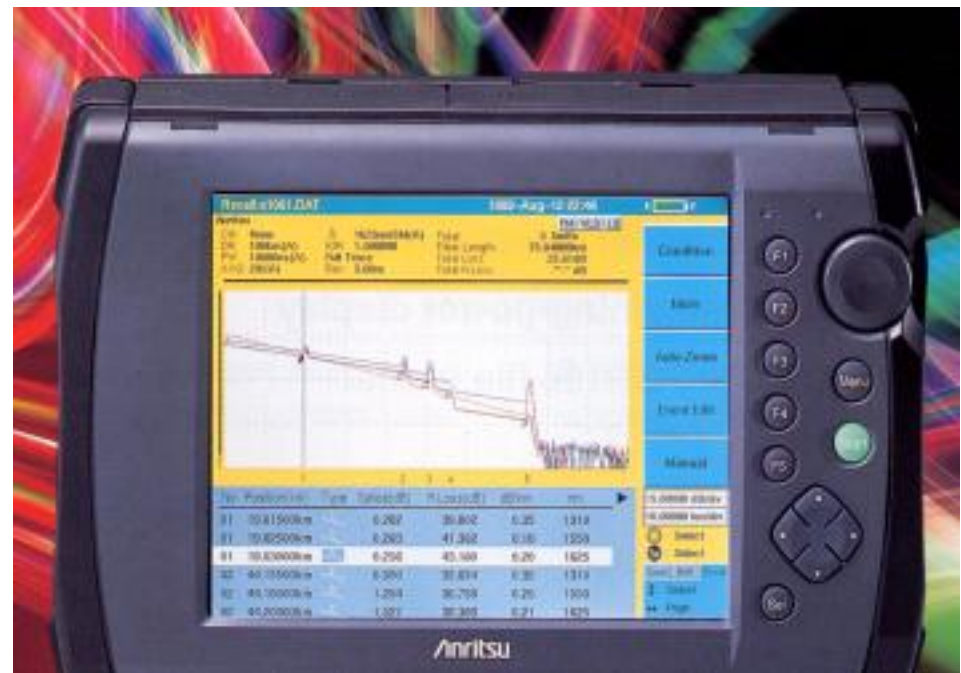
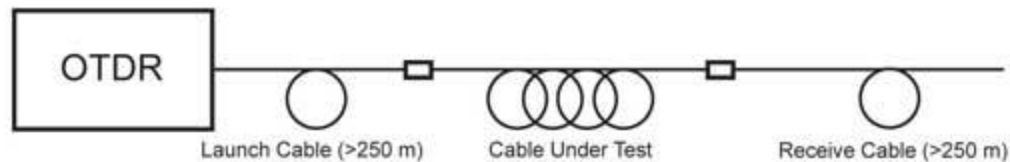
- ▶ Se elimina efectele fibrei





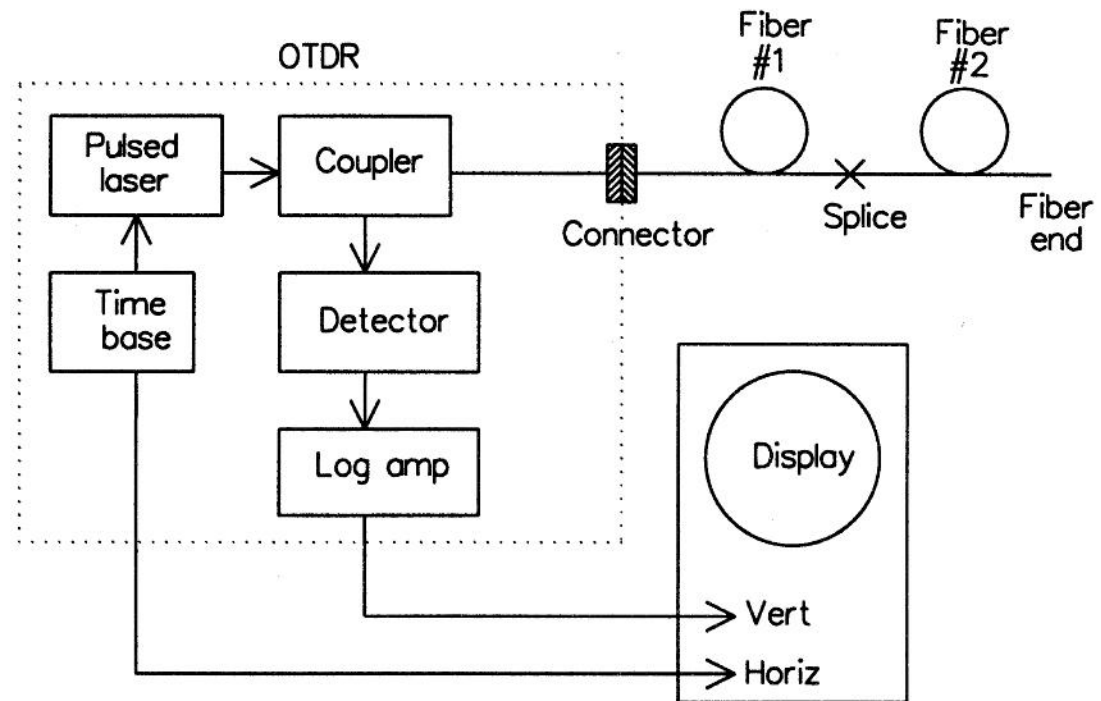
# OTDR

- ▶ Optical Time-Domain Reflectometer
- ▶ Localizarea defectelor

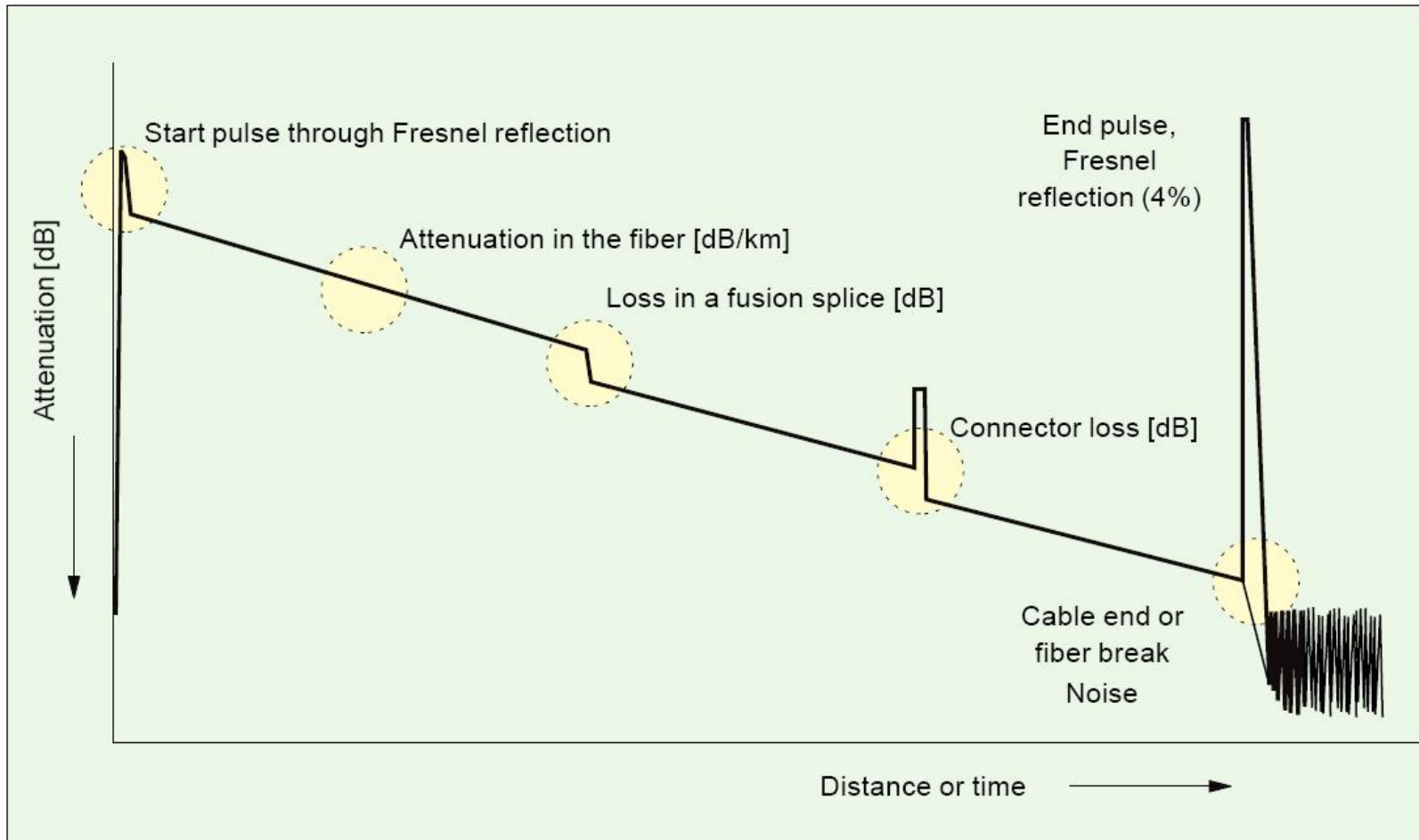


# OTDR

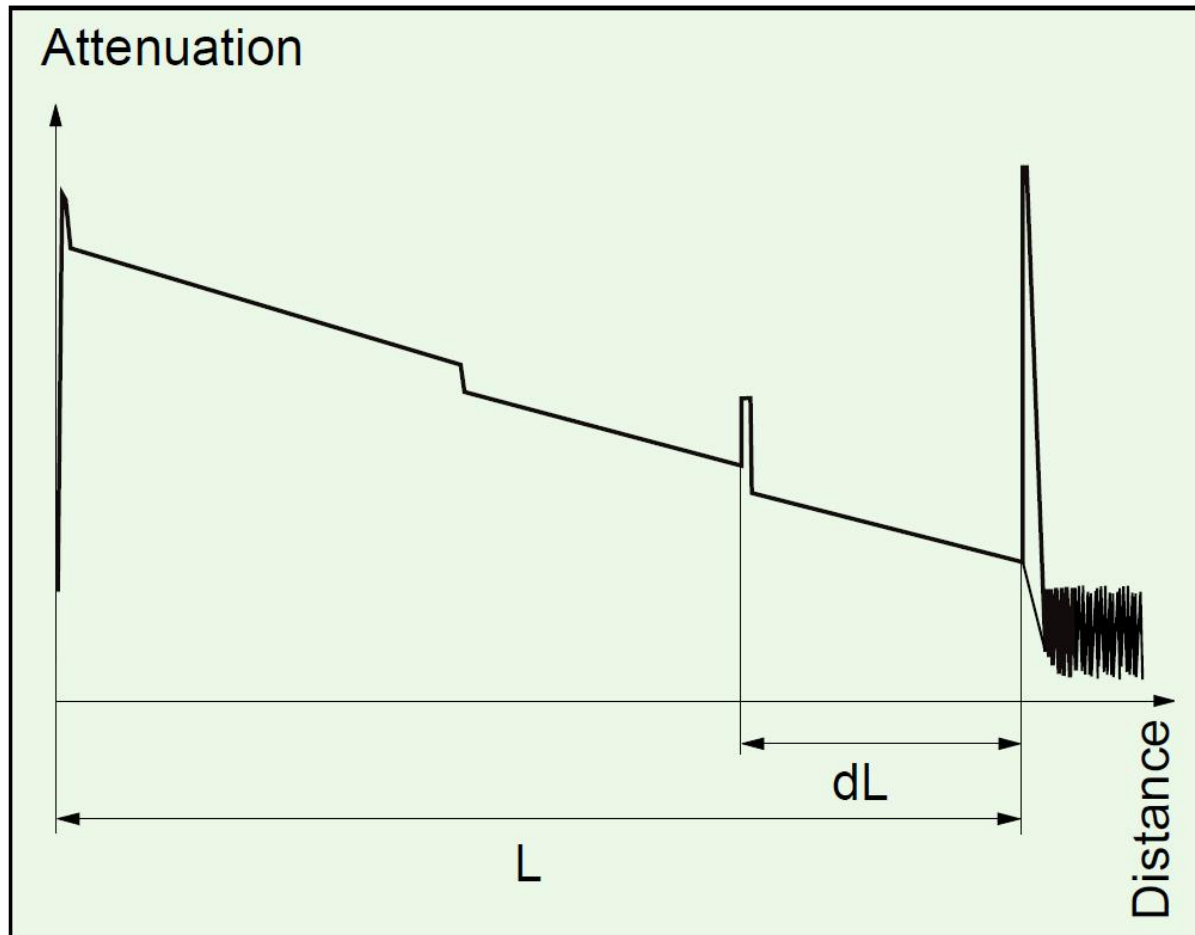
- ▶ Optical time-domain reflectometer
- ▶ Localizarea defectelor



