

Curs 5

2014/2015

Dispozitive și circuite de microunde pentru radiocomunicații

Fotografii

FLORESCU DAN-CONSTAN



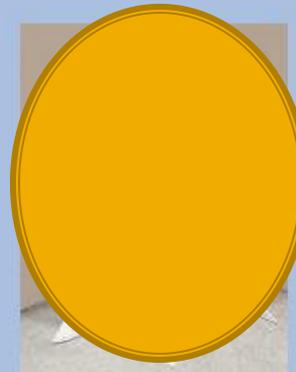
Date:

Grupa	5405 (2008)
Specializarea	Tehnologii si sisteme
Marca	3275

Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Ob
DCMR	Dispozitive si circuite de microunde pentru radiocomunicatii				
	Nota	19/06/2009	Nota finala	10	
	Exam	19/06/2009	Examen DCMR	9	
	Tema	05/06/2009	Proiect DCMR	10	

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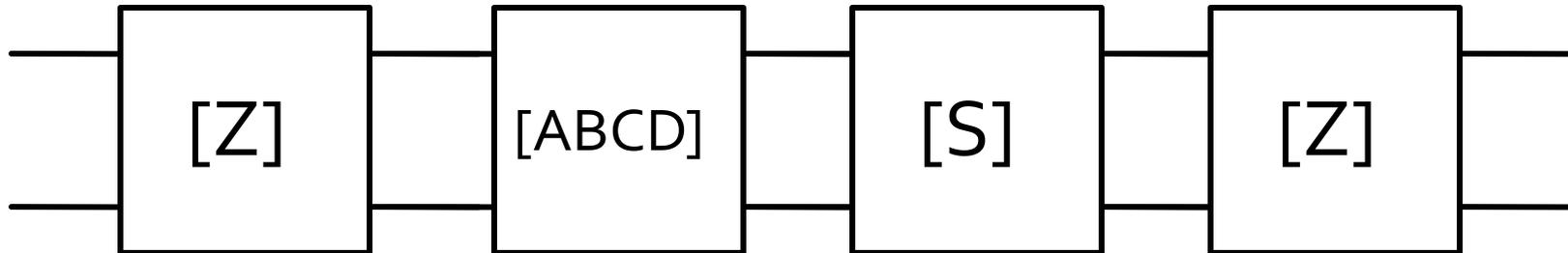
Detalii

Finantare	Buget
Bursa	Bursa de Studii
Domiciliu	Iasi, judet Iasi
Promovare	Promovare Integrala
Credite	60
Media	8.86

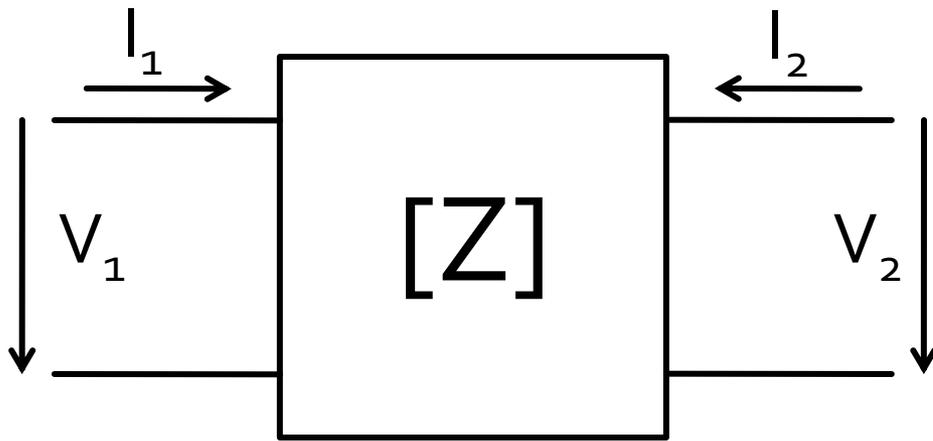
Analiza la nivel de rețea a circuitelor de microunde

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



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

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

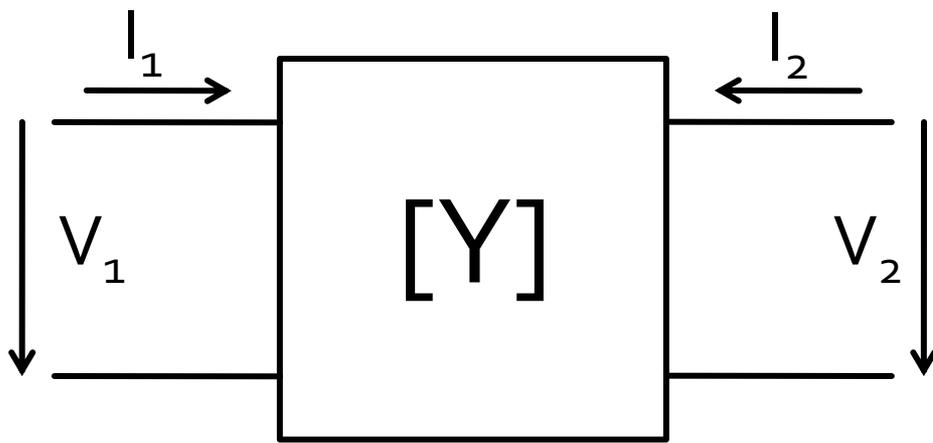
$$V_2 = Z_{21} \cdot I_1 + Z_{22} \cdot I_2$$

