

Optoelectronică

Curs 2

2023/2024

Disciplina 2023/2024

- ▶ 2C/1L Optoelectronică **OPTO**
- ▶ **Minim 7 prezente curs + laborator**
- ▶ Curs – conf. **Radu Damian**
 - an IV μ E
 - Marti 14(**:10**)-16:00, P8
 - E – 70% din nota (50%+20%)
 - **20% test (VP) la curs**, saptamana 4-6?
 - probleme + (2p prez. curs)
 - toate materialele permise
- ▶ Laborator – **drd. Stefan Stoica**
 - an IV μ E
 - Marti 16-20 par
 - Max. 7 prezente
 - L – 30% din nota (+Caiet de laborator)

Orar 2023/2024

▶ Curs

◦ Marti 14(:10)–16:00, P8

◦ ~~2C~~ ⇒ ~~3C~~

• ~~$14 * 2/3 \approx 9.33$~~

• ~~$9 : 10 C \approx 9C + E$~~

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)
- ▶ **Emițătoare 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)

* – VP

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
- ▶ John Powers – An Introduction to Fiber Optic Systems
- ▶ IBM – Understanding Optical Communications: on-line <http://www.redbooks.ibm.com>
- ▶ Radu Damian, I Casian, D Matăsară – „Comunicatii Optice” , Indrumar de laborator, 2005
- ▶ MIT Course – Fundamentals of Photovoltaics, <https://ocw.mit.edu>

Documentatie



Microwave and Optoelectronics Laboratory

We are enlisted in the Telecommunications Department of the Electronics, Telecommunication and Information Technology Faculty (ETTI) from the "Gh. Asachi" Technical University (TUIASI) in Iasi, Romania

We currently cover inside ETTI the fields related to:

- Microwave Circuits and Devices
- Optoelectronics
- Information Technology

Courses

Nr.	Course	Shortcut	Code	Type	Semester	Credits	Weekly	Examination	Link
1	Microwave Devices and Circuits for Radiocommunications	DCMR	DOS412T	DOS	7	4	0P,1L,0S,2C	Exam	
2	Monolithic Microwave Integrated Circuits	CIMM	RD.IA.207	DOMS	11	6	1.5L,0S,2C,0P	Exam	
3	Advanced Techniques in the Design of the Radio-communications Systems	TAPSR	RD.IA.103	DIMS	9	6	1.5P,0L,0S,2C	Exam	
4	Optical Communications	CO	DOS409T	DOS	7	5	0P,1L,0S,3C	Colloquiu	
5	Optical Communications	OC	EDOS409T	DOS	7	5	0P,1L,0S,3C	Exam	
6	Satellite Communications	CS	RC.IA.104	DIMS	9	6	0L,0S,2C,1.5P	Exam	
7	Applied Informatics 1	IA1	DOF135	DOF	1	4	0P,1L,0S,2C	Verificati	
8	Applied Informatics 1	AI1	EDOF135	DOF	1	4	0P,1L,0S,2C	Verificati	
9	Databases, Web Programming and Interfacing	DWPI	ITT.IA.601	DIS	11	5	1P,1L,0.25S,1C	Verificati	
10	Web Applications Design	PAW	RC.IA.108	DIMS	10	5	1L,0S,1.5C,1P	Exam	
11	Optoelectronics	OPTO	DID405M	DID	8	4	0P,1L,0S,2C	Colloquiu	
12	Microwave Devices and Circuits for Radiocommunications (English)	MDCR	EDOS412T	DOS	8	4	0P,1L,0S,2C	Exam	



Documentatie

- ▶ RF-OPTO
 - <http://rf-opto.etti.tuiasi.ro>
- ▶ Fotografie
 - “examen” online
 - necesara la laborator/curs

Bonus (~0.5–4.15)

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/3prez
- ▶ 3 teste
- ▶ foto <C**4**/ <C**6**

Online

- ▶ acces la **examene** necesita **parola** primita prin **email**

English | Romana |

Start Didactic Master Colectiv Cercetare Stud

Note Lista Studenti Examene Fotografii

POPESCU GOPO ION

Fotografia nu exista

Date:

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica si telecomunicatii
Marca	7000021

Acceseaza ca acest student | [here acces la licente](#)

Note obtinute

Inca nu a fost notat.

Start Didactic Master Colectiv C

Note Lista Studenti Examene Fotografii

Identificare

Introduceti numele si adresa de email utilizata la inscriere

Nume
POPESCU GOPO

E-mail/Parola

Introduceti codul afisat mai jos

4db4457

Trimite

Online

► acces email/parola

Start Didactic Master Colectiv

Note Lista Studenti Examene Fotografii

POPESCU GOPO ION

Fotografia nu exista

Date:

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica
Marca	7000021

Se acceseaza site-ul [ca acest student!](#)

Start Didactic Master Colectiv

Note Lista Studenti Examene Fotografii

POPESCU GOPO ION

Fotografia nu exista

Date:

Grupa	5700 (2019/2020)
Specializarea	Inginerie electronica s
Marca	7000021

Se acceseaza site-ul [ca acest student \(inclusiv examene\)!](#)

Parola

▶ primita prin email

Important message from RF-OPTO

Inbox x



Radu-Florin Damian

to me, POPESCU

Romanian > English Translate message



Laboratorul de Microunde si Optoelectronica
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei
Universitatea Tehnica "Gh. Asachi" Iasi

In atentie: POPESCU GOPO ION

Parola pentru a accesa examenele pe server-ul **rf-opto** este

Parola: [REDACTED]

Identificati-va pe [server](#), cu parola, cat mai rapid, pentru confirmare.

Memorati acest mesaj intr-un loc sigur, pentru utilizare ulterioara

Attention: POPESCU GOPO ION

The password to access the exams on the **rf-opto** server is

Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

Reply

Reply all

Forward

Subject

Correspondents

Important message from RF-OPTO → POPESCU GOPO ION

Validation of MIDCR exam from 02/05/2020

From: Me <rdamian@etti.tuiasi.ro>

Subject: Important message from RF-OPTO

To: [REDACTED]

Cc: Me <rdamian@etti.tuiasi.ro>

Laboratorul de Microunde si Optoelectronica
Facultatea de Electronica, Telecomunicatii si Tehnologia Informatiei
Universitatea Tehnica "Gh. Asachi" Iasi

In atentie: POPESCU GOPO ION

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Parola: [REDACTED]

Identificati-va pe [server](#), cu parola, cat mai rapid, pentru confirmare.

Memorati acest mesaj intr-un loc sigur, pentru utilizare ulterioara

Attention: POPESCU GOPO ION

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Password: [REDACTED]

Login to the [server](#), with this password, as soon as possible, for confirmation.

Save this message in a safe place for later use

Adrese email ✓

▶ Sefii de grupa!

- lista cu adrese de email **utilizate** de toti studentii care doresc acces la toate informatiile de pe site
 - poate fi @student.etti.tuiasi.ro (@gmail @yahoo etc.)
- -> **rdamian@etti.tuiasi.ro**

Manual examen online

- ▶ Aplicatia de examen online utilizata la:
 - ~~curs (prezenta)~~
 - ~~miniteste~~
 - ~~examen~~

Materials

Other data

[Manual examen on-line](#) (pdf, 2.65 MB, ro, 🇷🇴)

[Simulare Examen](#) (video) (mp4, 65.12 MB, ro, 🇷🇴)

Microwave Devices and Circuits (Englis

Introducere

Capitolul 1

Aplicatii majore

- ▶ Comunicatii
 - Infrarosu (InGaAsP)
- ▶ Vizibil
 - Spectru vizibil (GaAlAs)
- ▶ Iluminare
 - Putere ridicata, lumina alba (GaInN)
- ▶ Energie solara
 - Efect fotovoltaic (Si)

Aplicatii majore

▶ Comunicatii

- Infrarosu (InGaAsP)

▶ Vizibil

- Spectru vizibil (GaAlAs)

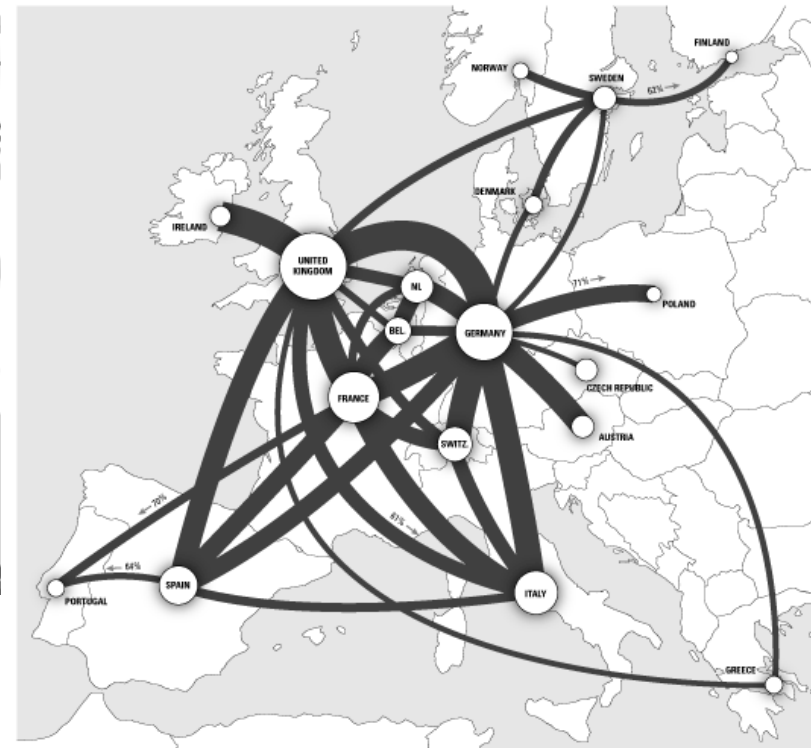
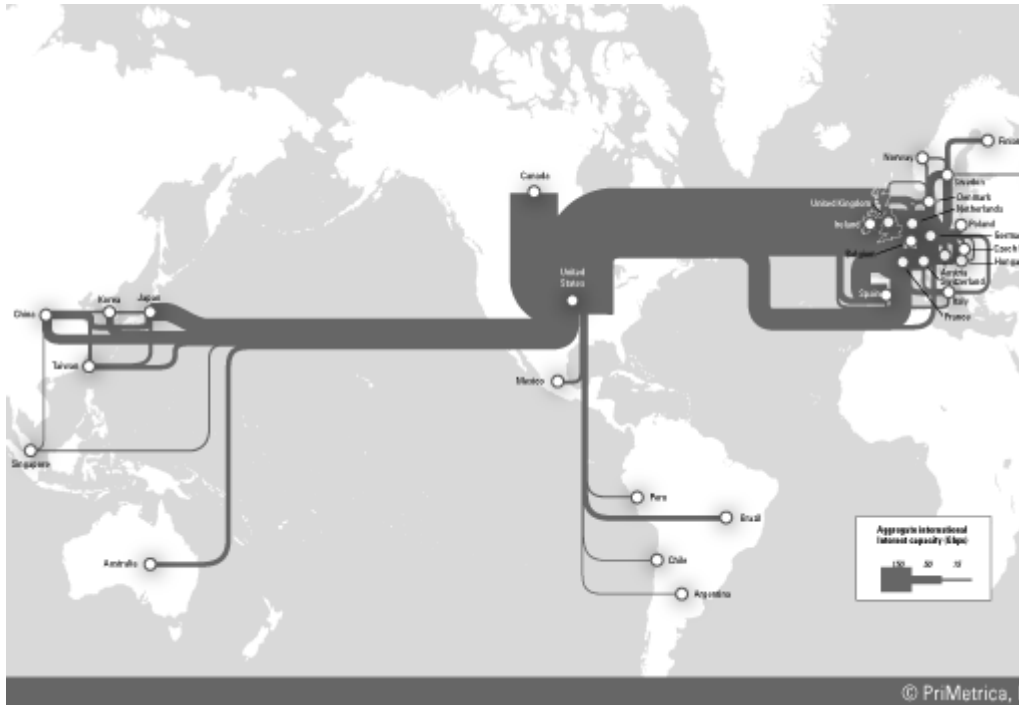
▶ Iluminare

- Putere ridicata, lumina alba (GaInN)

▶ Energie solara

- Efect fotovoltaic (Si)

Internet Backbone

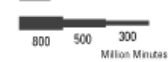


Key

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.

