Optoelectronică, structuri şi tehnologii

Curs 7

2014/2015

Capitolul 11

- Behzad Razavi
  Design of Integrated Circuits for Optical Communications
- carte1.pdf (2,3)
- 29 pg.

Lista subiecte

- Amplificatoare transimpedanţă
  - 4.1
  - 4.1.1
  - 4.2
  - 4.2.1
  - 4.3
  - 4.3.1
- Circuite pentru controlul emiţătoarelor optice
  - 10.3
  - 10.3.1
  - 10.4
  - 10.4.1

Reprezentare logaritmică

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

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

0 dB	= 1
+ 0.1 dB	= 1.023 (+2.3%)
+ 3 dB	= 2
+ 5 dB	= 3
+ 10 dB	= 10
−3 dB	= 0.5
−10 dB	= 0.1
−20 dB	= 0.01
−30 dB	= 0.001

0 dBm	= 1 mW
3 dBm	= 2 mW
5 dBm	= 3 mW
10 dBm	= 10 mW
20 dBm	= 100 mW
−3 dBm	= 0.5 mW
−10 dBm	= 100 μW
−30 dBm	= 1 μW
−60 dBm	= 1 nW

[dBm] + [dB] = [dBm]

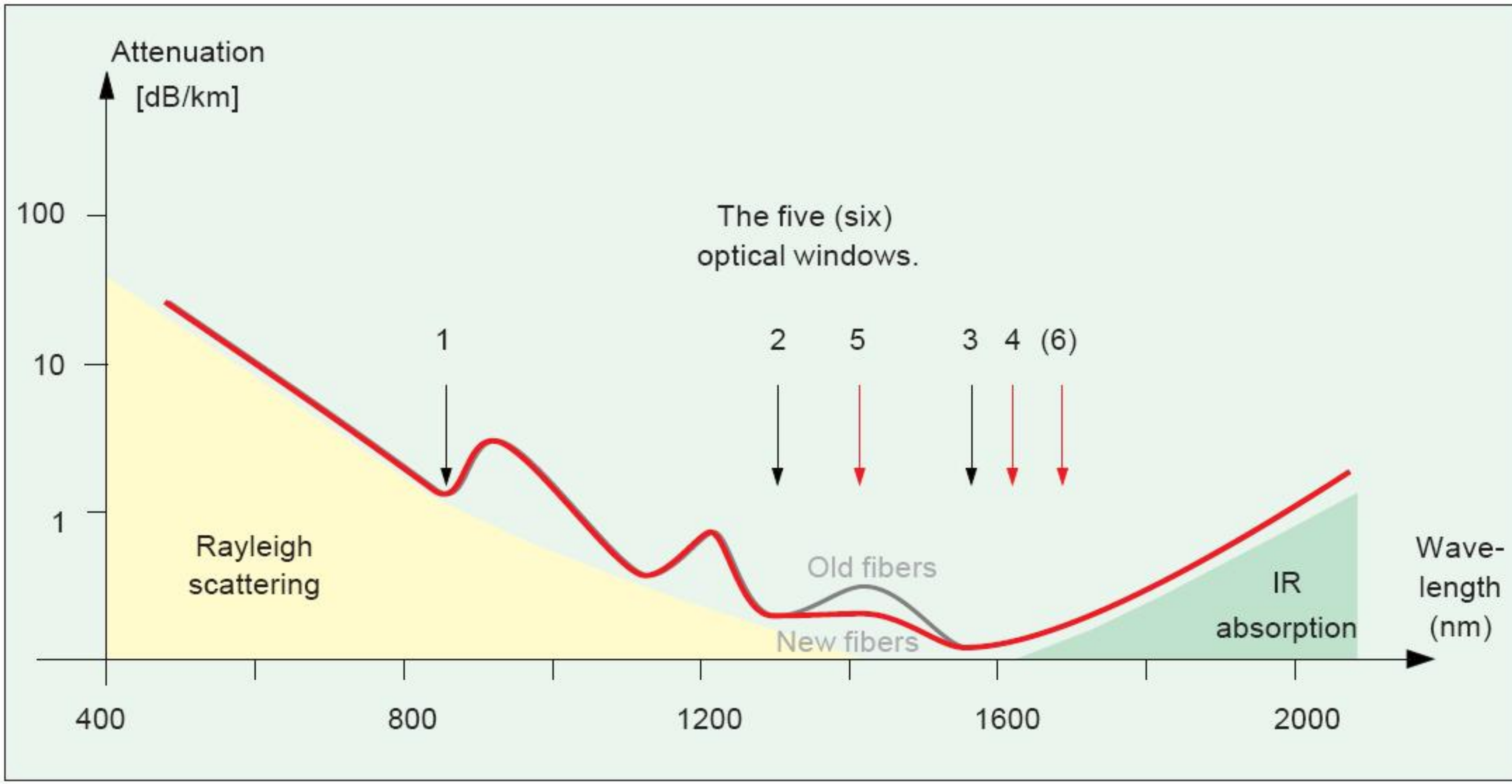
[dBm/Hz] + [dB] = [dBm/Hz]

[x] + [dB] = [x]

Fibra optică

Capitolul 5

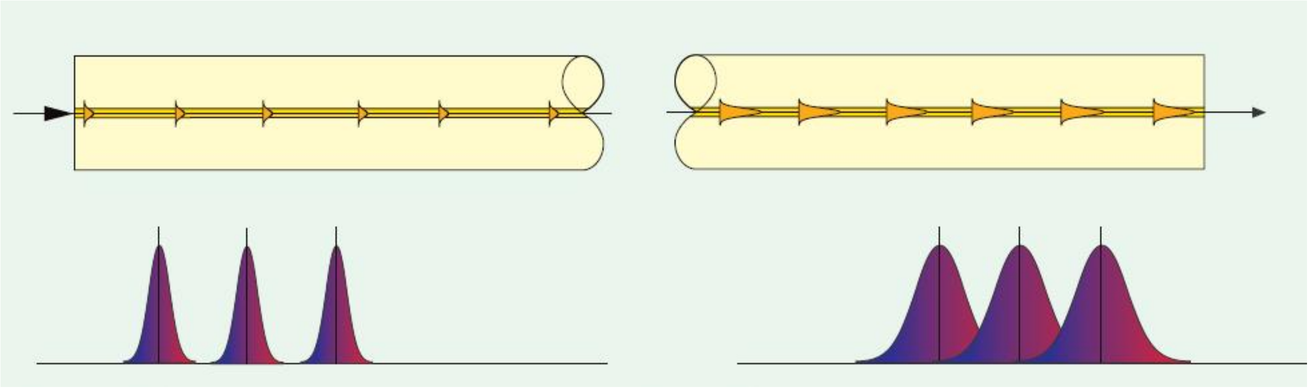
Absorbtie



Attenuation
[dB/km]
100
10
1
The five (six)
optical windows.
1
2
5
3
4
(6)
Rayleigh
scattering
Old fibers
New fibers
IR
absorption
Wave-
length
(nm)
400
800
1200
1600
2000

Dispersia

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



Dispersia

- 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

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

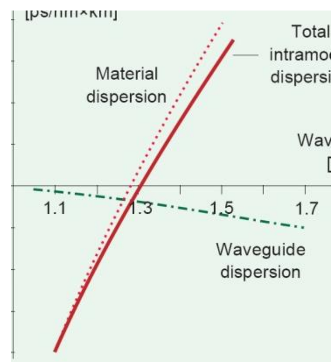
$$\Delta = 0.01 \div 0.02 << 1$$

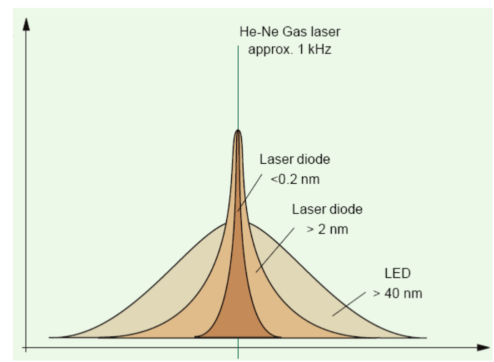
$$NA = 0.1 \div 0.2 < 1$$

- Dispersia cromatica

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

$$\text{D}(\lambda) = \frac{\text{S}_0}{4} \cdot \left(\lambda - \frac{\lambda_0^4}{\lambda^3} \right)$$





