

Curs 4
2018/2019

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2018/2019

- 2C/1L, DCMR (CDM)
- Minim 7 prezente (curs+laborator)
- Curs - conf. Radu Damian
 - Vineri 11-13, P7
 - E – 50% din nota
 - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
 - 3pz=+0.5p
 - toate materialele permise
- Laborator – conf. Radu Damian
 - Joi 8-14 impar II.13
 - L – 25% din nota
 - P – 25% din nota

Documentatie

■ <http://rf-opto.etti.tuiasi.ro>

Laboratorul de Microunde si Optică

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

RF-OPTO

Universitatea Tehnică "Gheorghe Asachi" din Iași

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)

Coordinator 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](#)

Fotografii

http://if-opto.eti.tuiasi.ro/presenza.php?act=153&nru=14&ext_supliz=26 eti.tuiasi.ro Laboratorul de Microonde s... ro.wikipedia.org

Start Didactic Master Colectiv Cercetare Studenti Admin

Note Lista Studenti Fotografi Statistici

Grupa 5403

Nr.	Student	Prezent	Nr.	Student	Prezent	Nr.	Student	Prezent	
1	ANGHELUS IONUT-MARCUS		<input type="checkbox"/> Prezent	2	ANTIGHIN FLORIN-RAZVAN	 Fotografia nu există	<input type="checkbox"/> Prezent	 Fotografia nu există	<input type="checkbox"/> Prezent
4	APOSTOL PAVEL-MANUEL	 Fotografia nu există	<input type="checkbox"/> Prezent	5	BALASCA TUDIAN-PETRU	 Fotografia nu există	<input checked="" type="checkbox"/> Prezent	 Fotografia nu există	<input type="checkbox"/> Prezent
7	BOTEZAT EMANUEL		<input type="checkbox"/> Prezent	8	BUTUNOI GEORGE-MADALIN	 Fotografia nu există	<input type="checkbox"/> Prezent	 Fotografia nu există	<input type="checkbox"/> Prezent
10	CHIRITOIU ECATERINA		<input type="checkbox"/> Prezent	11	CODOC MARCUS		<input checked="" type="checkbox"/> Prezent		<input type="checkbox"/> Prezent
				12	COJOCARU ALINA-FLORINA				

Nr. Student

Prezent

2 ANTIGHIN
FLORIN-RAZVAN

Prezent

Puncte: 0

Nota: 0

Obs:

Fotografia nu există

Acces

Personalizat



Date:

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

[Acceseaza ca acest student](#)

Note obtinute

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

Nume

Email

Cod de verificare

Trimite

Examen: Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$-20 \text{ dBm} = 1 \mu\text{W}$$

$$-30 \text{ dBm} = 1 \text{ nW}$$

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

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

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

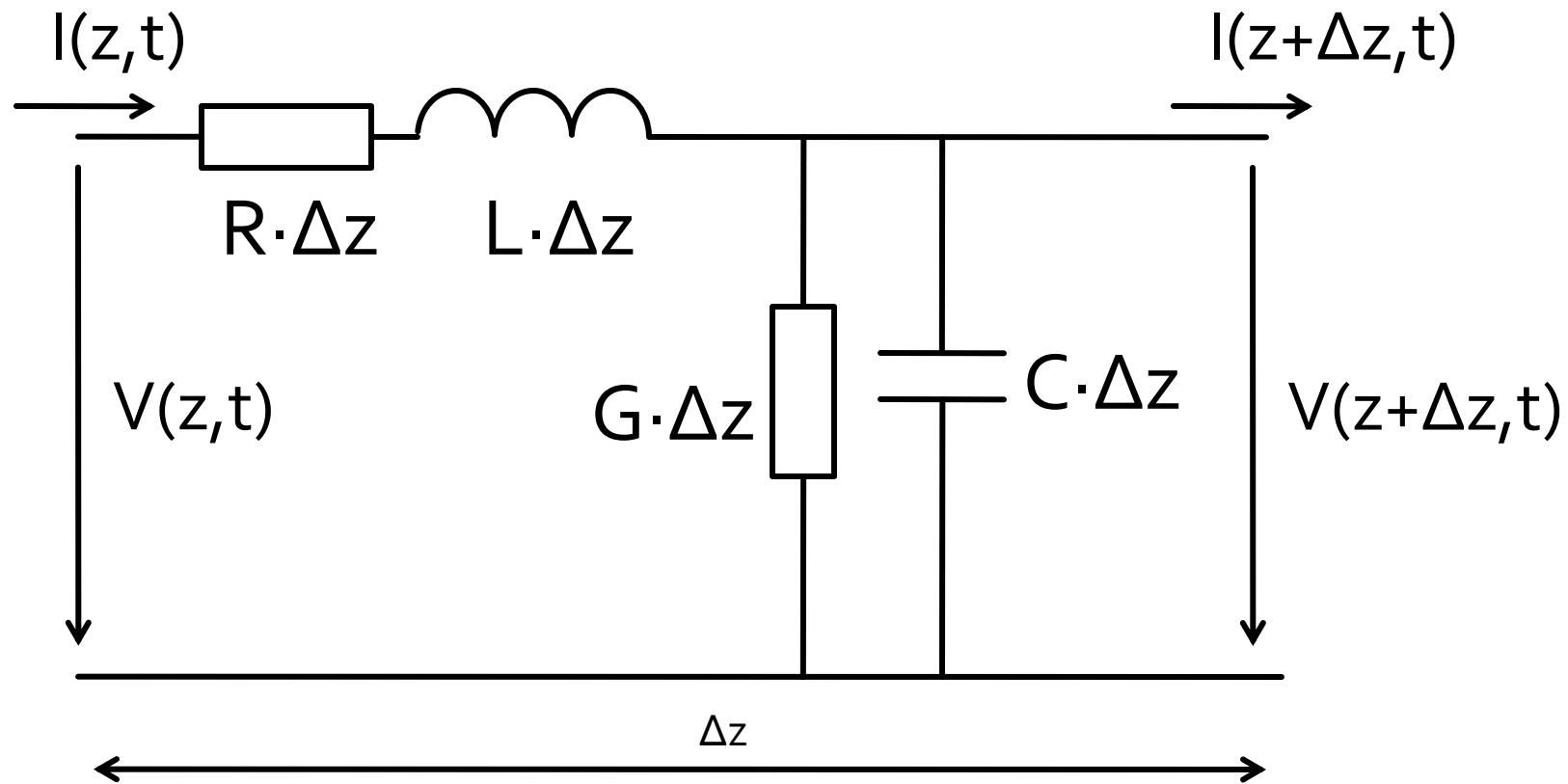
Examen

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

Linii de transmisie in mod TEM

Linie de transmisie model echivalent

- mod TEM, doi conductori



Solutiile

$$\begin{cases} V(z) = V_0^+ e^{-\gamma \cdot z} + V_0^- e^{\gamma \cdot z} \\ I(z) = I_0^+ e^{-\gamma \cdot z} + I_0^- e^{\gamma \cdot z} \end{cases}$$

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

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

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

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

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

- 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:** $R=G=0$

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

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

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

- Z_0 **real**

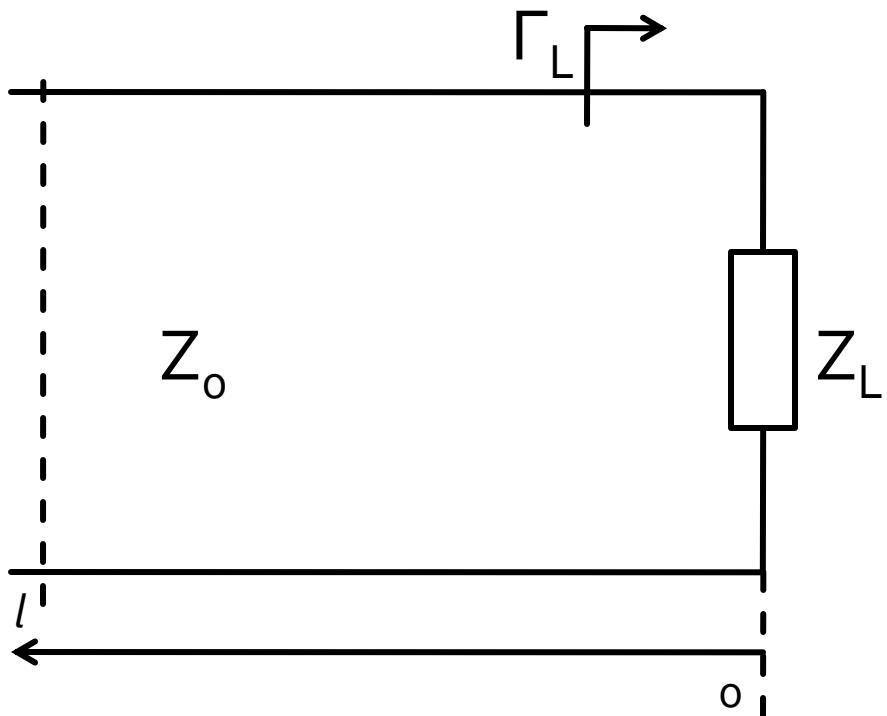
$$V(z) = V_0^+ e^{-j \cdot \beta \cdot z} + V_0^- e^{j \cdot \beta \cdot z}$$

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

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

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

Linie fara pierderi



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

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

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

- 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

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

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

■ Puterea medie

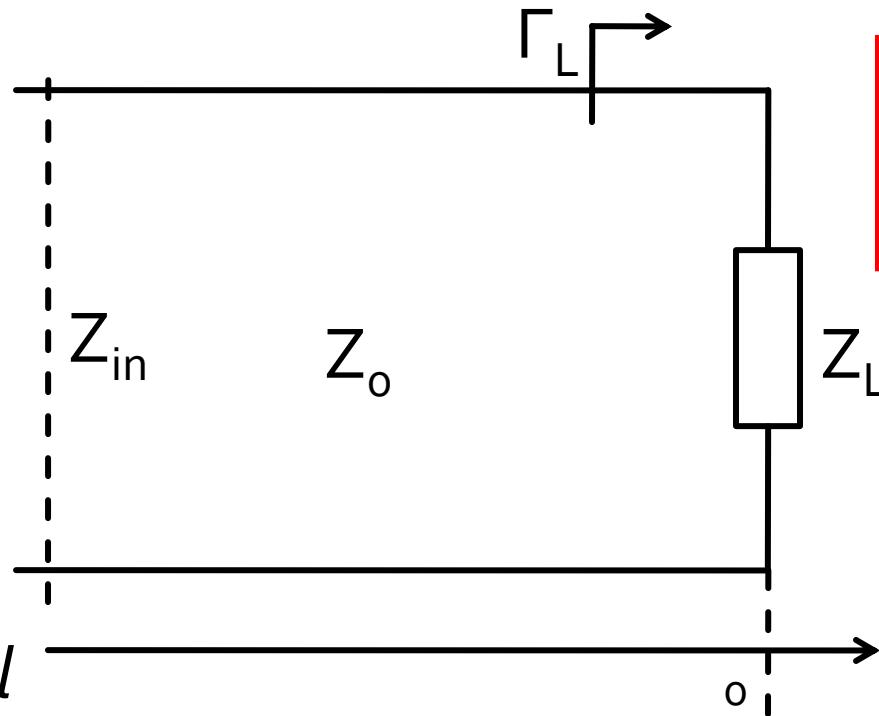
$$P_{avg} = \frac{1}{2} \cdot \operatorname{Re} \left\{ V(z) \cdot I(z)^* \right\} = \frac{1}{2} \cdot \frac{|V_0^+|^2}{Z_0} \cdot \operatorname{Re} \left\{ 1 - \Gamma^* \cdot e^{-2j\beta z} + \Gamma \cdot e^{2j\beta z} - |\Gamma|^2 \right\}$$
$$P_{avg} = \frac{1}{2} \cdot \frac{|V_0^+|^2}{Z_0} \cdot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

$(z - z^*) = \operatorname{Im}$

- Puterea transmisa sarcinii = Puterea incidenta - Puterea "reflectata"
- Return Loss [dB]
$$\text{RL} = -20 \cdot \log|\Gamma| \quad [\text{dB}]$$

Linie fara pierderi

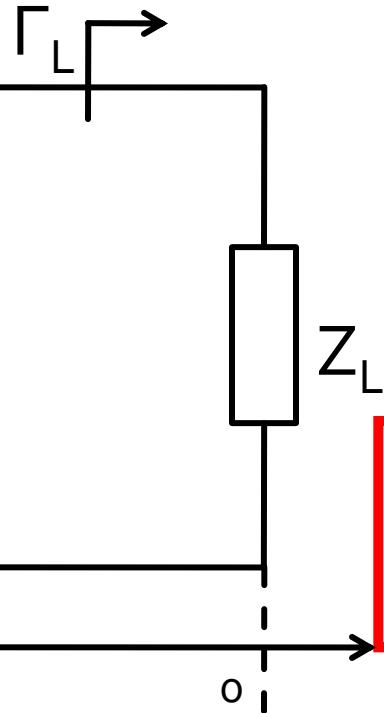
- impedanta la intrarea liniei de impedanta caracteristica Z_0 , de lungime l , terminata cu impedanta Z_L



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

Linie fara pierderi

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



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

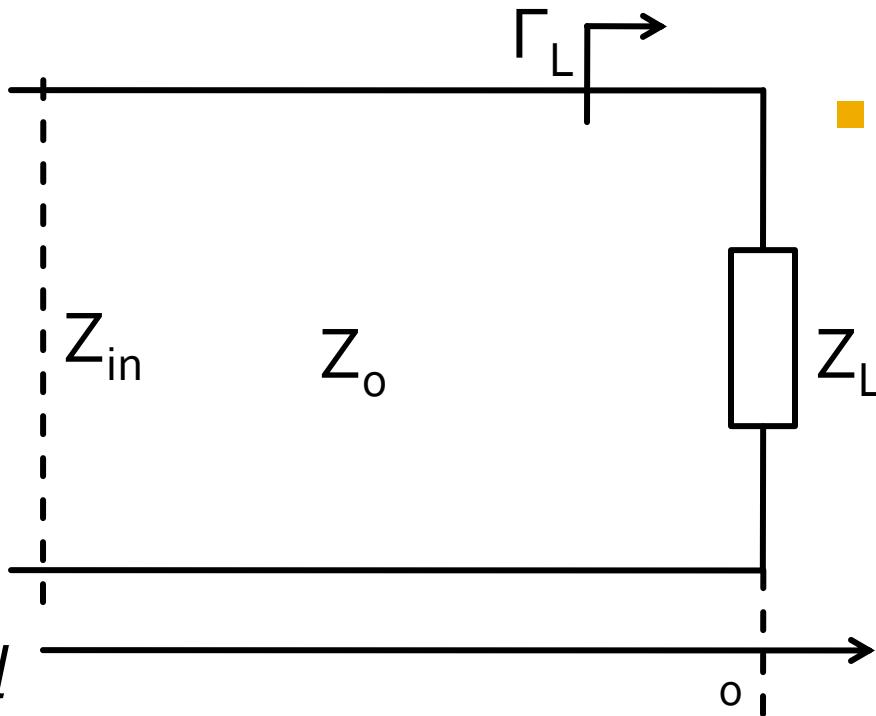
$$\beta \cdot l = \frac{2\pi}{\lambda} \cdot l = \frac{2\pi \cdot f}{v_f} \cdot l = \frac{2\pi \cdot l}{v_f} \cdot f$$

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

- $l = k \cdot \lambda / 2$ $\beta \cdot l = \frac{2\pi}{\lambda} \cdot l = k \cdot \pi$ $\tan \beta \cdot l = 0$ $Z_{in} = Z_0$
- $l = \lambda / 4 + k \cdot \lambda / 2$ $\tan \beta \cdot l \rightarrow \infty$ $Z_{in} = \frac{Z_0^2}{Z_L}$



- Transformatorul în sfert de lungime de undă

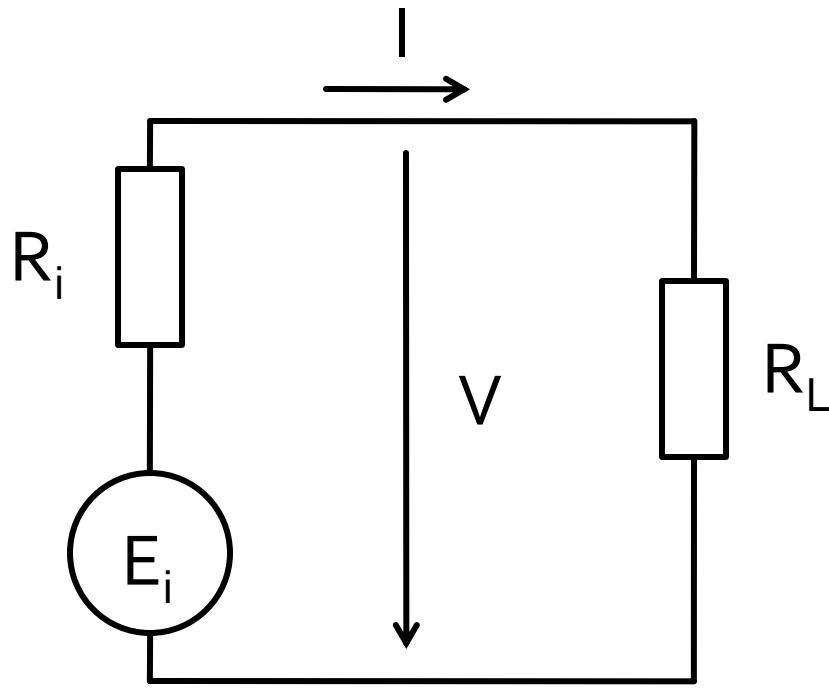
$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Adaptarea cu transformatoare de impedanta (Lab. 1)

