

Curs 2

2020/2021

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2020/2021

- 2C/1L, DCMR (CDM)
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
 - Vineri 8-10, Online/Video, Microsoft Teams
 - E – 50% din nota
 - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
 - primul test C2: 16.10.2020 (t2 si t3 neanuntate)
 - 3pz (C) \approx +0.5p (2p max)
 - toate materialele permise

Disciplina 2020/2021

- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
 - Luni 08-14 impar, Online, Microsoft Teams
 - L – **25%** din nota
 - ADS, 4 sedinte aplicatii
 - prezenta + rezultate personale
 - P – **25%** din nota
 - ADS, 3 sedinte aplicatii (-1? 21.12.2020)
 - tema personala

Documentatie

■ <http://rf-opto.etti.tuiasi.ro>

Laboratorul de Microunde si Opti

Not secure | rf-opto.etti.tuiasi.ro/microwave_cd.php?chg_lang=1

RF-OPTO

English | Romana

Start **Didactic** Master Colectiv Cercetare Studenti Admin

Microunde Comunicatii Optice Optoelectronica Internet Antene Practica Retele Soft didactic

Dispozitive si circuite de microunde pentru radiocomunicatii

Disciplina: DCMR (2017-2018)

Coordonator Disciplina: conf. dr. Radu-Florin Damian
Cod: DOS412T
Tip Disciplina: DOS; Disciplina Optionala, Disciplina de Specialitate
Credite: 4
An de Studiu: 4, Sem. 7

Activitati

Curs: Cadru Didactic: conf. dr. Radu-Florin Damian, 2 Ore/Saptamana, Sectie Specializare, Orar:
Laborator: Cadru Didactic: conf. dr. Radu-Florin Damian, 1 Ore/Saptamana, Grupa, Orar:

Evaluare

Tip: **Examen**

A: 50%, (Examen/Colocviu)
B: 25%, (Activitate Seminar/Laborator/Proiect)
D: 25%, (Teme de casa/Lucrari de specialitate)

Note

[Rezultate totale](#)

Prezenta

[Curs](#)
[Laborator](#)

Liste

[Bonus-uri acumulate \(final\)](#)
[Studenti care nu pot intra in examen](#)

Online

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

English | Romana |

Start Didactic Master Colectiv Cercetare Studii

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 | [Iere 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

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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](#) [C](#)

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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)!**

Scop curs 4



Sinapse
“înginerești”



Cuprins

- Linii de transmisie
- Adaptarea de impedanță
- Cuploare direcționale
- Divizoare de putere
- Amplificatoare de microunde
- Filtre de microunde
- Oscilatoare de microunde ?

Bibliografie

- <http://rf-opto.etti.tuiasi.ro>
- Irinel Casian-Botez: "Microunde vol. 1: Proiectarea de circuit", Ed. TEHNOPRES, 2008
- **David Pozar, Microwave Engineering, Wiley; 4th edition , 2011, ISBN : 978-1-118-29813-8 (E), ISBN : 978-0-470-63155-3 (P)**

Examen: Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

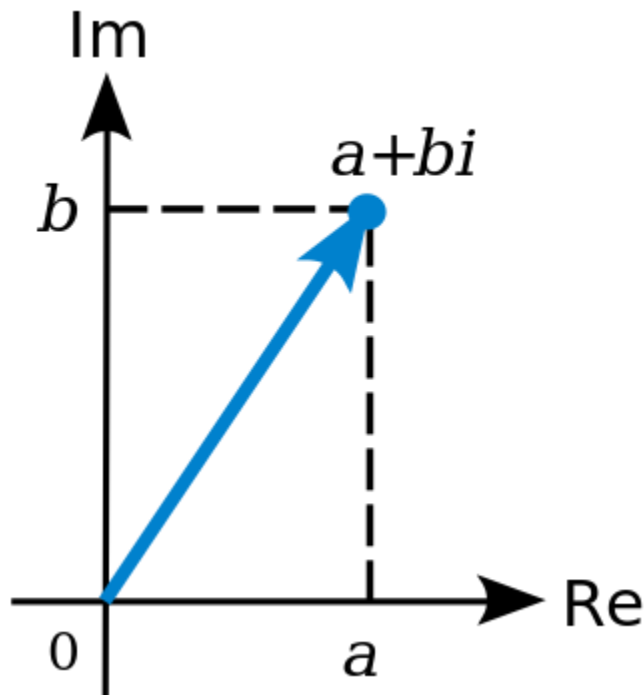
$$[x] + [\text{dB}] = [x]$$

Examen

- Operatii cu numere complexe!
- $z = a + j \cdot b ; j^2 = -1$

Plan complex

- abscisa – partea reala
- ordonata – partea imaginara
- oricare poate fi negativa, intregul plan, 4 cadrane



