Optoelectronică

Curs 4

2018/2019

Disciplina 2018/2019

- 2C/1L Optoelectronică OPTO
- **Minim 7 prezente curs + laborator**
- Curs – conf. Radu Damian
  - an IV μE
  - Vineri 8-11, P5
  - E – 70% din nota
    - **20% test la curs**, saptamana 5 – 22.03.2019 ora 10-11
  - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
  - toate materialele permise
- Laborator – sl. Daniel Matasaru
  - an IV μE
    - Marti 14-16
    - Joi 8-12 par/impar
  - L – 30% din nota (+Caiet de laborator)

Orar 2018/2019

- Curs
  - Vineri 8-11, P5
  - **2C ⇨ 3C**
    - 14*2/3≈9.33
    - 9÷10 C

Bibliografie

- http://rf-opto.etti.tuiasi.ro
- Irinel Casian-Botez, "Structuri Optoelectronice", Ed. "CANOVA", Iasi 2001, ISBN 973-96099-2-9
- Behzad Razavi – Design of Integrated Circuits for Optical Communications, Mc Graw Hill ~~http://rf-opto.etti.tuiasi.ro/docs/opto/~~
- IBM – Understanding Optical Communications: on-line **http://rf-opto.etti.tuiasi.ro**
- Radu Damian, I Casian, D Matăsaru – „Comunicatii Optice” , Indrumar de laborator, 2005

Fotografii

Date:

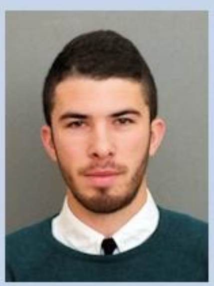
Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

Trimite email acestui student | Adauga acest student la lista (0)

Detalii curente

Observatii

Finantare	Buget
Bursa	Fara Bursa



Date:

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

Trimite email acestui student | Adauga acest student la lista (0)

Detalii curente

Observatii

Finantare	Buget
Bursa	Bursa de Studii

Date:

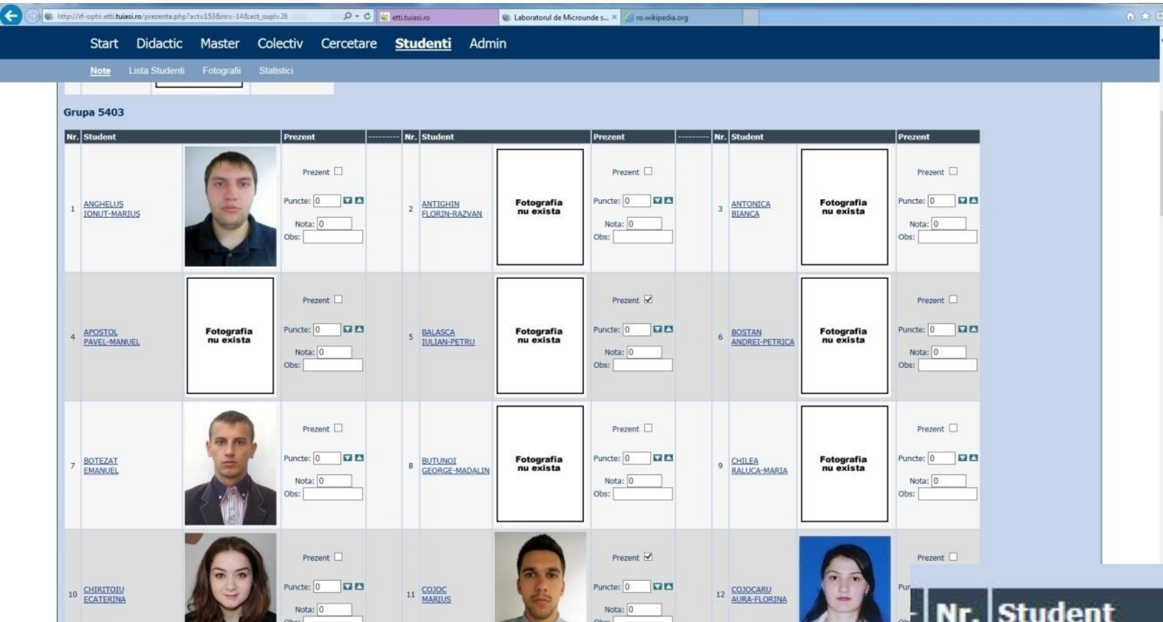
Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

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	-	

Fotografii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Didactic
Master
Colectiv
Cercetare
Studenti
Admin
Note
Lista Studenti
Fotografii
Statistici
Grupa 5403
Nr.
Student
Prezent
ANGHELUS IONUT-MARIUS
ANTIGHIN FLORIN-RAZVAN
ANTONICA BIANCA
APOSTOL PAVEL-MANUEL
BALASCA IULIAN-PETRU
BOSTAN ANDREI-PETRICA
BOTEZAT EMANUEL
BUTUNOI GEORGE-MADALIN
CHILEA RALUCA-MARIA
CHIRITOIU ECATERINA
COJOC MARIUS
COJOCARU AURA-FLORINA
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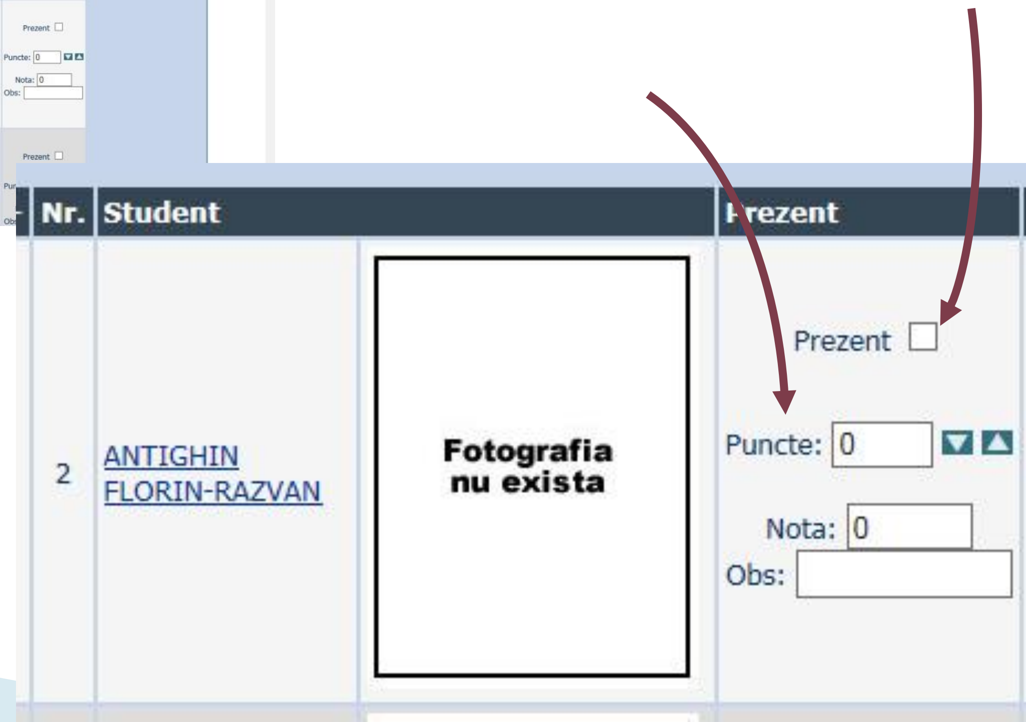
Puncte:
Nota:
Obs:


Nr.
Student
Prezent
2
ANTIGHIN FLORIN-RAZVAN
Fotografia nu exista
Prezent
Puncte: 0
Nota: 0
Obs:

Acces

- ~~Personalizat~~

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	-	
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	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	

Nume

[redacted]

Email

Cod de verificare

344bd9f

Trimite

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]

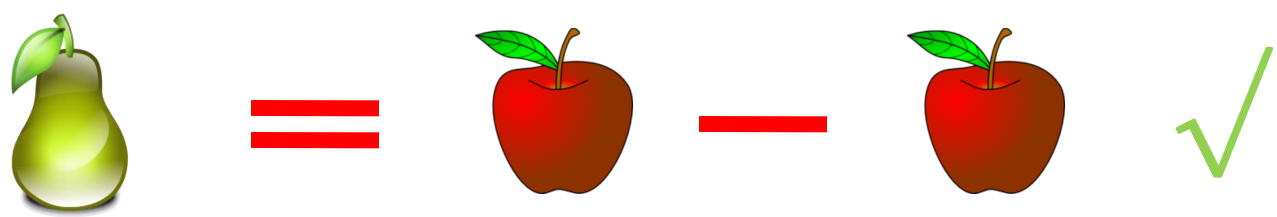
[x] + [dB] = [x]

Calculul atenuarii

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

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

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



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

Recapitulare

Lumina ca undă electromagnetică

Capitolul 2

Parametri, dependenta de mediu

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega$$

$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8\ m/s$$

$n = 1$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f}$$

$$\eta = \frac{\eta_0}{n}$$

$$c = \frac{c_0}{n}$$

$n = \sqrt{\varepsilon_r}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

$$\lambda = \lambda(n)$$

$$f = \text{indep.}$$

ITU G.692

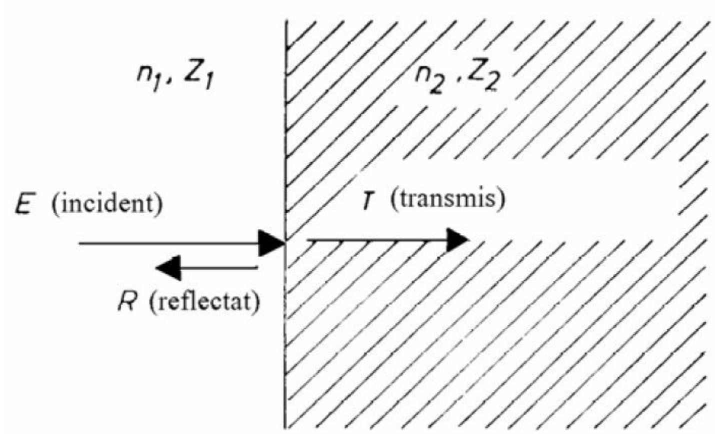
"the allowed channel frequencies are based on a 50 GHz grid with the reference frequency at 193.10 THz"

SI

"a source that emits monochromatic radiation of frequency $540 \cdot 10^{12}$ Hz"

Transmisia puterii intre medii

- incidenta normala
- reflexia in amplitudine



$$Z = \frac{Z_0}{n} \qquad \Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{n_1 - n_2}{n_1 + n_2}$$

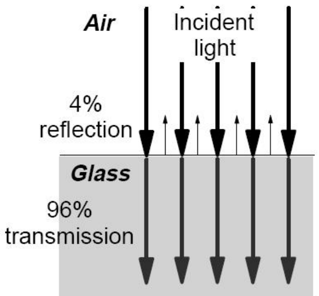
- densitatea de putere proportionala cu patratul amplitudinii câmpului

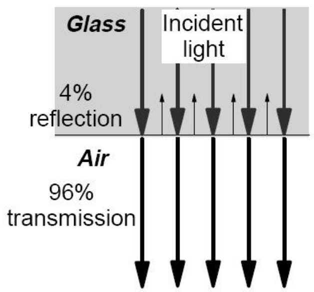
$$r = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \qquad t = \left(\frac{2n_1}{n_1 + n_2}\right)^2$$

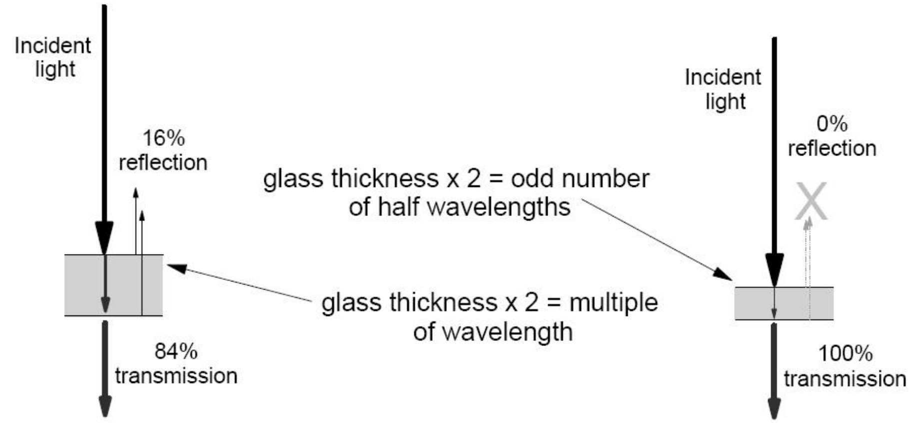
- interfata aer-sticla ($n_1 = 1$, $n_2 = 1.5$)

$$r = 0.04 = 4\%$$

Transmisia printr-o lamela



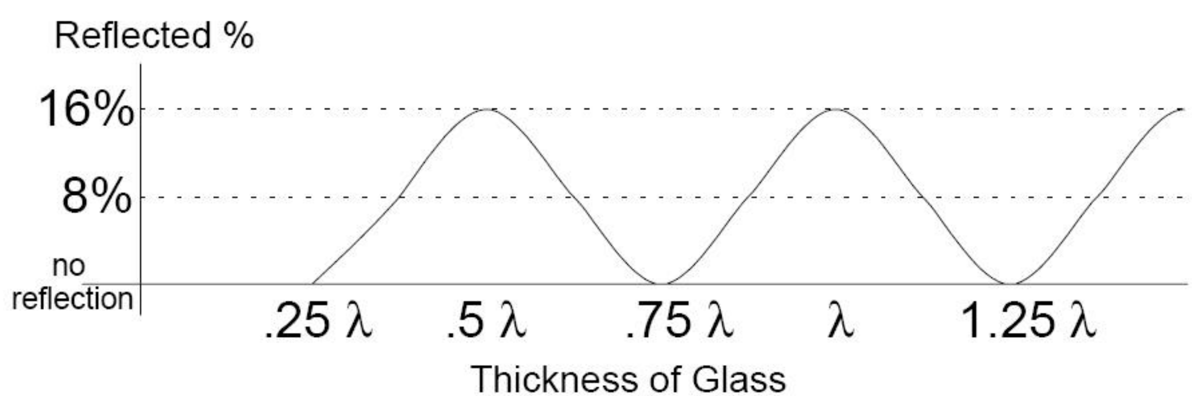




$$\Gamma = \frac{1.5-1}{1.5+1} = 0.2; \quad r = \Gamma^2 = 0.04 = 4\% \quad \Gamma_{max} = 0.2 + 0.2; \quad r_{max} = \Gamma_{max}^2 = 0.16 = 16\%$$

- apare interferenta intre diversele unde reflectate
- se aduna câmpurile nu puterile

- lamele antireflexive



Polarizarea luminii

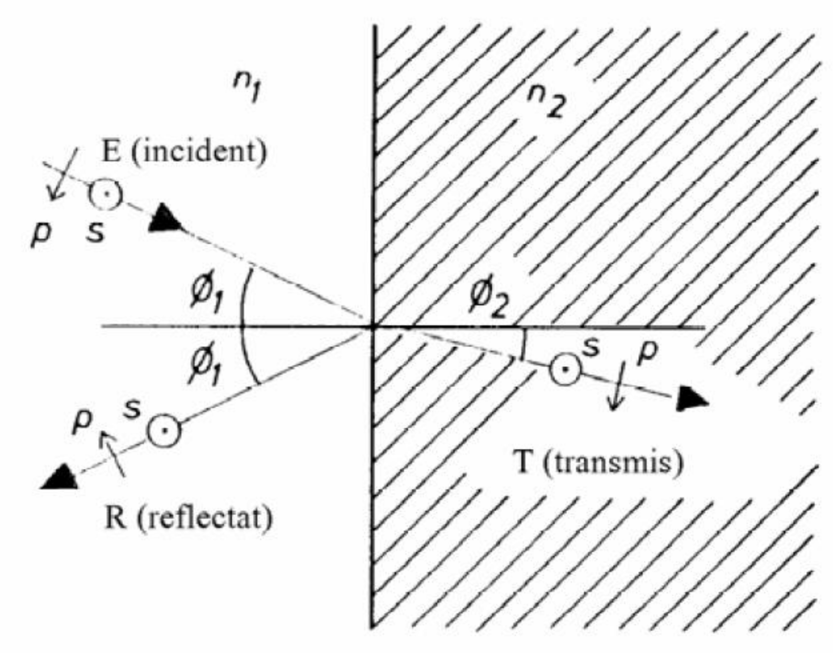
- incidenta oblica
- reflexiile in amplitudine a campului:

$$r_s = -\frac{\sin(\phi_1 - \phi_2)}{\sin(\phi_1 + \phi_2)}$$

$$r_p = \frac{\tan(\phi_1 - \phi_2)}{\tan(\phi_1 + \phi_2)}$$

$$t_s = \frac{2\sin\phi_2 \cos\phi_1}{\sin(\phi_1 + \phi_2)}$$

$$t_p = \frac{2\sin\phi_2 \cos\phi_1}{\sin(\phi_1 + \phi_2)\cos(\phi_1 - \phi_2)}$$