Adaptarea de impedanță

Adaptare, impedante reale

- Generator adaptat la sarcina



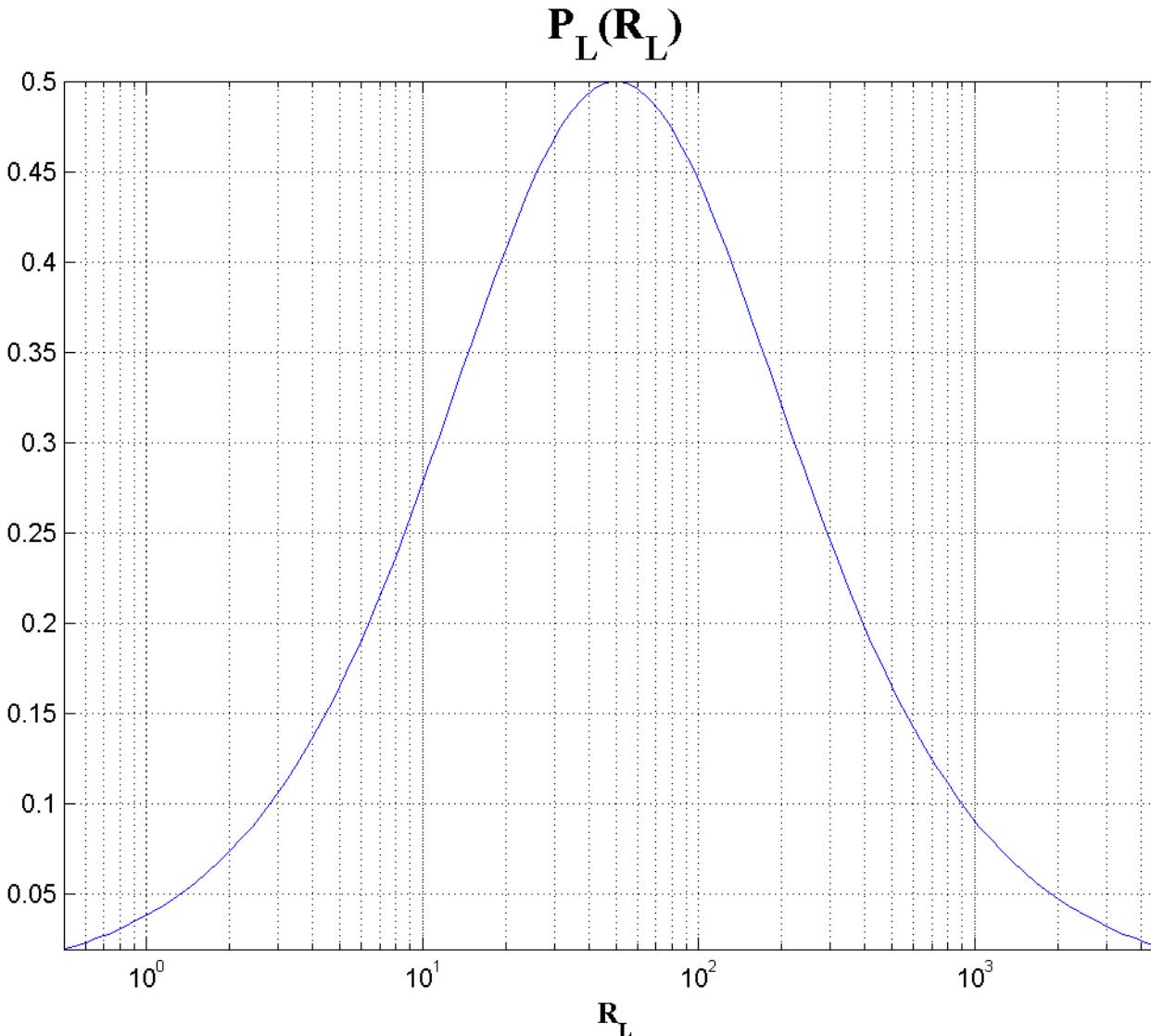
$$I = \frac{E_i}{R_i + R_L}$$

$$V = \frac{E_i \cdot R_L}{R_i + R_L}$$

$$P_L = R_L \cdot I^2$$

$$P_L = \frac{R_L \cdot E_i^2}{(R_i + R_L)^2}$$

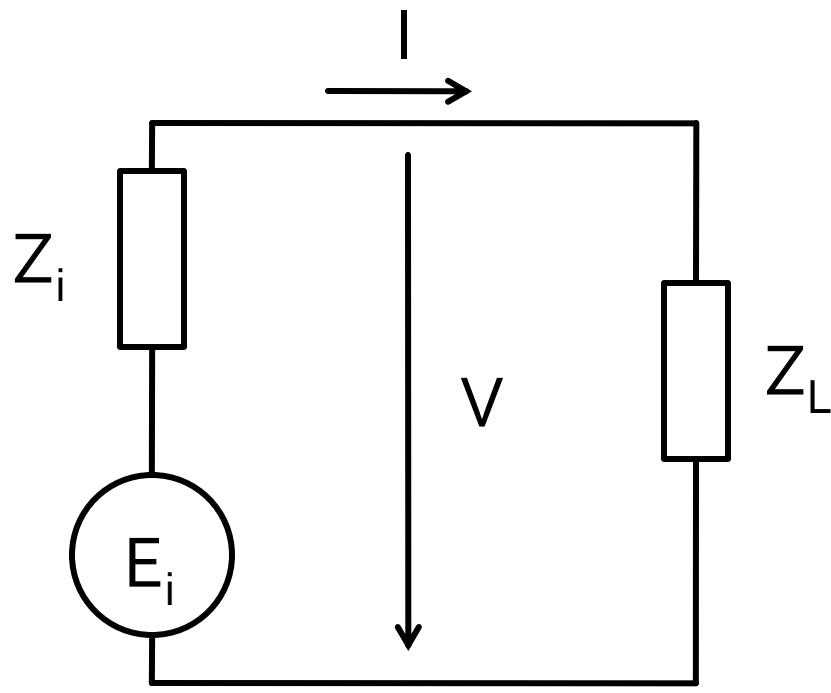
Adaptare , impedante reale



$$R_L = R_i$$

Adaptare, impedante complexe

- Generator adaptat la sarcina



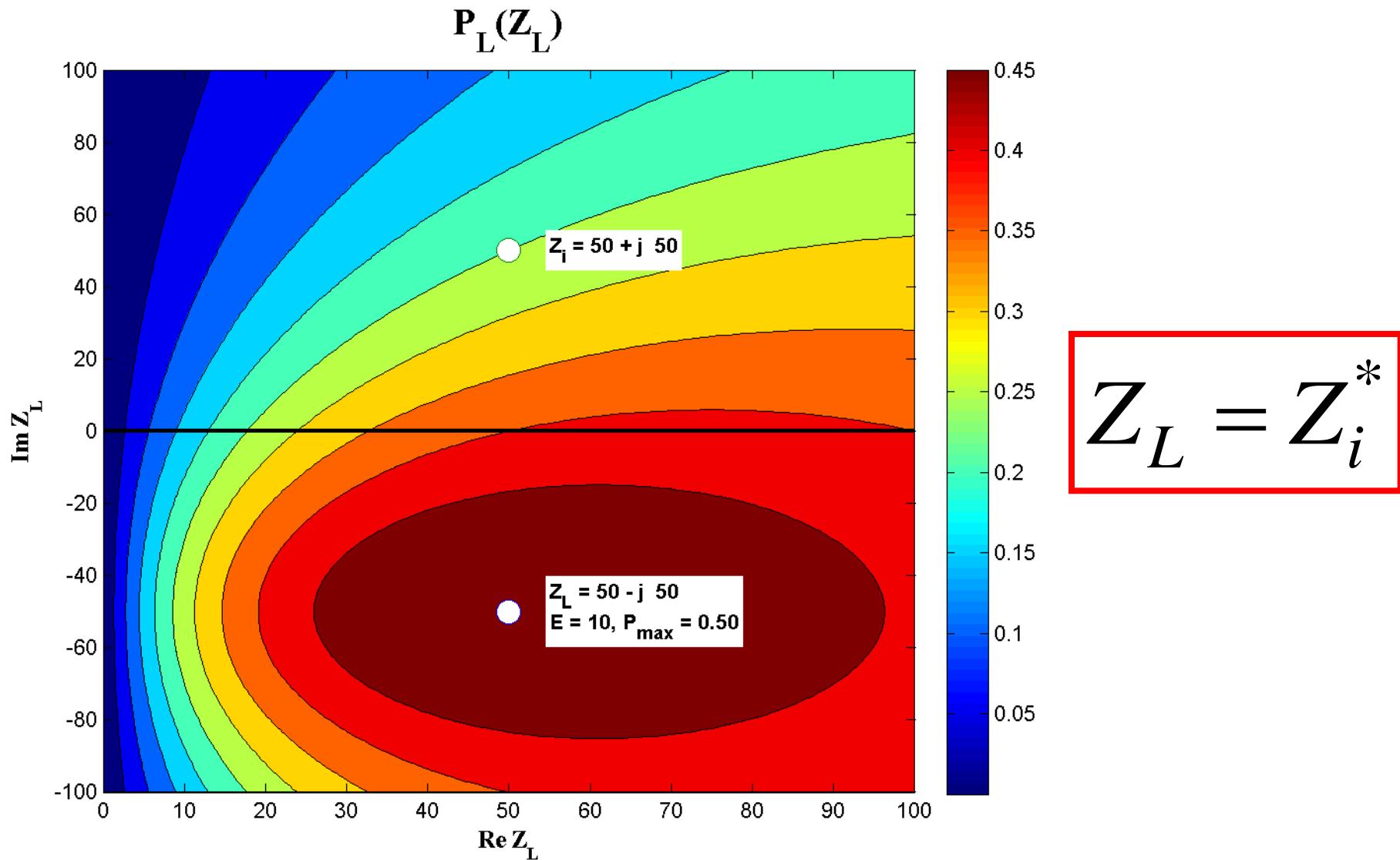
$$I = \frac{E_i}{Z_i + Z_L}$$

$$V = \frac{E_i \cdot Z_L}{Z_i + Z_L}$$

$$P_L = \operatorname{Re} Z_L \cdot |I|^2$$

$$P_L = \operatorname{Re} Z_L \cdot \left| \frac{E_i}{Z_i + Z_L} \right|^2$$

Adaptare, impedante complexe



Adaptare dpdv al puterii

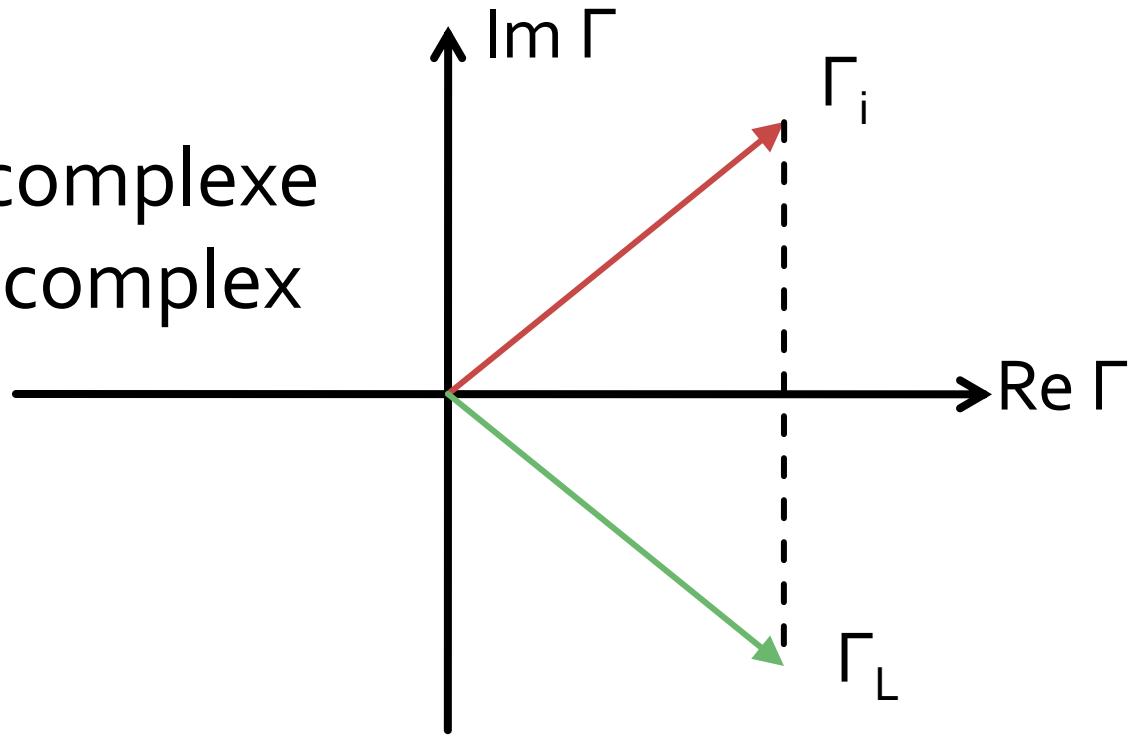
$$Z_L = Z_i^*$$

Daca se alege un Z_0 real

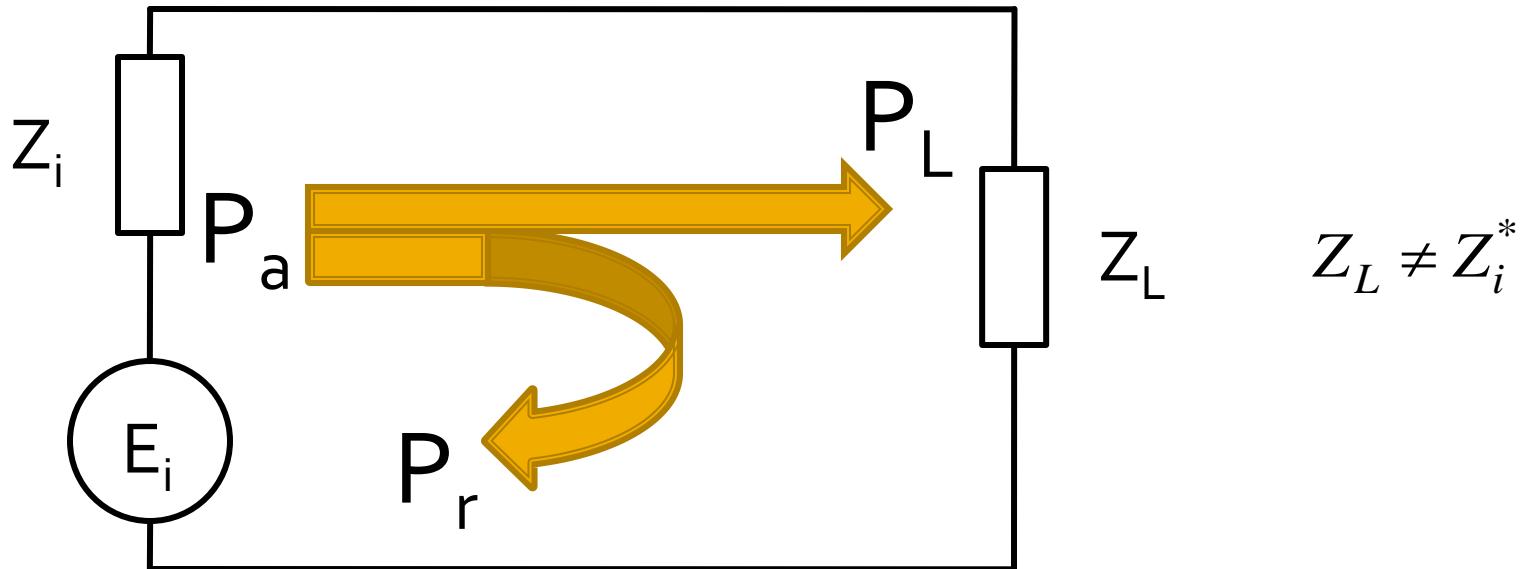
$$\Gamma = \frac{Z - Z_0}{Z + Z_0}$$

$$\Gamma_L = \Gamma_i^*$$

- numere complexe
- in planul complex

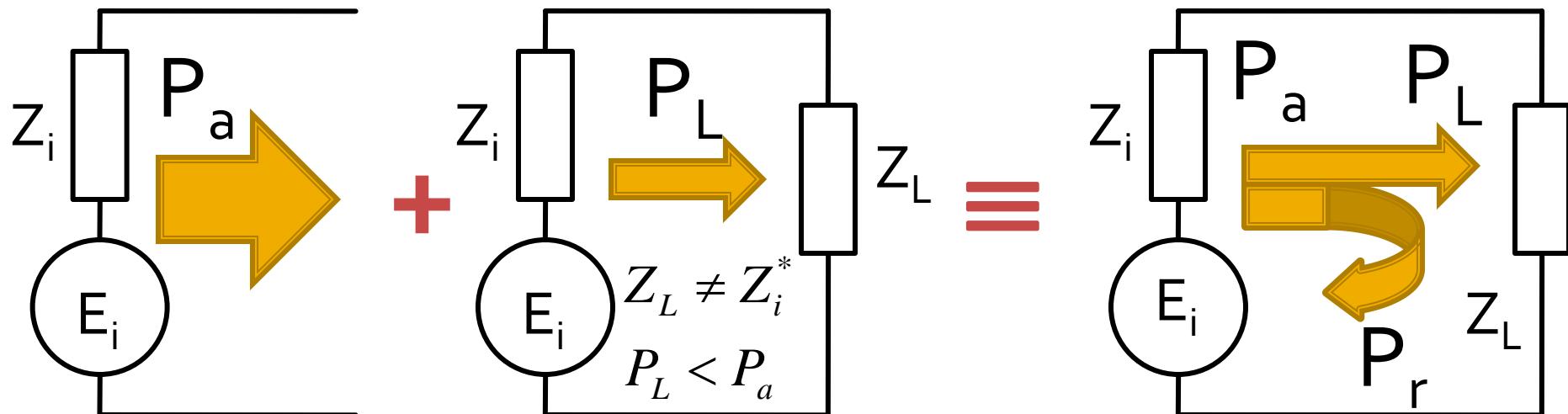


Reflexie de putere / Model



- Putere reflectata
- Putere a undei reflectate

Reflexie de putere / Model

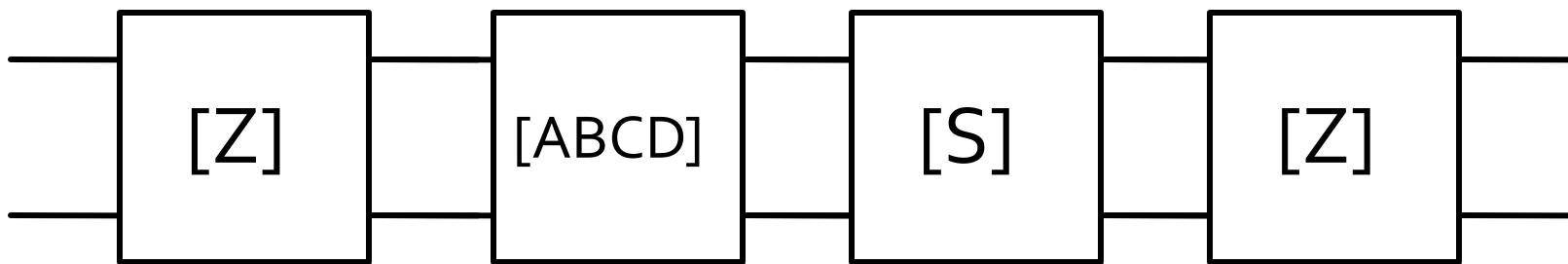


- Generatorul are posibilitatea de a oferi o anumita putere maxima de semnal P_a
- Pentru o sarcina oarecare, acesteia i se ofera o putere de semnal mai mica $P_L < P_a$
- Se intampla **“ca si cum”** (model) o parte din putere se reflecta $P_r = P_a - P_L$
- Puterea este o marime **scalara!**

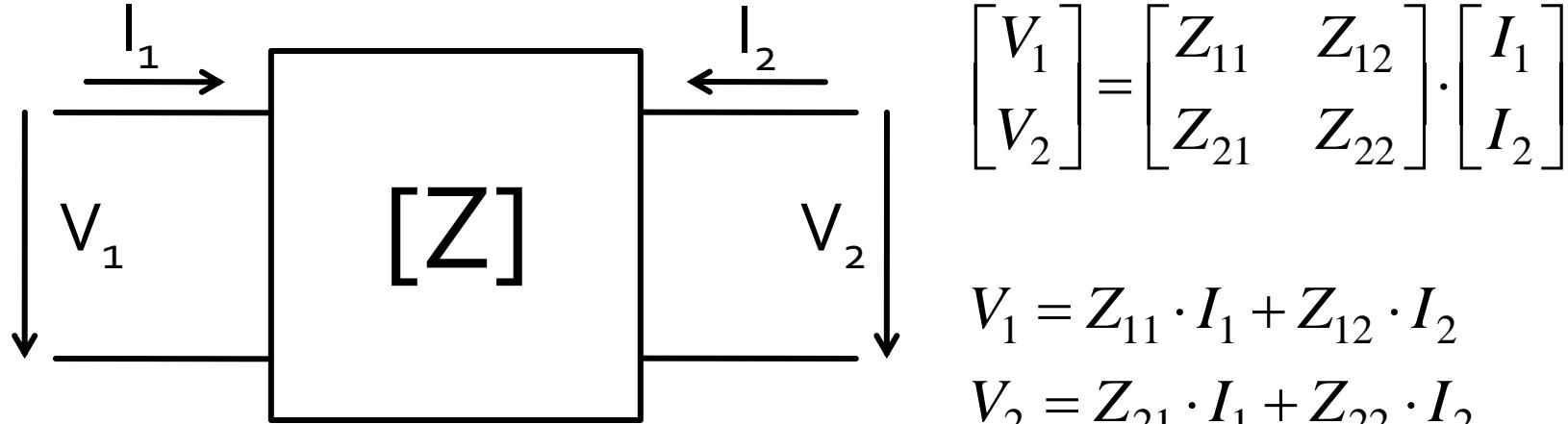
**Analiza la nivel de rețea a
circuitelor de microunde**

Analiza la nivel de bloc

- are ca scop separarea unui circuit complex în blocuri individuale
- acestea se analizează separat (decuplate de restul circuitului) și se caracterizează doar prin intermediul porturilor (**cutie neagră**)
- analiza la nivel de rețea permite cuplarea rezultatelor individuale și obținerea unui rezultat total pentru circuit



Matricea impedanta



$$V_1 = Z_{11} \cdot I_1 \Big|_{I_2=0} \quad Z_{11} = \frac{V_1}{I_1} \Big|_{I_2=0}$$

