Optoelectronică

Curs 2

2019/2020

Disciplina 2019/2020

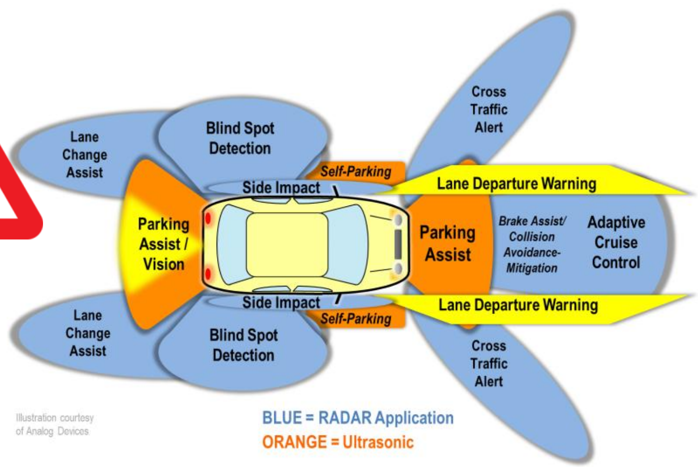
- 2C/1L Optoelectronică OPTO
- **Minim 7 prezente curs + laborator**
- Curs – conf. Radu Damian
  - an IV μE
  - Vineri 8-11, P5
  - E – 70% din nota
    - **20% test la curs**, saptamana 4-5?
  - probleme + (? 1 subiect teorie) + (2p prez. curs)
  - toate materialele permise
- Laborator – sl. Daniel Matasaru
  - an IV μE
    - Joi 8-14 impar
  - L – 30% din nota (+Caiet de laborator)

Orar 2019/2020

- Curs
  - Vineri 8-11, P5
  - 2C ⇨ 3C
    - $14*2/3 \approx 9.33$
    - $9 \div 10$ C $\approx$ 9C + E

Tehnologie

> 2010



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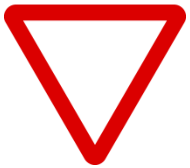


Tehnologie

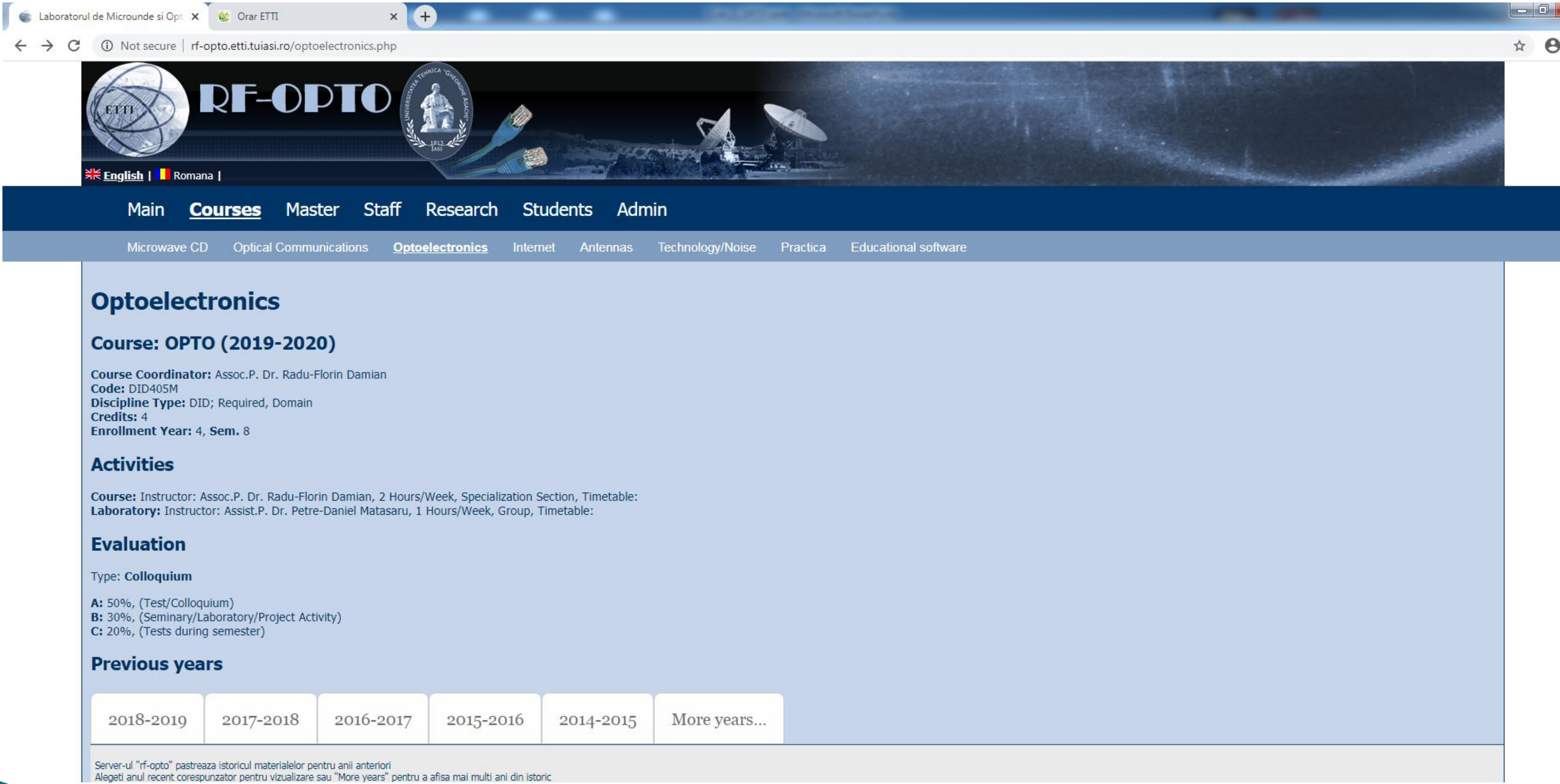
1x1 = 1	2x1 = 2	3x1 = 3	4x1 = 4	5x1 = 5
1x2 = 2	2x2 = 4	3x2 = 6	4x2 = 8	5x2 = 10
1x3 = 3	2x3 = 6	3x3 = 9	4x3 = 12	5x3 = 15
1x4 = 4	2x4 = 8	3x4 = 12	4x4 = 16	5x4 = 20
1x5 = 5	2x5 = 10	3x5 = 15	4x5 = 20	5x5 = 25
1x6 = 6	2x6 = 12	3x6 = 18	4x6 = 24	5x6 = 30
1x7 = 7	2x7 = 14	3x7 = 21	4x7 = 28	5x7 = 35
1x8 = 8	2x8 = 16	3x8 = 24	4x8 = 32	5x8 = 40
1x9 = 9	2x9 = 18	3x9 = 27	4x9 = 36	5x9 = 45
1x10 = 10	2x10 = 20	3x10 = 30	4x10 = 40	5x10 = 50
6x1 = 6	7x1 = 7	8x1 = 8	9x1 = 9	10x1 = 10
6x2 = 12	7x2 = 14	8x2 = 16	9x2 = 18	10x2 = 20
6x3 = 18	7x3 = 21	8x3 = 24	9x3 = 27	10x3 = 30
6x4 = 24	7x4 = 28	8x4 = 32	9x4 = 36	10x4 = 40
6x5 = 30	7x5 = 35	8x5 = 45	9x5 = 45	10x5 = 50
6x6 = 36	7x6 = 42	8x6 = 48	9x6 = 54	10x6 = 60
6x7 = 42	7x7 = 49	8x7 = 56	9x7 = 63	10x7 = 70
6x8 = 48	7x8 = 56	8x8 = 64	9x8 = 72	10x8 = 80
6x9 = 54	7x9 = 63	8x9 = 72	9x9 = 81	10x9 = 90
6x10 = 60	7x10 = 70	8x10 = 80	9x10 = 90	10x10 = 100

2x1 = 2
2x2 = 4
2x3 = 6
2x4 = 8
2x5 = 10
2x6 = 12
2x7 = 14
2x8 = 16
2x9 = 18
2x10 = 20

Cuprins

- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire - splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
- **Emiţătoare optice** (LED şi dioda laser - realizare fizică şi functionare)
- **Receptoare optice** (dioda PIN, dioda cu avalanşă - realizare fizică şi functionare)
- **Amplificatoare transimpedanţă** (parametri, scheme tipice, TIA în buclă deschisă, cu reacţie, diferenţiale, control automat al câştigului)
- **Realizarea circuitelor pentru controlul emiţătoarelor optice (**parametri, scheme tipice, controlul puterii, multiplexoare**)**
- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

Documentatie



Istoric

Optoelectronics

Course: OPTO (2019-2020)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DID405M
Discipline Type: DID; Required, Domain
Credits: 4
Enrollment Year: 4, **Sem.** 8

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assist.P. Dr. Petre-Daniel Matasaru, 1 Hours/Week, Group, Timetable:

Evaluation

Type: **Colloquium**

A: 50%, (Test/Colloquium)
B: 30%, (Seminary/Laboratory/Project Activity)
C: 20%, (Tests during semester)

Previous years

2018-2019 | 2017-2018 | 2016-2017 | 2015-2016 | 2014-2015 | More years...

Server-ul "rf-opto" pastreaza istoricul materialelor pentru anii anteriori
Alegeti anul recent corespunzator pentru vizualizare sau "More years" pentru a afisa mai multi ani din istoric

Istoric 2004-2019

Previous years

2018-2019 | 2017-2018 | 2016-2017 | 2015-2016 | 2014-2015 | More years...

Optoelectronics

Course: OPTO (2018-2019)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DIS405M
Discipline Type: DID; Required, Domain
Credits: 3
Enrollment Year: 4, **Sem.** 8

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Se
Laboratory: Instructor: Assist.P. Dr. Petre-Daniel Matasaru, 1 Hours/Week, Group, Ti

Evaluation

Type: **Colloquium**

A: 50%, (Test/Colloquium)
B: 30%, (Seminary/Laboratory/Project Activity)
C: 20%, (Tests during semester)

Grades

Aggregate Results

Attendance

Previous years

2018-2019 | 2017-2018 | 2016-2017 | 2015-2016 | 2014-2015 | 2013-2014 | 2012-201

Optoelectronics, Structures, Technologies, Circuits

Course: OSTC (2013-2014)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: DIS405M
Discipline Type: DIS; Required, Specialty
Credits: 4
Enrollment Year: 4, **Sem.** 7

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assist.P. Dr. Petre-Daniel Matasaru, 1 Hours/Week, Half Group, Timetable:

Evaluation

Type: **Colloquium**

A: 66%, (Test/Colloquium)
B: 17%, (Seminary/Laboratory/Project Activity)
D: 17%, (Homework/Specialty papers)

Grades

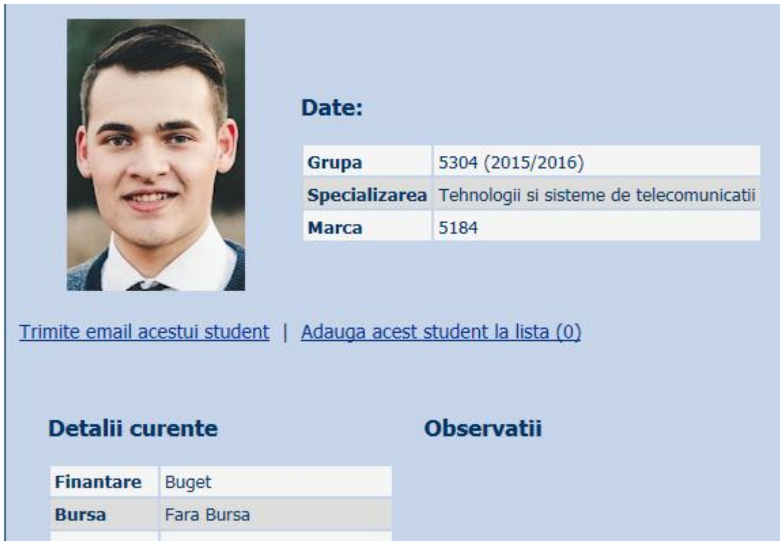
Aggregate Results

Materials

Documentatie

- RF-OPTO
  - http://rf-opto.etti.tuiasi.ro
- Fotografie
  - de trimis prin email: rdamian@etti.tuiasi.ro
  - necesara la laborator/curs

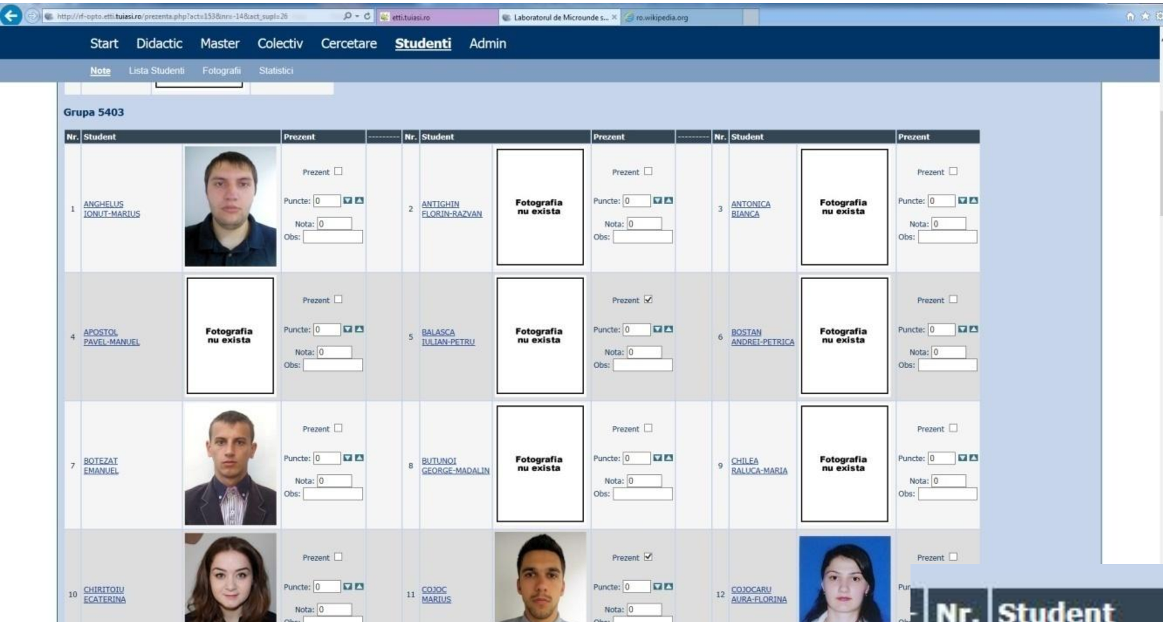
Fotografii


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

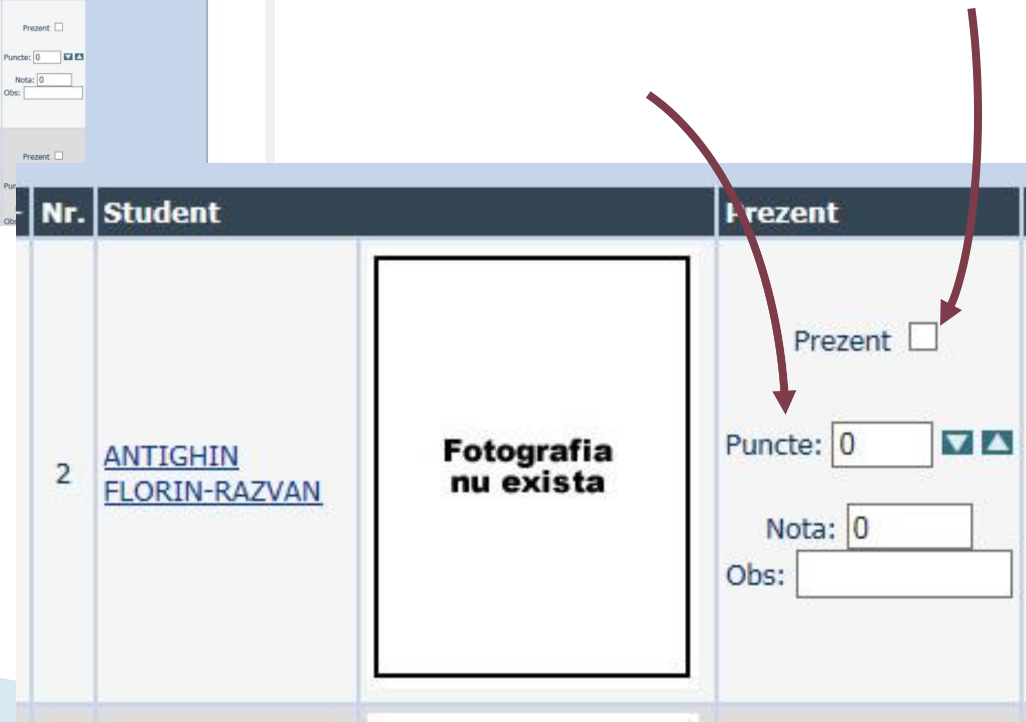

Date:
Grupa 5304 (2015/2016)
Specializarea Tehnologii si sisteme de telecomunicatii
Marca 5244
Trimite email acestui student | Adauga acest student la lista (0)
Detalii curente
Observatii
Finantare Buget
Bursa Bursa de Studii


Date:
Grupa 5304 (2015/2016)
Specializarea Tehnologii si sisteme de telecomunicatii
Marca 5184
Acceseaza ca acest student
Note obtinute
Tip Data Descriere Nota Obs.
TW
N 17/01/2014 10 -
A 17/01/2014 10 7.55
B Laborator Tehnologii Web 9 -
17/01/2014 Tema Tehnologii Web 2013/2014 9

Fotografii



Start
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
Fotografia nu exista
Puncte:
Nota:
Obs:



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

Acces

- ~~Personalizat~~

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

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	-	

Bonus

Disciplina: Optoelectronica, structuri, tehnologii, circuite
An: 2015/2016

Bonus-uri care se aplica la nota de la teza obtinute prin:
- prezenta la curs (0.5p / 3pr)
- 3 miniteste aplicate la curs (max. 3 X 1.5p)
- contributie la site rf-opto (foto <C5=1p, >C5=0.5p)

Nr.	Student	Grupa	Prezente curs	Bonus prezenta	Bonus foto	Bonus T1	Bonus T2	Bonus T3	Total Bonus	Obs.
1	CIOLPAN OCTAVIAN	5306	3	0.5					0.5	-
2	NITA COSTEL-CATALIN	5307	4	0.5	1				1.5	-
3	BARON BOGDAN-IONUT	5405	12	2	1	0.5		0.75	4.25	-

Prezenta

Curs
Laborator

Liste

Studenti care nu pot intra in examen
Bonus-uri acumulate

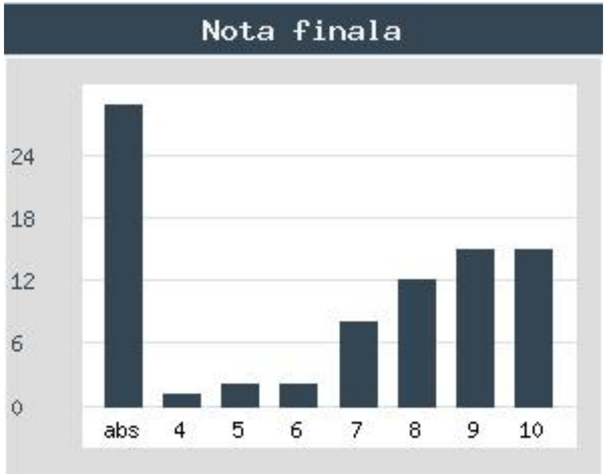
- Minim 7 prezente
- 0.5p/2(3)prez
- 3 teste
- foto <C3/<C5

