

Curs 3

2022/2023

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2022/2023

- 2C/1L, **DCMR (CDM)**
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
 - Marti 15-17, ~~Online~~/**Video (istoric)**, P2
 - E – **50%** din nota
 - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
 - primul test L1: 05.10.2022 (t2 si t3 neanuntate la **curs**)
 - 3pz (C) \approx +0.5p (**2p** max)
 - toate materialele permise

Disciplina 2022/2023

- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
 - Miercuri/Joi, 12/14 par/impar, **II.13**
 - L – **25%** din nota
 - ADS, 4 sedinte aplicatii
 - prezenta + **rezultate personale!**
 - P – **25%** din nota
 - ADS, 3 sedinte aplicatii (-1? 21-22.12.2022)
 - 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

Microunde Comunicatii Optice Optoelectronica Internet Antene Tehnologie/Zgomote Practica Soft didactic

Dispozitive si circuite de microunde pentru radiocomunicatii

Disciplina: DCMR (2021-2022)

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

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

Documentatie

- RF-OPTO
 - <http://rf-opto.etti.tuiasi.ro> Moodle
- Fotografie
 - de trimis pe [rf-opto](#)
 - necesara la laborator/curs
 - bonus activitate 0.5p/1p

Note

■ 2017/2018

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

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Tip Disciplina: DOS; Disciplina Optionala, Disciplina de Specialitate

Credite: 4

An de Studiu: 4, Sem. 7

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Note

[Rezultate totale](#)

Prezenta

[Curs](#)

[Laborator](#)

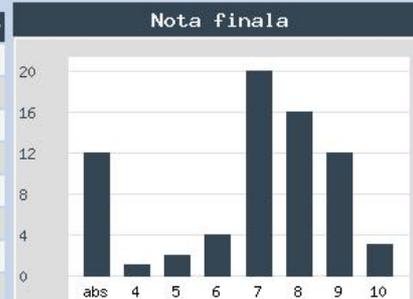
Liste

[Bonus-uri acumulate \(final\)](#)

[Studenti care nu pot intra in examen](#)

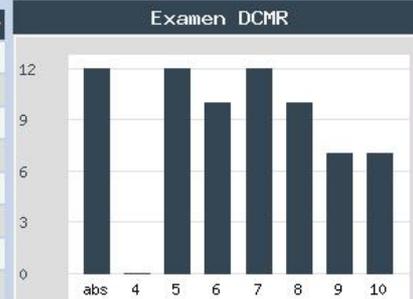
Statistici

Nota.	Numar
abs	12
4	1
5	2
6	4
7	20
8	16
9	12
10	3
TOTAL	70



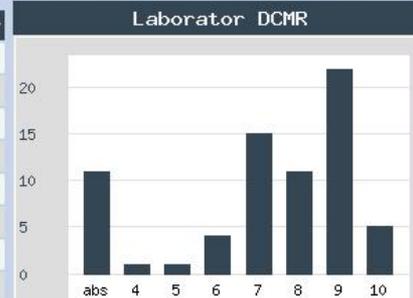
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Exam.	Numar
abs	12
4	0
5	12
6	10
7	12
8	10
9	7
10	7
TOTAL	70



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Labo.	Numar
abs	11
4	1
5	1
6	4
7	15
8	11
9	22
10	5
TOTAL	70



Powered by: RFTech - <http://www.rfttech.ro> 0.004 sec

Prezenta, Liste

D: 15%, (Teme de casa/Lucrari de specialitate)

Note

[Rezultate totale](#)

Prezenta

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

Liste

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

Materiale

- Prezenta
- Minim 7 prezente
- Bonus
- Teme proiect
- etc.

Bonus

Grupa	Prezente curs	B. prezenta	B. activitate	B. foto	B. T1	B. T2	B. T3	Total Bonus	Obs.
5408	2	0	0	1	0.5	0	0.1	1.6	-
5408	15.5	2	1.6	1	0	0.2	0.3	5.1	-
5408	2.1	0	0	1				1	-
5408	11	1.5	0	0	0.25	0	0	1.75	-
5408	5	0.5	0	1	0.75	0.2	0	2.45	-
5408	8.875	1	0.4	1	0.85	0.1		3.35	-
5408	0	0	0	1				1	-
5408	0	0	0	1				1	-
5408	14.5	2	0.6	1	0.63	0.2	0	4.43	-
5408	6.65	1	0	1	0.13	0	0.1	2.23	-
5408	9.2	1.5	0	1	0		0	2.5	-
5408	7.8	1	0	1	0.5	0	0.2	2.7	-
5408	3	0.5	0	1			0	1.5	-
5408	1.6	0	0	1	0			1	-
5408	4.5	0.5	0	1	0.48			1.98	-
5408	8	1	0.05	1	0.38	0	0	2.43	-
5408	1	0	0	1				1	-
5408	15.5	2	0.8	1	0	0.1	0.1	4	-
5408	10.5	1.5	0	1			0	2.5	-

Istoric

Alte informatii

[Online Exam manual](#) (pdf, 2.56 MB, en, 🇸🇬)

[Exam Simulation \(video\)](#) (mp4, 41.96 MB, en, 🇸🇬)

[Important Agilent Application Notes](#) (rar, 2.36 MB, ro, 🇷🇴)

Ani anteriori

2020-2021

2019-2020

2018-2019

2017-2018

2016-2017

Mai mult...

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

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

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

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

0 dB	= 1
+ 0.1 dB	= 1.023 (+2.3%)
+ 3 dB	= 2
+ 5 dB	= 3
+ 10 dB	= 10
-3 dB	= 0.5
-10 dB	= 0.1
-20 dB	= 0.01
-30 dB	= 0.001

0 dBm	= 1 mW
3 dBm	= 2 mW
5 dBm	= 3 mW
10 dBm	= 10 mW
20 dBm	= 100 mW
-3 dBm	= 0.5 mW
-10 dBm	= 100 μ W
-30 dBm	= 1 μ W
-60 dBm	= 1 nW

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

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

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

Examen

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

Reprezentare polara

■ Reprezentare polara

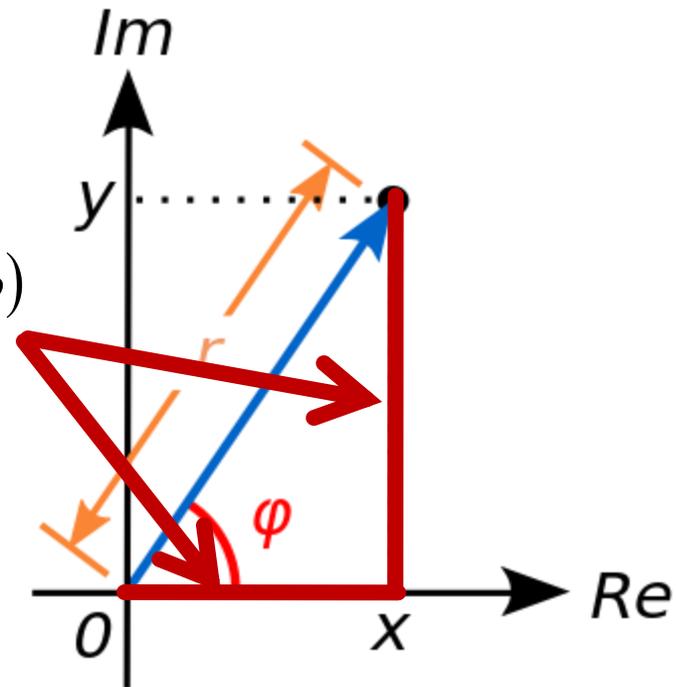
■ modul

■ faza

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

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

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



Reprezentare polara

- Formula lui Euler

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

- Reprezentare polara

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

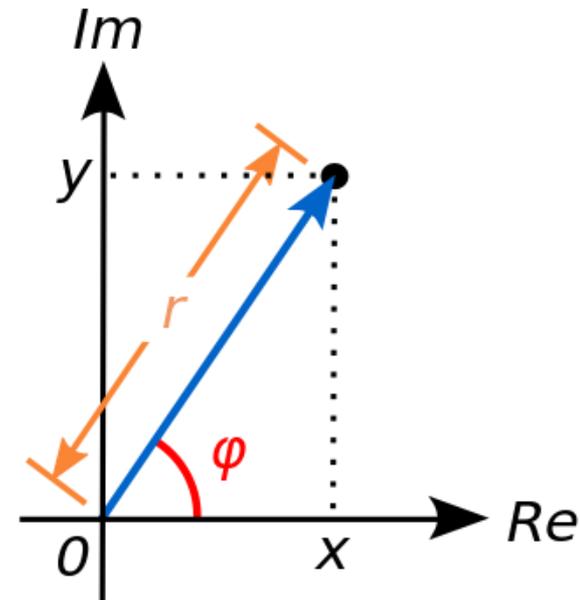
$$z = a + j \cdot b = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)$$

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

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

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

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



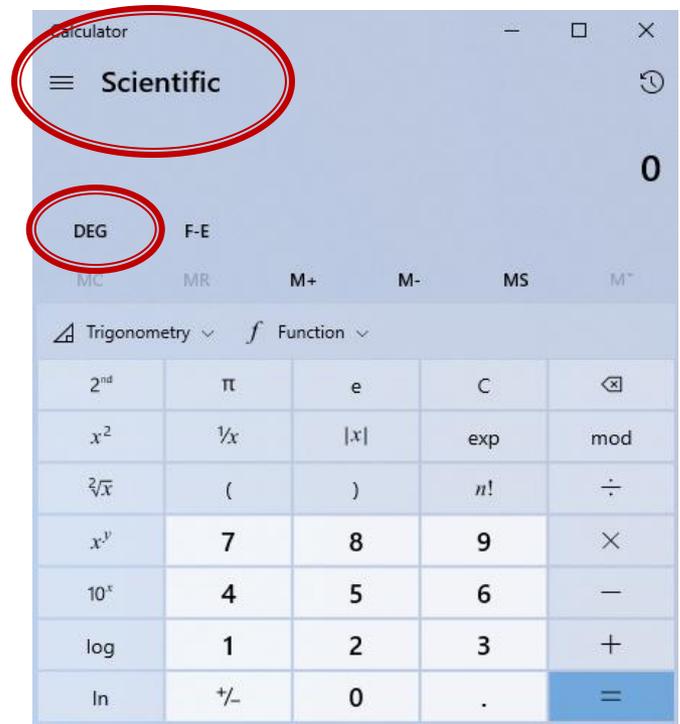
Reprezentare polara

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

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

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

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

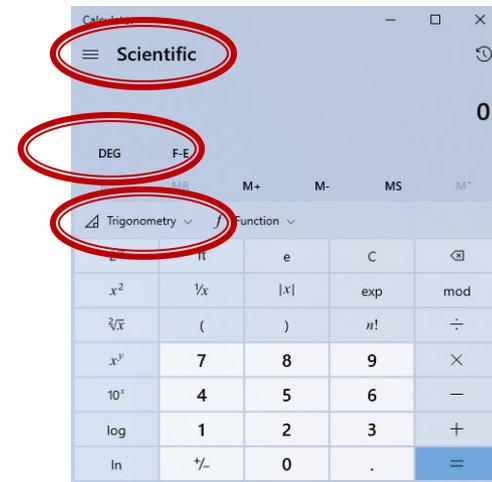
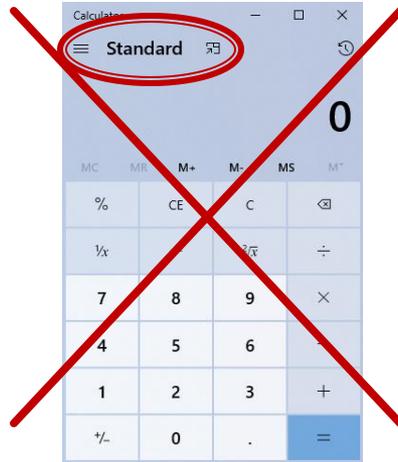


Reprezentare polara

- **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

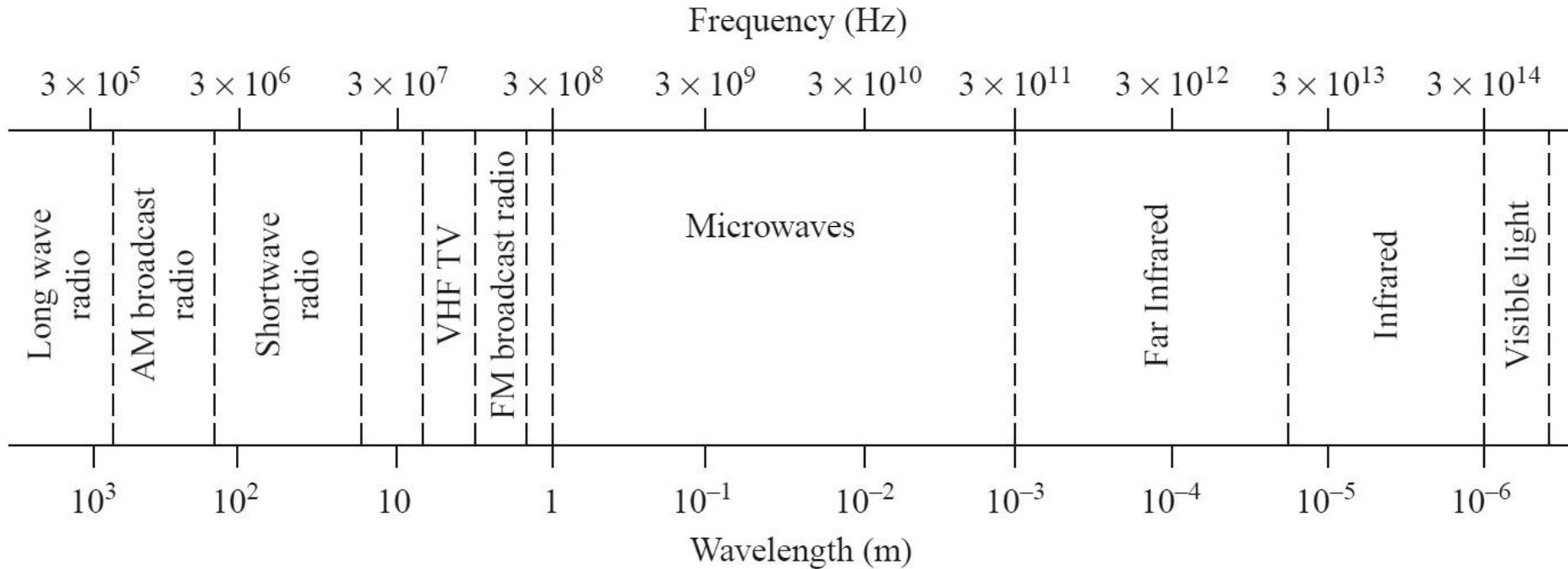
$$\varphi[^\circ] = 180^\circ \cdot \frac{\varphi[rad]}{\pi}$$