- Z_{11} – impedanta de intrare cu iesirea in gol

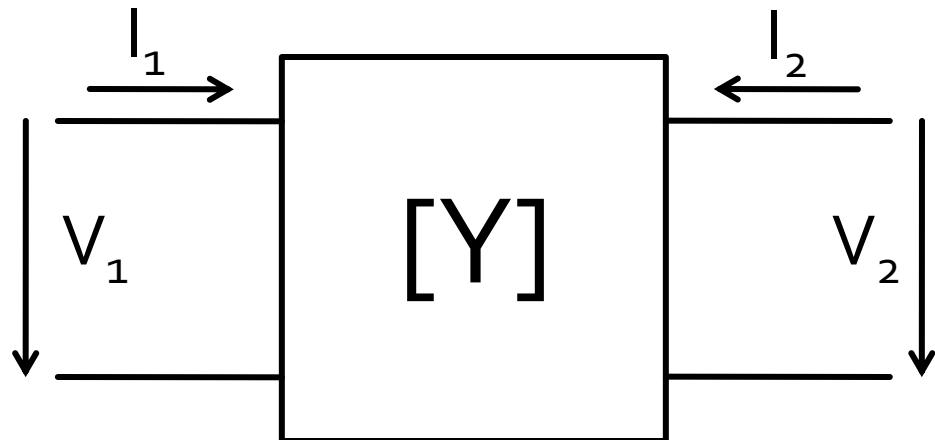
$$Z_{11} = \frac{V_1}{I_1} \Big|_{I_2=0}$$

$$Z_{12} = \frac{V_1}{I_2} \Big|_{I_1=0}$$

$$Z_{21} = \frac{V_2}{I_1} \Big|_{I_2=0}$$

$$Z_{22} = \frac{V_2}{I_2} \Big|_{I_1=0}$$

Matricea admitanta



$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

$$I_1 = Y_{11} \cdot V_1 + Y_{12} \cdot V_2$$

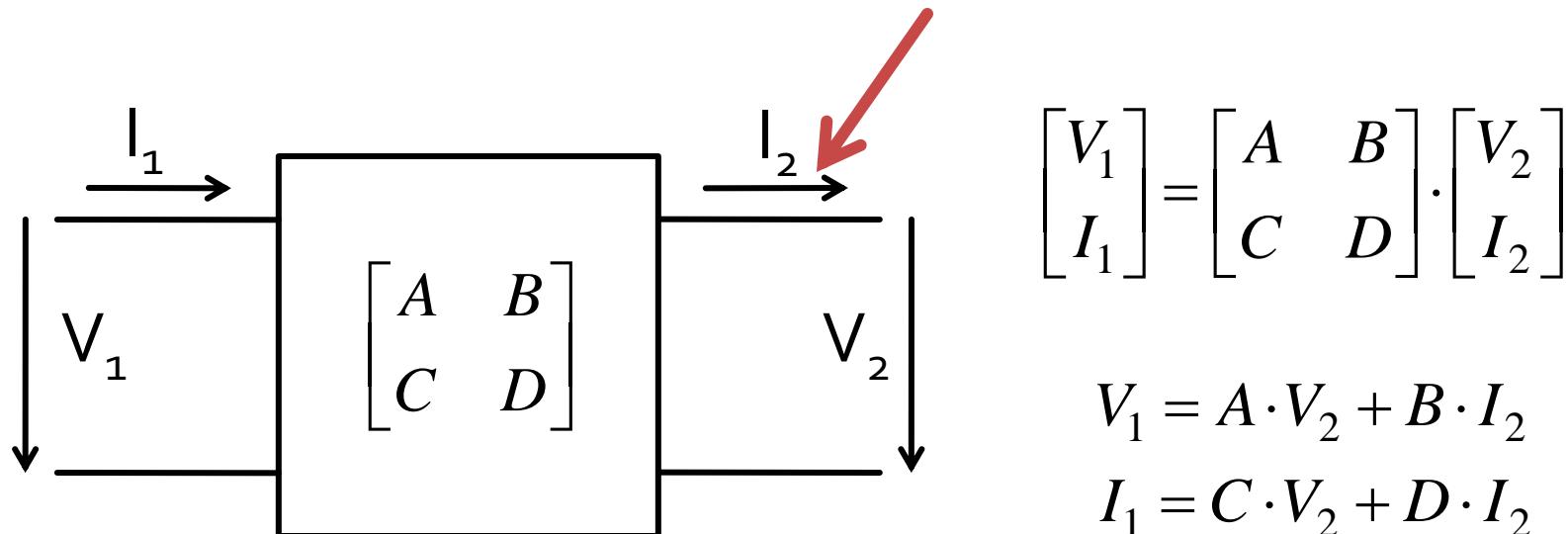
$$I_2 = Y_{21} \cdot V_1 + Y_{22} \cdot V_2$$

$$I_1 = Y_{11} \cdot V_1 \Big|_{V_2=0} \quad Y_{11} = \frac{I_1}{V_1} \Big|_{V_2=0}$$

- **Y₁₁** – admitanta de intrare cu ieșirea în scurtcircuit

$$Y_{11} = \frac{I_1}{V_1} \Big|_{V_2=0} \quad Y_{12} = \frac{I_1}{V_2} \Big|_{V_1=0} \quad Y_{21} = \frac{I_2}{V_1} \Big|_{V_2=0} \quad Y_{22} = \frac{I_2}{V_2} \Big|_{V_1=0}$$

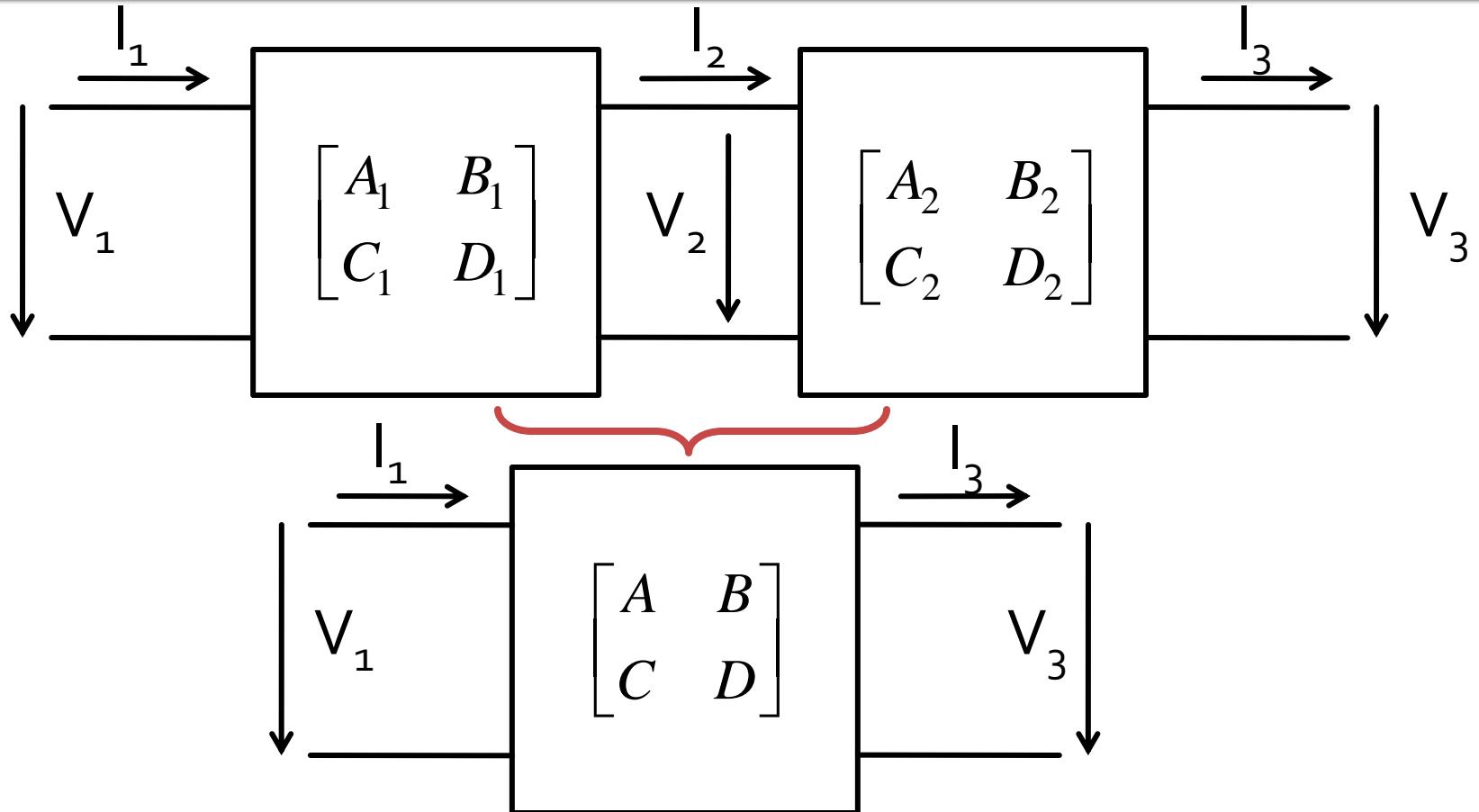
Matricea ABCD – de transmisie



$$\begin{bmatrix} V_2 \\ I_2 \end{bmatrix} = \frac{1}{A \cdot D - B \cdot C} \cdot \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \cdot \begin{bmatrix} V_1 \\ I_1 \end{bmatrix}$$

$$A = \left. \frac{V_1}{V_2} \right|_{I_2=0} \quad B = \left. \frac{V_1}{I_2} \right|_{V_2=0} \quad C = \left. \frac{I_1}{V_2} \right|_{I_2=0} \quad D = \left. \frac{I_1}{I_2} \right|_{V_2=0}$$

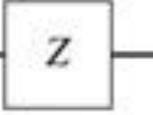
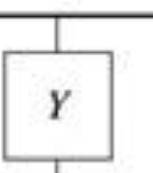
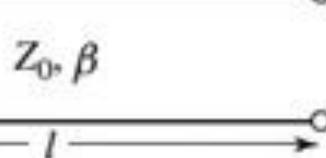
Matricea ABCD – de transmisie



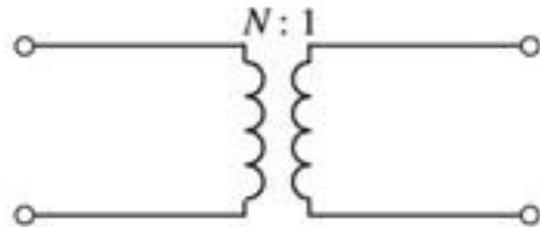
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdot \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$

Biblioteci de matrici ABCD

TABLE 4.1 *ABCD* Parameters of Some Useful Two-Port Circuits

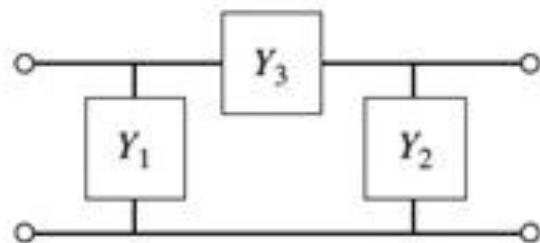
Circuit	<i>ABCD</i> Parameters	
	$A = 1$	$B = Z$
	$C = 0$	$D = 1$
	$A = 1$	$B = 0$
	$C = Y$	$D = 1$
	$A = \cos \beta l$	$B = j Z_0 \sin \beta l$
	$C = j Y_0 \sin \beta l$	$D = \cos \beta l$

Biblioteci de matrici ABCD



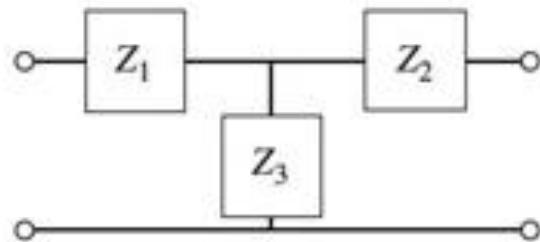
$$A = N$$
$$C = 0$$

$$B = 0$$
$$D = \frac{1}{N}$$



$$A = 1 + \frac{Y_2}{Y_3}$$
$$C = Y_1 + Y_2 + \frac{Y_1 Y_2}{Y_3}$$

$$B = \frac{1}{Y_3}$$
$$D = 1 + \frac{Y_1}{Y_3}$$



$$A = 1 + \frac{Z_1}{Z_3}$$
$$C = \frac{1}{Z_3}$$

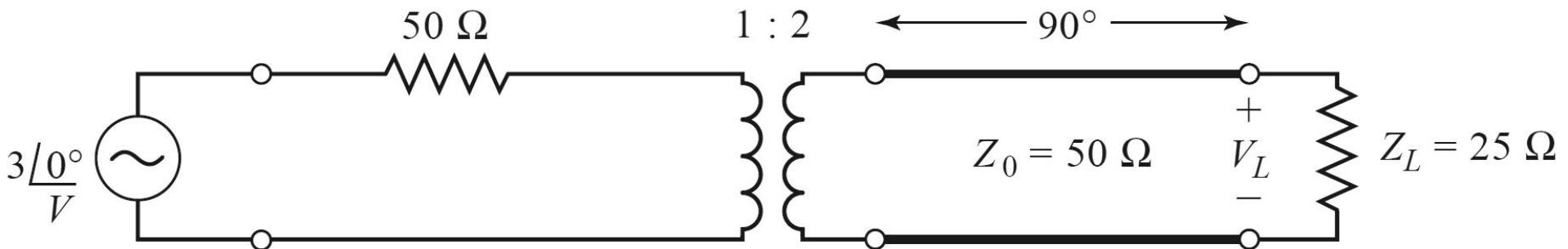
$$B = Z_1 + Z_2 + \frac{Z_1 Z_2}{Z_3}$$
$$D = 1 + \frac{Z_2}{Z_3}$$

Table 4.1

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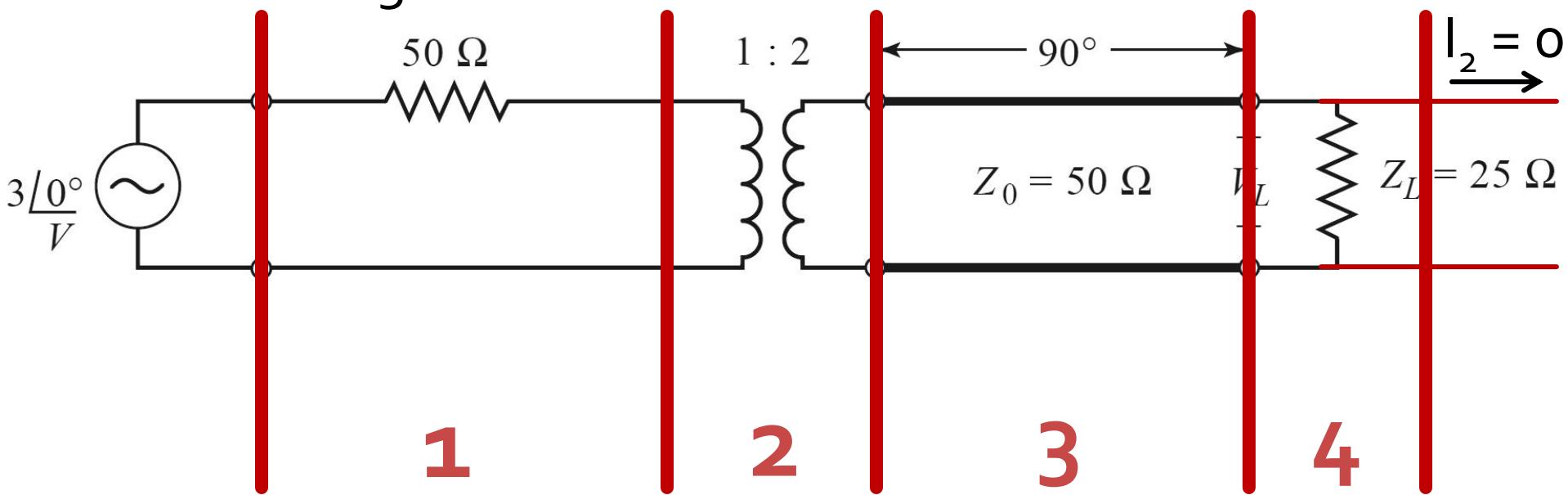
Exemplu utilizare matrice ABCD

- Determinati tensiunea pe sarcina in circuitul urmator



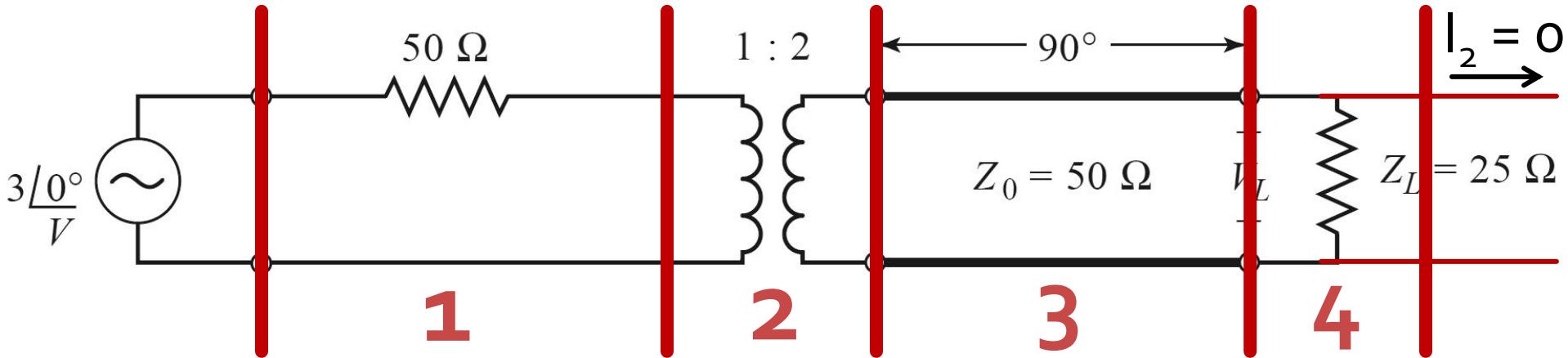
Exemplu utilizare matrice ABCD

- Sectionare circuit in elemente simple
- Generatoarele raman in exterior
- Daca e necesar, se creaza porturi de intrare si iesire lasate in gol



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = M_1 \cdot M_2 \cdot M_3 \cdot M_4 \quad V_1 = A \cdot V_2 + B \cdot I_2 \Big|_{I_2=0} \quad V = A \cdot V_L \rightarrow V_L = \frac{V}{A}$$

Exemplu utilizare matrice ABCD



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 50 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{2} & 0 \\ 0 & 2 \end{bmatrix} \cdot \begin{bmatrix} 0 & 50 \cdot j \\ \frac{j}{50} & 0 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ \frac{1}{25} & 1 \end{bmatrix} = \begin{bmatrix} 3 \cdot j & 25 \cdot j \\ \frac{j}{25} & 0 \end{bmatrix}$$

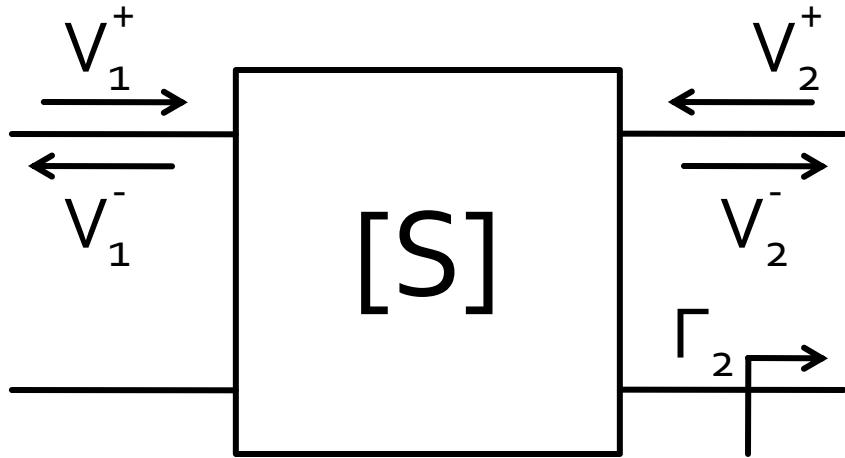
$$V_L = \frac{V}{A} = \frac{3\angle 0^\circ}{3 \cdot j} = 1\angle 90^\circ$$

Continuare

Analiza la nivel de rețea a circuitelor de microunde

Matricea S (repartitie)

- Scattering parameters



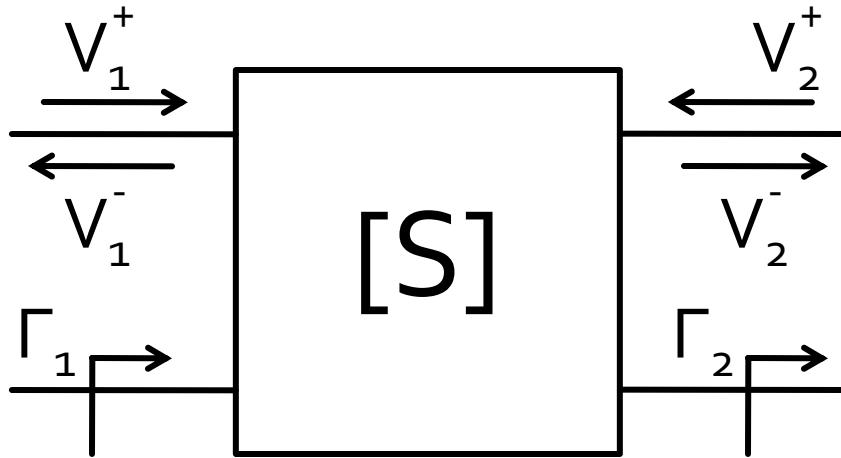
$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$S_{11} = \frac{V_1^-}{V_1^+} \Big|_{V_1^+=0} \quad S_{21} = \frac{V_2^-}{V_1^+} \Big|_{V_2^+=0}$$