Aplicatii majore

- ▶ Comunicatii
 - Infrarosu (InGaAsP)
- ▶ Vizibil
 - Spectru vizibil (GaAlAs)
- ▶ Iluminare
 - Putere ridicata, lumina alba (GaInN)
- ▶ Energie solara
 - Efect fotovoltaic (Si)

Spectru vizibil



Aplicatii majore

- ▶ Comunicatii
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Aplicatii



Aplicatii majore

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Aplicatii



Aplicatii majore

▶ Comunicatii

- Infrarosu (InGaAsP)

▶ Vizibil

- Spectru vizibil (GaAlAs)

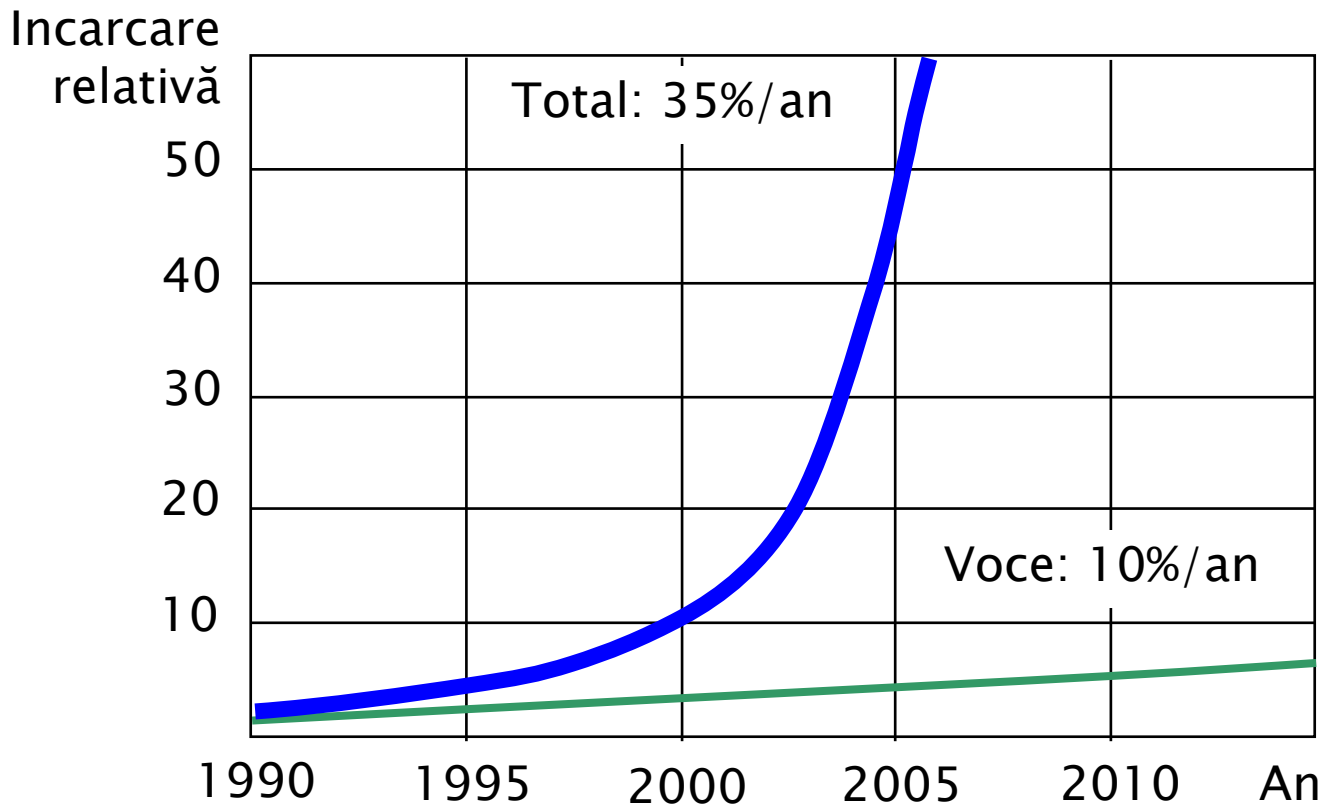
▶ Iluminare

- Putere ridicata, lumina alba (GaInN)

▶ Energie solara

- Efect fotovoltaic (Si)

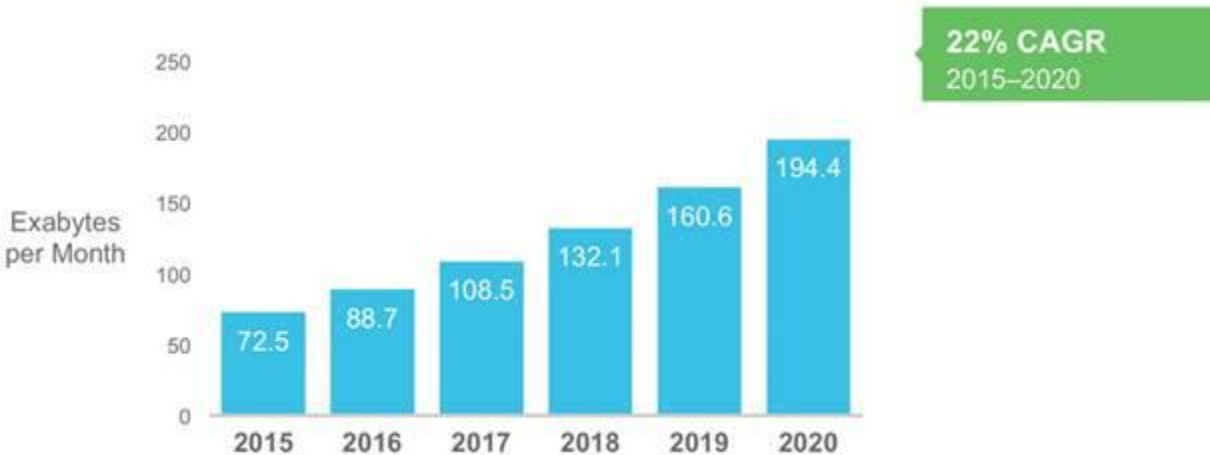
Evoluția lățimii de bandă utilizată în rețelele de telecomunicații



Sursa:

EC ELECTRONiCAST
CORPORATION

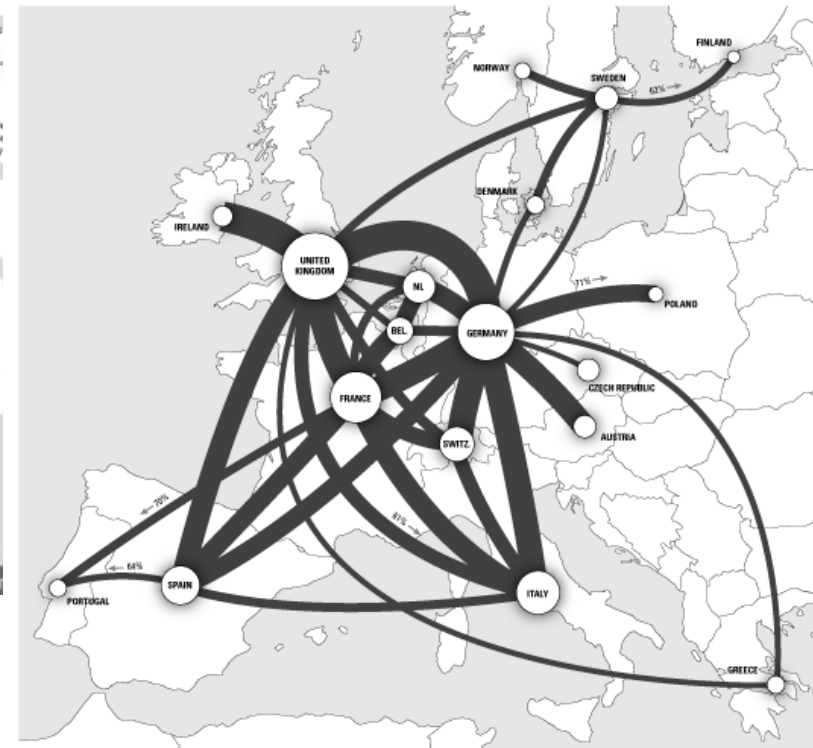
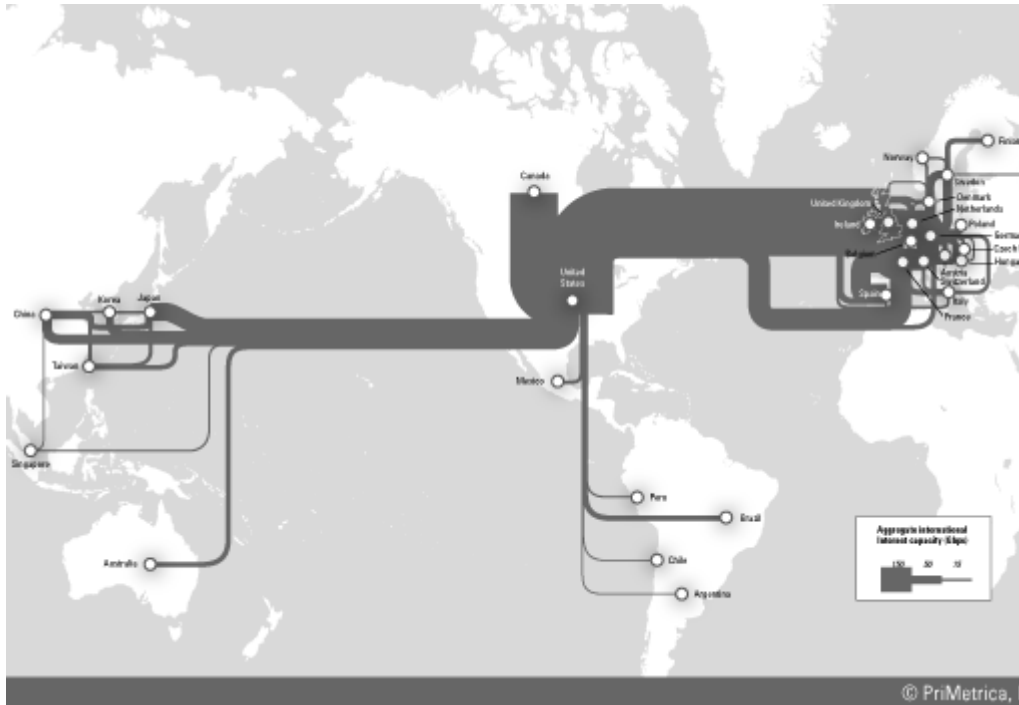
Evoluția lățimii de bandă



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

Internet Backbone

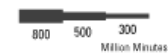


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Internet Backbone



Avantajele comunicațiilor prin fibra optică – 1

- ▶ Greutate și volum
- ▶ Costul materialelor primare
 - SiO_2/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

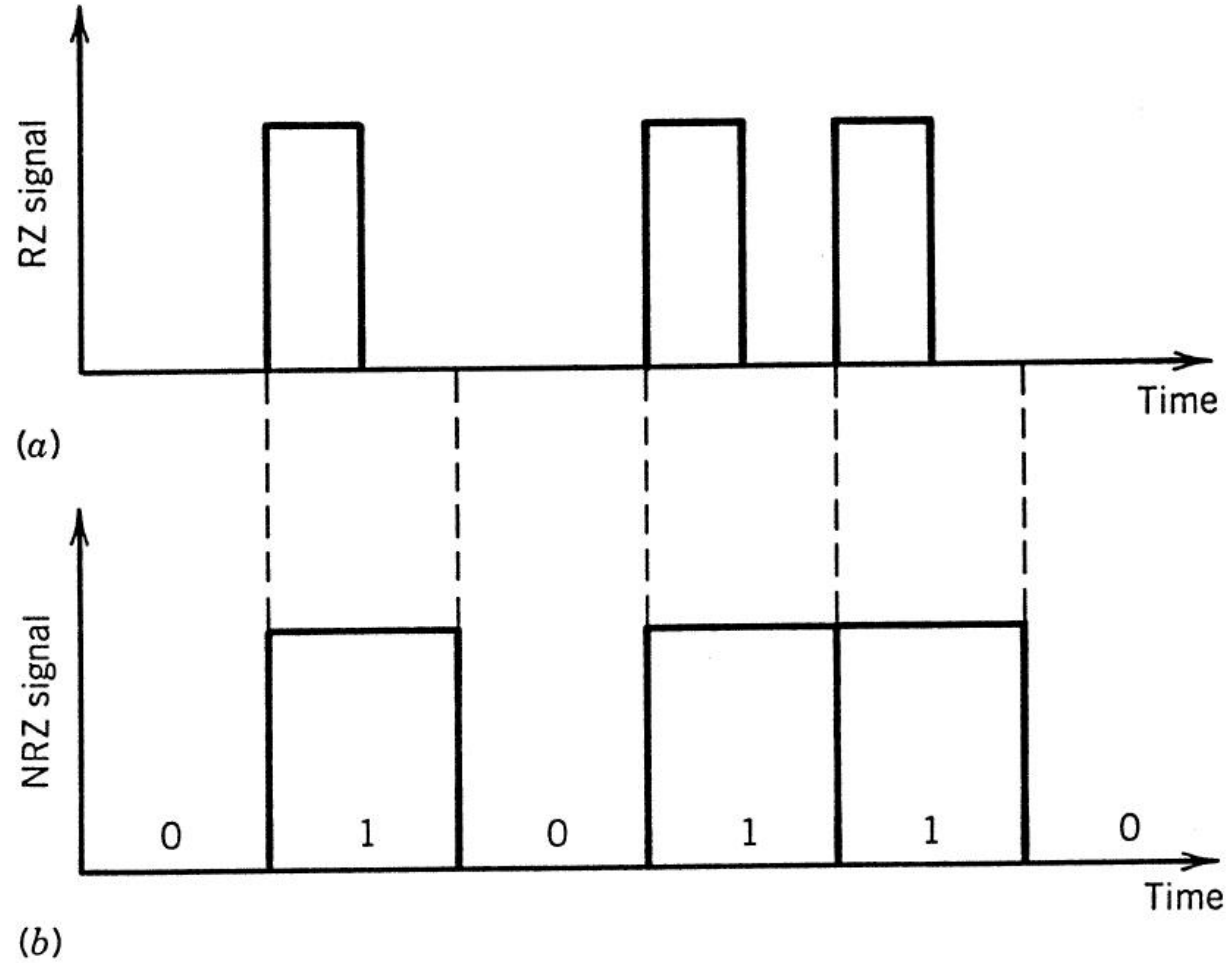
- ▶ Imunitate la interferență electromagnetică
- ▶ Distanța între repeatoare
 - 100km/2–5km
- ▶ Posibilitate de creștere a capacității de transmisie a informației
 - Teoretic extrem de mare (aproape infinită) $f \sim 200\text{THz}$
 - Reutilizarea cablurilor existente
- ▶ Securitate
 - Interceptare dificilă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