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

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

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

Matricea admitanta



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

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

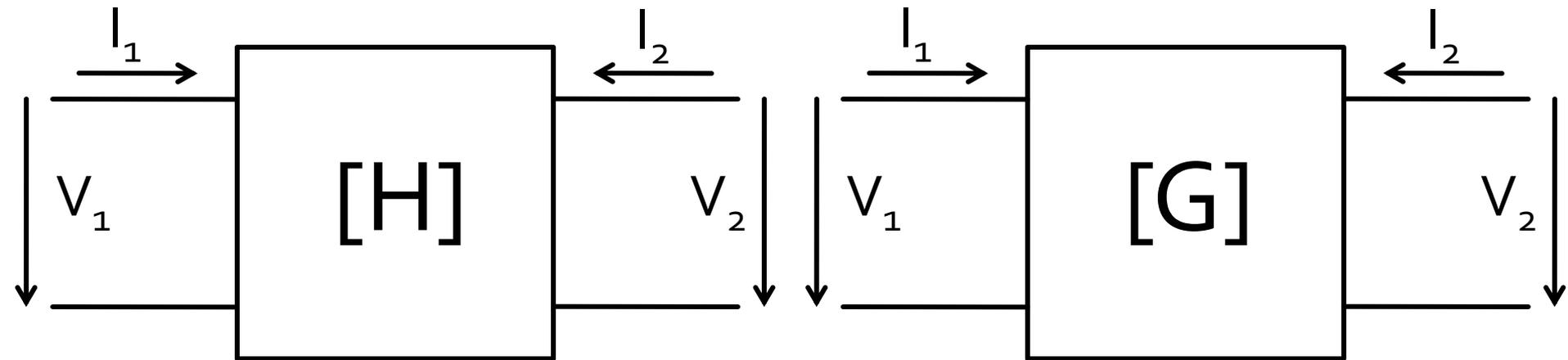
$$I_2 = Y_{21} \cdot V_1 + Y_{22} \cdot V_2$$

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

- Y_{11} – admitanta de intrare cu iesirea in scurtcircuit

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

Matrici hibride



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

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

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

- h_{21E} utilizat la TB, conexiune Emitter comun (β , h_{22} este foarte mare)

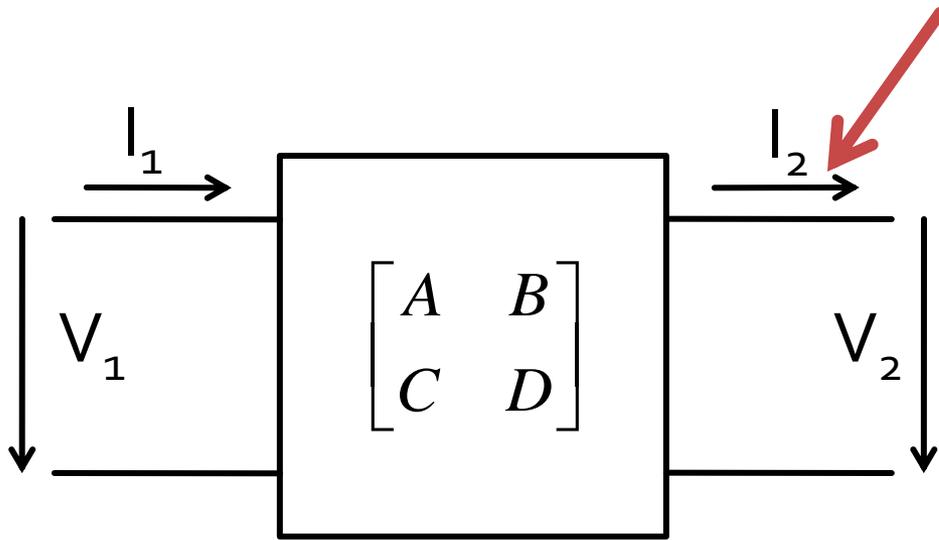
Analiza la nivel de bloc

- 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

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

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

Matricea ABCD – de transmisie



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

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

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

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

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

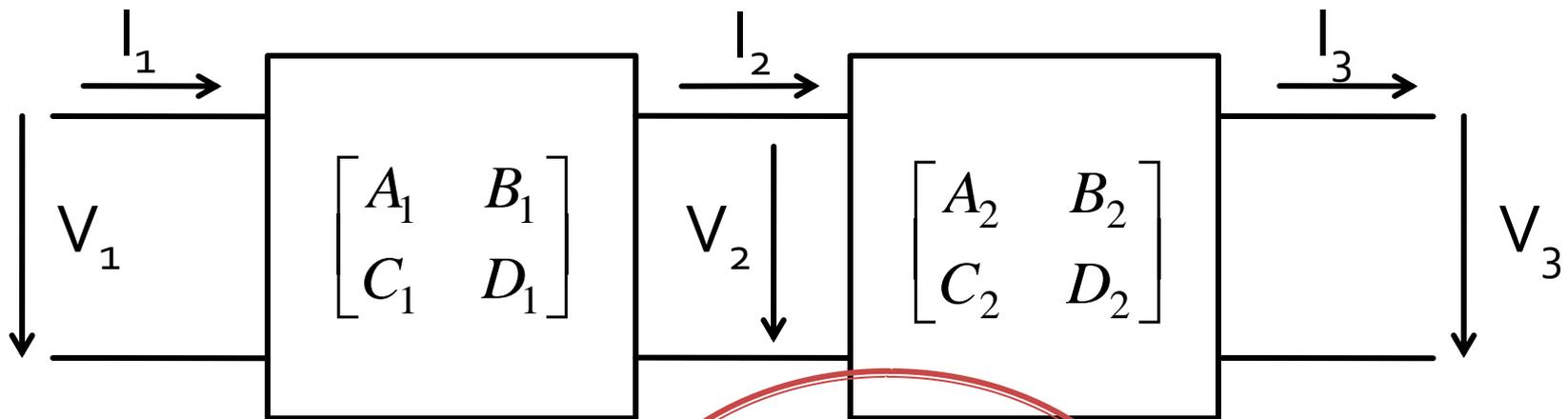
$$B = \left. \frac{V_1}{I_2} \right|_{V_2=0}$$

