

# Optoelectronică

Curs 1

2019/2020

- ▶ La facultate, profesorul intreaba:
  - Intrebare de "nota 10": cum ma numesc?  
Toti tac.
  - Intrebare de "nota 8": la ce obiect aveti examen?  
Toti tac.
  - Intrebare de "nota 5": ce culoare are manualul (site-ul laboratorului)?

Din ultimele randuri se aude o voce:

  - Vrea sa ne pice magaru'!

# Disciplina 2019/2020

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – conf. **Radu Damian**
  - an IV  $\mu E$
  - 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  $\mu E$ 
    - Joi 8-14 impar
  - L – 30% din nota (+Caiet de laborator)

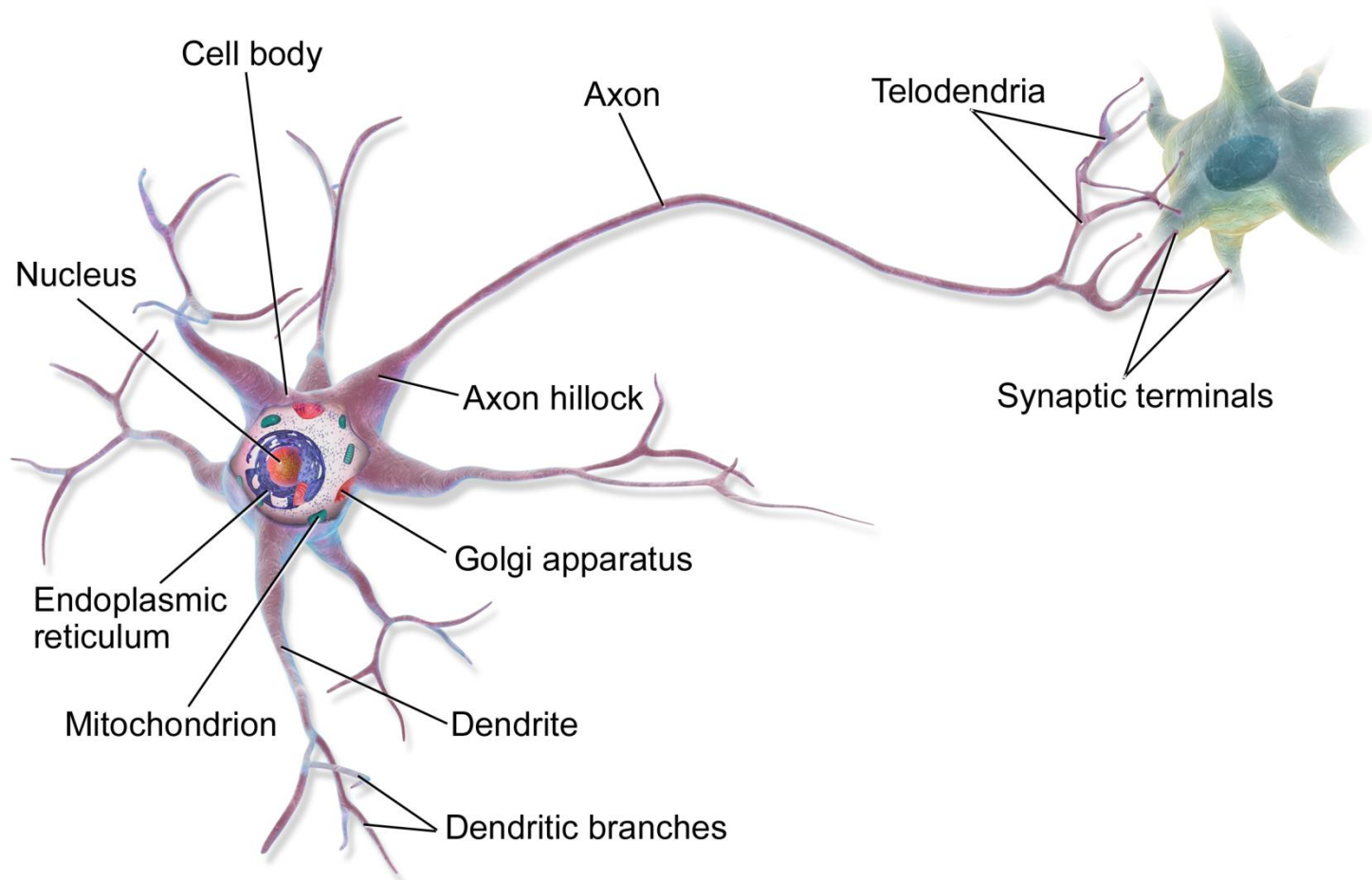
# Orar 2019/2020

## ▶ Curs

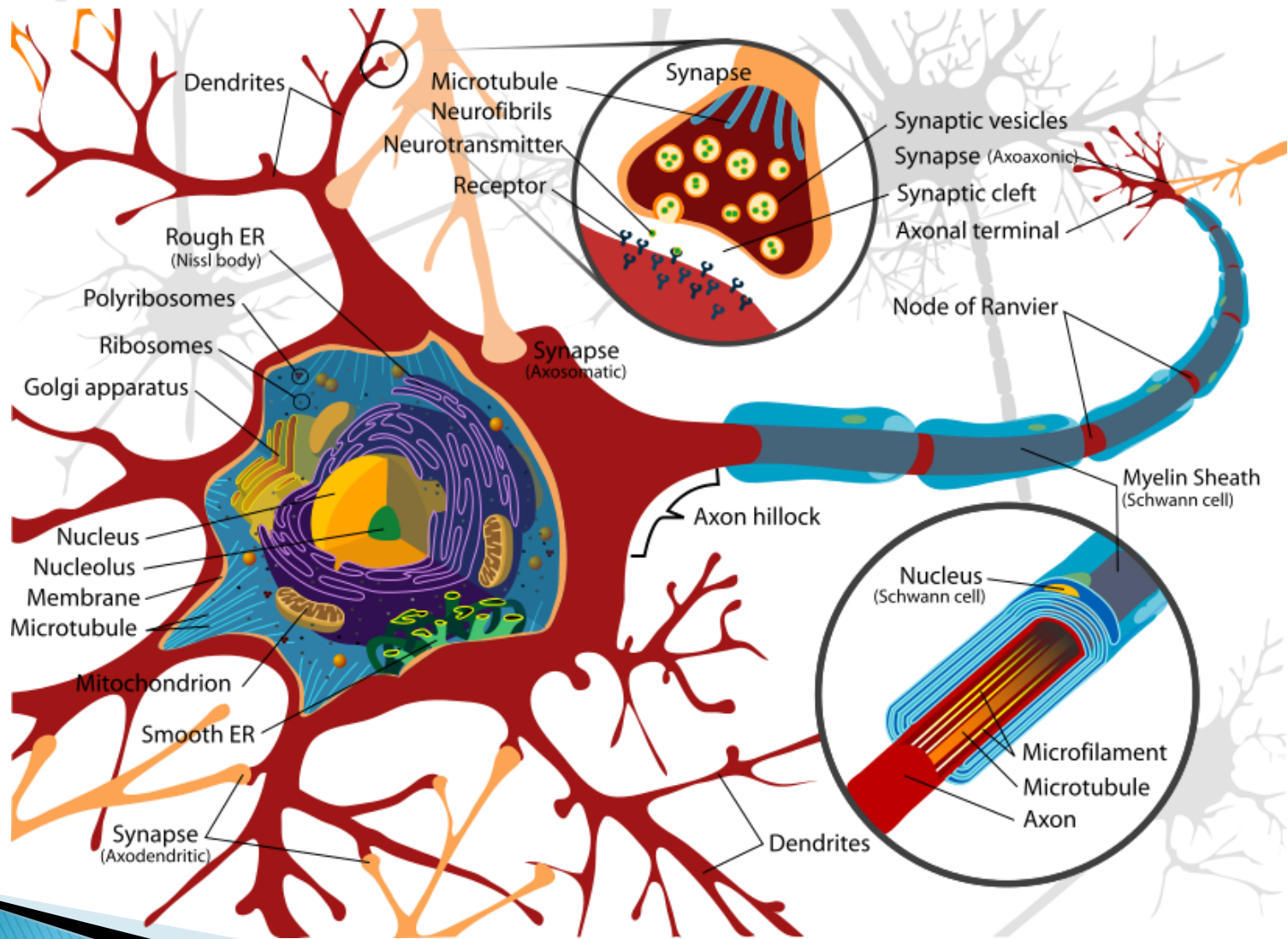
- Vineri 8–11, P5
- **2C  $\Rightarrow$  3C**
  - $14 * 2/3 \approx 9.33$
  - $9 \div 10 C \approx 9C + E$



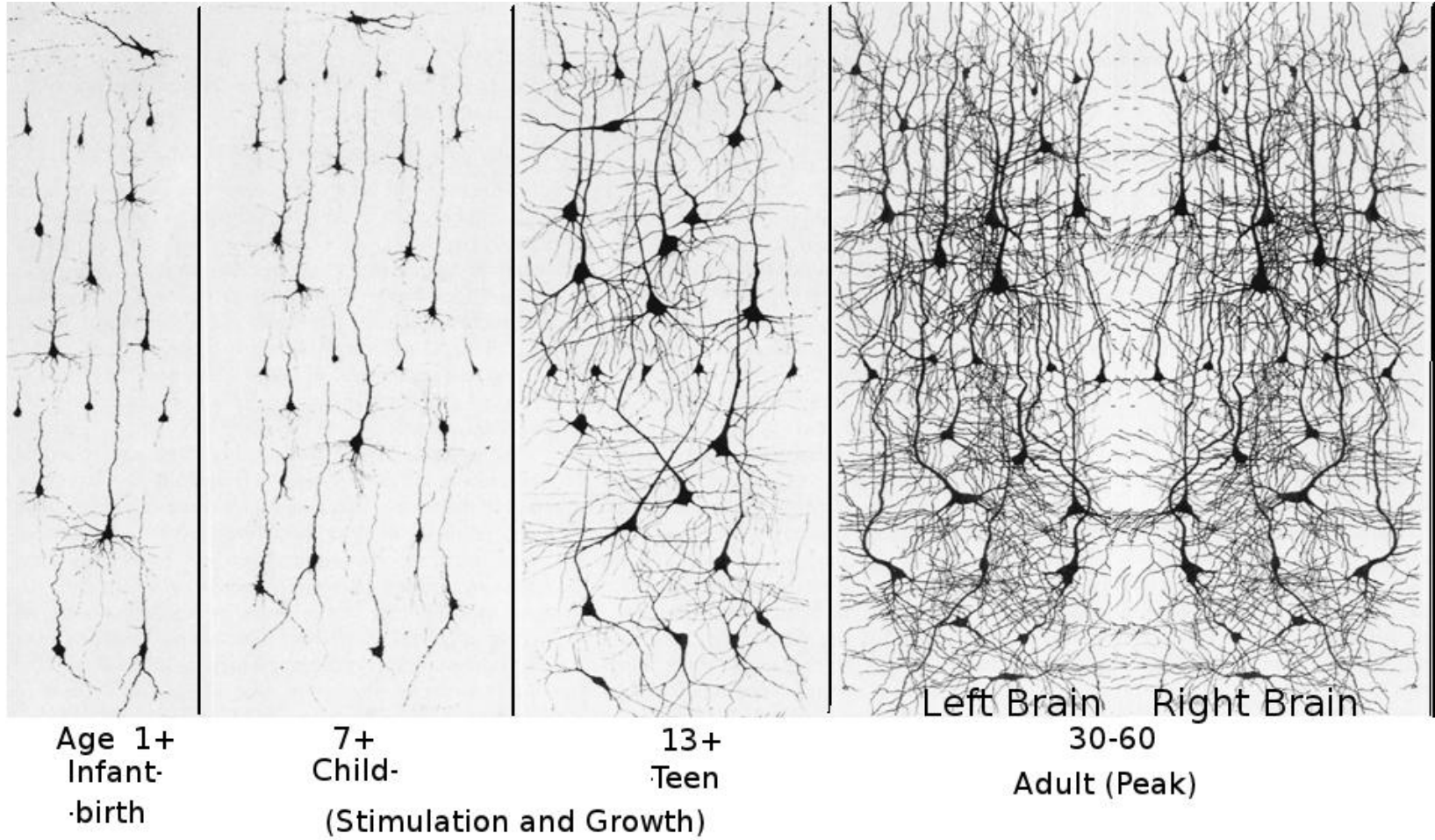
# Scop 1



# Scop 2



# Scop 3





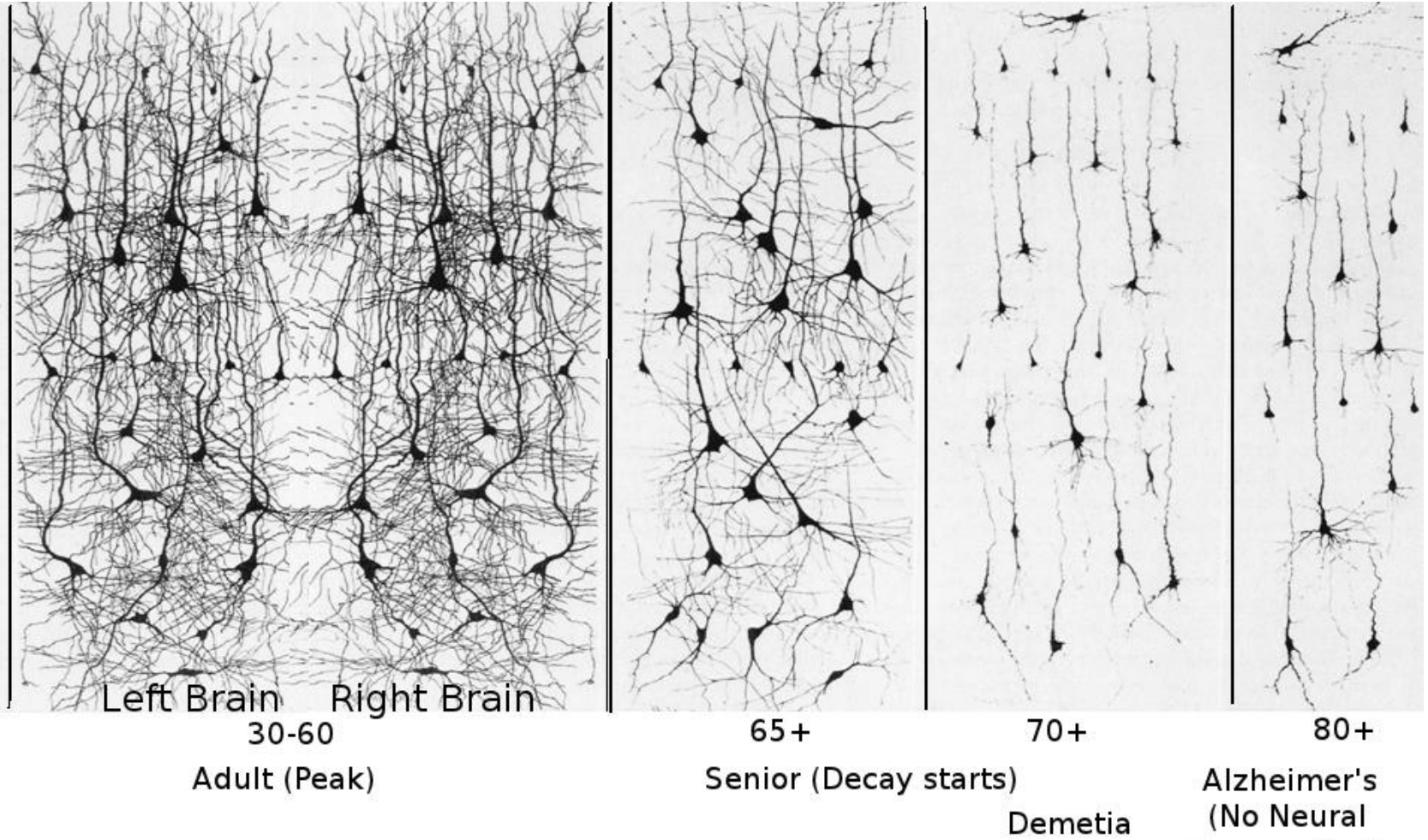
# Scop 4



**Sinapse  
“ingineresti”**



# Termen





~1930

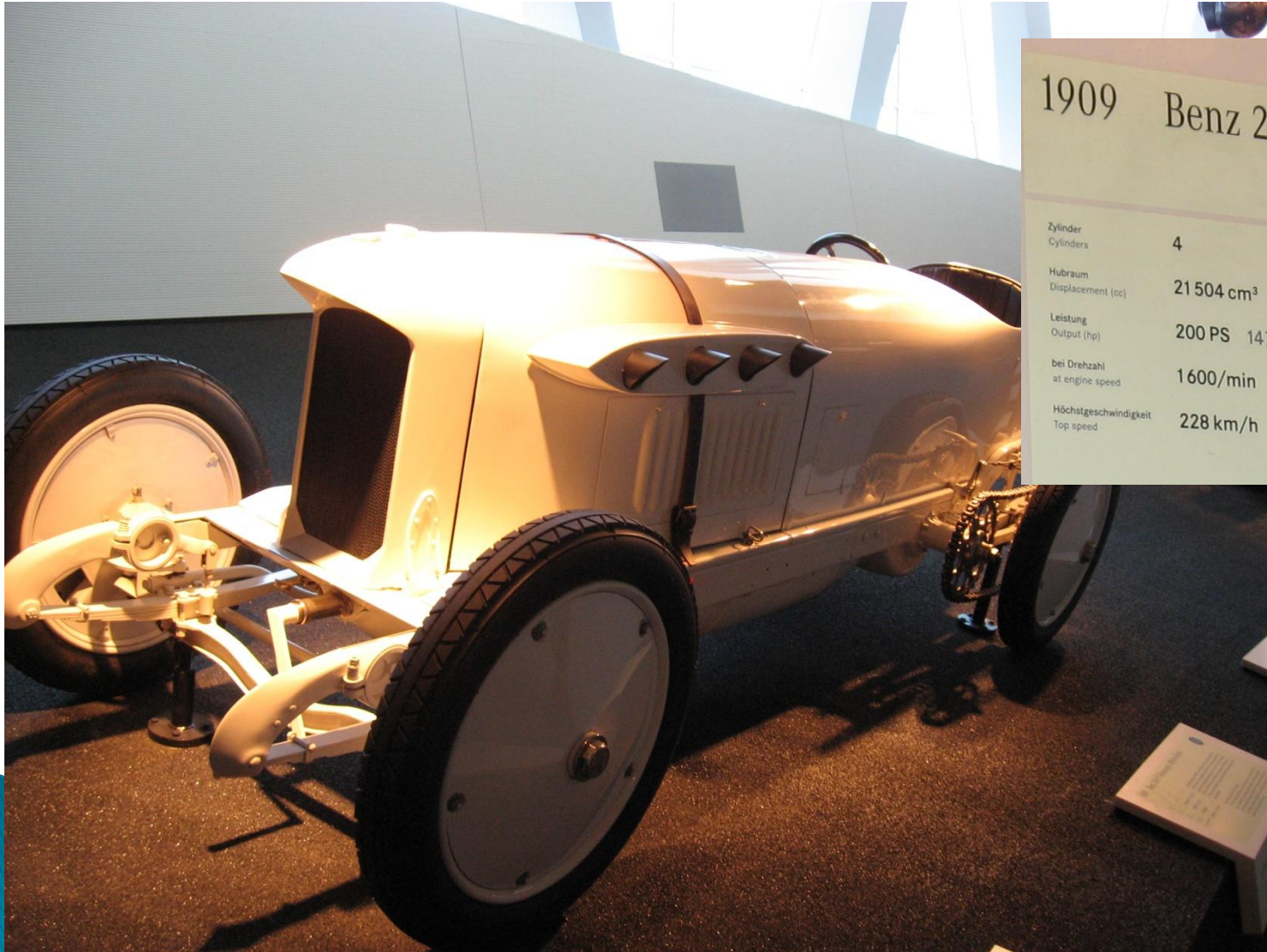


~1930





# 1909



## 1909 Benz 200 PS Rennwagen »Blitzen-Benz«

Zylinder Cylinders	4
Hubraum Displacement (cc)	21 504 cm <sup>3</sup> 1 312 cu in
Leistung Output (hp)	200 PS 147 kW
bei Drehzahl at engine speed	1 600/min
Höchstgeschwindigkeit Top speed	228 km/h 142 mph

Der »Blitzen-Benz« ist 1909 der erste 200 km/h fähige. Seine größten Erfolge feierte er mit dem 200 km/h zylindermotor ausgestattete Rekordfahrer Burman mit 228 km/h über die Saale. Er ist damit das schnellste Fahrzeug aller Zeiten auf jeder Eisenbahn.