Dezavantajele comunicațiilor prin fibra optică

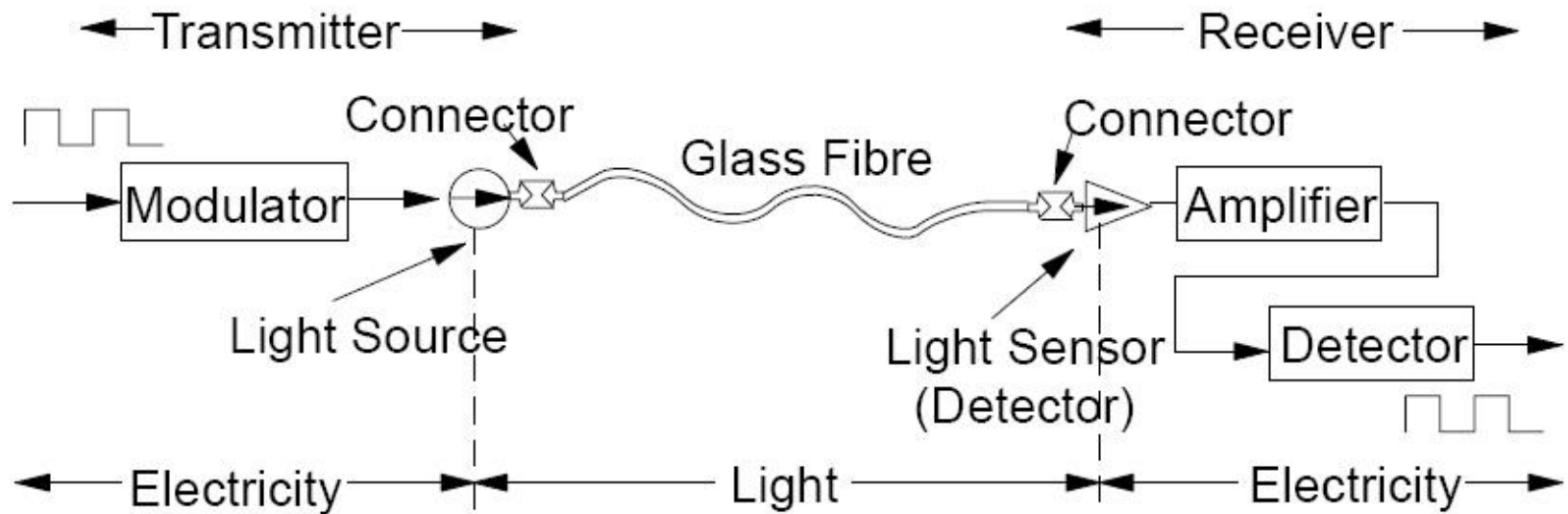
- ▶ Conexiuni complexe și esențiale
 - Costul circuitelor integrate crescut considerabil de cuplarea luminii în fibra
- ▶ Curbarea cablurilor optice
- ▶ Dezvoltarea greoaie a standardelor
- ▶ Optica folosită strict pentru transmisie (aproape)
 - EDFA – Erbium Doped Fiber Amplifier
- ▶ Sensibilitate la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

Modulare

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

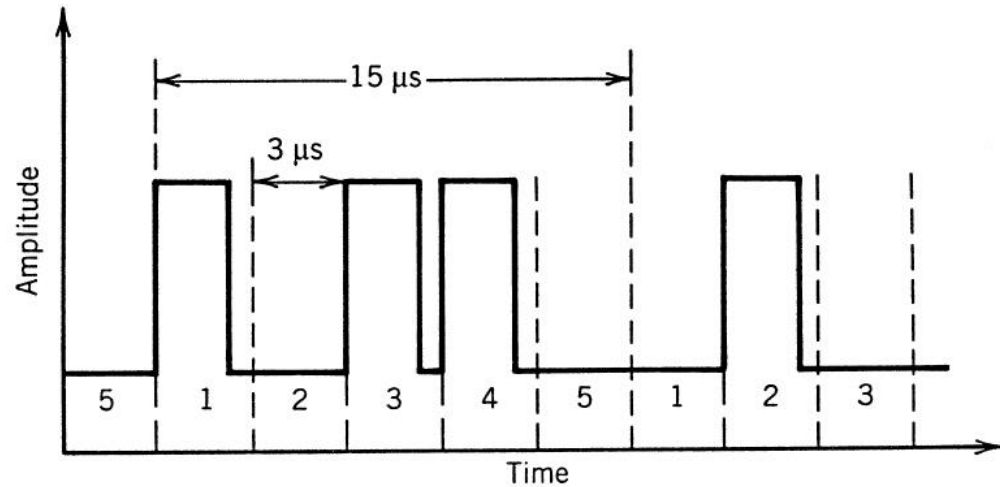


Transmisia optica

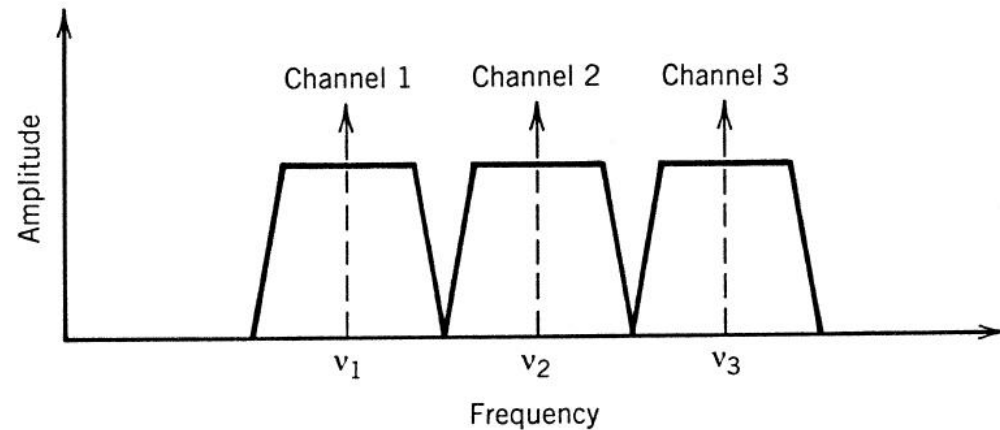


Multiplexare

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

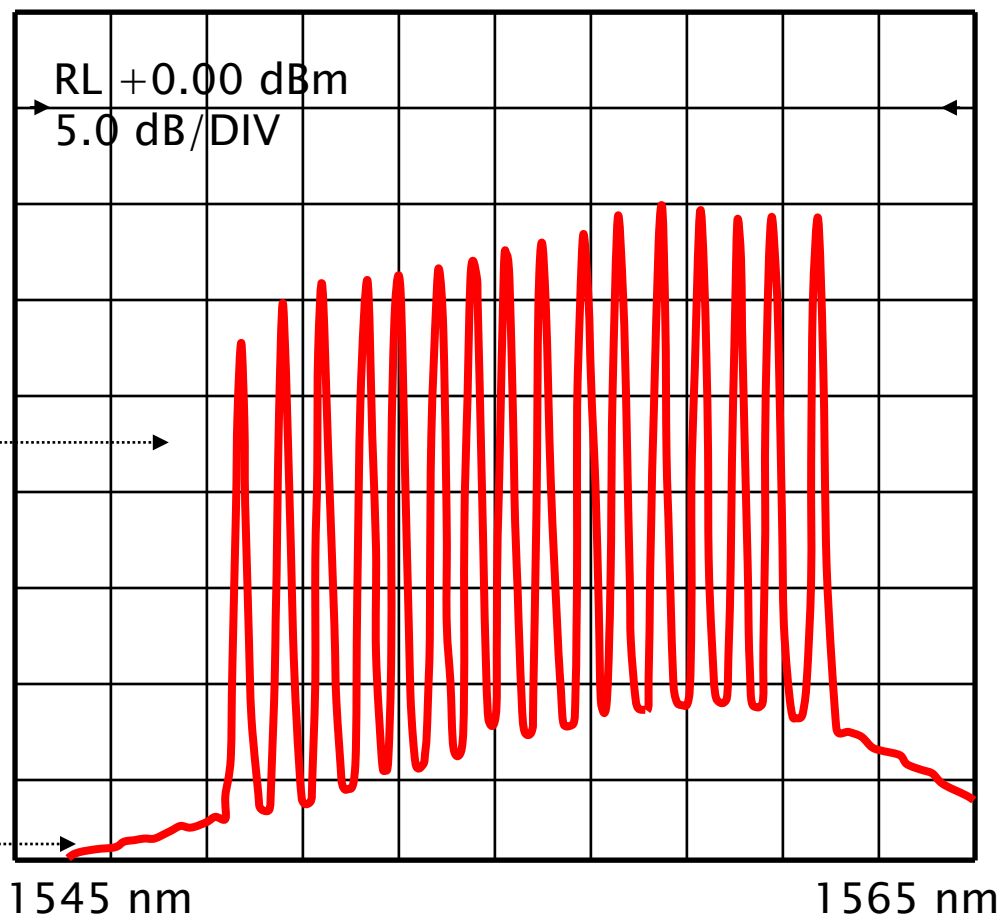


(a)



(b)

Spectrul WDM – Wavelength Division Multiplexing



Canale: 16
Spațiere: 0.8 nm

Emisie spontană
Amplificată (ASE)

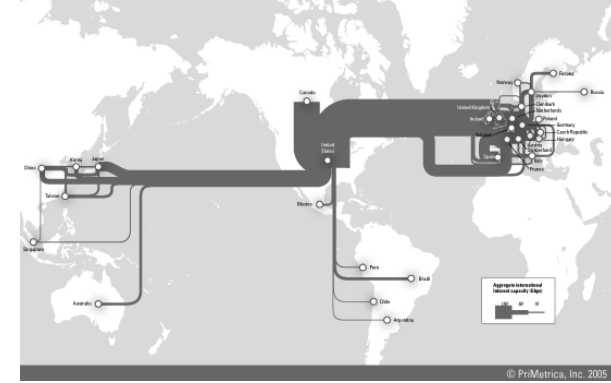
Standardde

- ▶ 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

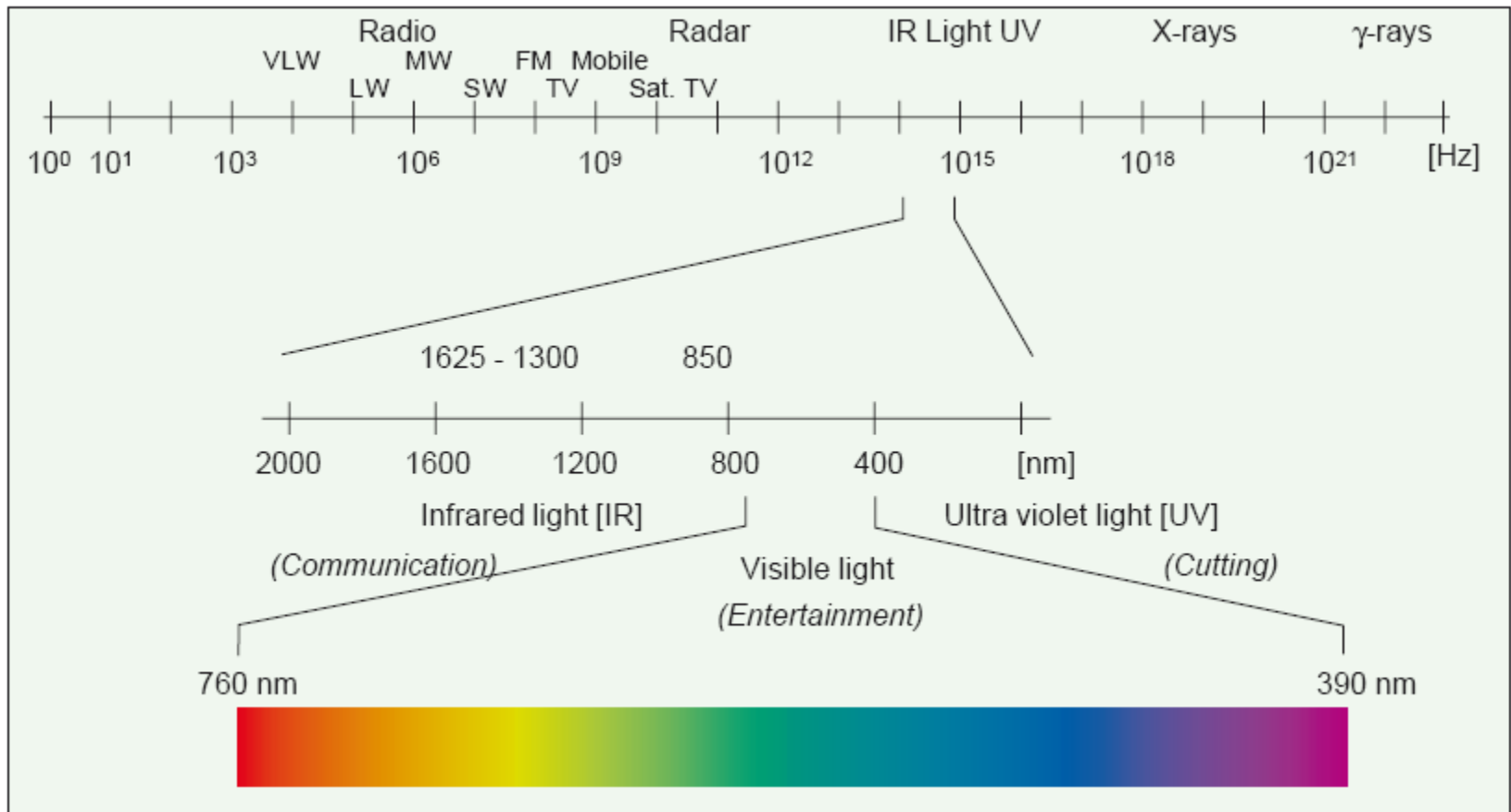
E0	64 Kb/s	
E1	2.048 Mb/s	
E2	8.448 Mb/s	4 E1s
E3	33.792 Mb/s	16 E1s
E4	139.264 Mb/s	64 E1s