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

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

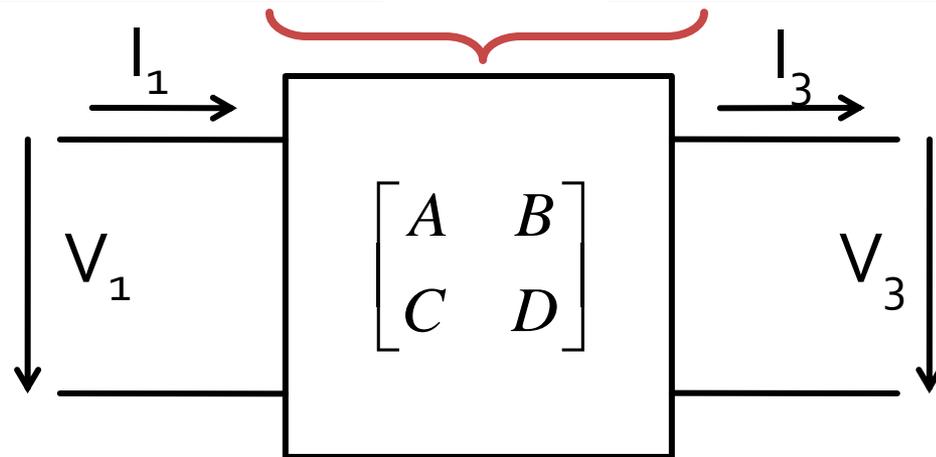
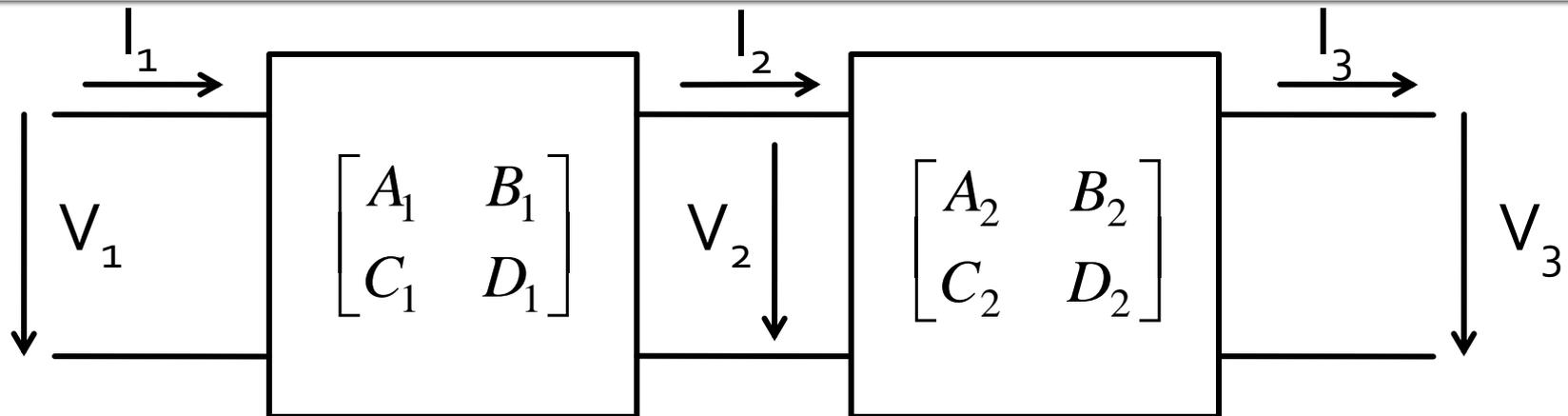
Matricea ABCD – de transmisie

- introduce o legatura intre "intrare" si "iesire"
- permite inlaturarea 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



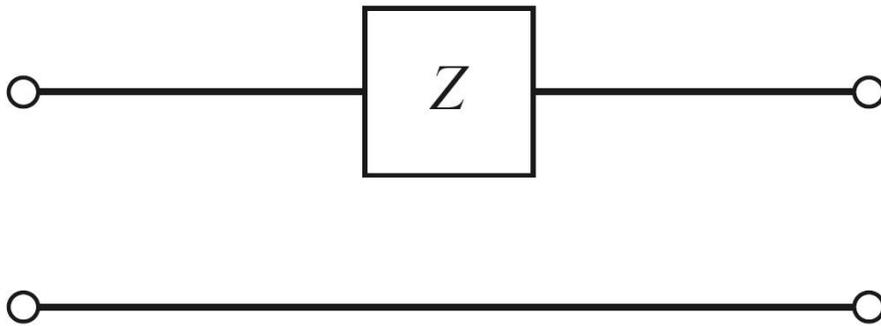
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdot \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$

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

- Impedanza serie



$$A = 1$$

$$B = Z$$

$$C = 0$$

$$D = 1$$

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

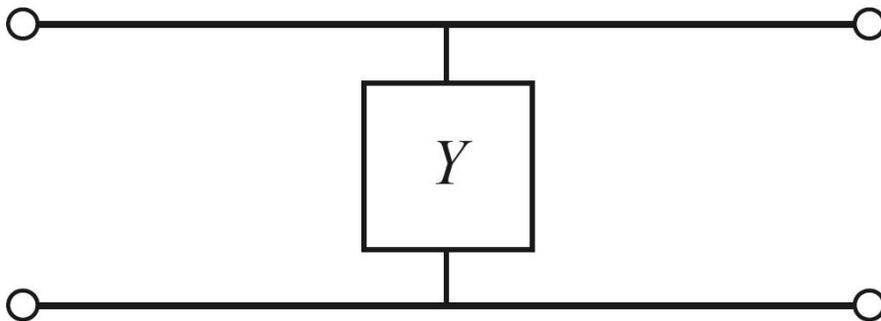
$$B = \left. \frac{V_1}{I_2} \right|_{V_2=0} = \frac{V_1}{V_1/Z} = Z$$

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

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

Matrici ABCD

- Admitanta paralela



$$A = 1$$

$$B = 0$$

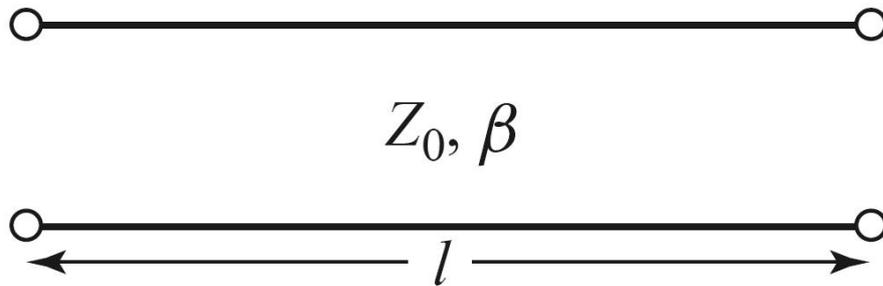
$$C = Y$$

$$D = 1$$

Verificare - tema!