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

Banda

- Dispersia totala

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

- Banda

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

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

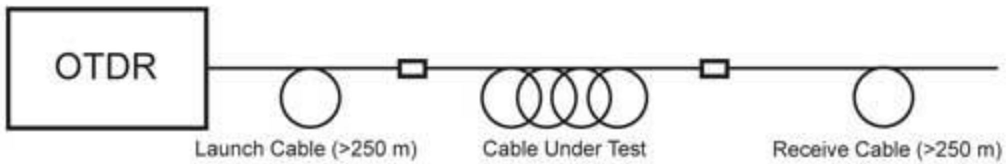
$$V[Gb/s] \cong 2 \cdot B_{el}[GHz]$$

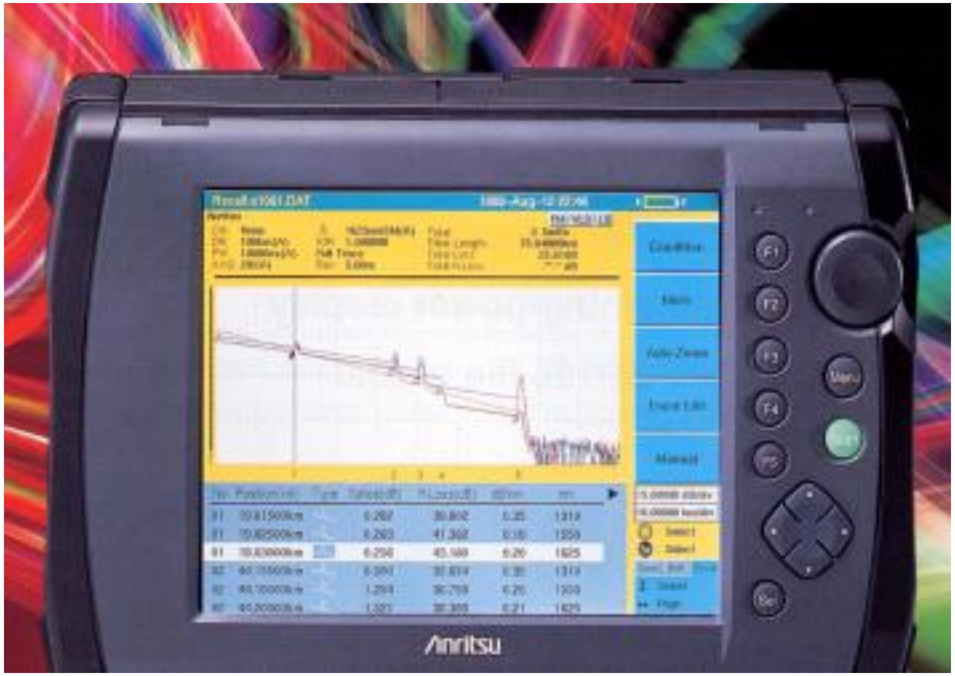
Fibra optică – Tehnologie

Capitolul 6

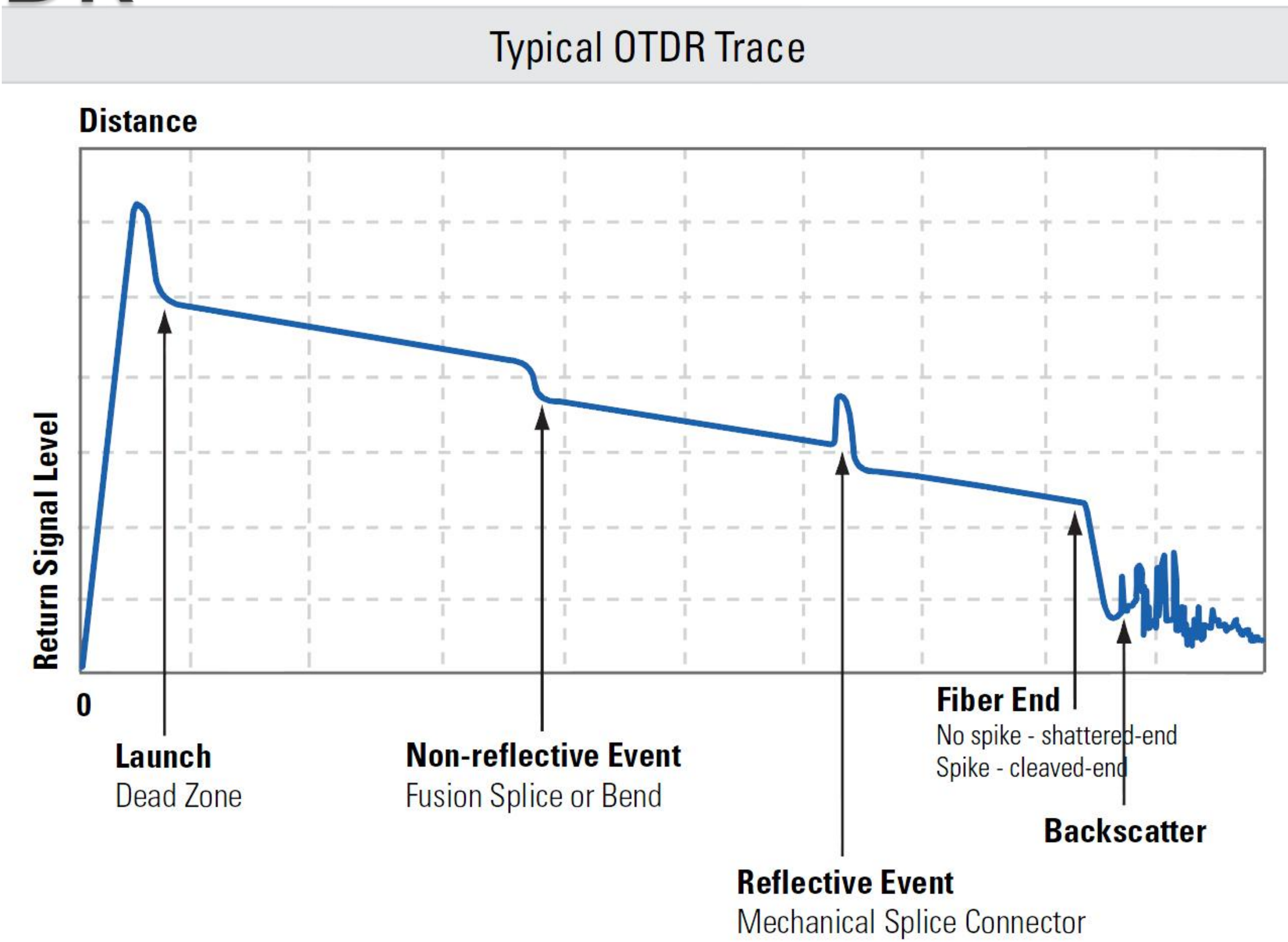
OTDR

- Optical time-domain reflectometer
- Localizarea defectelor



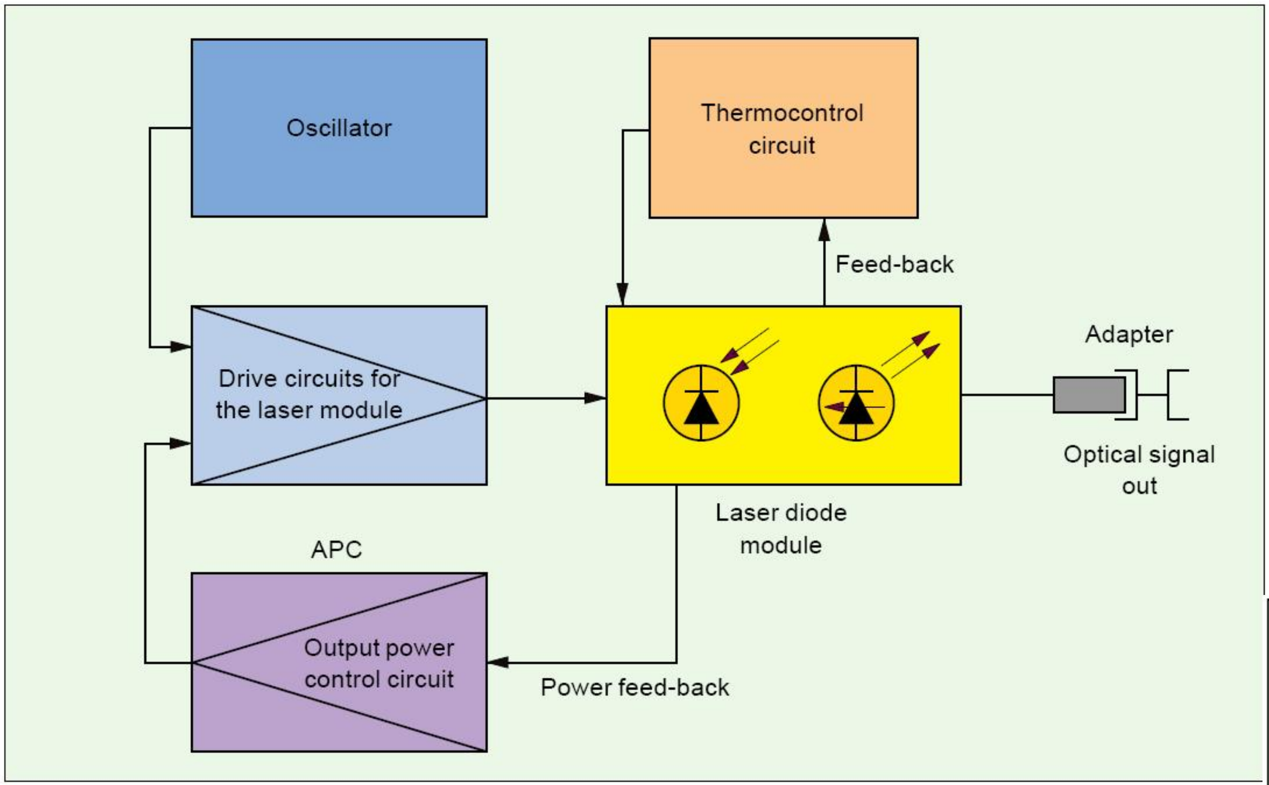


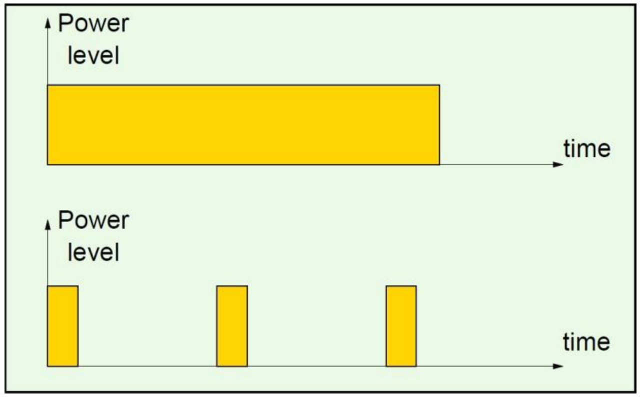
OTDR


Typical OTDR Trace
Distance
Return Signal Level
0
Launch
Dead Zone
Non-reflective Event
Fusion Splice or Bend
Reflective Event
Mechanical Splice Connector
Fiber End
No spike - shattered-end
Spike - cleaved-end
Backscatter

