

# Optoelectronică

Curs 8->s9

2025/2026

# Disciplina 2025/2026

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – conf. **Radu Damian**
  - an IV  $\mu$ E
  - Marti 14:00–16:00, P7  $\rightarrow$  **P6**
  - E – 70% din nota (50%+20%)
    - **20% test (VP) la curs**, saptamana **5–7?**
  - probleme + (2p prez. curs)
  - toate materialele permise
- ▶ Laborator – sl. **Catalin Iov**
  - an IV  $\mu$ E
    - Marti 16–18, I.08
    - Max. 7 prezente
  - L – 30% din nota (+Caiet de laborator +Probleme)

# 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 )

\* – VP

# Acces

- ▶ Personalizat (parola), Generic (email)



Student profile page showing a photo, personal details, and a table of grades. A red circle highlights the link "Acceseaza ca acest student" and a red arrow points from it to the login page.

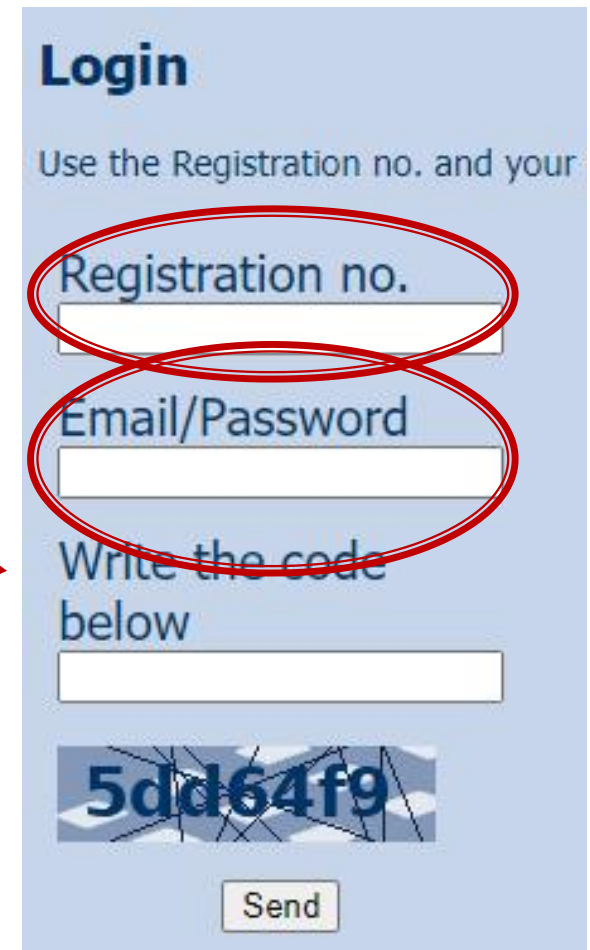
**Date:**

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	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	Colocviu 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	-	



Login page with a "Login" header and instructions: "Use the Registration no. and your". It features three input fields: "Registration no.", "Email/Password", and "Write the code below". A CAPTCHA image shows the code "5dd64f9". A "Send" button is at the bottom. Red circles highlight the "Registration no." and "Email/Password" fields.

## Login

Use the Registration no. and your

Registration no.

Email/Password

Write the code below

5dd64f9

Send

# Fibra optică

## Capitolul 4

# Aplicatii majore

## ▶ Comunicatii

- Infrarosu (InGaAsP)

## ▶ Vizibil

- Spectru vizibil (GaAlAs)

## ▶ Iluminare

- Putere ridicata, lumina alba (GaInN)

## ▶ Energie solara

- Efect fotovoltaic (Si)

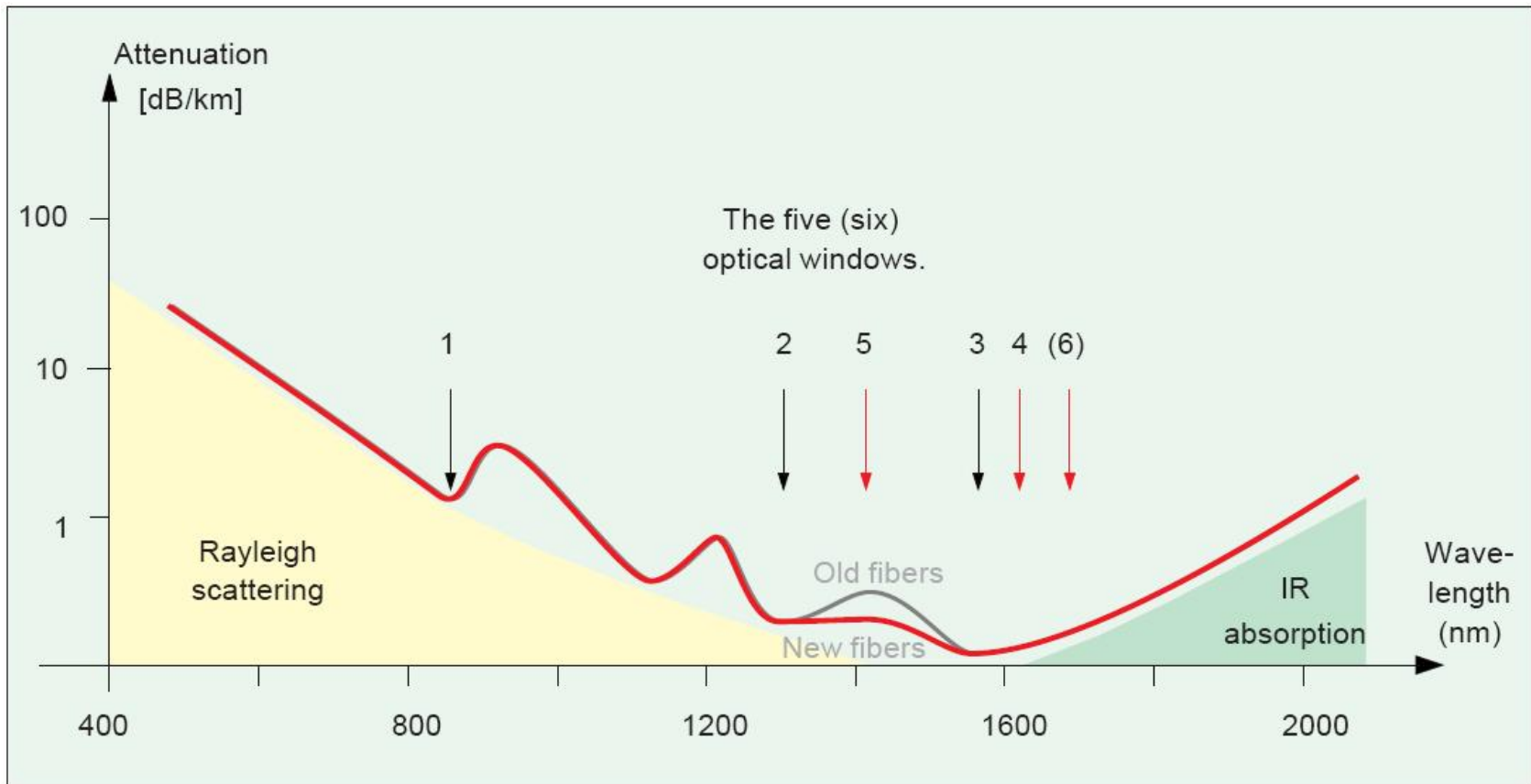
# Fenomene de interes

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

# 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**

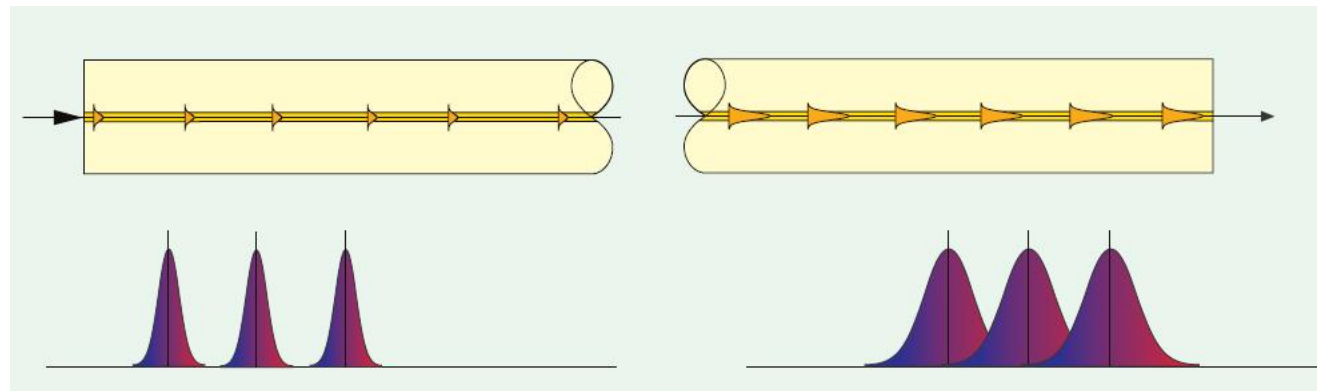
$$A[dB] = A_i[dB / km] \cdot L[km]$$

# Fenomene de interes

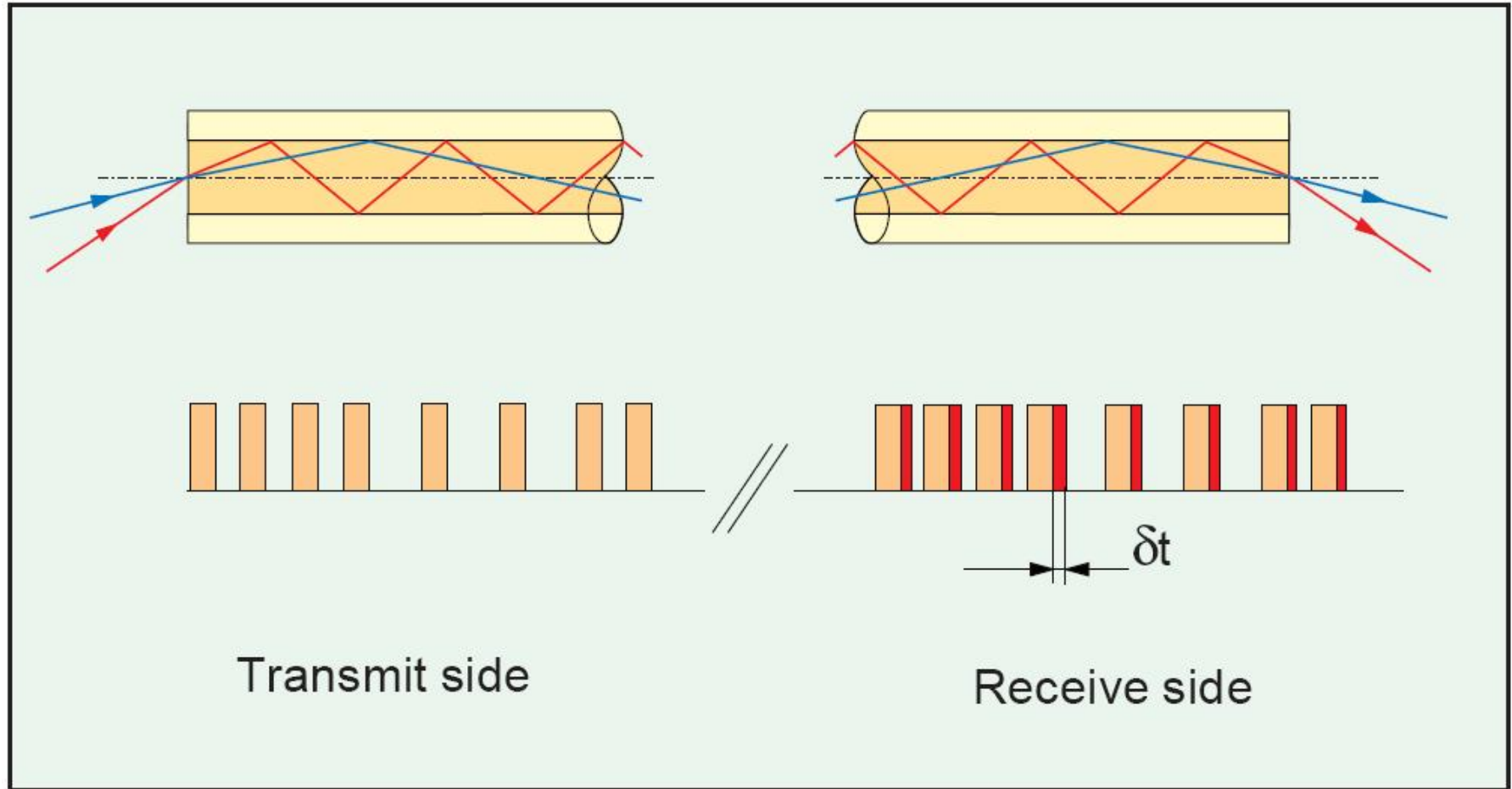
- ▶ Cat de departe pot transmite semnalul luminos pe fibra
  - atenuare
- ▶ Cat de rapid pot transmite informația
  - **dispersie**

# 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

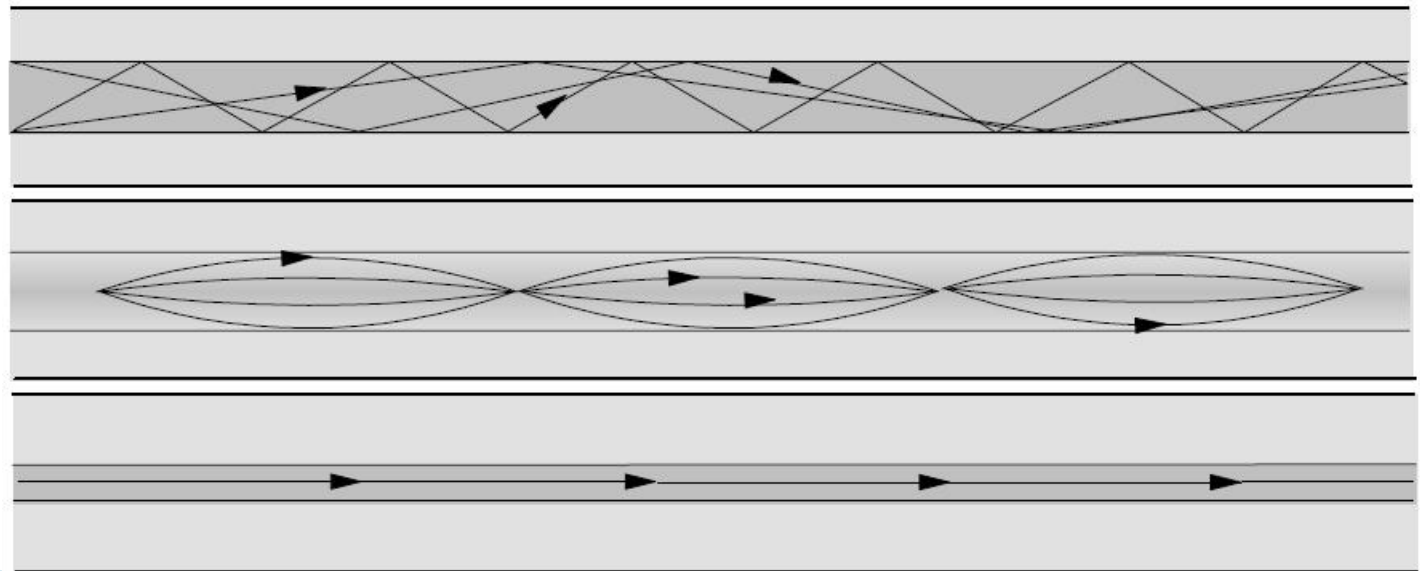


# Dispersia modala



# Dispersia modala

- ▶ 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**

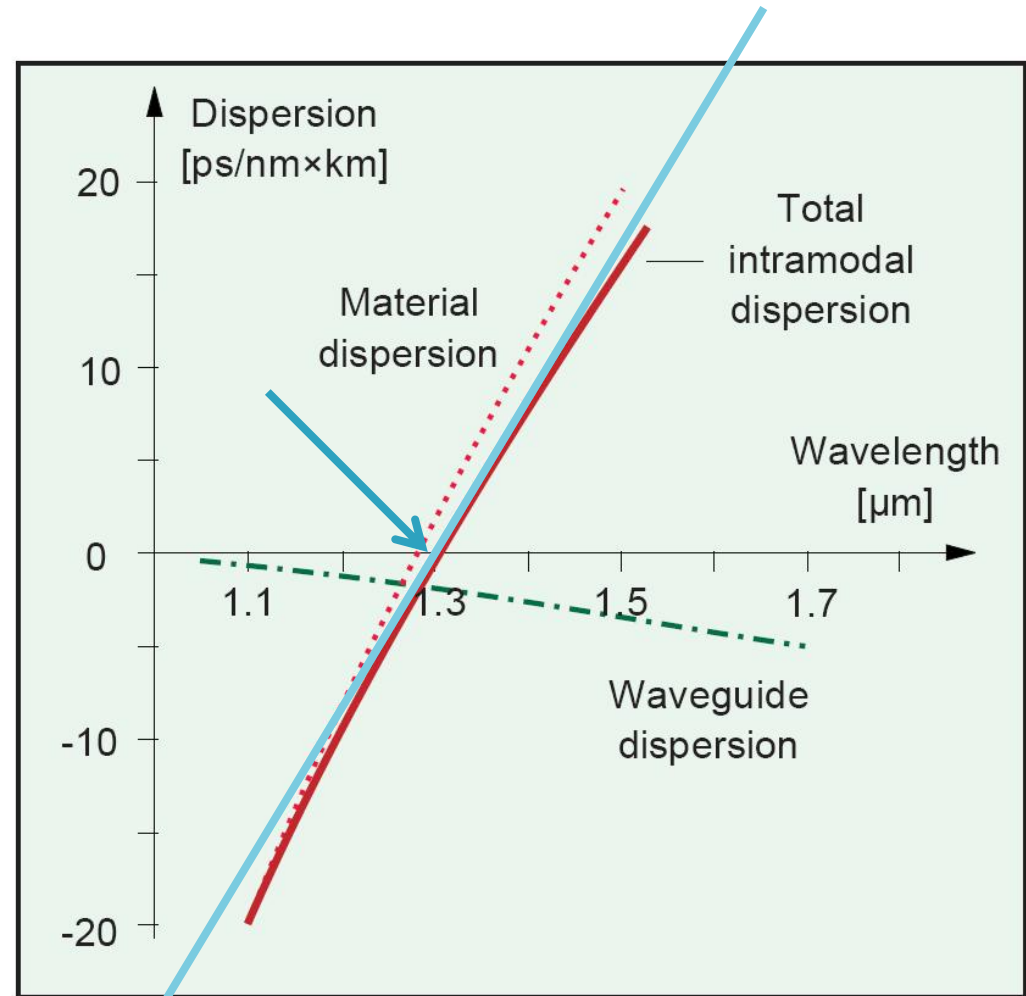


# Dispersia cromatica (gh+mat)

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

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

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



# 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

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

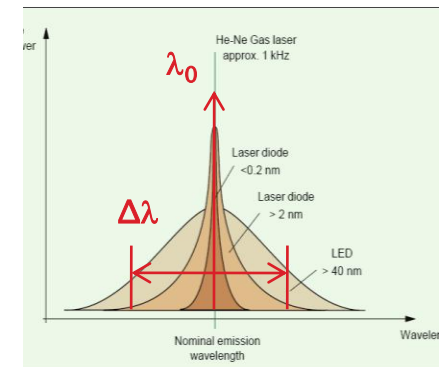
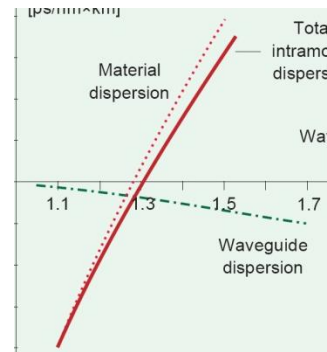
$$\Delta = 0.01 \div 0.02 \ll 1$$

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

## ▶ Dispersia cromatica

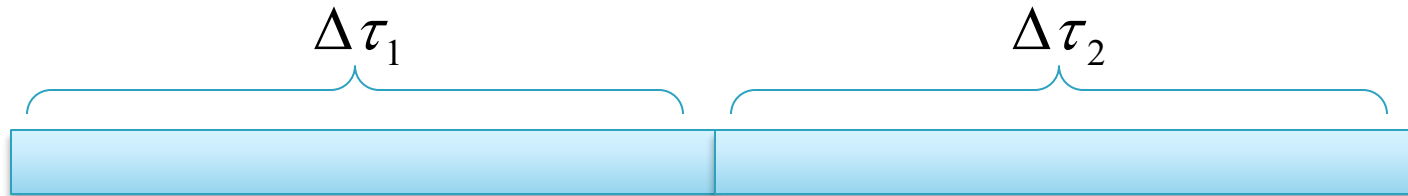
$$\Delta\tau_{cr} = D(\lambda) \cdot \Delta\lambda \cdot L$$

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



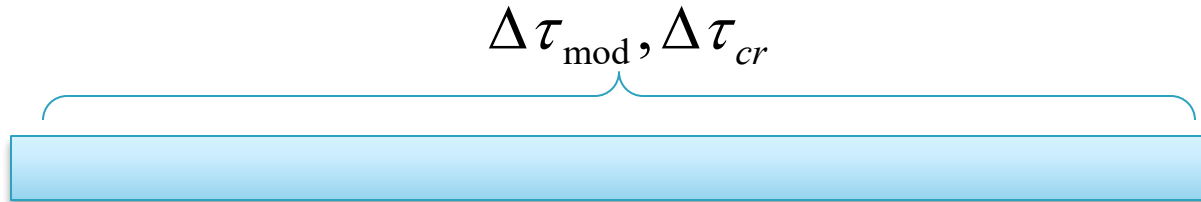
# Sumarea efectelor

- ▶ 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

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

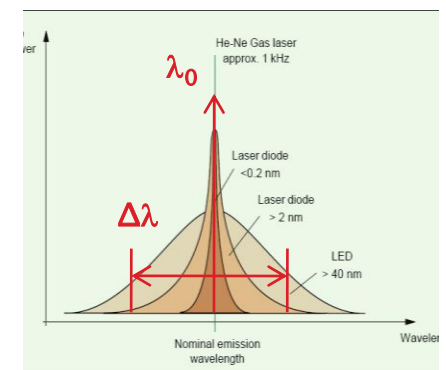
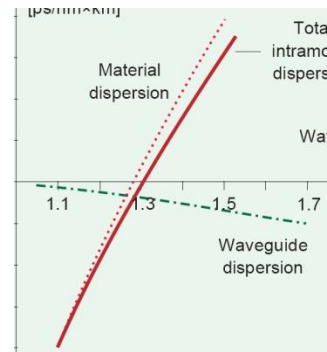
$$\Delta = 0.01 \div 0.02 \ll 1$$

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

## ▶ 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

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

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

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

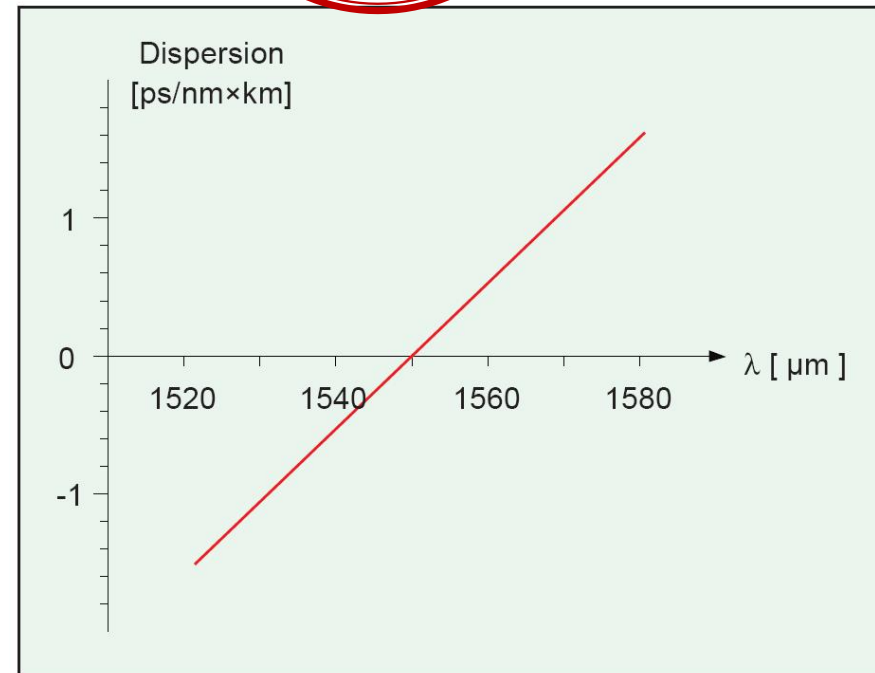
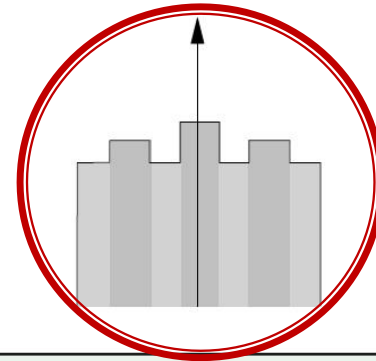
$$V[\text{Gb/s}] \sim B_{\text{el}}[\text{GHz}] \sim \frac{1}{\Delta\tau_{\text{tot}}} \sim \frac{1}{L[\text{km}]}$$

