

Curs 6
2015/2016

Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2015/2016

- 2C/1L, DCMR (CDM)
- **Minim 7 prezente (curs+laborator)**
- Curs - **sl. Radu Damian**
 - Marti 18-20, P2
 - E – 60% din nota
 - probleme + (2p prez. curs)
 - 3p=+0.5p
 - **toate materialele permise**
- Laborator – **sl. Radu Damian**
 - Miercuri 8-14 impar (14.10.2015 – prez. obligatorie)
 - L – 25% din nota
 - P – 15% din nota

Fotografii +0.5p

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	3	ANTONICA BIANCA	 Fotografia nu există	4	APOSTOL PAVEL-MANUEL	 Fotografia nu există	<input type="checkbox"/> Prezent	5	BALASCA TUDIAN-PETRU	 Fotografia nu există	6	BOSTAN ANDREI-PETRICA	 Fotografia nu există	7	BOTEZAT EMANUEL		<input type="checkbox"/> Prezent	8	BUTUNOI GEORGE-MADALIN	 Fotografia nu există	9	CHILEA SALUCA-MARIA	 Fotografia nu există	10	CHRITOIU CATERINA		<input type="checkbox"/> Prezent	11	CODOC MARIUS		12	COJOCARU AURA-FLORINA	

Nr. Student

Prezent

2 ANTIGHIN
FLORIN-RAZVAN

Prezent

Puncte: 0

Nota: 0

Obs:

Fotografia nu există

Reprezentare logarithmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Recapitulare

Adaptare dpdv al puterii

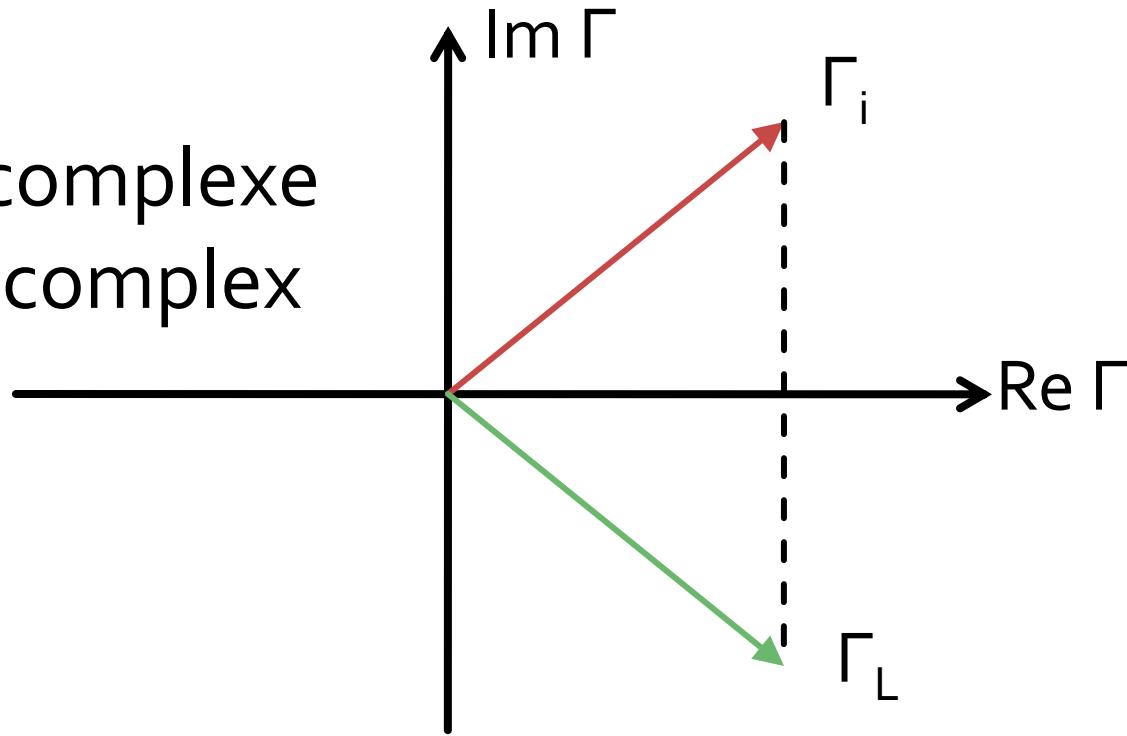
$$Z_L = Z_i^*$$

Daca se alege un Z_0 real

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

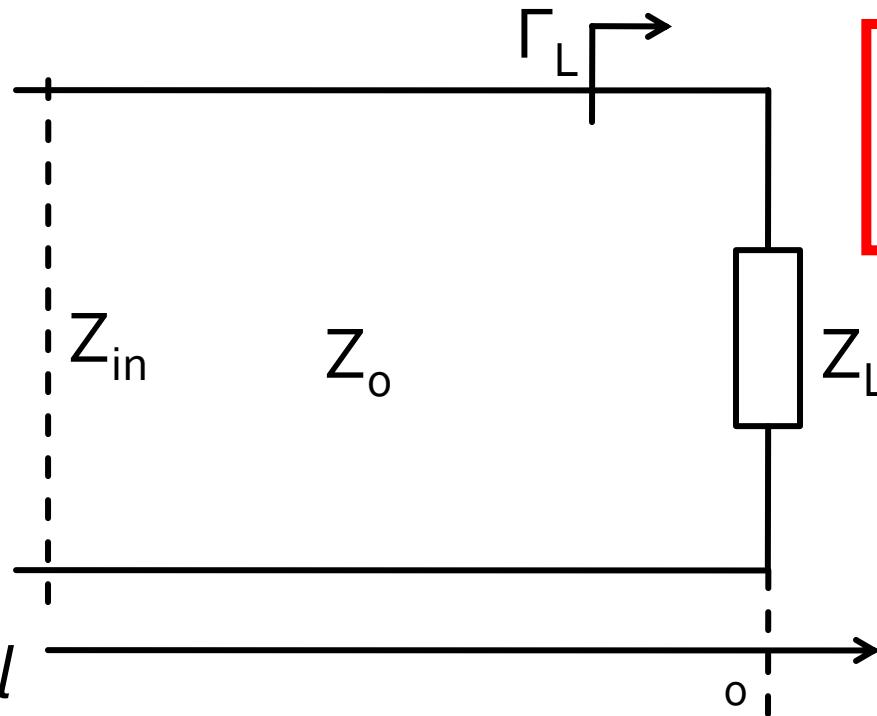
$$\Gamma_L = \Gamma_i^*$$

- numere complexe
- in planul complex



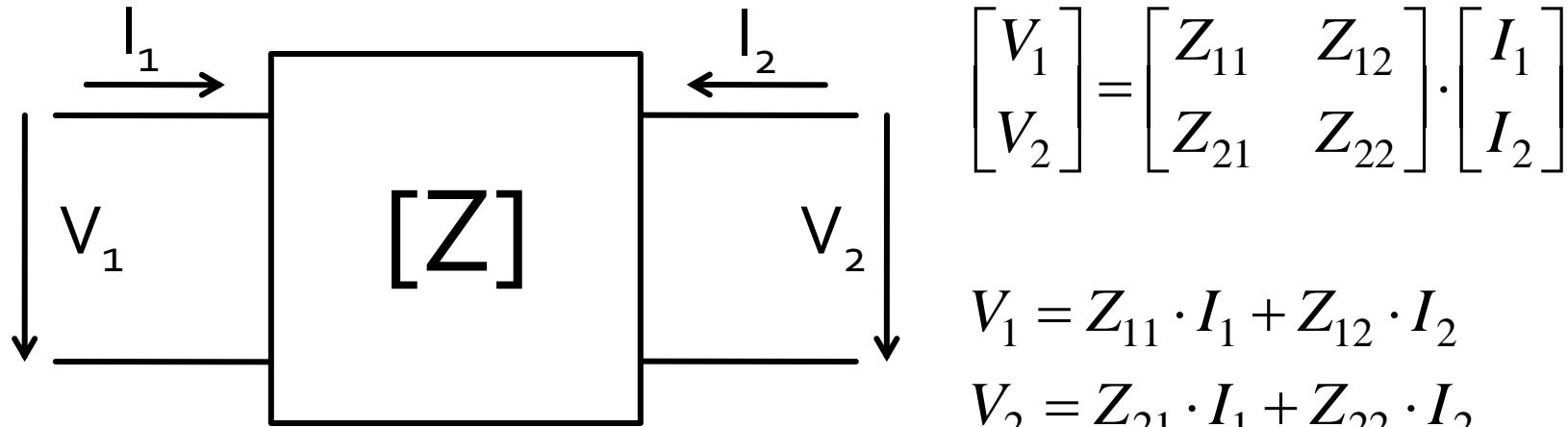
Linie fara pierderi

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



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

Matricea impedanta



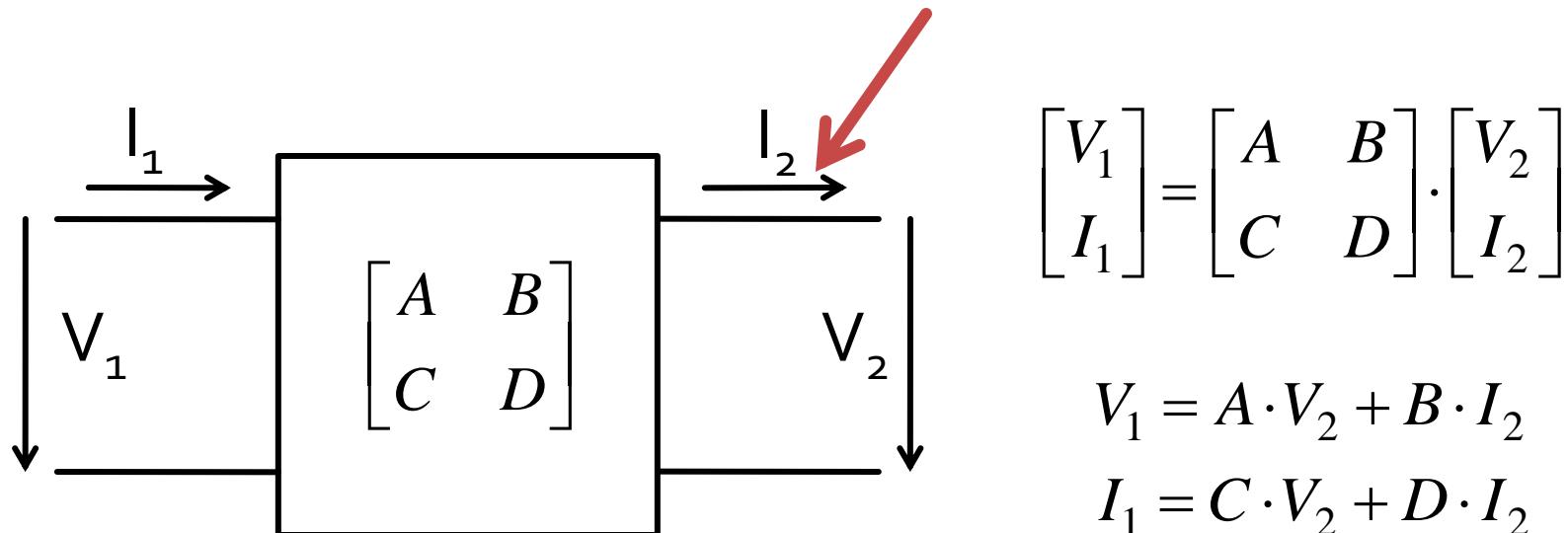
$$V_1 = Z_{11} \cdot I_1 \Big|_{I_2=0} \quad Z_{11} = \frac{V_1}{I_1} \Big|_{I_2=0}$$

$$Z_{11} = \frac{V_1}{I_1} \Big|_{I_2=0} \quad Z_{12} = \frac{V_1}{I_2} \Big|_{I_1=0}$$

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

$$Z_{21} = \frac{V_2}{I_1} \Big|_{I_2=0} \quad Z_{22} = \frac{V_2}{I_2} \Big|_{I_1=0}$$

Matricea ABCD – de transmisie



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

$$A = \left. \frac{V_1}{V_2} \right|_{I_2=0}$$

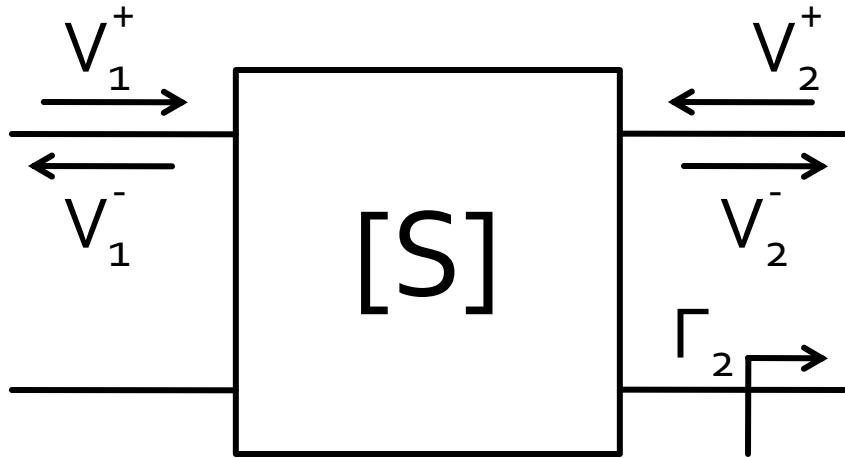
$$B = \left. \frac{V_1}{I_2} \right|_{V_2=0}$$

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

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

Matricea S (repartitie)

■ Scattering parameters



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

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

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

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

Proprietati [S]

- Circuite reciproce (fara circuite active, ferite)

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

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

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

$$[S] = [S]^t$$

- Circuite fara pierderi

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

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

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

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

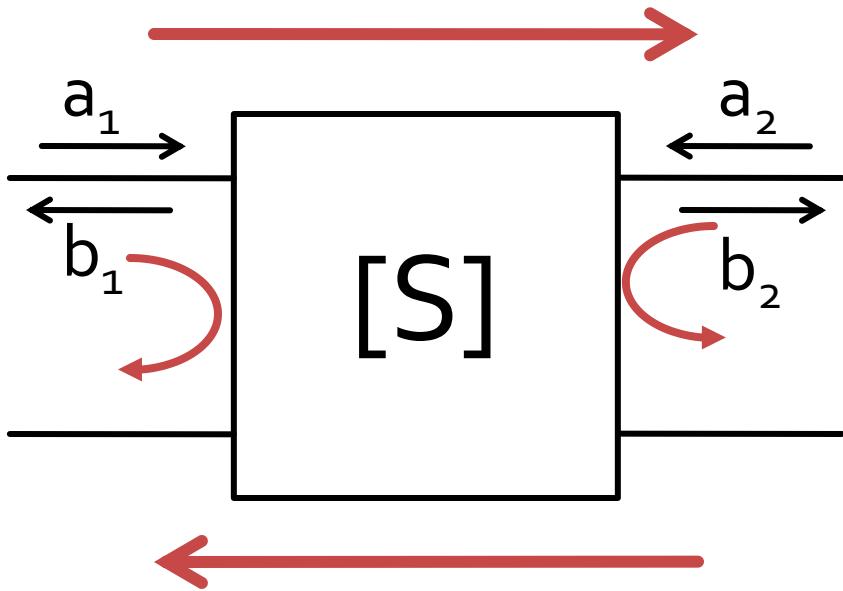
$$\sum_{k=1}^N S_{ki} \cdot S_{kj}^* = 0, \forall i \neq j$$

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

- Legatura cu matricea Z

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

Matricea S (repartitie)

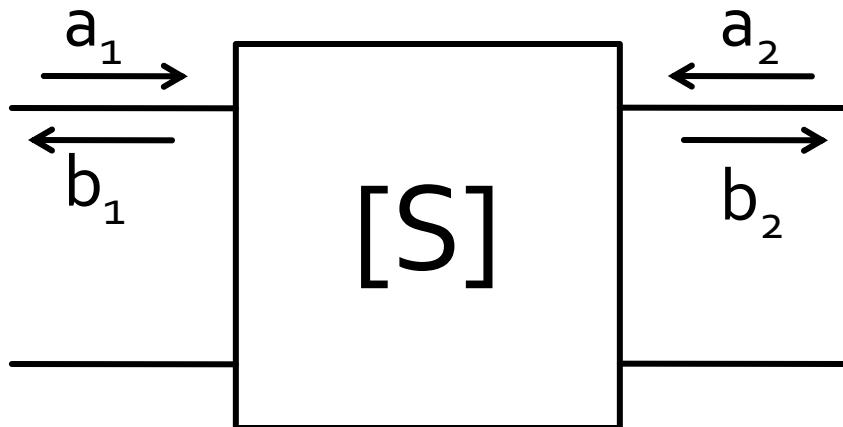


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{11} = \frac{b_1}{a_1} \Big|_{a_2=0} \quad S_{22} = \frac{b_2}{a_2} \Big|_{a_1=0}$$
$$S_{21} = \frac{b_2}{a_1} \Big|_{a_2=0} \quad S_{12} = \frac{b_1}{a_2} \Big|_{a_1=0}$$

- S_{11} și S_{22} sunt coeficienți de reflexie la intrare și ieșire cand celalalt port este adaptat
- 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

Continuare

**Cuploare directionale si
divizoare de putere**

Cuploare/Divizoare

- Funcționalitatea dorită:
 - divizarea
 - combinarea
- puterii semnalului

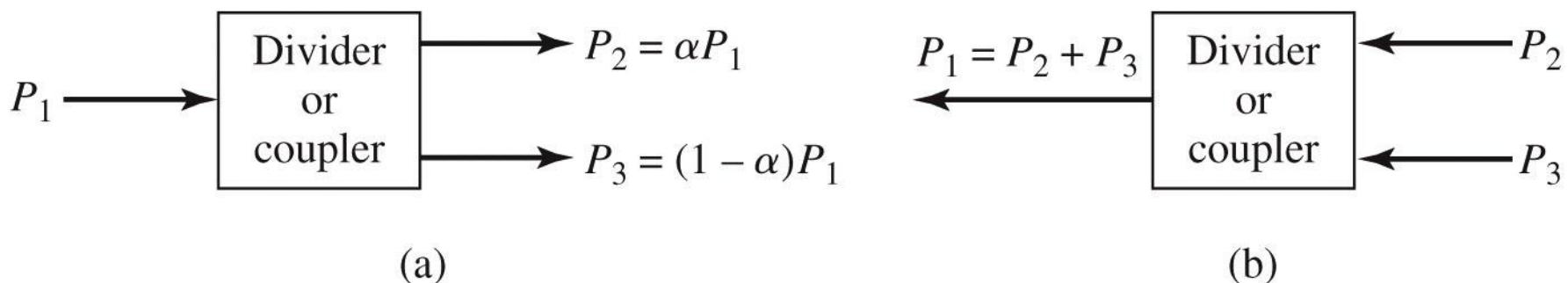


Figure 7.1
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Circuite cu trei porți

- 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

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

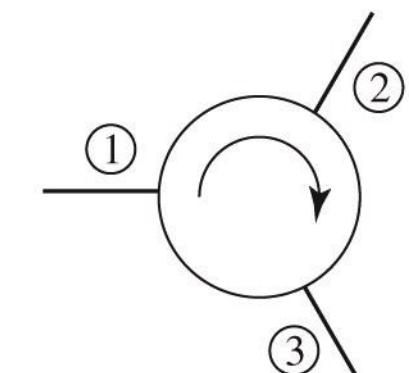
$$|S_{21}| = |S_{32}| = |S_{13}| = 1$$

- în sens orar invers

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

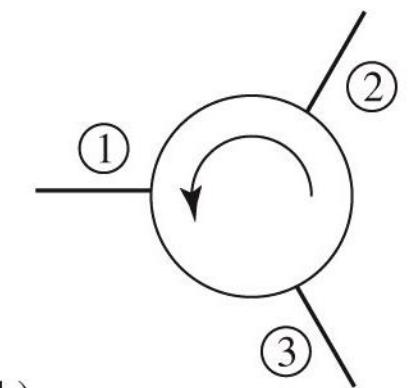
$$|S_{12}| = |S_{23}| = |S_{31}| = 1$$

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



(a)

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



(b)

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

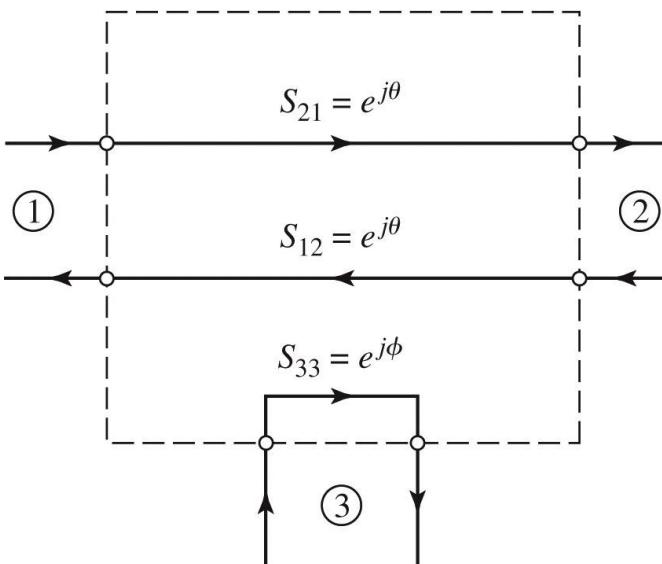
- Un circuit cu 3 porți reciproc și fără pierderi

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

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

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

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



- 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** e **separat** și **dezadaptat**

Divizoare de putere

Divizarea de putere a jonctiunii in T

- constă în separarea unei linii incidente în două linii separate
- se poate implementa în diverse tehnologii

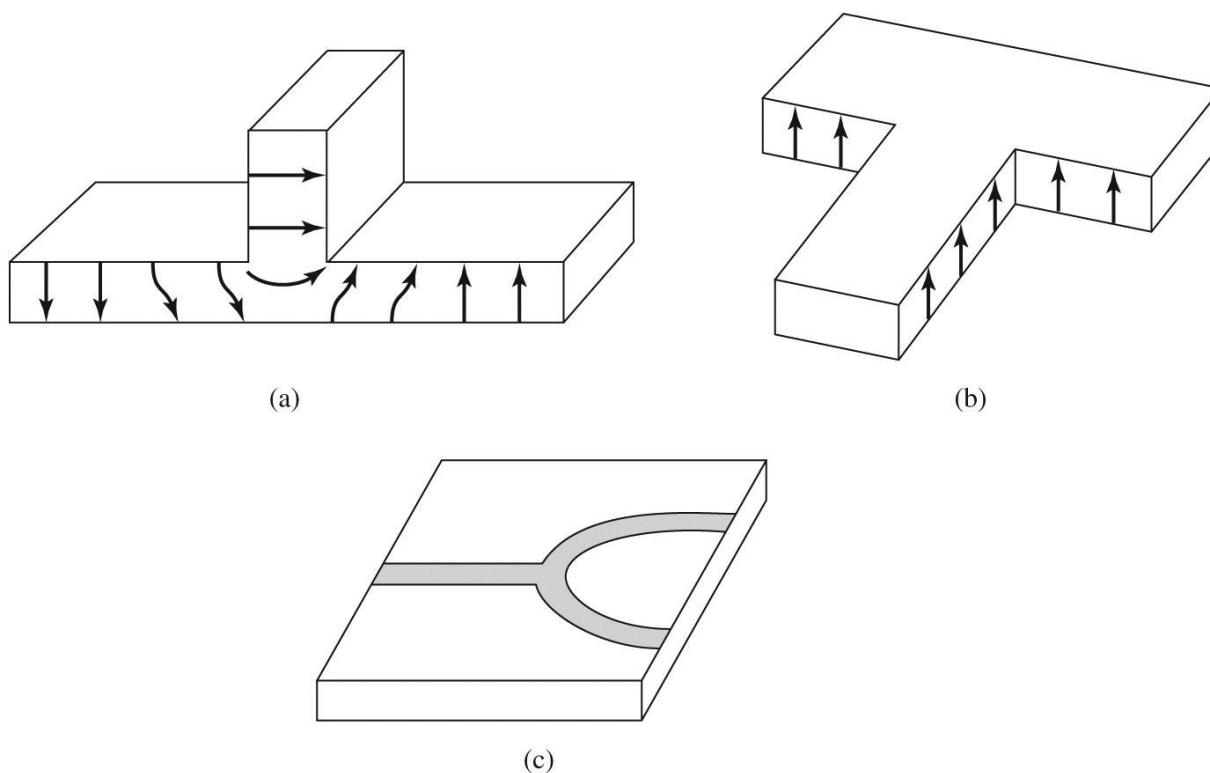
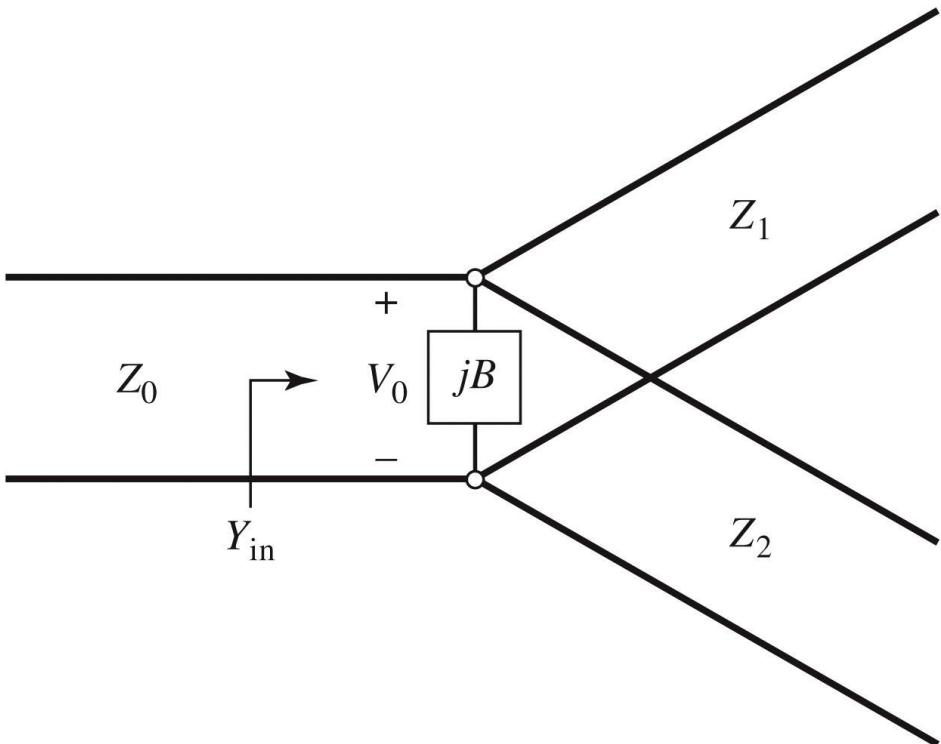


Figure 7.5
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Divizarea de putere a jonctiunii in T

- daca liniile sunt fără pierderi, diportul este reciproc, deci nu poate fi adaptat la toate portile simultan
 - la nivelul jonctiunii câmpurile sunt neuniforme, generând moduri de ordin superior localizate
 - aceasta energie localizată poate fi modelată cu o reactanță concentrată la nivelul jonctiunii: **B**
 - Proiectarea divizorului presupune adaptarea la linia de intrare cu Z_0
 - ieșirile pot fi adaptate mai departe cu circuite suplimentare ($\lambda/4$, binomial, Cebișev)
-

Divizarea de putere a jonctiunii in T



- $$Y_{in} = j \cdot B + \frac{1}{Z_1} + \frac{1}{Z_2} = \frac{1}{Z_0}$$
- daca liniile sunt fără pierderi, impedantele caracteristice sunt reale
 - conditia de adaptare poate fi indeplinita doar daca $B \cong 0$ caz in care conditia de adaptare este:

$$\frac{1}{Z_1} + \frac{1}{Z_2} = \frac{1}{Z_0}$$

In practica daca B nu poate fi neglijat, se introduce o reactanta externa de compensare, reglabilă, cu efect macar intr-o banda ingusta de frecventa.