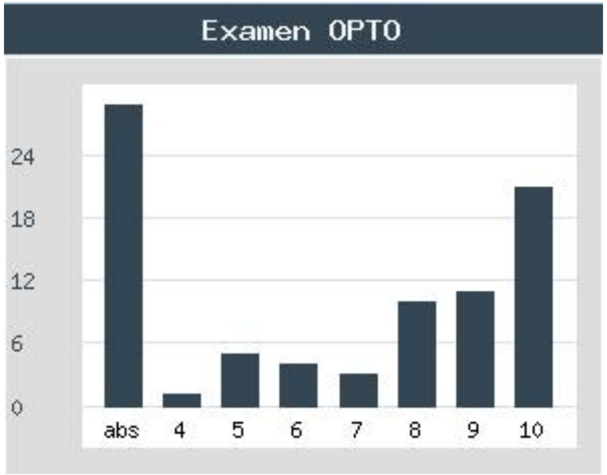
Examen

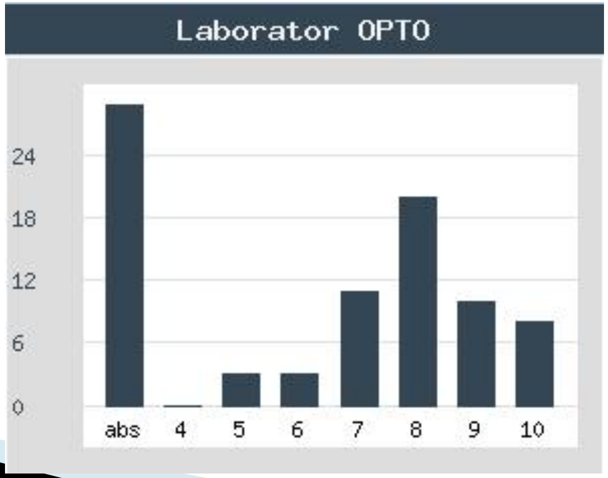
- subiecte **individuale**

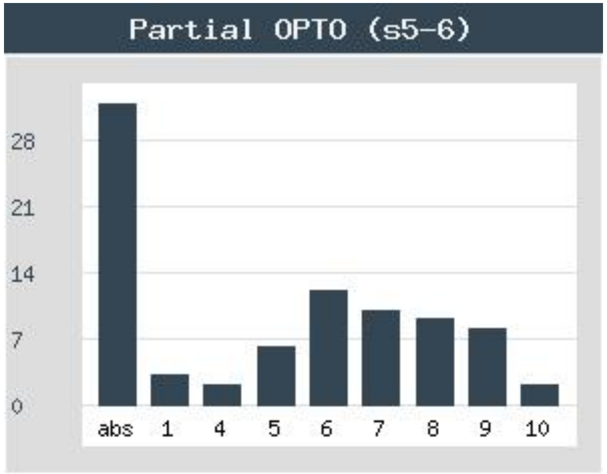
Note

- 2018/2019









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]

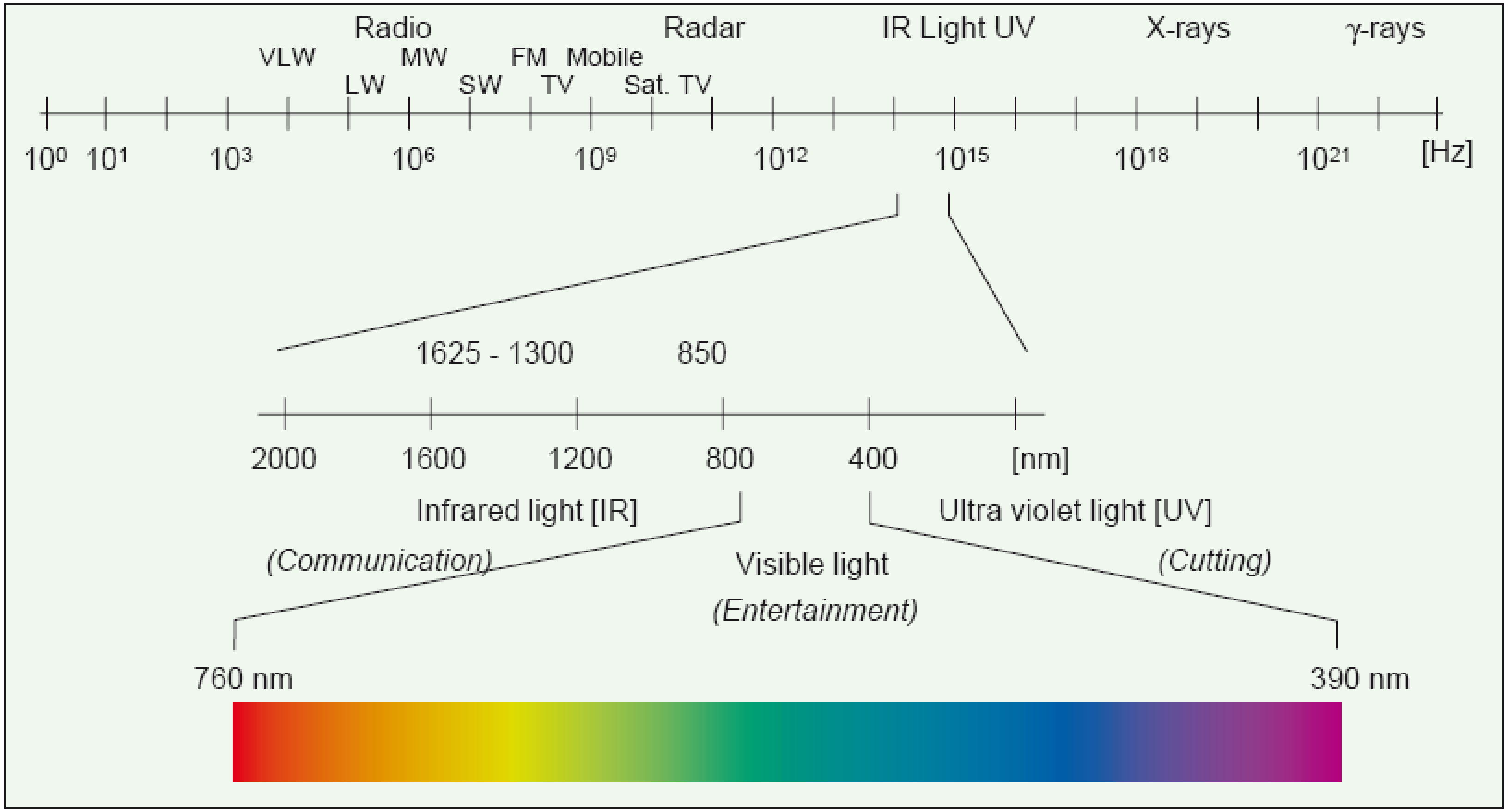
Introducere

Capitolul 1

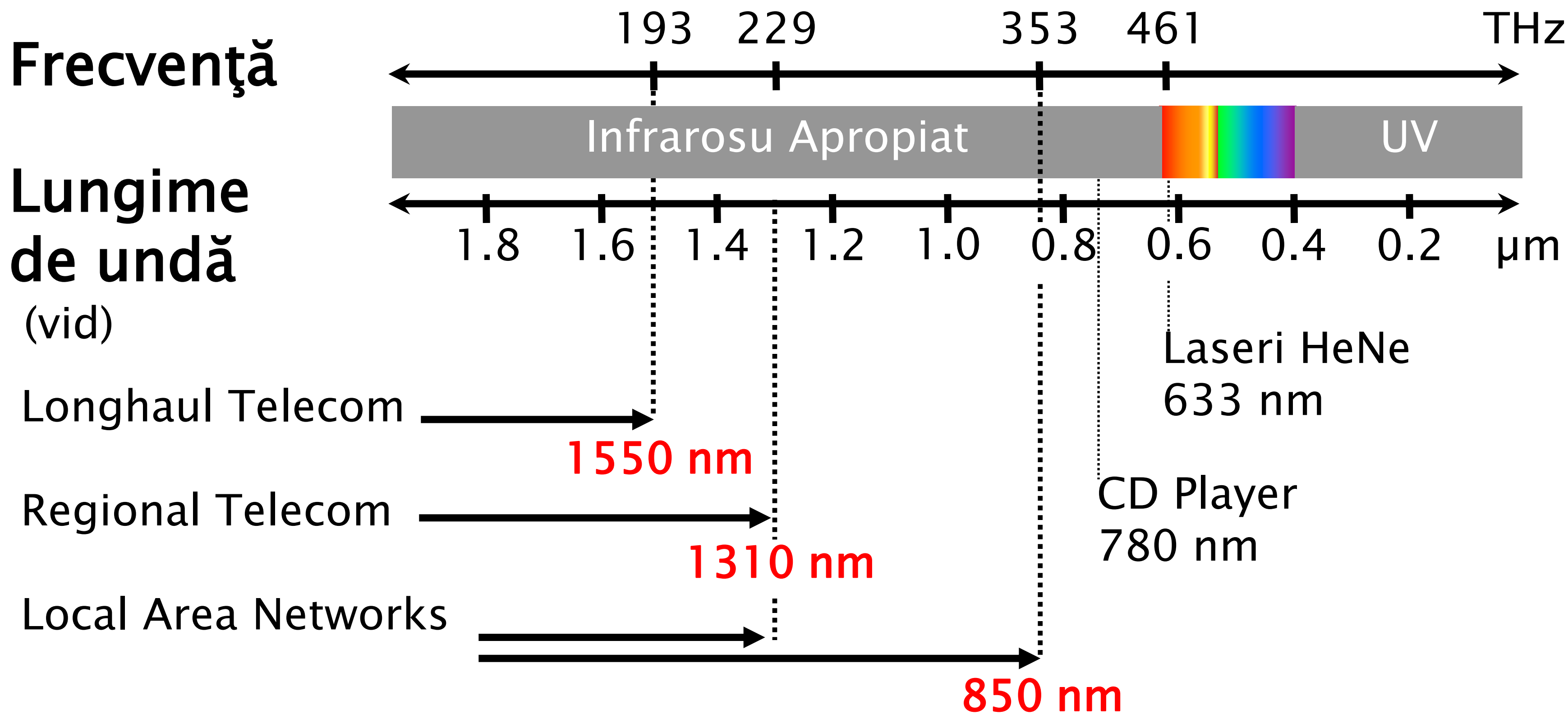
Aplicatii majore

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

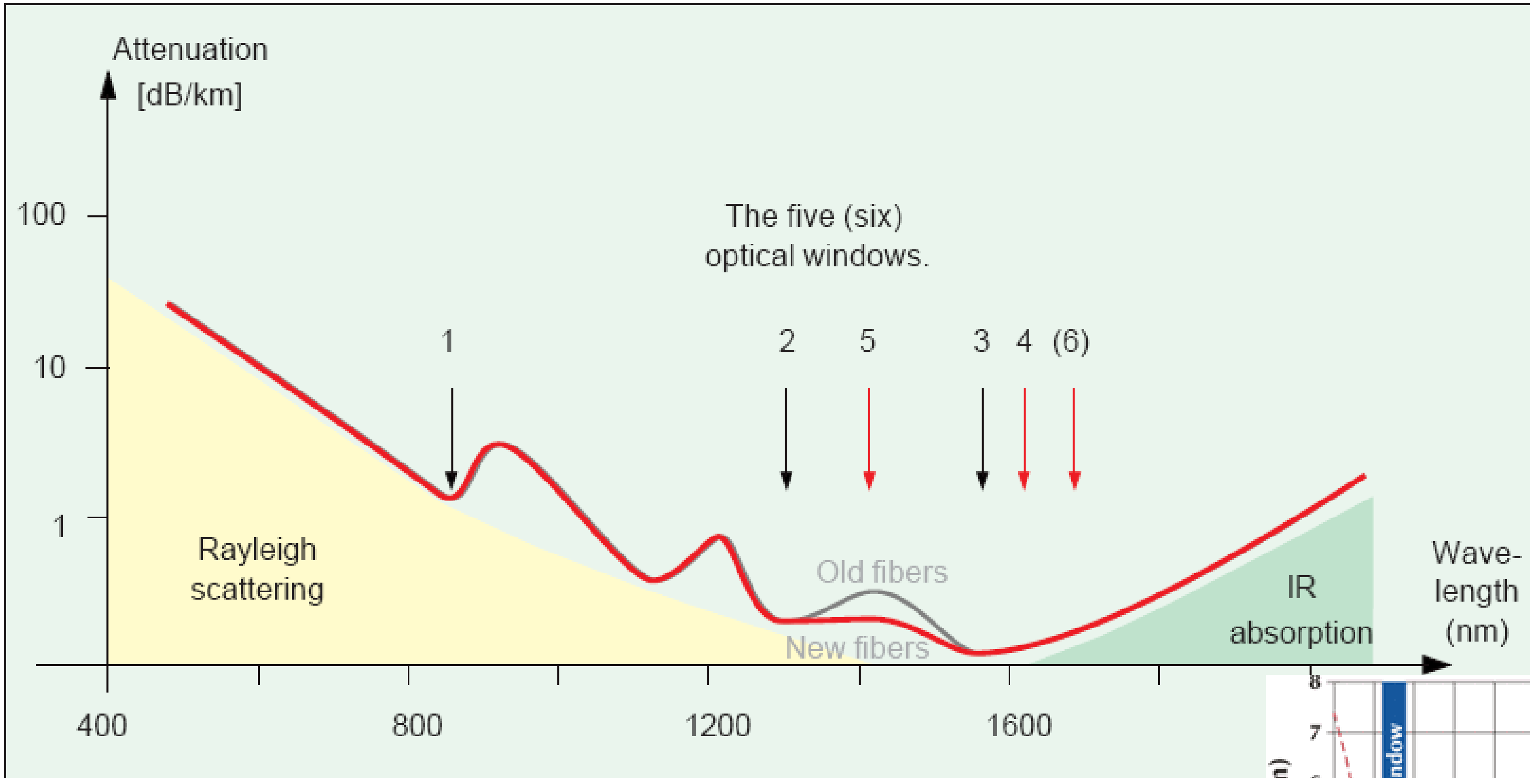
Spectrul electromagnetic

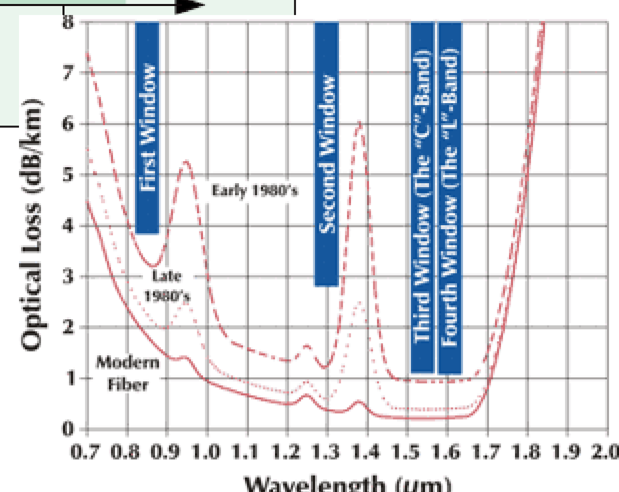


Benzi de lucru in comunicaţiile optice



Atenuarea în fibra optică (SiO_2)





850nm, 1310nm, 1550nm

Aplicatii majore

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

Premiul Nobel, Fizica, 2014

Aplicatii majore

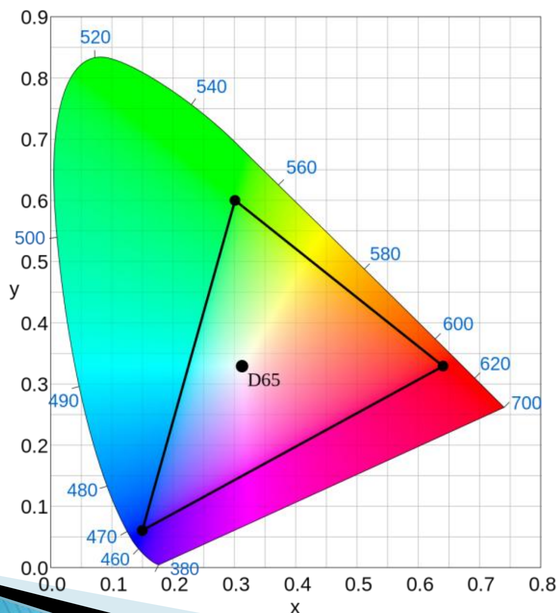
- Comunicatii
  - Infrarosu (InGaAsP)
- Vizibil
  - Spectru vizibil (GaAlAs)
- Iluminare
  - Putere ridicata, lumina alba (GaInN)

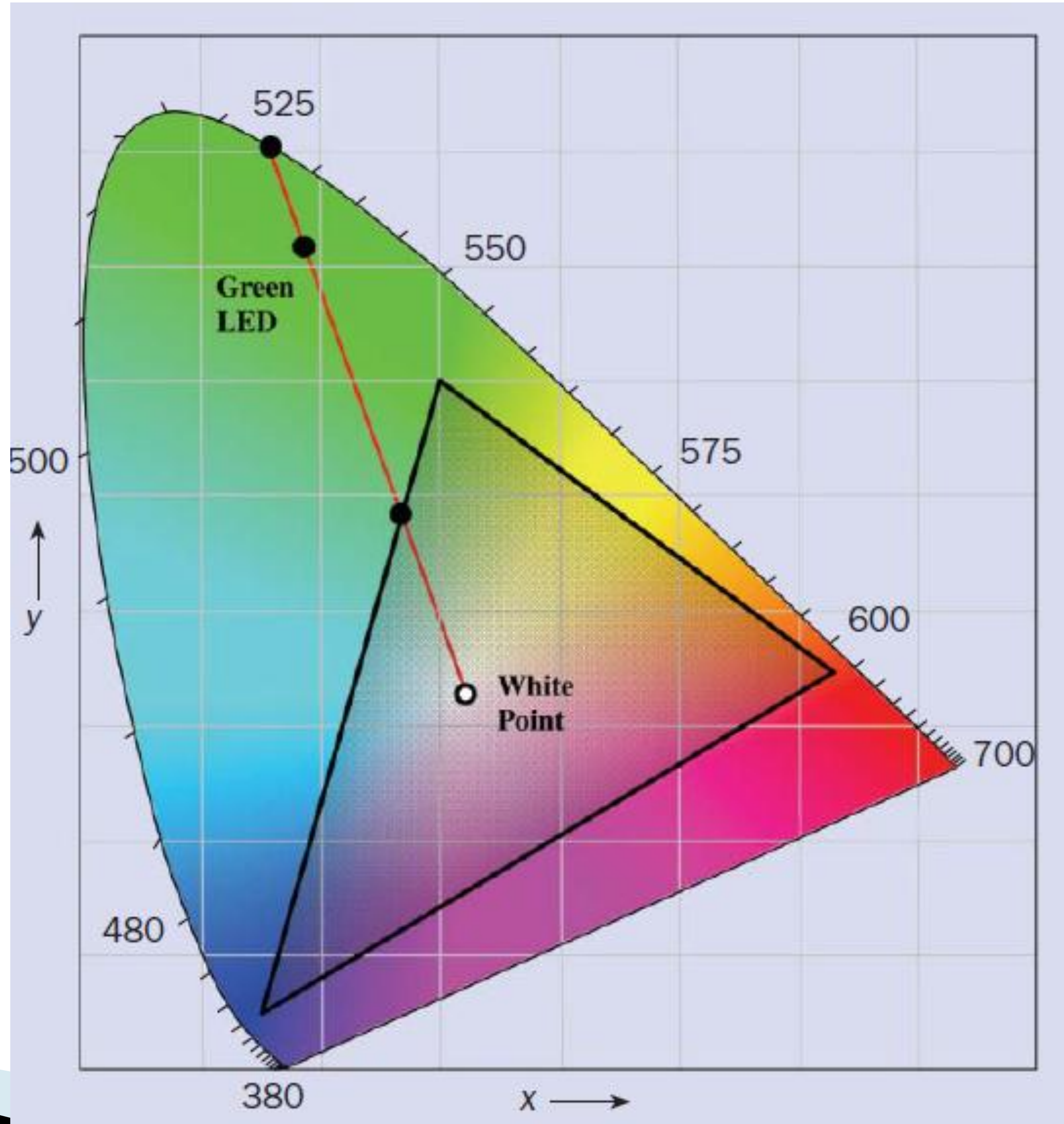
ITU-R BT.709

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].