# Rezultat grafic al OTDR



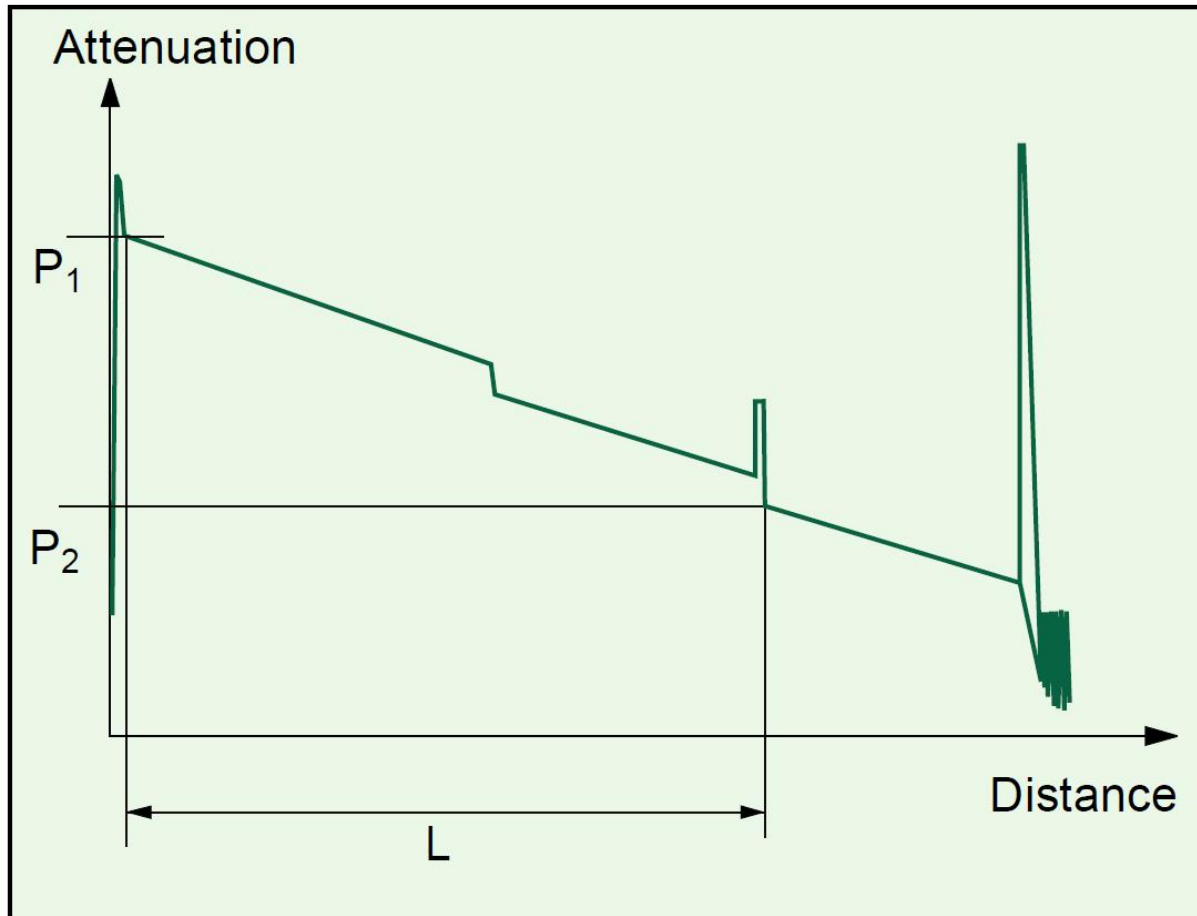
# Efecte vizibile OTDR



$$2 \cdot L = c \cdot t$$

$$L = \frac{c_0}{n} \cdot \frac{t}{2}$$

# Efecte vizibile OTDR



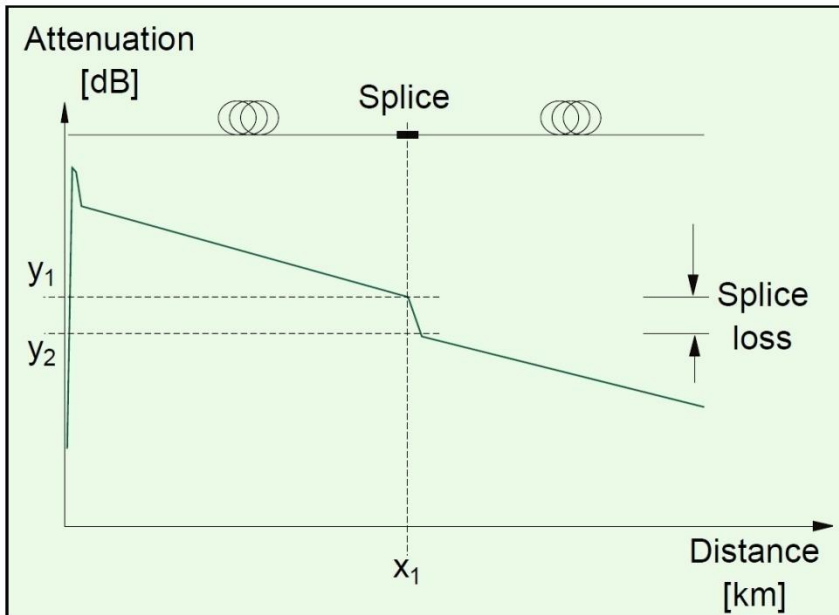
$$A[dB] = \frac{P_1 - P_2}{2}$$

$$A[dB / km] = \frac{P_1 - P_2}{2 \cdot L}$$

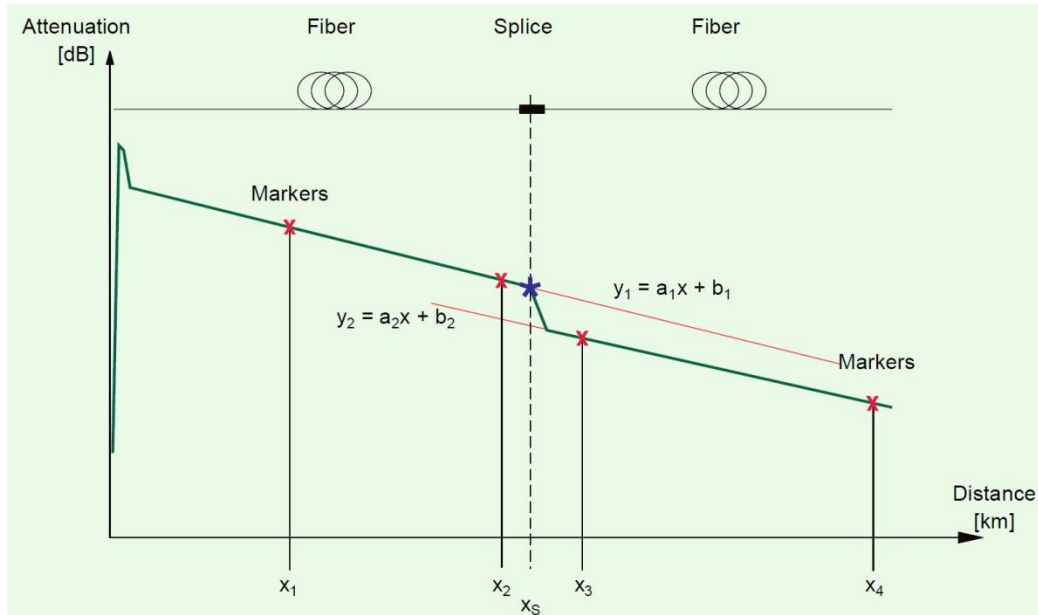
panta curbei

# Efecte vizibile OTDR - Splice

- ▶ splice loss -  $A(s)$



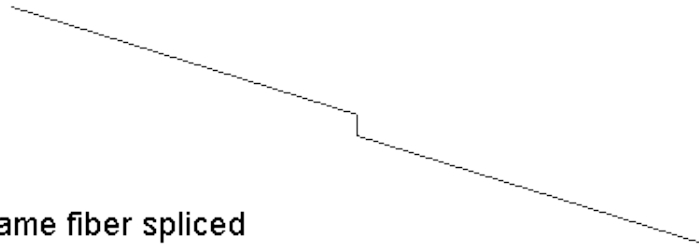
$$A(s) = y_1 - y_2$$



$$A(s) = y_1 - y_2 = x_s \cdot (a_1 - a_2) + (b_1 - b_2)$$

# Efecte vizibile OTDR – Splice

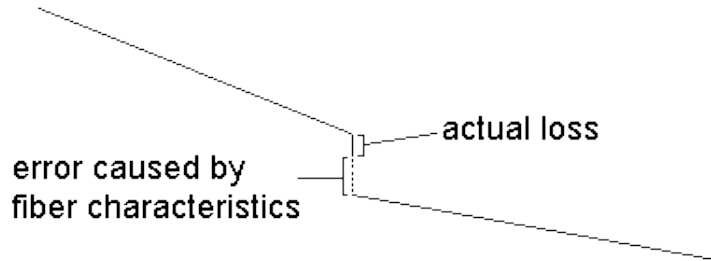
a. same fiber spliced



error caused by  
fiber characteristics

actual loss

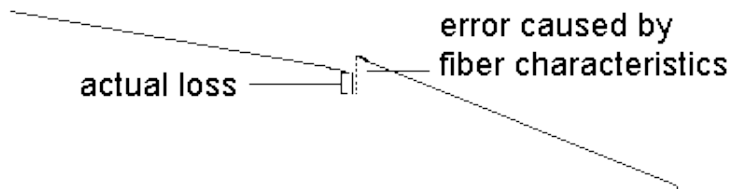
b. high loss fiber spliced to low loss fiber