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

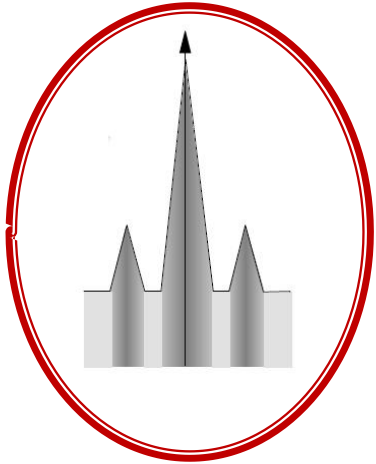
$$B_{\text{el}}[\text{MHz}] \times L[\text{km}] = \text{ct.}$$

# Dispersion shifted fibers

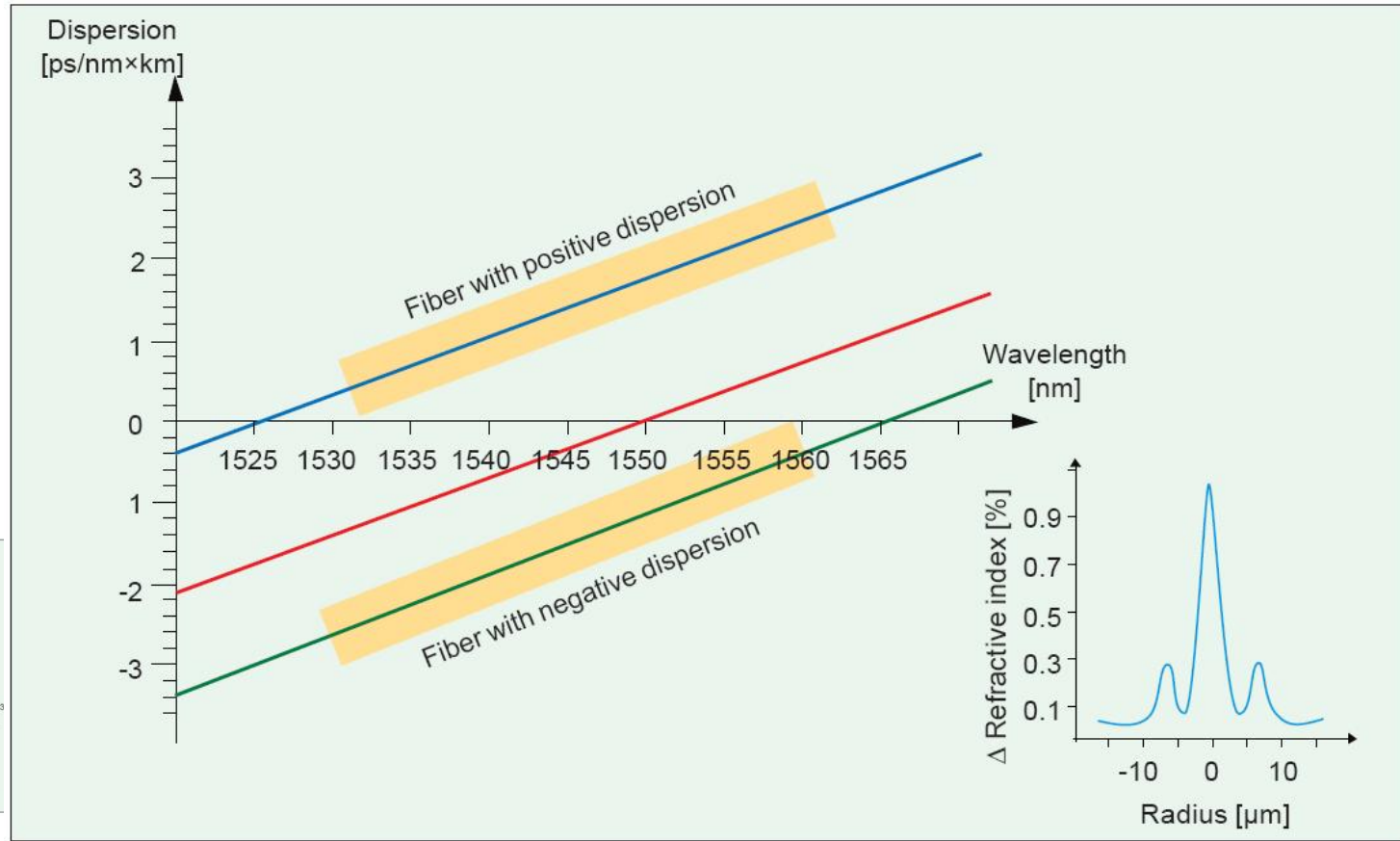
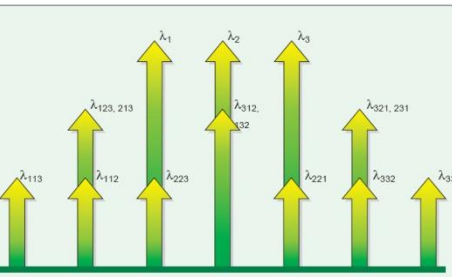
- ▶ Sticla are (nativ) dispersie cromatica 0 la 1310nm
- ▶ Atenuarea e mai mica la 1550 nm
- ▶ EDFA (Erbium doped fibre amplifiers) opereaza in banda 1550nm
- ▶ Sistemele WDM (Wavelength division Multiplexing) necesita banda larga amplificata



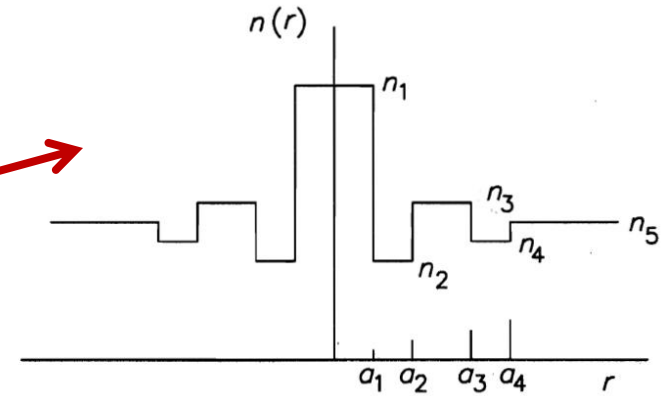
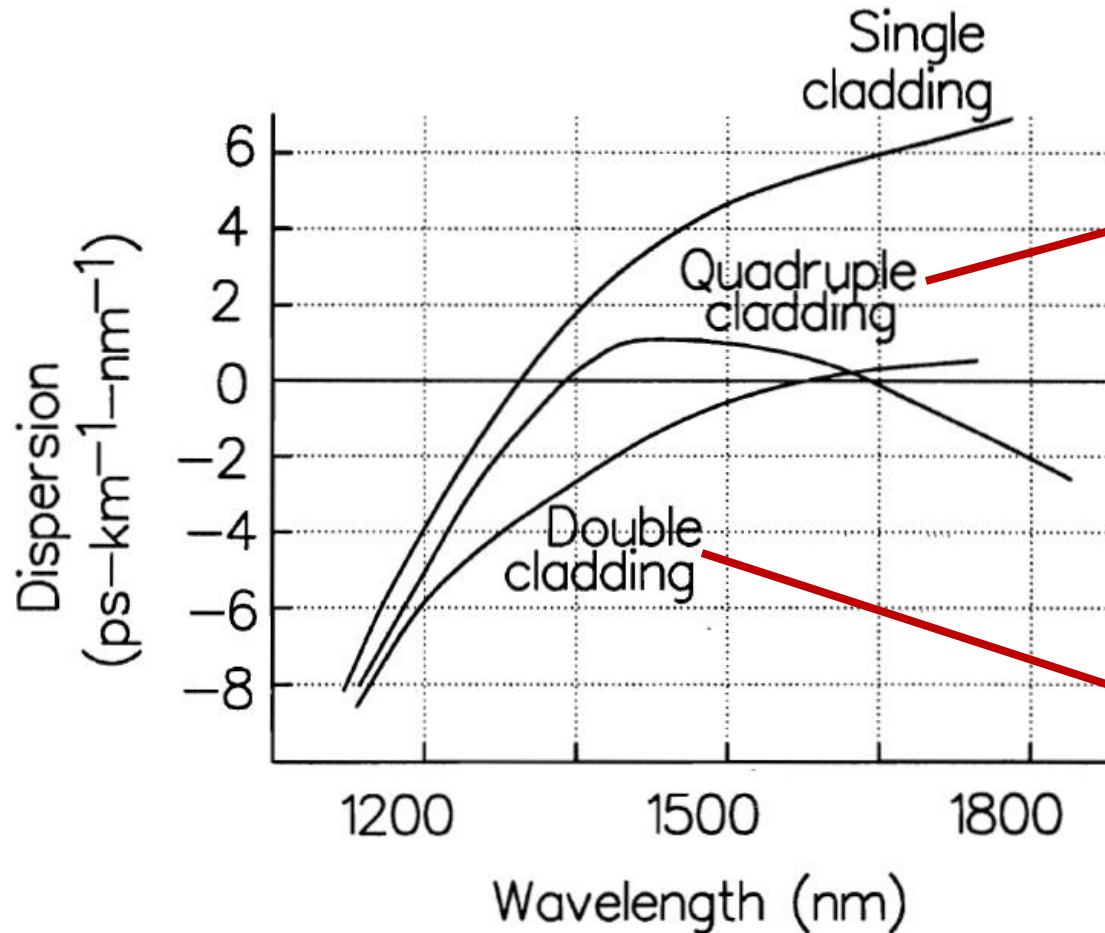
# Non-zero Dispersion shifted fibers



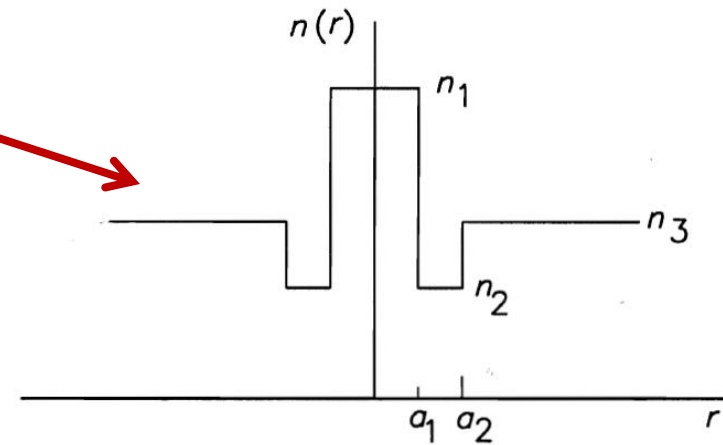
FWM



# Dispersion shifted fibers



(b)



(a)

# Fibra optică – Tehnologie

Capitolul 5

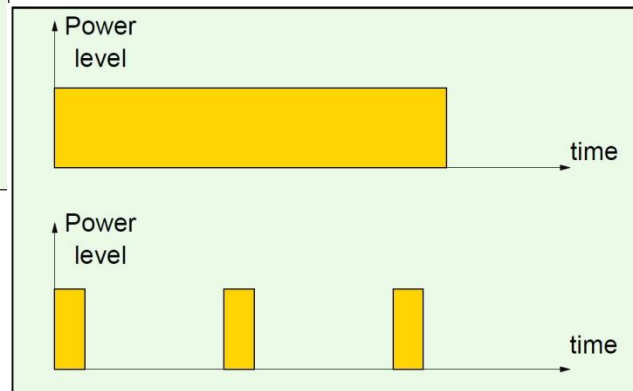
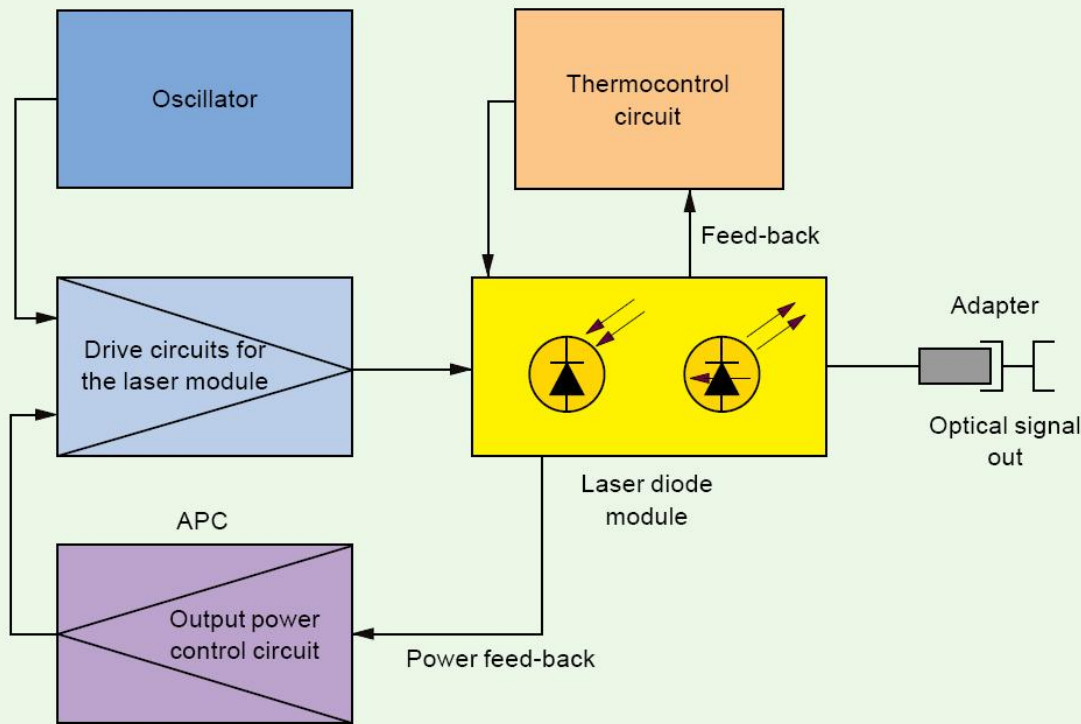
# Cuprins

- ▶ **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)
- ▶ **Emitătoare optice** (LED și dioda laser – realizare fizică și funcționare)
- ▶ **Receptoare optice** (dioda PIN, dioda cu avalanșă – realizare fizică și funcționare)
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- ▶ **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

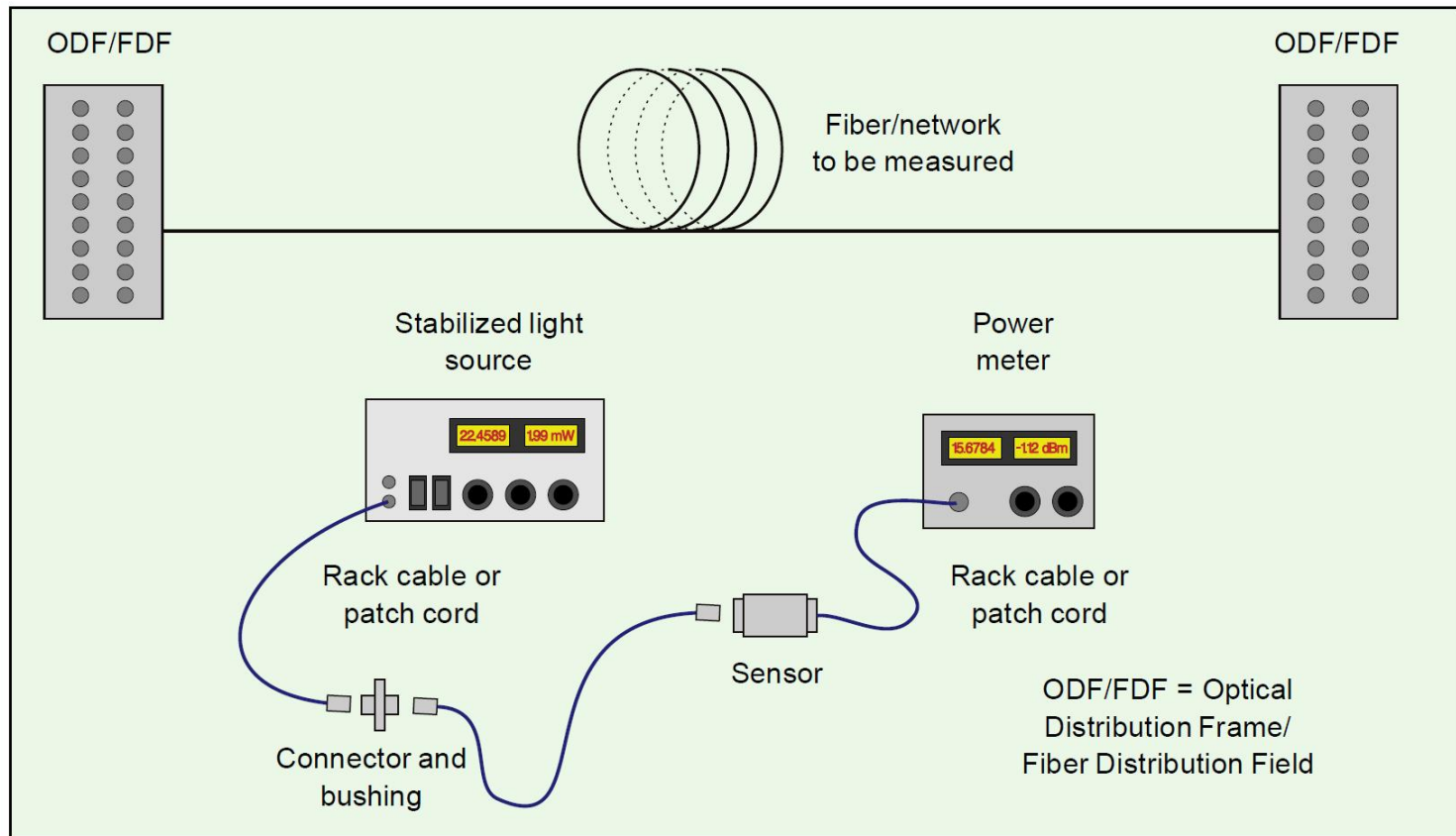
## Optical power meter

### ► Masurarea puterii si atenuarii



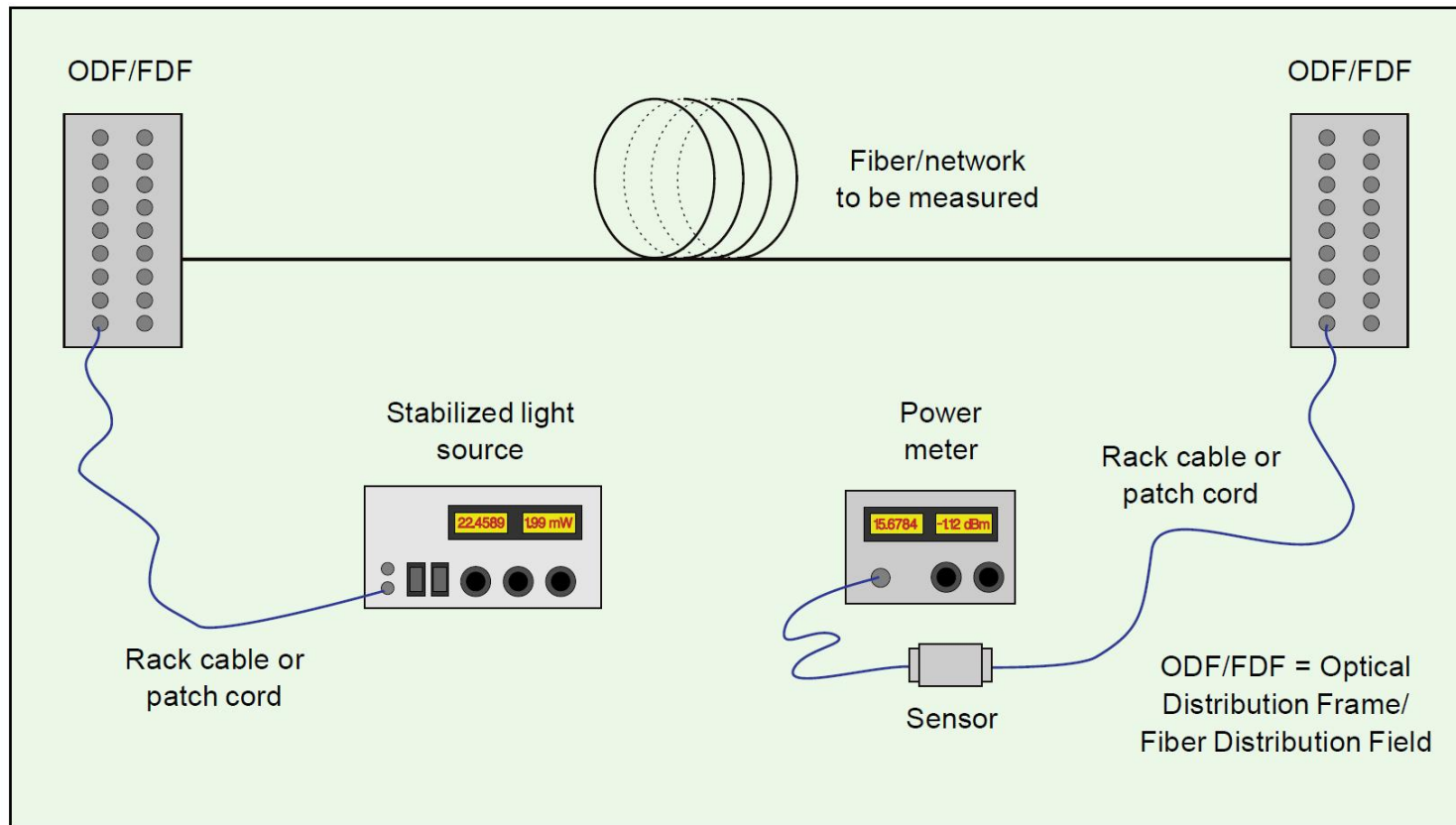
# Masurarea puterii si atenuarii

## ► Masuratoare referinta



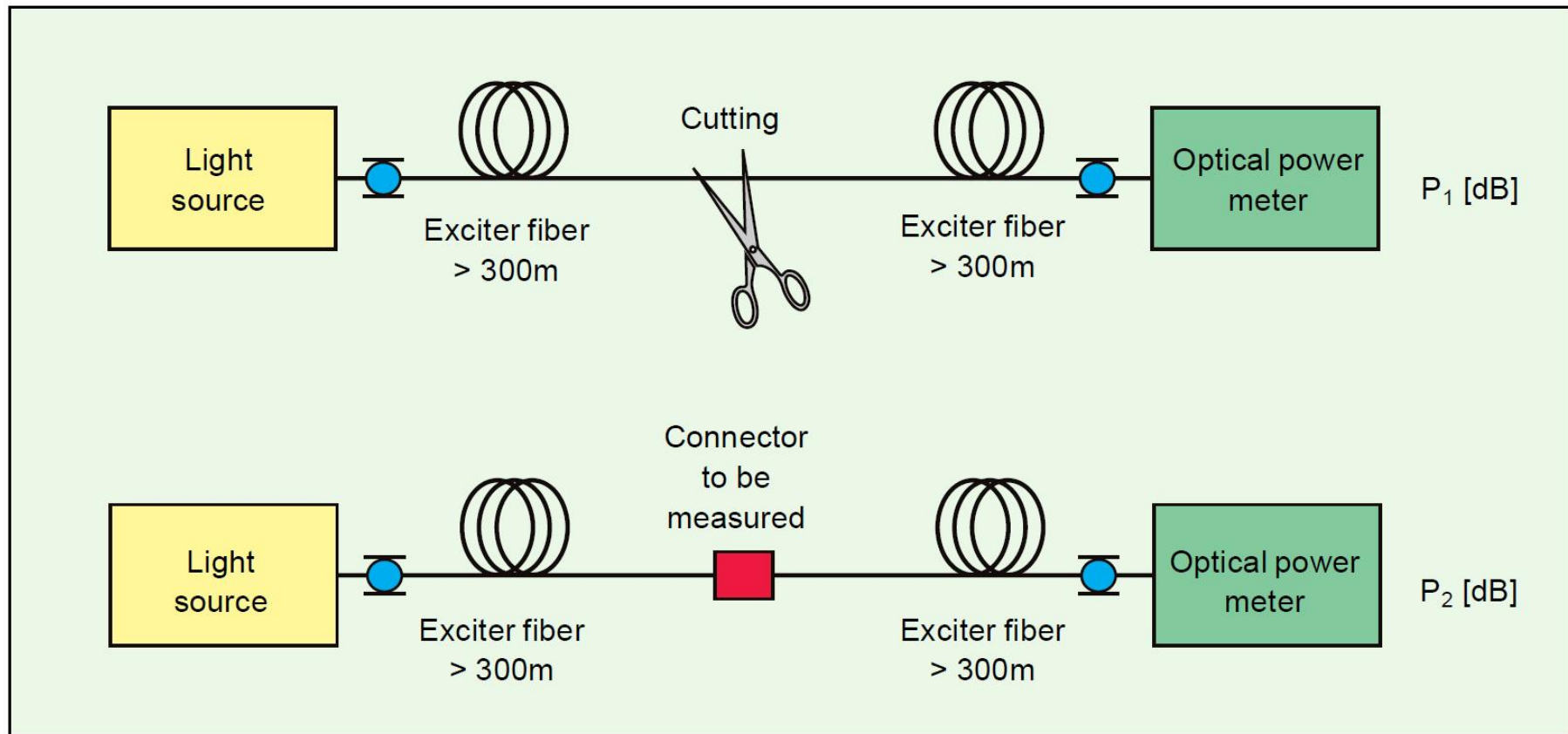
# Masurarea puterii si atenuarii

## ► Masuratoare instalatie



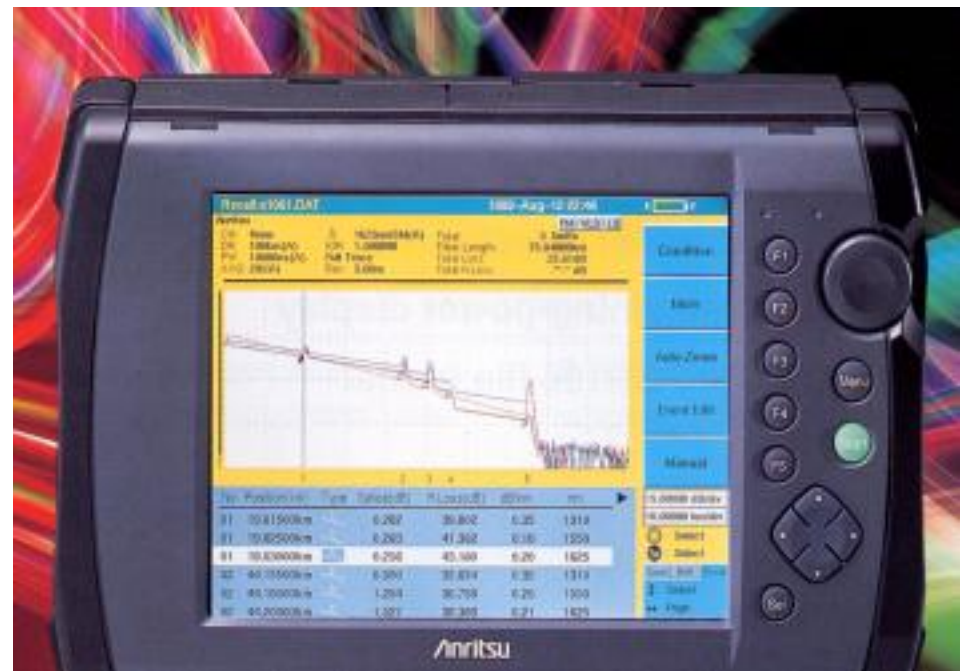
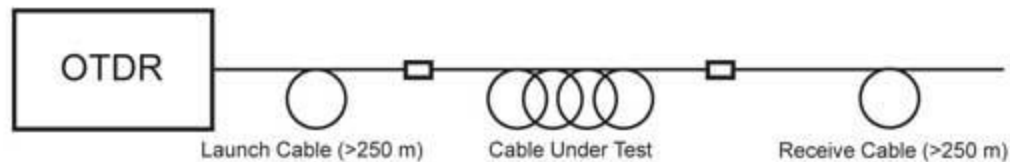
# Masurare conectori si splice

