Curs 5

2026/2027

# Dispozitive şi circuite de microunde pentru radiocomunicații

# Disciplina 2026/2027

- 2C/1L/1P, **DCMR (CDM)**
- **Minim 14 prezente (curs+laborator+proiect)**
- Curs - **conf. Radu Damian**
  - Vineri 8-10/**Video (istoric)**, C1, corp C
  - E – **40%** din nota
  - **probleme** + (2p prez. curs) + (3 teste) + (bonus activitate)
    - primul test L1: ~01.10.2025 (t2 si t3 neanuntate la **curs**)
    - 3pz (C) ≈ +0.5p (**2p** max)
  - **toate materialele permise**

# Disciplina 2026/2027

- 2C/1L/1P, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
  - Miercuri 08-16, **II.13**
  - Joi 12-20, **I.08**
  - L – **30%** din nota
    - ADS, tema personala
    - prezenta + **rezultate personale!**
  - P – **30%** din nota
    - ADS, tema personala
  - S1÷14: 3P, 7L, 4P
    - prezenta cu alte grupe **permisa** in limita numarului de calculatoare disponibile

# Documentatie

- https://rf-opto.etti.tuiasi.ro



# Cuprins

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

# Examen: Reprezentare logaritmică

- $\boldsymbol{X[dB] = 10 \cdot log_{10}(X[lin])}$
- $X[B] = log_{10}(X[lin])$
- X[lin] – adimensional
- $log(A \cdot B) = log(A) + log(B)$

- $\boldsymbol{X[lin] = 10^{X[dB]/10}}$

# Examen

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

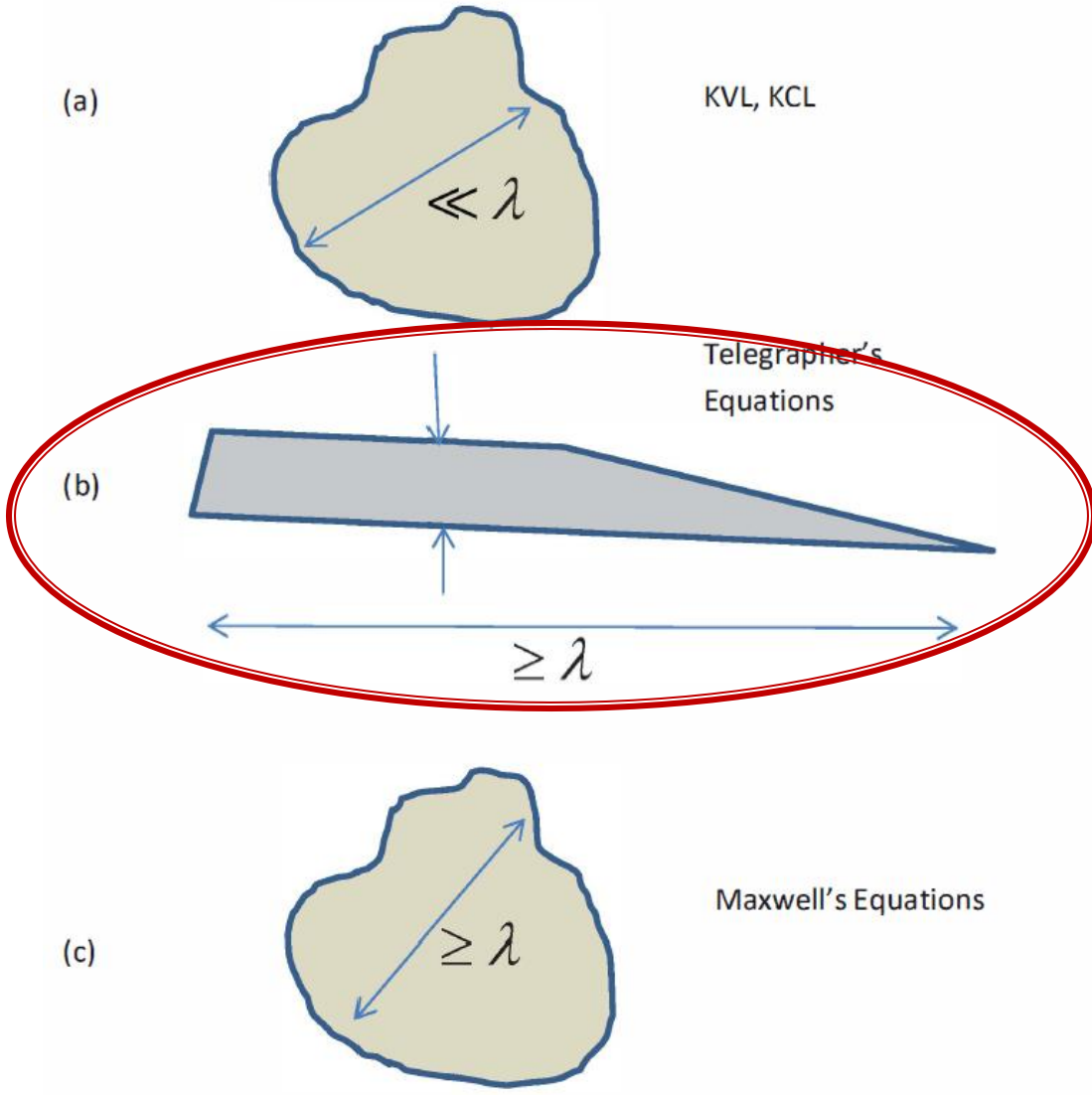
# Cuprins

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# Lungime electrica

- Comportarea (descrierea) unui circuit depinde de lungimea sa electrica la frecventele de interes
  - E≈o → Kirchhoff
  - E>o → propagare

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



# Ecuatiile telegrafistilor

- domeniu timp

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

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

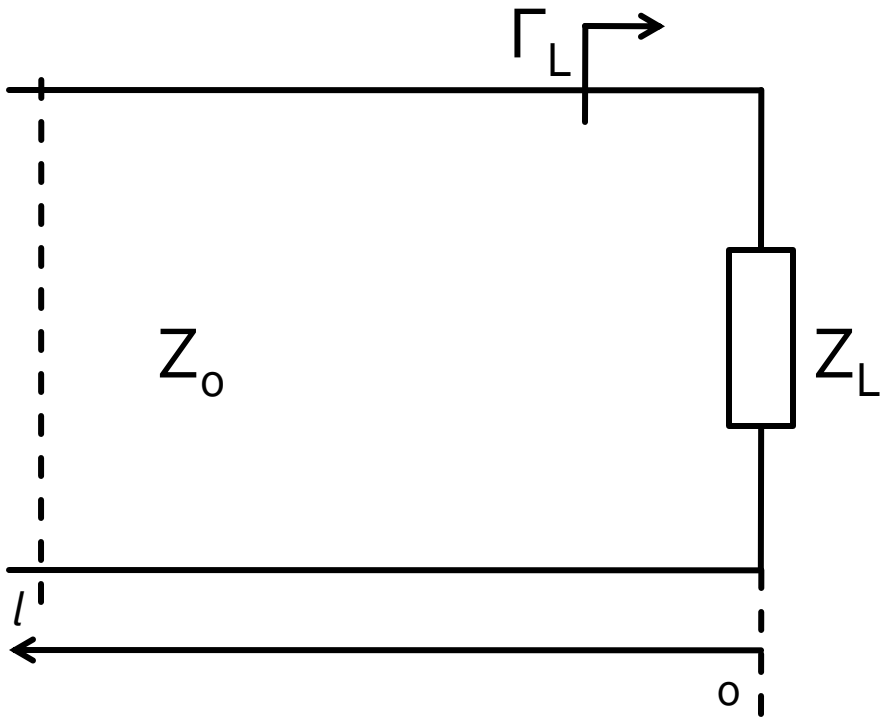
- semnale sinusoidale

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

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

$$\Big/ \frac{d}{dz}(\ldots)$$

# Linie fara pierderi




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

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

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

- coeficient de reflexie in tensiune

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

  - $Z_o$ real

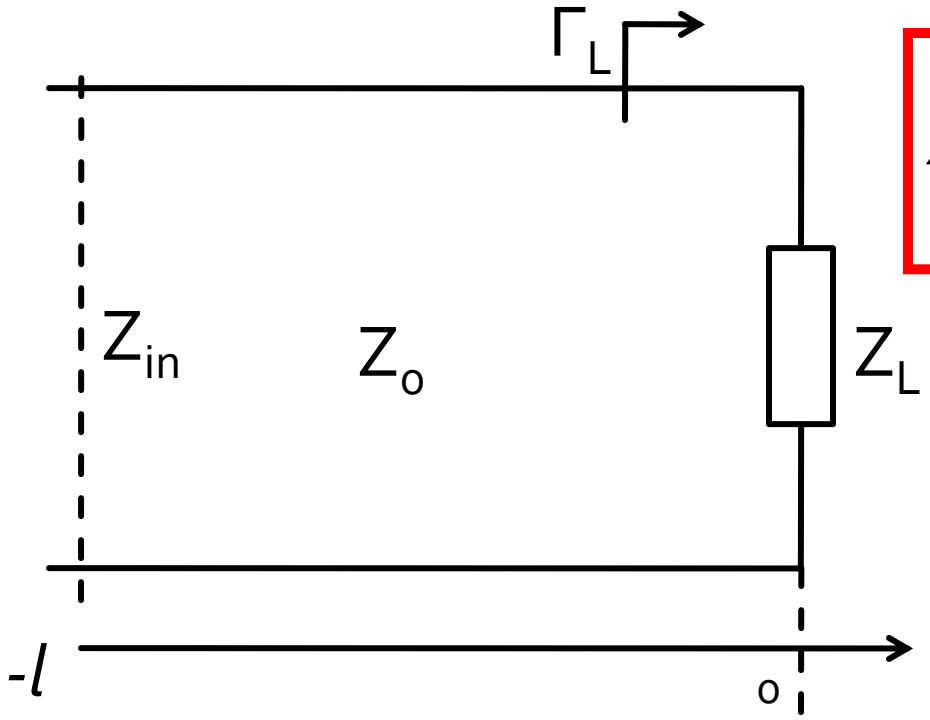
# Linie fara pierderi

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

- Puterea medie e constanta in lungul liniei
  - ( **fara** $P_{avg}$(**≠**) )
  - poate fi masurata
- Se utilizeaza puterea pentru a caracteriza amplitudinea semnalului
  - un punct de vedere "energetic" (fizica)
  - energie mai mare = semnal "mai mare"

# Linie fara pierderi

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




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

Transfer de putere

# Adaptarea de impedanța

# Adaptare dpdv al puterii

$$R_i > 0, R_L > 0$$

$$P_L = \frac{|E_i|^2}{4R_i + \frac{(R_i - R_L)^2}{R_L} + \frac{(X_i + X_L)^2}{R_L}}$$

$$P_{L\max} = \frac{|E_i|^2}{4R_i} \equiv P_a$$

$$R_L = R_i, X_L = -X_i$$

- $P_a$ : Puterea disponibila (**available**)

$$Z_L = Z_i^*$$

# Adaptare dpdv al puterii

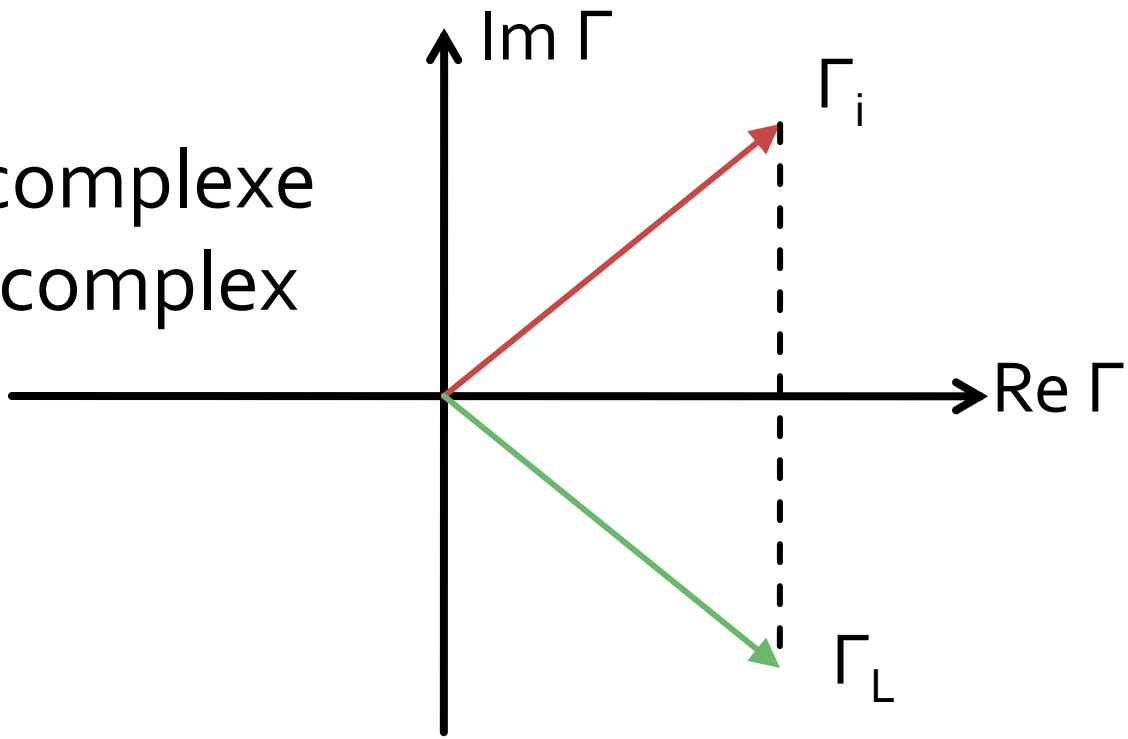
$$Z_L = Z_i^*$$

Daca se alege un Zo real

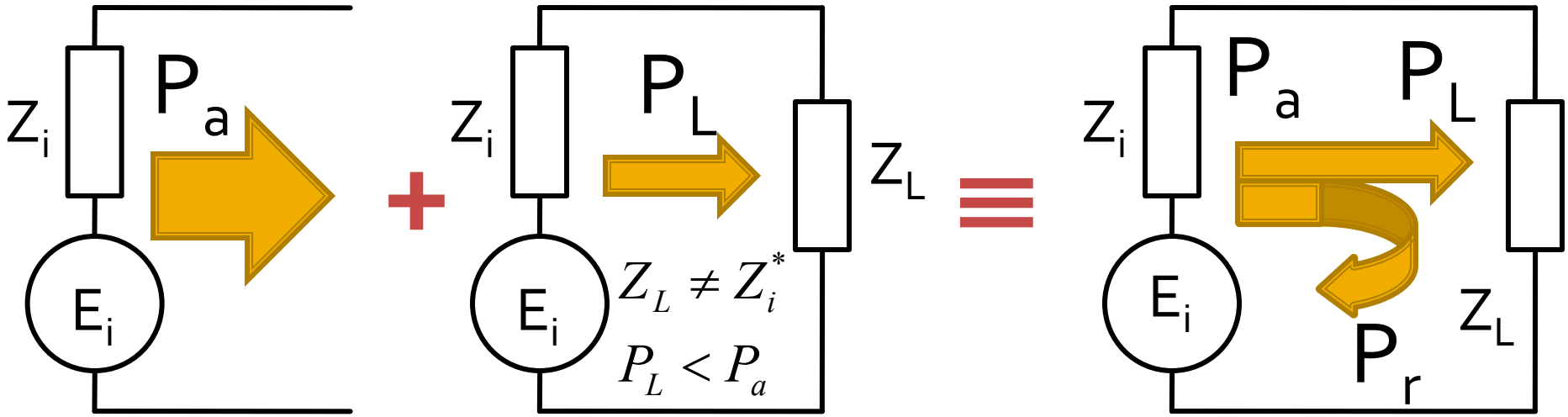
$$\Gamma = \frac{Z - Z_0}{Z + Z_0}$$

$$\Gamma_L = \Gamma_i^*$$

- numere complexe
- in planul complex



# Reflexie de putere / Model



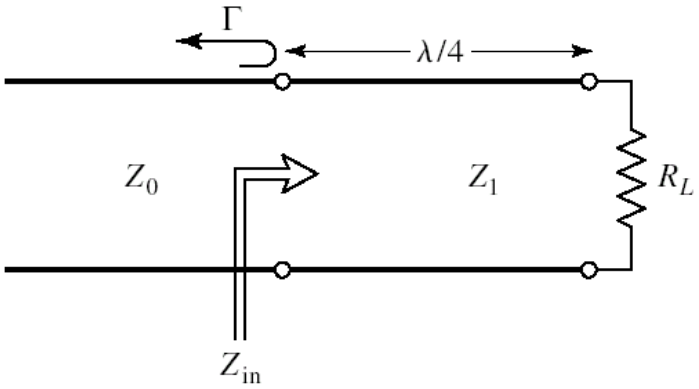

- Generatorul are posibilitatea de a oferi o anumita putere maxima de semnal $P_a$
- Pentru o sarcina oarecare, acesteia i se ofera o putere de semnal mai mica $P_L < P_a$
- Se intampla **"ca si cum"** (model) o parte din putere se reflecta $P_r = P_a - P_L$
- Puterea este o marime **scalara!**