error caused by  
fiber characteristics

actual loss

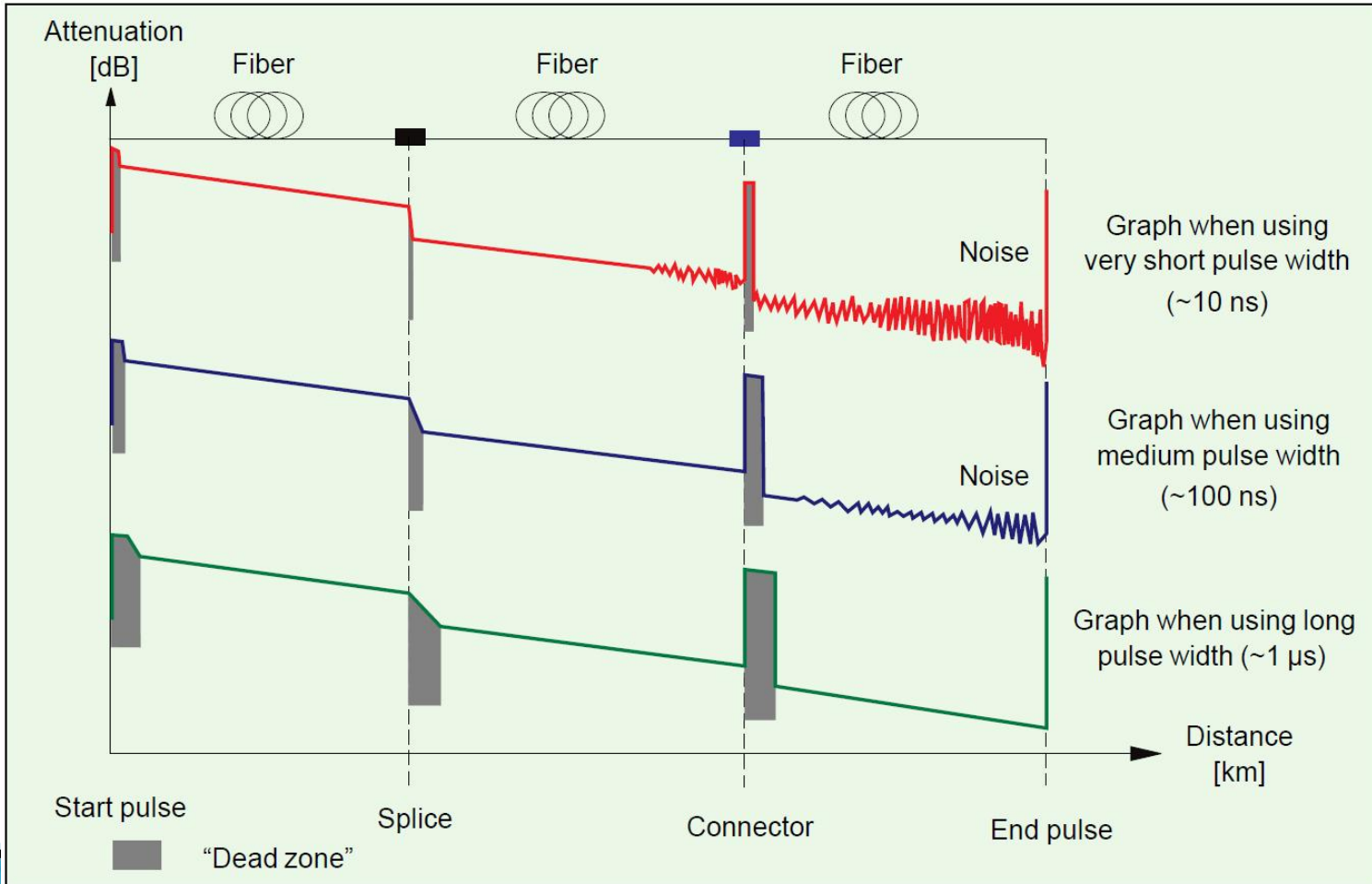
c. low loss fiber spliced to high loss fiber  
can cause an apparent gain at a splice



$$A(s) = \frac{A(s)_{A \rightarrow B} + A(s)_{B \rightarrow A}}{2}$$

# Rezultat grafic al OTDR

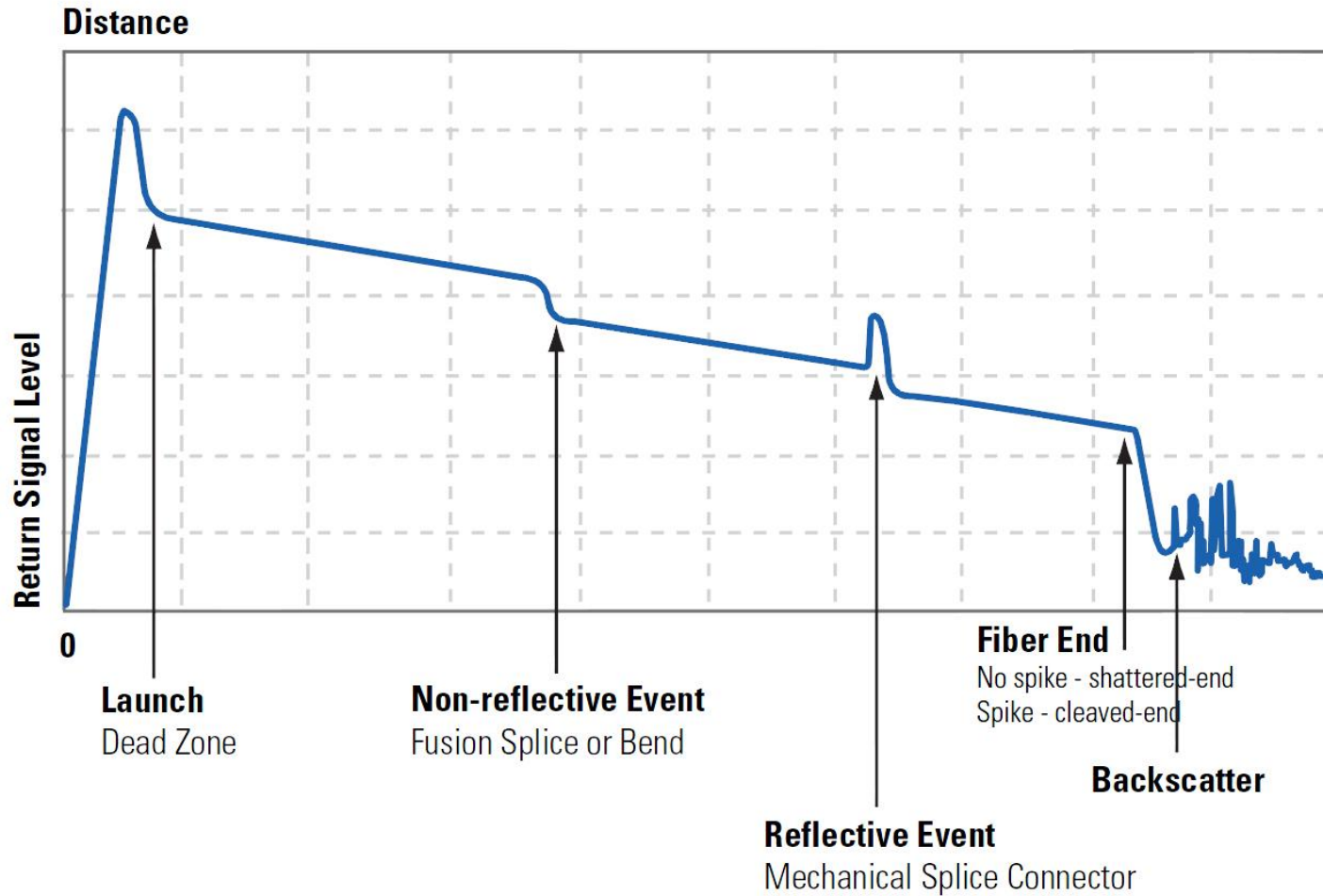
## ► latimea pulsurilor luminoase





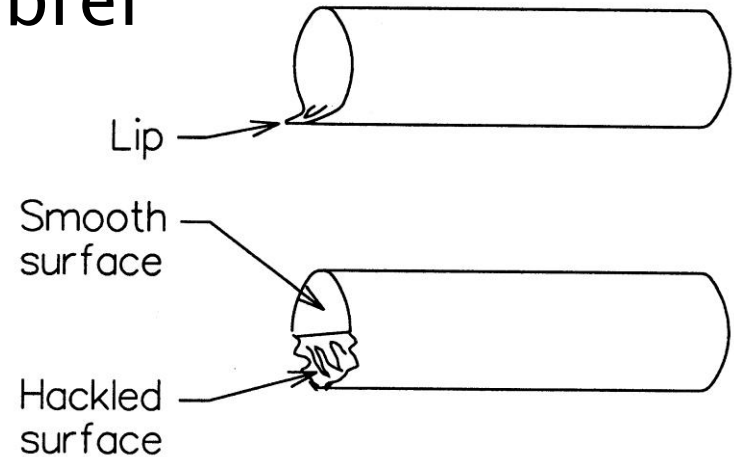
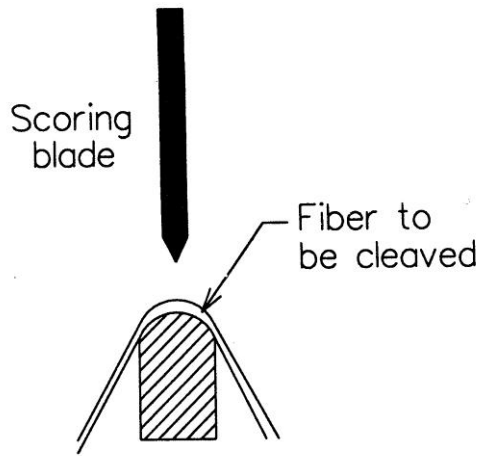
# OTDR

## Typical OTDR Trace



# Taiere – Cleaving

- ▶ Tehnici necesare pentru a asigura o taiere perpendiculara pe axa fibrei

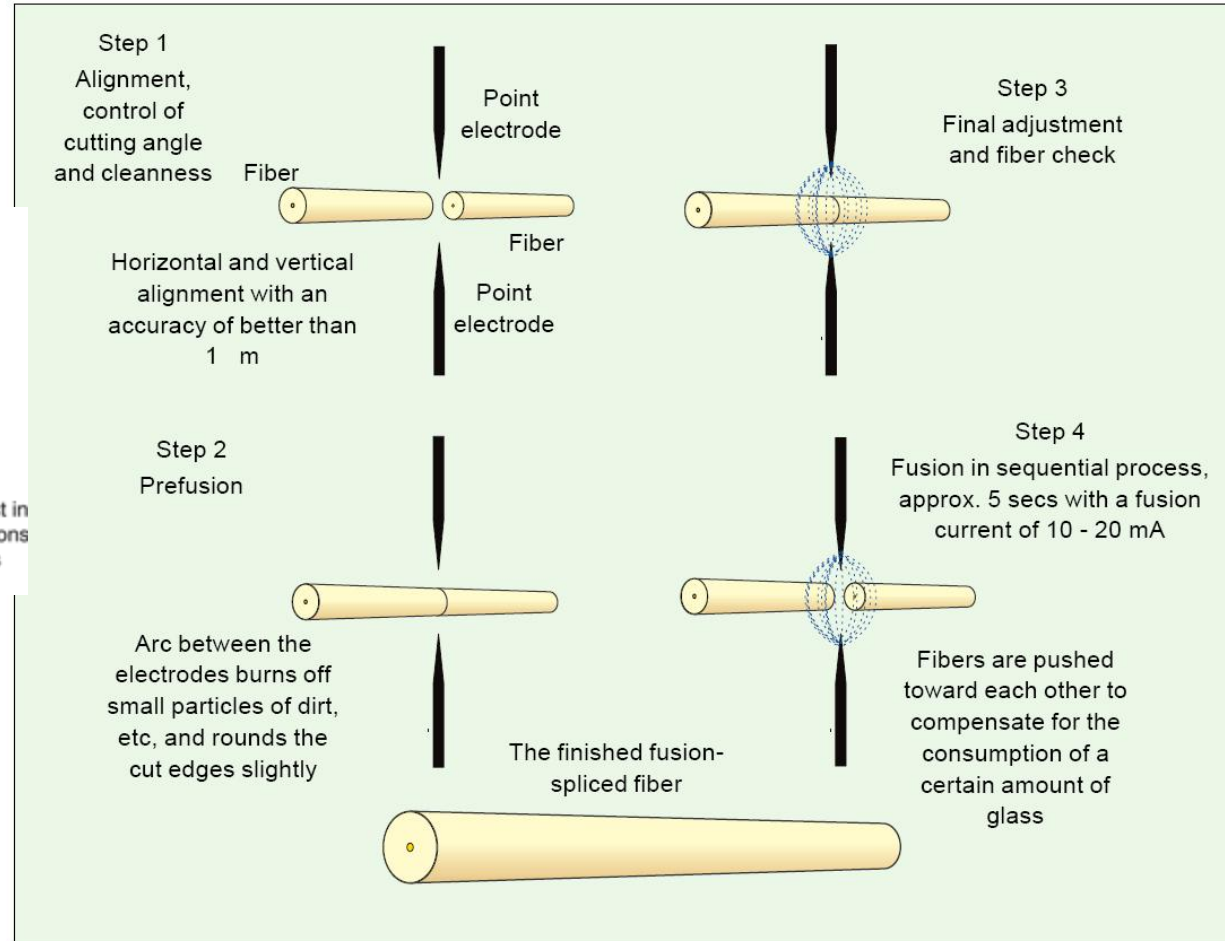
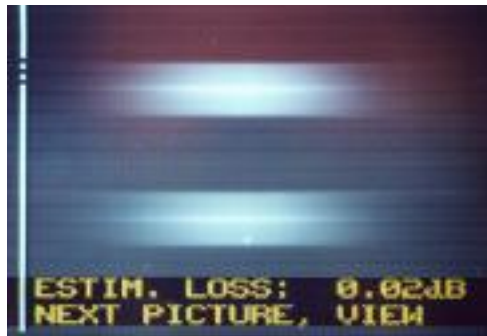
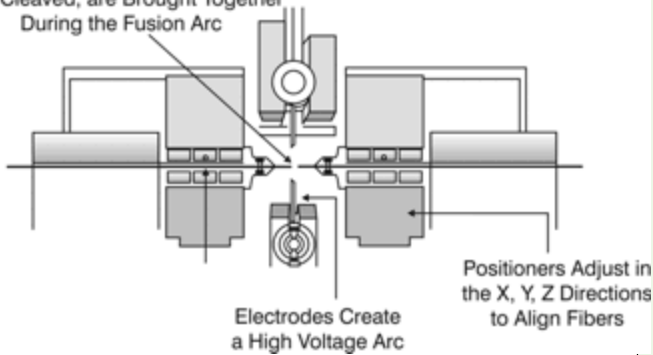