Divizarea de putere a jonctiunii in T

- daca V_o e amplitudinea semnalului la jonctiune

$$P_1 = \frac{1}{2} \cdot \frac{V_0^2}{Z_1}$$
$$P_{in} = \frac{1}{2} \cdot \frac{V_0^2}{Z_0}$$

deci:

$$P_2 = \frac{1}{2} \cdot \frac{V_0^2}{Z_2}$$

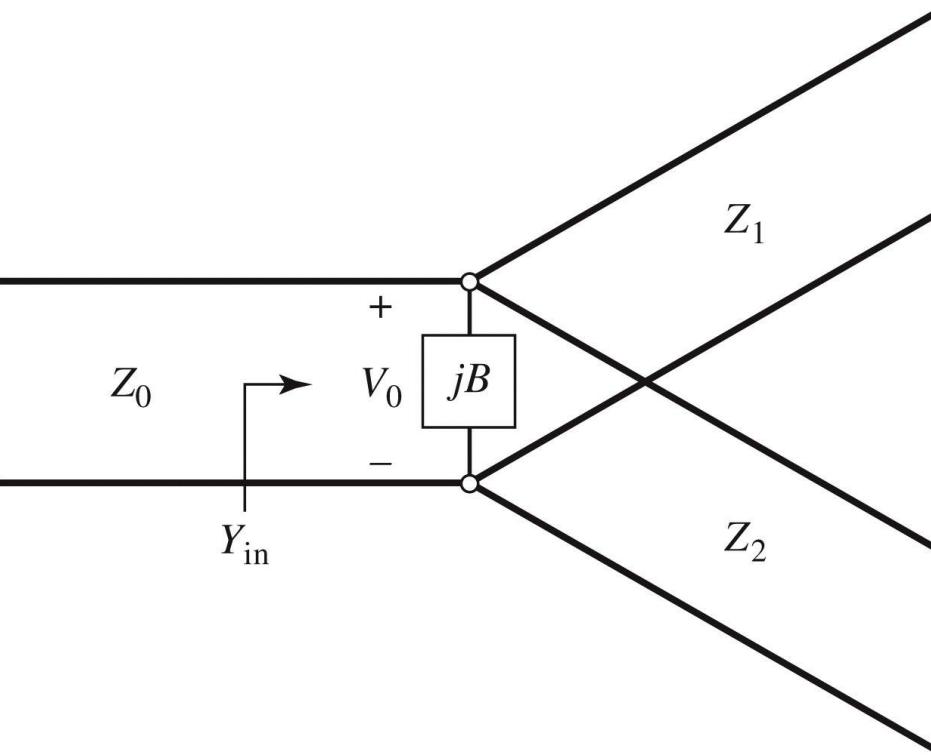
$$P_{in} = P_1 + P_2 \quad (\text{fara pierderi})$$

$$\frac{P_1}{P_2} = \frac{Z_2}{Z_1} = \alpha \quad (\text{impartirea puterii pe cele doua linii de iesire})$$

$$P_1 = P_{in} \cdot \frac{Z_2}{Z_1 + Z_2} \quad P_2 = P_{in} \cdot \frac{Z_1}{Z_1 + Z_2}$$

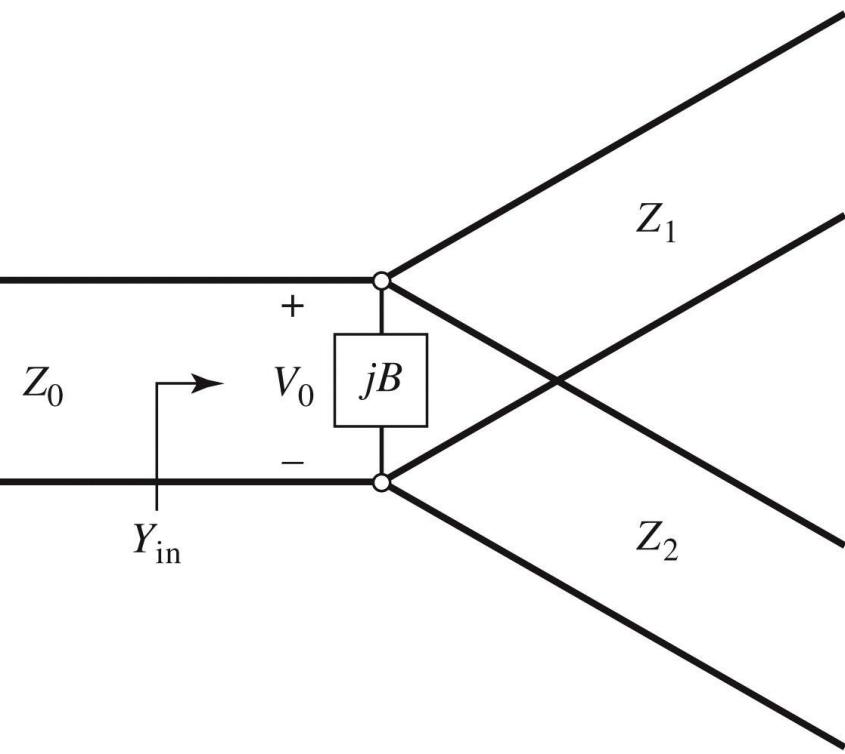
$$P_1 = P_{in} \cdot \frac{\alpha}{1 + \alpha} \quad P_2 = P_{in} \cdot \frac{1}{1 + \alpha}$$

$$Z_1 = Z_0 \cdot \left(1 + \frac{1}{\alpha}\right) \quad Z_2 = Z_0 \cdot (1 + \alpha)$$



Divizarea de putere a jonctiunii in T

- daca V_o e amplitudinea semnalului la jonctiune



$$P_{in} = \frac{1}{2} \cdot \frac{V_0^2}{Z_0}$$

deci:

$$P_1 = \frac{1}{2} \cdot \frac{V_0^2}{Z_1}$$
$$P_2 = \frac{1}{2} \cdot \frac{V_0^2}{Z_2}$$

$$P_{in} = P_1 + P_2 \quad (\text{fara pierderi})$$

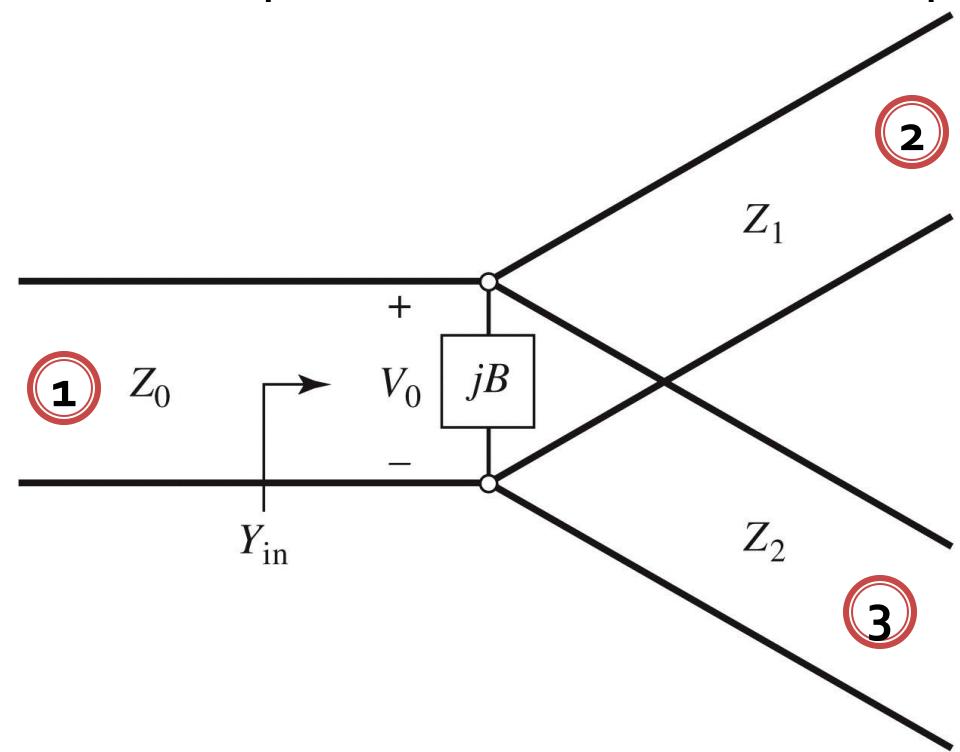
$$\frac{P_1}{P_2} = \frac{Z_2}{Z_1} = \alpha \quad (\text{impartirea puterii pe cele doua linii de iesire})$$

$$P_1 = P_{in} \cdot \frac{Z_2}{Z_1 + Z_2} \quad P_2 = P_{in} \cdot \frac{Z_1}{Z_1 + Z_2}$$

$$P_1 = P_{in} \cdot \frac{\alpha}{1+\alpha} \quad P_2 = P_{in} \cdot \frac{1}{1+\alpha}$$
$$Z_1 = Z_0 \cdot \left(1 + \frac{1}{\alpha}\right) \quad Z_2 = Z_0 \cdot \left(1 - \frac{1}{\alpha}\right)$$

Divizarea de putere a jonctiunii in T

- matricea S
 - fara pierderi (matrice unitara)
 - reciproc (matrice simetrica)
 - portul de intrare este adaptat $S_{11} = 0$



$$P_2 = P_1 \cdot \frac{\alpha}{1+\alpha}$$

$$P_3 = P_1 \cdot \frac{1}{1+\alpha}$$

$$S_{21} = S_{12} = \sqrt{\frac{\alpha}{1+\alpha}}$$

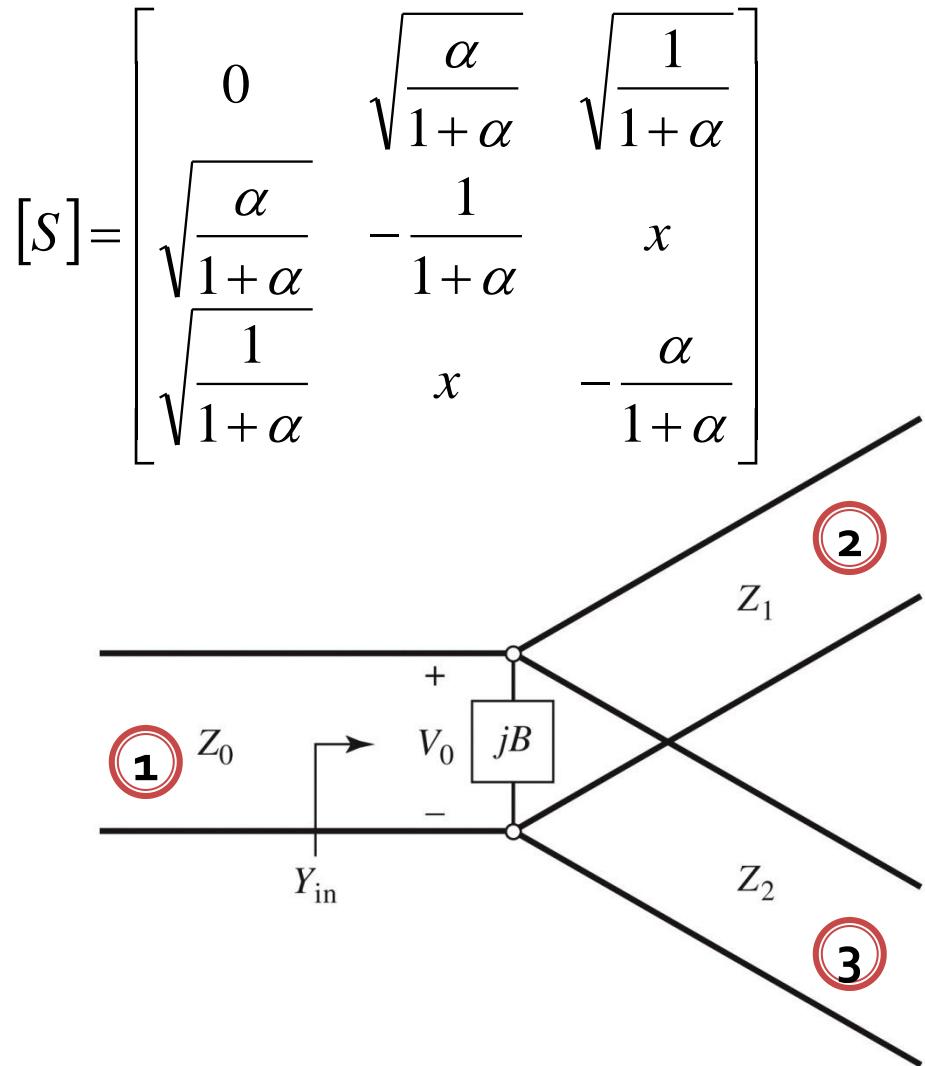
$$S_{31} = S_{13} = \sqrt{\frac{1}{1+\alpha}}$$

Coeficienti de reflexie la iesiri

$$S_{22} = \Gamma_1 = \frac{Z_0 \| Z_2 - Z_1}{Z_0 \| Z_2 + Z_1} = -\frac{1}{1+\alpha}$$

$$S_{33} = \Gamma_2 = \frac{Z_0 \| Z_1 - Z_2}{Z_0 \| Z_1 + Z_2} = -\frac{\alpha}{1+\alpha}$$

Divizarea de putere a jonctiunii in T



Matrice unitara, coloanele 1 si 2

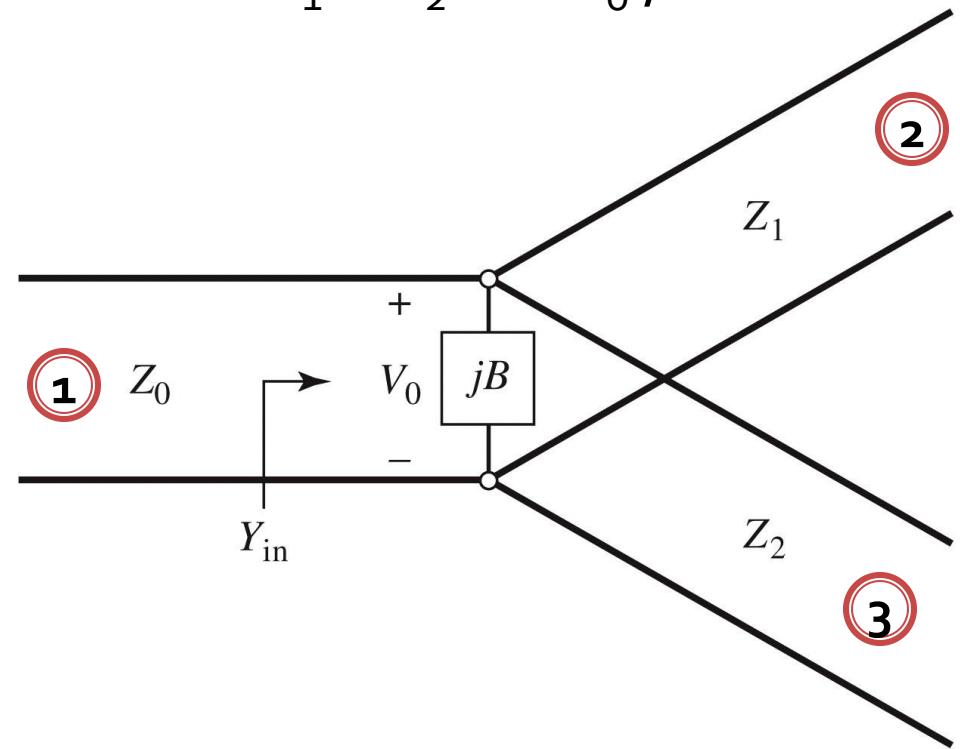
$$0 - \frac{1}{1+\alpha} \cdot \sqrt{\frac{\alpha}{1+\alpha}} + x \cdot \sqrt{\frac{1}{1+\alpha}} = 0$$

$$S_{23} = S_{32} = \frac{\sqrt{\alpha}}{1+\alpha}$$

$$[S] = \begin{bmatrix} 0 & \sqrt{\frac{\alpha}{1+\alpha}} & \sqrt{\frac{1}{1+\alpha}} \\ \sqrt{\frac{\alpha}{1+\alpha}} & -\frac{1}{1+\alpha} & \frac{\sqrt{\alpha}}{1+\alpha} \\ \sqrt{\frac{1}{1+\alpha}} & \frac{\sqrt{\alpha}}{1+\alpha} & -\frac{\alpha}{1+\alpha} \end{bmatrix}$$

Divizarea de putere a jonctiunii in T

- divizor de 3dB
 - impartire egala a puterii intre cele doua iesiri
 - $Z_1 = Z_2 = 2 \cdot Z_0, \alpha = 1$



$$[S] = \begin{bmatrix} 0 & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{1}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{2} & -\frac{1}{2} \end{bmatrix}$$

Daca se adauga transformatoare in $\lambda/4$ pentru a adapta iesirile la Z_0 matricea S devine:

$$[S] = \begin{bmatrix} 0 & -\frac{j}{\sqrt{2}} & -\frac{j}{\sqrt{2}} \\ -\frac{j}{\sqrt{2}} & \frac{1}{2} & -\frac{1}{2} \\ -\frac{j}{\sqrt{2}} & -\frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

Exemplu

- Proiectați un divizor cu joncțiune în T care are o impedanță a sursei de 30Ω , pentru a obține un raport de puteri la ieșire de $3:1$. Proiectați transformatoare în sfert de lungime de undă care să convertească impedanța liniilor de ieșire la 30Ω .

$$P_{in} = \frac{1}{2} \cdot \frac{V_0^2}{Z_0} \quad \begin{cases} P_1 + P_2 = P_{in} \\ P_1 : P_2 = 3:1 \end{cases} \Rightarrow \begin{cases} P_1 = \frac{1}{4} \cdot P_{in} \\ P_2 = \frac{3}{4} \cdot P_{in} \end{cases}$$

$$P_1 = \frac{1}{2} \cdot \frac{V_0^2}{Z_1} = \frac{1}{4} \cdot P_{in} \quad Z_1 = 4 \cdot Z_0 = 120\Omega$$

$$P_2 = \frac{1}{2} \cdot \frac{V_0^2}{Z_2} = \frac{3}{4} \cdot P_{in} \quad Z_2 = 4 \cdot Z_0 / 3 = 40\Omega$$

Transformatoare $Z_c^i = \sqrt{Z_i \cdot Z_L}$

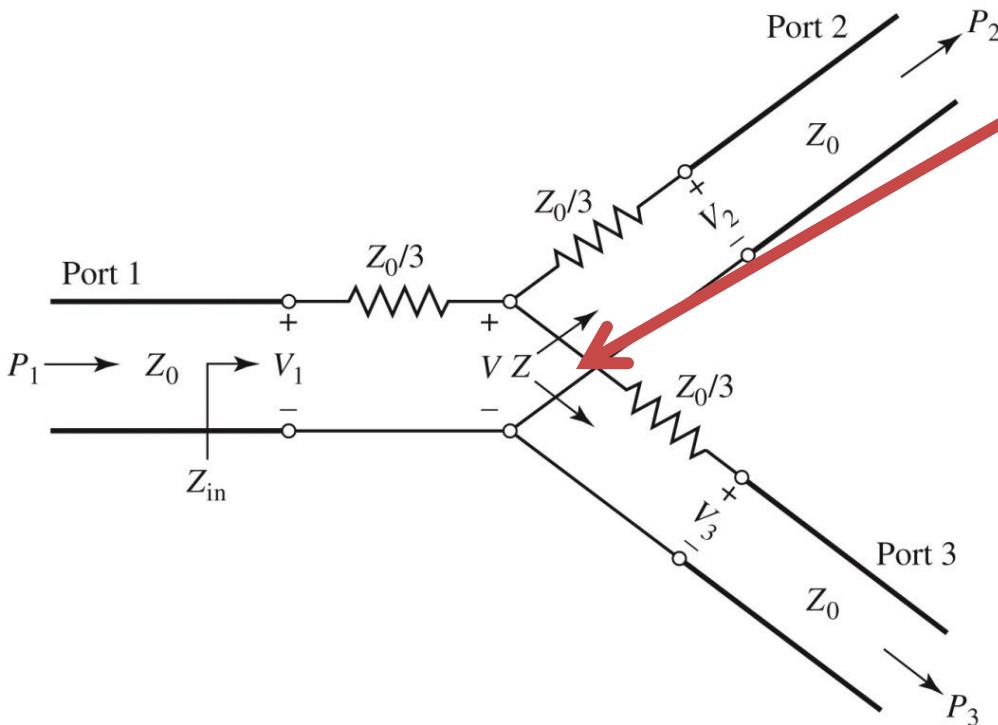
$$Z_c^1 = \sqrt{Z_1 \cdot Z_L} = \sqrt{120\Omega \cdot 30\Omega} = 60\Omega \quad Z_c^2 = \sqrt{Z_2 \cdot Z_L} = \sqrt{400\Omega \cdot 30\Omega} = 34.64\Omega$$

Verificare

$$Z_{in} = 40\Omega \parallel 120\Omega = 30\Omega$$

Divizorul de putere rezistiv

- Introducerea elementelor disipative (pierderi) permite realizarea divizorului:
 - reciproc
 - adaptat la toate cele porti



Impedanta Z vazuta de la nivelul jonctiunii spre una din linii:

$$Z = \frac{Z_0}{3} + Z_0 = \frac{4Z_0}{3}$$

Linia de intrare va vedea la capat o rezistenta in serie cu doua astfel de linii in paralel

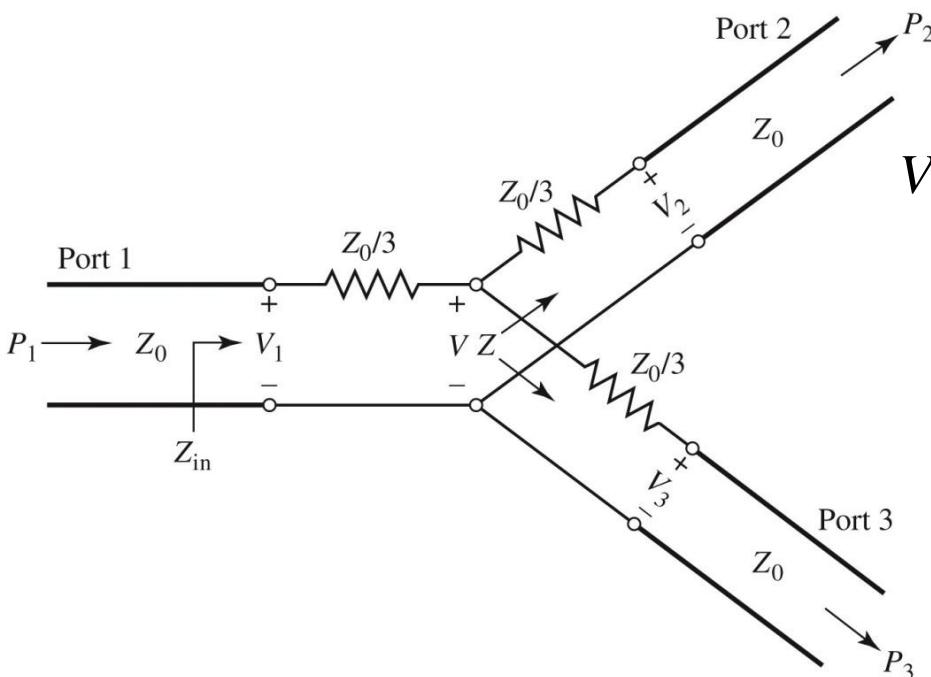
$$Z_{in} = \frac{Z_0}{3} + \frac{1}{2} \cdot \frac{4Z_0}{3} = Z_0$$

deci va fi adaptata: $S_{11} = 0$

din simetrie: $S_{11} = S_{22} = S_{33} = 0$

Divizorul de putere rezistiv

- Introducerea elementelor disipative (pierderi) permite realizarea divizorului:
 - reciproc (matricea S e simetrică)
 - adaptat la toate cele porti $S_{11} = S_{22} = S_{33} = 0$



V_1 e tensiunea la intrarea in portul 1, calculam tensiunea la nivelul jonctiunii V

$$V = V_1 \cdot \frac{Z/2}{Z/2 + Z_0/3} = V_1 \cdot \frac{2Z_0/3}{2Z_0/3 + Z_0/3} = \frac{2}{3} \cdot V_1$$

Tensiunile de ieșire se obțin tot prin divizare:

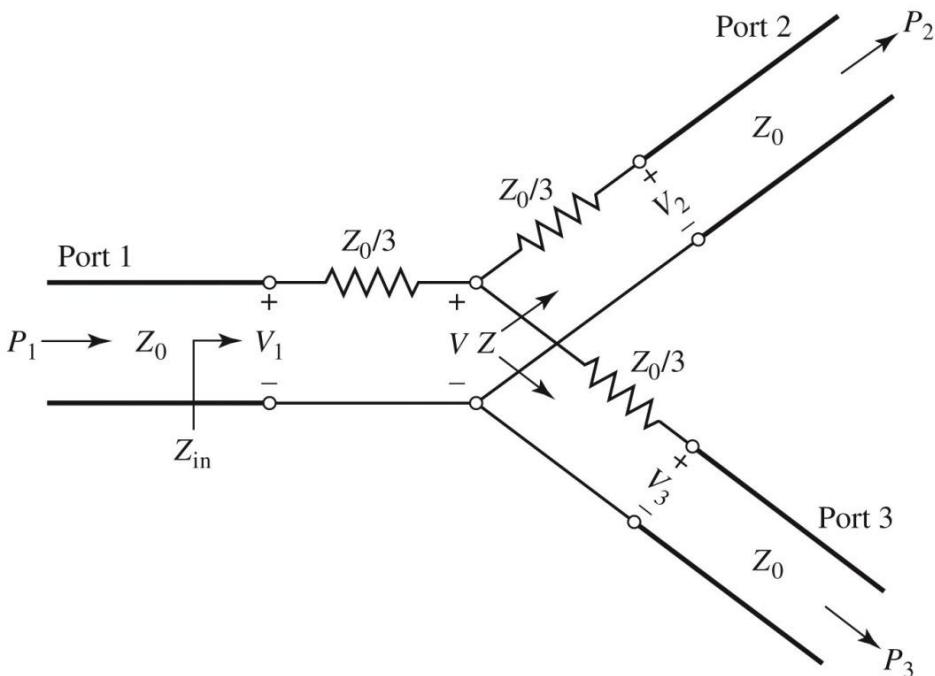
$$V_2 = V_3 = V \cdot \frac{Z_0}{Z_0 + Z_0/3} = \frac{3}{4} \cdot V = \frac{1}{2} \cdot V_1$$

$$S_{21} = S_{31} = \frac{1}{2}$$

din simetrie: $S_{21} = S_{31} = S_{23} = \frac{1}{2}$

Divizorul de putere rezistiv

- Introducerea elementelor disipative (pierderi) permite realizarea divizorului:
 - reciproc (matricea S e simetrică) $S_{21} = S_{31} = S_{23} = \frac{1}{2}$
 - adaptat la toate cele porti $S_{11} = S_{22} = S_{33} = 0$



$$\text{Matricea } S \quad [S] = \frac{1}{2} \cdot \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix}$$

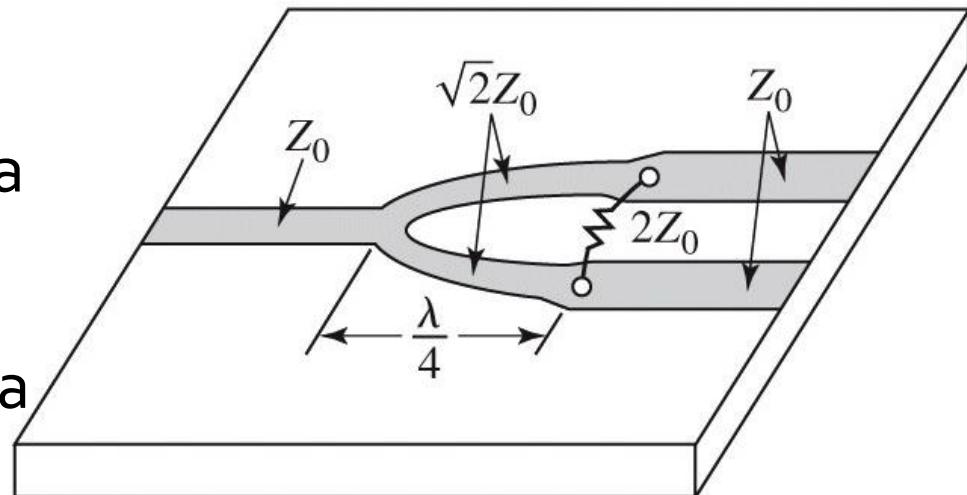
$$\text{Puteri: } P_{in} = \frac{1}{2} \cdot \frac{V_1^2}{Z_0}$$

$$P_2 = P_3 = \frac{1}{2} \cdot \frac{(1/2V_1)^2}{Z_0} = \frac{1}{8} \cdot \frac{V_1^2}{Z_0} = \frac{1}{4} \cdot P_{in}$$

Jumătate din putere se disipa pe cei 3 rezistori

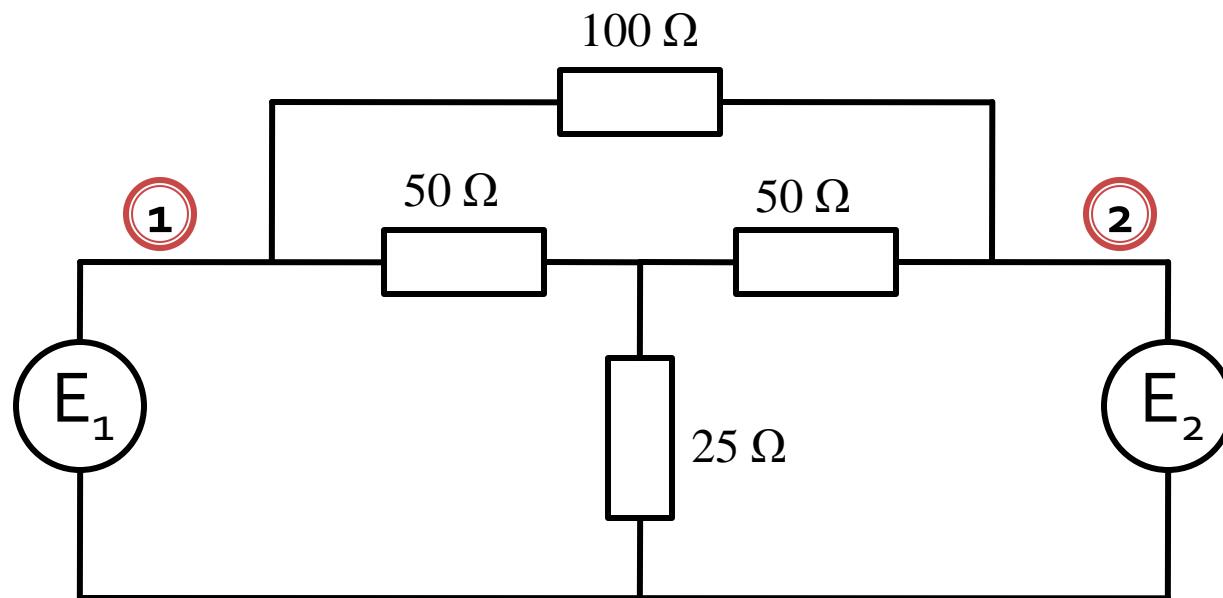
Divizorul de putere Wilkinson

- Divizoarele de putere anteroare au un dezavantaj major, nu există **izolare** între cele două porturi de ieșire $S_{23} = S_{32} \neq 0$
 - acest deziderat e important în anumite aplicații
- Divizorul Wilkinson este introdus pentru rezolvarea acestui impediment
 - o proprietate utilă suplimentară este că “pare” fără pierderi dacă porturile de ieșire sunt adaptate
 - numai energia reflectată din ieșiri este disipată



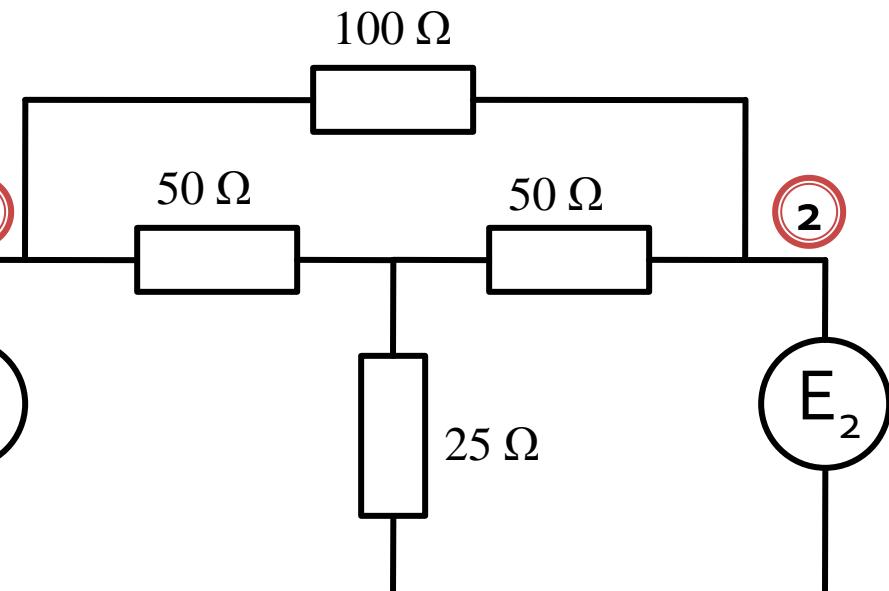
Analiza pe mod par/impar (even/odd)

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

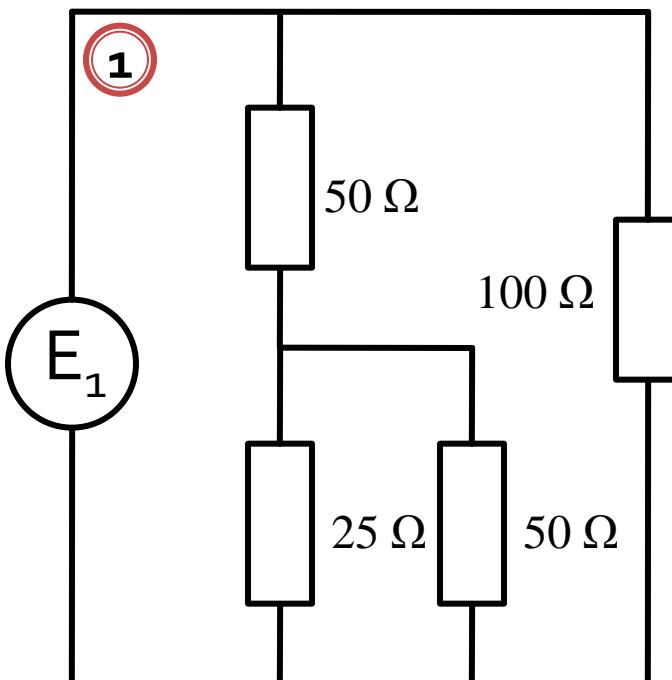


Analiza pe mod par/impar (even/odd)

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



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

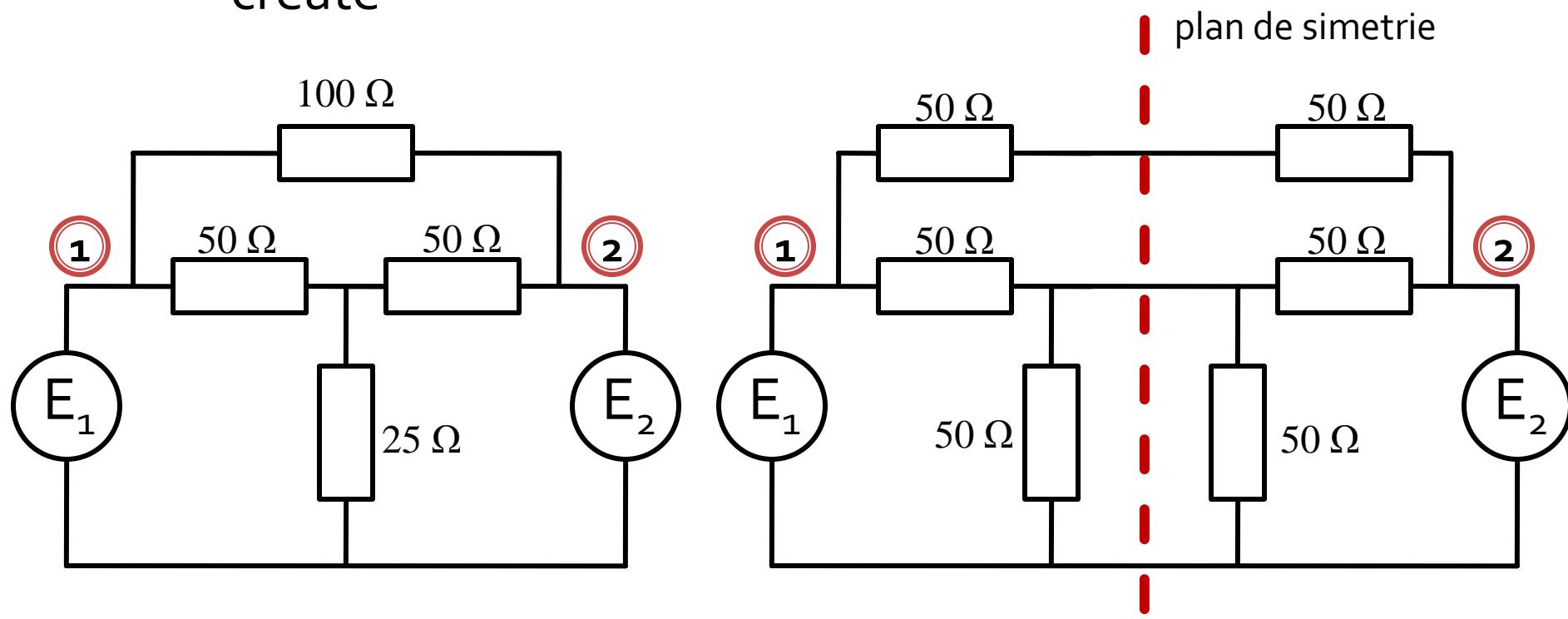


$$\begin{aligned} R_{ech} &= 100\Omega \parallel (50\Omega + 25\Omega \parallel 50\Omega) = \\ &= 100\Omega \parallel (50\Omega + 16.67\Omega) = 100\Omega \parallel 66.67\Omega = 40\Omega \end{aligned}$$

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

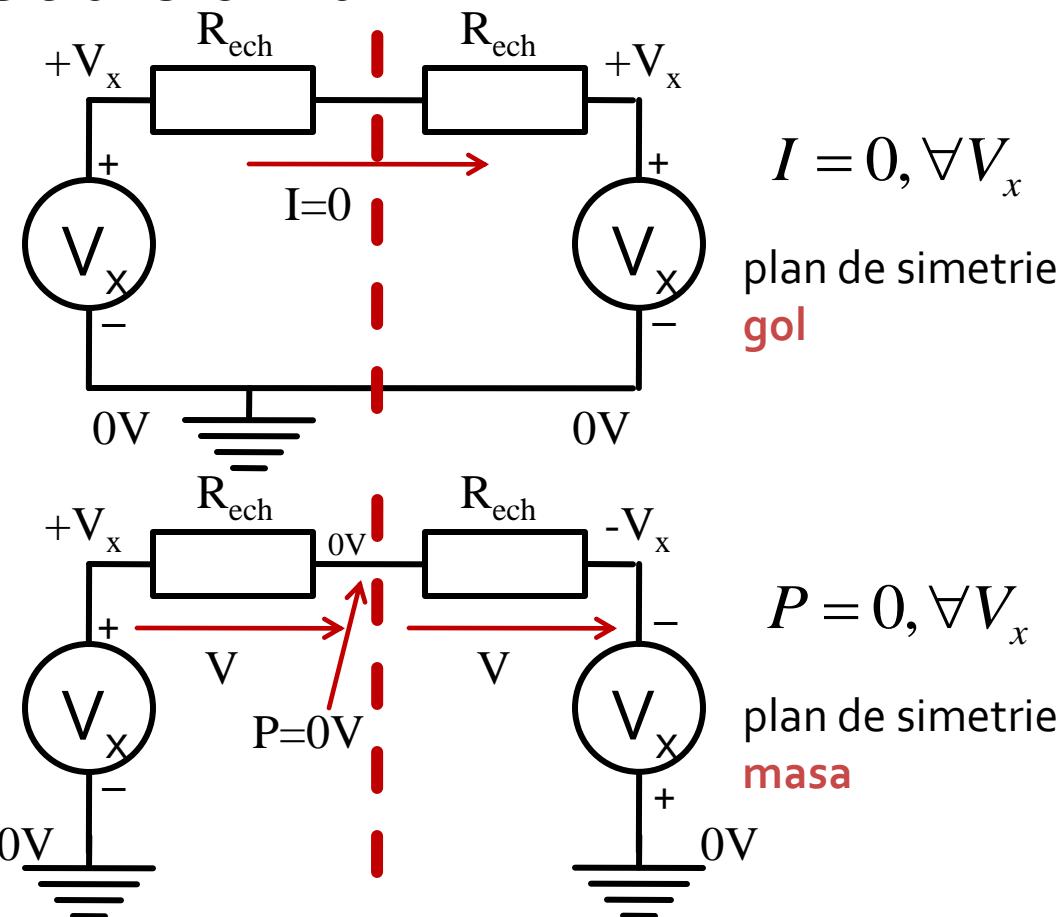
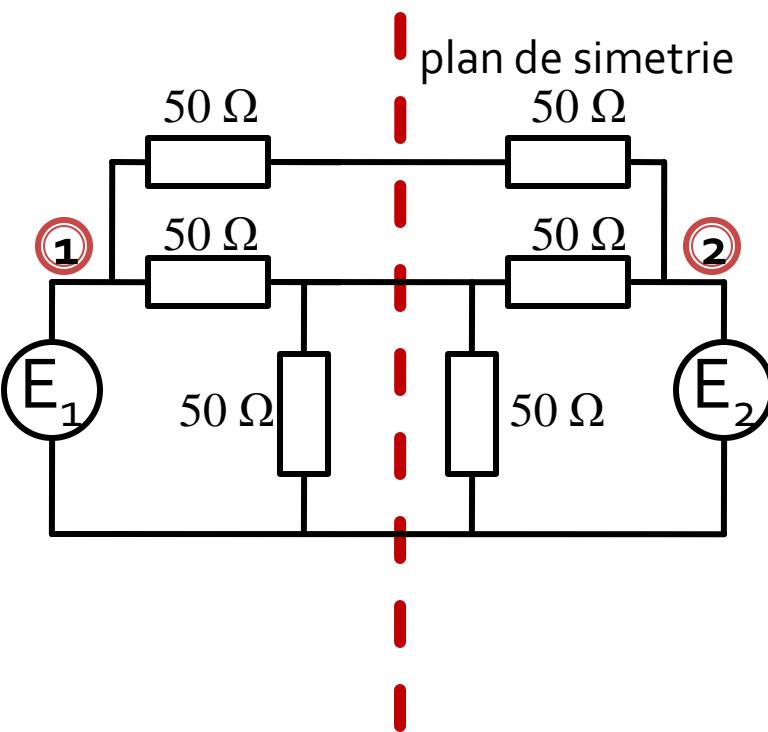
Analiza pe mod par/impar (even/odd)

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



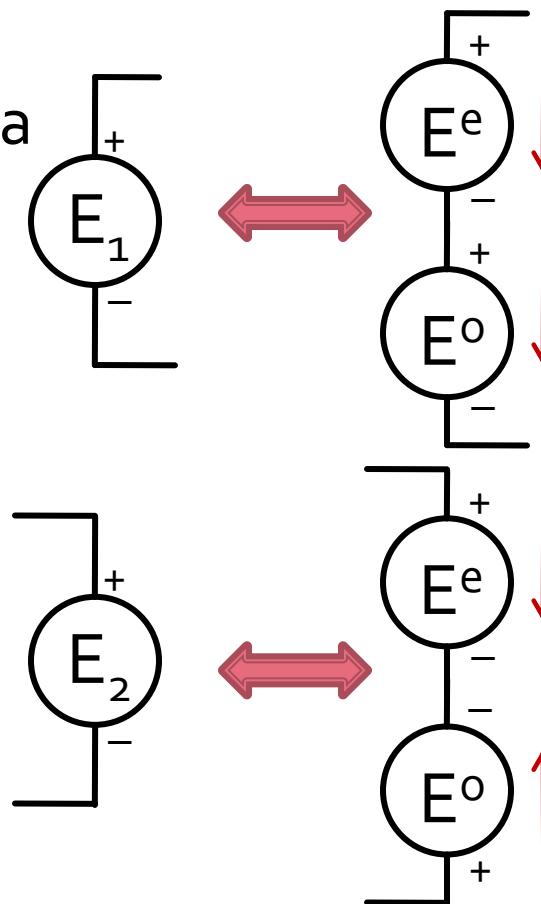
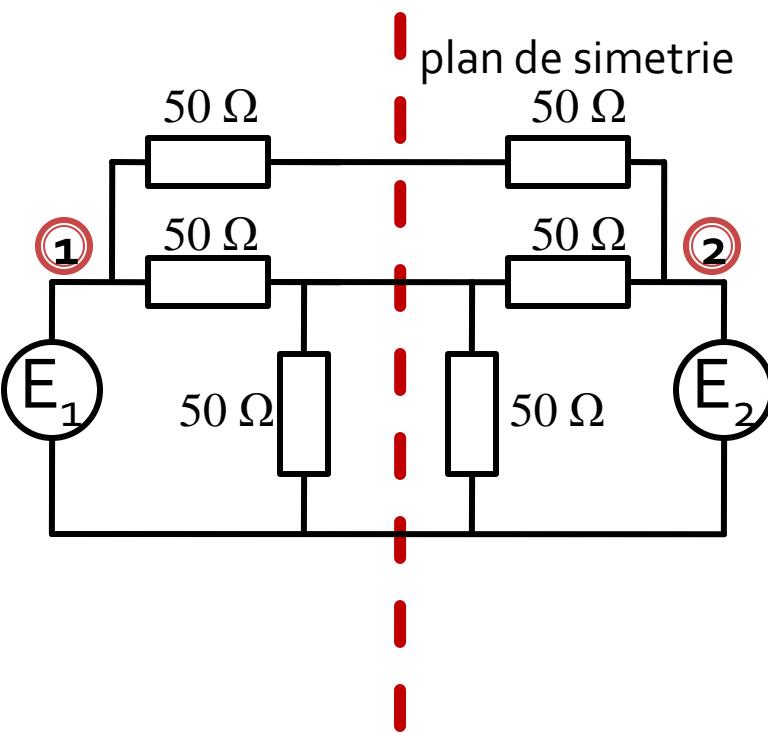
Analiza pe mod par/impar (even/odd)

- 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



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

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

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

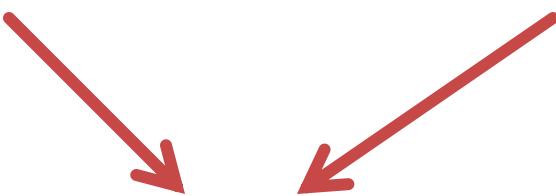
$$E^o = \frac{E_1 - E_2}{2}$$

Analiza pe mod par/impar (even/odd)

- In circuite liniare putem aplica suprapunerea efectelor

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

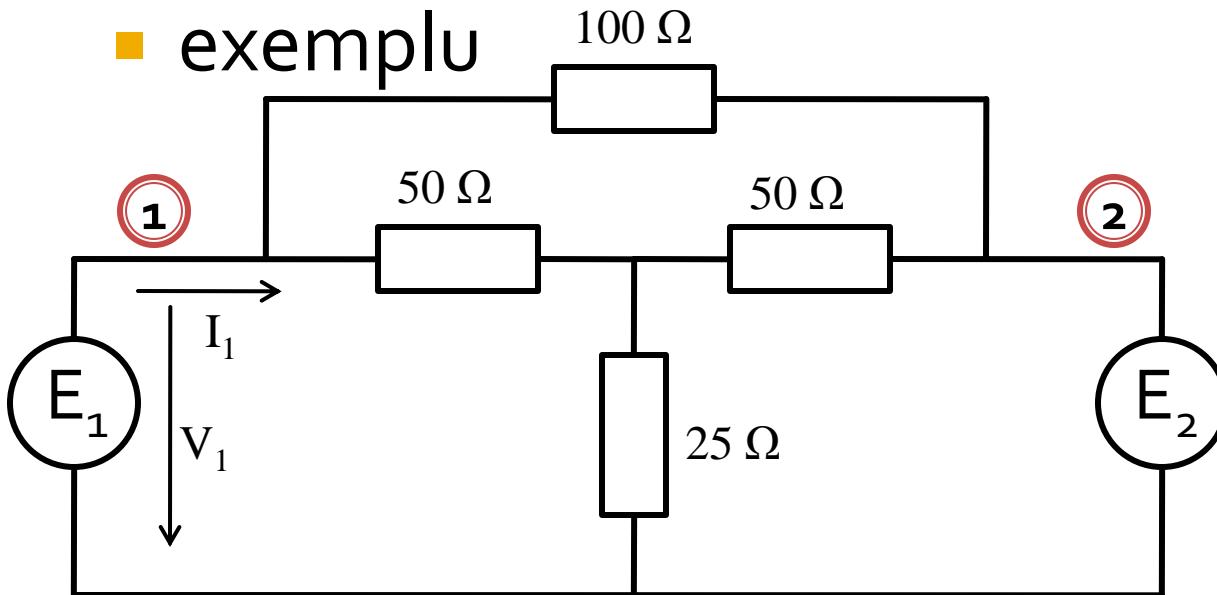
Efect (PAR+ IMPAR) = Efect (PAR) + Efect (IMPAR)



Putem beneficia de avantajele simetriilor!!