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



Introducere

Microunde



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

~ 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

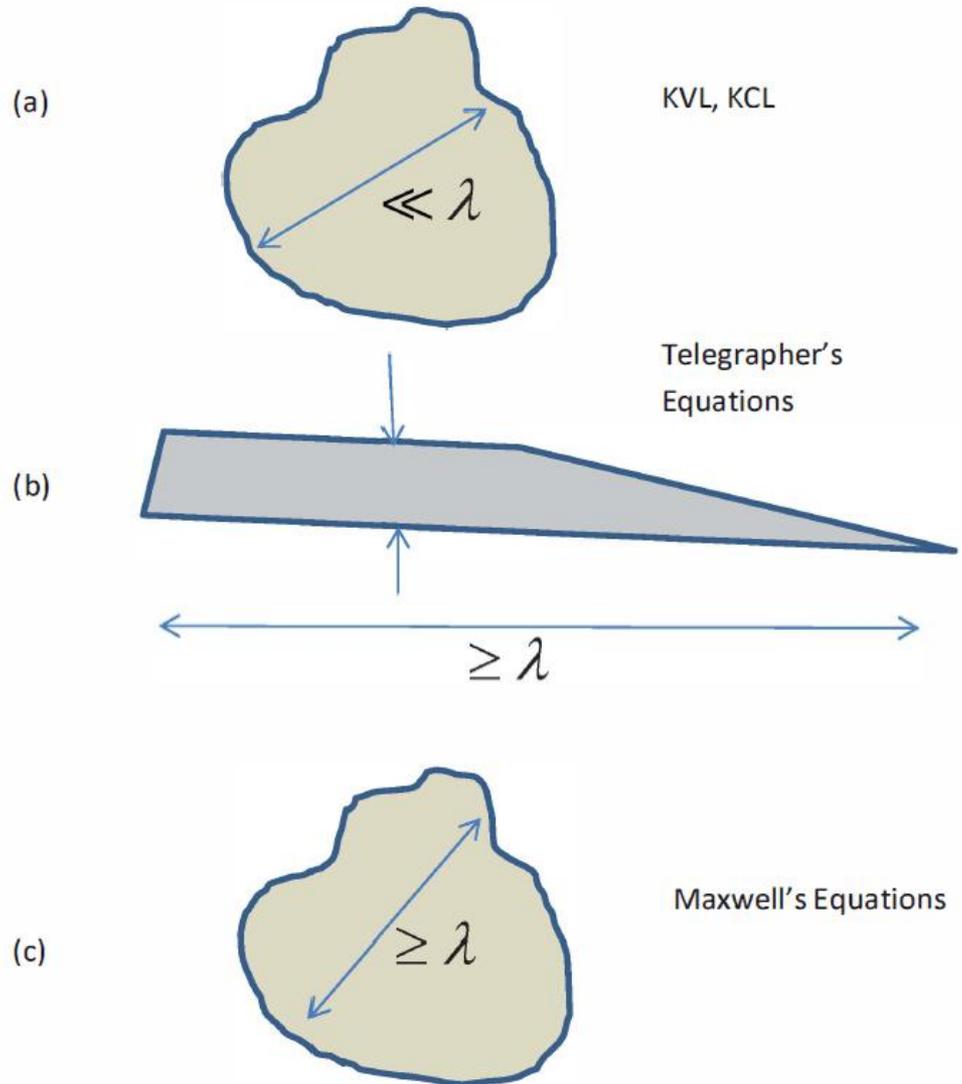
- Dependenta
 - castigul antenei
 - imaginea unui obiect pe radar

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

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

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

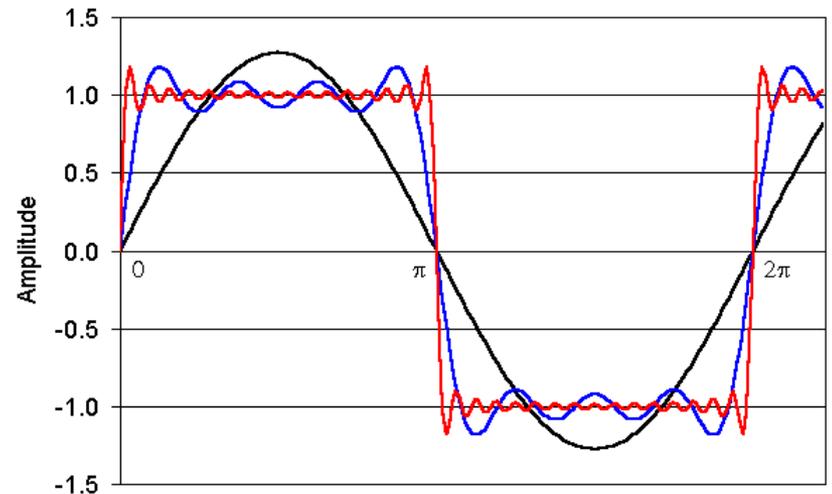
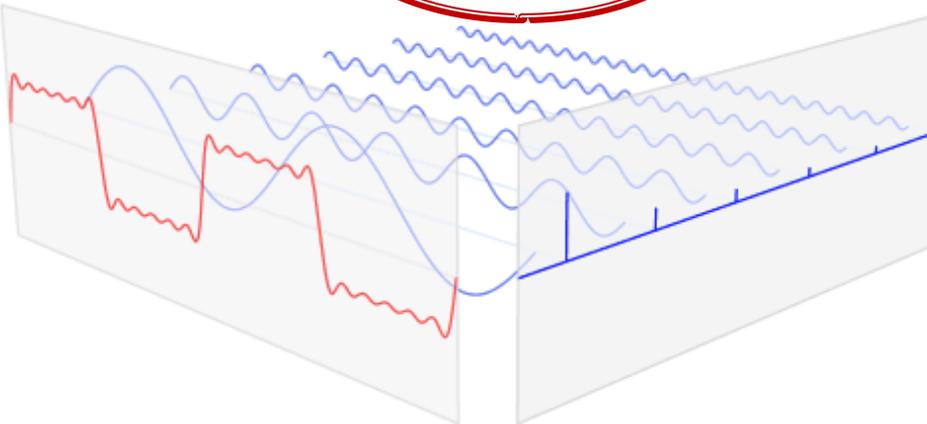
$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2,99790 \cdot 10^8 \text{ m/s}$$

Modele matematice

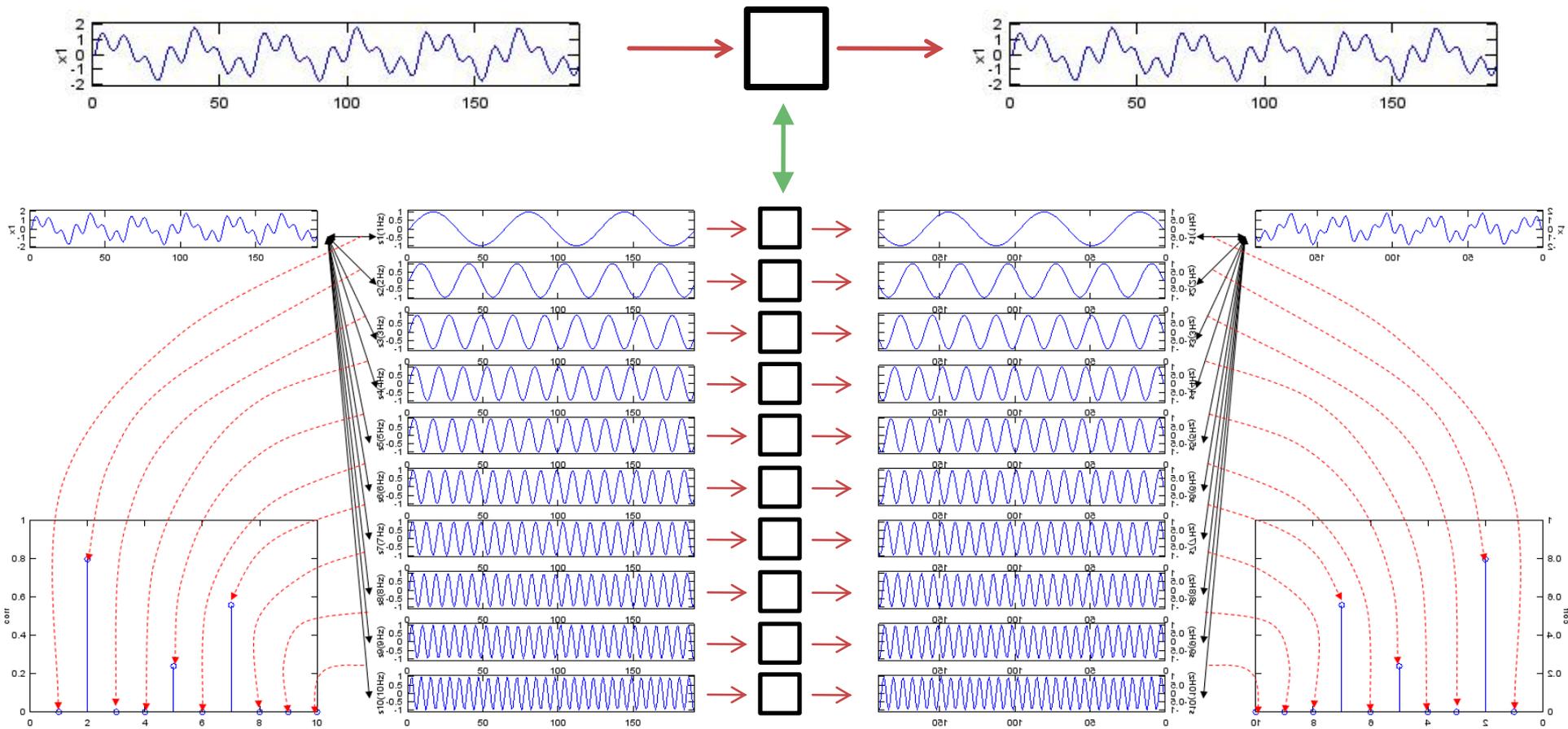
- cazuri particulare in care exista rezolvare analitica
 - semnale cu variație armonică în timp, transformata Fourier, spectru

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

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



Modele matematice

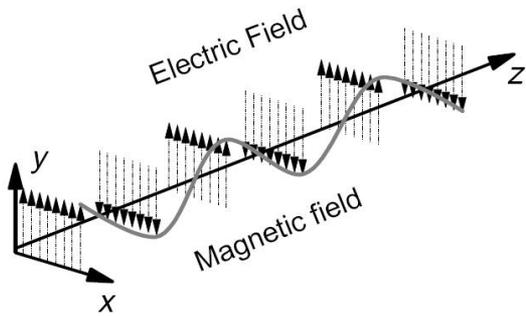


$$F(\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t} dt$$

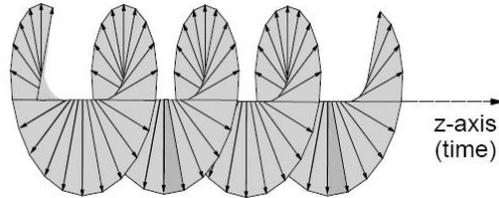
$$G(\omega)[F(\omega)]$$

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

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 $E_+ \Rightarrow A$

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

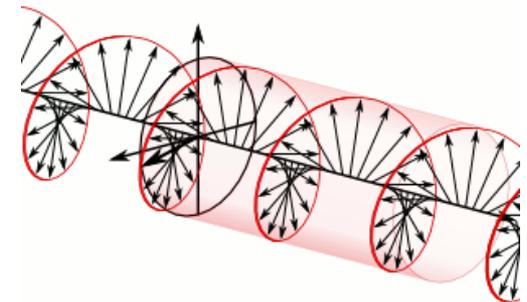
Camp armonic

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

Amplitudine

Atenuare

Propagare
(variatie in timp si spatiu)



Solutia ecuatiilor de propagare

$E_y = E^+ e^{-\gamma \cdot z} + E^- e^{\gamma \cdot z}$ Camp electric dupa directia Oy, ← prin alegere judicioasa
propagare dupa directia Oz ← a sistemului de referinta

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

- unda
 - incidenta
 - reflectata
- unda
 - directa
 - inversa

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

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

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

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

punctele
de faza
constanta:

Solutia ecuatiilor de propagare

- unda
 - incidenta
 - reflectata
- unda
 - directa
 - inversa

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

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

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

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

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

Modele matematice

- cazuri particulare in care exista rezolvare analitica

- Exista unda in o singura directie $E^+ (E^+), E^- (E^-)$

- unda

- incidenta

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

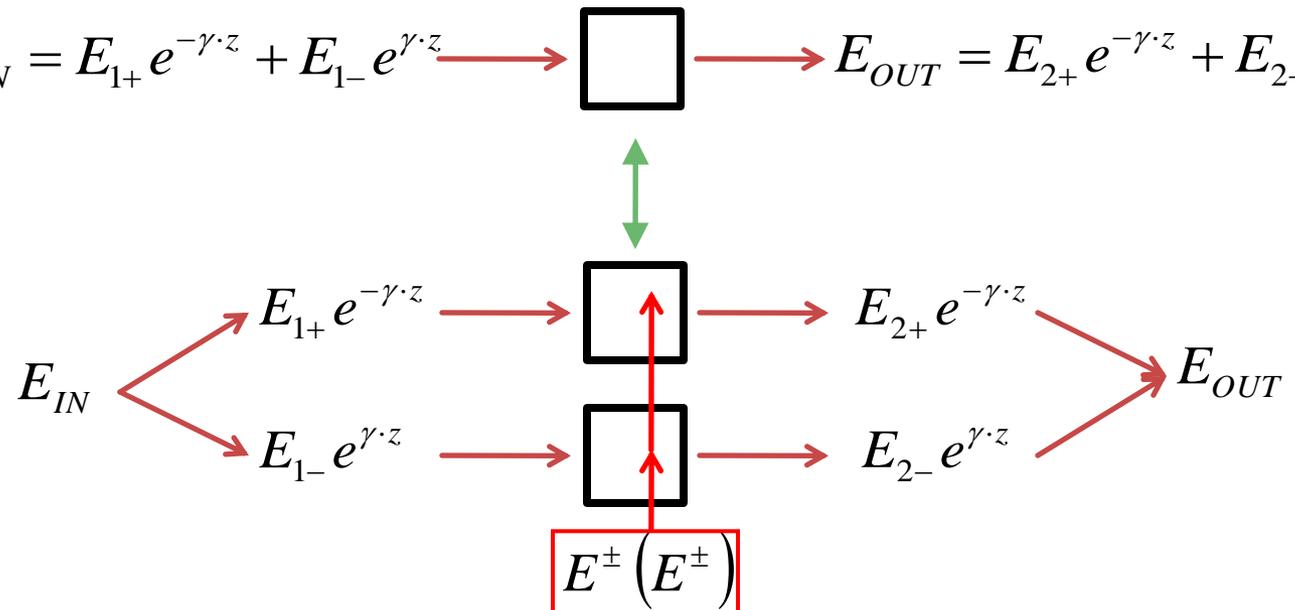
- reflectata

$$E_{IN} = E_{1+} e^{-\gamma \cdot z} + E_{1-} e^{\gamma \cdot z} \longrightarrow \square \longrightarrow E_{OUT} = E_{2+} e^{-\gamma \cdot z} + E_{2-} e^{\gamma \cdot z}$$