Stabilized light source
Optical power meter

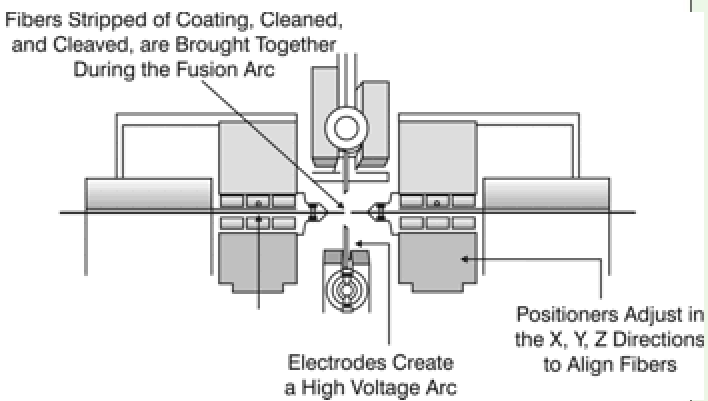
- Masurarea puterii si atenuarii

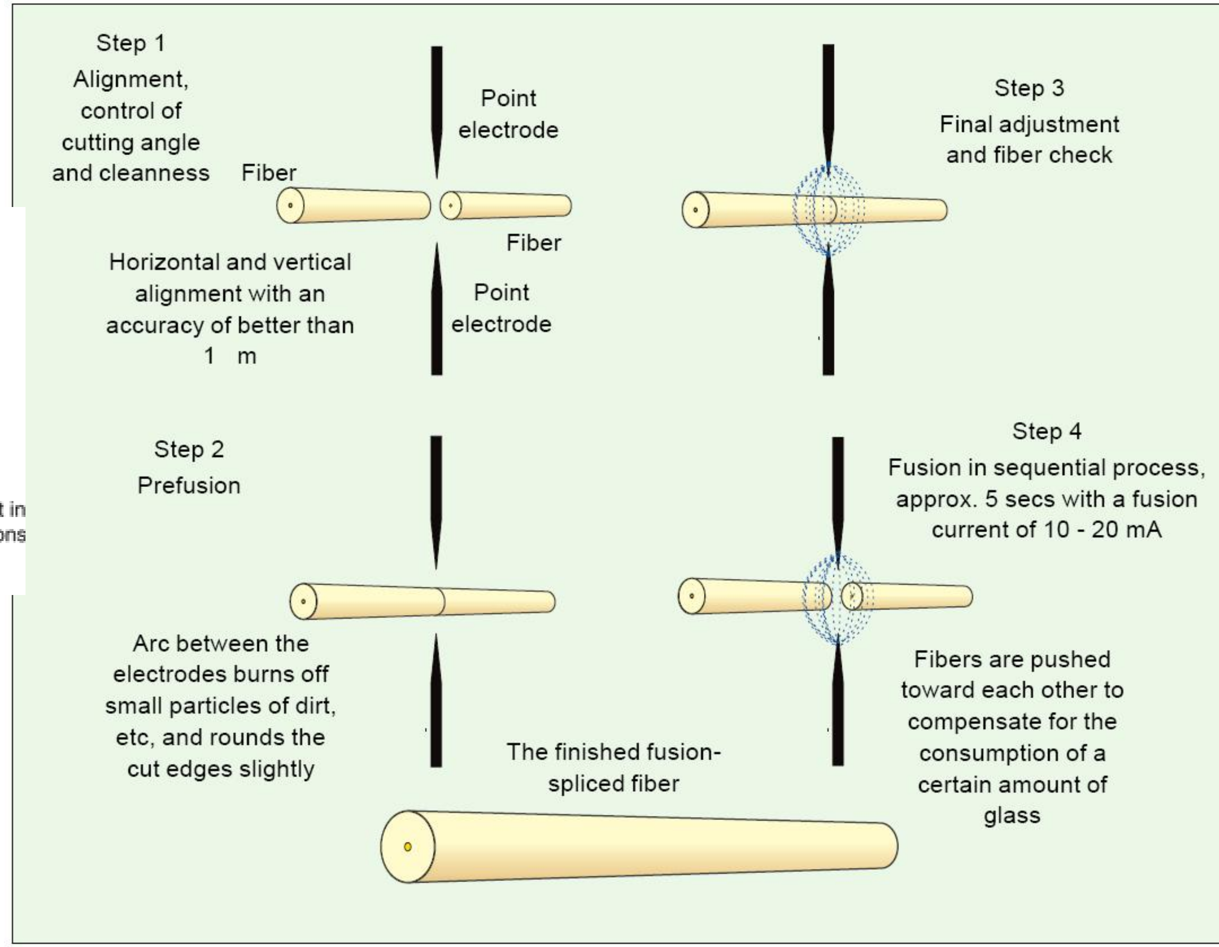




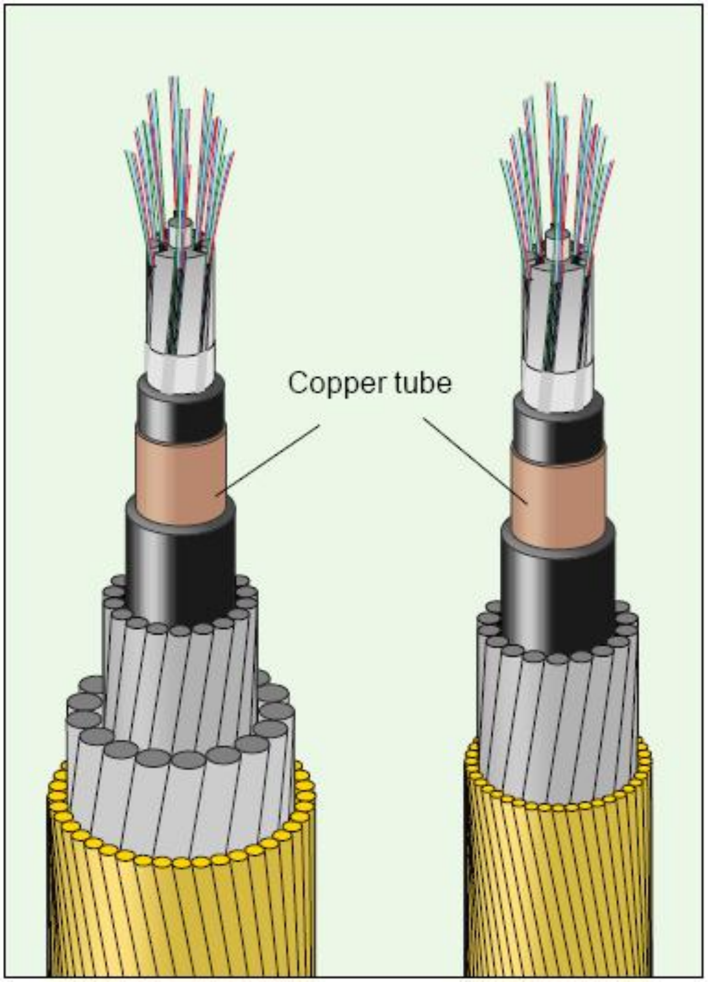
Lipire prin fuziune

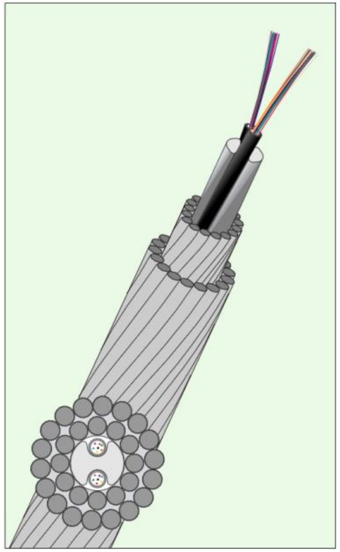
Splice prin fuziune

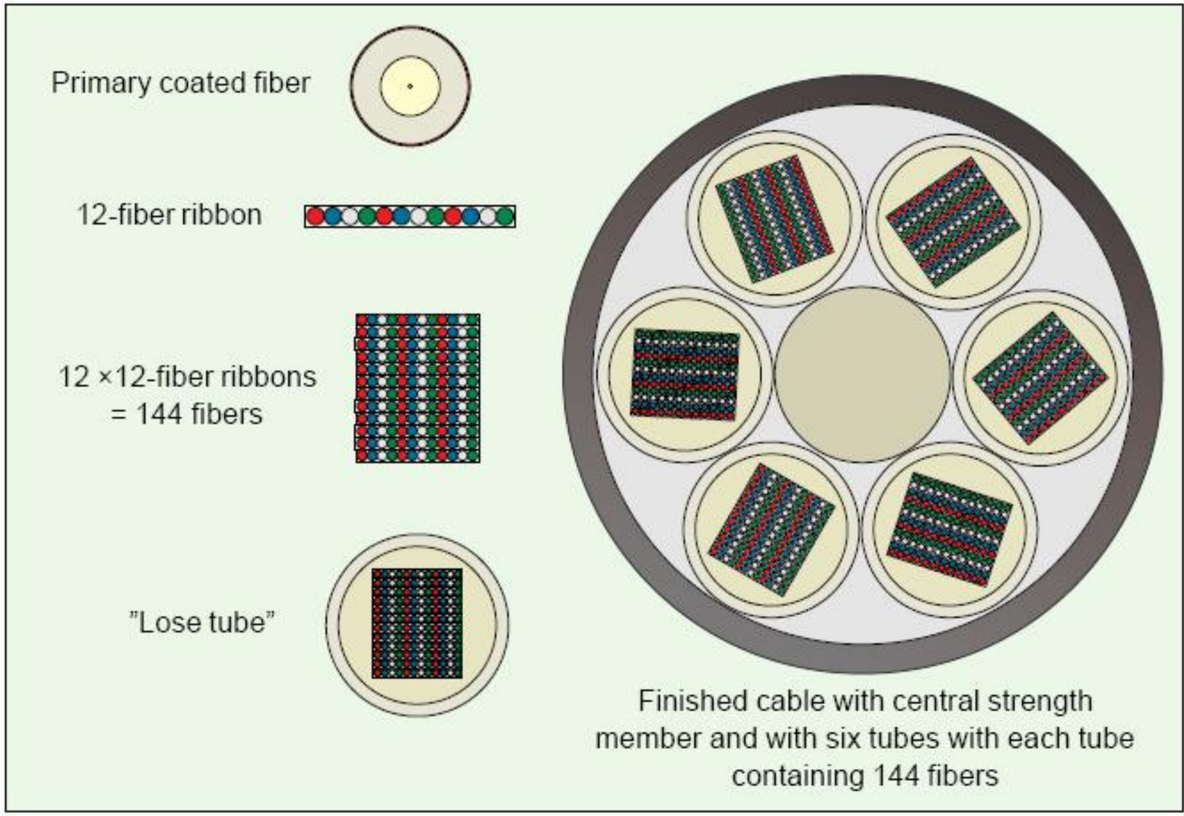




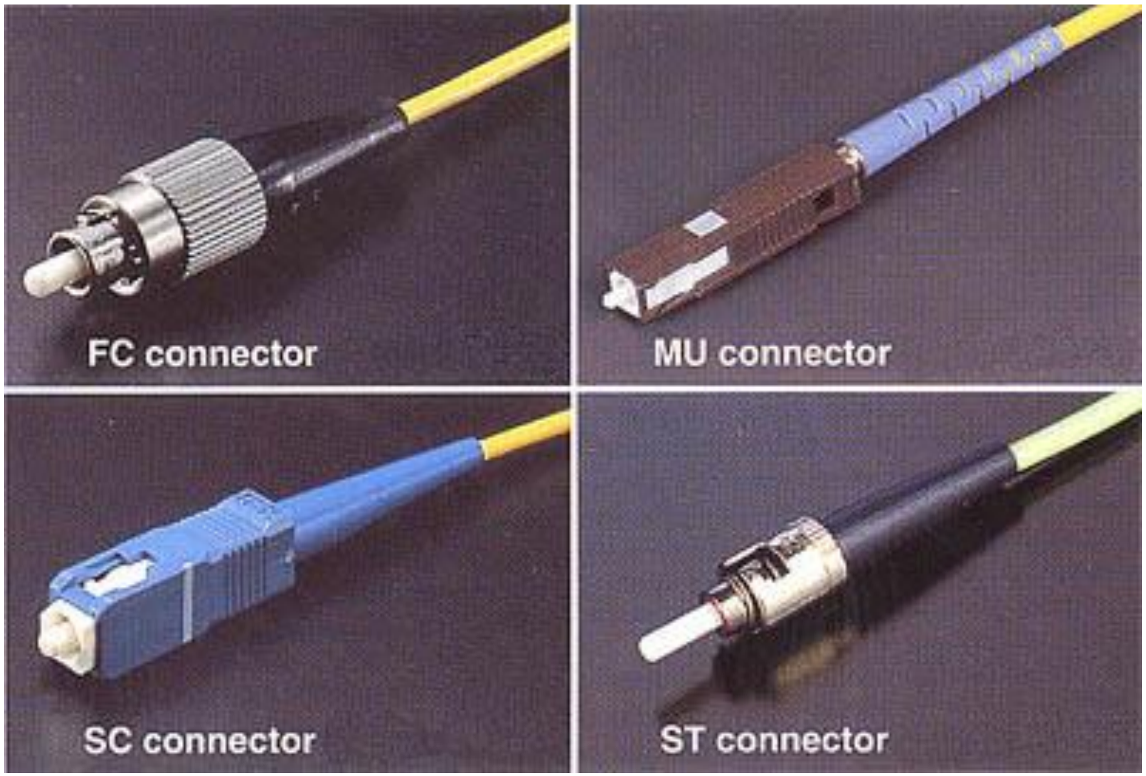
Cabluri

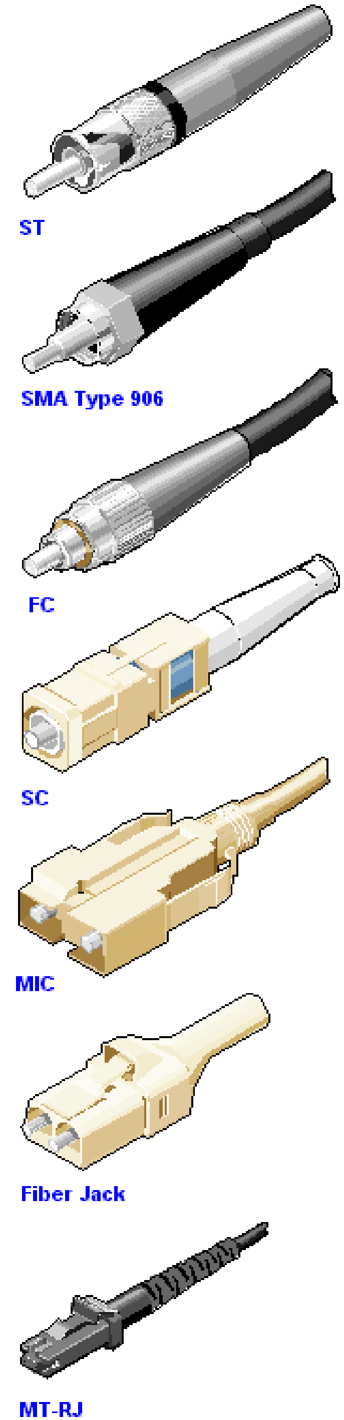

Copper tube




Primary coated fiber
12-fiber ribbon
12 ×12-fiber ribbons
= 144 fibers