- $V_2^+ = 0$ are semnificatia: la portul 2 este conectata impedanta care realizeaza conditia de adaptare (complex conjugat)

$$\Gamma_2 = 0 \rightarrow V_2^+ = 0$$

Matricea S (repartitie)



$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$S_{11} = \left. \frac{V_1^-}{V_1^+} \right|_{V_2^+ = 0} = \Gamma_1 \Big|_{\Gamma_2 = 0}$$

$$S_{21} = \left. \frac{V_2^-}{V_1^+} \right|_{V_2^+ = 0} = T_{21} \Big|_{\Gamma_2 = 0}$$

- S_{11} este coeficientul de reflexie la portul **1** cand portul **2** este terminat pe impedanta care realizeaza adaptarea
- S_{21} este coeficientul de transmisie de la portul **1** (**al doilea indice!**) la portul **2** (**primul indice!**) cand se depune semnal la portul **1** portul **2** este terminat pe impedanta care realizeaza adaptarea

Matricea S (repartitie)

- Matricea S poate fi extinsa (generalizata) pentru multiporti (n-porturi)

$$S_{ii} = \left. \frac{V_i^-}{V_i^+} \right|_{V_k^+=0, \forall k \neq i}$$

$$S_{ij} = \left. \frac{V_i^-}{V_j^+} \right|_{V_k^+=0, \forall k \neq j}$$

- S_{ii} este coeficientul de reflexie la portul i cand toate celelalte porturi sunt conectate la impedanta care realizeaza adaptarea
- S_{ij} este coeficientul de transmisie de la portul j (**al doilea** indice!) la portul i (**primul** indice!) cand se depune semnal la portul j si toate celelalte porturi sunt conectate la impedanta care realizeaza adaptarea

Proprietati [S]

- Daca portul i este conectat la o linie cu impedanta caracteristica Z_{oi}
- Curs 2

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

In planul de referinta al portului, $z=0$

$$V_i = V_i^+ + V_i^- \quad I_i = \frac{V_i^+}{Z_{0i}} - \frac{V_i^-}{Z_{0i}} \quad [Z_0] = \begin{bmatrix} Z_{01} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & Z_{0n} \end{bmatrix}$$

- Legatura cu matricea Z $[Z] \cdot [I] = [V]$

$$[Z] \cdot [I] = [Z_0]^{-1} \cdot [Z] \cdot [V^+] - [Z_0]^{-1} \cdot [Z] \cdot [V^-] \quad [V] = [V^+] + [V^-]$$

$$[Z_0]^{-1} \cdot [Z] \cdot [V^+] - [Z_0]^{-1} \cdot [Z] \cdot [V^-] = [V^+] + [V^-] \quad ([Z] - [Z_0]) \cdot [V^+] = ([Z] + [Z_0]) \cdot [V^-]$$

$$[V^-] = [S] \cdot [V^+]$$

$$[S] = ([Z] - [Z_0]) \cdot ([Z] + [Z_0])^{-1}$$

Deplasare a planului de referinta

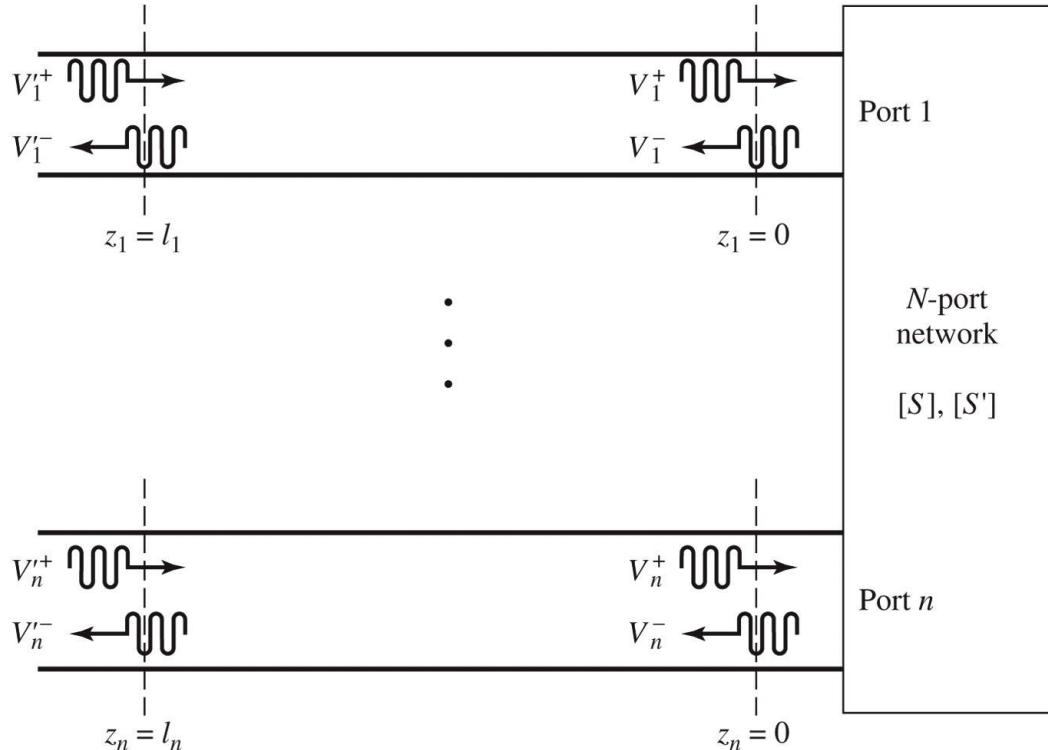


Figure 4.9
© John Wiley & Sons, Inc. All rights reserved.

$$[S'] = \begin{bmatrix} e^{-j\cdot\theta_1} & 0 & \dots & 0 \\ 0 & e^{-j\cdot\theta_2} & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \dots & \dots & e^{-j\cdot\theta_N} \end{bmatrix} \cdot [S] \cdot \begin{bmatrix} e^{-j\cdot\theta_1} & 0 & \dots & 0 \\ 0 & e^{-j\cdot\theta_2} & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \dots & \dots & e^{-j\cdot\theta_N} \end{bmatrix}$$

Proprietati [S]

- Circuite reciproce (fara circuite active, ferite)

$$Z_{ij} = Z_{ji}, \forall j \neq i$$

$$Y_{ij} = Y_{ji}, \forall j \neq i$$

$$S_{ij} = S_{ji}, \forall j \neq i \quad [S] = [S]^t$$

- Circuite fara pierderi

$$\operatorname{Re}\{Z_{ij}\} = 0, \forall i, j$$

$$\operatorname{Re}\{Y_{ij}\} = 0, \forall i, j$$

$$\sum_{k=1}^N S_{ki} \cdot S_{kj}^* = \delta_{ij}, \forall i, j$$

$$[S]^* \cdot [S]^t = [1]$$

$$\sum_{k=1}^N S_{ki} \cdot S_{ki}^* = 1$$

$$\sum_{k=1}^N S_{ki} \cdot S_{kj}^* = 0, \forall i \neq j$$

Matricea S generalizata

- Amplitudinile totale ale tensiunii si curentului in functie de amplitudinile undelor incidenta si reflectate pentru o linie

$$V = V_0^+ + V_0^- \quad I = \frac{1}{Z_0} \cdot (V_0^+ - V_0^-) \quad \text{planul de referinta al portului, } z=0$$

- Aflam amplitudinile undelor de tensiune

$$V_0^+ = \frac{V + Z_0 \cdot I}{2} \quad V_0^- = \frac{V - Z_0 \cdot I}{2}$$

- Puterea oferita sarcinii la iesirea din linie:

$$P_L = \frac{1}{2} \cdot \operatorname{Re}\{V \cdot I^*\} = \frac{1}{2 \cdot Z_0} \cdot \operatorname{Re}\left\{ |V_0^+|^2 - V_0^+ \cdot V_0^{-*} + V_0^{+*} \cdot V_0^- - |V_0^-|^2 \right\}$$

$$P_L = \frac{1}{2 \cdot Z_0} \cdot \left(|V_0^+|^2 - |V_0^-|^2 \right) \quad (z - z^*) = \operatorname{Im}$$

Matricea S generalizata

- Definim undele de putere

$$a = \frac{V + Z_R \cdot I}{2 \cdot \sqrt{R_R}} \text{ unda incidenta de putere}$$

$$b = \frac{V - Z_R^* \cdot I}{2 \cdot \sqrt{R_R}} \text{ unda reflectata de putere}$$

$$Z_R = R_R + j \cdot X_R$$

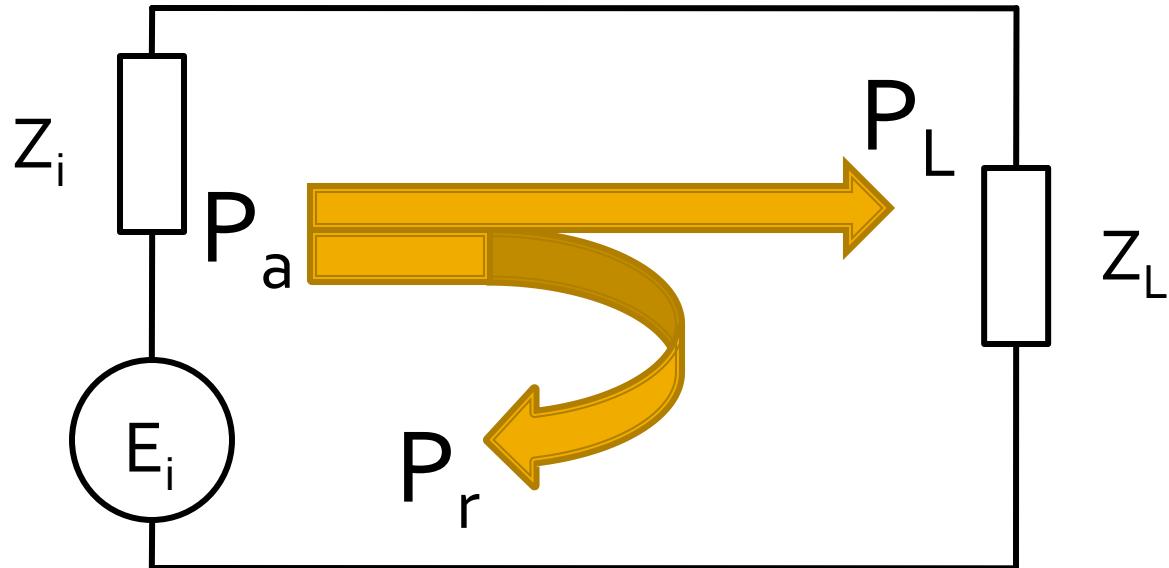
O impedanta de referinta
oarecare, complexa

- Tensiuni si curenti

$$V = \frac{Z_R^* \cdot a + Z_R \cdot b}{\sqrt{R_R}}$$

$$I = \frac{a - b}{\sqrt{R_R}}$$

Reflexie de putere / Model / C3



$$P_a = \frac{|E_i|^2}{4R_i}$$

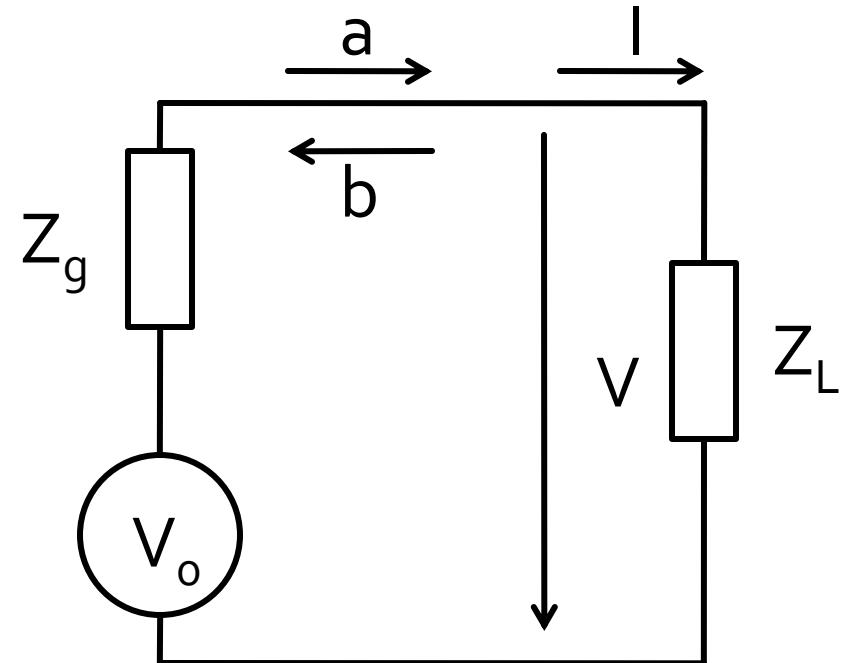
$$P_L = \frac{R_L \cdot |E_i|^2}{(R_i + R_L)^2 + (X_i + X_L)^2}$$

$$\Gamma_L = \frac{Z_L - Z_0^*}{Z_L + Z_0}$$

- coeficient de reflexie in putere

$$P_r = \frac{|E_i|^2}{4R_i} \cdot \left[\frac{(R_i - R_L)^2 + (X_i + X_L)^2}{(R_i + R_L)^2 + (X_i + X_L)^2} \right] = P_a \cdot |\Gamma|^2$$

Unde de putere



$$P_L = \frac{1}{2} \cdot \text{Re}\{V \cdot I^*\}$$

$$P_L = \frac{1}{2} \cdot \text{Re} \left\{ \frac{Z_R^* \cdot a + Z_R \cdot b}{\sqrt{R_R}} \cdot \left(\frac{a - b}{\sqrt{R_R}} \right)^* \right\}$$

$$P_L = \frac{1}{2R_R} \cdot \text{Re} \left\{ Z_R^* \cdot |a|^2 - Z_R^* \cdot a \cdot b^* + Z_R \cdot a^* \cdot b - Z_R \cdot |b|^2 \right\}$$

$$P_L = \frac{1}{2} \cdot |a|^2 - \frac{1}{2} \cdot |b|^2$$

$$\Gamma_p = \frac{b}{a} = \frac{V - Z_R^* \cdot I}{V + Z_R \cdot I} = \frac{Z_L - Z_R^*}{Z_L + Z_R}$$

Unde de putere

$$V = \frac{V_0 \cdot Z_L}{Z_g + Z_L}$$

$$I = \frac{V_0}{Z_g + Z_L}$$

$$P_L = \frac{V_0^2}{2} \cdot \frac{R_L}{|Z_g + Z_L|^2}$$

■ Daca aleg $Z_R = Z_L^*$

$$a = \frac{V + Z_R \cdot I}{2 \cdot \sqrt{R_R}} = V_0 \cdot \frac{\frac{Z_L}{Z_g + Z_L} + \frac{Z_L^*}{Z_g + Z_L}}{2 \cdot \sqrt{R_L}} = V_0 \cdot \frac{\sqrt{R_L}}{Z_g + Z_L}$$

$$b = \frac{V - Z_R^* \cdot I}{2 \cdot \sqrt{R_R}} = V_0 \cdot \frac{\frac{Z_L}{Z_g + Z_L} - \frac{Z_L}{Z_g + Z_L}}{2 \cdot \sqrt{R_L}} = 0$$

$$P_L = \frac{1}{2} \cdot |a|^2 = \frac{V_0^2}{2} \cdot \frac{R_L}{|Z_g + Z_L|^2}$$

Unde de putere

- Daca in plus generatorul este adaptat conjugat cu sarcina

$$Z_g = Z_L^* \quad P_{L\max} = \frac{1}{2} \cdot |a|^2 = \frac{V_0^2}{8 \cdot R_L}$$

- Reflexie in putere C3

$$Z_L = Z_i^* \quad P_{L\max} \equiv P_a$$

$$\Gamma = \frac{Z - Z_0^*}{Z + Z_0}$$

$$Z_L \neq Z_i^* \quad P_r = P_a \cdot |\Gamma|^2 \quad P_L = P_a - P_r = P_a - P_a \cdot |\Gamma|^2 = P_a \cdot (1 - |\Gamma|^2)$$

- Reflexie in putere C4

$$P_{L\max} \equiv P_a = \frac{1}{2} \cdot |a|^2 \quad P_L = \frac{1}{2} \cdot |a|^2 - \frac{1}{2} \cdot |b|^2 \quad \Gamma_p = \frac{b}{a} = \frac{V - Z_R^* \cdot I}{V + Z_R \cdot I} = \frac{Z_L - Z_R^*}{Z_L + Z_R}$$

$$P_L = \frac{1}{2} \cdot |a|^2 - \frac{1}{2} \cdot |a|^2 \cdot |\Gamma_p|^2 \quad P_L = P_a \cdot (1 - |\Gamma_p|^2) \quad P_r = P_a \cdot |\Gamma_p|^2 = \frac{1}{2} \cdot |b|^2$$

Unde de putere

- Definirile de unde pentru n-porti

$$[Z_R] = \begin{bmatrix} Z_{R1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & Z_{Rn} \end{bmatrix} \quad [F] = \begin{bmatrix} 1/2\sqrt{R_{R1}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1/2\sqrt{R_{Rn}} \end{bmatrix}$$

$$[a] = [F] \cdot ([V] + [Z_R] \cdot [I])$$

$$[b] = [F] \cdot ([V] - [Z_R]^* \cdot [I])$$

$$[Z] \cdot [I] = [V]$$

Unde de putere pentru multiporti

$$[b] = [F] \cdot ([Z] - [Z_R]^*) \cdot ([Z] + [Z_R])^{-1} \cdot [F]^{-1} \cdot [a]$$

- legatura intre undele de putere incidenta si reflectata

$$[b] = [S_p] \cdot [a]$$

$$[S_p] = [F] \cdot ([Z] - [Z_R]^*) \cdot ([Z] + [Z_R])^{-1} \cdot [F]^{-1}$$

$$[S] = ([Z] - [Z_0]) \cdot ([Z] + [Z_0])^{-1}$$

- tipic

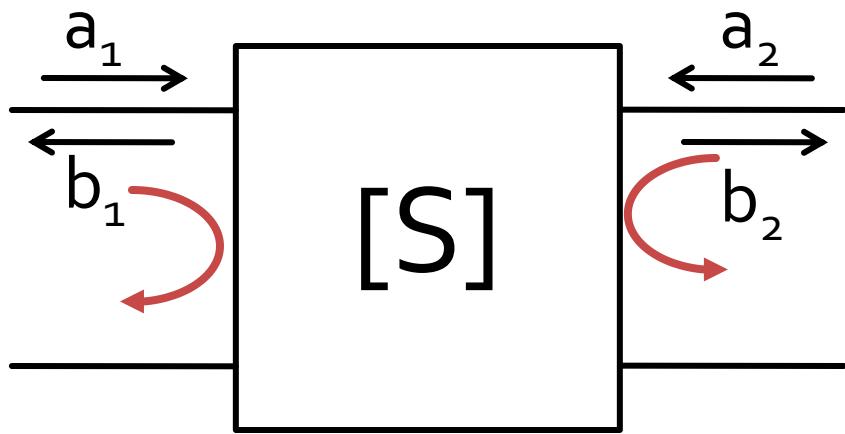
$$Z_{0i} = Z_{Ri} = R_0, \forall i$$

$$R_0 = 50\Omega$$

$$[S_p] \equiv [S]$$

■ coincid!!!

