Optoelectronică, structuri şi tehnologii

Curs 7
2015/2016

Disciplina 2015/2016

- 2C/1L Optoelectronică, structuri şi tehnologii, OSTC
- **Minim 7 prezente (C+L)**
- Curs – sl. Radu Damian
  - an IV μE
  - Luni 18-20, P5
  - E – 66% din nota
  - probleme + (~~? 1 subiect teorie~~) + (2p prez. curs)
  - toate materialele permise
- Laborator – sl. Daniel Matasaru
  - an IV μE, an IV Tc
    - Luni 16-18 impar
    - Marti 18-20
    - Joi 8-12 impar
  - L – 17% din nota
  - T – 17% din nota

Capitolul 11

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

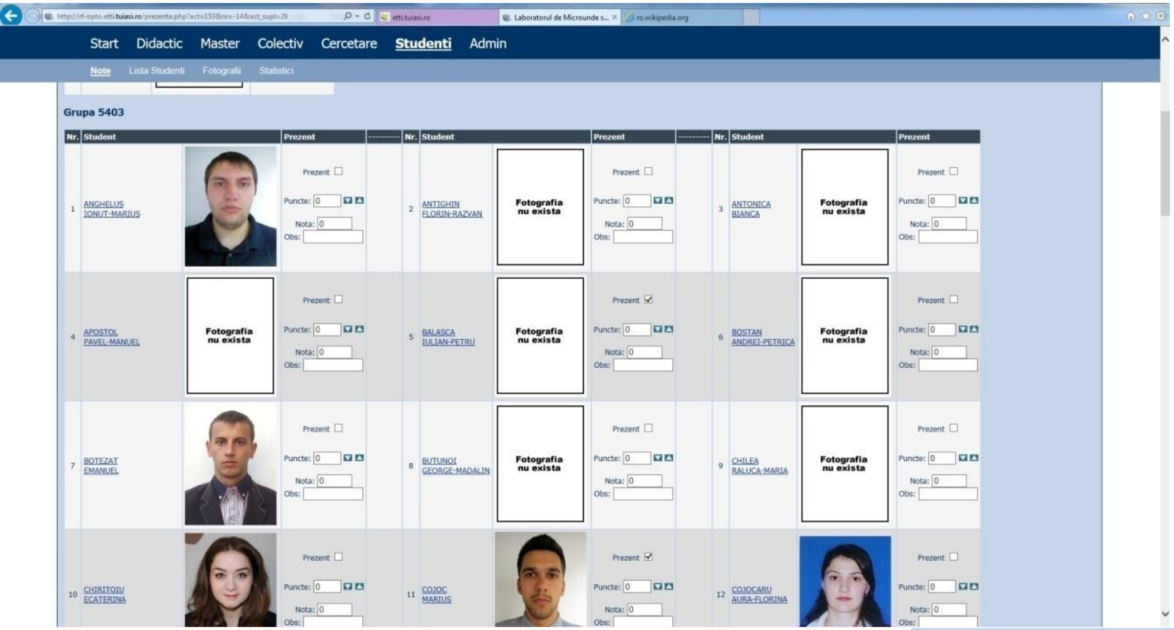
+1/2 probleme

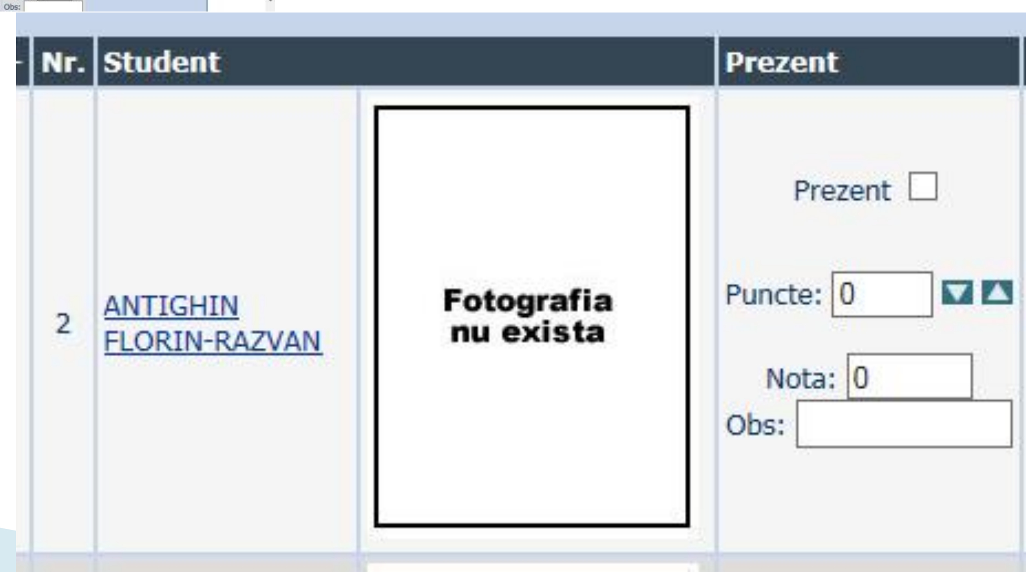
Lista subiecte

- 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

+1/2 probleme

Fotografii +0.5p





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]

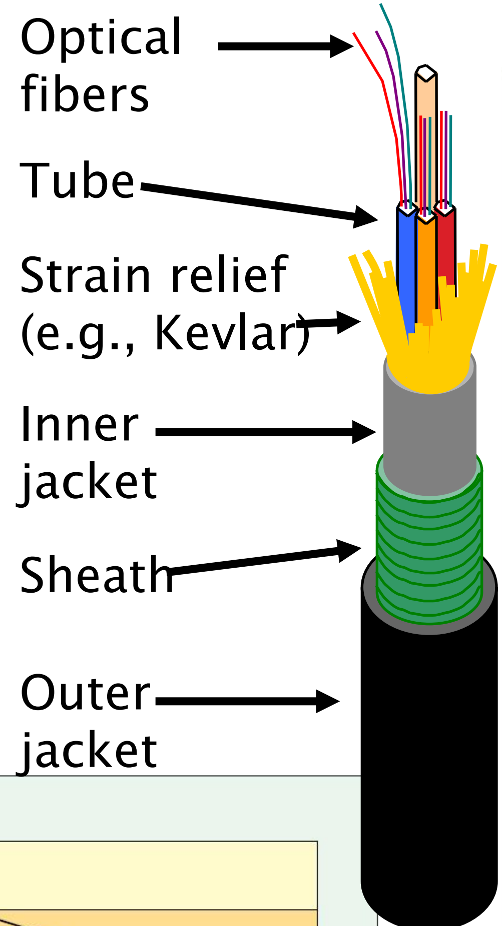
[x] + [dB] = [x]