Transformatorul in sfert de lungime de unda

# Adaptarea de impedanța

# 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 $Z_1$




$$Z_{in} = Z_1 \frac{1+\Gamma e^{-2j\beta l}}{1-\Gamma e^{-2j\beta l}}$$

$$\Gamma_O = \frac{V_0^-}{V_0^+} = \frac{R_L - Z_1}{R_L + Z_1}$$

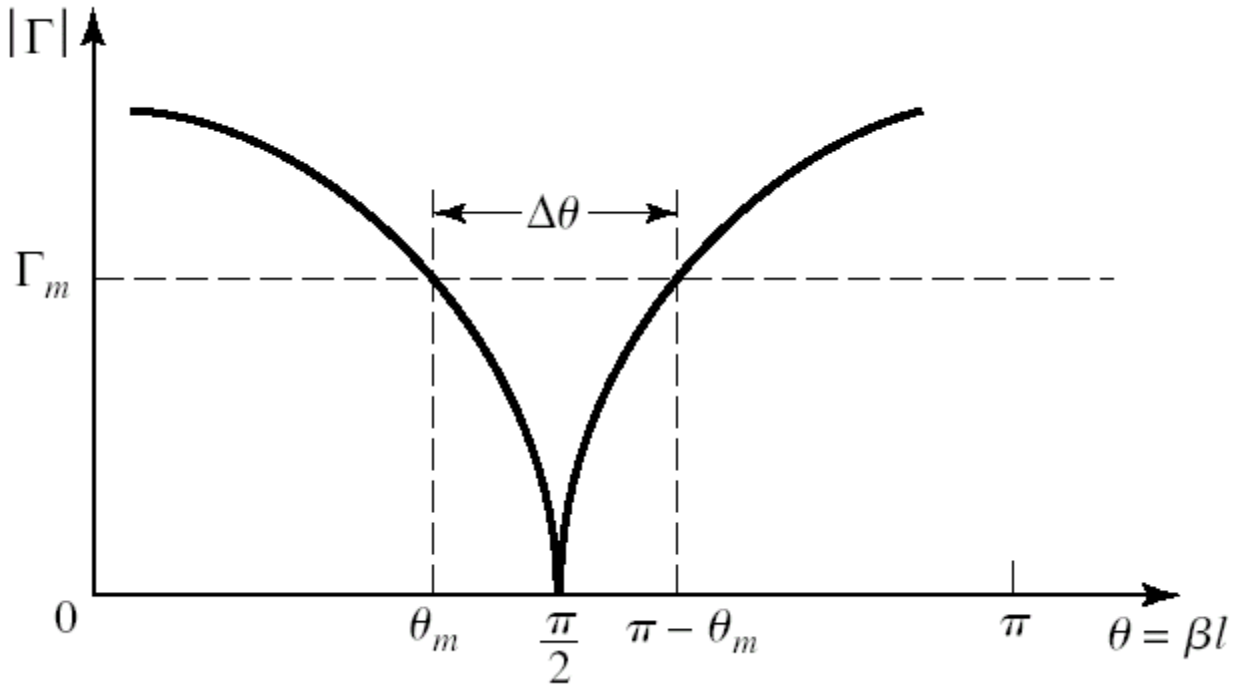
$$Z_{in} = Z_1 \frac{R_L + jZ_1 \tan(\beta l)}{Z_1 + jR_L \tan(\beta l)}$$

# Caracteristica de frecventa

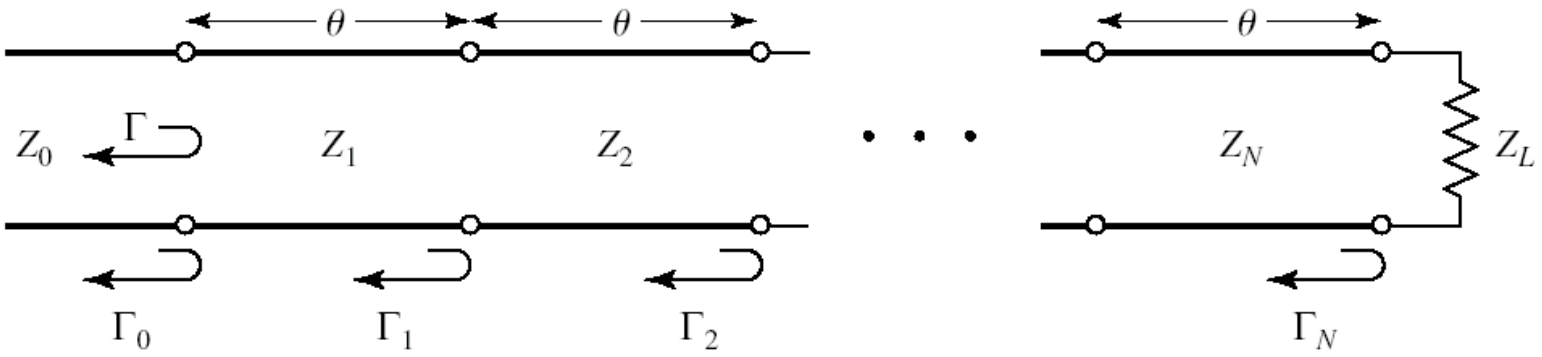
- ne intereseaza frecventa in jurul frecventei la care facem adaptarea (banda ingusta)

$$f \approx f_0 \qquad l \approx \frac{\lambda_0}{4} \qquad \theta \approx \frac{\pi}{2} \qquad \sec^2\theta = 1 + \tan^2\theta >> 1$$

$$|\Gamma| \cong \frac{|Z_L - Z_0|}{2 \cdot \sqrt{Z_0 \cdot Z_L}} \cdot |\cos\theta|$$



# Transformatoare cu mai multe sectiuni




- Presupunem ca toate impedantele **cresc sau descresc uniform**
- Toti coeficientii de reflexie vor fi reali si de acelasi semn
- Anterior $\Gamma \cong \Gamma_1 + \Gamma_3 \cdot e^{-2j\theta} \Rightarrow$

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

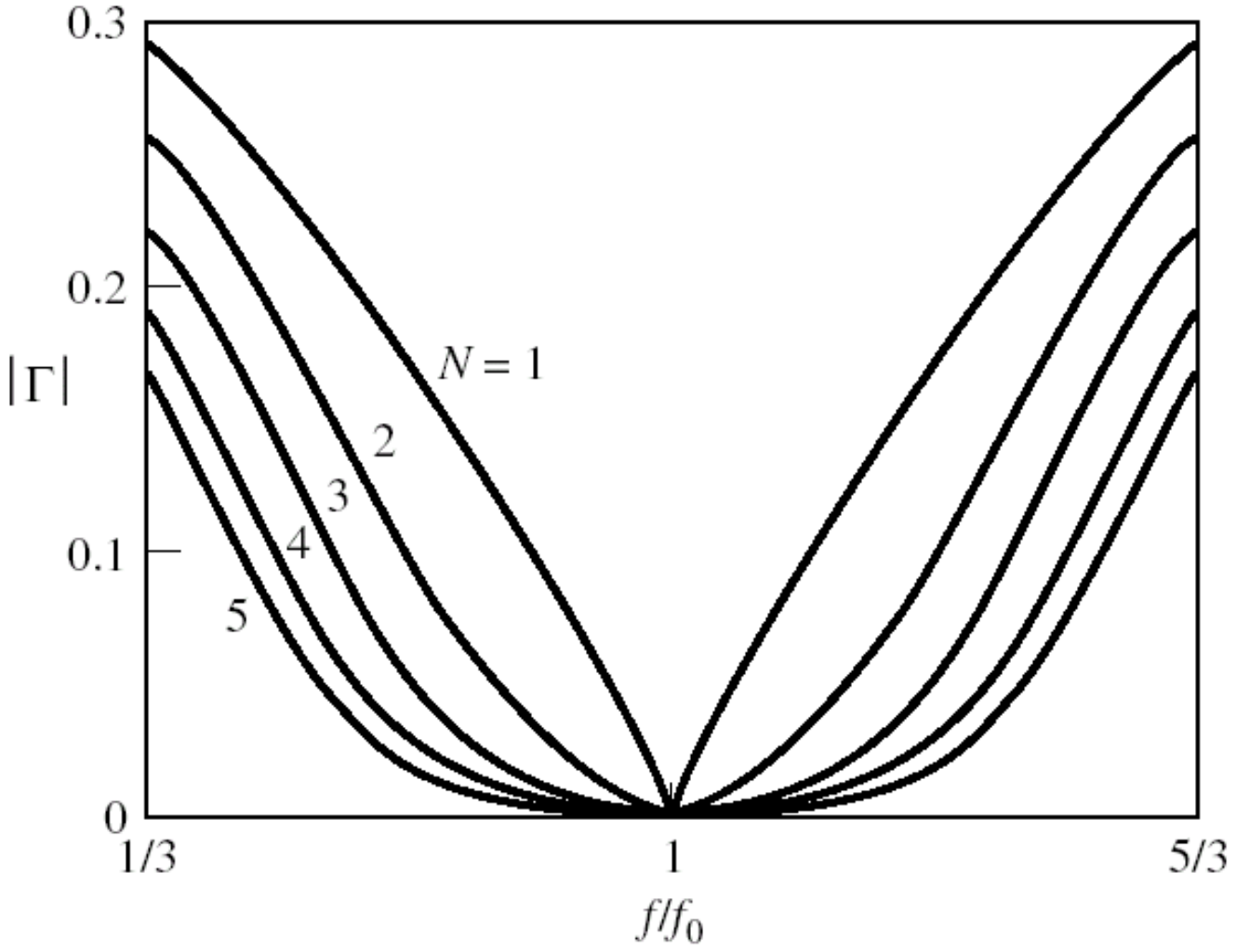
$$\Gamma_1 = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

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

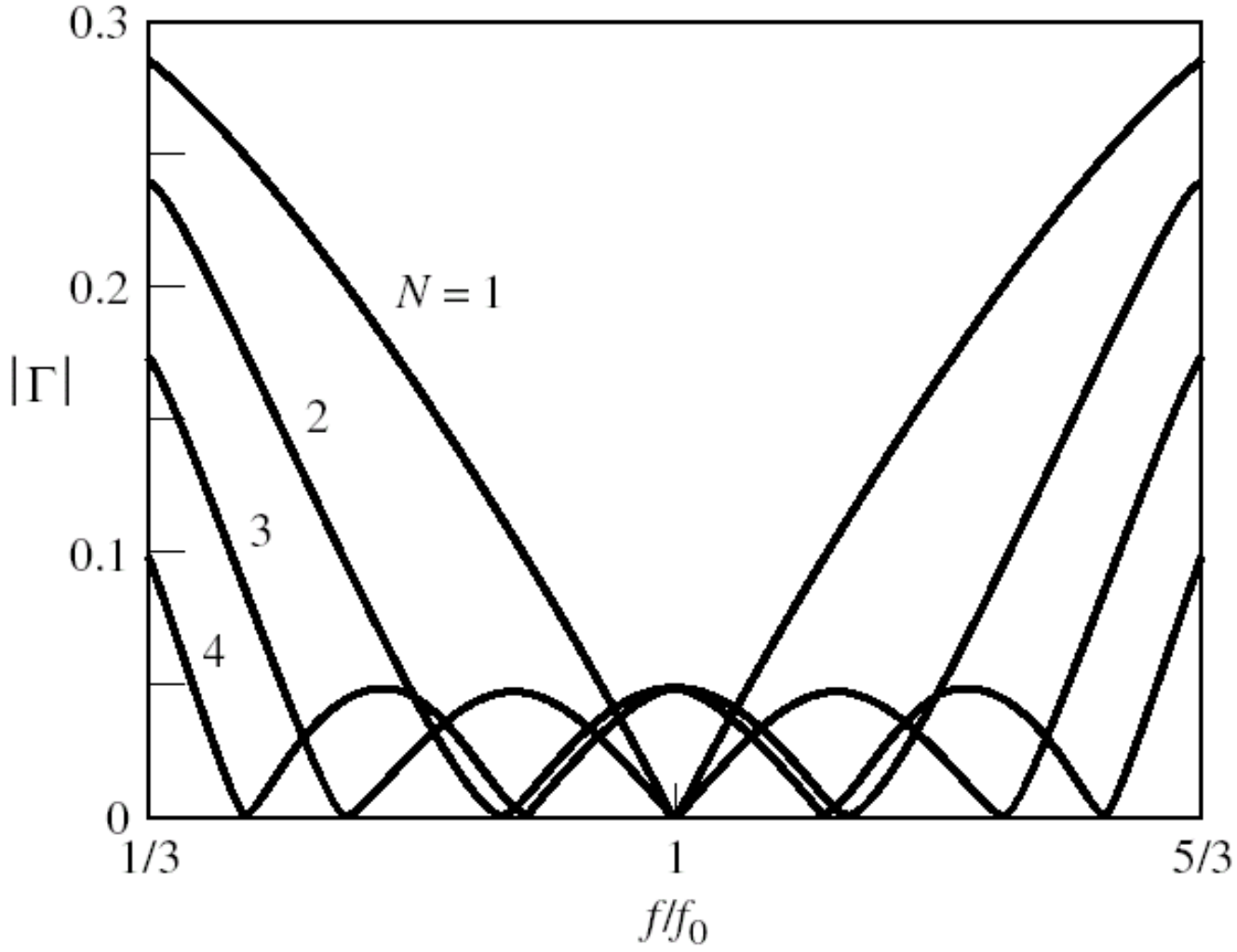
$$n = \overline{1, N-1}$$

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

# Banda



# Transformatoare cu mai multe sectiuni de tip Cebîşev



# Tema 3-4

- Scrieti pe o foaie de hartie (si scanati/foto) relatiile pentru:
  - determinarea conditiei de maxim de putere utilizand derivate partiale (impedante complexe)

$$\frac{\partial P_L}{\partial R_L} = 0 \qquad \frac{\partial P_L}{\partial X_L} = 0$$

  - determinarea expresiei pentru polinomul Cebîşev de ordinul 4

$$T_4\left(\sec\theta_m \cos\theta\right) = \sec^4\theta_m\left(\cos 4\theta + 4\cos 2\theta + 3\right) - 4\sec^2\theta_m\left(\cos 2\theta + 1\right) + 1$$

# Continuare

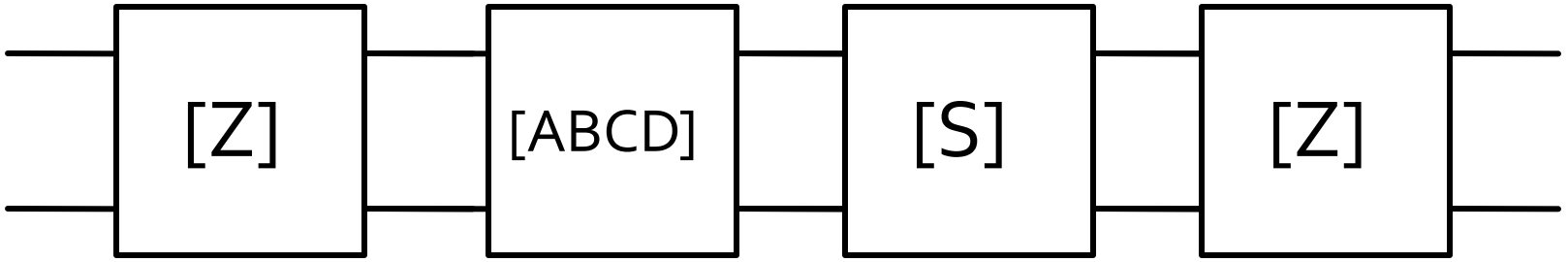
# Analiza la nivel de rețea a circuitelor de microunde