Analiza pe mod par/impar (even/odd)

■ exemplu

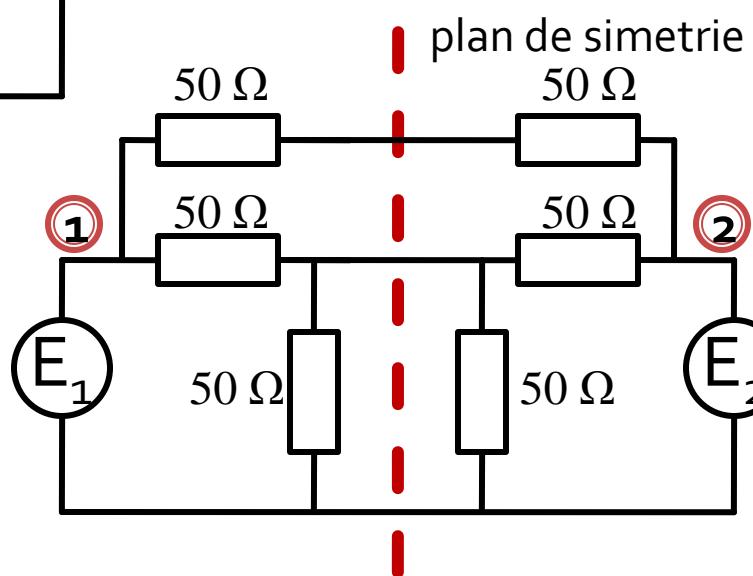


$$Y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2=0}$$

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

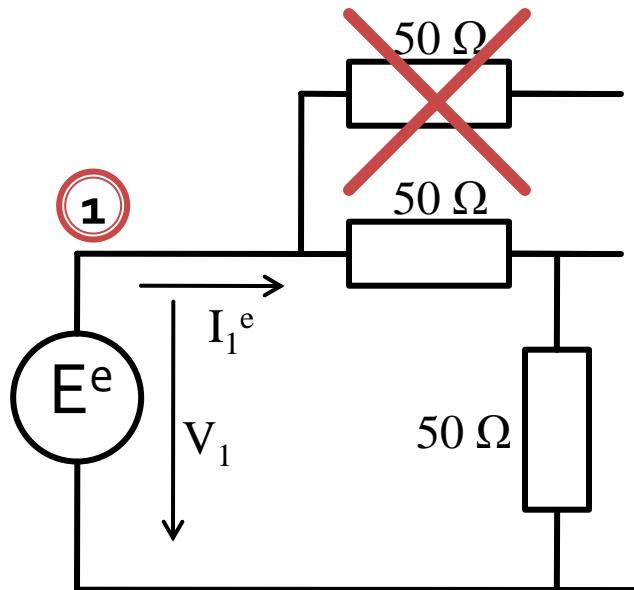
$$E^e = \frac{E_1}{2}$$

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



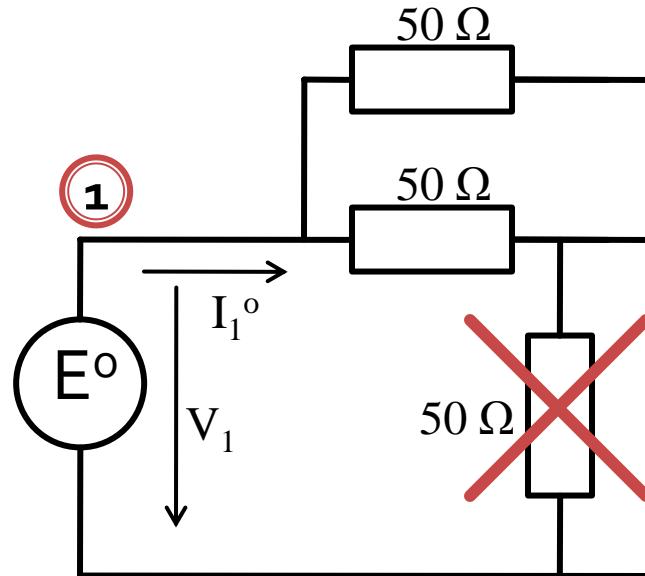
Analiza pe mod par/impar (even/odd)

- analiza pe mod par/impar



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

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

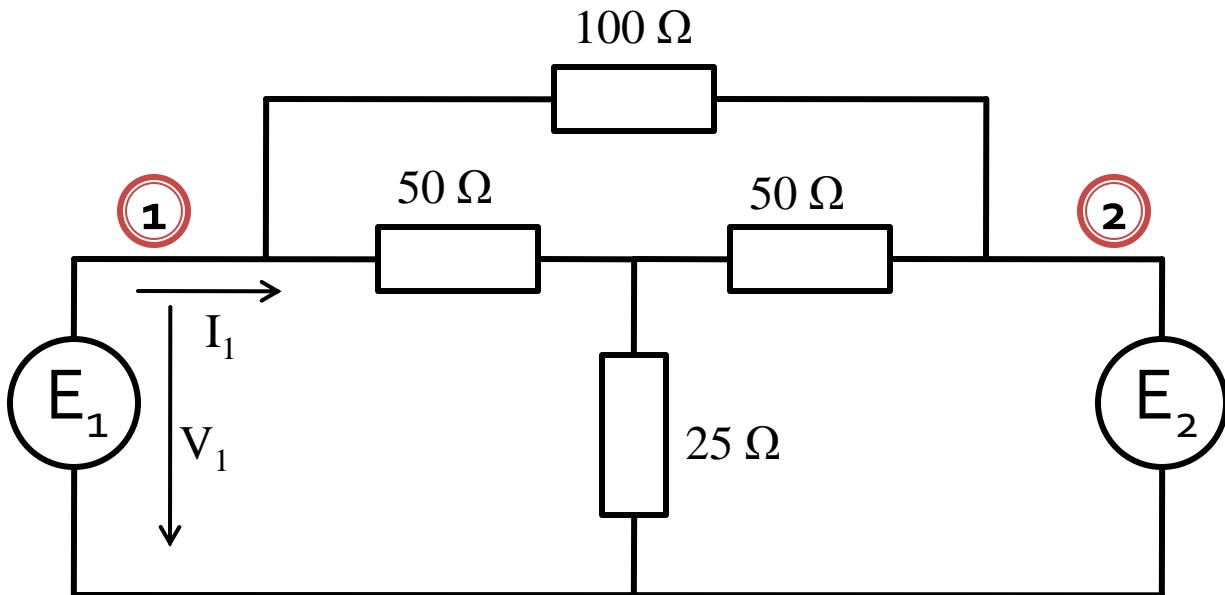


$$R_{ech}^o = 50\Omega || 50\Omega = 25\Omega$$

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

Analiza pe mod par/impar (even/odd)

- suprapunerea efectelor



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

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

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

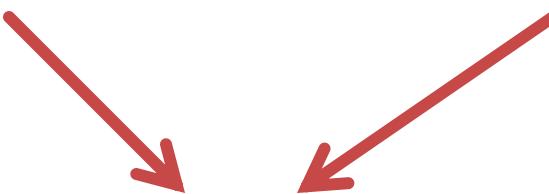
$$V_1 = V_1^e + V_1^o = E_1$$

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

Analiza pe mod par/impar (even/odd)

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

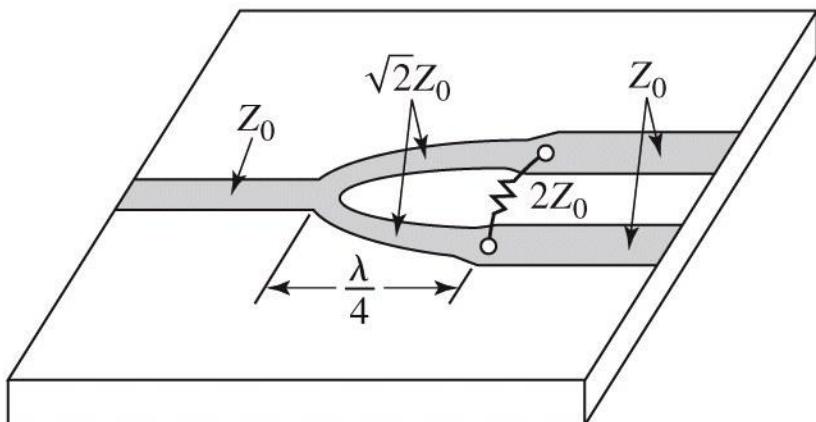
$$\text{Efect (PAR+ IMPAR)} = \text{Efect (PAR)} + \text{Efect (IMPAR)}$$



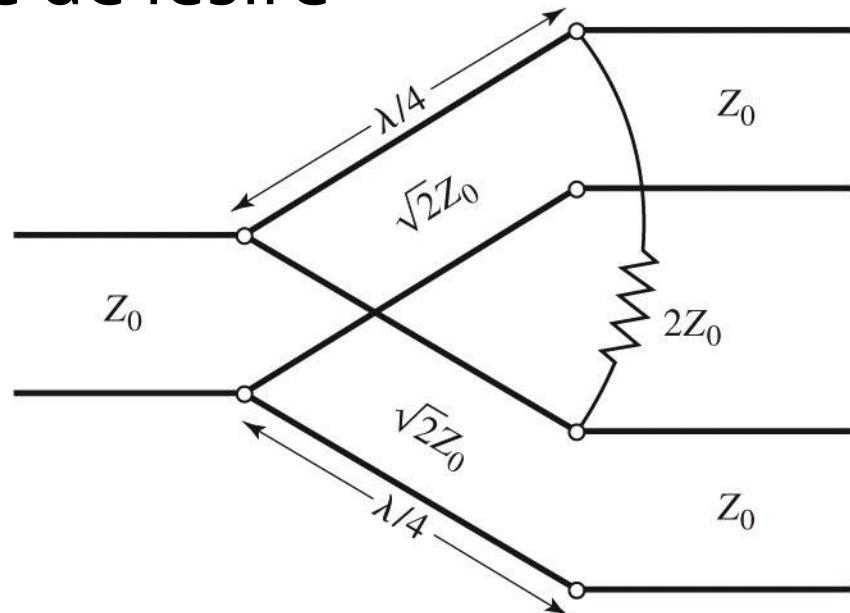
Putem beneficia de avantajele simetriilor!!

Divizorul de putere Wilkinson

- o linie de intrare
- doua transformatoare $\lambda/4$
- o rezistenta intre liniile de iesire



(a)



(b)

Divizorul de putere Wilkinson

- schema normalizata si “simetrizata”

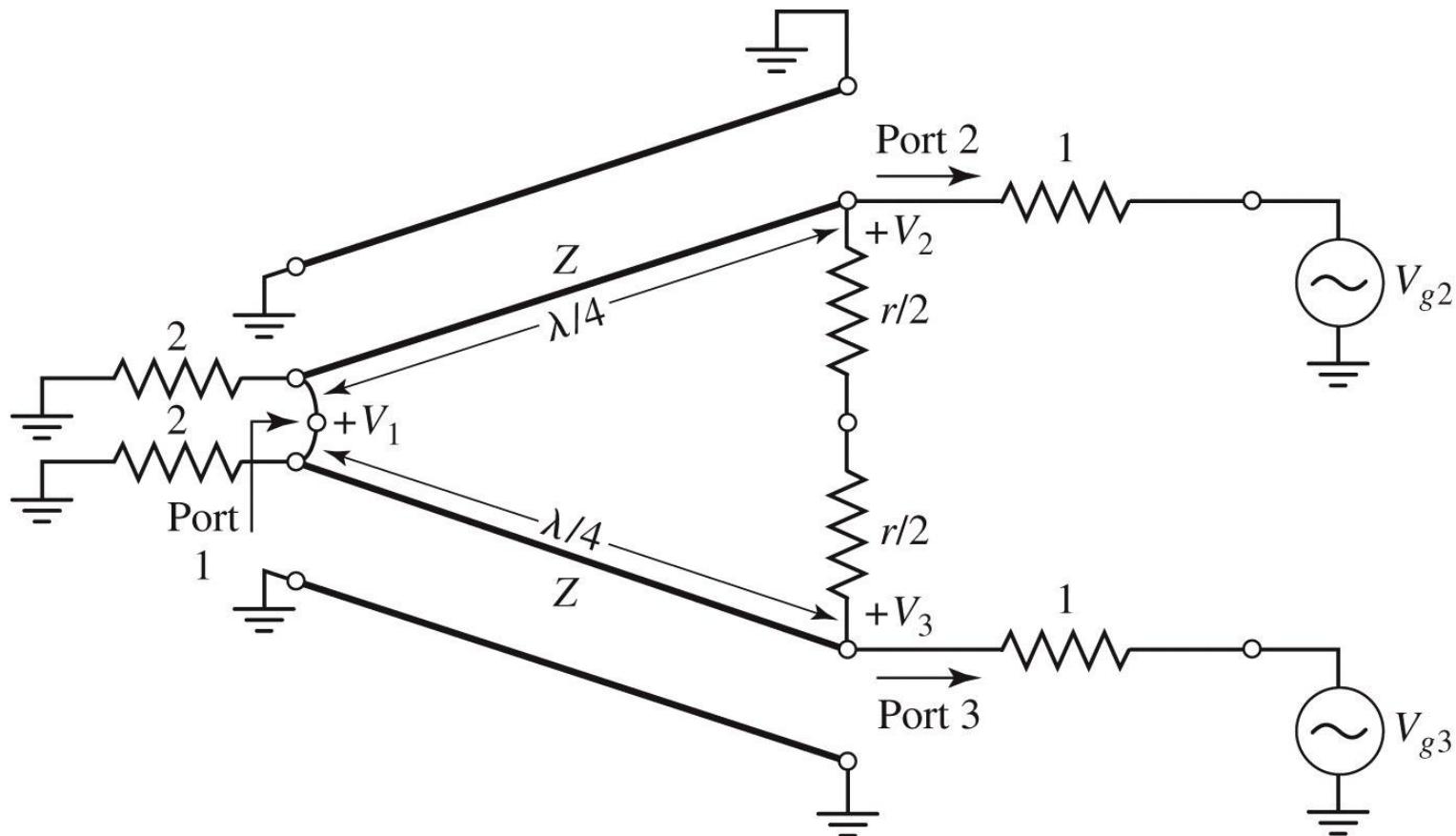
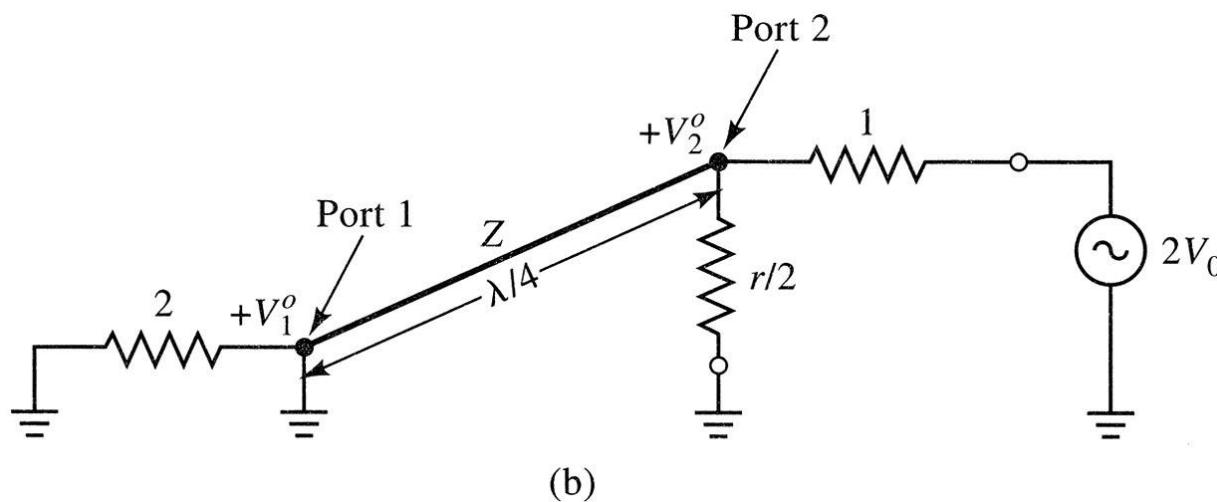
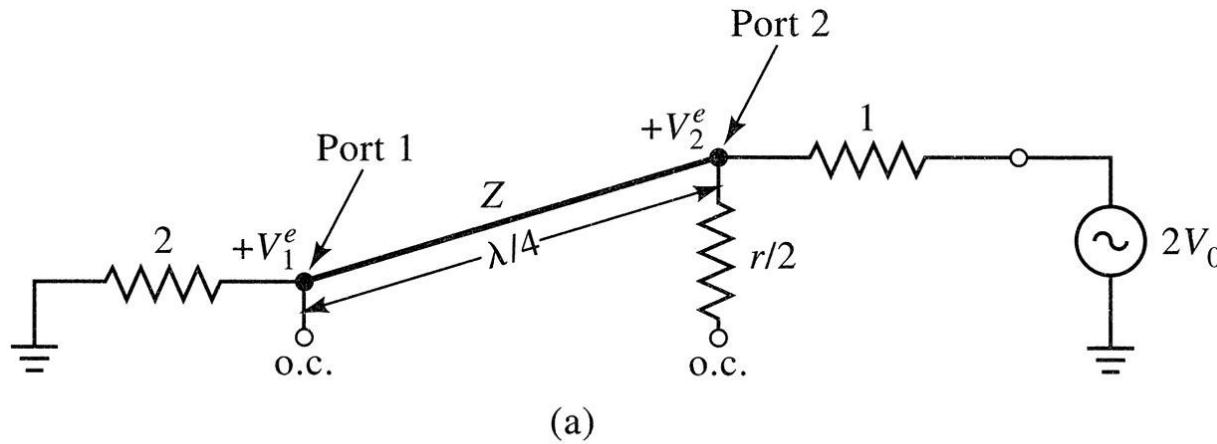


Figure 7.9

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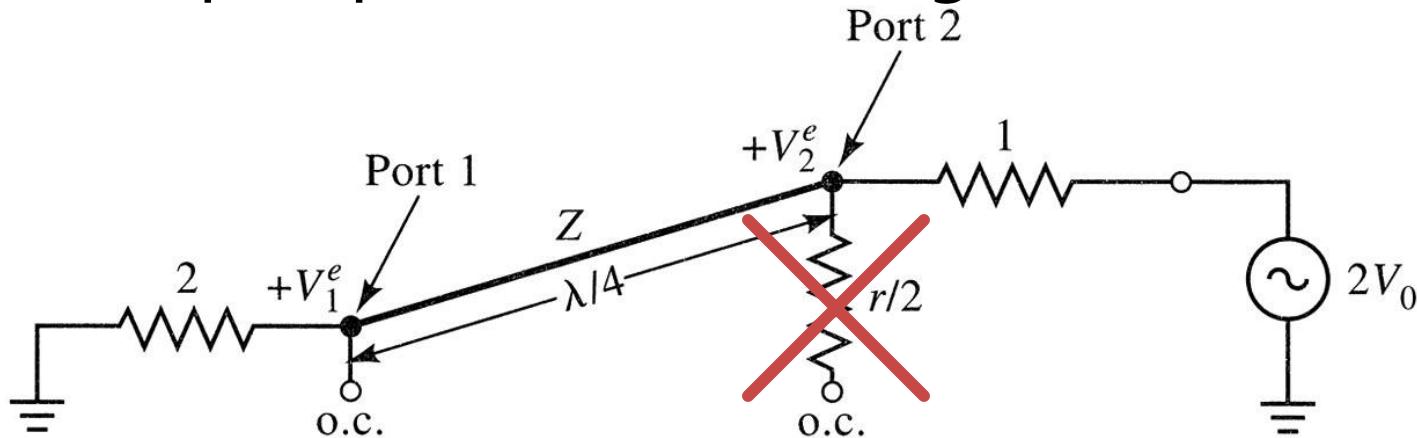
Divizorul de putere Wilkinson

- analiza pe mod par si impar



Divizorul de putere Wilkinson

- mod par, plan de simetrie gol



privind din portul 2,
transformator $\lambda/4$, $Z_{in2}^e = \frac{Z^2}{2}$ daca $Z = \sqrt{2}$ portul 2 este adaptat $Z_{in2}^e = 1$

$$V(x) = V^+ \cdot (e^{-j\beta \cdot x} + \Gamma \cdot e^{j\beta \cdot x}) \quad \begin{array}{l} x=0 \text{ la portul 1} \\ x=-\lambda/4 \text{ la portul 2} \end{array}$$

$$V_2^e = V(-\lambda/4) = jV^+ \cdot (1 - \Gamma) = V_0 \quad \text{red arrow pointing to } V_0 \quad Z_{in2}^e = 1$$

$$V_1^e = V(0) = V^+ \cdot (1 + \Gamma) = jV_0 \cdot \frac{\Gamma + 1}{\Gamma - 1}$$

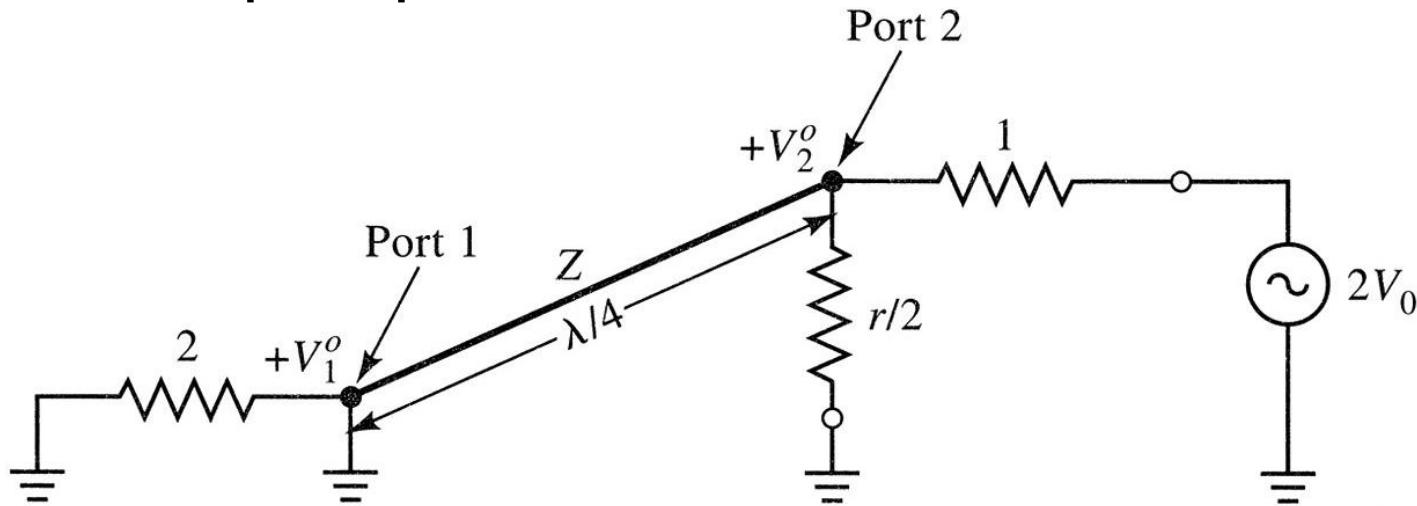
Γ : coeficientul de reflexie vazut dinspre transformatorul cu
 $Z = \sqrt{2}$ spre impedanta normalizata 2

$$\Gamma = \frac{2 - \sqrt{2}}{2 + \sqrt{2}}$$

$$V_1^e = -jV_0 \sqrt{2}$$

Divizorul de putere Wilkinson

- mod impar, plan de simetrie masa



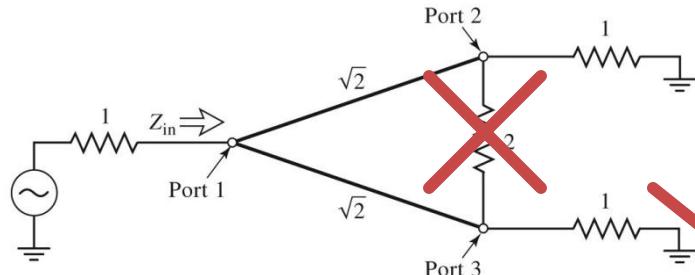
linia in $\lambda/4$ este scurtcircuitata la capat
impedanta vazuta dinspre portul 2 este ∞ $Z_{in2}^o = r/2$ daca $r = 2$ portul 2 este adaptat

$$Z_{in2}^o = 1 \rightarrow V_2^o = V_0$$

$V_1^o = 0$ in modul impar toata puterea se disipa in rezistorul $r/2$

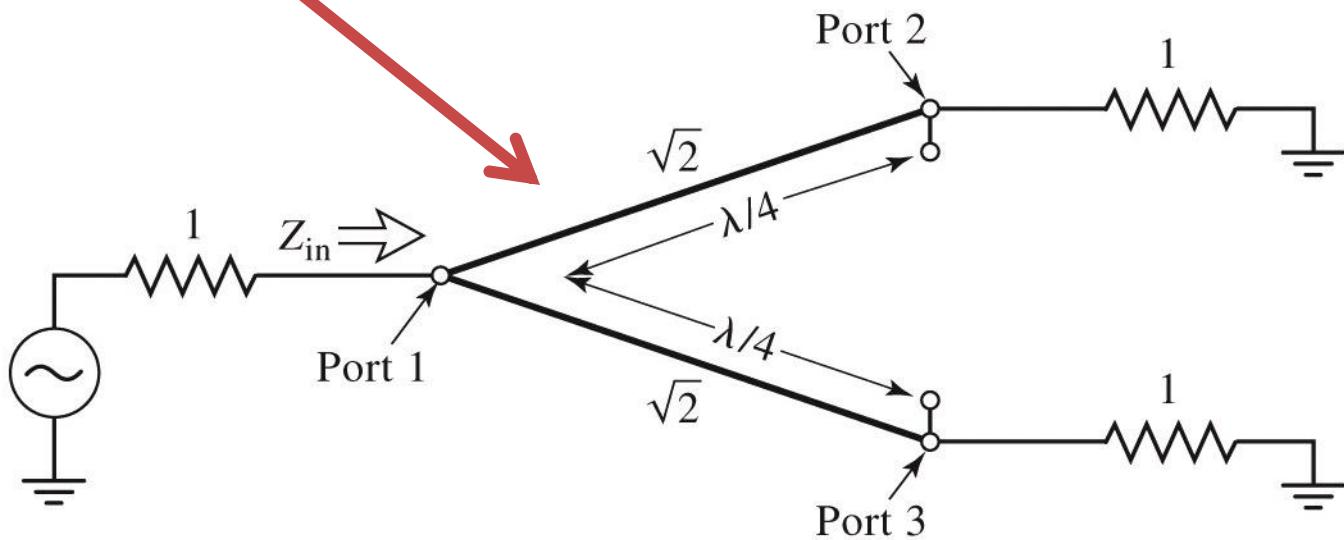
Divizorul de putere Wilkinson

- impedanta de intrare in portul 1



doua transformatoare $\lambda/4$ in paralel

$$Z_{in1} = \frac{1}{2}(\sqrt{2})^2 = 1$$



Divizorul de putere Wilkinson

■ parametrii S

$$Z_{in1} = \frac{1}{2}(\sqrt{2})^2 = 1 \quad S_{11} = 0$$

$$Z_{in2}^e = 1 \quad Z_{in2}^o = 1 \quad \text{si similar} \quad Z_{in3}^e = 1 \quad Z_{in3}^o = 1 \quad S_{22} = S_{33} = 0$$

$$S_{12} = S_{21} = \frac{V_1^e + V_1^o}{V_2^e + V_2^o} = -\frac{j}{\sqrt{2}}$$

$$\text{si similar} \quad S_{13} = S_{31} = -\frac{j}{\sqrt{2}}$$

$S_{23} = S_{32} = 0$ scurt sau gol intre porturile 2 si 3 elimina orice transfer de putere + circuit reciproc