Unghi Brewster

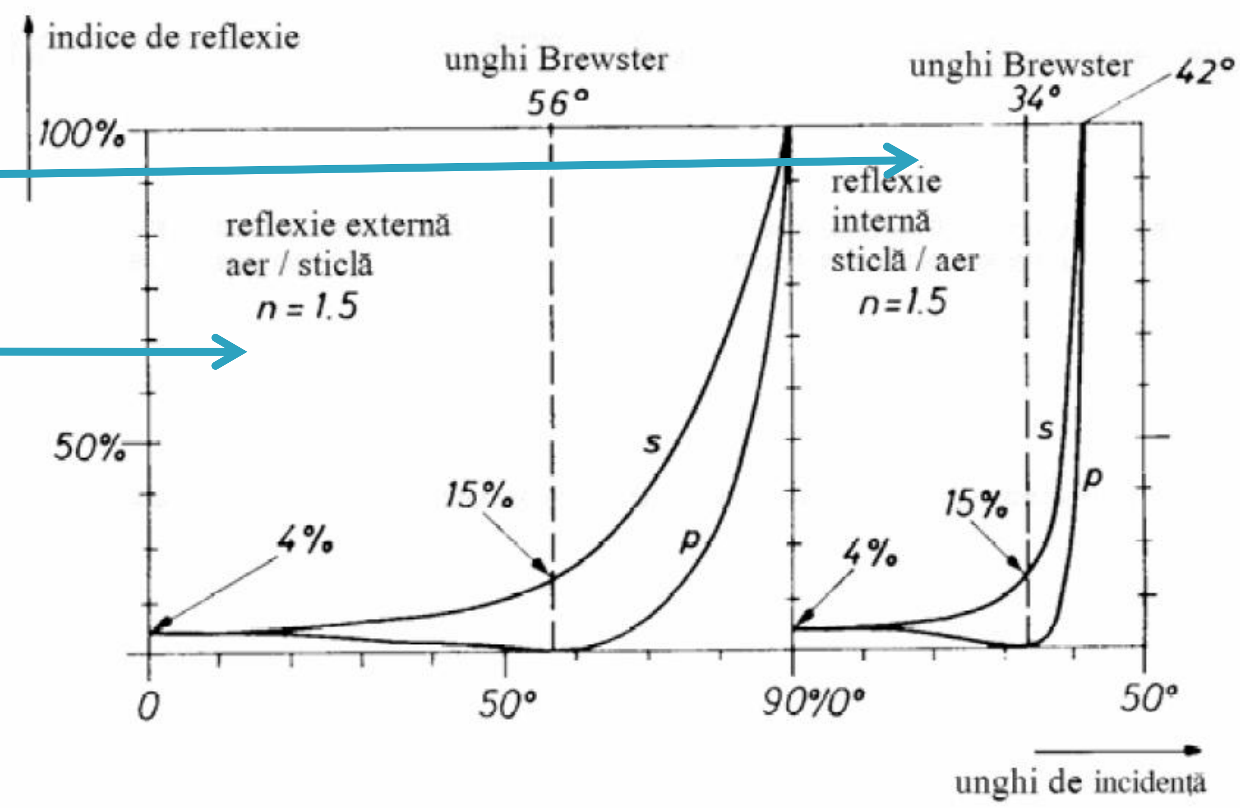
$$r_p = 0 \quad \Rightarrow \quad \tan(\phi_1 + \phi_2) \to \infty \quad \Rightarrow \quad \phi_1 + \phi_2 = \frac{\pi}{2}$$

$$n_1 \cdot \sin\phi_1 = n_2 \cdot \sin\phi_2 = n_2 \cdot \cos\phi_1$$

$$\phi_B = \arctan\left(\frac{n_2}{n_1}\right)$$

$$\phi_B = 34^\circ$$

$$\phi_B = 56^\circ$$



Optică geometrică

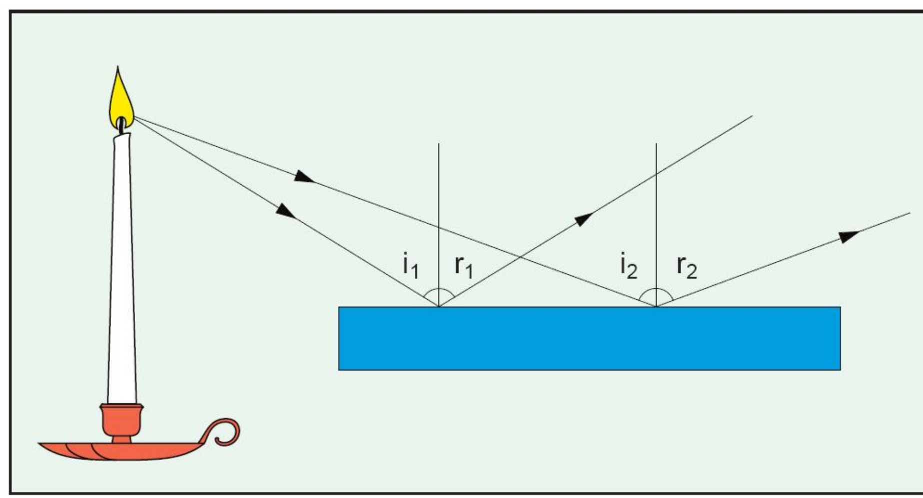
(tot) Capitolul 2

Reflexia luminii

- la suprafata de separatie dintre doua medii, (o parte din) lumina se intoarce in mediul de incidenta
- unghiul dintre raza incidenta si normala (ϕ_i) este egal cu unghiul dintre raza reflectata si normala (ϕ_r)

- Legea reflexiei

$$\phi_i = \phi_r$$



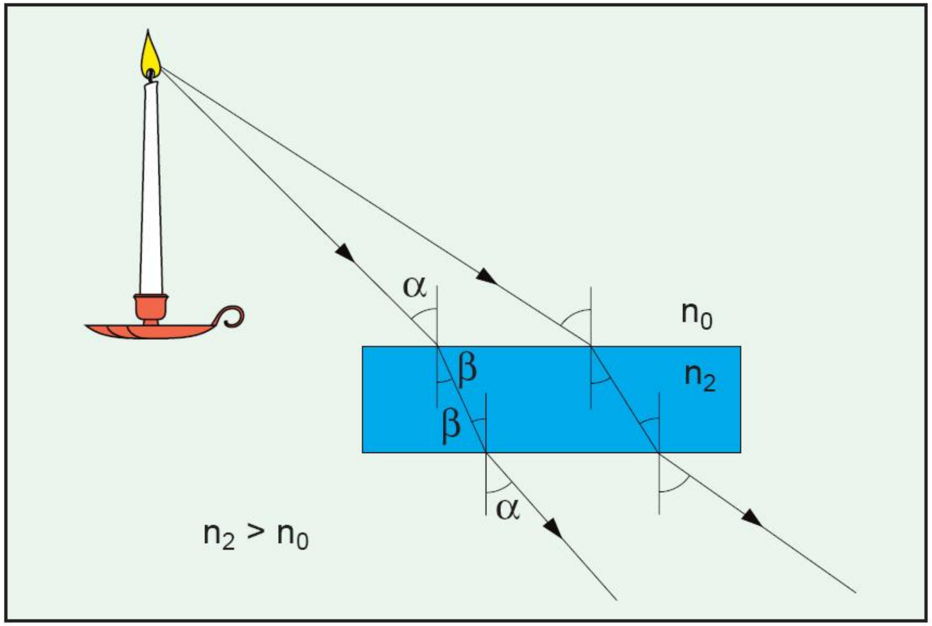
Refractia luminii

- la suprafața de separație dintre doua medii, (o parte din) lumina se (poate) propaga in mediul de transmisie sub un unghi diferit de unghiul incident
- la trecerea in medii mai “dense” (optic) lumina se apropie de normala
- la trecerea in medii mai “puțin dense” (optic) lumina se depărtează de normala

- Legea lui Snell (a refracției)

$$n_1 \cdot \sin \phi_i = n_2 \cdot \sin \phi_R$$

ϕ_i – unghi incident (in n_1)
ϕ_R – unghi de refracție (in n_2)



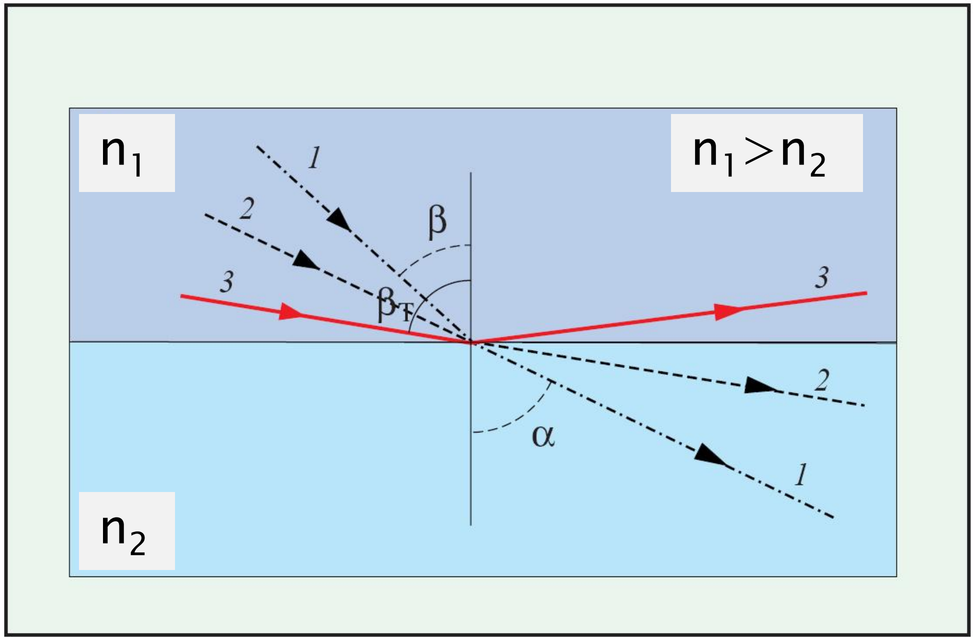
Reflexia totala

- Apare **numai când** lumina se propaga dintr-un mediu mai dens optic intr-un mediu mai puțin dens
- La intersecția luminii cu suprafața de separație a doua medii se întâlnesc in general raze reflectate **si** raze refractate
- Pentru un unghi de incidenta numit **unghi critic**, raza refractata se obține in lungul suprafeței de separație
- Pentru orice unghi mai mare decât unghiul critic exista numai raza reflectata

$$n_1 > n_2; \quad \phi_R = 90^\circ$$

$$n_1 \cdot \sin \phi_C = n_2$$

$$\phi_C = \arcsin\left(\frac{n_2}{n_1}\right)$$



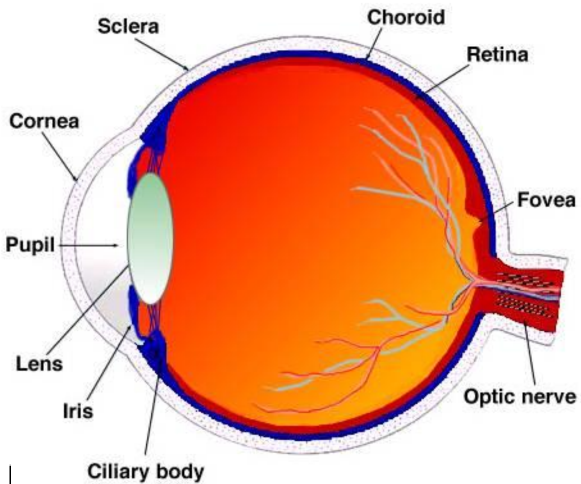
Fotometrie şi radiometrie

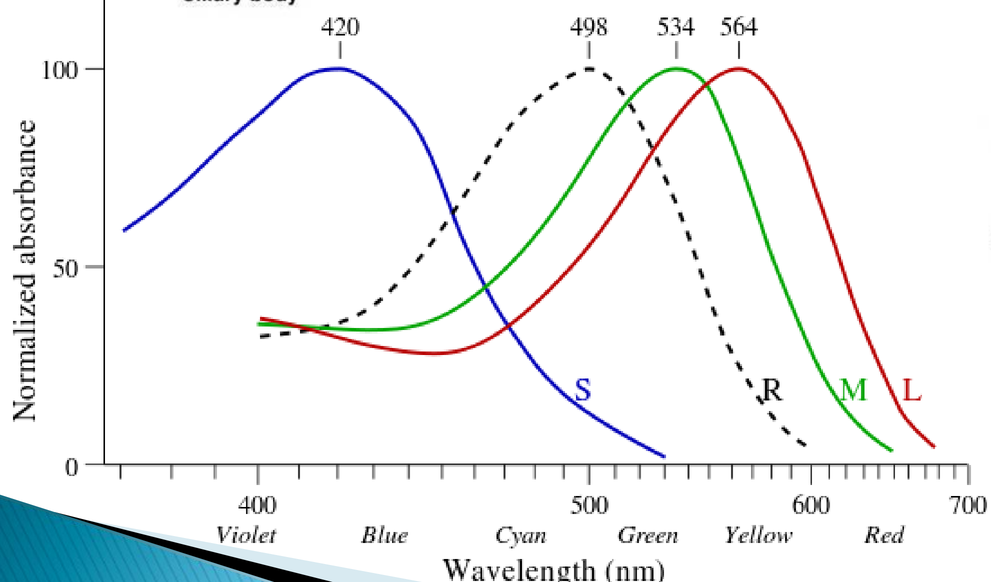
Capitolul 3

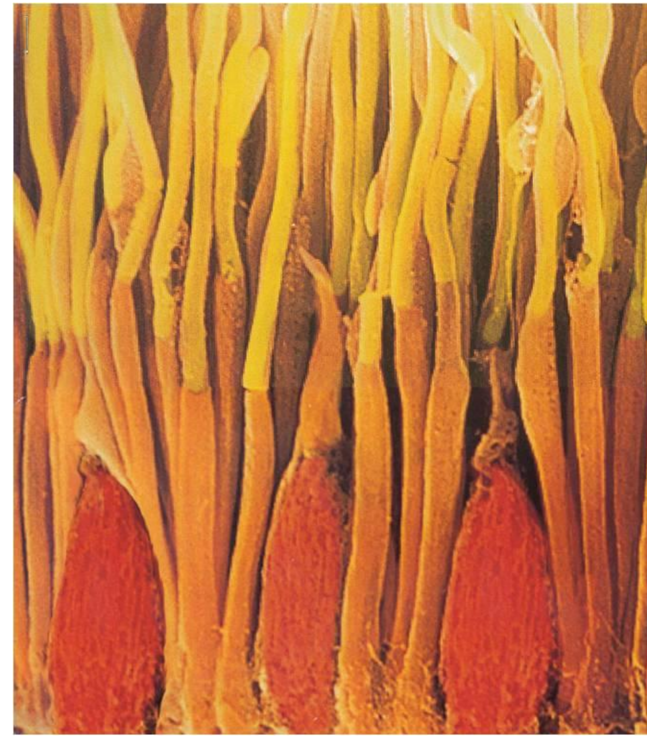
Aplicatii majore

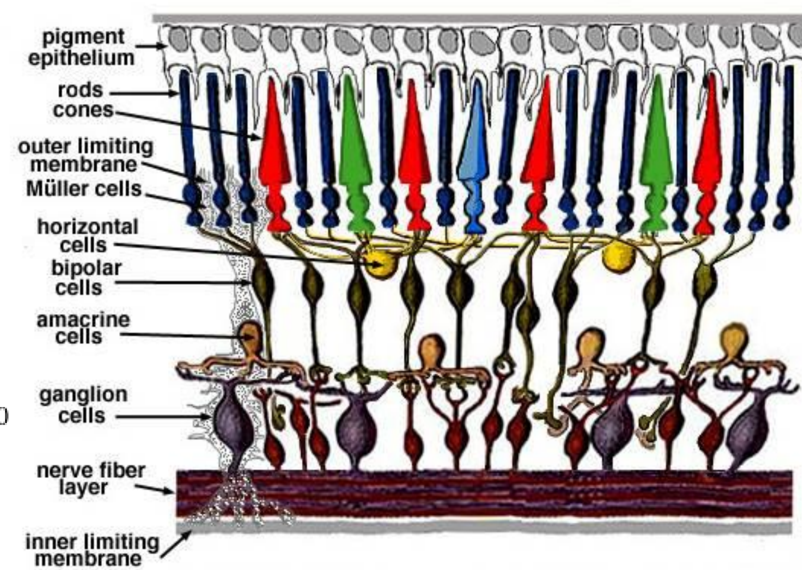
- Comunicatii
  - Infrarosu (InGaAsP)
- Vizibil
  - Spectru vizibil (GaAlAs)
- Iluminare
  - Putere ridicata, lumina alba (GaInN)

Ochiul uman


Sclera
Choroid
Retina
Cornea
Fovea
Pupil
Lens
Iris
Optic nerve
Ciliary body


420
498
534
564
100
50
0
Normalized absorbance
S
R
M
L
400
500
600
700
Violet
Blue
Cyan
Green
Yellow
Red
Wavelength (nm)




pigment epithelium
rods
cones
outer limiting membrane
Müller cells
horizontal cells
bipolar cells
amacrine cells
ganglion cells
nerve fiber layer
inner limiting membrane

Standarde

- Se incearca definirea omului "standard"
- CIE – Commission Internationale de l'Éclairage
  - 1931 – luminozitatea relativa standard V(λ) – **fotopic**
  - 1951 – luminozitatea relativa standard V(λ) – **scotopic**
  - 1978 – Vos
  - 2005 – Sharpe, Stockman, Jagla, Jägle
  - 2008 – CIE V(λ) – fotopic (~Sharpe)
- Sensibilitatea maxima a ochiului uman
  - vedere diurna (**fotopic**), λ=555 nm, η_v = 683 lm/W
  - vedere nocturna (**scotopic**), λ=507 nm , η_v = 1700 lm/W