Matrici ABCD

- Sectiune de linie de transmisie



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

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

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

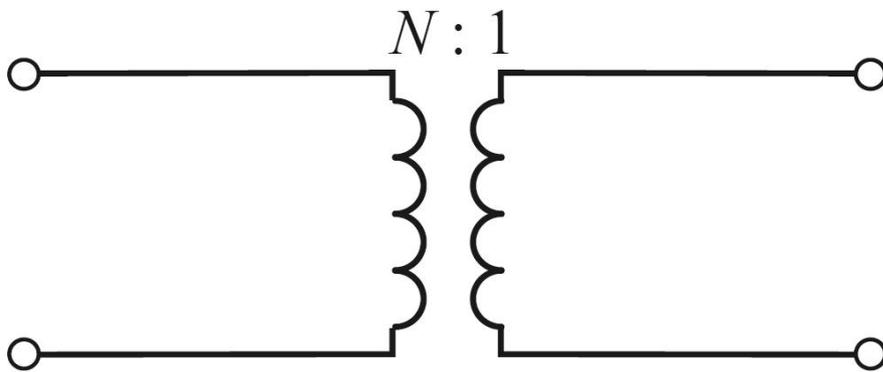
$$D = \cos \beta \cdot l$$

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



$$A = N$$

$$B = 0$$

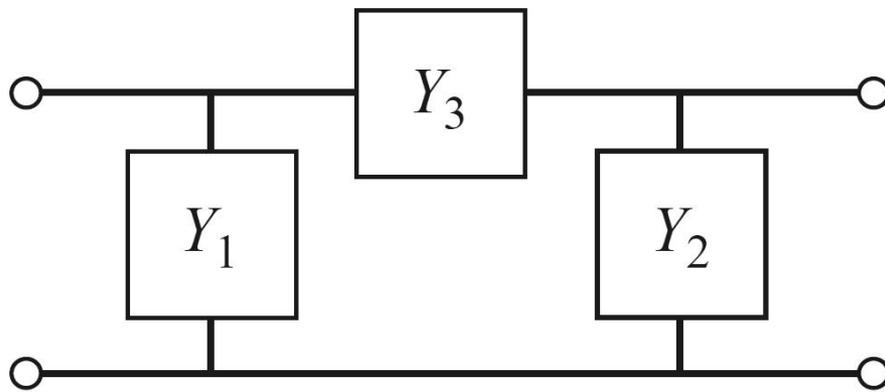
$$C = 0$$

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

Verificare - tema!

Matrici ABCD

- diport π



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

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

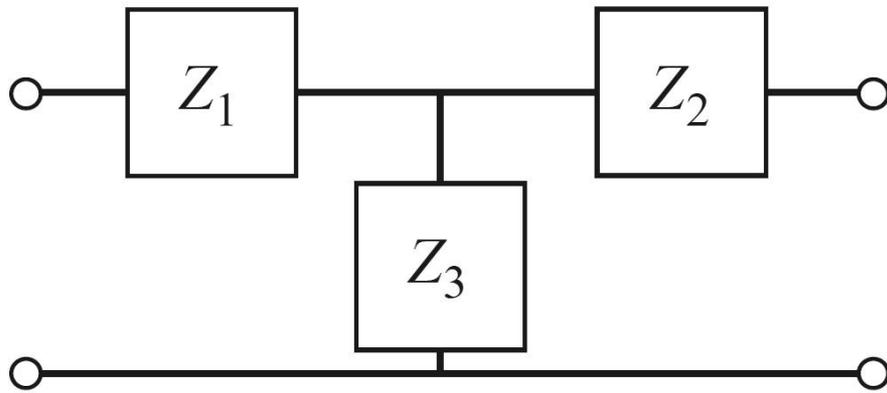
$$C = Y_1 + Y_2 + \frac{Y_1 \cdot Y_2}{Y_3}$$

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

Verificare - tema!

Matrici ABCD

- diport T



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

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

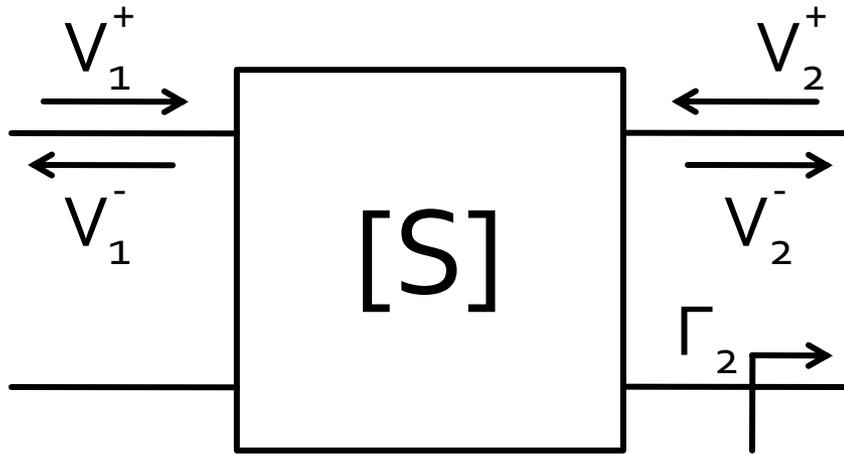
$$C = \frac{1}{Z_3}$$

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

Verificare - tema!