Matricea S (repartitie)

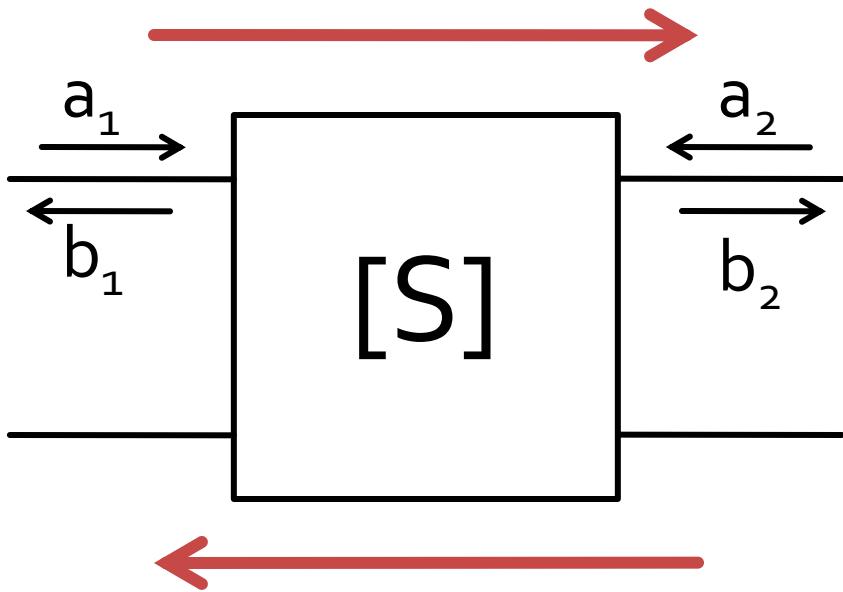


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{11} = \left. \frac{b_1}{a_1} \right|_{a_2=0} \quad S_{22} = \left. \frac{b_2}{a_2} \right|_{a_1=0}$$

- S_{11} și S_{22} sunt coeficienti de reflexie la intrare si iesire cand celalalt port este adaptat

Matricea S (repartitie)



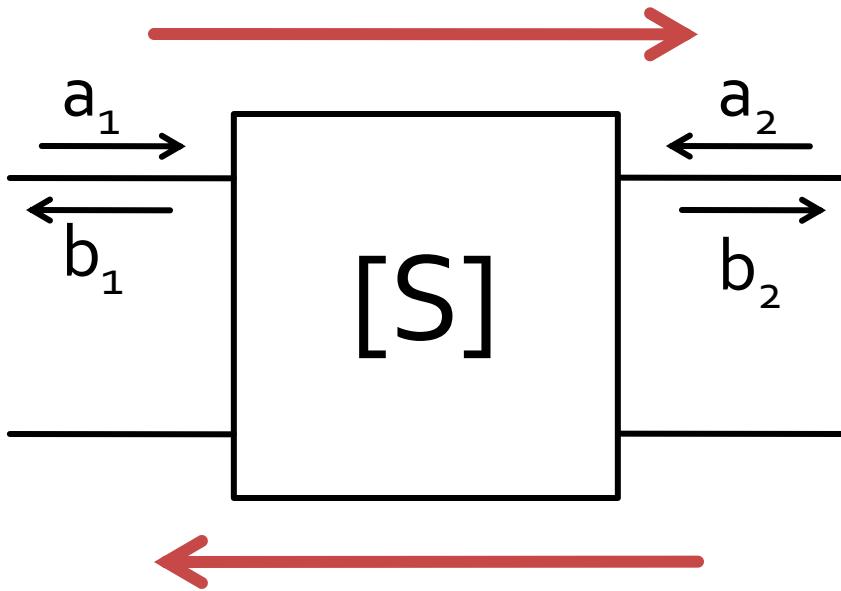
$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{21} = \frac{b_2}{a_1} \Big|_{a_2=0}$$

$$S_{12} = \frac{b_1}{a_2} \Big|_{a_1=0}$$

- S_{21} și S_{12} sunt amplificări de semnal cand celalalt port este adaptat

Matricea S (repartitie)



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$|S_{21}|^2 = \frac{\text{Putere sarcina } Z_0}{\text{Putere sursa } Z_0}$$

- a,b
 - informatia despre putere **SI** faza
- S_{ij}
 - influenta circuitului asupra puterii semnalului incluzand informatiile relativ la faza

Masurare S - VNA

■ Vector Network Analyzer

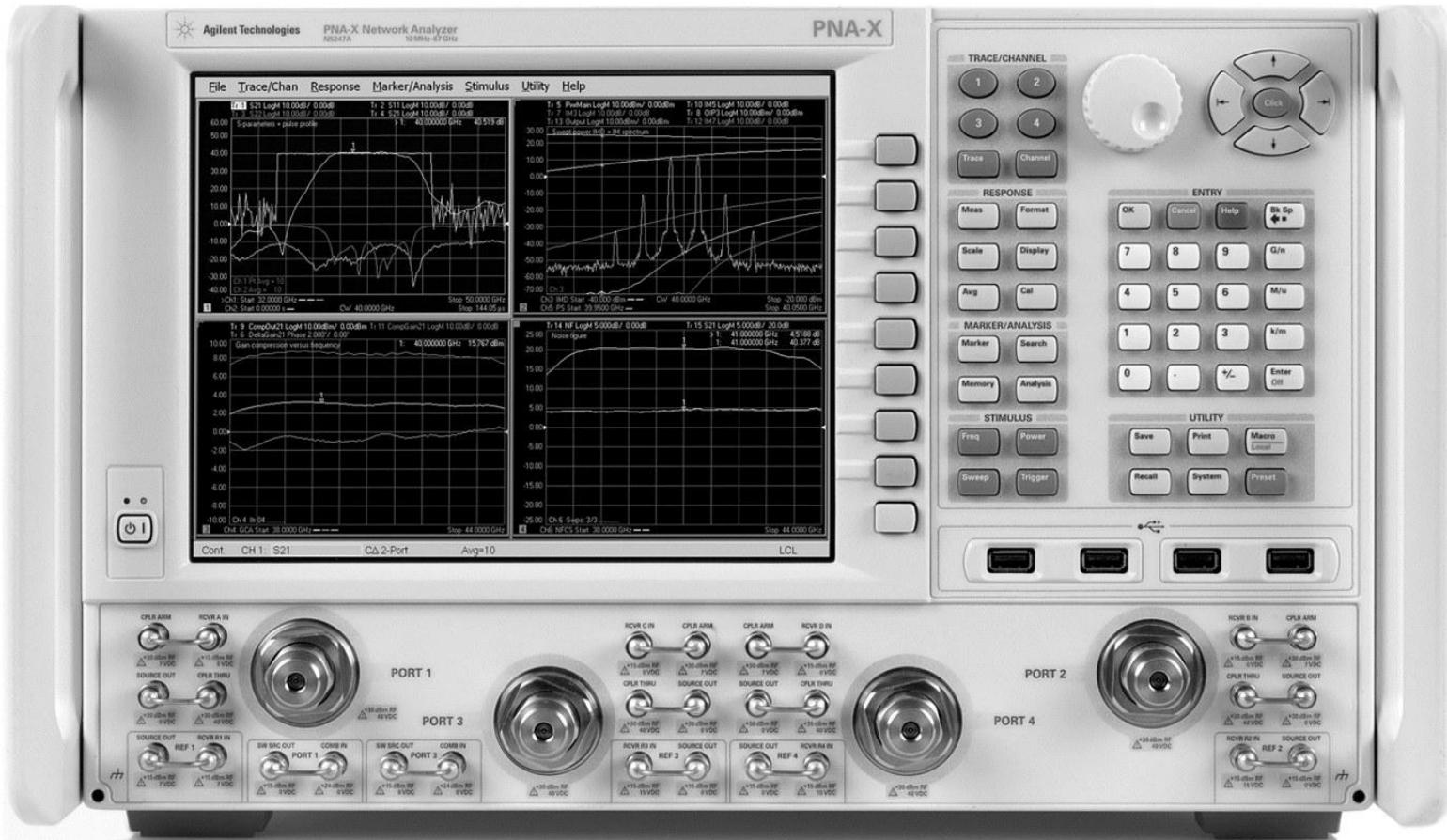


Figure 4.7

Courtesy of Agilent Technologies

Legatura dintre parametrii S si parametrii ABCD

$$A = \sqrt{\frac{Z_{01}}{Z_{02}}} \frac{(1 + S_{11} - S_{22} - \Delta S)}{2S_{21}}$$

$$B = \sqrt{Z_{01}Z_{02}} \frac{(1 + S_{11} + S_{22} + \Delta S)}{2S_{21}}$$

$$C = \frac{1}{\sqrt{Z_{01}Z_{02}}} \frac{1 - S_{11} - S_{22} + \Delta S}{2S_{21}}$$

$$D = \sqrt{\frac{Z_{02}}{Z_{01}}} \frac{1 - S_{11} + S_{22} - \Delta S}{2S_{21}}$$

$$\Delta S = S_{11}S_{22} - S_{12}S_{21}$$

$$S_{11} = \frac{AZ_{02} + B - CZ_{01}Z_{02} - DZ_{01}}{AZ_{02} + B + CZ_{01}Z_{02} + DZ_{01}}$$

$$S_{12} = \frac{2(AD - BC)\sqrt{Z_{01}Z_{02}}}{AZ_{02} + B + CZ_{01}Z_{02} + DZ_{01}}$$

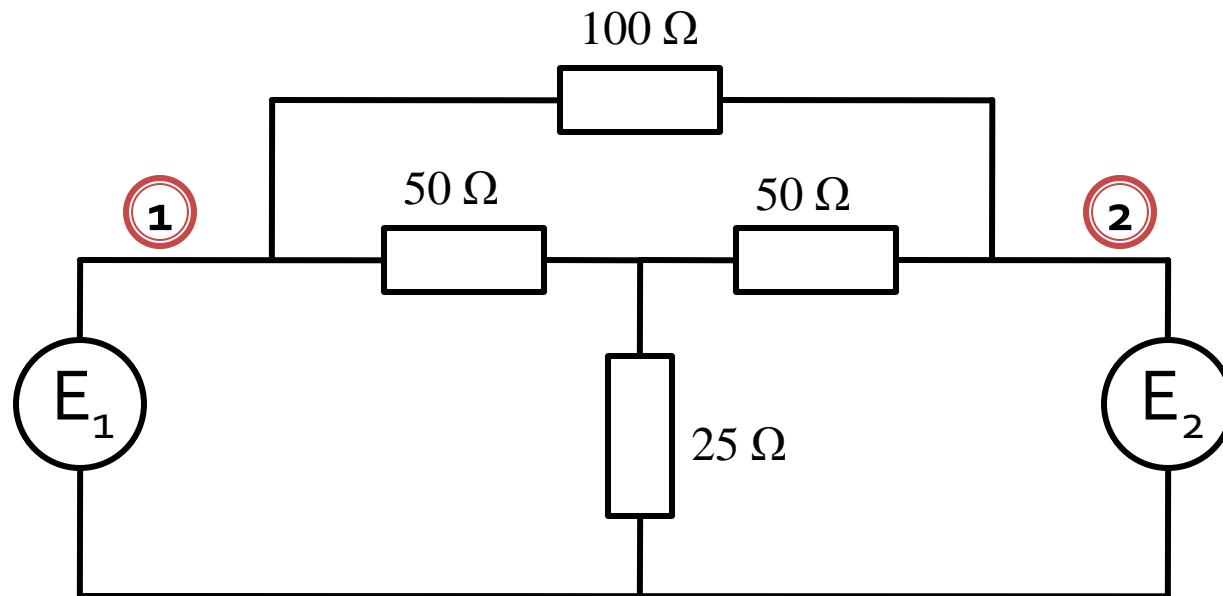
$$S_{21} = \frac{2\sqrt{Z_{01}Z_{02}}}{AZ_{02} + B + CZ_{01}Z_{02} + DZ_{01}}$$

$$S_{22} = \frac{-AZ_{02} + B - CZ_{01}Z_{02} + DZ_{01}}{AZ_{02} + B + CZ_{01}Z_{02} + DZ_{01}}$$

**Analiza la nivel de rețea a
circuitelor de microunde**

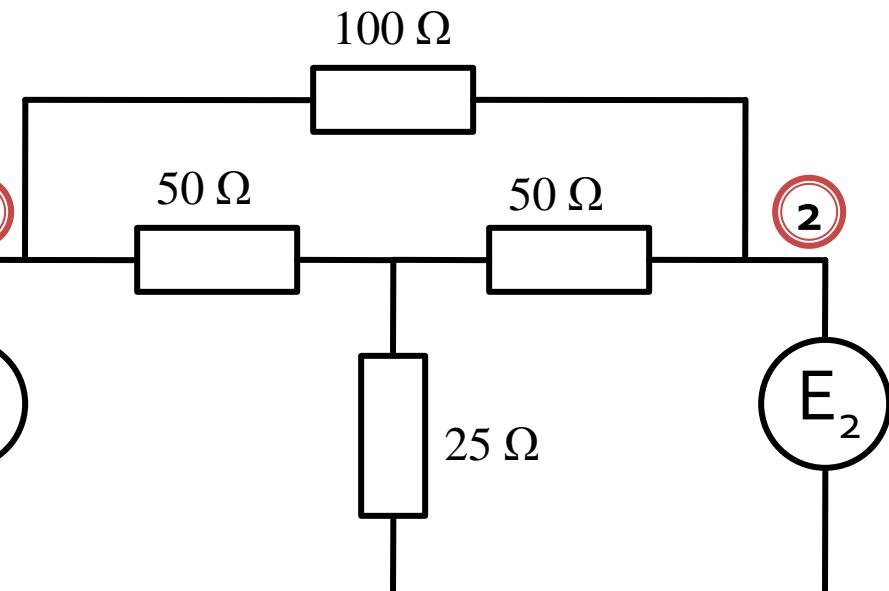
Analiza pe mod par/impar (even/odd)

- utilă/necesară pentru multiporti
- exemplu, rezistori, circuit cu 2 porturi

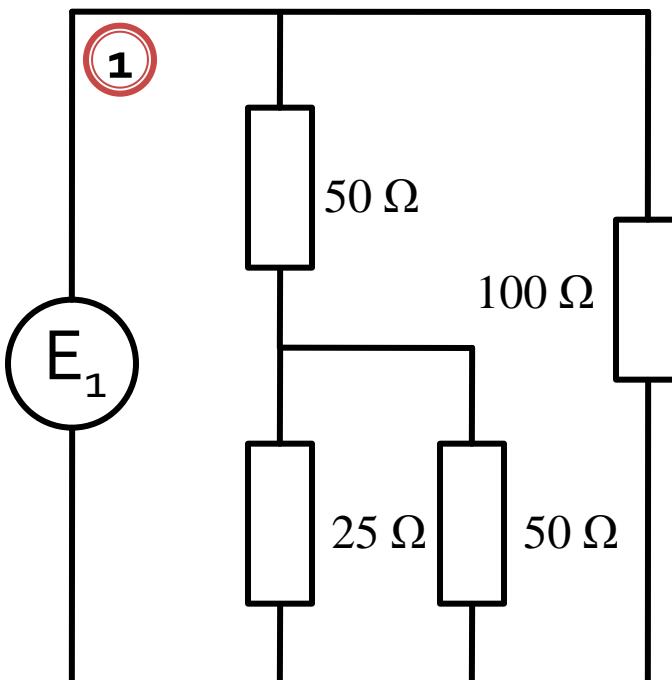


Analiza pe mod par/impar (even/odd)

- presupunem ca doresc Y_{11}
- $E_2 = 0$



$$Y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2=0}$$

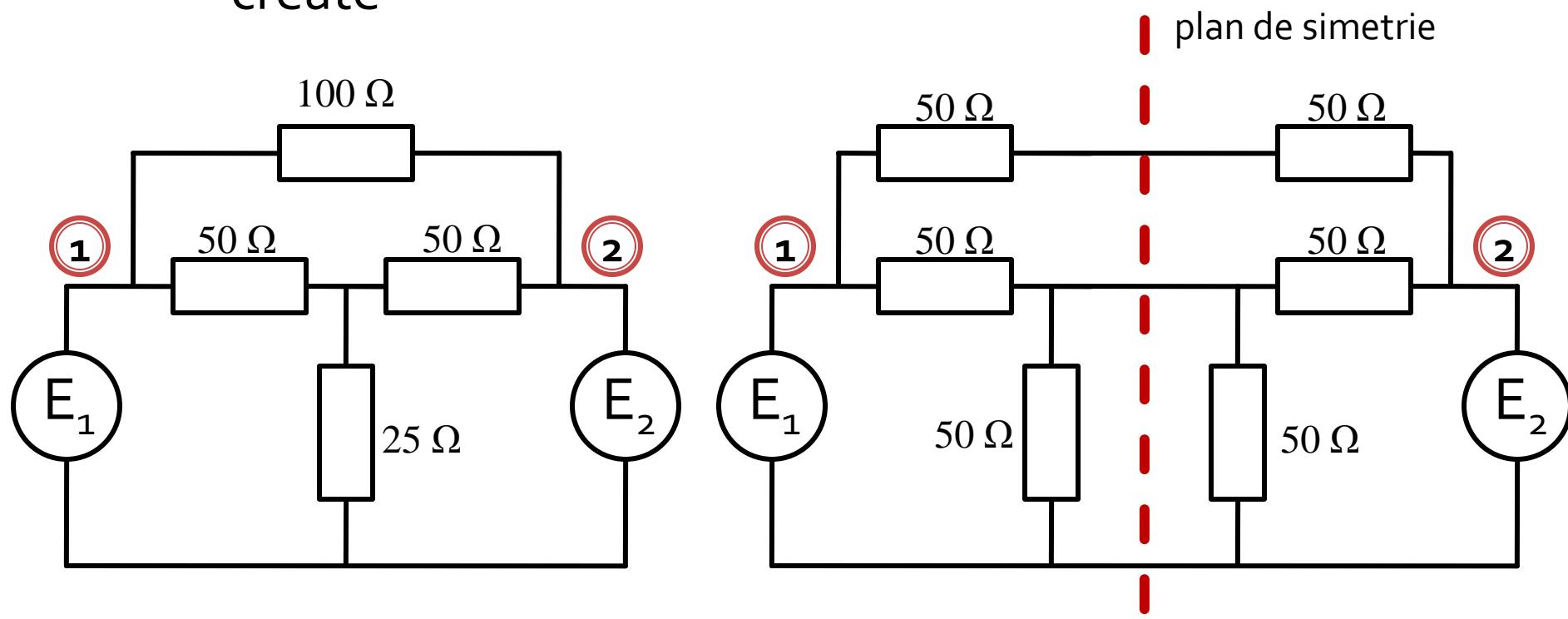


$$\begin{aligned} R_{ech} &= 100\Omega \parallel (50\Omega + 25\Omega \parallel 50\Omega) = \\ &= 100\Omega \parallel (50\Omega + 16.67\Omega) = 100\Omega \parallel 66.67\Omega = 40\Omega \end{aligned}$$

$$Y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2=0} = 0.025S$$

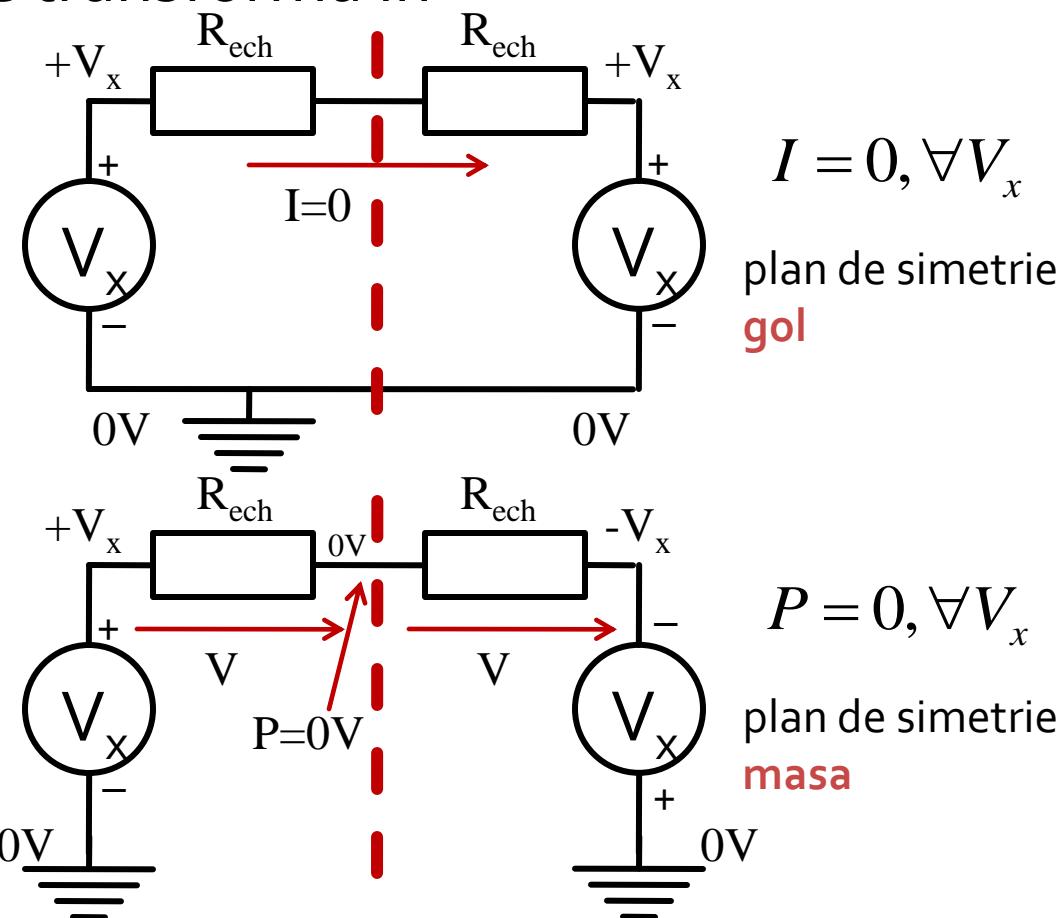
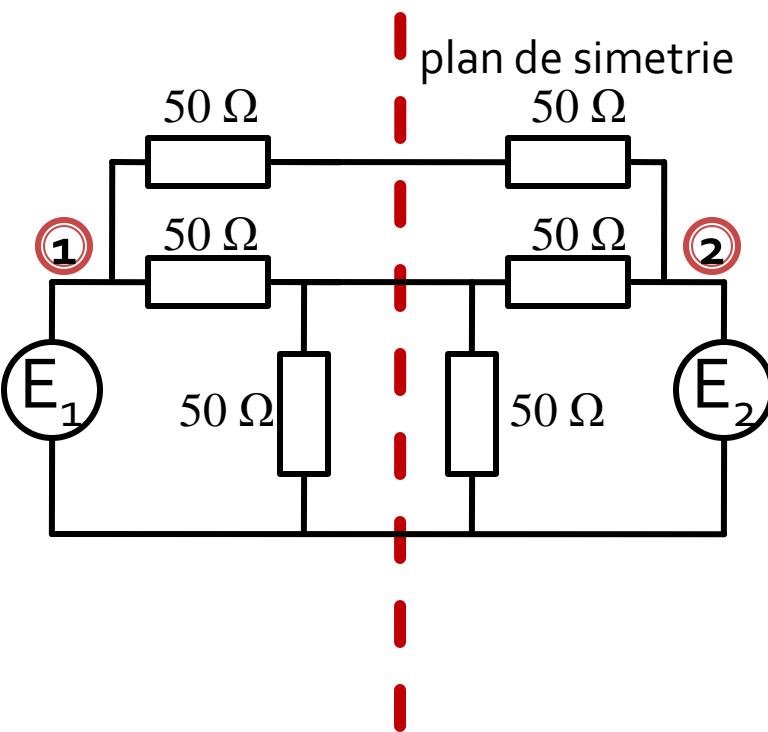
Analiza pe mod par/impar (even/odd)