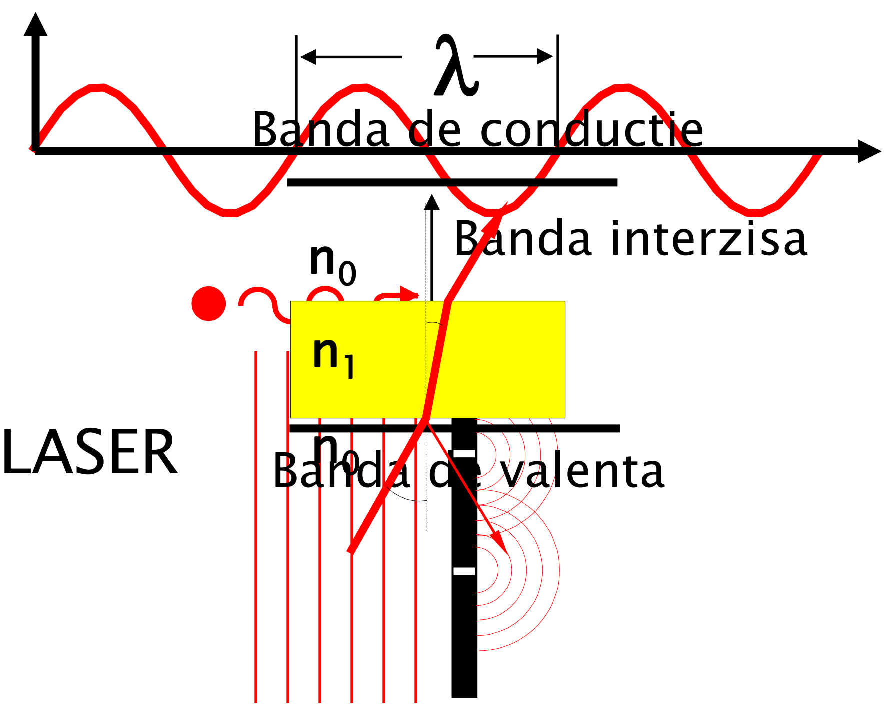
Spectru vizibil

Modelarea luminii

(tot) Capitolul 1

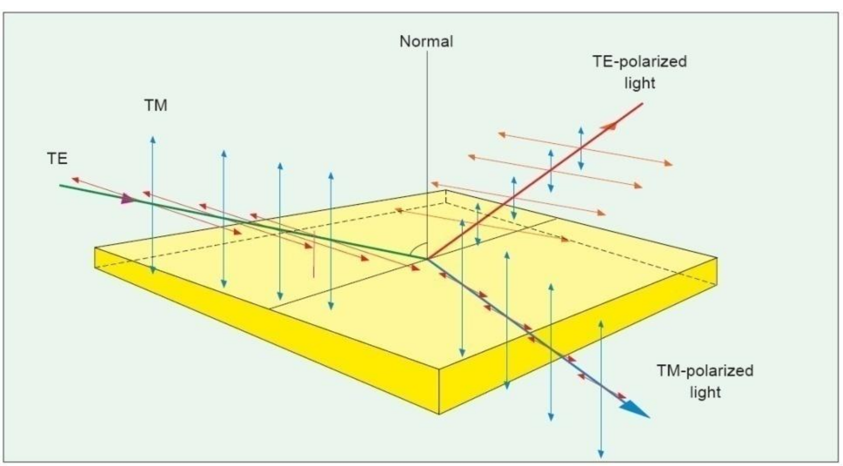
Modelarea luminii

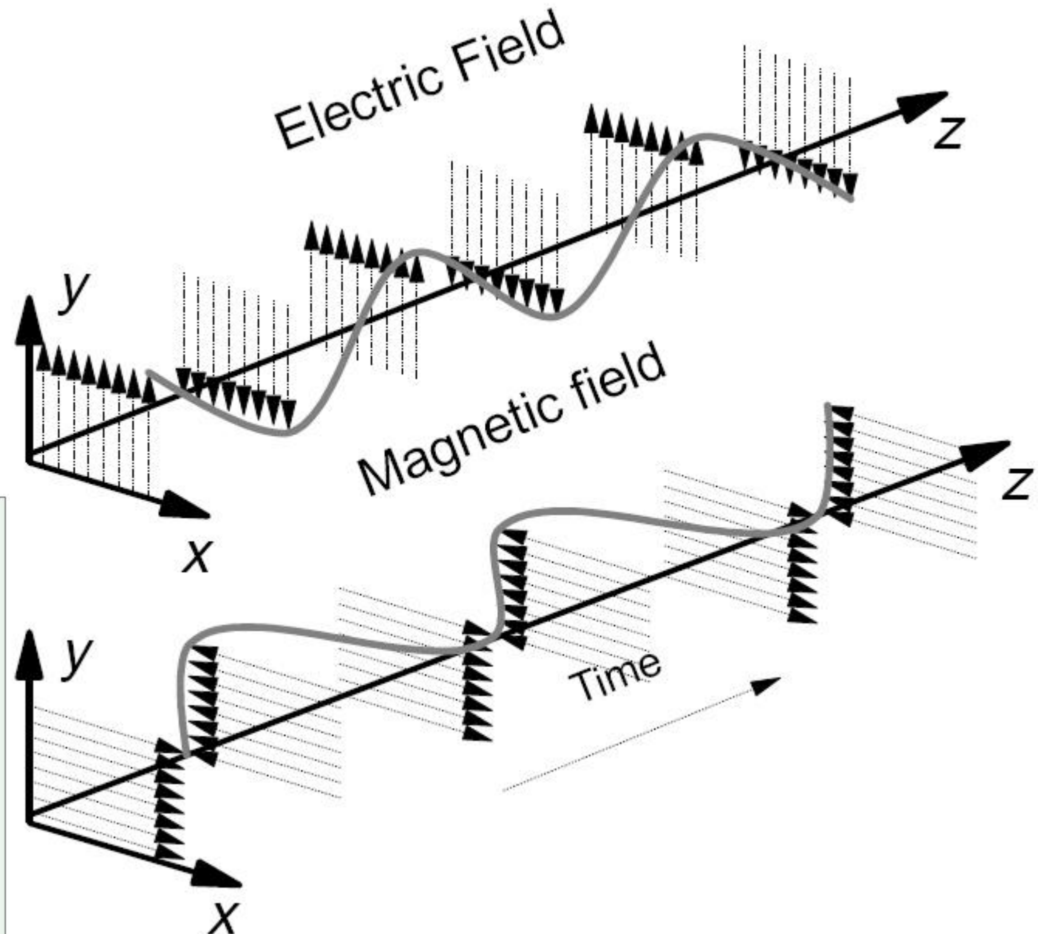
- Undă electromagnetică
  - Ecuaţiile lui Maxwell
  - λ, ε, ω, f
- Teoria cuantică
  - Benzi energetice $E = h\nu$
  - fotoni, emisie stimulată, LASER
- Optică geometrică
  - n, θ
  - raze de lumină
  - intuitivă



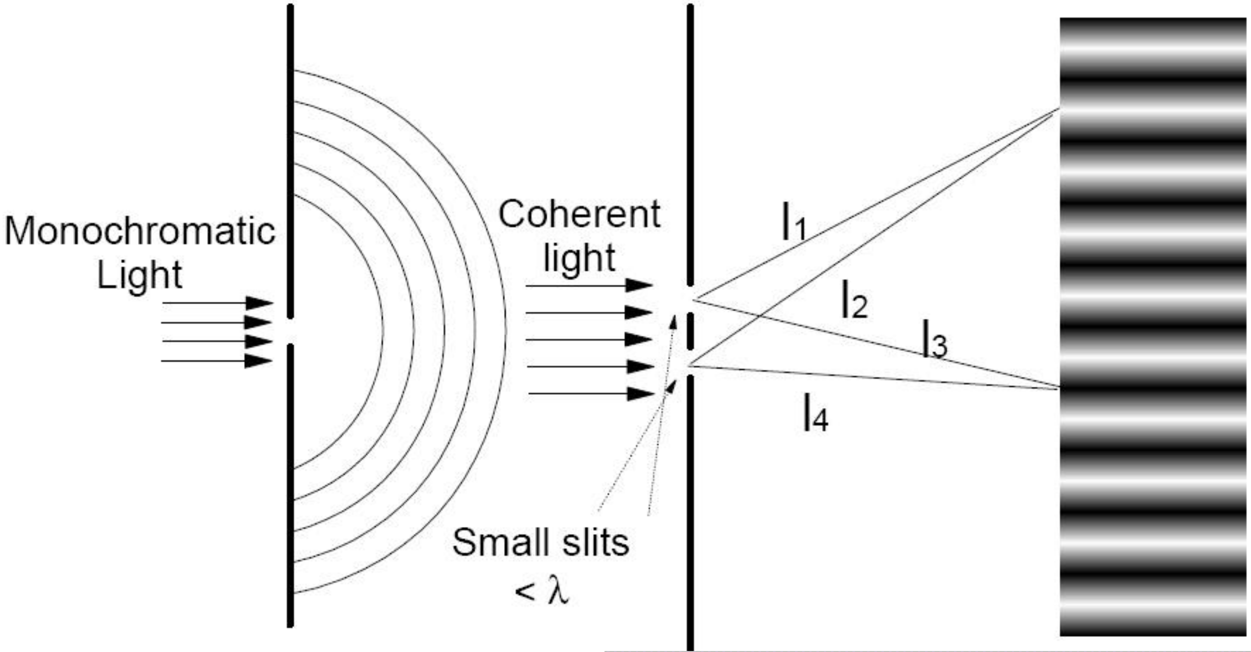
Unda electromagnetica

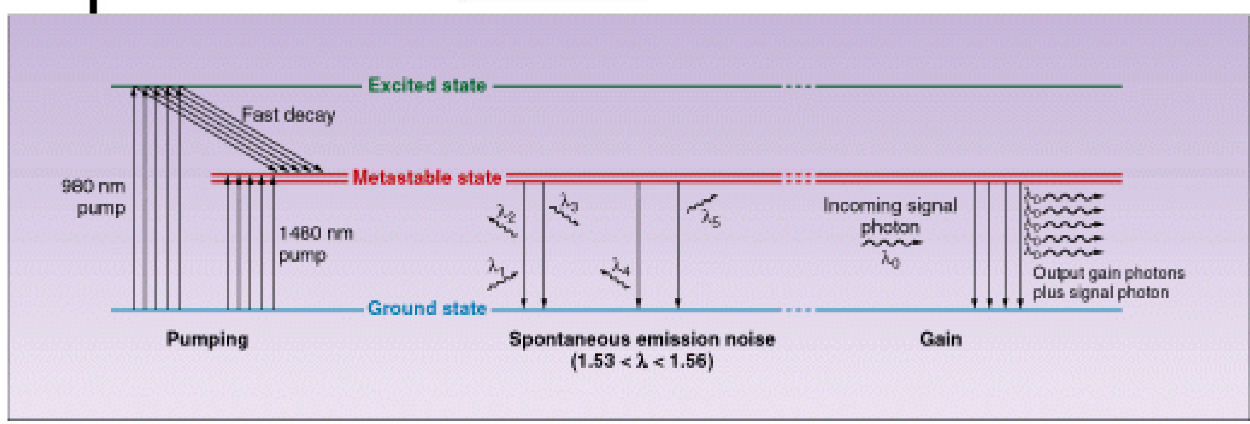
- Dispersie
- Fibre monomod
- Interferenta
- Polarizare





Fotoni/Unda

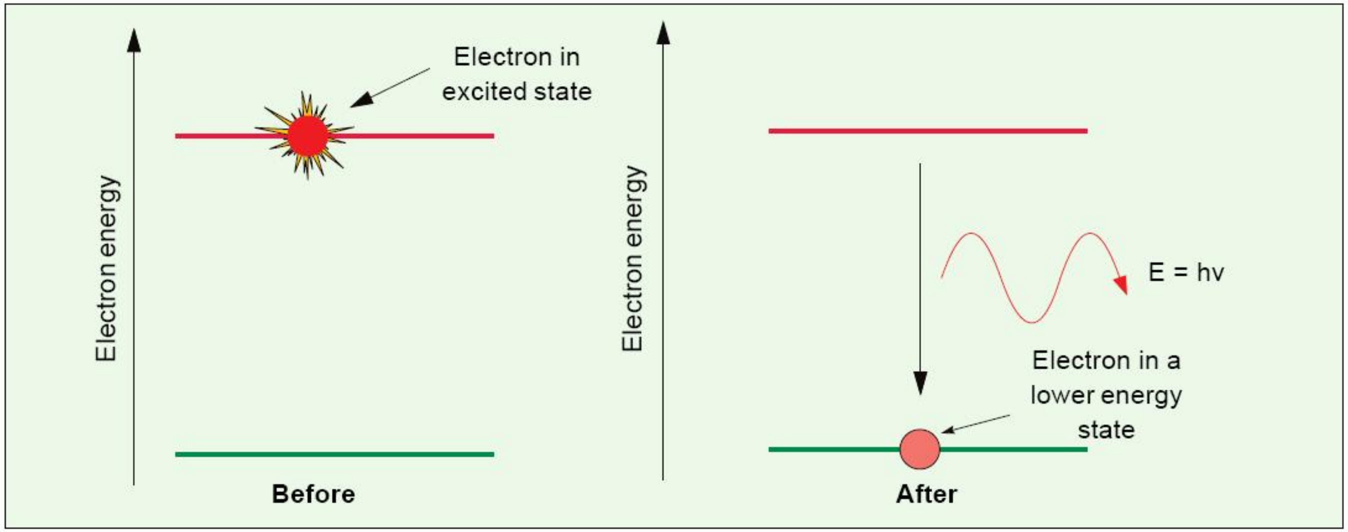




8-FEA-4 97 Fig. 2

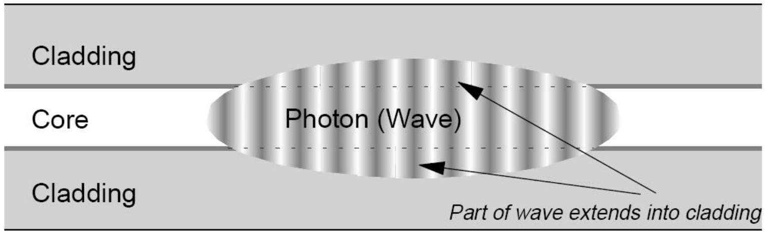
Through the Wormhole
S02E07 How Does the Universe Work

Model cuantic – foton



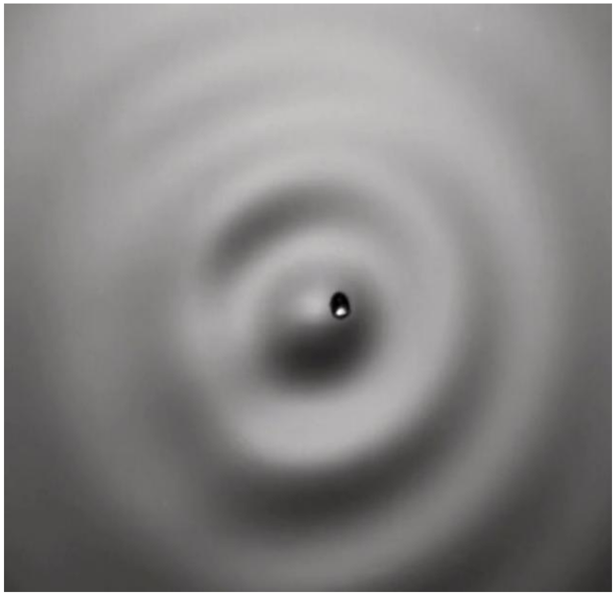
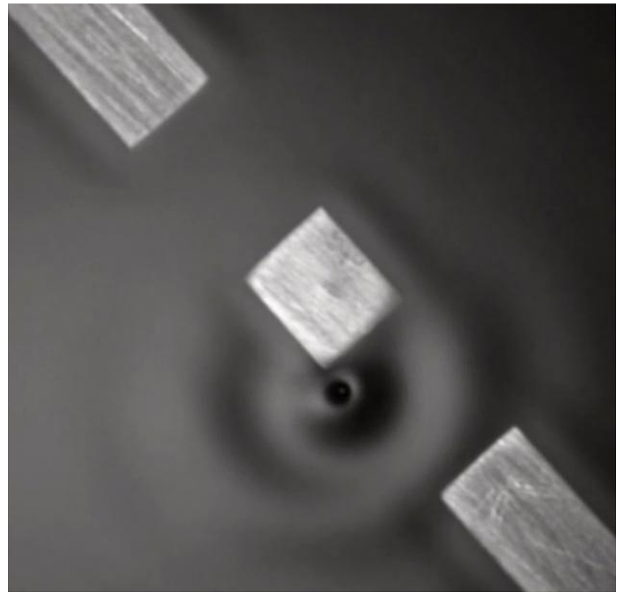
$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}; \quad \lambda[\mu m] = \frac{1.240}{E_g[eV]}$$

- h constanta lui Plank $6.62 \cdot 10^{-32}$ Ws^2
- c viteza luminii in vid $2.998 \cdot 10^8$m/s

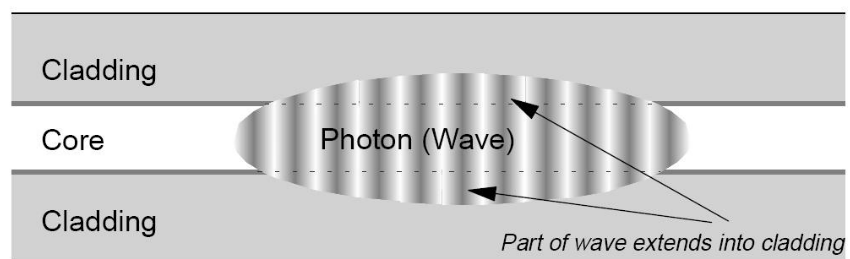


Through the Wormhole
S02E07 How Does the Universe Work

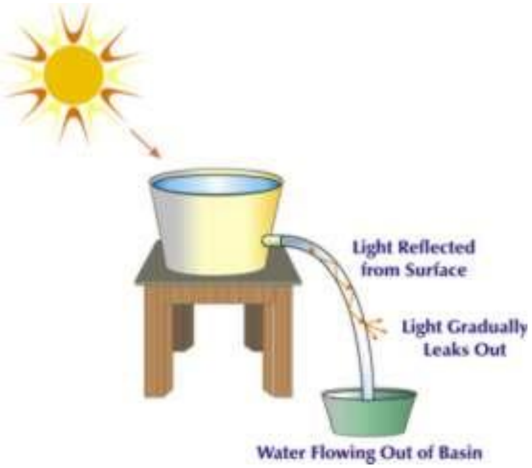
Modelare

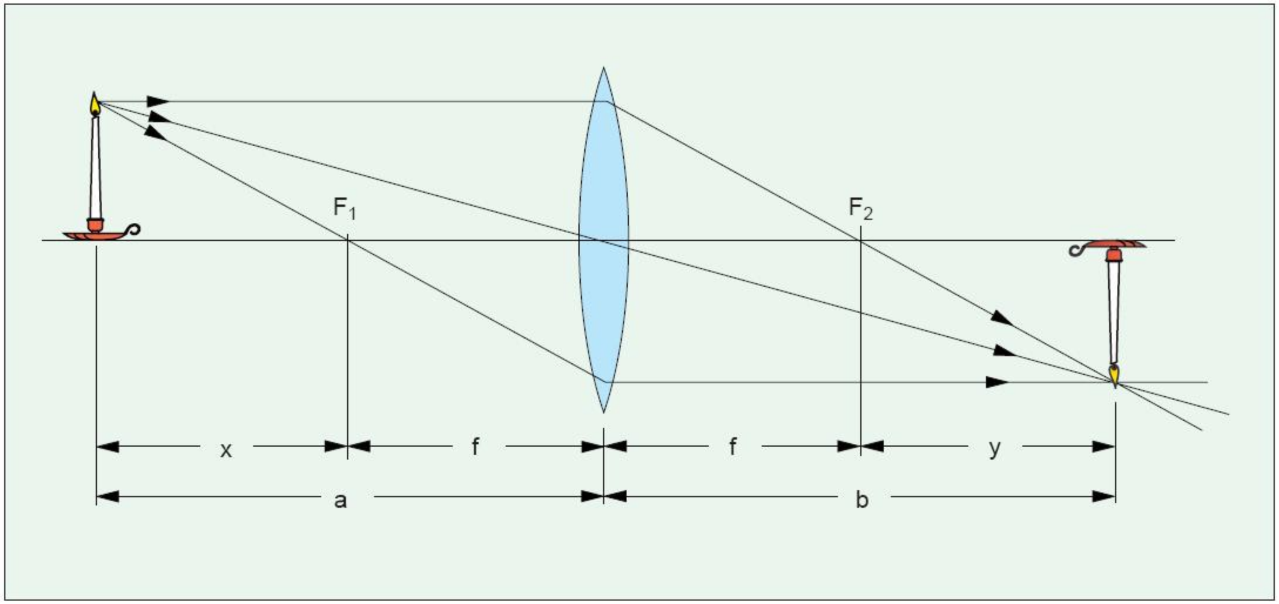



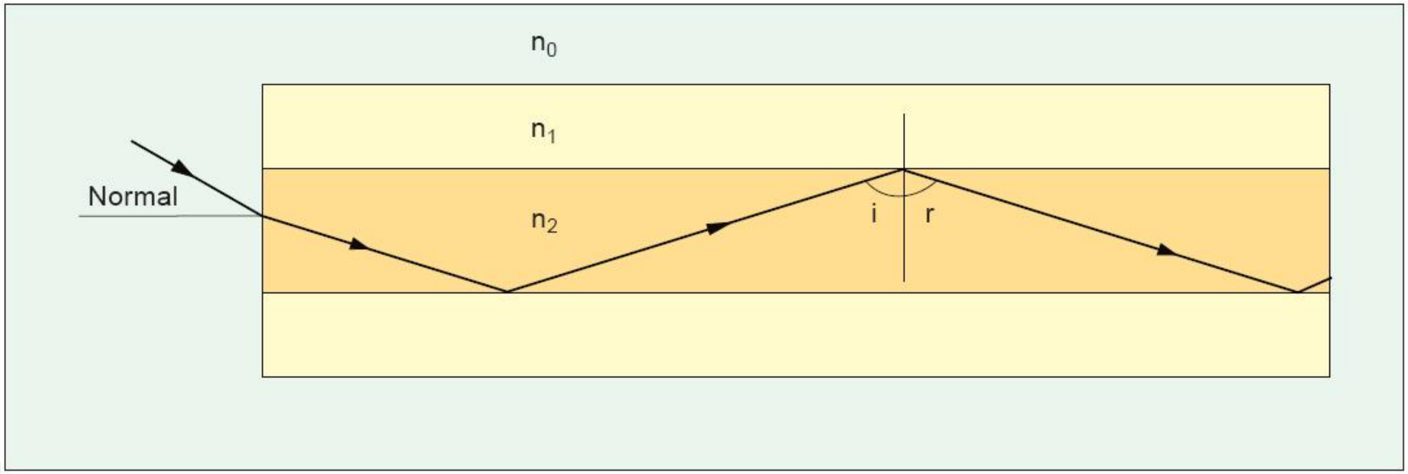

Through the Wormhole
S02E07 How Does the Universe Work



Optica geometrica







Lumina ca undă electromagnetică

Capitolul 2

Cuprins

- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire - splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
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- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