Reprezentare polara

■ Formula lui Euler

$$e^{j \cdot x} = \cos x + j \cdot \sin x; \forall x \in R$$

■ Reprezentare polara

$$z = a + j \cdot b = |z| \cdot e^{j \cdot \varphi}$$

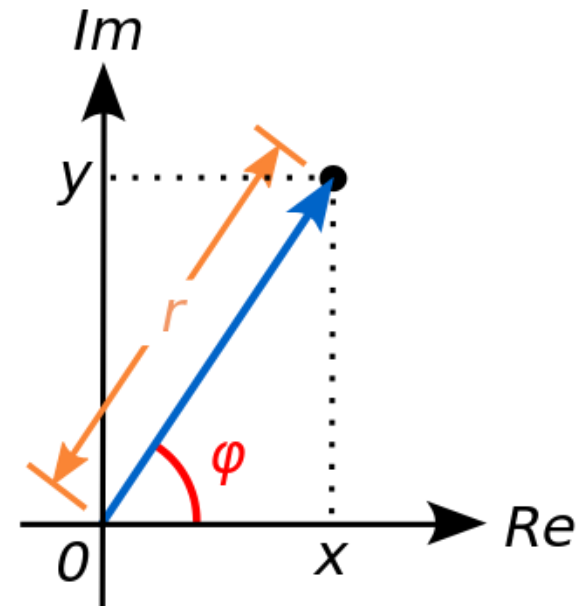
$$z = a + j \cdot b = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)$$

$$z^n = (|z| \cdot e^{j \cdot \varphi})^n = |z|^n \cdot e^{j \cdot n \cdot \varphi} = |z|^n \cdot [\cos(n \cdot \varphi) + j \cdot \sin(n \cdot \varphi)]$$

$$\rightarrow \sqrt{z} = (|z| \cdot e^{j \cdot \varphi})^{1/2} = \sqrt{|z|} \cdot e^{j \cdot \frac{\varphi}{2}} = \sqrt{|z|} \cdot \left(\cos \frac{\varphi}{2} + j \cdot \sin \frac{\varphi}{2} \right)$$

$$z \cdot w = |z| \cdot e^{j \cdot \varphi} \cdot |w| \cdot e^{j \cdot \theta} = |z| \cdot |w| \cdot e^{j \cdot (\varphi + \theta)} = |z| \cdot |w| \cdot [\cos(\varphi + \theta) + j \cdot \sin(\varphi + \theta)]$$

$$z/w = \frac{|z| \cdot e^{j \cdot \varphi}}{|w| \cdot e^{j \cdot \theta}} = \frac{|z|}{|w|} \cdot e^{j \cdot \varphi} \cdot e^{-j \cdot \theta} = \frac{|z|}{|w|} \cdot e^{j \cdot (\varphi - \theta)} = \frac{|z|}{|w|} \cdot [\cos(\varphi - \theta) + j \cdot \sin(\varphi - \theta)]$$

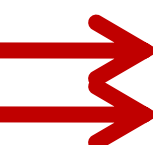


Reprezentare polara

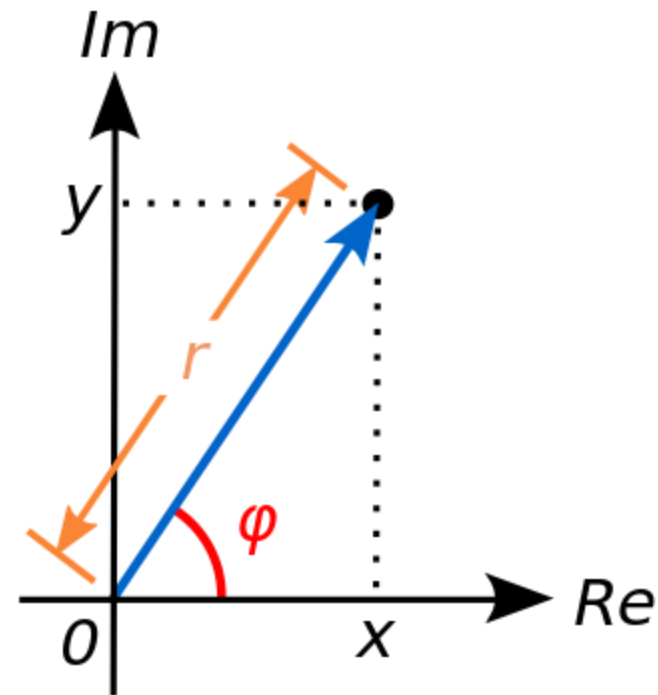
■ Reprezentare polara

$$|z| = \sqrt{a^2 + b^2}$$

$$|z|^2 = z \cdot z^*$$


$$\begin{aligned} |e^{j \cdot x}| &= |\cos x + j \cdot \sin x| = \sqrt{\cos^2 x + \sin^2 x} = 1 \\ |e^{j \cdot x}| &= 1; \quad \forall x \in R \end{aligned}$$

$$\begin{aligned} z^* &= (|z| \cdot e^{j \cdot \varphi})^* = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)^* = |z| \cdot (\cos \varphi - j \cdot \sin \varphi) = \\ &= |z| \cdot [\cos(-\varphi) + j \cdot \sin(-\varphi)] = |z| \cdot e^{-j \cdot \varphi} \end{aligned}$$



Reprezentare polara

- unitate de masura standard – radiani
- unitate de masura traditionala in microunde – **grade format zecimal** (55.89°)

$$\varphi = \arg(z) = \begin{cases} \arctan\left(\frac{b}{a}\right), & a > 0 \\ \arctan\left(\frac{b}{a}\right) + \pi, & a < 0, b \geq 0 \\ \arctan\left(\frac{b}{a}\right) - \pi, & a < 0, b < 0 \\ \frac{\pi}{2}, -\frac{\pi}{2}, \text{nedefinit} & a = 0 \end{cases}$$

$$\varphi[^\circ] = 180^\circ \cdot \frac{\varphi[\text{rad}]}{\pi} \qquad \varphi[\text{rad}] = \pi \cdot \frac{\varphi[^\circ]}{180^\circ}$$