# Lipire prin fuziune



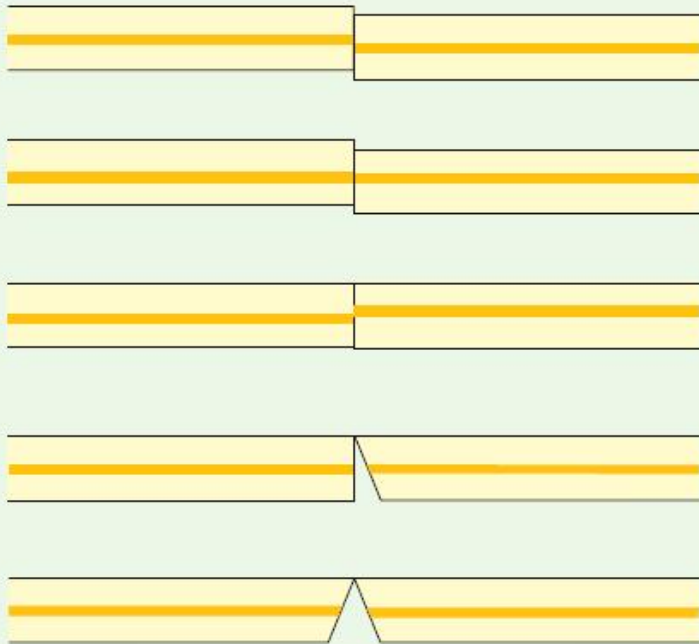
# Splice prin fuziune

Fibers Stripped of Coating, Cleaned, and Cleaved, are Brought Together During the Fusion Arc

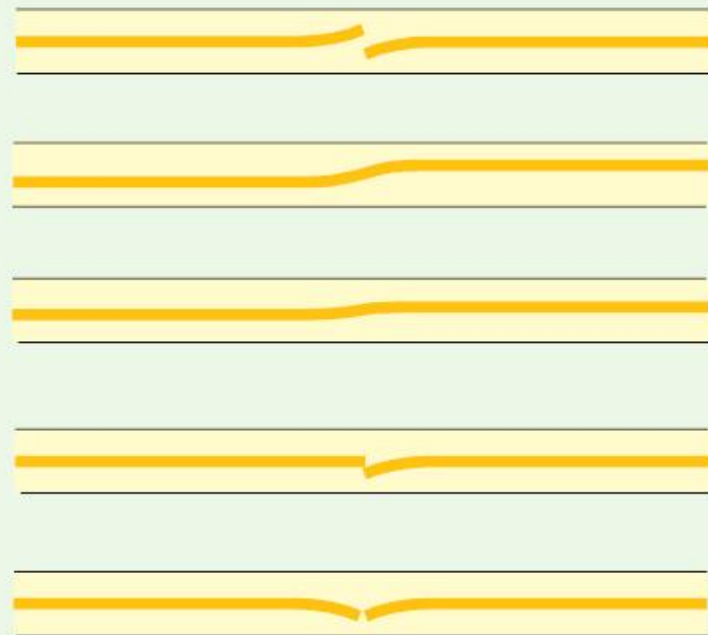


# Splice prin fuziune

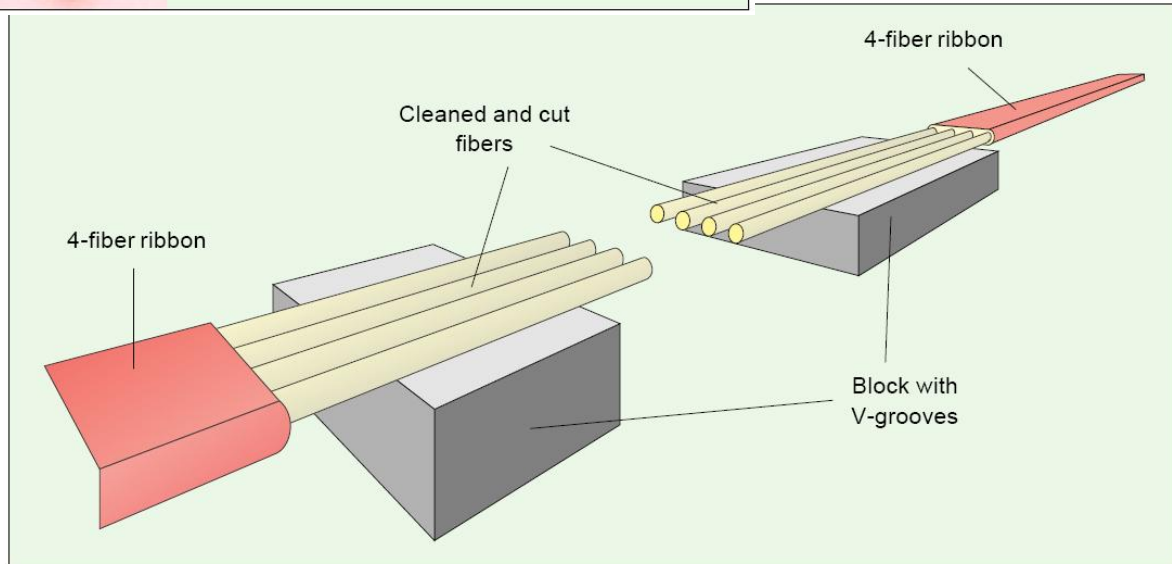
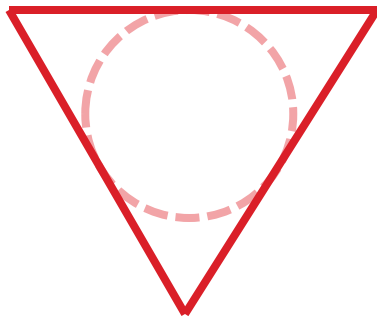
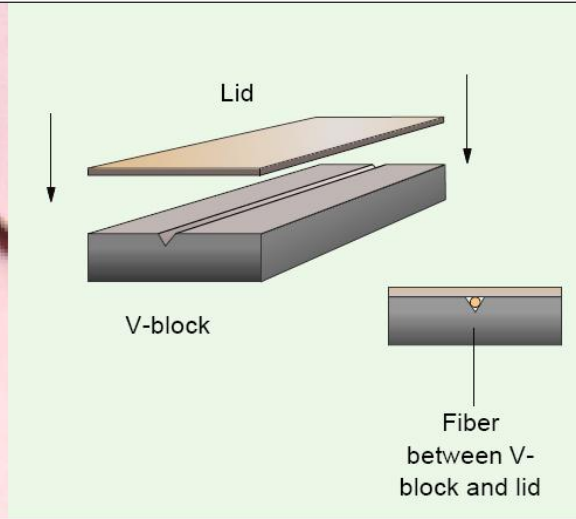
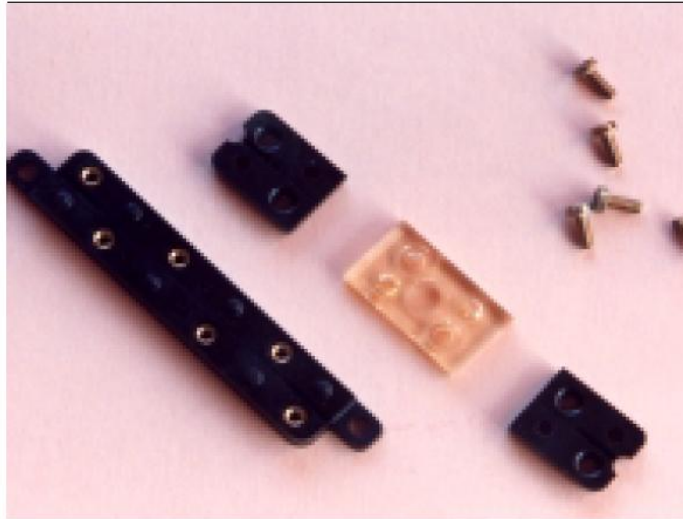
Causes of faults in fiber fusion