Ecuatiile lui Maxwell

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = \frac{\partial D}{\partial t} + J$$

$$\nabla \cdot D = \rho$$

$$\nabla \cdot B = 0$$

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t}$$

- Ecuatii constitutive

$$D = \varepsilon \cdot E$$

$$B = \mu \cdot H$$

$$J = \sigma \cdot E$$

- In vid

$$\mu_0 = 4\pi \times 10^{-7}\ H/m$$

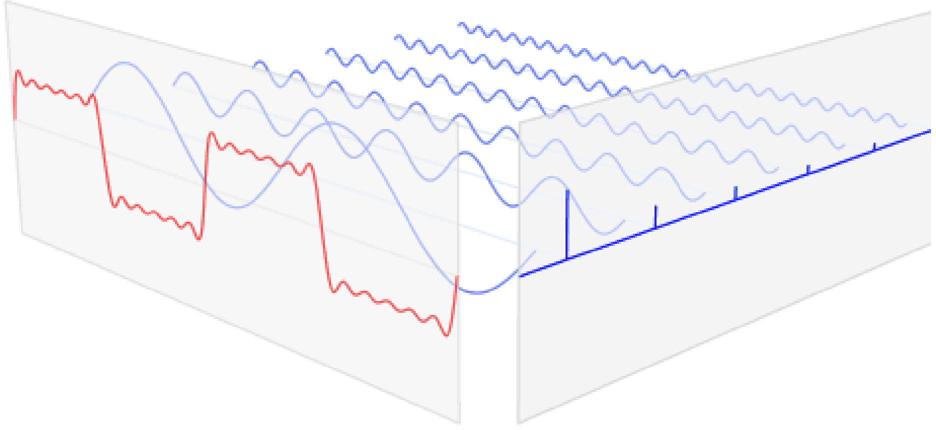
$$\varepsilon_0 = 8{,}854 \times 10^{-12}\ F/m$$

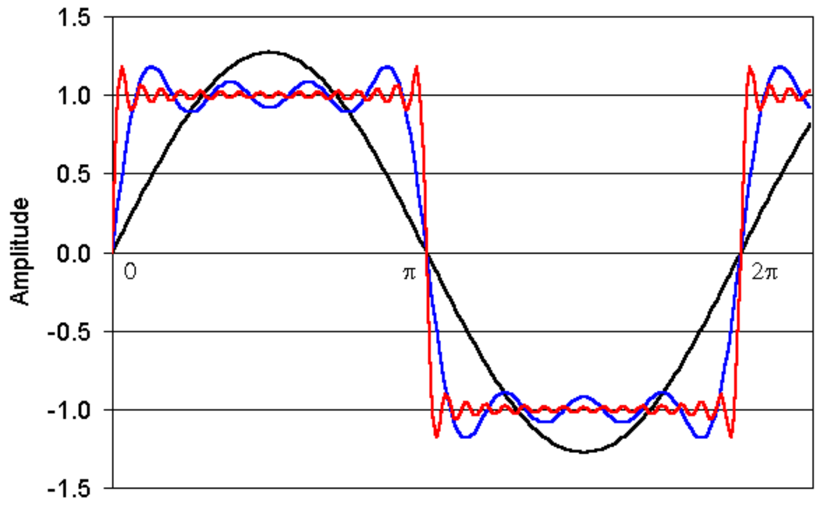
$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8\ m/s$$

Modele matematice

- cazuri particulare in care exista rezolvare analitica
  - semnale cu variaţie armonică în timp, transformata Fourier, spectru

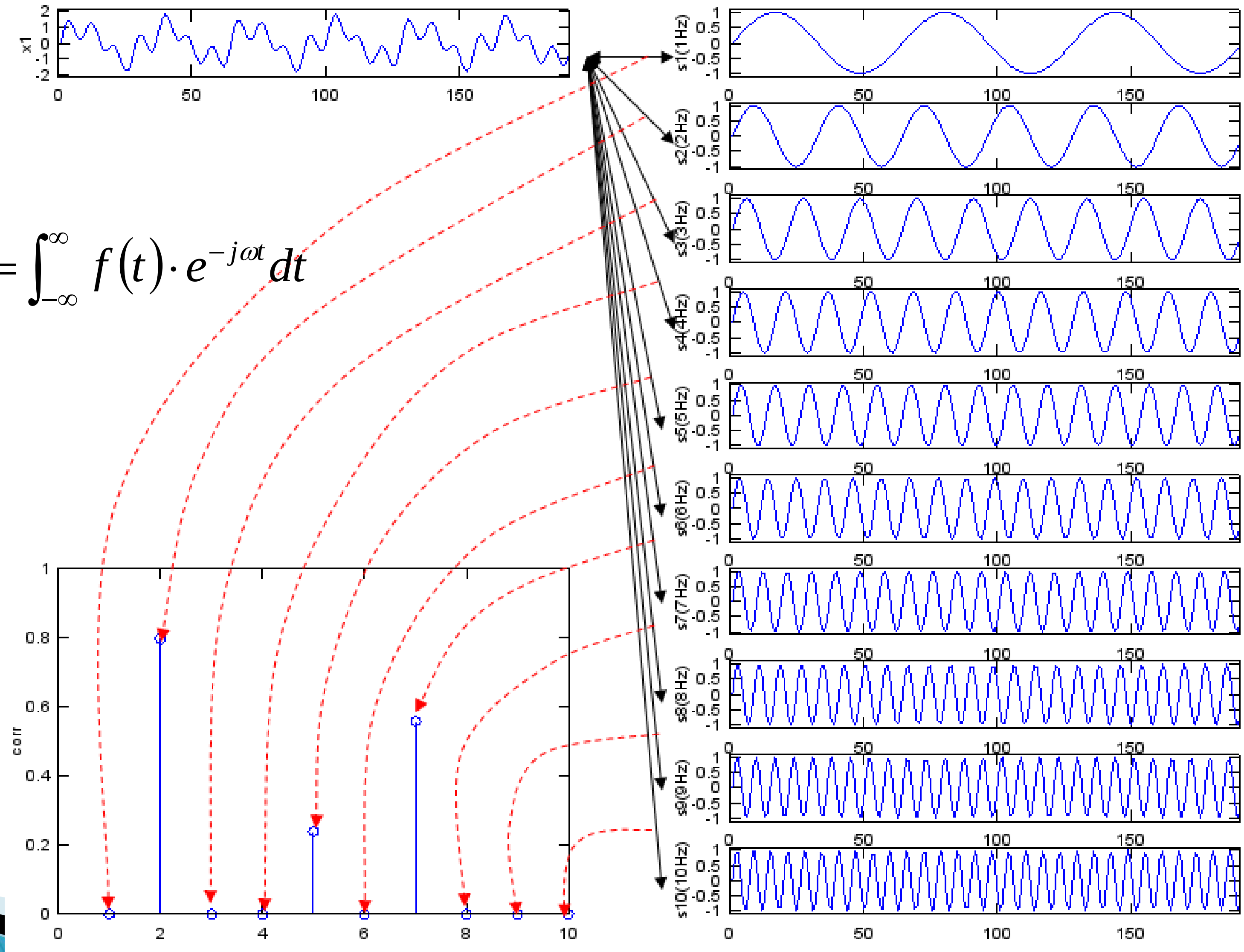
$$X = X_0 e^{j\cdot\omega\cdot t} \qquad \frac{\partial X}{\partial t} = j\cdot\omega\cdot X \qquad g(\omega) = \int_{-\infty}^{\infty} f(t)\cdot e^{-j\omega t}dt \qquad f(t) = \int_{-\infty}^{\infty} g(\omega)\cdot e^{j\omega t}d\omega$$



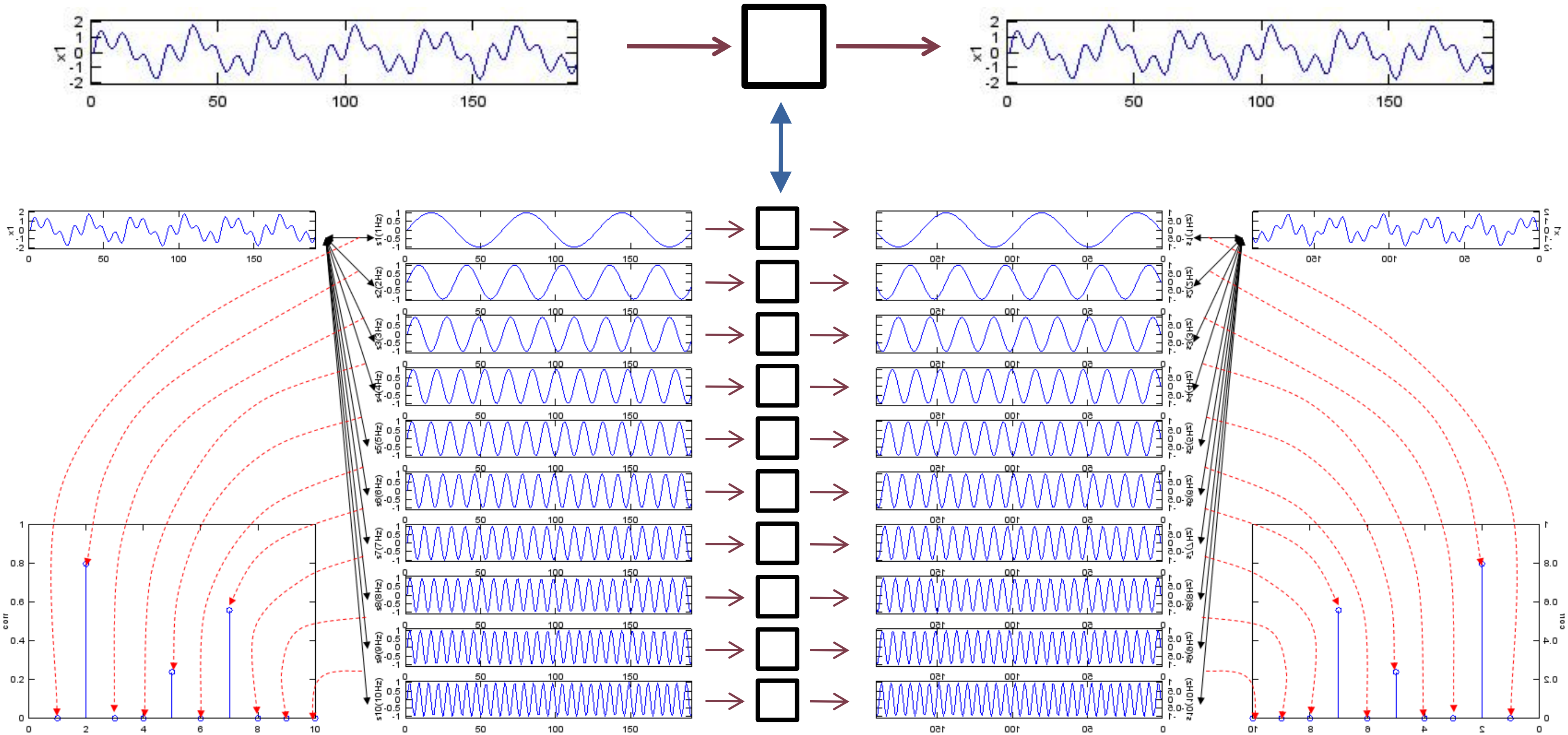


Modele matematice

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



Modele matematice



$$F(\omega)=\int_{-\infty}^{\infty} f(t)\cdot e^{-j\omega t}dt \qquad G(\omega)[F(\omega)] \qquad g(t)=\int_{-\infty}^{\infty} G(\omega)\cdot e^{j\omega t}d\omega$$

Câmpuri electromagnetic cu variaţie armonică în timp

$$X = X_0 e^{j\cdot\omega\cdot t} \qquad \frac{\partial X}{\partial t} = j\cdot\omega\cdot X$$

- Simplificarea ecuatiilor lui Maxwell

$$\nabla^2 E + \omega^2 \varepsilon\mu E = j\omega\mu J + \frac{1}{\varepsilon}\nabla\rho$$

$$\nabla^2 H + \omega^2 \varepsilon\mu H = -\nabla \times J$$

$$\nabla \cdot E = \frac{\rho}{\varepsilon}$$

$$\nabla \cdot H = 0$$

- Ecuaţiile Helmoltz sau ecuaţiile de propagare

Mediu lipsit de sarcini electrice

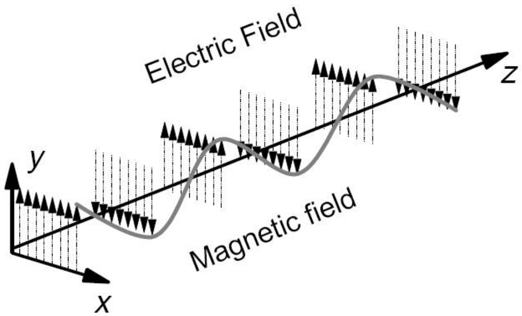
$$\nabla^2 E - \gamma^2 E = 0$$

$$\nabla^2 H - \gamma^2 H = 0$$

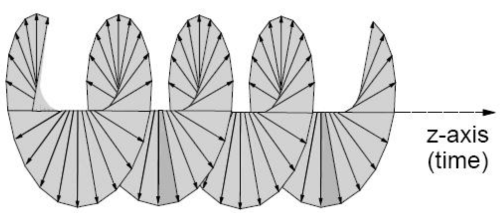
$$\gamma^2 = -\omega^2 \varepsilon\mu + j\omega\mu\sigma$$

γ – Constanta de propagare

Solutia ecuatiilor de propagare



Propagare



Polarizare circulara

Camp electric dupa directia Oy, ← prin <u>alegerea</u> judicioasa
propagare dupa directia Oz ← a sistemului de referinta

$$E_y = E_+ e^{-\gamma \cdot z} + E_- e^{\gamma \cdot z}$$

$$\gamma = \sqrt{-\omega^2 \varepsilon\mu + j\omega\mu\sigma} = \alpha + j \cdot \beta$$

Exista numai unda progresiva E_+ => A

$$E_y = Ae^{-(\alpha + j \cdot \beta) \cdot z}$$

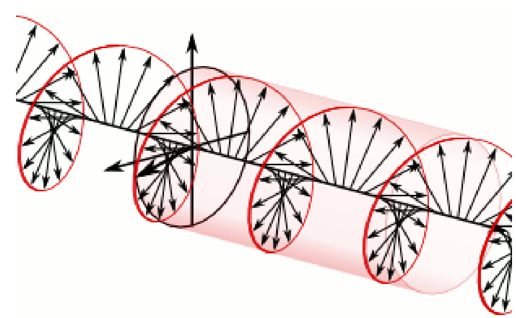
Camp armonic

$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$$

Amplitudine

Atenuare

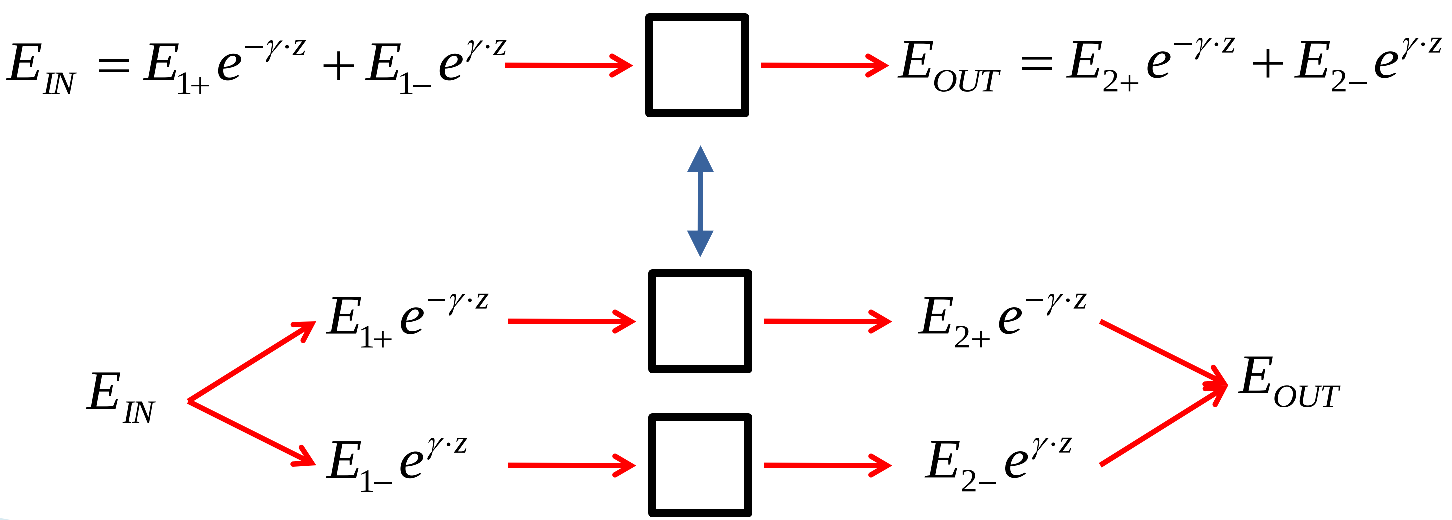
Propagare
(variatie in timp si spatiu)



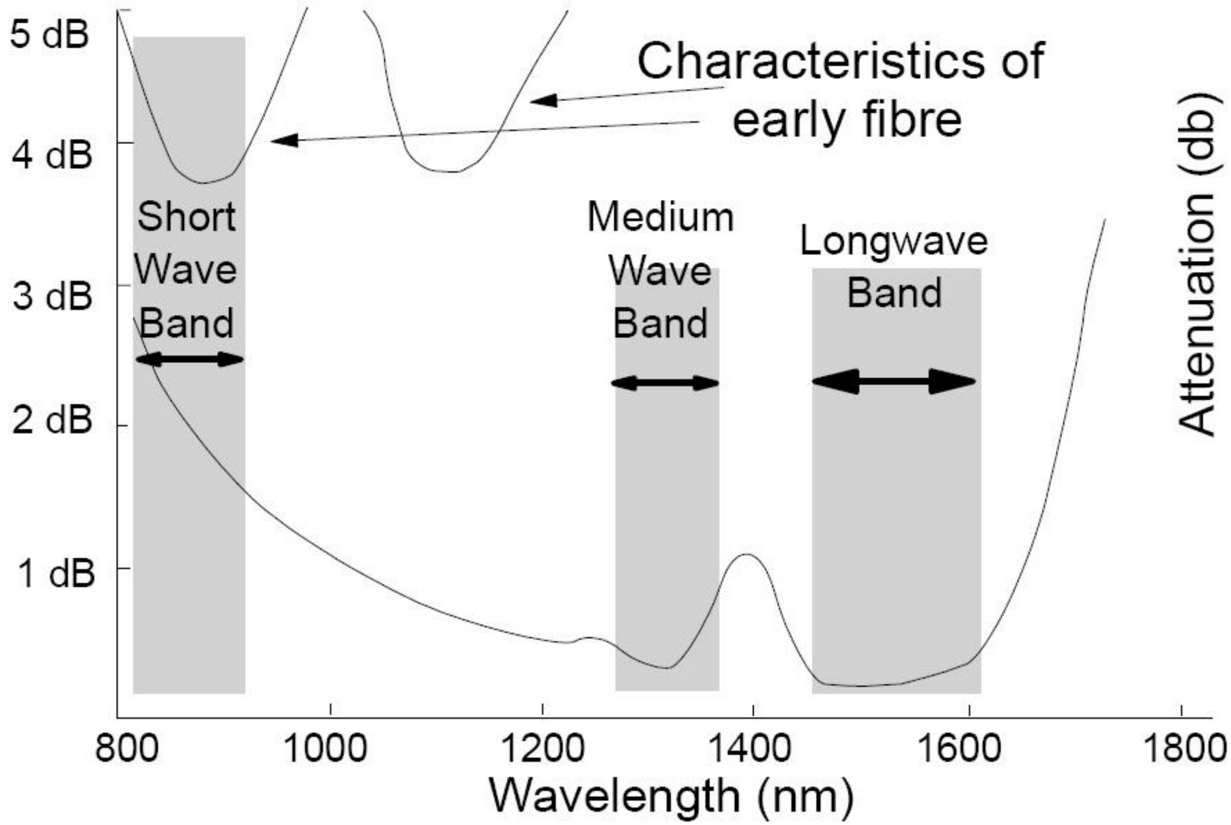
Modele matematice

- cazuri particulare in care exista rezolvare analitica
  - unda
    - incidenta
    - reflectata
  - unda
    - directa
    - inversa

$$E_y = E^+ \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t - \beta \cdot z)} + E^- \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega t + \beta \cdot z)}$$