"Lose tube"
Finished cable with central strength
member and with six tubes with each tube
containing 144 fibers

Conectori





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

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

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

The MIC is the standard FDDI connector.

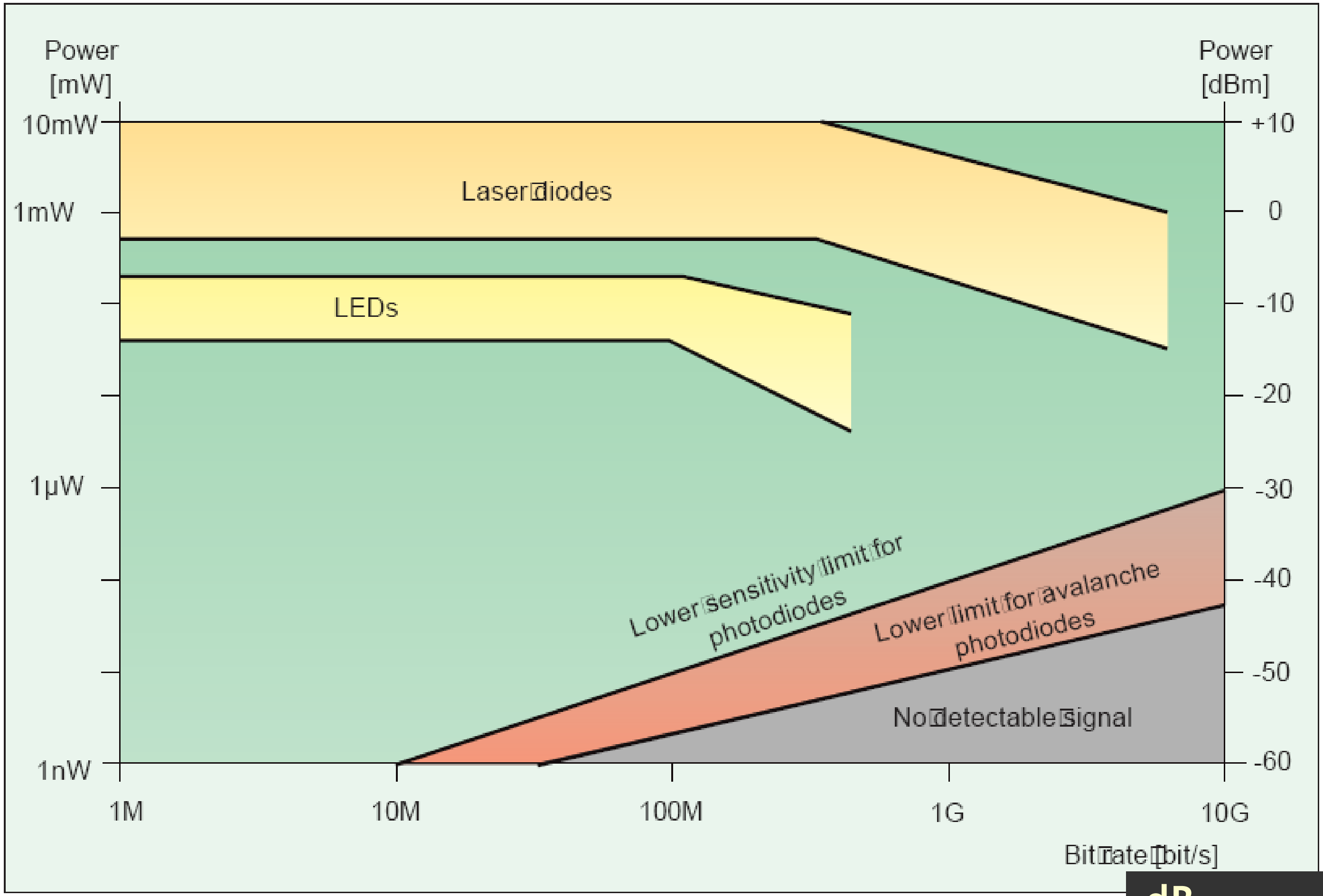
The Fiber Jack connector attaches two fibers in a snap lock connector similar in size and ease of use as an RJ-45 connector.