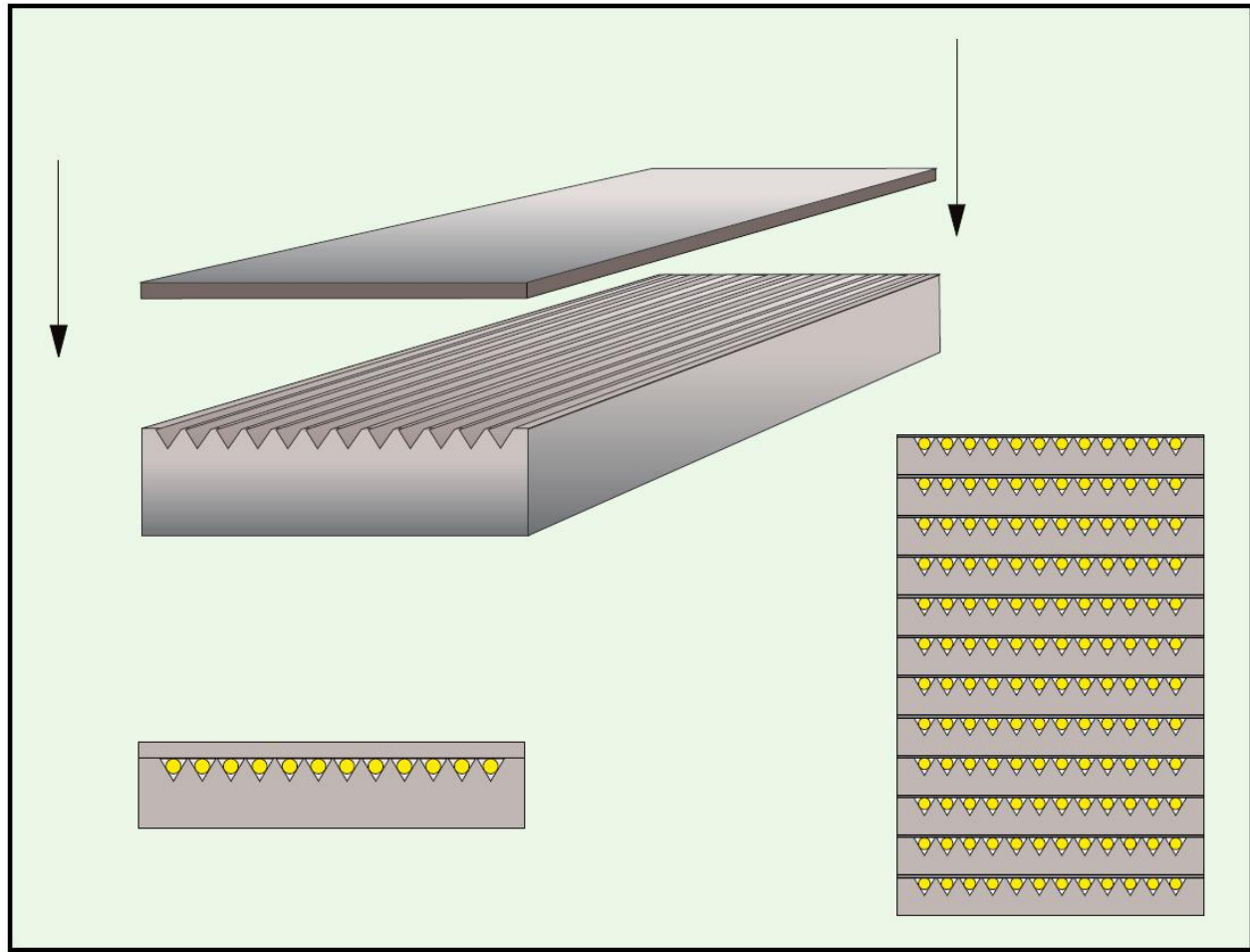
Appearance after fusion



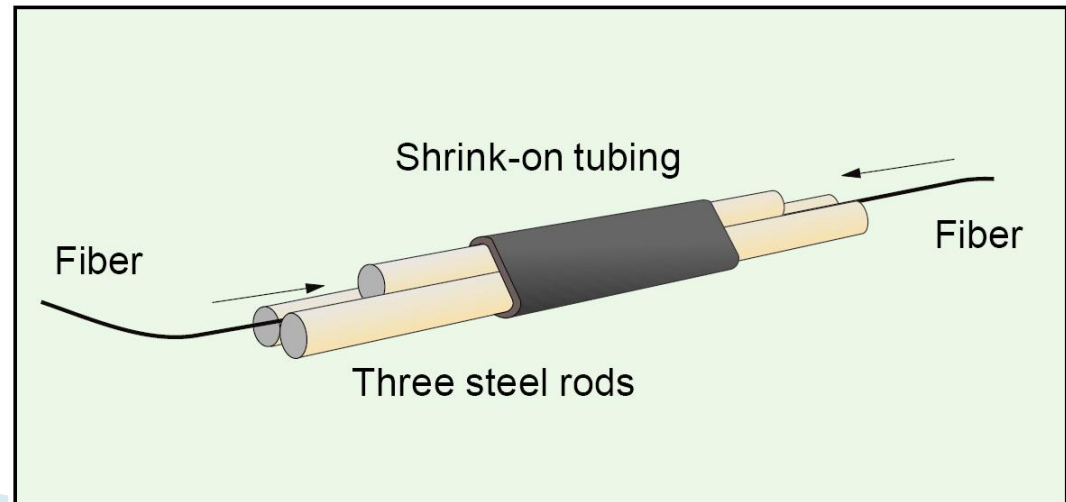
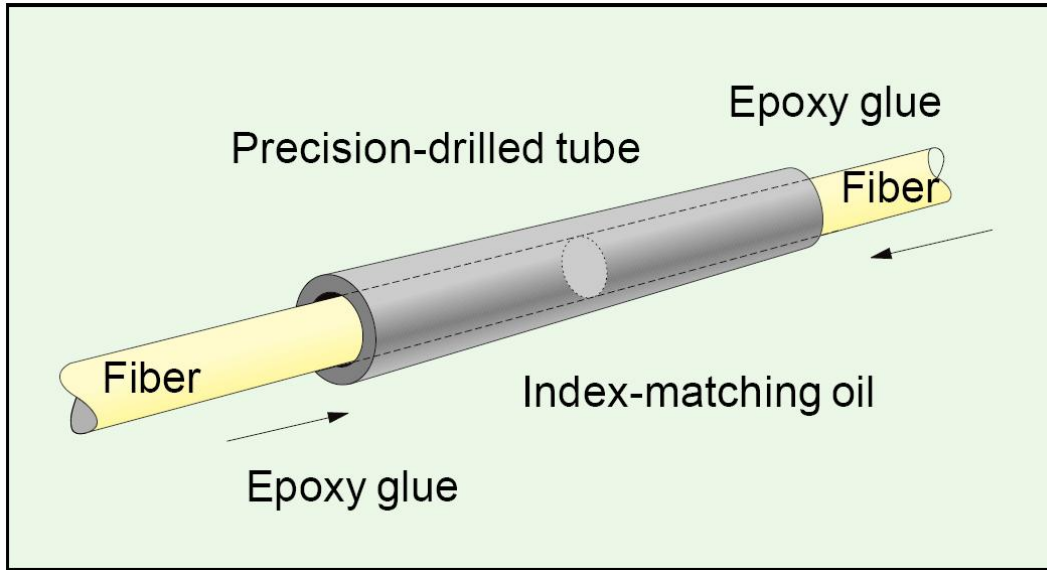
# Splice mechanic – bloc V



# Splice mechanic - bloc V



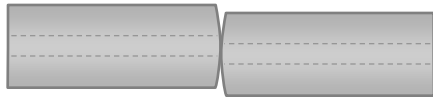
# Splice mechanic



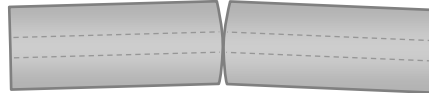


# Probleme Fibre/Conectori

Offset



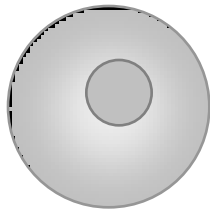
Angular Misalignment



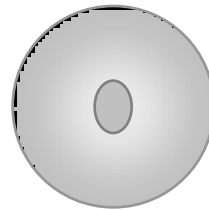
Separation



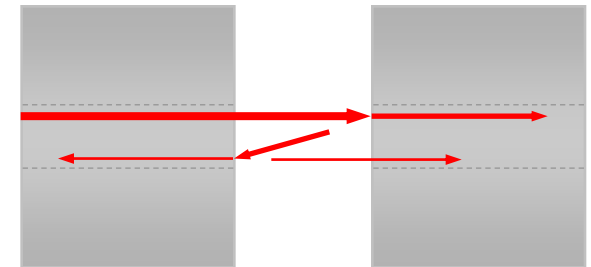
Core Eccentricity



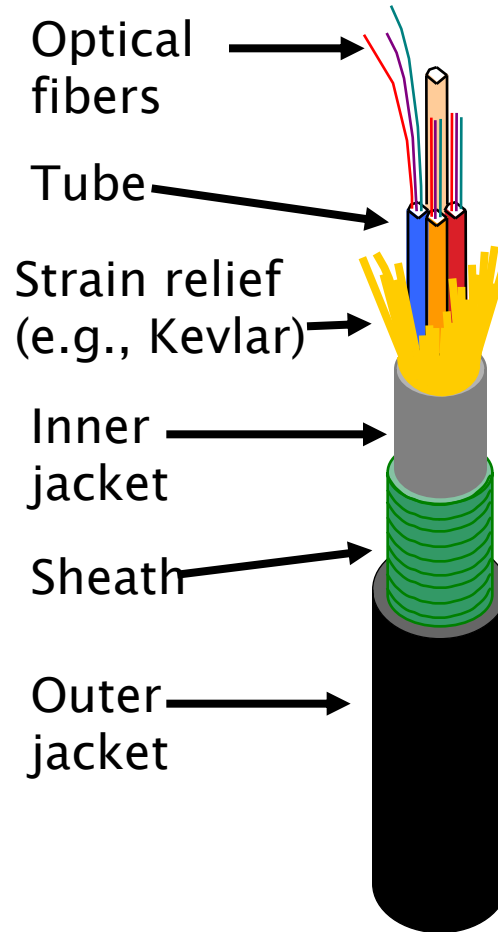
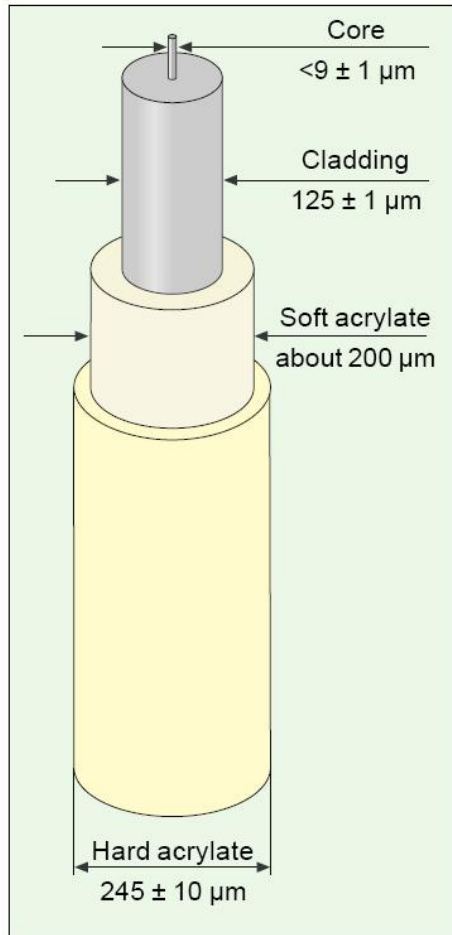
Core Ellipticity



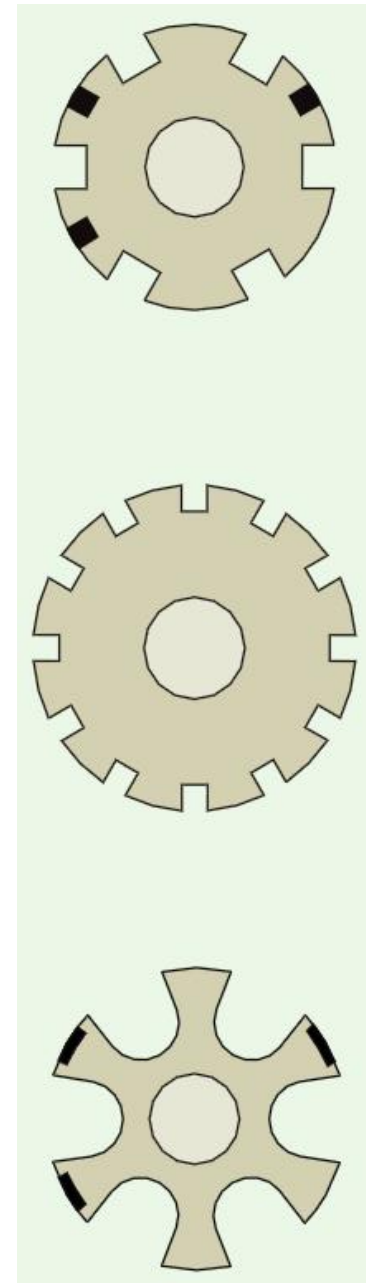
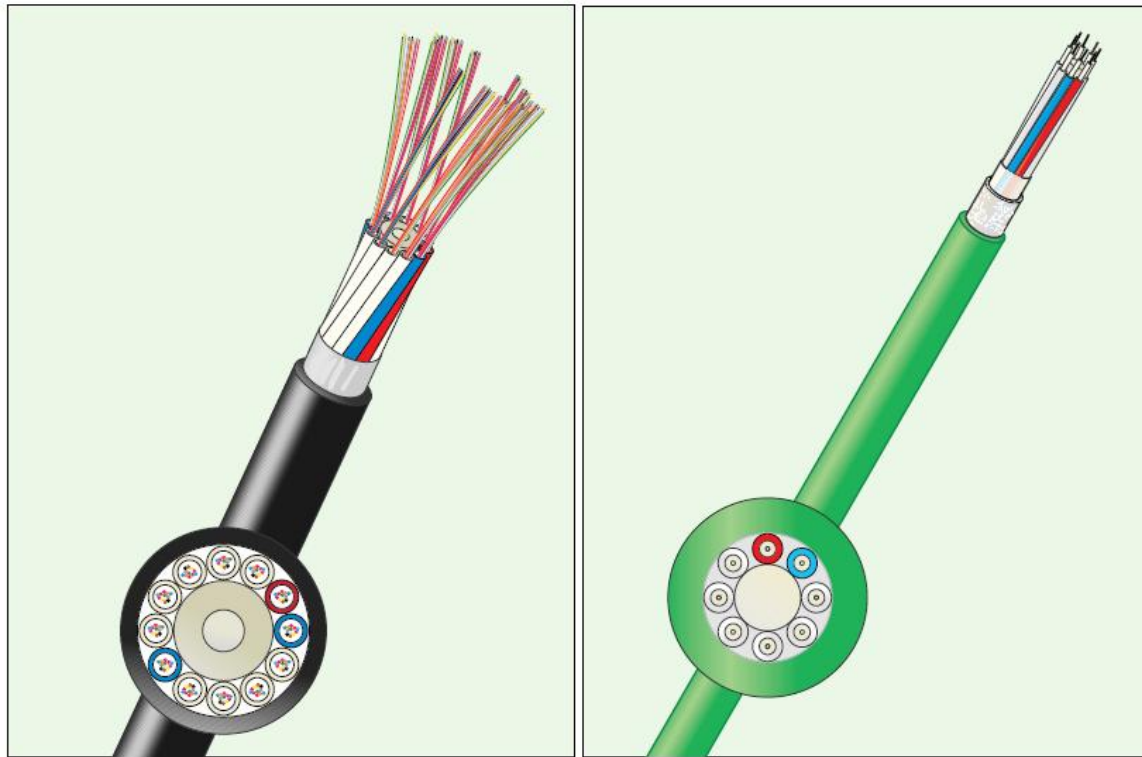
Reflections & Interference