Matricea S (repartitie)

- Scattering parameters



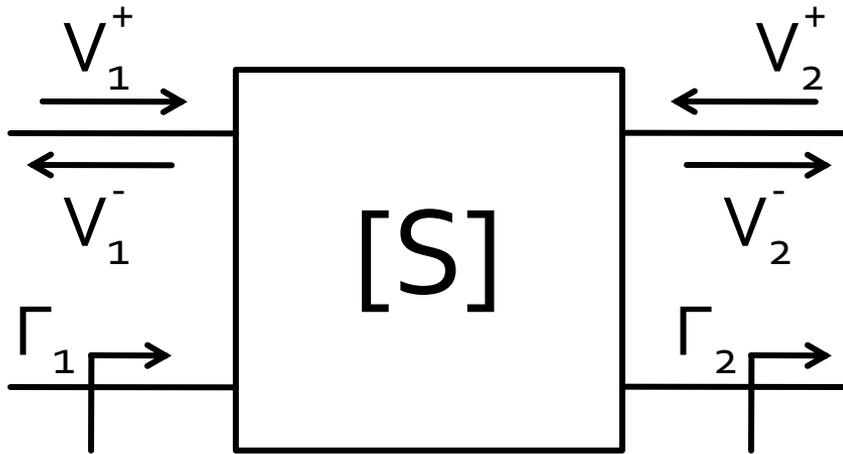
$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

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

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

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

Matricea S (repartitie)



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

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

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

- S_{11} este coeficientul de reflexie la portul 1 cand portul 2 este terminat pe impedanta care realizeaza adaptarea
- S_{21} este coeficientul de transmisie de la portul 1 la portul 2 cand portul 2 este terminat pe impedanta care realizeaza adaptarea

Matricea S (repartitie)

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

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

- 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 la portul i 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_{0i}

- Curs 2

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

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

- Legatura cu matricea Z

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

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

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

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

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

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

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

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

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

Matricea S generalizata

- Definim undele de putere

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

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

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

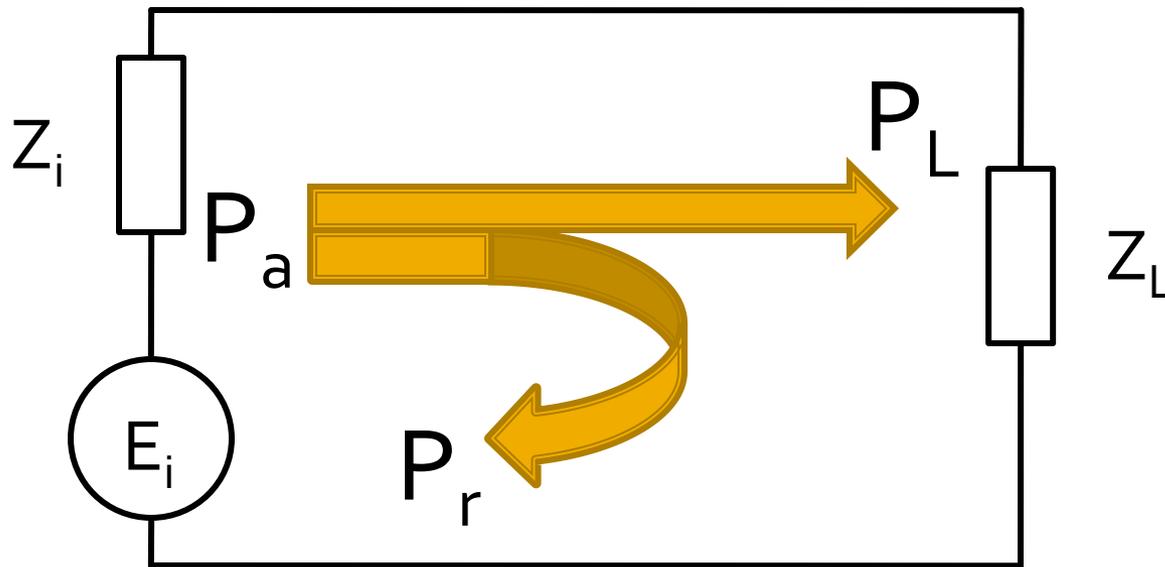
O impedanta de referinta
oarecare, complexa

- Tensiuni si curenti

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

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

Reflexie de putere / Model / C2



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

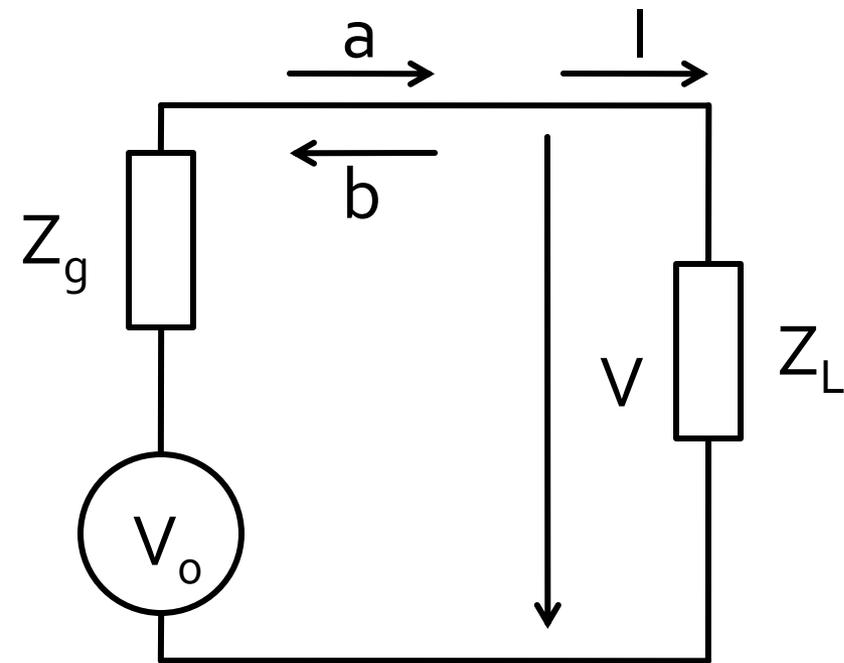
$$P_L = \frac{R_L \cdot |E_i|^2}{(R_i + R_L)^2 + (X_i + X_L)^2}$$