Divizorul de putere Wilkinson

- la frecventa de proiectare (lungimile transformatoarelor egale cu $\lambda_0/4$) avem izolare intre cele doua linii de iesire

$$[S] = \begin{bmatrix} 0 & -\frac{j}{\sqrt{2}} & -\frac{j}{\sqrt{2}} \\ -\frac{j}{\sqrt{2}} & 0 & 0 \\ -\frac{j}{\sqrt{2}} & 0 & 0 \end{bmatrix}$$

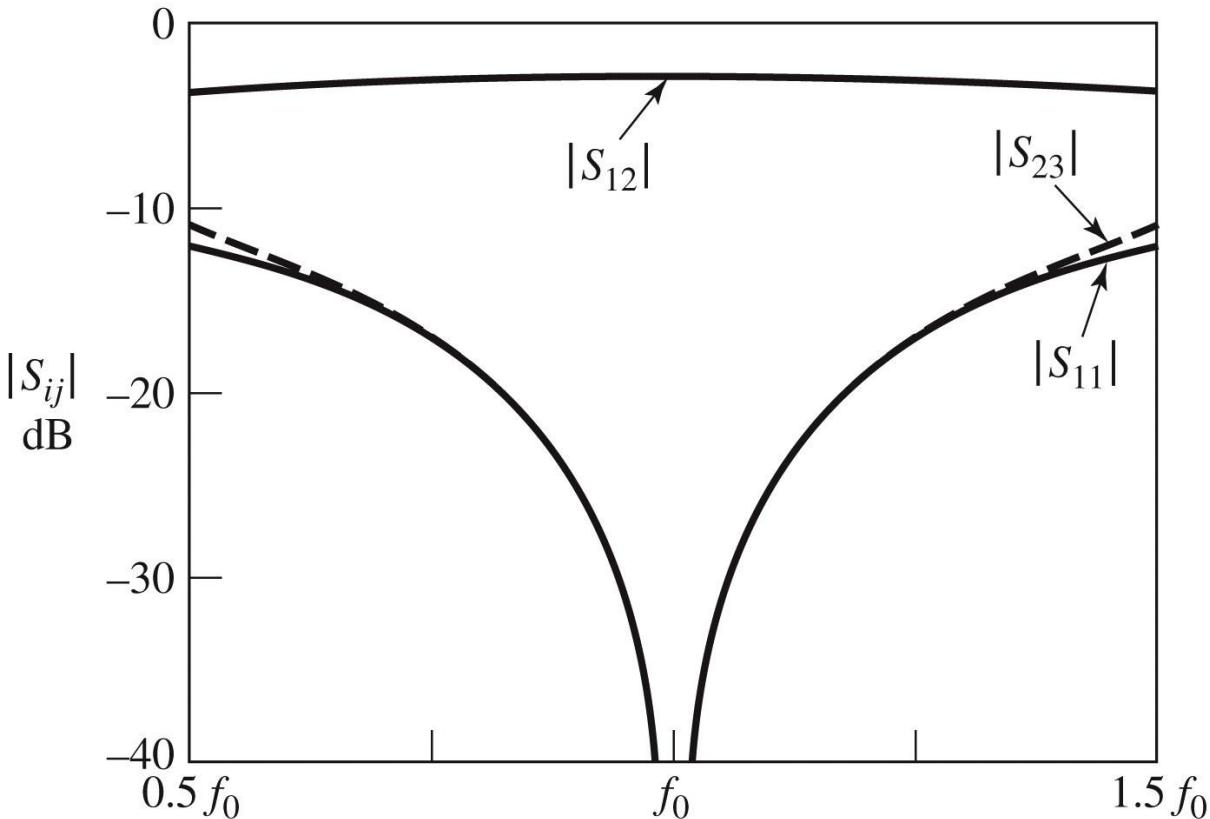


Figure 7.12
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Divizorul de putere Wilkinson

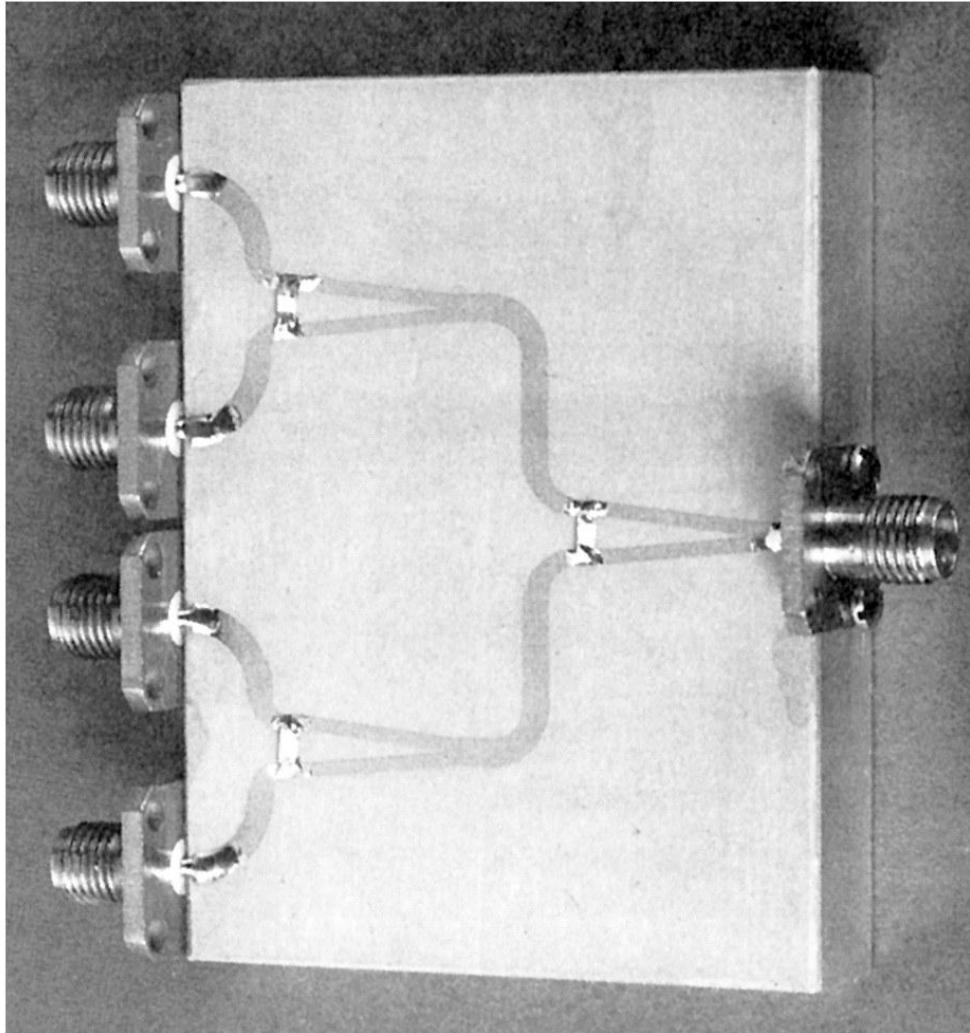


Figure 7.15

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

**Cuploare directionale si
divizoare de putere**

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

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

- 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

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

- 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

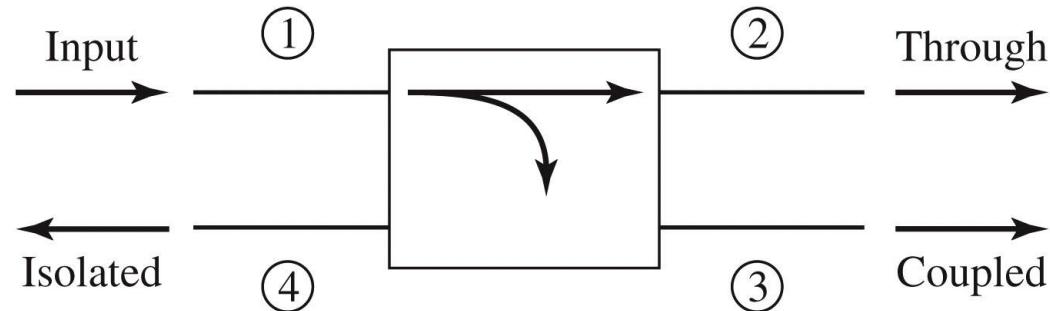
- 2 cazuri mai des întâlnite în practică
 - cupluri simetrie $\theta = \phi = \pi/2$

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

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

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

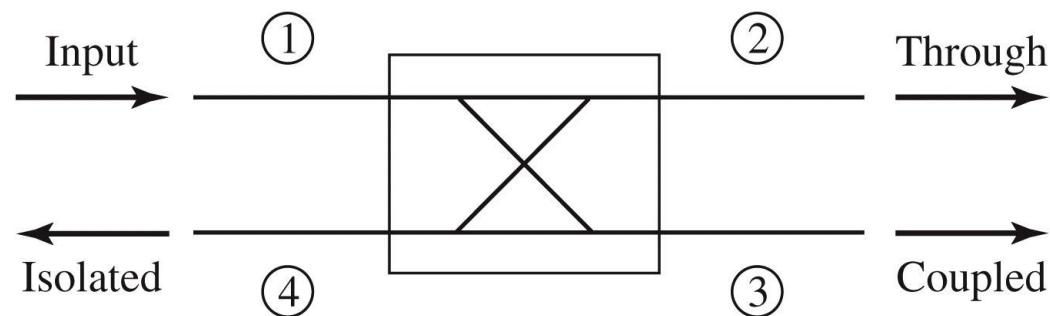
Cuplaj directional



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

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

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

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

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

Cuplor hibrid

Cuploul hibrid este cuploul directional de 3 dB

$$\alpha = \beta = 1/\sqrt{2}$$

Cuplor hibrid in cuadratura

$$(\theta = \phi = \pi/2)$$

$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix} \quad (\theta = 0, \phi = \pi)$$

Cuplor hibrid in inel

$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

Cuploul hibrid în cuadratură (90°)

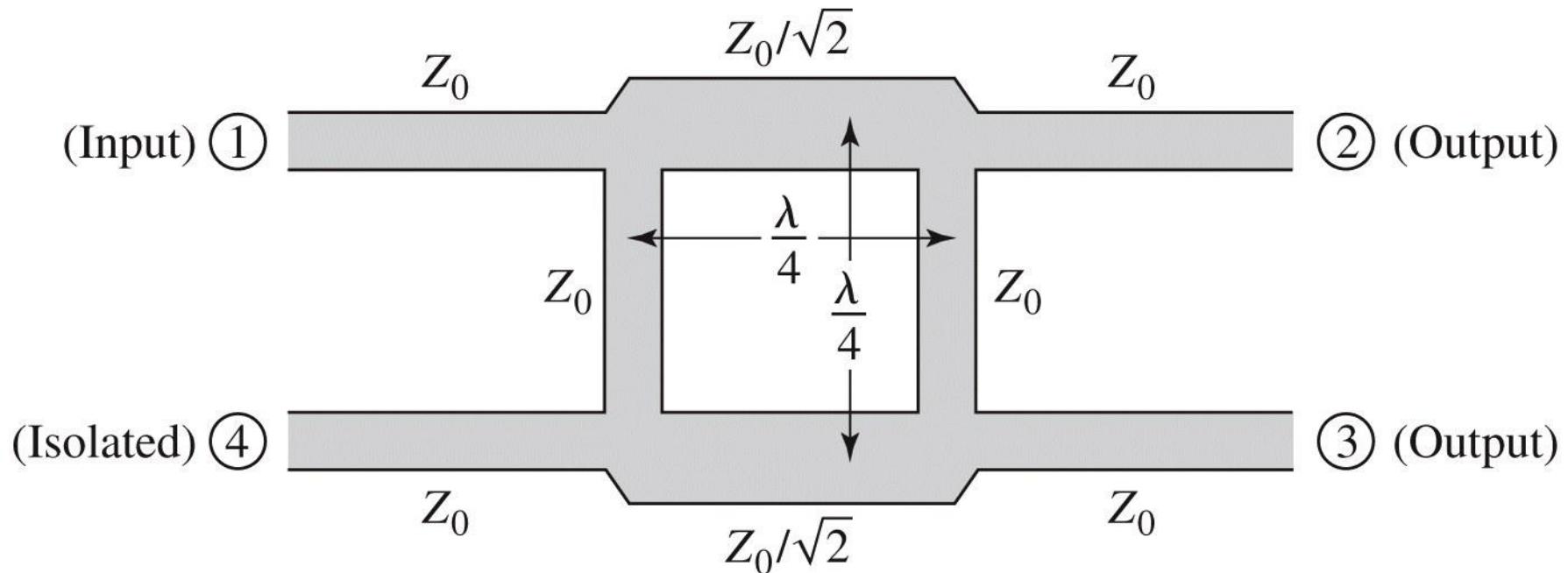
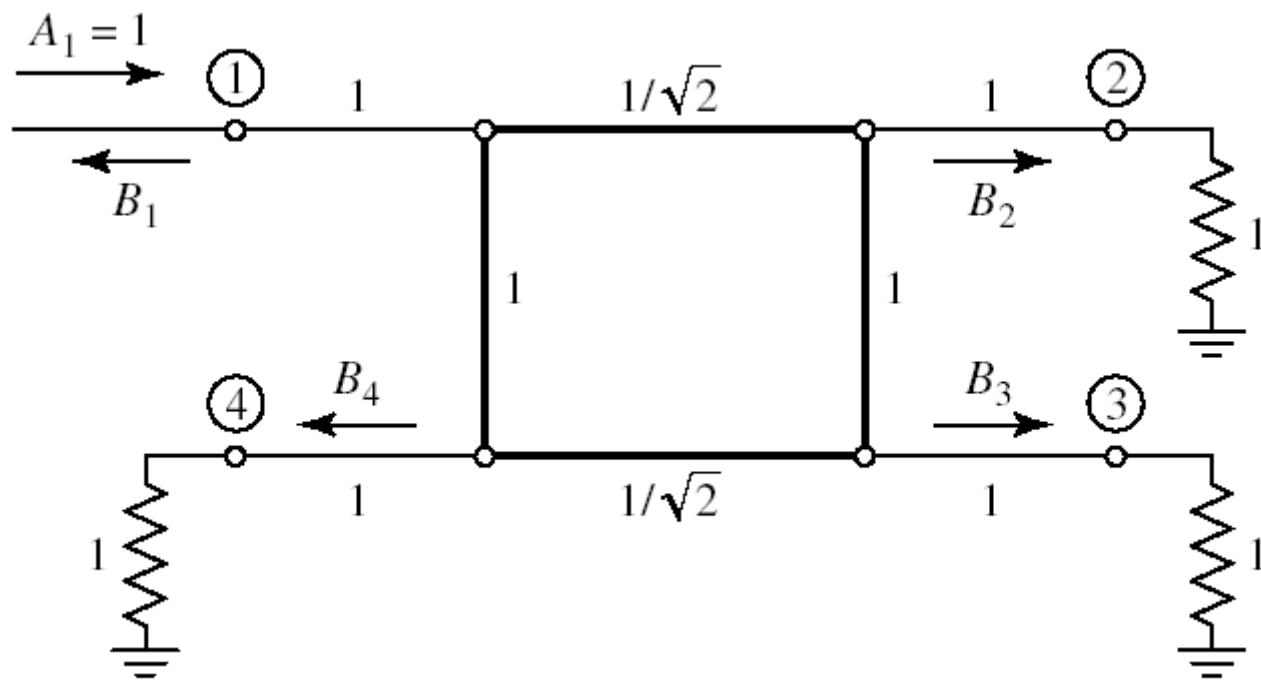


Figure 7.21
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$$[S] = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}$$

Analiza pe modul par-impar



Analiza pe modul par-impar

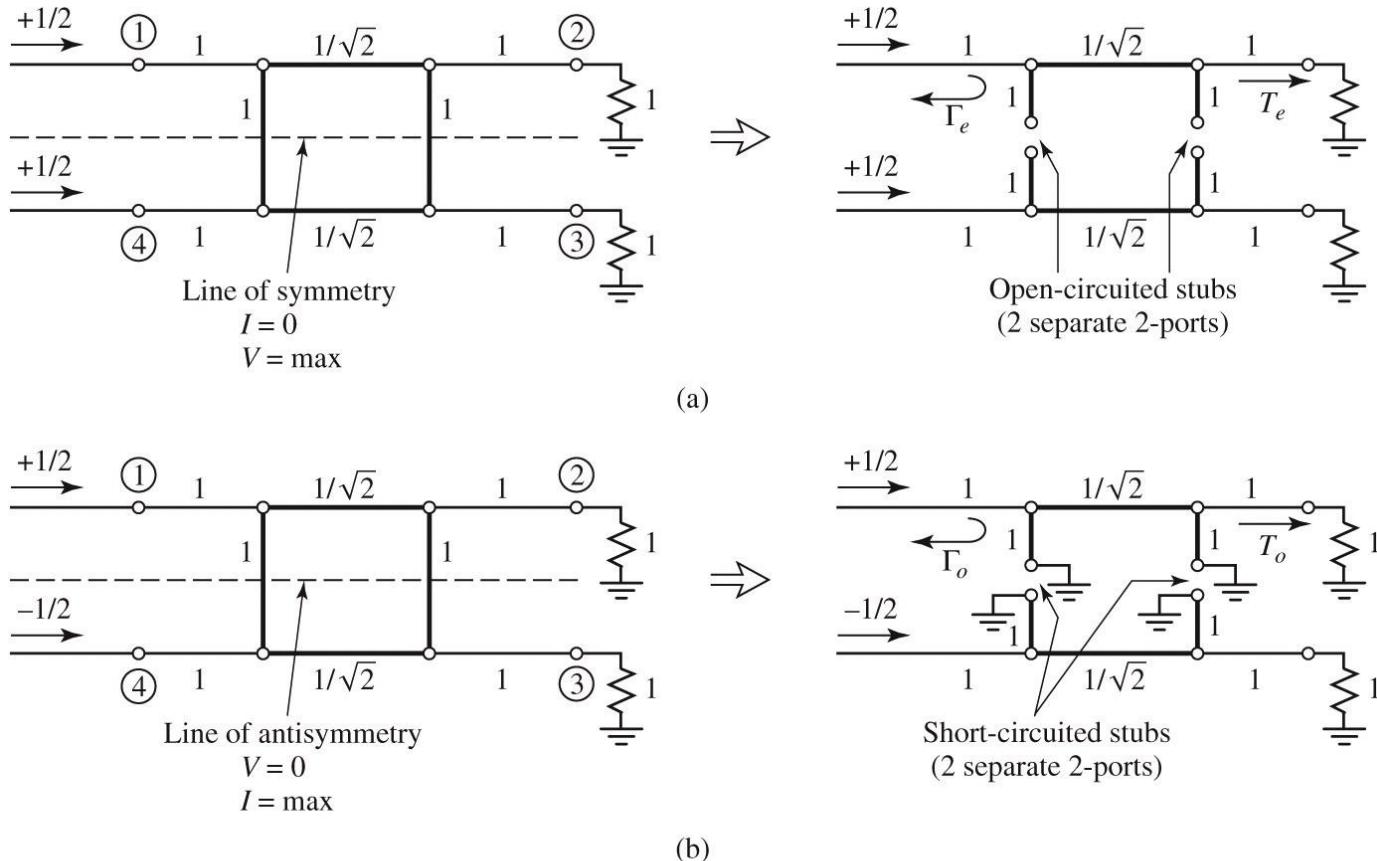
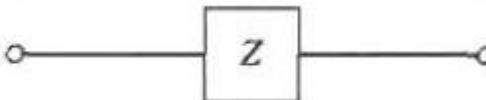
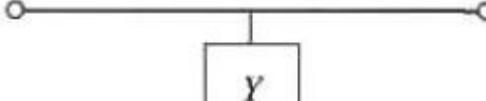
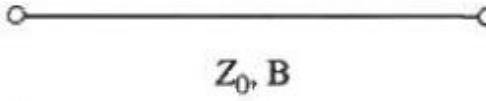


Figure 7.23
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$$b_1 = \frac{1}{2} \Gamma_e + \frac{1}{2} \Gamma_o$$

$$b_2 = \frac{1}{2} T_e + \frac{1}{2} T_o$$

$$b_3 = \frac{1}{2} T_e - \frac{1}{2} T_o \quad b_4 = \frac{1}{2} \Gamma_e - \frac{1}{2} \Gamma_o$$

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

Linie de transmisie cu impedanta de terminatie

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

$$= Z_0 \frac{Z_L \cos \beta \ell + j Z_0 \sin \beta \ell}{Z_0 \cos \beta \ell + j Z_L \sin \beta \ell}$$

$$= Z_0 \frac{Z_L + j Z_0 \tan \beta \ell}{Z_0 + j Z_L \tan \beta \ell}.$$

scurtcircuit

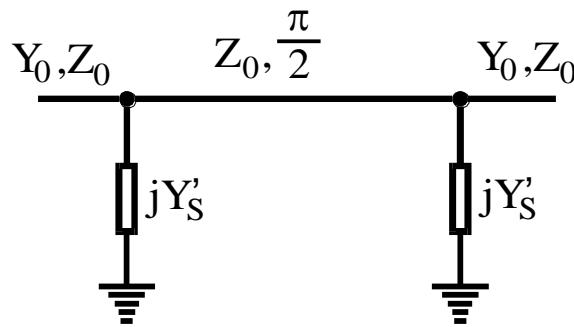
$$Z_{in} = j Z_0 \tan \beta \ell,$$

gol

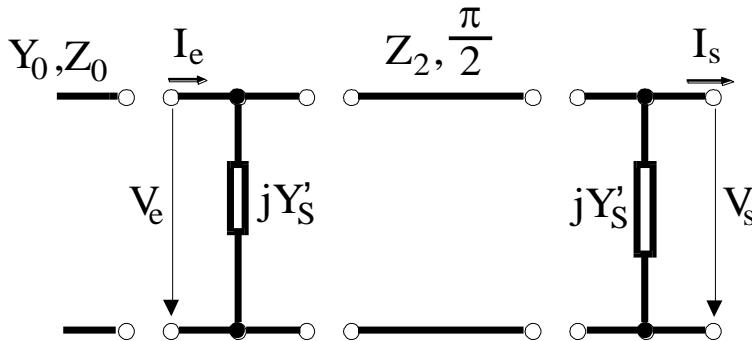
$$Z_{in} = -j Z_0 \cot \beta \ell,$$

Calculul cuploarelor cu două trepte

$$Y'_S = \begin{cases} Y_1 & \text{pentru modul par} \\ -Y_1 & \text{pentru modul impar} \end{cases}$$



a)



b)

$$\begin{bmatrix} V_e \\ I_e \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ jY'_S & 1 \end{bmatrix} \cdot \begin{bmatrix} 0 & jZ_2 \\ jY_2 & 0 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ jY'_S & 1 \end{bmatrix} \cdot \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$$\begin{bmatrix} V_e \\ I_e \end{bmatrix} = \begin{bmatrix} -Y'_S Z_2 & jZ_2 \\ -jY'^2_S Z_2 + jY_2 & -Y'_S Z_2 \end{bmatrix} \cdot \begin{bmatrix} V_s \\ I_s \end{bmatrix}$$

$$S_{11} = \frac{j \frac{Z_2}{Z_0} - Z_0(-jY'^2_S Z_2 + jY_2)}{-2Y'_S Z_2 + j \frac{Z_2}{Z_0} + Z_0(-jY'^2_S + jY_2)} \quad S_{12} = \frac{2(-Y'_S Z_2)^2 - jZ_2(-jY'^2_S Z_2 + jY_2)}{-2Y'_S Z_2 + j \frac{Z_2}{Z_0} + Z_0(-jY'^2_S Z_2 + jY_2)}$$

$$S_{21} = \frac{2}{-2Y'_S Z_2 + j \frac{Z_2}{Z_0} + Z_0(-jY'^2_S Z_2 + jY_2)} \quad S_{22} = \frac{j \frac{Z_2}{Z_0} - Z_0(-jY'^2_S Z_2 + jY_2)}{-2Y'_S Z_2 + j \frac{Z_2}{Z_0} + Z_0(-jY'^2_S Z_2 + jY_2)}$$

$$\Gamma = S_{11} = \frac{j(z_2 - y_2 + y'^2_S z_2)}{-2y'_S z_2 + j(z_2 + y_2 - y'^2_S z_2)} = S_{22}$$

$$T = S_{21} = \frac{2}{-2y'_S z_2 + j(z_2 + y_2 - y'^2_S z_2)} = S_{12}$$

Legatura dintre parametrii S si parametrii ABCD

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

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

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

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

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

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

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

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

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

Adaptarea cuplorului si coeficientul de cuplaj

$$\Gamma_e = \frac{j(z_2 - y_2 + y_1^2 z_2)}{-2y_1 z_2 + j(z_2 + y_2 - y_1^2 z_2)}$$

$$\Gamma_o = \frac{j(z_2 - y_2 + y_1^2 z_2)}{2y_1 z_2 + j(z_2 + y_2 - y_1^2 z_2)}$$

$$T_e = \frac{2}{-2y_1 z_2 + j(z_2 + y_2 - y_1^2 z_2)}$$

$$T_o = \frac{2}{2y_1 z_2 + j(z_2 + y_2 - y_1^2 z_2)}$$

$$b_1 = 0 \Rightarrow z_2 - y_2 + y_1^2 z_2 = 0 \Rightarrow z_2^2 = \frac{1}{1+y_1^2}$$

$$b_1 = 0 \quad b_4 = 0 \quad b_3 = -y_1 z_2 \quad b_2 = -jz_2$$

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

$$b_3 = -\frac{\sqrt{y_2^2 - 1}}{y_2}, \quad b_2 = -\frac{j}{y_2}$$

$$b_3 = -C$$

$$b_2 = -j\sqrt{1-C^2}$$

$$[S] = \begin{bmatrix} 0 & -j\sqrt{1-C^2} & -C & 0 \\ -j\sqrt{1-C^2} & 0 & 0 & -C \\ -C & 0 & 0 & -j\sqrt{1-C^2} \\ 0 & -C & -j\sqrt{1-C^2} & 0 \end{bmatrix}$$

$$b_1 = \frac{\Gamma_e + \Gamma_o}{2} = \frac{z_2^2 - (y_2 - y_1^2 z_2)^2}{(2y_1 z_2)^2 + (z_2 + y_2 - y_1^2 z_2)^2}$$

$$b_2 = \frac{T_e + T_o}{2} = \frac{-2j(z_2 + y_2 - y_1^2 z_2)}{(2y_1 z_2)^2 + (z_2 + y_2 - y_1^2 z_2)^2}$$

$$b_3 = \frac{T_e - T_o}{2} = \frac{-4y_1 z_2}{(2y_1 z_2)^2 + (z_2 + y_2 - y_1^2 z_2)^2}$$