1 mile = 1760 yards

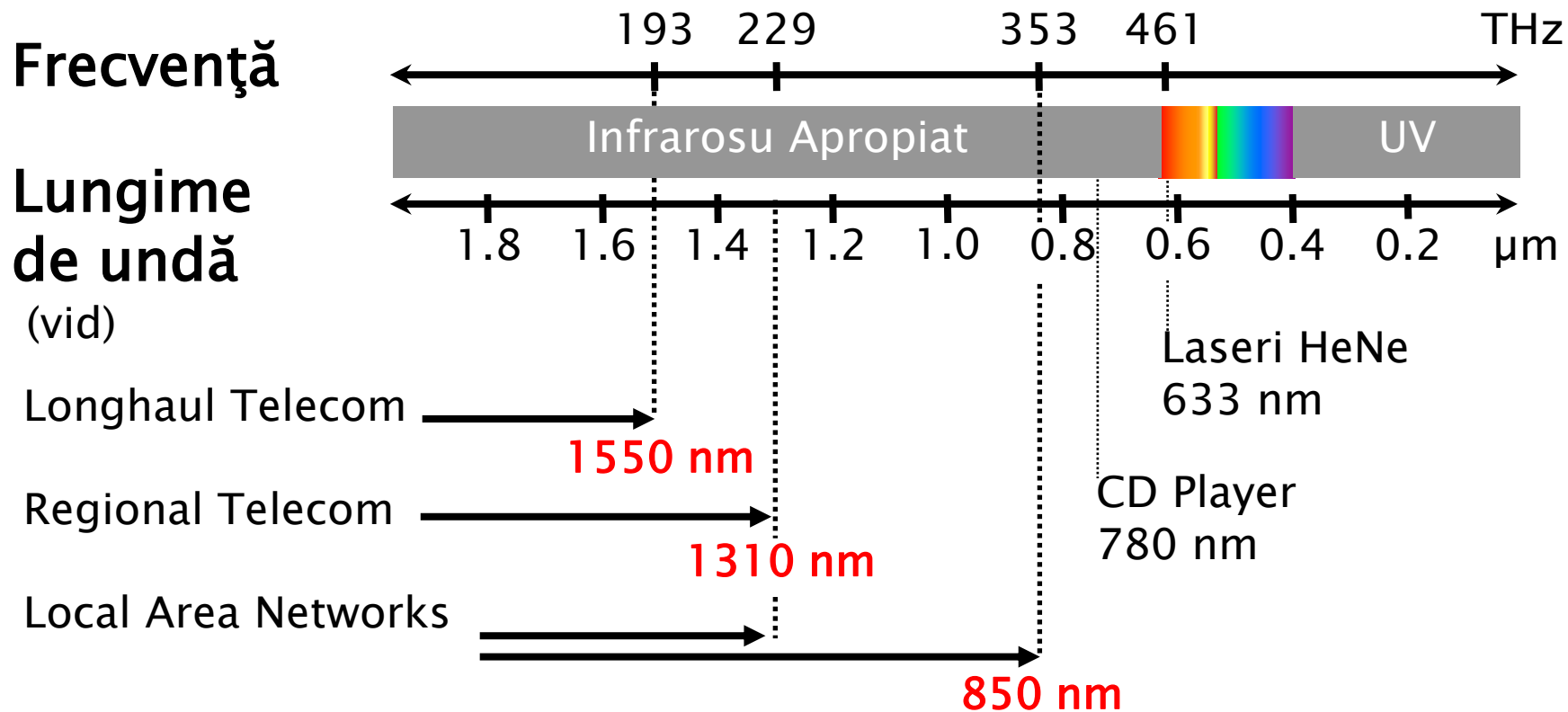
1 yards = 3 feet

1 mile ≈ 1609.34 m

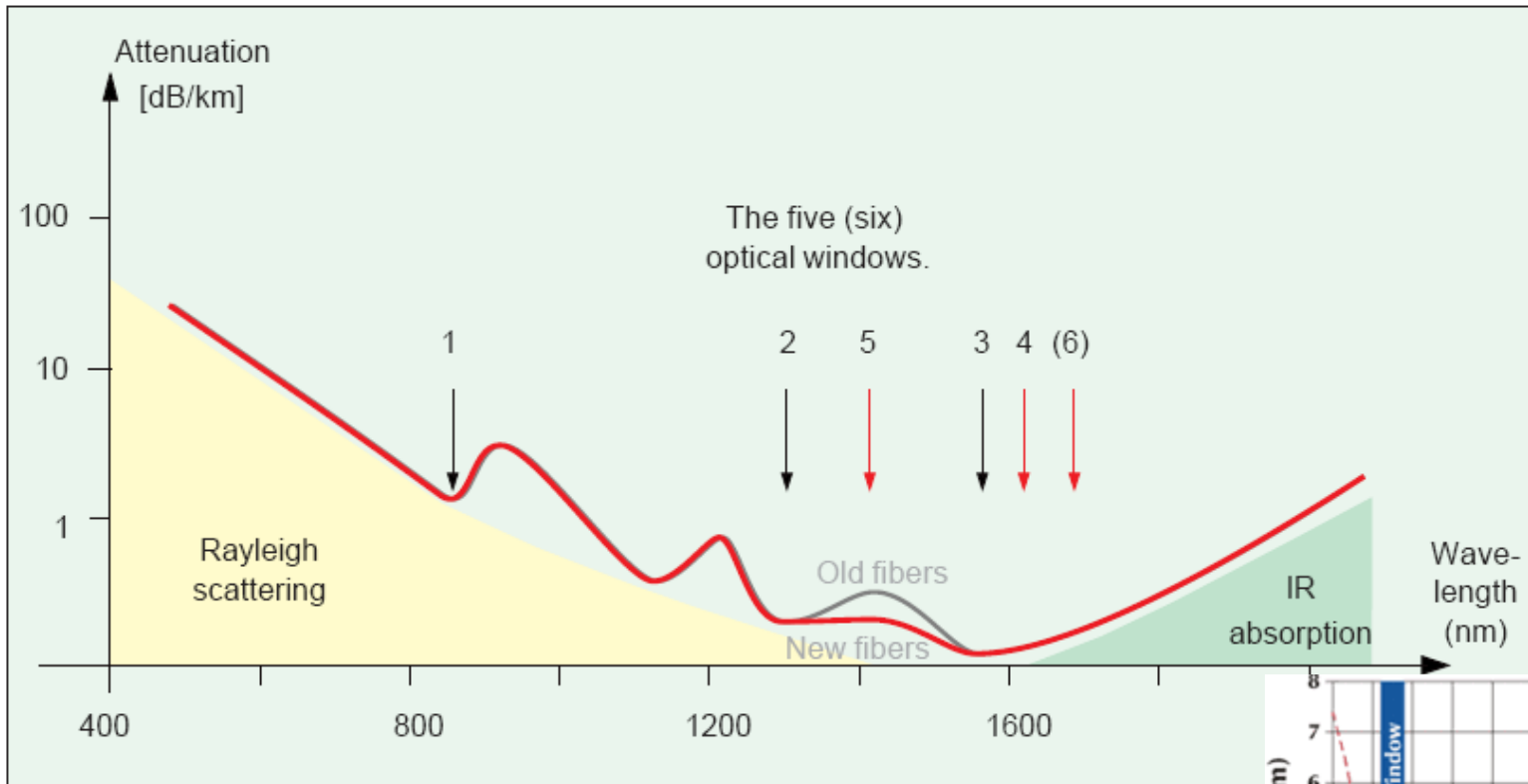
Spectrul electromagnetic



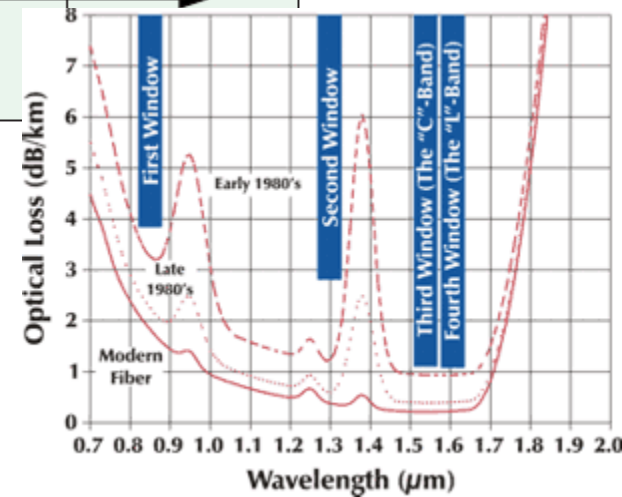
Benzi de lucru in comunicațiile optice



Atenuarea în fibra optică (SiO₂)



850nm, 1310nm, 1550nm



Aplicatii majore

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

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

Physics



The Nobel Prize in Physics 2014

Summary



The Nobel Prize in Physics 2014

Isamu Akasaki
Hiroshi Amano
Shuji Nakamura

Share this



The Nobel Prize in Physics 2014



© Nobel Media AB. Photo: A. Mahmoud

Isamu Akasaki

Prize share: 1/3



© Nobel Media AB. Photo: A. Mahmoud

Hiroshi Amano

Prize share: 1/3



© Nobel Media AB. Photo: A. Mahmoud

Shuji Nakamura

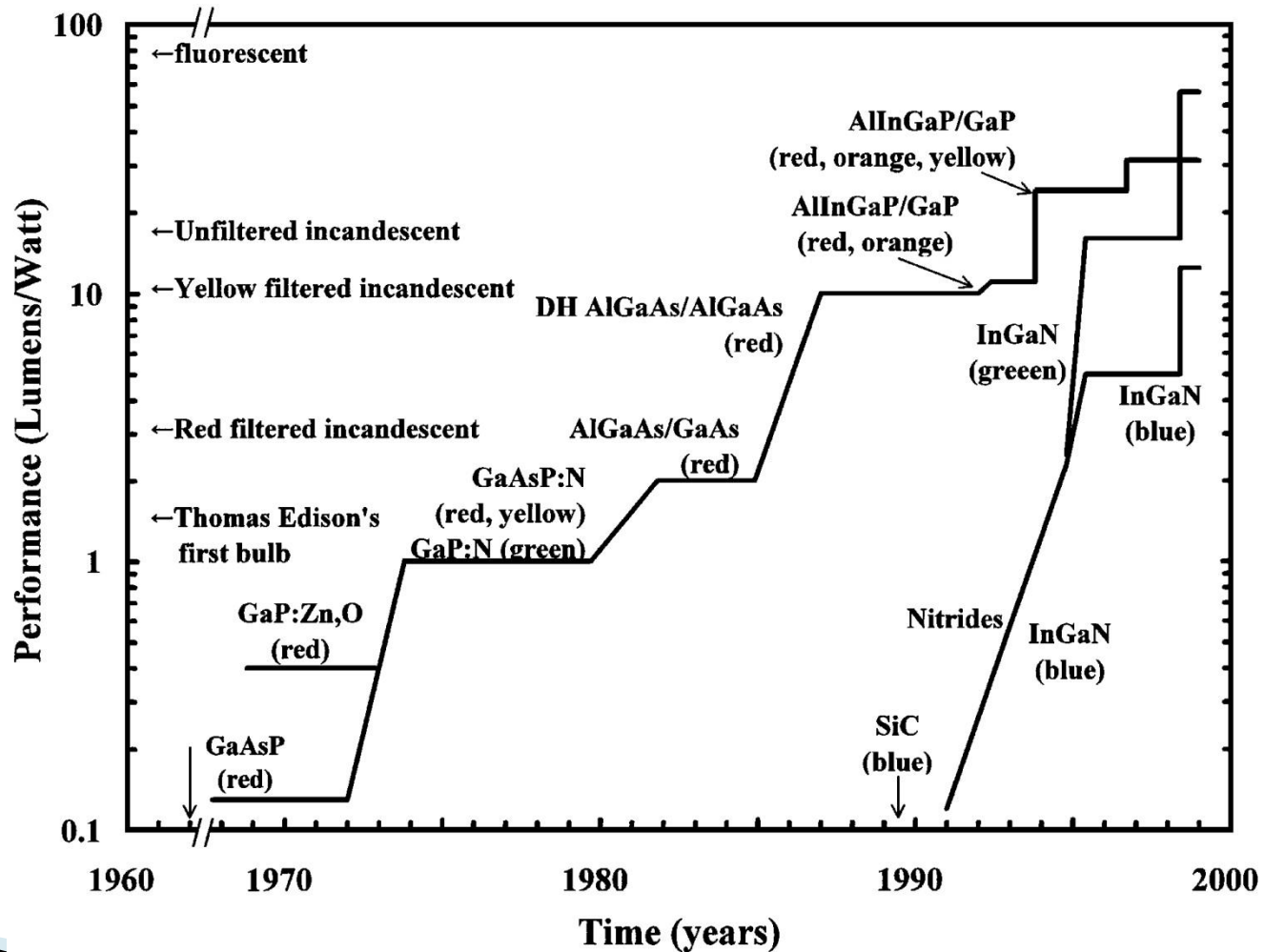
Prize share: 1/3

The Nobel Prize in Physics 2014 was awarded jointly to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura "for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources."

To cite this section

MLA style: The Nobel Prize in Physics 2014, NobelPrize.org, Nobel Media AB 2021. Tue, 2 Mar 2021.