- unda

- directa

- inversa



Linii de transmisie in mod TEM

Cuprins

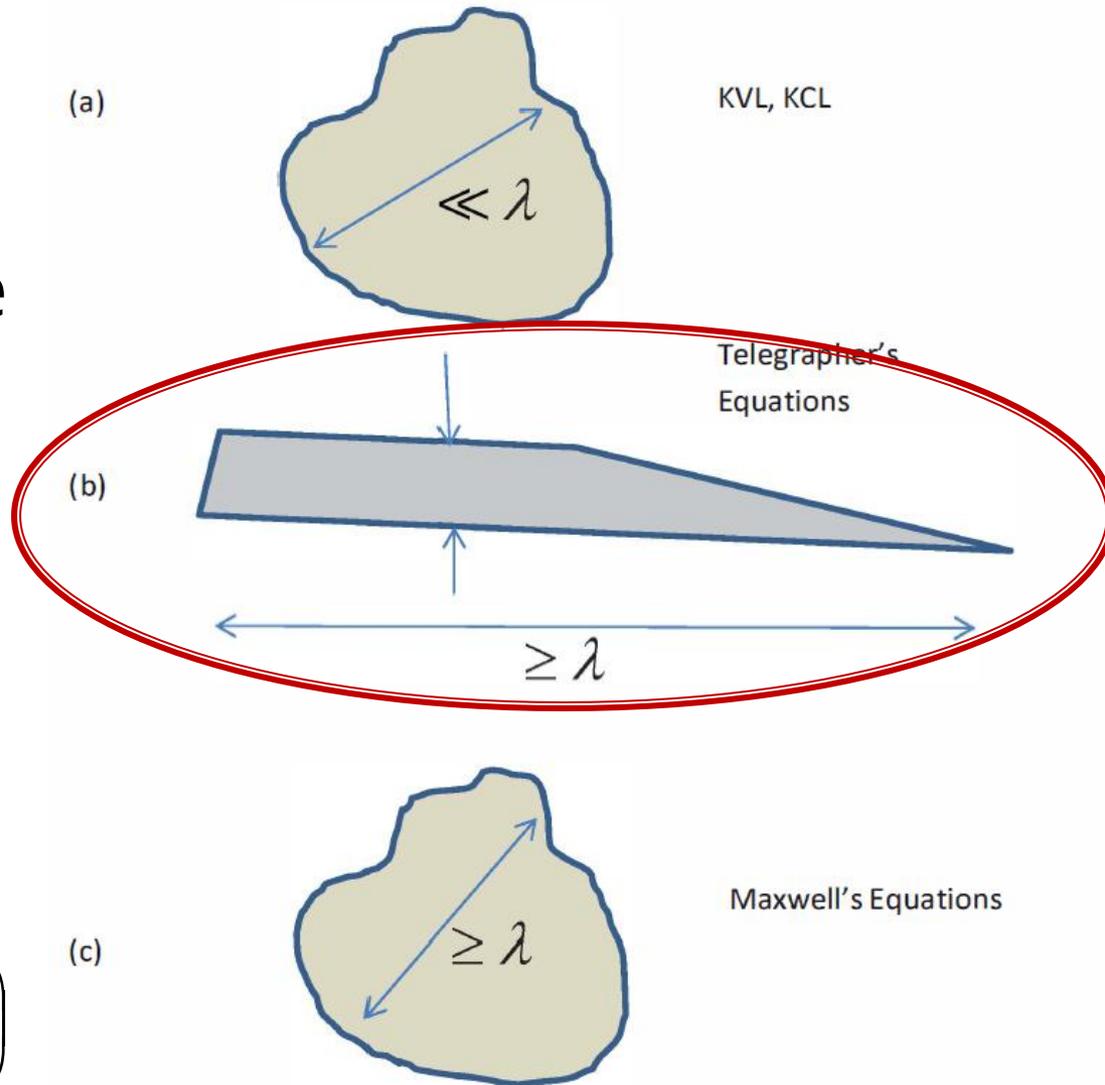
- **Linii de transmisie**
- **Adaptarea de impedanță**
- **Cuploare direcționale**
- **Divizoare de putere**
- **Amplificatoare de microunde**
- **Filtre de microunde**
- **Oscilatoare de microunde ?**

Lungime electrica

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

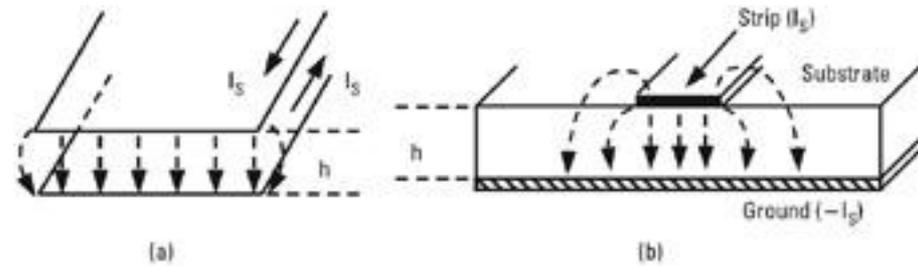
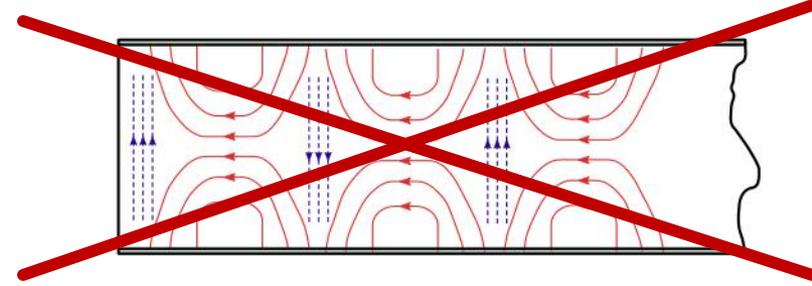
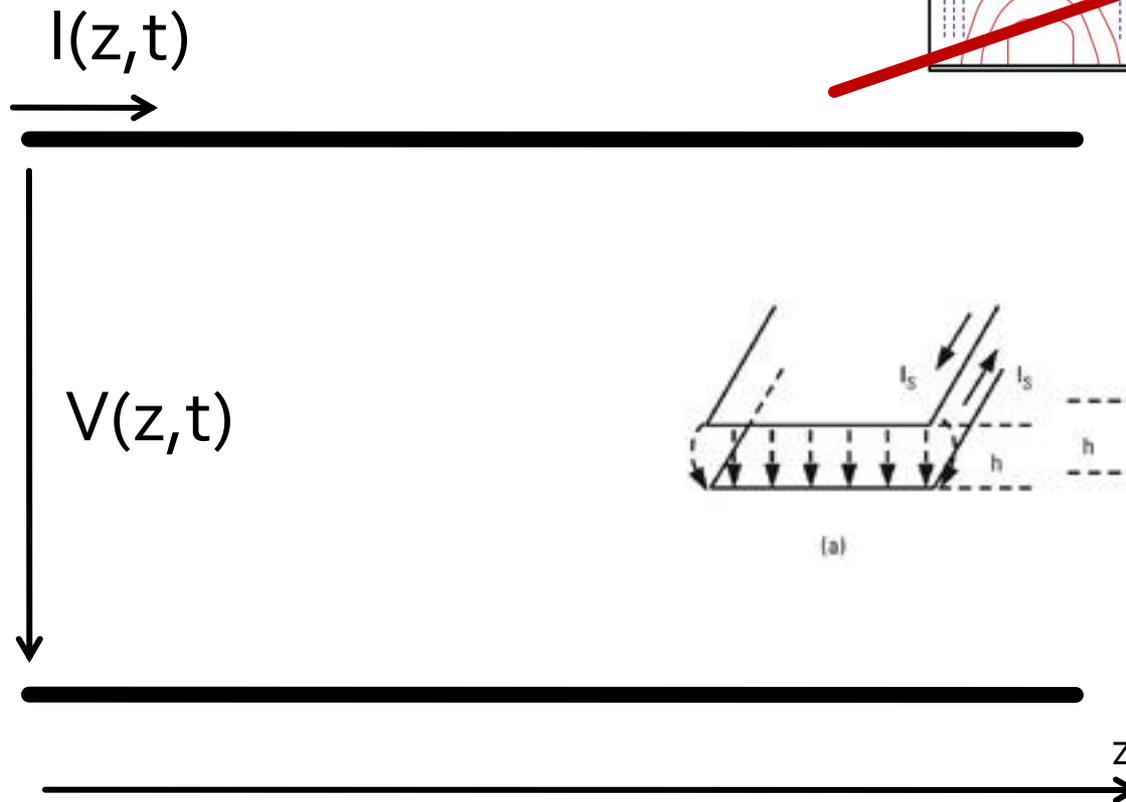
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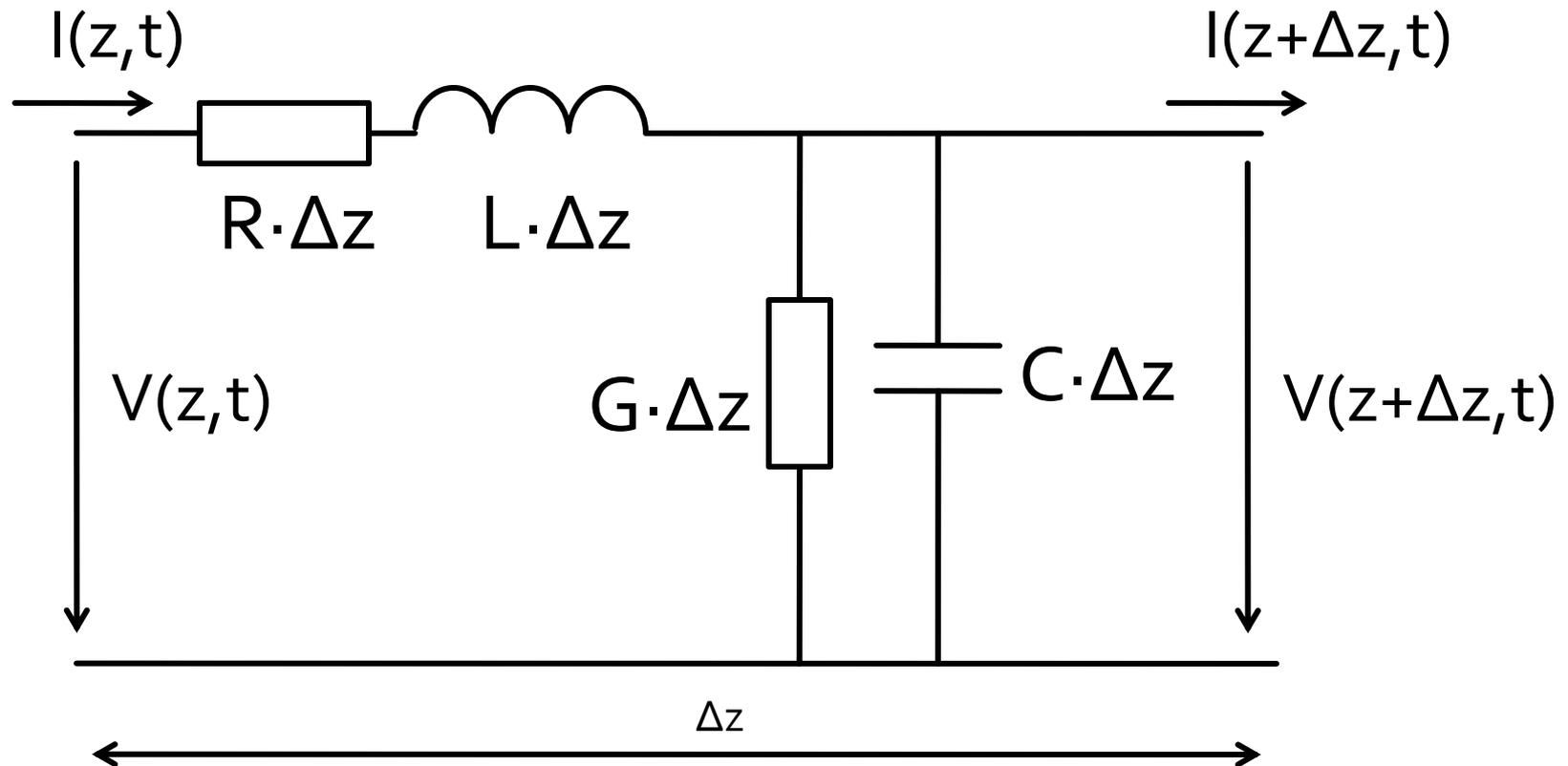
Linie de transmisie

- mod TEM, doi conductori



Linie de transmisie model echivalent

- mod TEM, doi conductori



Ecuatiile telegrafistilor

- domeniu timp

$$\frac{\partial v(z,t)}{\partial z} = -R \cdot i(z,t) - L \cdot \frac{\partial i(z,t)}{\partial t} \quad \text{K II}$$

$$\frac{\partial i(z,t)}{\partial z} = -G \cdot v(z,t) - C \cdot \frac{\partial v(z,t)}{\partial t} \quad \text{K I}$$

- semnale sinusoidale

$$\frac{dV(z)}{dz} = -(R + j \cdot \omega \cdot L) \cdot I(z)$$

$$\frac{dI(z)}{dz} = -(G + j \cdot \omega \cdot C) \cdot V(z)$$

$$\left/ \frac{d}{dz} (\dots) \right.$$

Rezolvare

$$\frac{d^2 V(z)}{dz^2} - \gamma^2 \cdot V(z) = 0$$

$$\frac{d^2 I(z)}{dz^2} - \gamma^2 \cdot I(z) = 0$$

$$\gamma = \alpha + j \cdot \beta = \sqrt{(R + j \cdot \omega \cdot L) \cdot (G + j \cdot \omega \cdot C)}$$