- ▶ Se elimina efectele fibrei



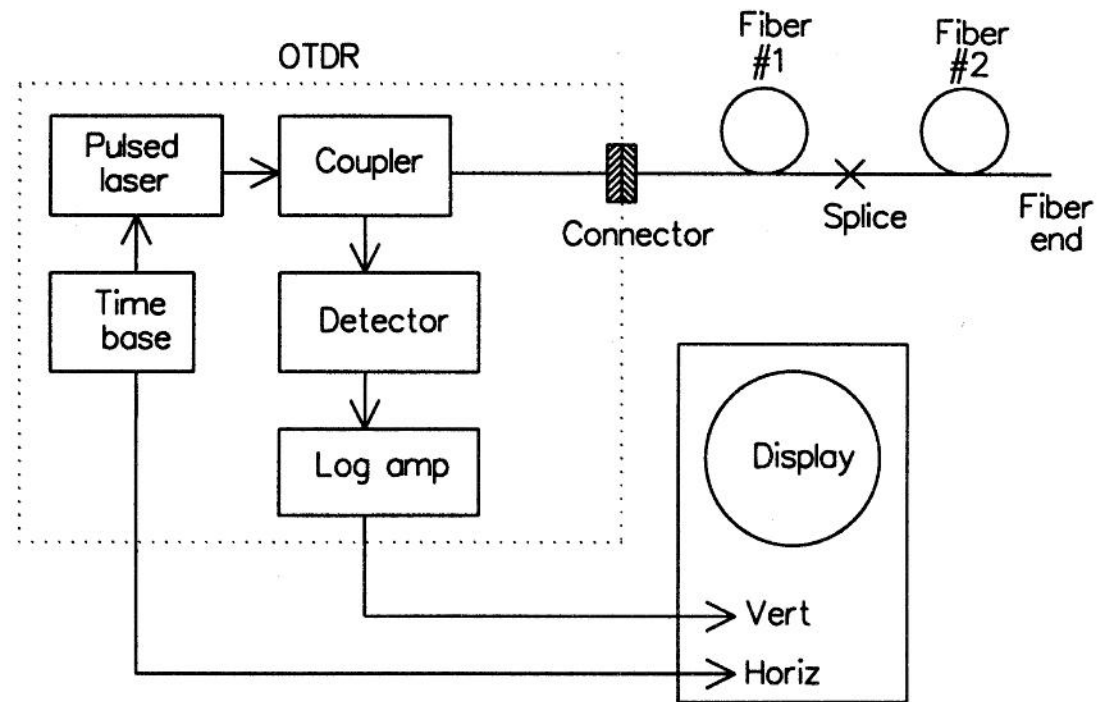
# OTDR

- ▶ Optical Time–Domain Reflectometer
- ▶ Localizarea defectelor

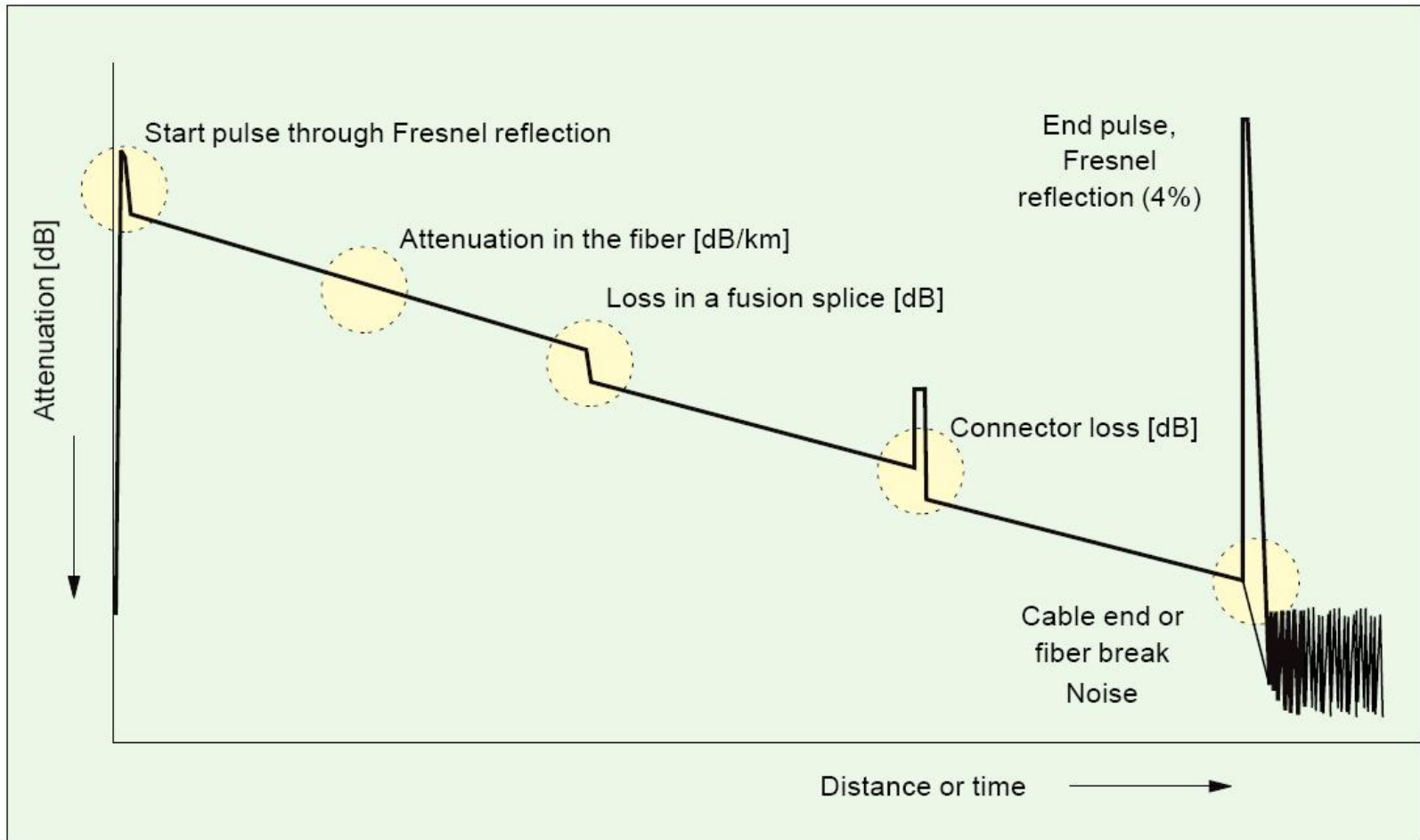


# OTDR

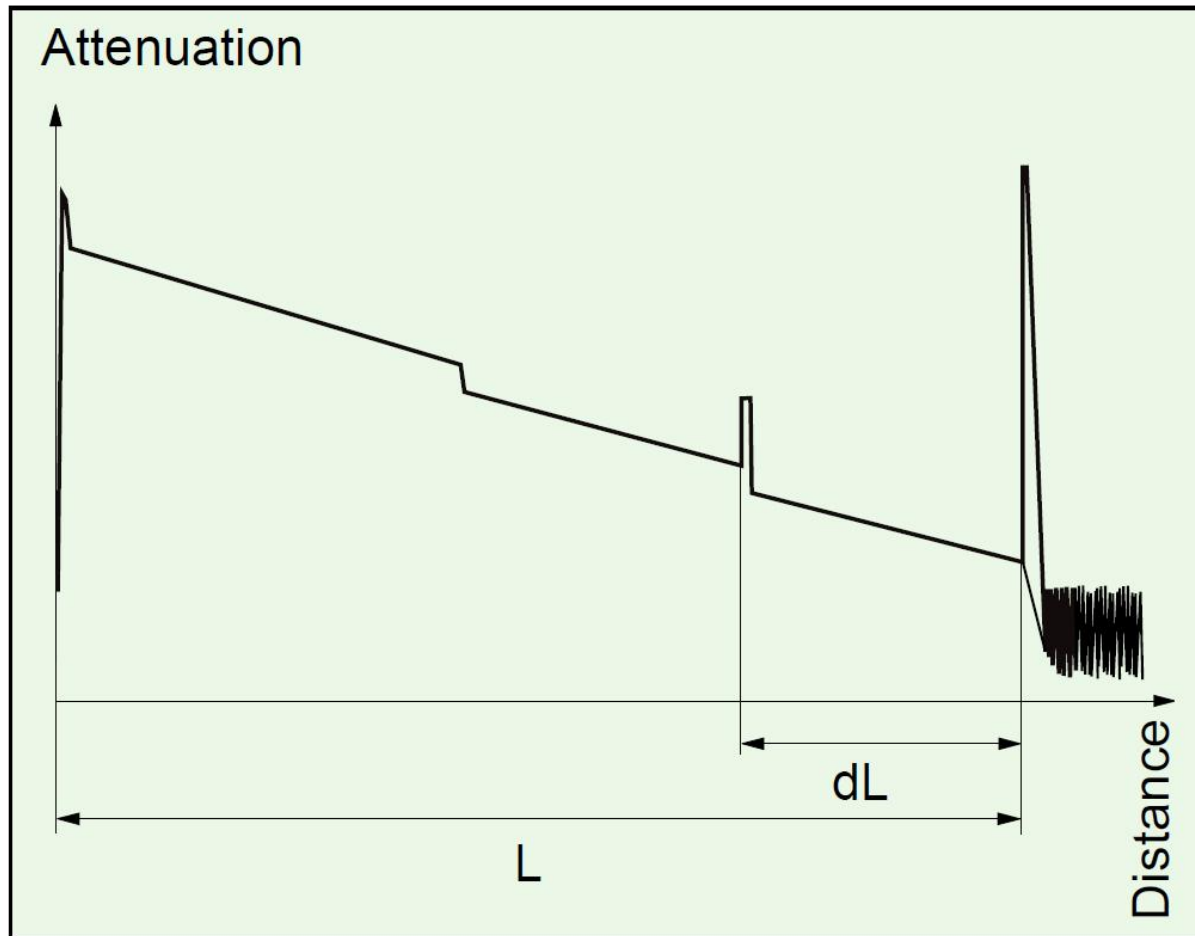
- ▶ Optical time-domain reflectometer
- ▶ Localizarea defectelor



# Rezultat grafic al OTDR



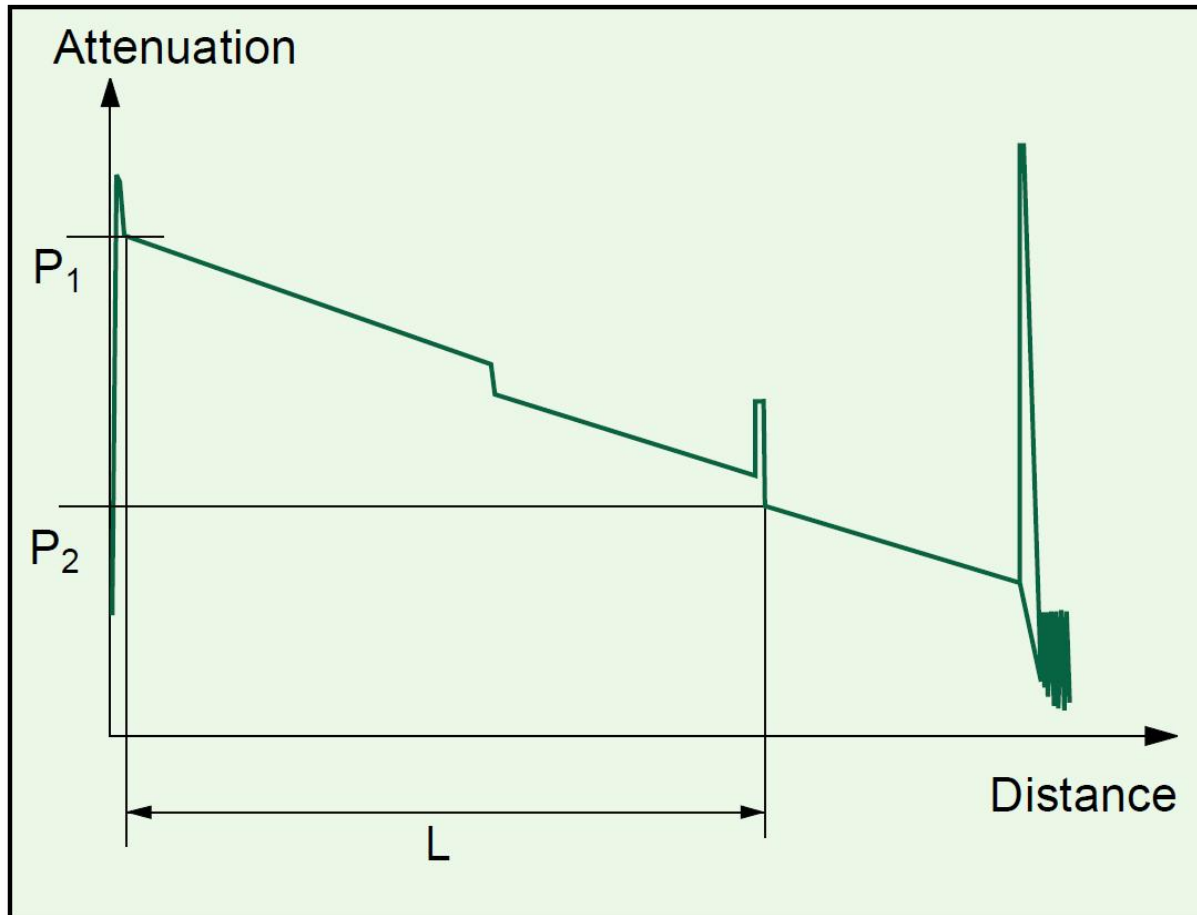
# Efecte vizibile OTDR



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

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

# Efecte vizibile OTDR



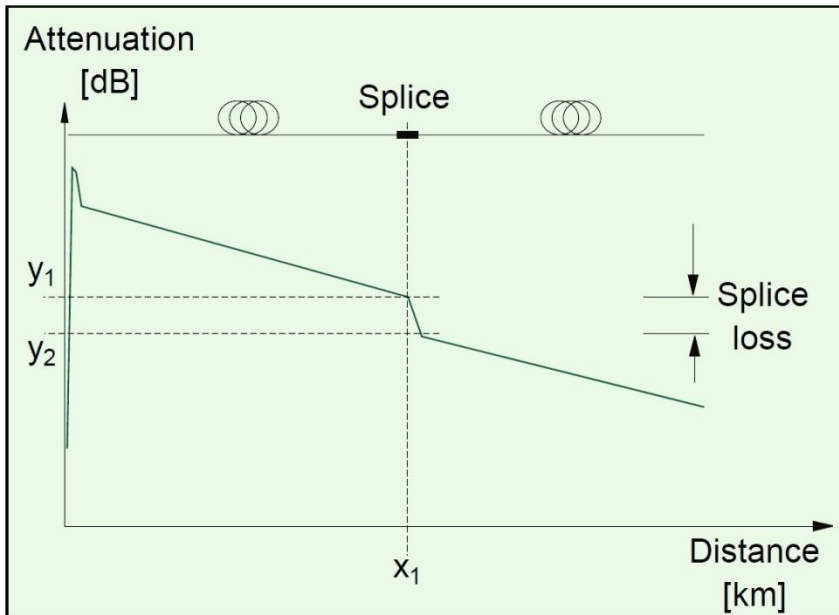
$$A[dB] = \frac{P_1 - P_2}{2}$$

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

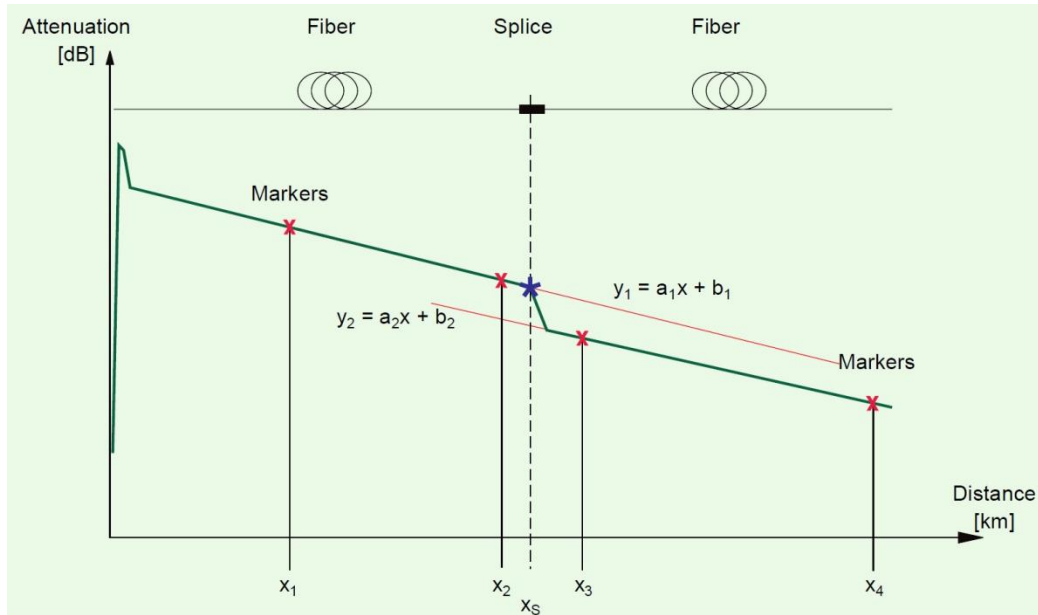
panta curbei

# Efecte vizibile OTDR – Splice

- ▶ splice loss –  $A(s)$



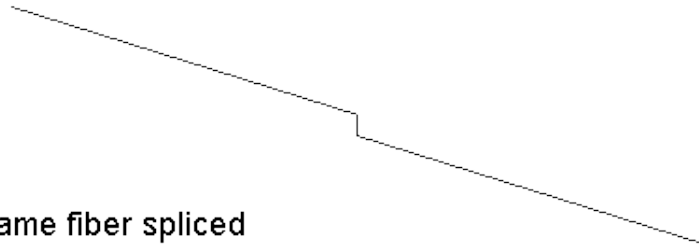
$$A(s) = y_1 - y_2$$



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

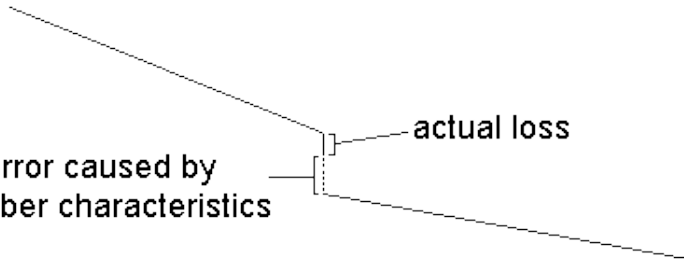
# Efecte vizibile OTDR – Splice

a. same fiber spliced



error caused by fiber characteristics

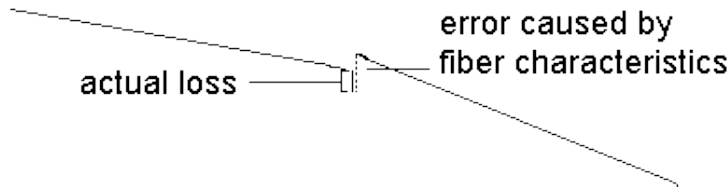
actual loss



b. high loss fiber spliced to low loss fiber

actual loss

error caused by fiber characteristics

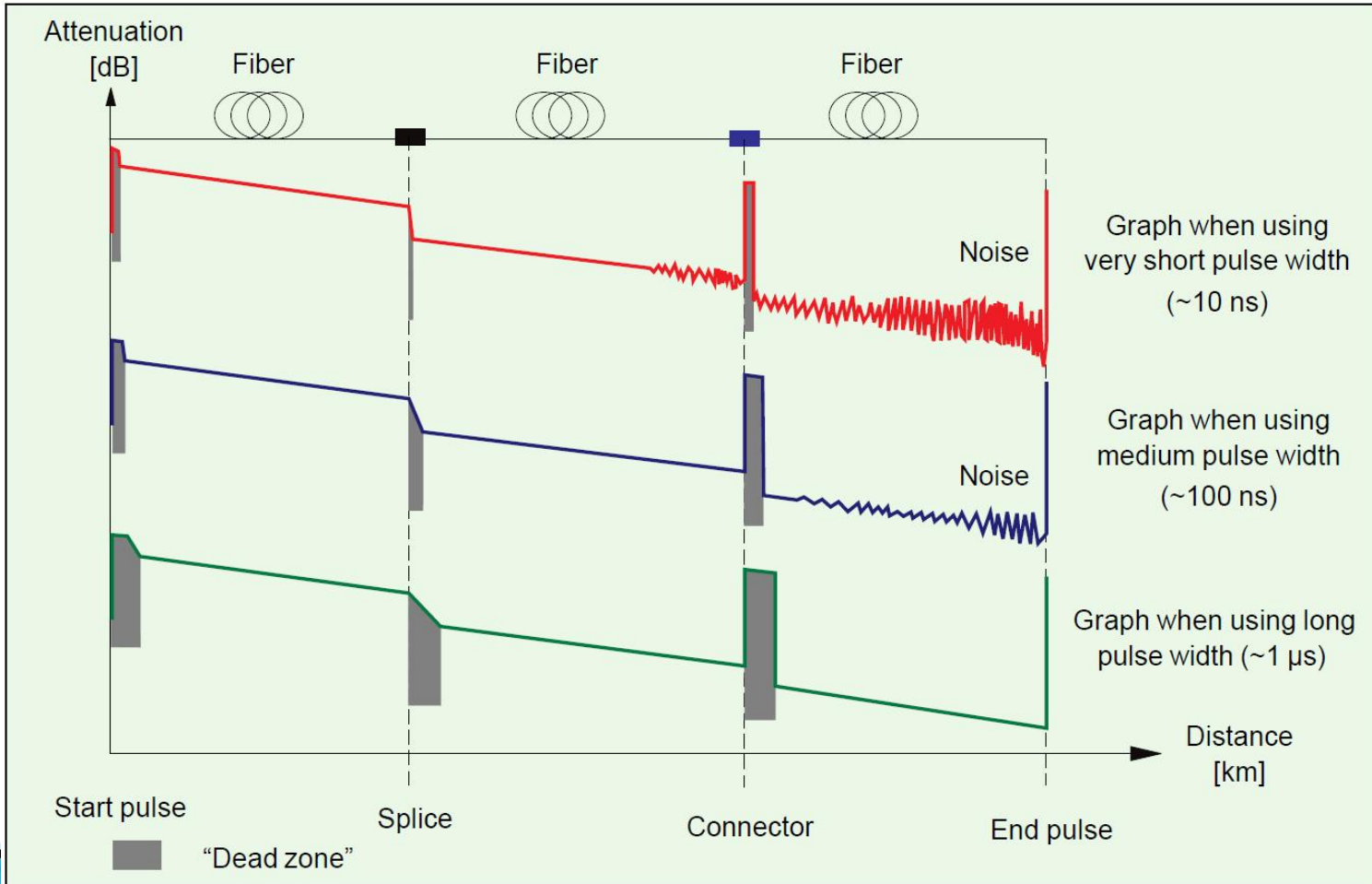


c. low loss fiber spliced to high loss fiber can cause an apparent gain at a splice