# Cuprins

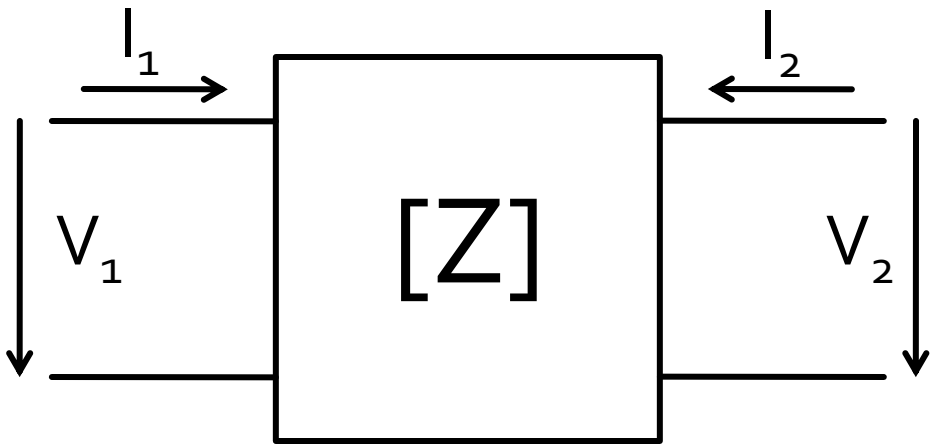
- Linii de transmisie
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# Analiza la nivel de bloc

- are ca scop separarea unui circuit complex in blocuri individuale
- acestea se analizeaza separat (decuplate de restul circuitului) si se caracterizeaza doar prin intermediul porturilor (**cutie neagra**)
- analiza la nivel de retea permite cuplarea rezultatelor individuale si obtinerea unui rezultat total pentru circuit



# Matricea impedanta




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

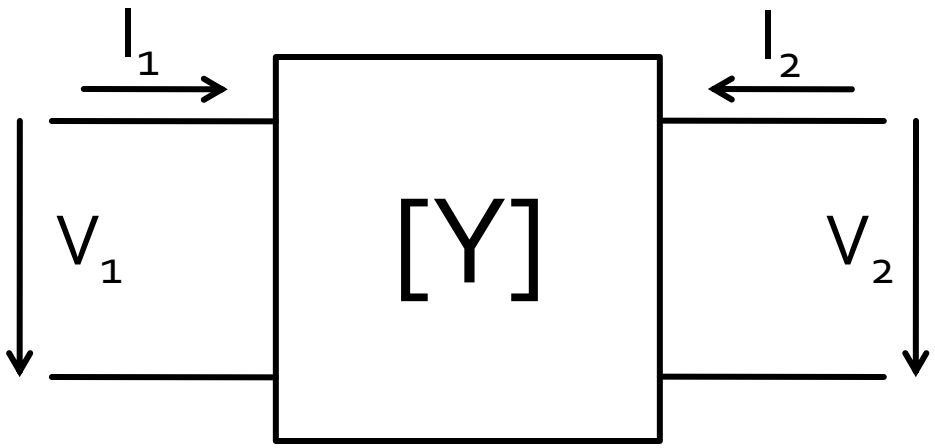
$$V_1 = Z_{11} \cdot I_1 + Z_{12} \cdot I_2$$
$$V_2 = Z_{21} \cdot I_1 + Z_{22} \cdot I_2$$

$$V_1 = Z_{11} \cdot I_1\big|_{I_2=0} \qquad Z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2=0}$$

- Z11 – impedanta de intrare cu iesirea in gol

$$Z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2=0} \qquad Z_{12} = \left.\frac{V_1}{I_2}\right|_{I_1=0} \qquad Z_{21} = \left.\frac{V_2}{I_1}\right|_{I_2=0} \qquad Z_{22} = \left.\frac{V_2}{I_2}\right|_{I_1=0}$$

# Matricea admitanta




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

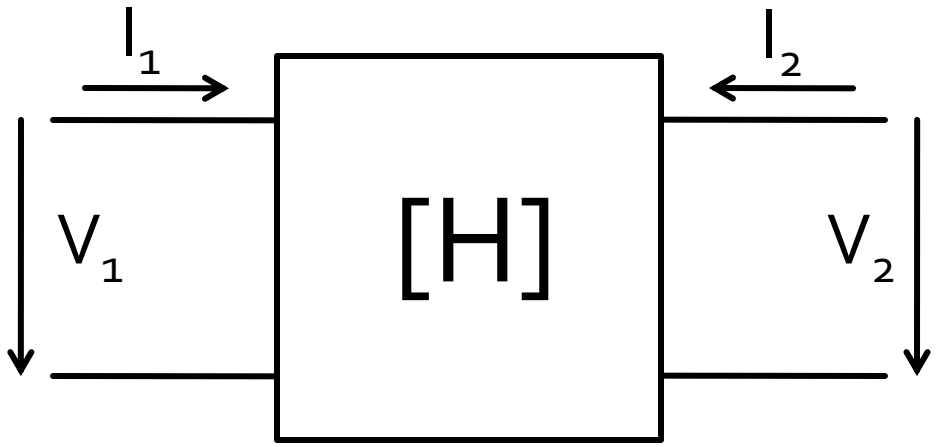
$$I_1 = Y_{11} \cdot V_1 + Y_{12} \cdot V_2$$
$$I_2 = Y_{21} \cdot V_1 + Y_{22} \cdot V_2$$

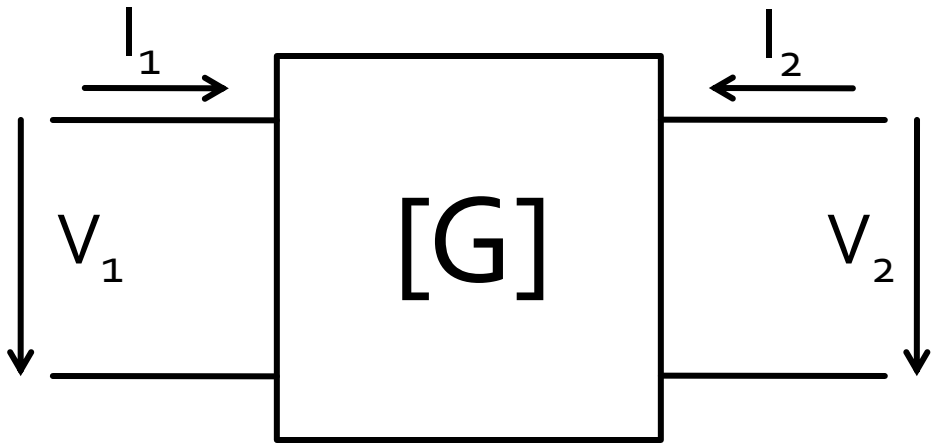
$$I_1 = Y_{11} \cdot V_1\big|_{V_2=0} \qquad Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0}$$

- Y11 – admitanta de intrare cu iesirea in scurtcircuit

$$Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0} \qquad Y_{12} = \left.\frac{I_1}{V_2}\right|_{V_1=0} \qquad Y_{21} = \left.\frac{I_2}{V_1}\right|_{V_2=0} \qquad Y_{22} = \left.\frac{I_2}{V_2}\right|_{V_1=0}$$

# Matrici hibride




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

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

$$H_{21} = \left.\frac{I_2}{I_1}\right|_{V_2=0 \; sau \; H_{22}\to\infty}$$

- $h_{21E}$ utilizat la TB, conexiune Emitor comun ($\beta$, $h_{22}$ este foarte mare)

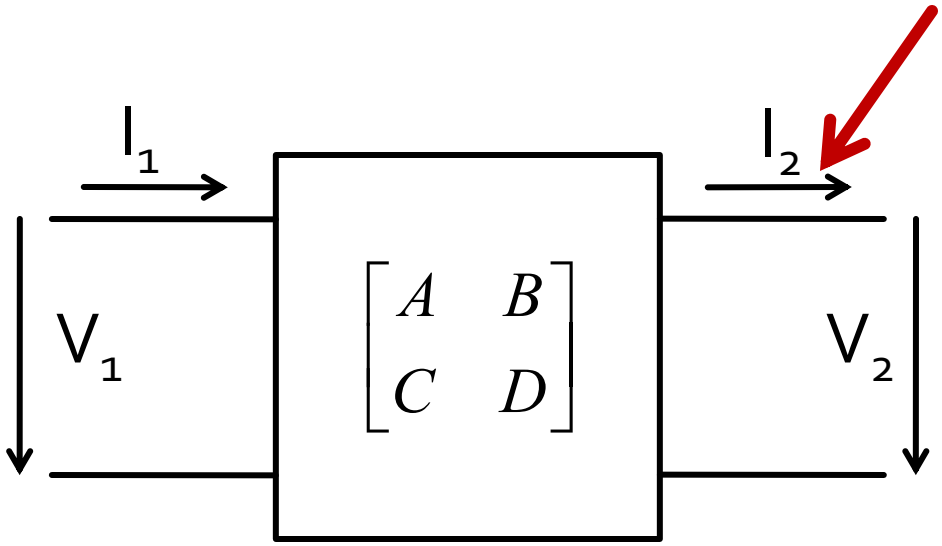
# Analiza la nivel de bloc

- fiecare matrice este potrivita pentru un anumit mod de excitare a porturilor (V,I)
  - matricea H in conexiune emitor comun pentru TB: $I_B$, $V_{CE}$
  - matricile ofera marimile asociate in functie de marimile de "atac"
- traditional parametrii Z,Y,G,H sunt notati cu litera mica (z,y,g,h)
- In microunde se prefera notatia cu litera mare pentru a nu exista confuzie cu parametrii raportati la o valoare de referinta

$$z = \frac{Z}{Z_0} \qquad y = \frac{Y}{Y_0} = \frac{1/Z}{1/Z_0} = \frac{Z_0}{Z} = Z_0 \cdot Y$$

$$z_{11} = \frac{Z_{11}}{Z_0} \qquad y_{11} = \frac{Y_{11}}{Y_0} = Z_0 \cdot Y_{11}$$

# Matricea ABCD – de transmisie




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

$$V_1 = A \cdot V_2 + B \cdot I_2$$

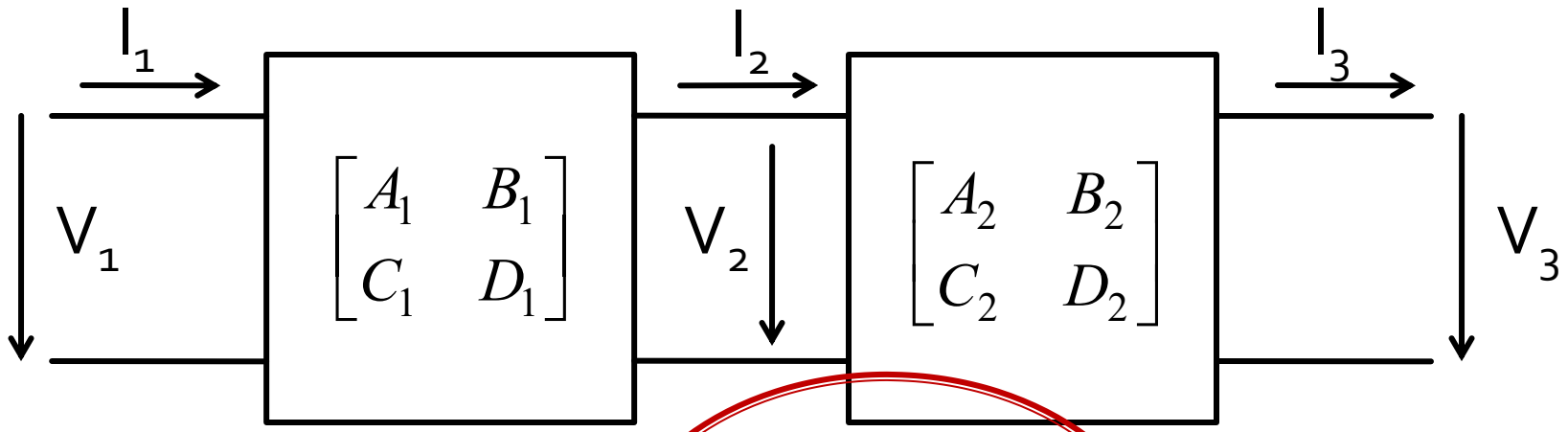
$$I_1 = C \cdot V_2 + D \cdot I_2$$

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

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

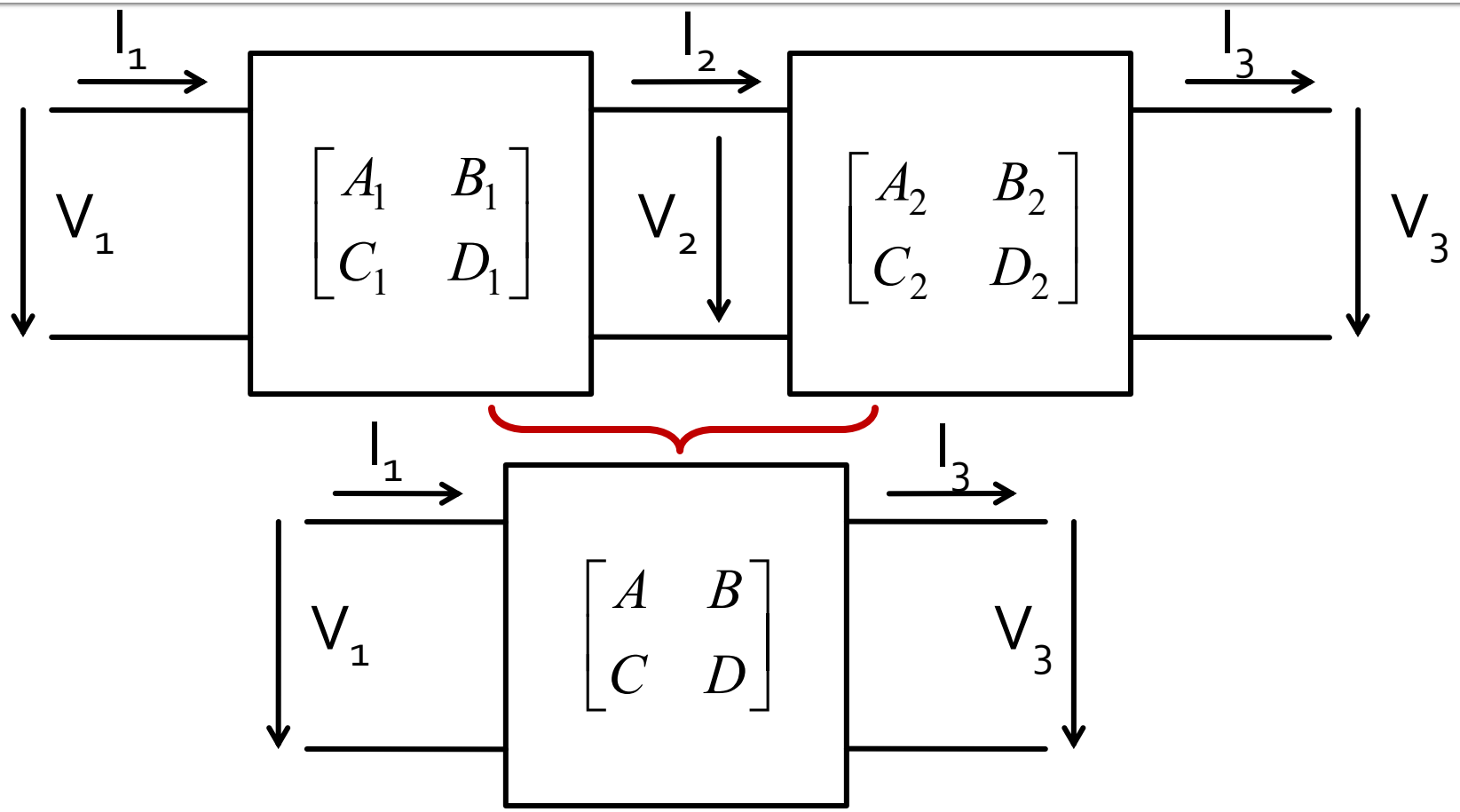
# Matricea ABCD – de transmisie

- introduce o legatura intre "intrare" si "iesire"
- permite inlantuirea usoara intre mai multe blocuri




$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdot \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdot \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \cdot \begin{bmatrix} V_3 \\ I_3 \end{bmatrix}$$

# Matricea ABCD – de transmisie



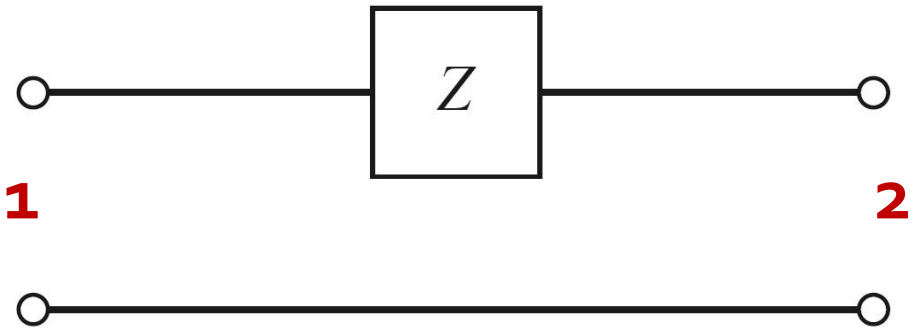

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdot \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$