Eficienta in timp



Aplicatii

▶ auto



Aplicatii

- ▶ casnic

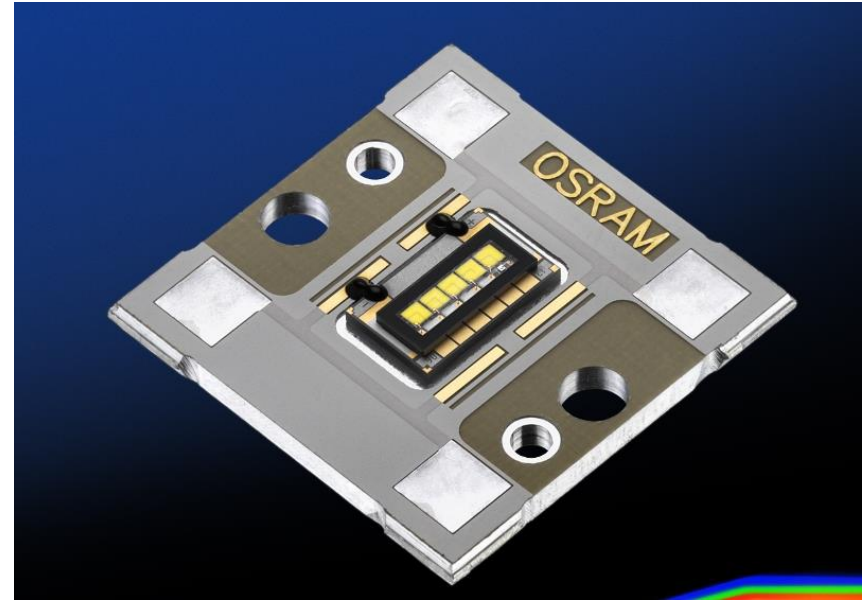


Aplicatii

- ▶ iluminat public



Aplicatii



Aplicatii majore

- ▶ Comunicatii
 - Infrarosu (InGaAsP)
- ▶ Vizibil
 - Spectru vizibil (GaAlAs)
- ▶ Iluminare
 - Putere ridicata, lumina alba (GaInN)
- ▶ Energie solara
 - Efect fotovoltaic (Si)

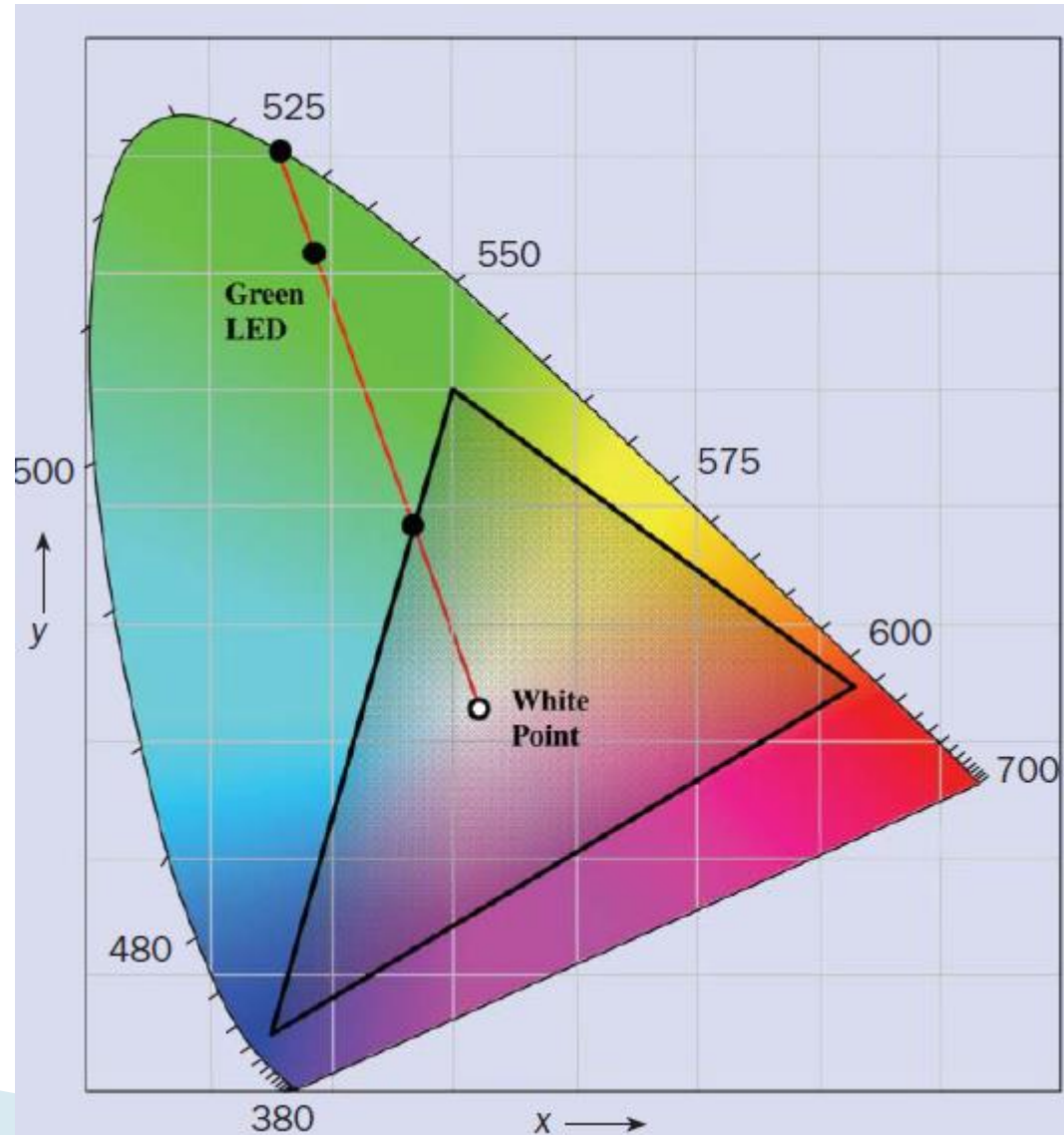
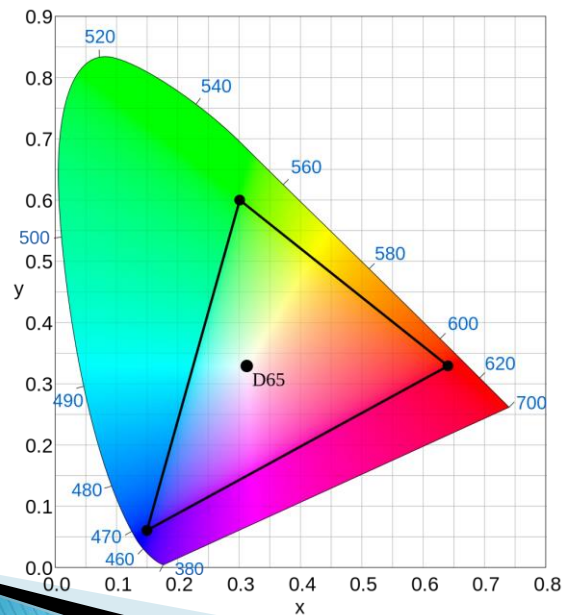
ITU-R BT.709



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

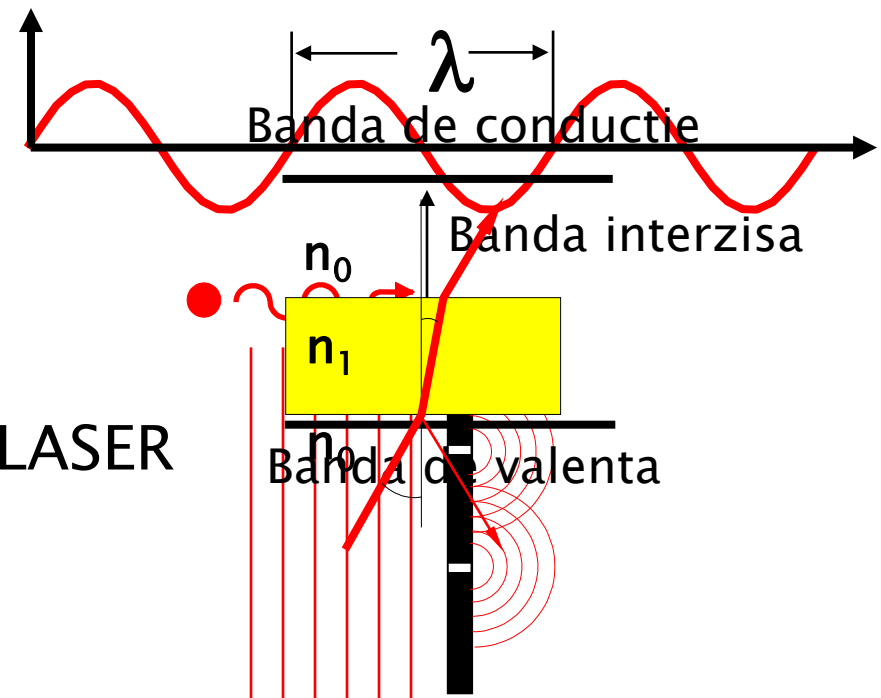
LED color	Dominant wavelength λ_D (nm)	RGB values
Royal blue	455	0.05, 0.00, 0.95
Blue	470	0.00, 0.11, 0.89
Cyan	505	0.00, 0.63, 0.37
Green	530	0.00, 0.77, 0.23
Amber	590	0.70, 0.30, 0.00
Red-orange	615	0.97, 0.00, 0.03
Red	625	0.92, 0.00, 0.08

Modelarea luminii

(tot) Capitolul 1

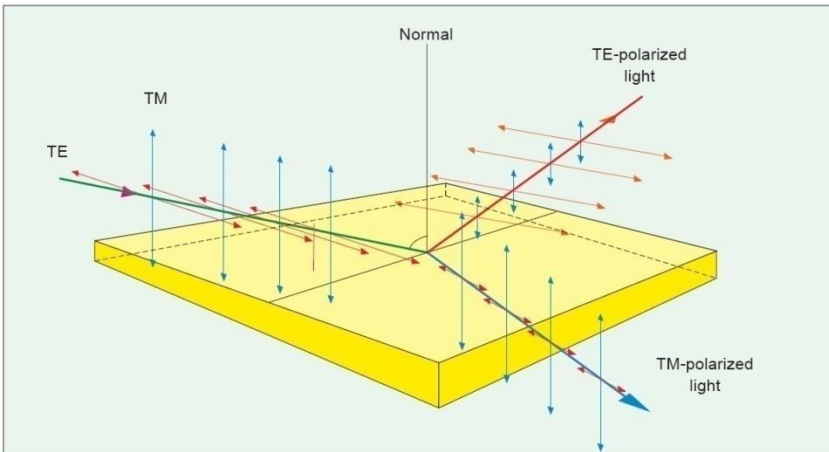
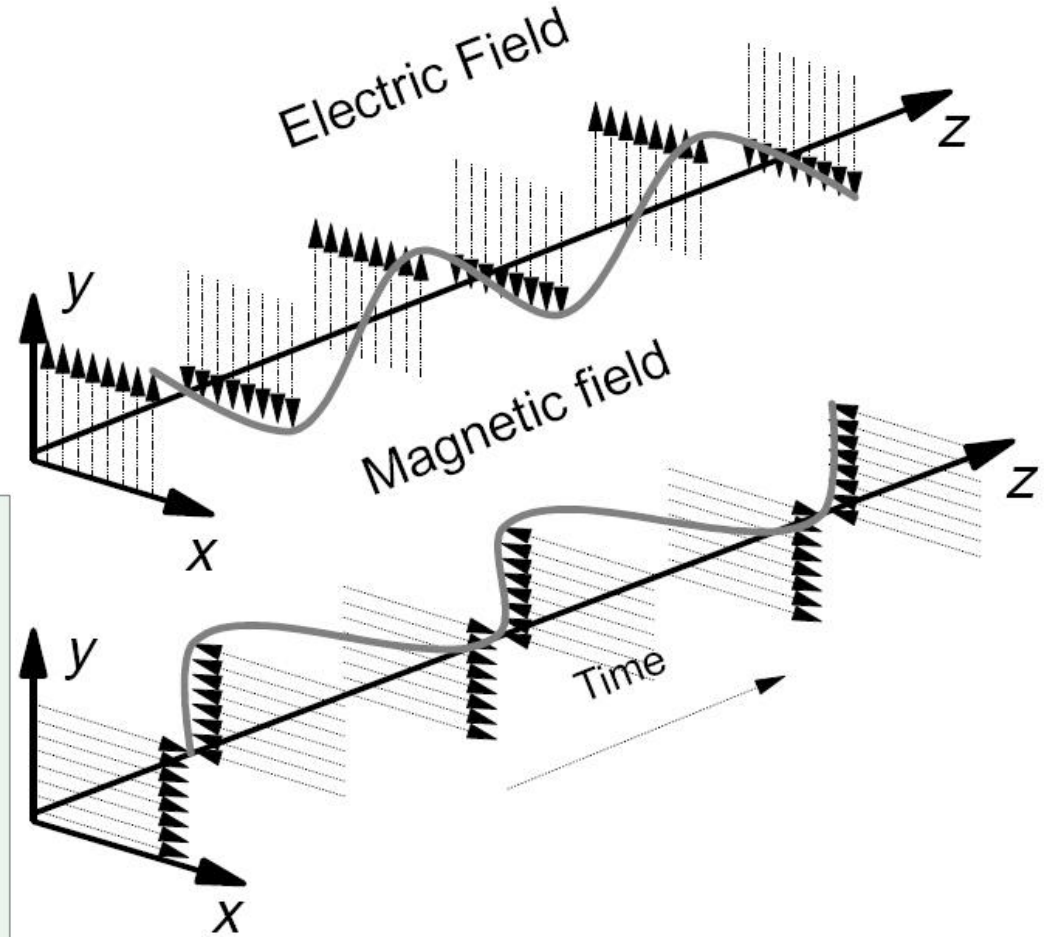
Modelarea luminii