Atenuarea pe 1 km in SiO_2



Atenuare

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

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

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

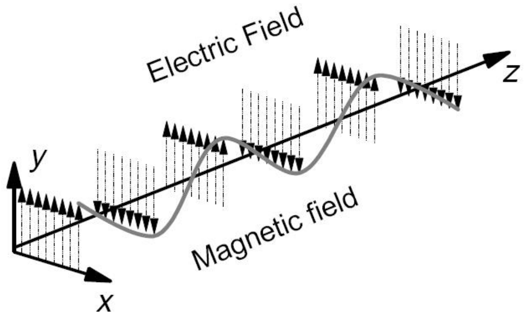
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

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

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

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

Parametri de propagare



$$\nabla \times E = -j\omega\mu \cdot H$$

$$H_x = \frac{j\gamma \cdot E_y}{\omega\mu}$$

Mediu fara pierderi, $\sigma = 0$ $\gamma = j\omega \cdot \sqrt{\varepsilon\mu}$

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\varepsilon}}$$ Impedanta intrinseca a mediului

$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$ punctele de faza constanta: $(\omega \cdot t - \beta \cdot z) = \mathrm{const}$

Viteza de faza $v = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{\varepsilon\mu}}$

Viteza de grup $v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta}$ in medii dispersive unde $\beta = \beta(\omega)$

Parametri de propagare

- In vid

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \qquad v = v_g = c_0 \qquad c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8 \ m/s$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f} \qquad T = \frac{2\pi}{\omega} = \frac{1}{f}$$

Periodicitate in spatiu   Periodicitate in timp

- In mediu nedispersiv ε_r

$$c = \frac{1}{\sqrt{\varepsilon \cdot \mu_0}} = \frac{1}{\sqrt{\varepsilon_0 \varepsilon_r \cdot \mu_0}} = \frac{c_0}{\sqrt{\varepsilon_r}}$$

$n = \sqrt{\varepsilon_r}$ Indice de refractie al mediului $c = \frac{c_0}{n}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f} \qquad \lambda = \frac{2\pi}{\beta} = \frac{c}{f} \qquad \lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

Parametri, dependenta de mediu

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \qquad c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8 \ m/s$$

$n = 1$

$$T = \frac{2\pi}{\omega} = \frac{1}{f} \qquad \lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f}$$

$$\eta = \frac{\eta_0}{n} \qquad c = \frac{c_0}{n}$$

$n = \sqrt{\varepsilon_r}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f} \qquad \lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

$$\lambda = \lambda(n)$$
$$f = \text{indep.}$$

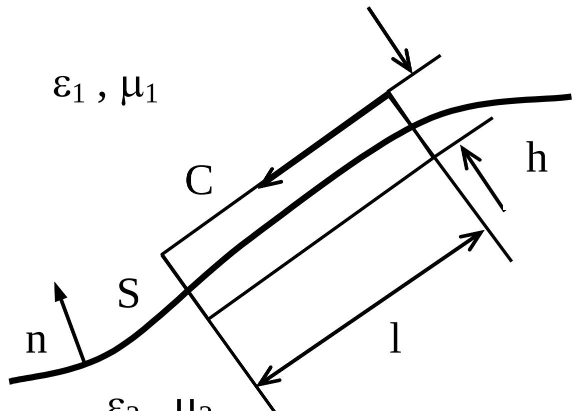
ITU G.692

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

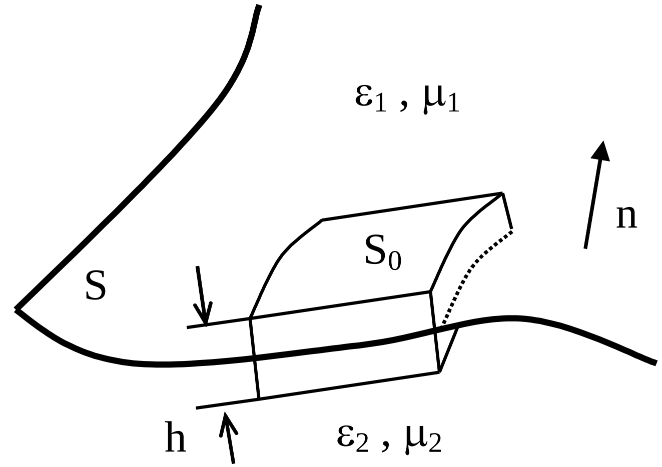
SI

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

Condiţii la limita de separaţie între două medii



a)



b)

$$n \times (E_1 - E_2) = 0 \qquad n \cdot (D_1 - D_2) = \rho_S$$

$$n \times (H_1 - H_2) = J_S \qquad n \cdot (B_1 - B_2) = 0$$

Moduri in medii delimitate

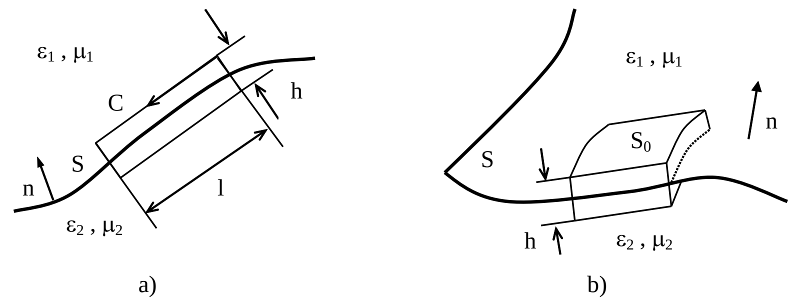
- Câmpuri electromagnetice cu variaţie armonică în timp
  - simplificarea ecuatiilor lui Maxwell

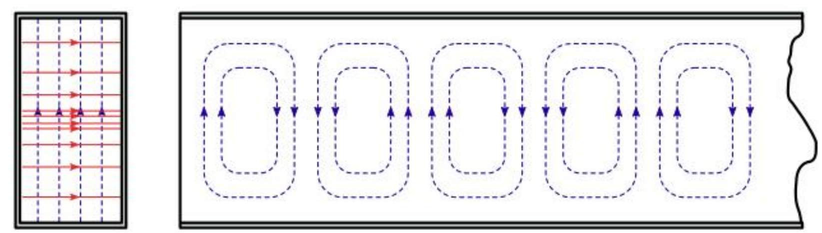
$$X = X_0 e^{j\cdot\omega\cdot t} \qquad \frac{\partial X}{\partial t} = j\cdot\omega\cdot X \qquad g(\omega) = \int_{-\infty}^{\infty} f(t)\cdot e^{-j\omega t}dt \qquad f(t) = \int_{-\infty}^{\infty} g(\omega)\cdot e^{j\omega t}d\omega$$

- In medii delimitate solutiile ecuatiilor lui Maxwell trebuie sa verifice conditiile la limita
  - solutiile trebuie sa respecte anumite conditii suplimentare

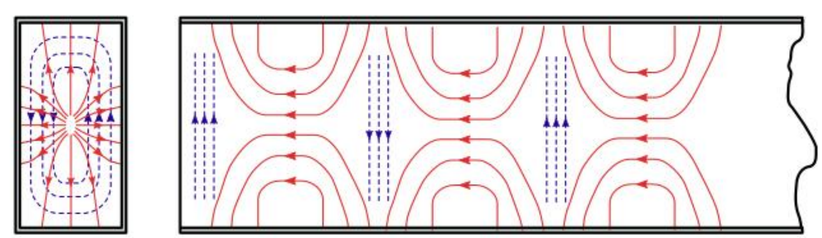
Moduri in medii delimitate

- Câmpul electric trebuie sa fie perpendicular pe un perete metalic sau nul
- Câmpul magnetic trebuie sa fie tangent la un perete metalic sau nul

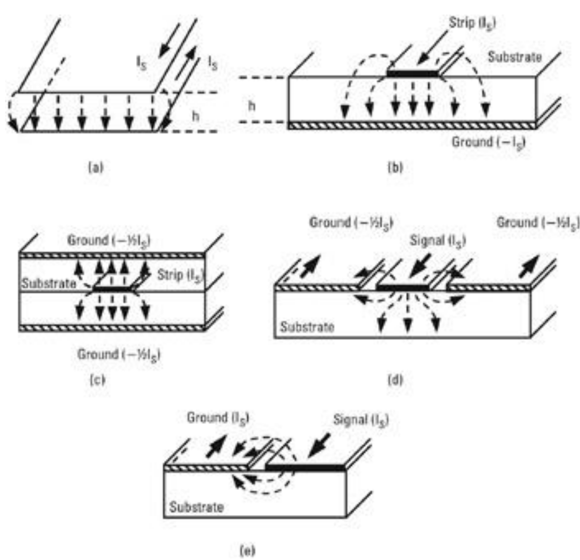




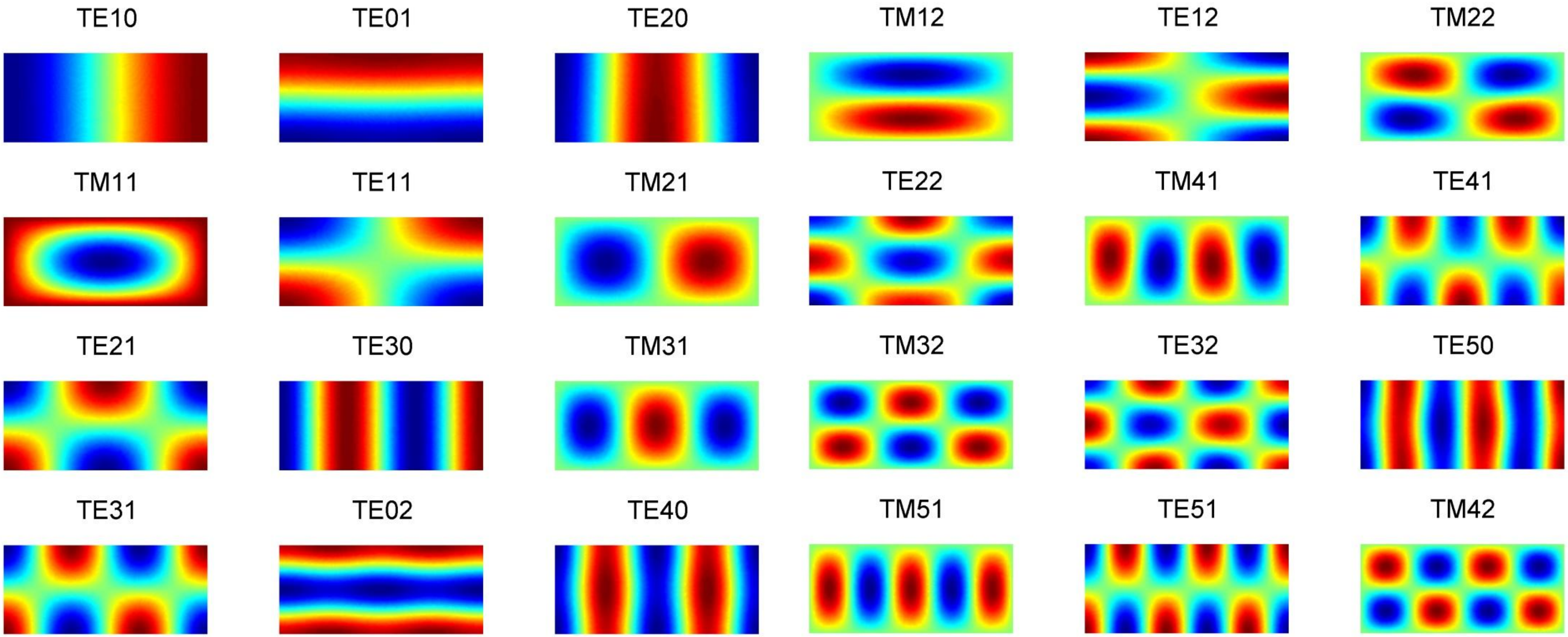
TE10



TM11



Moduri in medii delimitate



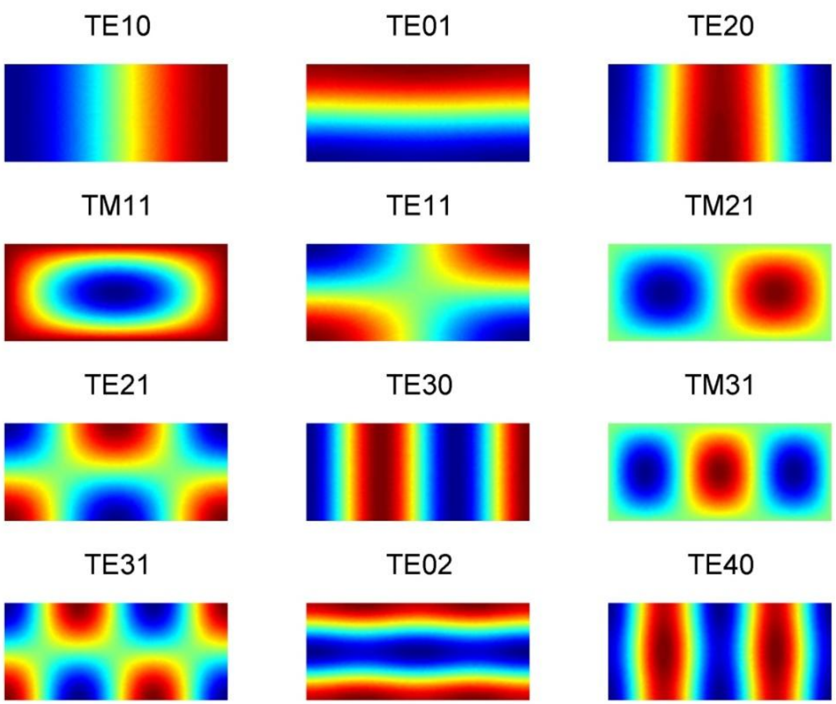
- Similar cu transformata Fourier

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

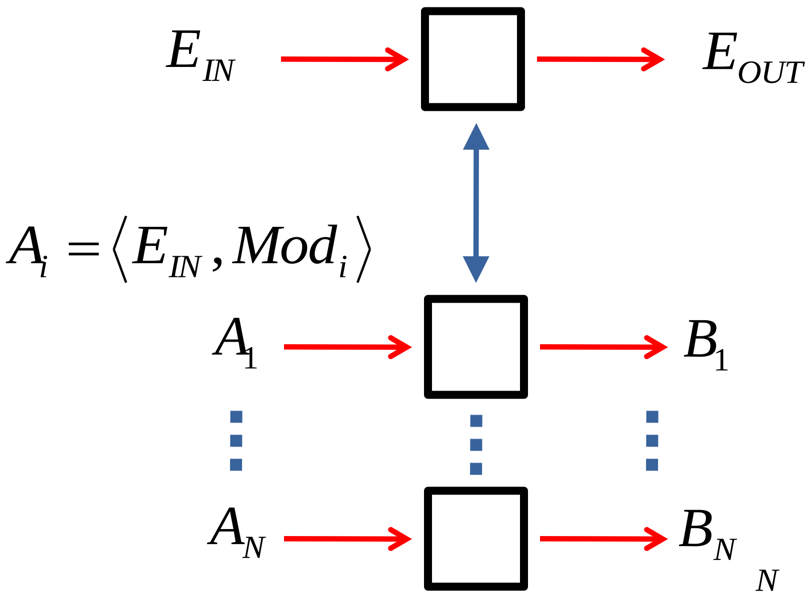
$$E^{+},E^{-}=\sum_{1}^{\infty} A_i \cdot Mod_i \qquad A_i=\langle E, Mod_i \rangle$$

Modele matematice

- cazuri particulare in care exista rezolvare analitica
  - moduri in medii delimitate



$$E = \sum_{1}^{\infty} A_i \cdot Mod_i \qquad A_i = \langle E, Mod_i \rangle$$



$$E_{OUT} = \sum_{1}^{N} B_i \cdot Mod_i$$

Ghid cilindric dielectric

- Ecuațiile 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)

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

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

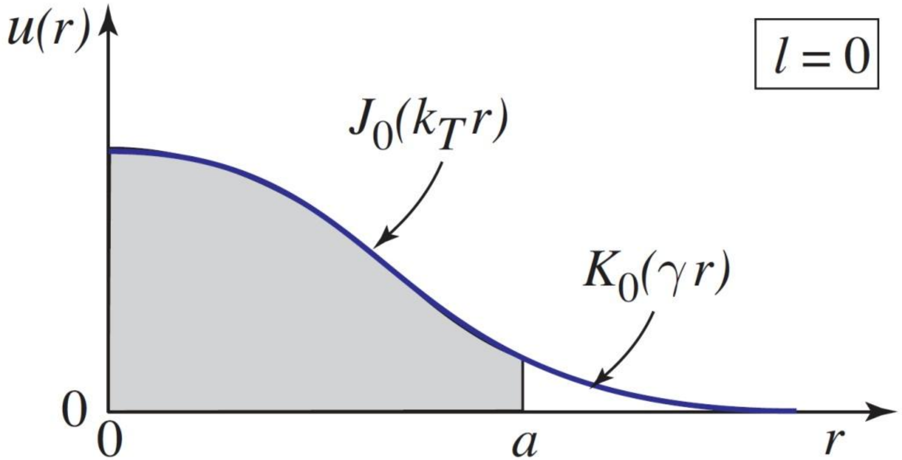
$$\frac{d^2 u}{dr^2} + \frac{1}{r}\frac{du}{dr} + \left(k_T^2 - \frac{l^2}{r^2} \right) u = 0, \qquad r < a$$

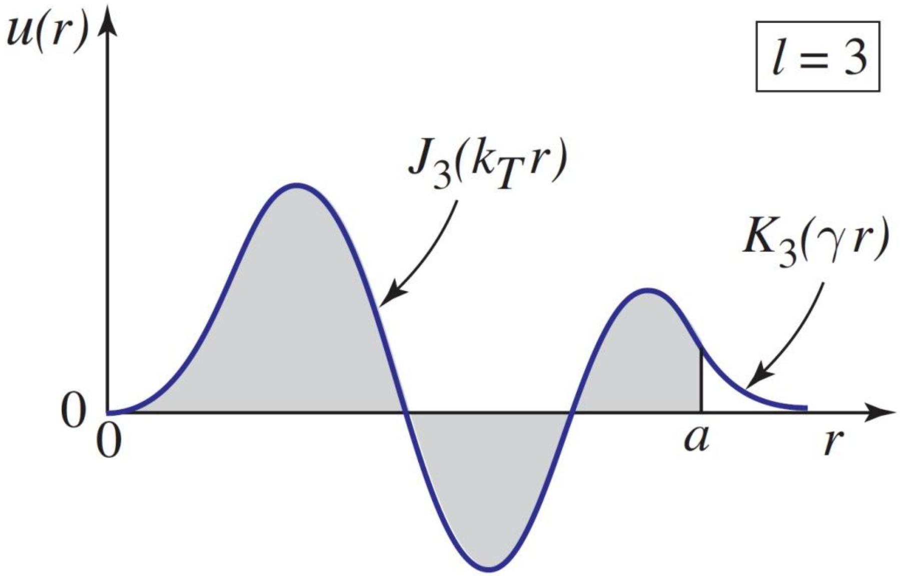
$$\frac{d^2 u}{dr^2} + \frac{1}{r}\frac{du}{dr} - \left(\gamma^2 + \frac{l^2}{r^2} \right) u = 0, \qquad r > a$$

Ghid cilindric dielectric

- soluții proporționale cu funcții Bessel

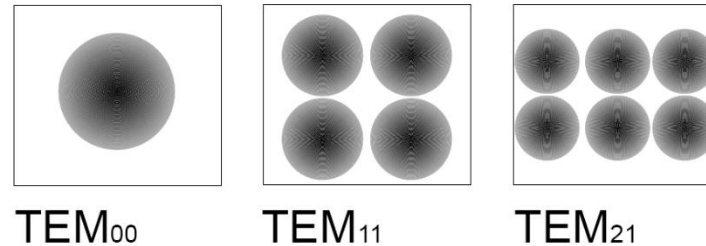
$$u(r) \propto \begin{cases} J_l(k_T r), & r < a \quad \text{(core)} \\ K_l(\gamma r), & r > a \quad \text{(cladding)} \end{cases}$$