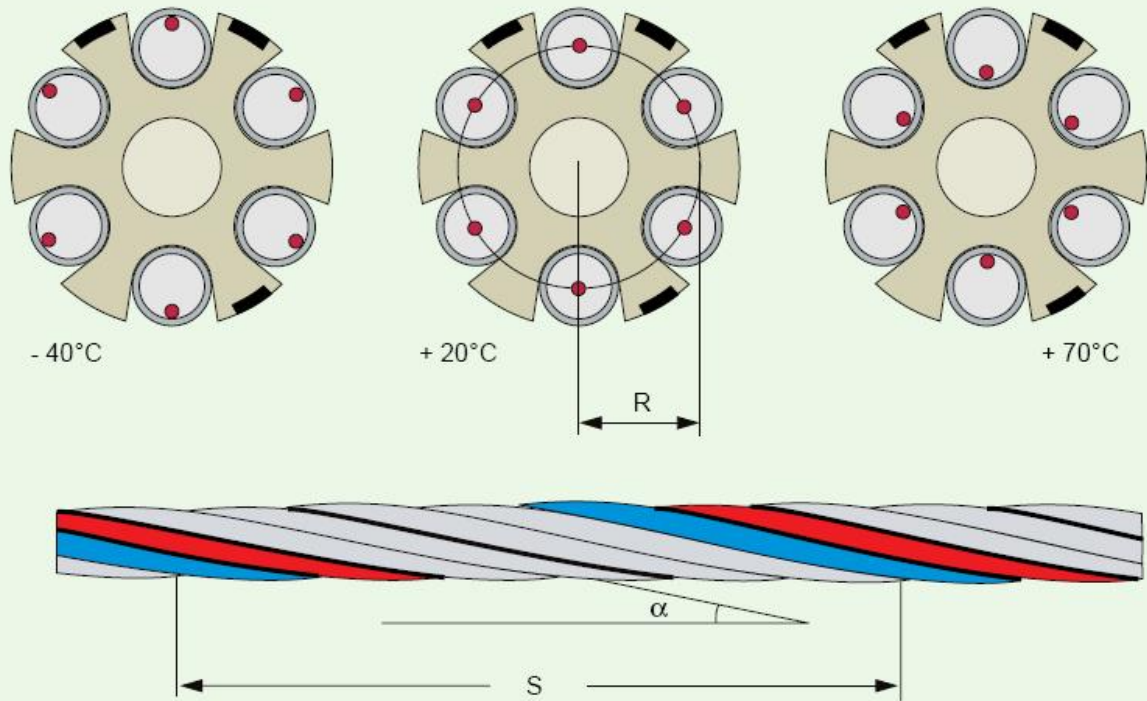
# Cabluri



# Cabluri

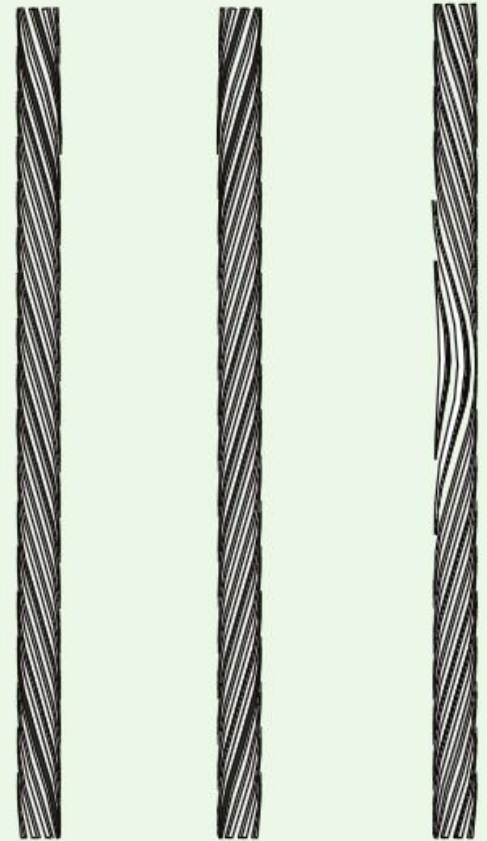


# Cabluri

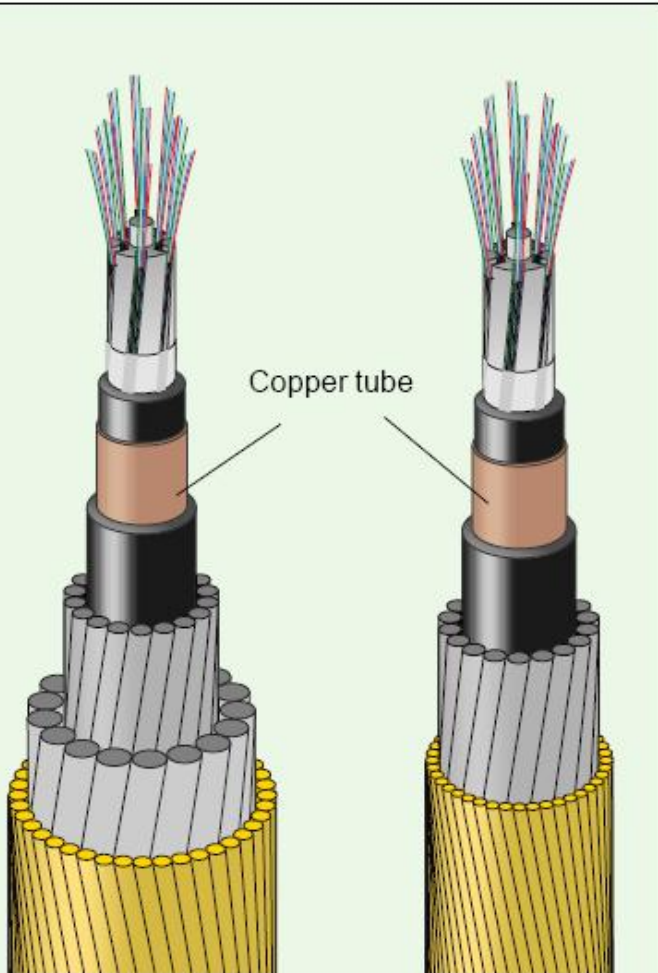
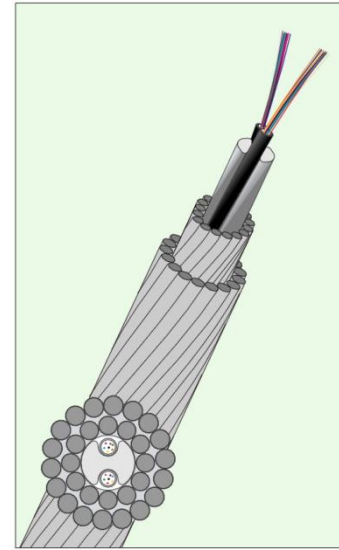


$$S' = S \cdot \sqrt{1 + \left(\frac{2\pi \cdot R}{S}\right)^2}$$

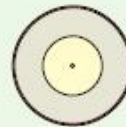
$$\frac{\Delta L}{L_0} = \sqrt{1 + \left(\frac{2\pi \cdot R}{S}\right)^2} - 1$$



# Cabluri



Primary coated fiber



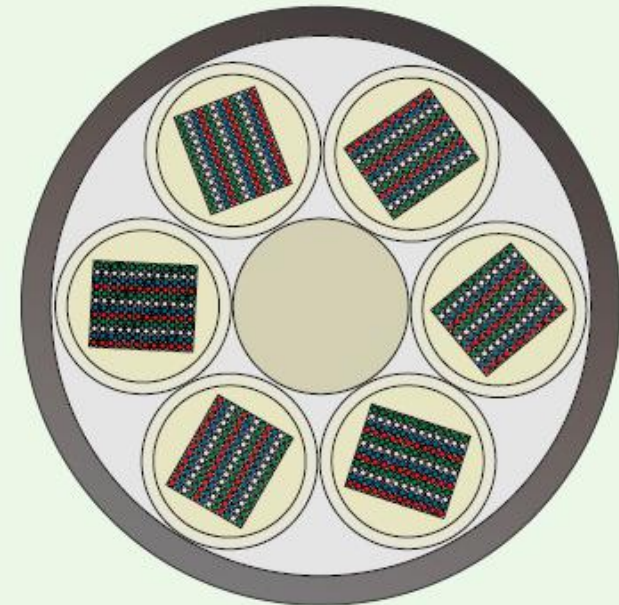
12-fiber ribbon



12 x 12-fiber ribbons  
= 144 fibers

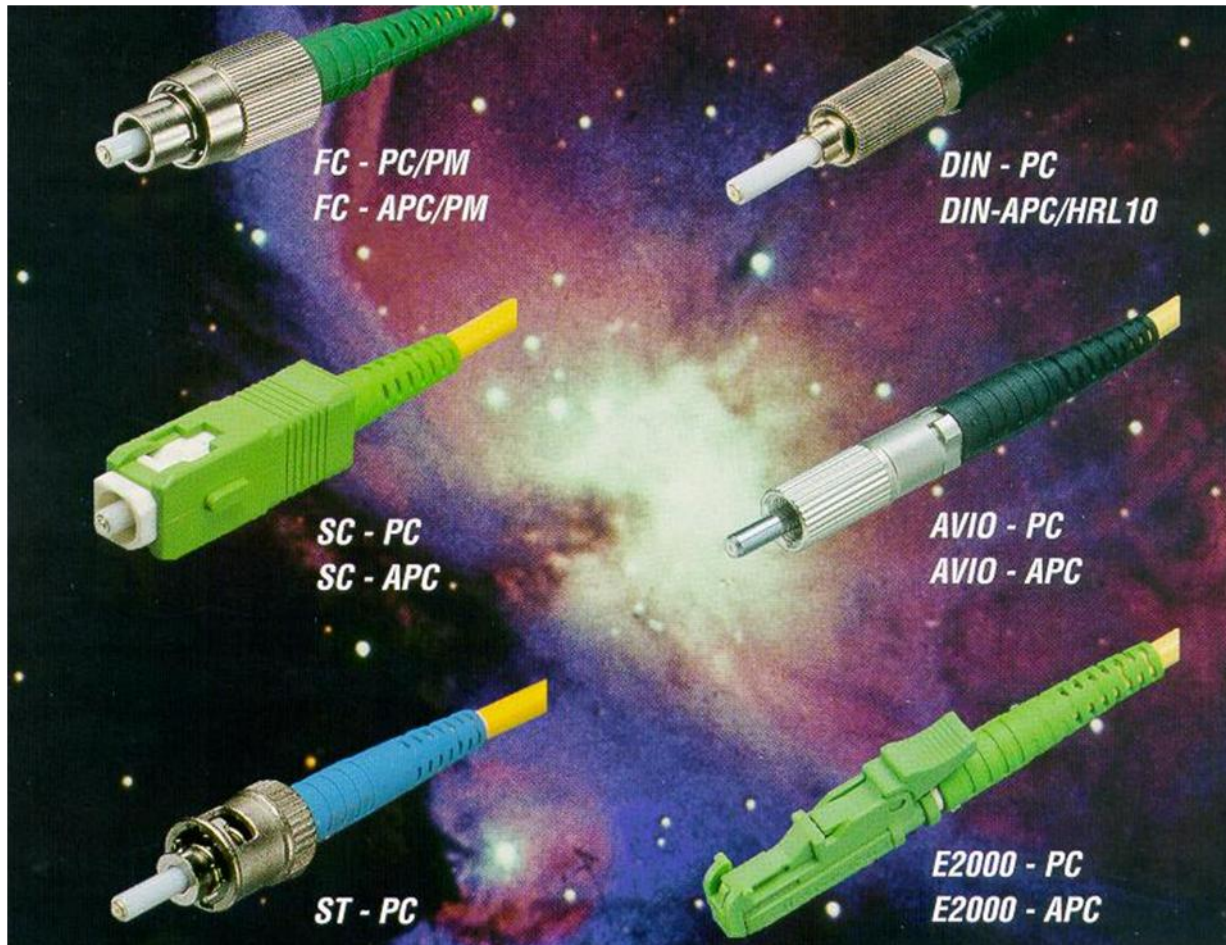


"Lose tube"