- analiza pe mod par/impar beneficiaza de existenta in circuit a unor plane de simetrie
 - initiale
 - create



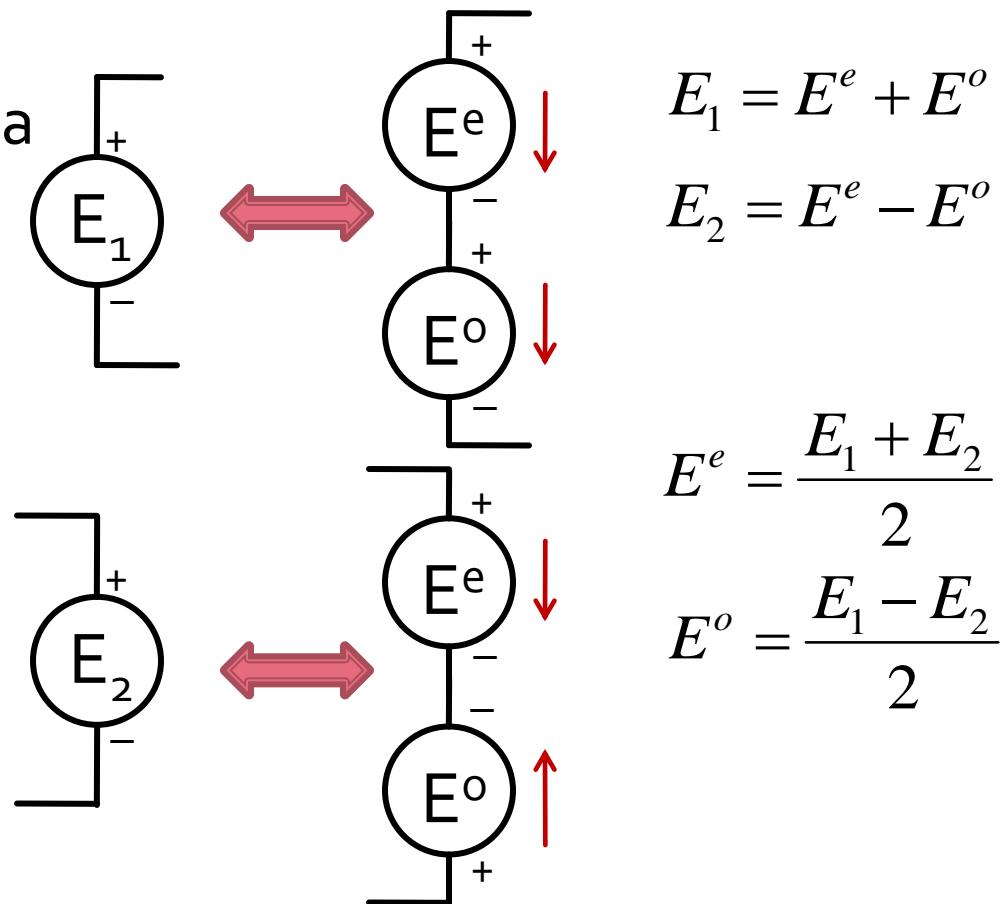
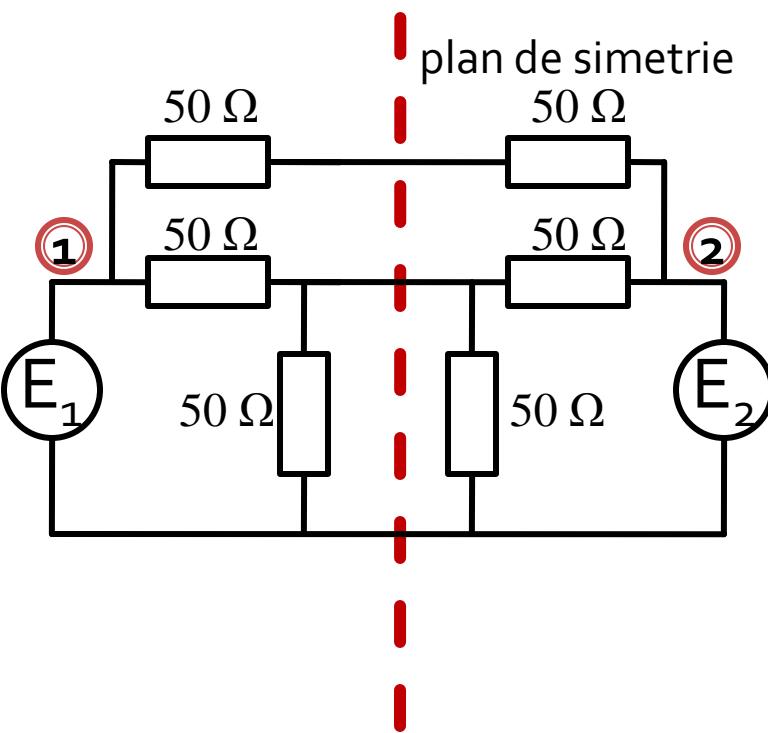
Analiza pe mod par/impar (even/odd)

- la atacul porturilor cu surse simetrice/antisimetrice planele de simetrie se transforma in
 - gol virtual
 - masa virtuala



Analiza pe mod par/impar (even/odd)

- orice combinatie de 2 surse poate fi echivalata pentru circuitele liniare cu o suprapunere:
 - o sursa simetrica
 - o sursa antisimetrica



$$E_1 = E^e + E^o$$

$$E_2 = E^e - E^o$$

$$E^e = \frac{E_1 + E_2}{2}$$

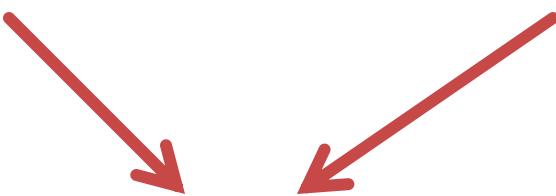
$$E^o = \frac{E_1 - E_2}{2}$$

Analiza pe mod par/impar (even/odd)

- In circuite liniare putem aplica suprapunerea efectelor

Efect (Sursa₁ + Sursa₂) = Efect (Sursa₁) + Efect (Sursa₂)

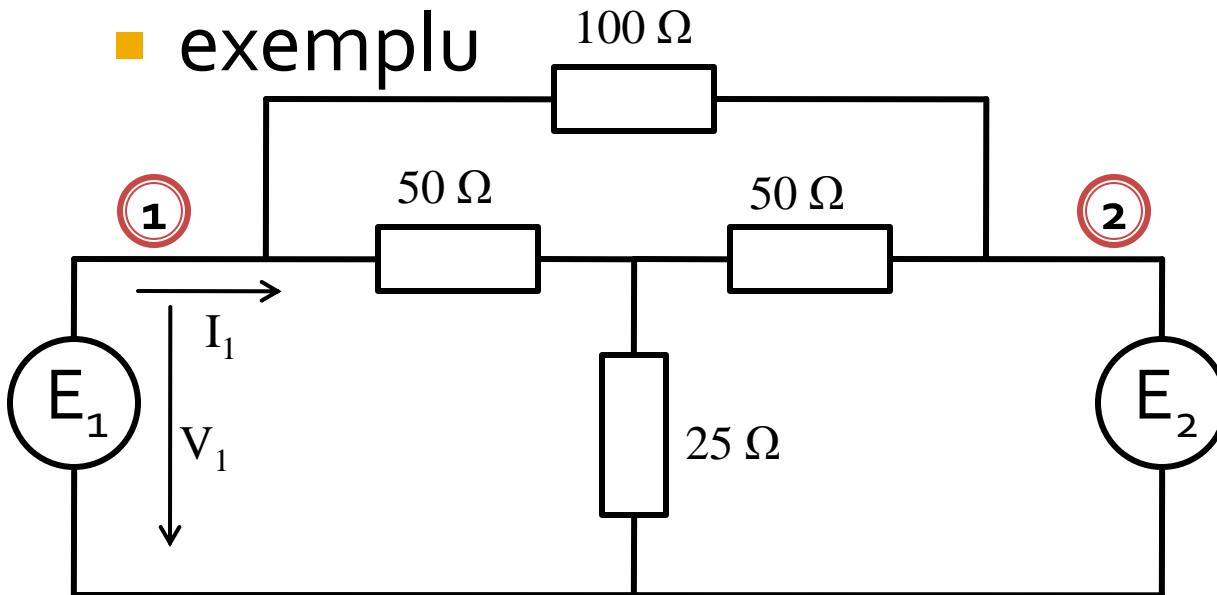
Efect (PAR+ IMPAR) = Efect (PAR) + Efect (IMPAR)



Putem beneficia de avantajele simetriilor!!

Analiza pe mod par/impar (even/odd)

■ exemplu

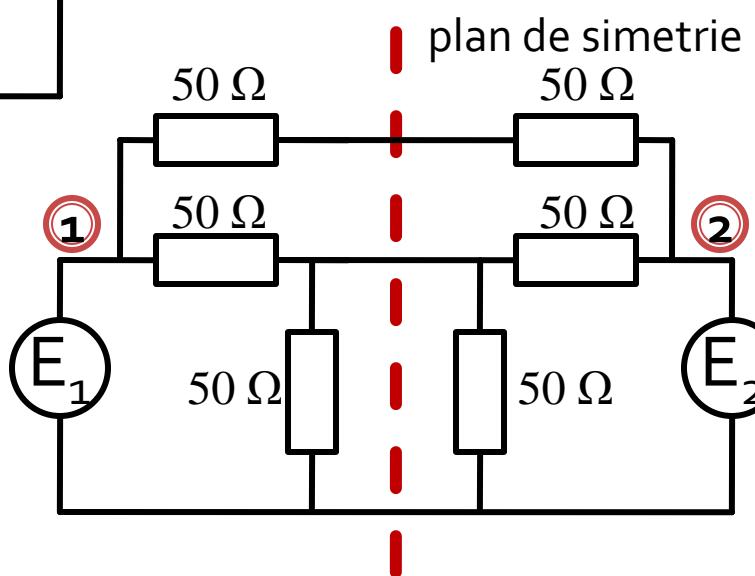


$$Y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2=0}$$

$$V_2 \equiv E_2 = 0 \Rightarrow$$

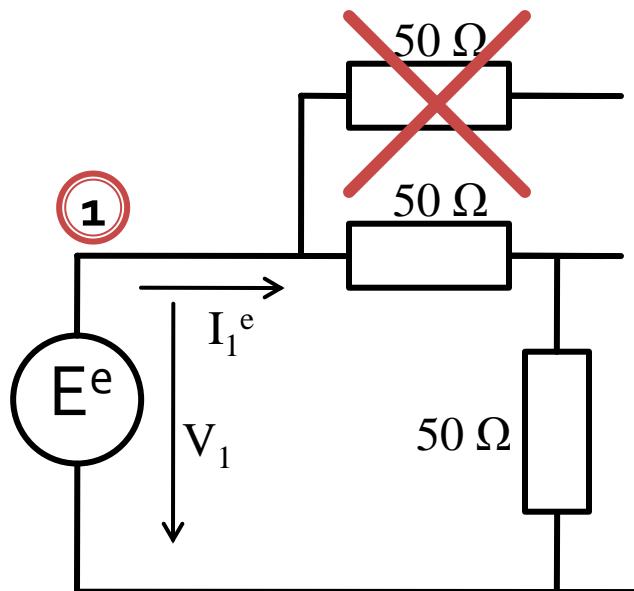
$$E^e = \frac{E_1}{2}$$

$$E^o = \frac{E_1}{2}$$



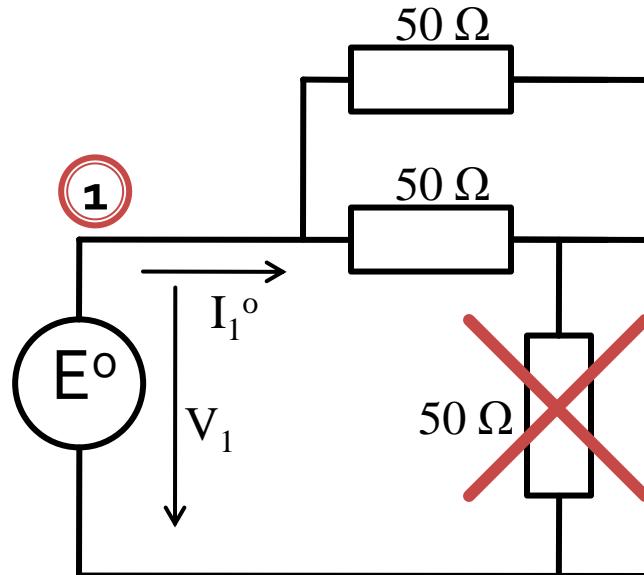
Analiza pe mod par/impar (even/odd)

- analiza pe mod par/impar



$$R_{ech}^e = 50\Omega + 50\Omega = 100\Omega$$

$$I_1^e = \frac{E^e}{R_{ech}^e} = \frac{E_1/2}{100\Omega} = \frac{E_1}{200\Omega}$$

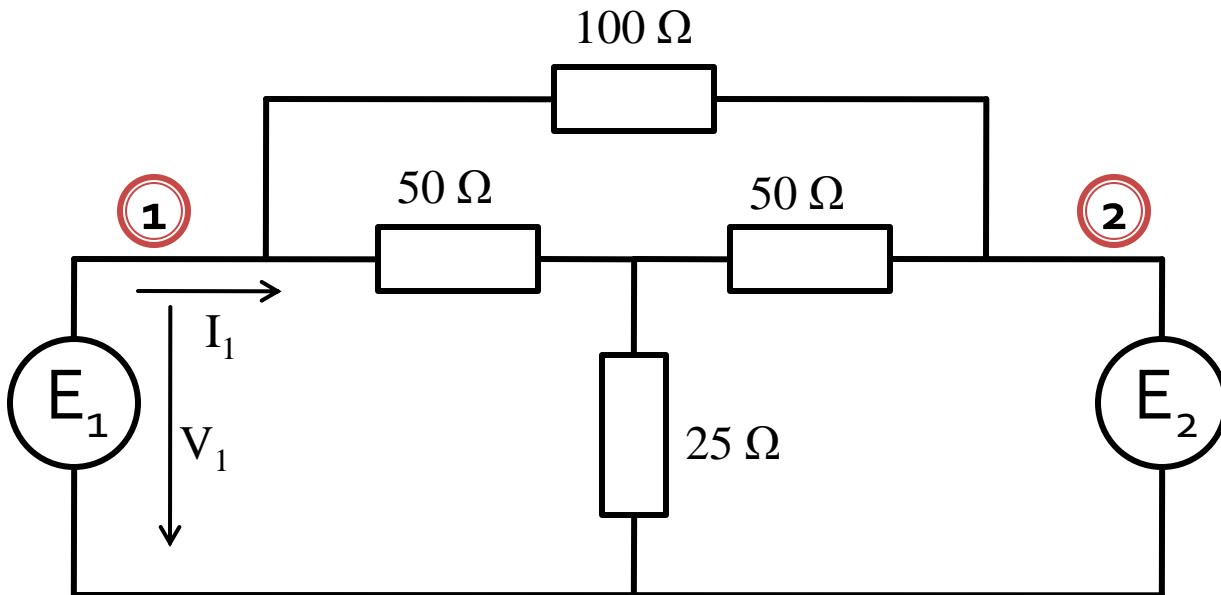


$$R_{ech}^o = 50\Omega || 50\Omega = 25\Omega$$

$$I_1^o = \frac{E^o}{R_{ech}^o} = \frac{E_1/2}{25\Omega} = \frac{E_1}{50\Omega}$$

Analiza pe mod par/impar (even/odd)

- suprapunerea efectelor



$$I_1 = I_1^e + I_1^o$$

$$V_1 = V_1^e + V_1^o$$

$$I_1 = I_1^e + I_1^o = \frac{E_1}{200\Omega} + \frac{E_1}{50\Omega} = \frac{E_1}{40\Omega}$$

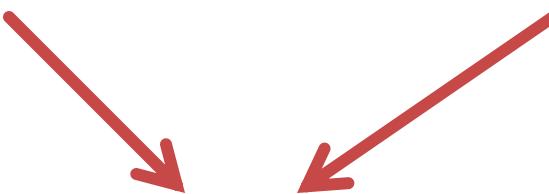
$$V_1 = V_1^e + V_1^o = E_1$$

$$Y_{11} = \frac{I_1}{V_1} = \frac{1}{40\Omega} = 0.025S$$

Analiza pe mod par/impar (even/odd)

- În circuite liniare putem aplica suprapunerea efectelor
- avantaje
 - reducerea complexității circuitului
 - reducerea numărului de porturi (**principalul** avantaj)

$$\text{Efect (PAR+ IMPAR)} = \text{Efect (PAR)} + \text{Efect (IMPAR)}$$



Putem beneficia de avantajele simetriilor!!