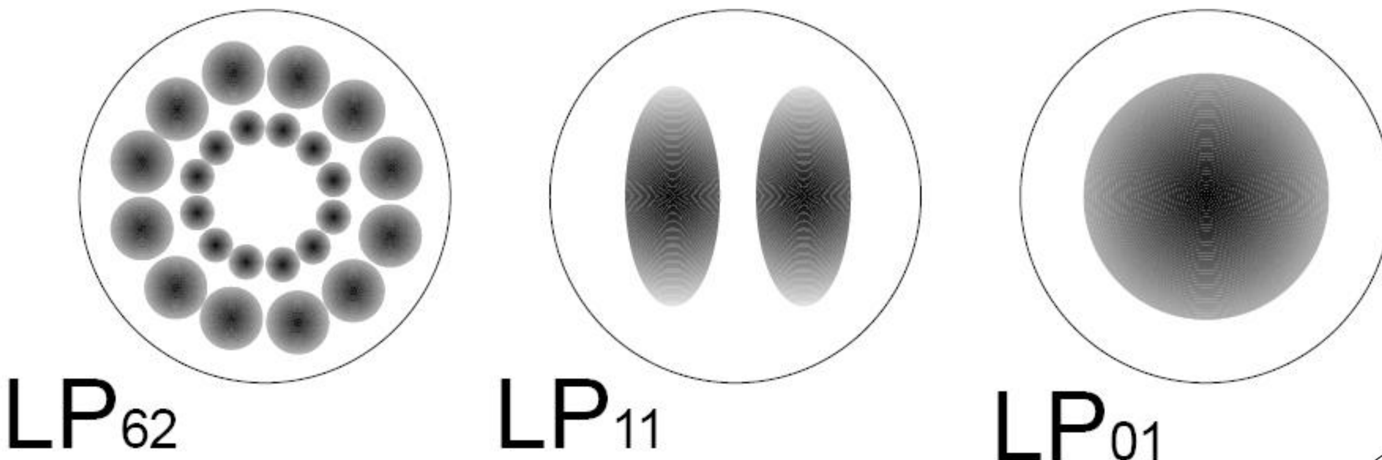


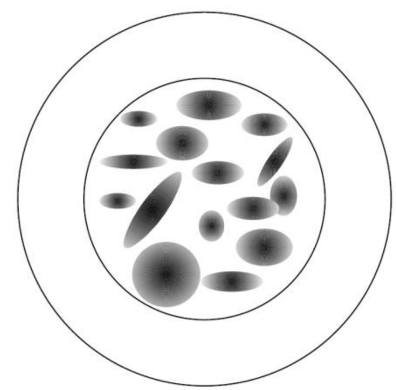
Moduri in fibra

- Moduri in ghid rectangular



- Moduri linear polarizate in fibra

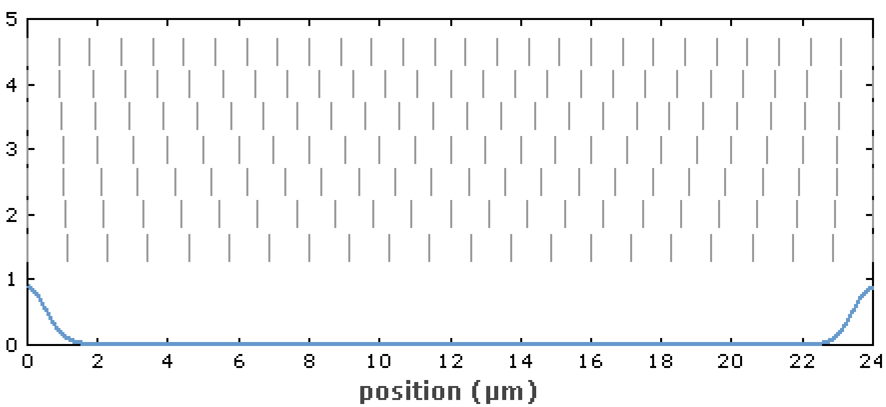


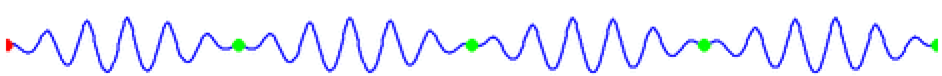


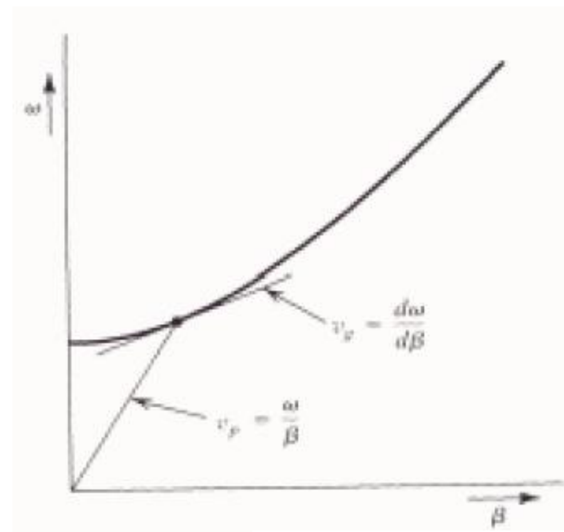
“Sparkle” pattern

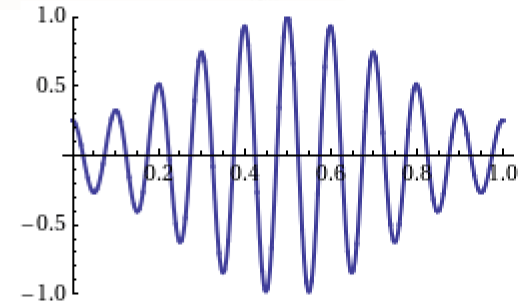
Viteze de grup si faza

- Viteza de faza – viteza virtuala cu care circula punctul cu o anumita faza
- Viteza de grup – viteza cu care circula informatia (energia) – in medii cu dispersie normala









Dispersia

- In medii dispersive $\beta = \beta(\omega)$, $n = n(\omega)$

$$\frac{d\beta}{d\omega} = \frac{d}{d\omega}\left(\frac{\omega \cdot n}{c}\right) = \frac{1}{c}\left(n + \omega\frac{dn}{d\omega}\right)$$

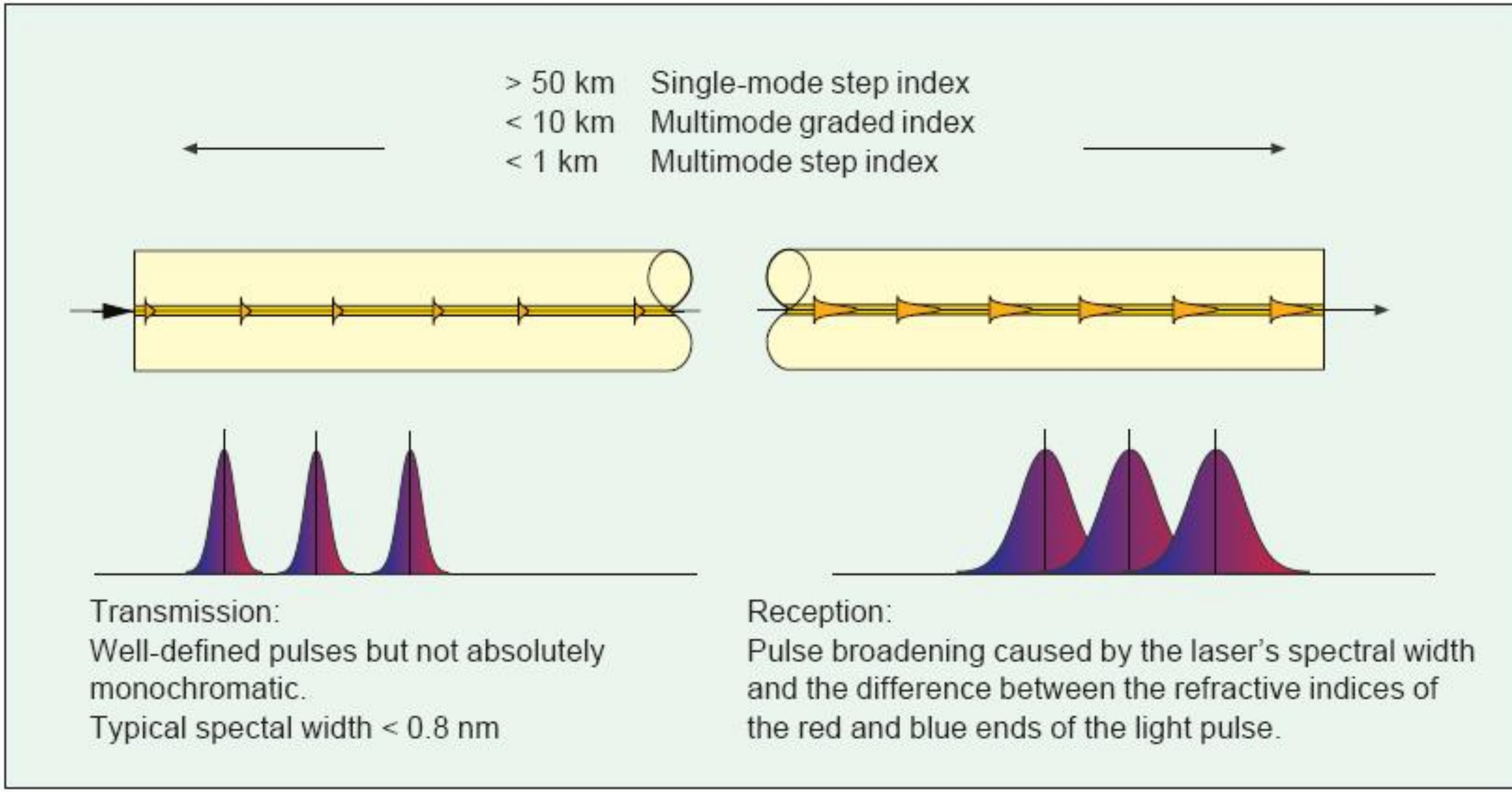
$$\frac{d\beta}{d\omega} = -\frac{\lambda}{\omega} \cdot \frac{d\beta}{d\lambda} = \frac{1}{c}\left(n - \lambda\frac{dn}{d\lambda}\right) = \tau \quad (s/m)$$

$$D = \frac{d\tau}{d\lambda} = \frac{1}{c}\left(\frac{dn}{d\lambda} - \lambda\frac{d^2 n}{d\lambda^2} - \frac{dn}{d\lambda}\right) = -\frac{\lambda}{c}\frac{d^2 n}{d\lambda^2} \quad (s/m^2)$$

- Dispersia se exprima de obicei in **ps/nm/km** si permite aflarea intarzierilor aparute intre "moduri" (latirea impulsurilor) pentru o anumita latime spectrala si o anumita distanta parcursa

$$\Delta\tau = D \cdot \Delta\lambda \cdot L$$

Dispersie

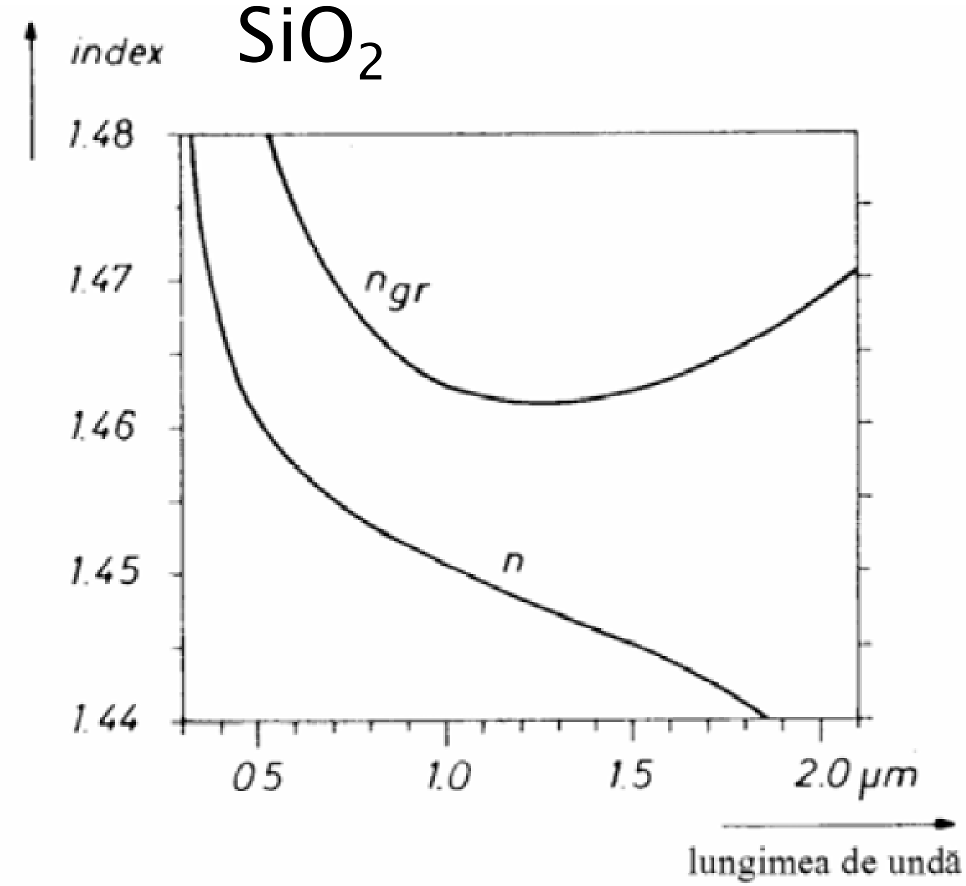


> 50 km Single-mode step index
< 10 km Multimode graded index
< 1 km Multimode step index
Transmission:
Well-defined pulses but not absolutely monochromatic.
Typical spectal width < 0.8 nm
Reception:
Pulse broadening caused by the laser's spectral width and the difference between the refractive indices of the red and blue ends of the light pulse.

Dispersie normala

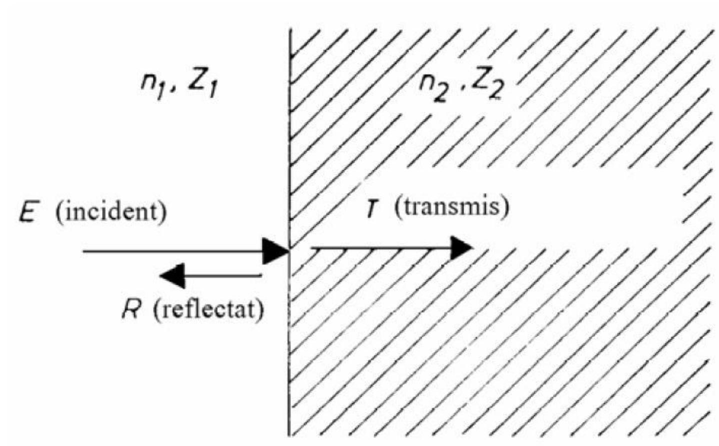
$$n_{gr} = n - \lambda \frac{dn}{d\lambda}$$

$$D = \frac{d\tau}{d\lambda} = \frac{1}{c} \cdot \frac{dn_{gr}}{d\lambda}$$



Transmisia puterii intre medii

- incidenta normala
- reflexia in amplitudine



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

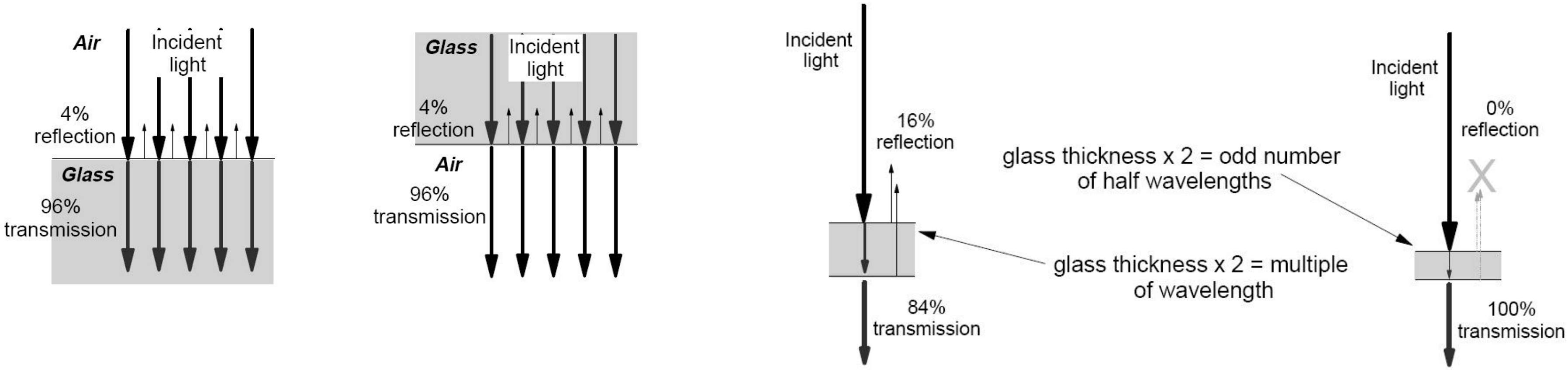
- densitatea de putere proportionala cu patratul amplitudinii câmpului

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

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

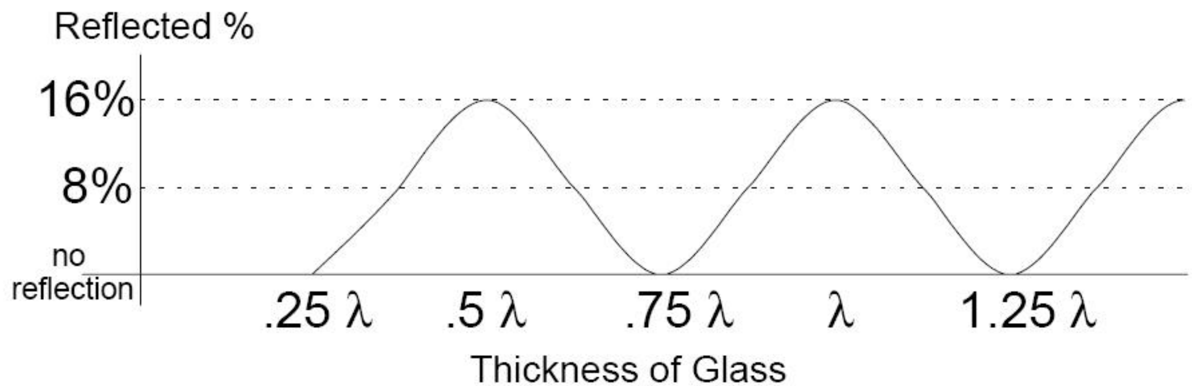
$$r = 0.04 = 4\%$$

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

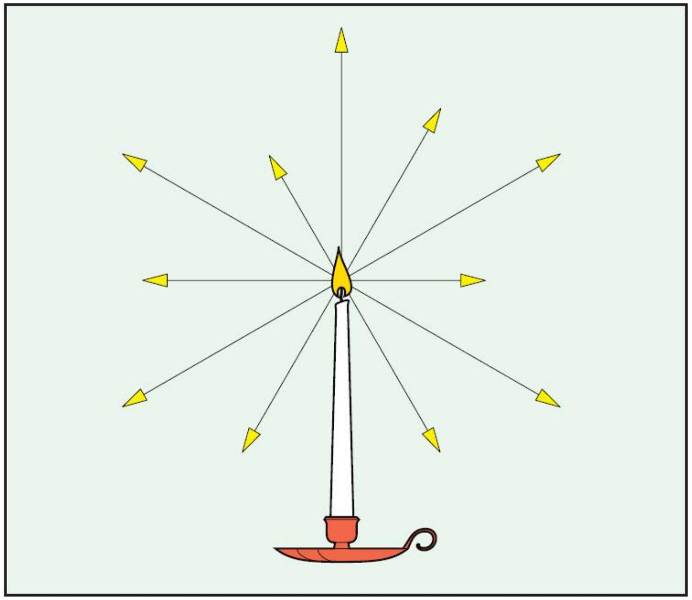


Optică geometrică

(tot) Capitolul 2

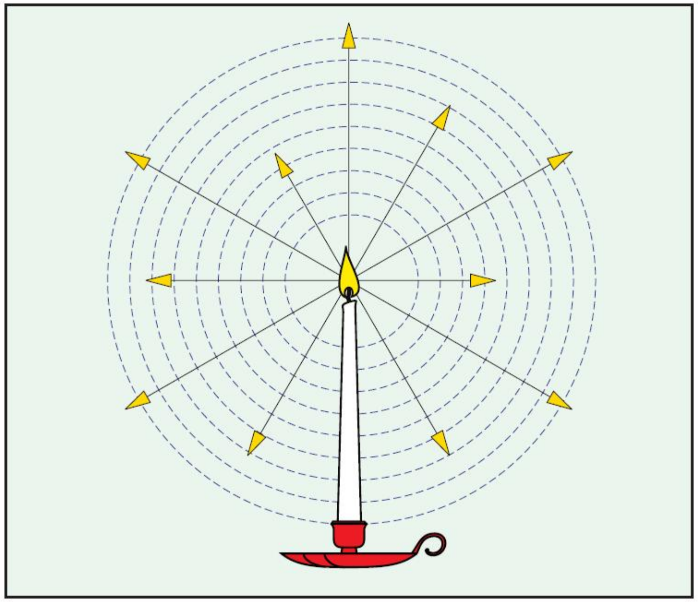
Raze de lumina

- Lumina este constituita din raze care se propaga in linie dreapta in medii omogene
- Sursa omnidirecționala: emite similar in toate direcțiile