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

Dimensionarea unei legături pe fibra optică

Capitolul 7

Limite putere/bandă a dispozitivelor optoelectronice

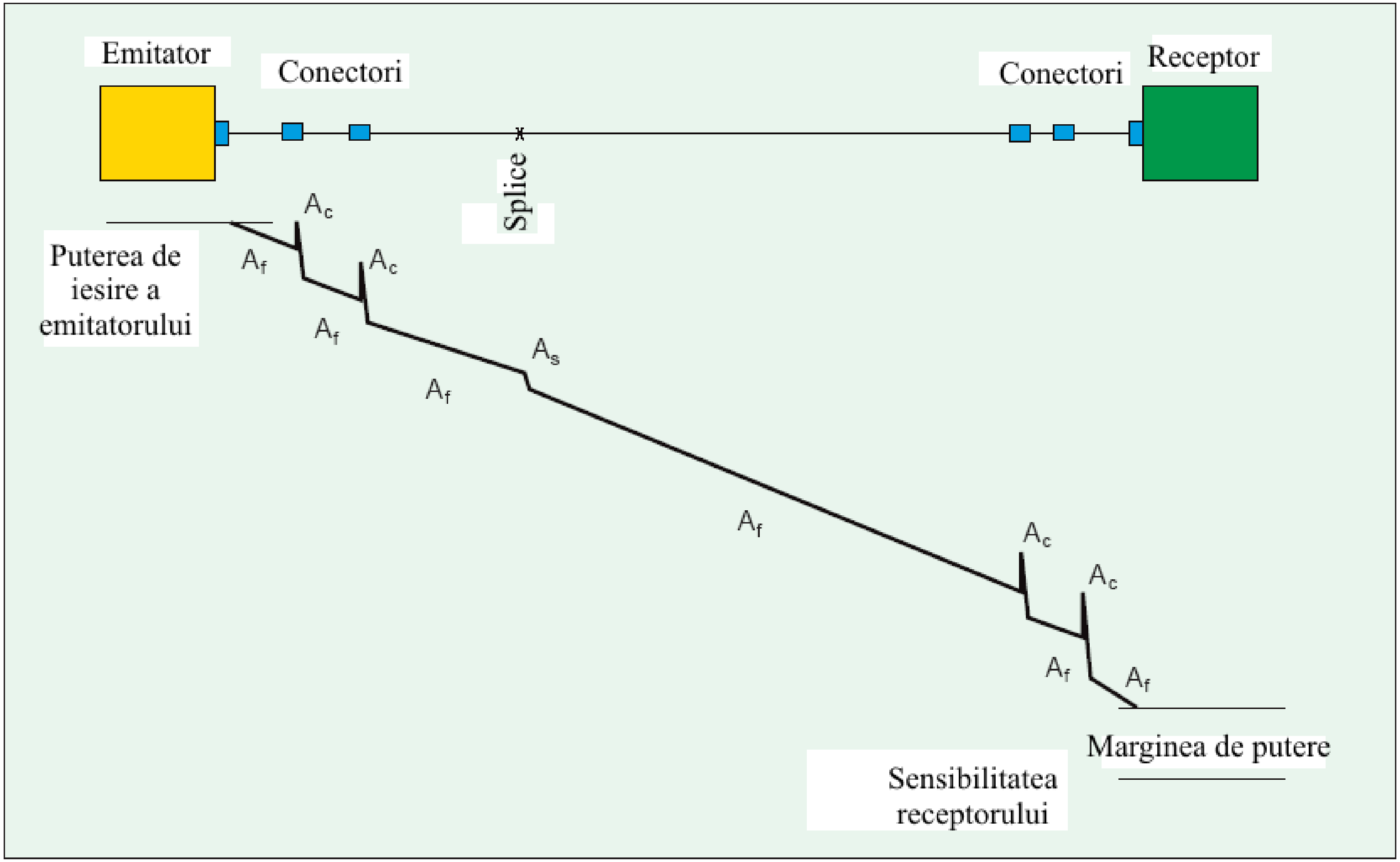


$$dB = 10 \cdot \log_{10} (P_2 / P_1)$$

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

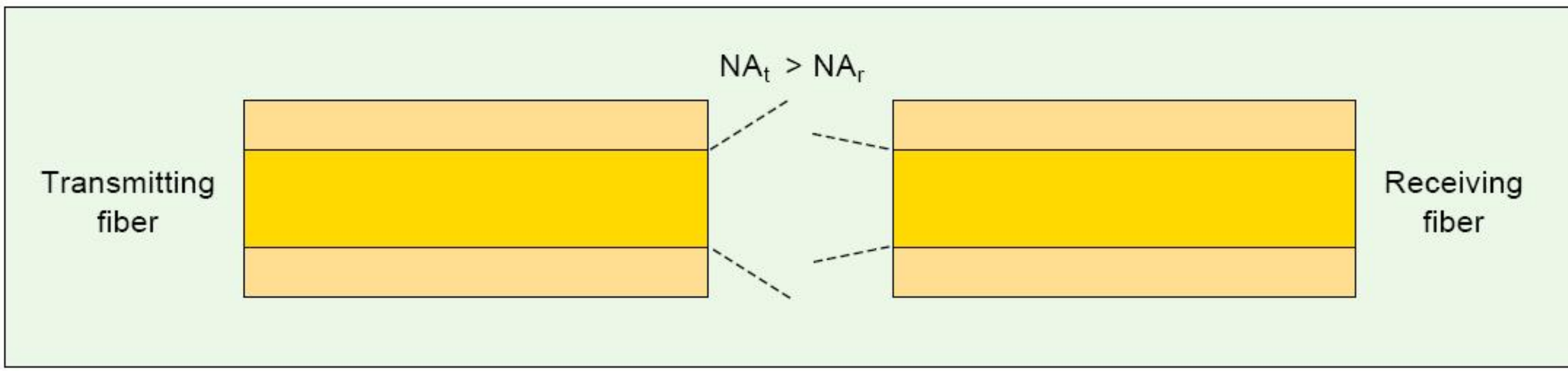
$$[dBm] + [dB] = [dBm]$$

Legatura pe fibra optica



Pierderi – Apertura numerica

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



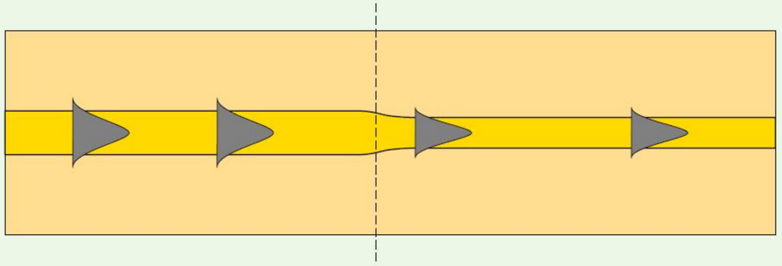
$$\text{Atenuare}_{\text{NA}}[\text{dB}] = -10 \cdot \log_{10}\left(\frac{NA_r}{NA_t}\right)^2$$

$$\text{numai pentru } NA_r < NA_t$$

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

Pierderi – Diametrul miezului

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



- multimod

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

- monomod

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

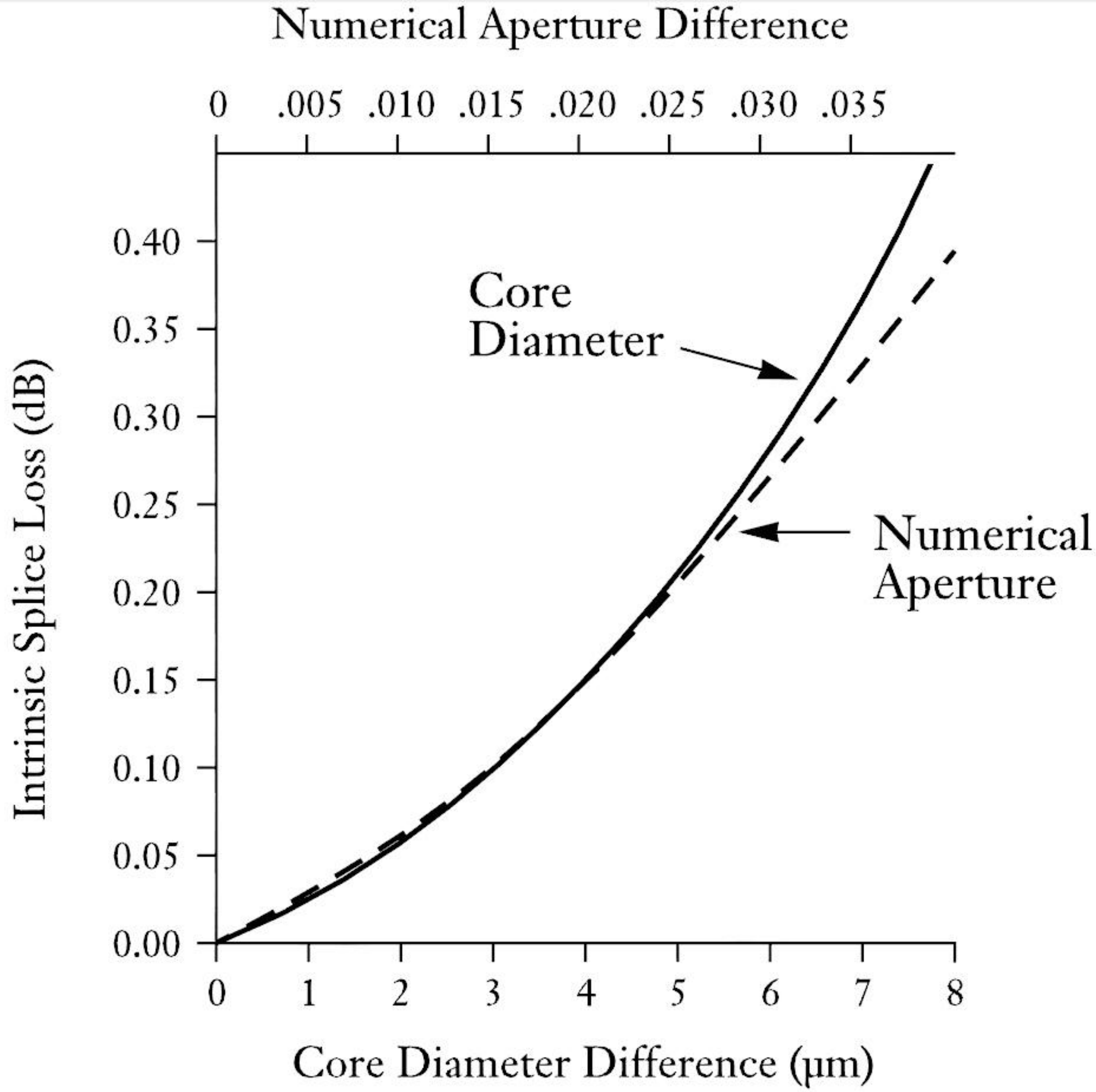
w = MFD !!