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

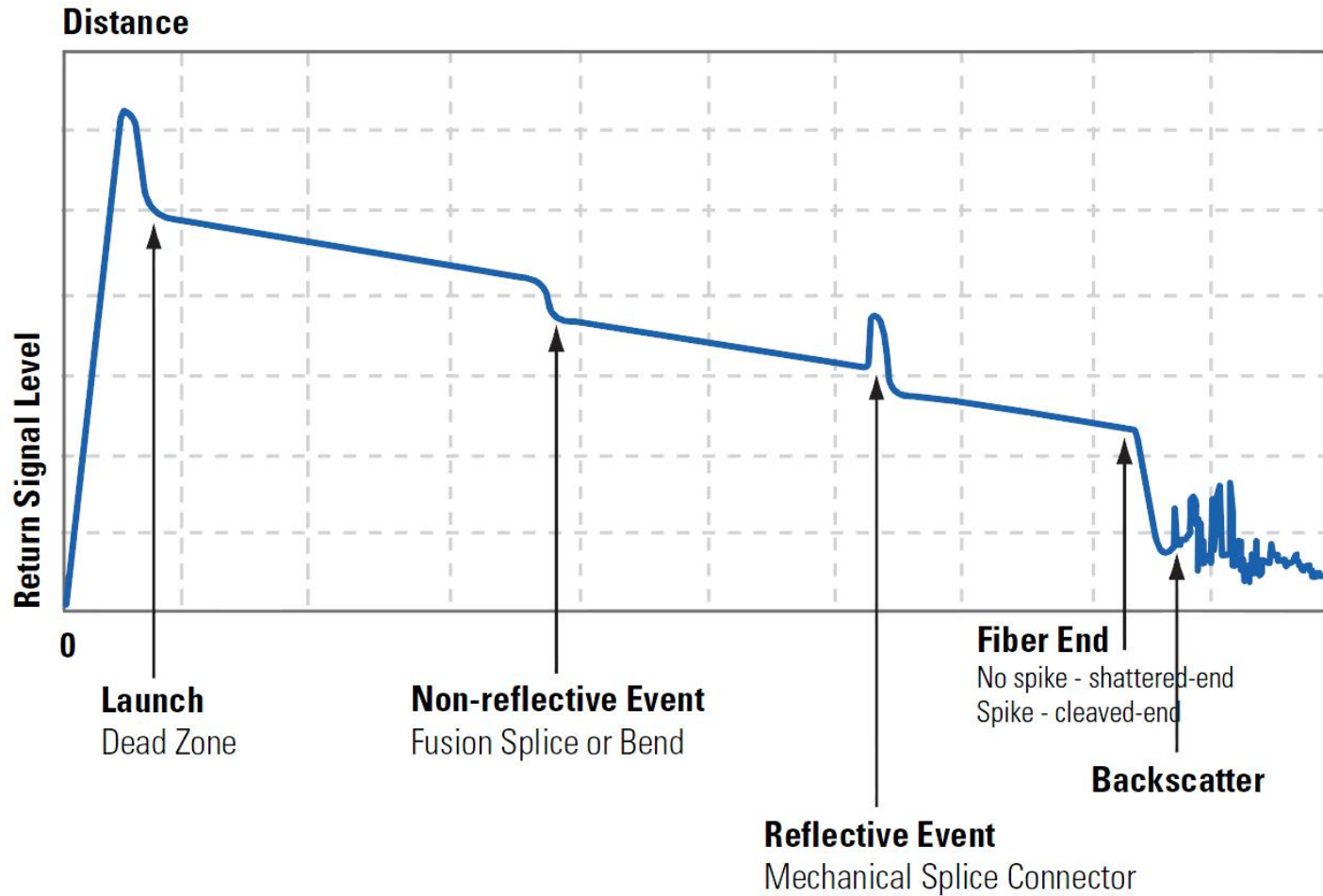
# Rezultat grafic al OTDR

## ▶ latimea pulsurilor luminoase



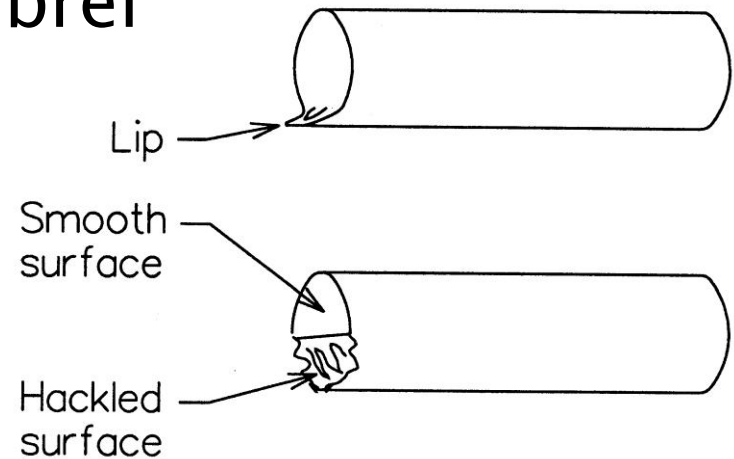
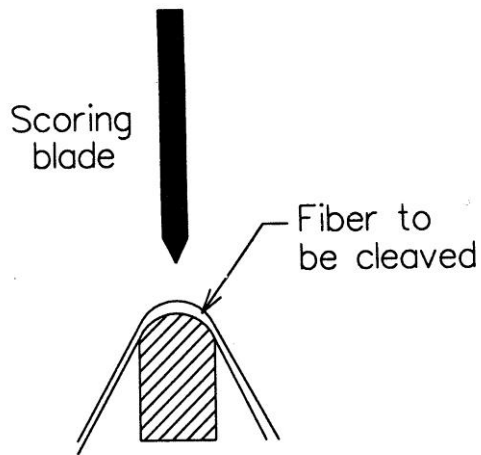
# OTDR

## Typical OTDR Trace



# Taiere – Cleaving

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

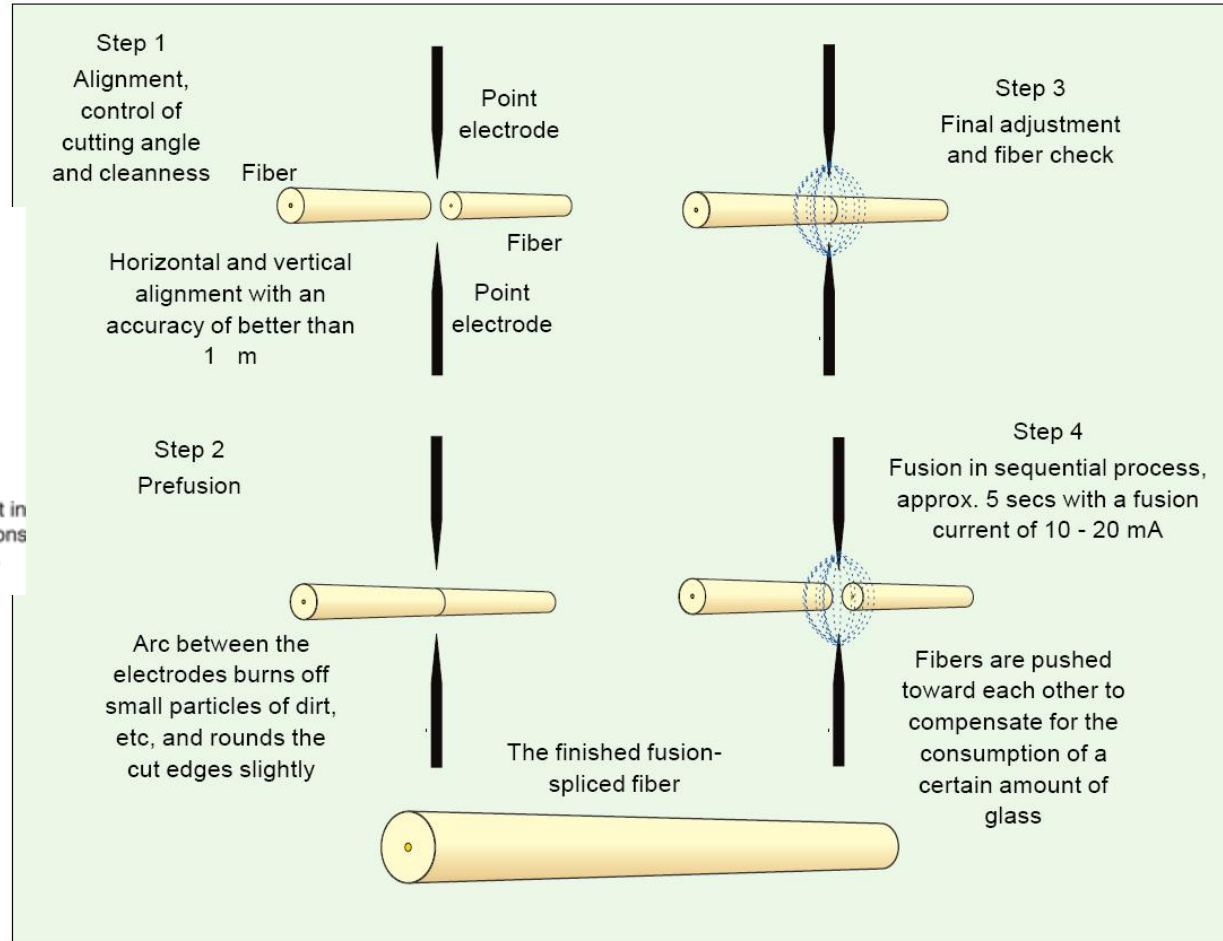
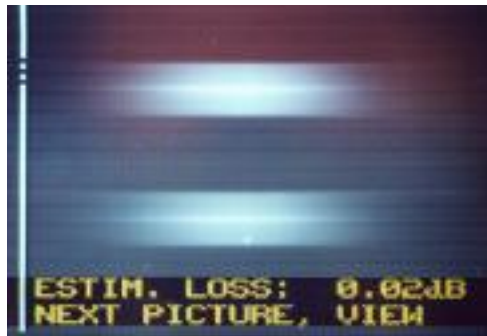
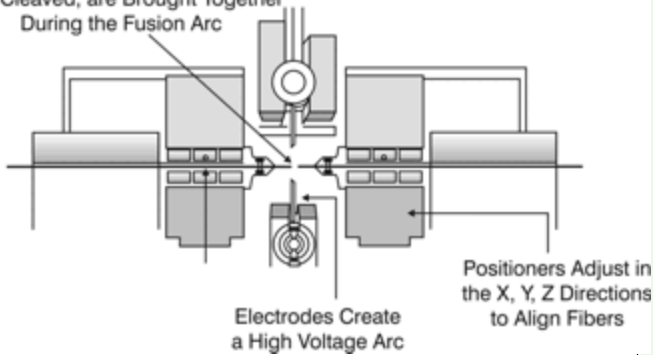


# Lipire prin fuziune



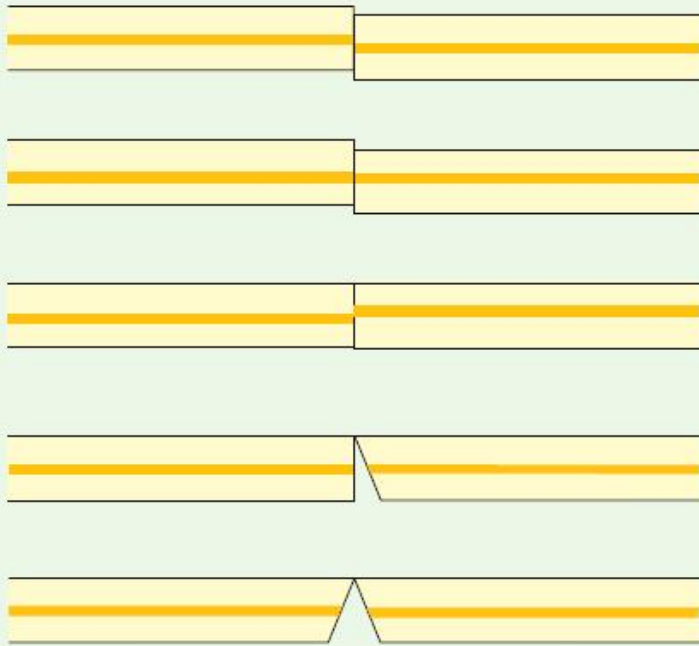
# Splice prin fuziune

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

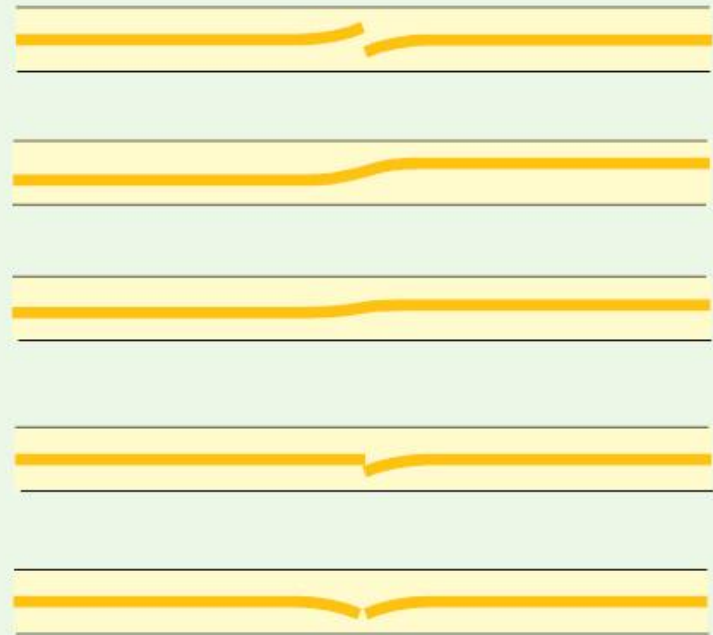


# Splice prin fuziune

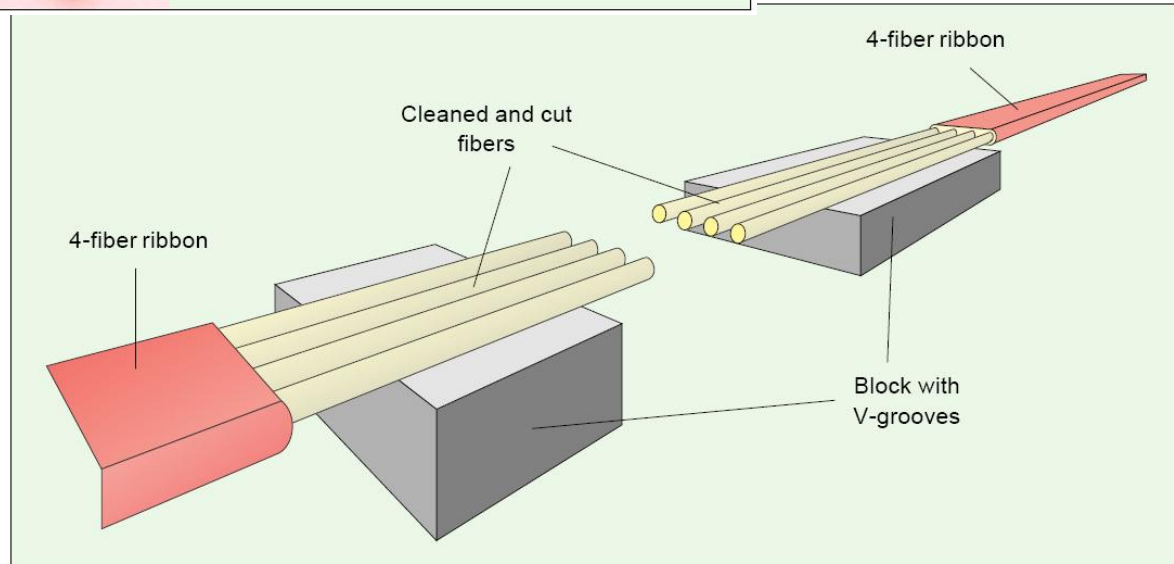
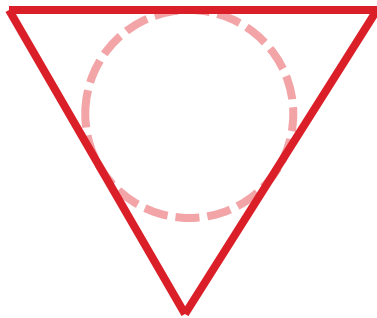
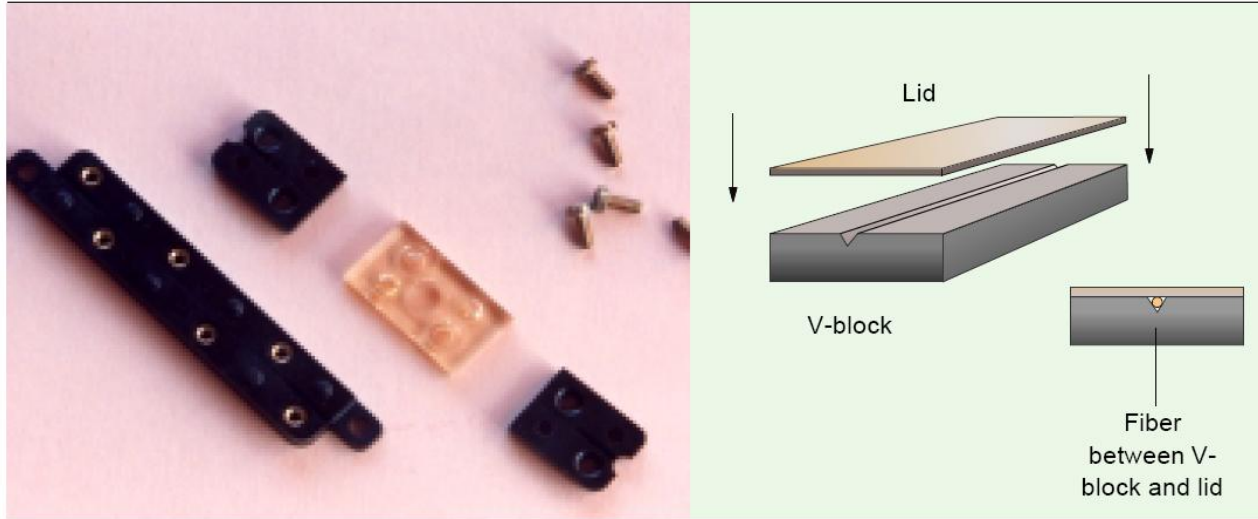
Causes of faults in fiber fusion



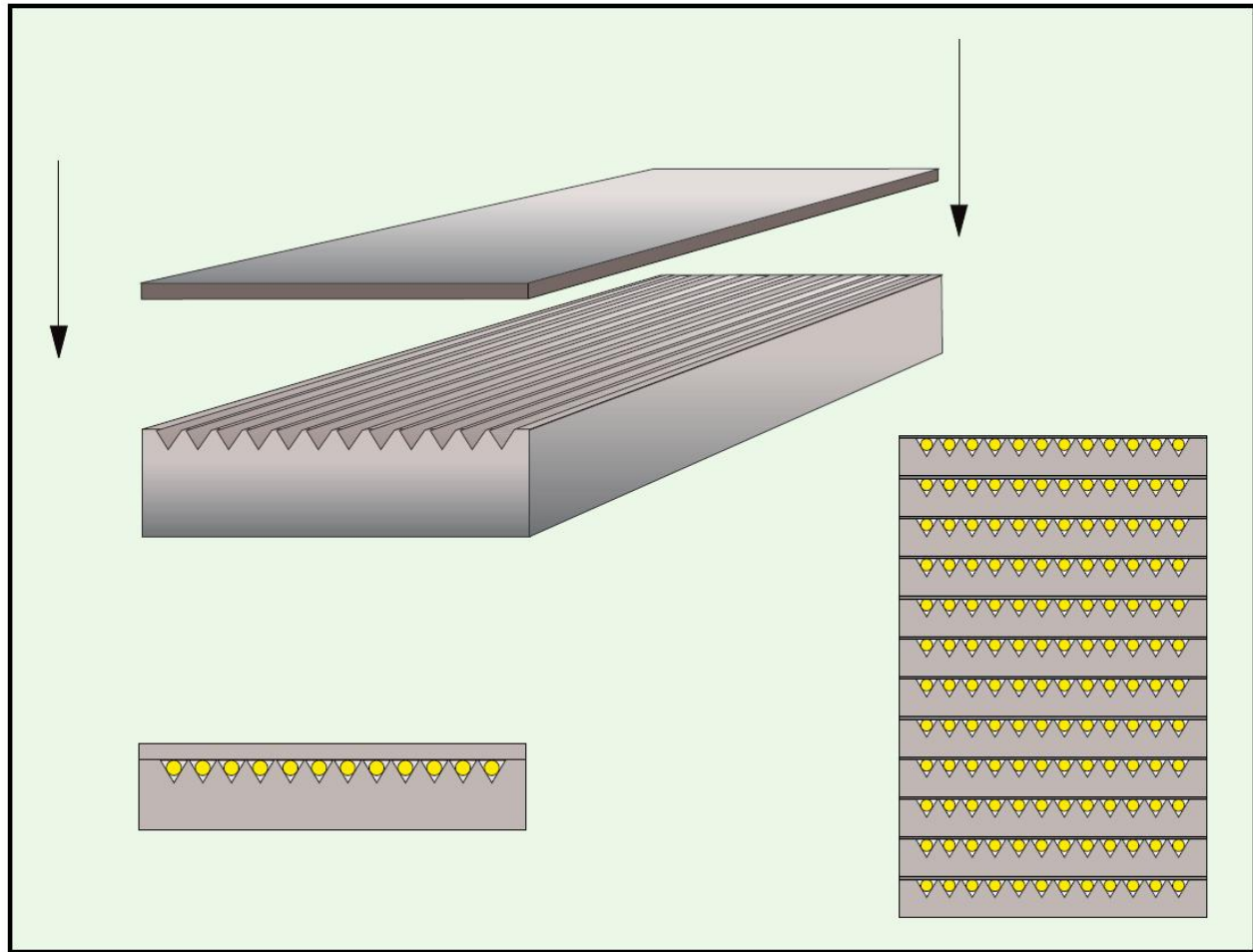
Appearance after fusion



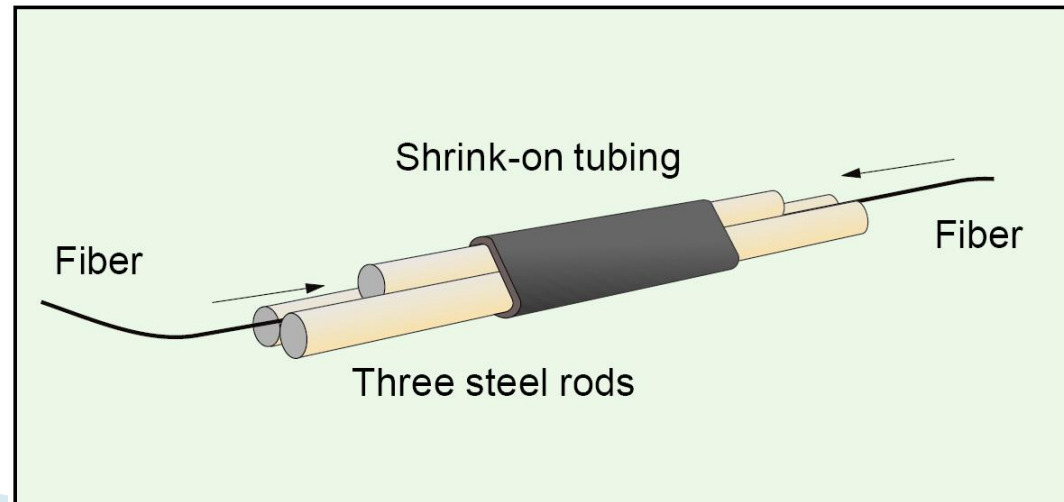
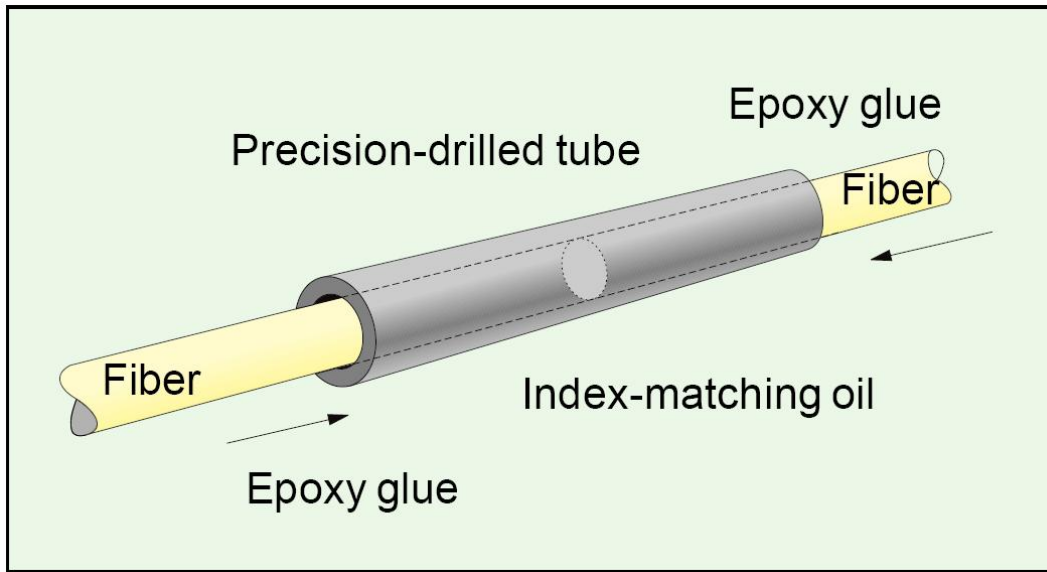
# Splice mechanic – bloc V