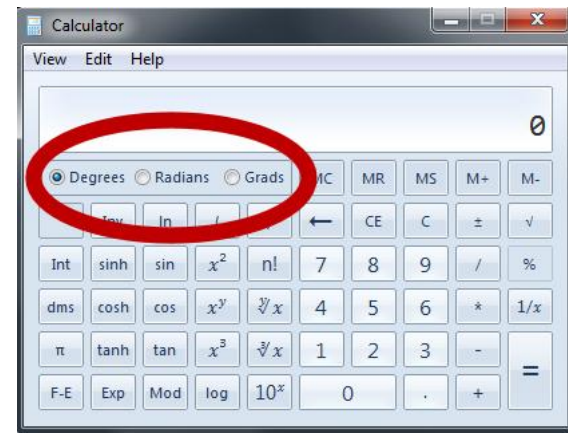
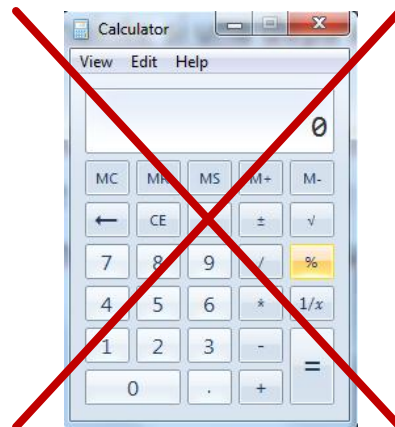


Reprezentare polara

- **Atentie la reprezentarea unghiurilor!!**
 - programele matematice – lucreaza standard in radiani
 - e necesara o **conversie** inainte si una dupa aplicarea unei functii trigonometrice
 - calculatoarele (stiintifice) au posibilitatea (de obicei) de a stabili unitatea de masura pentru unghiuri
 - e necesara **verificarea** unitatii de masura curente

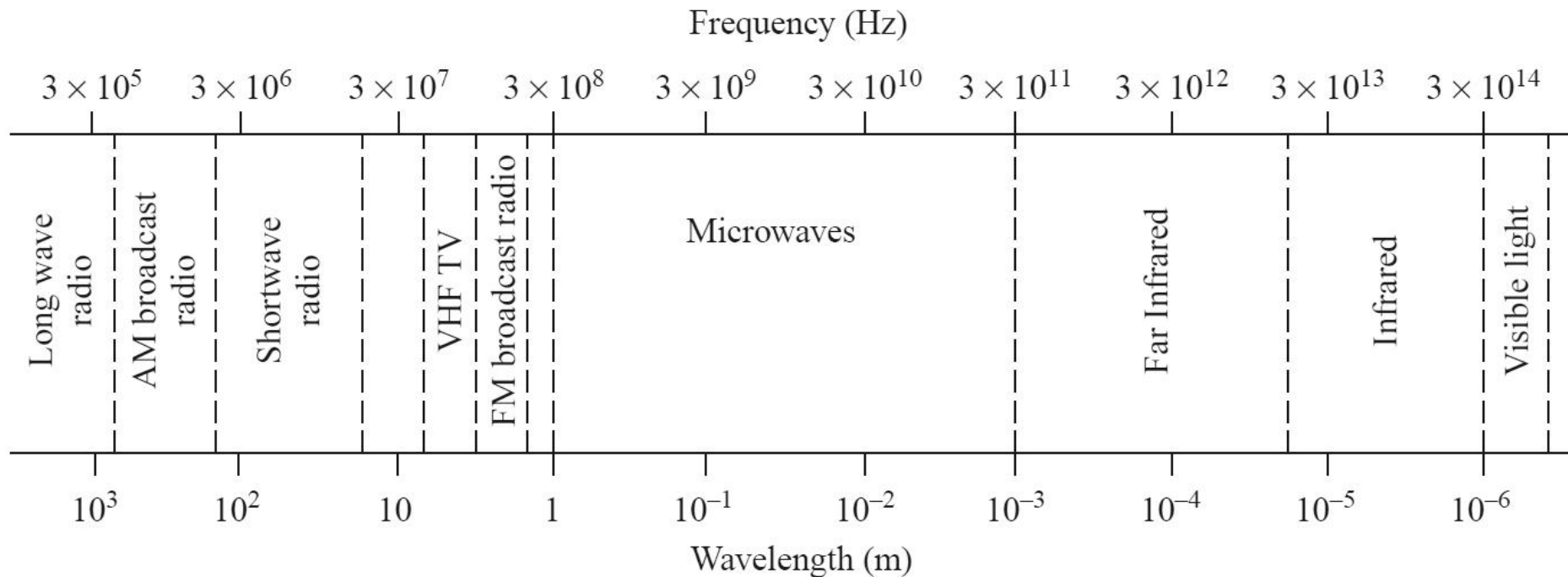
$$\varphi[^\circ] = 180^\circ \cdot \frac{\varphi[rad]}{\pi}$$

$$\varphi[rad] = \pi \cdot \frac{\varphi[^\circ]}{180^\circ}$$



Introdurre

Microunde



- tipic
 - $f \approx 1 \div 3 \text{GHz} - 300 \text{GHz}$
 - $\lambda \approx 1 \text{mm} - 10 \text{cm}$