Benz »Lightning Benz« 200 hp racing car  
In 1909 the Lightning Benz



# 1930-1950



# Tehnologie

> 2010

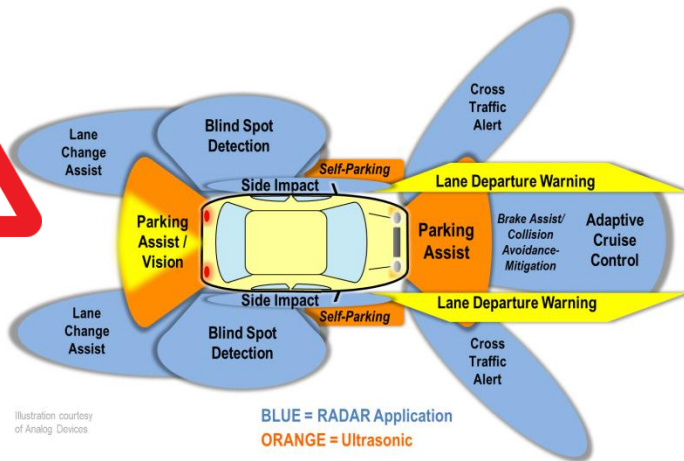


Illustration courtesy of Analog Devices

< 1950



# Tehnologie

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

$$2 \times 1 = 2$$

$$2 \times 2 = 4$$

$$2 \times 3 = 6$$

$$2 \times 4 = 8$$

$$2 \times 5 = 10$$

$$2 \times 6 = 12$$

$$2 \times 7 = 14$$

$$2 \times 8 = 16$$

$$2 \times 9 = 18$$

$$2 \times 10 = 20$$

# Cuprins

- ▶ **Lumina ca undă electromagnetică** (ecuațiile lui Maxwell, ecuația undelor, parametri de propagare)
- ▶ **Elemente de fotometrie și radiometrie** (mărimi energetice/luminoase)
- ▶ **Fibra optică** (realizare, principiu de funcționare, atenuare, dispersie, banda de frecvență)
- ▶ **Cabluri optice** (tehnologie, conectori, lipire – splice)
- ▶ **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvență, balanța puterilor)
- ▶ **Emitătoare optice** (LED și dioda laser – realizare fizică și funcționare)
- ▶ **Receptoare optice** (dioda PIN, dioda cu avalanșă – realizare fizică și funcționare)
- ▶ **Amplificatoare transimpedanță** (parametri, scheme tipice, TIA în buclă deschisă, cu reacție, diferențiale, control automat al câștigului)
- ▶ **Realizarea circuitelor pentru controlul emițătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- ▶ **Dispozitive de captare a energiei solare** (principiu de funcționare, utilizare, proiectare )



# 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://www.redbooks.ibm.com>
- ▶ Radu Damian, I Casian, D Matăsaru - „Comunicatii Optice” , Indrumar de laborator, 2005

# Documentatie




STARECAT.COM

# Documentatie

Laboratorul de Microunde si Opto x Orar ETTI x

Not secure | rf-opto.etti.tuiasi.ro/optoelectronics.php



English | Romana

Main **Courses** Master Staff Research Students Admin

Microwave CD Optical Communications **Optoelectronics** Internet Antennas Technology/Noise Practica Educational software

## 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.

# Documentatie

- ▶ RF-OPTO

- <http://rf-opto.etti.tuiasi.ro>

- ▶ Fotografie

- de trimis prin email: [rdamian@etti.tuiasi.ro](mailto:rdamian@etti.tuiasi.ro)

- necesara la laborator/curs



# 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 Section

**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)

### Grades

[Aggregate Results](#)

### Attendance

## Previous years

2018-2019

2017-2018

2016-2017

2015-2016

2014-2015

2013-2014

2012-2011

## 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

# Fotografii



## Date:

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

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

## Detalii curente

<b>Finantare</b>	Buget
<b>Bursa</b>	Fara Bursa

## Observatii



## Date:

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

[Acceseaza ca acest student](#)

## Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Pondere	Obs.
TW			Tehnologii Web			
	N	17/01/2014	Nota Finala	10	-	
	A	17/01/2014	Colocenta 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		



## Date:

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

[Trimite email acestui student](#) | [Adauga acest student la lista \(0\)](#)

## Detalii curente

<b>Finantare</b>	Buget
<b>Bursa</b>	Bursa de Studii

## Observatii

# Fotografii

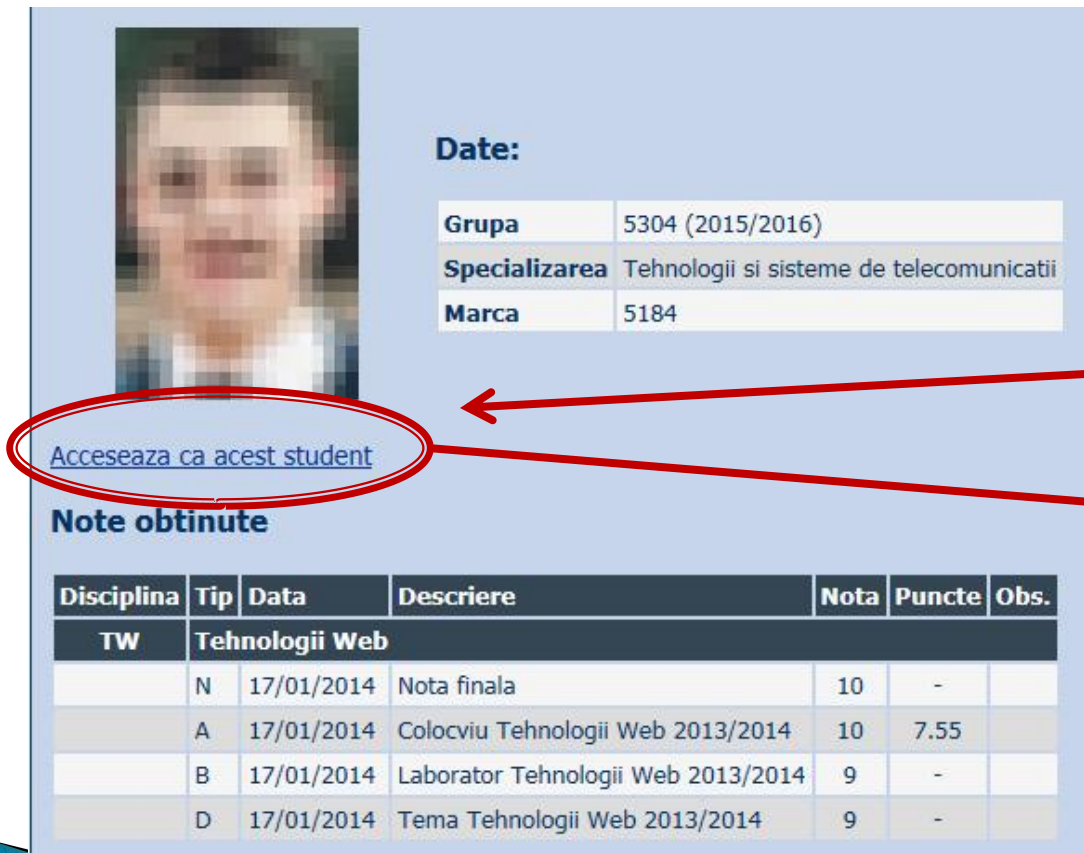
Nr. Student	Student	Prezent	Nr. Student	Student	Prezent	Nr. Student	Student	Prezent
1	ANGHELUS IONUT-MARIUS	<input type="checkbox"/>	2	ANTIGHIN FLORIN-RAZVAN	<input type="checkbox"/>	3	ANTONICA BIANCA	<input type="checkbox"/>
4	APOSTOL PAVEL-MANUEL	<input type="checkbox"/>	5	BALASCA DULIAN-PETRU	<input checked="" type="checkbox"/>	6	BOSTAN ANDREI-PETRIKA	<input type="checkbox"/>
7	BOTEZAT EMANUEL	<input type="checkbox"/>	8	BUTUNOI GEORGE-MADALIN	<input type="checkbox"/>	9	CHILEA SALUCA-MARIA	<input type="checkbox"/>
10	CHIRITOIU ECATERINA	<input type="checkbox"/>	11	COJOC MARIUS	<input checked="" type="checkbox"/>	12	COJOCARIU AURA-FLORINA	<input type="checkbox"/>

Nr. Student	Student	Prezent
2	<u>ANTIGHIN</u> <u>FLORIN-RAZVAN</u>	<input type="checkbox"/>
	<b>Fotografia nu exista</b>	Puncte: 0 Nota: 0 Obs:



# Acces

## ▶ Personalizat



Student profile card showing a blurred photo, a 'Date:' section with a table, a link 'Acceseaza ca acest student', and a 'Note obtinute' table.

**Date:**

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

[Acceseaza ca acest student](#)

**Note obtinute**

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TW	Tehnologii Web					
N		17/01/2014	Nota finala	10	-	
A		17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
B		17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
D		17/01/2014	Tema Tehnologii Web 2013/2014	9	-	



Login form with fields for Name, Email, and Verification Code, and a 'Trimite' button. A verification code '344bd9f' is displayed below the code field.

Nume

Email

Cod de verificare

344bd9f

Trimite

# 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	<a href="#">CIOLPAN OCTAVIAN</a>	5306	3	0.5					0.5	-
2	<a href="#">NITA COSTEL-CATALIN</a>	5307	4	0.5	1				1.5	-
3	<a href="#">BARON BOGDAN-IONUT</a>	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
  - 2007:  $9.67 \pm 0.66 / 8.81 \pm 1.22$
  - 2008:  $6.24 \pm 1.36 / 4.82 \pm 2.10$
  - 2009:  $5.10 \pm 1.46$
  - 2010:  $3.89 \pm 1.32$
- ▶ La prima aplicare (neanuntata)
  - 50% din studenti au parasit examenul in primele 10 minute
  - 50% din cei ramasi nu au promovat
  - promovabilitate totala **25%**, rata contestatiilor: **0%**
- ▶ Urmatoarele examinari (anuntate)
  - rata contestatiilor: 0%

# Examen



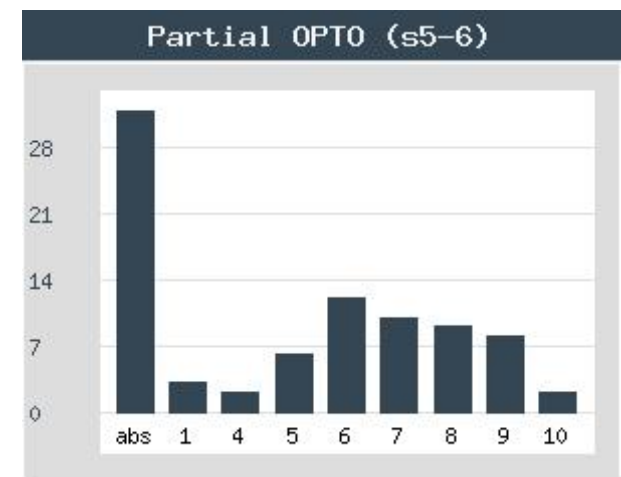
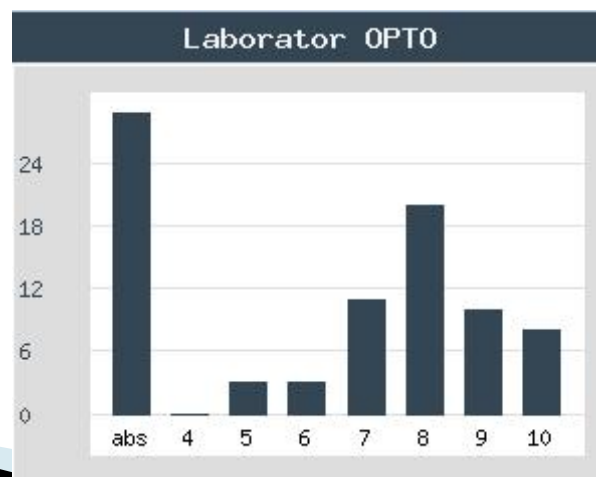
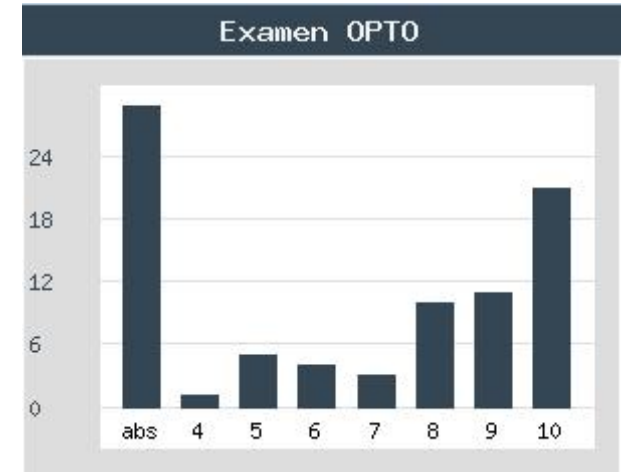
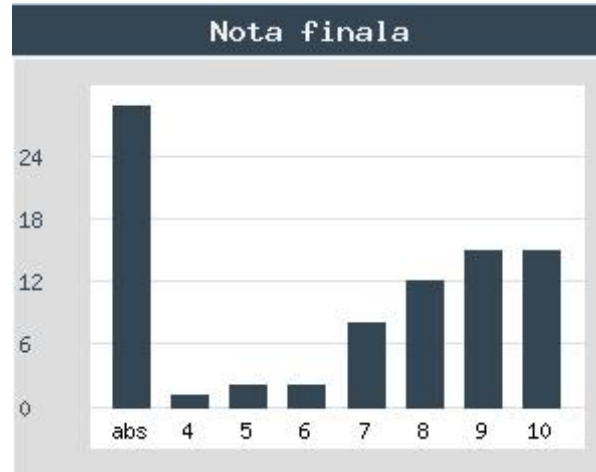


# Examen

- ▶ subiecte **individuale**

# Note

## ▶ 2018/2019



# Reprezentare logaritmică

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

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

$$0 \text{ dB} = 1$$

$$+ 0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$+ 3 \text{ dB} = 2$$

$$+ 5 \text{ dB} = 3$$

$$+ 10 \text{ dB} = 10$$

$$-3 \text{ dB} = 0.5$$

$$-10 \text{ dB} = 0.1$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dB} = 0.001$$

$$0 \text{ dBm} = 1 \text{ mW}$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$5 \text{ dBm} = 3 \text{ mW}$$

$$10 \text{ dBm} = 10 \text{ mW}$$

$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dBm} = 100 \mu\text{W}$$

$$-30 \text{ dBm} = 1 \mu\text{W}$$

$$-60 \text{ dBm} = 1 \text{ nW}$$

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

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

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

# Introducere

## Capitolul 1

# Aplicatii majore

- ▶ Comunicatii

- Infrarosu (InGaAsP)

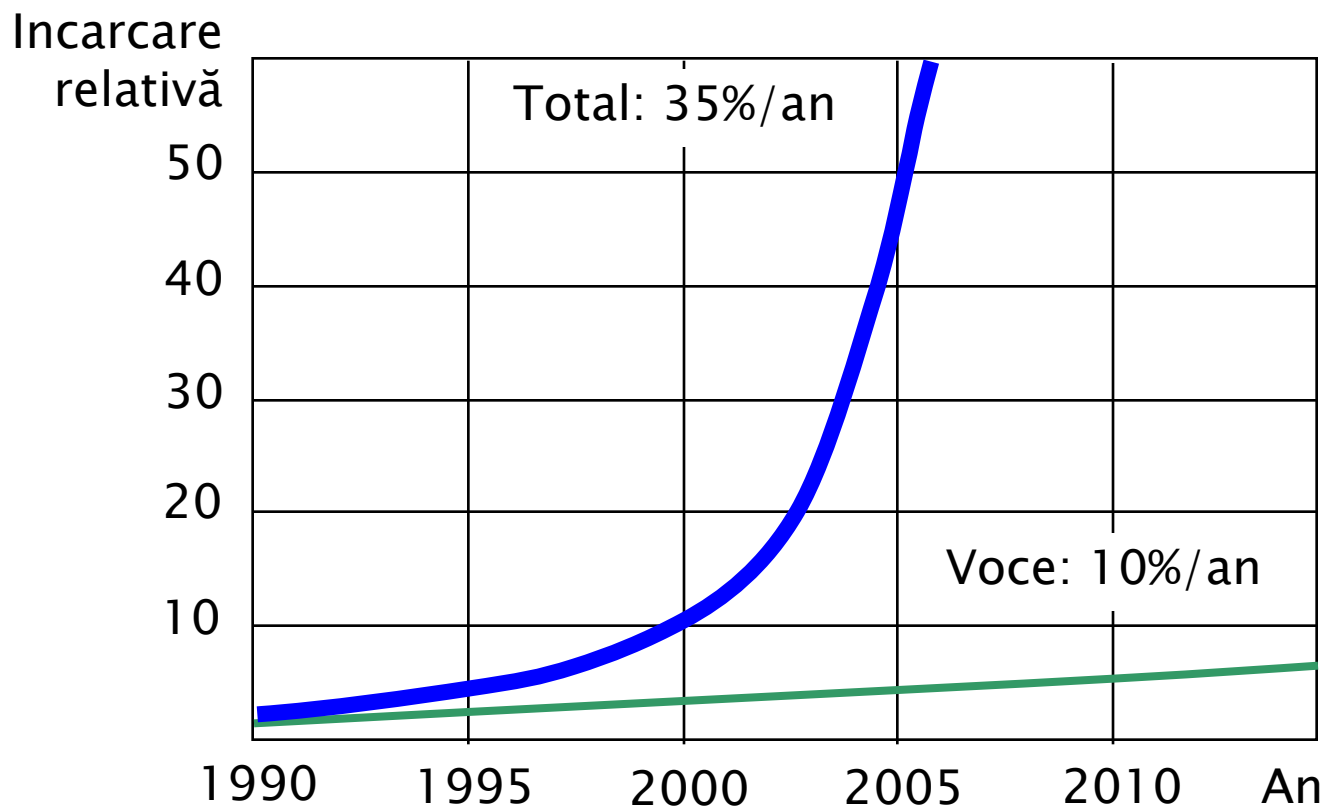
- ▶ Vizibil

- Spectru vizibil (GaAlAs)

- ▶ Iluminare

- Putere ridicata, lumina alba (GaInN)

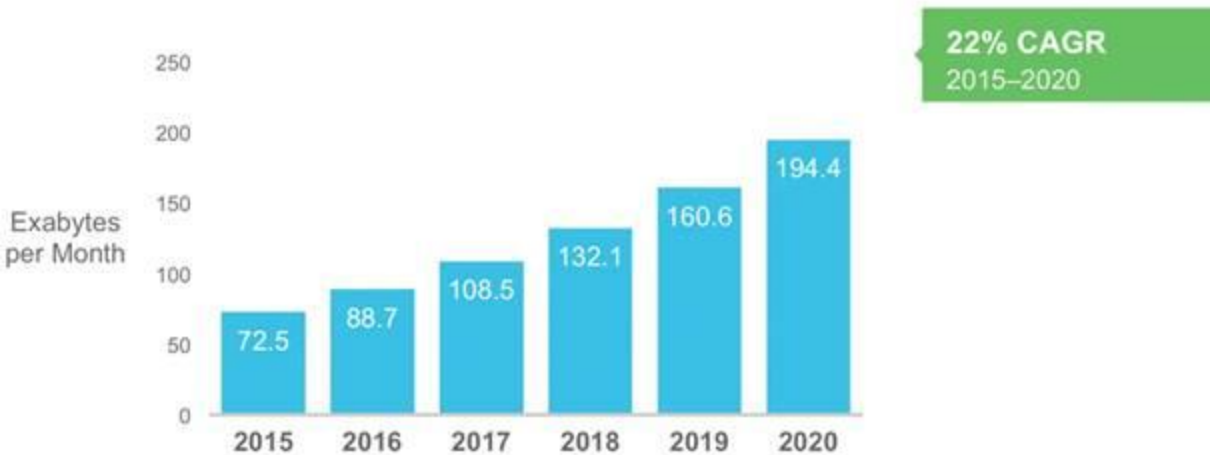
# Evoluția lățimii de bandă utilizată în rețelele de telecomunicații



Sursa:

**EC** ELECTRONICAST  
CORPORATION

# Evoluția lățimii de bandă

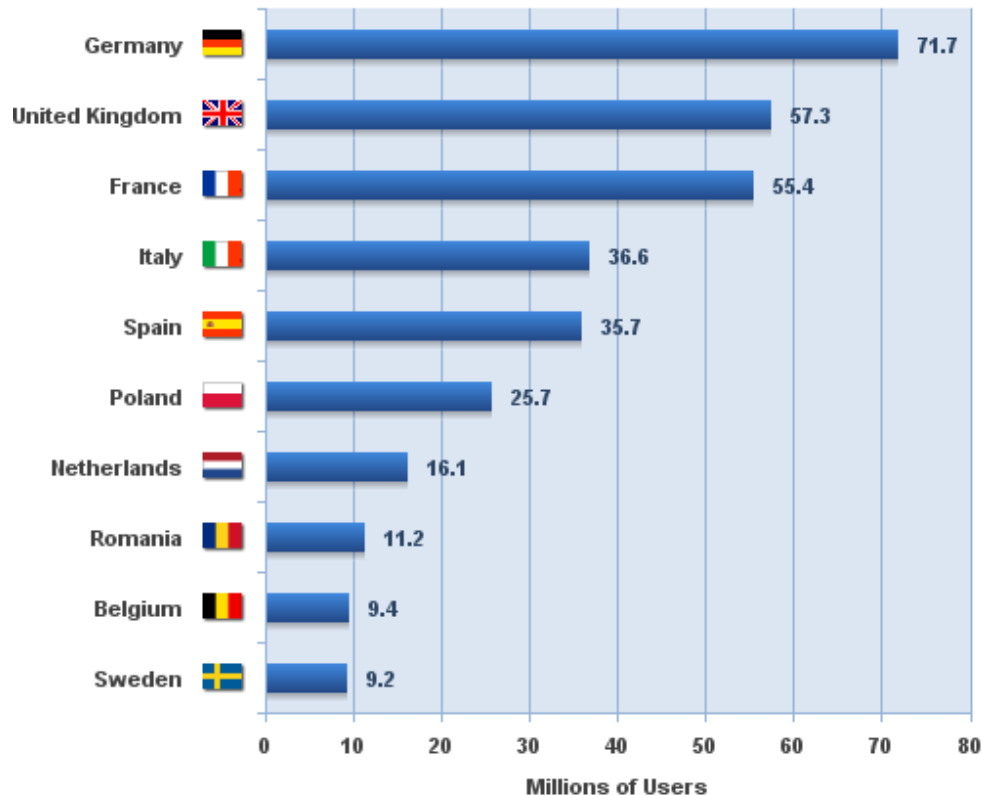


Source: Cisco VNI, 2016

Year	Global Internet Traffic
1992	100 GB per day
1997	100 GB per hour
2002	100 GBps
2007	2,000 GBps
2015	20,235 GBps
2020	61,386 GBps

# Utilizzatori Internet in EU

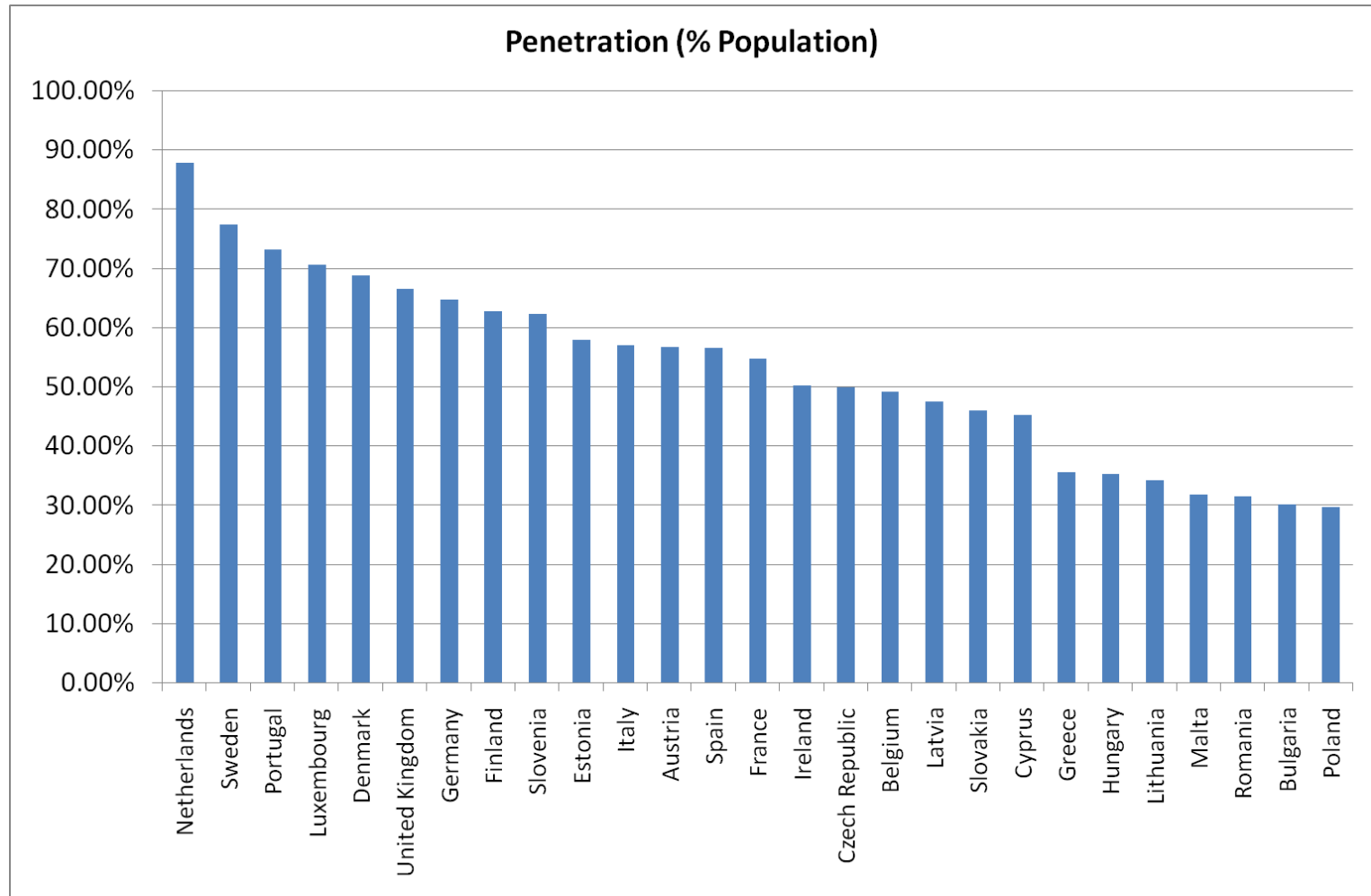
## European Union - Top 10 Internet Countries December 31, 2014



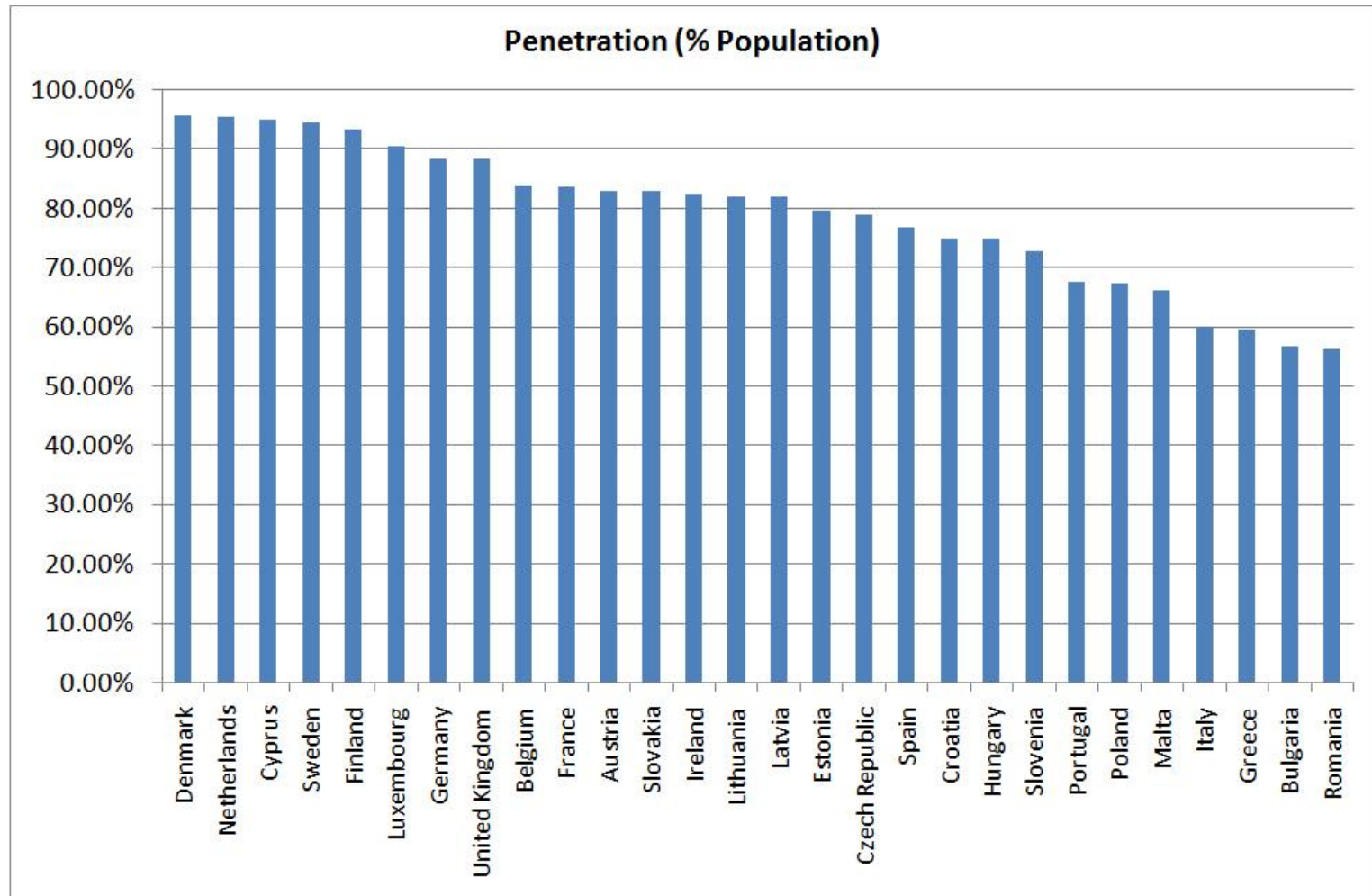
Source: Internet World Stats - [www.internetworldstats.com/stats9.htm](http://www.internetworldstats.com/stats9.htm)  
398,972,533 estimated EU Internet users for 2014Q4  
Copyright © 2015, Miniwatts Marketing Group