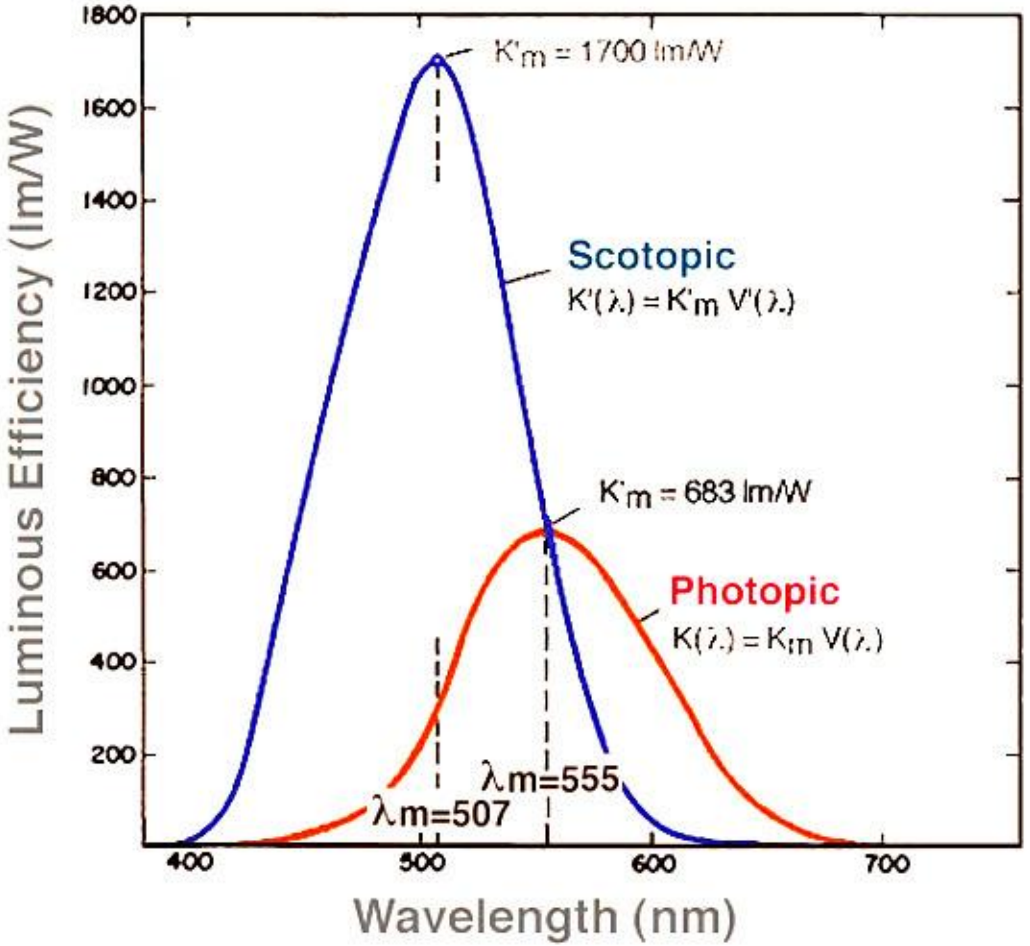
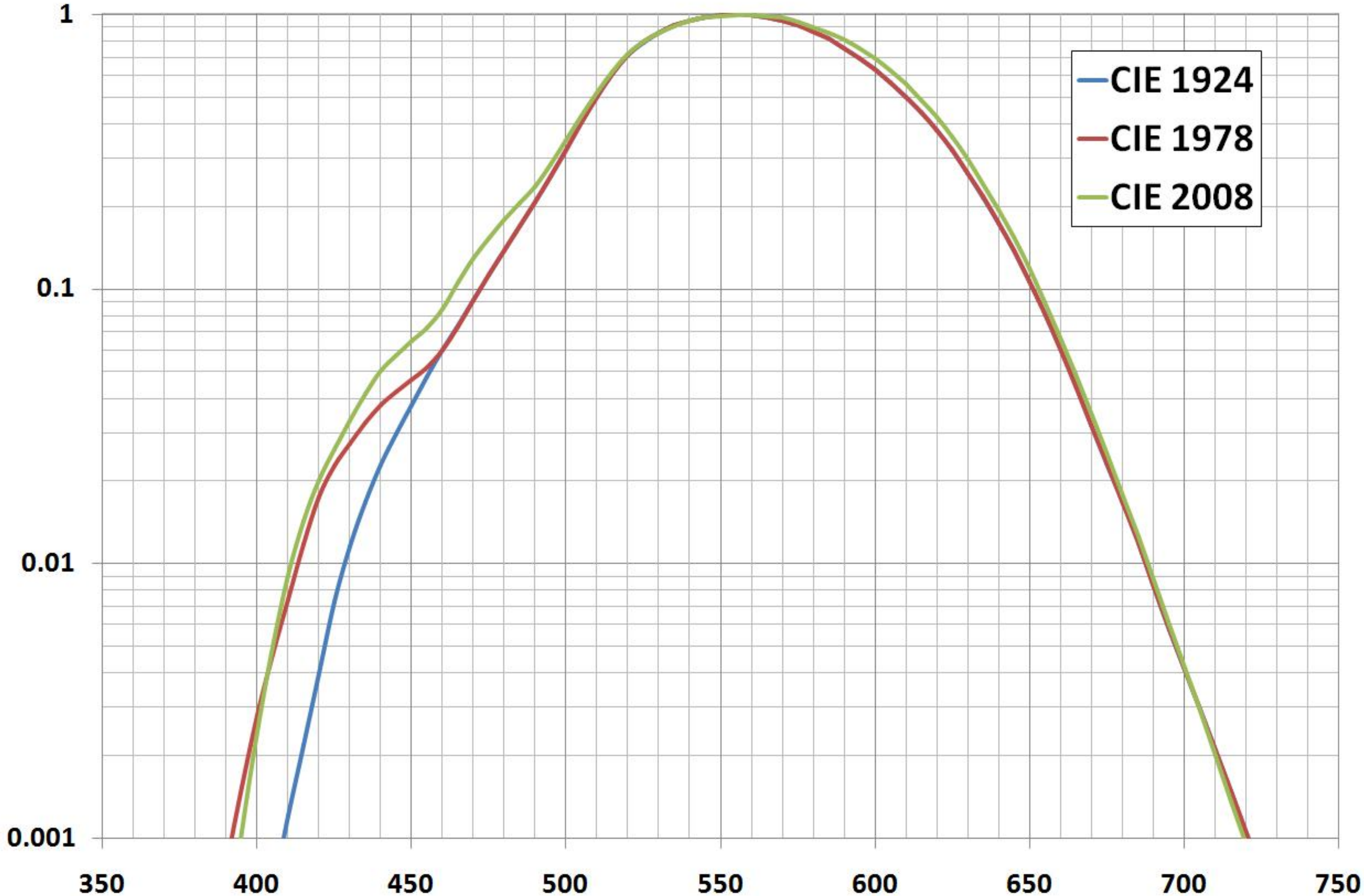


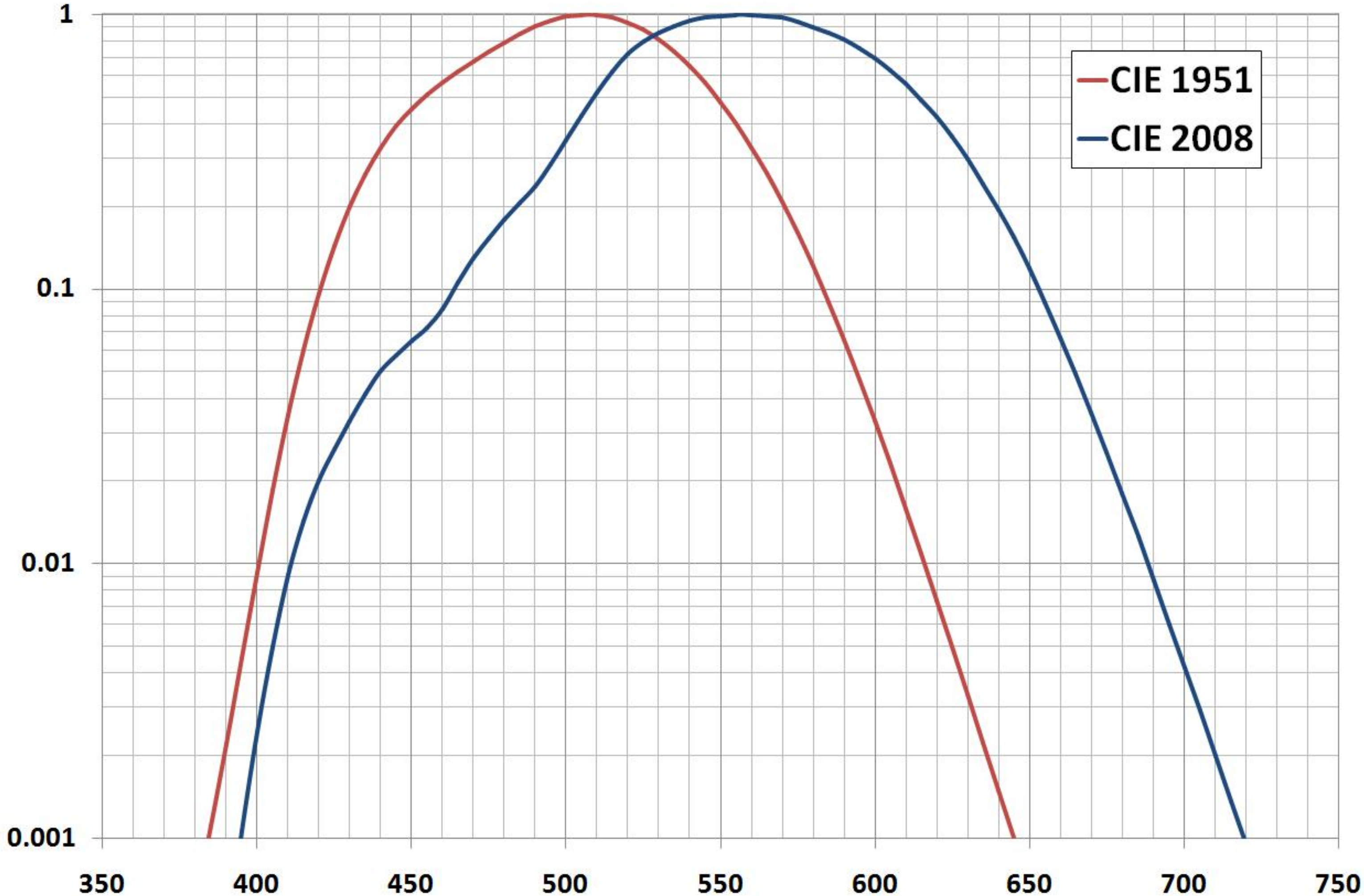
Figure 9. The scotopic and the photopic curves of spectral luminous efficacy (non-normalised values).

efect Purkinje

CIE V(λ) fotopic



CIE V(λ) fotopic / scotopic



Relatie radiometrie/fotometrie

- Pentru radiatii monocromatice

$$\Phi_v = 683\frac{lm}{W}\cdot\Phi_e[W]\cdot V(\lambda) \quad [lm] \qquad \Phi'_v = 1700\frac{lm}{W}\cdot\Phi_e[W]\cdot V'(\lambda) \quad [lm]$$

- Pentru radiatii complexe:

$$\Phi_v = 683\frac{lm}{W}\int_0^{\infty}\frac{d\Phi_e}{d\lambda}\cdot V(\lambda)\,d\lambda = 683\frac{lm}{W}\int_{390nm}^{830nm}\frac{d\Phi_e}{d\lambda}\cdot V(\lambda)\,d\lambda \quad [lm]$$

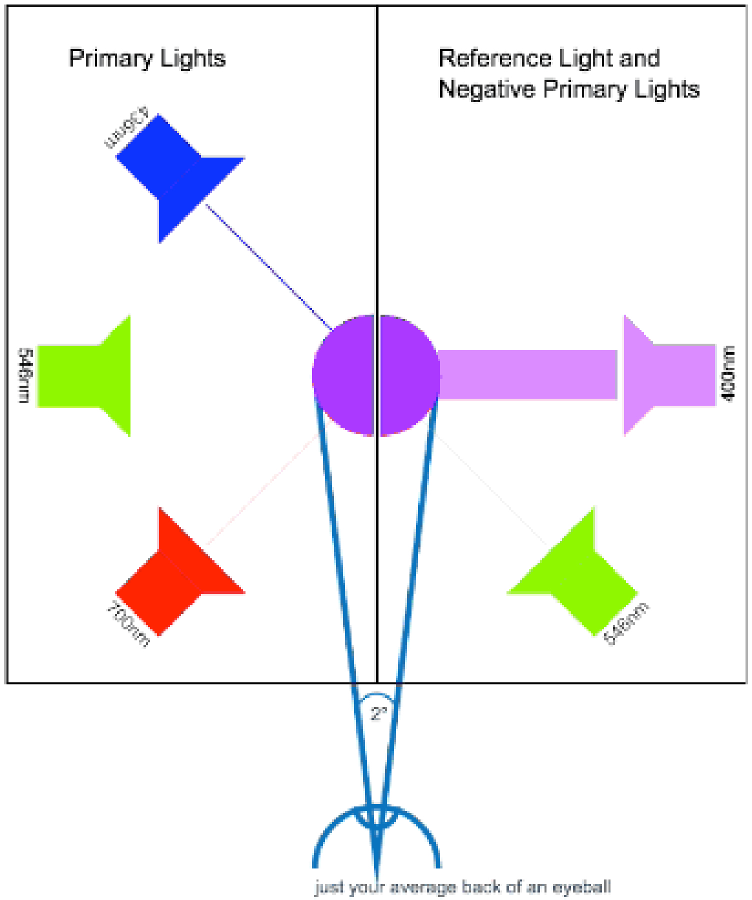
$$\Phi'_v = 1700\frac{lm}{W}\int_0^{\infty}\frac{d\Phi_e}{d\lambda}\cdot V'(\lambda)\,d\lambda = 1700\frac{lm}{W}\int_{390nm}^{830nm}\frac{d\Phi_e}{d\lambda}\cdot V'(\lambda)\,d\lambda \quad [lm]$$

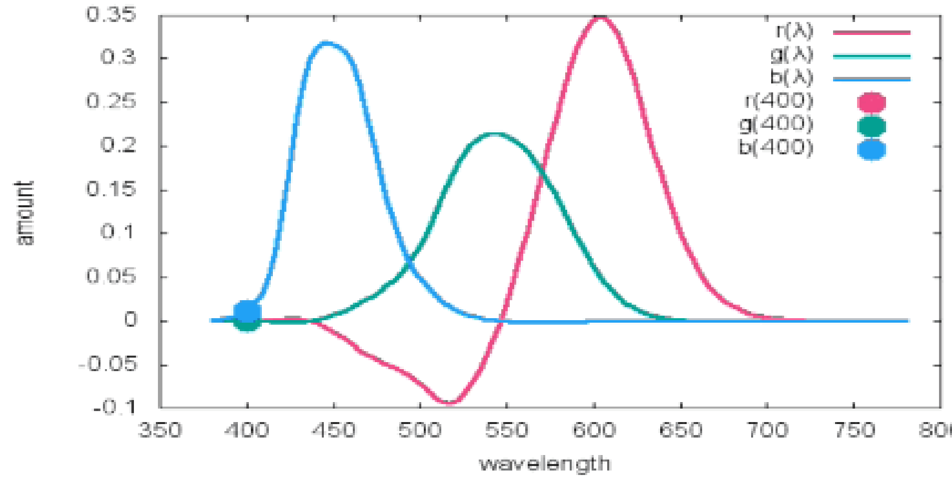
- De cele mai multe ori, sursele sunt discrete, λ_i

$$\Phi_v = 683\frac{lm}{W}\cdot\sum_i\Phi_e(\lambda_i)\cdot V(\lambda_i) \quad [lm]$$

$$\Phi'_v = 1700\frac{lm}{W}\cdot\sum_i\Phi_e(\lambda_i)\cdot V'(\lambda_i) \quad [lm]$$

CIE 1931


Primary Lights
Reference Light and
Negative Primary Lights
435nm
546nm
700nm
400nm
546nm
2°
just your average back of an eyeball

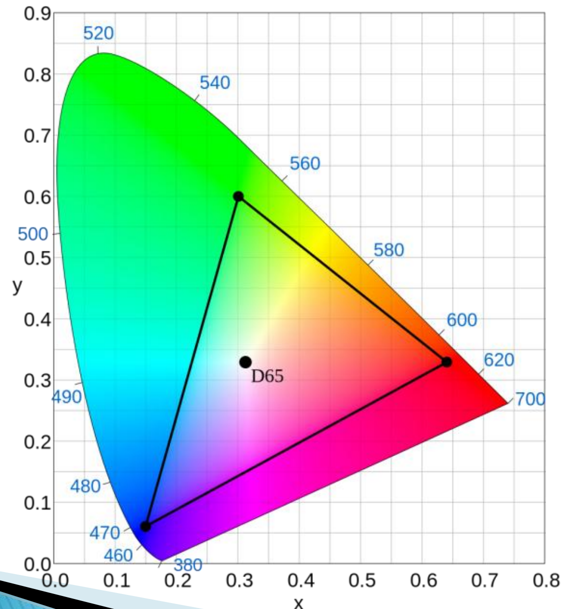

r(λ)
g(λ)
b(λ)
r(400)
g(400)
b(400)
amount
wavelength
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
350
400
450
500
550
600
650
700
750