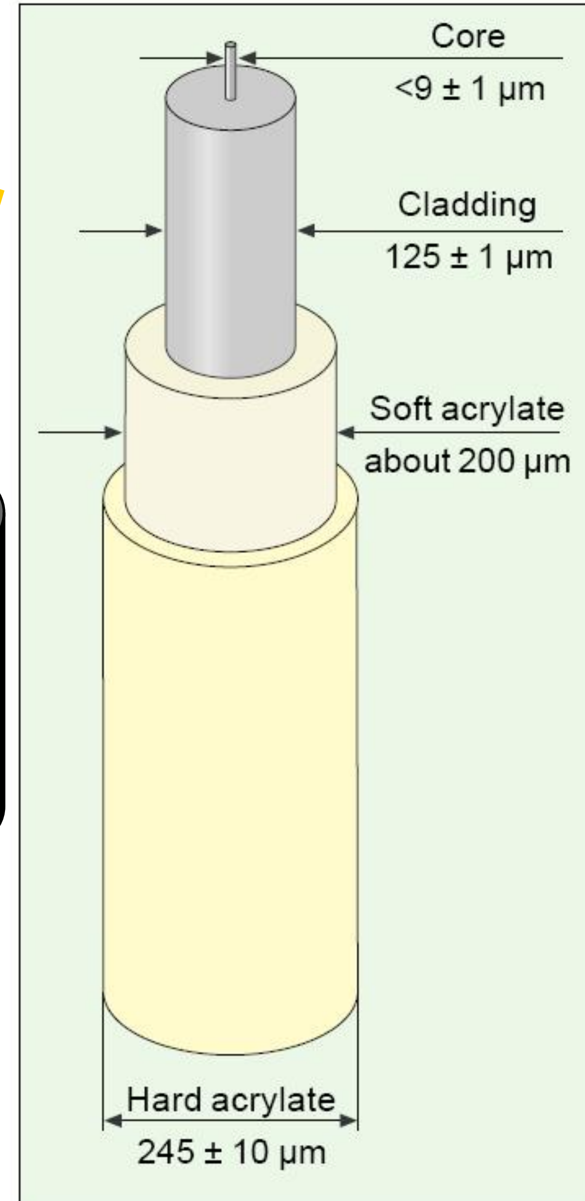
Recapitulare

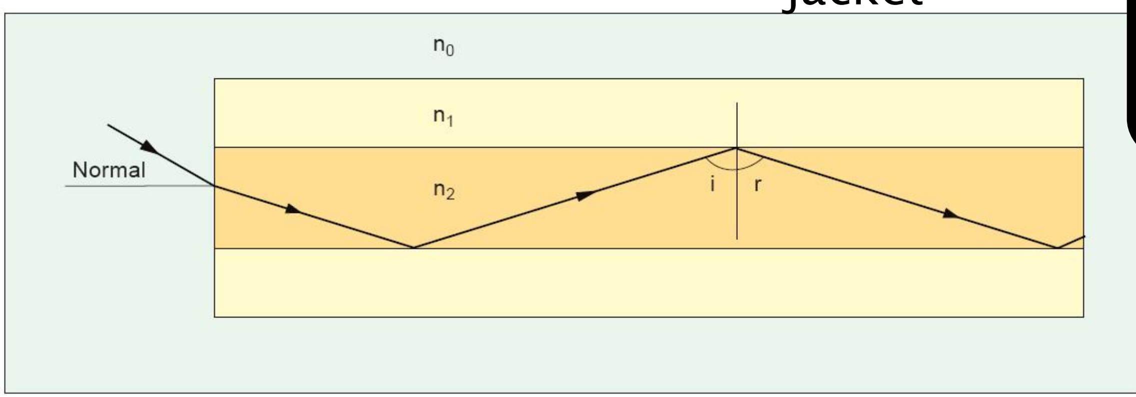
Curs 5

Fibra optica

- un ghid de unda dielectric
  - miez
  - teaca

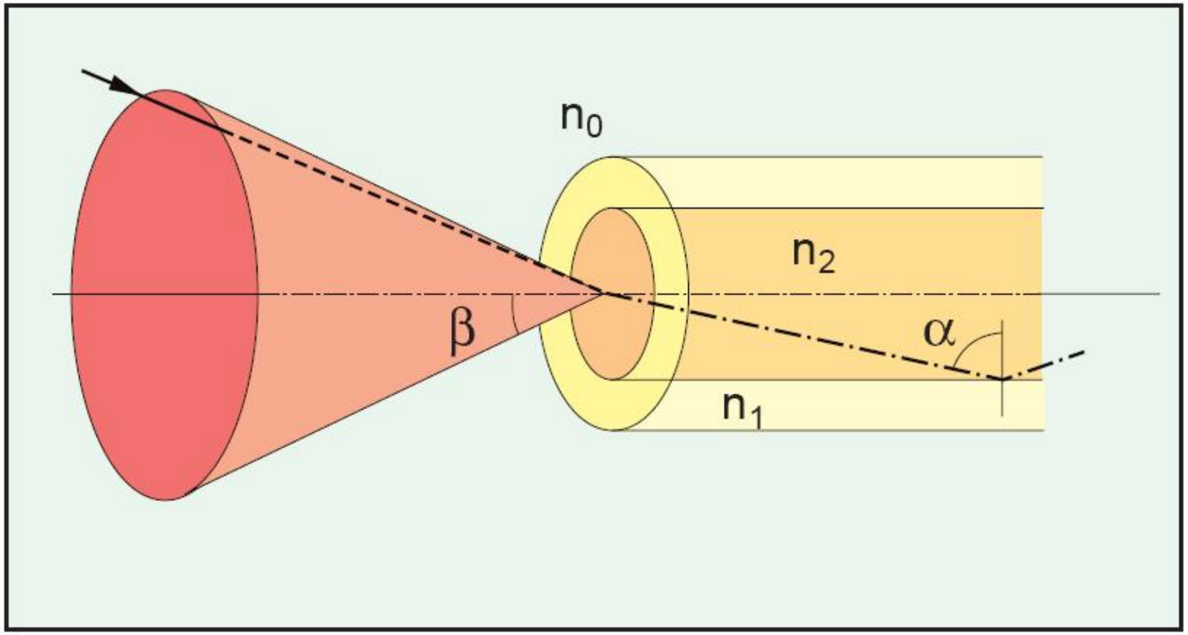






Unghi de acceptanta, apertura numerica

- Unghi de acceptanta

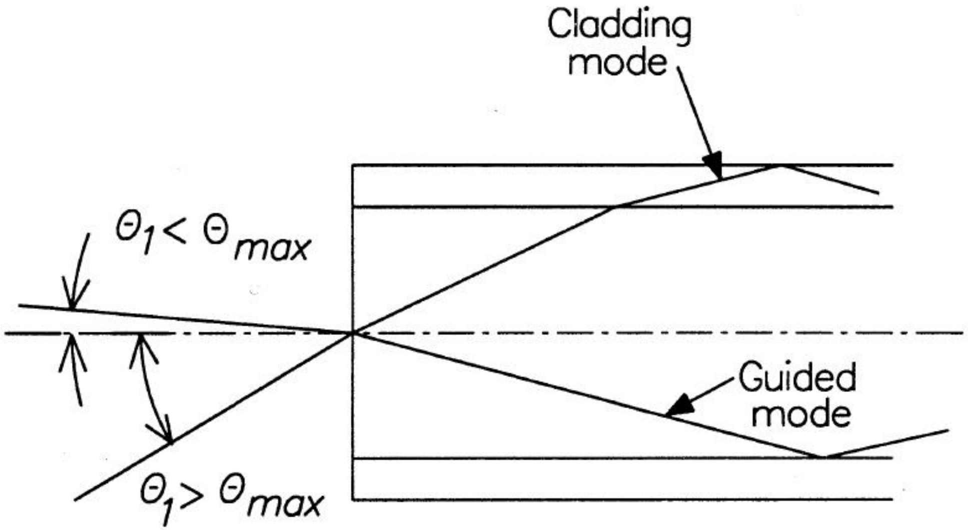


$$n_0 \cdot \sin\theta_{ACC} = n_2 \cdot \sin\phi_c$$

- **Apertura numerica**

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

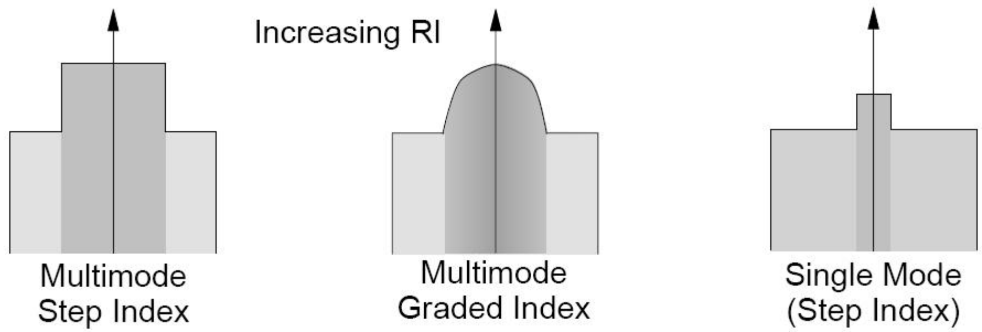
$$NA = n_2\sqrt{\frac{n_2^2 - n_1^2}{n_2^2}} = \sqrt{n_2^2 - n_1^2}$$

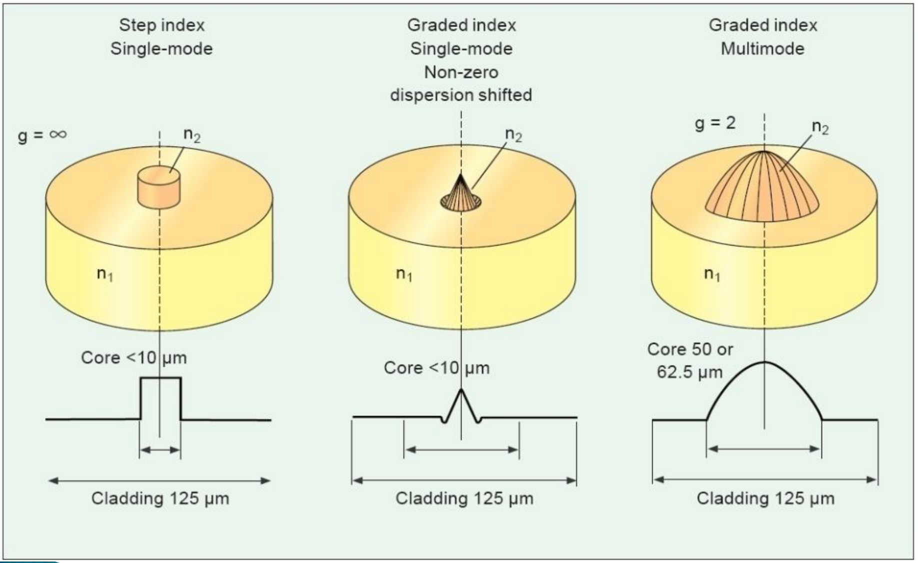


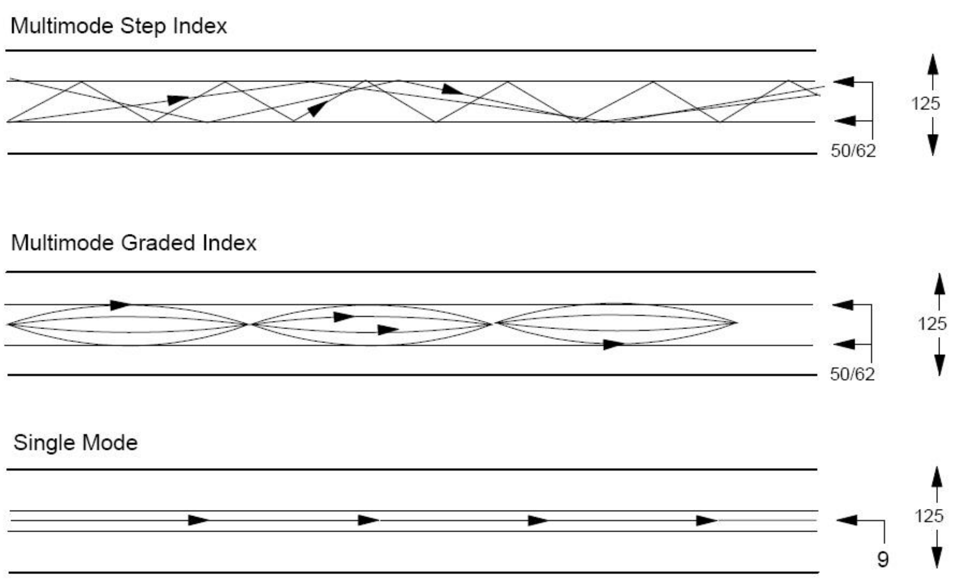
n_2 – miez
n_1 – teaca
$n_2 > n_1$!!