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

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

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

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

Solutiile

$$\left\{ \begin{array}{l} V(z) = V_0^+ e^{-\gamma \cdot z} + V_0^- e^{\gamma \cdot z} \\ I(z) = I_0^+ e^{-\gamma \cdot z} + I_0^- e^{\gamma \cdot z} \end{array} \right. \quad \gamma = \alpha + j \cdot \beta = \sqrt{(R + j \cdot \omega \cdot L) \cdot (G + j \cdot \omega \cdot C)}$$

$$V(z) = V_0^+ e^{-\gamma \cdot z} + V_0^- e^{\gamma \cdot z}$$

$$\frac{dV(z)}{dz} = -(R + j \cdot \omega \cdot L) \cdot I(z)$$

$$I(z) = \frac{\gamma}{R + j \cdot \omega \cdot L} (V_0^+ e^{-\gamma \cdot z} - V_0^- e^{\gamma \cdot z})$$

$$Z_0 \equiv \frac{R + j \cdot \omega \cdot L}{\gamma} = \sqrt{\frac{R + j \cdot \omega \cdot L}{G + j \cdot \omega \cdot C}}$$

- Impedanta caracteristica a liniei

$$\frac{V_0^+}{I_0^+} = Z_0 = -\frac{V_0^-}{I_0^-}$$

$$\lambda = \frac{2\pi}{\beta} \quad v_f = \frac{\omega}{\beta} = \lambda \cdot f$$

Linie fara pierderi

- **Fara pierderi:** $R=G=0$

$$\gamma = \alpha + j \cdot \beta = \sqrt{(R + j \cdot \omega \cdot L) \cdot (G + j \cdot \omega \cdot C)} = j \cdot \omega \cdot \sqrt{L \cdot C}$$

$$\alpha = 0 \quad ; \quad \beta = \omega \cdot \sqrt{L \cdot C}$$

$$Z_0 = \sqrt{\frac{R + j \cdot \omega \cdot L}{G + j \cdot \omega \cdot C}} = \sqrt{\frac{L}{C}} \quad \blacksquare \quad Z_0 \text{ real}$$

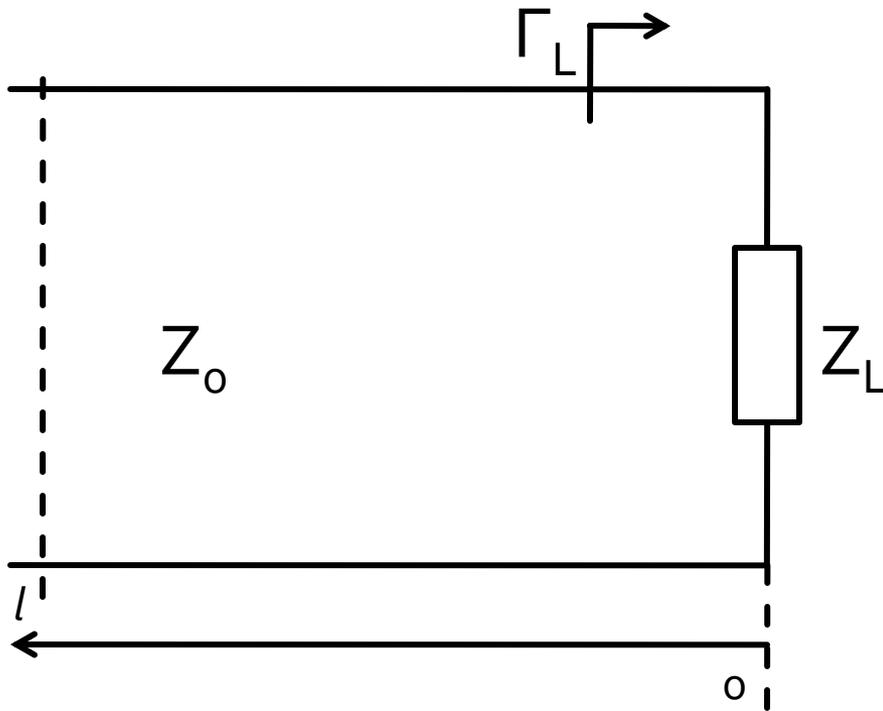
$$V(z) = V_0^+ e^{-j \cdot \beta \cdot z} + V_0^- e^{j \cdot \beta \cdot z}$$

$$I(z) = \frac{V_0^+}{Z_0} e^{-j \cdot \beta \cdot z} - \frac{V_0^-}{Z_0} e^{j \cdot \beta \cdot z}$$

$$\lambda = \frac{2\pi}{\omega \cdot \sqrt{LC}}$$

$$v_f = \frac{1}{\sqrt{LC}}$$

Linie fara pierderi



$$V(z) = V_0^+ e^{-j\beta \cdot z} + V_0^- e^{j\beta \cdot z}$$

$$I(z) = \frac{V_0^+}{Z_0} e^{-j\beta \cdot z} - \frac{V_0^-}{Z_0} e^{j\beta \cdot z}$$

$$Z_L = \frac{V(0)}{I(0)} \quad Z_L = \frac{V_0^+ + V_0^-}{V_0^+ - V_0^-} \cdot Z_0$$

- coeficient de reflexie in tensiune

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

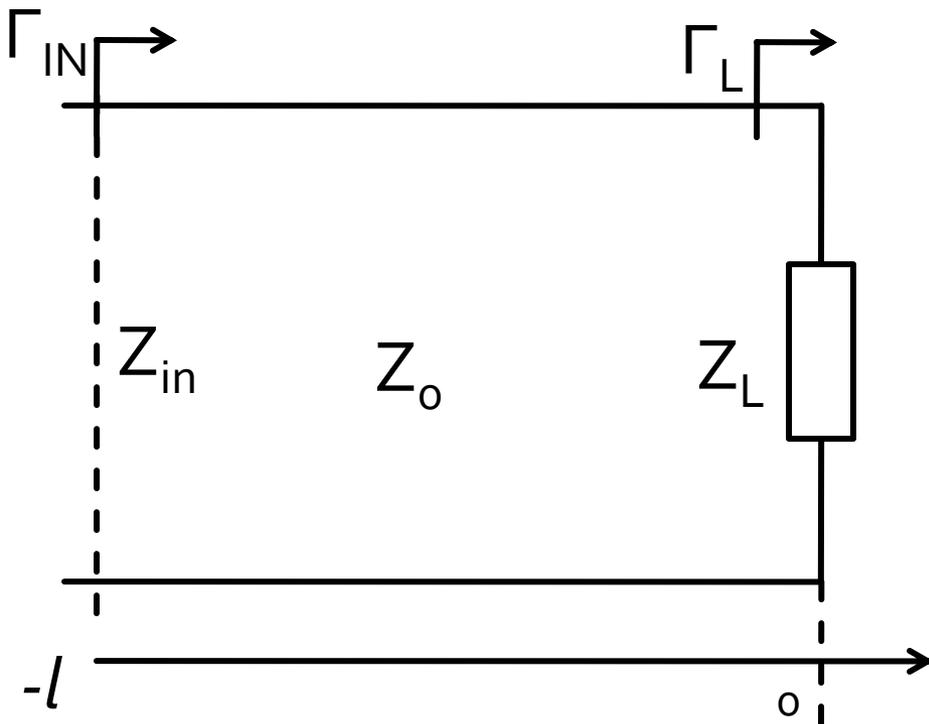
- Z_0 real

Linie fara pierderi

- coeficientul de reflexie la intrarea liniei

$$V(z) = V_0^+ e^{-j\beta \cdot z} + V_0^- e^{j\beta \cdot z}$$

$$\Gamma = \Gamma(z) = \frac{V_0^-(z)}{V_0^+(z)}$$



$$V(0) = V_0^+ + V_0^- \quad \Gamma(0) = \Gamma_L = \frac{V_0^-}{V_0^+}$$

$$V(-l) = V_0^+ e^{j\beta \cdot l} + V_0^- e^{-j\beta \cdot l}$$

$$\Gamma(-l) = \Gamma_{IN} = \frac{V_0^- \cdot e^{-j\beta \cdot l}}{V_0^+ \cdot e^{j\beta \cdot l}} = \Gamma(0) \cdot e^{-2j\beta \cdot l}$$

$$|\Gamma(-l)| = |\Gamma(0)| \cdot |e^{-2j\beta \cdot l}| = |\Gamma(0)|$$

$$\Gamma_{IN} = \Gamma_L \cdot e^{-2j\beta \cdot l}$$

$$|\Gamma_{IN}| = |\Gamma_L|$$

Linie fara pierderi

$$V(z) = V_0^+ \cdot (e^{-j\beta \cdot z} + \Gamma \cdot e^{j\beta \cdot z})$$

$$I(z) = \frac{V_0^+}{Z_0} \cdot (e^{-j\beta \cdot z} - \Gamma \cdot e^{j\beta \cdot z})$$

■ Puterea medie

$$P_{avg} = \frac{1}{2} \cdot \text{Re}\{V(z) \cdot I(z)^*\} = \frac{1}{2} \cdot \frac{|V_0^+|^2}{Z_0} \cdot \text{Re}\left\{1 - \Gamma^* \cdot \underbrace{e^{-2j\beta \cdot z} + \Gamma \cdot e^{2j\beta \cdot z}}_{(z - z^*) = \text{Im}} - |\Gamma|^2\right\}$$

$$P_{avg} = \frac{1}{2} \cdot \frac{|V_0^+|^2}{Z_0} \cdot (1 - |\Gamma|^2)$$

- Puterea transmisa sarcinii = Puterea incidenta - Puterea "reflectata"

- Return Loss [dB]

$$\text{RL} = -20 \cdot \log|\Gamma| \quad [\text{dB}]$$

Reprezentare polara

■ Formula lui Euler

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

■ Reprezentare polara

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

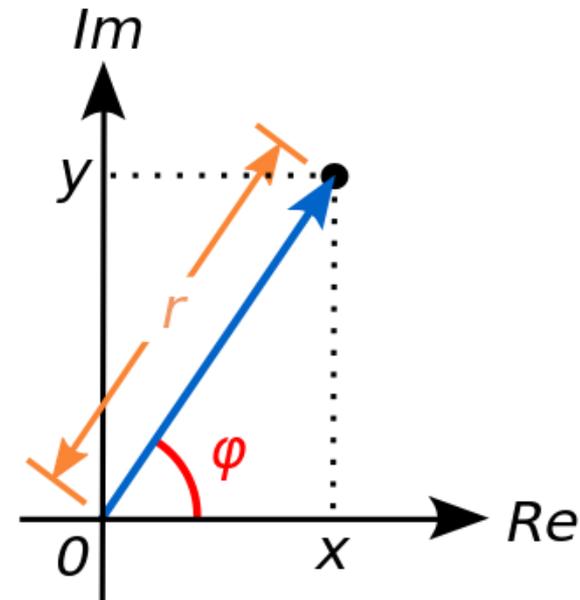
$$z = a + j \cdot b = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)$$

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

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

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

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



Reprezentare polara

- Formula lui Euler

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

$$e^{j \cdot x} + e^{-j \cdot x} = \cos x + j \cdot \sin x + \cos(-x) + j \cdot \sin(-x)$$

$$e^{j \cdot x} + e^{-j \cdot x} = \cos x + j \cdot \sin x + \cos x - j \cdot \sin x = 2 \cdot \cos x$$

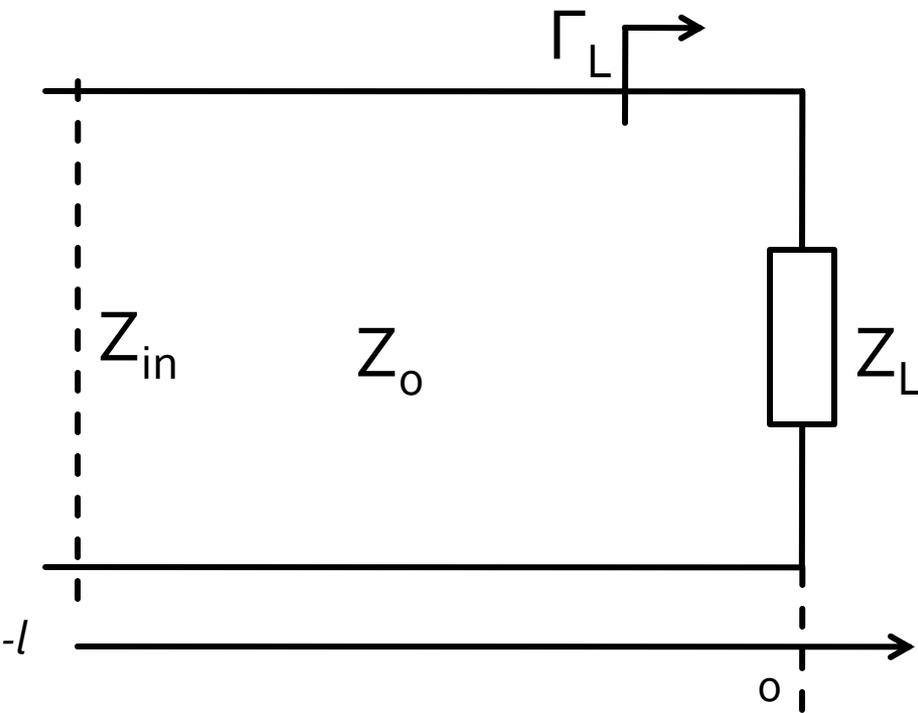

$$\cos x = \frac{e^{j \cdot x} + e^{-j \cdot x}}{2}$$

$$e^{j \cdot x} - e^{-j \cdot x} = \cos x + j \cdot \sin x - \cos(-x) - j \cdot \sin(-x)$$

$$e^{j \cdot x} - e^{-j \cdot x} = \cos x + j \cdot \sin x - \cos x + j \cdot \sin x = 2j \cdot \sin x$$


$$\sin x = \frac{e^{j \cdot x} - e^{-j \cdot x}}{2j}$$

Linie fara pierderi



$$V(-l) = V_0^+ e^{j\beta \cdot l} + V_0^- e^{-j\beta \cdot l}$$

$$I(-l) = \frac{V_0^+}{Z_0} e^{j\beta \cdot l} - \frac{V_0^-}{Z_0} e^{-j\beta \cdot l}$$

$$Z_{in} = \frac{V(-l)}{I(-l)} \quad Z_{in} = Z_0 \cdot \frac{1 + \Gamma \cdot e^{-2j\beta \cdot l}}{1 - \Gamma \cdot e^{-2j\beta \cdot l}}$$