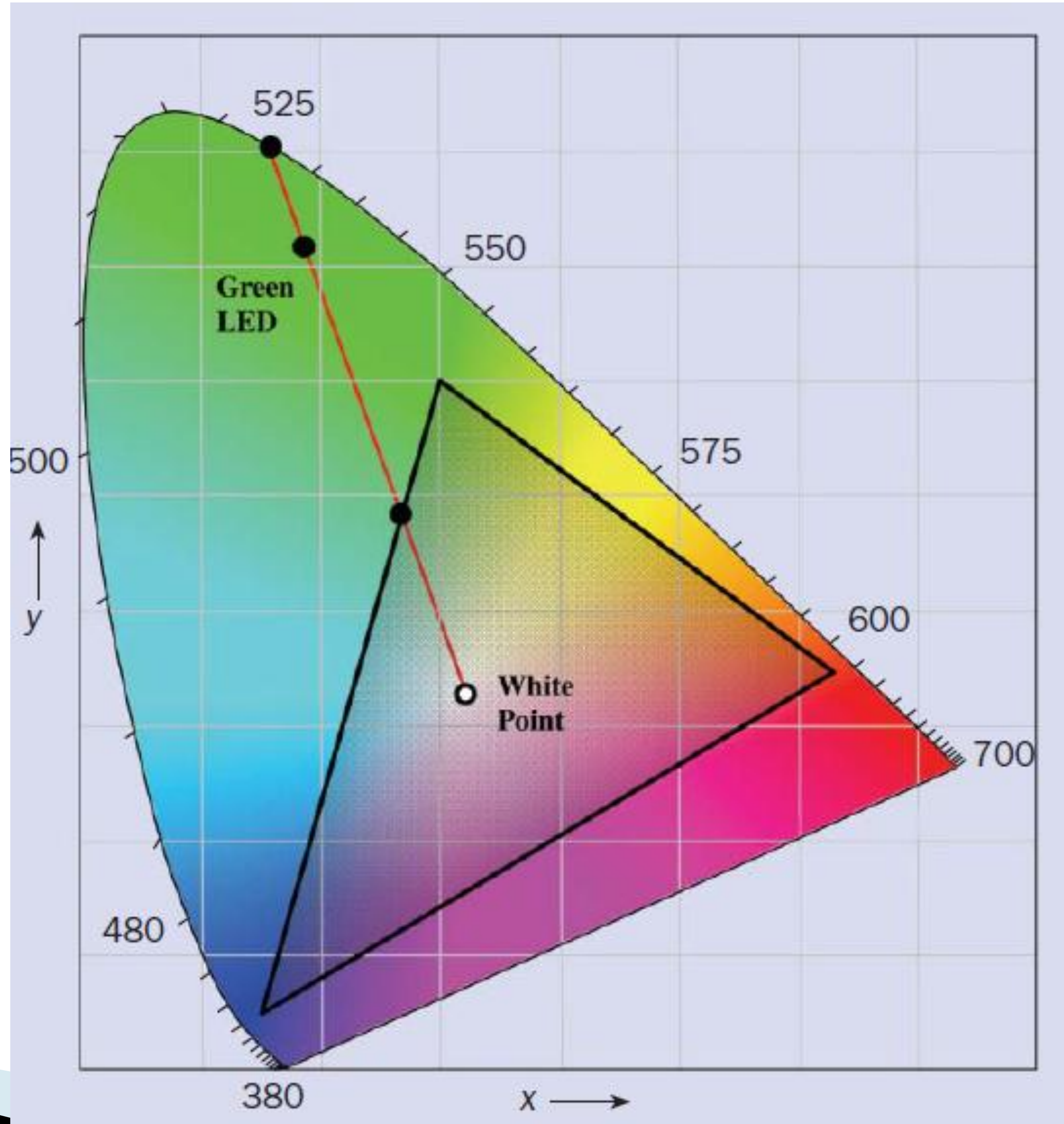
ITU-R BT.709

ITU-R BT.709 phosphor properties

Phosphor	x	y
Red	0.640	0.330
Green	0.300	0.600
Blue	0.150	0.060

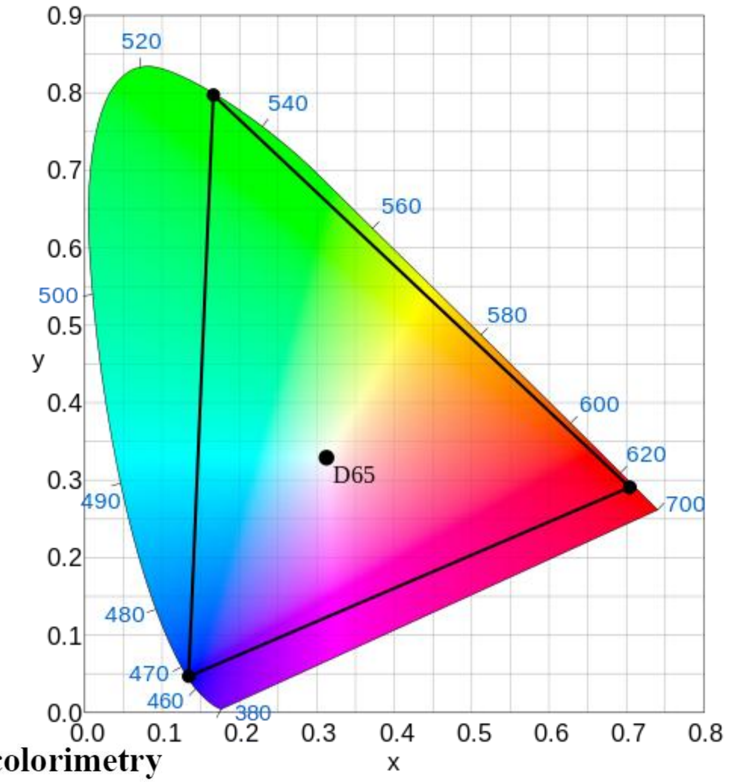
Data refers to xy chromaticity co-ordinates of ITU-R BT.709 phosphors which are used in most CRT displays [1].





ITU-R BT.2020

- **Parameter values for ultra-high definition television systems**
- UHDTV



System colorimetry

Parameter	Values		
Opto-electronic transfer characteristics before non-linear pre-correction	Assumed linear[1]		
Primary colours and reference white[2]	Chromaticity coordinates (CIE, 1931)	x	y
	Red primary (R)	0.708	0.292
	Green primary (G)	0.170	0.797
	Blue primary (B)	0.131	0.046
	Reference white (D65)	0.3127	0.3290

[1] Picture information can be linearly indicated by the tristimulus values of RGB in the range of 0-1.

Temperatura de culoare

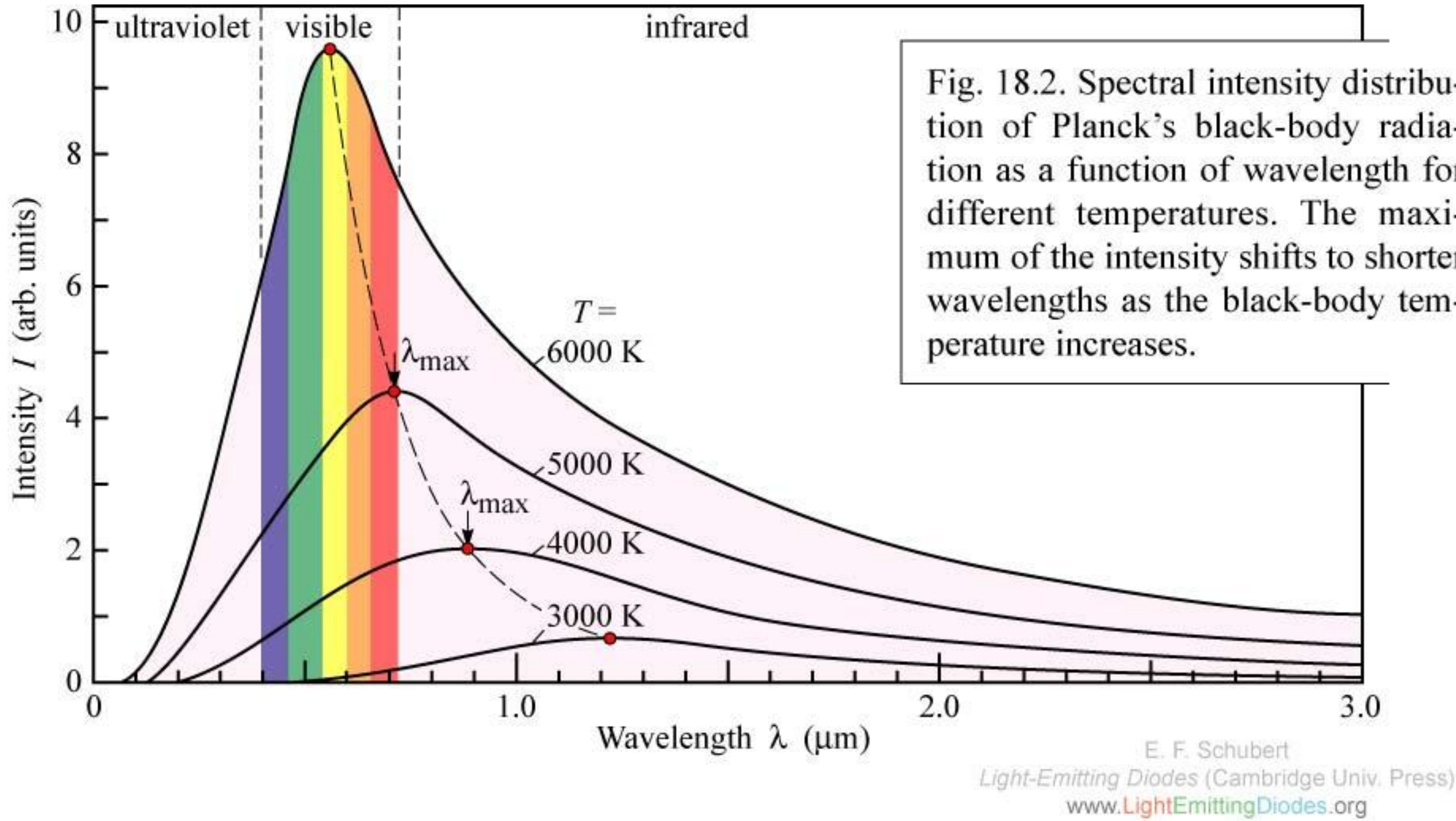
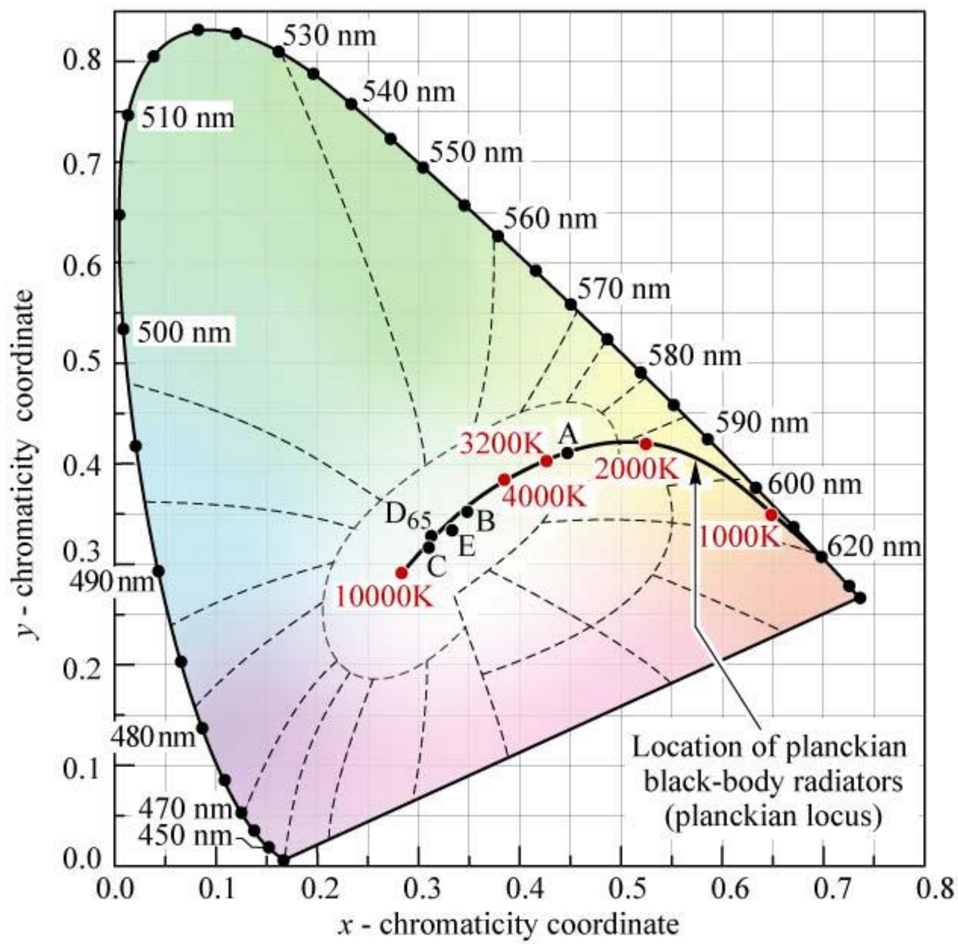


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

Temperatura de culoare



Illuminant A
$(x, y) = (0.4476, 0.4074)$
(Incandescent source, $T = 2856$ K)

Illuminant B
$(x, y) = (0.3484, 0.3516)$
(Direct sunlight, $T = 4870$ K)

Illuminant C
$(x, y) = (0.3101, 0.3162)$
(Overcast source, $T = 6770$ K)

Illuminant D_{65}
$(x, y) = (0.3128, 0.3292)$
(Daylight, $T = 6500$ K)

Illuminant E (equal-energy point)
$(x, y) = (0.3333, 0.3333)$

Fig. 18.3. Chromaticity diagram showing planckian locus, the standardized white Illuminants A, B, C, D_{65}, and E, and their color temperature (after CIE, 1978).

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Marimi luminoase

- Intensitatea
  - raportul dintre fluxul care părăseşte sursa şi se propagă într-un element de unghi solid ce conţine direcţia de propagare şi elementul de unghi solid.
  - o masura a puterii emise de o sursa intr-un element de unghi solid

Intensitatea			
Fotometrie		Radiometrie	
$I_v = \frac{d\Phi_v}{d\Omega}$	SI: cd	$I_e = \frac{d\Phi_e}{d\Omega}$	SI: W/sr

Marimi luminoase

- Iluminarea
  - raportul dintre fluxul primit de un element de suprafaţă conţinînd punctul şi aria acestui element (definita într-un punct al unei suprafeţe la **receptie**):
  - o masura a intensitatii luminii incidente pe o suprafata

Iluminarea			
Fotometrie		Radiometrie	
$E_v = \frac{d\Phi_v}{dS}$	SI: lx	$E_e = \frac{d\Phi_e}{dS}$	SI: W/m^2

Marimi luminoase

- Excitanţa
  - raportul dintre fluxul care părăseşte un element de suprafaţă conţinînd punctul şi aria elementului de suprafaţă (definita într-un punct al unei suprafeţe la **emisie**):
  - o masura a intensitatii luminii emise de o suprafata

Excitanţa			
Fotometrie		Radiometrie	
$M_v = \frac{d\Phi_v}{dS}$	SI: lm/m²	$M_e = \frac{d\Phi_e}{dS}$	SI: W/m²

Marimi luminoase

- Luminanţa
  - raportul dintre fluxul care părăseşte, atinge sau traversează un element de suprafaţă şi care se propagă în direcţii conţinute într-un con elementar, dΩ, conţinînd direcţia dată, şi produsul dintre unghiul solid al conului şi aria proiecţiei ortogonale a elementului de suprafaţă pe un plan perpendicular pe direcţia dată, dS (definita într-o direcţie, într-un punct de pe suprafaţa unei surse sau unui receptor, sau într-un punct pe traiectul unui fascicol):
  - o masura a densitatii de intensitate luminoasa intr-o anumita directie

Luminanţa			
Fotometrie		Radiometrie	
$L_v = \frac{d^2\Phi_v}{d\Omega \cdot dS}$	SI: cd/m^2	$L_e = \frac{d^2\Phi_e}{d\Omega \cdot dS}$	SI: $W/m^2/sr$

Marimi luminoase

- Standardele pentru surse luminoase (de ex. semne de circulatie), iluminarea spatiilor de lucru/odihna
  - sunt concepute cu marimi luminoase
  - lm, cd, lx, cd/m² etc.
- de multe ori se adapteaza relatiile pentru surse mai simple:

$$I_v = \frac{d\Phi_v}{d\Omega} \rightarrow I_v = \left.\frac{\Phi_v}{\Omega}\right|_{I_v \approx ct.\, in\, \Omega} \qquad E_v = \frac{d\Phi_v}{dS} \rightarrow E_v = \left.\frac{\Phi_v}{S}\right|_{\Phi_v \approx ct.\, pe\, S}$$

$$\Phi_v = 683\frac{lm}{W}\int_{390nm}^{830nm}\frac{d\Phi_e}{d\lambda}\cdot V(\lambda)\,d\lambda \rightarrow \Phi_v = 683\frac{lm}{W}\cdot\sum_i \Phi_e(\lambda_i)\cdot V(\lambda_i)$$