$\text{numai pentru } \Phi_r < \Phi_t$ $\qquad$ $\text{bidirectional } \forall w_1, w_2$

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

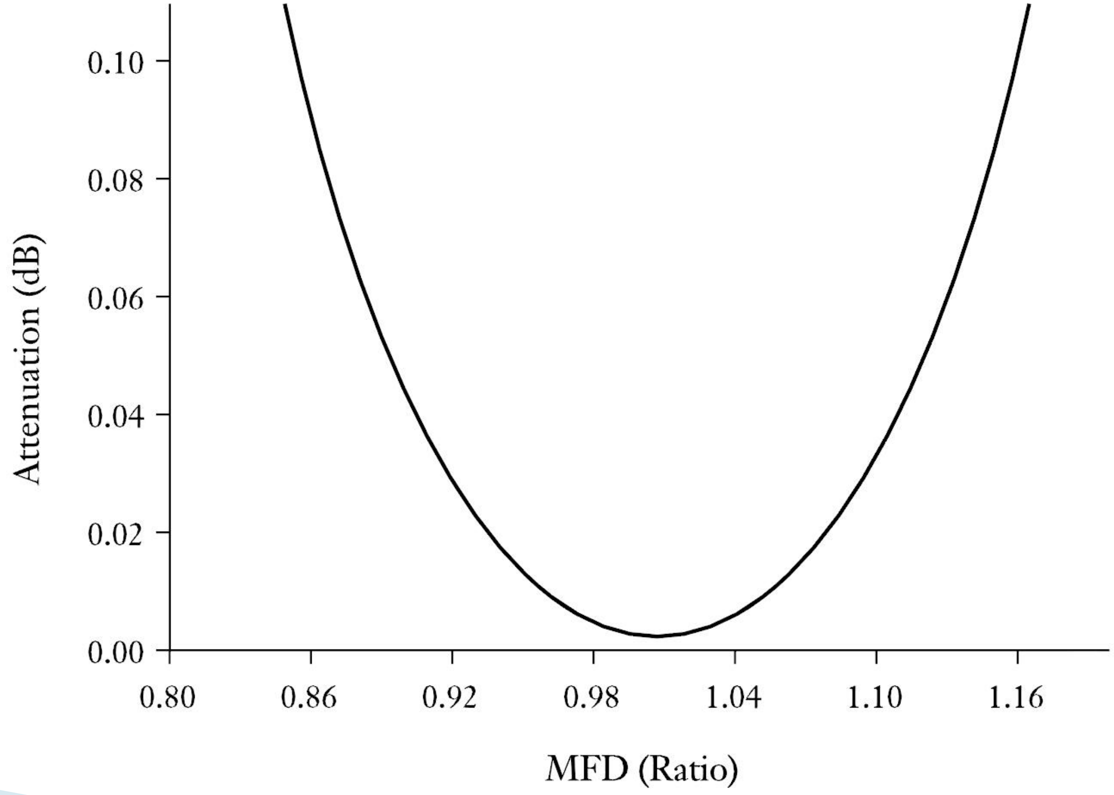
Pierderi

- multimod



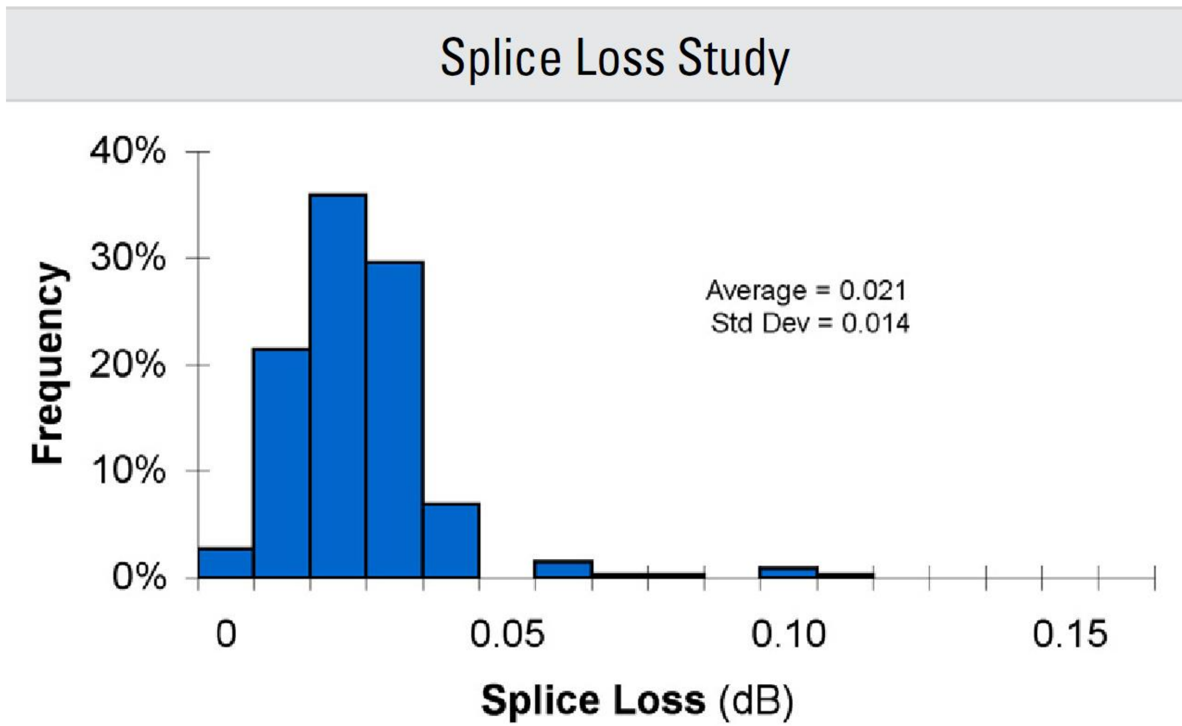
Pierderi

- multimod
  - predomina pierderile datorate diferentelor de MFD
  - se poate neglija NA