Microunde

Typical Frequencies

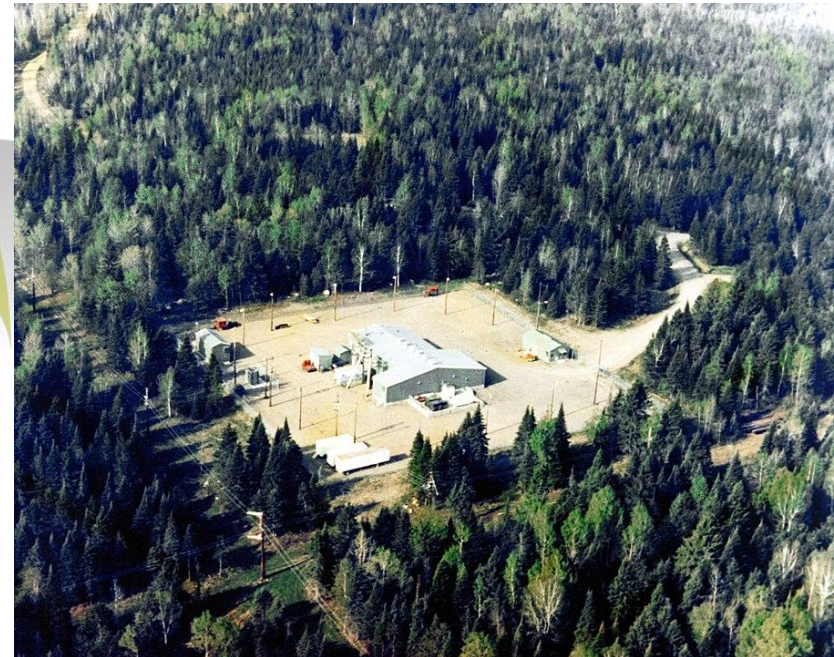
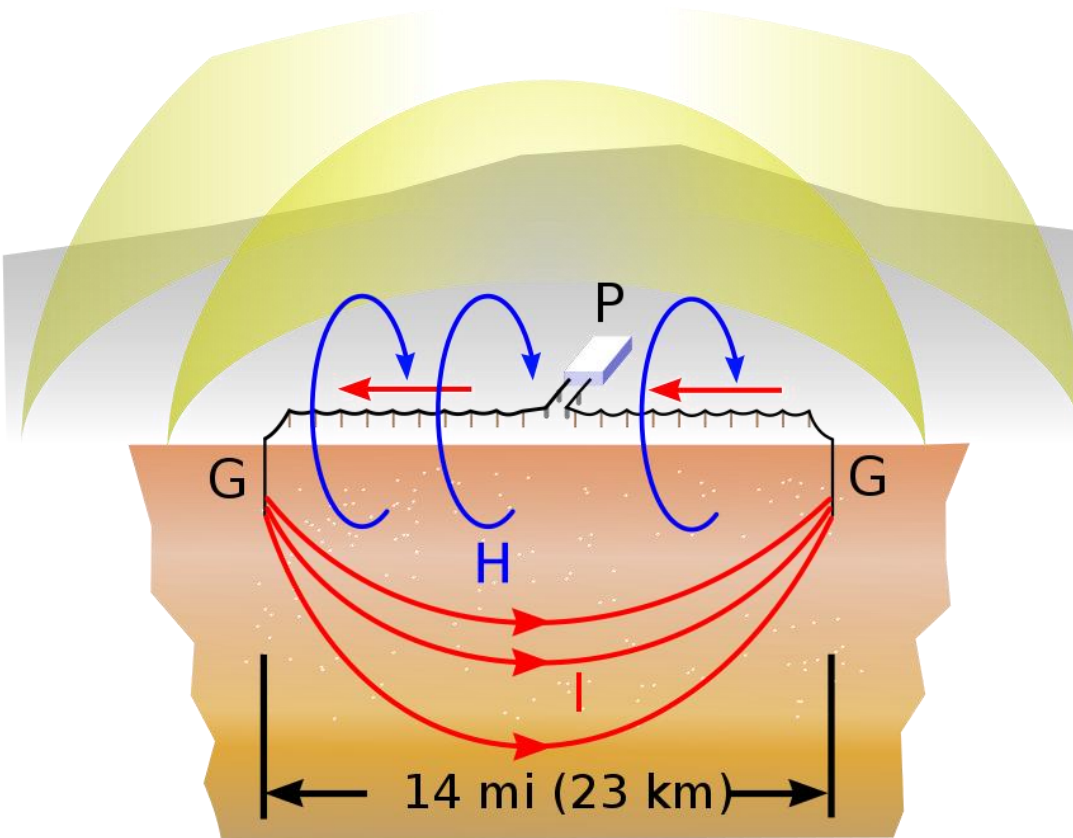
AM broadcast band	535–1605 kHz
Short wave radio band	3–30 MHz
FM broadcast band	88–108 MHz
VHF TV (2–4)	54–72 MHz
VHF TV (5–6)	76–88 MHz
UHF TV (7–13)	174–216 MHz
UHF TV (14–83)	470–890 MHz
US cellular telephone	824–849 MHz 869–894 MHz
European GSM cellular	880–915 MHz 925–960 MHz
GPS	1575.42 MHz 1227.60 MHz
Microwave ovens	2.45 GHz
US DBS	11.7–12.5 GHz
US ISM bands	902–928 MHz 2.400–2.484 GHz 5.725–5.850 GHz
US UWB radio	3.1–10.6 GHz

Approximate Band Designations

Medium frequency	300 kHz–3 MHz
High frequency (HF)	3 MHz–30 MHz
Very high frequency (VHF)	30 MHz–300 MHz
Ultra high frequency (UHF)	300 MHz–3 GHz
L band	1–2 GHz
S band	2–4 GHz
C band	4–8 GHz
X band	8–12 GHz
Ku band	12–18 GHz
K band	18–26 GHz
Ka band	26–40 GHz
U band	40–60 GHz
V band	50–75 GHz
E band	60–90 GHz
W band	75–110 GHz
F band	90–140 GHz