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

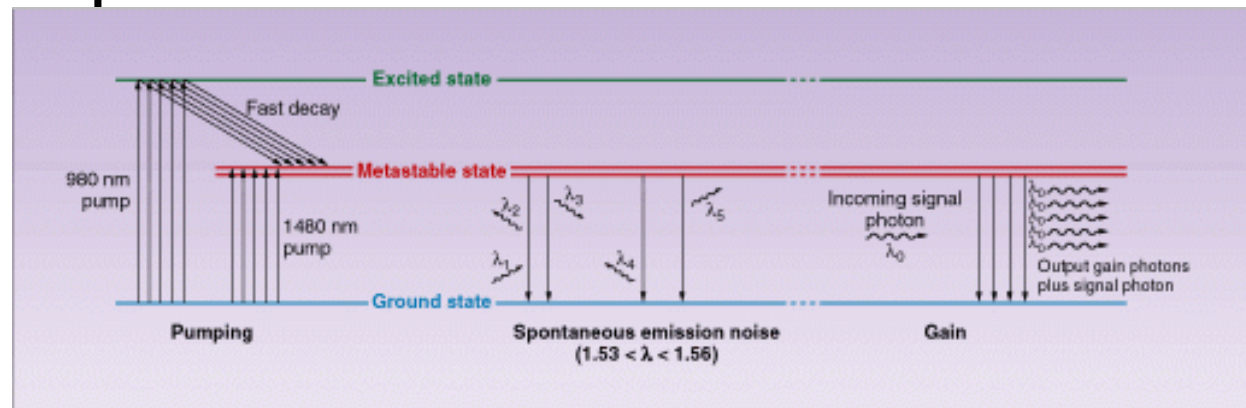
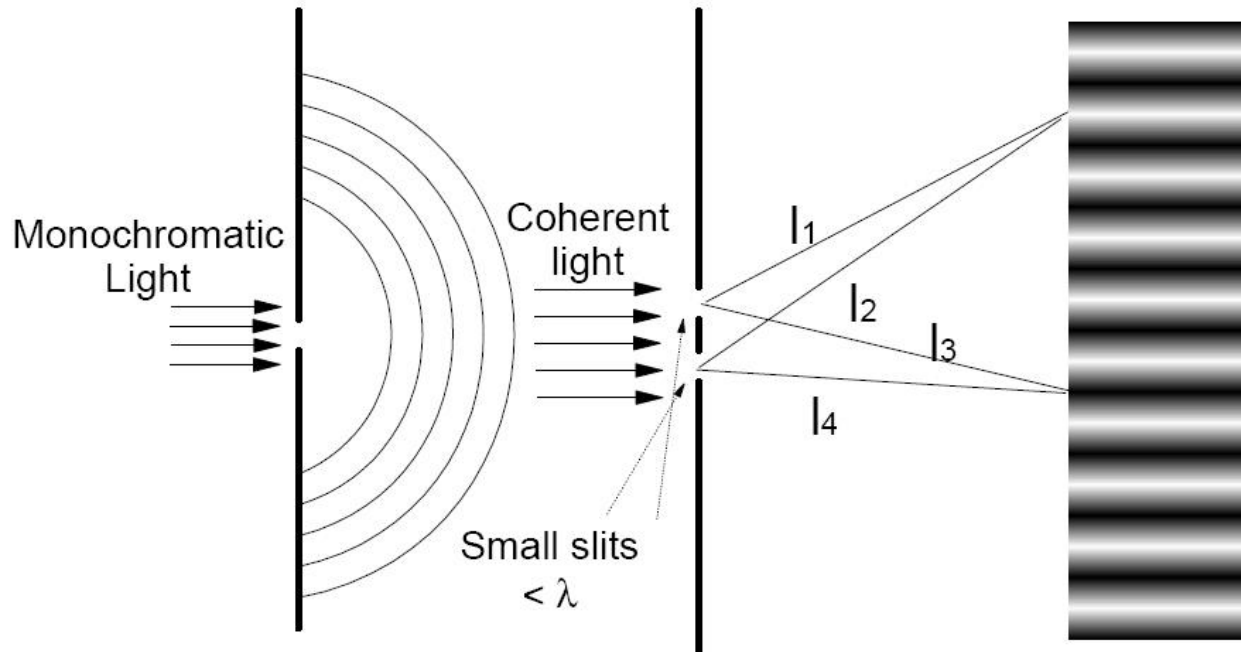


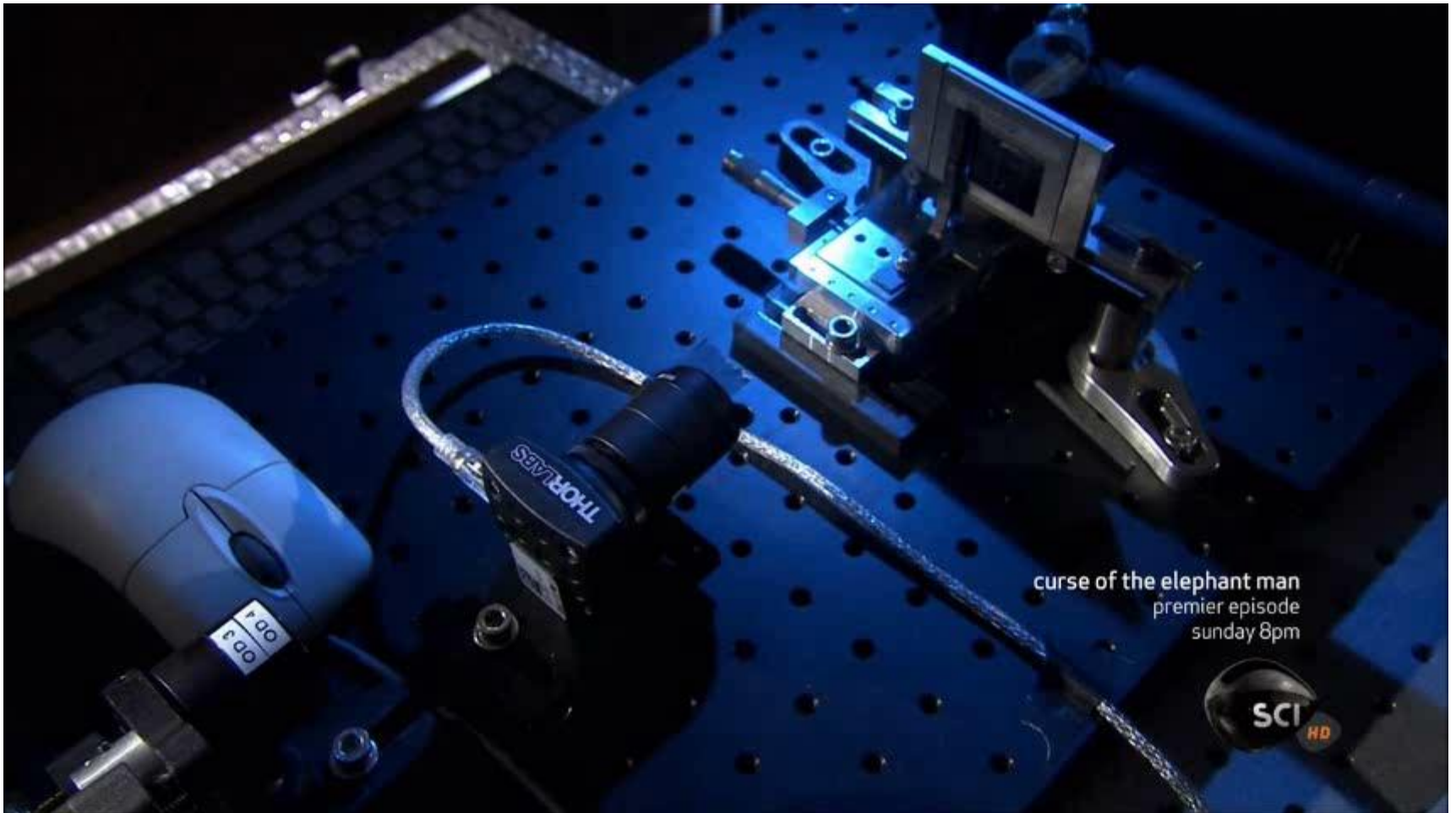
Unda electromagnetica

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



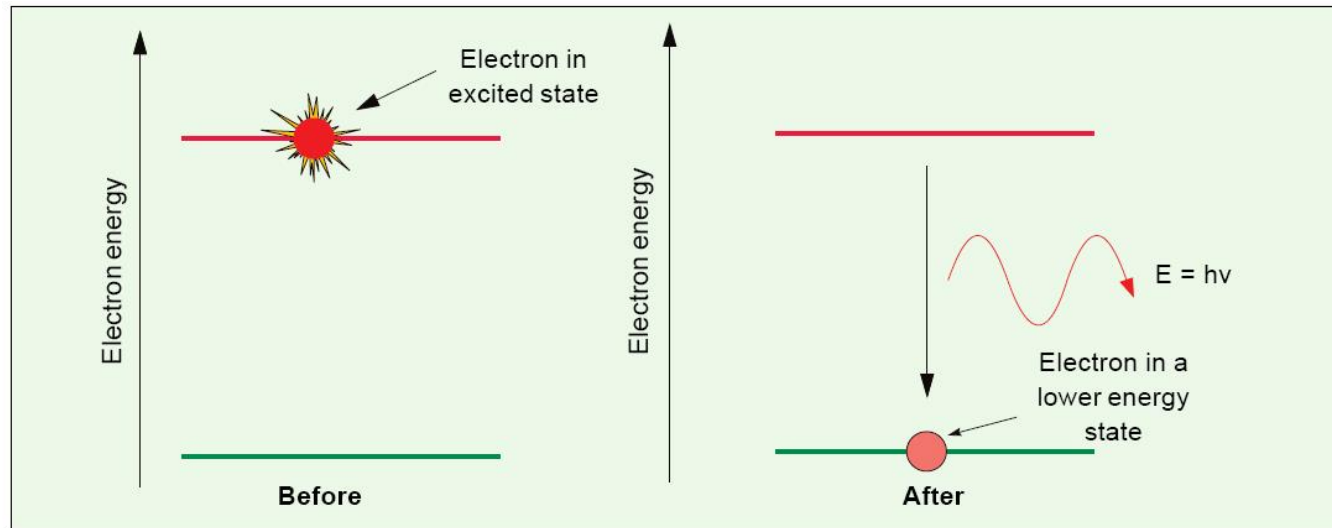
Fotoni/Unda





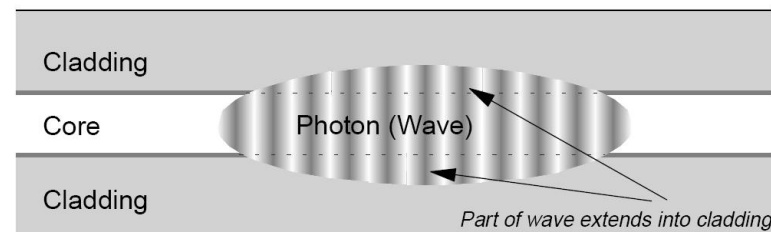
Through the Wormhole
S02E07 How Does the Universe Work

Model cuantic – foton



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

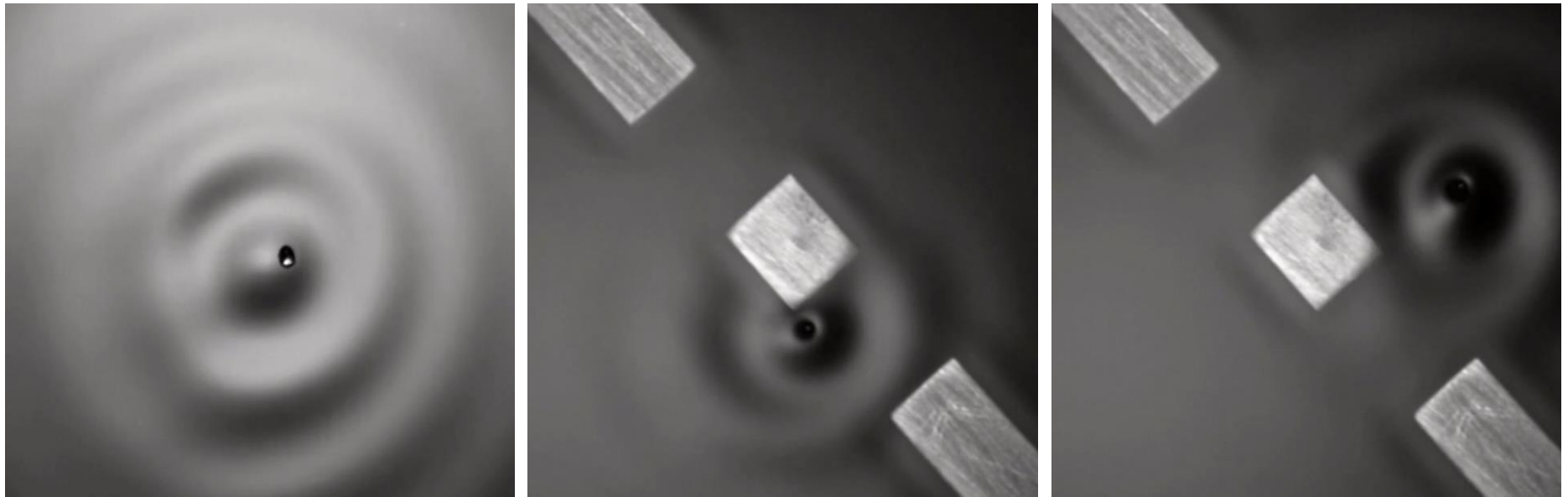
- ▶ h constanta lui Plank
 $6.62 \cdot 10^{-32} \text{ Ws}^2$
- ▶ c viteza luminii **in vid**
 $2.998 \cdot 10^8 \text{ m/s}$