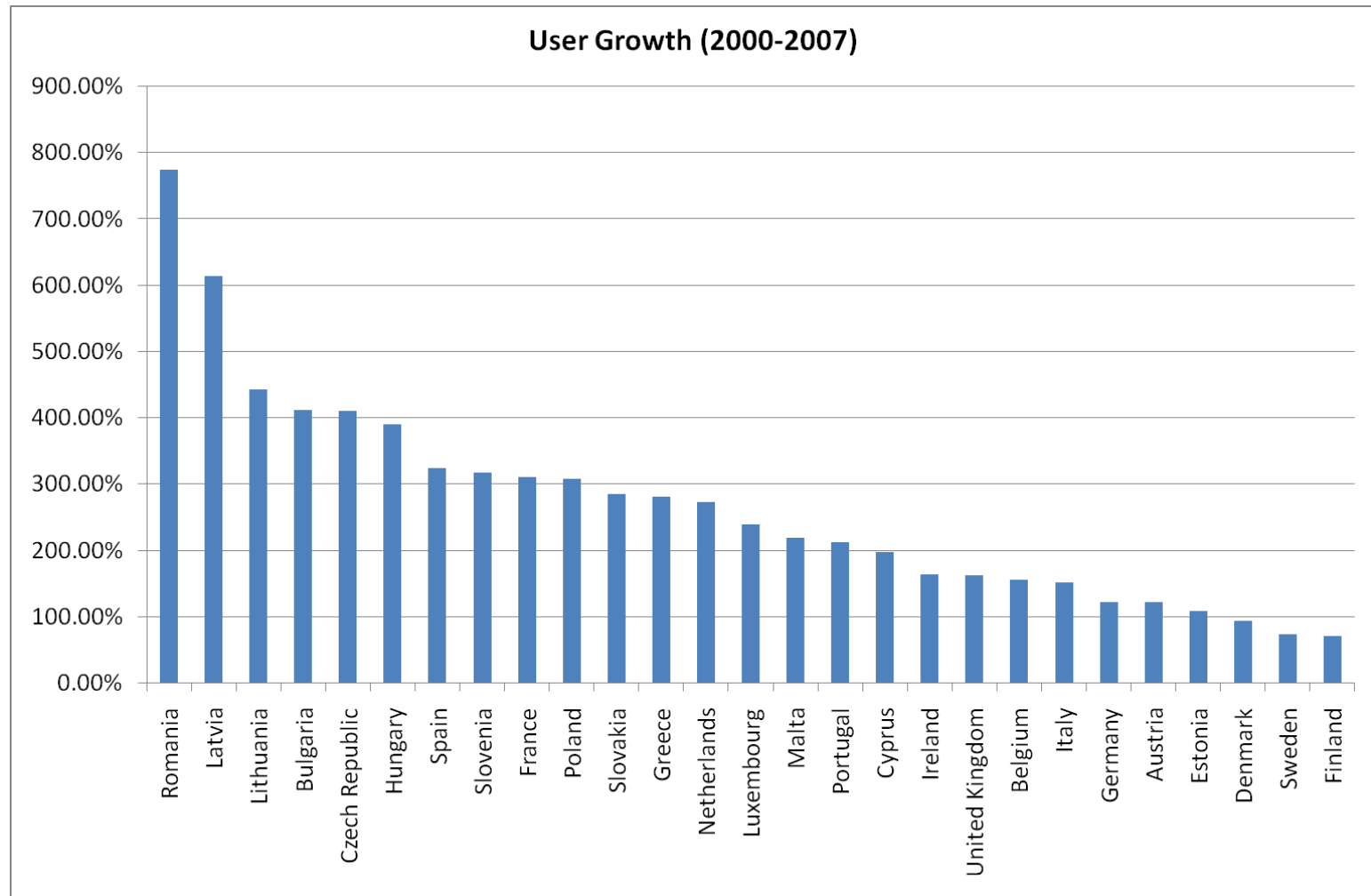
# Rata de penetrare in EU 2007



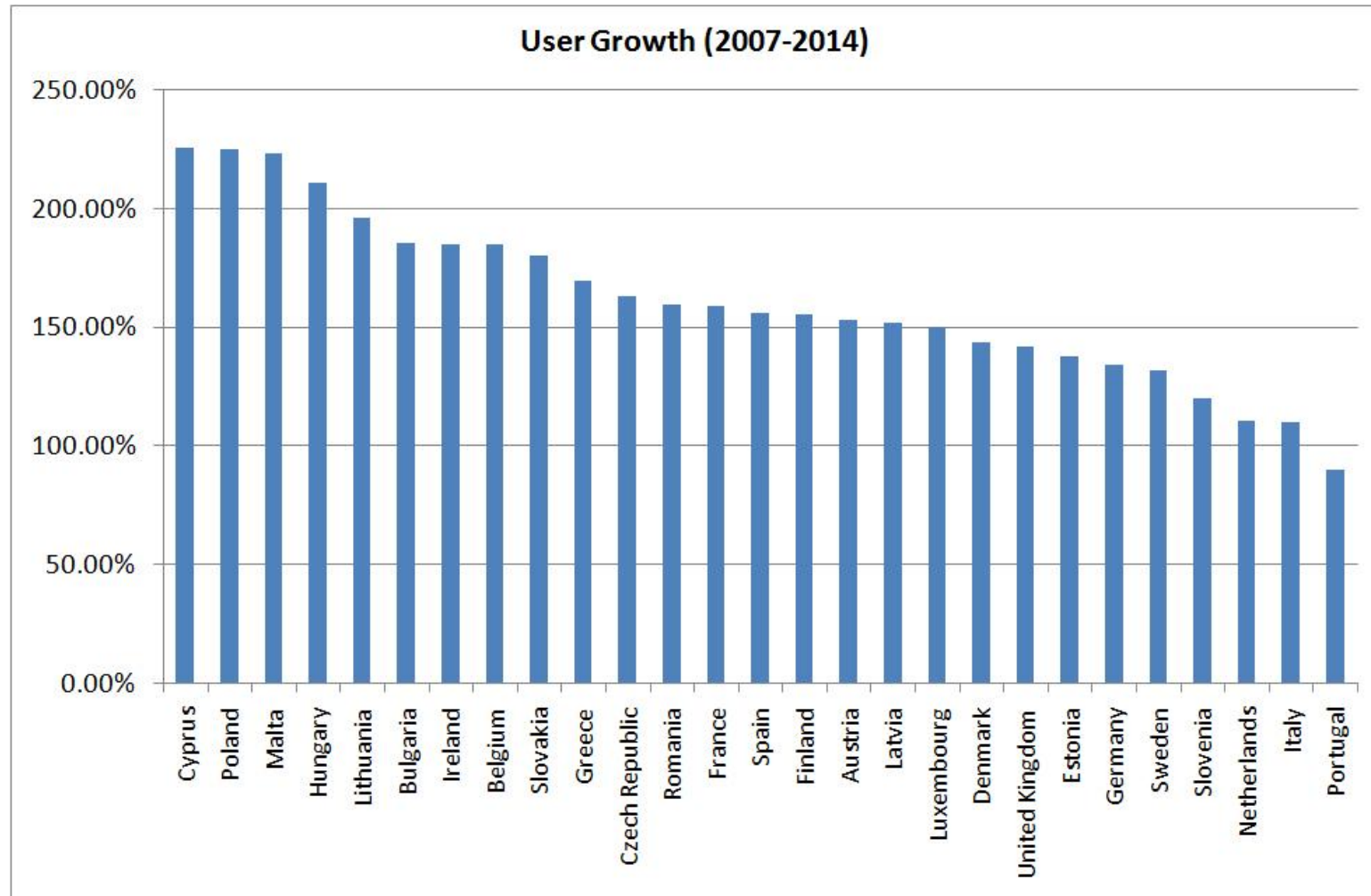
# Rata de penetrare in EU 2014



# Crestere 2000-2007

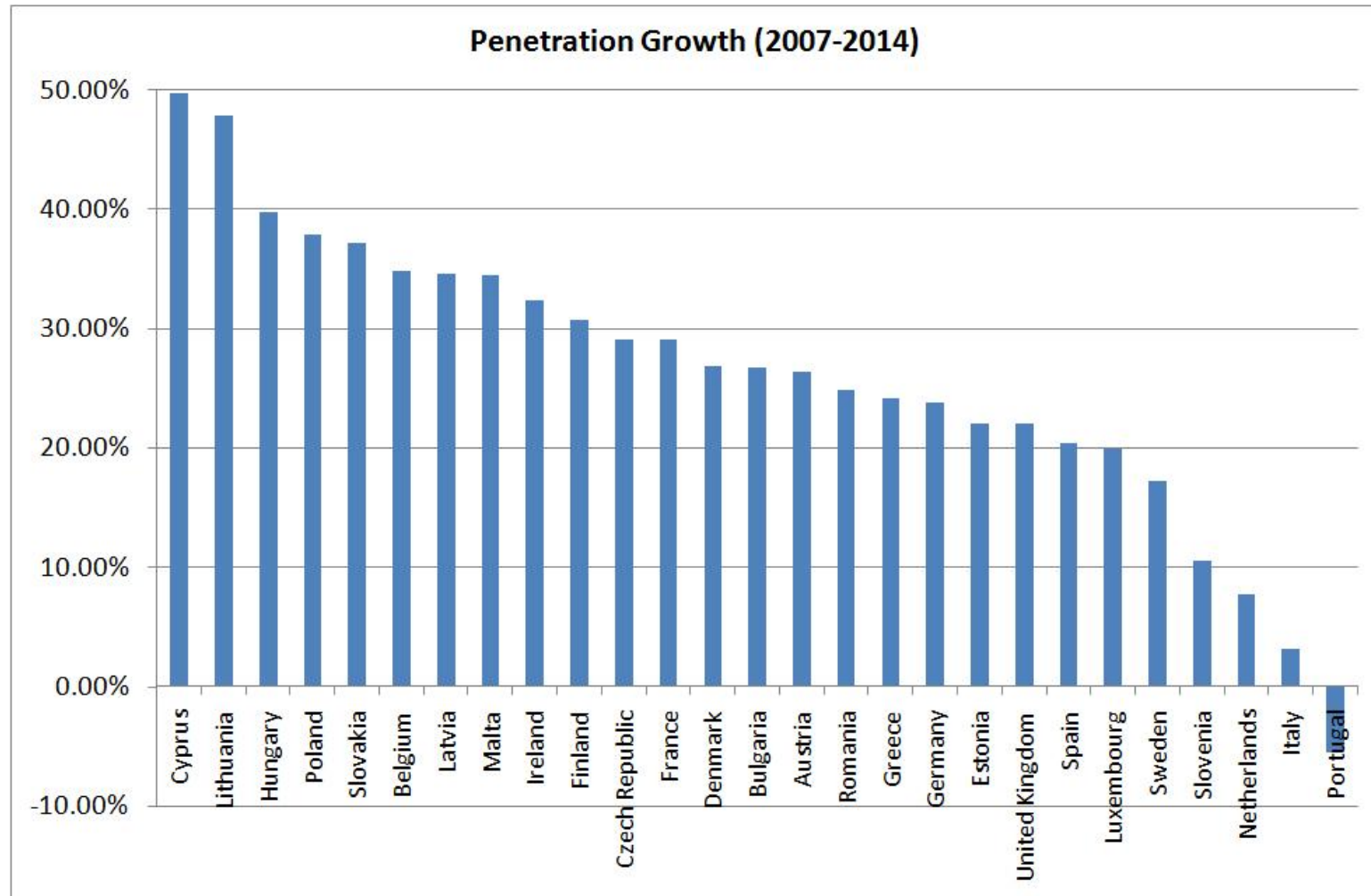


# Crestere 2007-2014

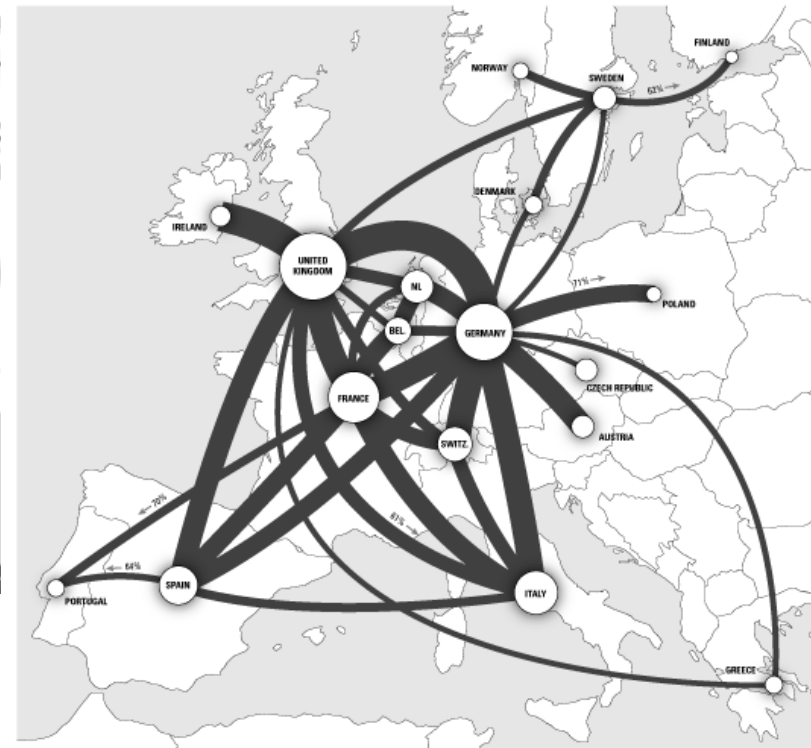
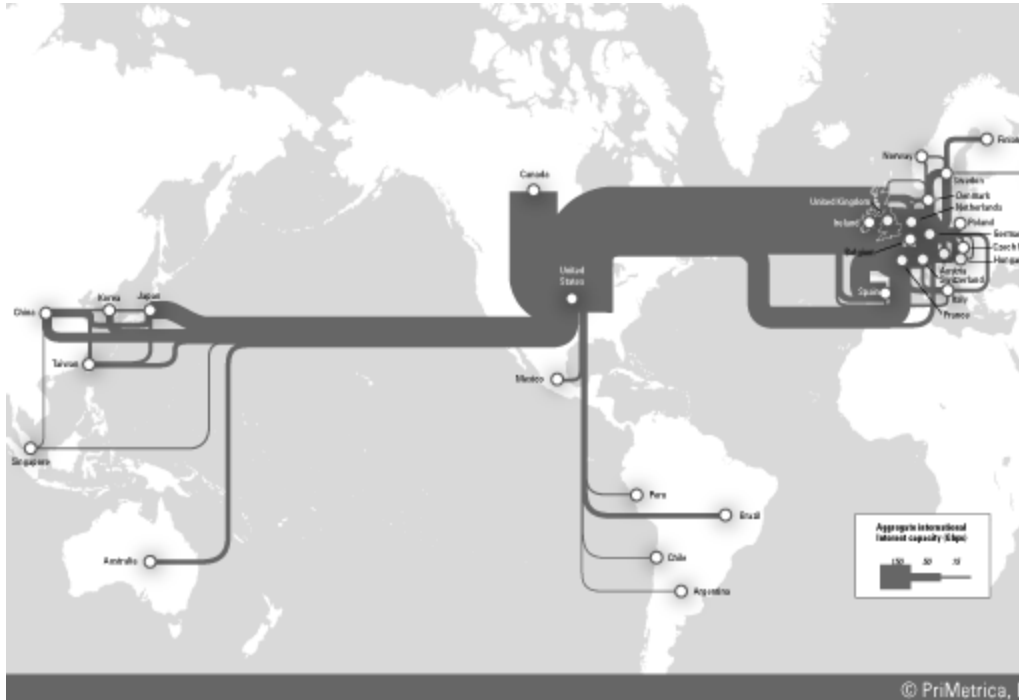




# Crestere 2007-2014



# Internet Backbone

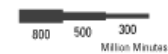


## Key

All figures are given in millions of minutes of telecommunications traffic for the public telephone network.

The map shows all intra-European routes with a combined 2004 volume of more than 300 million minutes.

## Traffic Flows



Each band is proportional to the total annual traffic on the public telephone network in both directions between each pair of countries.

## Total Outgoing Traffic



The area of each circle is proportional to the volume of the total annual outgoing traffic from each country.

## Balance of Traffic

On routes where traffic in one direction accounts for more than 80 percent of the total, an arrow shows the direction most of the traffic flows.

# Internet Backbone



# Avantajele comunicațiilor prin fibra optică – 1

- ▶ Greutate și volum
- ▶ Costul materialelor primare
  - $\text{SiO}_2/\text{Cu}$
- ▶ Capacitate de transmisie a informației  **$f \sim 200\text{THz}$** 
  - 15.5 Tbit/s @ 7000 km, 69.1Tb/s @ 240km
  - 159 Tb/s @ 1045 km
  - Banda (Viteza) x Distanță [MHz · km] [ ? MHz/km]
- ▶ Lipsa conexiunilor electrice
  - Bucle de masă (1–2V/km)
  - Siguranță în exploatare
  - Imunitate la fulgere/lipsa scânteilor



# Avantajele comunicațiilor prin fibra optică – 2

- ▶ Imunitate la interferență electromagnetică
- ▶ Distanța între repeatoare
  - 100km/2–5km
- ▶ Posibilitate de creștere a capacității de transmisie a informației
  - Teoretic extrem de mare (aproape infinită) **f~200THz**
  - Reutilizarea cablurilor existente
- ▶ Securitate
  - Interceptare dificilă și detectabilă
  - Inserare de semnal practic imposibilă

# Dezavantajele comunicațiilor prin fibra optică

- ▶ Conexiuni complexe și esențiale
  - Costul circuitelor integrate crescut considerabil de cuplarea luminii în fibra
- ▶ Curbarea cablurilor optice
- ▶ Dezvoltarea greoaie a standardelor
- ▶ Optica folosită strict pentru transmisie (aproape)
  - EDFA – Erbium Doped Fiber Amplifier
- ▶ Sensibilitate la radiații gama și câmpuri electrice intense
- ▶ Rozătoare și termite

# Esantionare

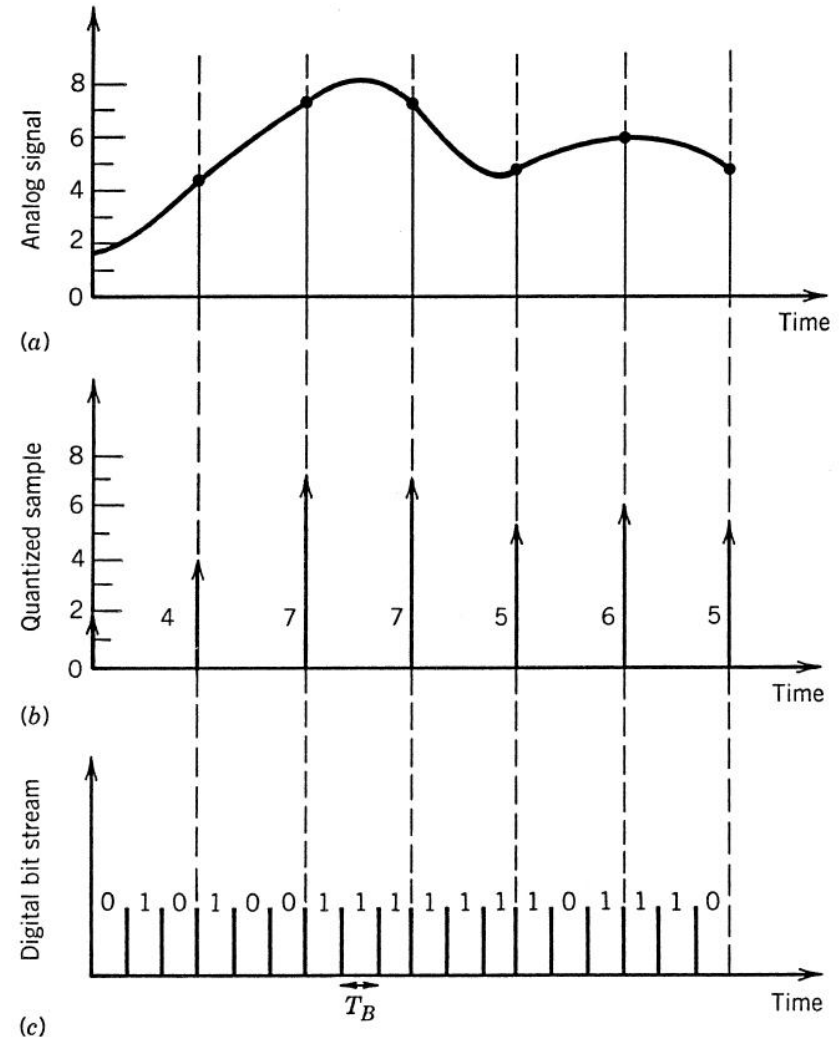
- ▶ pulse–position modulation
- ▶ pulse–duration modulation
- ▶ pulse–code modulation (PCM)

- ▶ esantionare (Nyquist)

$$f_s \geq 2 \cdot \Delta f$$

- ▶ cuantizare **M** intervale discrete
- ▶ zgomot de cuantizare
- ▶ minimizat

$$M \geq \frac{A_{\max}}{A_N}$$



# Esantionare

- ▶ pulse-code modulation (PCM)
- ▶ cuantizare  $M$  intervale discrete, codificate cu  $m$  biți

$$M = 2^m$$

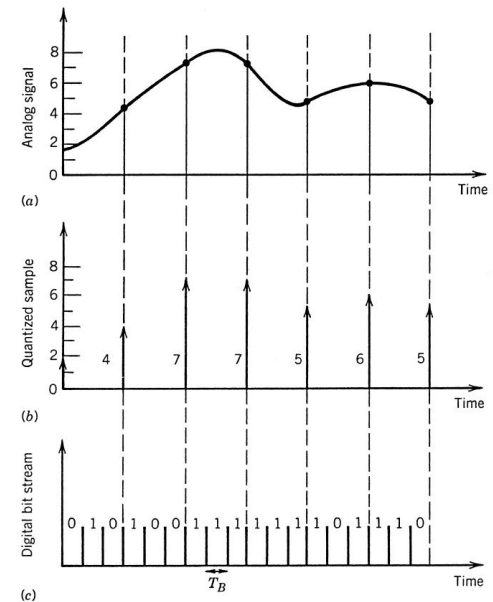
- ▶ viteza necesara (bit rate) [b/s]

$$B = m \cdot f_s \geq (2\Delta f) \cdot \log_2 M$$

$$M \geq \frac{A_{\max}}{A_N} \quad SNR [\text{dB}] = 10 \cdot \log_{10} \left( \frac{P_{\max}}{P_N} \right) = 20 \cdot \log_{10} \left( \frac{A_{\max}}{A_N} \right) \quad \log_2 10 \approx 3.33$$

$$B > (\Delta f / 3) \cdot SNR$$

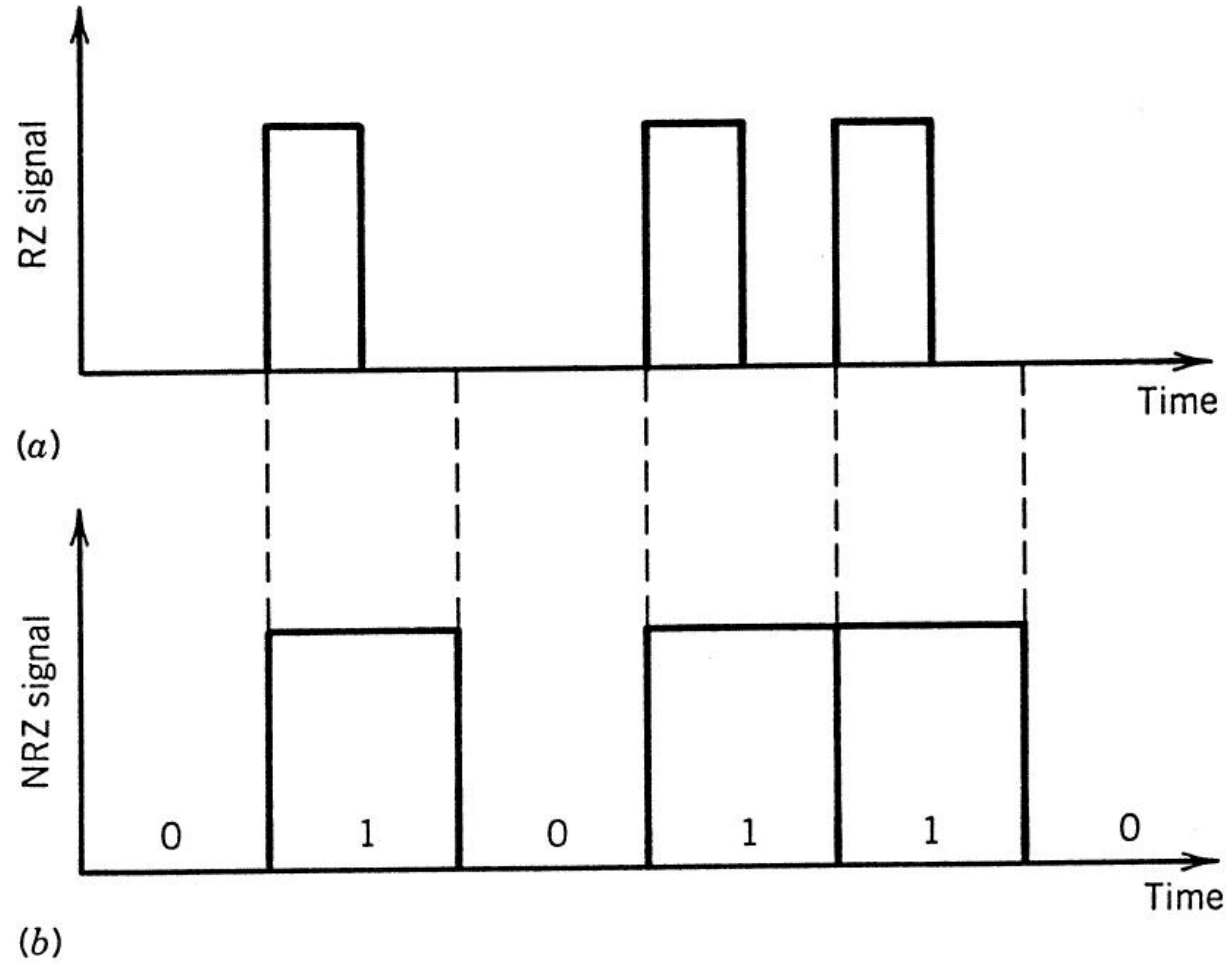
- ▶ telefonie: 3.1 kHz @ SNR=30dB
  - ▶ B=31 kb/s (64 kb/s)
- ▶ televiziune: 4 MHz @ SNR=50dB
  - ▶ B=66 Mb/s (100 Mb/s)



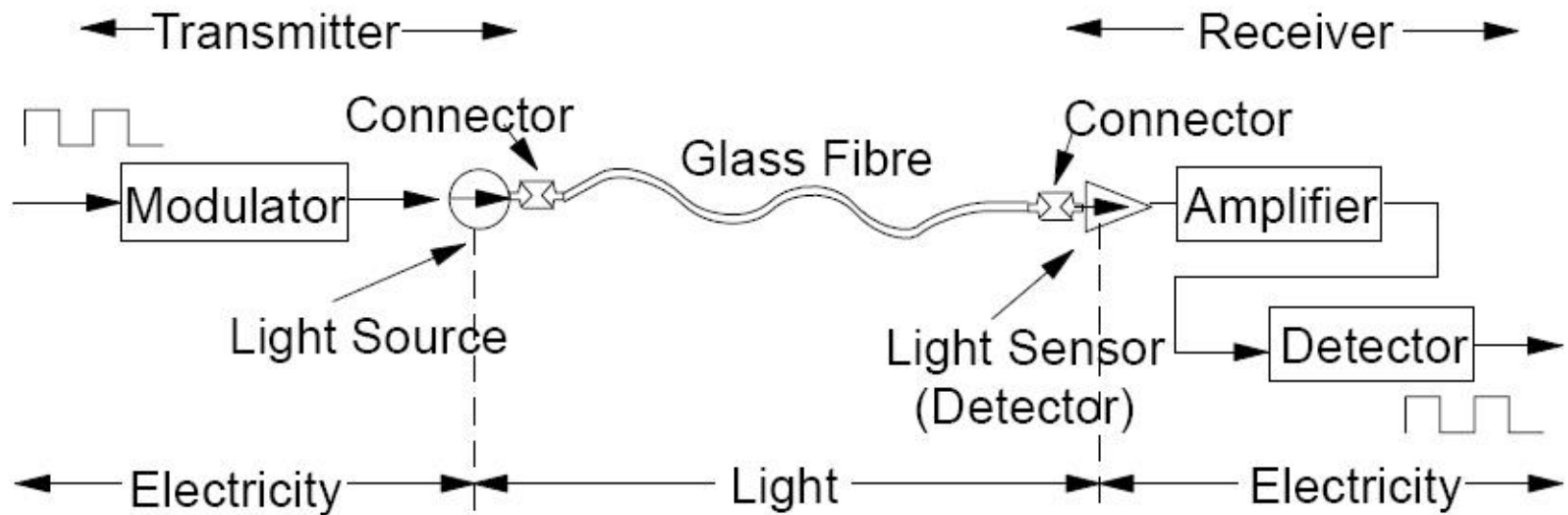


# Modulare

- ▶ return-to-zero (RZ)
- ▶ nonreturn-to-zero (NRZ)

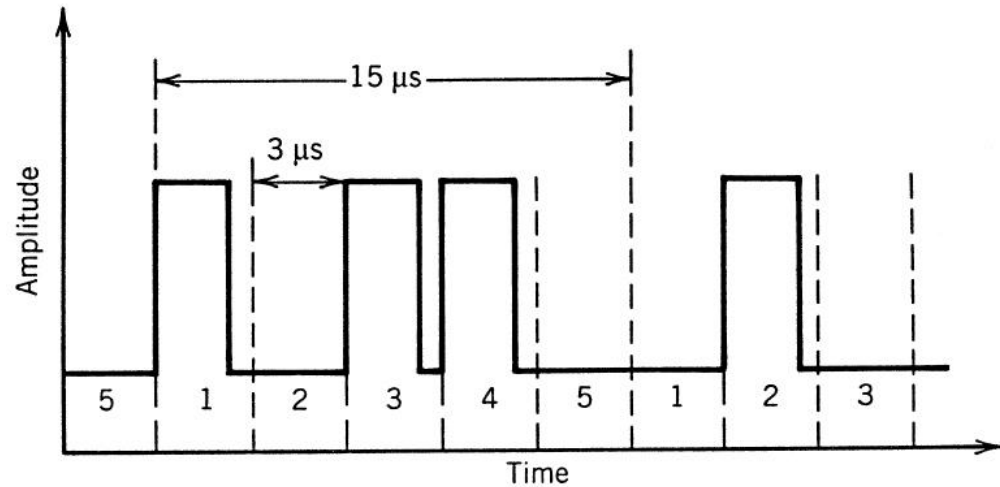


# Transmisia optica

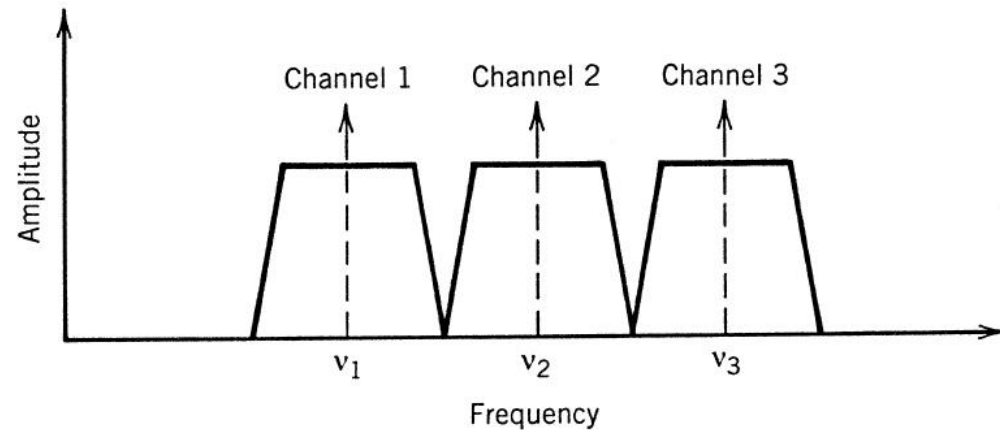


# Multiplexare

- ▶ TDM
  - time-division multiplexing
- ▶ FDM
  - frequency-division multiplexing
- ▶ Realizabila in domeniul **electric/optic**
- ▶ WDM
  - wavelength division multiplexing