ELF, VLF

- Extremely low frequency, 3 - 30 Hz
- Very low frequency, 3 - 30 kHz



~ Microunde

- Lungimea electrica a unui circuit
 - l – lungimea fizica
 - $E = \beta \cdot l$ – lungimea electrica

$$E = \beta \cdot l = \frac{2\pi}{\lambda} \cdot l = 2\pi \cdot \left(\frac{l}{\lambda} \right)$$

$$E = \beta \cdot l = \frac{2\pi}{c_0} \cdot (l \cdot f \cdot \sqrt{\epsilon_r})$$

V, I variabile
~ inutile

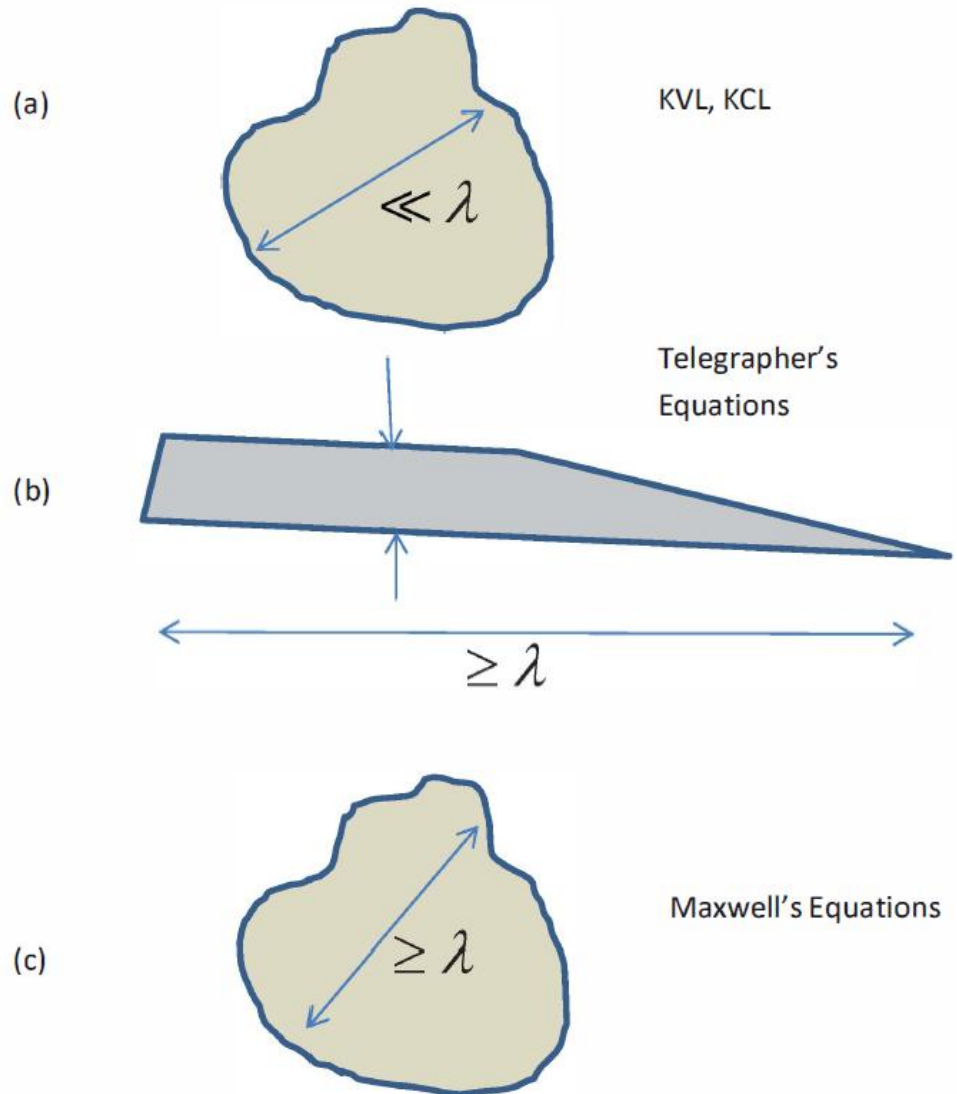
- Dependenta
 - castigul antenei
 - imaginea unui obiect pe radar

Lungime electrica

- Comportarea (descrierea) unui circuit depinde de lungimea sa electrica la frecventele de interes

- $E \approx 0 \rightarrow$ Kirchhoff
- $E > 0 \rightarrow$ propagare

$$E = \beta \cdot l = \frac{2\pi}{\lambda} \cdot l = 2\pi \cdot \left(\frac{l}{\lambda} \right)$$