Tipuri de fibra

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







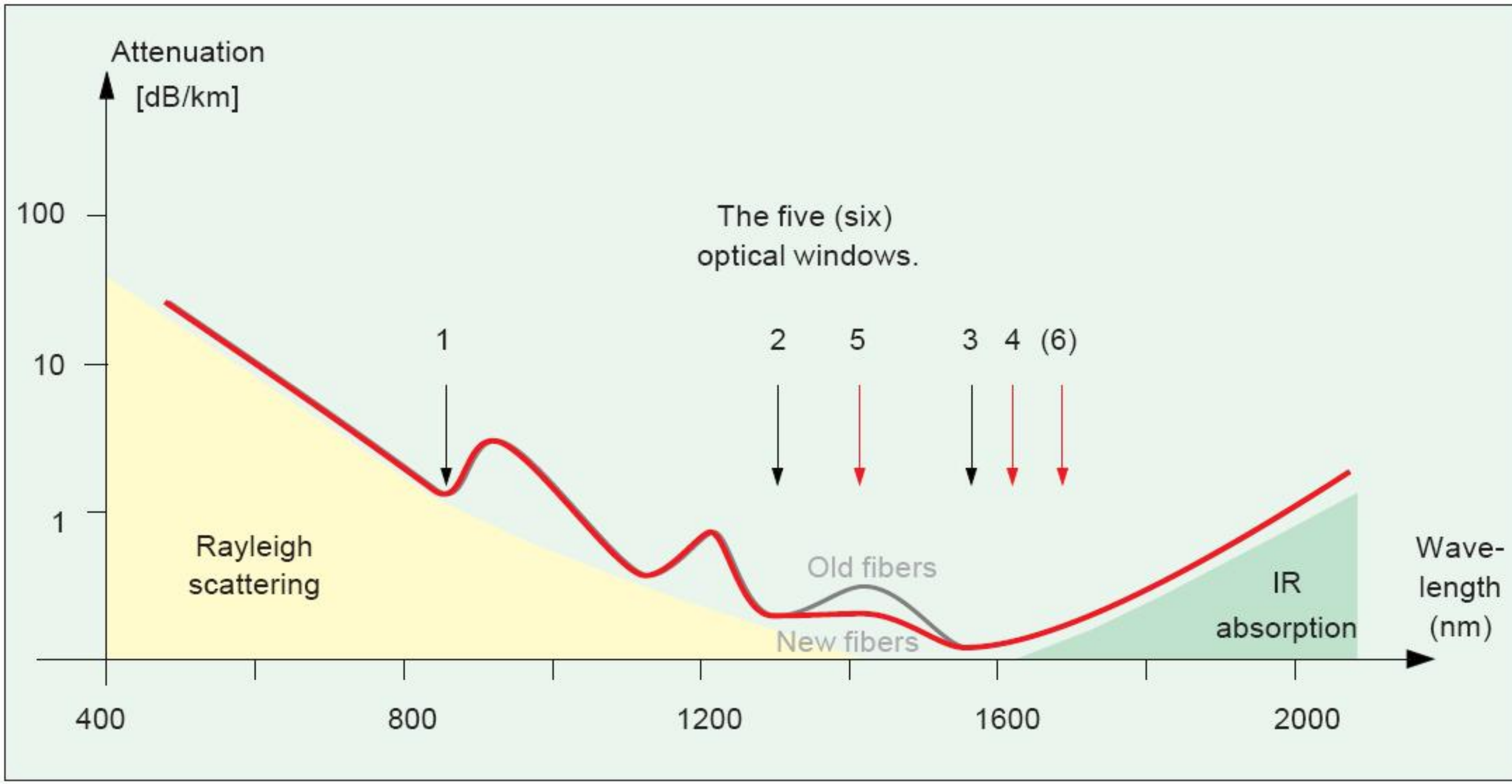
Fenomene de interes

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

Atenuare

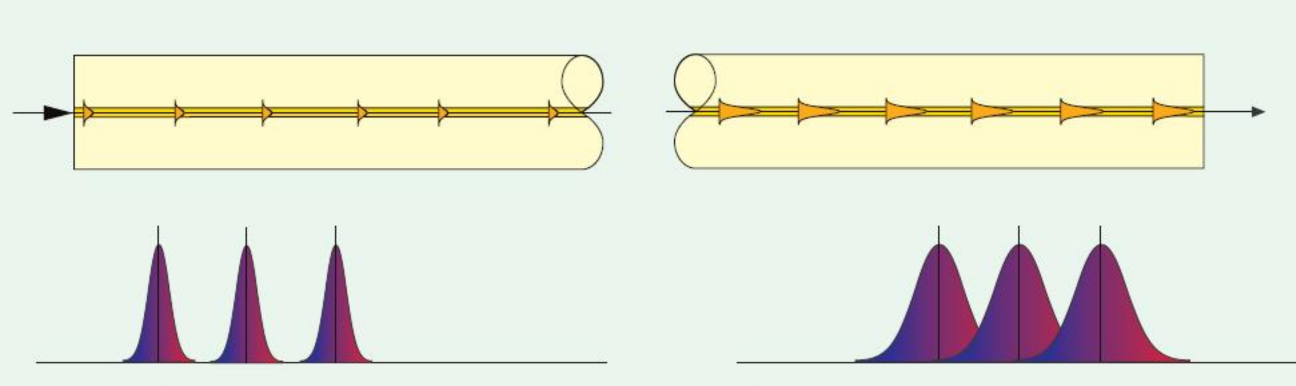
- Macrocurburi
  - utilizator, localizat, dB
- Microcurburi
  - distribuit, tehnologie, dB/km
- Imprastiere
  - distribuit, tehnologie, dB/km
- Absorbtie
  - distribuit, material, dB/km

Absorbtie

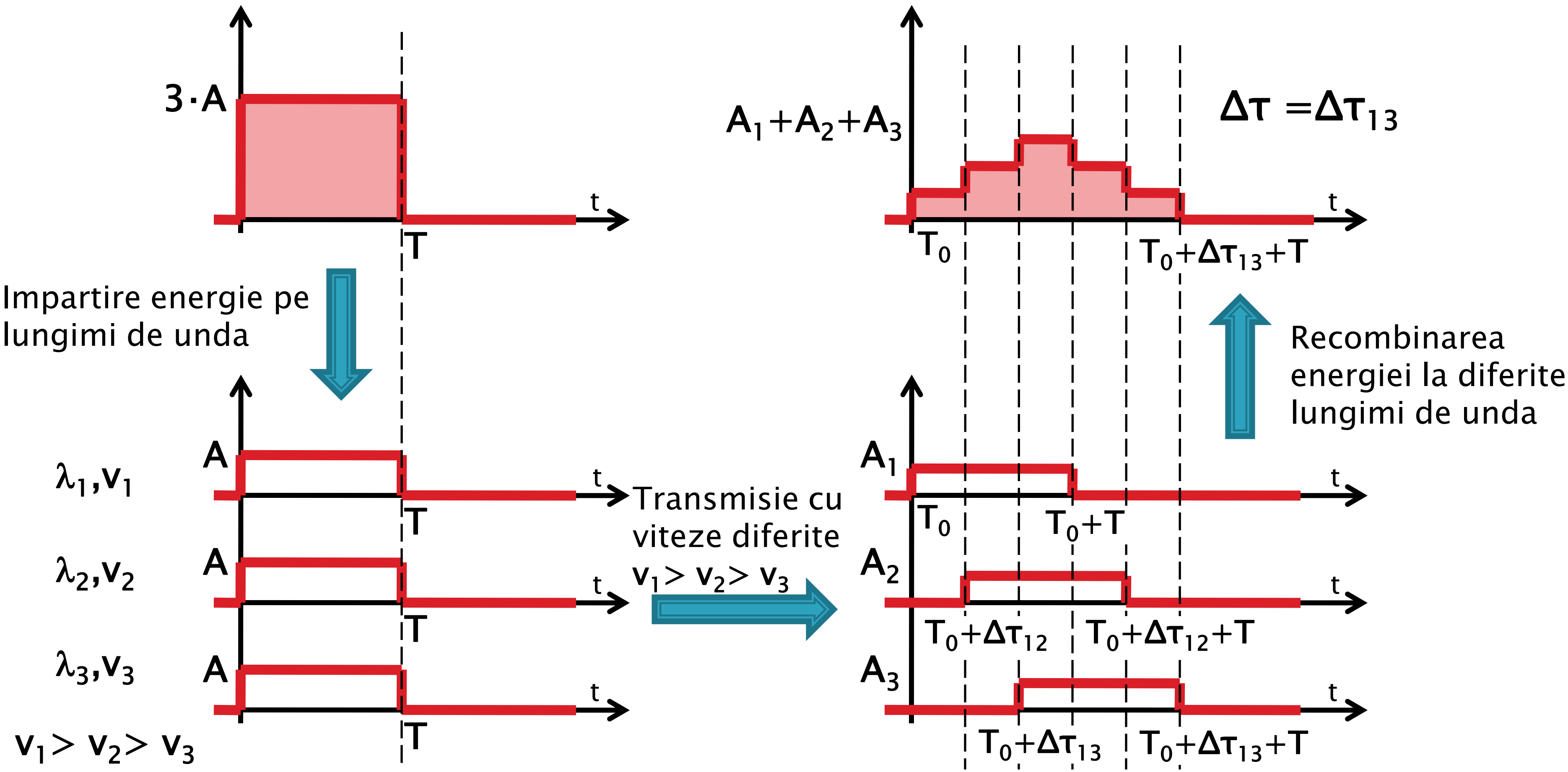

Attenuation
[dB/km]
100
10
1
The five (six)
optical windows.
1
2
5
3
4
(6)
Rayleigh
scattering
Old fibers
New fibers
IR
absorption
Wave-
length
(nm)
400
800
1200
1600
2000

Dispersia

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



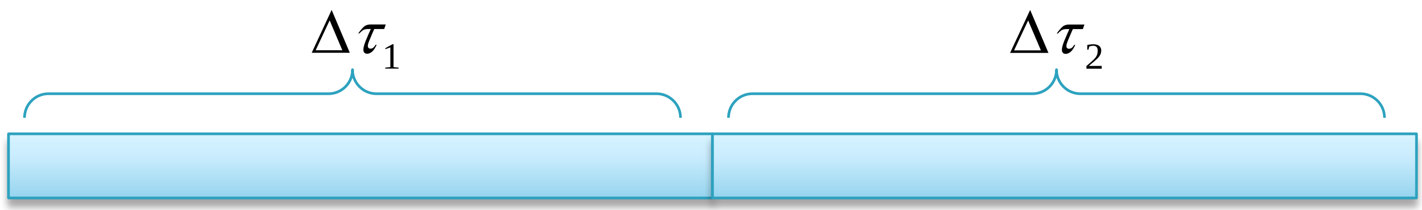
Dispersia cromatica (gh+mat)