# Matricea ABCD – de transmisie

- potrivita **numai** pentru diporti (Z,Y pot fi usor extinse pentru multiporti/n-porturi)
- permite cuplarea facila a mai multor elemente
- permite calculul unor circuite complexe cu o intrare si o iesire prin spargerea in blocuri individuale componente
- se pot crea "biblioteci" de matrici pentru blocuri mai des utilizate

# Matrici ABCD

- Impedanta serie




$$A = 1 \qquad B = Z$$
$$C = 0 \qquad D = 1$$

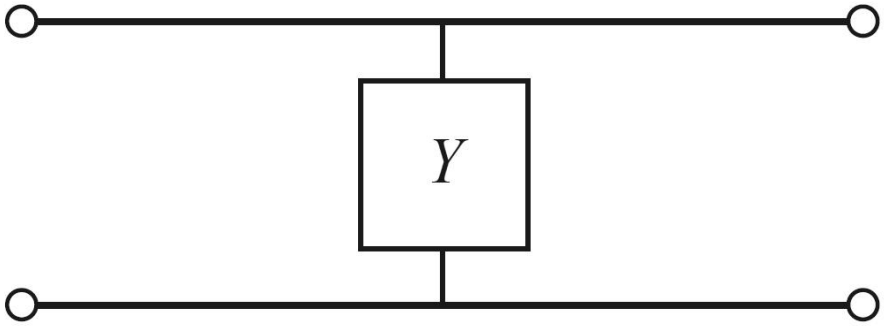
$$\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

$$A = \left.\frac{V_1}{V_2}\right|_{I_2=0} = 1 \qquad B = \left.\frac{V_1}{I_2}\right|_{V_2=0} = \frac{V_1}{V_1/Z} = Z$$

$$C = \left.\frac{I_1}{V_2}\right|_{I_2=0} = 0 \qquad D = \left.\frac{I_1}{I_2}\right|_{V_2=0} = \frac{I_1}{I_1} = 1$$

# Matrici ABCD

- Admitanta paralel




$$A = 1 \qquad B = 0$$

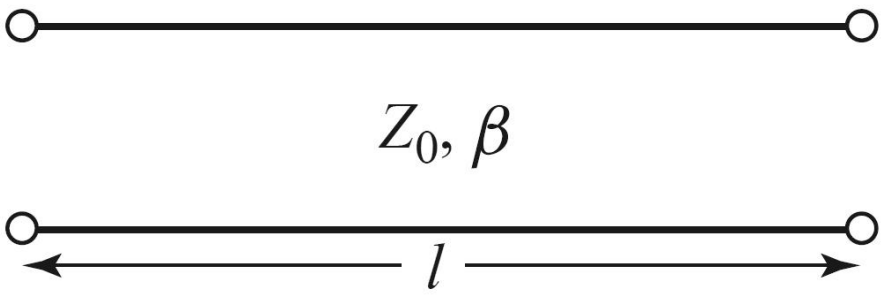
$$C = Y \qquad D = 1$$

$$\begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

Verificare - tema!

# Matrici ABCD

- Sectiune de linie de transmisie




$$A = \cos\beta \cdot l$$

$$B = j \cdot Z_0 \cdot \sin\beta \cdot l$$

$$C = j \cdot Y_0 \cdot \sin\beta \cdot l$$

$$D = \cos\beta \cdot l$$

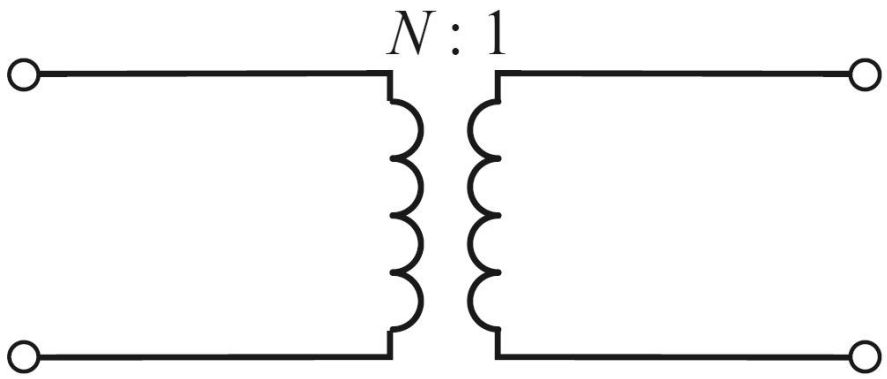
$$\begin{bmatrix} \cos\beta \cdot l & j \cdot Z_0 \cdot \sin\beta \cdot l \\ j \cdot Y_0 \cdot \sin\beta \cdot l & \cos\beta \cdot l \end{bmatrix}$$

Verificare - tema!

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

# Matrici ABCD

- Transformator




$$A = N \qquad B = 0$$

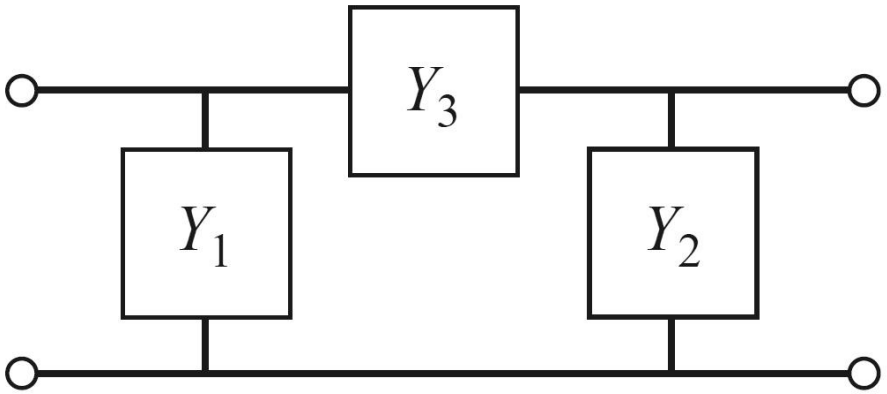
$$C = 0 \qquad D = \frac{1}{N}$$

$$\begin{bmatrix} N & 0 \\ 0 & \frac{1}{N} \end{bmatrix}$$

Verificare - tema!

# Matrici ABCD

- diport π




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

$$B = \frac{1}{Y_3}$$

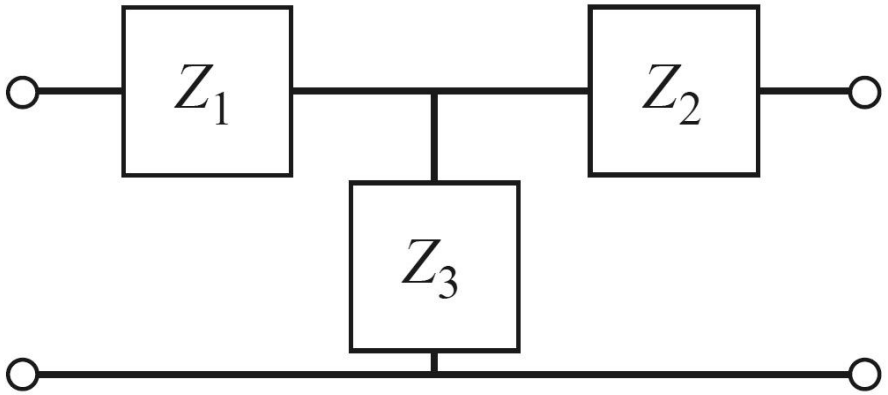
$$C = Y_1 + Y_2 + \frac{Y_1 \cdot Y_2}{Y_3}$$

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

Verificare - tema!

# Matrici ABCD

- diport T




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

$$B = Z_1 + Z_2 + \frac{Z_1 \cdot Z_2}{Z_3}$$

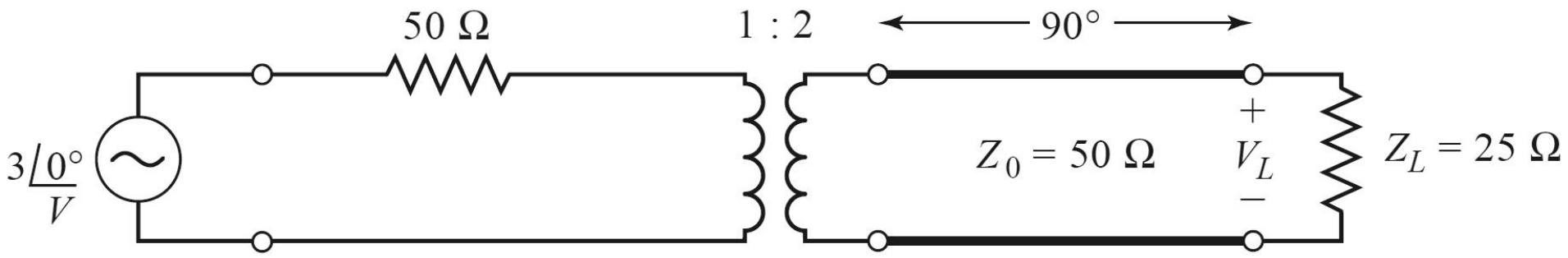
$$C = \frac{1}{Z_3}$$

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

Verificare - tema!

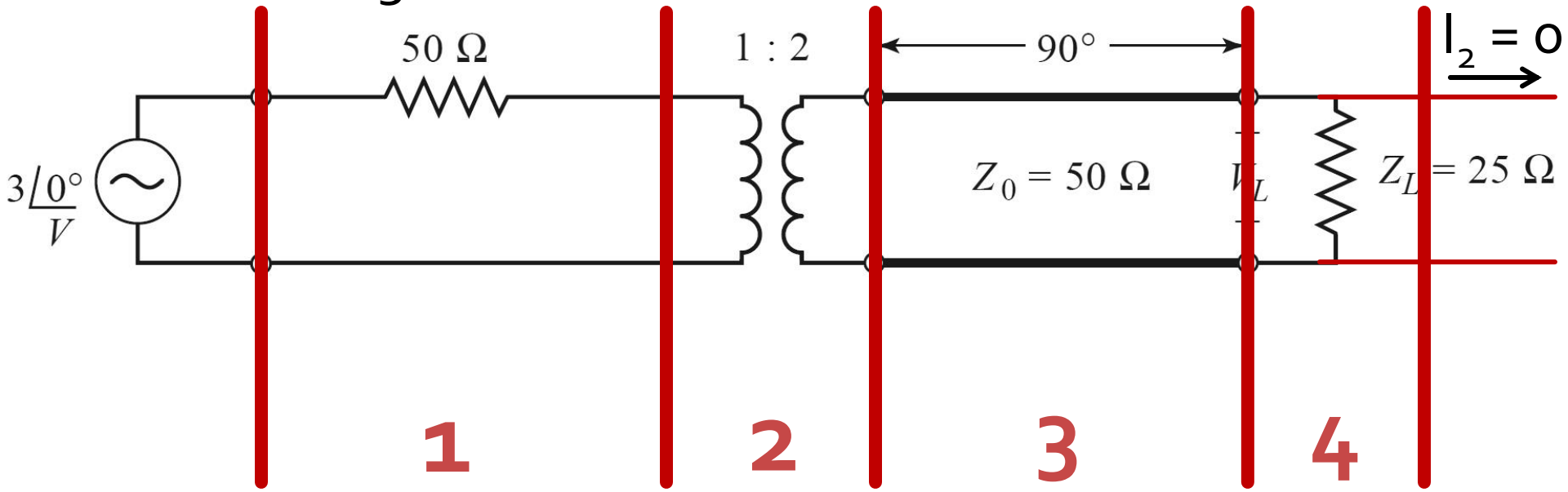
# Exemplu utilizare matrice ABCD

- Determinati tensiunea pe sarcina in circuitul urmator



# Exemplu utilizare matrice ABCD

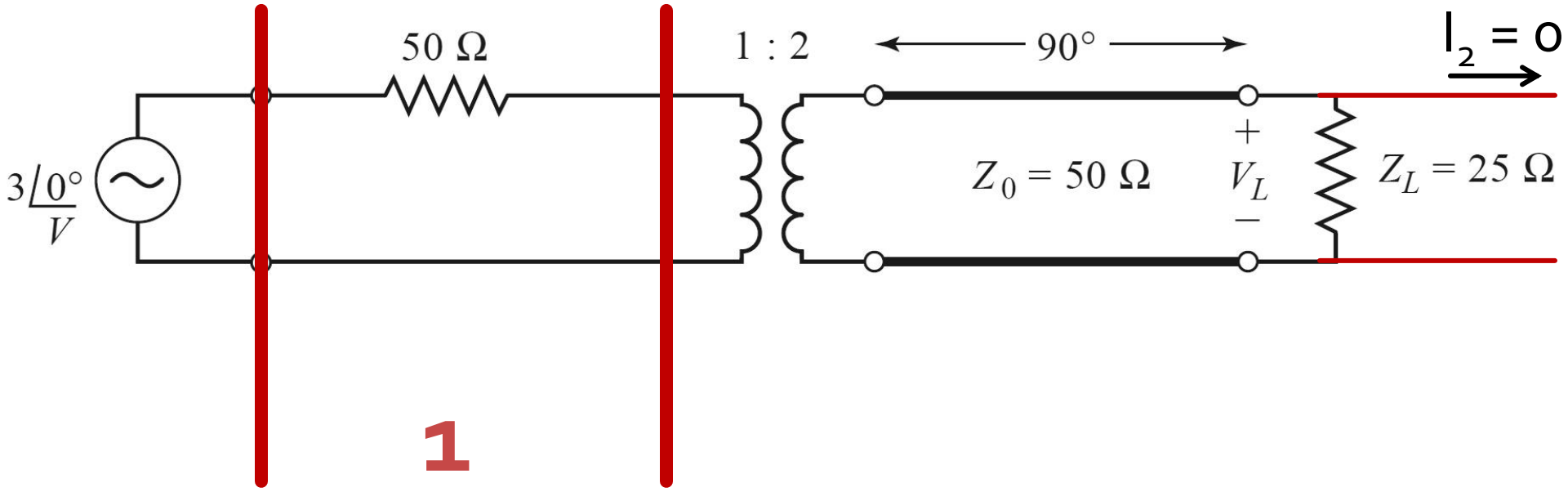
- Sectionare circuit in elemente simple
- Generatoarele raman in exterior
- Daca e necesar, se creaza porturi de intrare si iesire lasate in gol




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

# Exemplu utilizare matrice ABCD

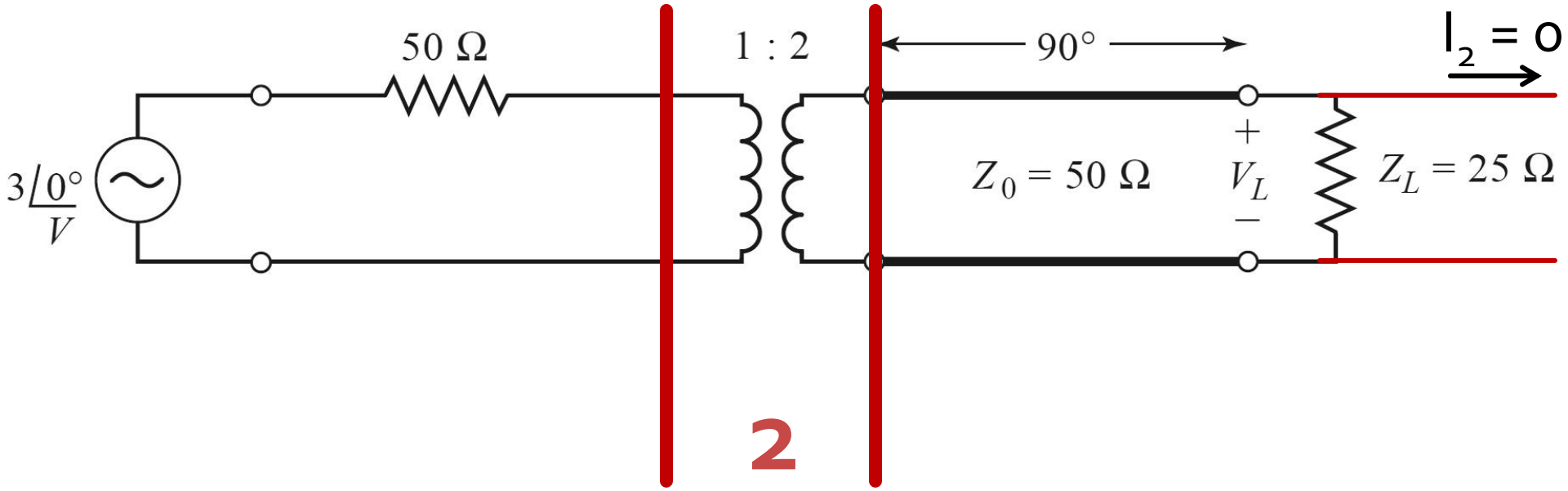
- $M_1$ , impedanta serie




$$M_1 = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 50 \\ 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