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

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

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

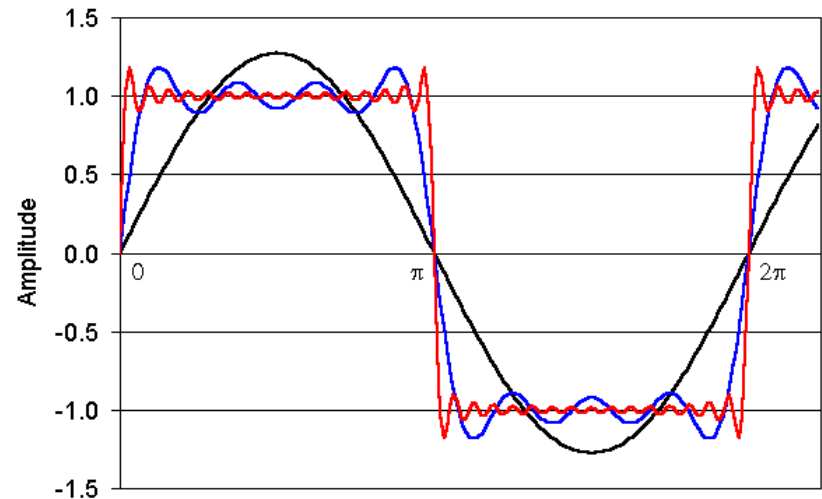
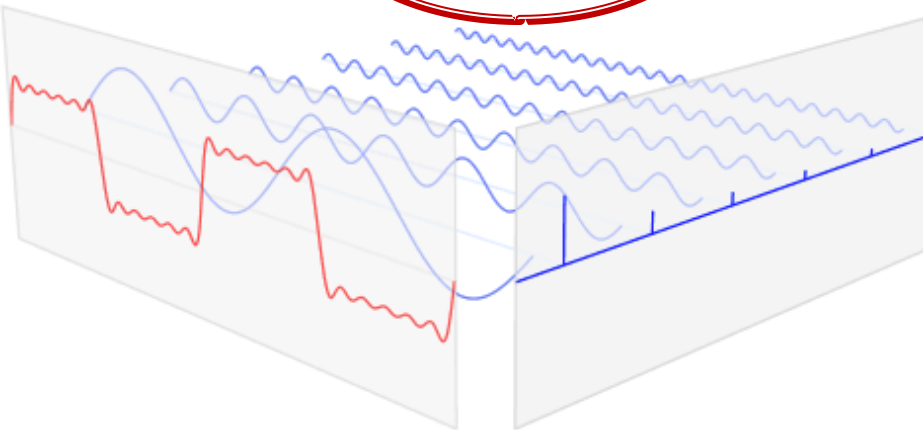
$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

Modele matematice

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

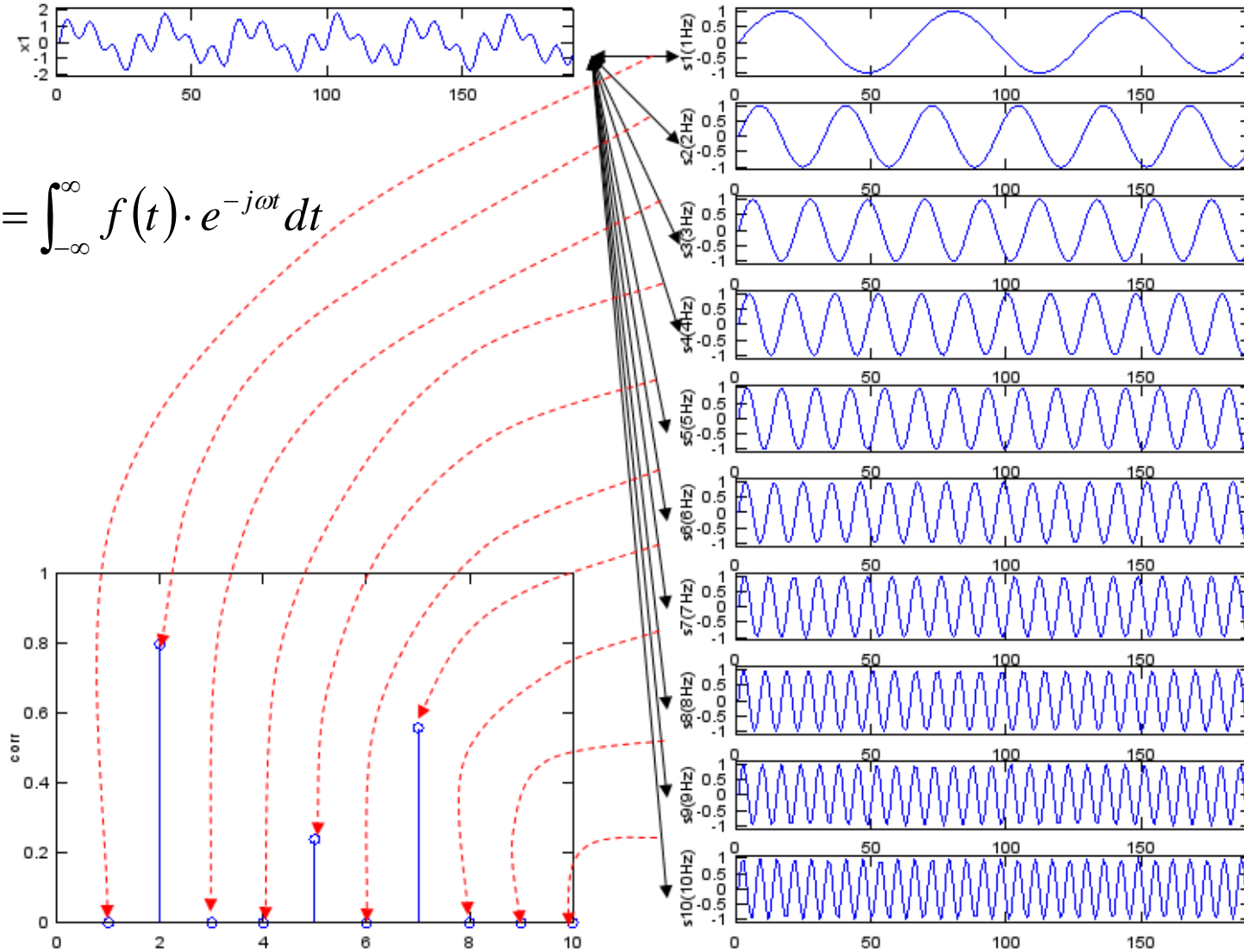
$$X = X_0 e^{j \cdot \omega \cdot t} \quad \frac{\partial X}{\partial t} = j \cdot \omega \cdot X$$