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

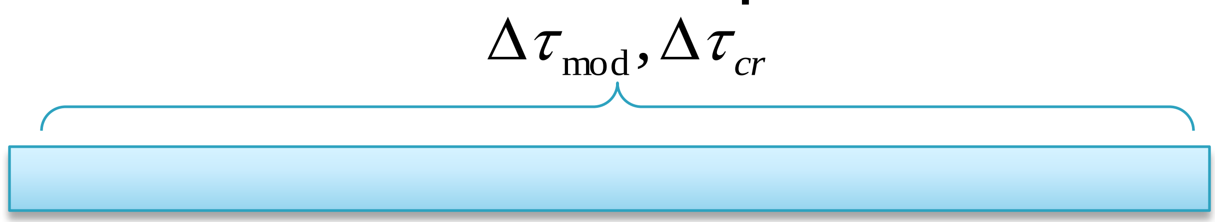
Sumarea efectelor

- efecte **succesive** se adună liniar



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

- efecte **simultane** se adună pătratic



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

Dispersia

- Dispersia modala
  - salt de indice

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

  - indice gradat

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

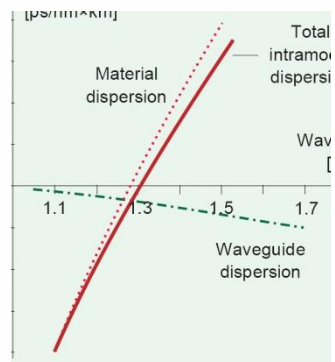
$$\Delta = 0.01 \div 0.02 << 1$$

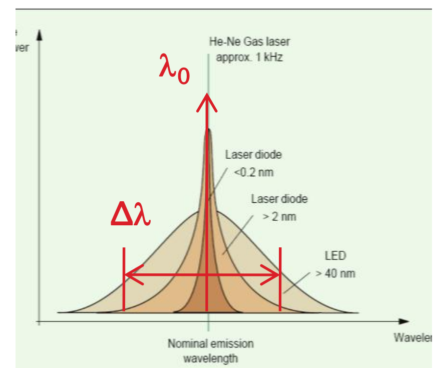
$$NA = 0.1 \div 0.2 < 1$$

- Dispersia cromatica

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

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





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

Banda

- Dispersia totala

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

- Banda

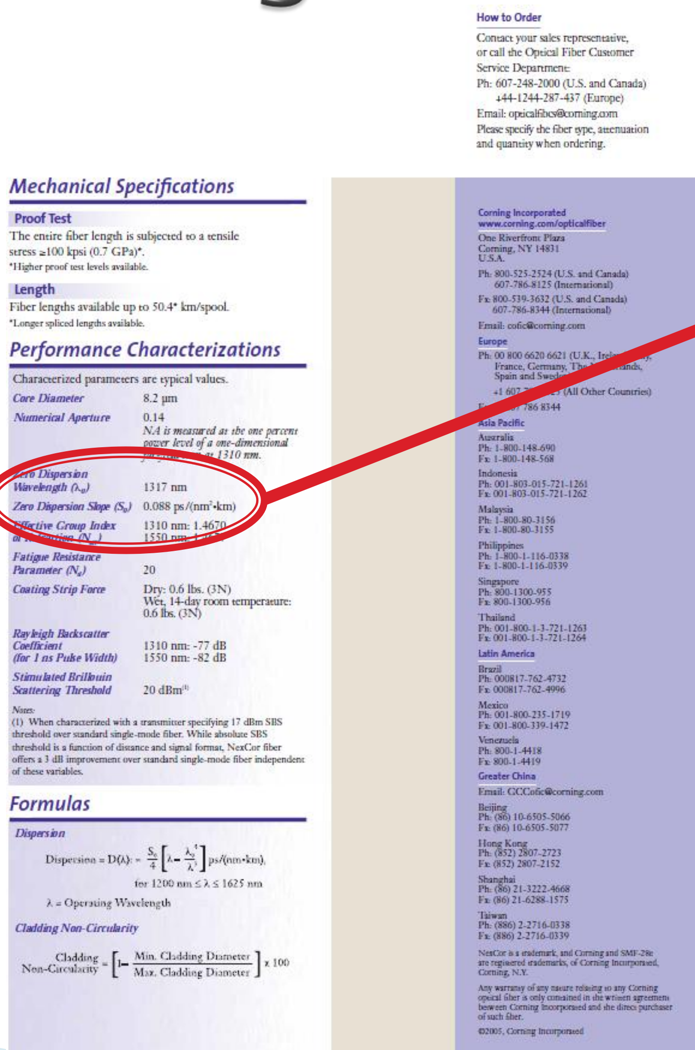
$$B_{opt} \cong \frac{0.44}{\Delta\tau_{tot}[ns]} \quad [GHz]$$

- 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

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

Catalog – monomod

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



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: opticalfiber@corning.com
Please specify the fiber type, attenuation and quantity when ordering.

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 ... at 1310 nm.*
Zero Dispersion Wavelength (λ_0)	1317 nm
Zero Dispersion Slope (S_0)	0.088 ps/(nm²·km)
Effective Group Index ...	1310 nm: 1.4670 1550 nm: ...
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

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

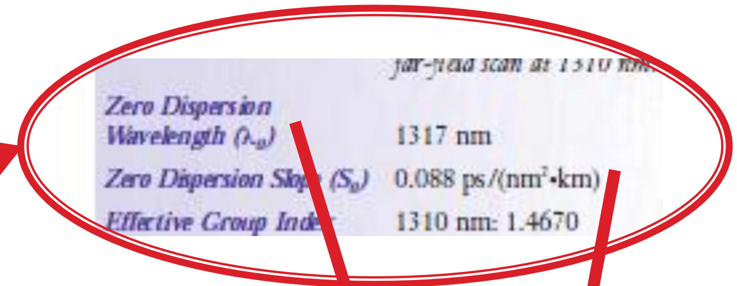
Corning Incorporated
www.corning.com/opticalfiber
One Riverfront Plaza
Corning, NY 14831
U.S.A.
Ph: 800-525-2524 (U.S. and Canada)
607-786-8125 (International)
Fx: 800-539-3632 (U.S. and Canada)
607-786-8344 (International)
Email: cofic@corning.com

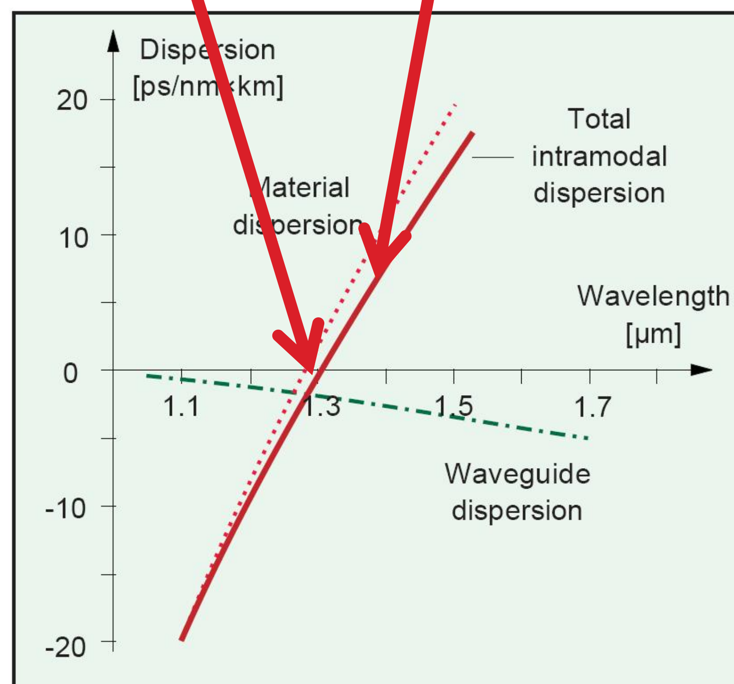
Europe
Ph: 00 800 6620 6621 (U.K., Irel... France, Germany, The ...ands, Spain and Swed...
+1 607 ... (All Other Countries)
786 8344