# Exemplu utilizare matrice ABCD

- $M_2$ , transformator 1:2

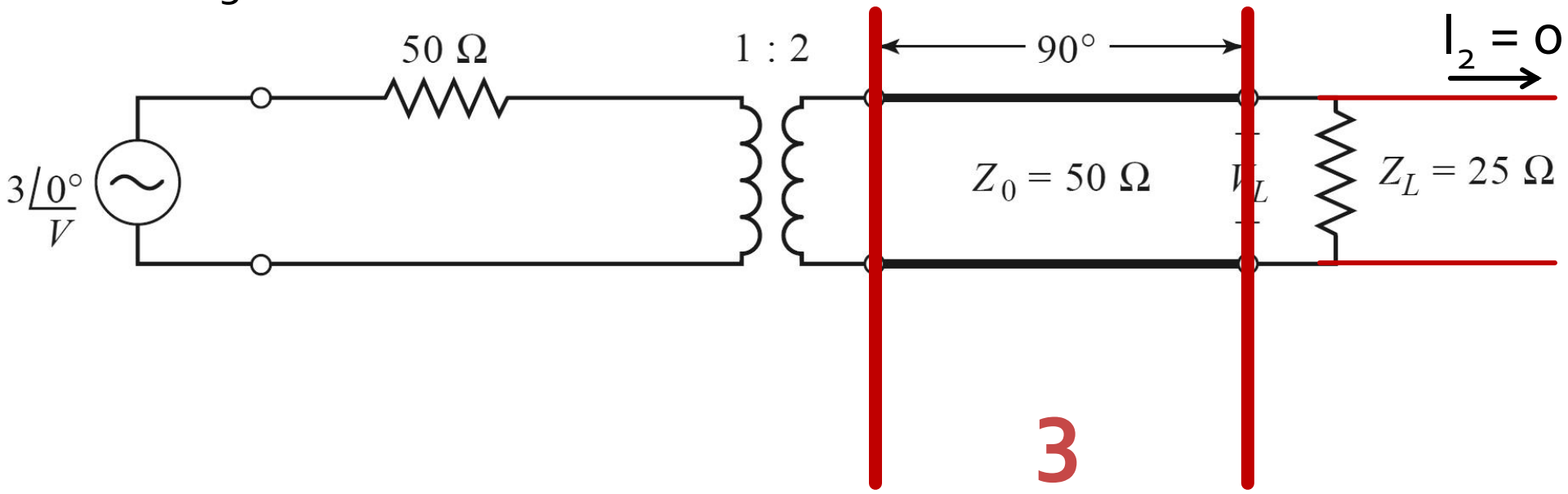



$$M_2 = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1/2 & 0 \\ 0 & 2 \end{bmatrix}$$

$$\begin{bmatrix} N & 0 \\ 0 & \frac{1}{N} \end{bmatrix}$$

# Exemplu utilizare matrice ABCD

- $M_3$ , linie serie, E = 90°

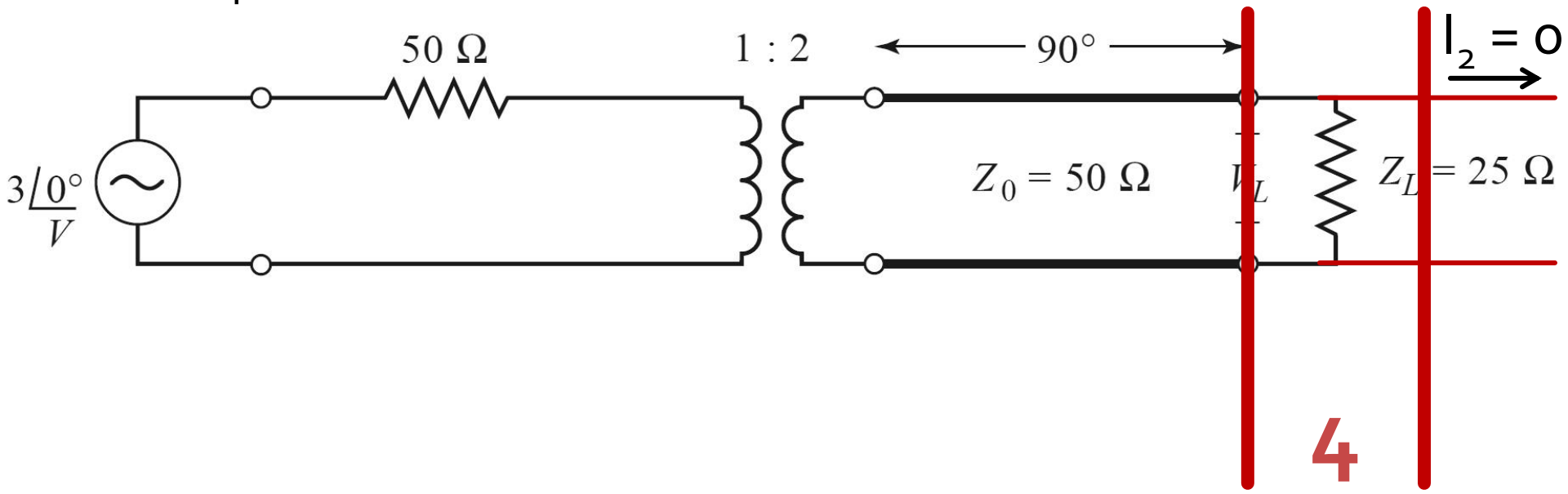



$$M_3 = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 0 & 50 \cdot j \\ \frac{j}{50} & 0 \end{bmatrix}$$

$$\begin{bmatrix} \cos\beta \cdot l & j \cdot Z_0 \cdot \sin\beta \cdot l \\ j \cdot Y_0 \cdot \sin\beta \cdot l & \cos\beta \cdot l \end{bmatrix}$$

# Exemplu utilizare matrice ABCD

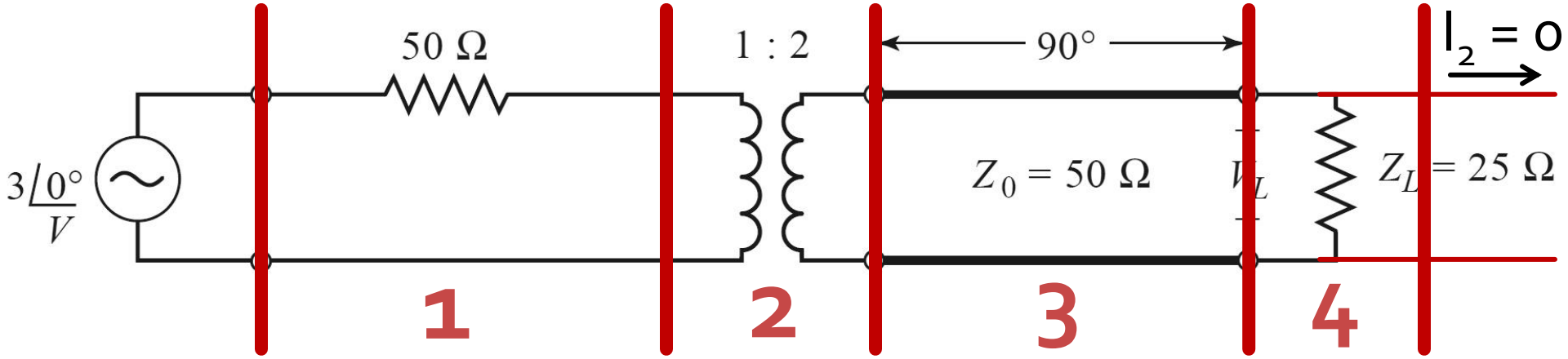
- $M_4$ , impedanta/admitanta paralel




$$M_4 = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{1}{25} & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

# Exemplu utilizare matrice ABCD

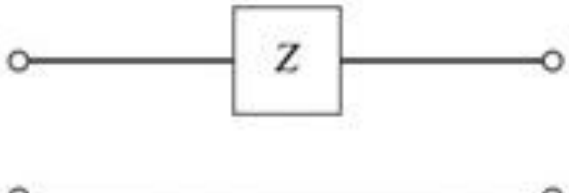
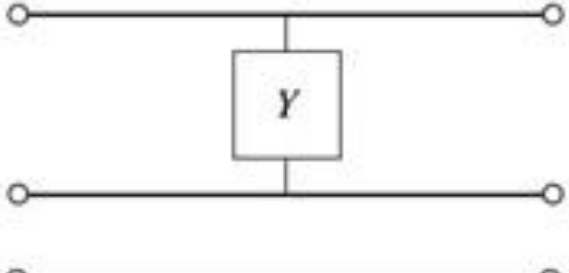
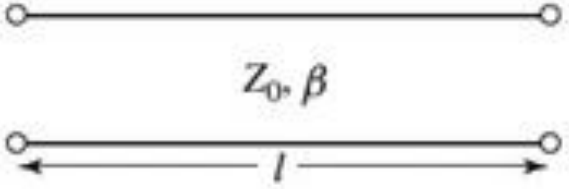



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 50 \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \frac{1}{2} & 0 \\ 0 & 2 \end{bmatrix} \cdot \begin{bmatrix} 0 & 50 \cdot j \\ \frac{j}{50} & 0 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ \frac{1}{25} & 1 \end{bmatrix} = \begin{bmatrix}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

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

# Biblioteci de matrici ABCD

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

| Circuit | *ABCD* Parameters | |
|---|---|---|
|  | $A = 1$<br>$C = 0$ | $B = Z$<br>$D = 1$ |
|  | $A = 1$<br>$C = Y$ | $B = 0$<br>$D = 1$ |
|  | $A = \cos \beta\ell$<br>$C = jY_0 \sin \beta\ell$ | $B = jZ_0 \sin \beta\ell$<br>$D = \cos \beta\ell$ |

# Biblioteci de matrici ABCD

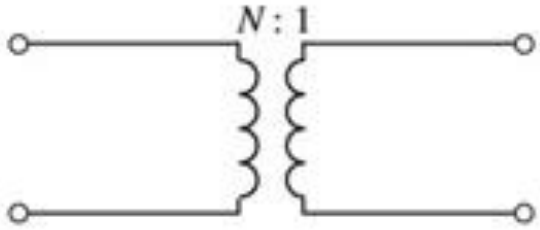
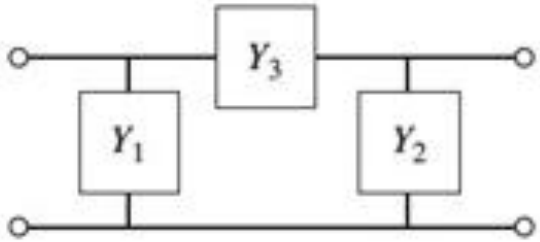
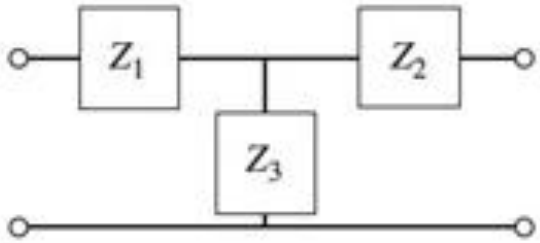
| | | |
|---|---|---|
|  | $A = N$<br>$C = 0$ | $B = 0$<br>$D = \frac{1}{N}$ |
|  | $A = 1 + \frac{Y_2}{Y_3}$<br>$C = Y_1 + Y_2 + \frac{Y_1 Y_2}{Y_3}$ | $B = \frac{1}{Y_3}$<br>$D = 1 + \frac{Y_1}{Y_3}$ |
|  | $A = 1 + \frac{Z_1}{Z_3}$<br>$C = \frac{1}{Z_3}$ | $B = Z_1 + Z_2 + \frac{Z_1 Z_2}{Z_3}$<br>$D = 1 + \frac{Z_2}{Z_3}$ |

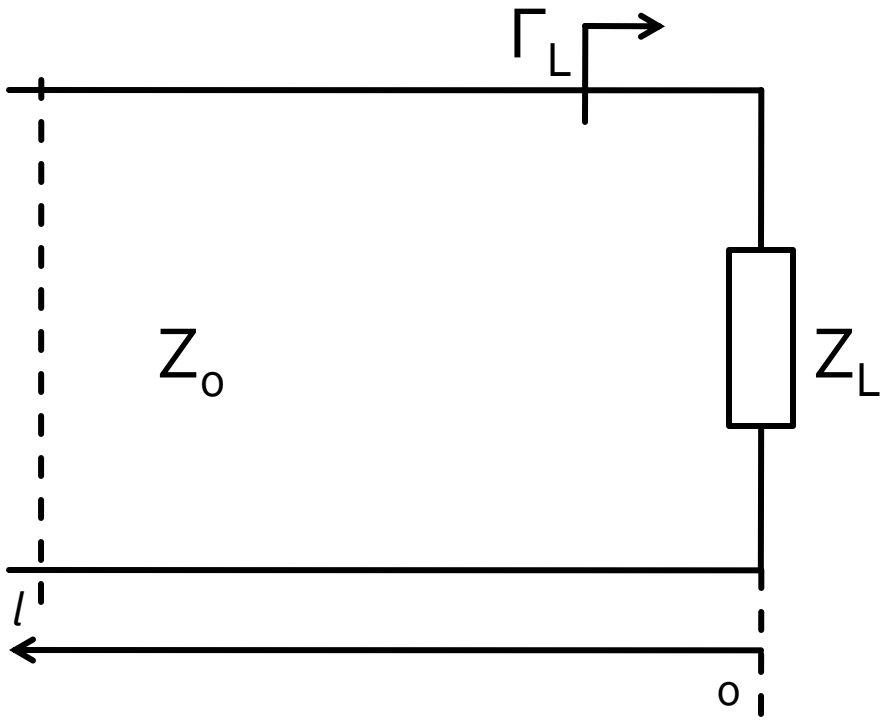
**Table 4.1**

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Matricea S

# Analiza la nivel de rețea a circuitelor de microunde

# Linie fara pierderi – C3




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

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

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

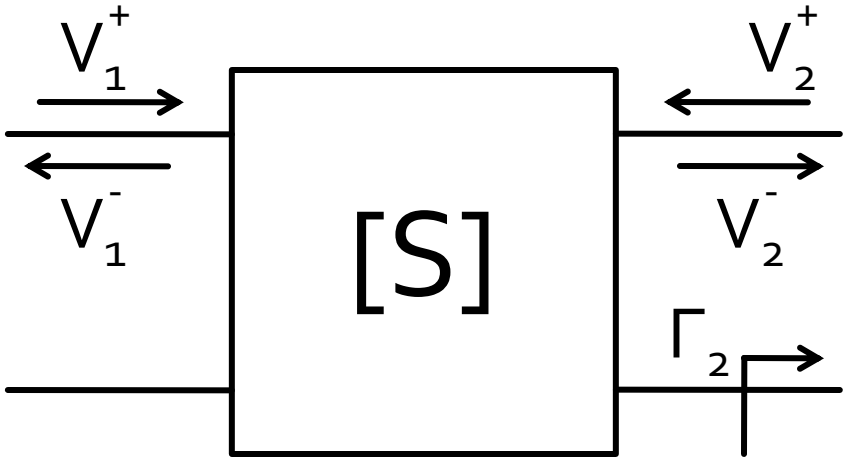
- coeficient de reflexie in tensiune

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

  - $Z_o$ real

# Matricea S (repartitie)

- Scattering parameters



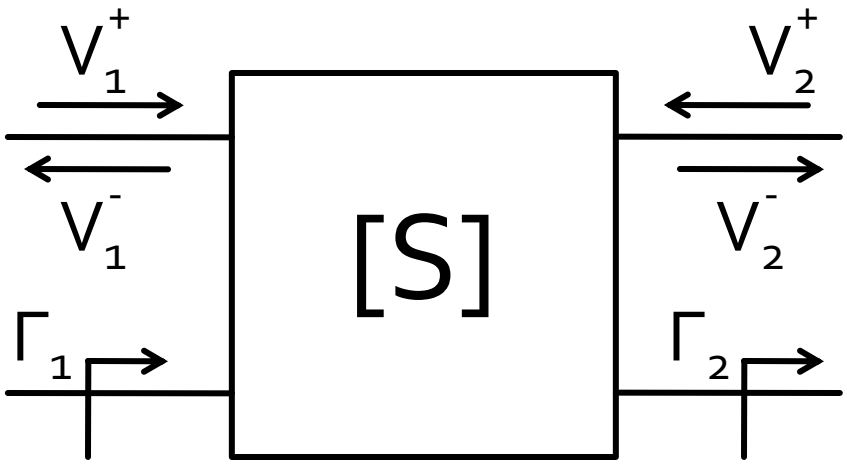

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$S_{11} = \left.\frac{V_1^-}{V_1^+}\right|_{V_2^+=0} \qquad S_{21} = \left.\frac{V_2^-}{V_1^+}\right|_{V_2^+=0}$$