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

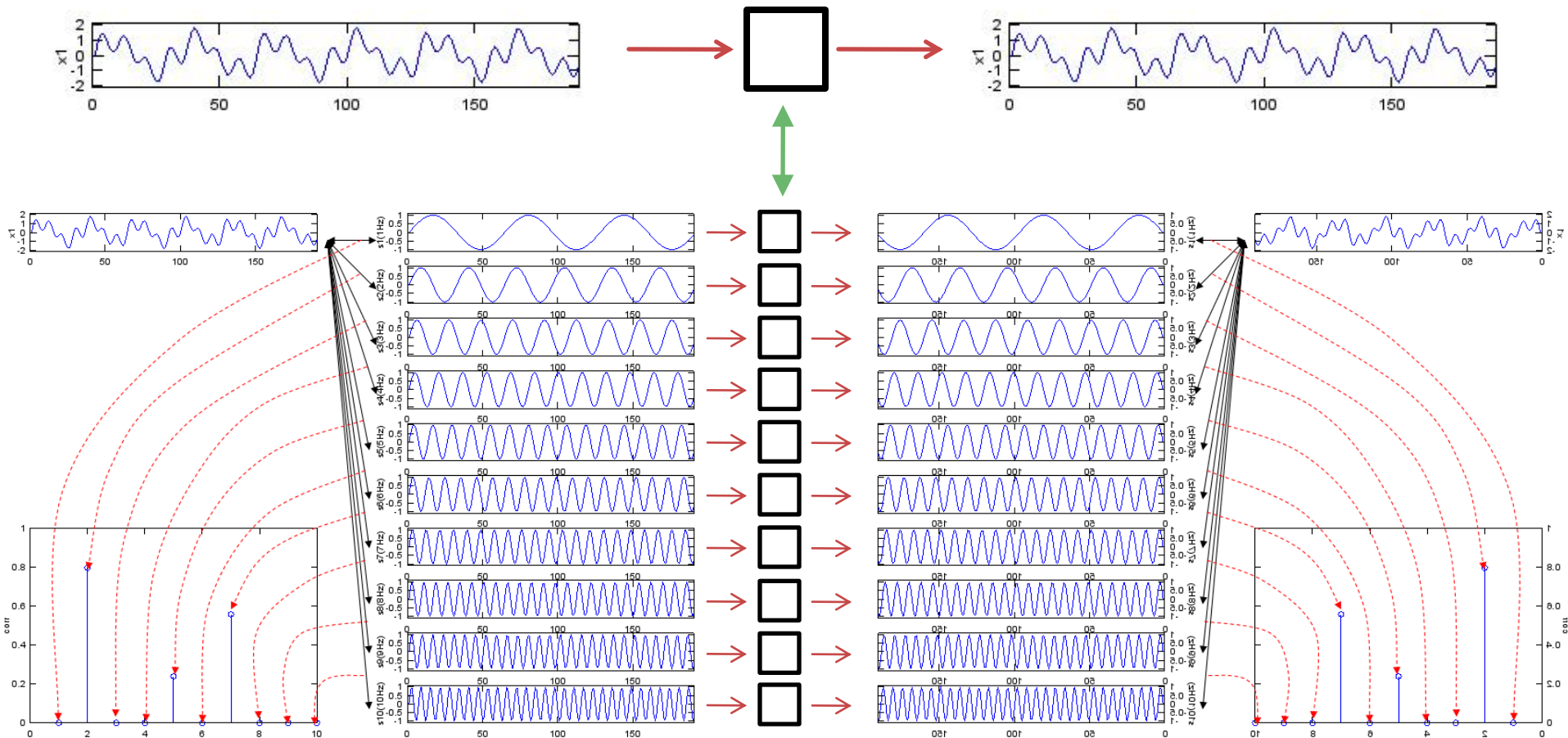


Modelle matematiche

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



Modele 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

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

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

■ 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 de propagare

- Ecuațiile Helmholtz sau ecuațiile de propagare

Mediu lipsit de sarcini electrice

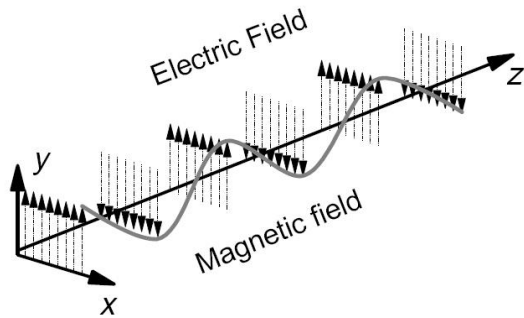
$$\nabla^2 E - \gamma^2 E = 0$$

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

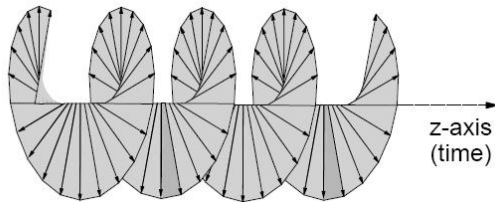
$$\gamma^2 = -\omega^2 \varepsilon \mu + j \omega \mu \sigma$$