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

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

- coeficient de reflexie in putere

Unde de putere



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

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

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

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

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

Unde de putere

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

- Daca aleg $Z_R = Z_L^*$

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

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

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

Unde de putere

- Daca in plus generatorul este adaptat conjugat cu sarcina

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

- Definitii de unde pentru n-porti

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

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

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

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

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

Unde de putere pentru multiporti

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

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

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

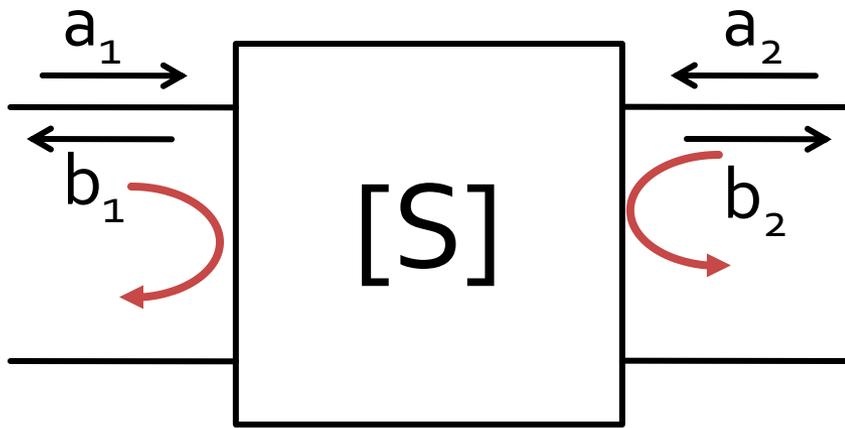
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$$Z_{0i} = Z_{Ri} = R_0, \forall i$$

$$R_0 = 50\Omega$$

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

Matricea S (repartitie)

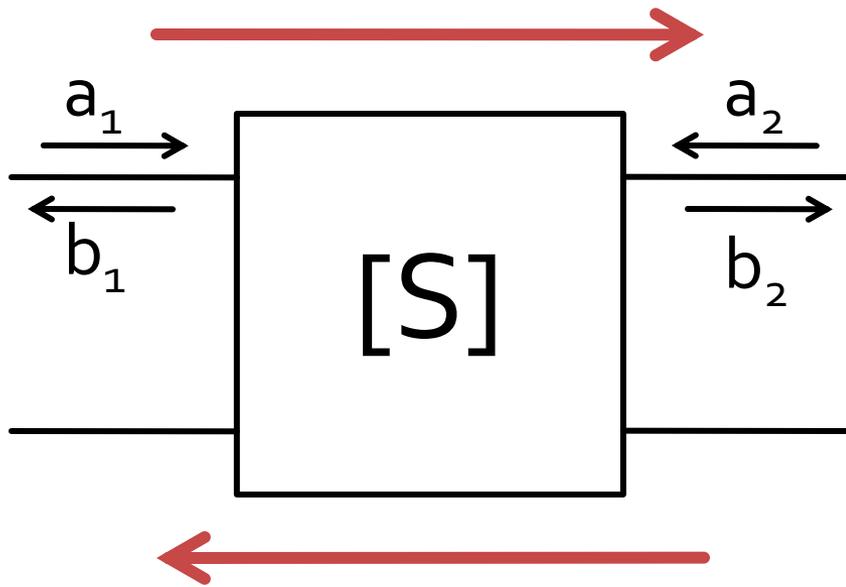


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

Matricea S (repartitie)

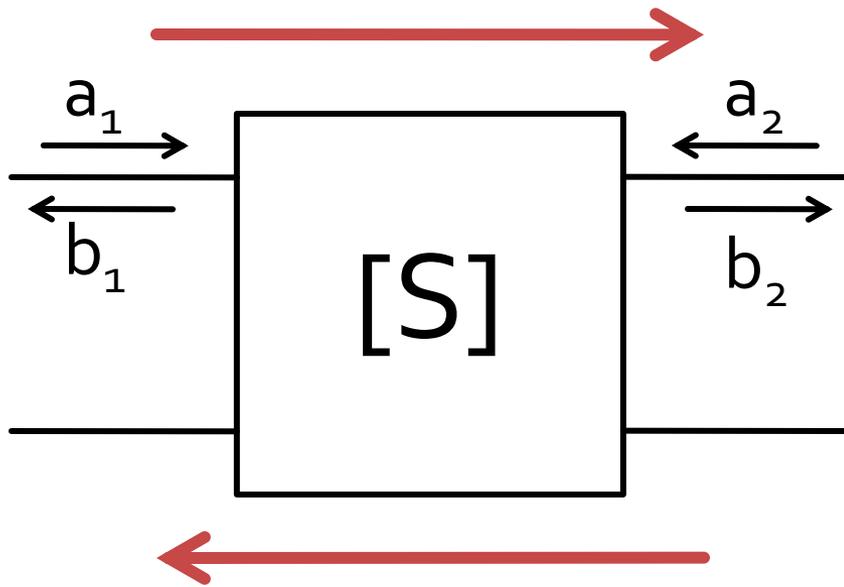


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

Matricea S (repartitie)



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

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

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

Cuploare directionale si divizoare de putere

Proprietati de baza ale cuploarelor directionale

Circuite cu trei porti

$$(S_{ij} = S_{ji})$$

Reciproc

$$S_{ii} = 0$$

Adaptare simultana
la toate portile

$$\sum_k S_{ik} S_{kj}^* = \delta_{ij}$$

Fara pierderi



$$|S_{13}|^2 + |S_{23}|^2 = 1$$

$$|S_{12}|^2 + |S_{23}|^2 = 1$$

$$|S_{12}|^2 + |S_{13}|^2 = 1$$

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

$$S_{23}^* S_{12} = 0$$

$$S_{12}^* S_{13} = 0$$



Un circuit cu trei porti **NU** poate fi fara pierderi,
reciproc si adaptat simultan la toate portile