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





Fibra optică – Tehnologie

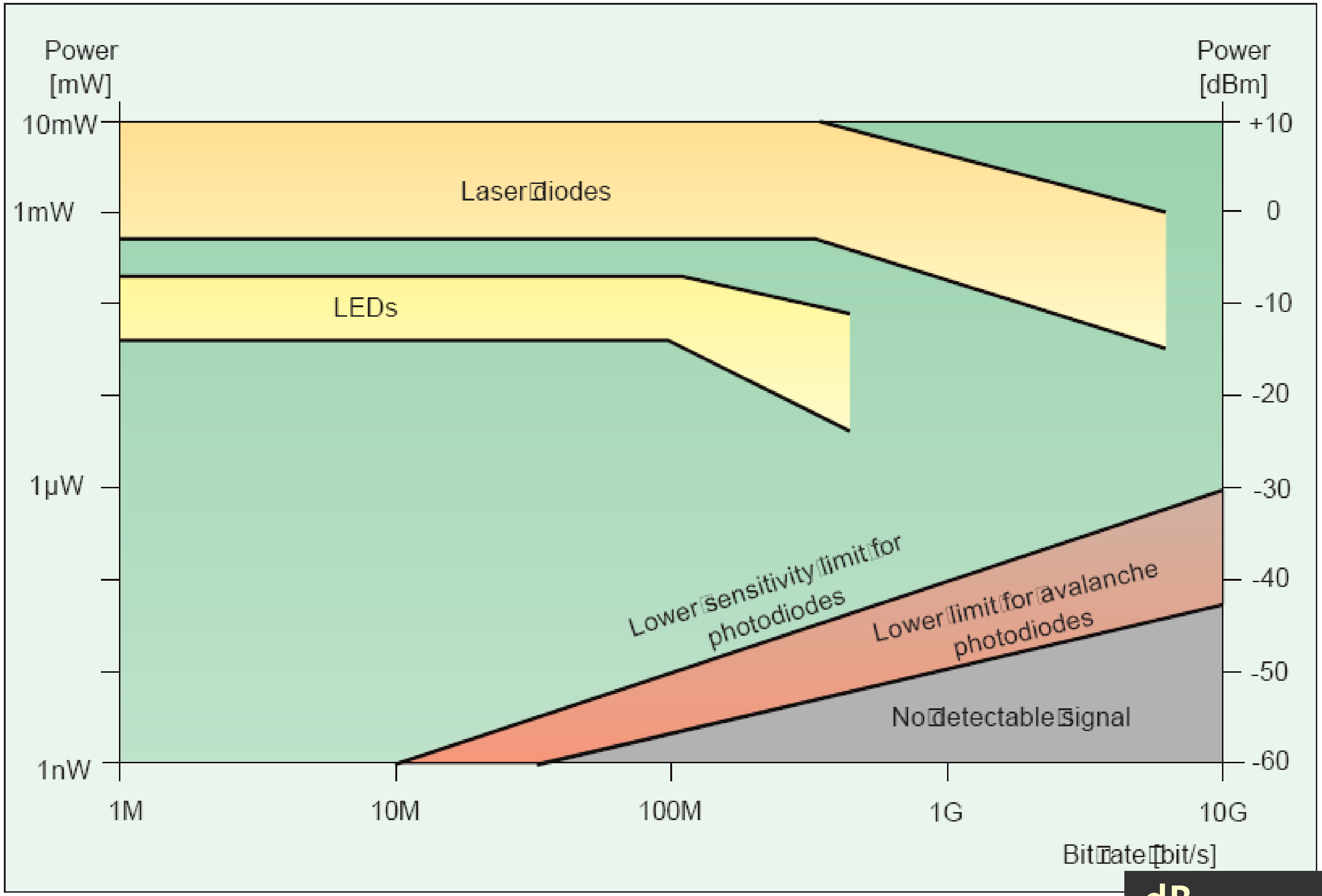
Capitolul 6

Continuare

Dimensionarea unei legături pe fibra optică

Capitolul 7

Limite putere/bandă a dispozitivelor optoelectronice

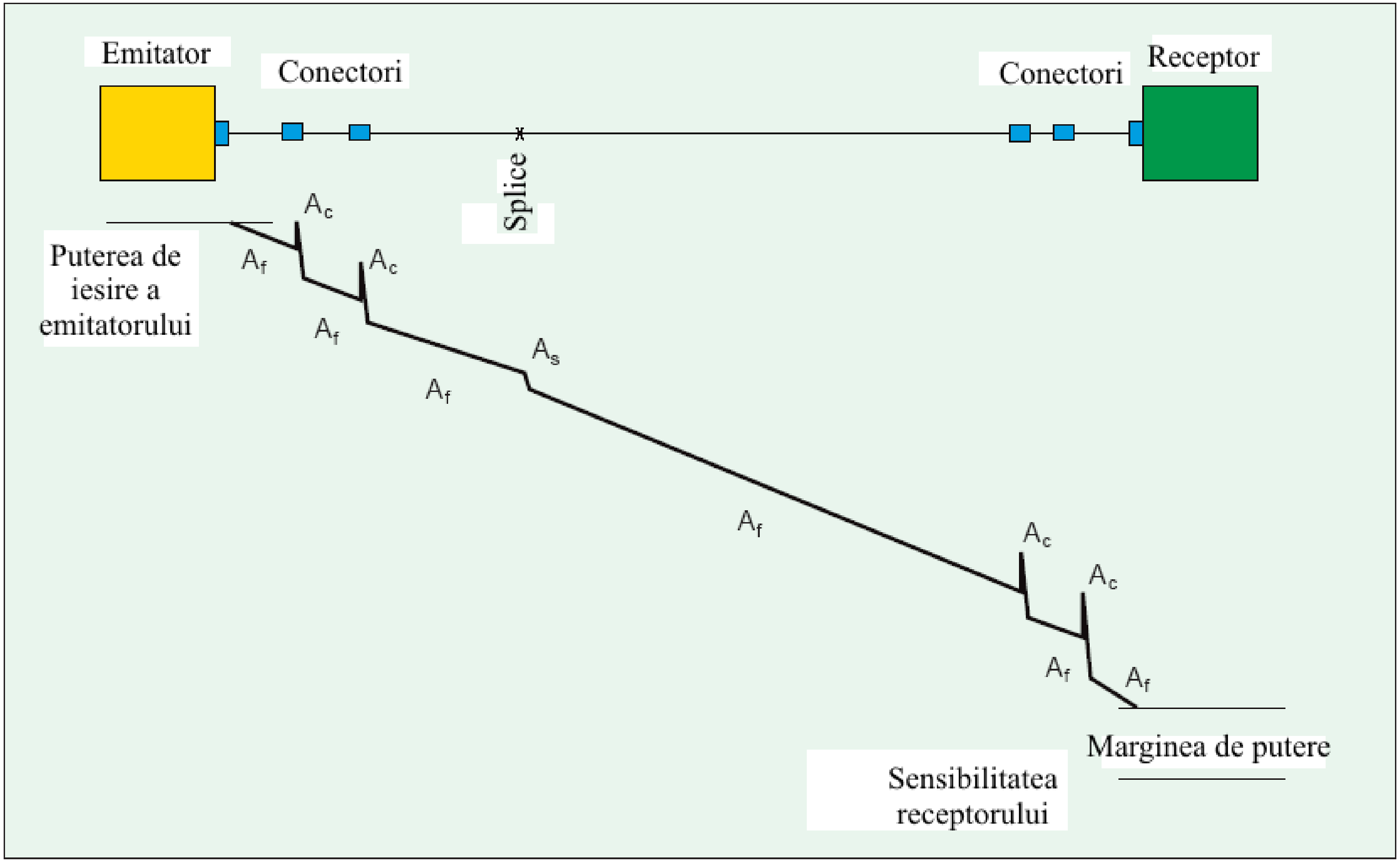


$$dB = 10 \cdot \log_{10}(P_2 / P_1)$$

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

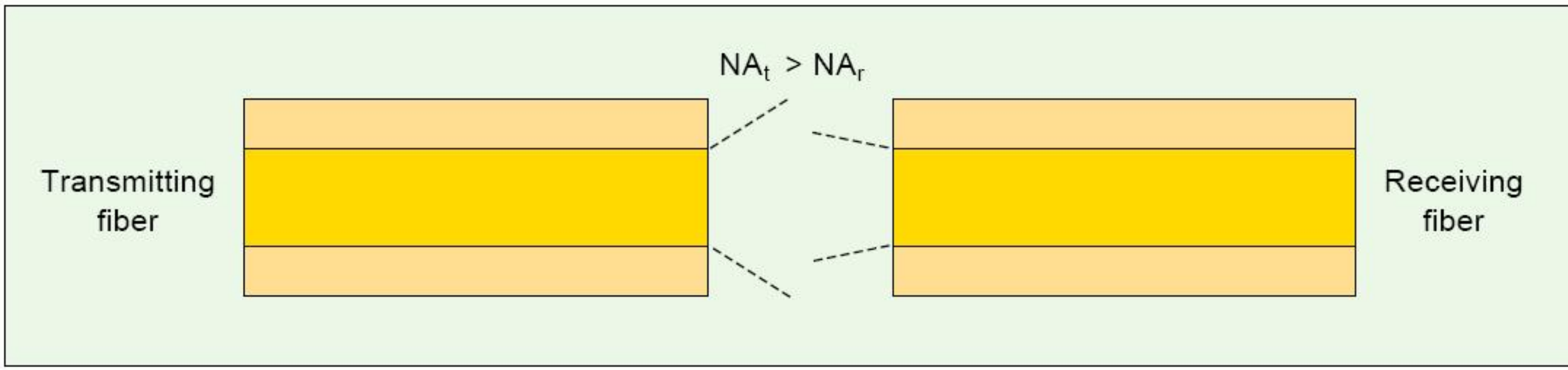
$$[dBm] + [dB] = [dBm]$$

Legatura pe fibra optica



Pierderi – Apertura numerica

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



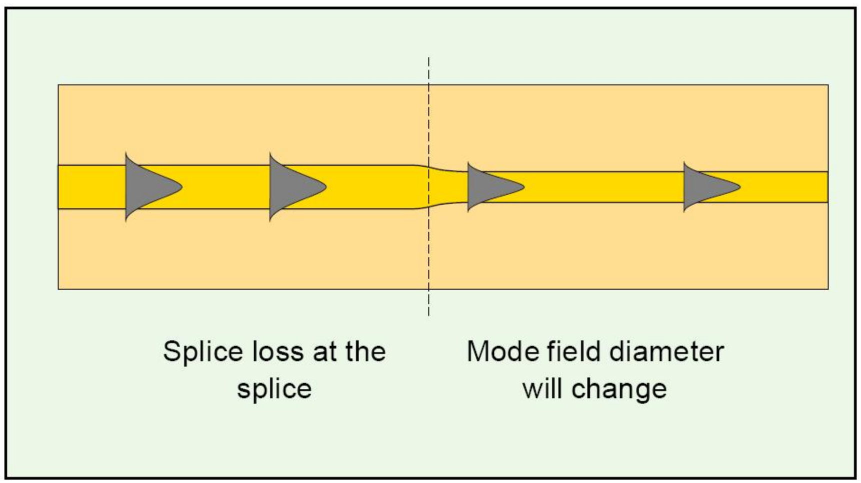
$$\text{Atenuare}_{\text{NA}}[\text{dB}] = -10 \cdot \log_{10}\left(\frac{NA_r}{NA_t}\right)^2$$

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

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

Pierderi – Diametrul miezului

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



- multimod

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

numai pentru $\Phi_r < \Phi_t$

- monomod

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

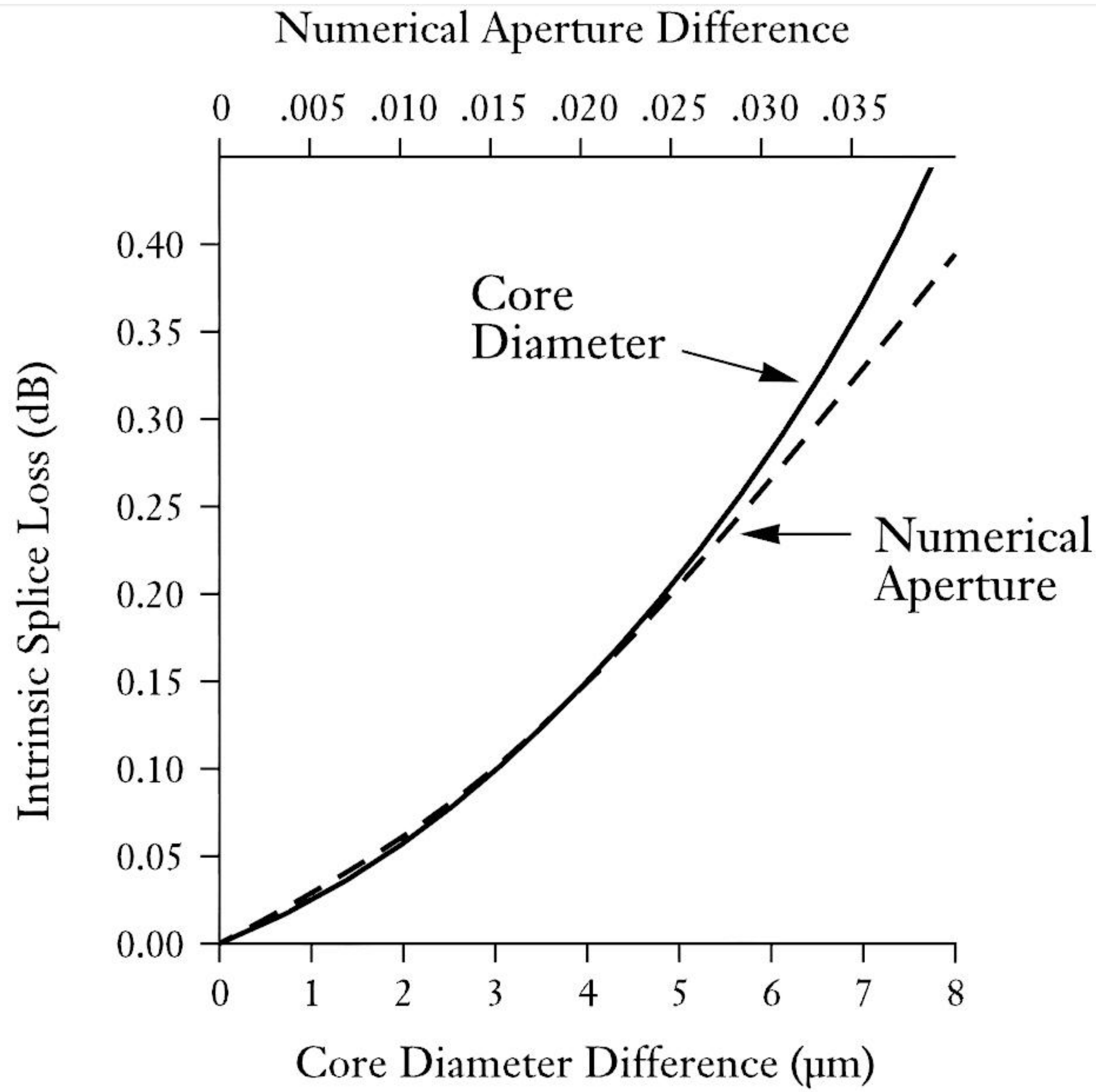
bidirectional $\forall w_1, w_2$

w = MFD !!