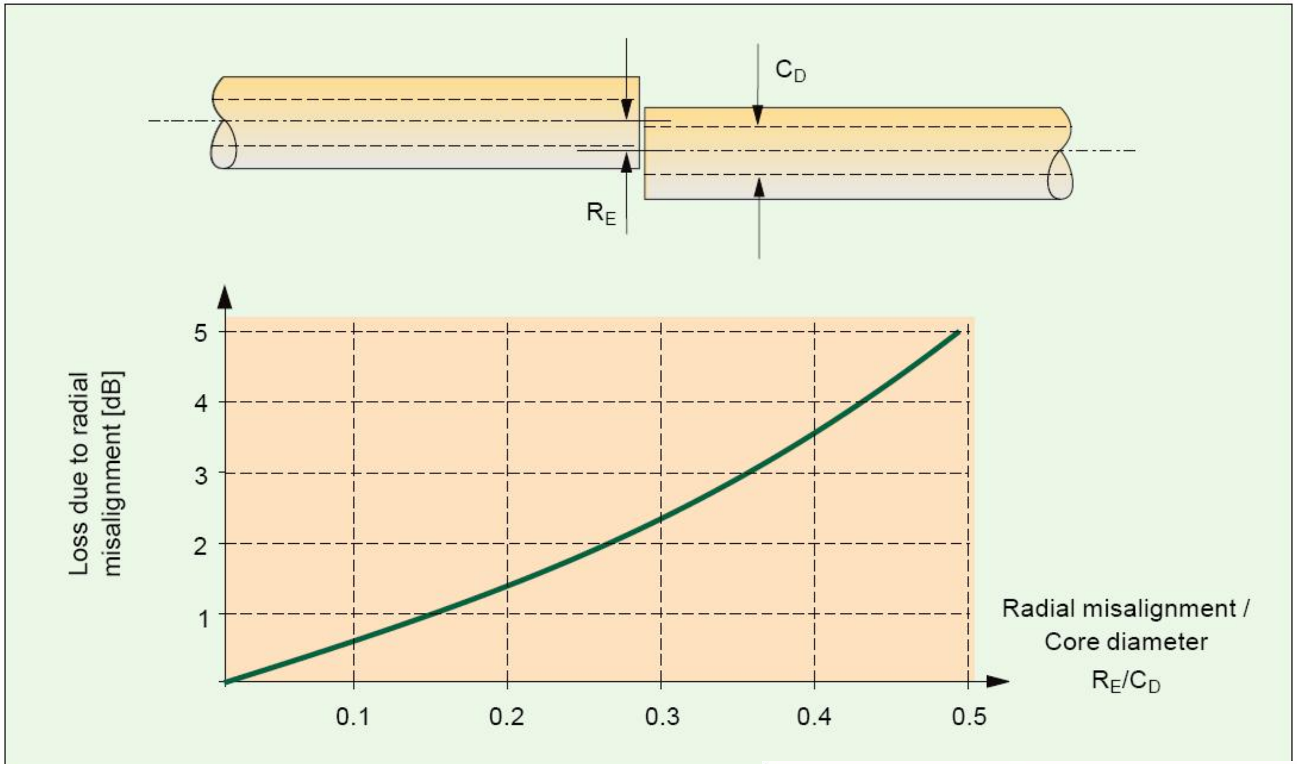


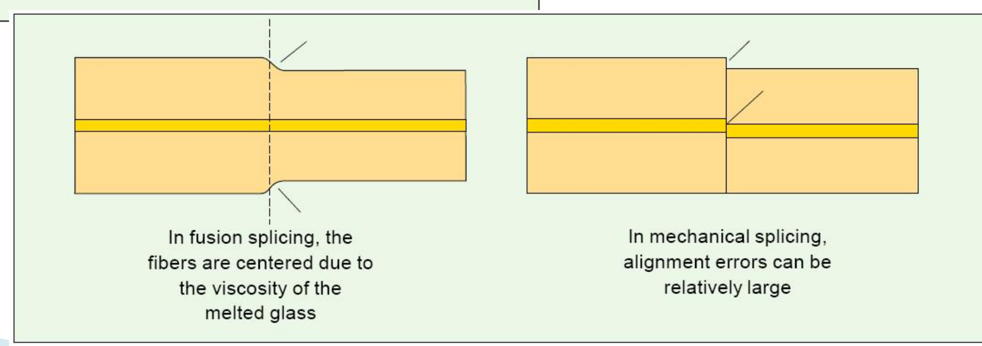
Pierderi

- multimod
- tipic: cel mai dezavantajos pentru MFD = 9.3±0.5μm → A=0.04dB

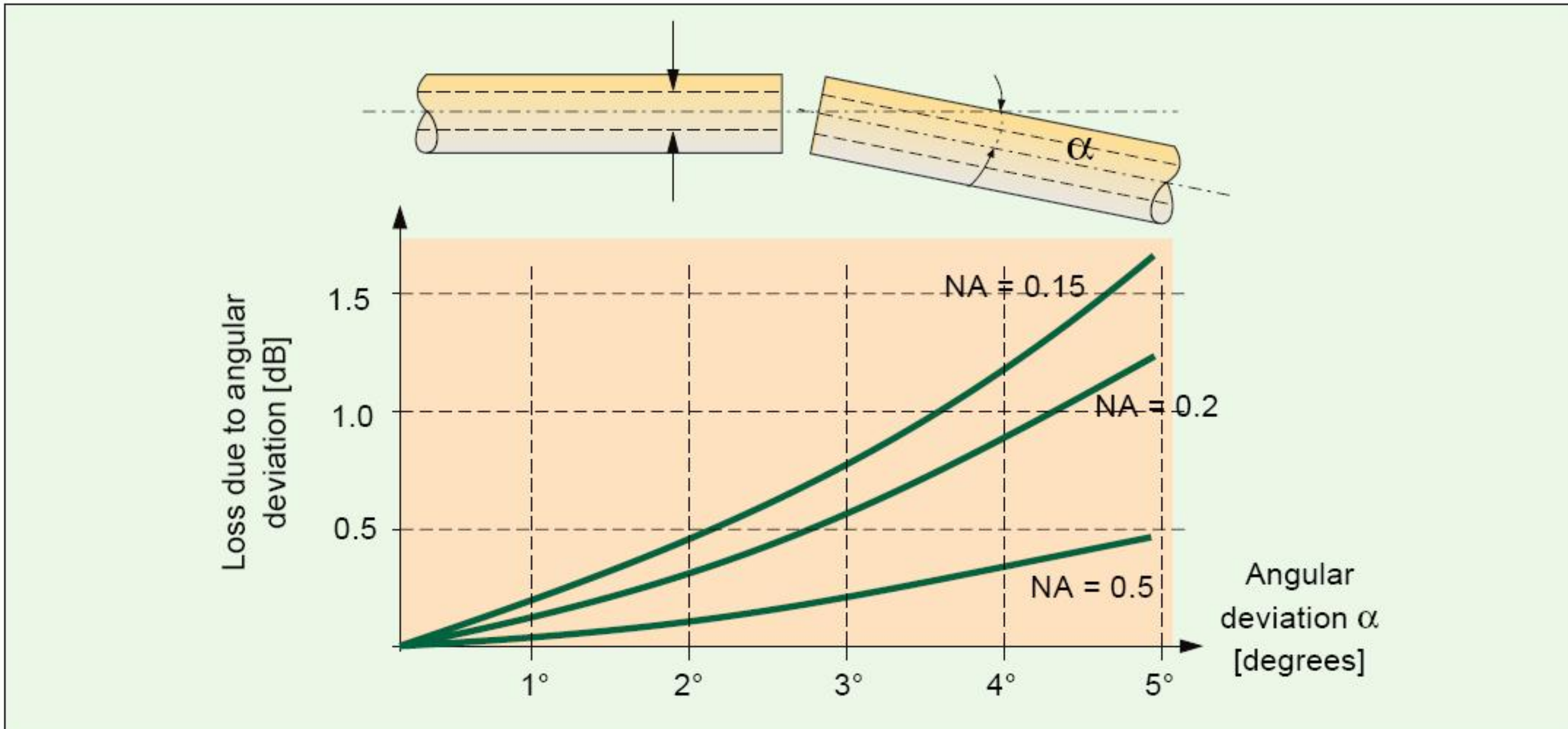


Pierderi – Nealinierea axelor



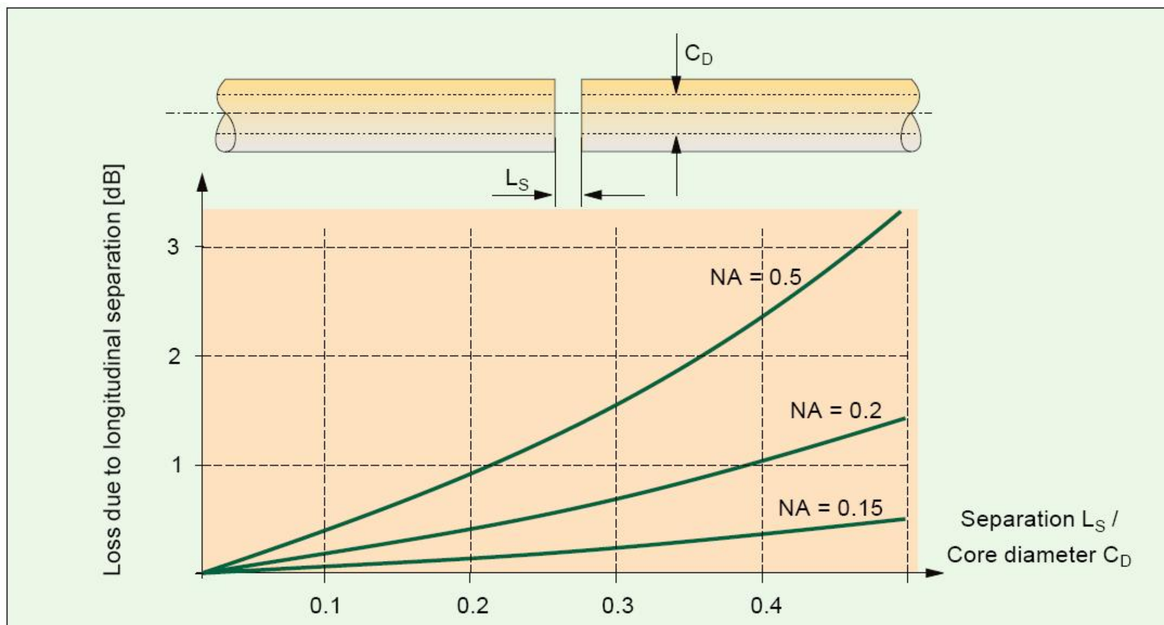


Pierderi – unghi



Pierderi – distanta

- 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 realizaţi o legătură pe fibră optică pe o distanţă de 50 km la o viteză de 1Gb/s.

Emiţători: = 1.5mW (Δλ=2nm, diverse λ)	NA = 0.17	Φ = 13μm
Pierderi splice (tehnologie)	0.15 dB/splice	
Pierderi conector	0.5 dB/conector	
Cablu conexiune: L = 20m	NA = 0.12	fibră: 11/125 μm
Cablu conexiune: L = 20m	NA = 0.15	fibră: 11/125 μm
Fibra 1	8 X 5km	
Fibra 2	4 X 10km	
Fibra 3	8 X 5km	
Fibra 4	4 X 10km	
Receptor: Sensitivitate = 1μW	NA = 0.25	Φ = 30μm

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. λ (nm)	Max. α 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 (λ) by more than the value α.

Macrobend Loss

Mandrel Diameter (mm)	Number of Turns	Wavelength (nm)	Induced Attenuation* (dB)
32	1	1550	≤0.03
50	100	1310	≤0.03
50	100	1550	≤0.03
60	100	1625	≤0.03

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

Point Discontinuity

Wavelength (nm)	Point Discontinuity (dB)
1310	≤0.05
1550	≤0.05

Cable Cutoff Wavelength (λ_{ccf})

$\lambda_{ccf} \leq 1260$ nm

Mode-Field Diameter

Wavelength (nm)	MFD (μm)
1310	9.4 ± 0.4
1550	10.6 ± 0.5

Dispersion

Wavelength (nm)	Dispersion Value [ps/(nm•km)]
1550	≤18
1625	≤23

Zero Dispersion Wavelength (λ_0): 1310 nm $\leq \lambda_0 \leq$ 1324 nm
Zero Dispersion Slope (S_0): ≤ 0.092 ps/(nm²•km)

Polarization Mode Dispersion (PMD)

	Value (ps/√km)
PMD Link Design Value	≤0.06*
Maximum Individual Fiber	≤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_Q). 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/√km maximum PMD.

Dimensional Specifications

Glass Geometry

Fiber Curl	≥ 4.0 m radius of curvature
Cladding Diameter	125.0 ± 0.7 μm
Core-Clad Concentricity	≤ 0.5 μm
Cladding Non-Circularity	≤ 0.7%

Coating Geometry

Coating Diameter	245 ± 5 μm
Coating-Cladding Concentricity	<12 μm

Environmental Specifications

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

*Reference temperature = +23°C

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

Mechanical Specifications

Proof Test

The entire fiber length is subjected to a tensile stress ≥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 μm
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 (λ_0)	1317 nm
Zero Dispersion Slope (S_0)	0.088 ps/(nm²•km)
Effective Group Index of Refraction (N_{eff})	1310 nm: 1.4670 1550 nm: 1.4677
Fatigue Resistance Parameter (N_d)	20
Coating Strip Force	Dry: 0.6 lbs. (3N) Wet, 14-day room temperature: 0.6 lbs. (3N)
Rayleigh Backscatter Coefficient (for 1 ns Pulse Width)	1310 nm: -77 dB 1550 nm: -82 dB
Stimulated Brillouin Scattering Threshold	20 dBm(1)

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

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

for 1200 nm ≤ λ ≤ 1625 nm

λ = Operating Wavelength

Cladding Non-Circularity

$$\text{Cladding Non-Circularity} = \left[1 - \frac{\text{Min. Cladding Diameter}}{\text{Max. Cladding Diameter}}\right] \times 100$$

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: opticalfibcs@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: 800-525-2524 (U.S. and Canada)
607-786-8125 (International)
Fx: 800-539-3632 (U.S. and Canada)
607-786-8344 (International)
Email: cofic@corning.com

Europe
Ph: 00 800 6620 6621 (U.K., Ireland, Italy, France, Germany, The Netherlands, Spain and Sweden)
+1 607 786 8125 (All Other Countries)
Fx: +1 607 786 8344

Asia Pacific
Australia
Ph: 1-800-148-690
Fx: 1-800-148-568
Indonesia
Ph: 001-803-015-721-1261
Fx: 001-803-015-721-1262
Malaysia
Ph: 1-800-80-3156
Fx: 1-800-80-3155
Philippines
Ph: 1-800-1-116-0338
Fx: 1-800-1-116-0339
Singapore
Ph: 800-1300-955
Fx: 800-1300-956
Thailand
Ph: 001-800-1-3-721-1263
Fx: 001-800-1-3-721-1264

Latin America
Brazil
Ph: 000817-762-4732
Fx: 000817-762-4996
Mexico
Ph: 001-800-235-1719
Fx: 001-800-339-1472
Venezuela
Ph: 800-1-4418
Fx: 800-1-4419

Greater China
Email: GCCofic@corning.com
Beijing
Ph: (86) 10-6505-5066
Fx: (86) 10-6505-5077
Hong Kong
Ph: (852) 2807-2723
Fx: (852) 2807-2152
Shanghai
Ph: (86) 21-3222-4668
Fx: (86) 21-6288-1575
Taiwan
Ph: (886) 2-2716-0338
Fx: (886) 2-2716-0339

Intrebari

- (1p) Ce lungime de undă veţi alege pentru emiţător? Justificaţi.
- (2p) Alegeţi fibrele pe care le veţi utiliza. Justificaţi. Realizaţi schiţa legăturii
- (1p) Puteţi realiza o legătură funcţională? Justificaţi.