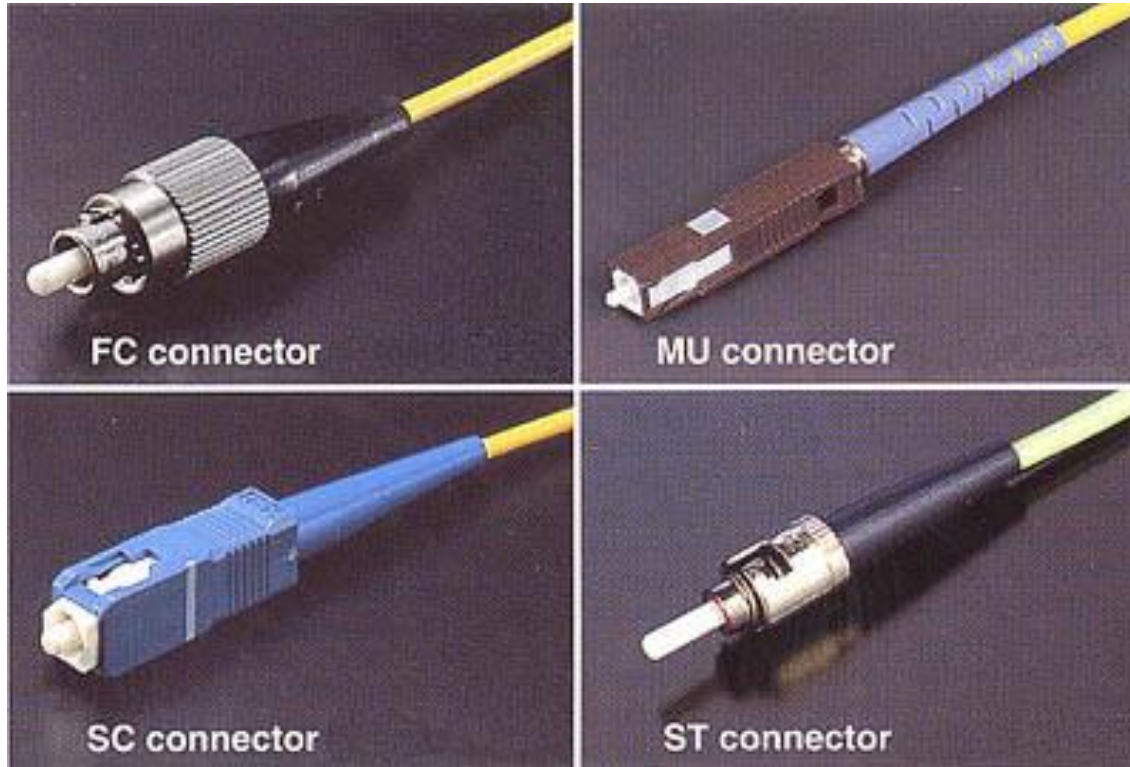


Finished cable with central strength member and with six tubes with each tube containing 144 fibers

# Conettori



# Conettori



ST

All fiber-optic connectors use ferrules to hold the ends of the fiber and keep them properly aligned.



SMA Type 906

The ST connector uses a half-twist bayonet type of lock, while SMA and FC use threaded connections.



FC

The SC uses a push-pull connector similar to common audio and video plugs and sockets.



SC

The MIC is the standard FDDI connector.



MIC

The Fiber Jack connector attaches two fibers in a snap lock connector similar in size and ease of use as an RJ-45 connector.



Fiber Jack

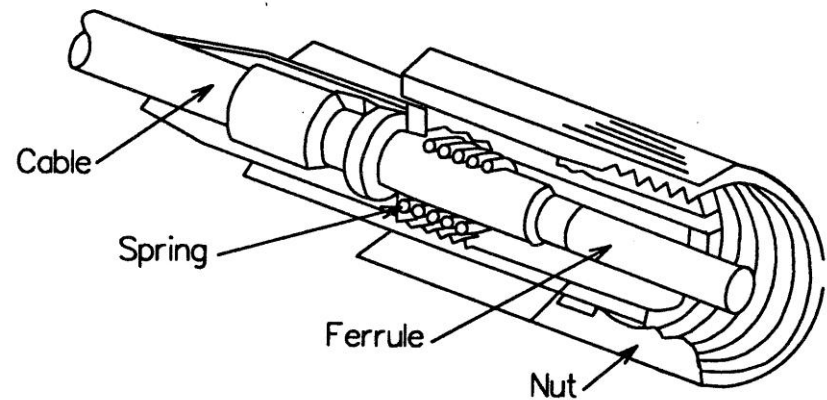
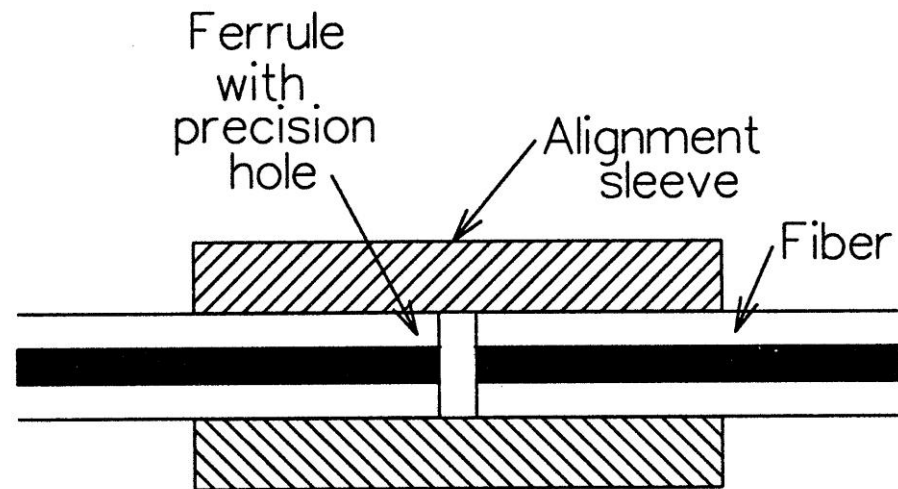
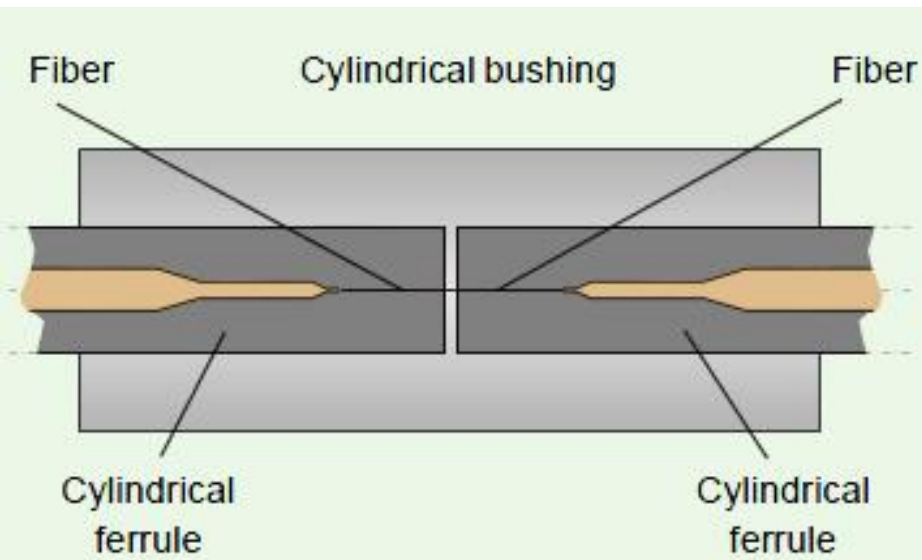


MT-RJ

MT-RJ is a popular connector for two fibers in a very small form factor.

# Conettori

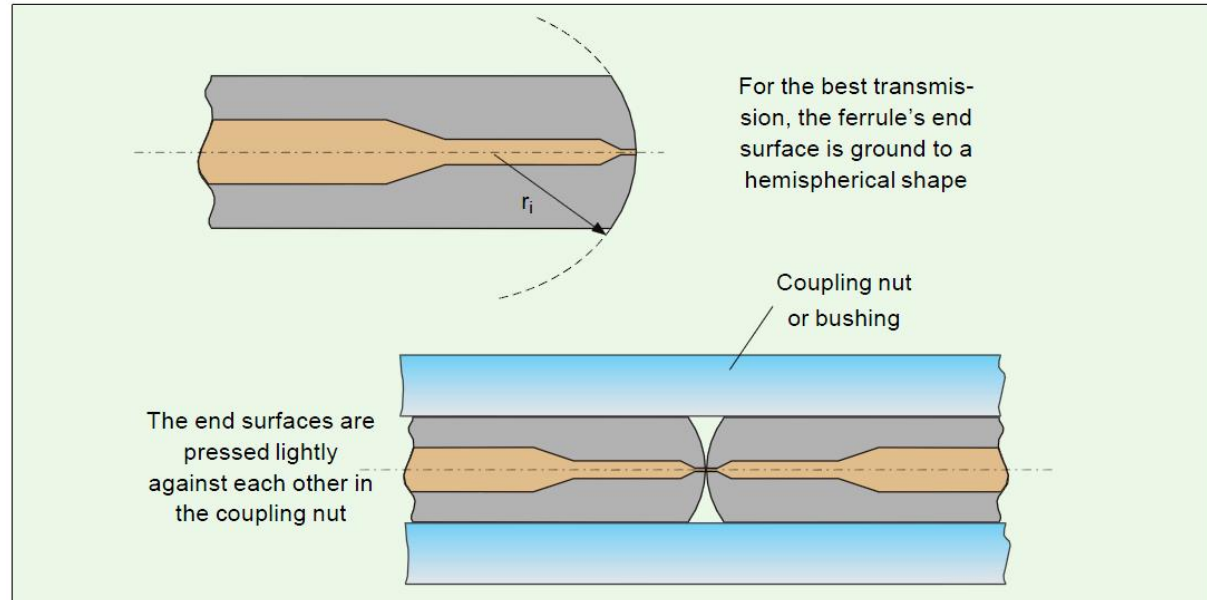
- ▶ Verificati <http://rf-opto.etti.tuiasi.ro>