# Splice mechanic - bloc V

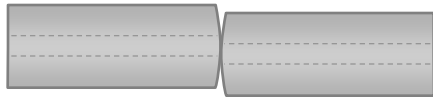


# Splice mechanic

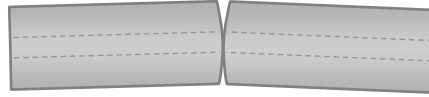


# Probleme Fibre/Conectori

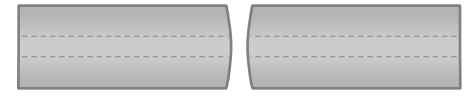
Offset



Angular Misalignment



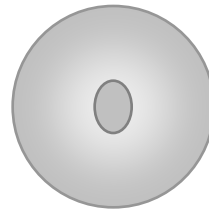
Separation



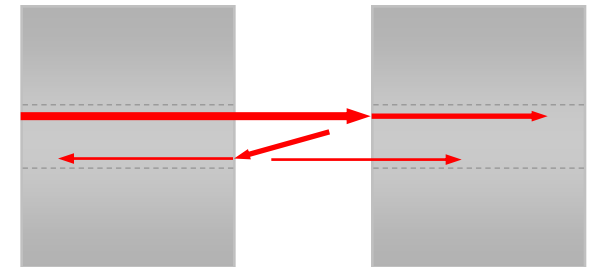
Core Eccentricity



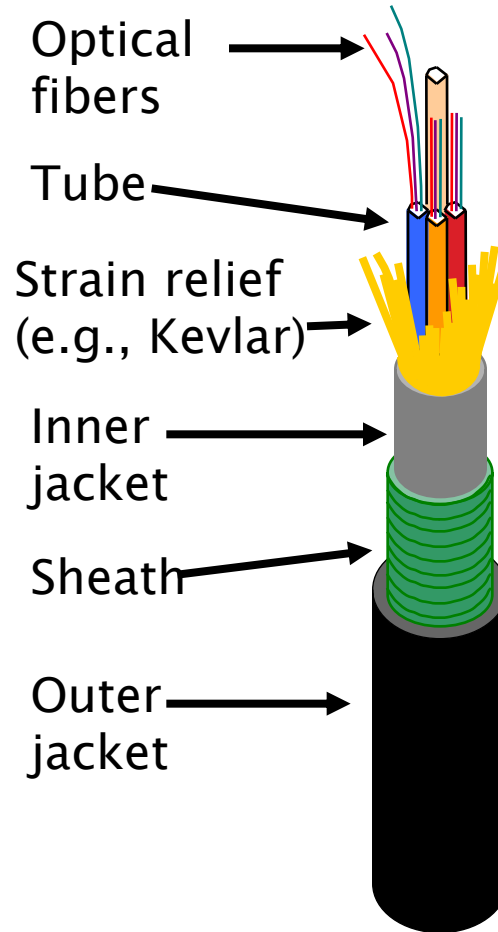
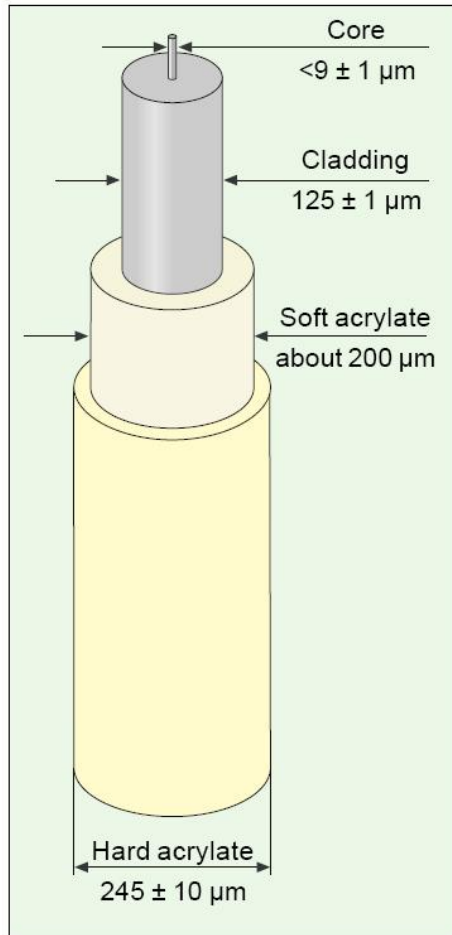
Core Ellipticity



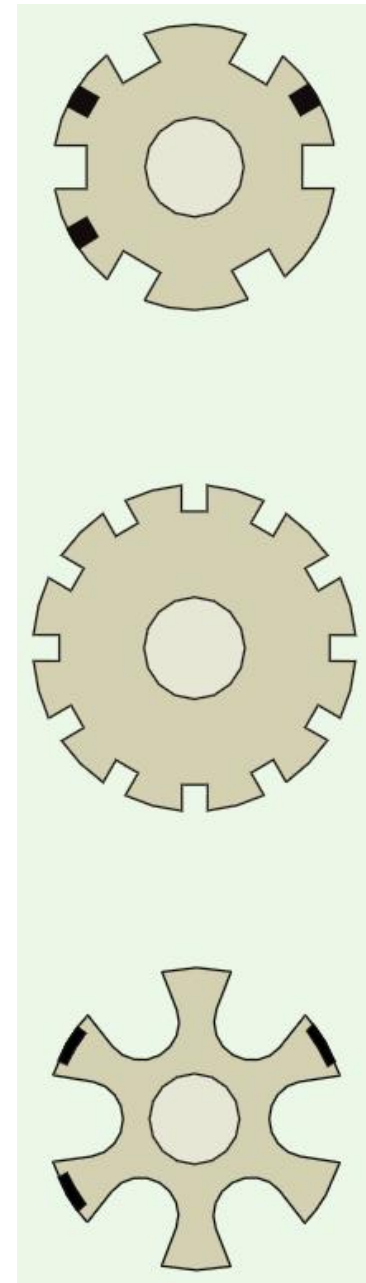
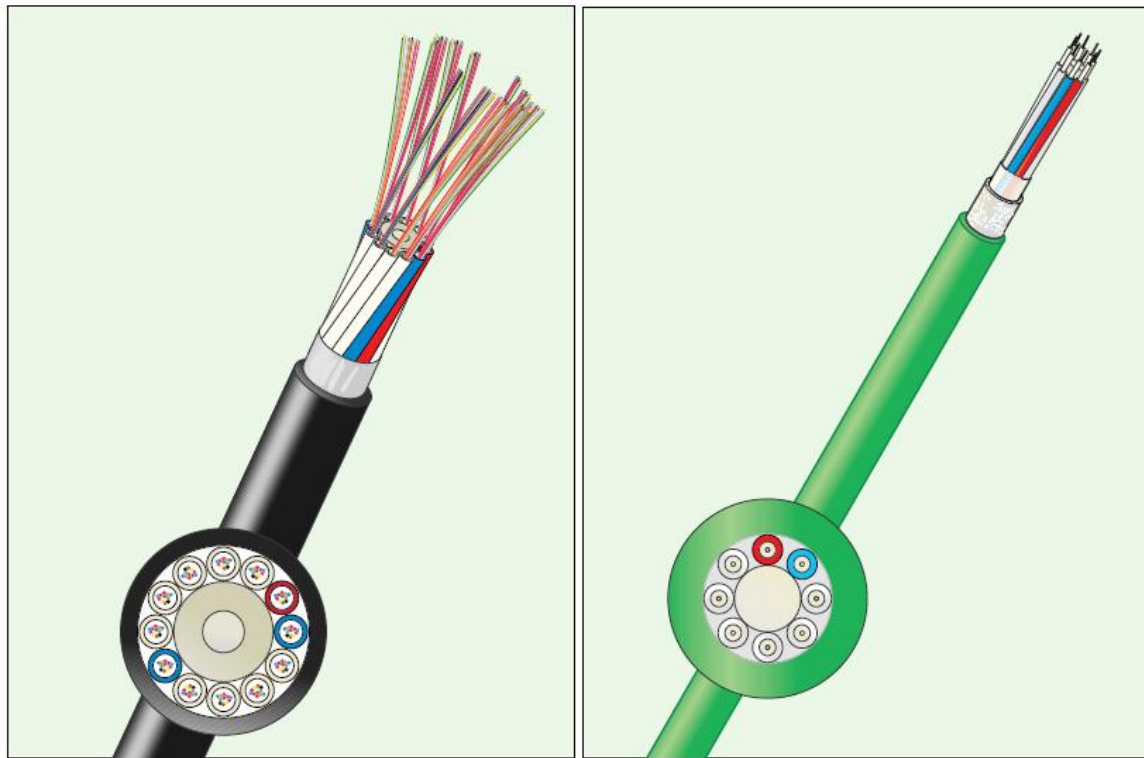
Reflections & Interference



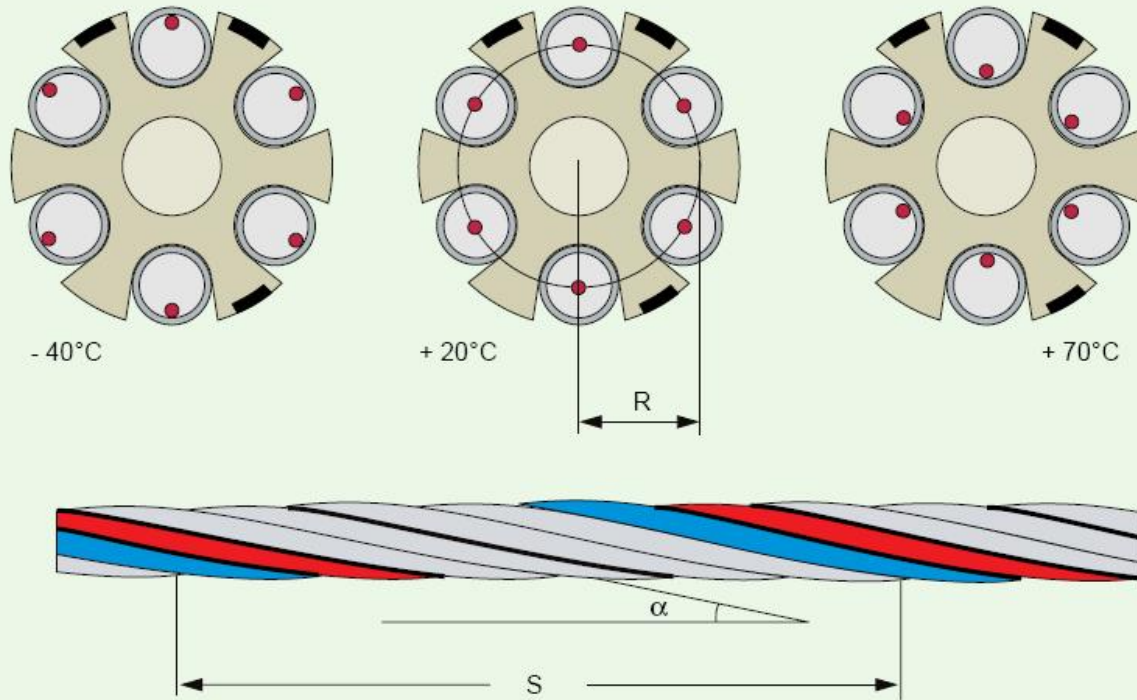
# Cabluri



# Cabluri

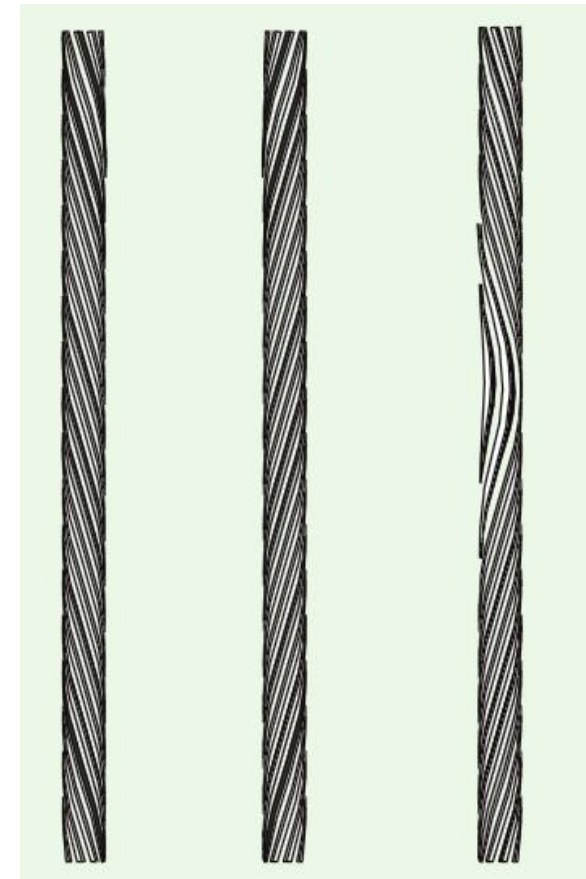


# Cabluri

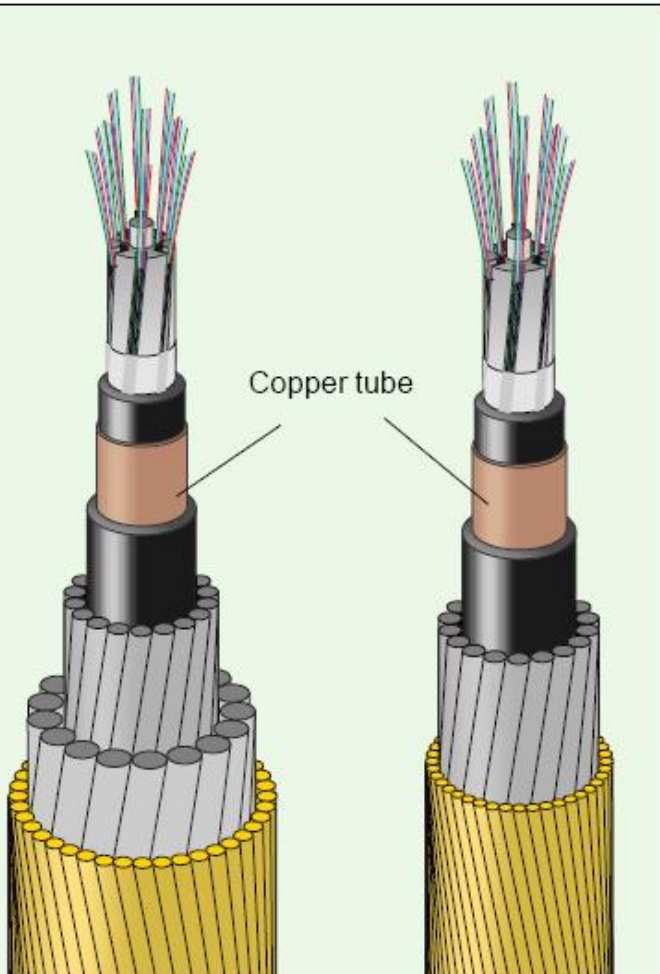
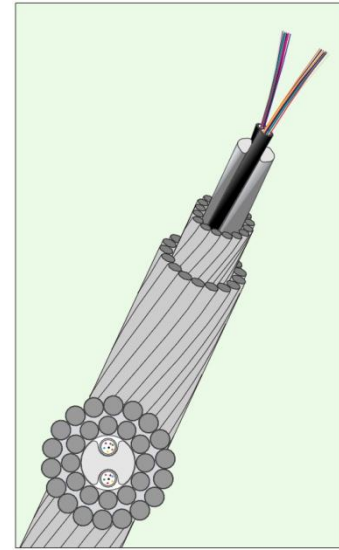


$$S' = S \cdot \sqrt{1 + \left(\frac{2\pi \cdot R}{s}\right)^2}$$

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

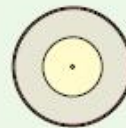


# Cabluri



Copper tube

Primary coated fiber



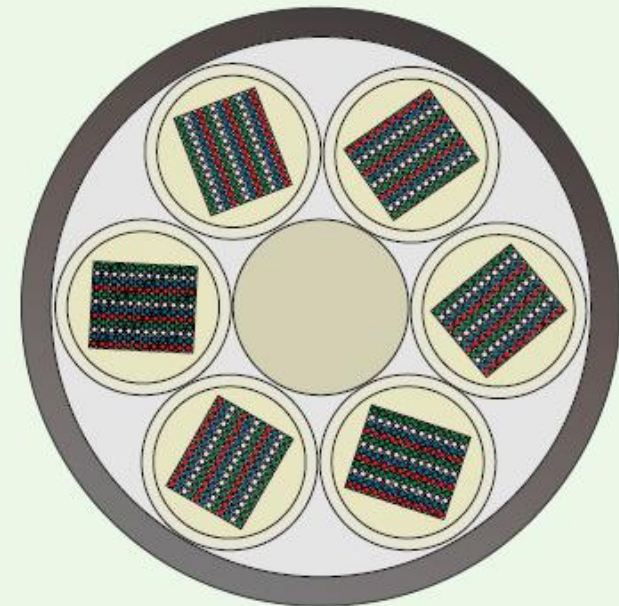
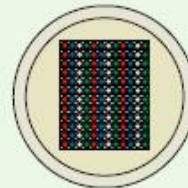
12-fiber ribbon



12 x 12-fiber ribbons  
= 144 fibers



"Lose tube"

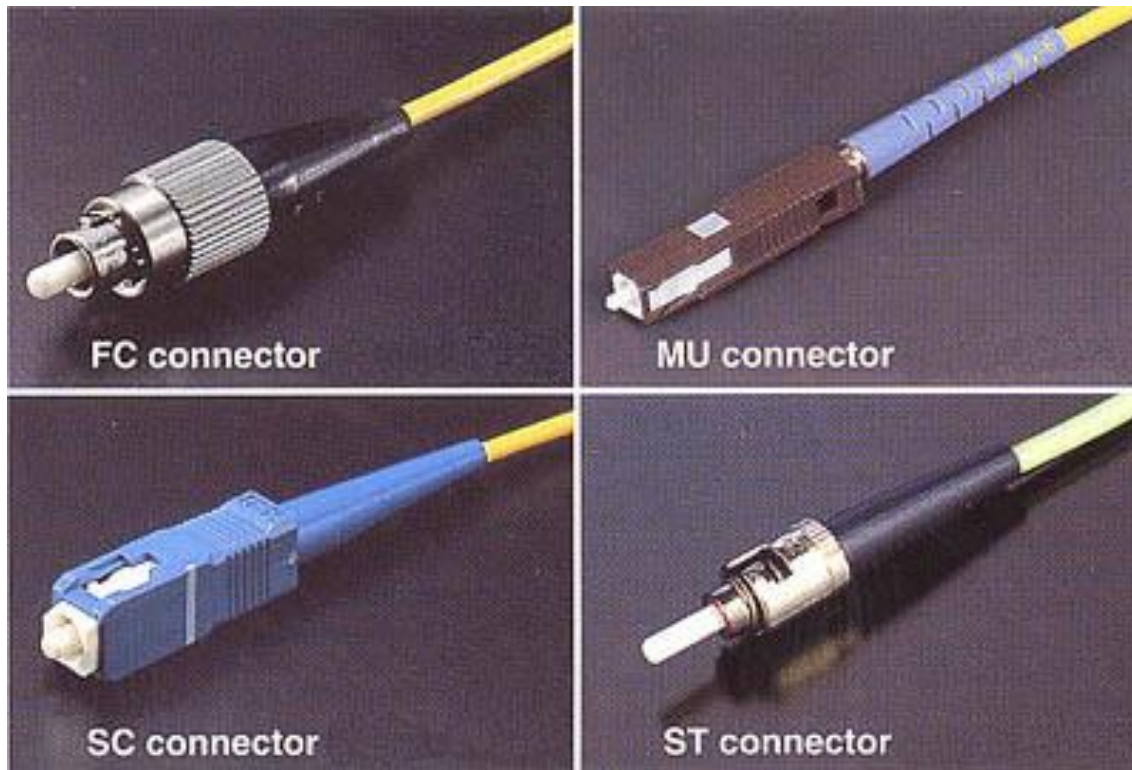


Finished cable with central strength member and with six tubes with each tube containing 144 fibers

# Conettori



# Conettori



ST

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



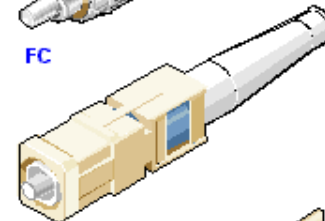
SMA Type 906

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

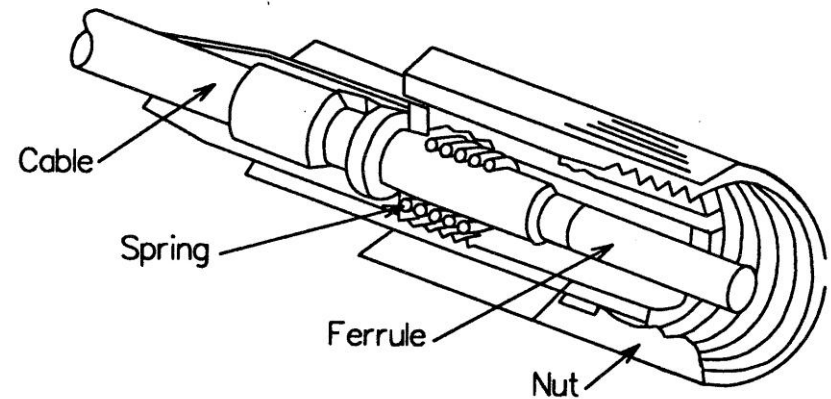
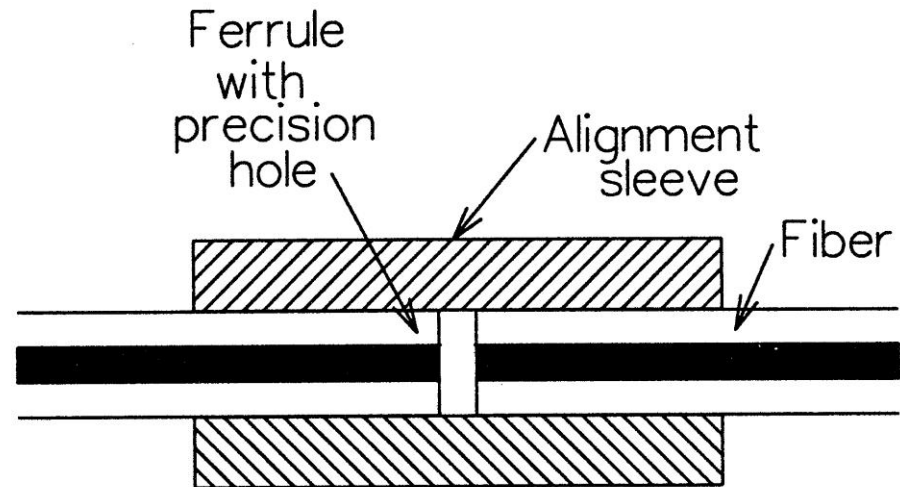
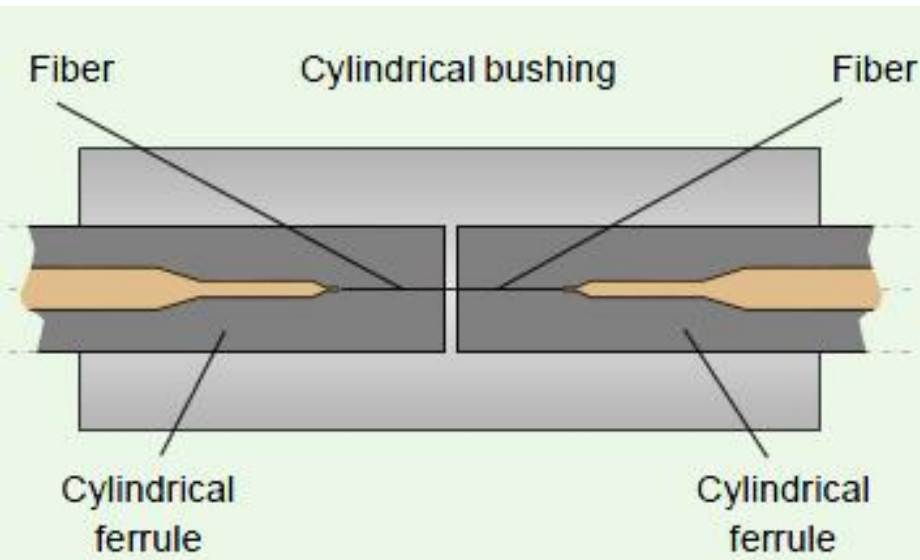