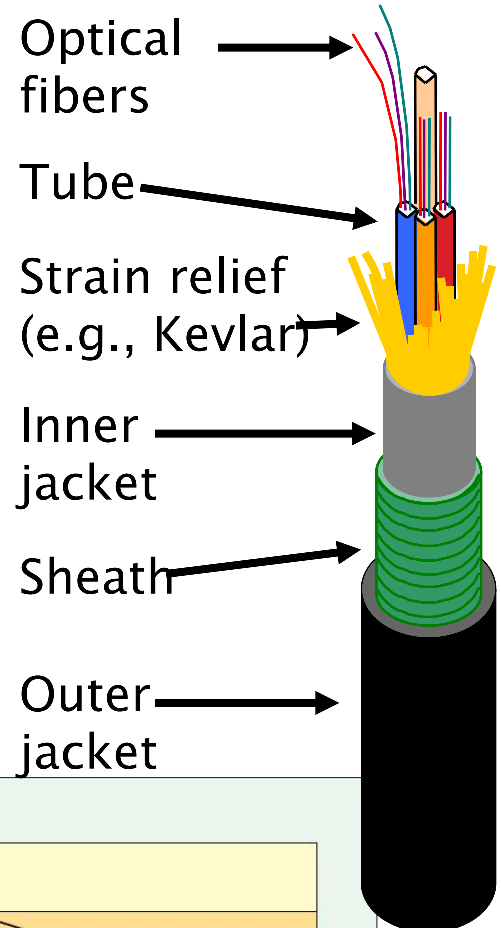
Continuare

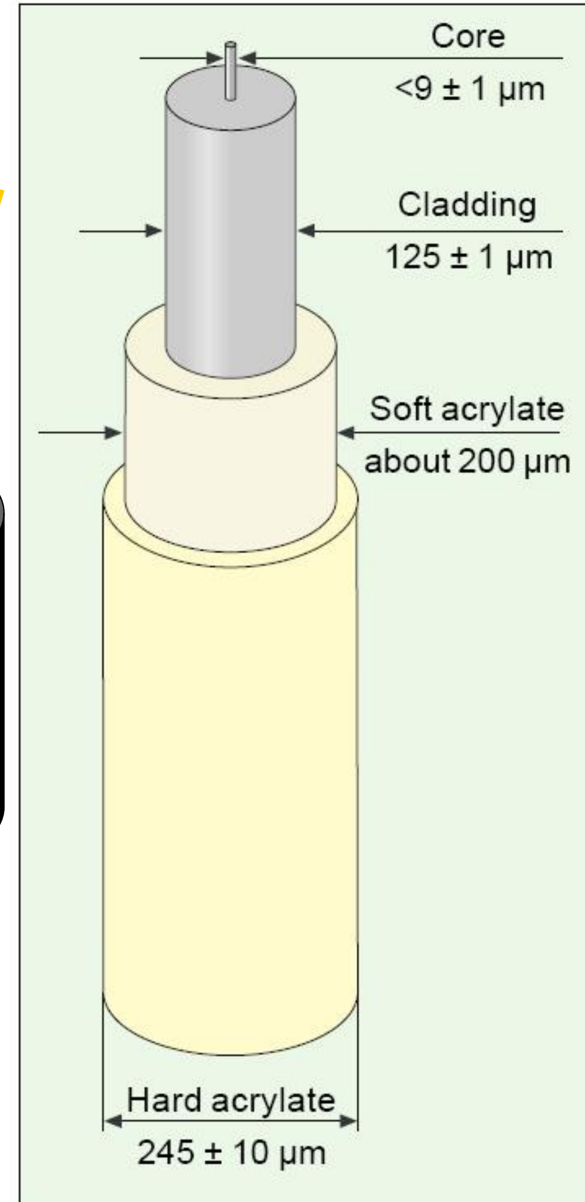
Fibra optică

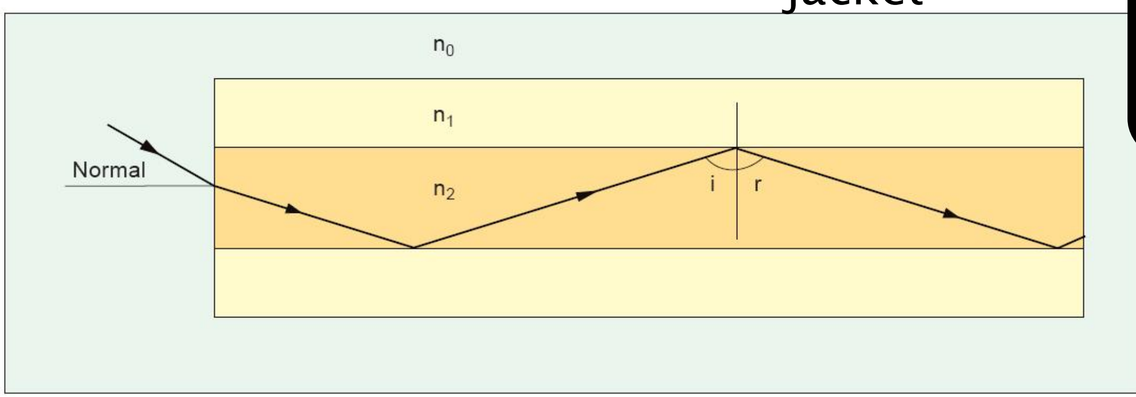
Capitolul 4

Fibra optica

- un ghid de unda dielectric
  - miez
  - teaca



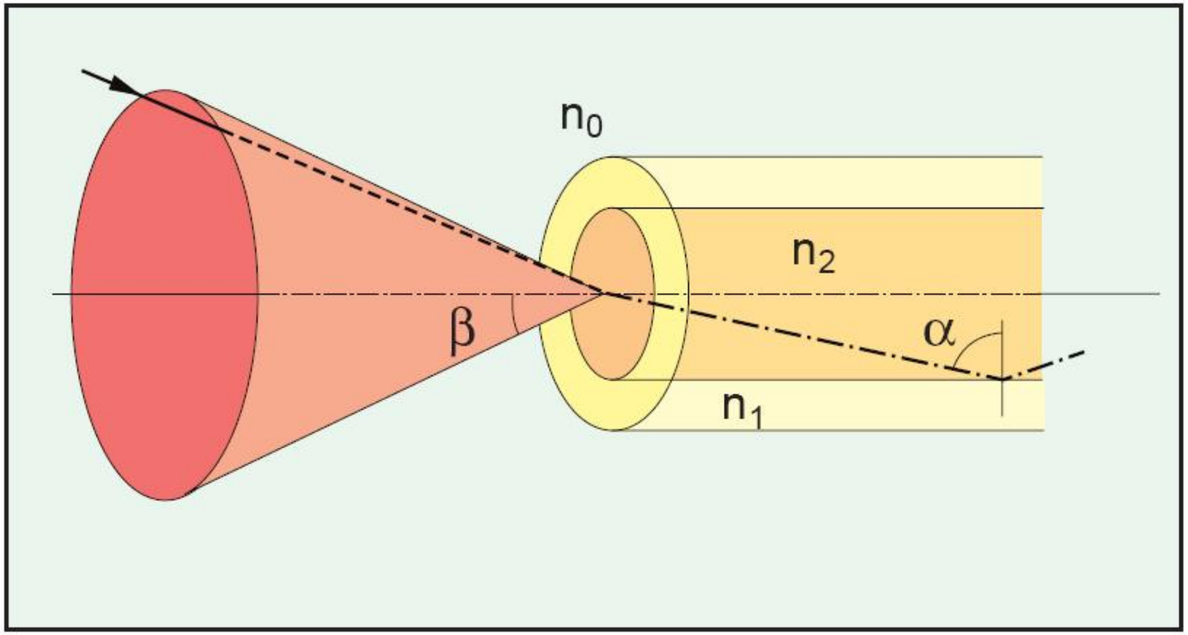




Unghi de acceptanta, apertura numerica

- Unghi de acceptanta

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

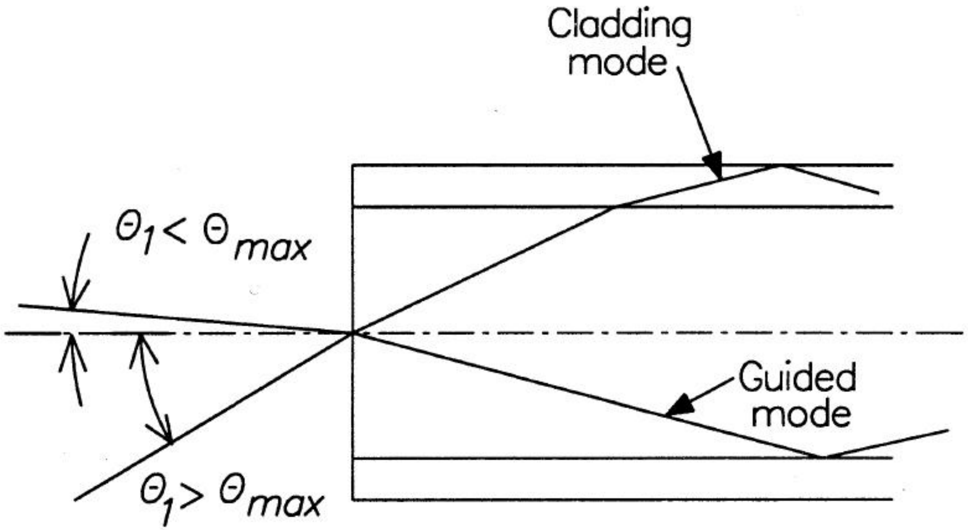


- **Apertura numerica**

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

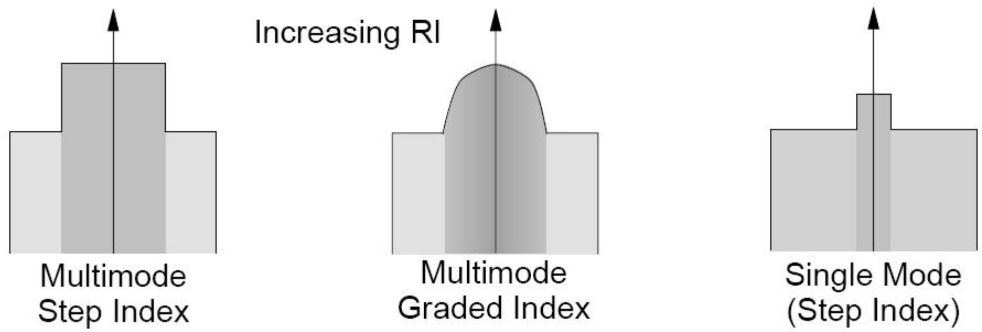
$$NA = n_2 \sqrt{\frac{n_2^2 - n_1^2}{n_2^2}} = \sqrt{n_2^2 - n_1^2}$$

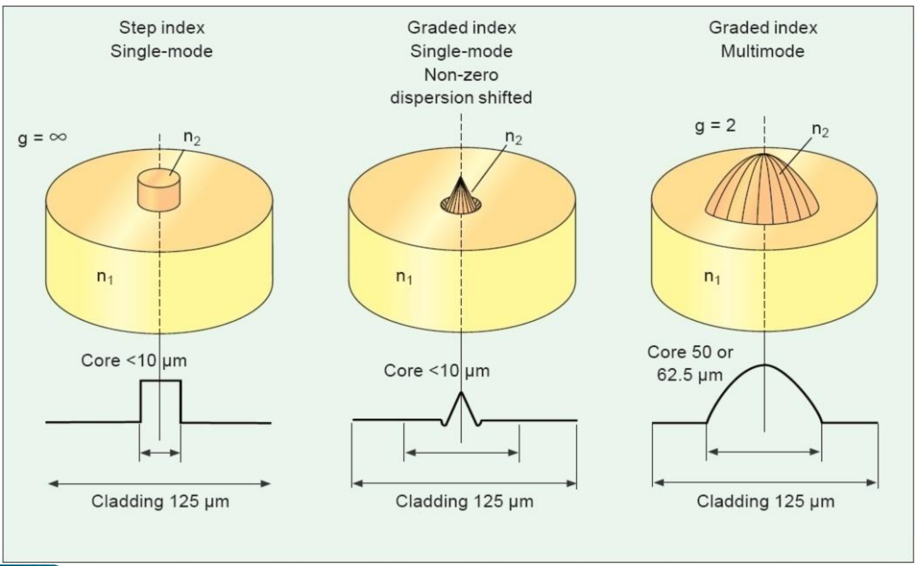
n_2 – miez
n_1 – teaca
$n_2 > n_1$!!

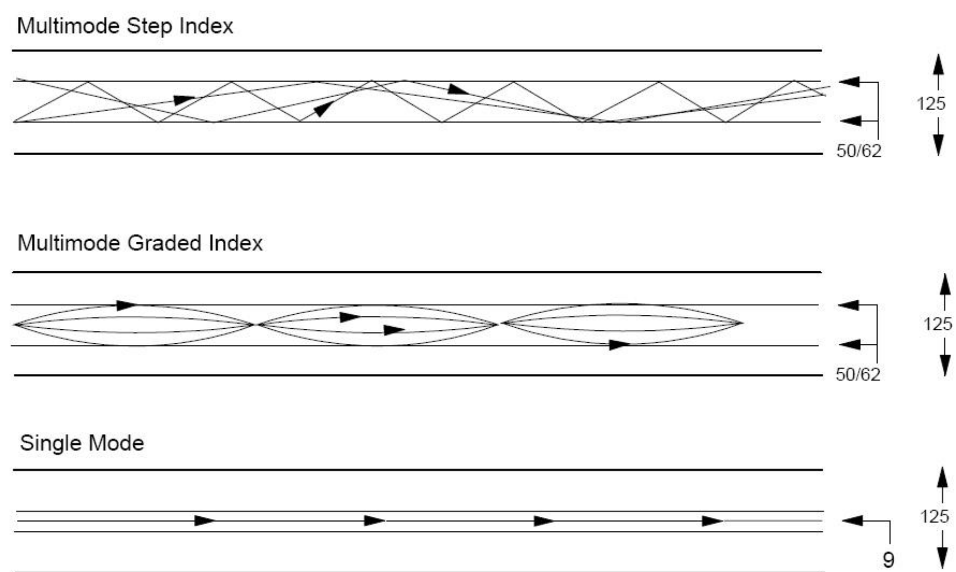


Tipuri de fibra

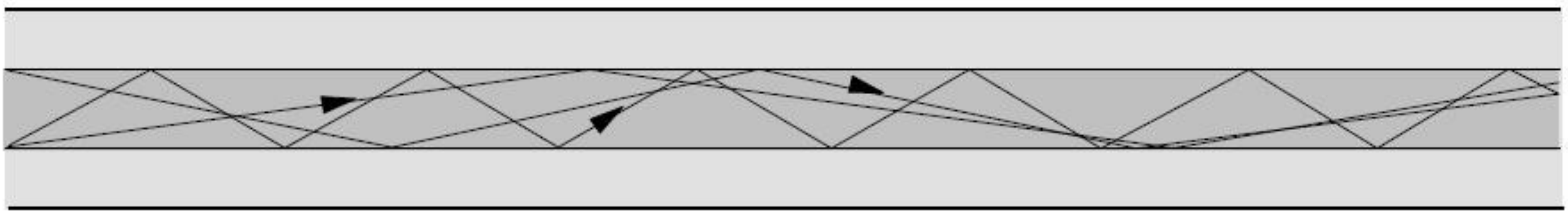
- Monomod
- Multimod
  - cu salt de indice
  - cu indice gradat



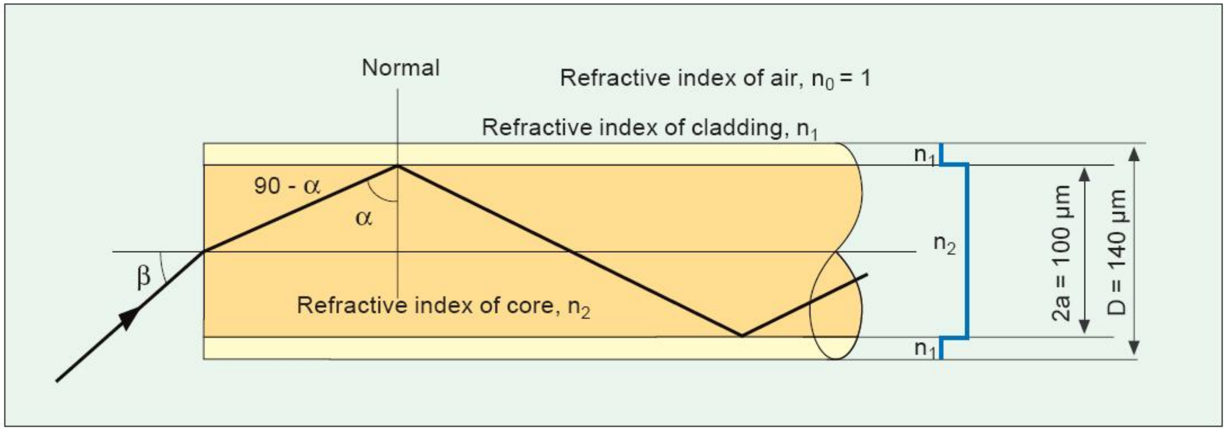


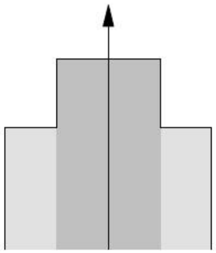


Fibre multimod cu salt de indice



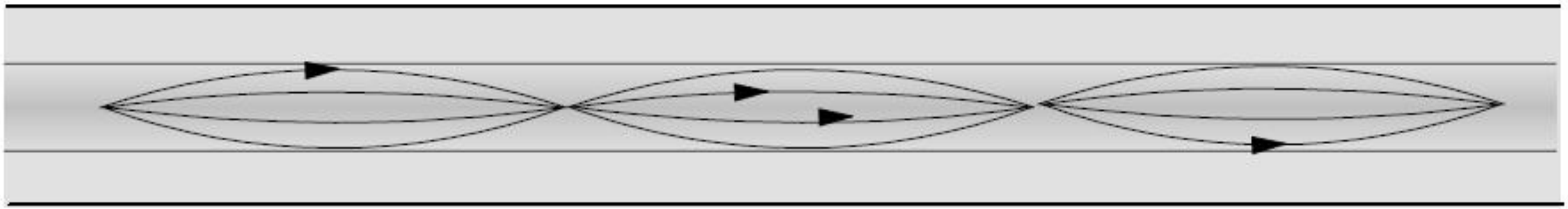
- 50/125 sau 62.5/125 (µm)
- 15-50 MHz·km



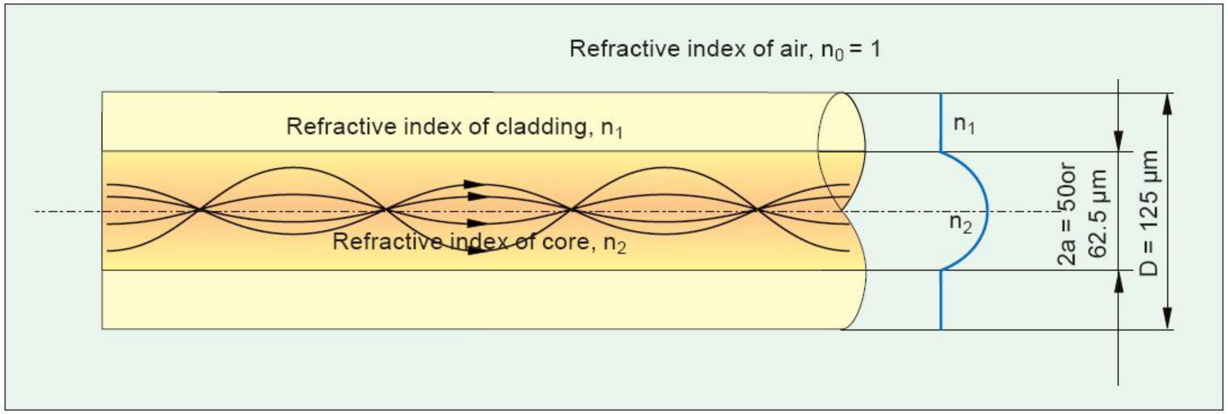


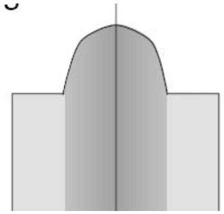
	glass	plastic
core diameter 2a	100 µm	980 µm
cladding diameter D	140 µm	1000 µm
core refractive index n_2	1.48	
cladding refractive index n_1	1.45	

Fibre multimod cu indice gradat



- 50/125 sau 62.5/125 (µm)
- 700-1200 MHz·km

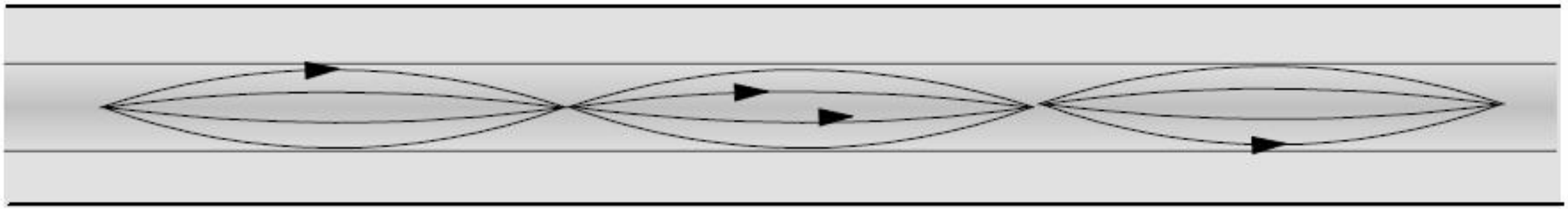




Core diameter 2a	50 or 62.5 µm
Cladding diameter D	125 µm
Maximum refractive index, core	1.46
Relative differential refractive index	0.010