- impedanta la intrarea liniei

$$Z_{in} = Z_0 \cdot \frac{(Z_L + Z_0) \cdot e^{j\beta \cdot l} + (Z_L - Z_0) \cdot e^{-j\beta \cdot l}}{(Z_L + Z_0) \cdot e^{j\beta \cdot l} - (Z_L - Z_0) \cdot e^{-j\beta \cdot l}}$$

$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan(\beta \cdot l)}{Z_0 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$

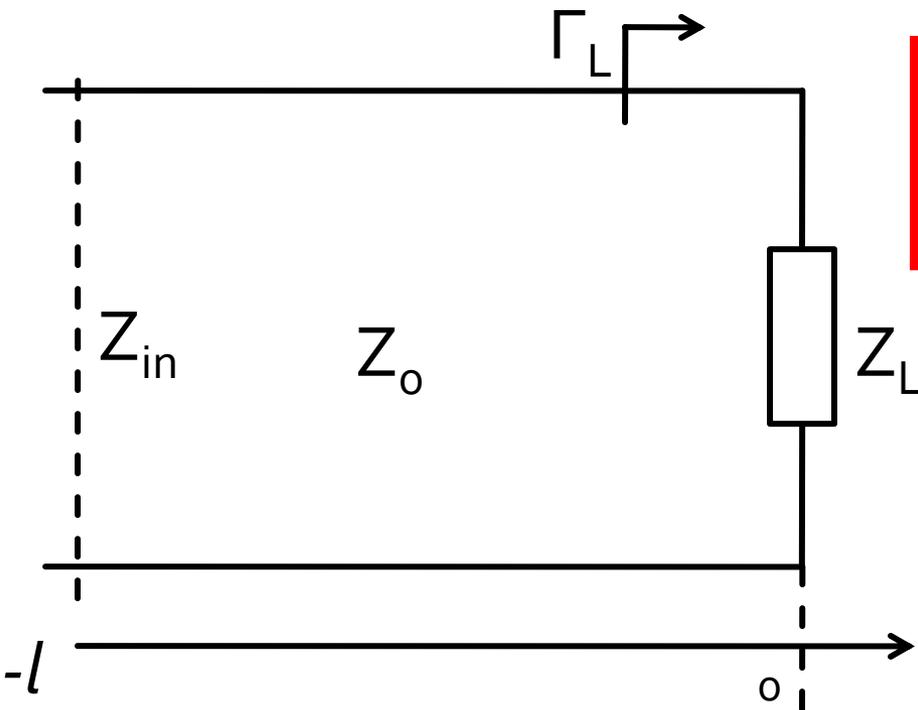
Linie fara pierderi

- impedanta la intrarea liniei

$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Linie fara pierderi

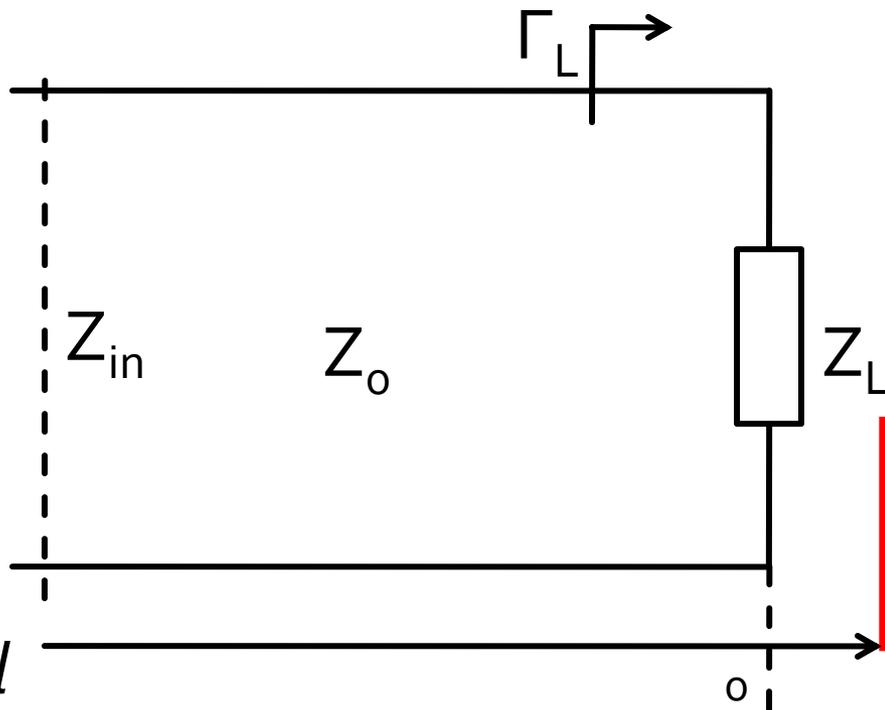
- impedanta la intrarea liniei de impedanta caracteristica Z_0 , de lungime l , terminata cu impedanta Z_L



$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Linie fara pierderi

- relatia este **dependenta de frecventa** prin valoarea $\beta \cdot l$



$$v_f = \frac{\omega}{\beta} = \lambda \cdot f \quad \lambda = \frac{2\pi}{\beta}$$
$$\beta \cdot l = \frac{2\pi}{\lambda} \cdot l = \frac{2\pi \cdot f}{v_f} \cdot l = \frac{2\pi \cdot l}{v_f} \cdot f$$

dependenta de frecventa este **periodica**,
impusa de functia tangenta

$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

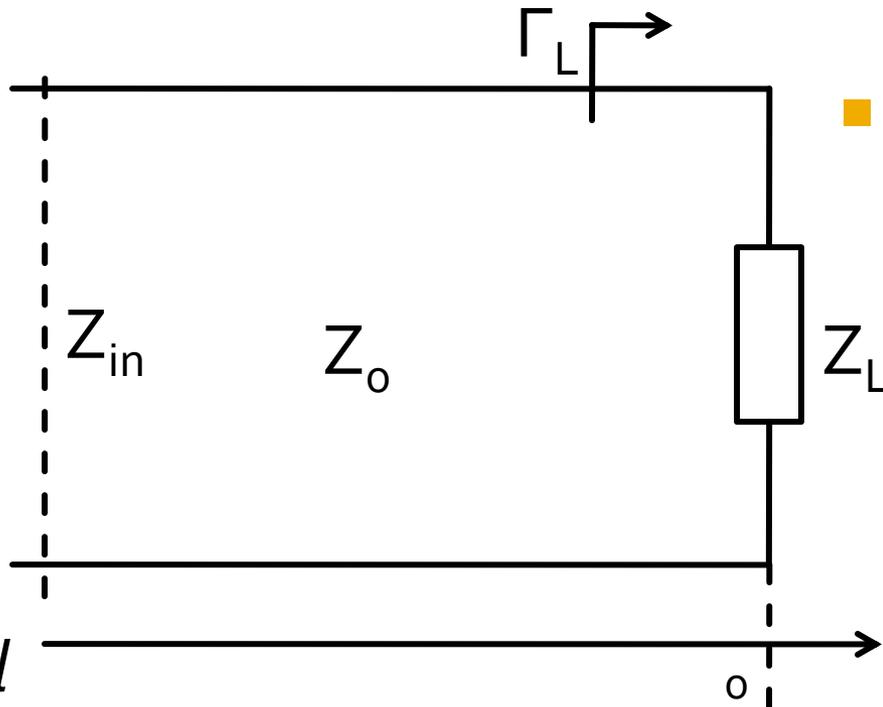
Linie fara pierderi, cazuri particulare

- $l = k \cdot \lambda / 2$ $\beta \cdot l = \frac{2\pi}{\lambda} \cdot l = k \cdot \pi$ $\tan \beta \cdot l = 0$

$$Z_{in} = Z_L$$

- $l = \lambda / 4 + k \cdot \lambda / 2$ $\tan \beta \cdot l \rightarrow \infty$

$$Z_{in} = \frac{Z_0^2}{Z_L}$$



- Transformatorul in sfert de lungime de unda

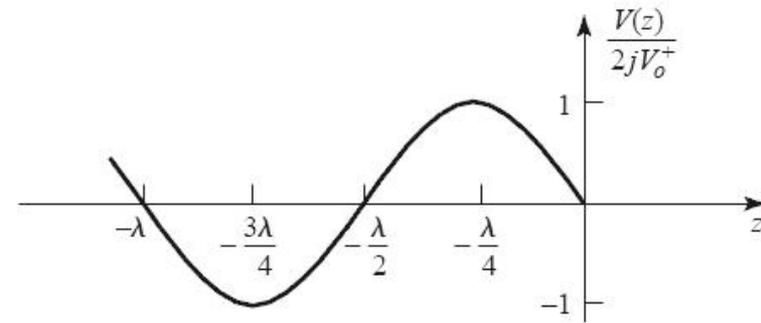
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Linie in scurtcircuit

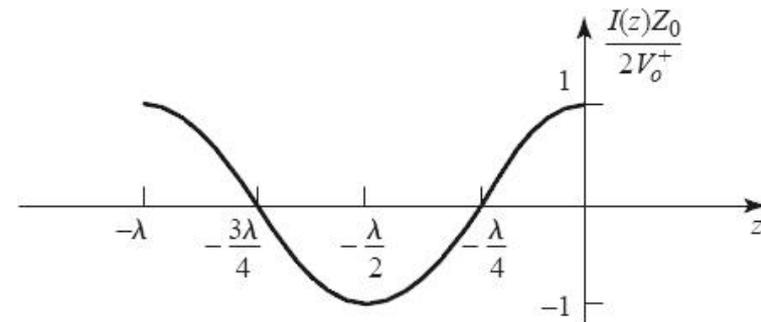
- $Z_L = 0$
- reactanța pură
 - +/- → in funcție de l

$$Z_{in} = j \cdot Z_0 \cdot \tan \beta \cdot l$$

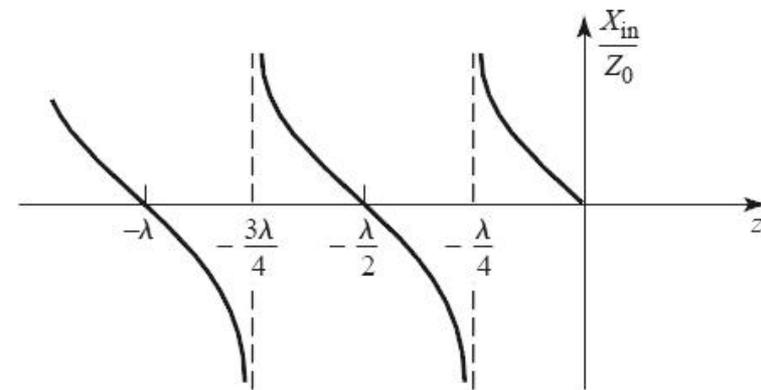
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan(\beta \cdot l)}{Z_0 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$



(a)



(b)



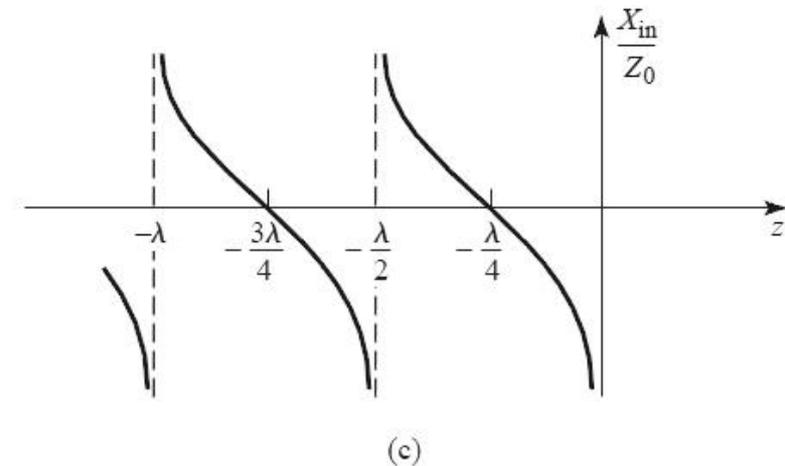
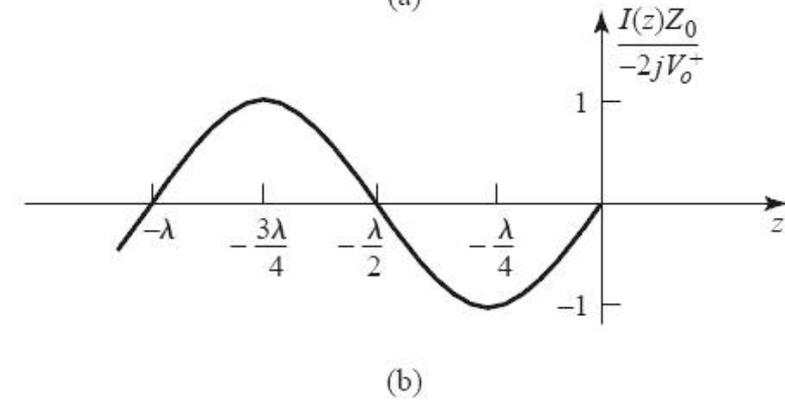
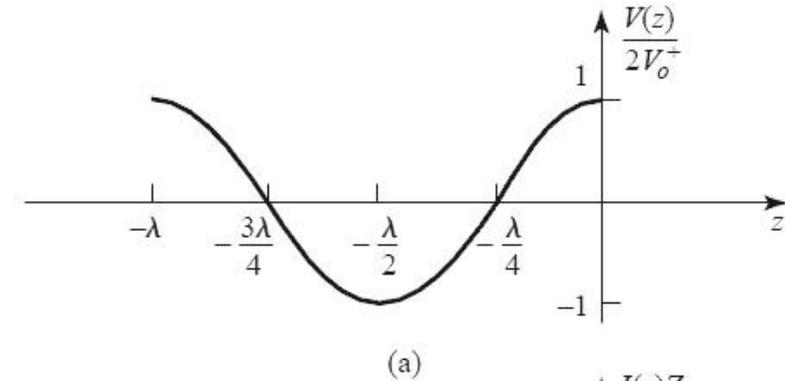
(c)