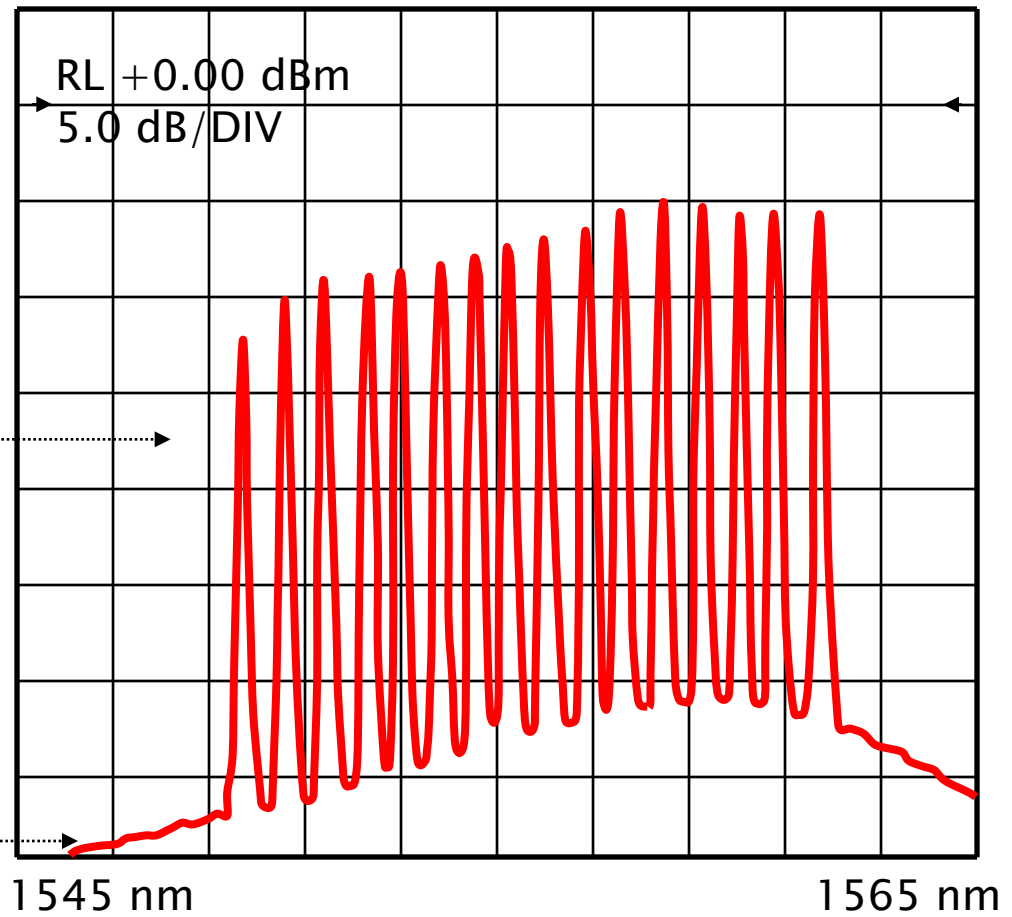


(a)



(b)

# Spectrul WDM – Wavelength Division Multiplexing



Canale: 16  
Spațiere: 0.8 nm

Emisie spontană  
Amplificată (ASE)

# Standardde

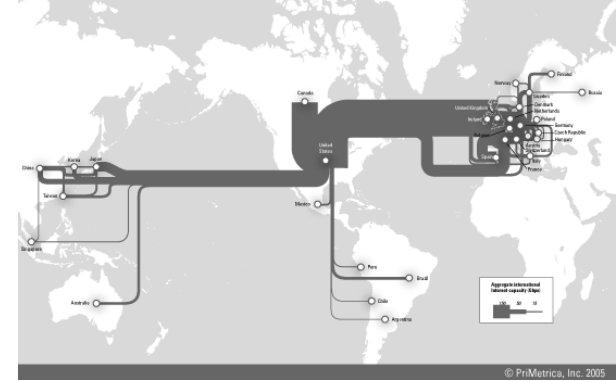
- ▶ SUA, Japonia

SONET	SDH	$B$ (Mb/s)	Channels
OC-1		51.84	672
OC-3	STM-1	155.52	2,016
OC-12	STM-4	622.08	8,064
OC-48	STM-16	2,488.32	32,256
OC-192	STM-64	9,953.28	129,024
OC-768	STM-256	39,813.12	516,096

- ▶ SONET – synchronous optical network
  - ▶ inlocuit de
- ▶ SDH – synchronous digital hierarchy



# Standard



## ▶ SUA

STS-1 and OC-1	51.840 Mb/s	
STS-3 and OC-3	155.52 Mb/s	same as STM-1
STS-9 and OC-9	466.56 Mb/s	
STS-12 and OC-12	622.08 Mb/s	same as STM-4
STS-18 and OC-18	933.12 Mb/s	
STS-24 and OC-24	1244.16 Mb/s	same as STM-8
STS-36 and OC-36	1866.24 Mb/s	
STS-48 and OC-48	2488.32 Mb/s	same as STM-16
STS-192 and OC-192	9953.28 Mb/s	same as STM-64
STS-256 and OC-256	13271.04 Mb/s	same as STM-86
STS-768 and OC-768	39813.12 Mb/s	same as STM-256
STS-3072 and OC-3072	159252.48 Mb/s	same as STM-1024
STS-12288 and OC-12288	639009.92 Mb/s	same as STM-4096

## ▶ Europa

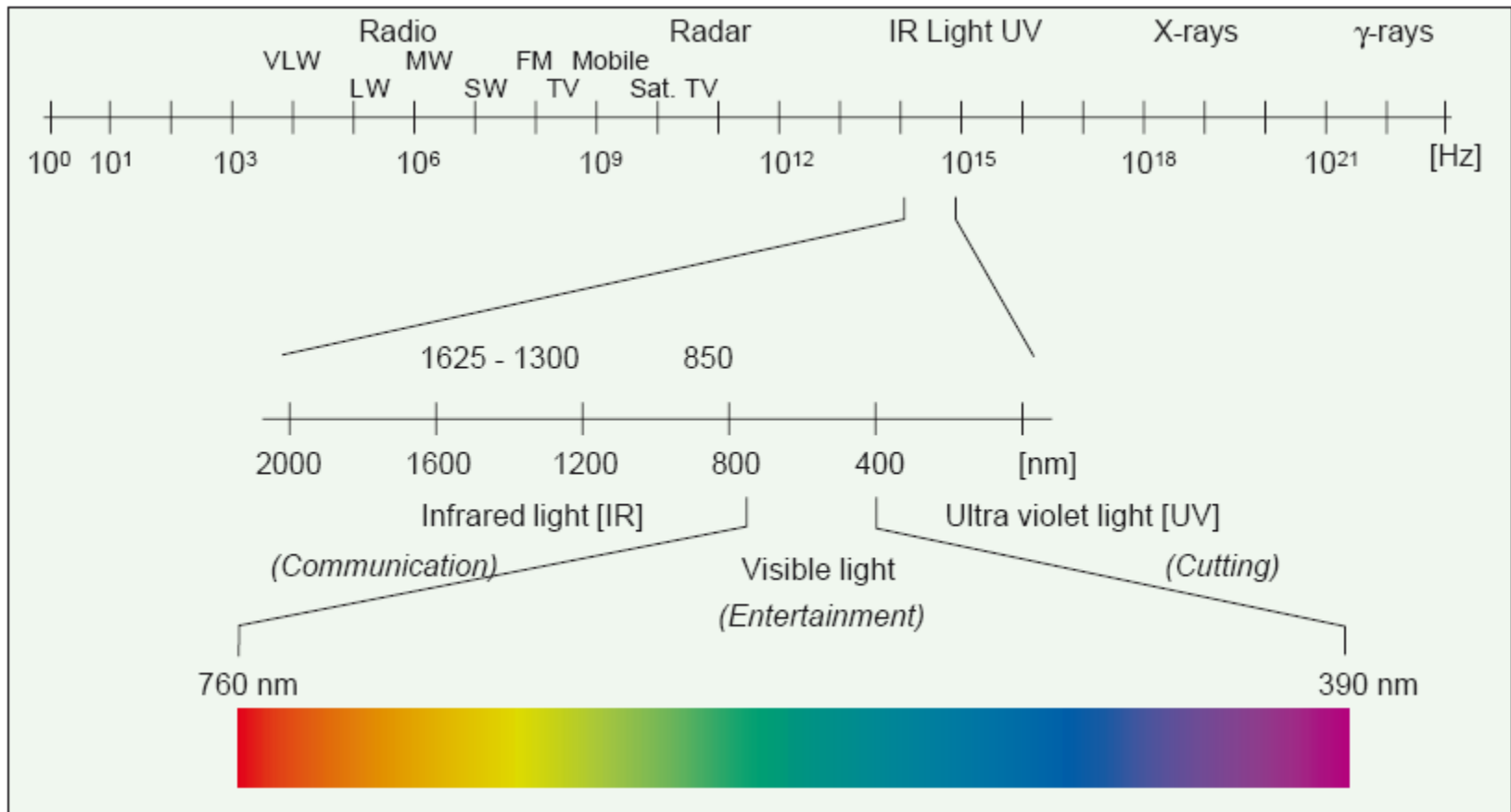
E0	64 Kb/s	
E1	2.048 Mb/s	
E2	8.448 Mb/s	4 E1s
E3	34.364 Mb/s	16 E1s
E4	139.264 Mb/s	64 E1s

1 mile = 1760 yards

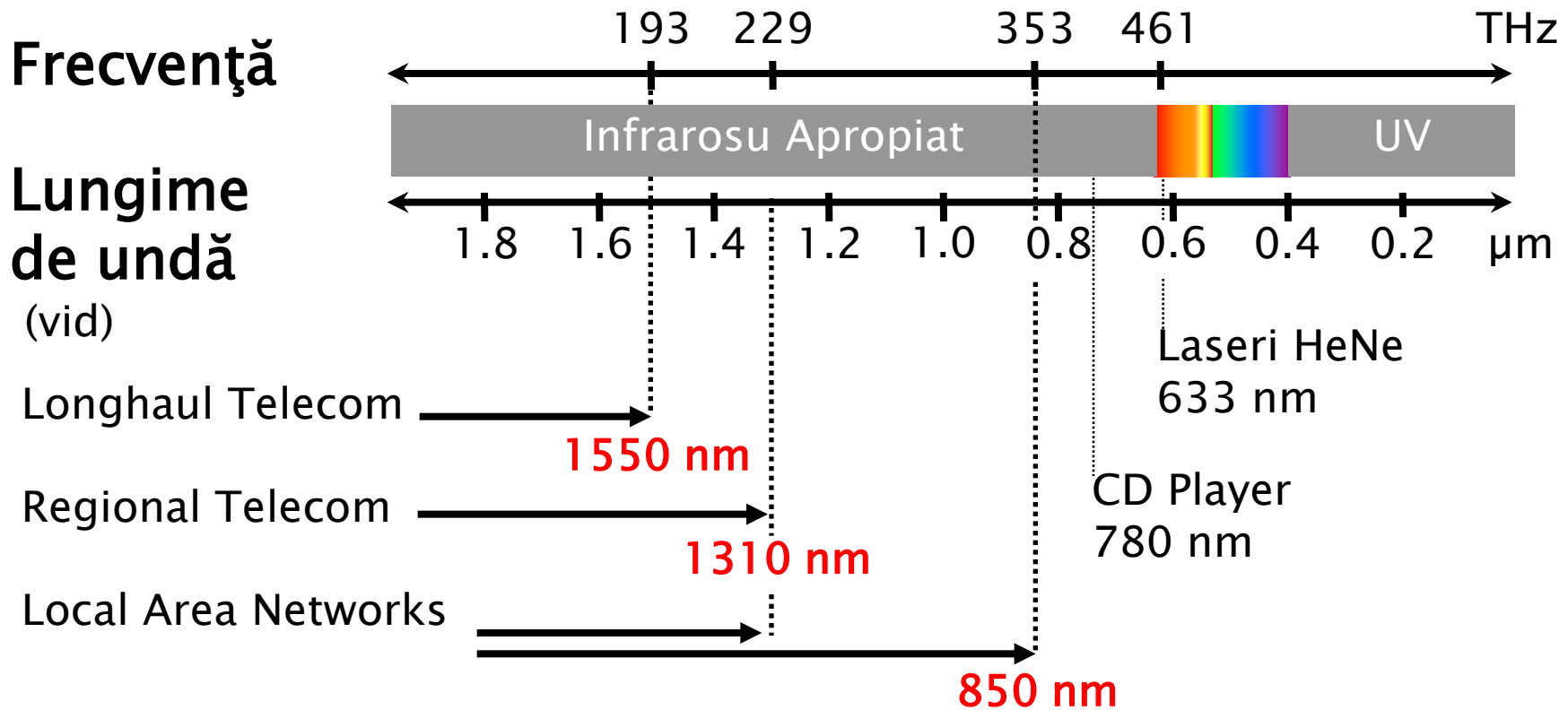
1 yards = 3 feet

1 mile ≈ 1609.34 m

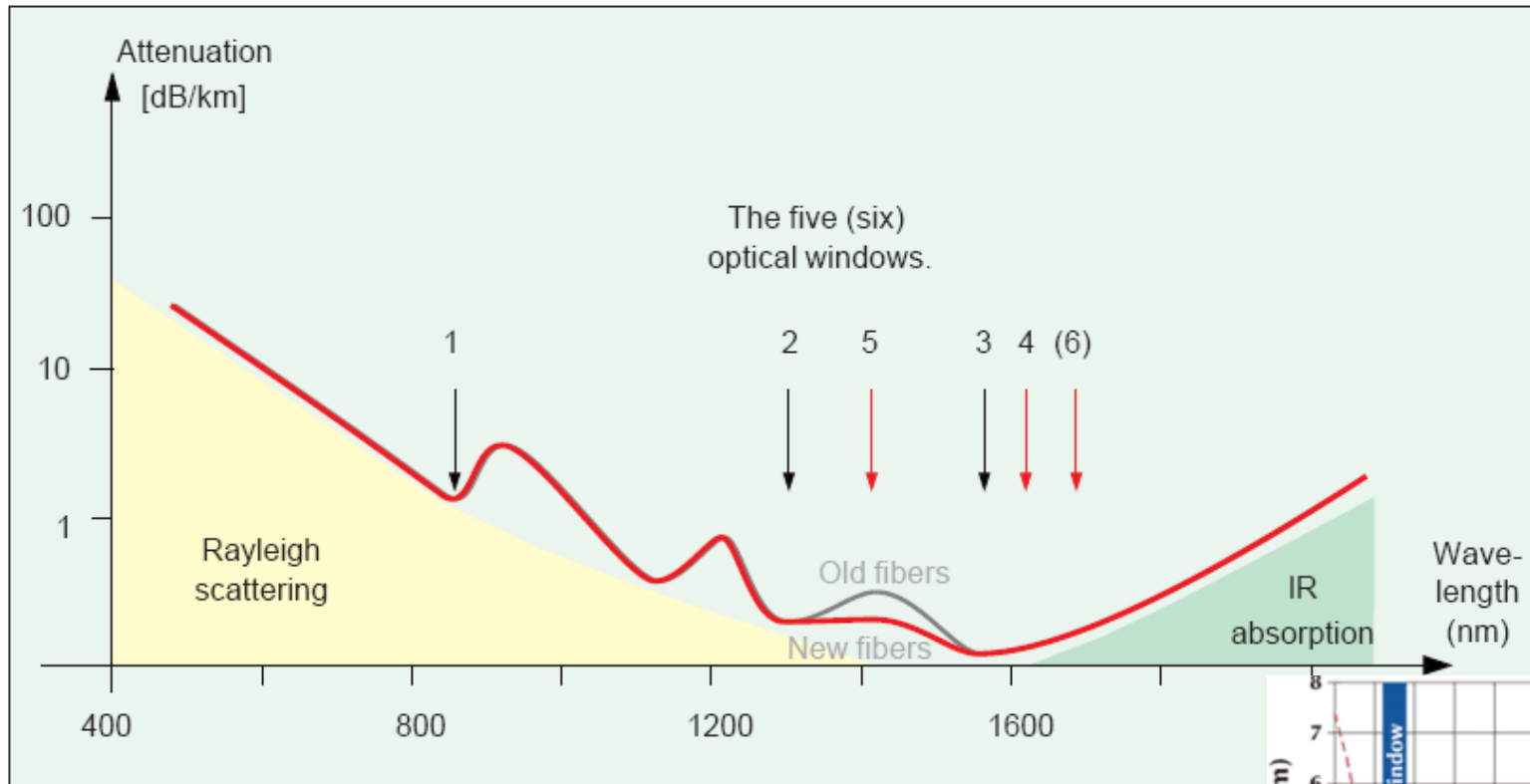
# Spectrul electromagnetic



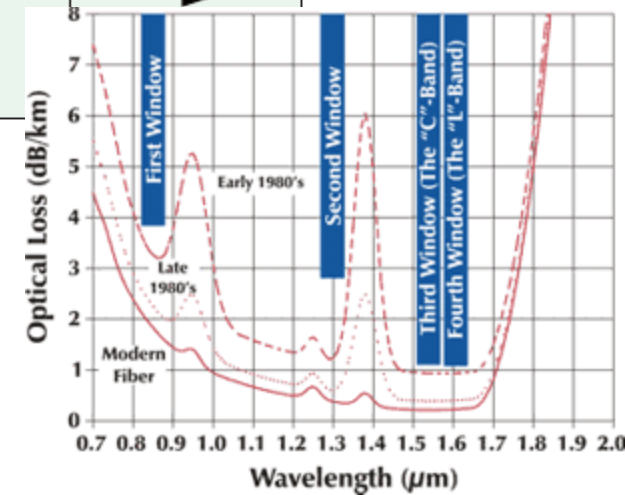
# Benzi de lucru in comunicațiile optice



# Atenuarea în fibra optică (SiO<sub>2</sub>)



850nm, 1310nm, 1550nm



# Aplicatii majore

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



# Eficiența

- ▶ Bec cu incandescenta
  - 16 lm/W
- ▶ Tub fluorescent
  - 100 lm/W
- ▶ LED
  - curent: 250 lm/W
  - curand: 300 lm/W

# Premiul Nobel, Fizica, 2014



The image is a graphic announcement for the Nobel Prize in Physics 2014. It features a blue background with a gold Nobel Prize medal icon in the top left. The text is in both Swedish and English. At the top, it says "Nobelpriset i fysik 2014" and "The Nobel Prize in Physics 2014". Below this, the Swedish text "Nobelpriset i fysik 2014" is prominently displayed. To the right is the logo of the Royal Swedish Academy of Sciences, "KUNGL. VETENSKAPSKAS AKADEMIEN". Three portraits of the laureates are shown in a row: Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura. Each portrait is accompanied by their name and affiliation. Below the portraits is the award citation in Swedish and English. At the bottom left is the date "2014-10-07" and at the bottom right is the copyright notice "© Kungl. Vetenskapsakademien".