Fata Morgana

Fibre multimod cu indice gradat

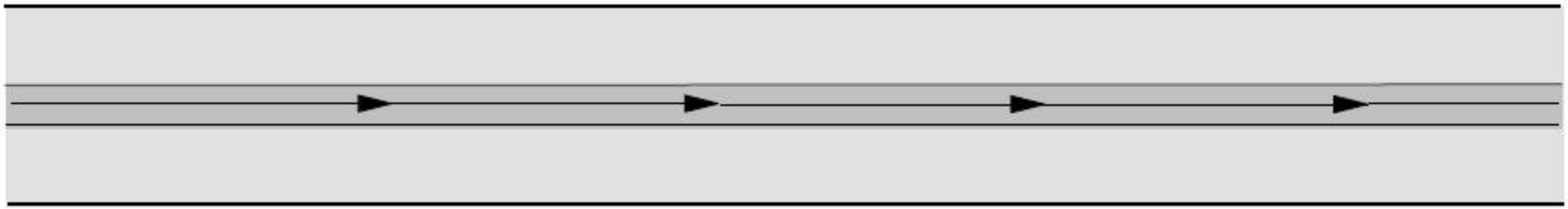


$$n(r) = n_2\left[1 - \Delta\left(\frac{r}{a}\right)^g\right]$$

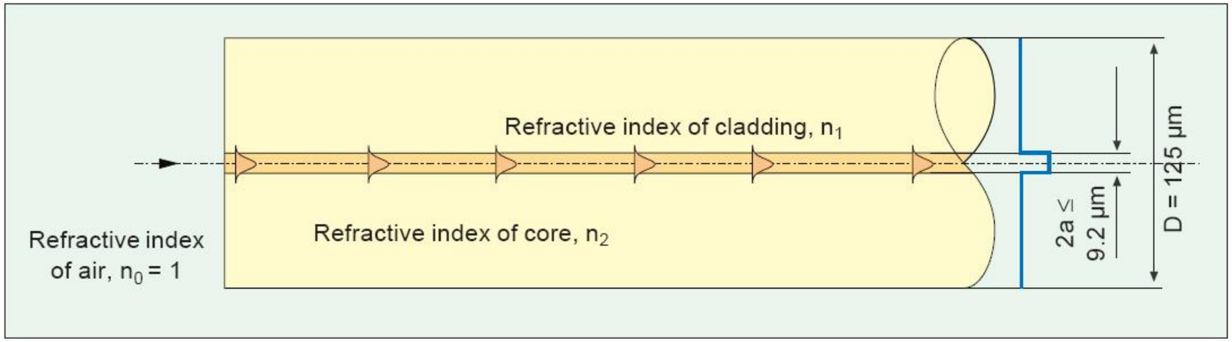
$$\Delta = \frac{NA^2}{2n_2^2} = \frac{n_2^2 - n_1^2}{2n_2^2} \approx \frac{n_2 - n_1}{n_2} \approx \frac{\Delta n}{n} \quad \text{for } \Delta << 1$$

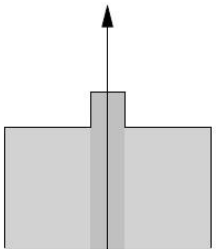
- g = 1 – indice gradat triunghiular
- g = 2 – indice gradat parabolic
- g = ∞ – salt de indice

Fibre monomod



- 6–8/125 (µm)
- MHz·km nerelevant
- MFD – Mode Field Diameter





Cladding diameter D	125 µm
Core refractive index n_2	1.4485
Cladding refractive index n_1	1.4440
Refractive index differential	0.003 = 0.3%

Ghid cilindric dielectric

- Ecuatiile lui Maxwell in coordonate cilindrice

$$\frac{\partial^2 U}{\partial r^2} + \frac{1}{r}\frac{\partial U}{\partial r} + \frac{1}{r^2}\frac{\partial^2 U}{\partial \phi^2} + \frac{\partial^2 U}{\partial z^2} + n^2 k_o^2 U = 0$$

a – raza miezului
U – E(r) sau H(r)

$$U(r,\phi,z) = u(r)e^{-jl\phi}e^{-j\beta z}, \qquad l = 0, \pm 1, \pm 2, \ldots$$

$$\frac{d^2 u}{dr^2} + \frac{1}{r}\frac{du}{dr} + \left(n^2(r)k_o^2 - \beta^2 - \frac{l^2}{r^2}\right)u = 0$$

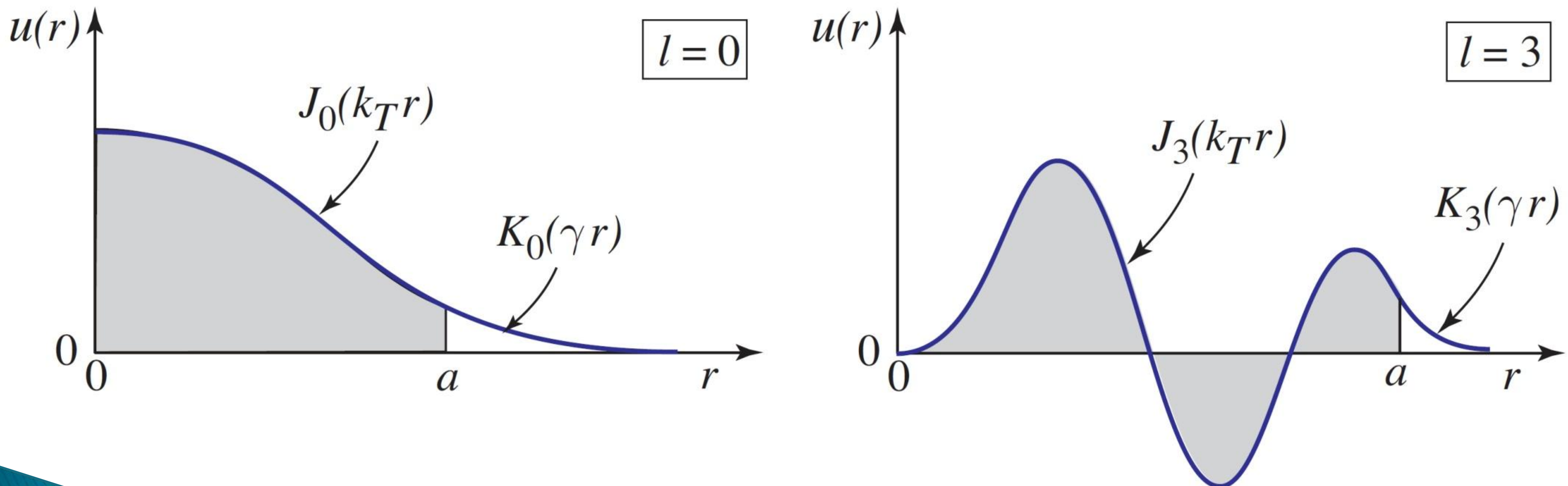
$$\frac{d^2 u}{dr^2} + \frac{1}{r}\frac{du}{dr} + \left(k_T^2 - \frac{l^2}{r^2}\right)u = 0, \qquad r < a$$

$$\frac{d^2 u}{dr^2} + \frac{1}{r}\frac{du}{dr} - \left(\gamma^2 + \frac{l^2}{r^2}\right)u = 0, \qquad r > a$$

Ghid cilindric dielectric

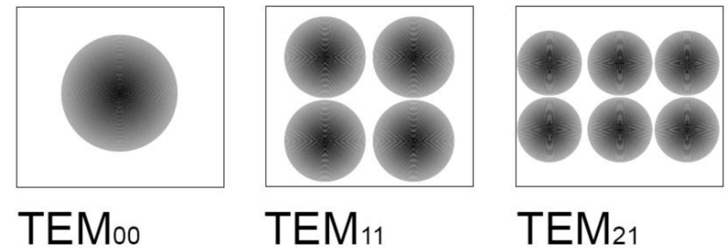
- solutii proportionale cu functii Bessel

$$u(r) \propto \begin{cases} J_l(k_T r), & r < a \quad \text{(core)} \\ K_l(\gamma r), & r > a \quad \text{(cladding)} \end{cases}$$

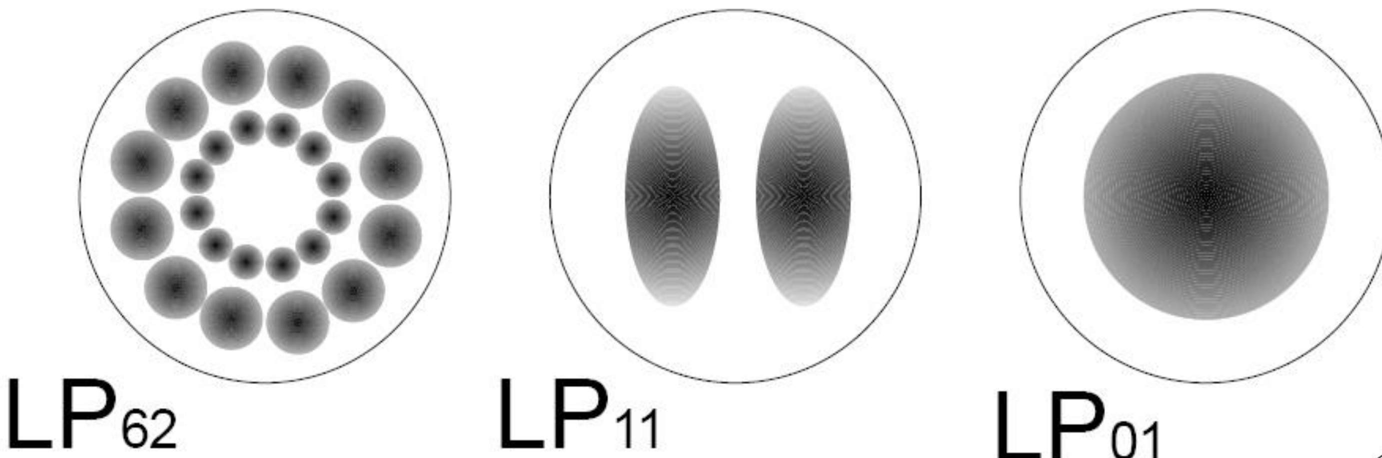


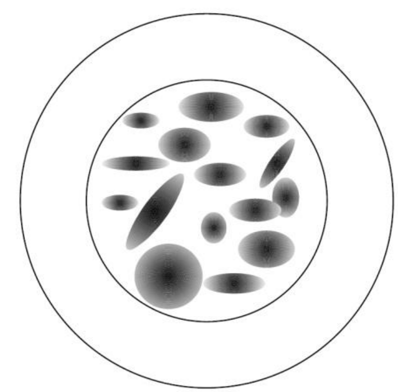
Moduri in fibra

- Moduri in ghid rectangular



- Moduri linear polarizate in fibra





“Sparkle” pattern

Frecventa normalizata

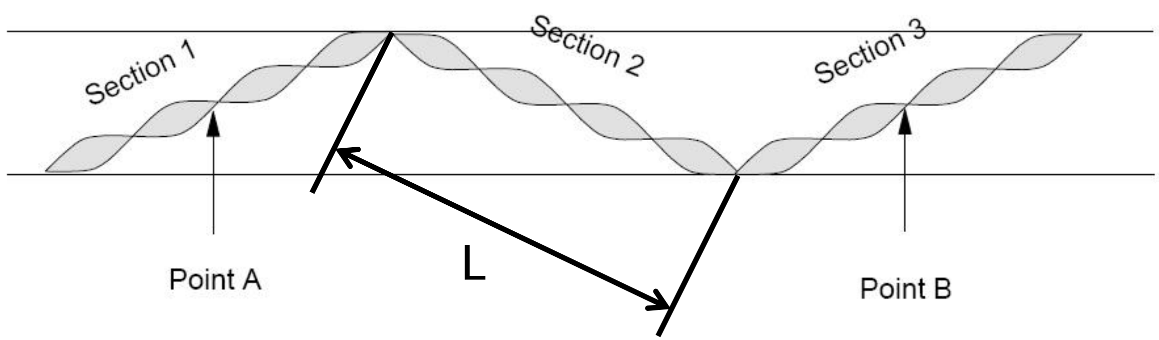
- Frecventa normalizata

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

a – raza miezului

$$k = \frac{2\pi}{\lambda}$$

- Numar de moduri

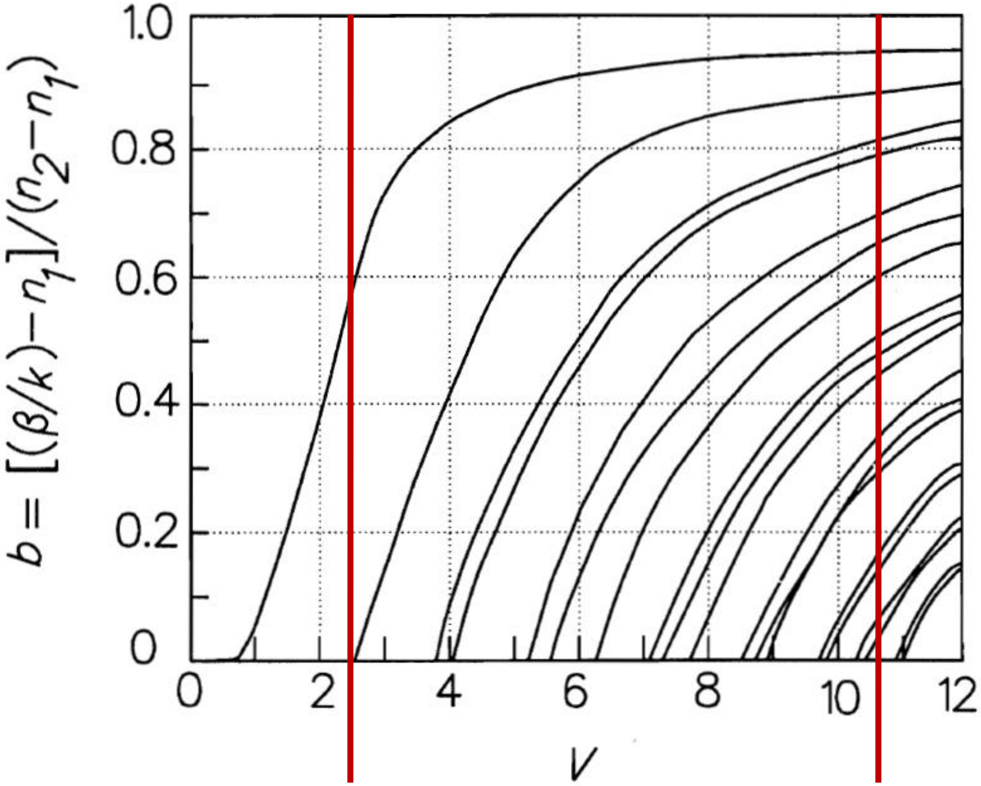


$$L = m \cdot \lambda$$

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

Frecventa normalizata – monomod

- Fibre monomod



b – coeficient de propagare modal relativ

$$V \le V_C = 2.405$$

exista un **singur** mod (solutii fc. Bessel)

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

Exemplu:

2a = 8.5μm

NA = 0.11

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

Frecventa normalizata

- Numar de moduri
  - Multimod cu salt de indice

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

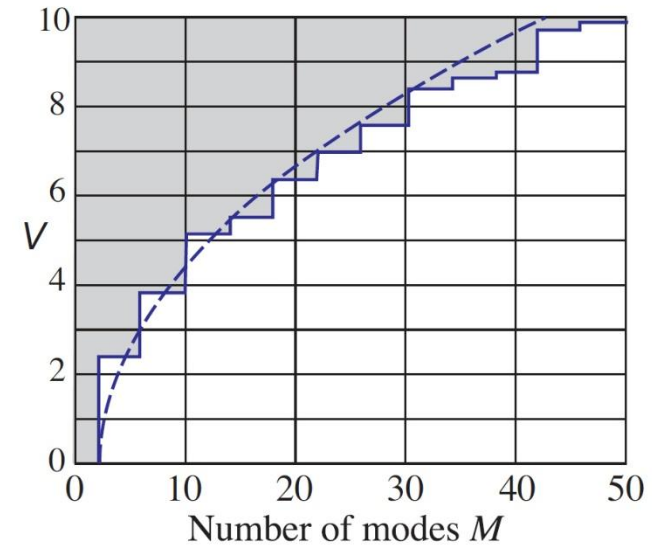
  - Multimod cu indice gradat

$$g = 2 \quad \Rightarrow \quad N \approx \frac{V^2}{4}$$

  - Monomod

$$V \le V_C = 2.405$$ exista un singur mod (solutii fc. Bessel)

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



Exemplu

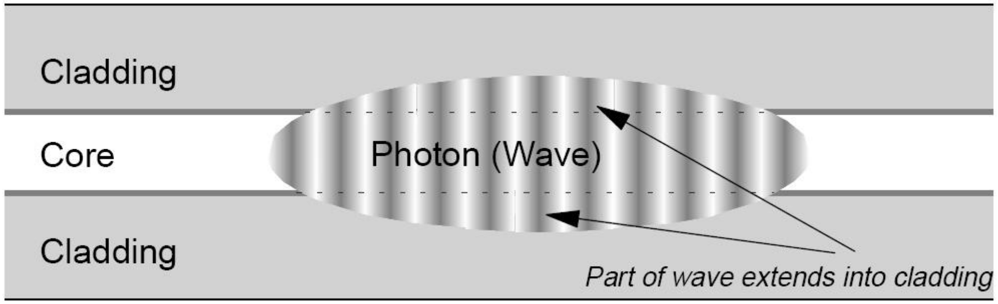
- fibra tipica multimod
  - g=2
  - 2a = 50µm -> a = 25µm
  - NA = 0.2 la λ = 1µm

$$V = 2\pi \frac{a}{\lambda} NA = 2\pi \frac{25}{1} 0.2 = 2 \cdot \pi \cdot 5 \approx 31.4$$