Zero Dispersion Wavelength (λ_0)	1317 nm
Zero Dispersion Slope (S_0)	0.088 ps/(nm²•km)

Legatura

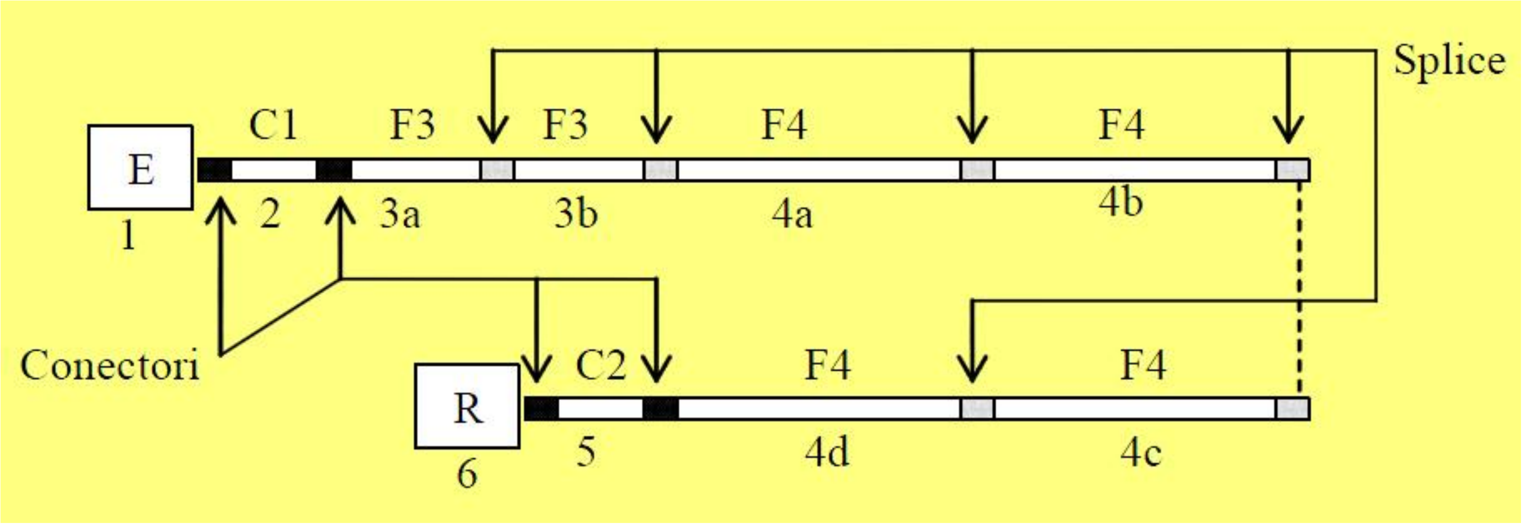
- Bilantul puterilor

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

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

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
  - Macrocurburi
  - Microcurburi
  - Imprastiere
  - Absorbtie
- Localizata
  - conectori
  - splice
  - tranzitii

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

$$Atenuare_L[dB] = Pierderi[dB]$$

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

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** la fibre monomod
- 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

Dispersie

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

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

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

$$\mathrm{D}(\lambda) = \frac{\mathrm{S}_0}{4} \cdot \left(\lambda - \frac{\lambda_0^4}{\lambda^3}\right)$$

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

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

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

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

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

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

$$\mathrm{NRZ}_{\text{viteza date}}(\mathrm{Gbit/s}) = \frac{1}{\mathrm{T}_{\mathrm{impuls}}(\mathrm{ns})} \le \frac{0.67}{\mathrm{T(ns)}}$$

Produs Banda · Distanta

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

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

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

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

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

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

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

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

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

Lungime maxima

- limitata de atenuare

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

$$Atenuare[dB/km] = \frac{Pierderi_D[dB]}{lungime[km]} \qquad L_{max} \Rightarrow \Delta P_{min}, A_{D\max}$$

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

Lungime maxima

- limitata de viteza

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

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

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

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

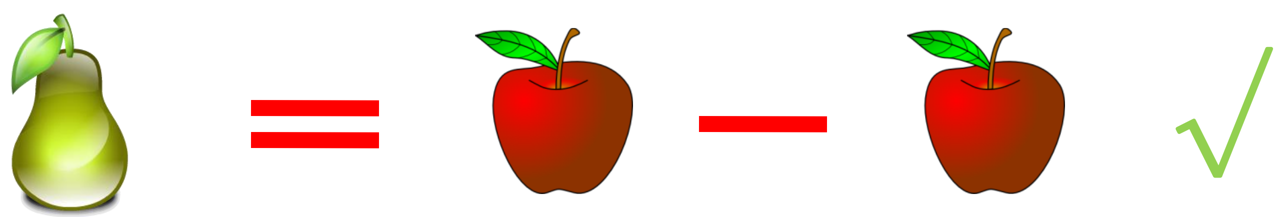
de obicei problema distantei maxime se pune numai pentru fibre monomod

Calculul atenuarii

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

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

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



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

Problema simpla?

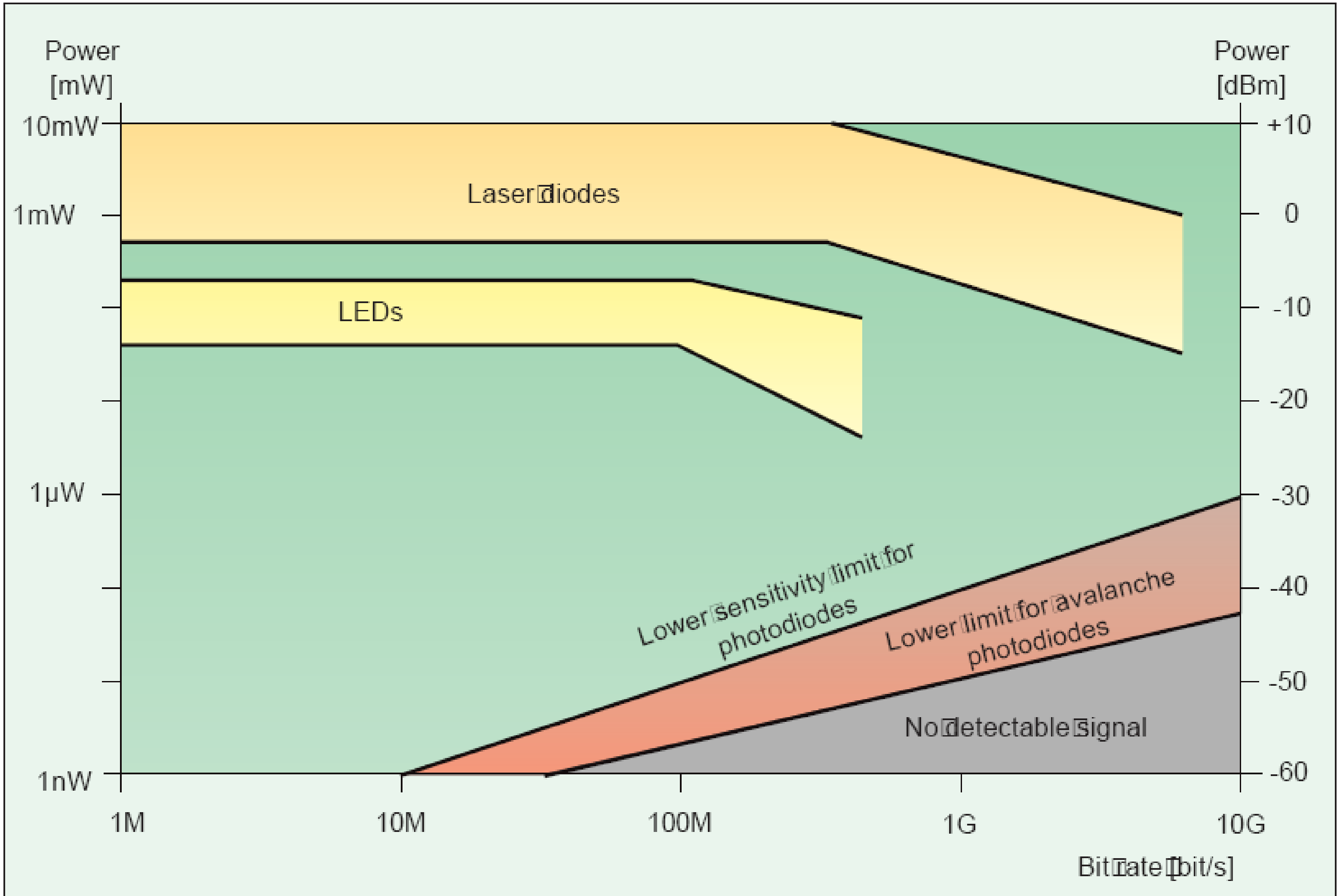
- Sursa luminoasa: 7.7 dBm
- Atenuarea fibrei: 1.16 dB/km
- Puterea la iesire: 105 μW

- Lungimea fibrei: ?

Problema simpla?

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

Limite putere/bandă a dispozitivelor optoelectronice



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