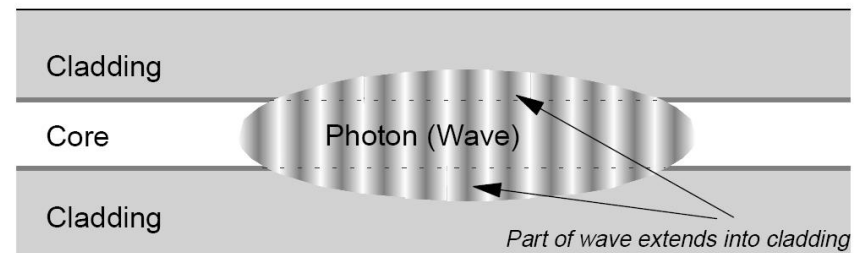


Through the Wormhole
S02E07 How Does the Universe Work

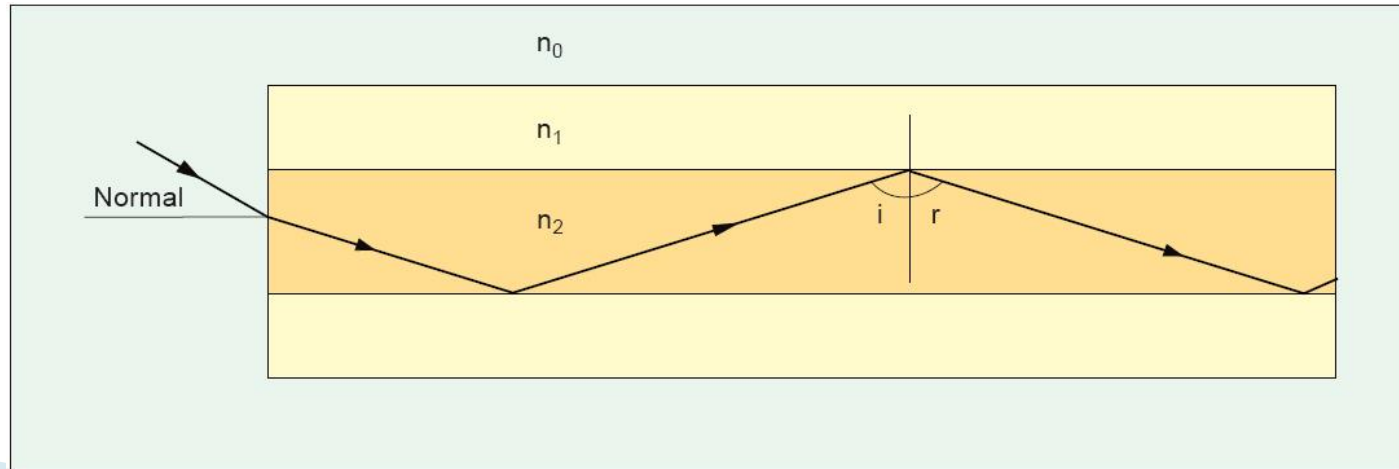
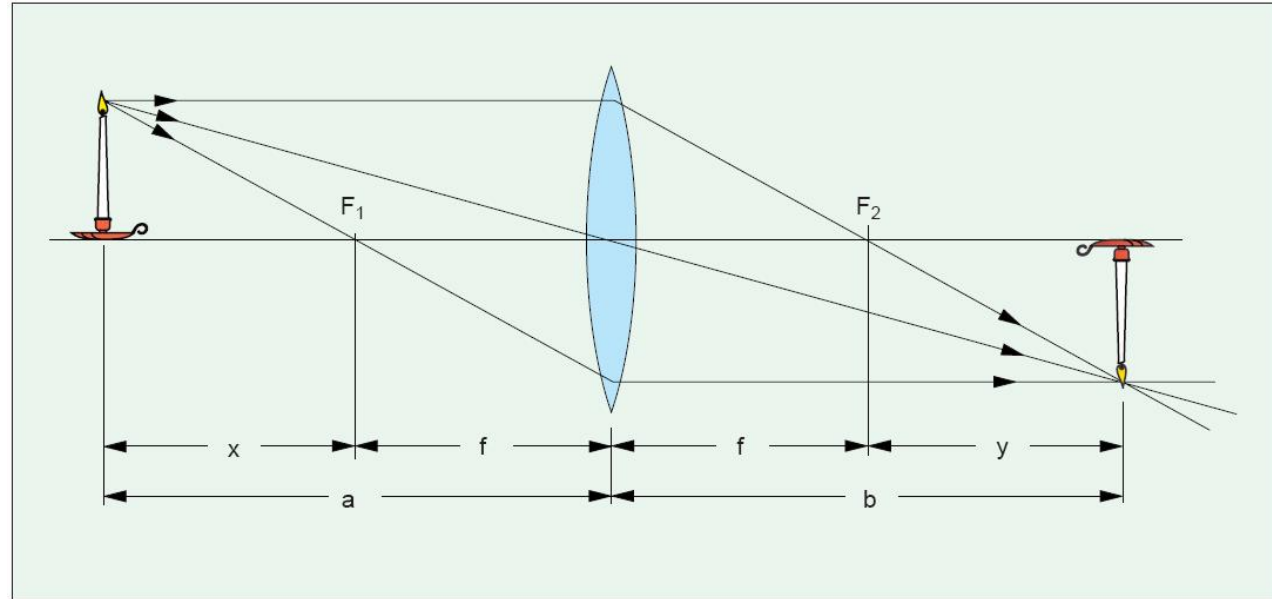
Modelare



Through the Wormhole
S02E07 How Does the Universe Work



Optica geometrica



Lumina ca undă electromagnetică

Capitolul 2

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)
- ▶ **Emițătoare 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)

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

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

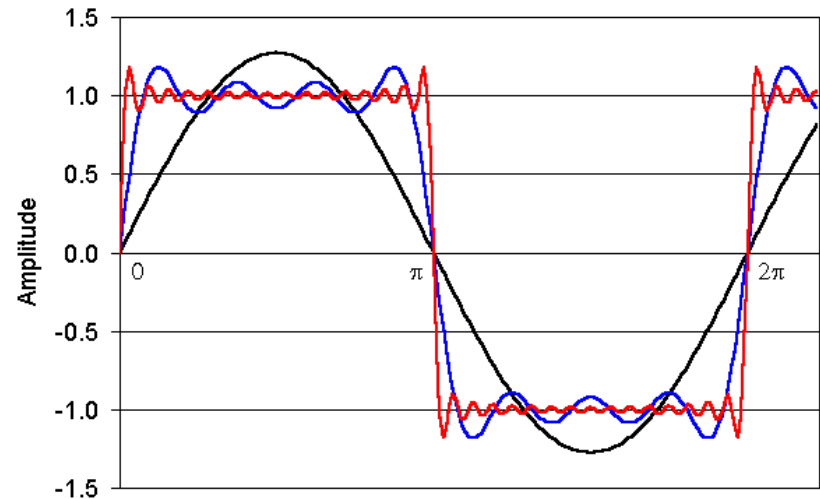
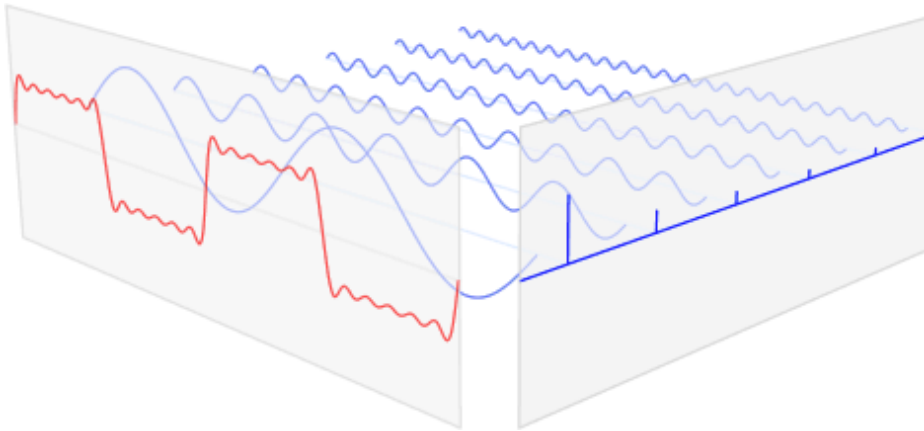
$$\varepsilon_0 = 8,854 \times 10^{-12} \text{ F/m}$$

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

Modele matematice

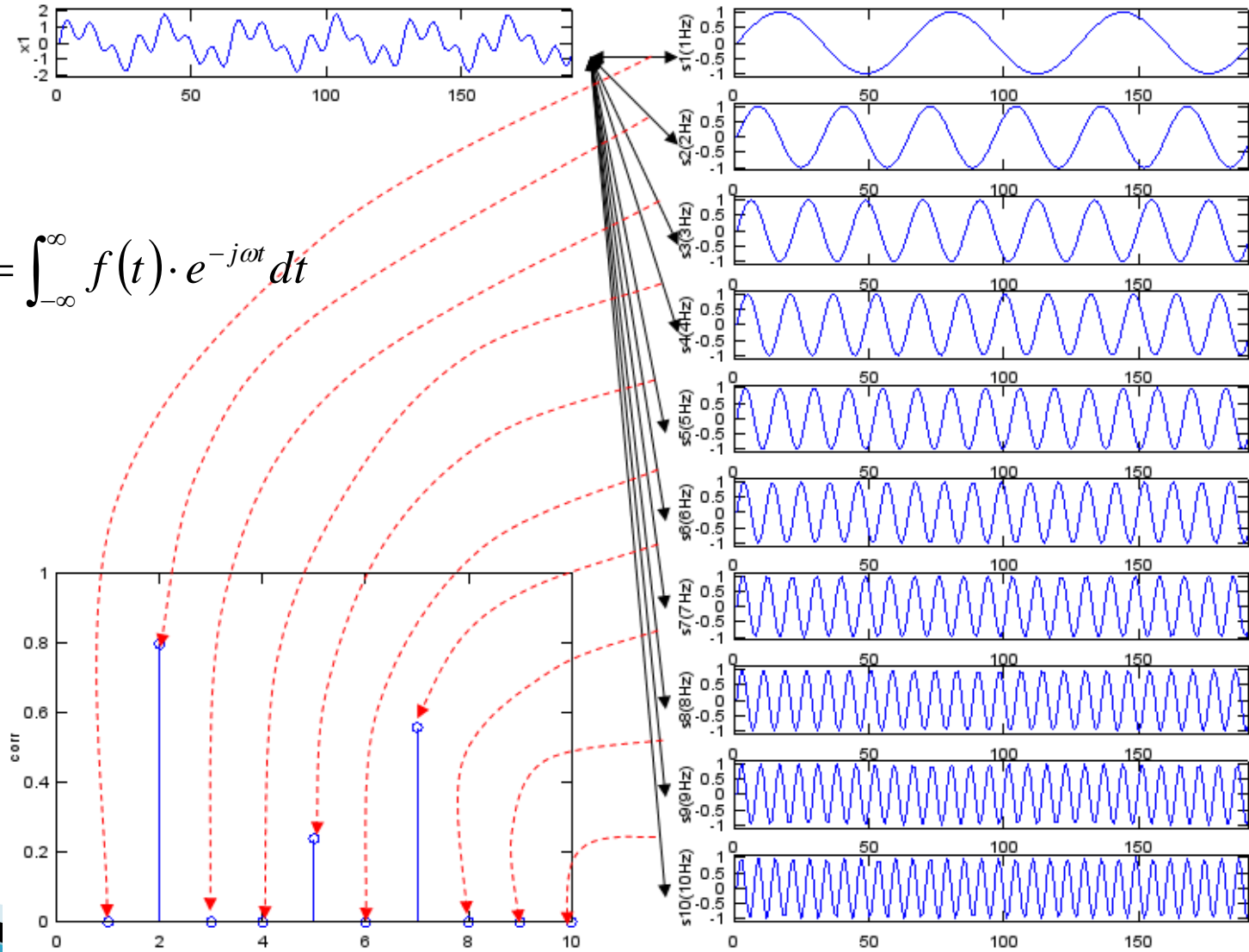
- ▶ cazuri particulare in care exista rezolvare analitica
 - semnale cu variație armonică în timp, transformata Fourier, spectru

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

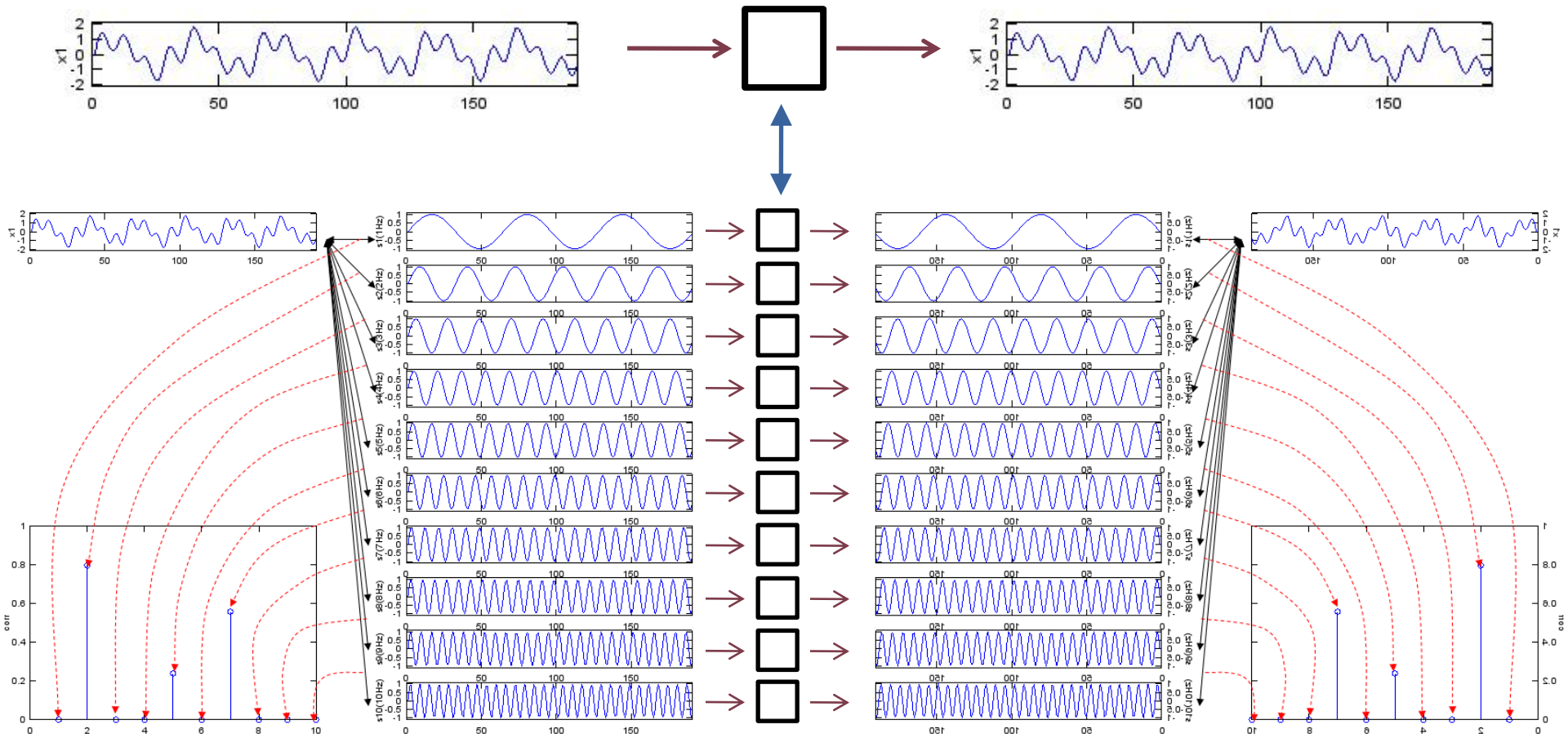


Modelle matematiche

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



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

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

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

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

$$\nabla \cdot H = 0$$

▶ Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

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

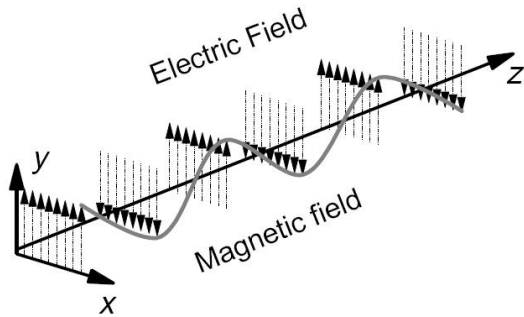
$$\nabla^2 H - \gamma^2 H = 0$$

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

γ – Constanta de propagare

Solutia ecuatiilor de propagare

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



Propagare

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

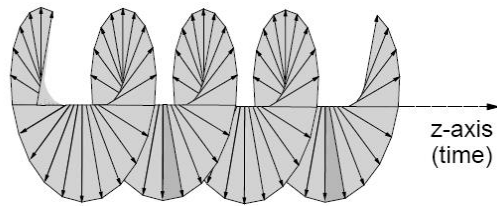
$$\gamma = \sqrt{-\omega^2 \epsilon \mu + j \omega \mu \sigma} = \alpha + j \cdot \beta$$