- $V_2^+ = 0$ 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)




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

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

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

- S11 este coeficientul de reflexie la portul ***1*** cand cand portul ***2*** este terminat pe impedanta care realizeaza adaptarea
- S21 este coeficientul de transmisie de la portul ***1*** (**al doilea** indice**!**) la portul ***2*** (**primul** indice**!**) cand se depune semnal la portul ***1*** si portul ***2*** este terminat pe impedanta care realizeaza adaptarea

# Matricea S (repartitie)

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

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

- $S_{ii}$ 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 3

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

In planul de referinta al portului, z=o

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

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

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

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

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

# Deplasare a planului de referinta

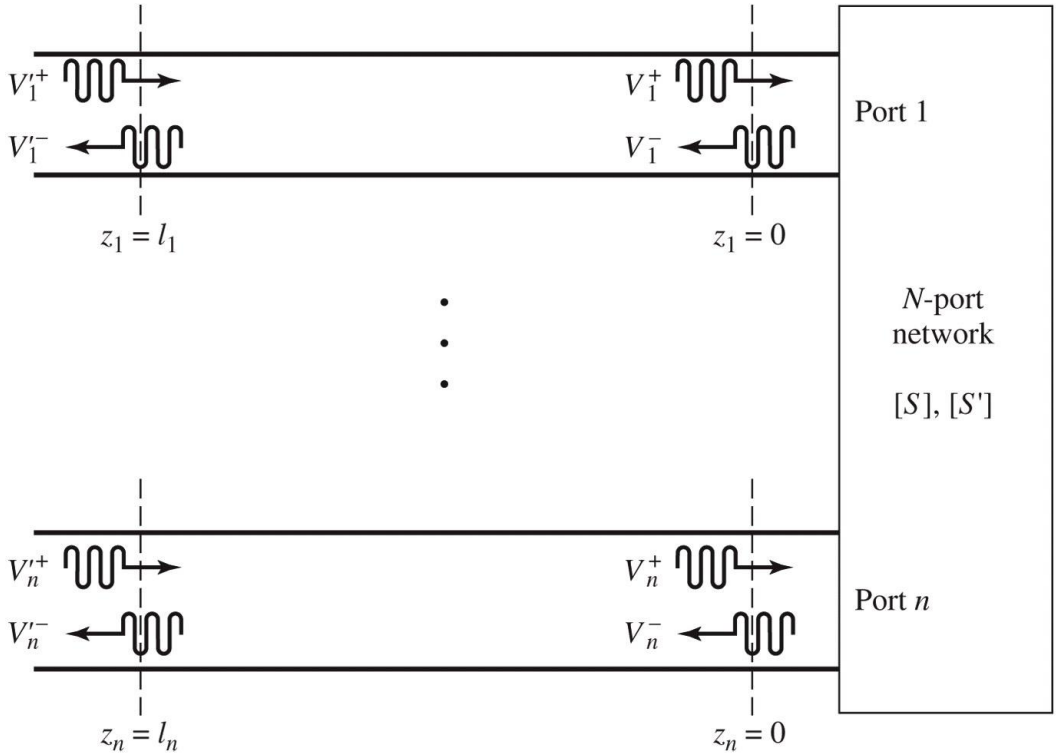



Figure 4.9
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- De-Embedding
- Decapsulare

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

# Proprietati [S]

- Circuite reciproce (fara circuite active, ferite)

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

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

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

- Circuite fara pierderi

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

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

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

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

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

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

# Matricea S generalizata

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

$$V = V_0^+ + V_0^- \qquad I = \frac{1}{Z_0}\cdot\left(V_0^+ - V_0^-\right)$$

planul de referinta al portului, z=o

- Aflam amplitudinile undelor de tensiune

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

- Puterea oferita sarcinii la iesirea din linie:

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

$$\left(z - z^*\right) = \mathrm{Im}$$

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

# Matricea S generalizata

- Puterea oferita sarcinii la iesirea din linie:

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

- Restrictii
  - Rezultat valid pentru Zo real
  - Necesita prezenta unei linii cu impedanta caracteristica Zo intre generator si sarcina

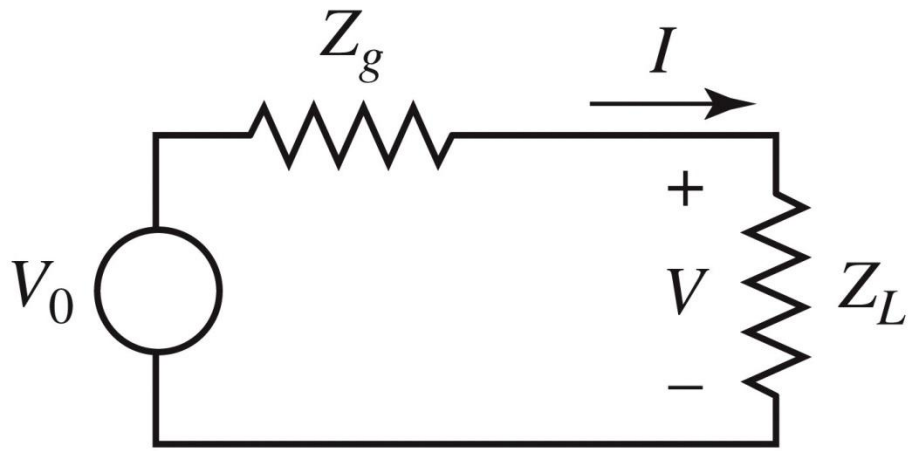



Figure 4.10
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# Matricea S generalizata

- Definim undele de putere

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

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

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

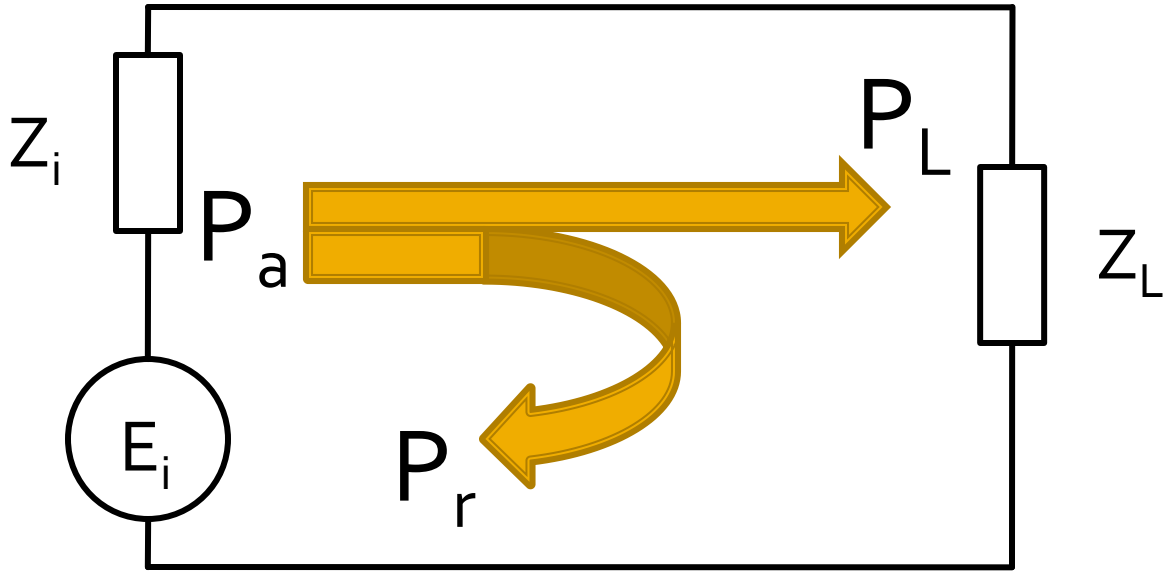
O impedanta de referinta oarecare, complexa

- 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 / C4




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

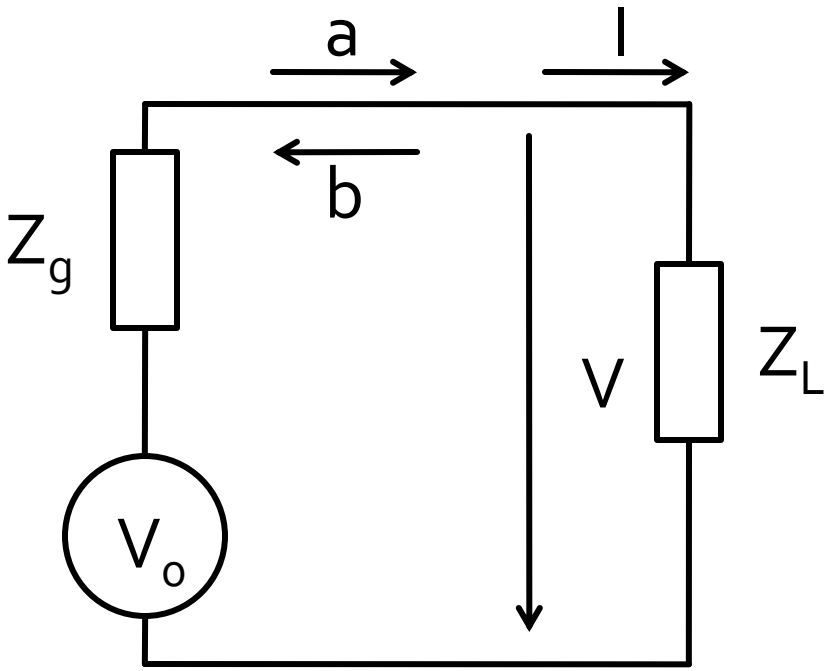
$$P_L = \frac{R_L \cdot |E_i|^2}{(R_i+R_L)^2 + (X_i+X_L)^2}$$

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

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

- coeficient de reflexie in putere

# Unde de putere




$$P_L = \frac{1}{2} \cdot \mathrm{Re}\left\{V \cdot I^*\right\}$$

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

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

$$\left(z - z^*\right) = \mathrm{Im}$$

$$\forall Z_R \in C$$

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

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

# Unde de putere

$$V = \frac{V_0 \cdot Z_L}{Z_g + Z_L} \qquad I = \frac{V_0}{Z_g + Z_L} \qquad P_L = \frac{V_0^2}{2} \cdot \frac{R_L}{\left|Z_g + Z_L\right|^2}$$

- Daca aleg $Z_R = Z_L^*$

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

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

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

# Unde de putere

- Daca in plus generatorul este adaptat conjugat cu sarcina

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

- Reflexie in putere C4

$$Z_L = Z_i^* \qquad P_{L\max} \equiv P_a \qquad \Gamma = \frac{Z - Z_0^*}{Z + Z_0}$$

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

- Reflexie in putere C5

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

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

# Unde de putere

- Definitii de unde pentru n-porti

$$[Z_R]=\begin{bmatrix} Z_{R1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & Z_{Rn} \end{bmatrix}$$

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

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

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

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

# Unde de putere pentru multiporti

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

- legatura intre undele de putere incidenta si reflectata

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

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

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

- tipic

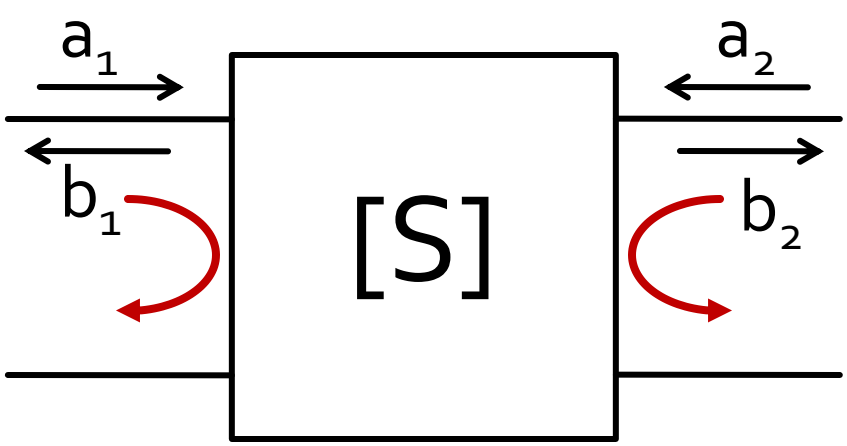
$$Z_{0i}=Z_{Ri}=R_0,\forall i$$

$$R_0=50\Omega$$

$$\boxed{[S_p]\equiv[S]}$$

- **coincid!!!**

# Matricea S (repartitie)

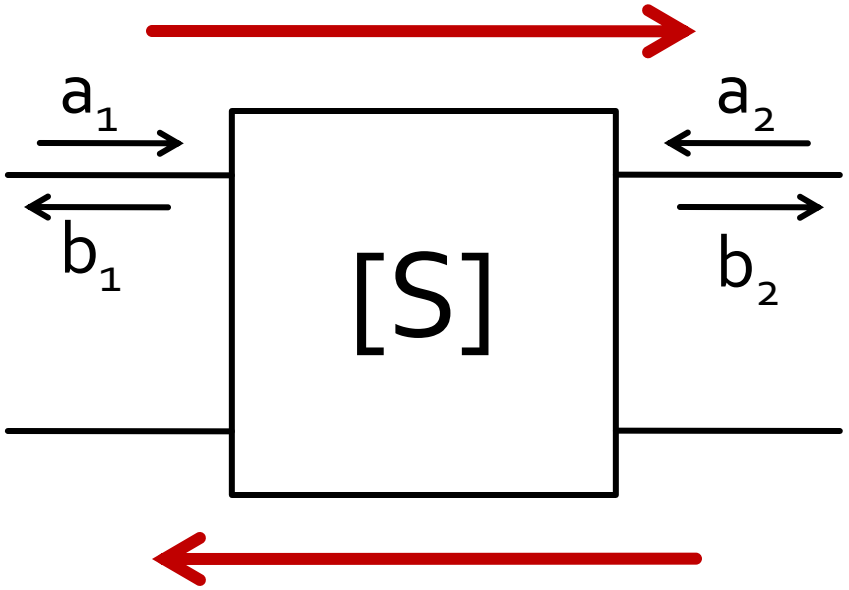



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

# Matricea S (repartitie)

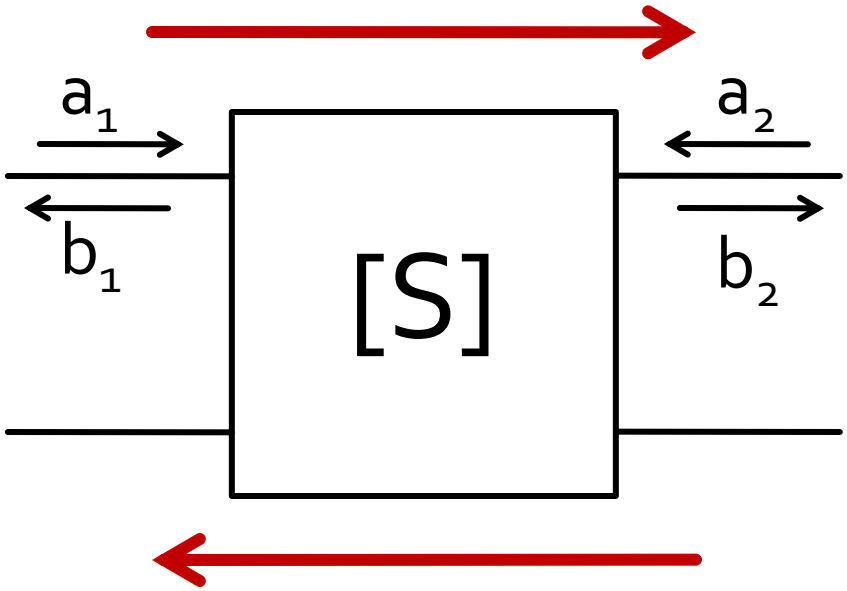



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} \qquad S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0}$$