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

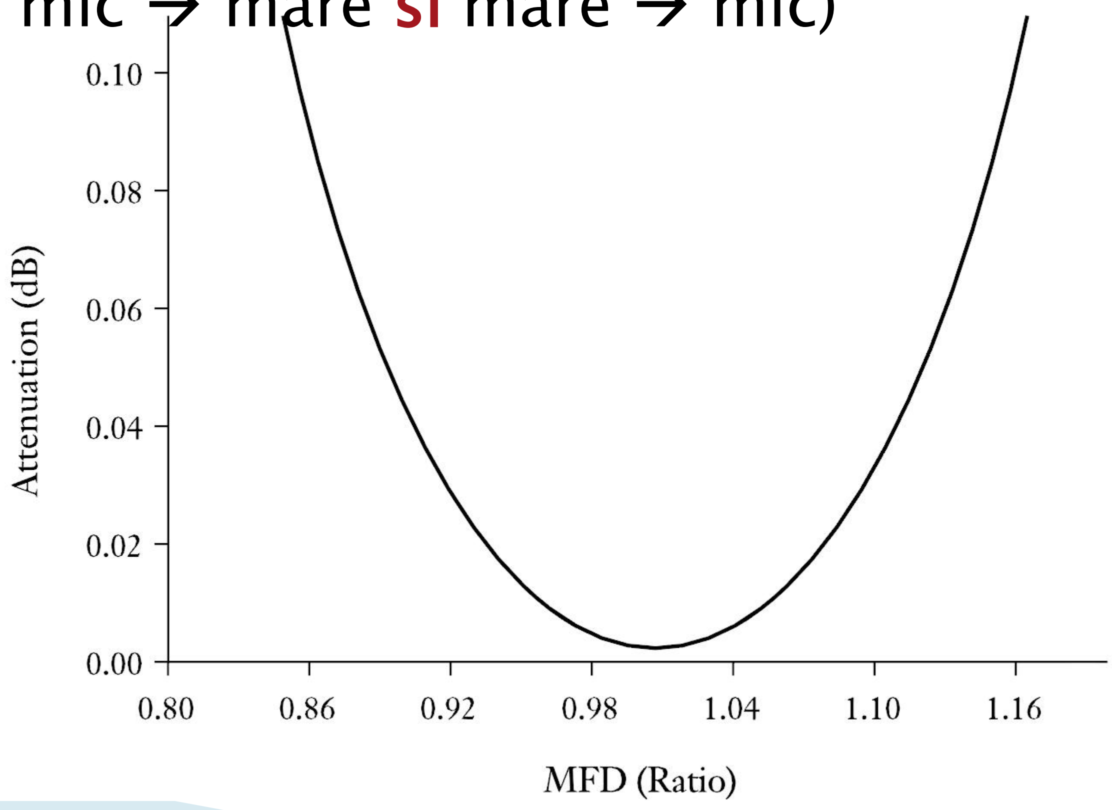
Pierderi

- multimod



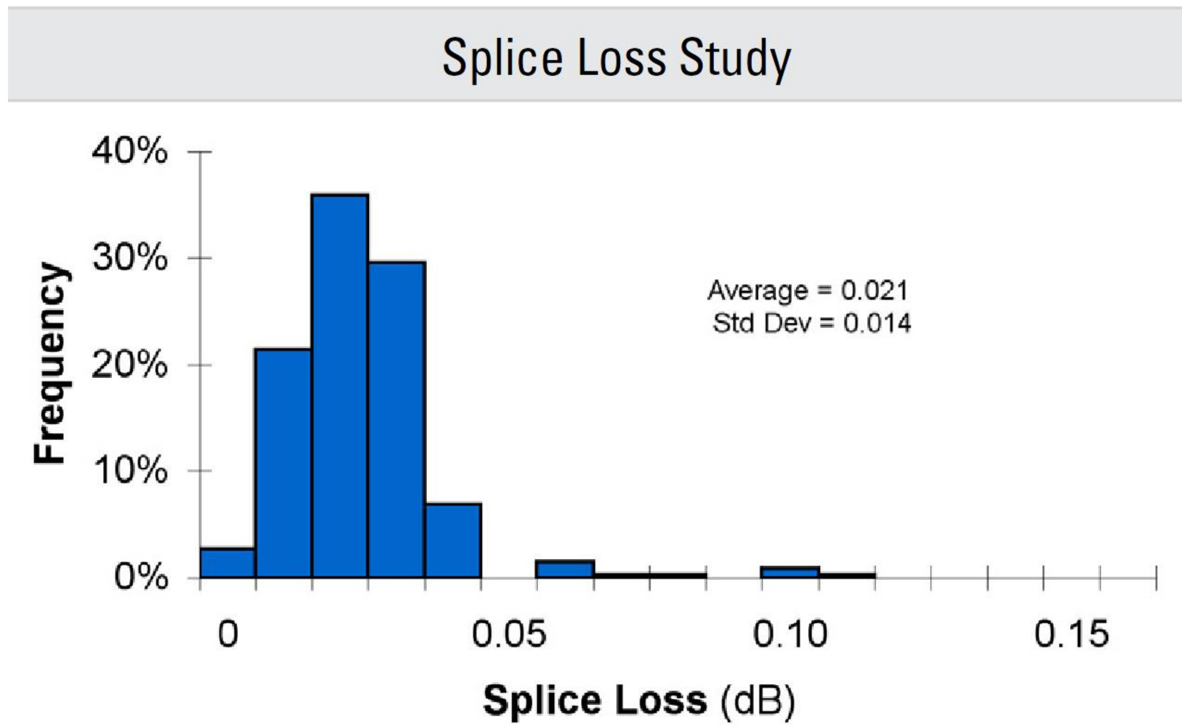
Pierderi

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

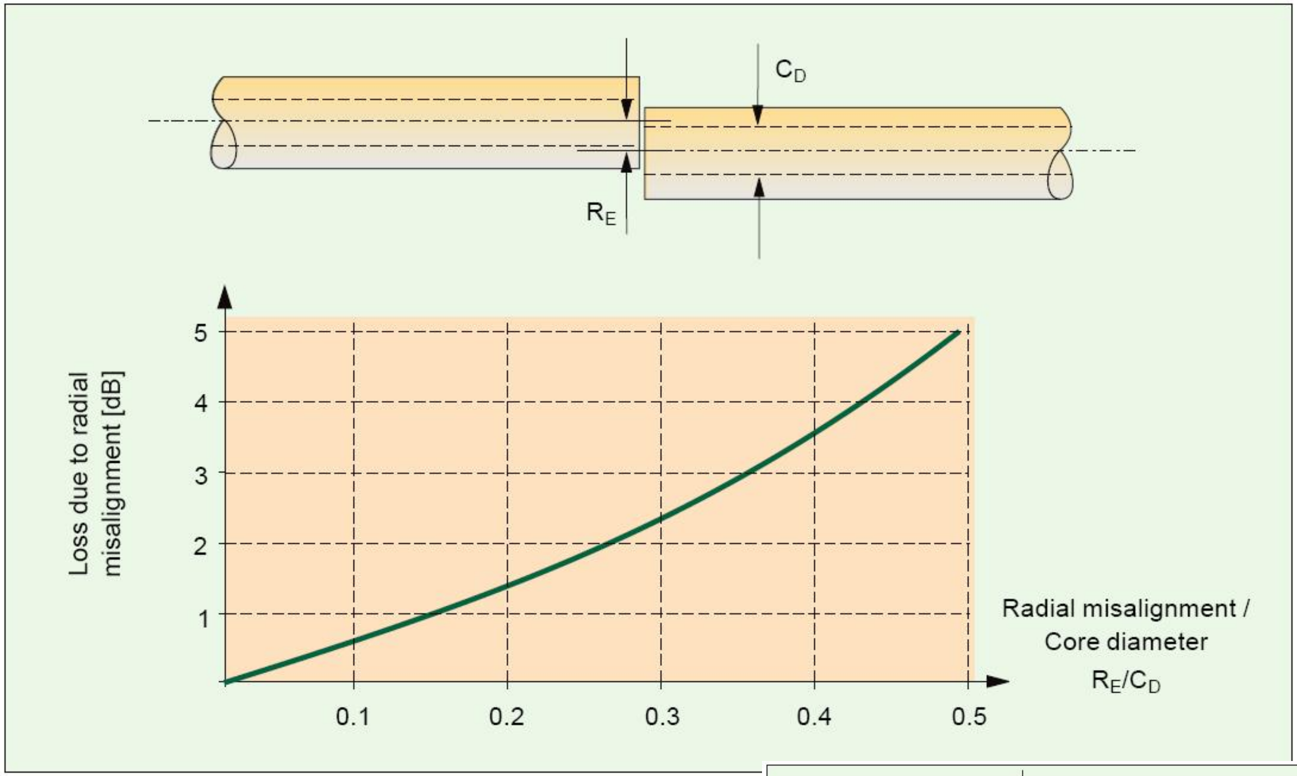


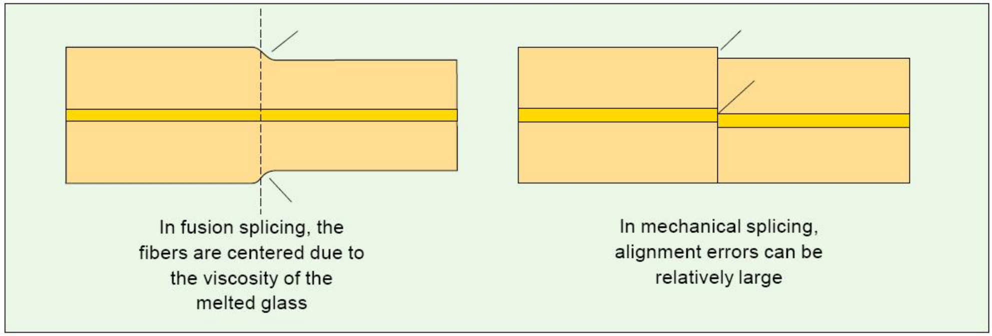
Pierderi

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

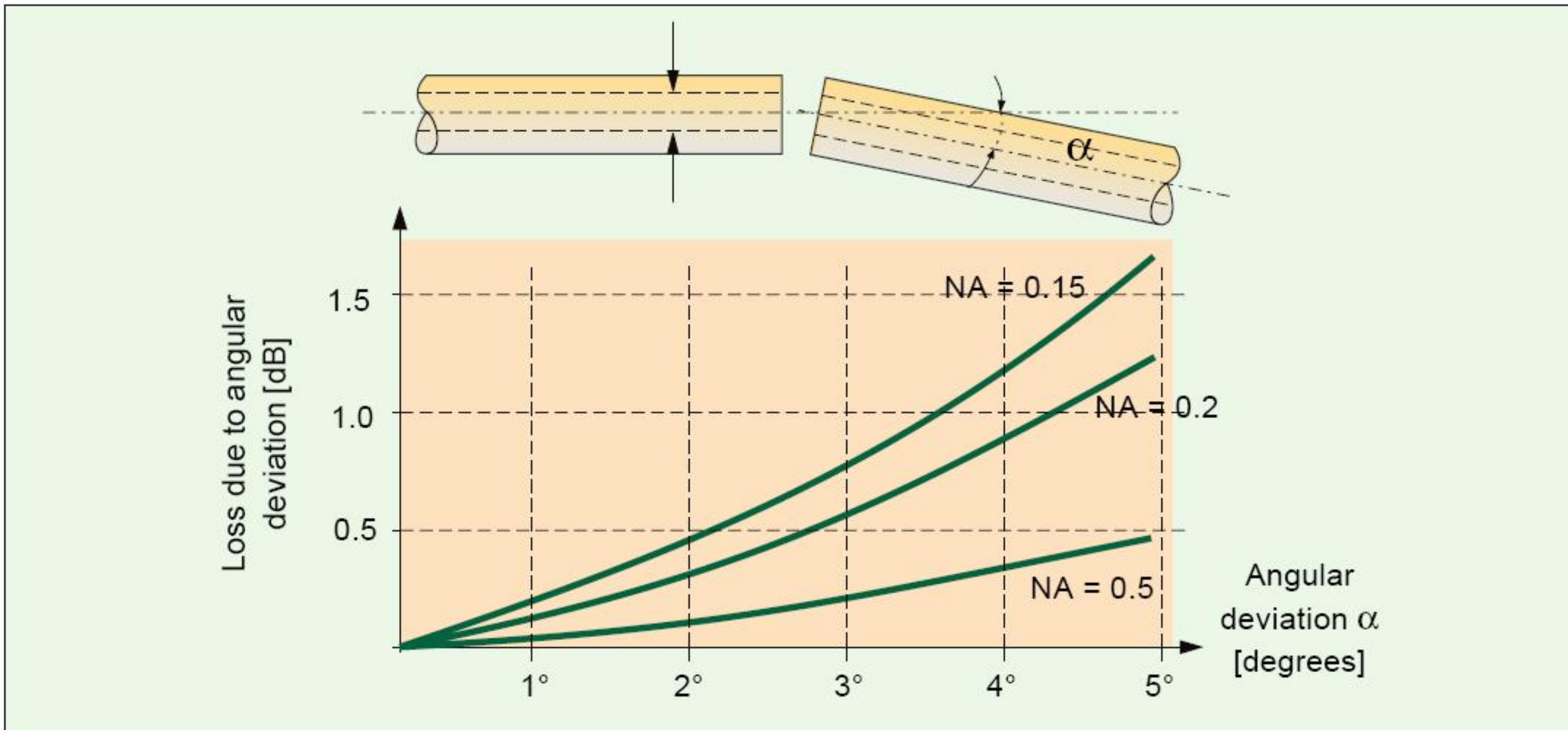


Pierderi – Nealinierea axelor



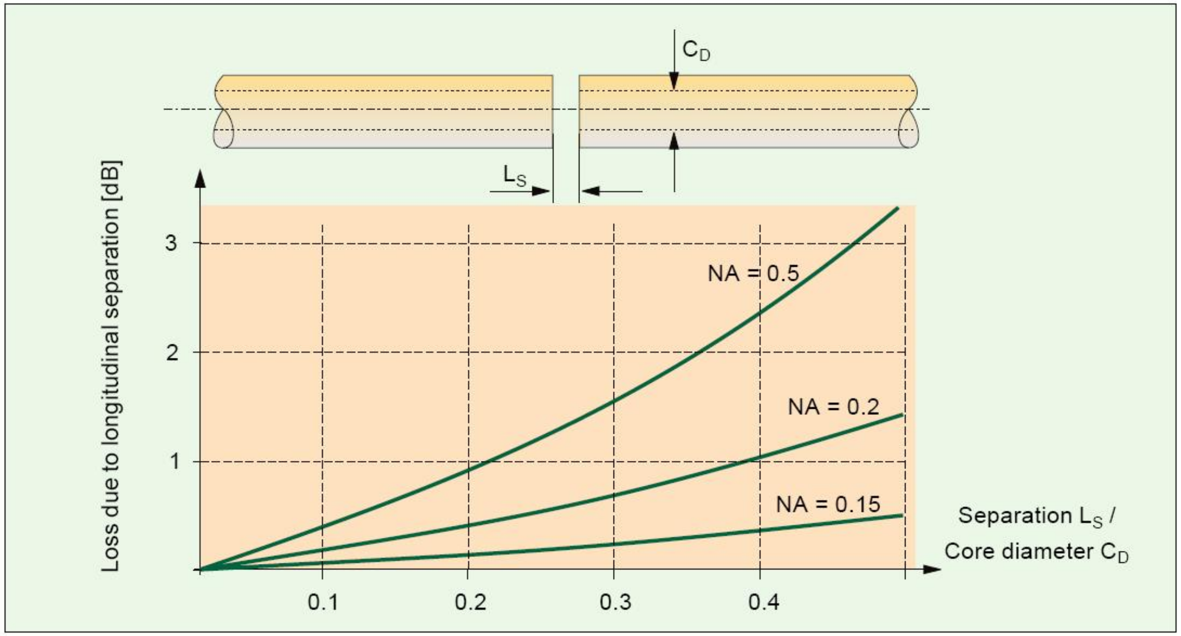


Pierderi – unghi



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})

$\lambda_{ccf} \le 1260$ 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 ≤ λ_0 ≤ 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: opticalfiber@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

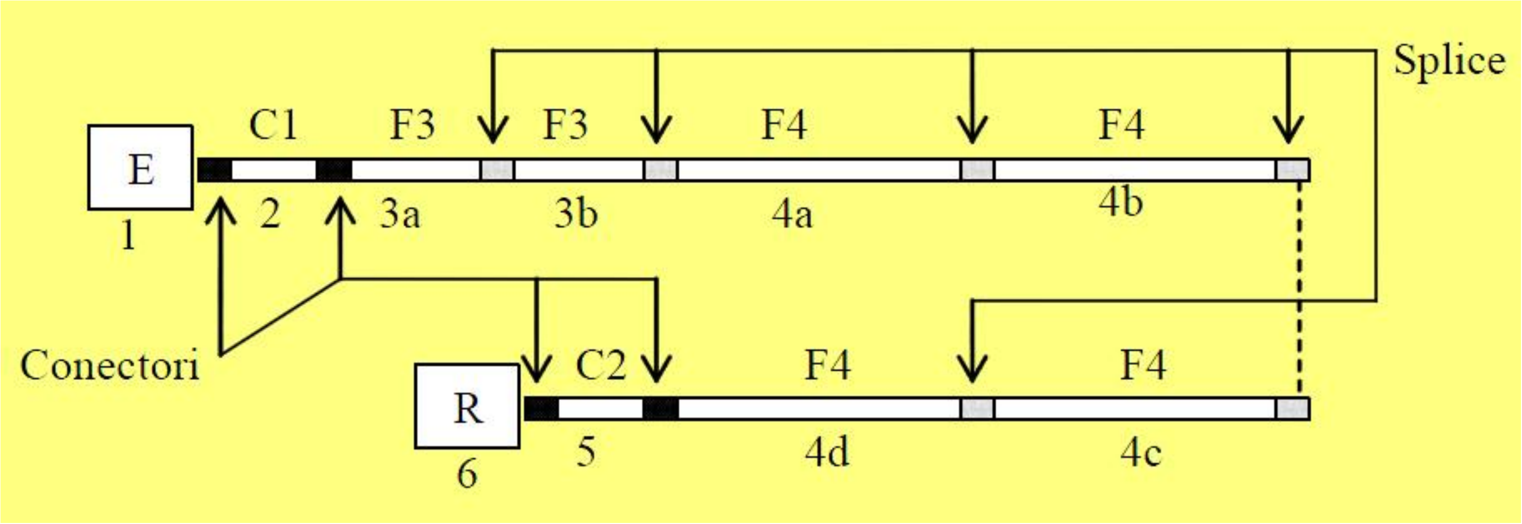
- Bilantul puterilor

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 Attenuation

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

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



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
- Localizata
  - macrocurburi
  - conectori