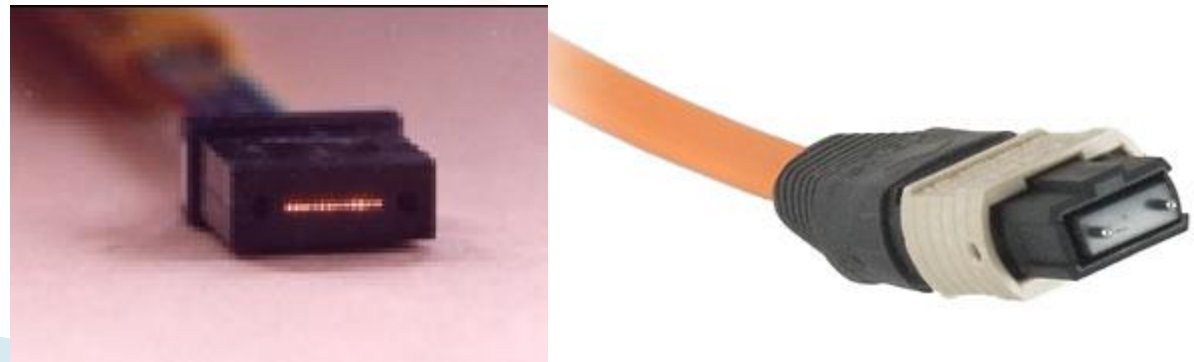


# Conettori

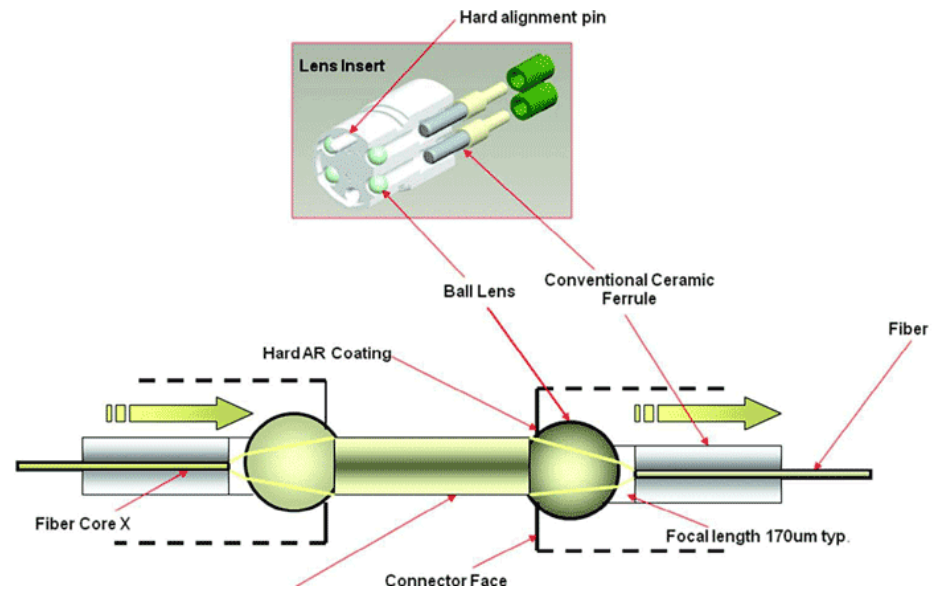
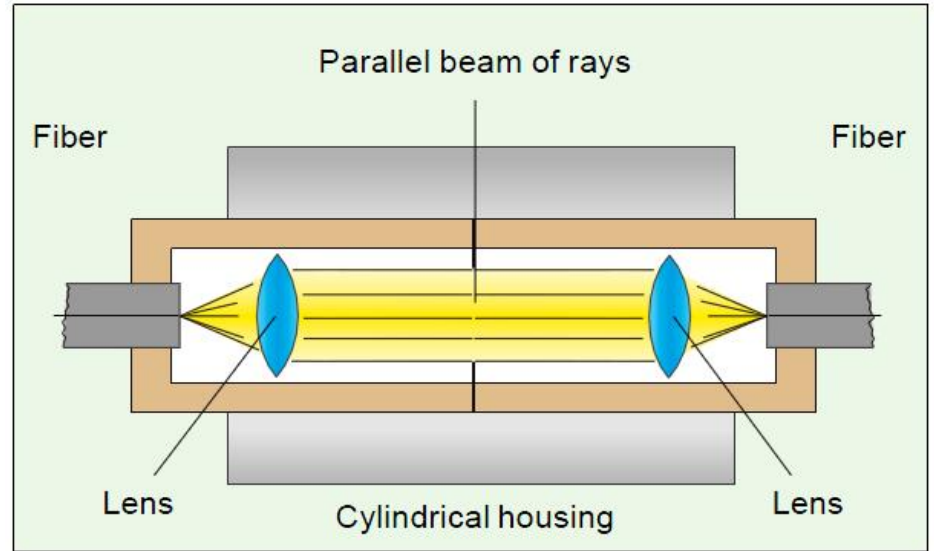
- ▶ Ferula semisferica
  - 20mm
  - 60mm



- ▶ Conettori multifibra

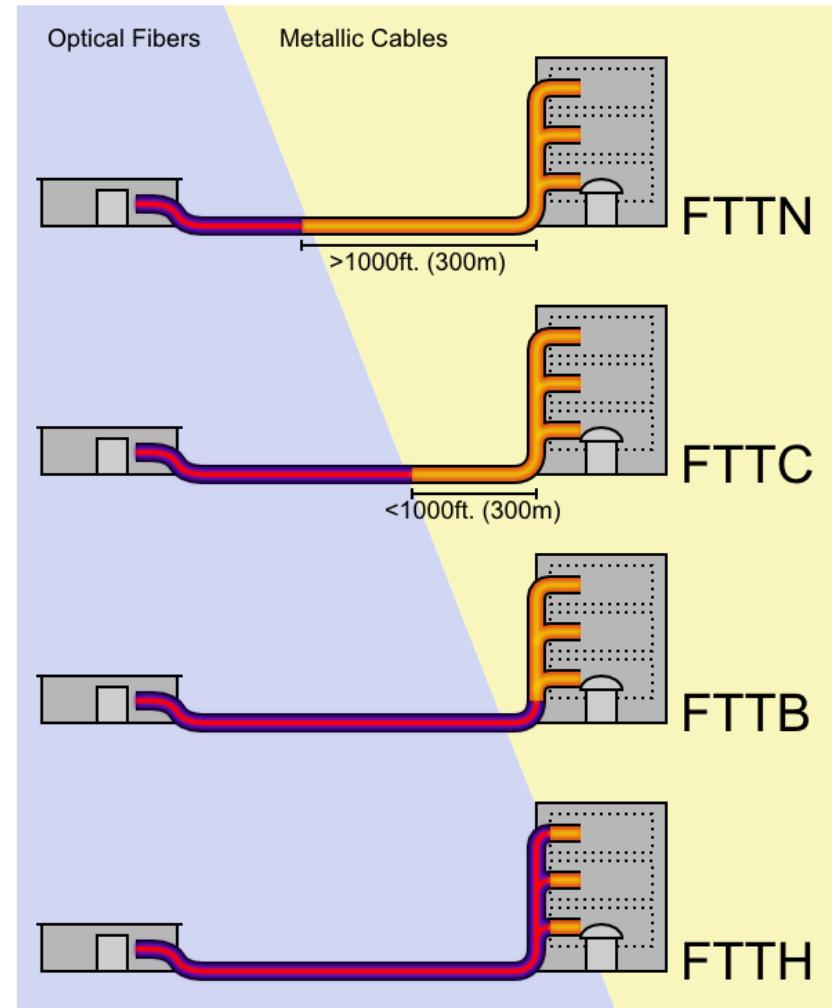


# Expanded beam connector



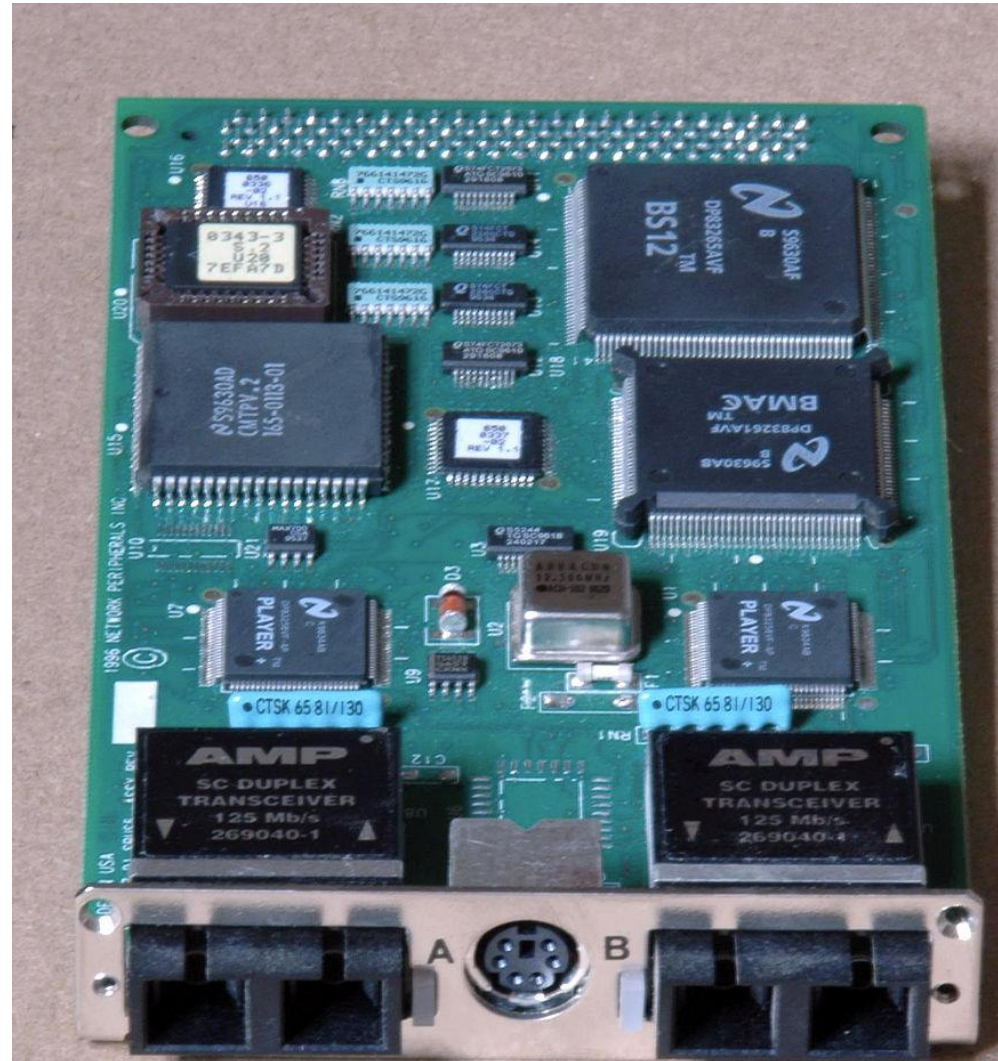
# FTTH

- ▶ FTTN: Fiber to the node, neighborhood
- ▶ FTTC: Fiber to the curb
- ▶ FTTB: Fiber to the building
- ▶ FTTH: Fiber to the home



# FDDI

- ▶ Fiber Distributed Data Interface



# Cabluri, Conectori, rf-opto

rf-opto.etti.tuiasi.ro says  
Request access!  
OK

Microwave CD  
Optoelectronics

Educational software

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[Curs 4 OPTO Fibra 2020](#) (pdf, 8.18 MB, ro, 🇷🇴)

[Curs Fibra \(video, prezenta prin interfata examen\)](#) (mp4, 215.77 MB, ro, 🇷🇴)

### Textbooks

[IBM Redbooks - Understanding Optical Communications](#) (pdf, 5.24 MB, en, 🇸🇪)

[Behzad Razavi - Design of Integrated Circuits for Optical Communications](#) (pdf, 11.18 MB, en, 🇸🇪)

[John Powers - An Introduction to Fiber Optic Systems](#) (pdf, 50.54 MB, en, 🇸🇪)

[Stefan Nilsson-Gistvik - Optical Fiber Theory for Communication Networks](#) (pdf, 17.62 MB, en, 🇸🇪)

[Structurii Optoelectronice](#) (pdf, 3.13 MB, ro, 🇷🇴)

[EU Photovoltaic Geographical Information System \(PVGIS\)](#) (link, 0 Bytes, en, 🇸🇪)

[MIT Course - Fundamentals of Photovoltaics](#) (link, 0 Bytes, en, 🇸🇪)

### Laboratory

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[Laborator 5](#) (pdf, 161.33 KB, ro, 🇷🇴)

[Laborator 6](#) (pdf, 138.19 KB, ro, 🇷🇴)

[Laborator 7](#) (pdf, 139.17 KB, ro, 🇷🇴)

# Contact

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- ▶ <http://rf-opto.etti.tuiasi.ro>
- ▶ [rdamian@etti.tuiasi.ro](mailto:rdamian@etti.tuiasi.ro)