MT-RJ

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

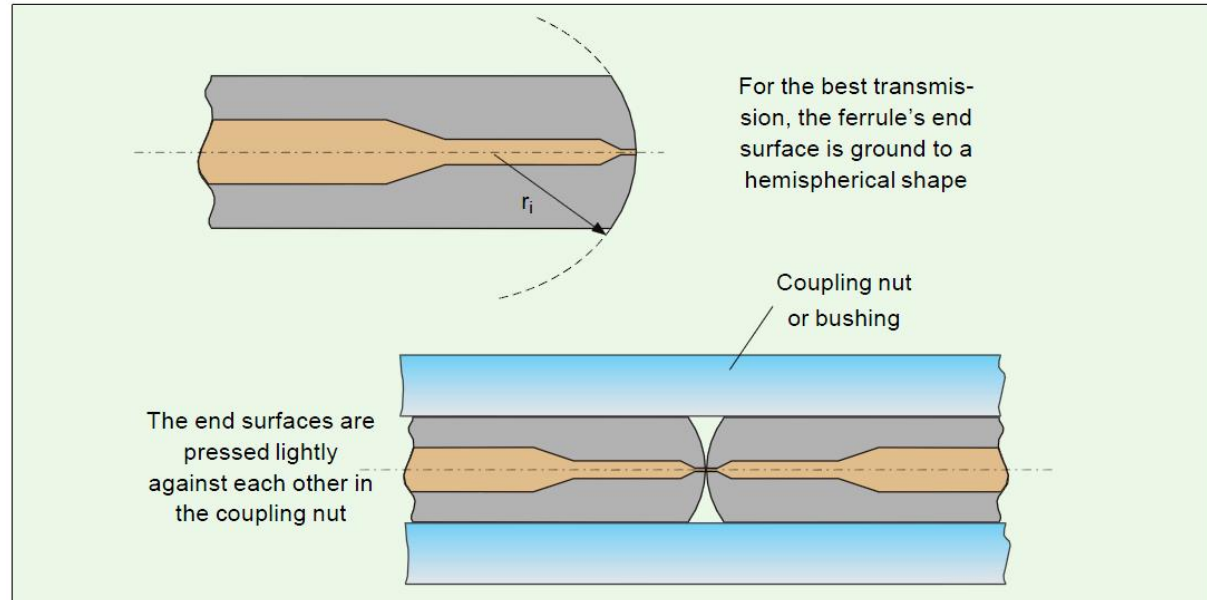
# Conettori

► Verificati <https://rf-opto.etti.tuiasi.ro>

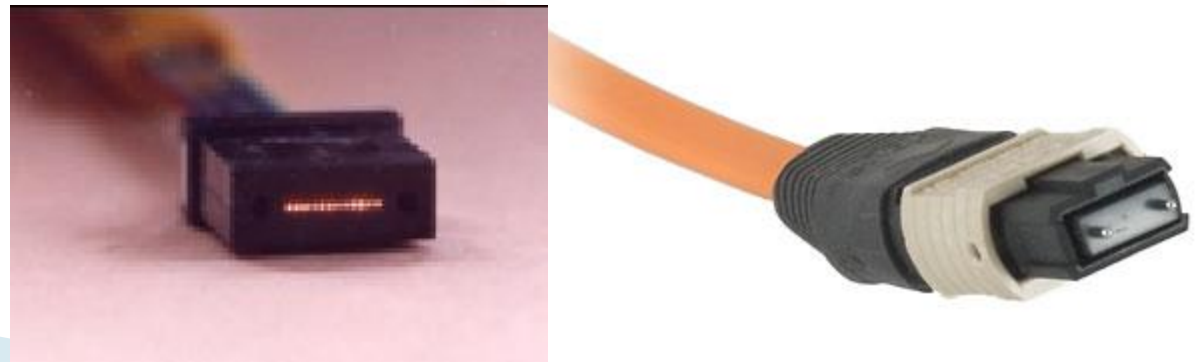


# Conettori

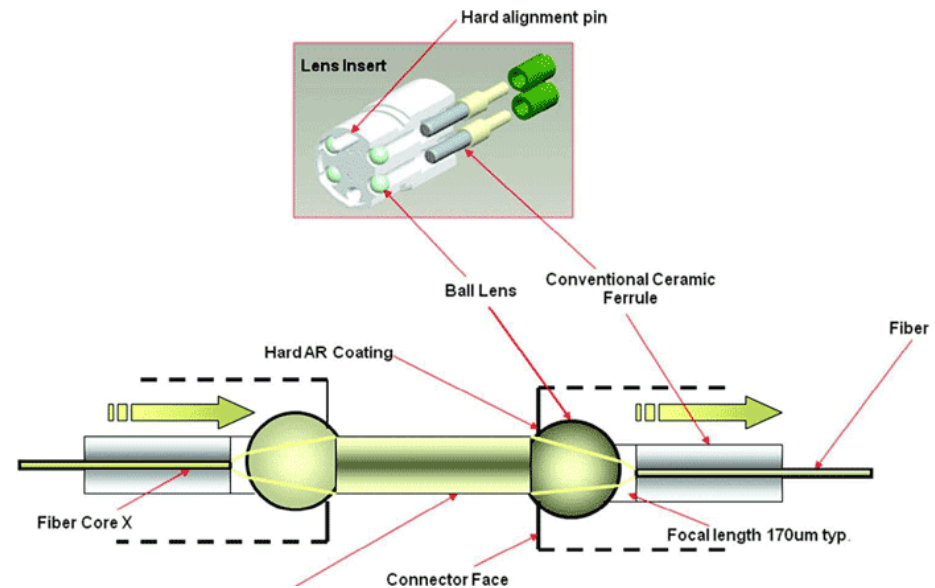
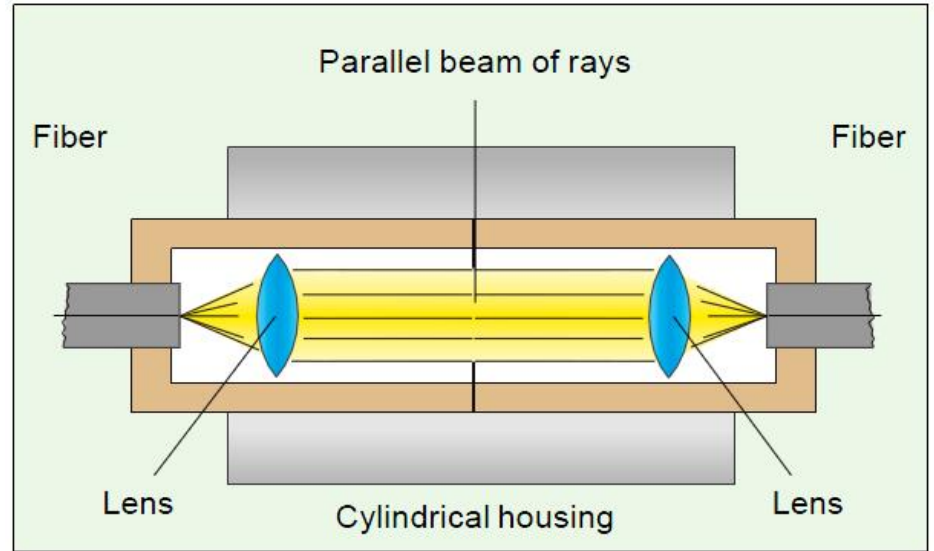
- ▶ Ferula semisferica
  - 20mm
  - 60mm



- ▶ Conettori multifibra

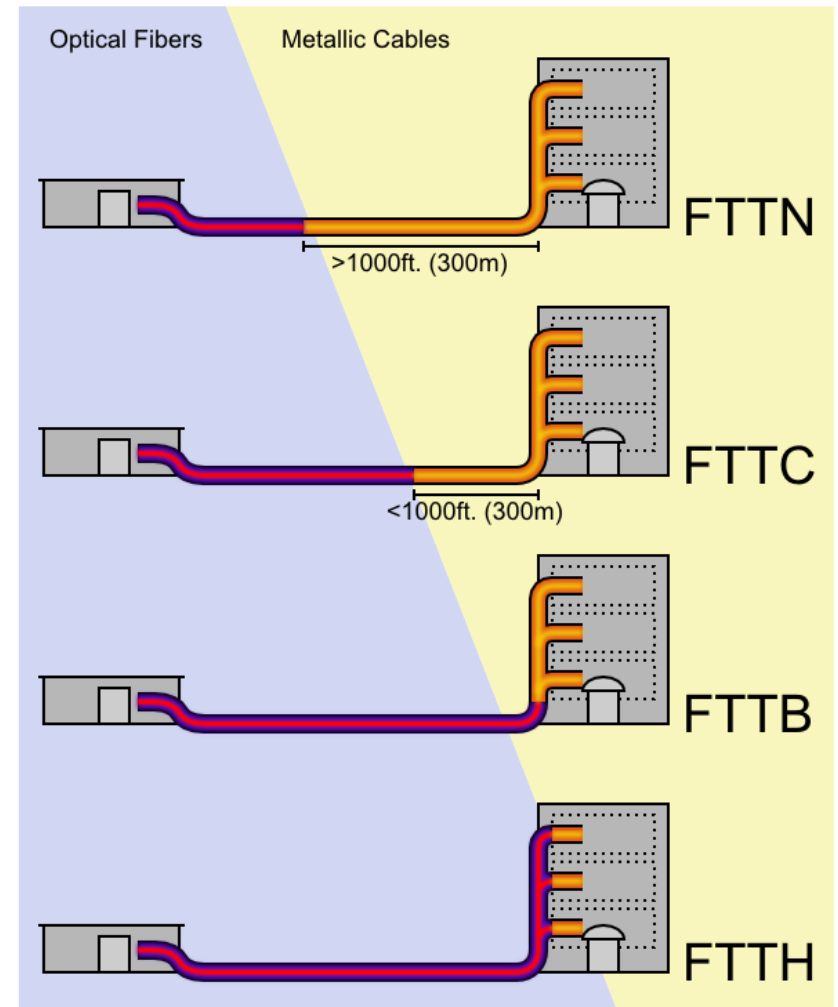


# Expanded beam connector



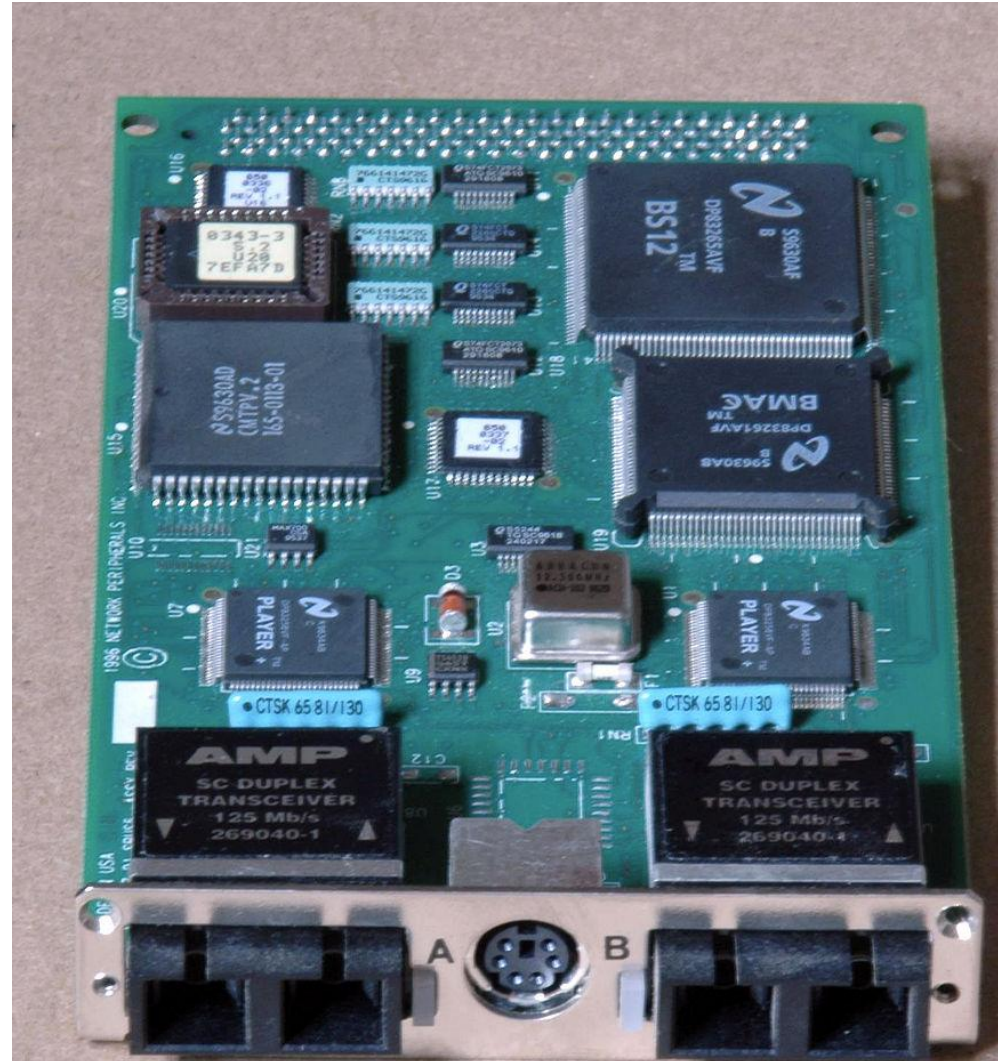
# FTTH

- ▶ 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

[Curs 3 OPTO 2020](#) (pdf, 9.01 MB, ro, 🇷🇴)

[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

[Laborator 1](#) (pdf, 159.01 KB, ro, 🇷🇴)

[Laborator 2](#) (pdf, 269.94 KB, ro, 🇷🇴)

[Laborator 3](#) (pdf, 143.82 KB, ro, 🇷🇴)

[Laborator 4](#) (pdf, 156.42 KB, ro, 🇷🇴)

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

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

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

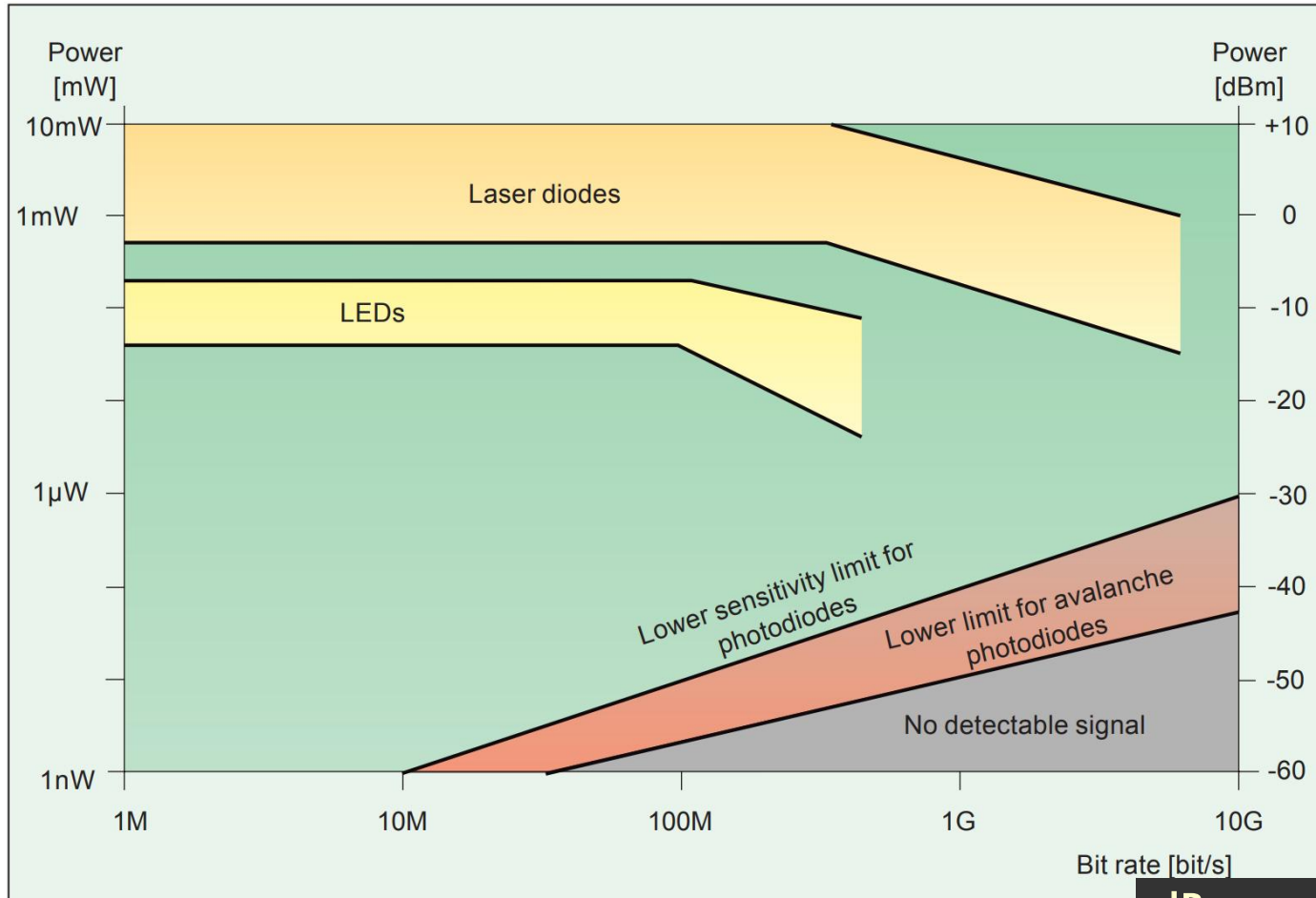
# Dimensionarea unei legături pe fibra optică

Capitolul 6

# 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 )

# Limite putere/bandă a dispozitivelor optoelectronice

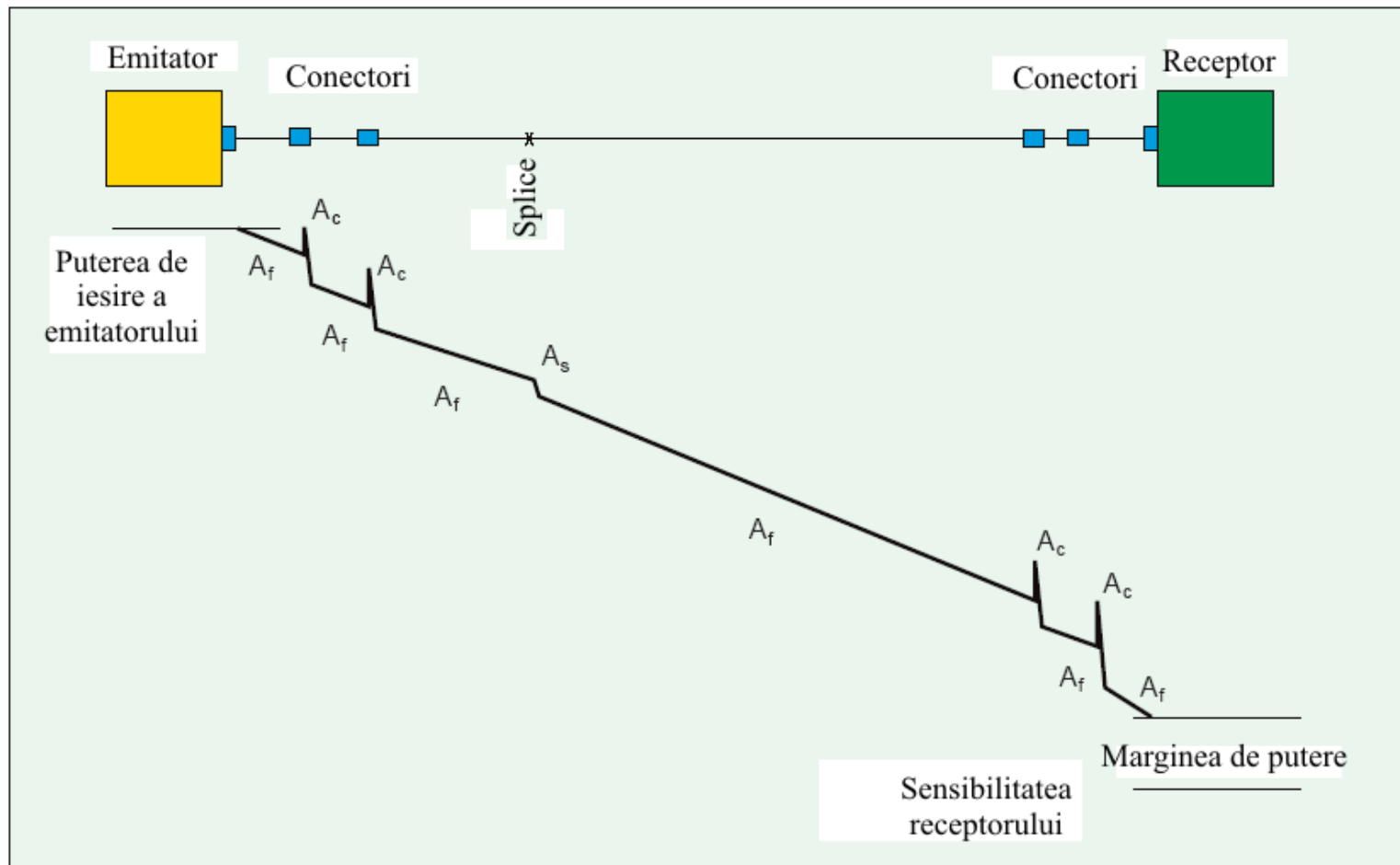


$$\text{dB} = 10 \cdot \log_{10} (P_2 / P_1)$$

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

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

# Legatura pe fibra optica

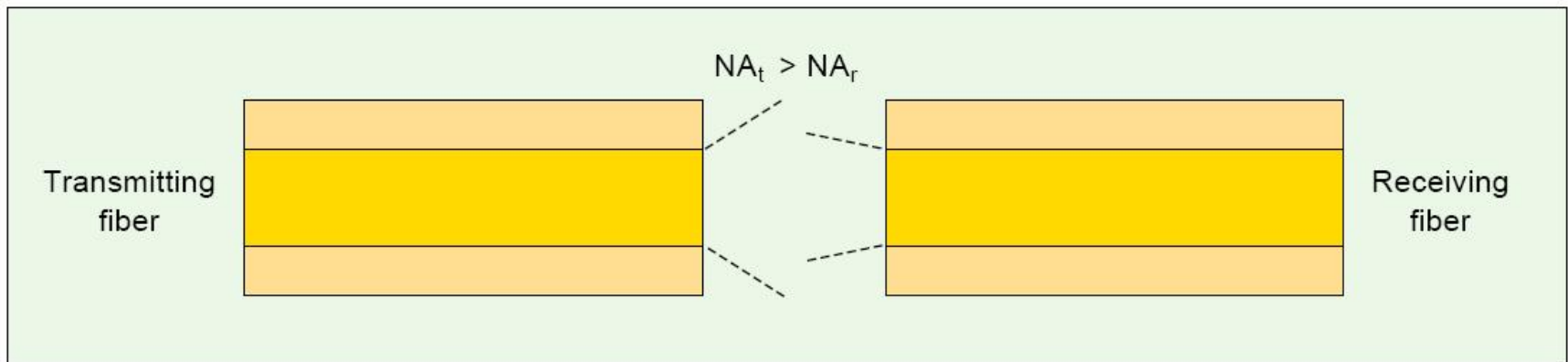


# Atenuare

- ▶ 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

# Pierderi – Apertura numerica

- ▶ **Numai** la trecerea de la apertura numerica mai mare la apertura numerica mai mica



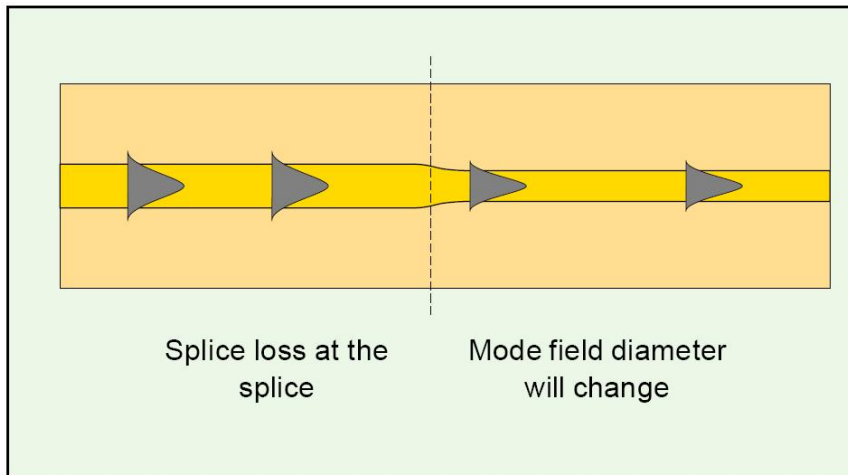
$$\text{Atenuare}_{\text{NA}} [\text{dB}] = -10 \cdot \log_{10} \left( \frac{NA_r}{NA_t} \right)^2$$

numai pentru  $NA_r < NA_t$

$$\text{Atenuare}_{\text{NA}} [\text{dB}] > 0$$

# Pierderi – Diametrul miezului

- ▶ **Numai** la trecerea de la diametru mai mare la diametru mai mic (multimod)
- ▶ **Bidirectional** (monomod)