Nobelpriset i fysik 2014

The Nobel Prize in Physics 2014

KUNGL. VETENSKAPSKAS AKADEMIEN  
THE ROYAL SWEDISH ACADEMY OF SCIENCES

**Isamu Akasaki**  
Meijo University, Nagoya, Japan  
Nagoya University, Japan

**Hiroshi Amano**  
Nagoya University, Japan

**Shuji Nakamura**  
University of California,  
Santa Barbara, CA, USA

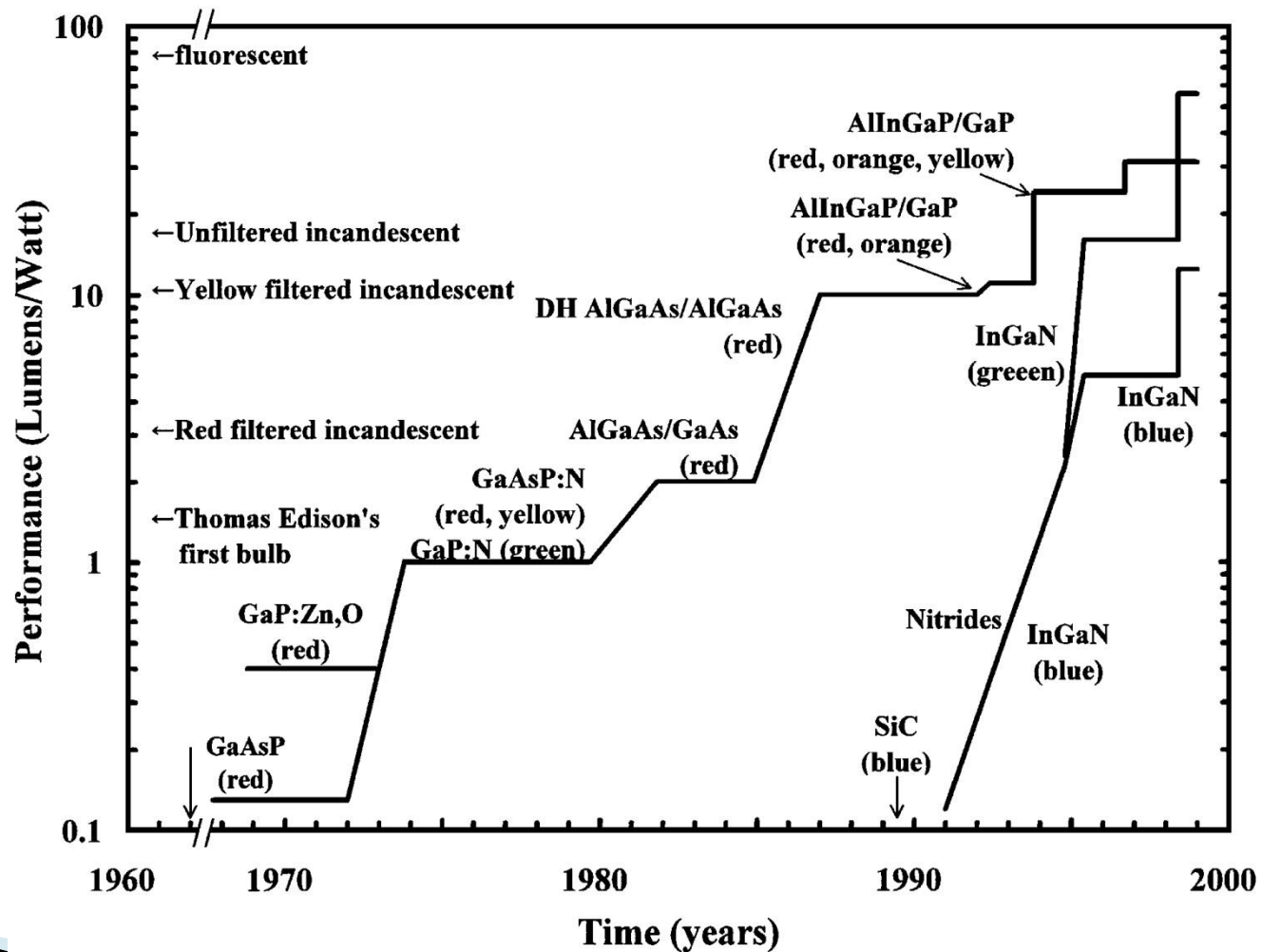
*"För uppfinningen av effektiva blå lysdioder vilka möjliggjort ljusstarka och energisnåla vita ljuskällor"*

*"For the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"*

2014-10-07

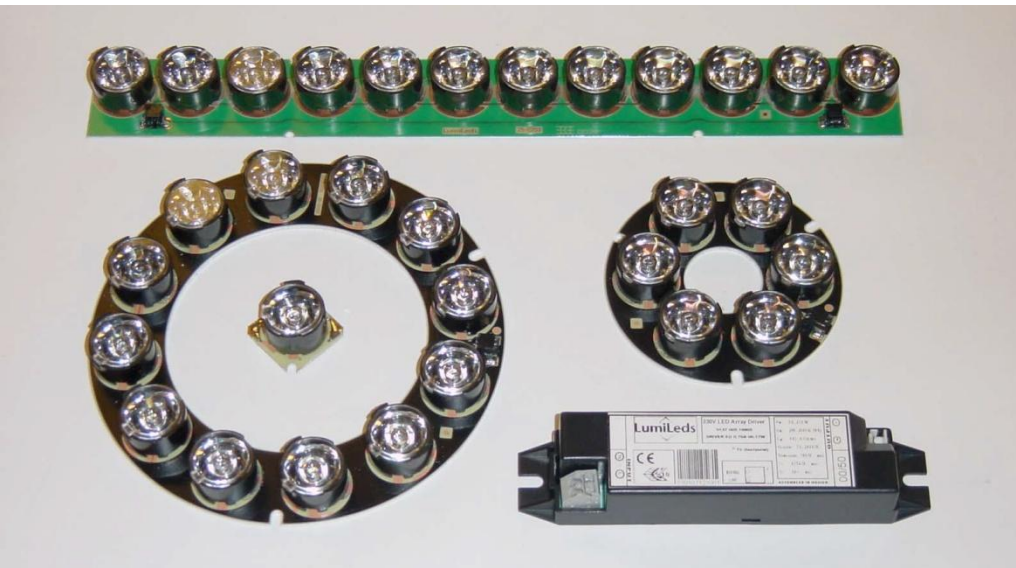
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# Eficienta in timp



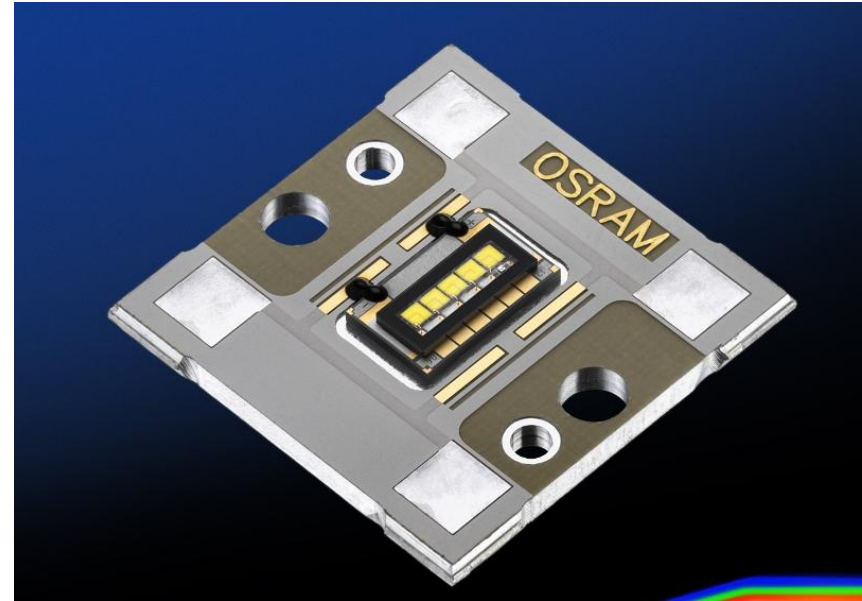
# Aplicatii

## ▶ auto





# Aplicatii





# Aplicatii majore

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

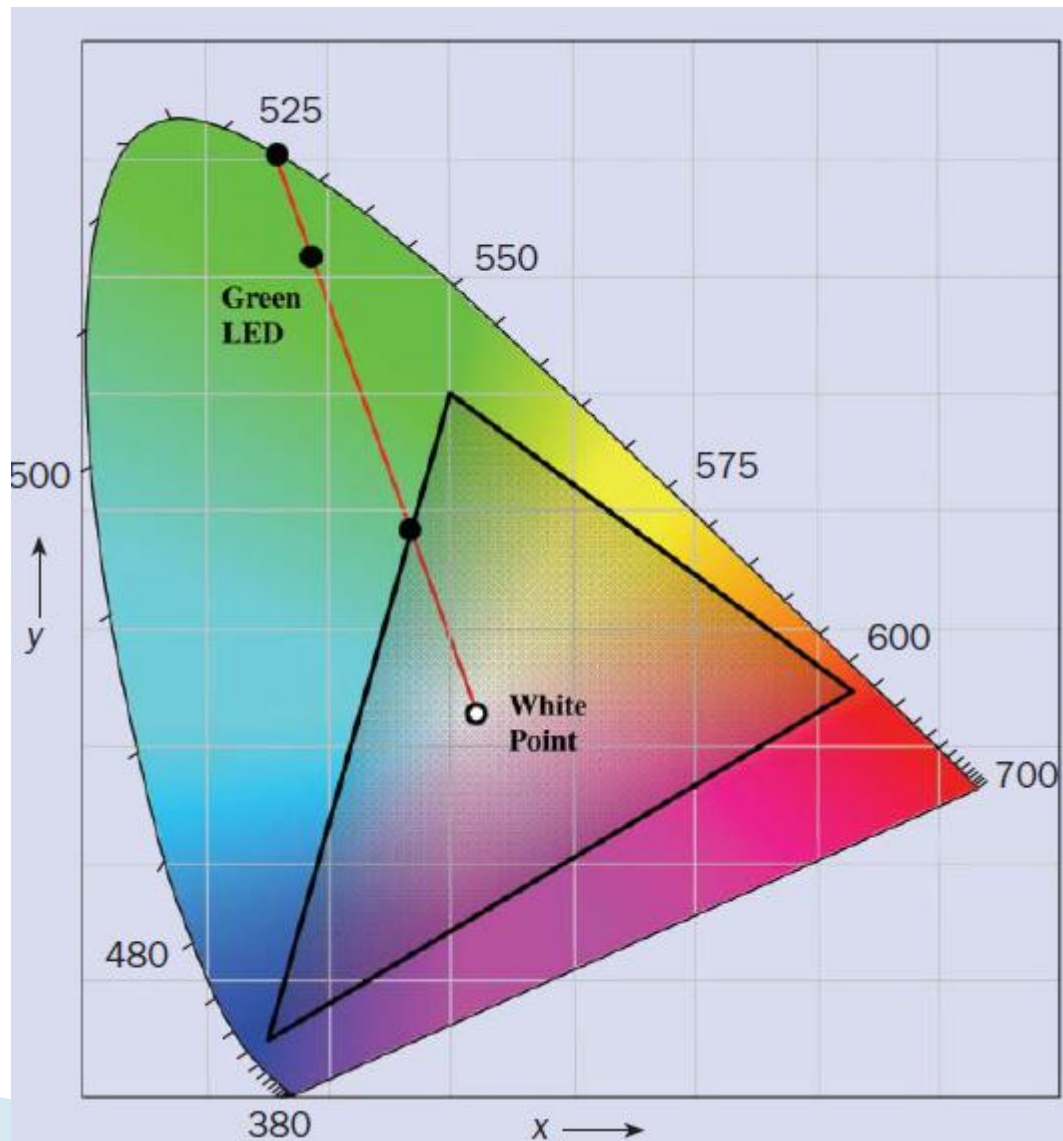
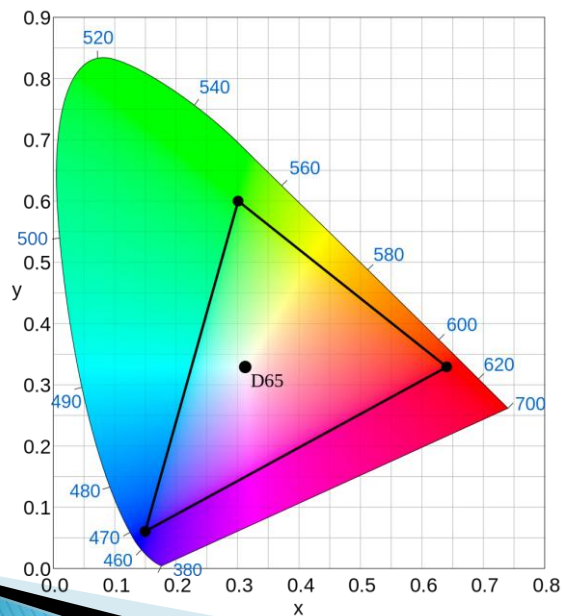
# ITU-R BT.709



## 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].

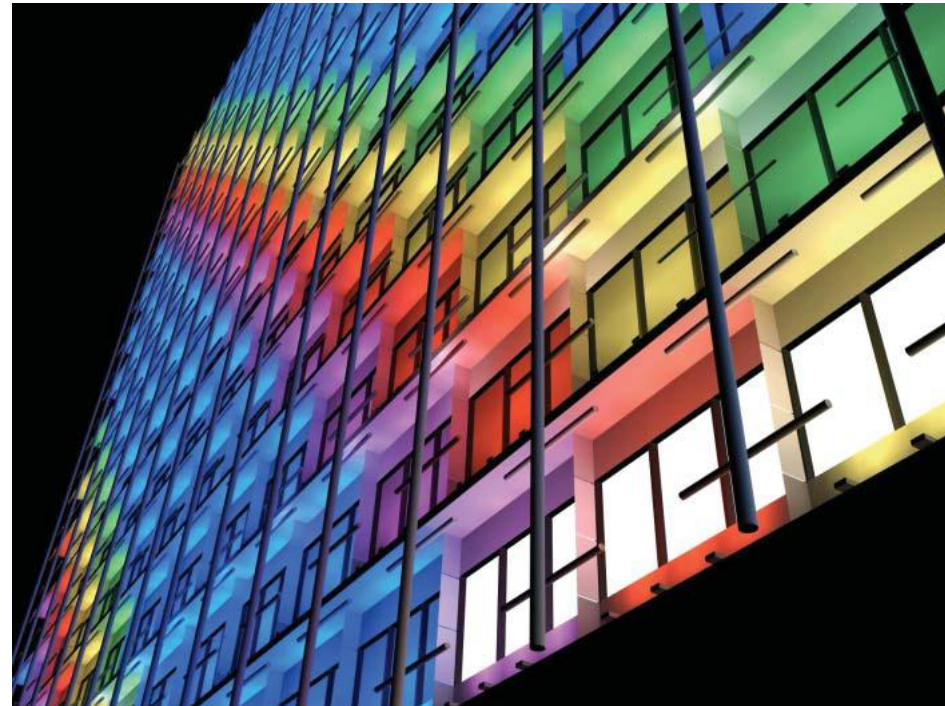


# Spectru vizibil





# ITU-R BT.709



## RGB values for Luxeon LEDs

LED color	Dominant wavelength $\lambda_D$ (nm)	RGB values
Royal blue	455	0.05, 0.00, 0.95
Blue	470	0.00, 0.11, 0.89
Cyan	505	0.00, 0.63, 0.37
Green	530	0.00, 0.77, 0.23
Amber	590	0.70, 0.30, 0.00
Red-orange	615	0.97, 0.00, 0.03
Red	625	0.92, 0.00, 0.08

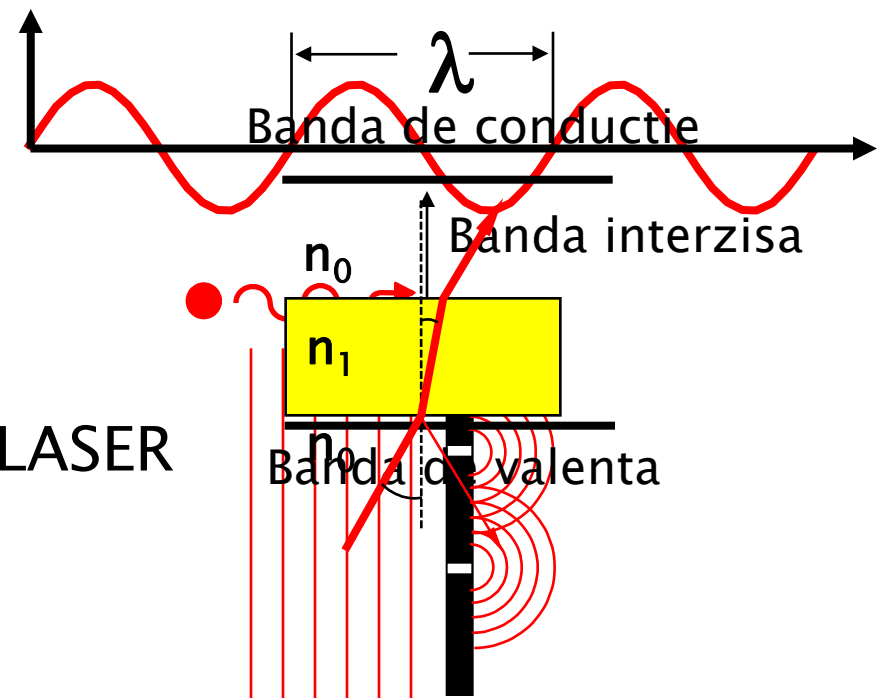
# Modelarea luminii

(tot) Capitolul 1



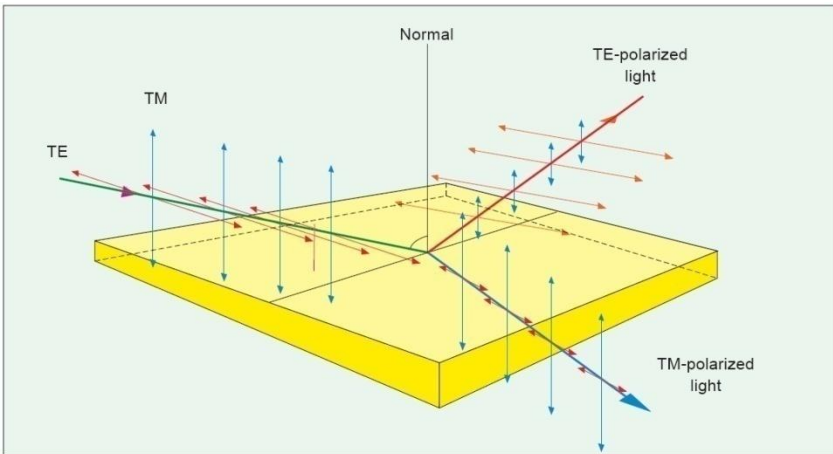
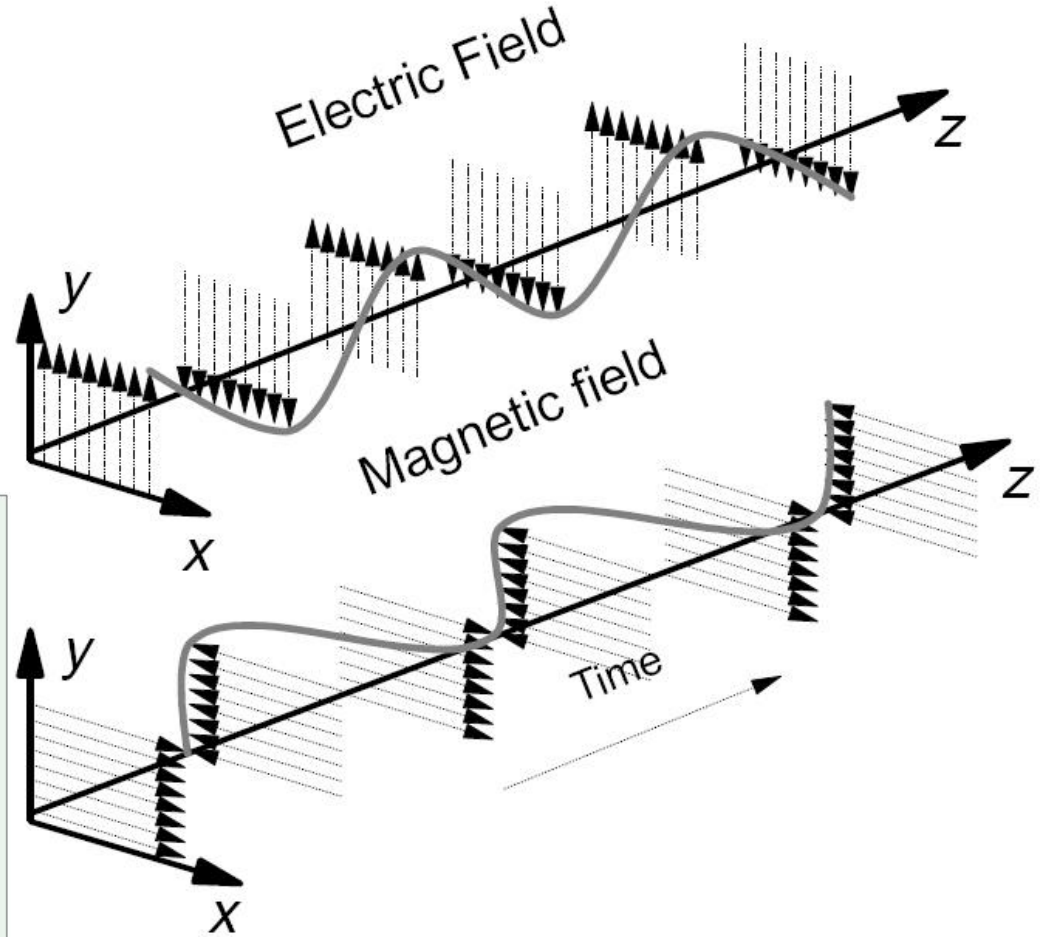
# Modelarea luminii

- ▶ Undă electromagnetică
  - Ecuațiile lui Maxwell
  - $\lambda$ ,  $\epsilon$ ,  $\omega$ ,  $f$
- ▶ Teoria cuantică
  - Benzi energetice  $E = h \nu$
  - fotoni, emisie stimulată, LASER
- ▶ Optică geometrică
  - $n$ ,  $\theta$
  - raze de lumină
  - intuitivă