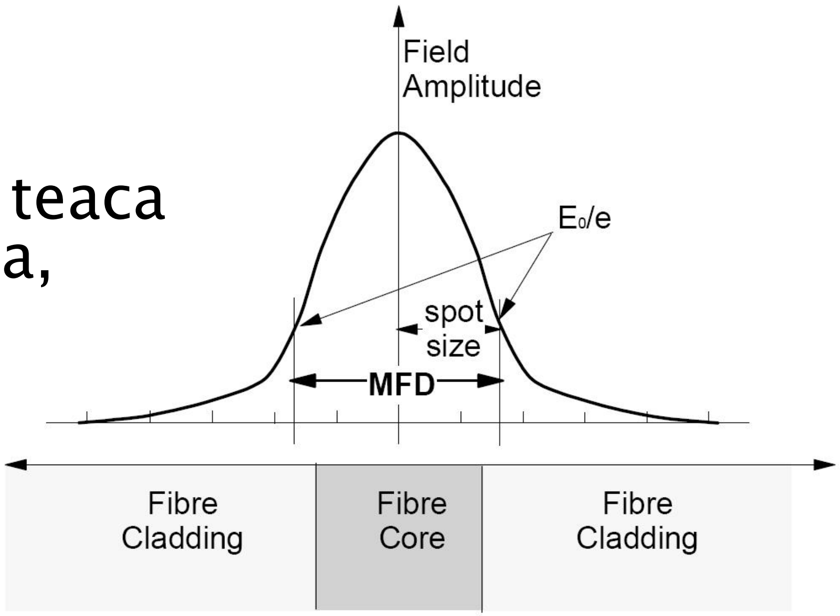
$$g = 2 \quad \Rightarrow \quad N = \frac{V^2}{4} = \frac{31.4^2}{4} = 247$$

Propagarea in fibra monomod

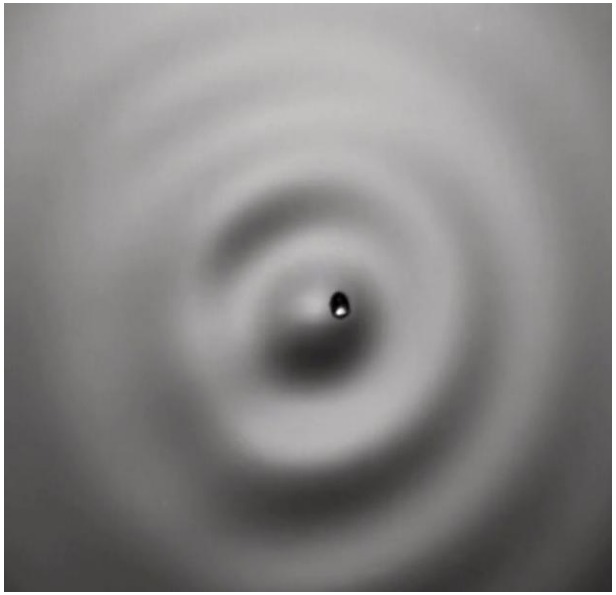
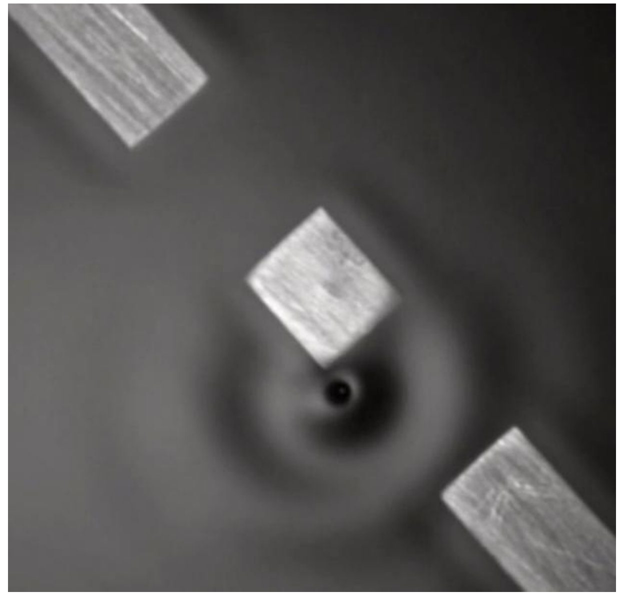
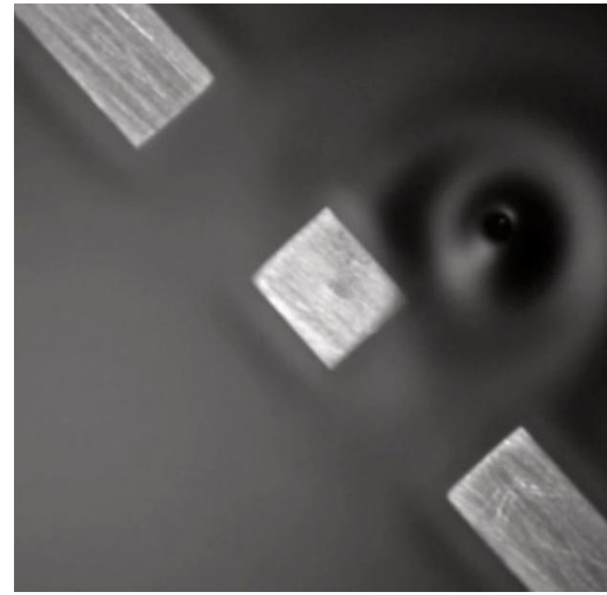
- Propagarea luminii poate fi explicata doar prin teoria electromagnetica



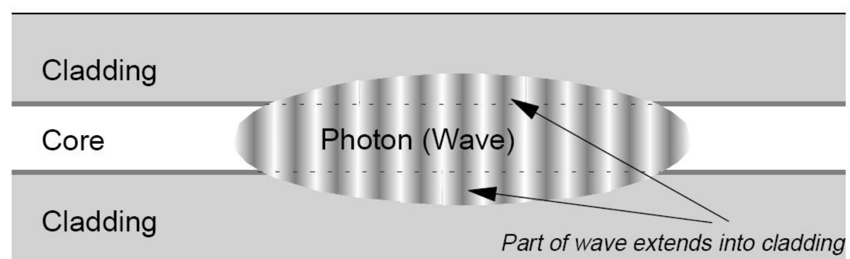
- Energia campului se extinde in teaca (diametrul efectiv al spotului luminos – MFD, Mode Field Diameter)
- MFD > 2a
- Adancimea de patrundere in teaca depinde de lungimea de unda, generand dispersia de ghid



Modelare

Through the Wormhole
S02E07 How Does the Universe Work



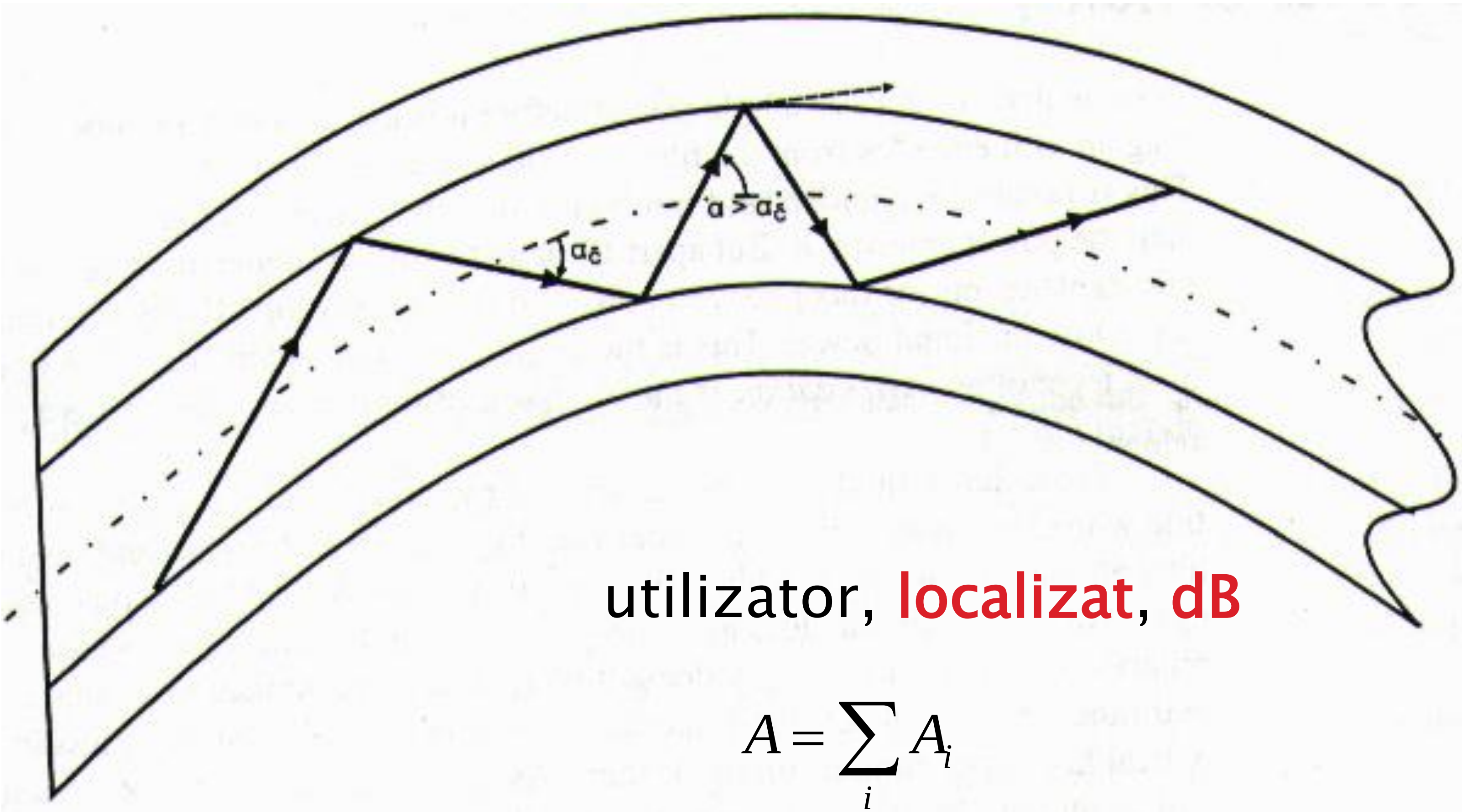
Fenomene de interes

- 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
- Absorbtie
  - distribuit, material, dB/km

Macrocurburi



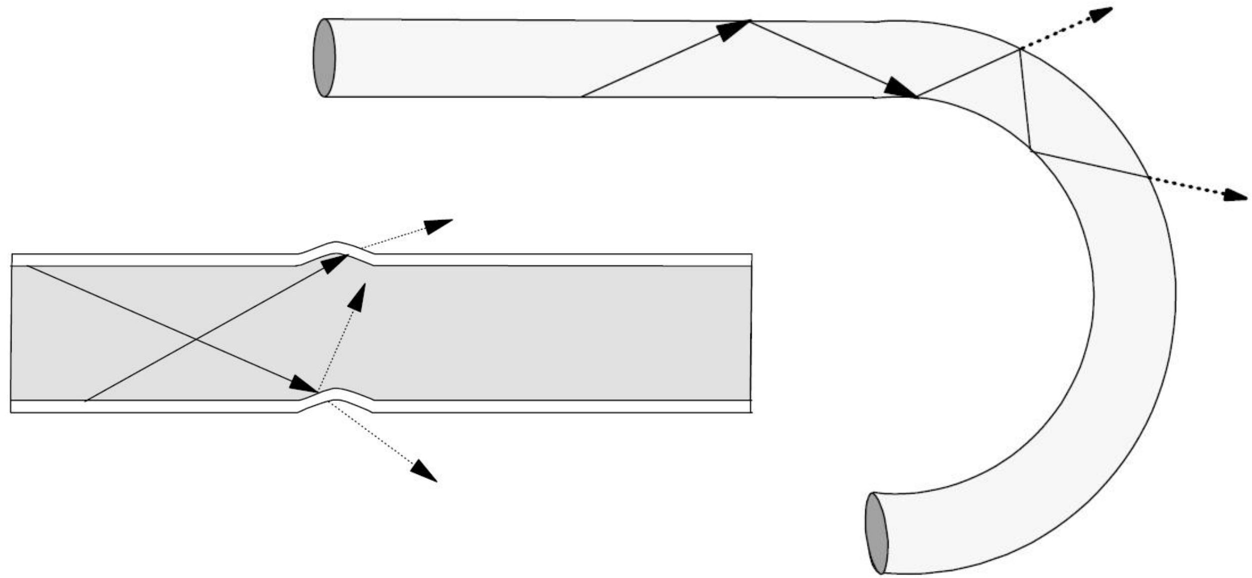
utilizator, localizat, dB

$$A = \sum_i A_i$$

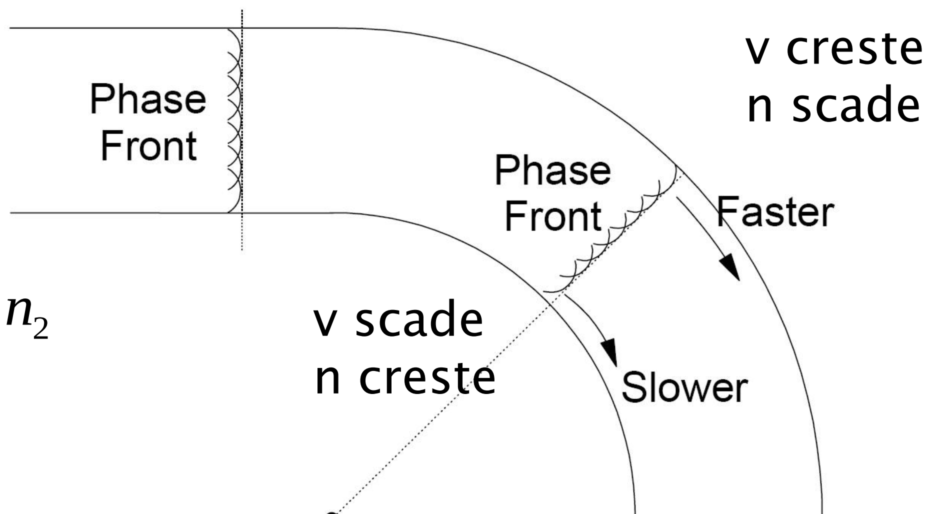
$$A = N \cdot A_i$$

Efectul curburilor

- Multimod



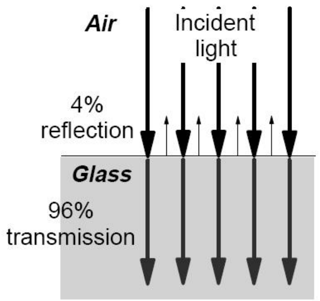
- Monomod

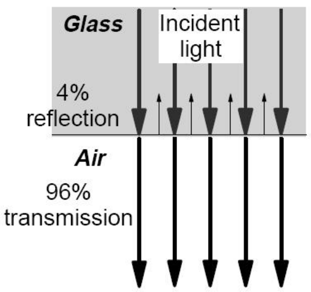


$$R > R_C \quad \Rightarrow \quad n_{1,ext} > n_2$$

Discontinuitate in fibra

- Apare cand nu putem considera fibra un singur ghid dielectric
  - defectiuni
  - conectori