Exista numai unda progresiva $E_+ \Rightarrow A$

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

Camp armonic

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



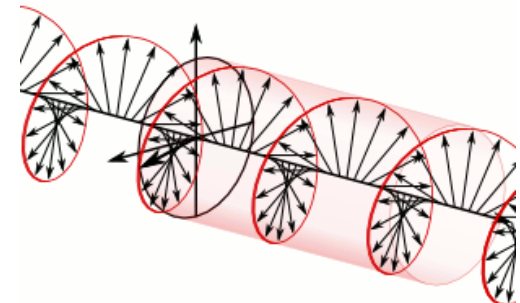
Polarizare circulara

Amplitudine

Atenuare

Propagare

(variatie in timp si spatiu)

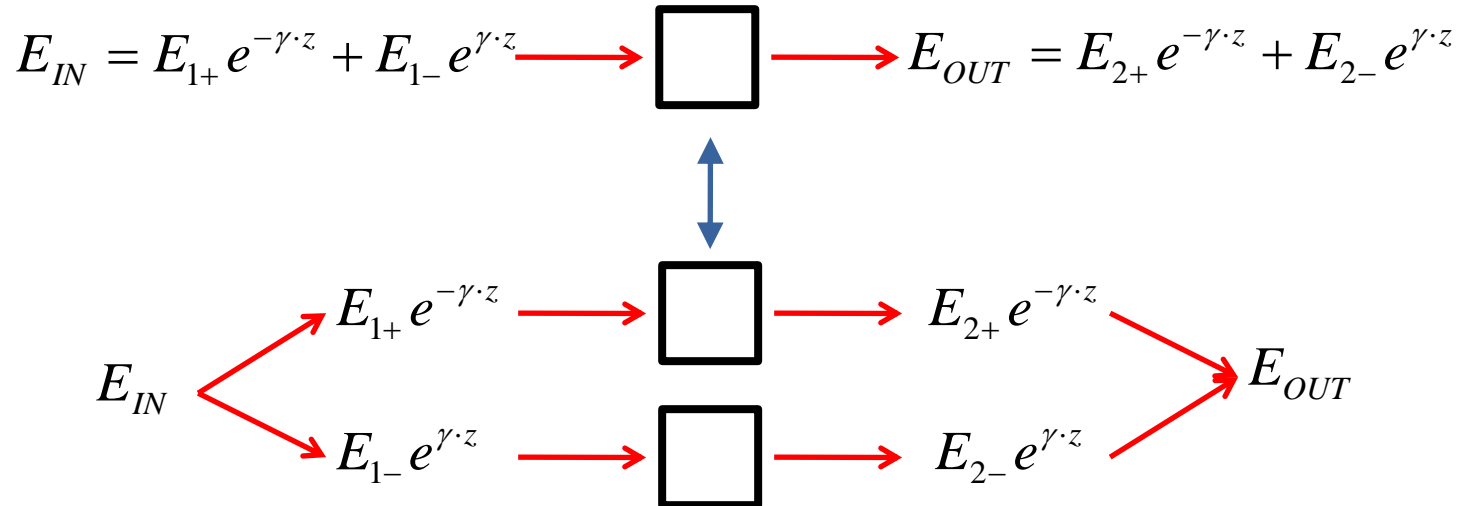


Modele matematice

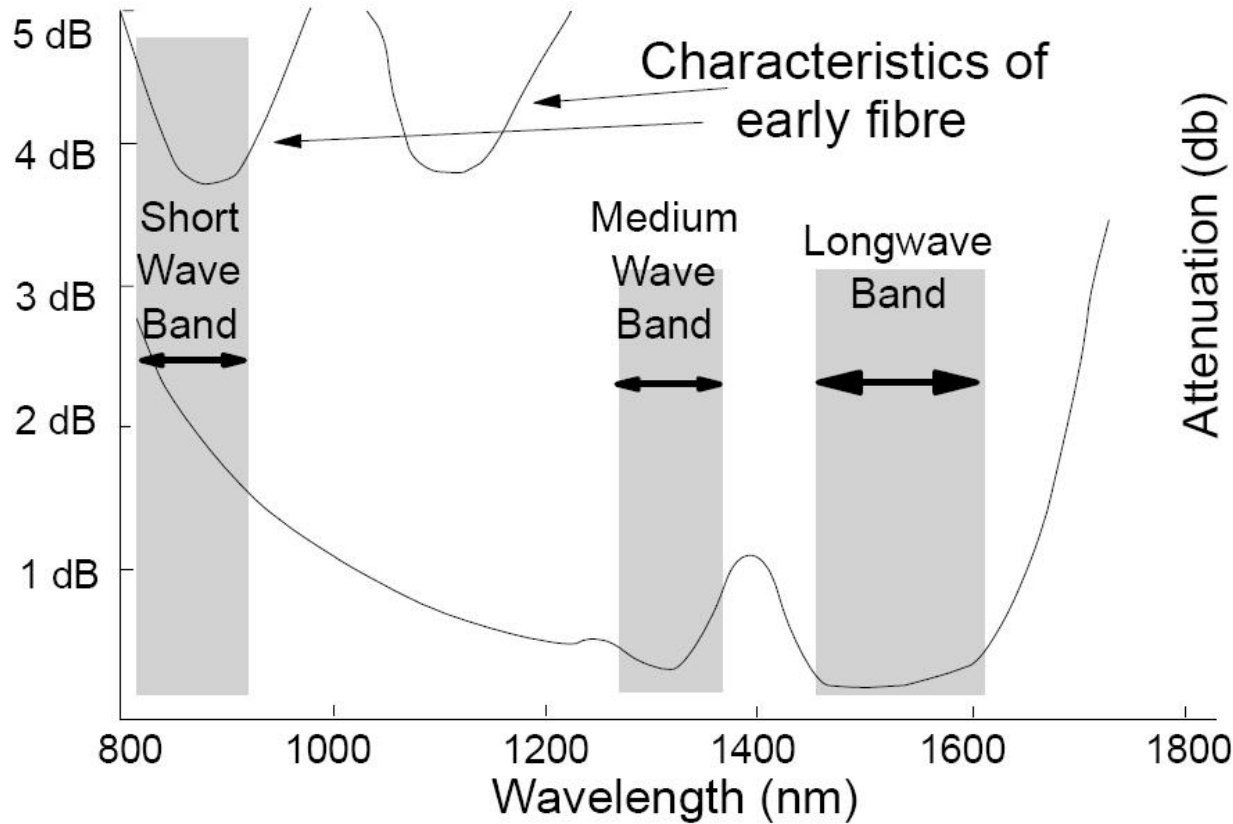
► cazuri particulare in care exista rezolvare analitica

- 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 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**

Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

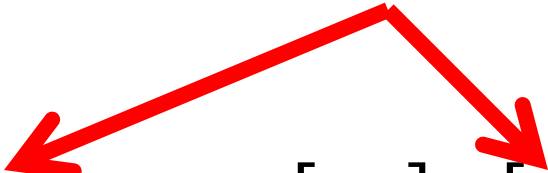
$$[\text{dBm/Hz}] + [\text{dB}] = [\text{dBm/Hz}]$$

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

Calculul atenuarii

$$\text{Pierderi} = \frac{P_{out}}{P_{in}} < 1$$

$$\text{Pierderi[dB]} = 10 \cdot \log_{10} \left(\frac{P_{out}}{P_{in}} \right) < 0$$


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

$$\text{Castig} = \frac{P_{out}}{P_{in}} > 1$$

$$\text{Castig[dB]} = 10 \cdot \log_{10} \left(\frac{P_{out}}{P_{in}} \right) > 0$$

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

Calculul atenuarii

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

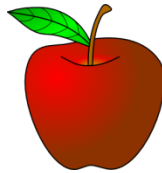
$$\text{Pierderi[dB]} = [-] 10 \cdot \log_{10} \left(\frac{P_{out}}{P_{in}} \right)$$

$$\text{Pierderi[dB]} = [-] 10 \cdot \log_{10} \left(\frac{P_{out}}{P_0} \cdot \frac{P_0}{P_{in}} \right) = [-] 10 \cdot \left[\log_{10} \left(\frac{P_{out}}{P_0} \right) - \log_{10} \left(\frac{P_{in}}{P_0} \right) \right]$$

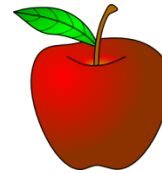
$$\text{Pierderi[dB]} = [-] (P_{out} [\text{dBm}] - P_{in} [\text{dBm}])$$



=



-



Calculul atenuarii

Pierderi/Atenuare $\rightarrow P_{out} < P_{in} \rightarrow P_{out} [\text{dBm}] < P_{in} [\text{dBm}]$

$$P_{out} [\text{dBm}] = P_{in} [\text{dBm}] - \text{Pierderi/Atenuare} [\text{dB}]$$



Castig/Amplificare $\rightarrow P_{out} > P_{in} \rightarrow P_{out} [\text{dBm}] > P_{in} [\text{dBm}]$

$$P_{out} [\text{dBm}] = P_{in} [\text{dBm}] + \text{Castig/Amplificare} [\text{dB}]$$



Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

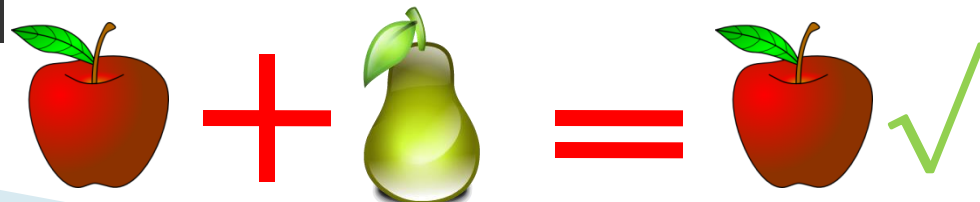
$$-30 \text{ dBm} = 1 \mu\text{W}$$

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

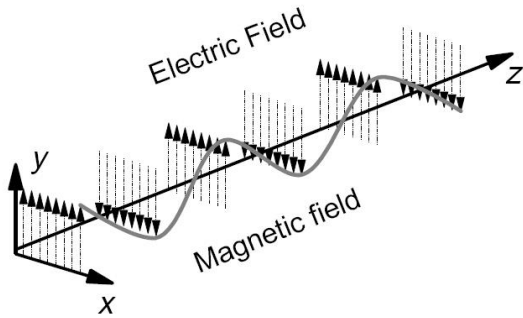
$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

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

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



Parametri de propagare



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

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

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

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

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

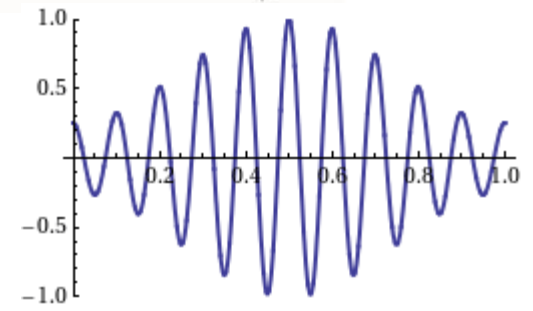
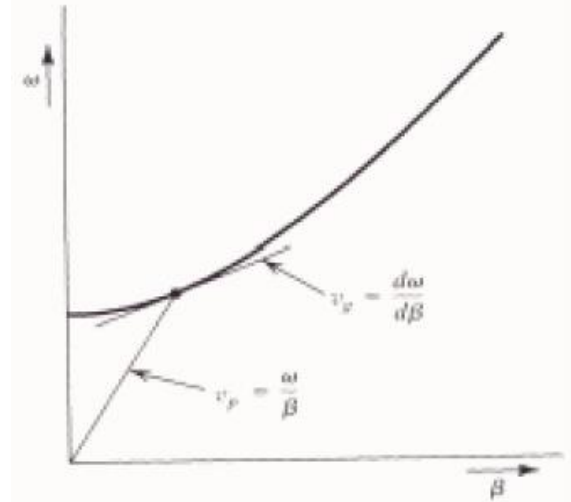
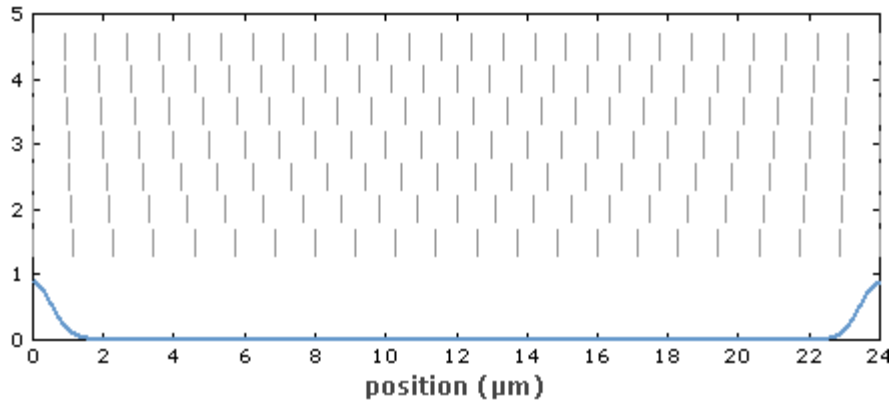
$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)} \quad \text{punctele de faza constanta: } (\omega \cdot t - \beta \cdot z) = \text{const}$$

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 $\beta = \beta(\omega)$

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



Contact

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