γ – Constanta de propagare

Solutia ecuatiilor de propagare



Propagare



Polarizare circulara

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

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

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

Exista numai unda progresiva $E_+ \Rightarrow A$

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

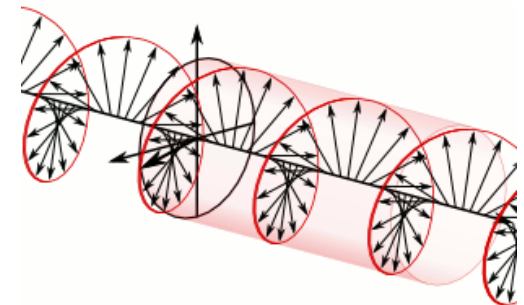
Camp armonic

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

Amplitudine

Atenuare

Propagare
(variatie in timp si spatiu)



Atenuare

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

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

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

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

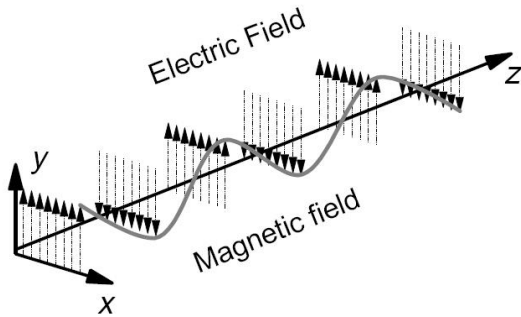
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

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

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

- ▶ 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, $\sigma = 0$

$$\gamma = j\omega \cdot \sqrt{\epsilon\mu}$$

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\epsilon}}$$

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:

$$(\omega \cdot t - \beta \cdot z) = \text{const}$$

Viteza de faza

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

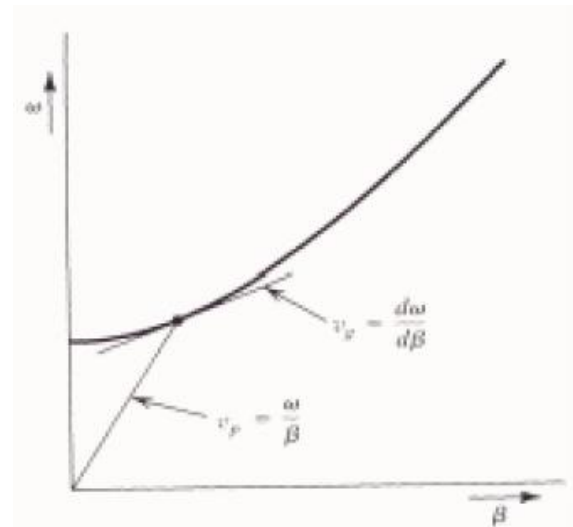
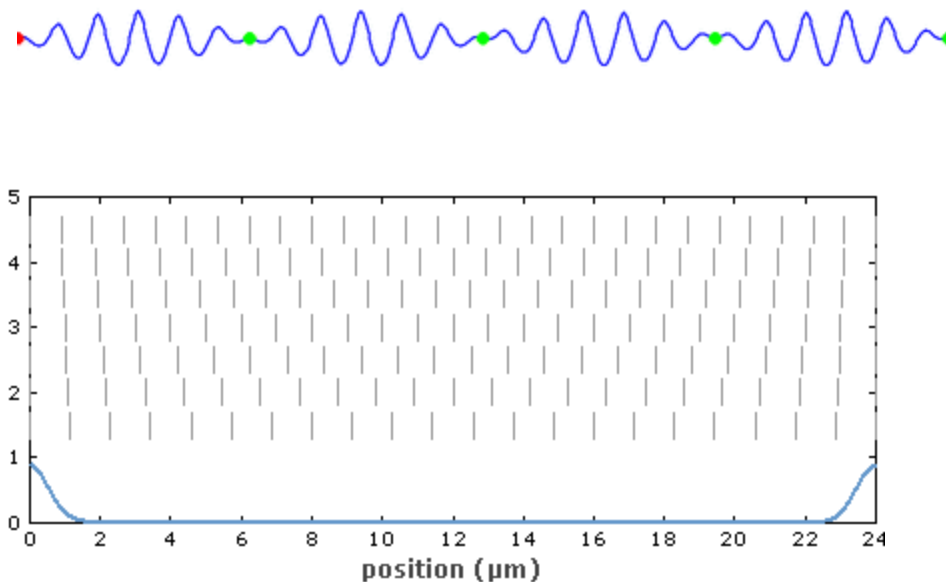
Viteza de grup

$$v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta}$$

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)



Parametri de propagare

■ In vid

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\Omega \quad v = v_g = c_0 \quad c_0 = \frac{1}{\sqrt{\epsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

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

Periodicitate in spatiu

Periodicitate in timp

■ In mediu nedispersiv ϵ_r


$$c = \frac{1}{\sqrt{\epsilon \cdot \mu_0}} = \frac{1}{\sqrt{\epsilon_0 \epsilon_r \cdot \mu_0}} = \frac{c_0}{\sqrt{\epsilon_r}}$$

$$n = \sqrt{\epsilon_r} \quad \text{Indice de refractie al mediului}$$

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

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

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

$$\lambda = \frac{c_0}{\sqrt{\epsilon_r} \cdot f} = \frac{\lambda_0}{\sqrt{\epsilon_r}}$$


Contact

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