**Cuploare directionale si
divizoare de putere**

Cuploare/Divizoare

- Funcționalitatea dorită:
 - divizarea
 - combinarea
- puterii semnalului

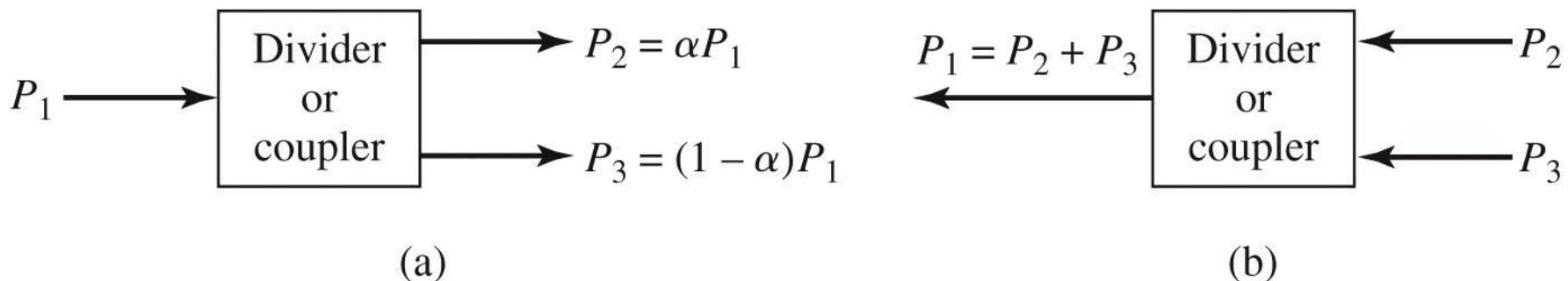


Figure 7.1
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Circuite cu trei porți

- numite și joncțiune în T
- caracterizate de o matrice S 3×3

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

- circuitul este **reciproc** dacă **nu** conține:
 - materiale anizotrope (de obicei ferite)
 - circuite active
- e de dorit să obținem funcționalitatea dorită de divizare/combinare de putere **fără pierderi** interne
- e de dorit să obținem circuitul **adaptat simultan la toate porțile**
 - evitarea unor pierderi externe de putere

Circuite cu trei porți

- circuit reciproc

$$[S] = [S]^t \quad S_{ij} = S_{ji}, \forall j \neq i$$

$$S_{12} = S_{21}, S_{13} = S_{31}, S_{23} = S_{32}$$

- adaptat simultan la toate portile

$$S_{ii} = 0, \forall i \quad S_{11} = 0, S_{22} = 0, S_{33} = 0$$

- matricea S devine:

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix}$$

Circuite cu trei porți

- reciproc, adaptat, matricea S:

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix}$$

- circuit unitar (fără pierderi)

- toata puterea introdusa pe un port se regaseste la celelalte porturi

$$[S]^* \cdot [S]^t = [1] \quad \sum_{k=1}^N S_{ki} \cdot S_{kj}^* = \delta_{ij}, \forall i, j$$

$$\sum_{k=1}^N S_{ki} \cdot S_{ki}^* = 1 \quad \sum_{k=1}^N S_{ki} \cdot S_{kj}^* = 0, \forall i \neq j$$

Circuite cu trei porți

- circuit unitar (fără pierderi)

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix} \quad \sum_{k=1}^N S_{ki} \cdot S_{ki}^* = 1$$
$$\sum_{k=1}^N S_{ki} \cdot S_{kj}^* = 0, \forall i \neq j$$

- 6 ecuații / 3 necunoscute

$$|S_{12}|^2 + |S_{13}|^2 = 1 \quad S_{13}^* S_{23} = 0$$

$$|S_{12}|^2 + |S_{23}|^2 = 1 \quad S_{12}^* S_{13} = 0$$

$$|S_{13}|^2 + |S_{23}|^2 = 1 \quad S_{23}^* S_{12} = 0$$

- nici o soluție posibila

Circuite cu trei porți

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix}$$

- 6 ecuații / 3 necunoscute
 - nici o soluție posibila
- Un circuit cu 3 porți **NU** poate fi simultan:
 - reciproc
 - fara pierderi
 - adaptat simultan la toate cele 3 porți
- Renunțarea la una din cele 3 condiții conduce la circuite realizabile

Circuit cu trei porți nereciproc

- de obicei cu materiale anizotrope, ferite
- **nereciproc**, dar adaptat simultan și fără pierderi

$$S_{ij} \neq S_{ji}$$

- matricea S

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$$

- 6 ecuații / 6 necunoscute

$$|S_{12}|^2 + |S_{13}|^2 = 1 \quad S_{31}^* S_{32} = 0$$

$$|S_{21}|^2 + |S_{23}|^2 = 1 \quad S_{21}^* S_{23} = 0$$

$$|S_{31}|^2 + |S_{32}|^2 = 1 \quad S_{12}^* S_{13} = 0$$

Circuit cu trei porți nereciproc

- două solutii posibile
- circulatoare
 - în sens orar direct

$$S_{12} = S_{23} = S_{31} = 0$$

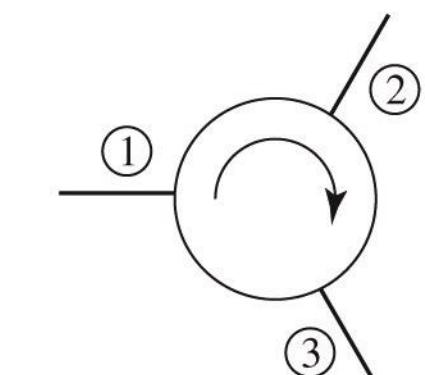
$$|S_{21}| = |S_{32}| = |S_{13}| = 1$$

- în sens orar invers

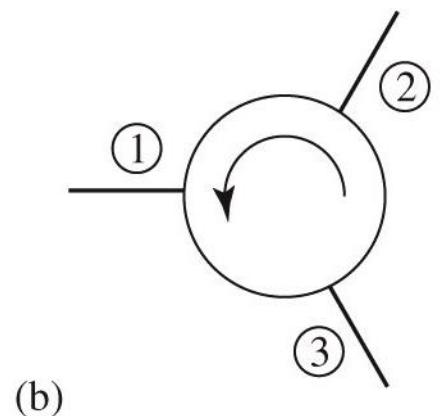
$$S_{21} = S_{32} = S_{13} = 0$$

$$|S_{12}| = |S_{23}| = |S_{31}| = 1$$

$$[S] = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$



$$[S] = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$



Circuit cu trei porți neadaptat

- Un circuit cu 3 porți reciproc și fără pierderi poate fi adaptat numai la 2 porți

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

$$S_{13}^* S_{23} = 0$$

$$\begin{aligned} S_{12}^* S_{13} + S_{23}^* S_{33} &= 0 \\ S_{23}^* S_{12} + S_{33}^* S_{13} &= 0 \end{aligned}$$

$$\begin{aligned} S_{13} &= S_{23} = 0 \\ |S_{13}| &= |S_{23}| \end{aligned}$$

$$\begin{aligned} |S_{12}|^2 + |S_{13}|^2 &= 1 \\ |S_{12}|^2 + |S_{23}|^2 &= 1 \\ |S_{13}|^2 + |S_{23}|^2 + |S_{33}|^2 &= 1 \end{aligned}$$

$$|S_{12}| = |S_{33}| = 1$$

Circuit cu trei porți neadaptat

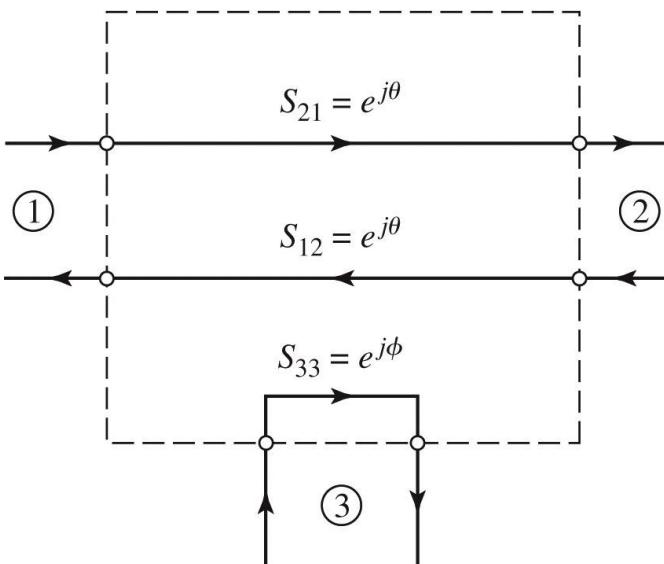
- Un circuit cu 3 porți reciproc și fără pierderi

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

$$S_{13} = S_{23} = 0 \quad |S_{12}| = |S_{33}| = 1$$

$$S_{12} = e^{j\theta} \quad S_{33} = e^{j\phi}$$

$$[S] = \begin{bmatrix} 0 & e^{j\theta} & 0 \\ e^{j\theta} & 0 & 0 \\ 0 & 0 & e^{j\phi} \end{bmatrix}$$



- Un circuit cu 3 porți reciproc și fără pierderi **degenerează** în două componente separate:
 - **o linie** fără pierderi, adaptată, între două dintre porturi
 - **al treilea port** este **separat** și **dezadaptat**

Circuite cu patru porți

- caracterizate de o matrice $S_{4 \times 4}$

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

- circuitul este **reciproc** dacă nu conține:
 - materiale anizotrope (de obicei ferite)
 - circuite active
- e de dorit să obținem funcționalitatea dorită de divizare/combinare de putere **fără pierderi** interne
- e de dorit să obținem circuitul **adaptat simultan la toate porțile**
 - evitarea unor pierderi externe de putere

Circuite cu patru porți

- circuit reciproc

$$[S] = [S]^t \quad S_{ij} = S_{ji}, \forall j \neq i$$

$$S_{12} = S_{21}, S_{13} = S_{31}, S_{23} = S_{32}$$

- adaptat simultan la toate portile

$$S_{ii} = 0, \forall i \quad S_{11} = 0, S_{22} = 0, S_{33} = 0, S_{44} = 0$$

- matricea S devine:

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{bmatrix}$$

Circuite cu patru porți

- reciproc, adaptat, matricea S :

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{bmatrix}$$

- circuit unitar (fără pierderi)

- toata puterea introdusa pe un port se regaseste la celelalte porturi

$$[S]^* \cdot [S]^t = [1] \quad \sum_{k=1}^N S_{ki} \cdot S_{kj}^* = \delta_{ij}, \forall i, j$$

$$\sum_{k=1}^N S_{ki} \cdot S_{ki}^* = 1 \quad \sum_{k=1}^N S_{ki} \cdot S_{kj}^* = 0, \forall i \neq j$$

Circuite cu patru porți

$$S_{13}^* \cdot S_{23} + S_{14}^* \cdot S_{24} = 0 \quad / \cdot S_{24}$$

$$S_{14}^* \cdot S_{13} + S_{24}^* \cdot S_{23} = 0 \quad / \cdot S_{13}^*$$

$$\underline{S_{14}^* \cdot (|S_{13}|^2 - |S_{24}|^2) = 0}$$

$$S_{12}^* \cdot S_{23} + S_{14}^* \cdot S_{34} = 0 \quad / \cdot S_{12}$$

$$S_{14}^* \cdot S_{12} + S_{34}^* \cdot S_{23} = 0 \quad / \cdot S_{34}^*$$

$$\underline{S_{23} \cdot (|S_{12}|^2 - |S_{34}|^2) = 0}$$

- o solutie: $S_{14} = S_{23} = 0$
- cuploul rezulta **directional**

$$|S_{12}|^2 + |S_{13}|^2 = 1 \quad \rightarrow |S_{13}| = |S_{24}|$$

$$|S_{12}|^2 + |S_{24}|^2 = 1 \quad \rightarrow |S_{12}| = |S_{34}|$$

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & 0 \\ S_{12} & 0 & 0 & S_{24} \\ S_{13} & 0 & 0 & S_{34} \\ 0 & S_{24} & S_{34} & 0 \end{bmatrix}$$

Circuite cu patru porți

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & 0 \\ S_{12} & 0 & 0 & S_{24} \\ S_{13} & 0 & 0 & S_{34} \\ 0 & S_{24} & S_{34} & 0 \end{bmatrix} \quad |S_{12}| = |S_{34}| = \alpha \quad |S_{13}| = |S_{24}| = \beta$$

β – coeficientul de cuplaj în tensiune

■ Alegem referintele de fază

$$S_{12} = S_{34} = \alpha \quad S_{13} = \beta \cdot e^{j\theta} \quad S_{24} = \beta \cdot e^{j\phi}$$

$$S_{12}^* \cdot S_{13} + S_{24}^* \cdot S_{34} = 0 \quad \rightarrow \quad \theta + \phi = \pi \pm 2 \cdot n \cdot \pi$$

$$|S_{12}|^2 + |S_{24}|^2 = 1 \quad \rightarrow \quad \alpha^2 + \beta^2 = 1$$

■ Cealalta solutie posibila pentru ecuatiiile anterioare ofera fie aceeasi solutie (cu alta referinta de fază) fie un caz degenerat

$$S_{14}^* \cdot (|S_{13}|^2 - |S_{24}|^2) = 0 \quad S_{23} \cdot (|S_{12}|^2 - |S_{34}|^2) = 0$$

Circuite cu patru porți

- Un circuit cu 4 porti care este simultan:
 - adaptat la toate portile
 - reciproc
 - fara pierderi
- este **intotdeauna directional**
 - puterea de semnal introdusa pe un port este trimisa **numai spre doua** din celelalte trei porturi

$$[S] = \begin{bmatrix} 0 & \alpha & \beta \cdot e^{j\theta} & 0 \\ \alpha & 0 & 0 & \beta \cdot e^{j\phi} \\ \beta \cdot e^{j\theta} & 0 & 0 & \alpha \\ 0 & \beta \cdot e^{j\phi} & \alpha & 0 \end{bmatrix}$$

Circuite cu patru porți

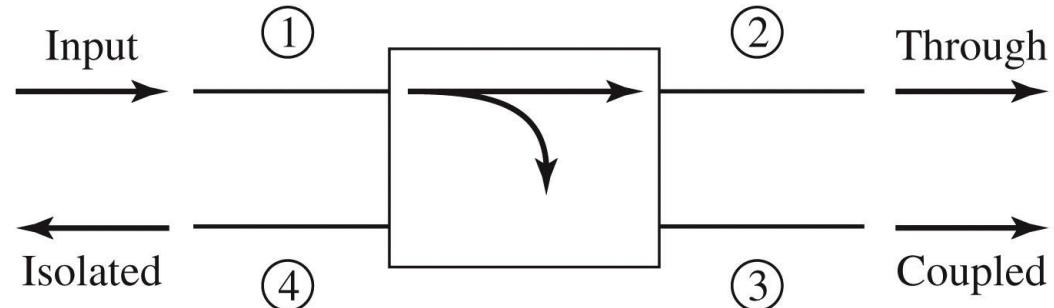
- 2 cazuri mai des întâlnite în practică
 - cupluri simetrie $\theta = \phi = \pi/2$

$$[S] = \begin{bmatrix} 0 & \alpha & j\beta & 0 \\ \alpha & 0 & 0 & j\beta \\ j\beta & 0 & 0 & \alpha \\ 0 & j\beta & \alpha & 0 \end{bmatrix}$$

- cupluri asymmetrice $\theta = 0, \phi = \pi$

$$[S] = \begin{bmatrix} 0 & \alpha & \beta & 0 \\ \alpha & 0 & 0 & -\beta \\ \beta & 0 & 0 & \alpha \\ 0 & -\beta & \alpha & 0 \end{bmatrix}$$

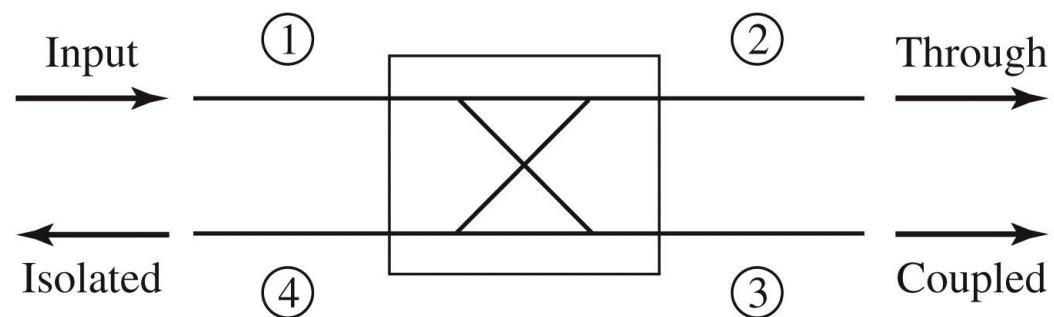
Cuplaj directional



$$|S_{12}|^2 = \alpha^2 = 1 - \beta^2$$

$$|S_{13}|^2 = \beta^2$$

Cuplaj



$$C = 10 \log \frac{P_1}{P_3} = -20 \cdot \log(\beta) [\text{dB}]$$

Directivitate

$$D = 10 \log \frac{P_3}{P_4} = 20 \cdot \log \left(\frac{\beta}{|S_{14}|} \right) [\text{dB}]$$

Izolare

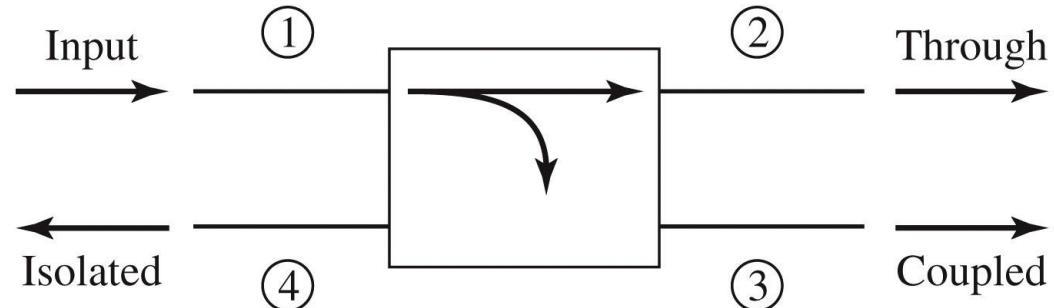
$$I = 10 \log \frac{P_1}{P_4} = -20 \cdot \log |S_{14}| [\text{dB}]$$

$$I = D + C, \text{ dB}$$

Cuploare directionale

Laborator 2

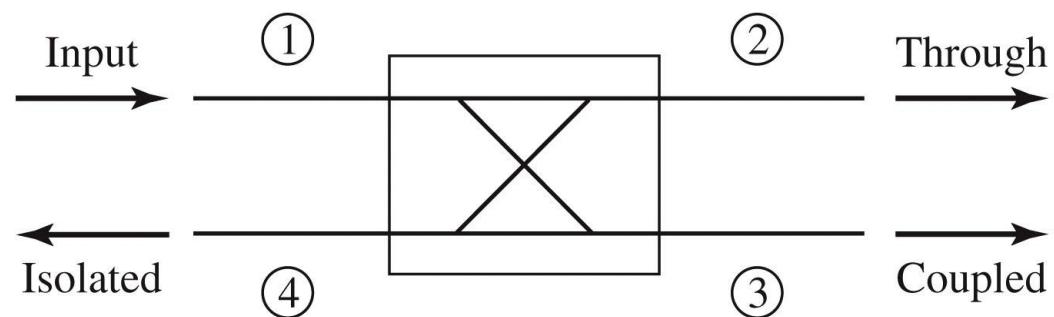
Cuplaj directional



$$|S_{12}|^2 = \alpha^2 = 1 - \beta^2$$

$$|S_{13}|^2 = \beta^2$$

Cuplaj



$$C = 10 \log \frac{P_1}{P_3} = -20 \cdot \log(\beta) [\text{dB}]$$

Directivitate

$$D = 10 \log \frac{P_3}{P_4} = 20 \cdot \log \left(\frac{\beta}{|S_{14}|} \right) [\text{dB}]$$