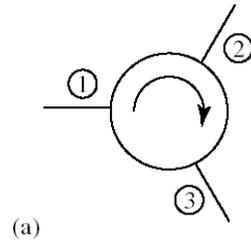
Circuitul fara pierderi si adaptat simultan la toate portile este nereziproc

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

$$\begin{aligned} & S_{31}^* S_{32} = 0 \\ & S_{21}^* S_{23} = 0 \\ & S_{12}^* S_{13} = 0 \end{aligned}$$

$$1 \left\{ \begin{aligned} & S_{12} = S_{23} = S_{31} = 0 \\ & |S_{21}| = |S_{32}| = |S_{13}| = 1 \end{aligned} \right.$$

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



$$\sum_k S_{ik} S_{kj}^* = \delta_{ij}$$

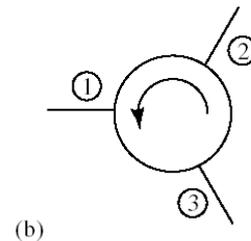
$$|S_{12}|^2 + |S_{13}|^2 = 1$$

$$|S_{21}|^2 + |S_{23}|^2 = 1$$

$$|S_{31}|^2 + |S_{32}|^2 = 1$$

$$2 \left\{ \begin{aligned} & S_{21} = S_{32} = S_{13} = 0 \\ & |S_{12}| = |S_{23}| = |S_{31}| = 1 \end{aligned} \right.$$

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



CIRCULATOR

Circuitul fara pierderi si reciproc poate fi adaptat doar la doua porti

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

$$\sum_k S_{ik} S_{kj}^* = \delta_{ij}$$

$$S_{13}^* S_{23} = 0(a)$$

$$S_{12}^* S_{13} + S_{23}^* S_{33} = 0(b)$$

$$S_{23}^* S_{12} + S_{33}^* S_{13} = 0(c)$$

>

$$|S_{12}|^2 + |S_{13}|^2 = 1(d)$$

$$|S_{12}|^2 + |S_{23}|^2 = 1(e)$$

$$|S_{13}|^2 + |S_{23}|^2 + |S_{33}|^2 = 1(f)$$

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

**Linie fara pierderi adaptata
+
Poarta dezadaptata**

Proprietati de baza ale cuploarelor directionale

Circuite cu patru porti

$$(S_{ij} = S_{ji})$$

Reciproc

$$S_{ii} = 0$$

Adaptare simultana
la toate portile



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

$$(11) \quad S_{14}^* (|S_{13}|^2 - |S_{24}|^2) = 0$$

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

+

$$(14a) \quad |S_{12}|^2 + |S_{13}|^2 = 1$$

$$(14b) \quad |S_{12}|^2 + |S_{24}|^2 = 1$$

$$(14c) \quad |S_{13}|^2 + |S_{34}|^2 = 1$$

$$(14d) \quad |S_{24}|^2 + |S_{34}|^2 = 1$$

$$(15) \quad S_{12}^* S_{13} + S_{24}^* S_{34} = 0$$

$$\sum_k S_{ik} S_{kj}^* = \delta_{ij}$$

Fara pierderi

||



10 ecuatii

Cazul 1

$$(11) \text{ si } (13) > \quad S_{14} = S_{23} = 0 \Rightarrow [S] = \begin{bmatrix} 0 & S_{12} & S_{13} & 0 \\ S_{12} & 0 & 0 & S_{24} \\ S_{13} & 0 & 0 & S_{34} \\ 0 & S_{24} & S_{34} & 0 \end{bmatrix} \Leftrightarrow$$

Cuplor direccional

$$(14a) \text{ si } (14b) > \quad |S_{13}| = |S_{24}| \quad \text{Alegem:} \quad S_{12} = S_{34} = \alpha \quad S_{13} = \beta e^{j\theta} \quad S_{24} = \beta e^{j\phi}$$

$$(14b) \text{ si } (14d) > \quad |S_{12}| = |S_{34}|$$

$$(15) > \quad \theta + \phi = \pi \pm 2n\pi$$

Cuplor simetric $\theta = \phi = \pi/2$

Cuplor antisimetric $\theta = 0, \phi = \pi$

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

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

$$(14a) > \quad \alpha^2 + \beta^2 = 1$$

Cazul 2

$$(11) \text{ si } (13) > \left\{ \begin{array}{l} |S_{13}| = |S_{24}| \\ |S_{12}| = |S_{34}| \end{array} \right. \text{ Alegem: } S_{13} = S_{24} = \alpha \quad S_{12} = S_{34} = j\beta$$
$$(14a) > \alpha^2 + \beta^2 = 1$$

$$S_{13}^* S_{23} + S_{14}^* S_{24} = 0 \Rightarrow \alpha(S_{23} + S_{14}^*) = 0$$

$$\longrightarrow S_{14} = S_{23} = 0$$

Cuplor direccional

$$S_{12}^* S_{23} + S_{14}^* S_{34} = 0 \Rightarrow \beta(S_{14}^* - S_{23}) = 0$$



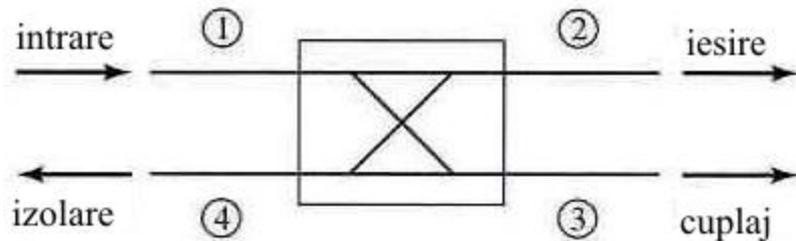
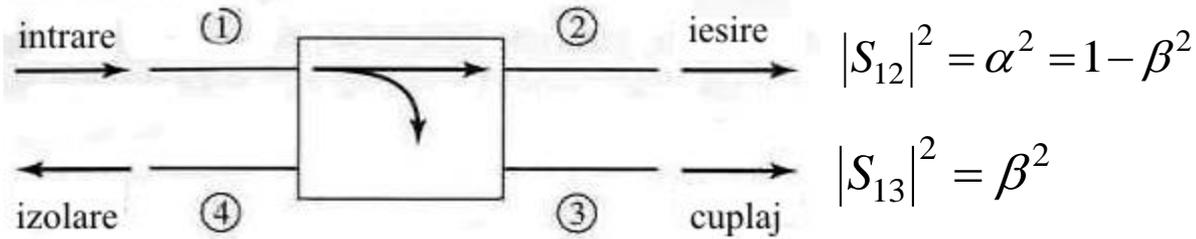
$$\alpha = \beta = 0 \quad \text{Caz banal}$$