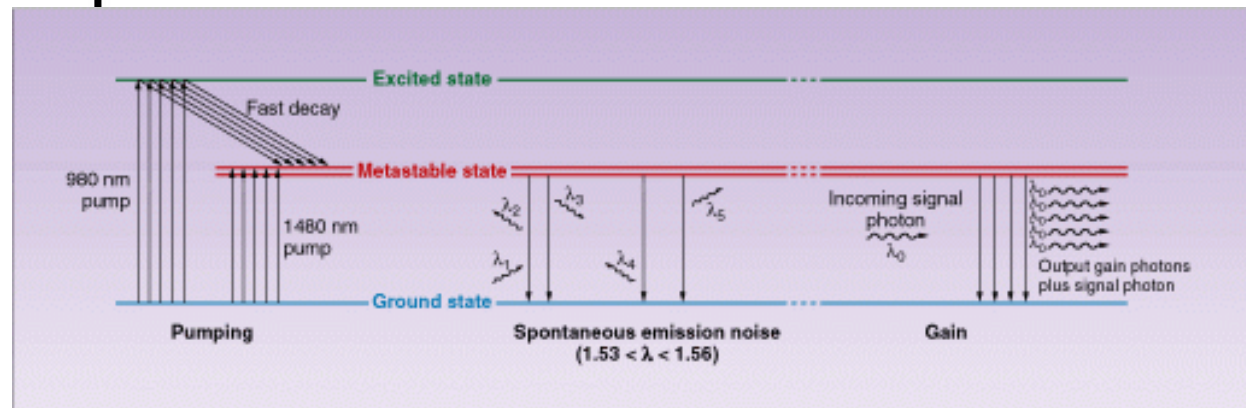
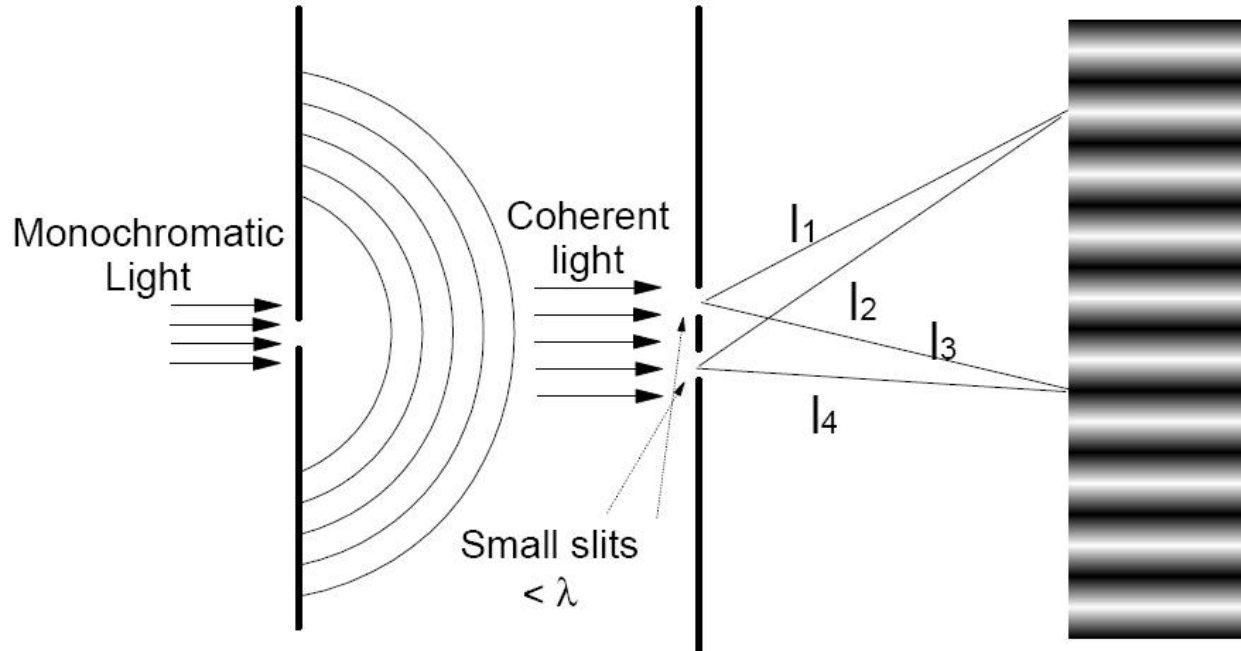


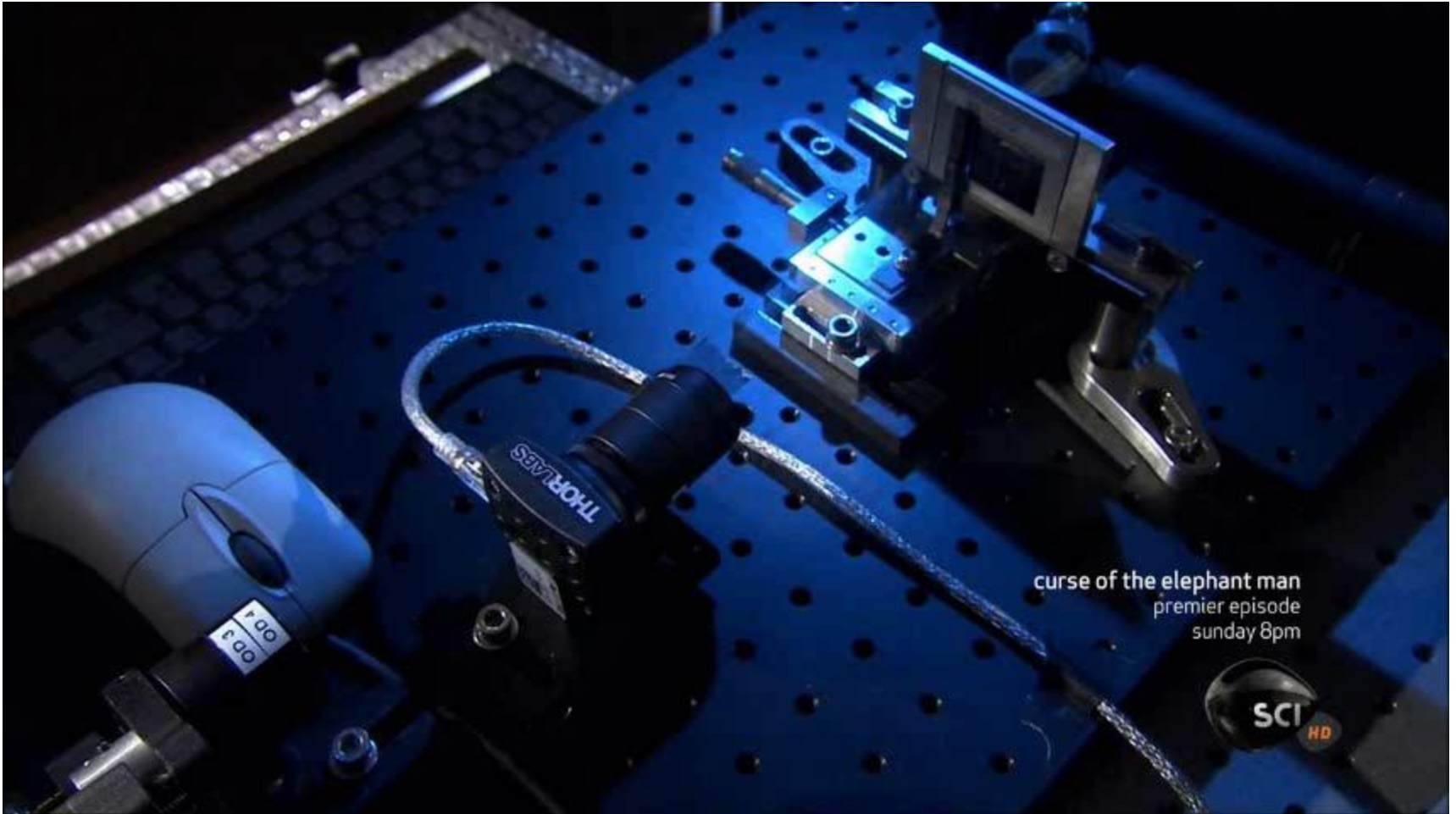
# Unda electromagnetica

- ▶ Dispersie
- ▶ Fibre monomod
- ▶ Interferenta
- ▶ Polarizare



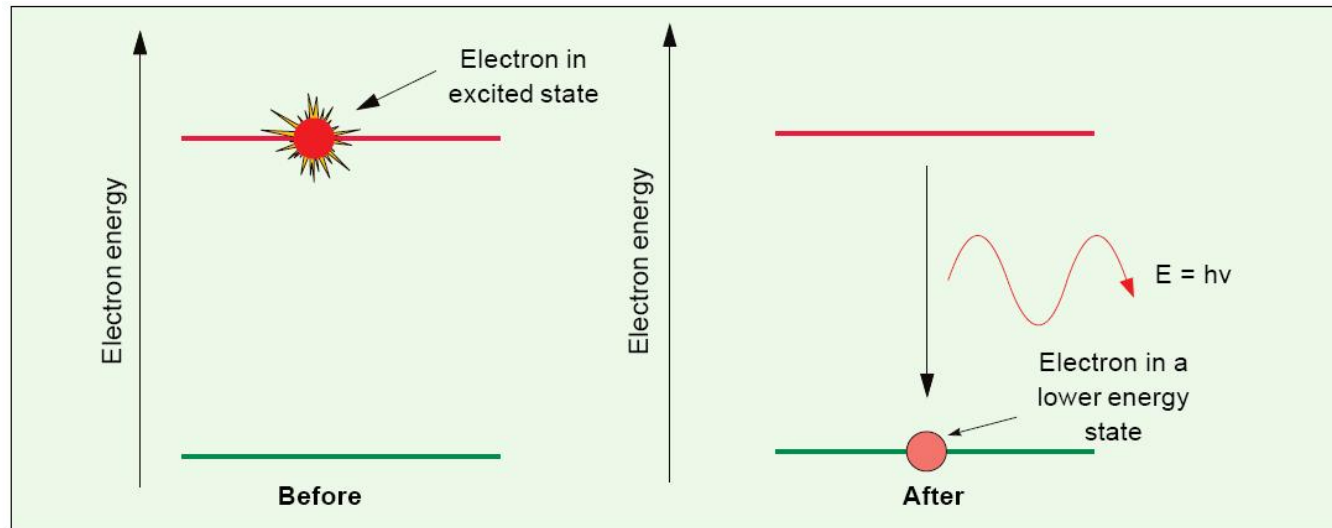
# Fotoni/Unda





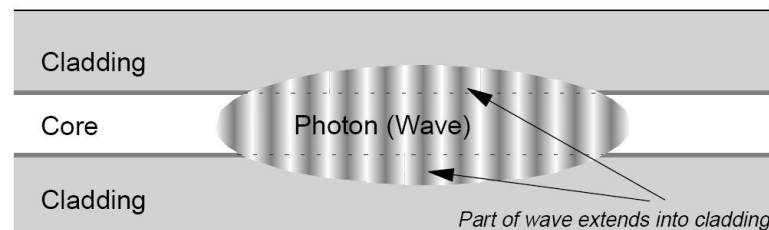
Through the Wormhole  
S02E07 How Does the Universe Work

# Model cuantic – foton



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

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

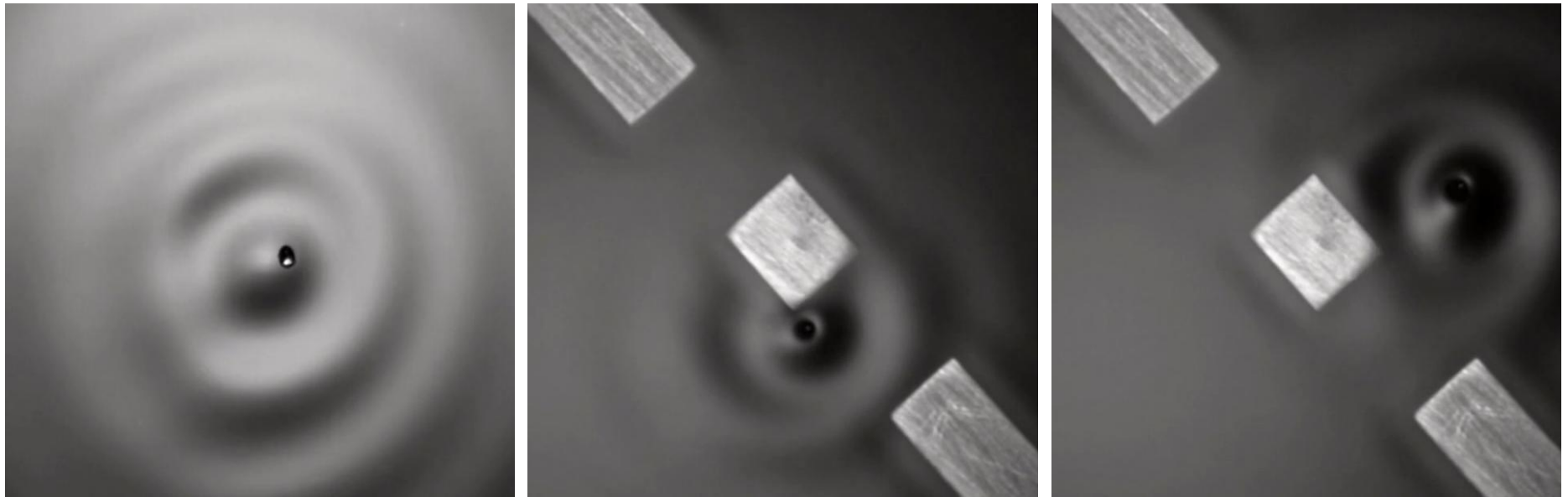




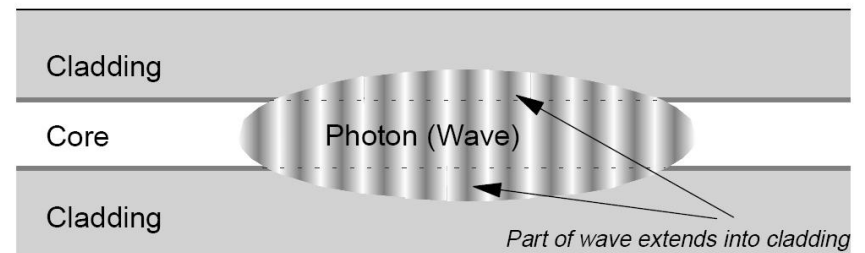


Through the Wormhole  
S02E07 How Does the Universe Work

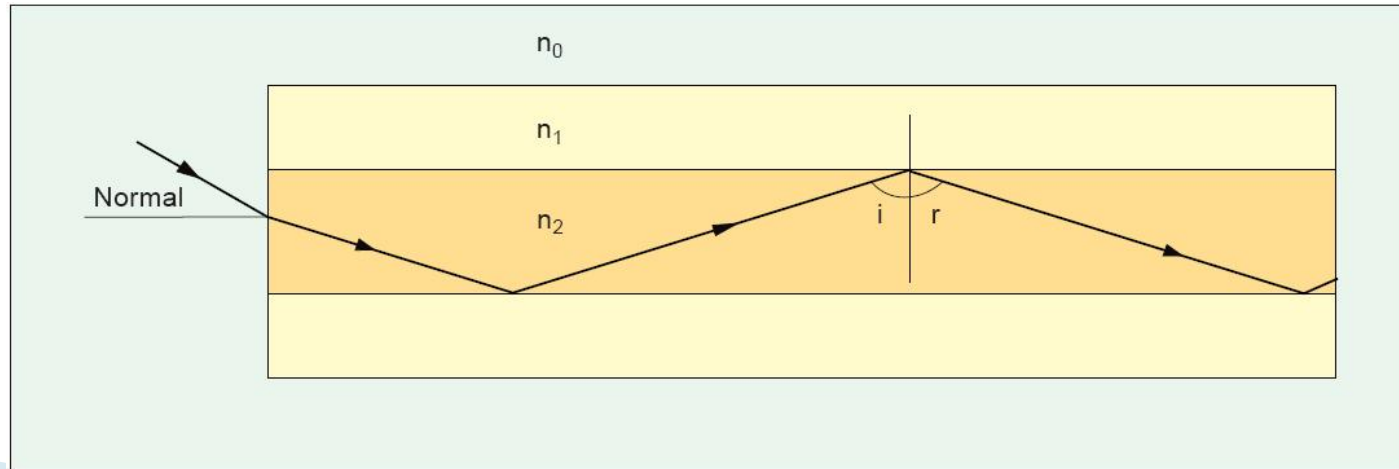
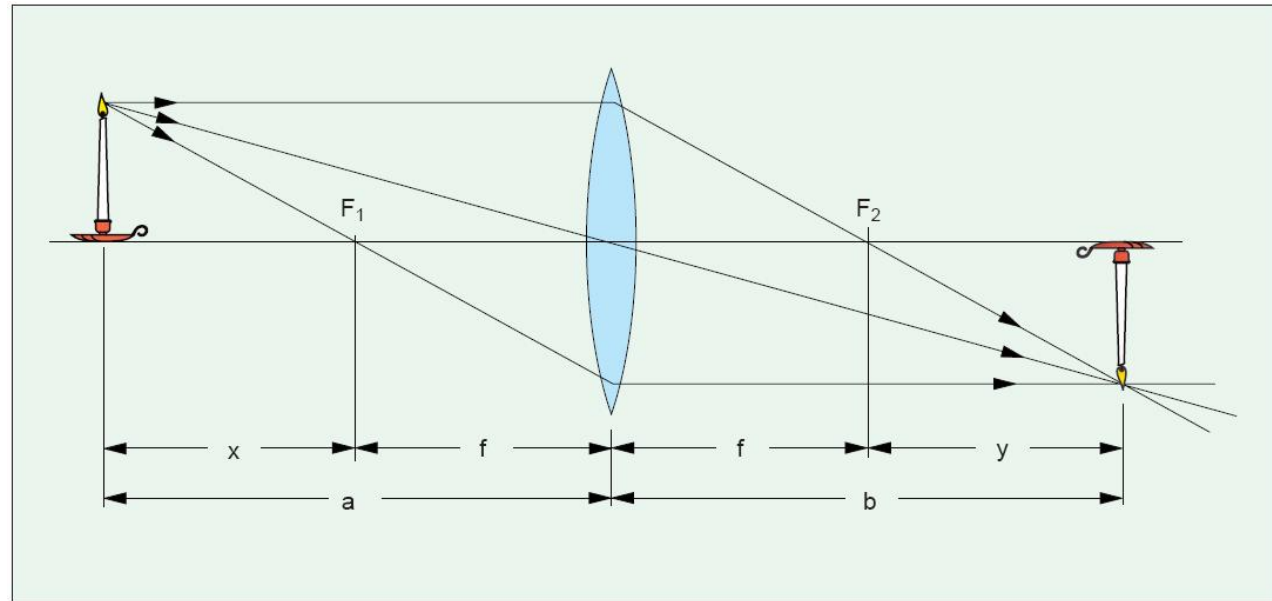
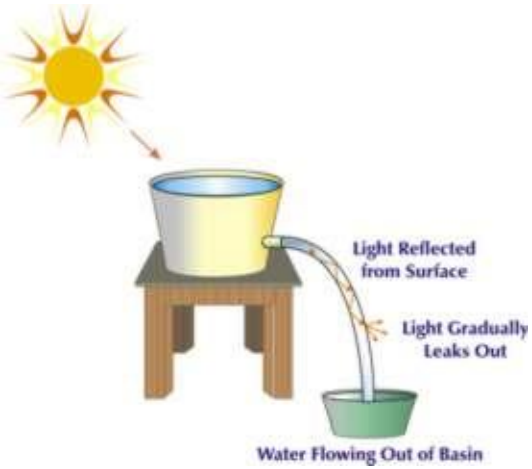
# Modelare



Through the Wormhole  
S02E07 How Does the Universe Work



# Optica geometrica



# Lumina ca undă electromagnetică

Capitolul 2

# 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

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

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

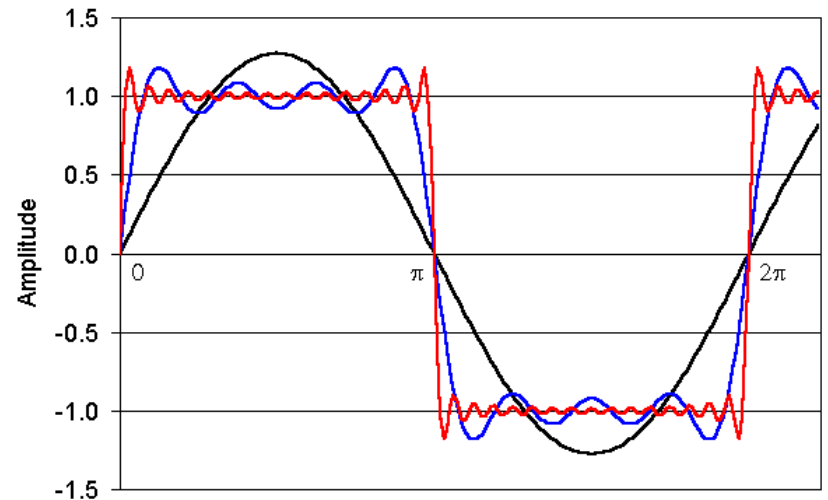
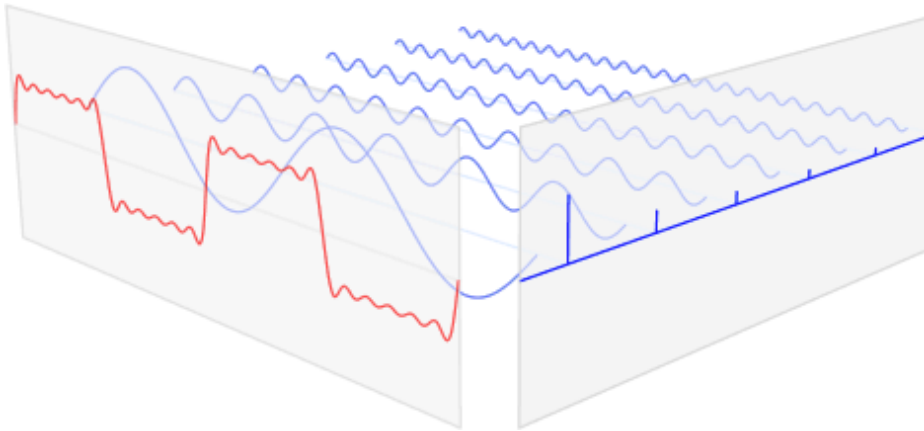
$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$