Izolare

$$I = 10 \log \frac{P_1}{P_4} = -20 \cdot \log |S_{14}| [\text{dB}]$$

$$I = D + C, \text{ dB}$$

Cuplорul in cuadratura

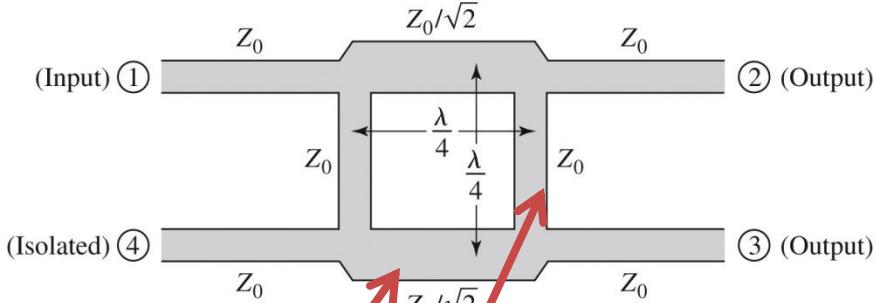


Figure 7.21
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$$y_2^2 = 1 + y_1^2$$

$$|\beta| = \frac{\sqrt{y_2^2 - 1}}{y_2}$$

$$C[\text{dB}] = -20 \cdot \log_{10} \frac{\sqrt{y_2^2 - 1}}{y_2}$$

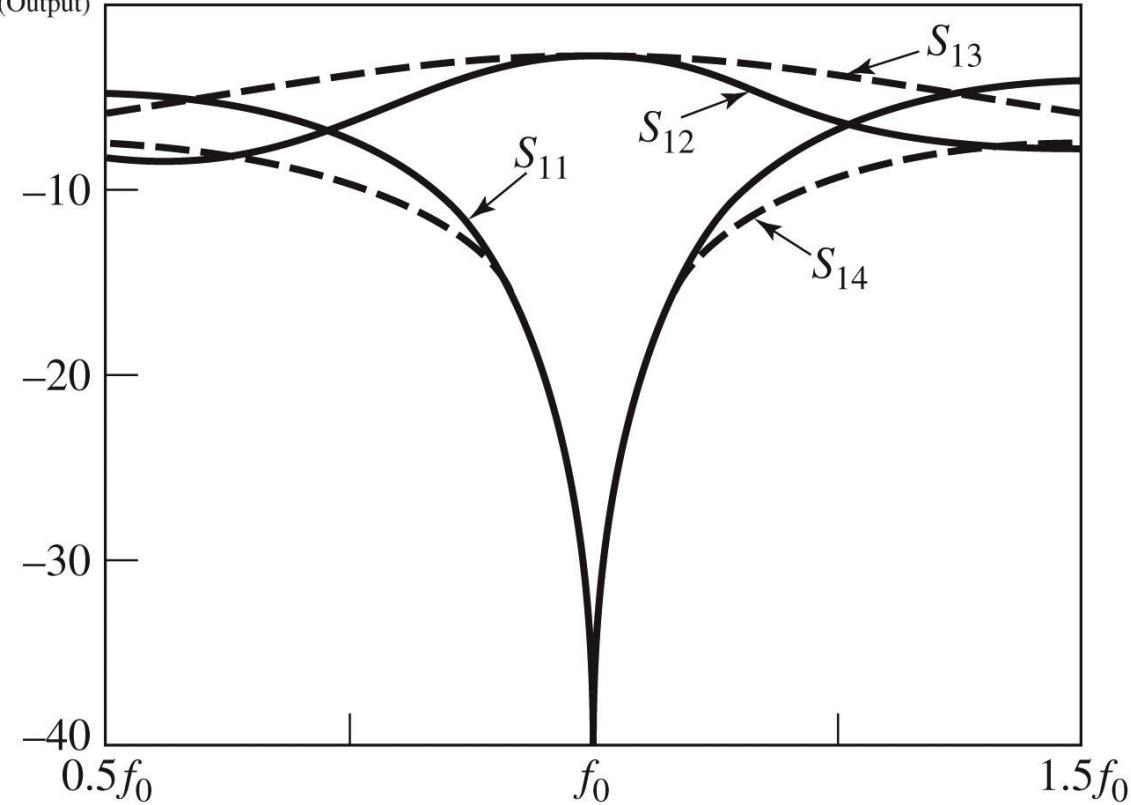
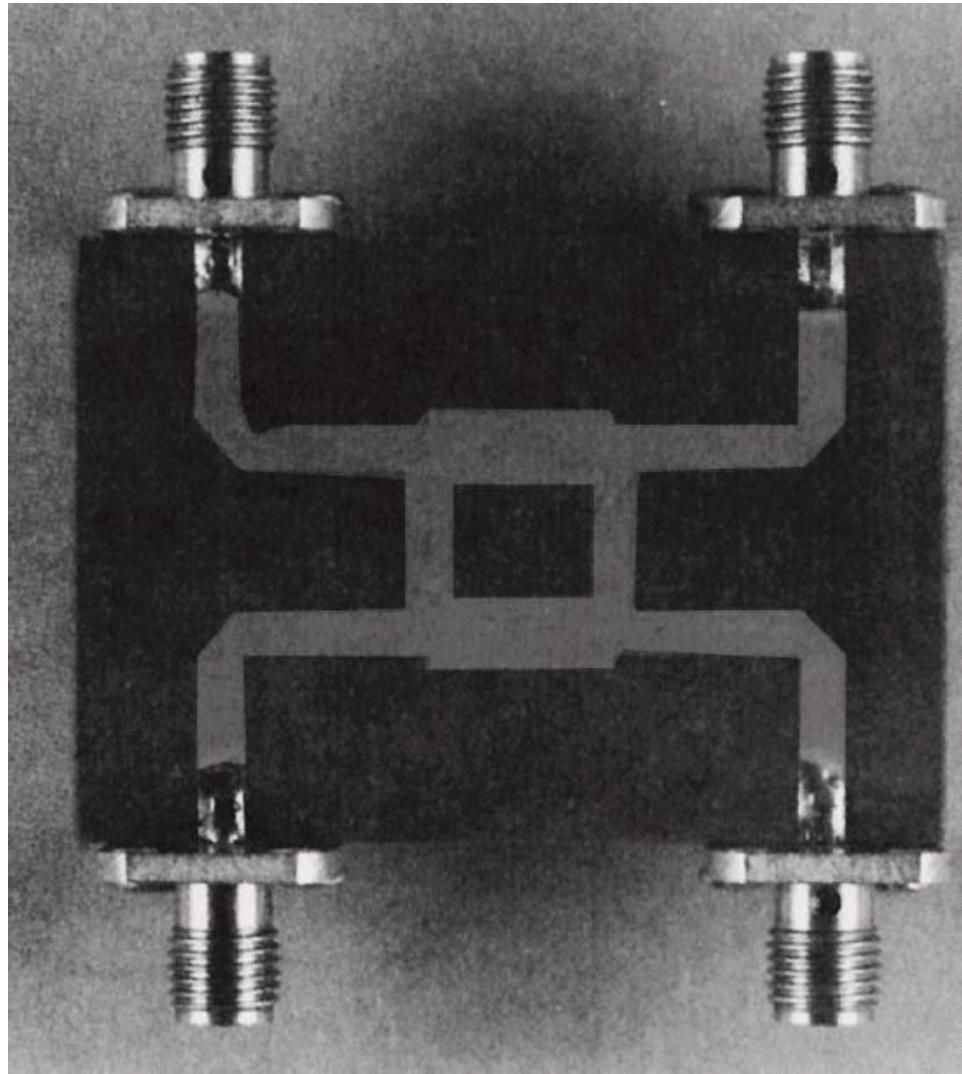
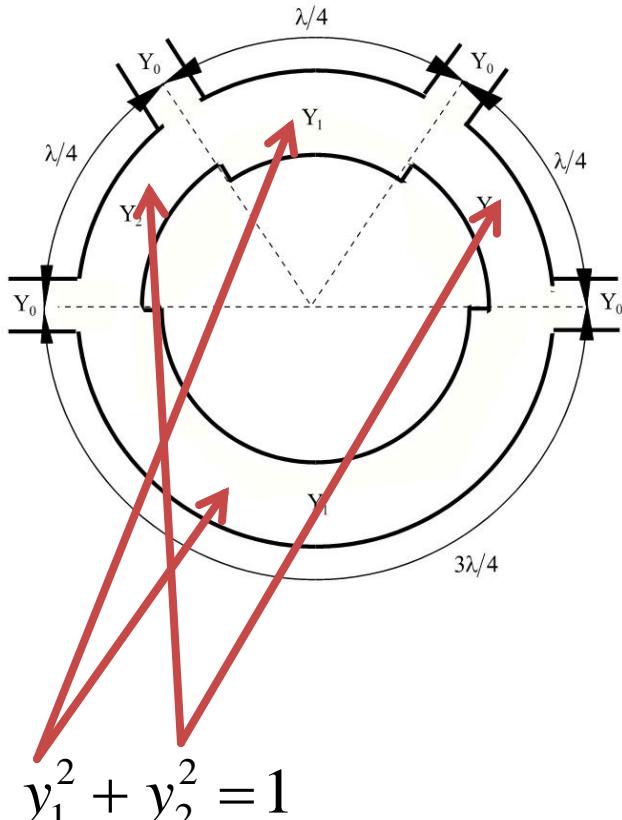


Figure 7.25
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Cuploul în inel



$$|\beta| = y_1$$

$$C \text{ [dB]} = -20 \cdot \log_{10}(y_1)$$

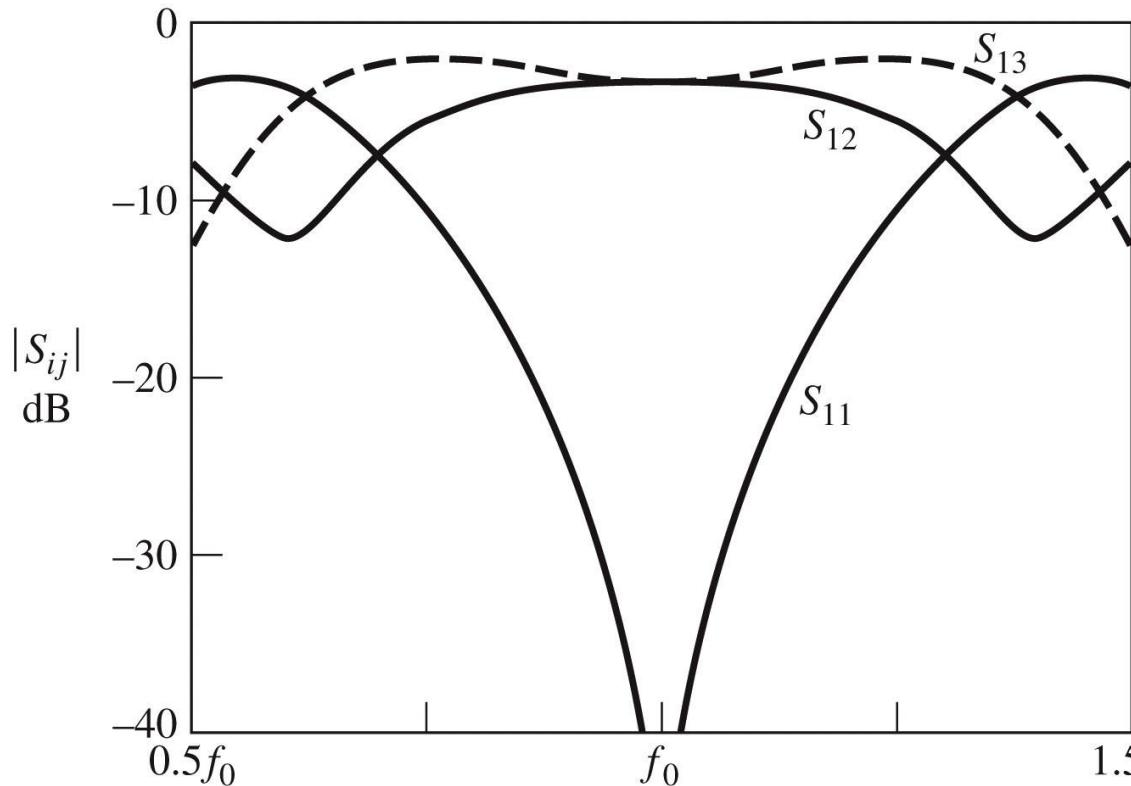


Figure 7.46
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Cupluri în inel

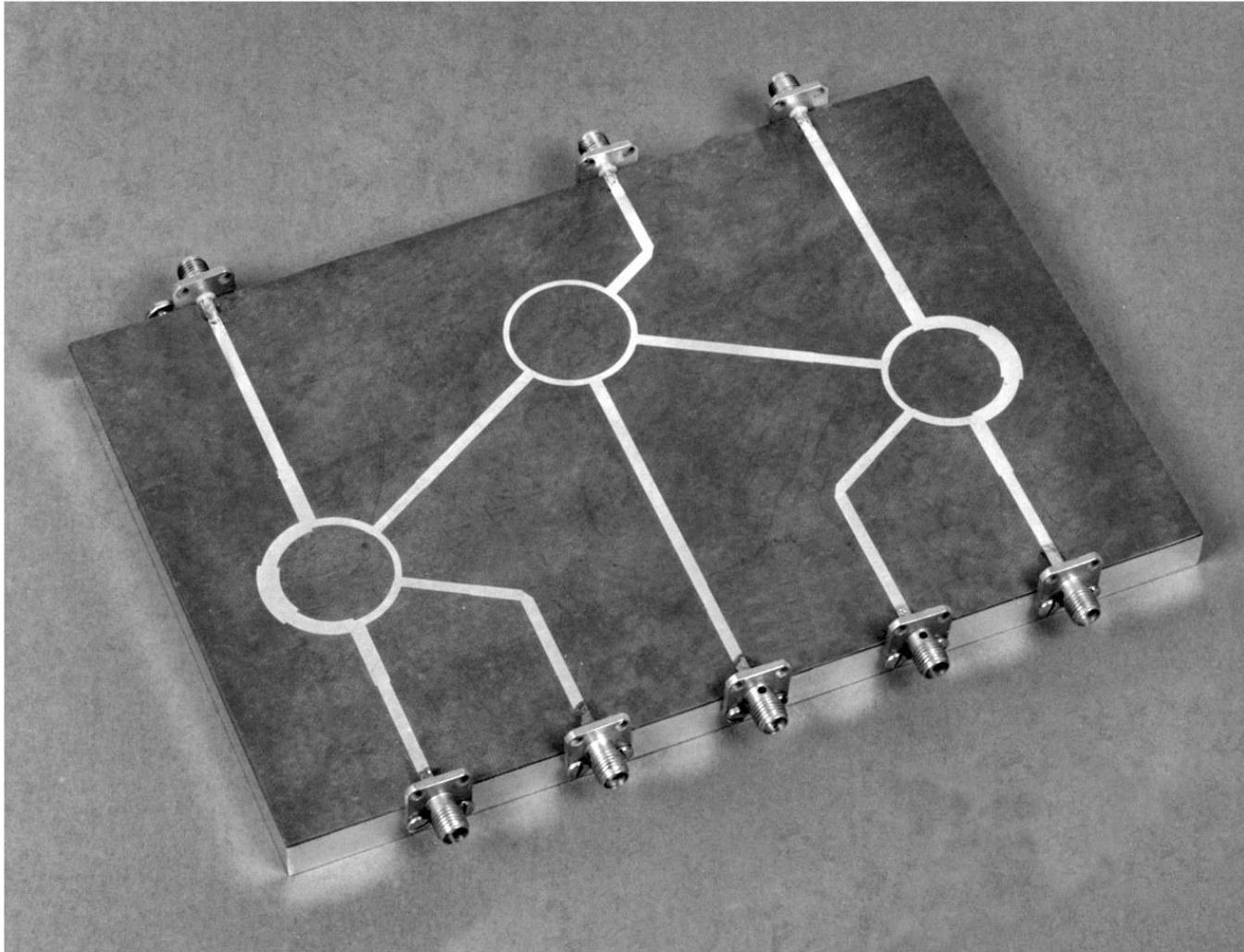
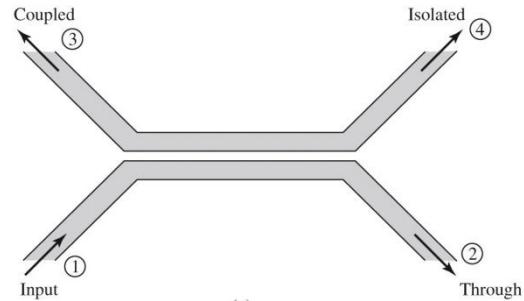


Figure 7.43
Courtesy of M. D. Abouzahra, MIT Lincoln Laboratory, Lexington, Mass.

Cuplă prin proximitate



$$Z_{ce} Z_{co} = Z_0^2$$

$$|\beta| = \frac{Z_{ce} - Z_{co}}{Z_{ce} + Z_{co}}$$

$$C [\text{dB}] = -20 \cdot \log_{10} \left(\frac{Z_{ce} - Z_{co}}{Z_{ce} + Z_{co}} \right)$$

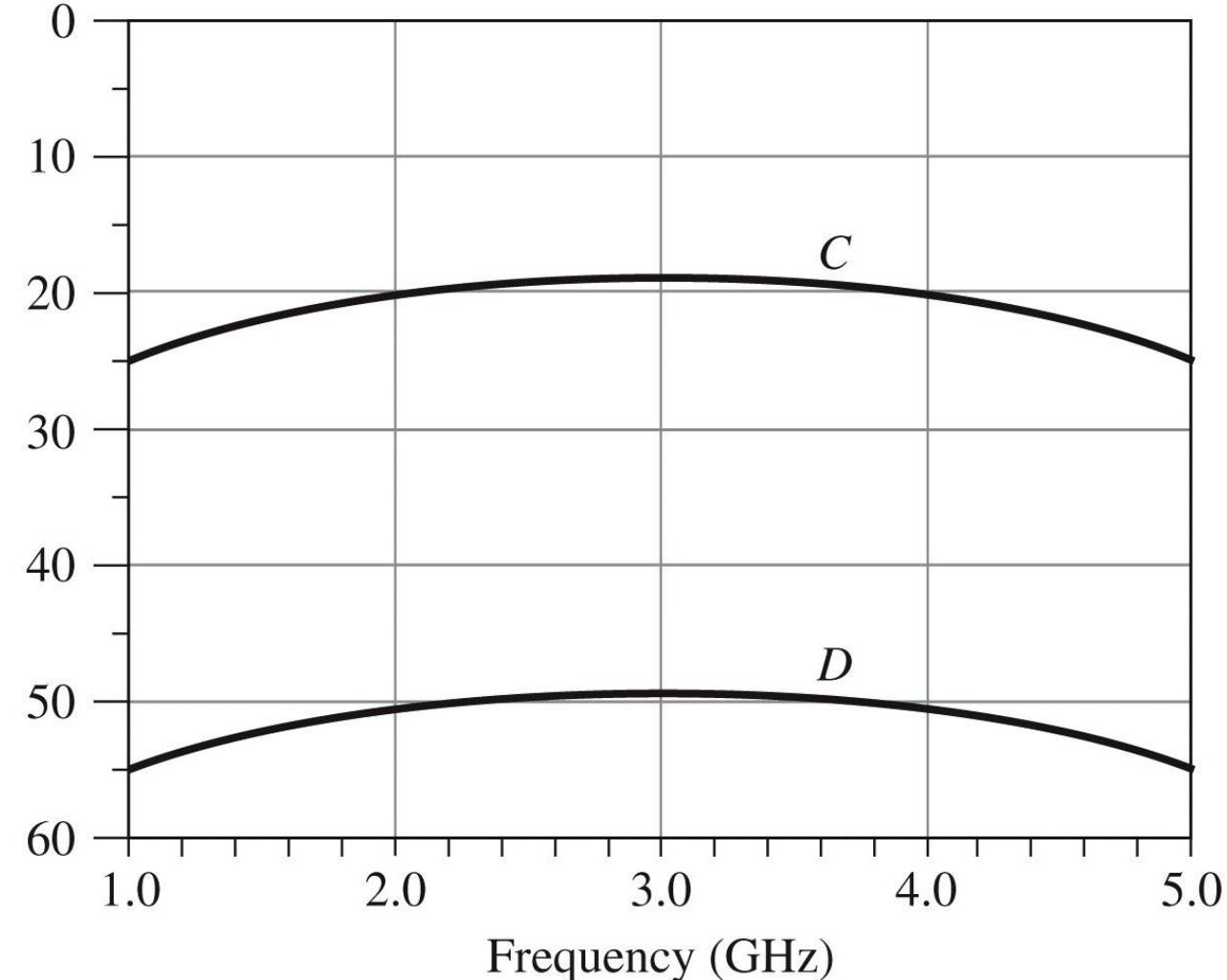
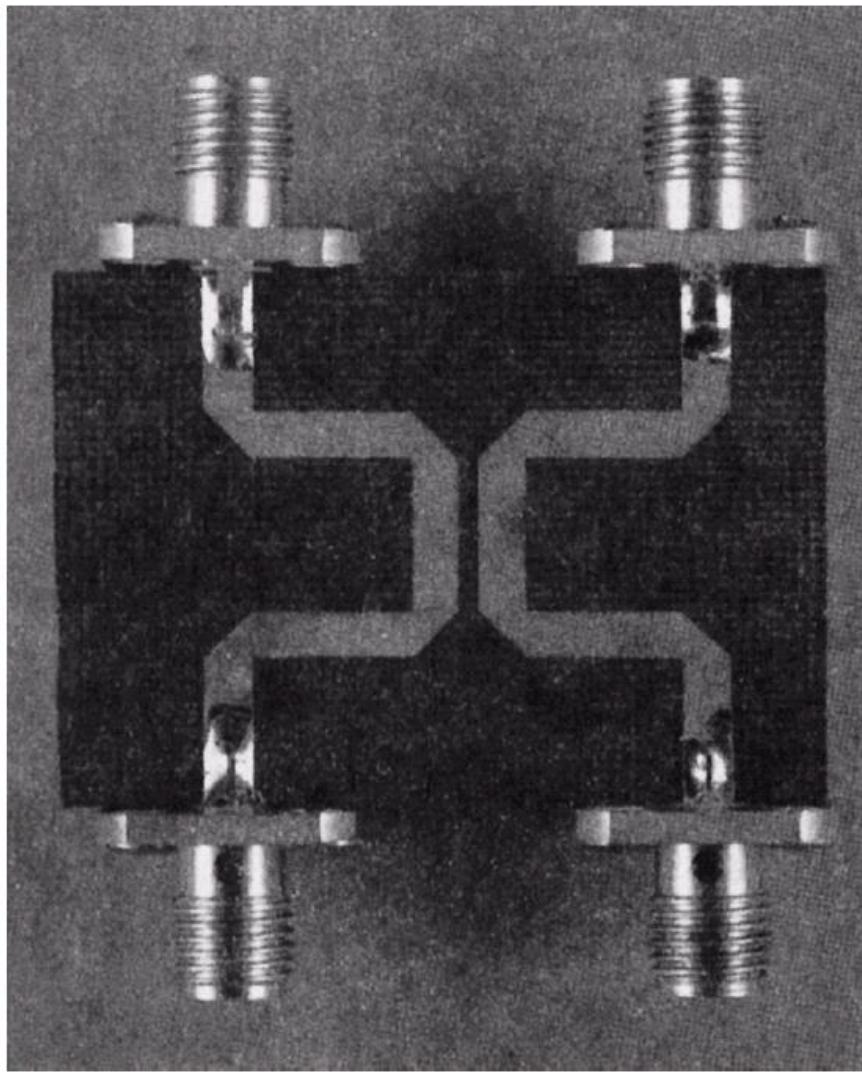


Figure 7.34

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