  - splice
  - tranzitii

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

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

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

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

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

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

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

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

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

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

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

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

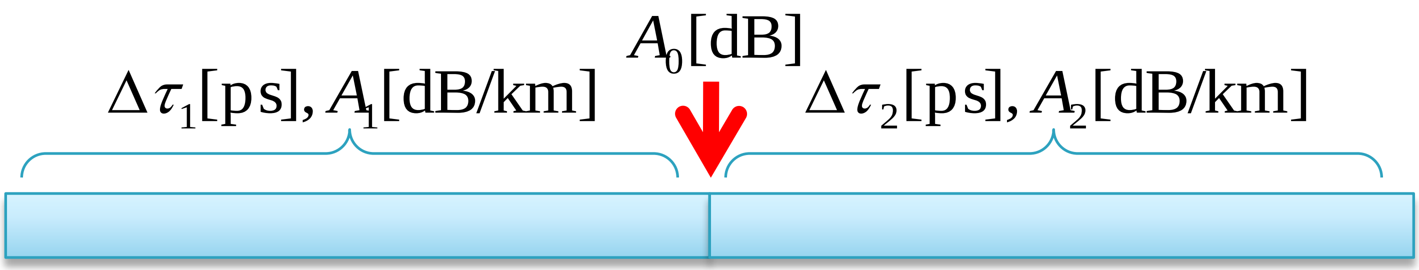
$$V[Gb/s] \cong 2\cdot B_{el}$$

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

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

Sisteme cu mai multe tipuri de fibra

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

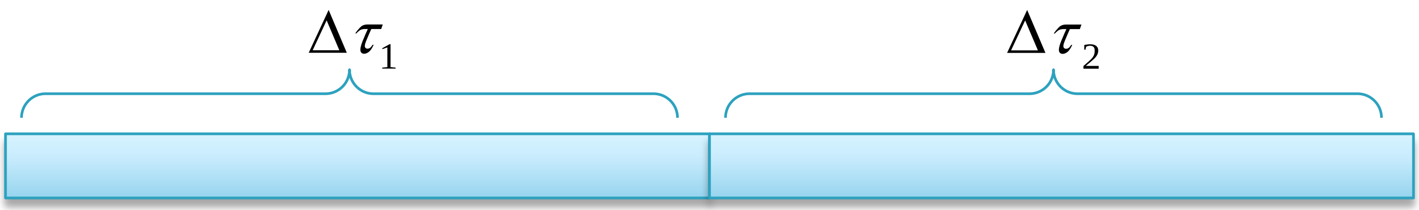


$$A_{tot}[\text{dB}] = A_1[\text{dB/km}] \cdot L_1[\text{km}] + A_2[\text{dB/km}] \cdot L_2[\text{km}] + A_0[\text{dB}]$$