Linie in gol

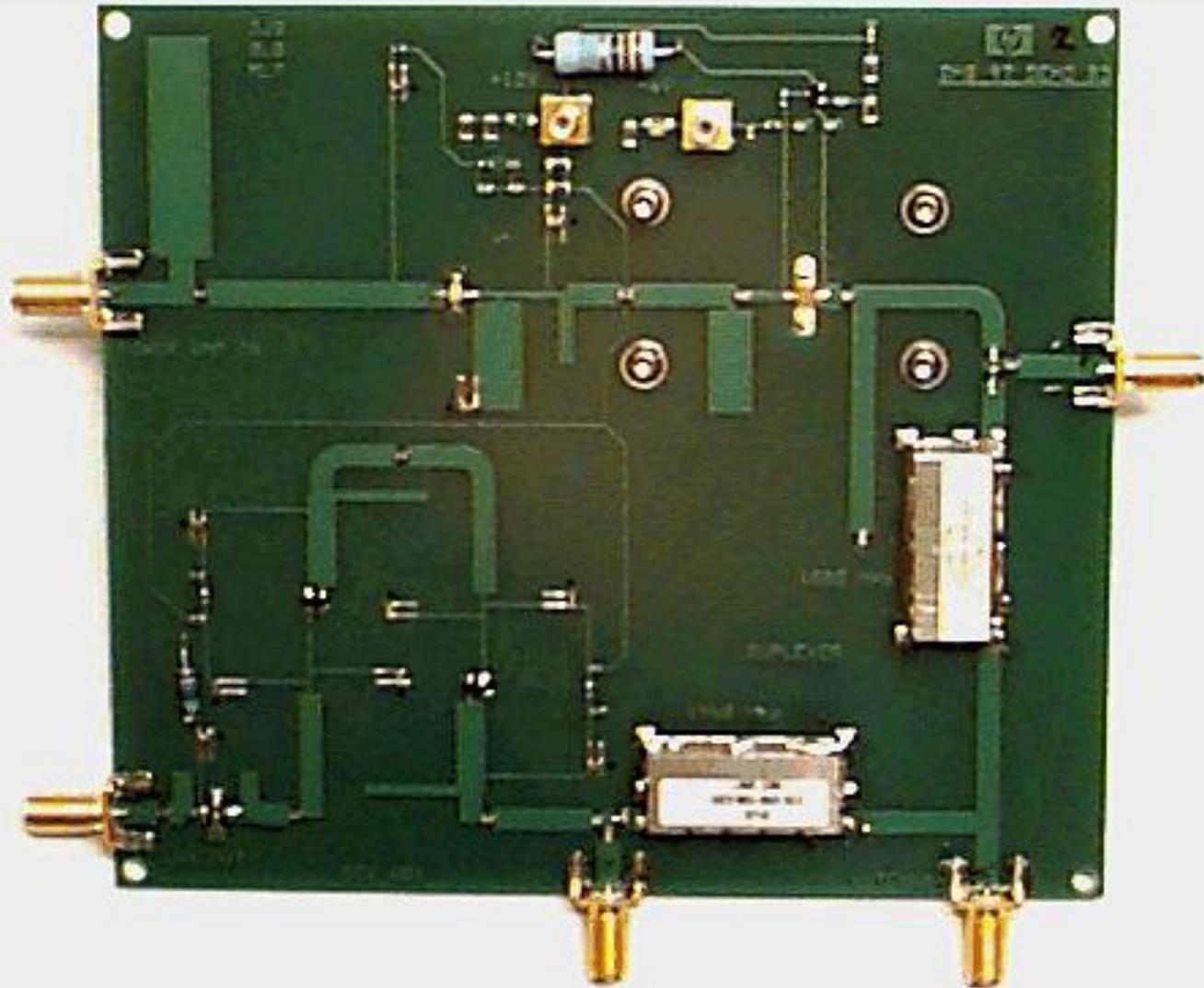
- $Z_L = \infty \rightarrow 1/Z_L = 0$
- reactanța pură
 - +/- \rightarrow în funcție de l

$$Z_{in} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

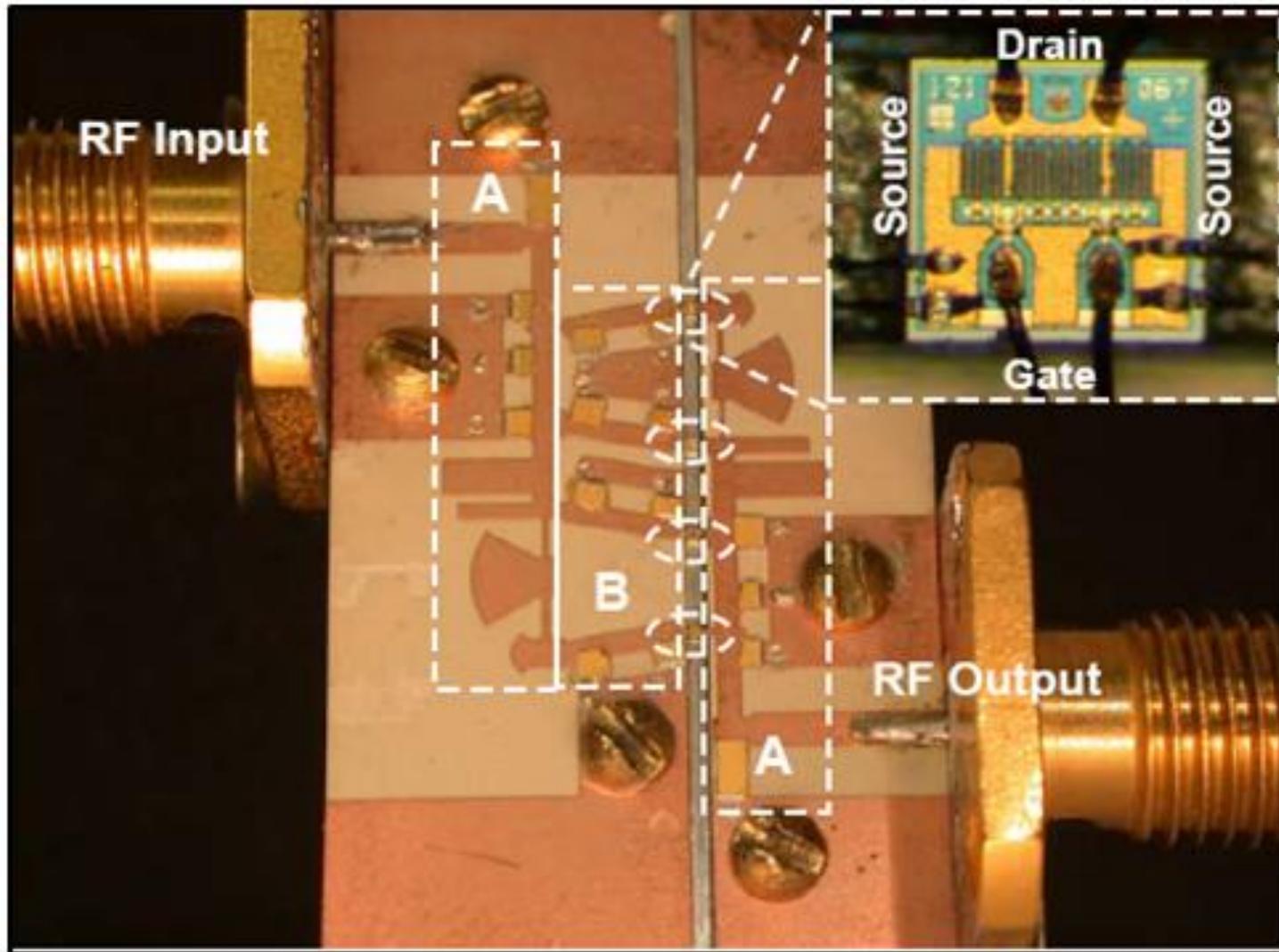
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan(\beta \cdot l)}{Z_0 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$