- Densitatea de energie luminoasa descrește invers proporțional cu pătratul distantei fata de sursa (energia se împarte uniform pe suprafața întregii sfere)

$$P = \frac{P_0}{r^2}$$

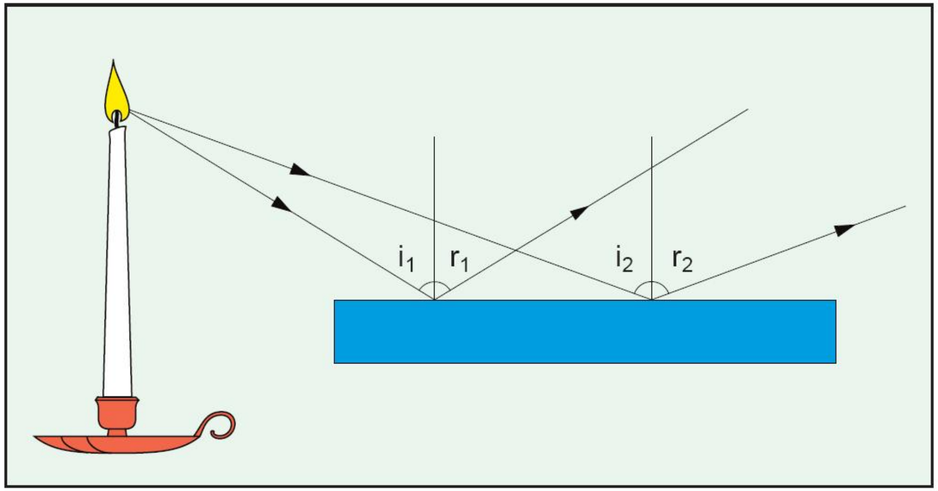


Reflexia luminii

- 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

$$\phi_i = \phi_r$$



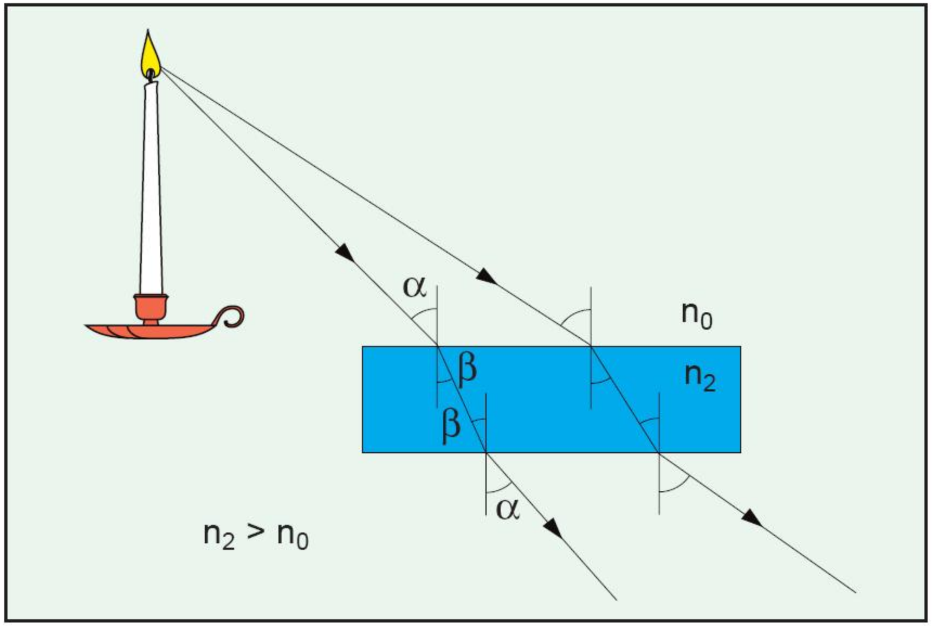
Refractia luminii

- 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)



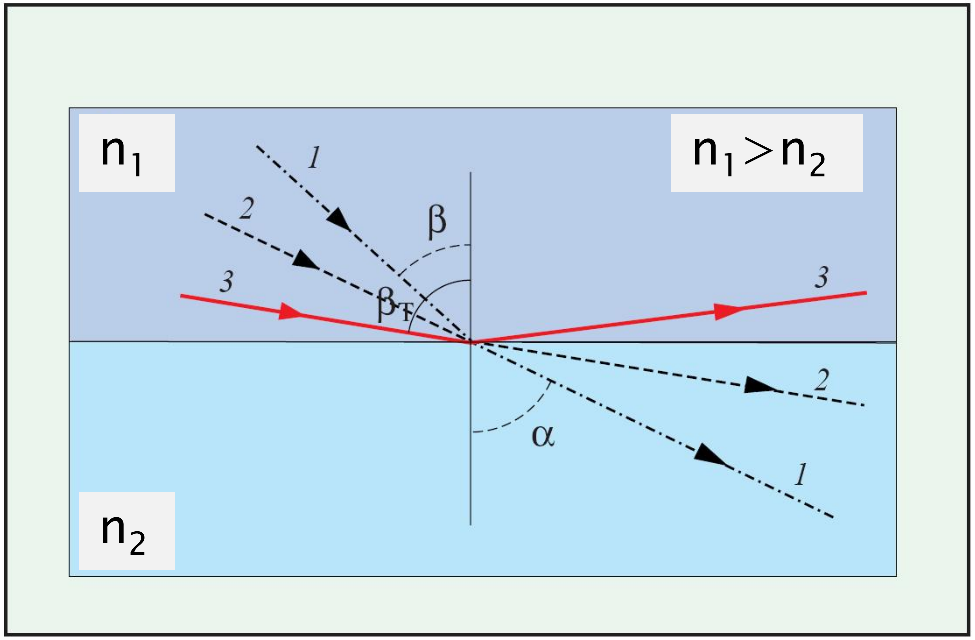
Reflexia totala

- 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

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

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

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

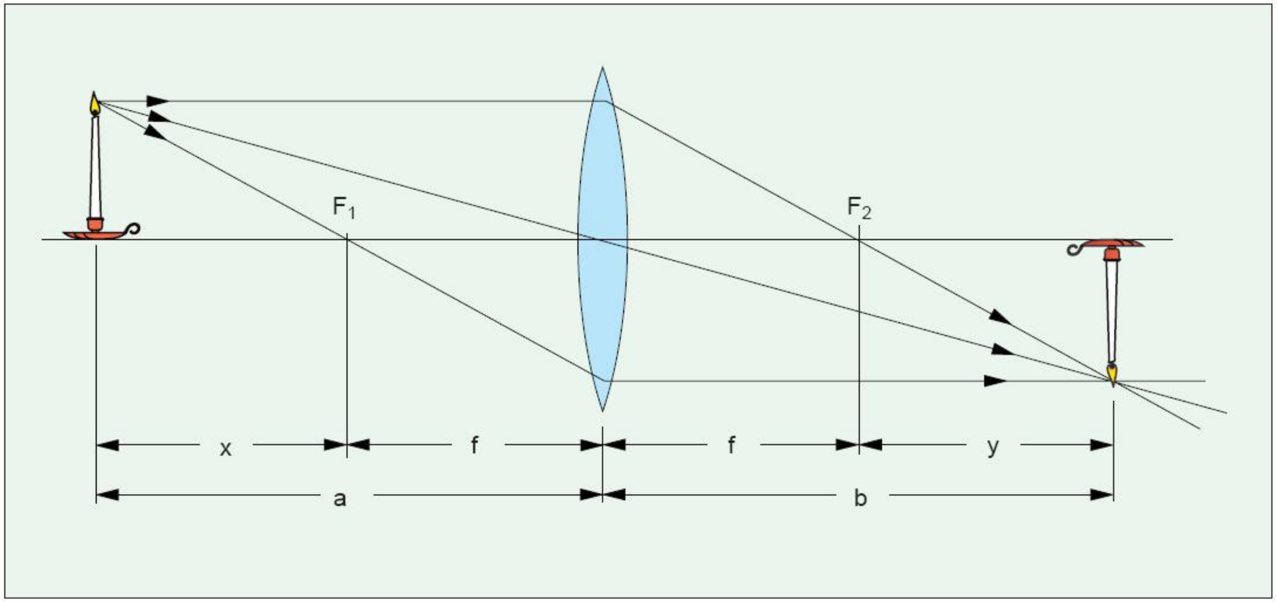


Lentile

- Razele de lumina paralele sunt concentrate intr-un punct numit focar, aflat la distanta focala de planul lentilei
- O sursa omnidirectionala pozitionata in focar va permite obtinerea unui fascicul paralel

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{f}$$

$$x \cdot y = f^2$$

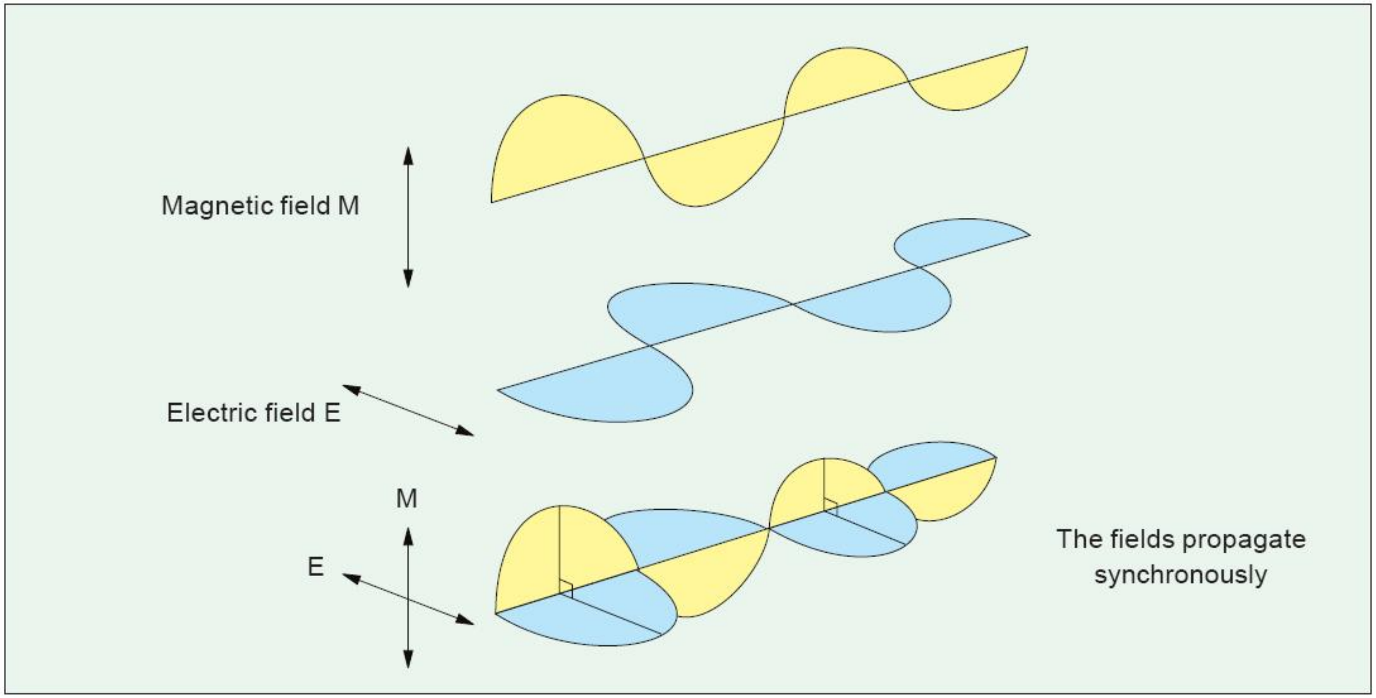


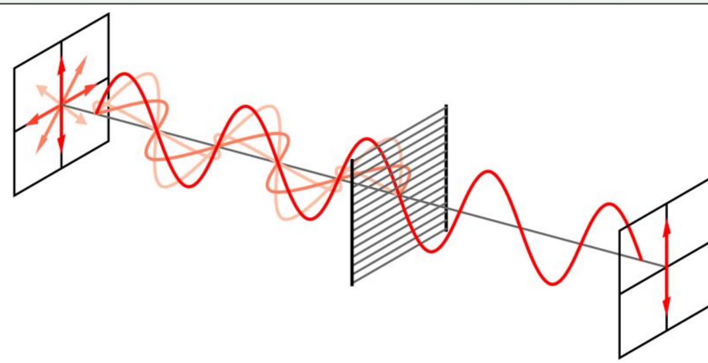
Lumina ca undă electromagnetică

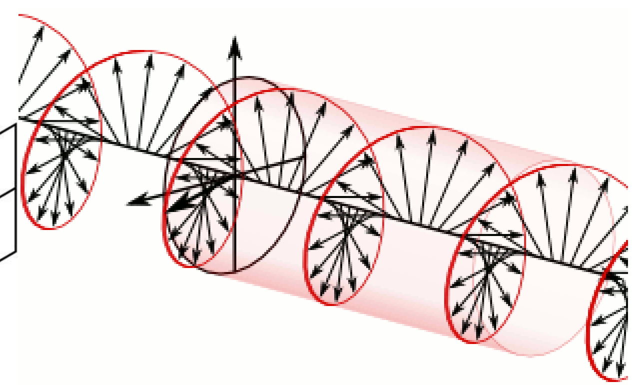
Capitolul 2

Continuare

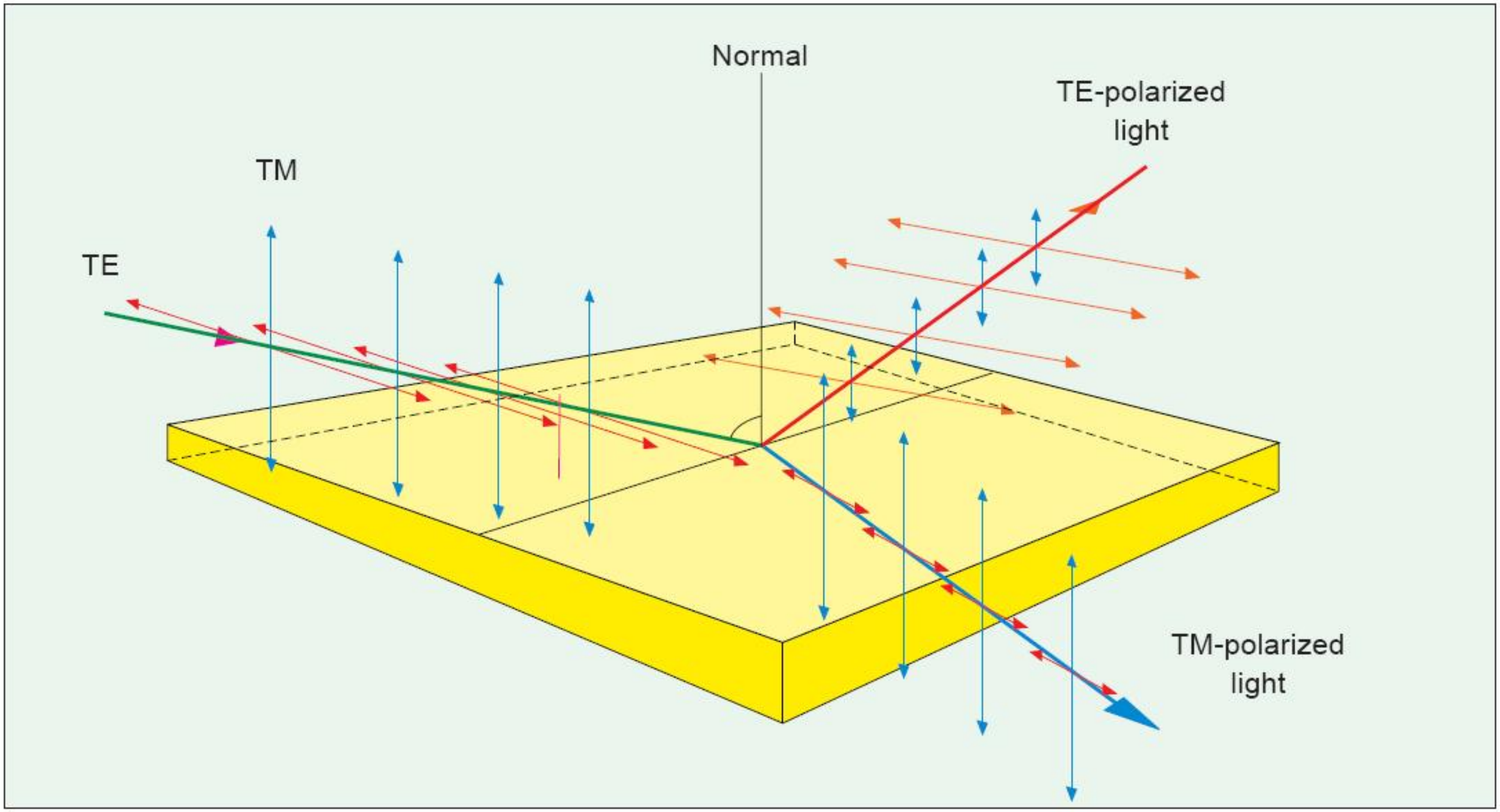
Polarizarea luminii







Polarizarea luminii



Polarizarea luminii

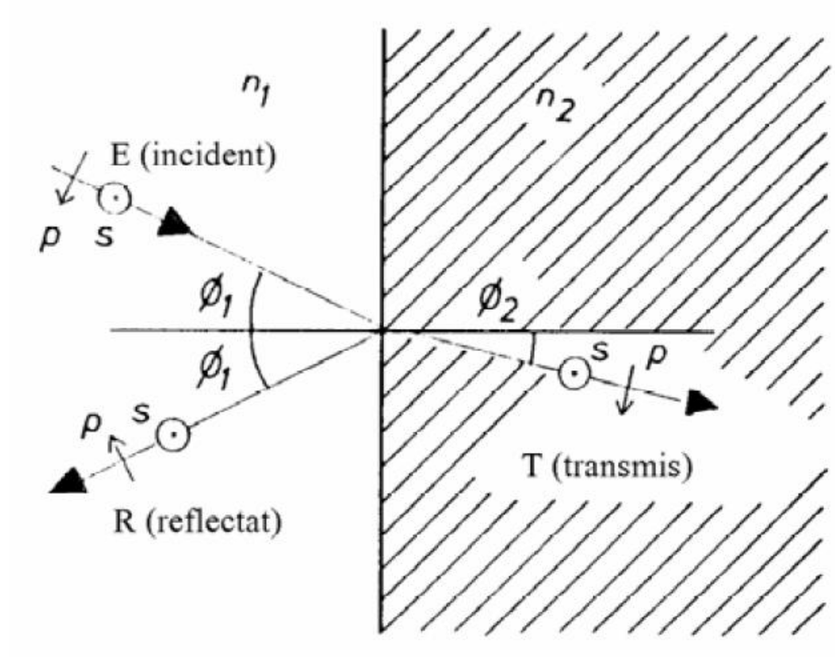
- incidenta oblica
- reflexiile in amplitudine a campului:

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

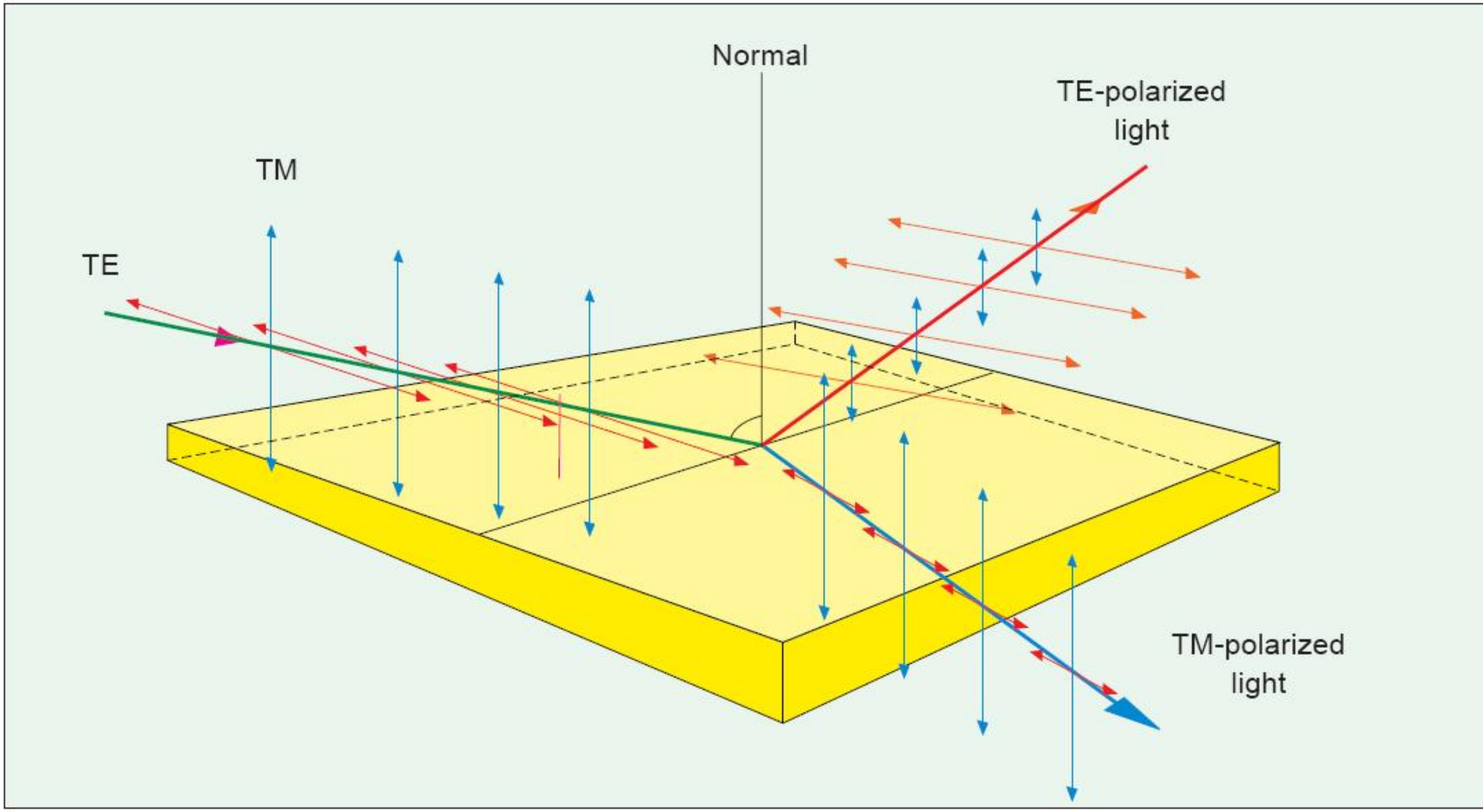
$$r_p = \frac{\tan(\phi_1 - \phi_2)}{\tan(\phi_1 + \phi_2)}$$