$$b_4 = \frac{\Gamma_e - \Gamma_o}{2} = \frac{-2jy_1 z_2 (z_2 - y_2 + y_1^2 z_2)}{(2y_1 z_2)^2 + (z_2 + y_2 - y_1^2 z_2)^2}$$

$$C = 10 \log \frac{P_1}{P_3} = -20 \log |b_3|, dB$$

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

Cuplорul in cuadratura

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

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

y_2

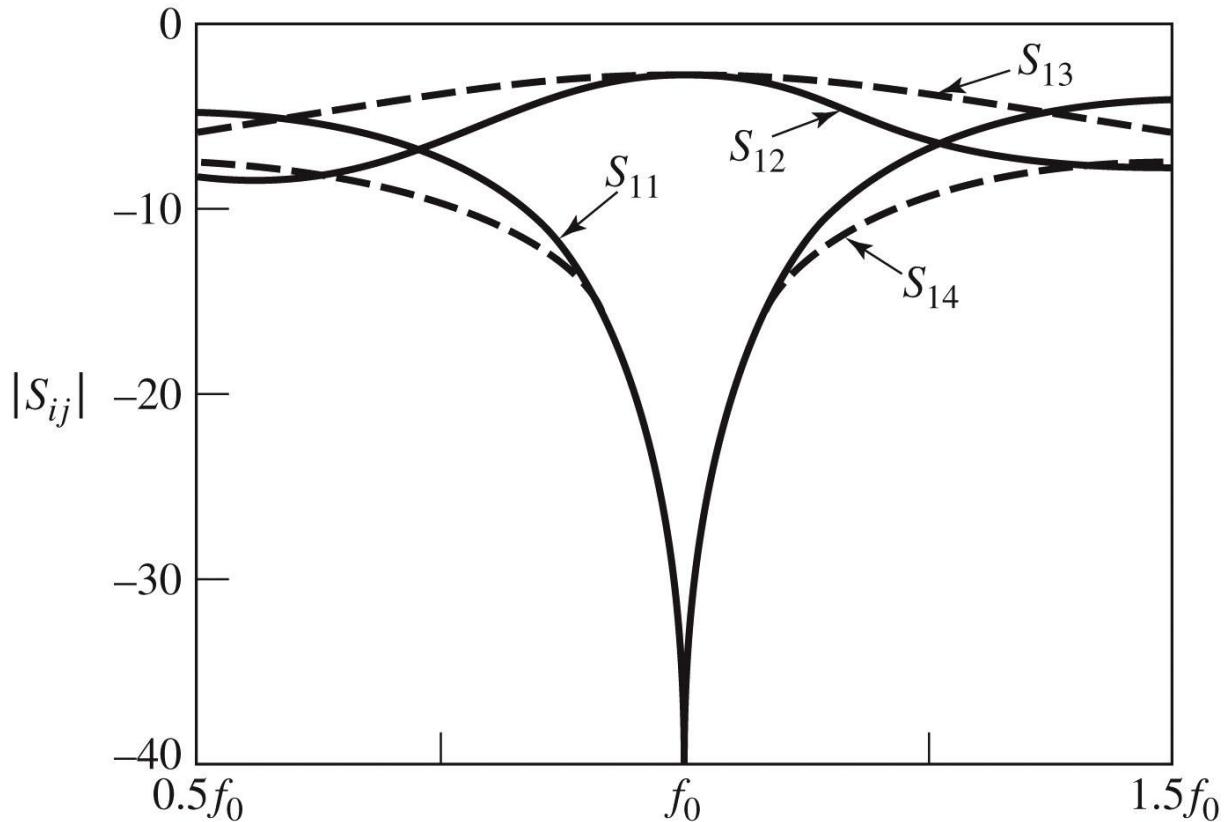


Figure 7.25
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Exemplu

Proiectați un cuplor în scară pe impedanță caracteristică de 50Ω , și reprezentati mărimea parametrilor S între

$$0.5f_0 \text{ și } 1.5f_0, \text{ unde } f_0$$

este frecvența de proiectare la care liniile cuplorului sunt de lungime $\lambda/4$

Solutie

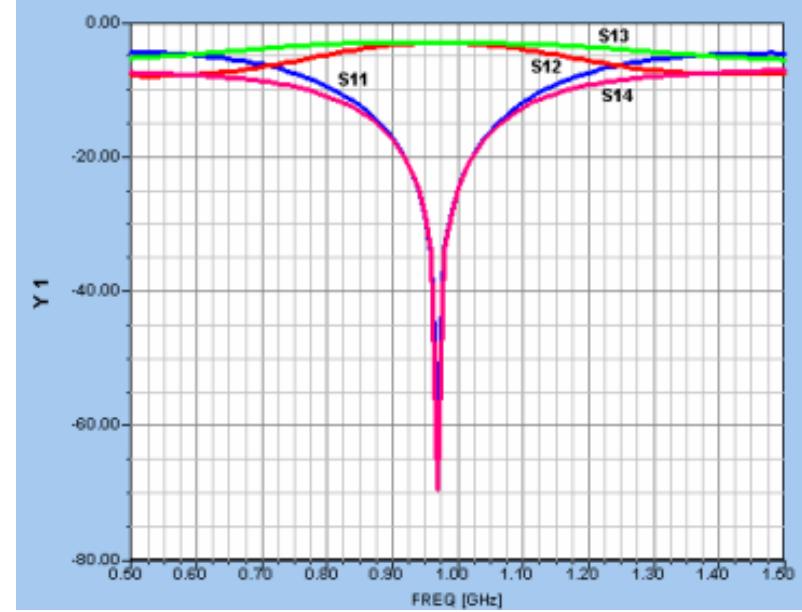
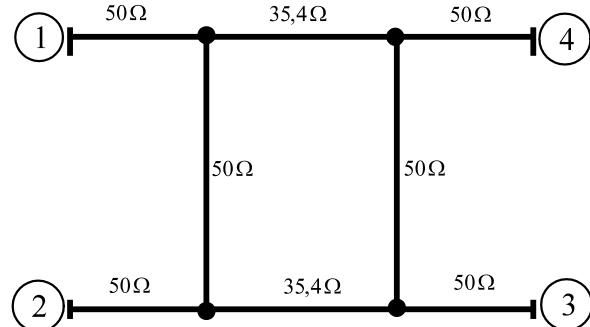
Un cuplător în scară cu $C = 3\text{dB}$, are $C = 1/\sqrt{2}$

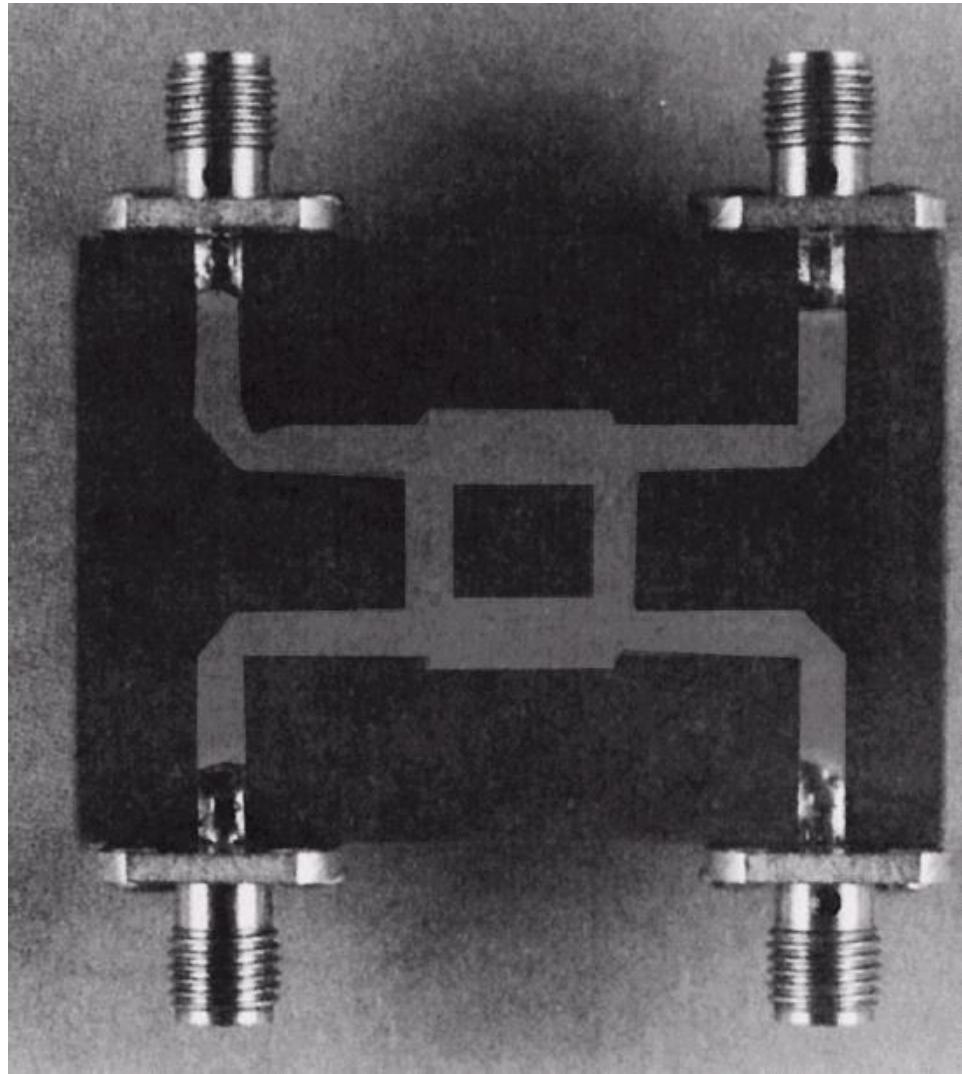
. Atunci $y_2 = \sqrt{2}$ și $y_1 = 1$

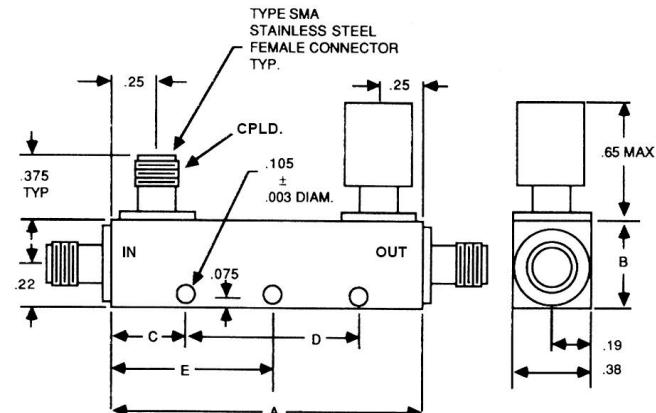
. Astfel matricea S din relația (&.47) devine cea din relația (&.38). În plus, pentru $Z_0 = 50\Omega$

, impedanțele caracteristice ale liniilor cuplătorului vor fi:

$$Z_1 = Z_0 = 50\Omega \quad Z_2 = \frac{Z_0}{\sqrt{2}} = 35.4\Omega$$

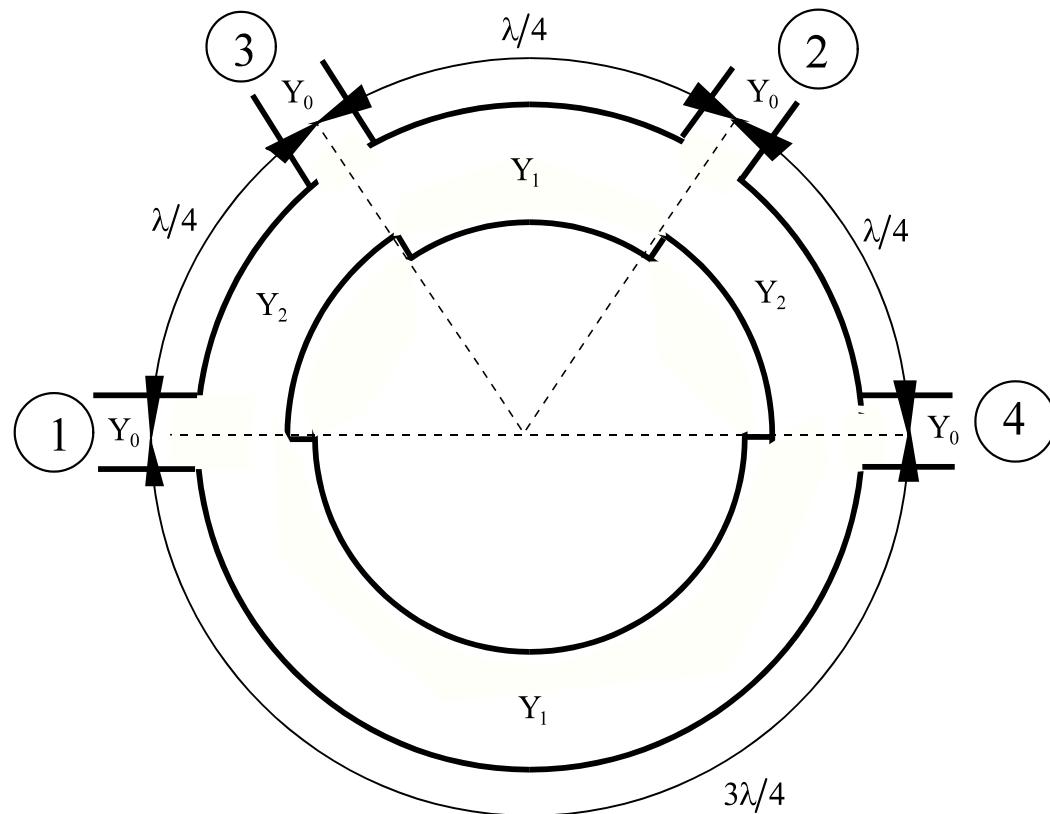




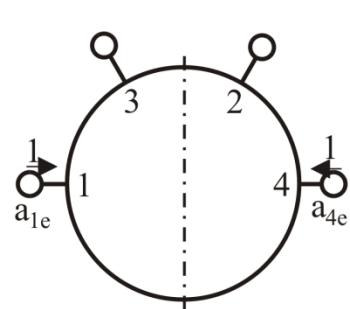


Model No.	Frequency Range (Ghz)	Coupling † (dB)	Freq. Sens. (dB)	Insertion Loss (dB)		Directivity (dB min.)	VSWR max.	
				Excl. Cpld Pwr	True		Primary Line	Secondary Line
MDC6223-6	0.5-1.0	6 ±1.00	±0.60	0.20	1.80	25	1.15	1.15
MDC6223-10	0.5-1.0	10 ±1.25	±0.75	0.20	0.80	25	1.10	1.10
MDC6223-20	0.5-1.0	20 ±1.25	±0.75	0.15	0.20	25	1.10	1.10
MDC6223-30	0.5-1.0	30 ±1.25	±0.75	0.15	0.20	25	1.10	1.10
MDC6224-6	1.0-2.0	6 ±1.00	±0.60	0.20	1.80	25	1.15	1.15
MDC6224-10	1.0-2.0	10 ±1.25	±0.75	0.20	0.80	25	1.10	1.10
MDC6224-20	1.0-2.0	20 ±1.25	±0.75	0.15	0.20	25	1.10	1.10
MDC6224-30	1.0-2.0	30 ±1.25	±0.75	0.15	0.20	25	1.10	1.10
MDC6225-6	2.0-4.0	6 ±1.00	±0.60	0.20	1.80	22	1.15	1.15
MDC6225-10	2.0-4.0	10 ±1.25	±0.75	0.20	0.80	22	1.15	1.15
MDC6225-20	2.0-4.0	20 ±1.25	±0.75	0.15	0.20	22	1.15	1.15
MDC6225-30	2.0-4.0	30 ±1.25	±0.75	0.15	0.20	22	1.15	1.15
MDC6266-6	2.6-5.2	6 ±1.00	±0.60	0.20	1.80	20	1.25	1.25
MDC6266-10	2.6-5.2	10 ±1.25	±0.75	0.20	0.80	20	1.25	1.25
MDC6266-20	2.6-5.2	20 ±1.25	±0.75	0.20	0.25	20	1.25	1.25
MDC6266-30	2.6-5.2	30 ±1.25	±0.75	0.20	0.20	20	1.25	1.25
MDC6226-6	4.0-8.0	6 ±1.00	±0.60	0.25	1.90	20	1.25	1.25
MDC6226-10	4.0-8.0	10 ±1.25	±0.75	0.25	0.90	20	1.25	1.25
MDC6226-20	4.0-8.0	20 ±1.25	±0.75	0.25	0.30	20	1.25	1.25
MDC6226-30	4.0-8.0	30 ±1.25	±0.75	0.25	0.25	20	1.25	1.25
MDC6227-6	7.0-12.4	6 ±1.00	±0.50	0.30	2.00	17	1.30	1.30
MDC6227-10	7.0-12.4	10 ±1.00	±0.50	0.30	1.00	17	1.30	1.30
MDC6227-20	7.0-12.4	20 ±1.00	±0.50	0.30	0.35	17	1.30	1.30
MDC6227-30	7.0-12.4	30 ±1.00	±0.50	0.30	0.30	17	1.30	1.30

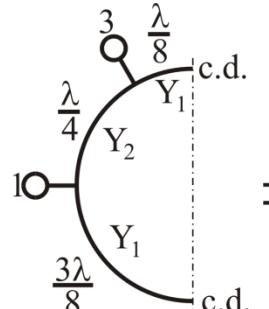
Cuploul in inel



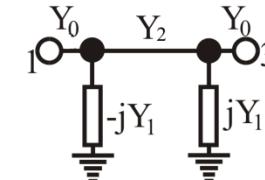
Analiza cuplului in inel



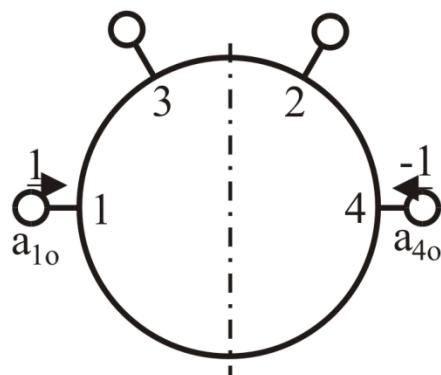
plan de simetrie
a)



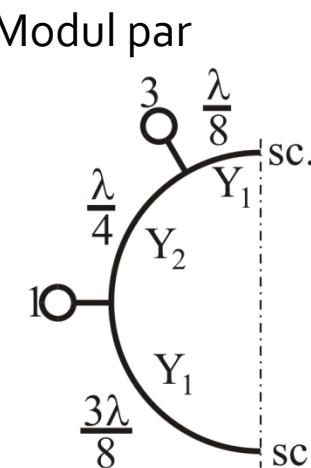
circuit deschis (c.d.)
b)



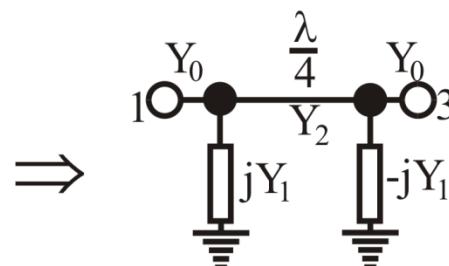
c)



plan de simetrie
a)



scurtcircuit (sc.)
Modul impar
b)



c)

Analiza cuplului in inel

$$S_{11} = \frac{jz_2y_s + jz_2 - j(y_2 + y_e y_s z_2) - jy_e z_2}{jz_2y_s + jz_2 + j(y_2 + y_e y_s z_2) + jy_e z_2}$$

$$S_{12} = \frac{2}{jz_2y_s + jz_2 + j(y_2 + y_e y_s z_2) + jy_e z_2}$$

Pentru modul par:

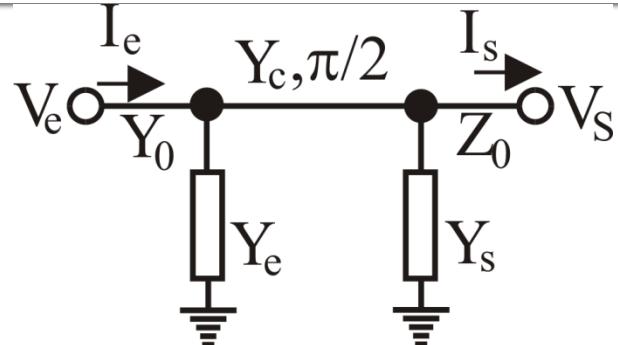
$$y_e = -jy_1$$

$$y_s = jy_1$$

$$S_{11e} = \frac{z_2 - y_2 - y_1^2 z_2 + 2jz_2 y_1}{z_2 + y_2 + y_1^2 z_2}$$

$$S_{12e} = S_{21e} = \frac{-2j}{z_2 + y_2 + y_1^2 z_2}$$

$$S_{22e} = \frac{z_2 - y_2 - y_1^2 z_2 - 2jz_2 y_1}{z_2 + y_2 + y_1^2 z_2}$$



Conditia de adaptare

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

$$[S] = \begin{bmatrix} 0 & 0 & -jy_2 & jy_1 \\ 0 & 0 & -jy_1 & -jy_2 \\ -jy_2 & -jy_1 & 0 & 0 \\ jy_1 & -jy_2 & 0 & 0 \end{bmatrix}$$

$$S_{21} = \frac{2}{jz_2y_s + jz_2 + j(y_2 + y_e y_s z_2) + jy_e z_2}$$

$$S_{22} = \frac{-jz_2y_s + jz_2 - j(y_2 + y_e y_s z_2) + jy_e z_2}{jz_2y_s + jz_2 + j(y_2 + y_e y_s z_2) + jy_e z_2}$$

Pe modul impar:

$$y_e = jy_1$$

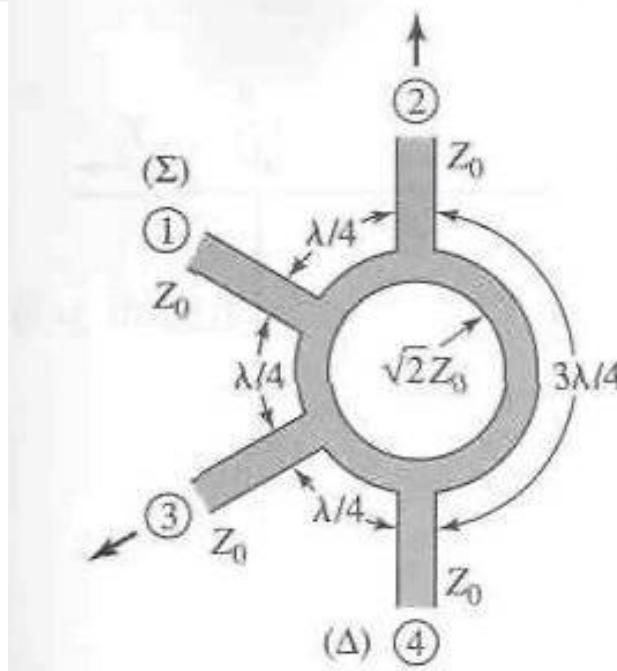
$$y_s = -jy_1$$

$$S_{11o} = \frac{z_2 - y_2 - y_1^2 z_2 - 2jz_2 y_1}{z_2 + y_2 + y_1^2 z_2}$$

$$S_{12o} = S_{21o} = \frac{-2j}{z_2 + y_2 + y_1^2 z_2}$$

$$S_{22o} = \frac{z_2 - y_2 - y_1^2 z_2 + 2jz_2 y_1}{z_2 + y_2 + y_1^2 z_2}$$

Cuploul în inel



$$[S] = \begin{bmatrix} 0 & -jy_2 & -jy_1 & 0 \\ -jy_2 & 0 & 0 & jy_1 \\ -jy_1 & 0 & 0 & -jy_2 \\ 0 & jy_1 & -jy_2 & 0 \end{bmatrix} = -j \begin{bmatrix} 0 & \alpha & \beta & 0 \\ \alpha & 0 & 0 & -\beta \\ \beta & 0 & 0 & \alpha \\ 0 & -\beta & \alpha & 0 \end{bmatrix}$$

$$C(dB) = -20 \log(\beta) = -20 \log(y_1)$$

Proiectarea și performanța unui cuplор în inel

Proiectați un cuplор în inel pe impedanță de 50Ω și reprezentati mărimea parametrilor S între 0.5 si 1.5 din frecventa centrală.