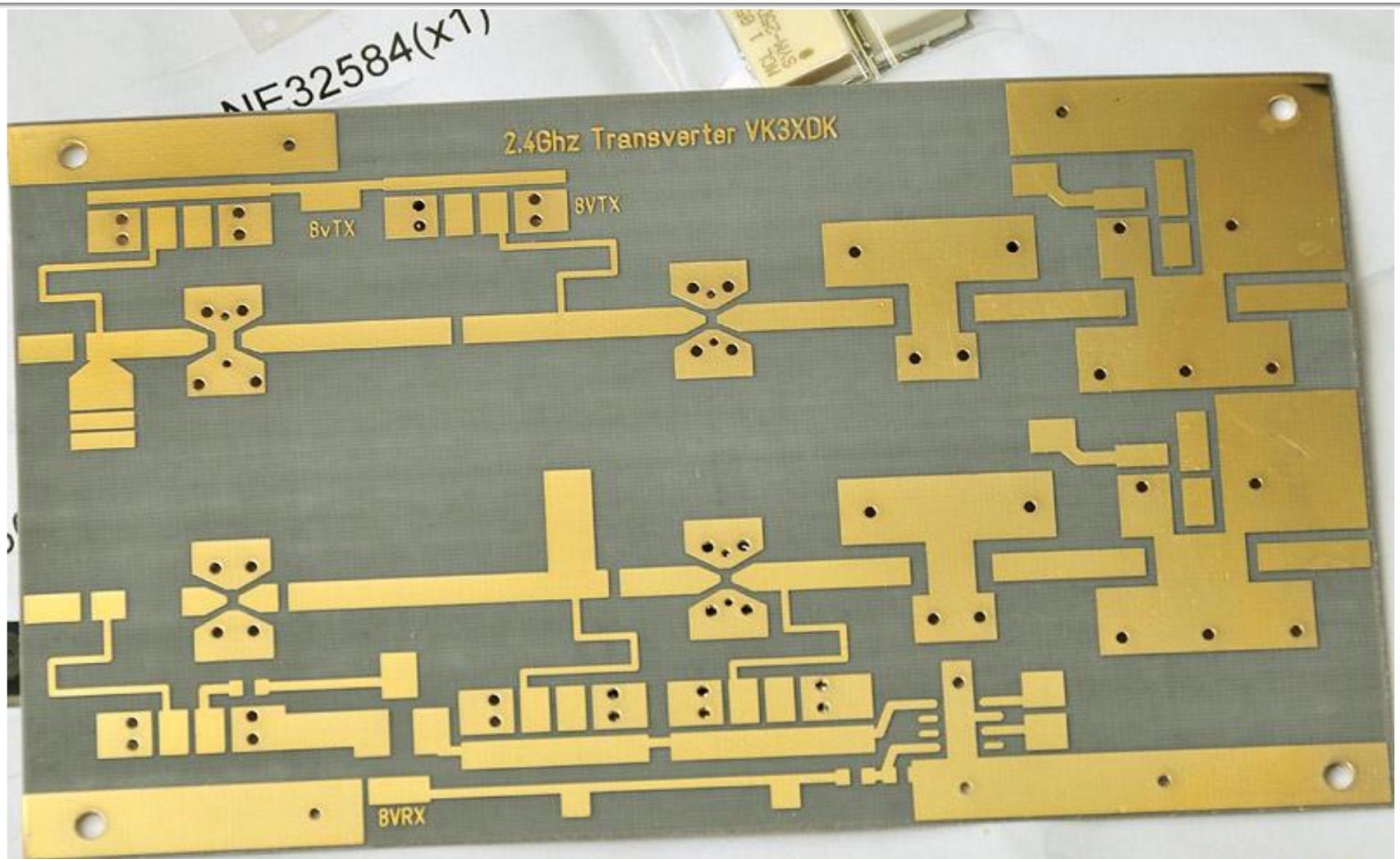
Exemple



Example

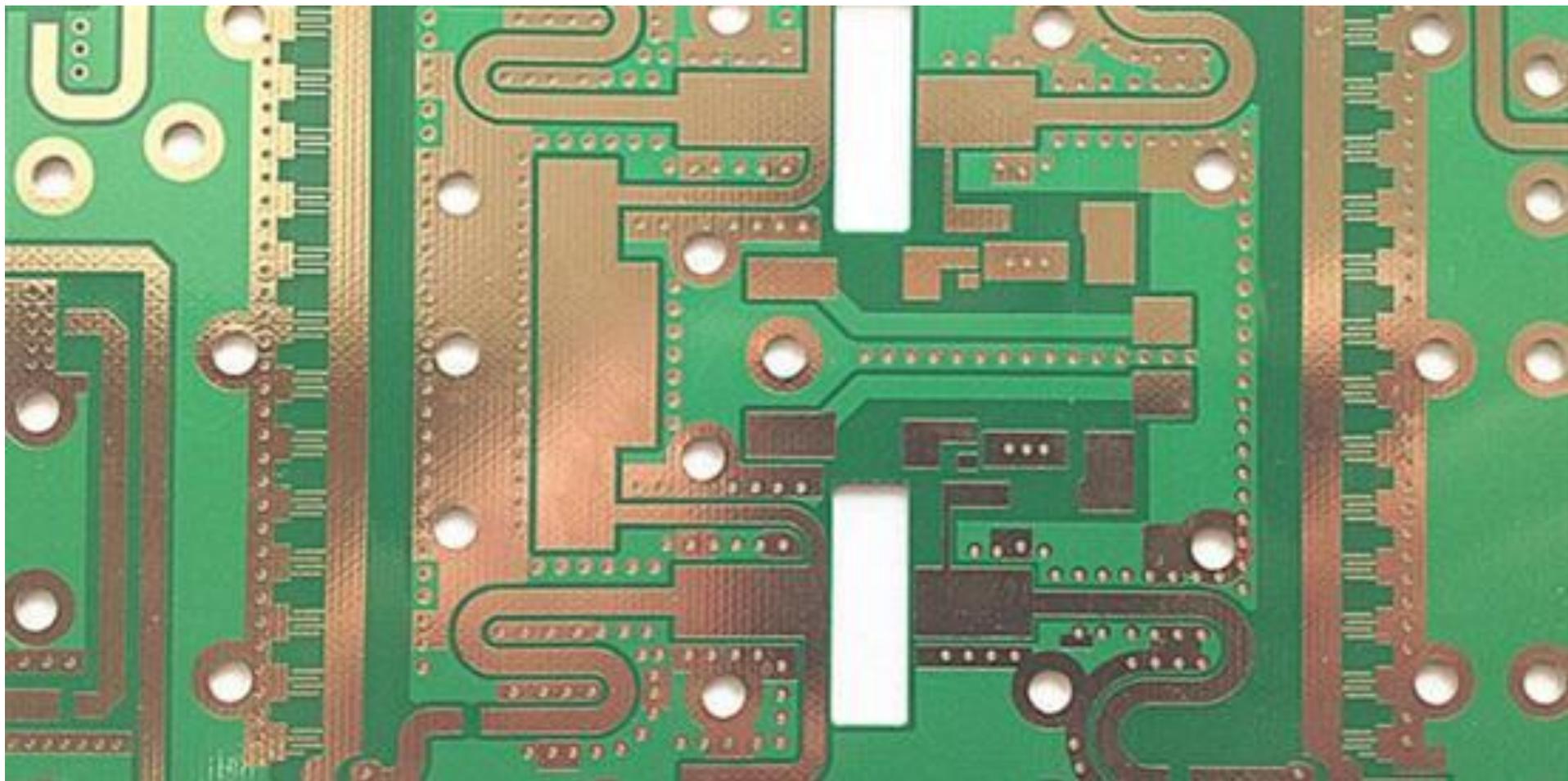


Exemple

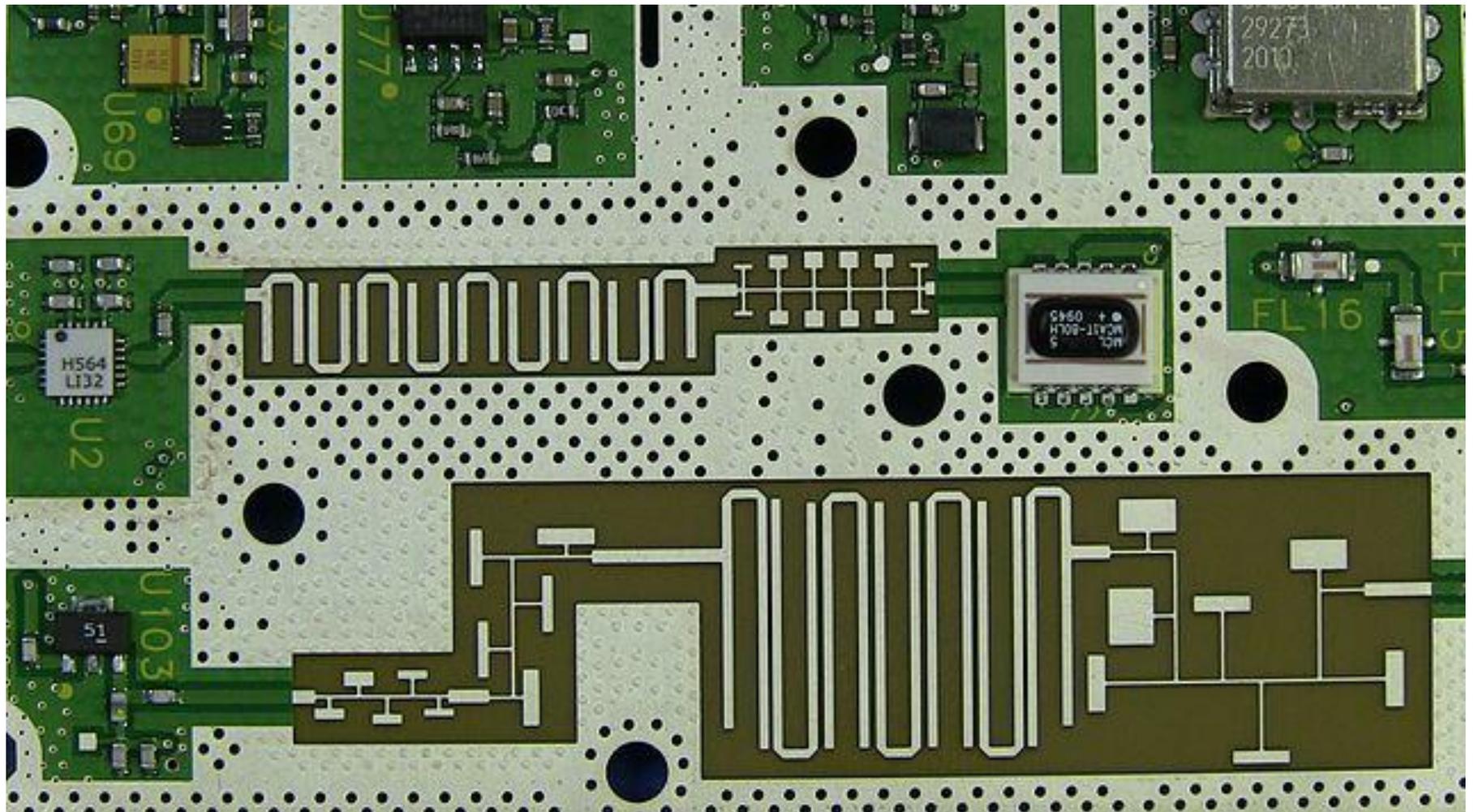


VK4CP

Exemple



Exemple



Factor de unda stationara

$$V(z) = V_0^+ \cdot (e^{-j\beta \cdot z} + \Gamma \cdot e^{j\beta \cdot z}) \quad |V(z)| = |V_0^+| \cdot |e^{-j\beta \cdot z}| \cdot |1 + \Gamma \cdot e^{2j\beta \cdot z}| \quad \Gamma = |\Gamma| \cdot e^{j\theta}$$

$$|V(z)| = |V_0^+| \cdot |1 + |\Gamma| \cdot e^{\theta + 2j\beta \cdot z}|$$

amplitudine maxima pentru $e^{\theta + 2j\beta \cdot z} = 1$ $V_{\max} = |V_0^+| \cdot (1 + |\Gamma|)$

amplitudine minima pentru $e^{\theta + 2j\beta \cdot z} = -1$ $V_{\min} = |V_0^+| \cdot (1 - |\Gamma|)$

- se definește factorul de unda stationara

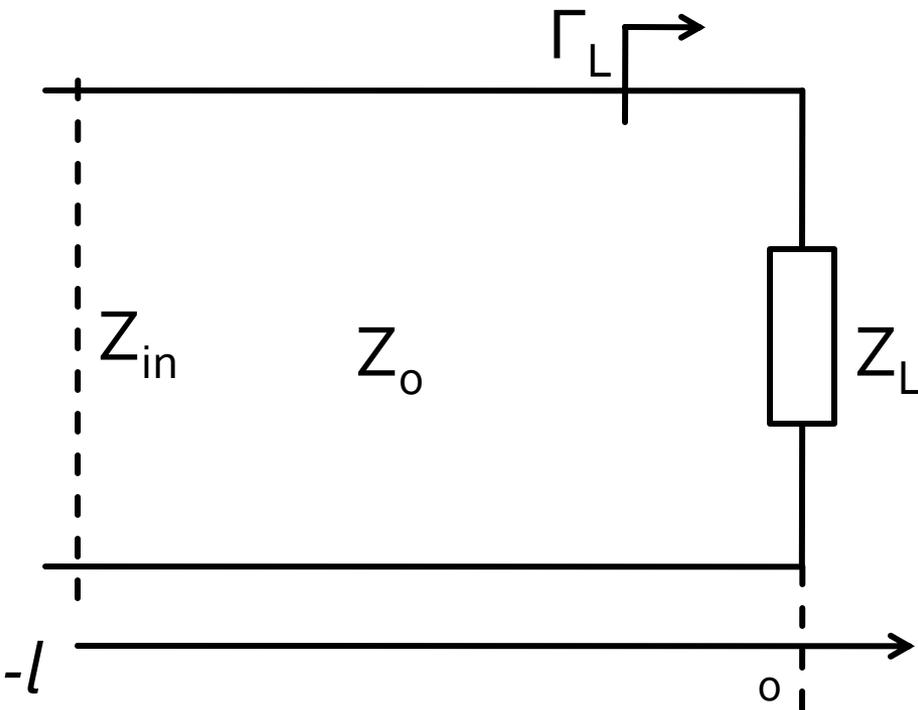
- (Voltage) Standing Wave Ratio

$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

- număr real $1 \leq VSWR < \infty$

- o măsură a dezadaptării (SWR = 1 semnifică adaptare)

Linie fara pierderi +/-



$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

$$V(z) = V_0^+ e^{-\gamma \cdot z} + V_0^- e^{\gamma \cdot z}$$

$$I(z) = I_0^+ e^{-\gamma \cdot z} + I_0^- e^{\gamma \cdot z}$$

$$\Gamma(-l) = \Gamma(0) \cdot e^{-2j \cdot \beta \cdot l}$$

$$\Gamma_{in} = \Gamma_L \cdot e^{-2j \cdot \beta \cdot l}$$

Laborator 1

2021/2022

Dispozitive și circuite de microunde pentru radiocomunicații

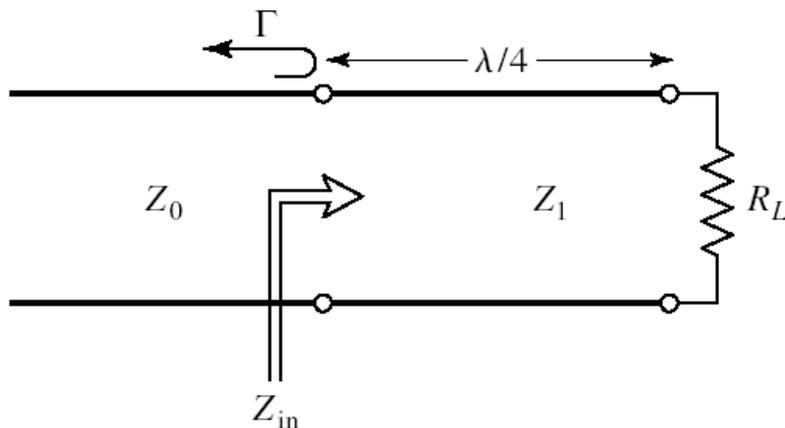
Scurta teorie

Adaptare de impedanta

- Adaptarea de impedanta este necesara atunci cand are loc o variatie in salt a impedantei/impedantei caracteristice
- Se caracterizeaza prin valoarea coeficientului de reflexie (Γ)
 - $|\Gamma|=0$ adaptare perfecta
 - $|\Gamma|\approx 0, |\Gamma|<\Gamma_{\max}$ adaptare "suficienta"
- in simulare $|\Gamma|=|S_{11}|$

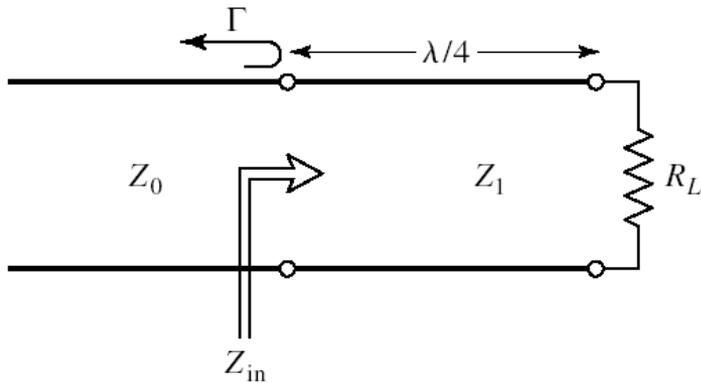
Transformatorul in sfert de lungime de unda

- Feed line – linie de intrare cu impedanta caracteristica Z_0
- Sarcina cu impedanta (**rezistiva!**) R_L
- Dorim adaptarea sarcinei la fider cu o linie de lungime $\lambda/4$ si impedanta caracteristica Z_1



$$\Gamma_{in} = 0 \Rightarrow Z_1 = \sqrt{Z_0 R_L}$$

Transformatorul in sfert de lungime de unda



$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

$$\beta \cdot l = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4} = \frac{\pi}{2}$$

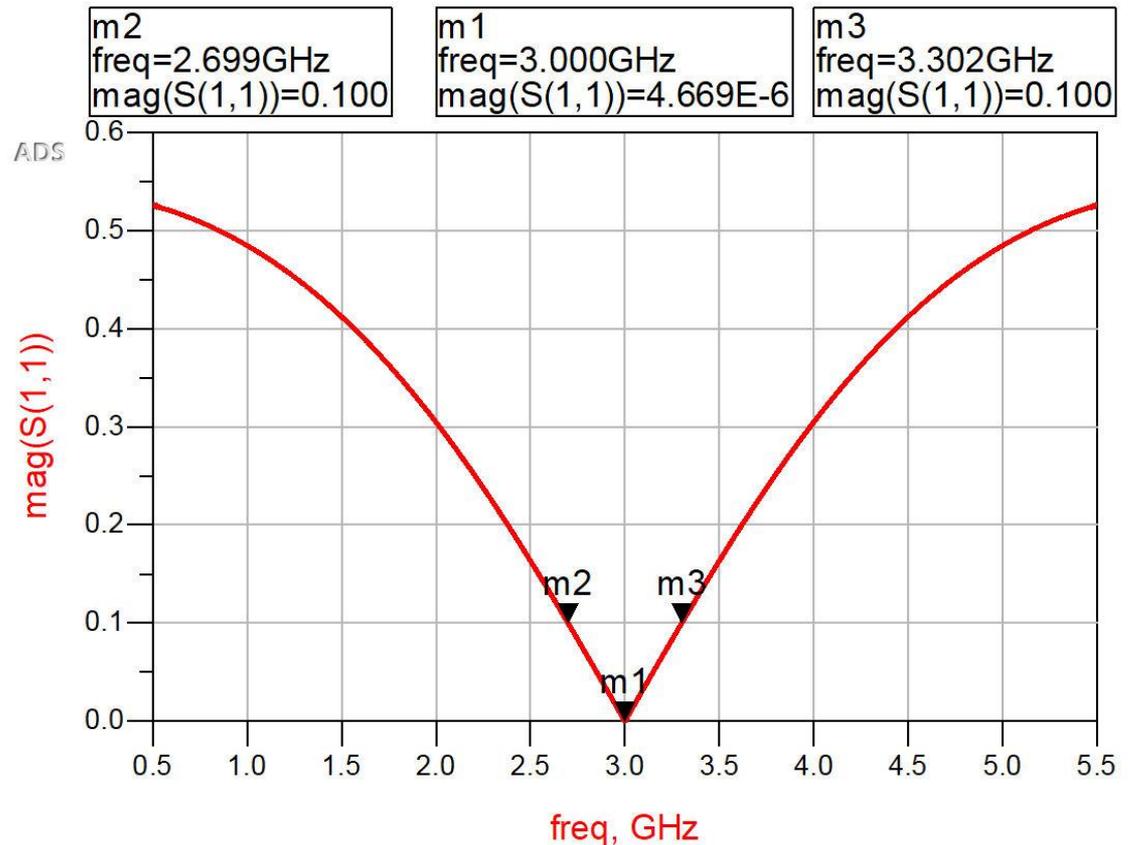
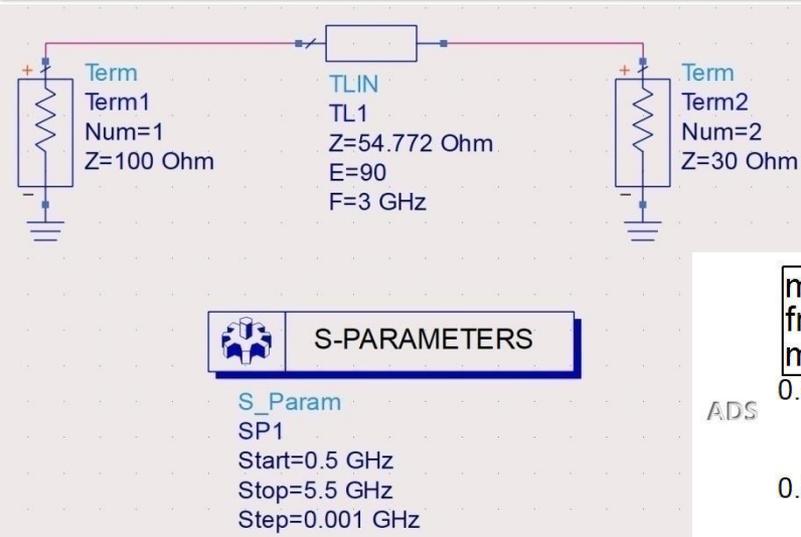
$$Z_{in} = \frac{Z_1^2}{R_L}$$

$$\Gamma_{in} = \frac{Z_1^2 - Z_0 \cdot R_L}{Z_1^2 + Z_0 \cdot R_L}$$

$$\Gamma_{in} = 0 \Rightarrow Z_1 = \sqrt{Z_0 R_L}$$

- Pe fider (Z_0) avem doar unda progresiva
- Pe linia in sfert de lungime de unda (Z_1) avem unda stationara