- $S_{21}$ si $S_{12}$ sunt amplificari de semnal cand celalalt port este adaptat

# Matricea S (repartitie)




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

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

- 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

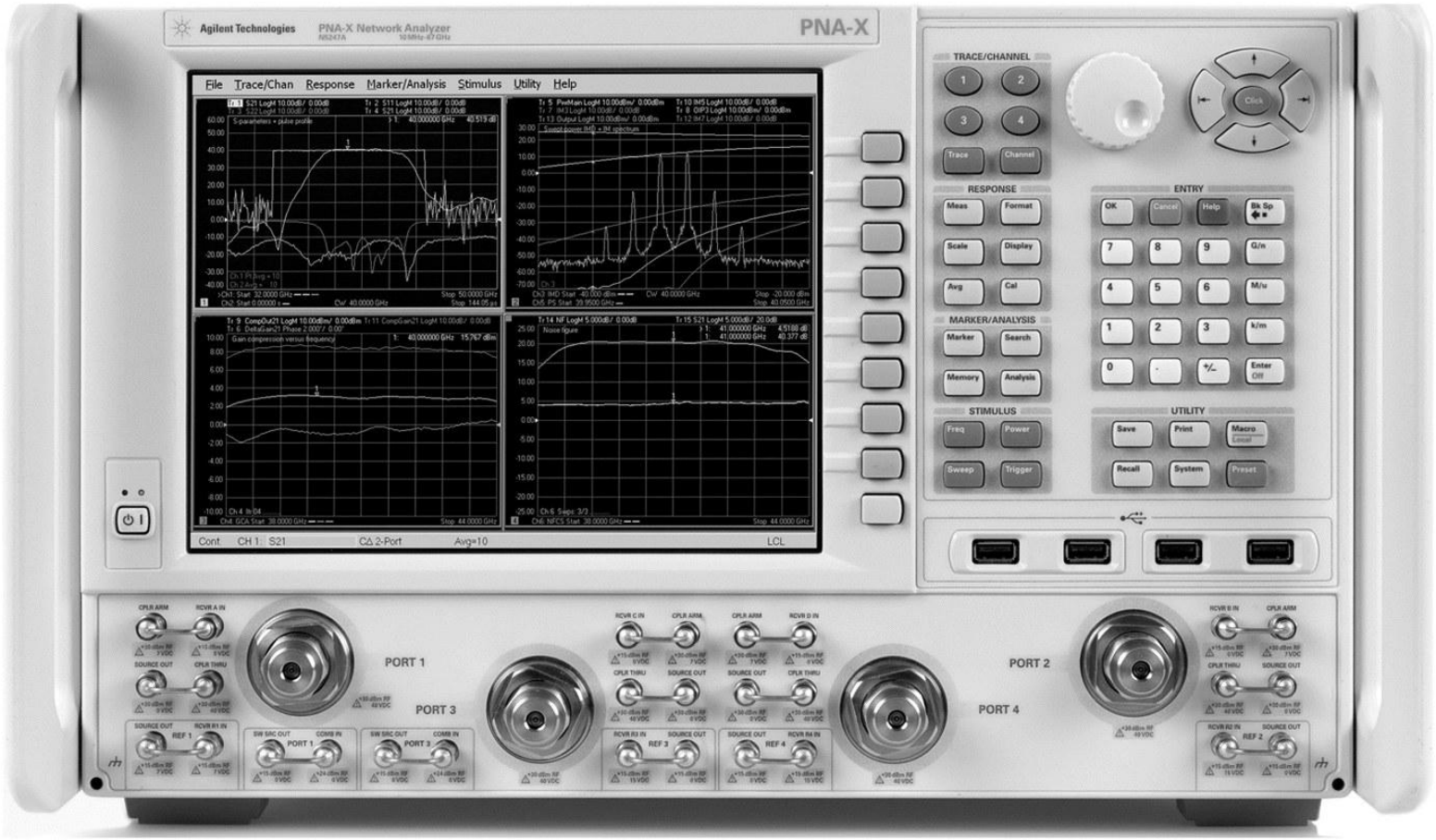



**Figure 4.7**
**Courtesy of Agilent Technologies**

# Legatura dintre parametrii S si parametrii ABCD

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

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

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

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

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

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

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

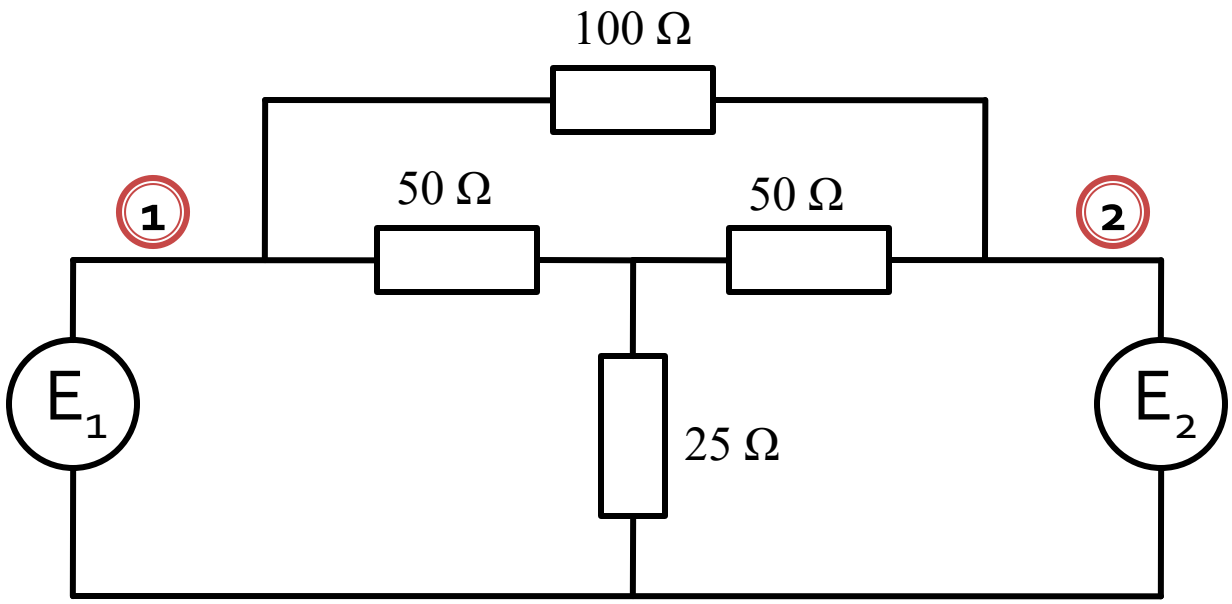
$$S_{21} = \frac{2\sqrt{Z_{01}Z_{02}}}{AZ_{02}+B+CZ_{01}Z_{02}+DZ_{01}}$$

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

# Analiza pe mod par/impar

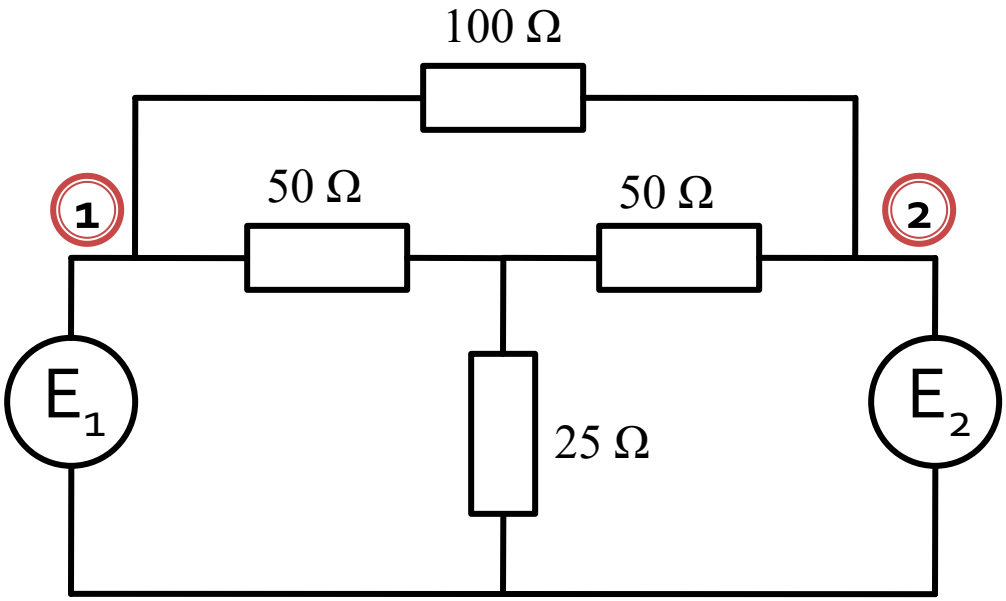
# Analiza pe mod par/impar (even/odd)

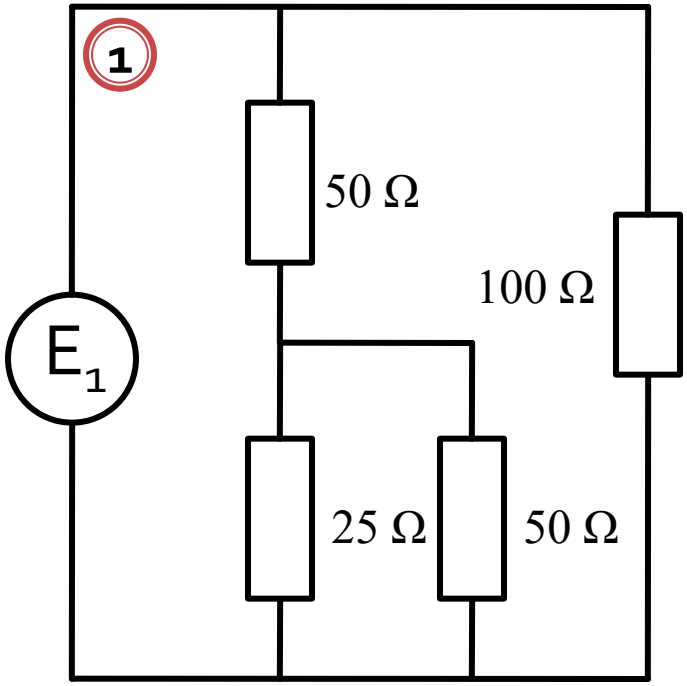
- utila/necesara pentru multiporti
- exemplu, rezistori, circuit cu 2 porturi



# Analiza pe mod par/impar (even/odd)

- presupunem ca doresc $Y_{11}$ $\quad Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0}$
- $E_2 = 0$



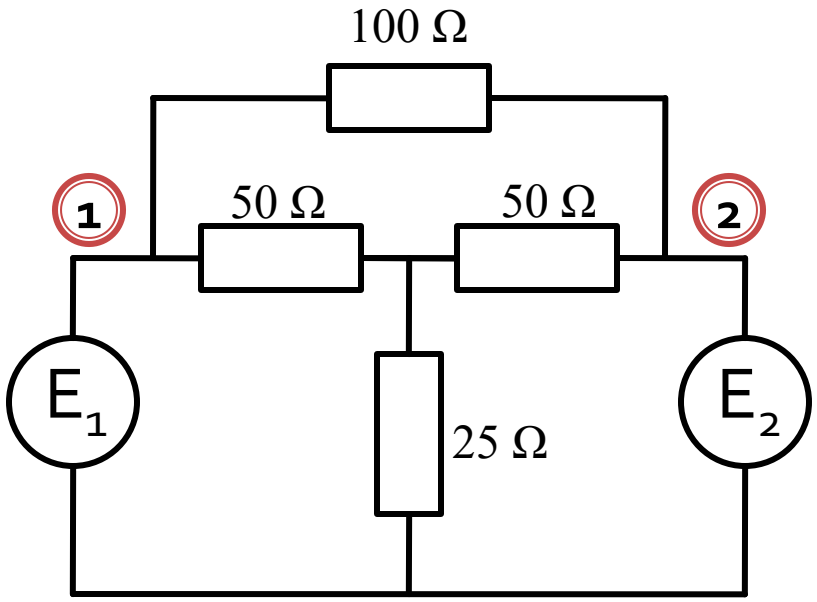



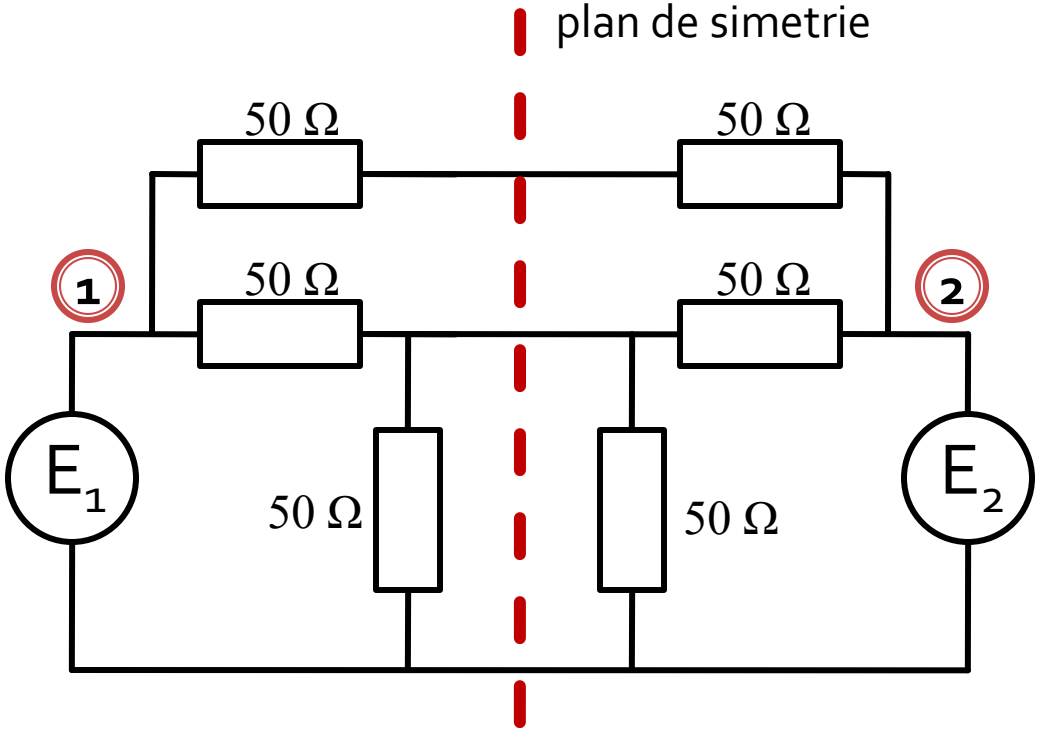

$$R_{ech} = 100\Omega \,||\, (50\Omega + 25\Omega \,||\, 50\Omega) =$$
$$= 100\Omega \,||\, (50\Omega + 16.67\Omega) = 100\Omega \,||\, 66.67\Omega = 40\Omega$$

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

# Analiza pe mod par/impar (even/odd)

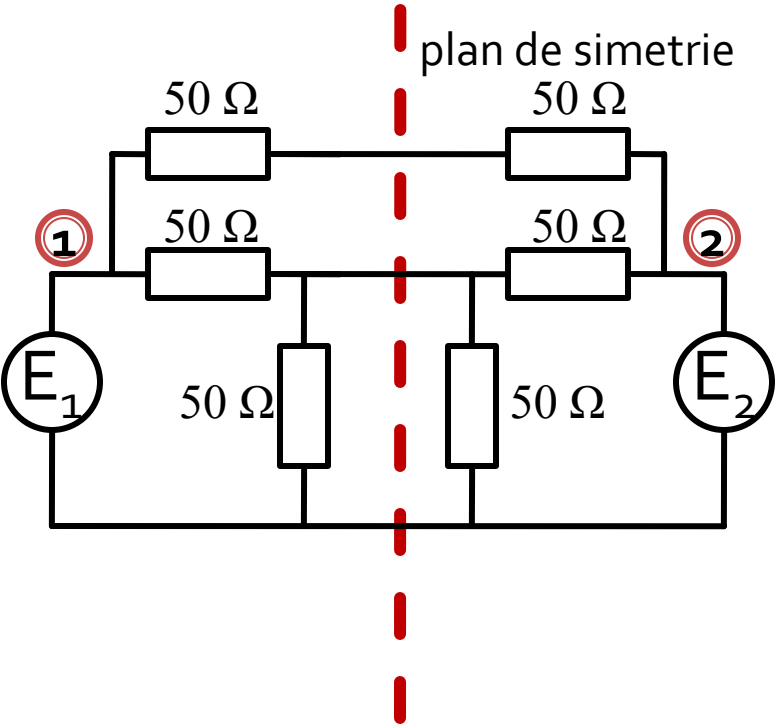
- analiza pe mod par/impar beneficiaza de existenta in circuit a unor plane de simetrie
  - initiale
  - create