$$C [\text{dB}] = -20 \log(y_1)$$

$$\sqrt{2}Z_0 = 70.7\Omega$$

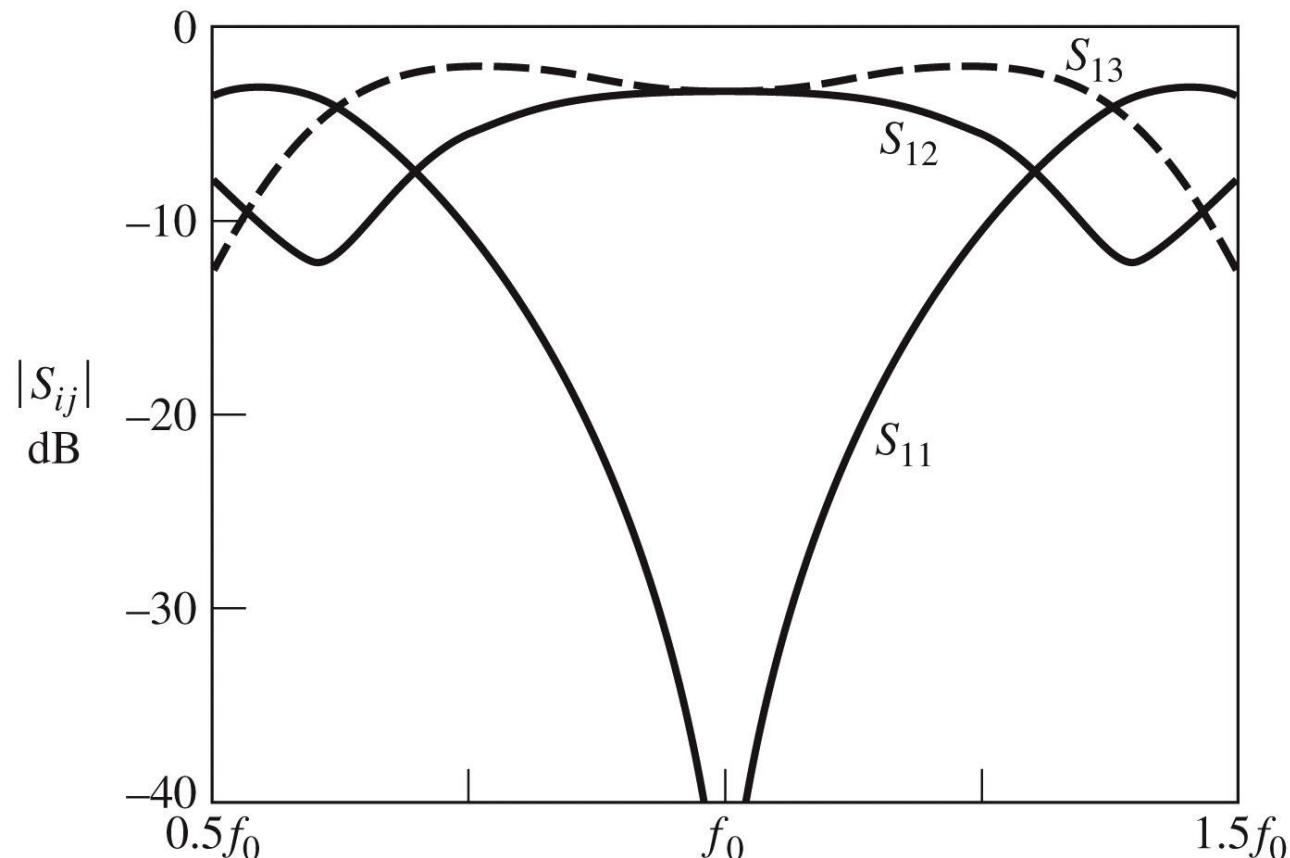


Figure 7.46
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Cupluri în inel

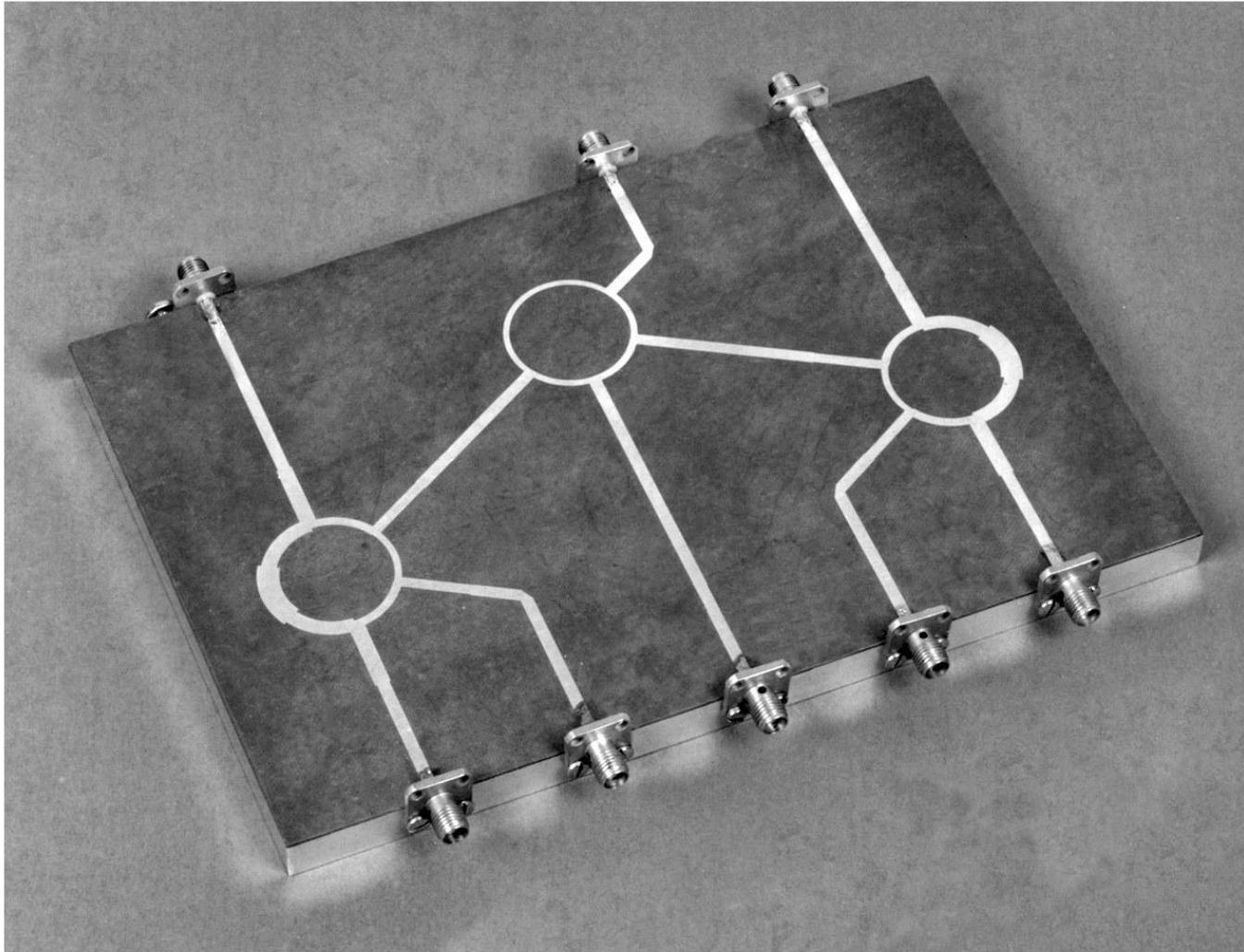
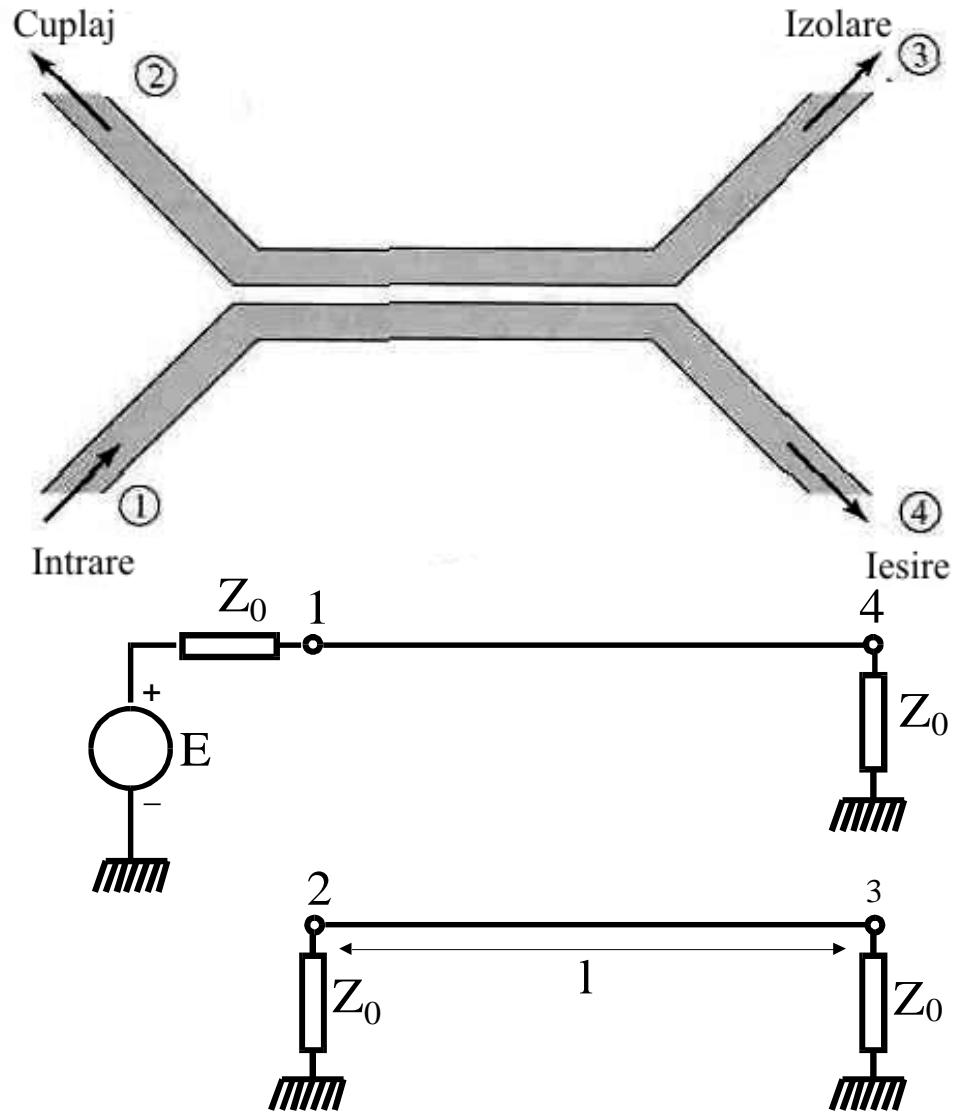
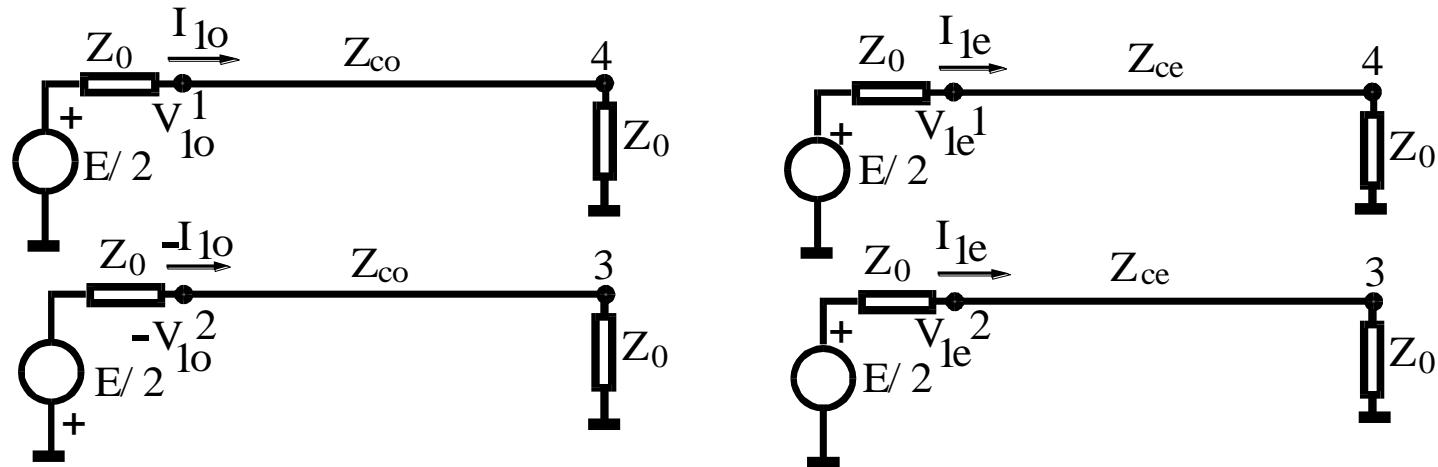


Figure 7.43
Courtesy of M. D. Abouzahra, MIT Lincoln Laboratory, Lexington, Mass.

Cuplajul prin proximitate

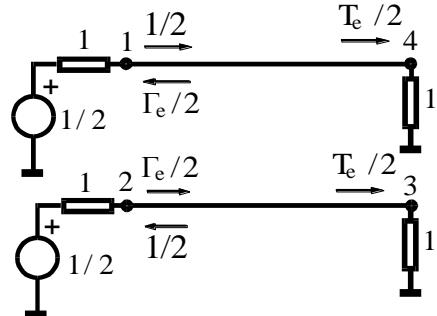


Adaptarea cuplului prin proximitate

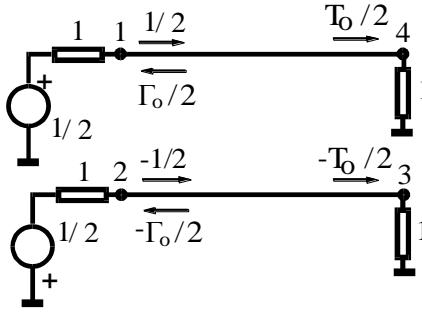


$$\left\{ \begin{array}{l} Z_{ce}Z_{co} = Z_0^2 \\ \theta_e = \theta_o \end{array} \right.$$

Directivitatea și coeficientul de cuplaj ale cuplorului prin proximitate



modul par



modul impar

$$a_1 = a_{1e} + a_{1o} = 1, \quad a_2 = a_3 = a_4 = 0$$

$$b_1 = \frac{1}{2}(\Gamma_e + \Gamma_o) = 0 \Leftrightarrow$$

$$b_2 = \frac{1}{2}(\Gamma_e - \Gamma_o) = \frac{jC \sin(\theta)}{\cos(\theta)\sqrt{1-C^2} + j\sin(\theta)}$$

$$b_3 = \frac{1}{2}(T_e - T_o) = 0$$

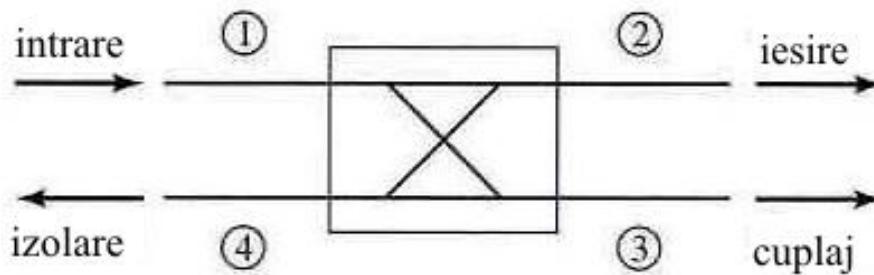
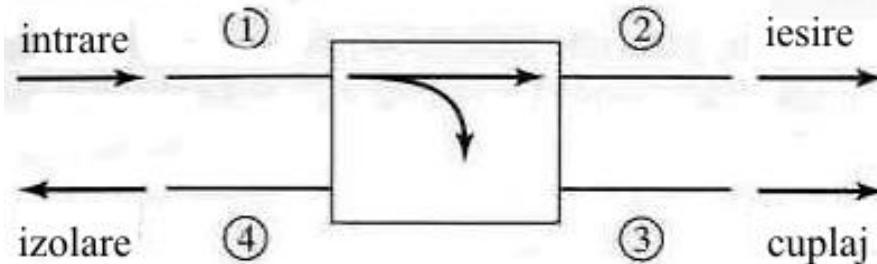
$$b_4 = \frac{1}{2}(T_e + T_o) = \frac{\sqrt{1-C^2}}{\cos(\theta)\sqrt{1-C^2} + j\sin(\theta)}$$

$$C = \frac{Z_{ce} - Z_{co}}{Z_{ce} + Z_{co}}$$

$$\theta = \pi/2$$

$$[S] = \begin{bmatrix} 0 & C & 0 & -j\sqrt{1-C^2} \\ C & 0 & -j\sqrt{1-C^2} & 0 \\ 0 & -j\sqrt{1-C^2} & 0 & C \\ -j\sqrt{1-C^2} & 0 & C & 0 \end{bmatrix}$$

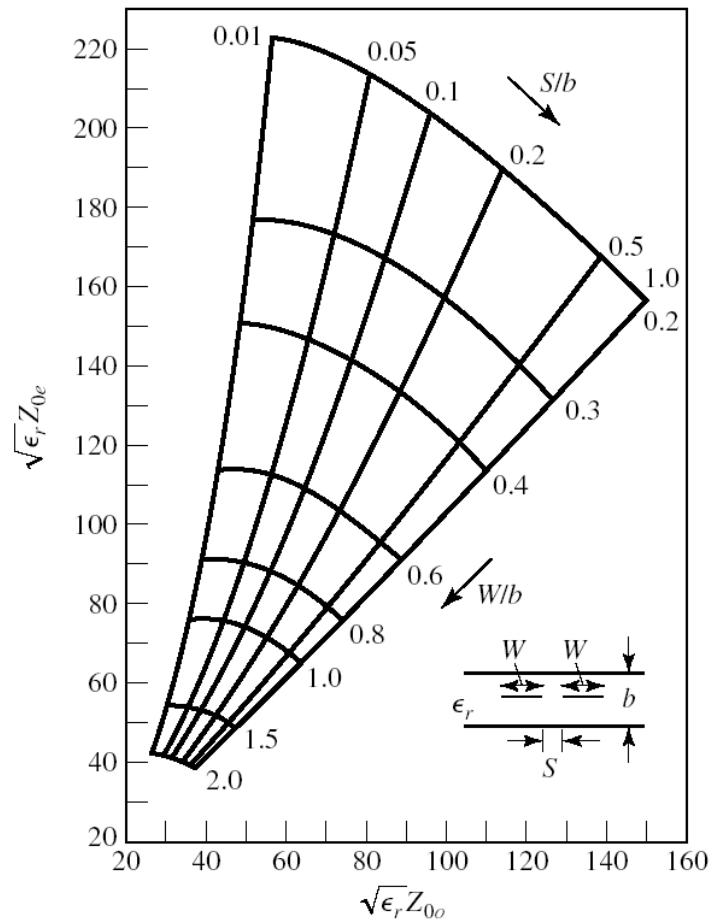
Cuplaj prin proximitate



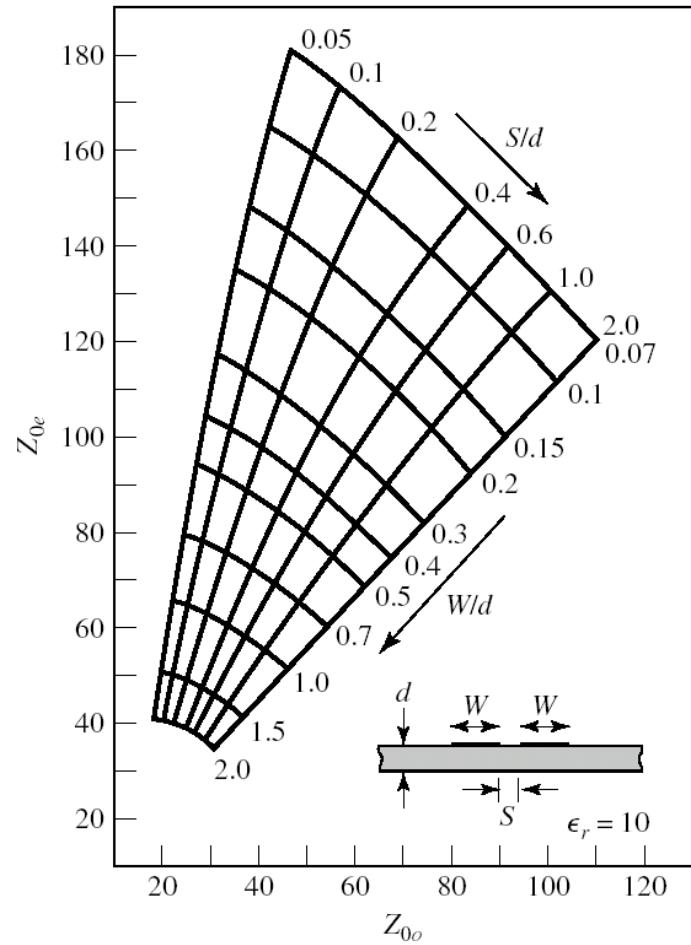
$$[S] = -j \cdot \begin{bmatrix} 0 & \sqrt{1-C^2} & jC & 0 \\ \sqrt{1-C^2} & 0 & 0 & jC \\ jC & 0 & 0 & \sqrt{1-C^2} \\ 0 & jC & \sqrt{1-C^2} & 0 \end{bmatrix}$$

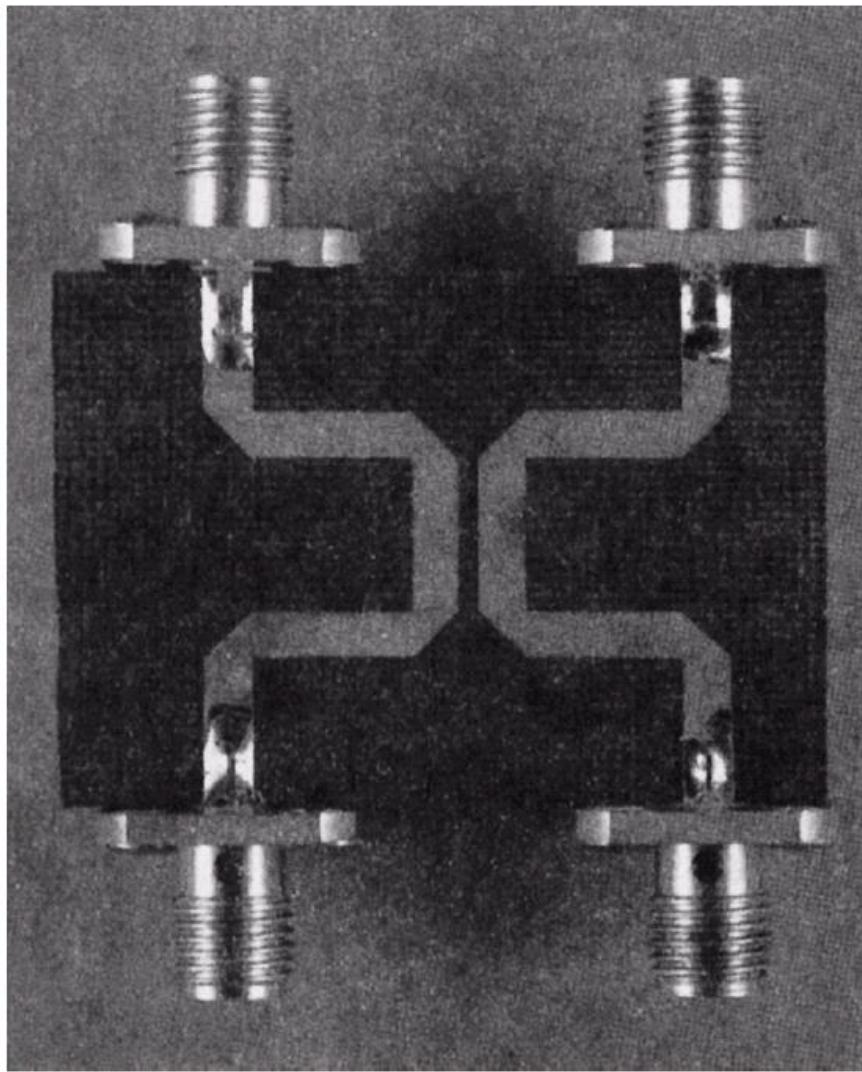
$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix}$$

Normalized even- and odd-mode characteristic impedance design data for edge-coupled striplines.



Even- and odd-mode characteristic impedance design data for coupled microstrip lines on a substrate with $\epsilon_r = 10$.