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

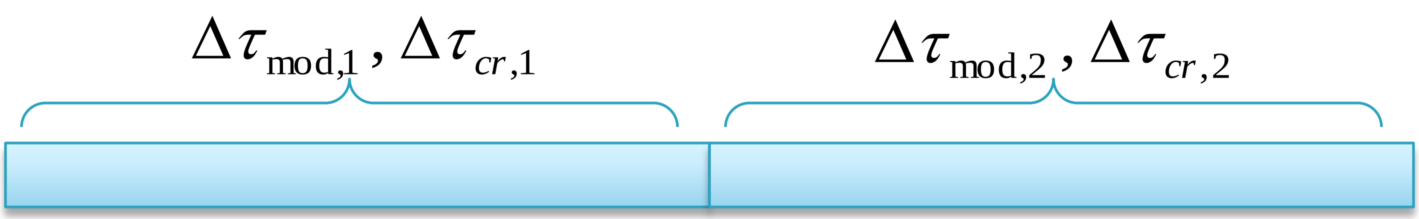
Sisteme cu mai multe tipuri de fibra

- 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

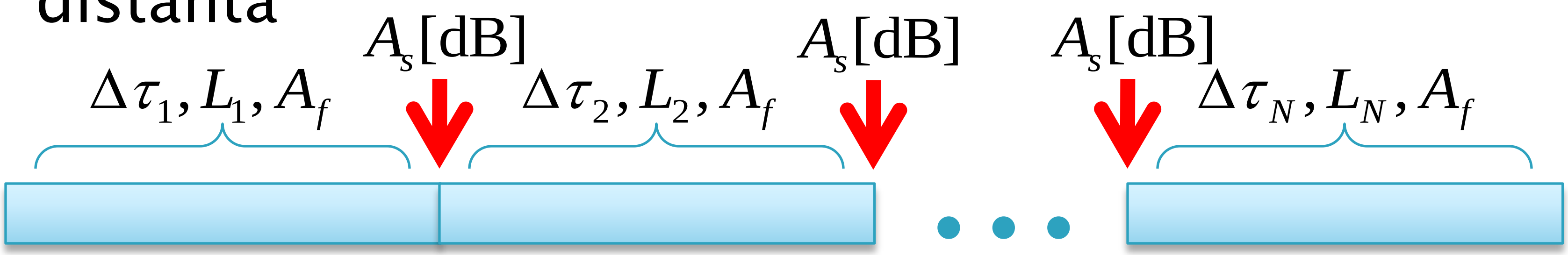


$$\Delta\tau_1 = \sqrt{\Delta\tau_{cr,1}^2 + \Delta\tau_{\mathrm{mod},1}^2}$$

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

Sisteme cu acelasi tip de fibra

- N tronsoane cu acelasi tip de fibra conectate/sudate
  - atenuare datorita NA **nula** (**acelasi tip**)
  - atenuare datorita Φ **nula** (**acelasi tip**)
  - atenuare pe splice/conector: N-1 conectori
  - lungime totala: $L_{tot}[\text{km}] = \sum_{1}^{N} L_i[\text{km}]$
- efecte **succesive** se adună liniar
- efectele (dispesie si atenuare) proportionale cu distanta



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

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

Produs Banda · Distanta

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

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

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

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

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

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

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

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

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

Lungime maxima

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

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

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

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

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×L [MHz·km]
  - S_0[ps/nm^2/km], λ_0[nm]

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

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

$$B_{opt\min} = \sqrt{2}B_{el\min} \qquad \Delta\tau_{tot\max}[\mathrm{ns}] = \frac{0.44}{B_{opt\min}[\mathrm{GHz}]} \qquad L_{\max} = \frac{\Delta\tau_{tot\max}}{D(\lambda)\cdot\Delta\lambda}$$

$$B\times L\,[\mathrm{MHz\cdot km}]$$

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

Lungime maxima

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

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

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

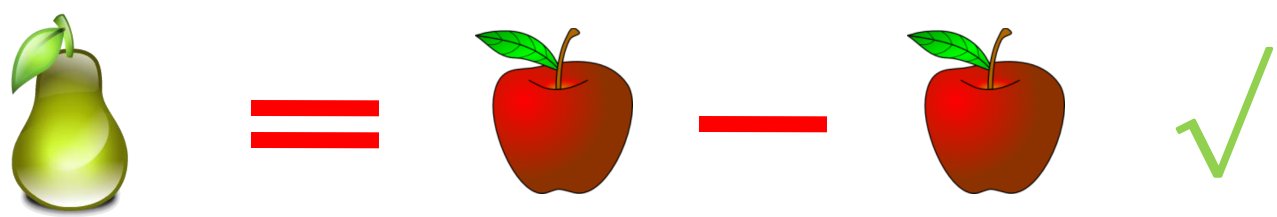
- de obicei
  - monomod: limita impusa de atenuare
    - cu exceptia cazurilor in care nu se functioneaza la λ optim dpdv al dispersiei
  - multimod: limita impusa de viteza

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 : $A_f = P_{in}[dBm] - P_{out}[dBm] = 17.5dB$!
  - $L = A_f\ /\ A_{dB/km} = 17.5dB\ /\ 1.16dB/km = 15.08\ km$
- Liniar
  - $P_{in} = 1mW \cdot 10^{\ 7.7/10} = 5.888\ mW$
  - Atenuarea : $A_f = P_{in}\ /\ P_{out} = 5.888\ mW\ /\ 0.105\ mW = = 56.0762\ [1]$!
  - Atenuarea pe unitatea de lungime $A_{1/km} = 10^{\ 1.16/10} = 1.3062\ [1]$!
  - $A_f = (A_{1/km})^{\ L/1km} \rightarrow L = 1km \cdot \log(A_f)/\log(A_{1/km}) = 1.749/0.116\ km = 15.08\ km$

Problema simpla? 2

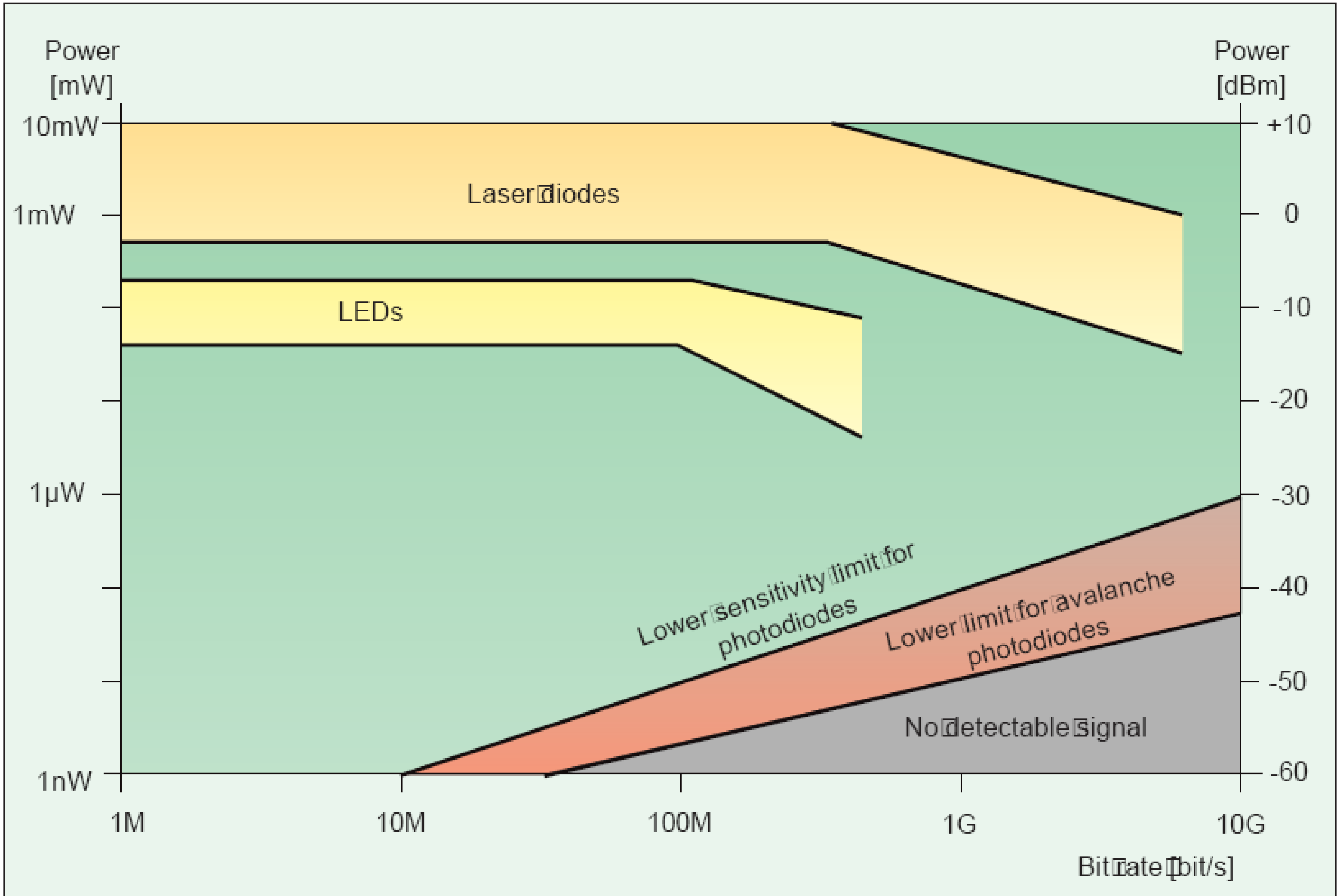
- Sursa luminoasa: 4.9 dBm
- Atenuarea fibrei: 0.32 dB/km
- Lungimea fibrei: 17 km

- Puterea la iesire: ? [μW]

Problema simpla? 2

- Logaritmic
  - Atenuarea : $A_f = A_{dB/km} \cdot L[km] = 5.44$ dB
  - $P_{out}[dBm] = P_{in}[dBm] - A_f [dB] = -0.54$ dBm **!**
  - $P_{out} = 1mW \cdot 10^{-0.54/10} = 0.883$ mW = 883 μW
- Liniar
  - Atenuarea : $A_f [dB] = A_{dB/km} \cdot L[km] = 5.44$ dB **!**
  - Atenuarea : $A_f [1] = 10^{Af [dB] / 10} = 3.499$ [1] **!**
  - $P_{in} = 1mW \cdot 10^{4.9/10} = 3.09$ mW
  - $P_{out} = P_{in} / A_f = 3.09$ mW / 3.499 = 0.883 mW = 883 μW

Limite putere/bandă a dispozitivelor optoelectronice



LED

Dioda electroluminescenta
Capitolul 8

Caracteristici LED

- Dezavantaje
  - Putere redusa (cuplata in fibra) ~ 100μW
  - Banda (viteza) reduse ~ 150MHz (300Mb/s)
  - Spectru larg ~ 0.05 λ
  - Lumina necoerenta si nedirectiva
- Avantaje
  - Structura interna mult mai simpla (fara suprafete reflective, straturi planare)
  - Cost (dispozitiv si circuit de comanda)
  - Durata de viata
  - Insenzitivitate la temperatura
  - Liniaritate (modulatie analogica)

Aplicatii majore LED

- Comunicatii
  - Infrarosu (InGaAsP)
- Vizibil
  - Spectru vizibil (GaAlAs)
- Iluminare
  - Putere ridicata, lumina alba (GaInN)

Contact

- Laboratorul de microunde si optoelectronica
- http://rf-opto.etti.tuiasi.ro
- rdamian@etti.tuiasi.ro