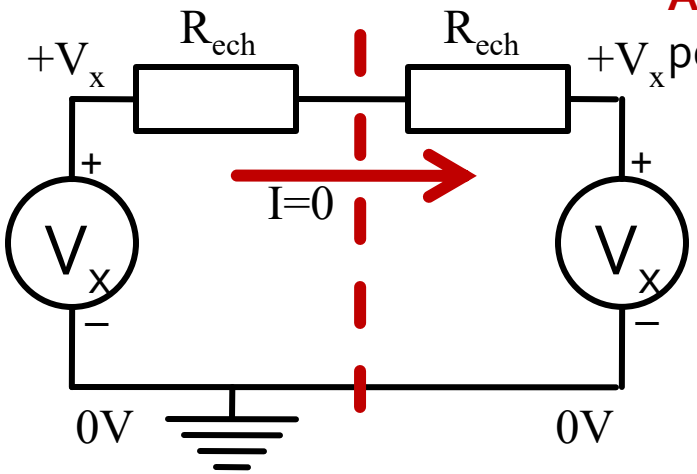



# Analiza pe mod par/impar (even/odd)

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



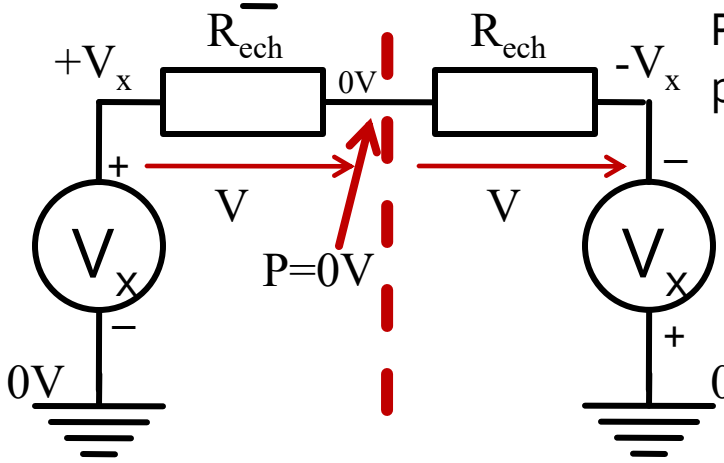

**Aceeasi** polaritate pentru surse




$$I = 0, \forall V_x$$

plan de simetrie **gol**

Polaritate **diferita** pentru surse

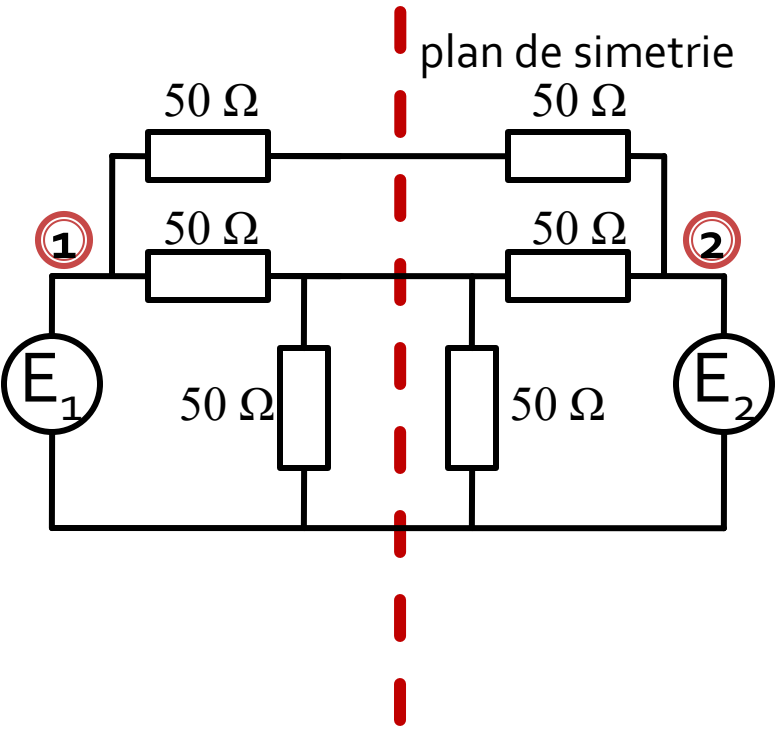


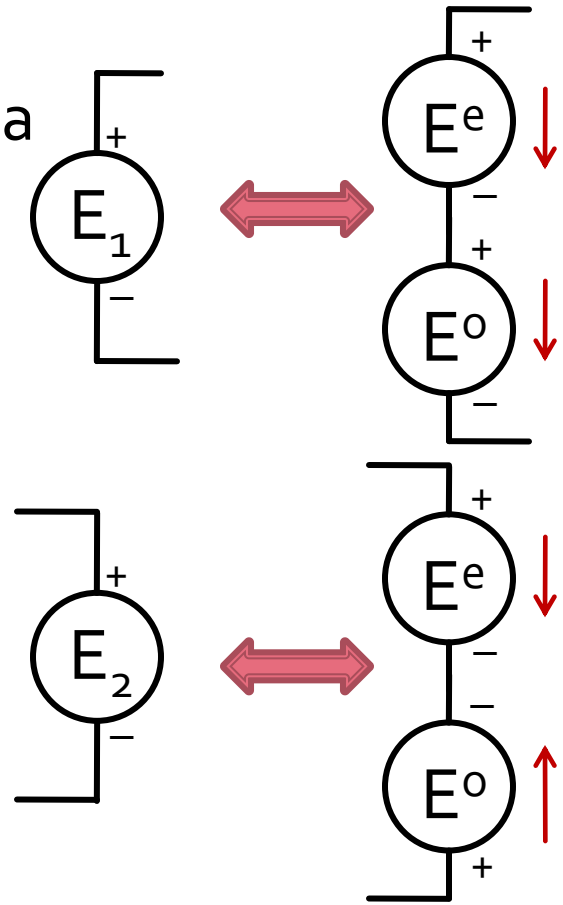

$$P = 0, \forall V_x$$

plan de simetrie **masa**

# 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 )**

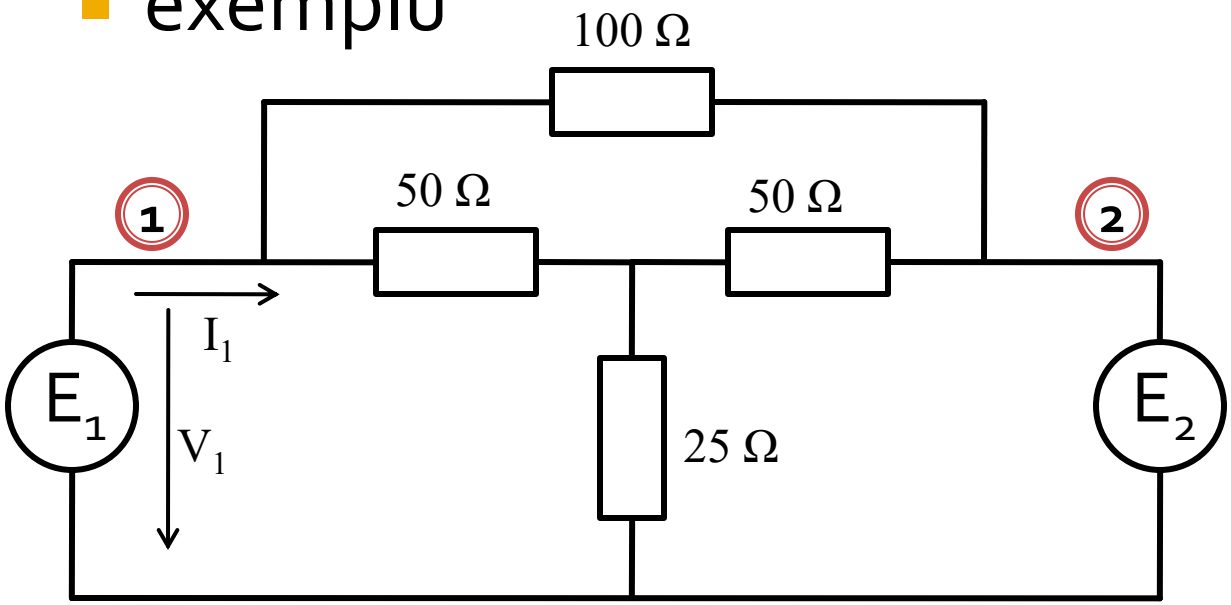
**Efect ( PAR + IMPAR ) = Efect ( PAR ) + Efect ( IMPAR )**

OARECARE

**Putem beneficia de avantajele simetriilor!!**

# Analiza pe mod par/impar (even/odd)

- exemplu

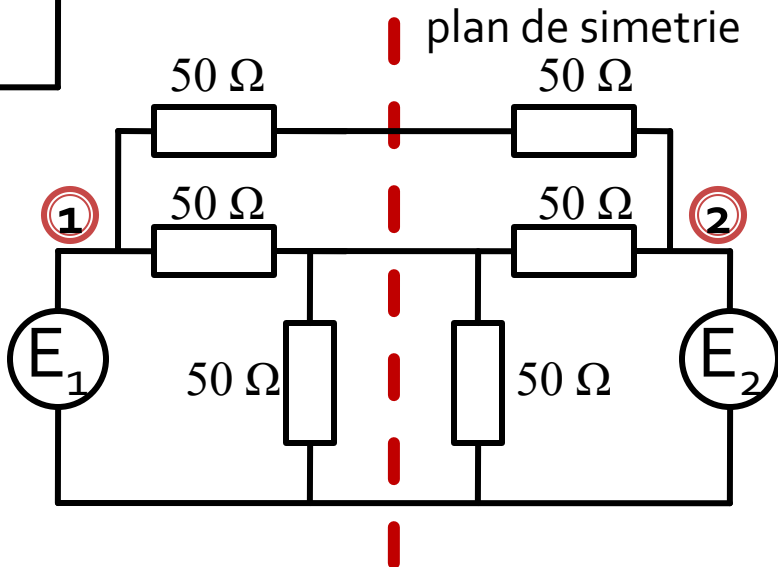



$$Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0}$$

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

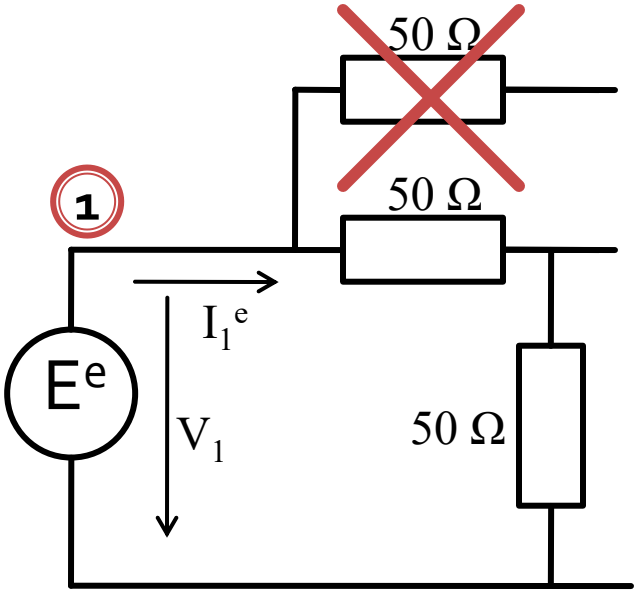
$$E^e = \frac{E_1}{2}$$

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



# Analiza pe mod par/impar (even/odd)

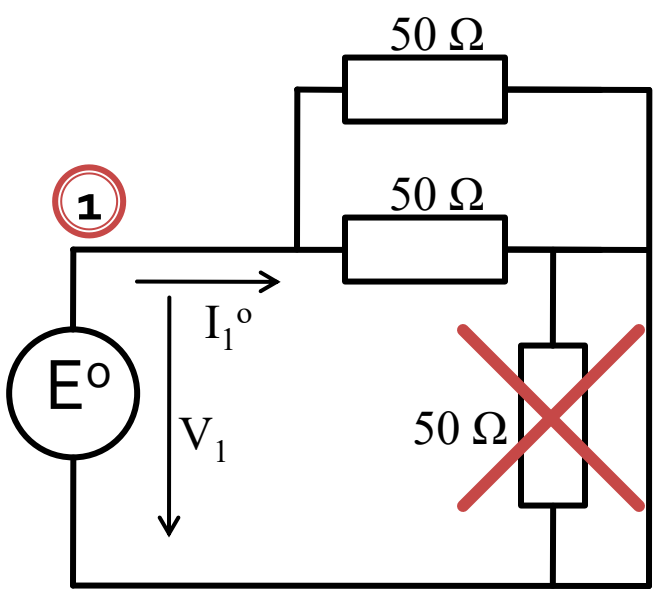
- analiza pe mod par/impar




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

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

**PAR** → plan de simetrie **gol**



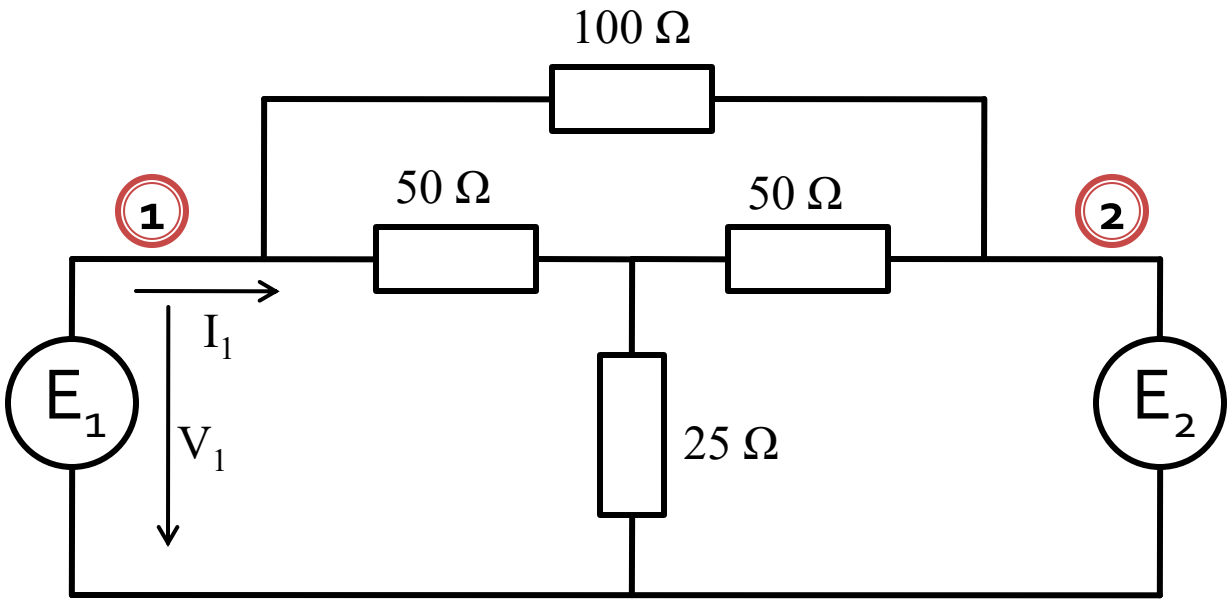

$$R_{ech}^{o} = 50\Omega \,||\, 50\Omega = 25\Omega$$

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

**IMPAR** → plan de simetrie **masa**

# Analiza pe mod par/impar (even/odd)

- suprapunerea efectelor




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

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

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

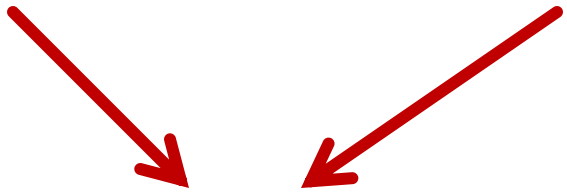
$$V_1 = V_1^e + V_1^o = E_1$$

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

# Analiza pe mod par/impar (even/odd)

- In circuite liniare putem aplica suprapunerea efectelor
- avantaje
  - reducerea complexitatii circuitului
  - reducerea numarului de porturi (**principalul** avantaj)

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



**Putem beneficia de avantajele simetriilor!!**

Puncte suplimentare

# Tema

# Tema C5

- Scrieți pe o foaie de hârtie (si scanați/foto) modalitatea de determinare a matricii ABCD pentru:
  - admitanță paralel
  - linie de transmisie
  - transformator
  - diport π
  - diport T

# Contact

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