Cuplor prin proximitate

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

$$C = \frac{Z_{ce} - Z_{co}}{Z_{ce} + Z_{co}}$$

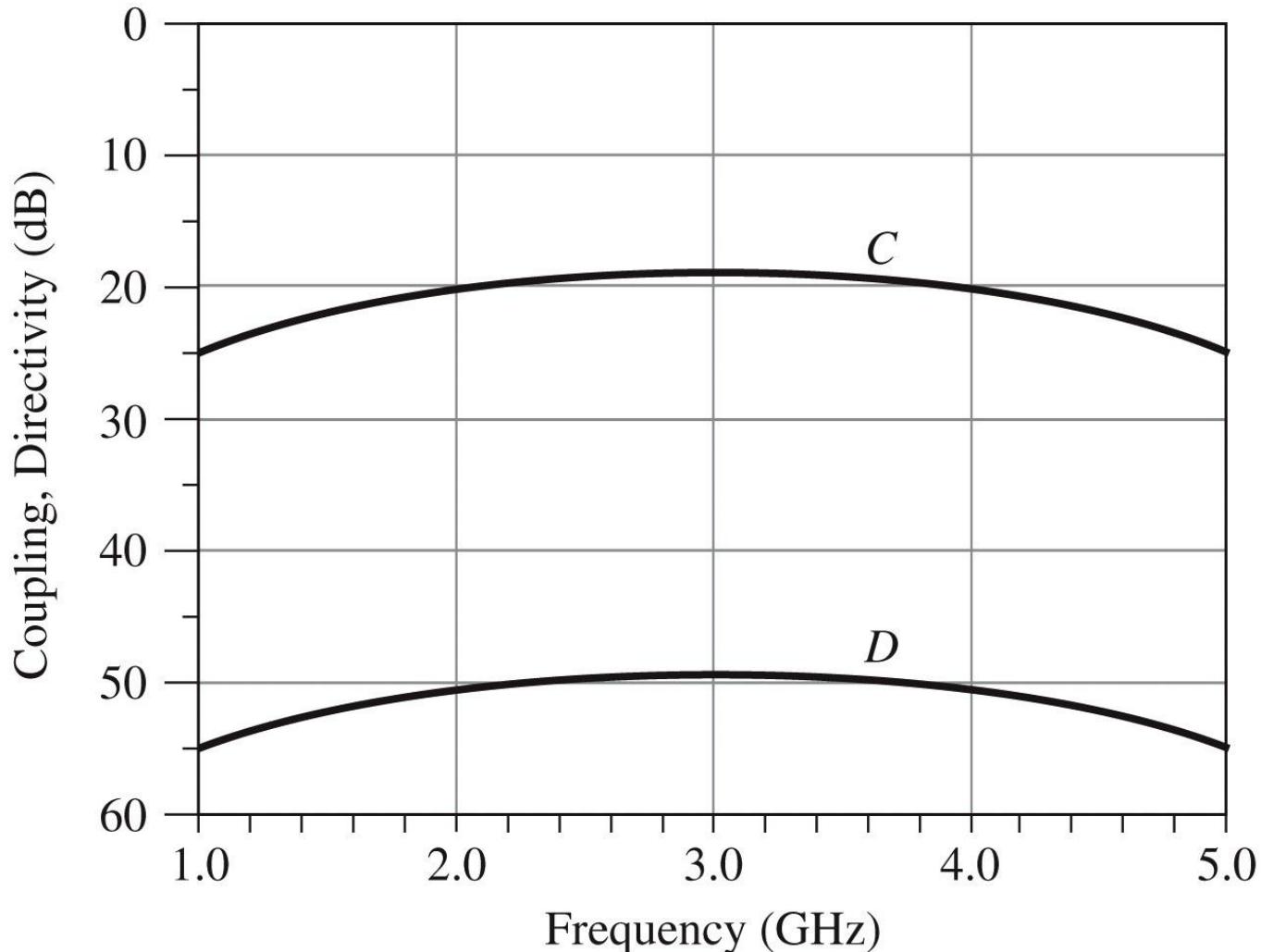


Figure 7.34

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Exemplu

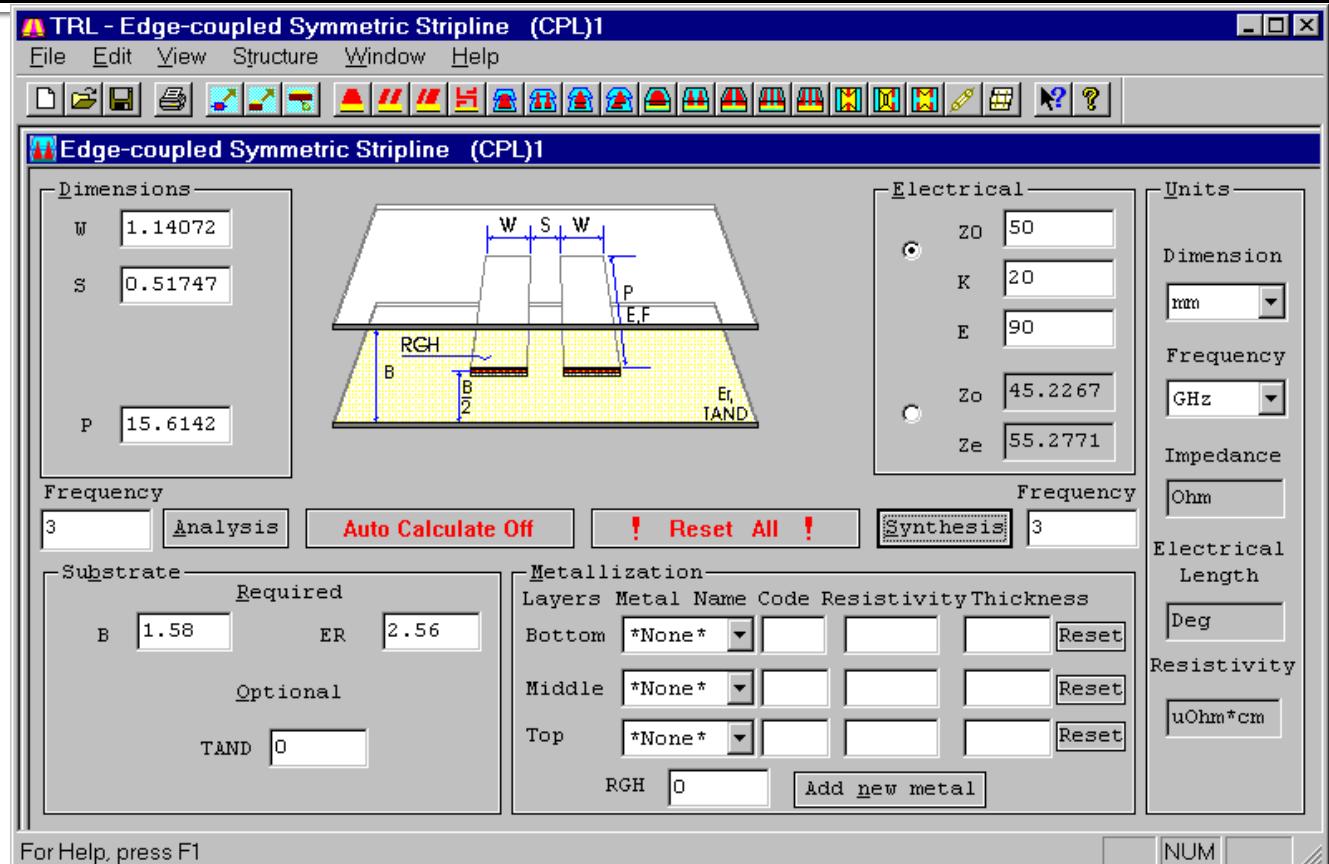
Proiectați un cuplor prin proximitate de 20 dB, în tehnologie stripline, folosind o distanță între planele de masă de 0.158 cm și cu o permisivitate electrică relativă de 2.56, pe o impedanță de 50Ω , la frecvența de 3 GHz. Reprezentați cuplajul și directivitatea între 1 și 5 GHz.

Soluție

$$C = 10^{-20/20} = 0.1$$

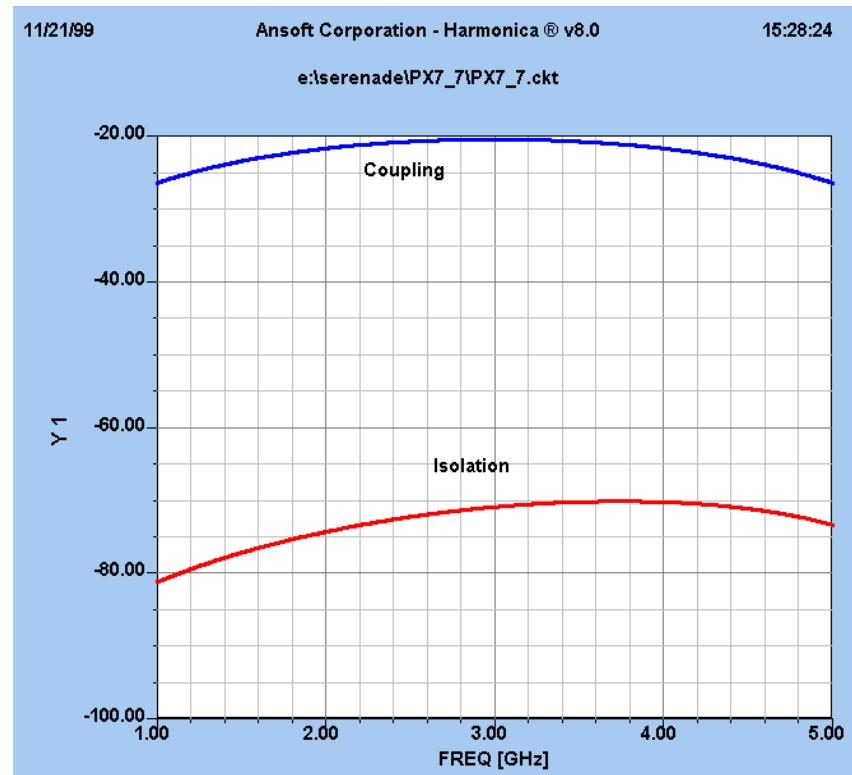
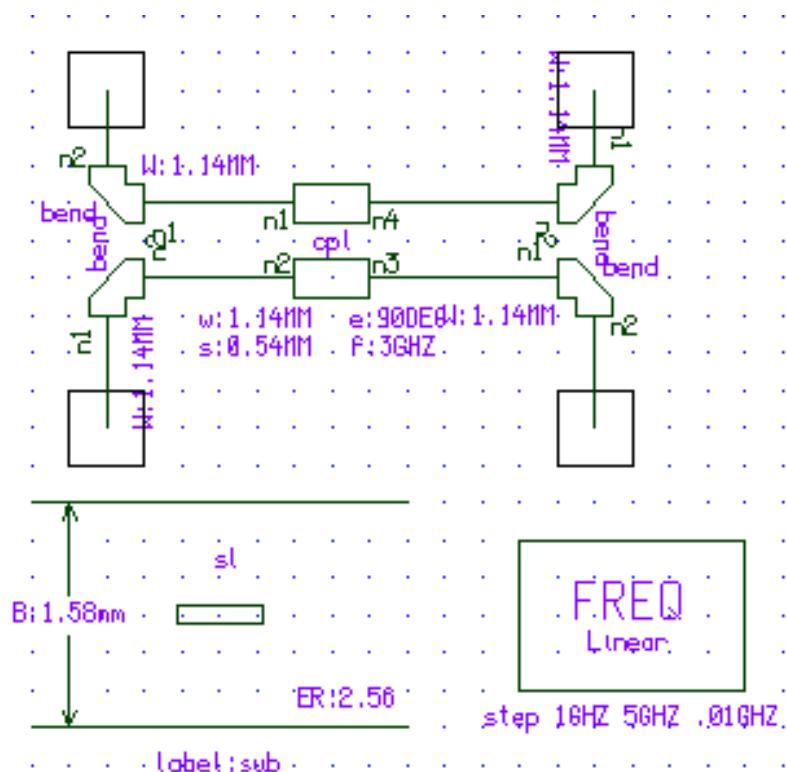
$$Z_{co} = 50 \sqrt{\frac{0.9}{1.1}} = 45.23\Omega$$

$$Z_{ce} = 50 \sqrt{\frac{1.1}{0.9}} = 55.28\Omega$$

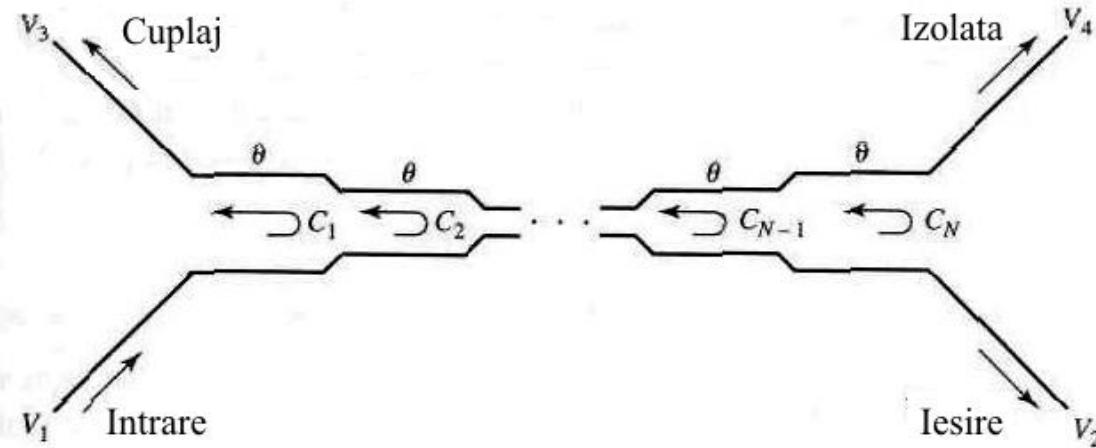


$$Z_{ce} = Z_0 \sqrt{\frac{1+C}{1-C}}, Z_{co} = Z_0 \sqrt{\frac{1-C}{1+C}}$$

Simulare



Cuplaj prin proximitate cu mai multe secțiuni



$C \ll 1$

$$\frac{V_3}{V_1} = b_3 = \frac{jC \sin \theta}{\cos \theta \sqrt{1 - C^2} + j \sin \theta} = \frac{jC \operatorname{tg} \theta}{\sqrt{1 - C^2} + j \operatorname{tg} \theta} \approx \frac{jC \operatorname{tg} \theta}{1 + j \operatorname{tg} \theta} = jC \sin \theta e^{-j\theta}$$

$$\frac{V_2}{V_1} = b_2 = \frac{\sqrt{1 - C^2}}{\cos \theta \sqrt{1 - C^2} + j \sin \theta} \approx \frac{1}{\cos \theta + j \sin \theta} = e^{-j\theta}$$

$$C = \frac{V_3}{V_1} = 2j \sin \theta e^{-j\theta} e^{-j(N-1)\theta} \left[C_1 \cos((N-1)\theta) + C_2 \cos((N-3)\theta) + \dots + \frac{1}{2} C_{\frac{N+1}{2}} \right]$$

Exemplu

Să se proiecteze un cuplaj cu trei secțiuni, având un cuplaj de 20 dB, cu caracteristică binomială (maxim plat), pe o impedanță de 50Ω , la frecvența centrală de 3 GHz. Să se reprezinte grafic cuplajul și directivitatea între 1 și 5 GHz.

Solutie

$$\left. \frac{d^n}{d\theta^n} C(\theta) \right|_{\theta=\pi/2} = 0, n=1,2$$

$$C = \left| \frac{V_3}{V_1} \right| = 2 \sin \theta \left[C_1 \cos 2\theta + \frac{1}{2} C_2 \right] = C_1 (\sin 3\theta - \sin \theta) + C_2 \sin \theta$$

$$\frac{dC}{d\theta} = [3C_1 \cos 3\theta + (C_2 - C_1) \cos \theta] \Big|_{\theta=\pi/2} = 0$$

$$\frac{d^2C}{d\theta^2} = [-9C_1 \sin 3\theta - (C_2 - C_1) \sin \theta] \Big|_{\theta=\pi/2} = 10C_1 - C_2 = 0$$

$$\begin{cases} C_2 - 2C_1 = 0.1 \\ 10C_1 - C_2 = 0 \end{cases}$$

$$\begin{cases} C_1 = C_3 = 0.0125 \\ C_2 = 0.125 \end{cases}$$

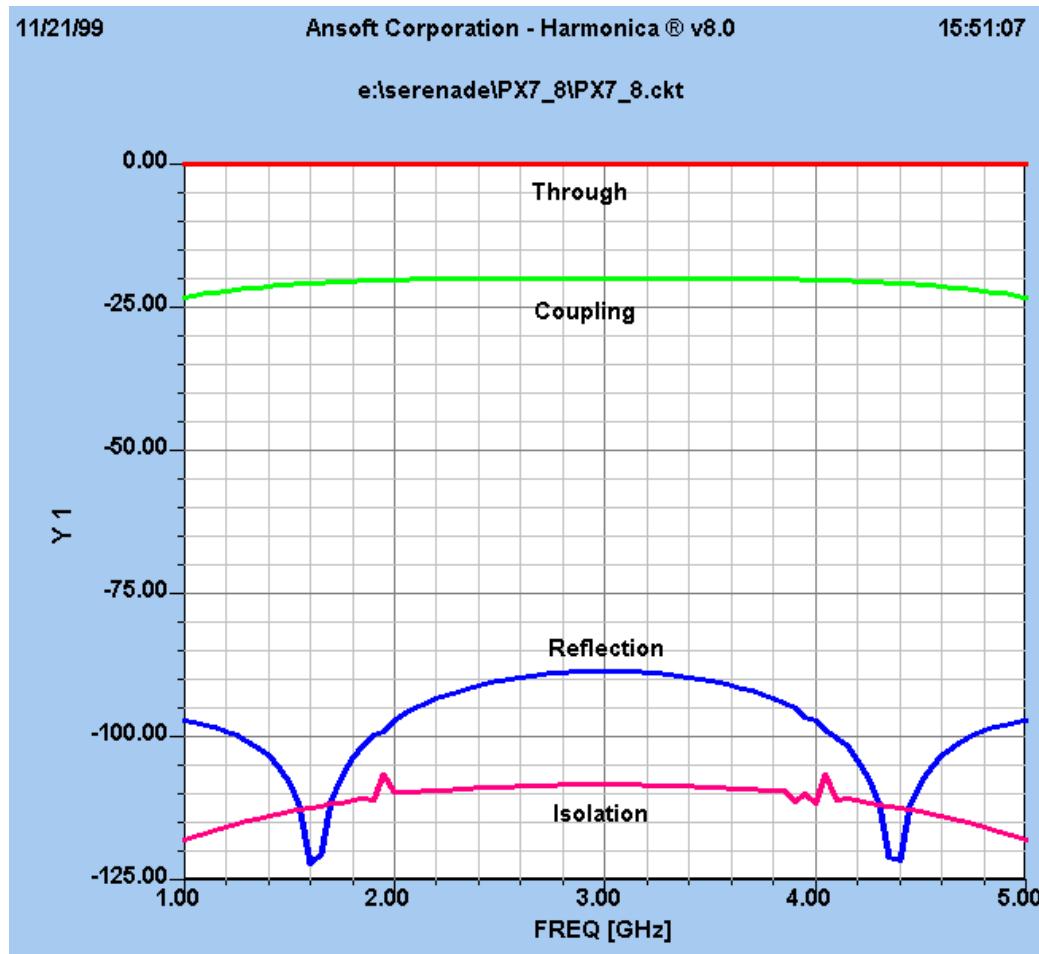
$$Z_{0e}^1 = Z_{0e}^3 = 50 \sqrt{\frac{1.0125}{0.9875}} = 50.63 \Omega$$

$$Z_{0o}^1 = Z_{0o}^3 = 50 \sqrt{\frac{0.9875}{1.0125}} = 49.38 \Omega$$

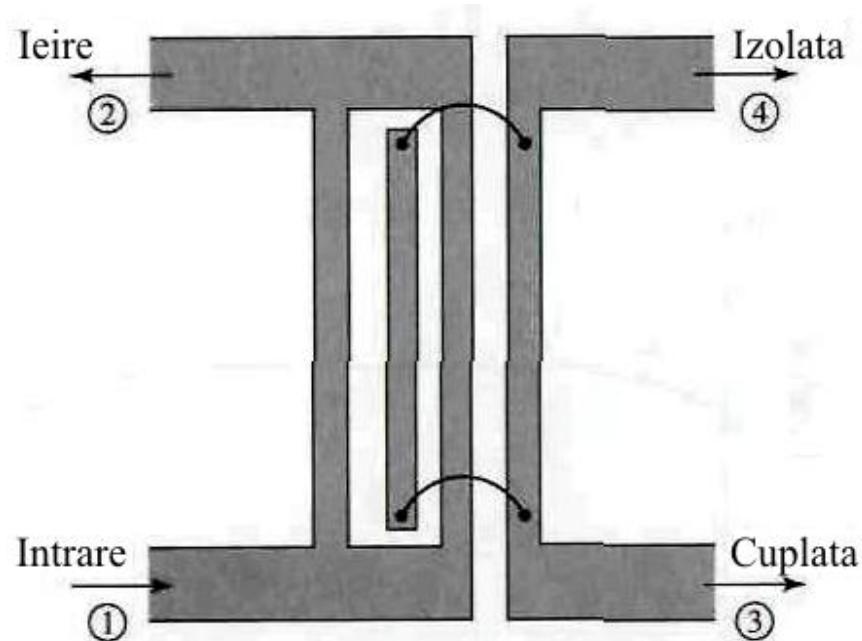
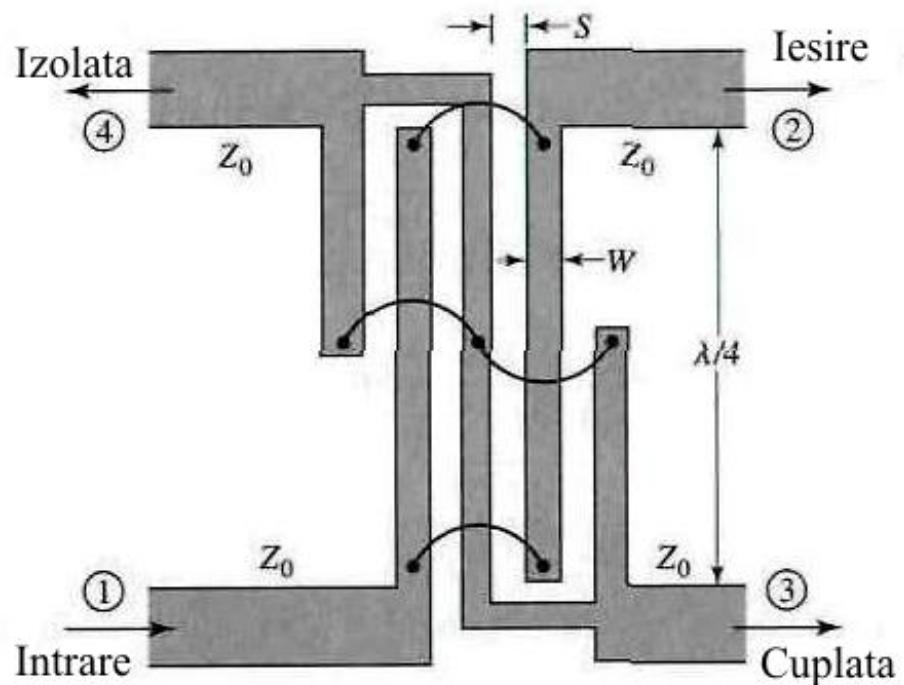
$$Z_{0e}^2 = 50 \sqrt{\frac{1.125}{0.875}} = 56.69 \Omega$$

$$Z_{0o}^2 = 50 \sqrt{\frac{0.875}{1.125}} = 44.10 \Omega$$

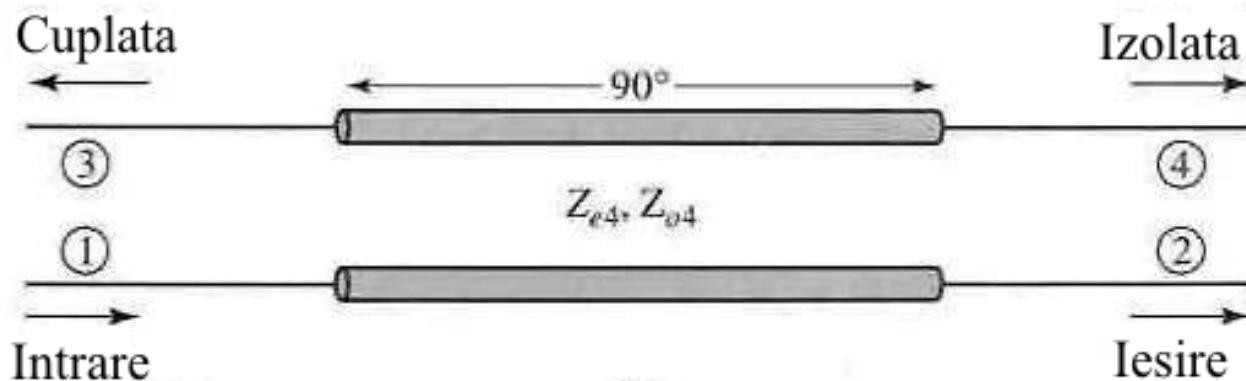
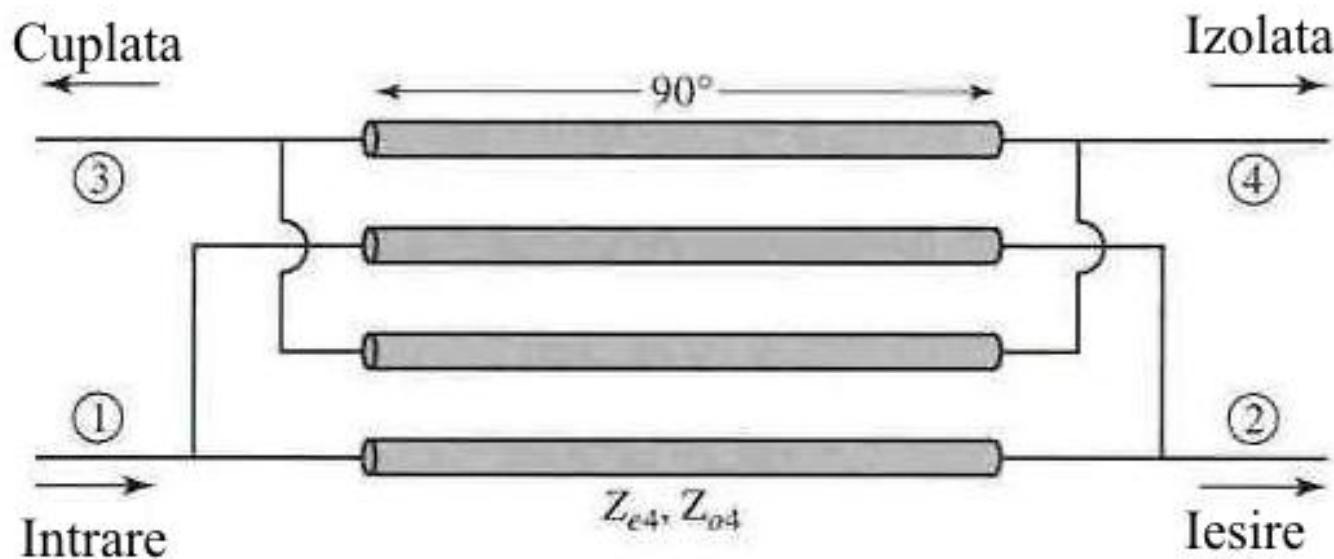
Simulare



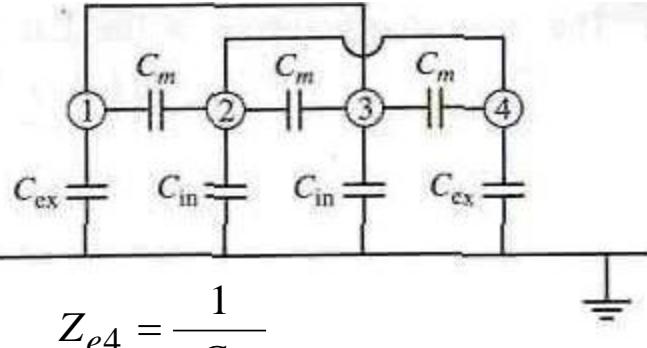
Cuploul Lange



Cuplor Lange



Modelul de circuit



$$Z_{e4} = \frac{1}{vC_{e4}}$$

$$Z_{o4} = \frac{1}{vC_{o4}}$$

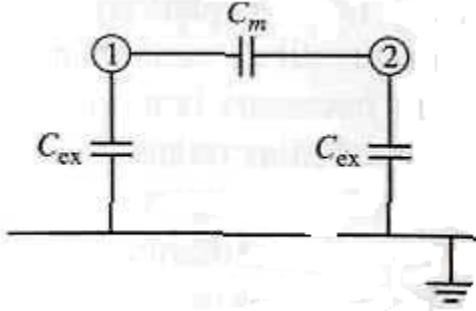
$$C_{e4} = \frac{C_e(3C_e + C_o)}{C_e + C_o}$$

$$C_{o4} = \frac{C_o(3C_o + C_e)}{C_e + C_o}$$

$$C_{in} = C_{ex} - \frac{C_{ex}C_m}{C_{ex} + C_m}$$

$$C_{e4} = C_{ex} + C_{in}$$

$$C_{o4} = C_{ex} + C_{in} + 6C_m$$



$$C_o = C_{ex} + 2C_m$$

$$Z_0 = \sqrt{Z_{e4}Z_{o4}} = \sqrt{\frac{Z_{0e}Z_{0o}(Z_{0o} + Z_{0e})^2}{(3Z_{0o} + Z_{0e})(3Z_{0e} + Z_{0o})}}$$

$$C = \frac{Z_{e4} - Z_{o4}}{Z_{e4} Z_{0eo}} \frac{3\sqrt{Z_{0e}^2 - Z_{0o}^2}}{4C + 3 + \sqrt{9 - 8C^2}}$$

$$Z_{0o} = \frac{4C + 3 - \sqrt{9 - 8C^2}}{2C\sqrt{(1+C)/(1-C)}} Z_0$$

Contact

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