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

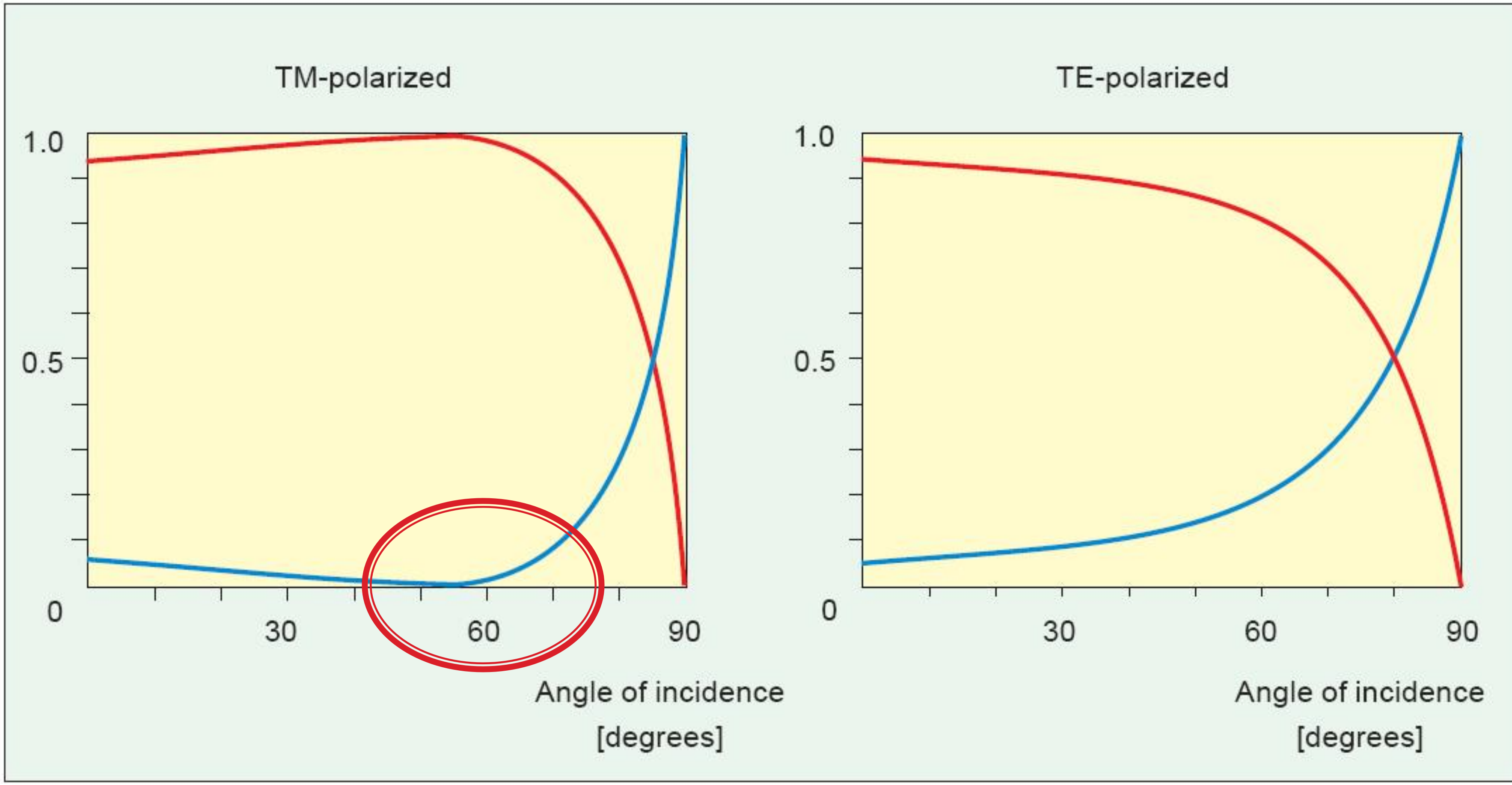
$$t_p = \frac{2\sin\phi_2\cos\phi_1}{\sin(\phi_1 + \phi_2)\cos(\phi_1 - \phi_2)}$$



Polarizarea luminii



Polarizarea luminii



Unghi Brewster

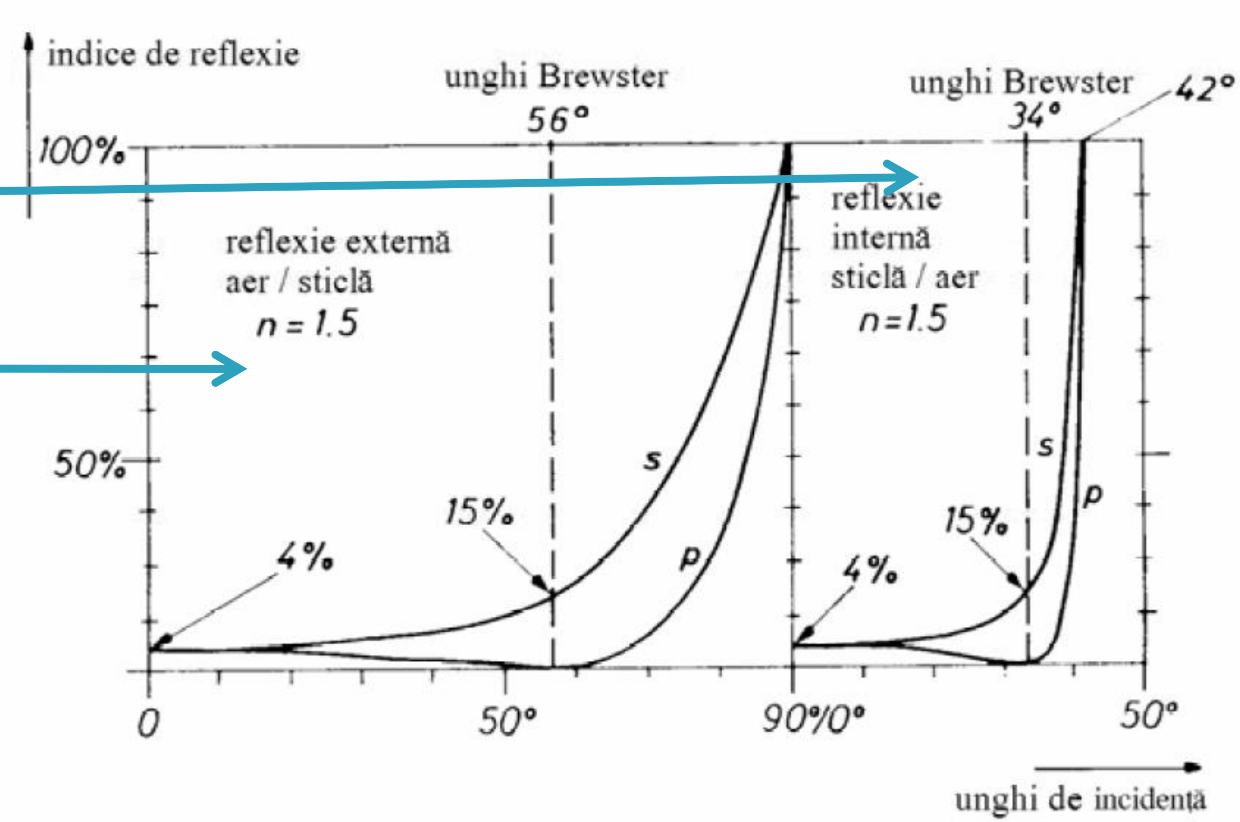
$$r_p = 0 \quad \Rightarrow \quad \tan(\phi_1 + \phi_2) \rightarrow \infty \quad \Rightarrow \quad \phi_1 + \phi_2 = \frac{\pi}{2}$$

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

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

$$\phi_B = 34°$$

$$\phi_B = 56°$$



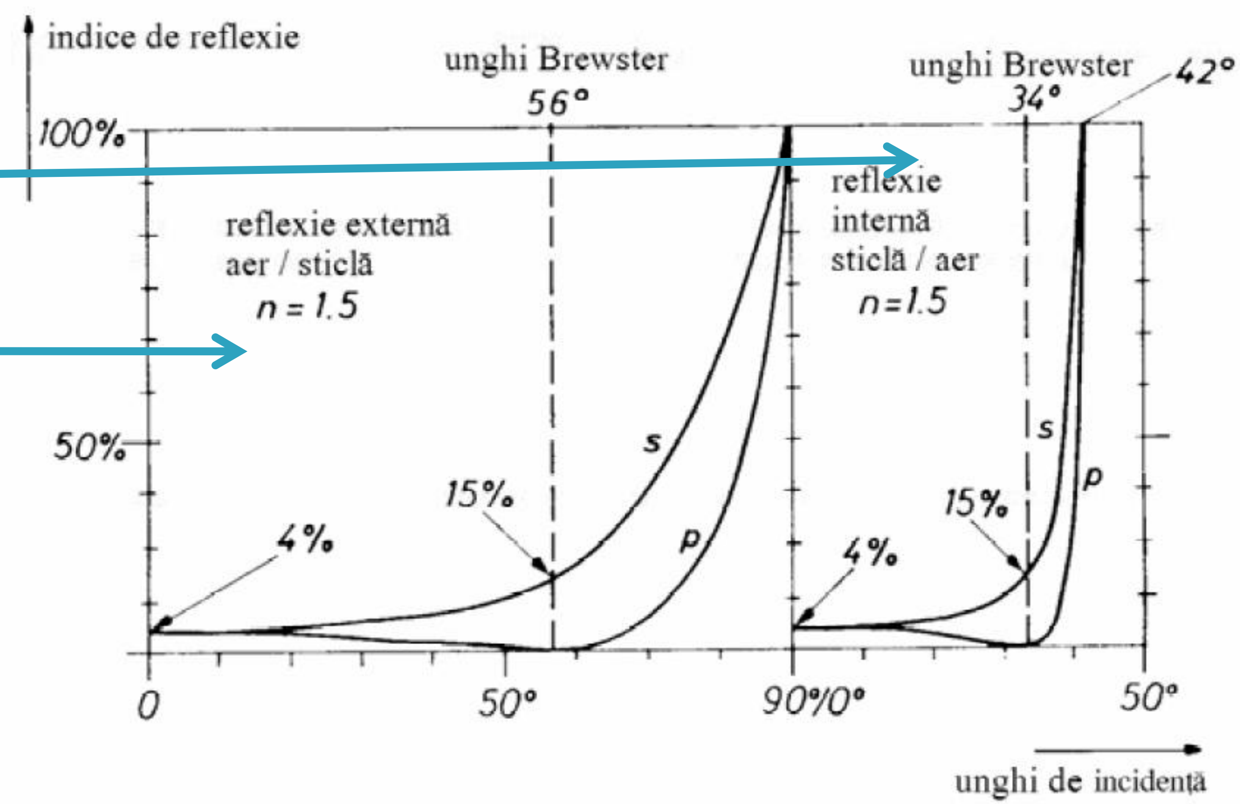
Unghi Brewster

- transmisia totala a polarizarii p
- lumina reflectata este total polarizata (s)

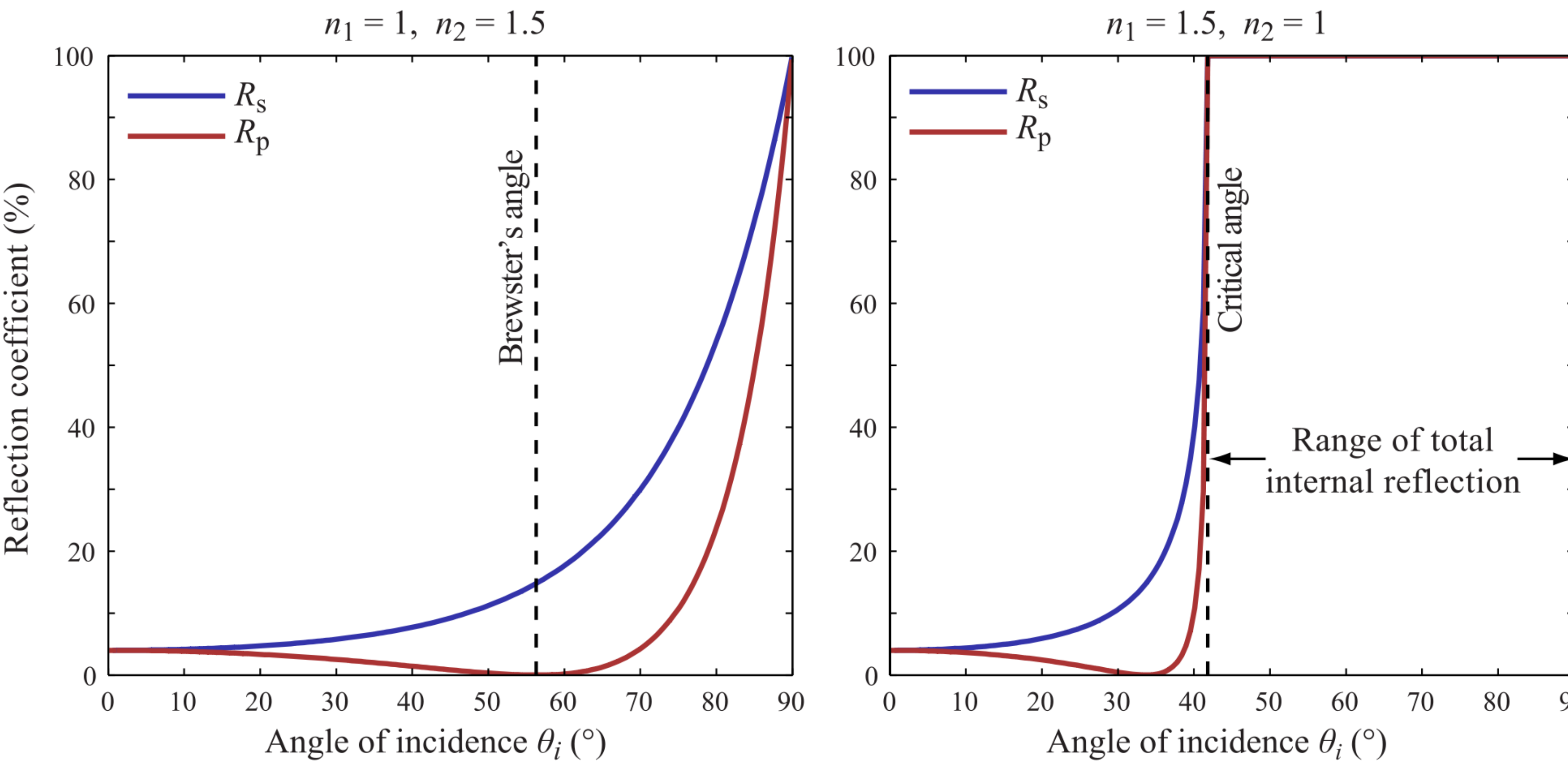
$$\phi_B = \arctan\left(\frac{n_2}{n_1}\right)$$

$$\phi_B = 34°$$

$$\phi_B = 56°$$



Unghi Brewster



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]

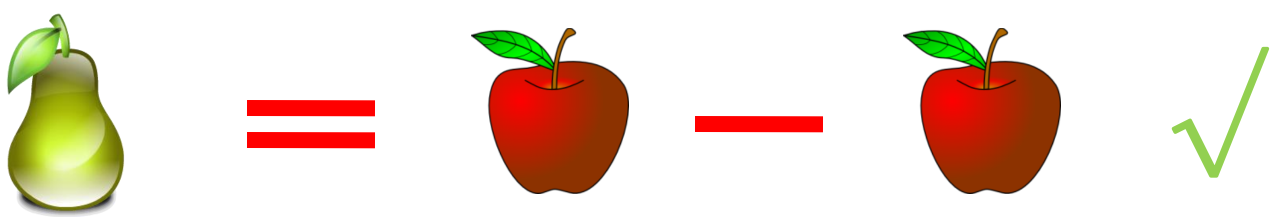
[x] + [dB] = [x]

Calculul atenuarii

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

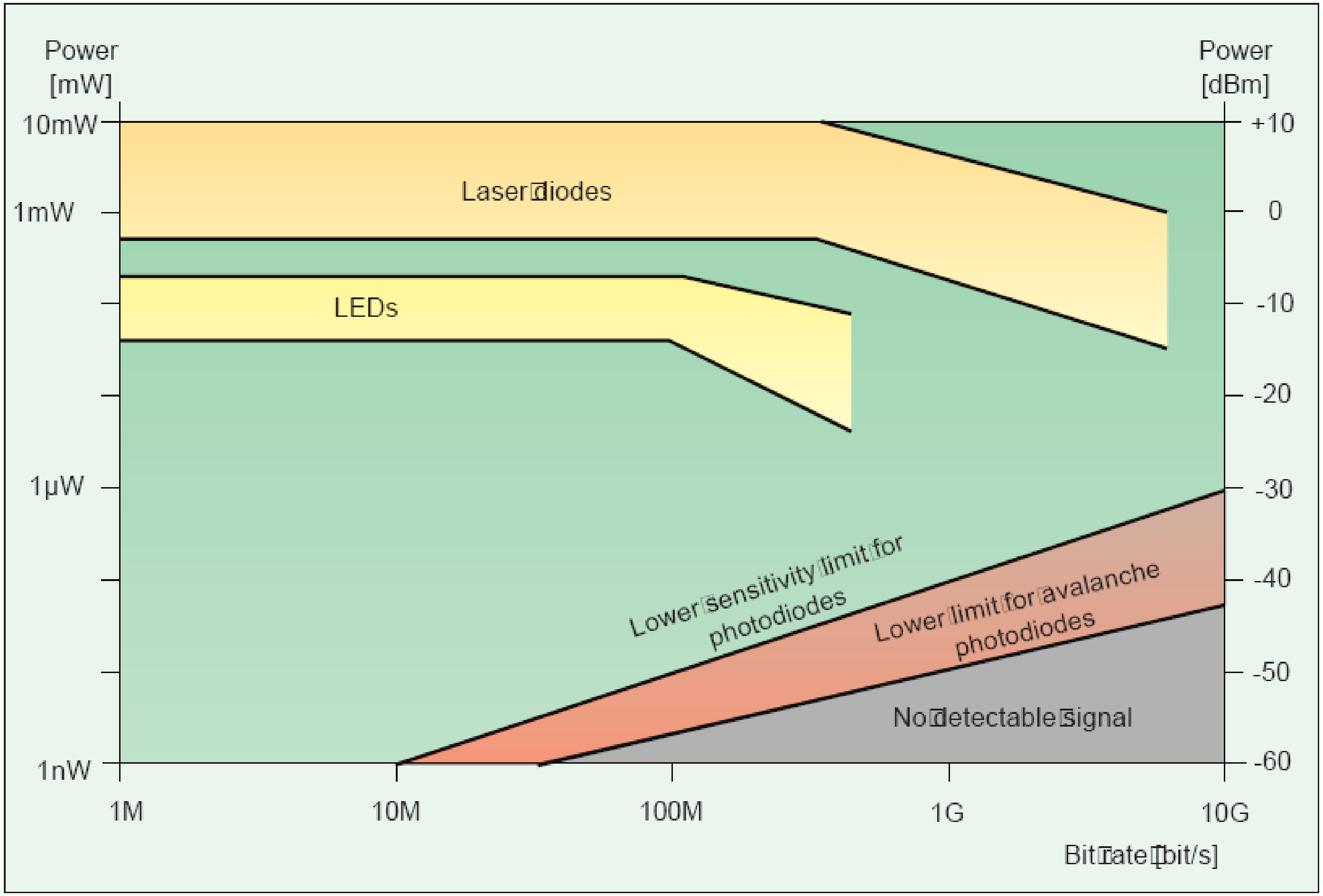
$$\text{Pierderi}[\text{dB}] = [-]\,10 \cdot \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

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



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

Limite putere/bandă a dispozitivelor optoelectronice



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