- ▶ multimod

$$\text{Atenuare}_\Phi [\text{dB}] = -10 \cdot \log_{10} \left( \frac{\phi_r}{\phi_t} \right)^2$$

numai pentru  $\Phi_r < \Phi_t$

- ▶ monomod

$$\text{Atenuare}_\Phi [\text{dB}] = -20 \cdot \log_{10} \left( \frac{2 \cdot w_1 \cdot w_2}{w_1^2 + w_2^2} \right)$$

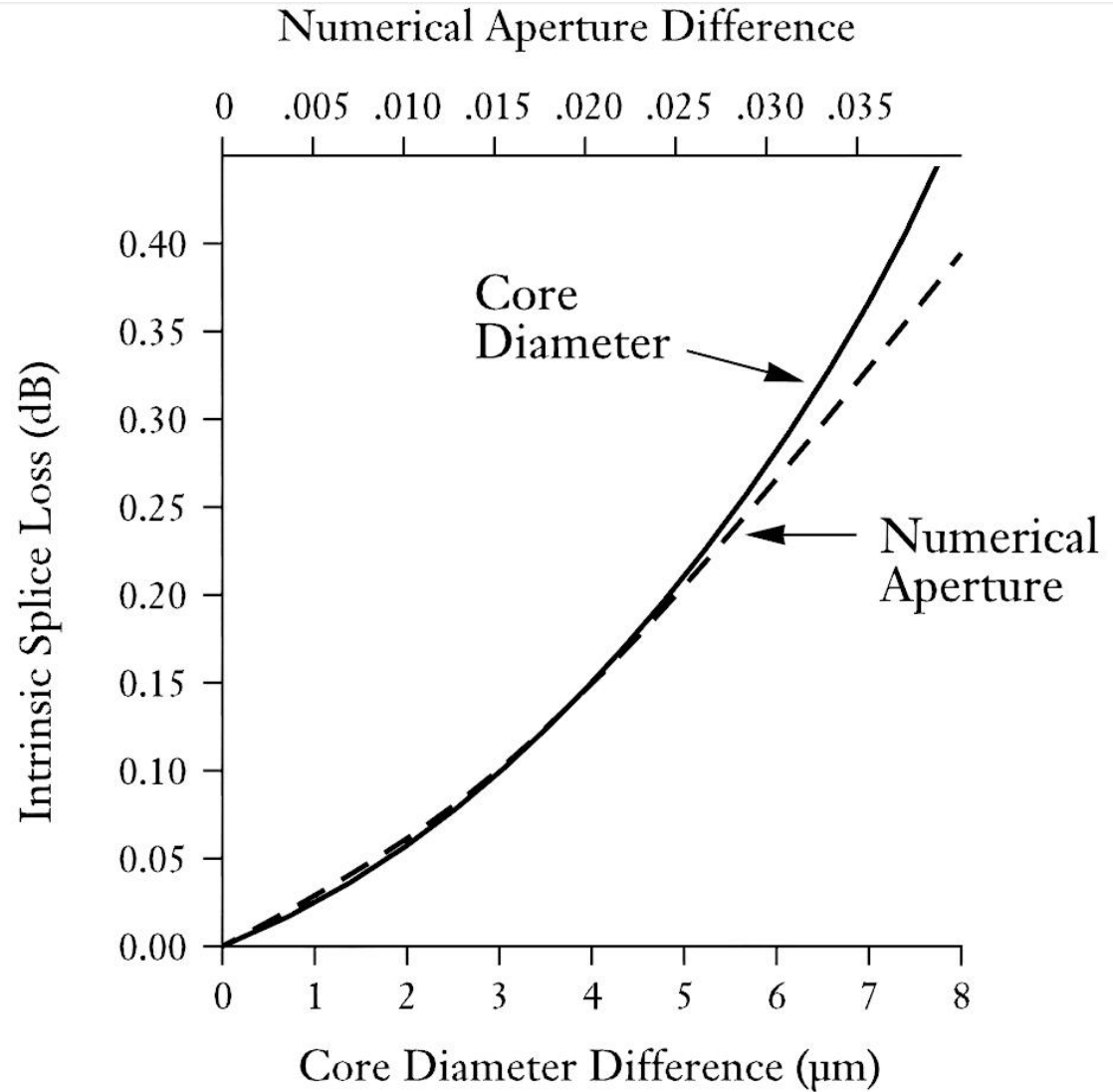
bidirectional  $\forall w_1, w_2$

**w = MFD !!**

$$\text{Atenuare}_\Phi [\text{dB}] > 0$$

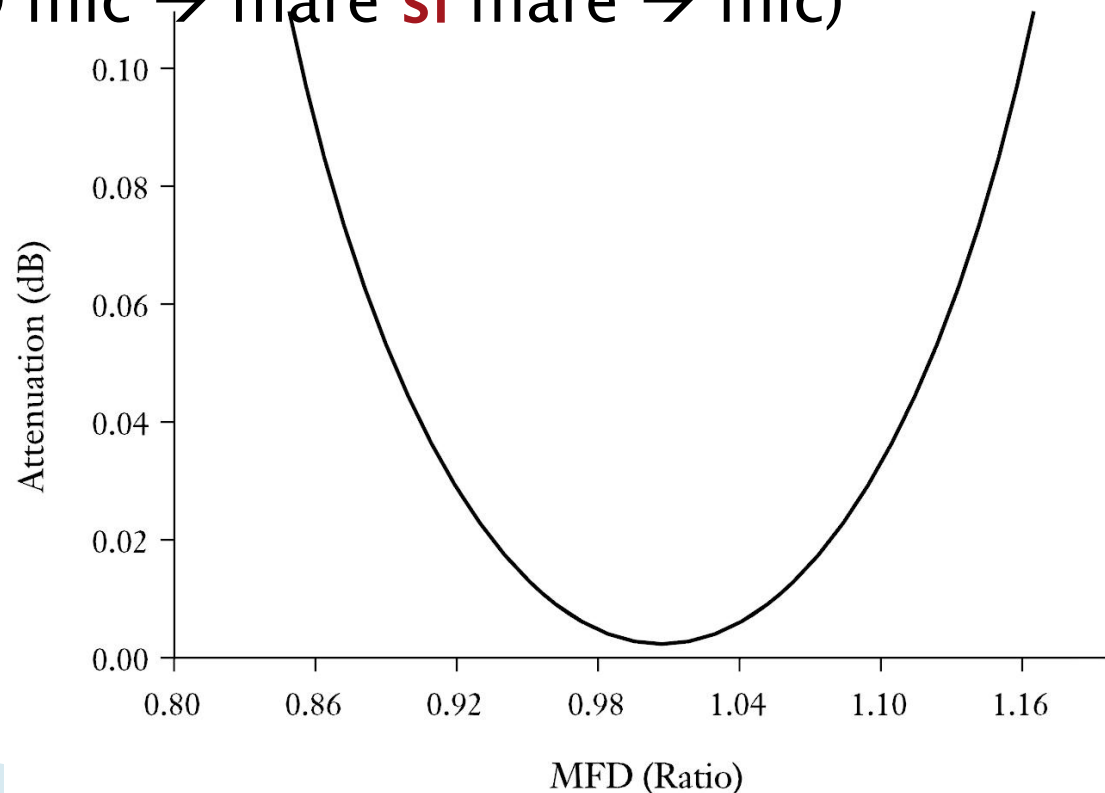
# Pierderi

- ▶ multimod



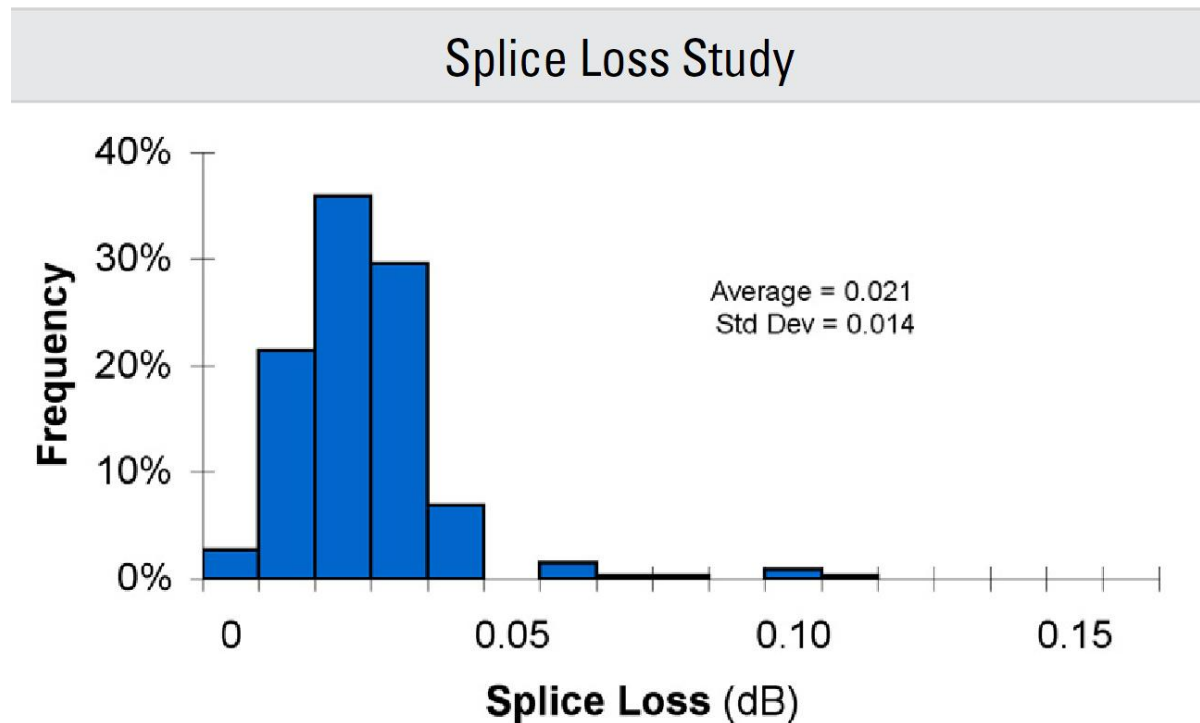
# Pierderi

- ▶ monomod
  - predomina pierderile datorate diferentelor de MFD
  - se poate neglija NA
  - **Bidirectional** (MFD mic → mare **si** mare → mic)

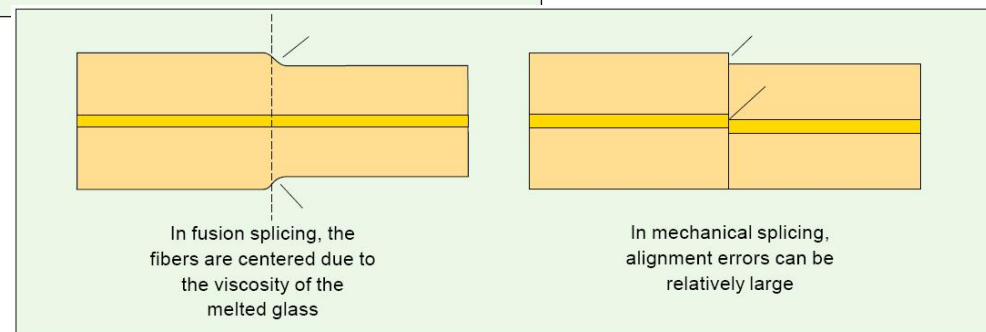
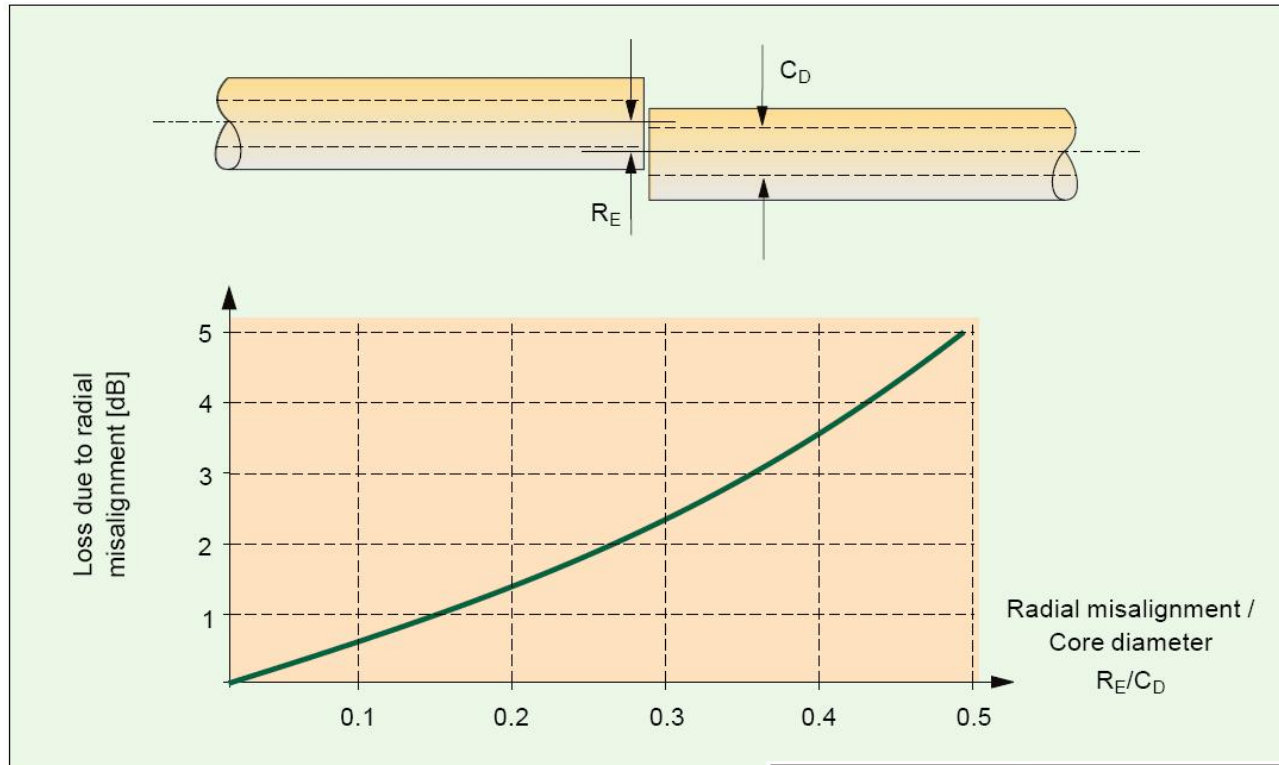


# Pierderi

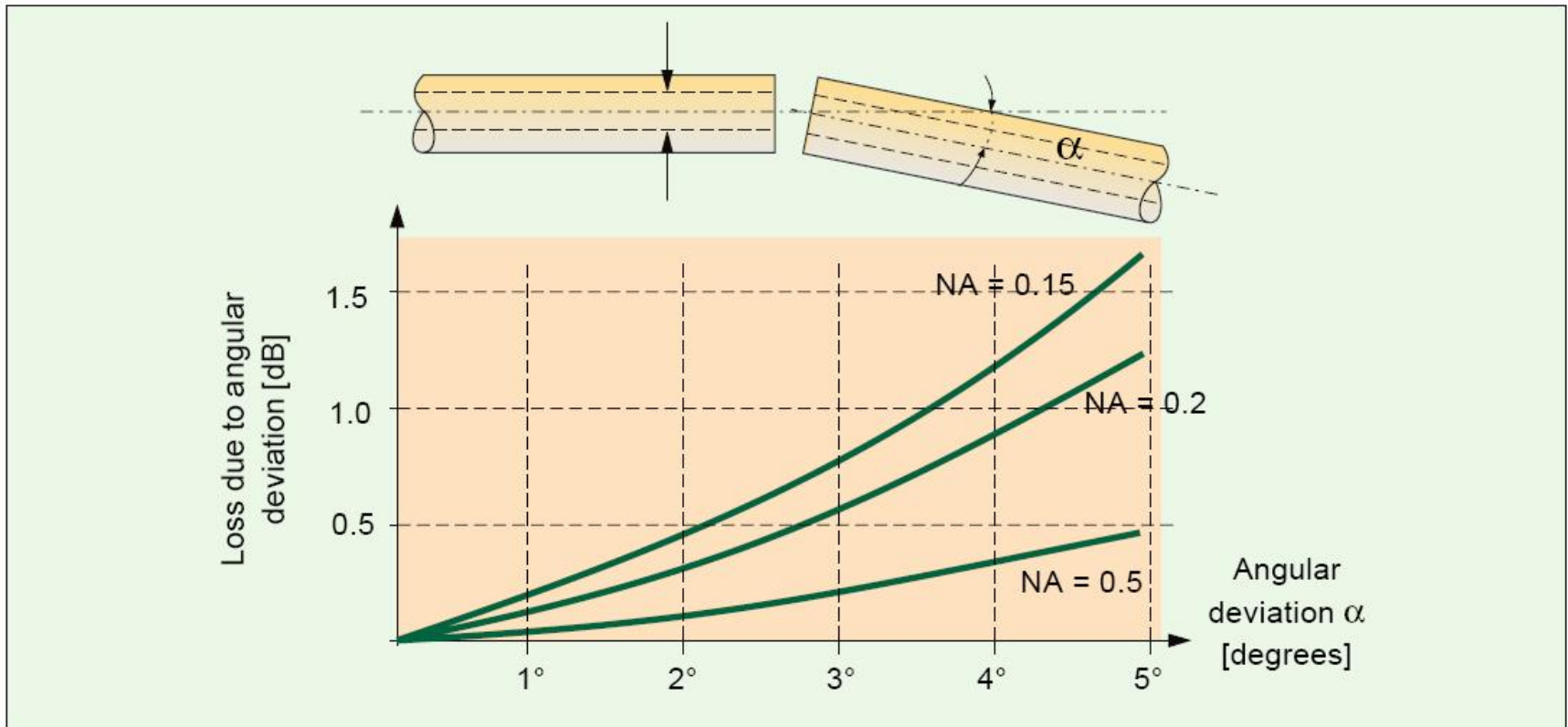
- ▶ monomod
- ▶ tipic: cel mai dezavantajos pentru MFD =  $9.3 \pm 0.5 \mu\text{m}$   $\rightarrow A = 0.04\text{dB}$



# Pierderi – Nealinierarea axelor

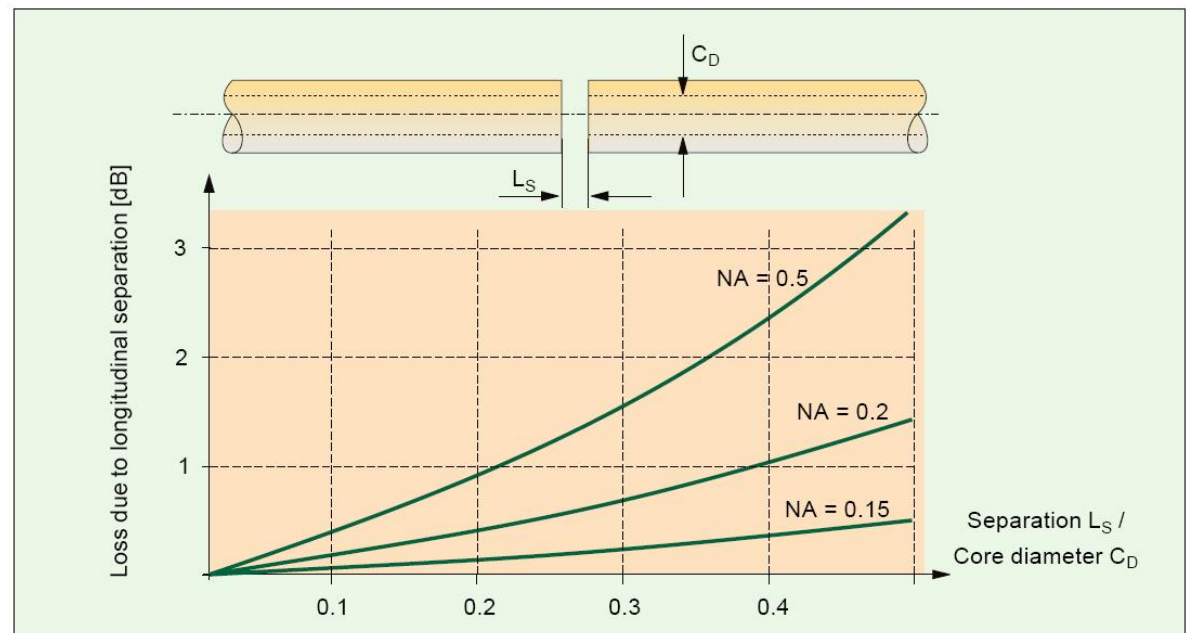


# Pierderi – unghi



# Pierderi – distanta fibre

- ▶ Se foloseste un gel cu indice de refractie egal cu al fibrelor
- ▶ Se aduna pierderile generate de reflexie pe o lamela (pana la 16%)



# Exemplu

- ▶ Trebuie să realizați o legătură pe fibră optică pe o distanță de 50 km la o viteză de 1Gb/s.

Emițători: = 1.5mW ( $\Delta\lambda=2\text{nm}$ , diverse $\lambda$ )	NA = 0.17	$\Phi = 13\mu\text{m}$
Pierderi splice (tehnologie)	0.15 dB/splice	
Pierderi conector	0.5 dB/conector	
Cablu conexiune: L = 20m	NA = 0.12	fibră: 11/125 $\mu\text{m}$
Cablu conexiune: L = 20m	NA = 0.15	fibră: 11/125 $\mu\text{m}$
Fibra 1	8 X 5km	
Fibra 2	4 X 10km	
Fibra 3	8 X 5km	
Fibra 4	4 X 10km	
Receptor: Sensitivitate = 1 $\mu\text{W}$	NA = 0.25	$\Phi = 30\mu\text{m}$

# Catalog

## Fibra nr. 3

### Optical Specifications

#### Fiber Attenuation

Maximum Attenuation	
Wavelength (nm)	Maximum Value* (dB/km)
1310	0.33 - 0.35
1383**	0.31 - 0.35
1490	0.21 - 0.24
1550	0.19 - 0.20
1625	0.20 - 0.23

\*Maximum specified attenuation value available within the stated ranges.  
 \*\*Attenuation values at this wavelength represent post-hydrogen aging performance.  
 Alternate attenuation offerings available upon request.

Attenuation vs. Wavelength		
Range (nm)	Ref. $\lambda$ (nm)	Max. $\alpha$ Difference (dB/km)
1285 - 1330	1310	0.03
1525 - 1575	1550	0.02

The attenuation in a given wavelength range does not exceed the attenuation of the reference wavelength ( $\lambda_r$ ) by more than the value  $\alpha$ .

Macro-bend Loss				
Mandrel Diameter (mm)	Number of Turns	Wavelength (nm)	Induced Attenuation* (dB)	
32	1	1550	$\leq 0.03$	
50	100	1310	$\leq 0.03$	
50	100	1550	$\leq 0.03$	
60	100	1625	$\leq 0.03$	

\*The induced attenuation due to fiber wrapped around a mandrel of a specified diameter.

Point Discontinuity		
Wavelength (nm)	Point Discontinuity (dB)	
1310	$\leq 0.05$	
1550	$\leq 0.05$	

### Dimensional Specifications

#### Glass Geometry

Fiber Curl	$\geq 4.0$ m radius of curvature
Cladding Diameter	$125.0 \pm 0.7$ $\mu$ m
Core-Clad Concentricity	$\leq 0.5$ $\mu$ m
Cladding Non-Circularity	$\leq 0.7\%$

### Environmental Specifications

Environmental Test	Test Condition	Induced Attenuation	
		1310 nm, 1550 nm & 1625 nm	(dB/km)
Temperature Dependence	-60°C to +85°C*	$\leq 0.05$	
Temperature Humidity Cycling	-10°C to +85°C* up to 98% RH	$\leq 0.05$	
Water Immersion	23 $\pm$ 2°C*	$\leq 0.05$	
Heat Aging	85 $\pm$ 2°C*	$\leq 0.05$	

\*Reference temperature = +23°C

Operating Temperature Range: -60°C to +85°C

#### Cable Cutoff Wavelength ( $\lambda_{ccf}$ )

$\lambda_{ccf} \leq 1260$  nm

#### Mode-Field Diameter

Wavelength (nm)	MFD ( $\mu$ m)
1310	9.4 $\pm$ 0.4
1550	10.6 $\pm$ 0.5

#### Dispersion

Wavelength (nm)	Dispersion Value [ps/(nm $\cdot$ km)]
1550	$\leq 18$
1625	$\leq 23$

Zero Dispersion Wavelength ( $\lambda_0$ ): 1310 nm  $\leq \lambda_0 \leq 1324$  nm  
 Zero Dispersion Slope ( $S_0$ ):  $\leq 0.092$  ps/(nm $\cdot$ km)

#### Polarization Mode Dispersion (PMD)

PMD Link Design Value	Value (ps $\sqrt$ /km)
Maximum Individual Fiber	$\leq 0.2$

\*Complies with IEC 60794-3: 2001, Section 5.5, Method 1, September 2001.