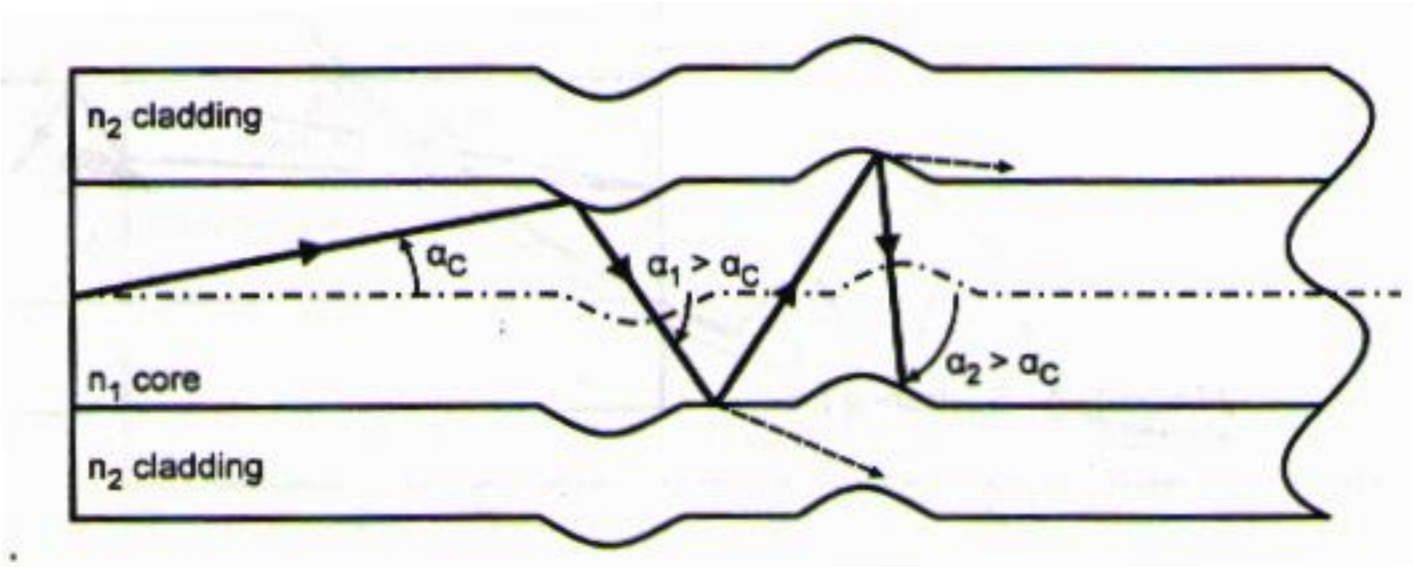


utilizator, localizat, dB

$$A = \sum_i A_i$$

$$A = N \cdot A_i$$

Microcurburi

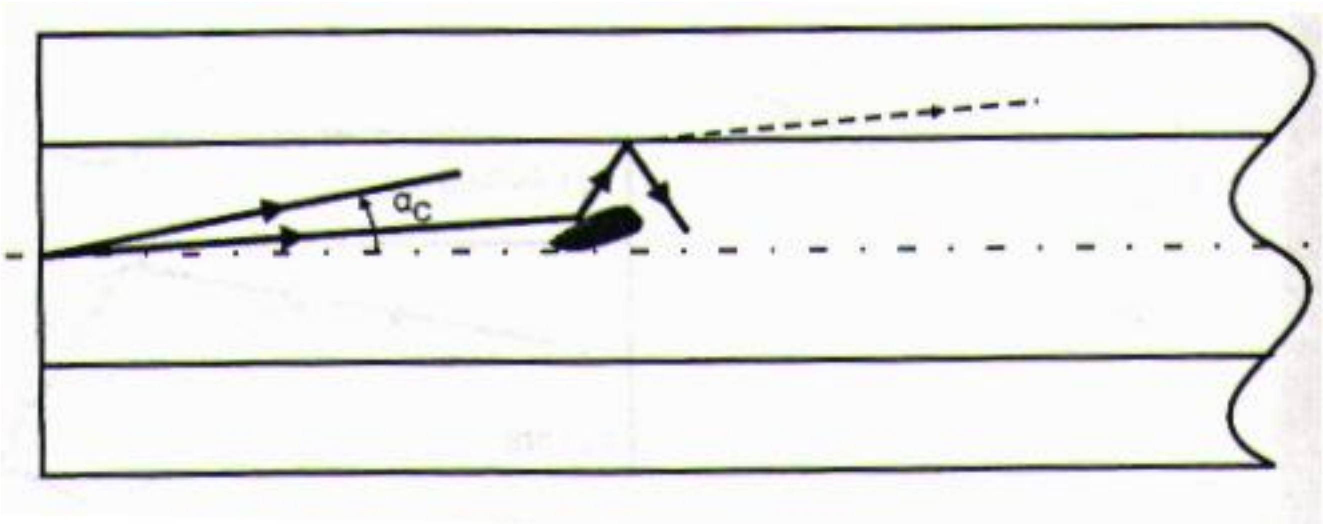


distribuit, tehnologie, dB/km

$$A = A_i \cdot L$$

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

Imprastiere

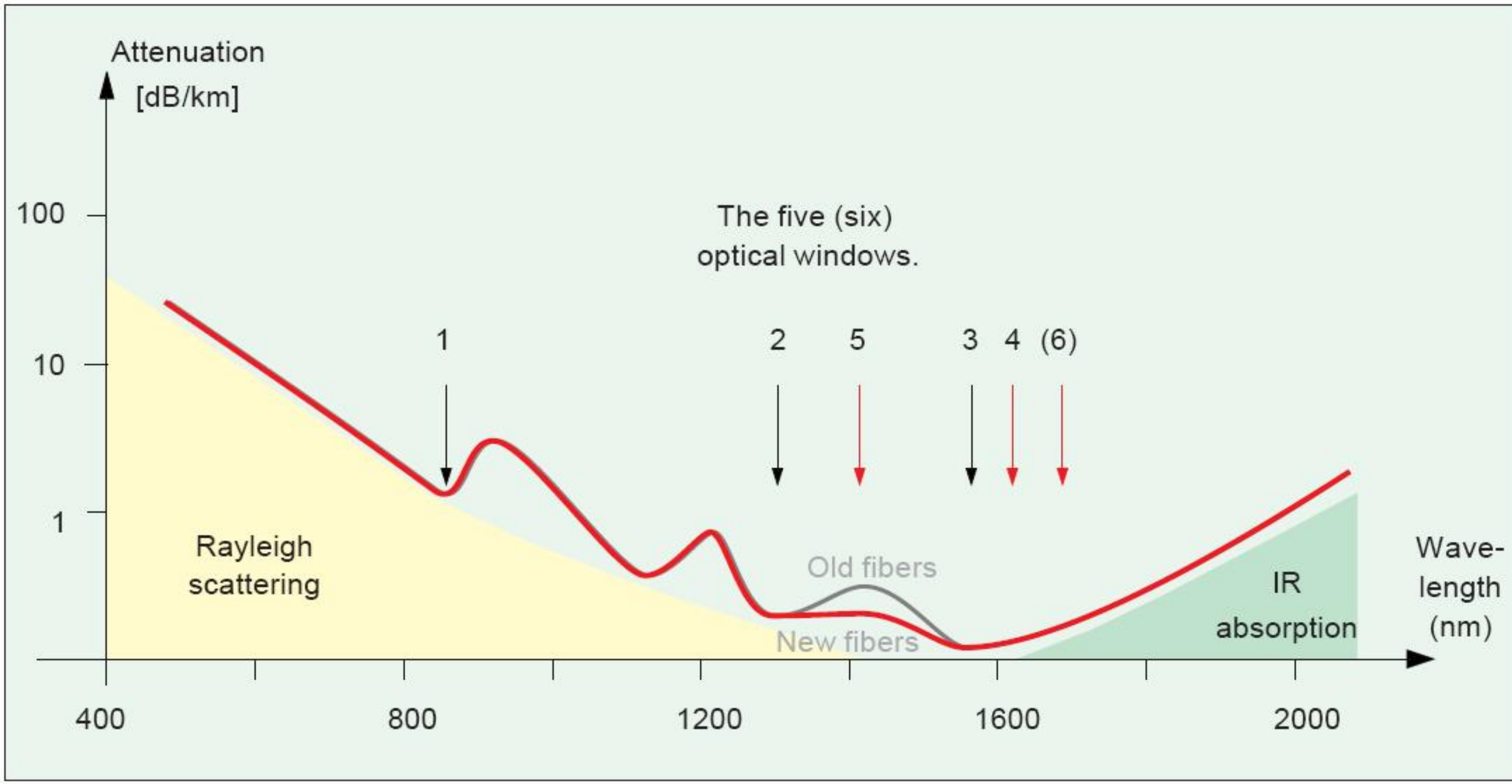


distribuit, tehnologie, dB/km

$$A = A_i \cdot L$$

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

Absorbtie

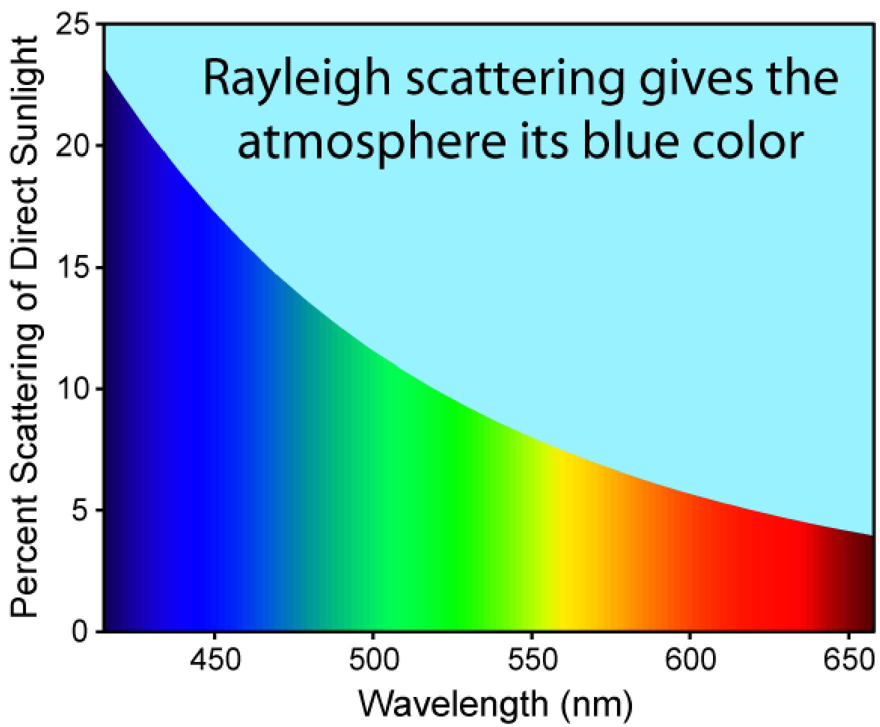


distribuit, material, **dB/km**

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

Difractie Rayleygh

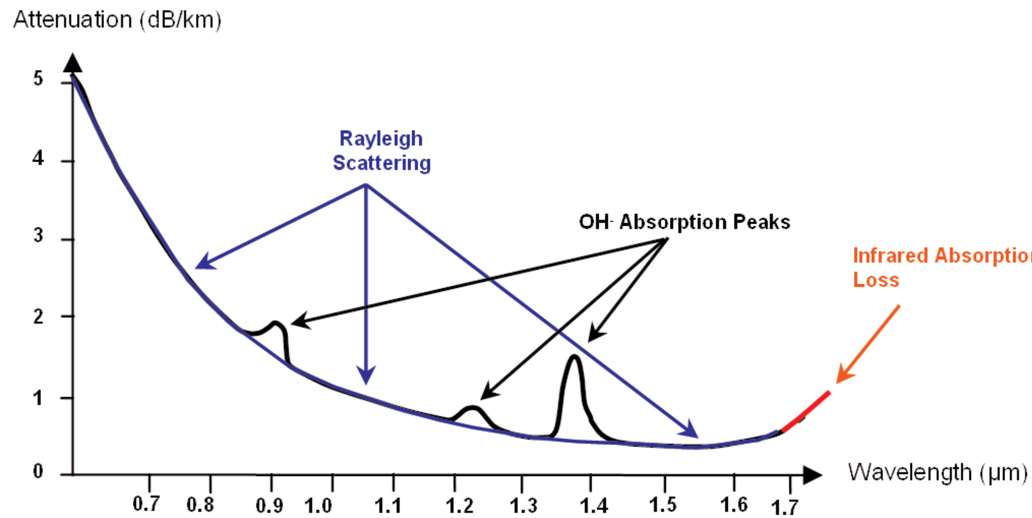
- imprastierea luminii (si a altor radiatii electromagnetice) de particule (molecule) mult mai mici decat lungimea de unda

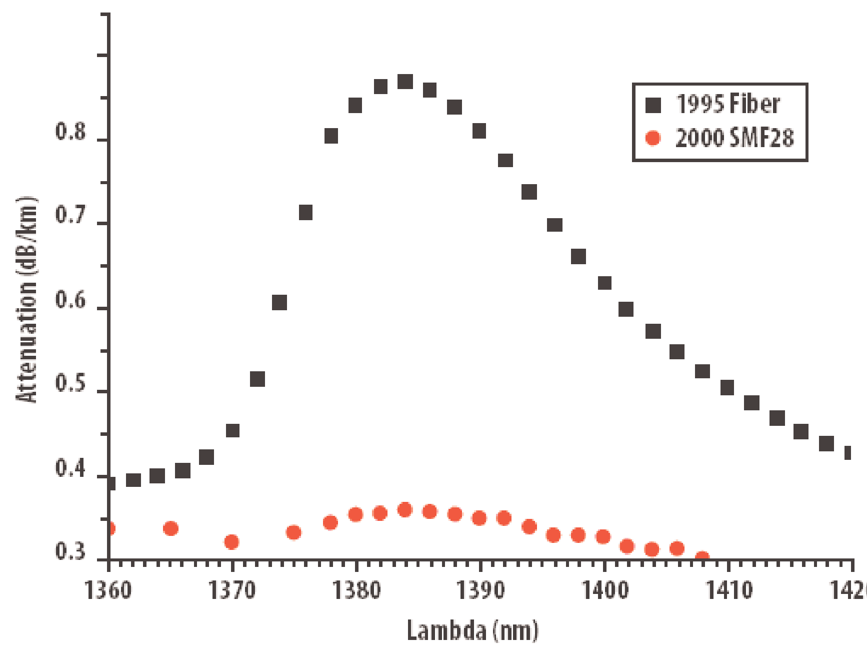


$$A \sim \frac{1}{\lambda^4}$$

Absorbtie OH

- Absorbtie
  - 950nm
  - 1244nm
  - 1383nm
- Apa!





Fiber Attenuation Comparison

Atenuare

$$E_y(z_1) = Ct \cdot e^{-\alpha \cdot z_1} \cdot e^{j(\omega t - \beta \cdot z_1)} \qquad E_y(z_2) = Ct \cdot e^{-\alpha \cdot z_2} \cdot e^{j(\omega t - \beta \cdot z_2)}$$

$$W, P \sim \int E^2$$

$$A = \frac{P_2}{P_1} = \frac{Ct^2 \cdot e^{-2\alpha \cdot z_2}}{Ct^2 \cdot e^{-2\alpha \cdot z_1}} = e^{-2\alpha \cdot (z_2 - z_1)}$$

$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

$$A[dB] = -20 \cdot \alpha \cdot (z_2 - z_1) \log_{10} e = -8.686 \cdot \alpha \cdot (z_2 - z_1)$$

$$A / L[dB/km] = -8.686 \cdot \alpha < 0$$

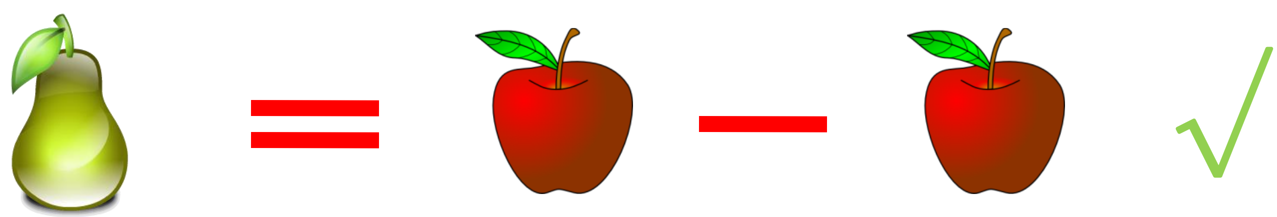
- Atenuarea se exprima de obicei in **dB/km**
  - de obicei valori pozitive
  - semnul = **implicit**

Calculul atenuarii

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

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

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

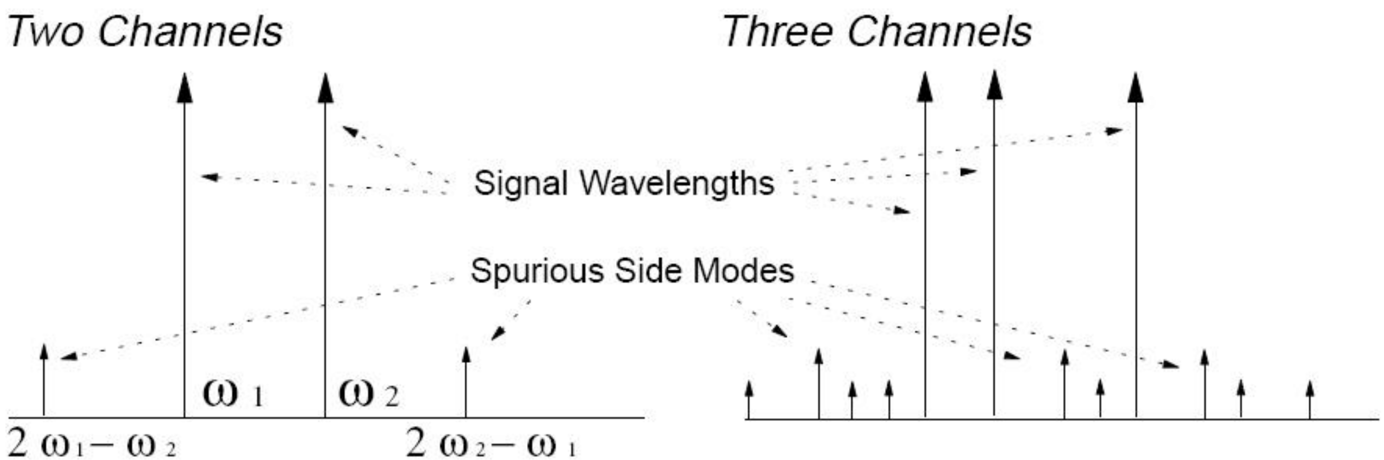


$$\text{Atenuare}\left[\text{dB/km}\right] = \frac{\text{Pierderi}[\text{dB}]}{\text{lungime}[\text{km}]}$$

Efecte neliniare in fibra

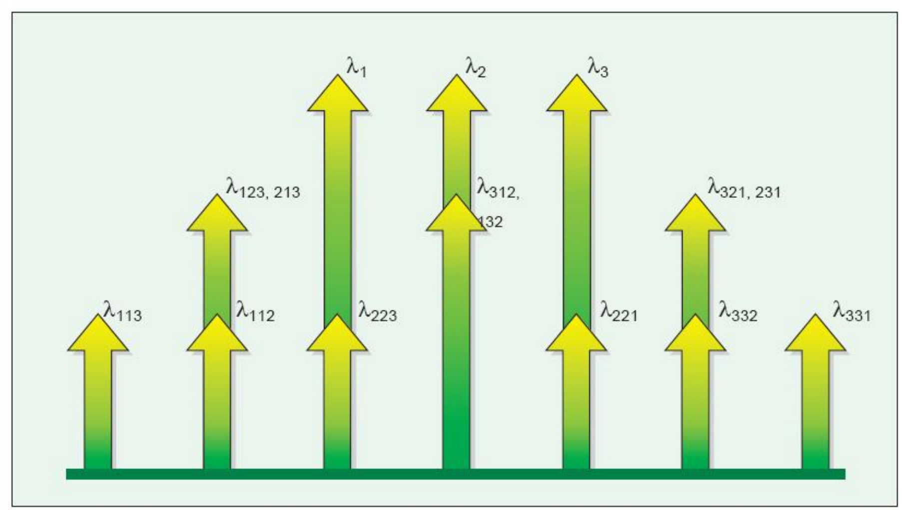
- Stimulated Brillouin Scattering, SBC
  - difractia luminii inspre emitator datorita undelor mecano-acustice generate in fibra
  - 6-10 dBm
- Stimulated Raman Scattering, SRS
  - interactiunea luminii cu vibratiile moleculare
  - 27 dBm (~1W)
- Self Phase Modulation, SPM
  - Frontiera impulsului implica indice de refractie variabil in timp moduland faza impulsului
  - 5 dBm
  - Cross Phase Modulation, CPM
- Four-Wave Mixing, FWM
  - 0 dBm

Four-Wave Mixing, FWM



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

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



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