# Modele matematice

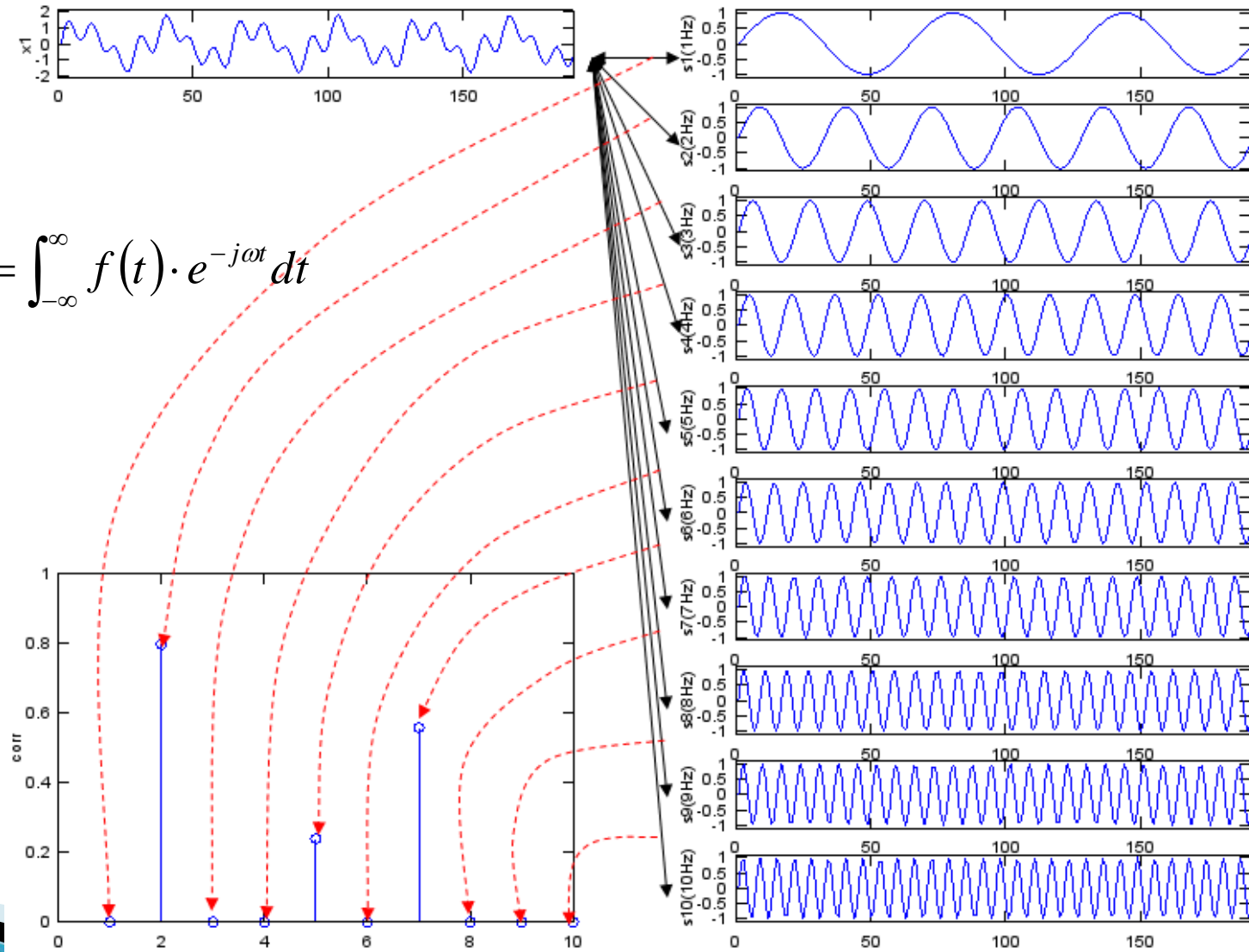
- ▶ cazuri particulare in care exista rezolvare analitica
  - semnale cu variație armonică în timp, transformata Fourier, spectru

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

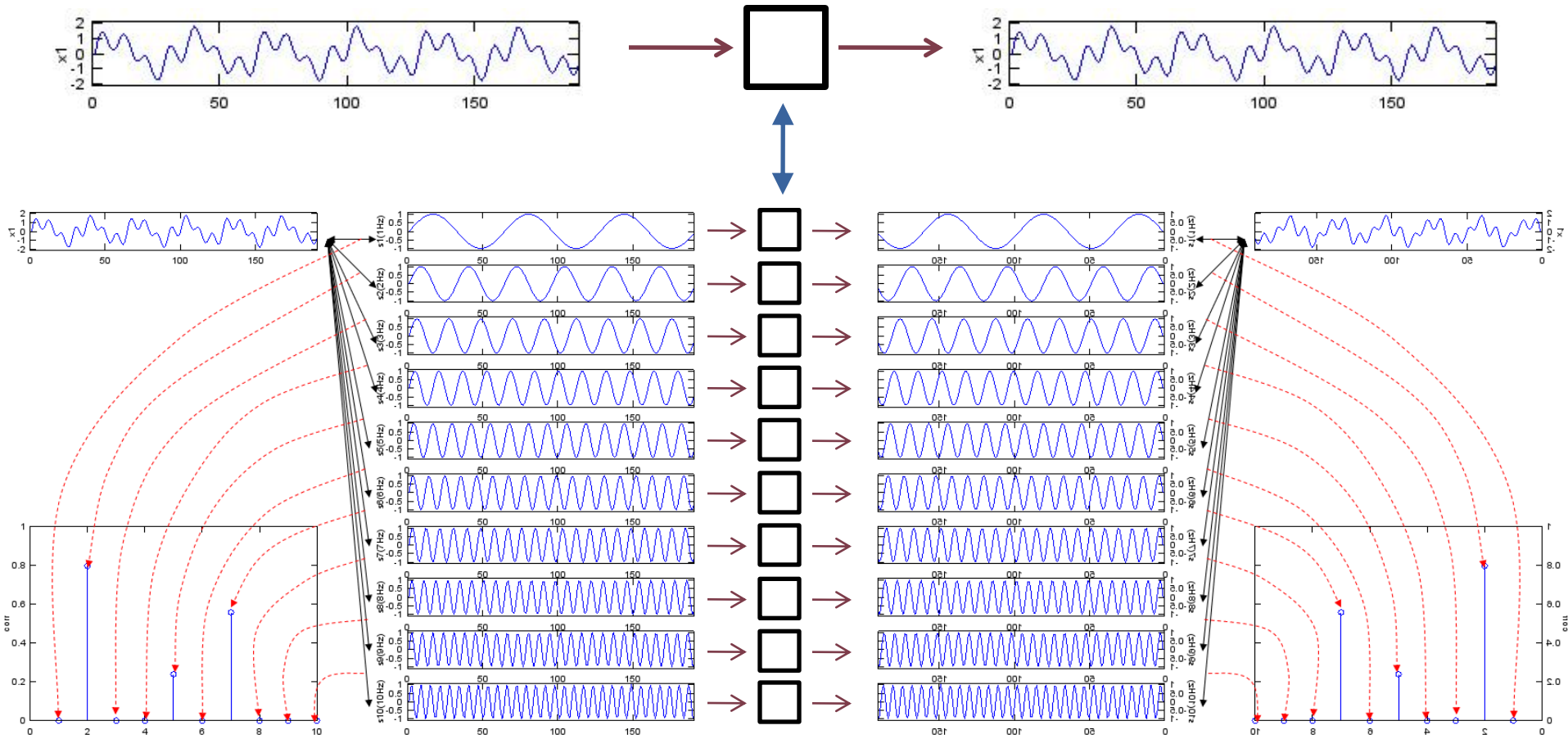


# Modelle matematiche

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



# Modelle matematiche



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

$$G(\omega)[F(\omega)]$$

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

# Câmpuri electromagnetice cu variație armonică în timp

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

## ▶ Simplificarea ecuațiilor lui Maxwell

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

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

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

$$\nabla \cdot H = 0$$

## ▶ Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

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

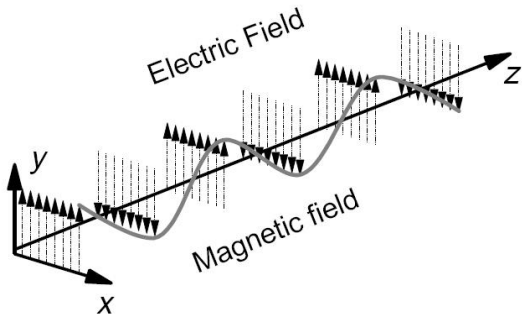
$$\nabla^2 H - \gamma^2 H = 0$$

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

$\gamma$  – Constanta de propagare

# Solutia ecuatiilor de propagare

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



Propagare

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

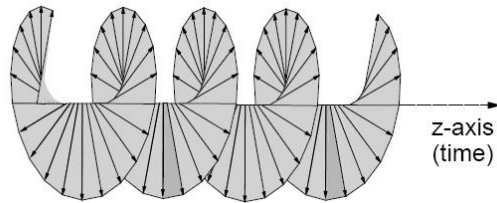
$$\gamma = \sqrt{-\omega^2 \epsilon \mu + j \omega \mu \sigma} = \alpha + j \cdot \beta$$

Exista numai unda progresiva  $E_+ \Rightarrow A$

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

Camp armonic

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



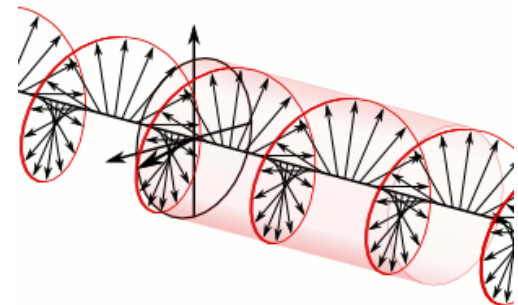
Polarizare circulara

Amplitudine

Atenuare

Propagare

(variatie in timp si spatiu)



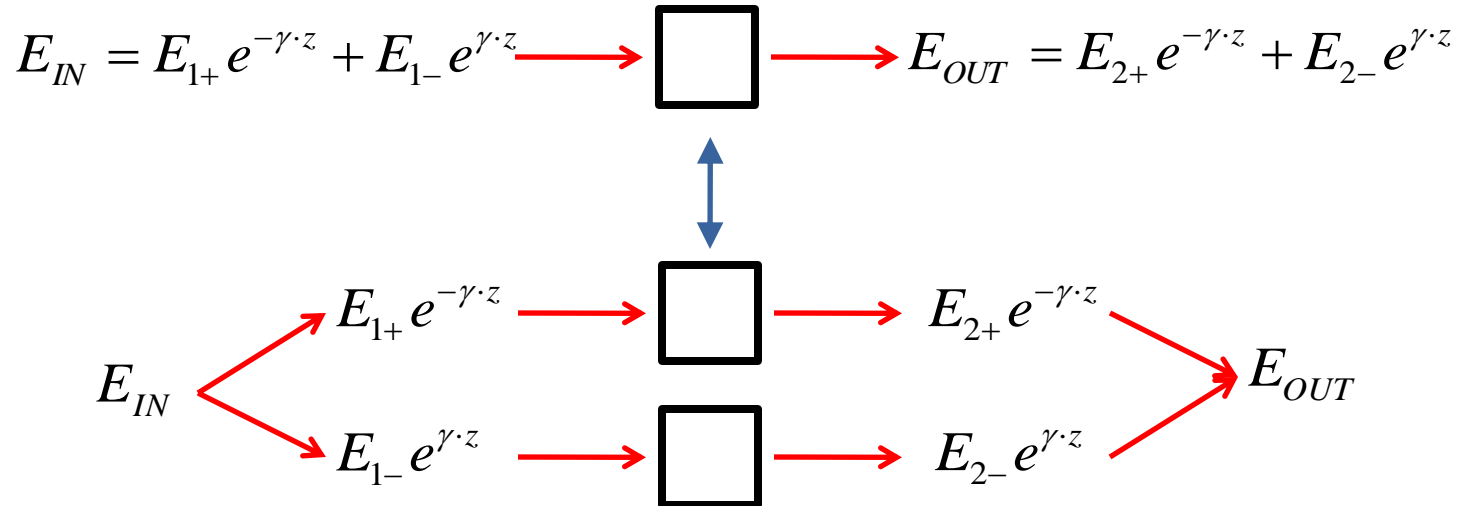


# Modele matematice

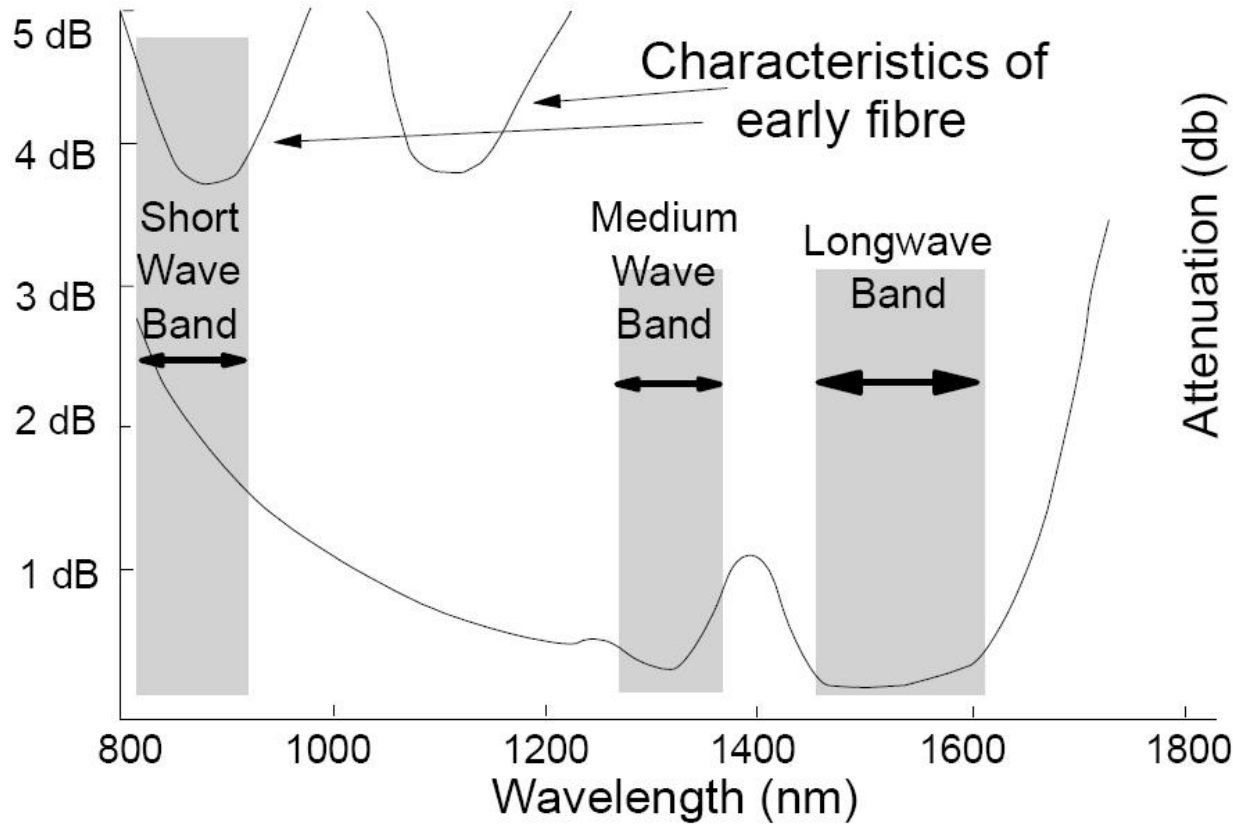
► cazuri particulare in care exista rezolvare analitica

- 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 $\text{SiO}_2$



# Atenuare

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

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

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

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

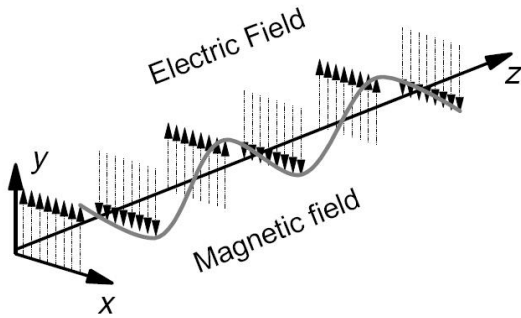
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[ e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

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

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

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

# Parametri de propagare



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

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

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

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\epsilon}} \quad \text{Impedanta intrinseca a mediului}$$

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

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

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

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

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

Periodicitate in spatiu

Periodicitate in timp

## ▶ In mediu nedispersiv $\varepsilon_r$

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

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

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

$$\lambda = \frac{2\pi}{\beta} = \frac{c}{f}$$

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





# Parametri, dependenta de mediu

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

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

$n=1$

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

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

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

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

$n = \sqrt{\varepsilon_r}$

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

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

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

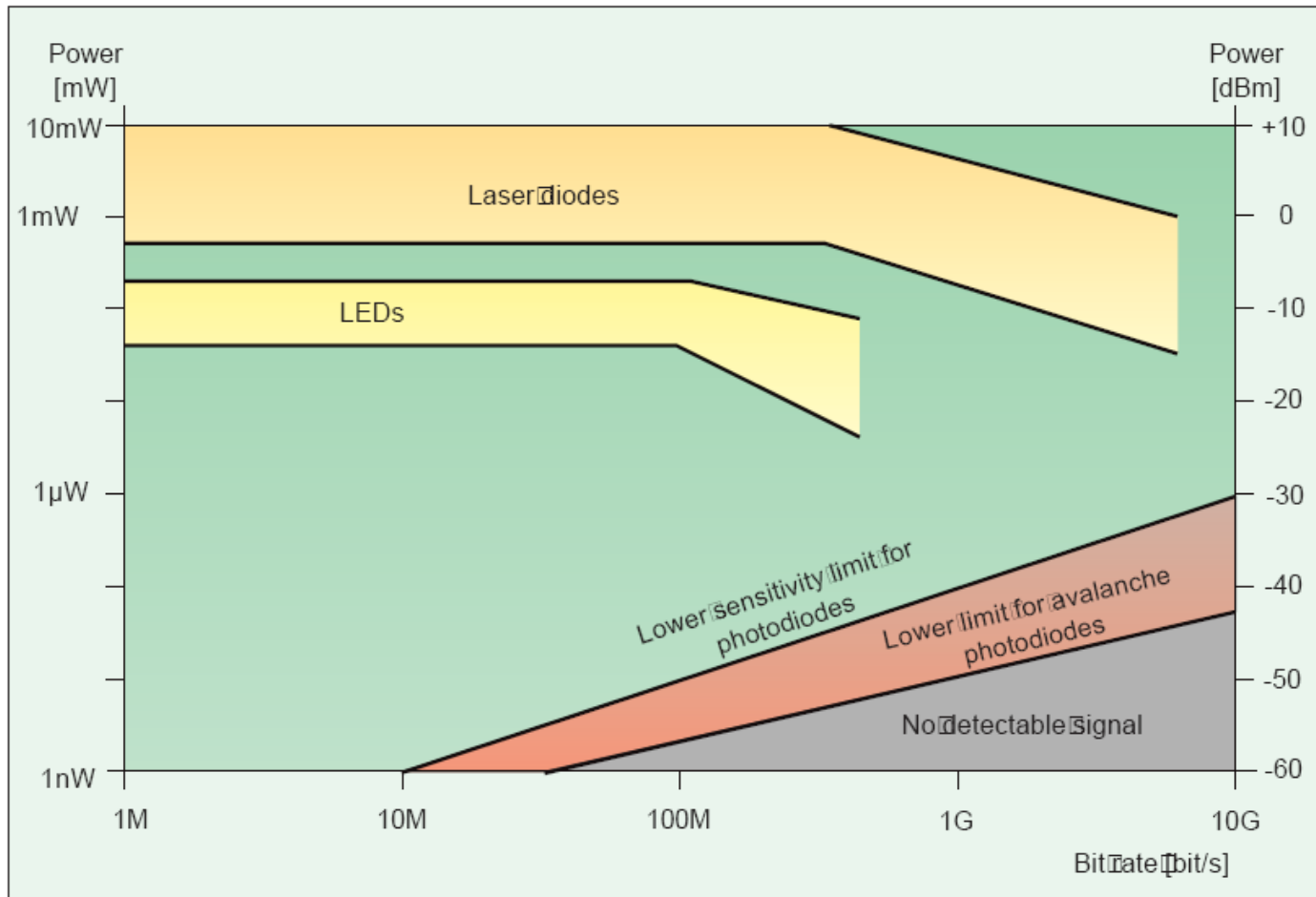
## ITU G.692

"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"

# Limite putere/bandă a dispozitivelor optoelectronice



# Contact

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