The PMD link design value is a term used to describe the PMD of concatenated lengths of fiber (also known as PMD $_0$ ). This value represents a statistical upper limit for total link PMD. Individual PMD values may change when cabled. Corning's fiber specification supports network design requirements for a 0.5 ps $\sqrt$ /km maximum PMD.

#### Coating Geometry

Coating Diameter	245 $\pm$ 5 $\mu$ m
Coating-Cladding Concentricity	$< 12$ $\mu$ m

### Mechanical Specifications

#### Proof Test

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

#### Length

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

### Performance Characterizations

Characterized parameters are typical values.

Core Diameter	8.2 $\mu$ m
Numerical Aperture	0.14 NA is measured at the one percent power level of a one-dimensional far-field scan at 1310 nm.
Zero Dispersion Wavelength ( $\lambda_0$ )	1317 nm
Zero Dispersion Slope ( $S_0$ )	0.088 ps/(nm $\cdot$ km)
Effective Group Index of Refraction ( $N_{eff}$ )	1310 nm: 1.4670 1550 nm: 1.4677
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 1 $\mu$ s Pulse Width)	1310 nm: -77 dB 1550 nm: -82 dB
Stimulated Brillouin Scattering Threshold	20 dBm $^{\dagger}$
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, NexCor fiber offers a 3 dB improvement over standard single-mode fiber independent of these variables.	

### Formulas

#### Dispersion

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

for 1200 nm  $\leq \lambda \leq 1625$  nm

$\lambda =$  Operating Wavelengths

#### Cladding Non-Circularity

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

#### How to Order

Contact your sales representative, or call the Optical Fiber Customer Service Department:  
 Ph: 607-248-2000 (U.S. and Canada)  
 +44-1244-287-4317 (Europe)  
 Email: opticalfibres@corning.com  
 Please specify the fiber type, attenuation and quantity when ordering.

Corning Incorporated  
[www.corning.com/opticalfiber](http://www.corning.com/opticalfiber)  
 One Riverfront Plaza  
 Corning, NY 14831  
 U.S.A.  
 Ph: 800-525-2324 (U.S. and Canada)  
 607-786-8125 (International)  
 Fax: 800-539-1632 (U.S. and Canada)  
 607-786-8344 (International)  
 Email: cofc@corning.com

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 +1 607 786 8125 (All Other Countries)  
 Fax: +1 607 786 8344

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

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

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

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# Intrebari

- ▶ (1 p) Ce lungime de undă veți alege pentru emițător? Justificați.
- ▶ (2p) Alegeți fibrele pe care le veți utiliza. Justificați. Realizați schița legăturii
- ▶ (1 p) Puteți realiza o legătură funcțională? Justificați.

<i>Zero Dispersion Wavelength (<math>\lambda_0</math>)</i>	1317 nm
<i>Zero Dispersion Slope (<math>S_0</math>)</i>	0.088 ps/(nm <sup>2</sup> •km)

# Legatura

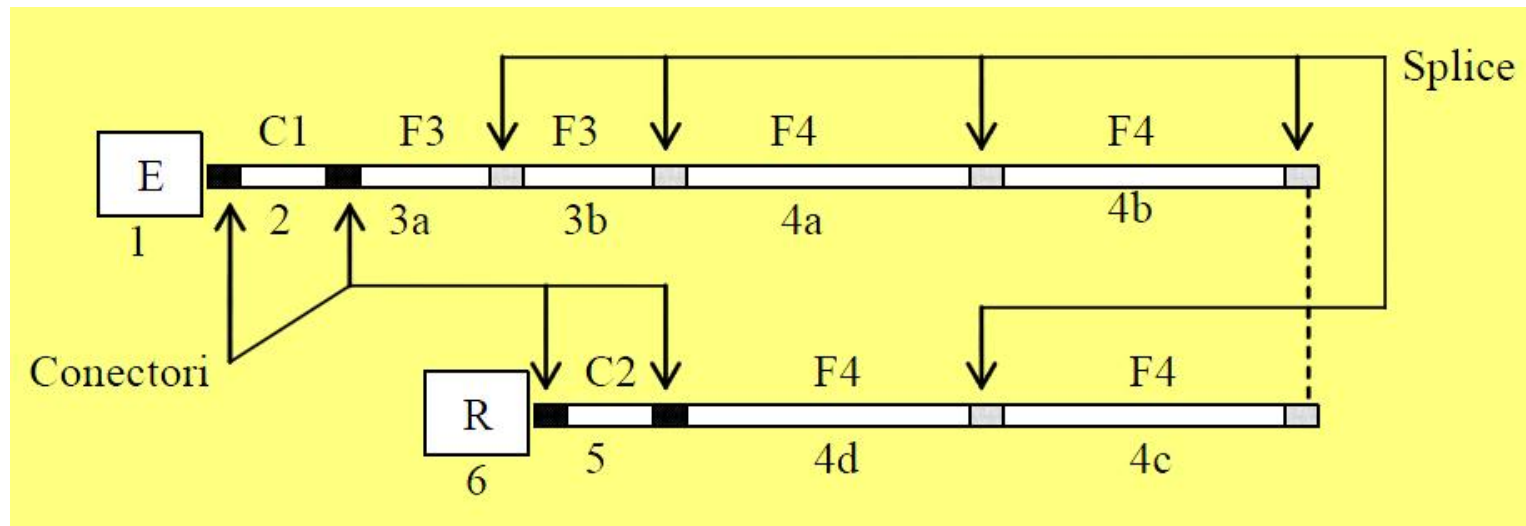
## ► Bilantul puterilor

$$A_{tot} [\text{dB}] = \sum_i A_i [\text{dB}]$$

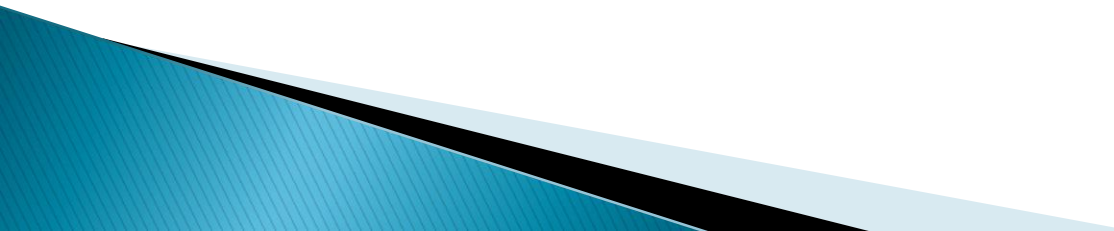
$$P_e [\text{dBm}] \pm A_{tot} [\text{dB}] \geq S_r [\text{dBm}] + M [\text{dB}]$$

*Maximum Attenuation*

Wavelength (nm)	Maximum Value* (dB/km)
1310	0.33 – 0.35
1383**	0.31 – 0.35
1490	0.21 – 0.24
1550	0.19 – 0.20
1625	0.20 – 0.23



# Sistem

- ▶ 1. Emitator
  - ▶ 2. Cablu 1 de conexiune
  - ▶ 3. Fibra 3 (2 cabluri a 5 km fiecare: 3a,3b)
  - ▶ 4. Fibra 4 (4 cabluri a 10 km fiecare: 4a,4b,4c,4d)
  - ▶ 5. Cablu 2 de conexiune
  - ▶ 6. Receptor
- 

# Atenuare

## ▶ Distribuita

- microcurburi
- imprastiere
- absorbtie

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

## ▶ Localizata

- macrocurburi
- conectori
- splice
- tranzitii

$$\text{Atenuare}_L [\text{dB}] = \text{Pierderi}[\text{dB}]$$

$$A_{\text{TOT}} [\text{dB}] = A_L [\text{dB}] + A_D [\text{dB/km}] \cdot L [\text{km}]$$

# Pierderi

- ▶ Atenuare in fibra
- ▶ Atenuare datorata conectorilor
- ▶ Atenuare datorata splice-urilor
- ▶ Atenuare datorata diferentelor de apertura numerica
  - apare **numai** la trecerea de la un dispozitiv cu NA mai mare la un dispozitiv cu NA mai mic
  - **neglijabil** intre 2 fibre monomod sudate
- ▶ Atenuare datorata diferentelor de diametru
  - apare **numai** la trecerea de la un dispozitiv cu diametru mai mare la un dispozitiv cu diametru mai mic
  - **bidirectional** la fibre monomod sudate

# Dispersie

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

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

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

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

$$\Delta\tau_{tip} = \sum_i \Delta\tau_i$$

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

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

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

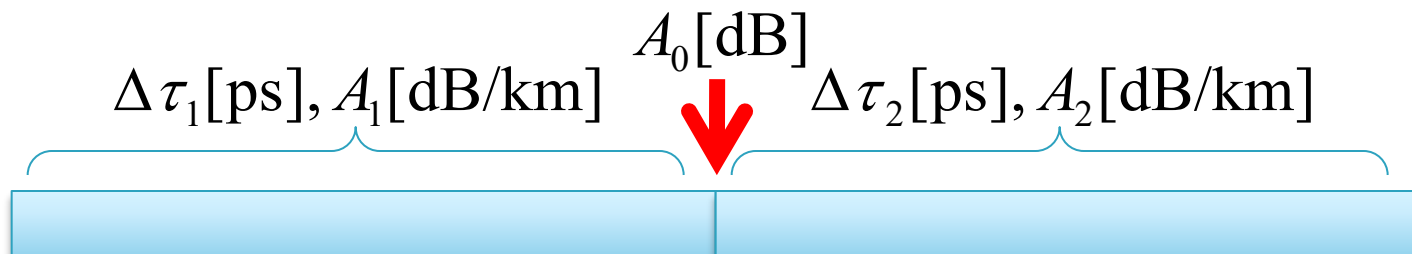
$$V [Gb/s] \cong 2 \cdot B_{el}$$

$$B_{3dB,electric} (GHz) = \frac{0.35}{T(ns)}$$

$$NRZ_{viteza\ date} (Gbit/s) = \frac{1}{T_{impuls} (ns)} \leq \frac{0.67}{T(ns)}$$

# Sisteme cu mai multe tipuri de fibra

- ▶ Fibra tip 1 conectata/sudata cu fibra tip 2
- ▶ efecte **successive** se adună liniar
- ▶ la nivelul splice-ului apare o atenuare **localizata**:
  - atenuare pe splice/conector
  - atenuare datorita **NA** diferit (**daca** este cazul)
  - atenuare datorita  **$\Phi$**  diferit (**daca** este cazul)

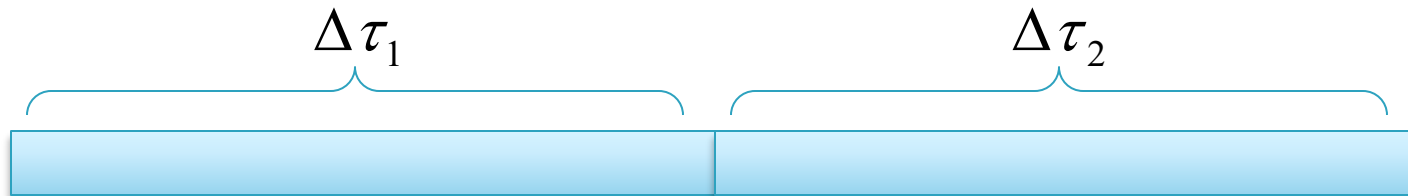


$$A_{tot} [\text{dB}] = A_1 [\text{dB/km}] \cdot L_1 [\text{km}] + A_2 [\text{dB/km}] \cdot L_2 [\text{km}] + A_0 [\text{dB}]$$

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

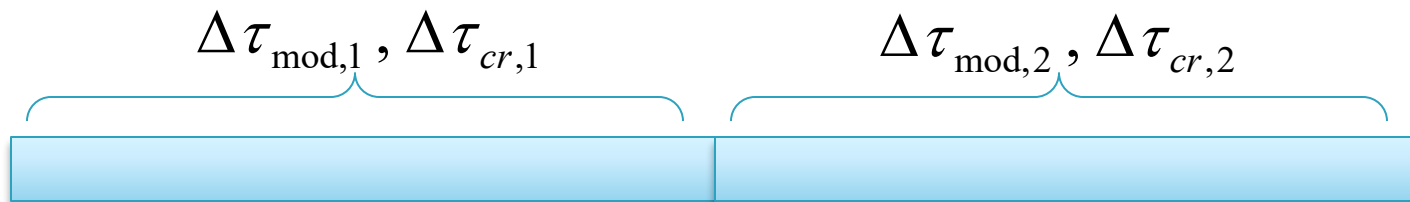
# Sisteme cu mai multe tipuri de fibra

- ▶ efecte **succesive** se adună liniar



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

- ▶ dar pe fiecare fibra exista efecte **simultane** (pentru dispersie) care se adună pătratic

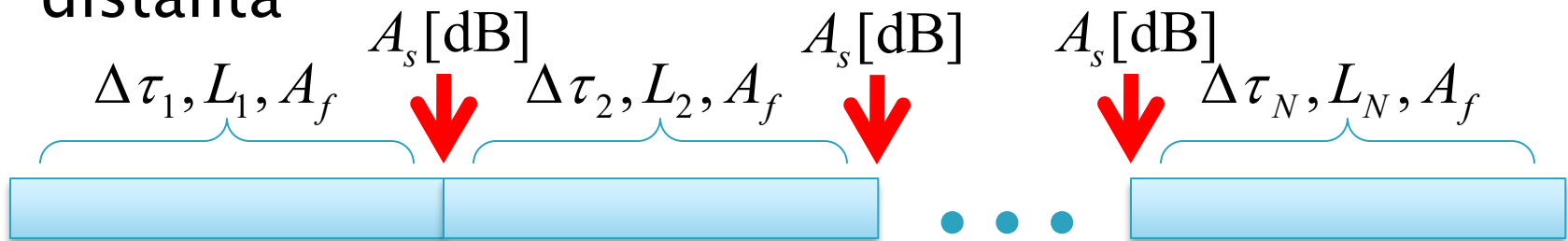


$$\Delta\tau_1 = \sqrt{\Delta\tau_{cr,1}^2 + \Delta\tau_{mod,1}^2}$$

$$\Delta\tau_2 = \sqrt{\Delta\tau_{cr,2}^2 + \Delta\tau_{mod,2}^2}$$

# Sisteme cu același tip de fibra

- ▶ N tronsoane cu același tip de fibra conectate/sudate
  - atenuare datorită NA **nula (același tip)**
  - atenuare datorită  $\Phi$  **nula (același tip)**
  - atenuare pe splice/conector: N-1 conectori
  - lungime totală:  $L_{tot} [\text{km}] = \sum_1^N L_i [\text{km}]$
- ▶ efecte **sucsesive** se adună liniar
- ▶ efectele (dispersie și atenuare) proporționale cu distanța



$$\Delta\tau_{tot} = \sum_{i=1}^N \Delta\tau(L_i) = \Delta\tau(L_{tot}) = \sqrt{\Delta\tau_{cr}(L_{tot})^2 + \Delta\tau_{mod}(L_{tot})^2}$$

$$A_{tot} [\text{dB}] = A_f [\text{dB/km}] \cdot L_{tot} [\text{km}] + (N - 1) \cdot A_s [\text{dB}]$$

# Produs Banda · Distanta

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

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

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

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

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

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

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

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

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

# Lungime maxima

- ▶ **limitata de atenuare**
- ▶ lungimea cea mai mare la care pot face transmisia este obtinuta in cazul cel mai **defavorabil**
  - cele mai mici pierderi permise
  - atenuare distribuita maxima

$$A_{\text{TOT}} [\text{dB}] = A_L [\text{dB}] + A_D [\text{dB/km}] \cdot L [\text{km}]$$

$$\text{Atenuare} [\text{dB/km}] = \frac{\text{Pierderi}_D [\text{dB}]}{\text{lungime} [\text{km}]} \quad L_{\text{max}} \Rightarrow \Delta P_{\text{min}}, A_{D\text{max}}$$

$$L_{\text{max}} = \frac{\Delta P_{\text{min}} [\text{dB}]}{A_{D\text{max}} [\text{dB/km}]} = \frac{P_{e\text{min}} [\text{dBm}] - S_{r\text{max}} [\text{dBm}] - A_L [\text{dB}]}{A_{D\text{max}} [\text{dB/km}]}$$

de obicei problema distantei maxime limitate de atenuare se pune pentru fibre **monomod**

# Lungime maxima

- ▶ **limitata de viteza**
- ▶ lungimea cea mai mare la care pot face transmisia este obtinuta in cazul cel mai **defavorabil**
  - dispersie maxima
- ▶ doua cazuri in functie de cum e specificata dispersia
  - $B \times L$  [MHz·km]
  - $S_0$  [ps/nm<sup>2</sup>/km],  $\lambda_0$  [nm]

$$B_{el\ min} \cong \frac{V_{\min} [Gb/s]}{2}$$

$$\Delta\tau_{tot\ max} [ns]$$

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

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

$$L_{\max} = \frac{\Delta\tau_{tot\ max}}{D(\lambda) \cdot \Delta\lambda}$$

$$B \times L [MHz \cdot km]$$

$$L_{\max} [km] = \frac{B \times L [MHz \cdot km]}{B_{el\ min} [MHz]}$$

# Lungime maxima

- ▶ **limitata de atenuare**  $L_{\max}^a$  [km]
- ▶ **limitata de viteza**  $L_{\max}^v$  [km]

- ▶ lungimea cea mai mare la care pot face transmisia este obtinuta in cazul cel mai **defavorabil** (din cele doua limitari)

$$L_{\max} [\text{km}] = \min(L_{\max}^a [\text{km}], L_{\max}^v [\text{km}])$$

- ▶ **de obicei**
  - monomod: limita impusa de atenuare
    - cu exceptia cazurilor in care nu se functioneaza la  $\lambda$  optim dpdv al dispersiei
  - multimod: limita impusa de viteza

# Calculul atenuarii

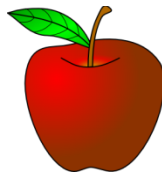
$$\text{Pierderi} = \frac{P_{out}}{P_{in}}$$

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

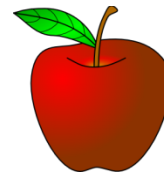
$$\text{Pierderi[dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-



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

# Problema simpla?

- ▶ Sursa luminoasa: 7.7 dBm
- ▶ Atenuarea fibrei: 1.16 dB/km
- ▶ Puterea la iesire: 105  $\mu$ W
  
- ▶ Lungimea fibrei: ?

# Problema simpla?

## ▶ Logaritmic

- $P_{\text{out}} = 10 \cdot \log(105 \mu\text{W}/1 \text{ mW}) = -9.8 \text{ dBm} !$
- Atenuarea :  $A_f = P_{\text{in}}[\text{dBm}] - P_{\text{out}}[\text{dBm}] = 17.5 \text{ dB} !$
- $L = A_f / A_{\text{dB/km}} = 17.5 \text{ dB} / 1.16 \text{ dB/km} = 15.08 \text{ km}$

## ▶ Liniar

- $7.7 \text{ dBm} = 10 \cdot \log(P_{\text{in}}/1 \text{ mW}); P_{\text{in}} = 1 \text{ mW} \cdot 10^{7.7/10} = 5.888 \text{ mW}$
- Atenuarea :  $A_f = P_{\text{in}} / P_{\text{out}} = 5.888 \text{ mW} / 0.105 \text{ mW} = 56.0762 [1] !$
- Atenuarea pe unitatea de lungime  $A_{1/\text{km}} = 10^{1.16/10} = 1.3062 [1] !$
- $A_f = (A_{1/\text{km}})^{L/1\text{km}} \rightarrow L = 1 \text{ km} \cdot \log(A_f) / \log(A_{1/\text{km}}) = 1.749 / 0.116 \text{ km} = 15.08 \text{ km}$

# Problema simpla? 2

- ▶ Sursa luminoasa: 4.9 dBm
- ▶ Atenuarea fibrei: 0.32 dB/km
- ▶ Lungimea fibrei: 17 km
  
- ▶ Puterea la iesire: ? [ $\mu$ W]

# Problema simpla? 2

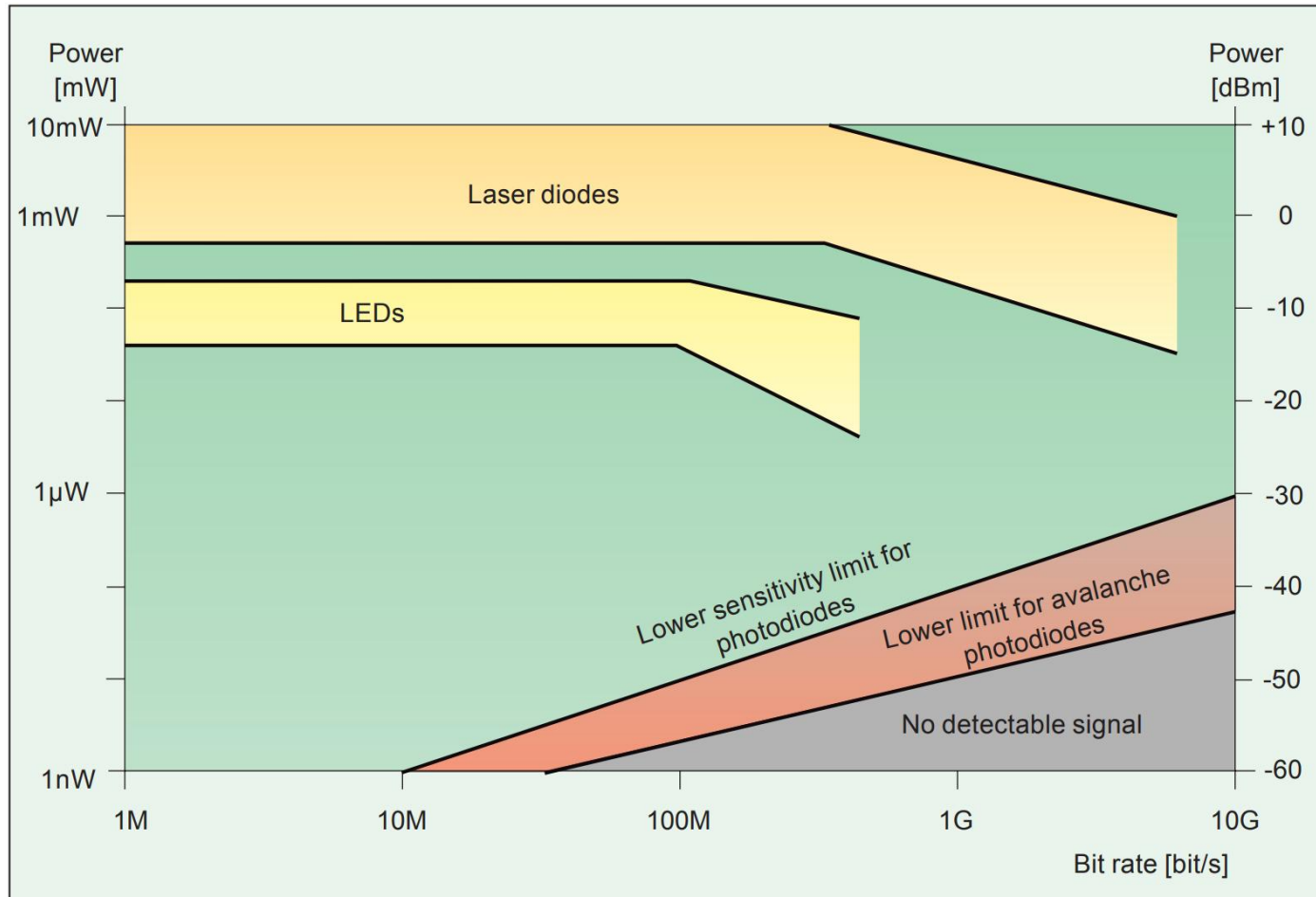
## ▶ Logaritmic

- Atenuarea :  $A_f = A_{\text{dB/km}} \cdot L[\text{km}] = 5.44 \text{ dB}$
- $P_{\text{out}}[\text{dBm}] = P_{\text{in}}[\text{dBm}] - A_f [\text{dB}] = -0.54 \text{ dBm} !$
- $P_{\text{out}} = 1 \text{ mW} \cdot 10^{-0.54/10} = 0.883 \text{ mW} = 883 \text{ } \mu\text{W}$

## ▶ Liniar

- Atenuarea :  $A_f [\text{dB}] = A_{\text{dB/km}} \cdot L[\text{km}] = 5.44 \text{ dB} !$
- Atenuarea :  $A_f [1] = 10^{A_f [\text{dB}] / 10} = 3.499 [1] !$
- $P_{\text{in}} = 1 \text{ mW} \cdot 10^{4.9/10} = 3.09 \text{ mW}$
- $P_{\text{out}} = P_{\text{in}} / A_f = 3.09 \text{ mW} / 3.499 = 0.883 \text{ mW} = 883 \text{ } \mu\text{W}$

# Limite putere/bandă a dispozitivelor optoelectronice



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