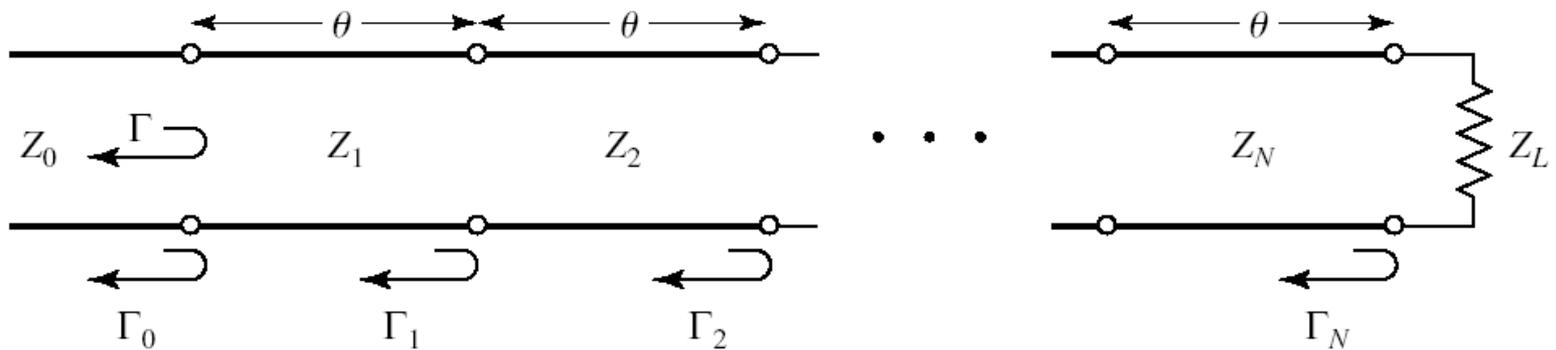
Sfert de lungime de unda



Transformatoare de impedanta multisectiune

- Transformatorul in sfert de lungime de unda permite adaptarea oricarei impedante reale cu orice impedanta a fiderului (liniei).
- Daca banda necesara este mai mare decat cea oferita de transformatorul in sfert de lungime de unda se folosesc transformatoare multisectiune
 - caracteristica binomiala
 - tip Cebîșev

Transformatoare cu mai multe sectiuni



- Presupunem ca toate impedantele **cresc sau descrec uniform**

- Toti coeficientii de reflexie vor fi reali si de acelasi semn

- Anterior $\Gamma \cong \Gamma_1 + \Gamma_3 \cdot e^{-2j\theta} \Rightarrow$

$$\Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \dots + \Gamma_N \cdot e^{-2jN\theta}$$

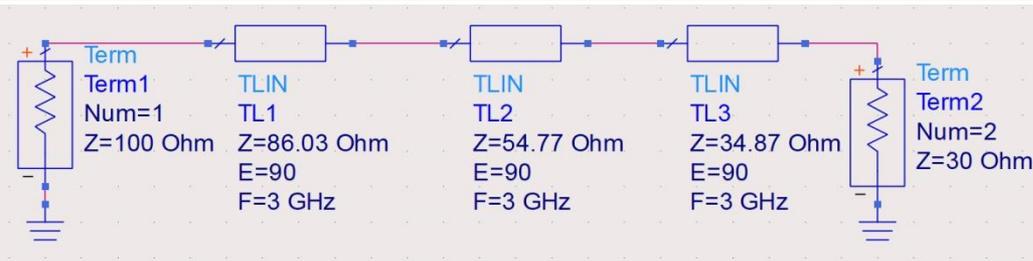
$$\Gamma_1 = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

$$\Gamma_n = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n}$$

$$n = \overline{1, N-1}$$

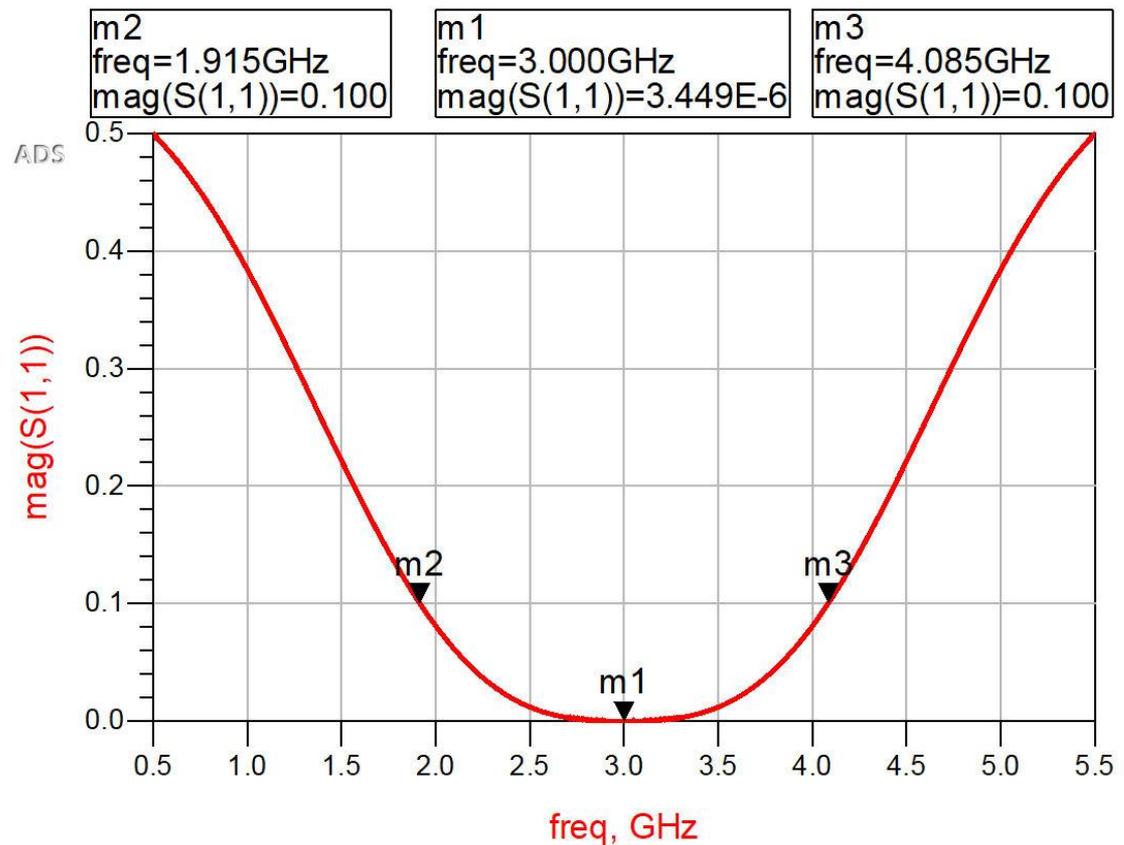
$$\Gamma_N = \frac{Z_L - Z_N}{Z_L + Z_N}$$

Binomial

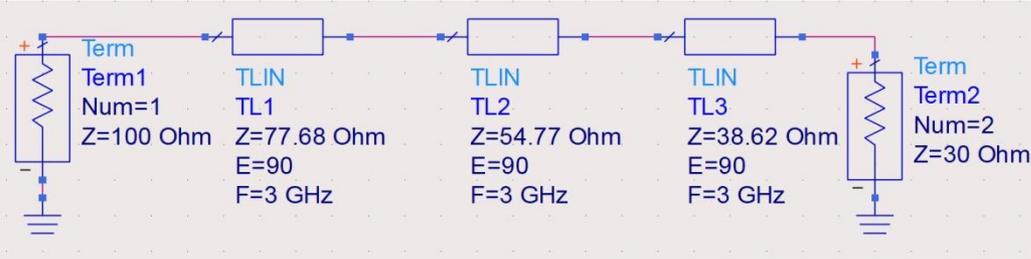


S-PARAMETERS

S_Param
SP1
Start=0.5 GHz
Stop=5.5 GHz
Step=0.001 GHz

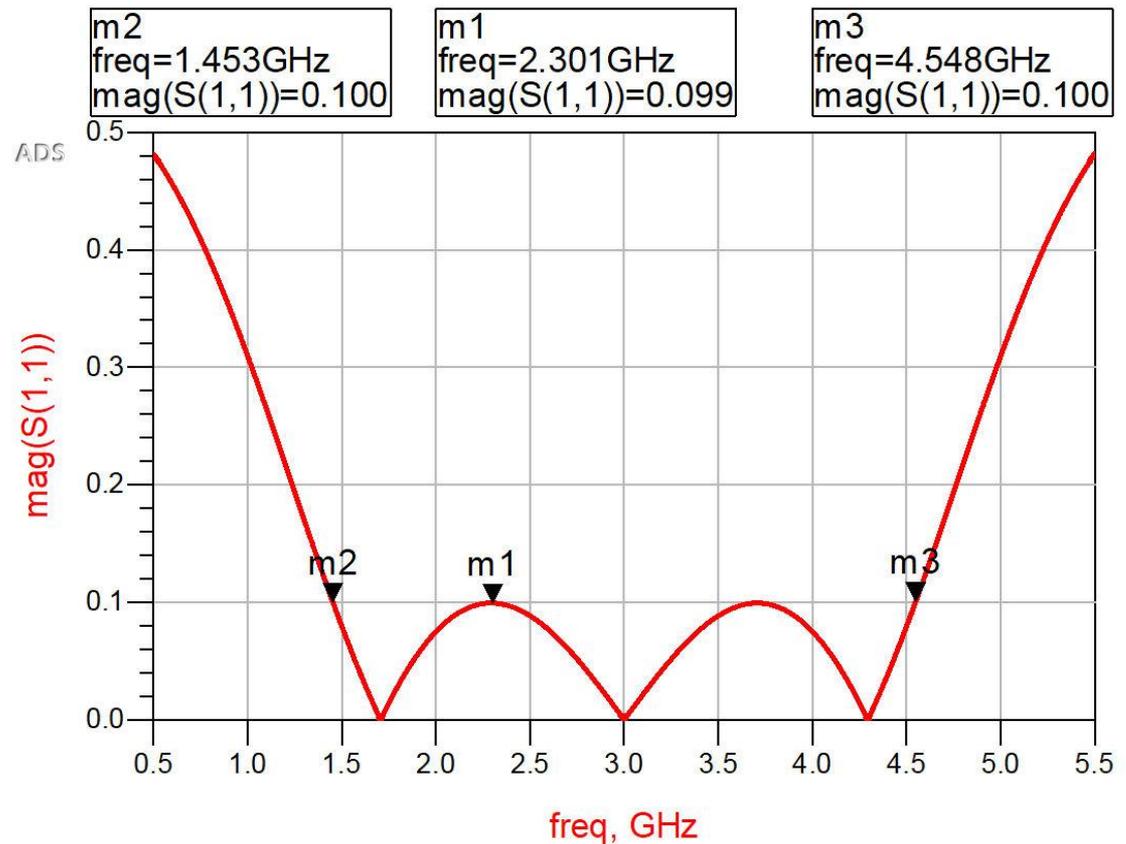


Cebâşev



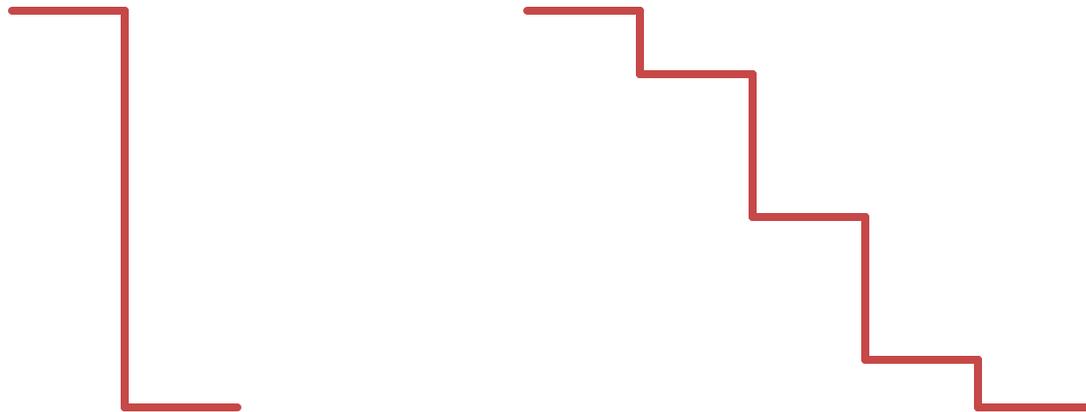
S-PARAMETERS

S_Param
SP1
Start=0.5 GHz
Stop=5.5 GHz
Step=0.001 GHz



Adaptare de impedanta

- Principial se inlocuieste o **variatie in salt** a impedantei cu o **crestere/descrestere graduala** a impedantei
- Pasii de crestere/descrestere graduala a impedantei trebuiesc atent calculati



Contact

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- rdamian@etti.tuiasi.ro