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

CONCLUZIE

Orice circuit cu patru porti,
reciproc, fara pierderi si adaptat la toate portile
este un cuplor directiona

Cuplor directional



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

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

$$\text{Izolare} = I = 10 \log \left(\frac{P_1}{P_4} \right) = -20 \log |S_{14}| \text{ dB}$$

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

Cuplor hibrid

Cuplorul hibrid este cuplorul direccional de 3 dB

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

Cuplor hibrid in cuadratura

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

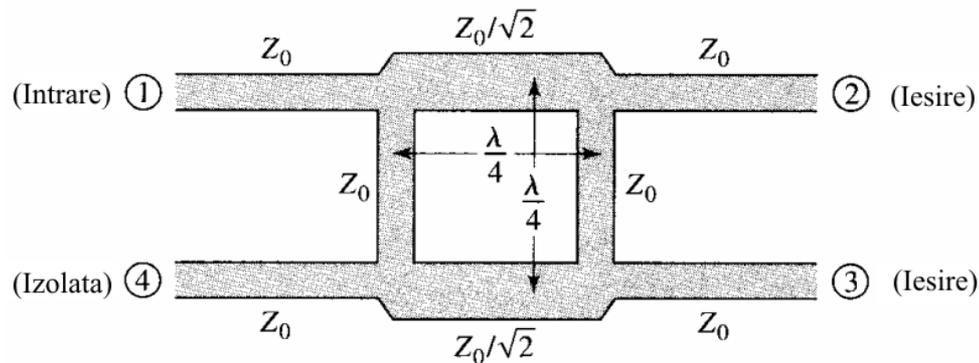
$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix}$$

Cuplor hibrid in inel

$$(\theta = 0, \phi = \pi)$$

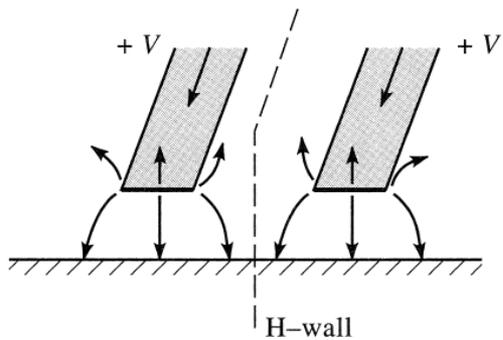
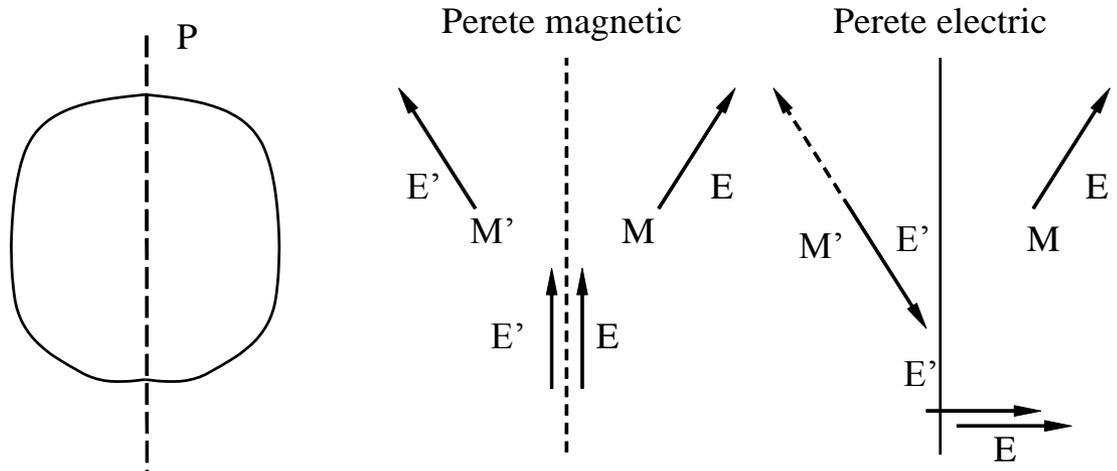
$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix}$$

Cuplorul hibrid în cuadratură (90°)

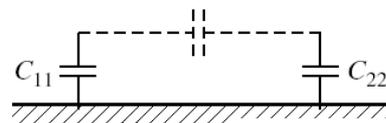


$$[S] = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}$$

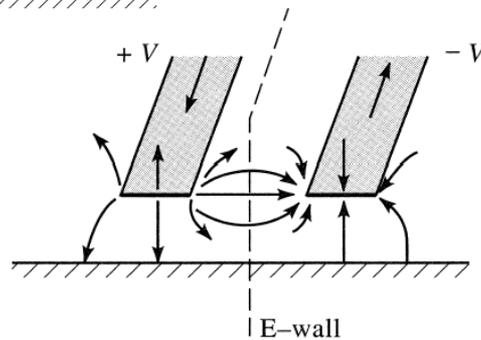
Simetria fizică se transformă în simetrie sau antisimetrie a câmpului electromagnetic



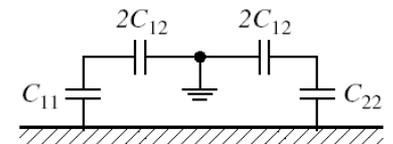
⇒



(a)

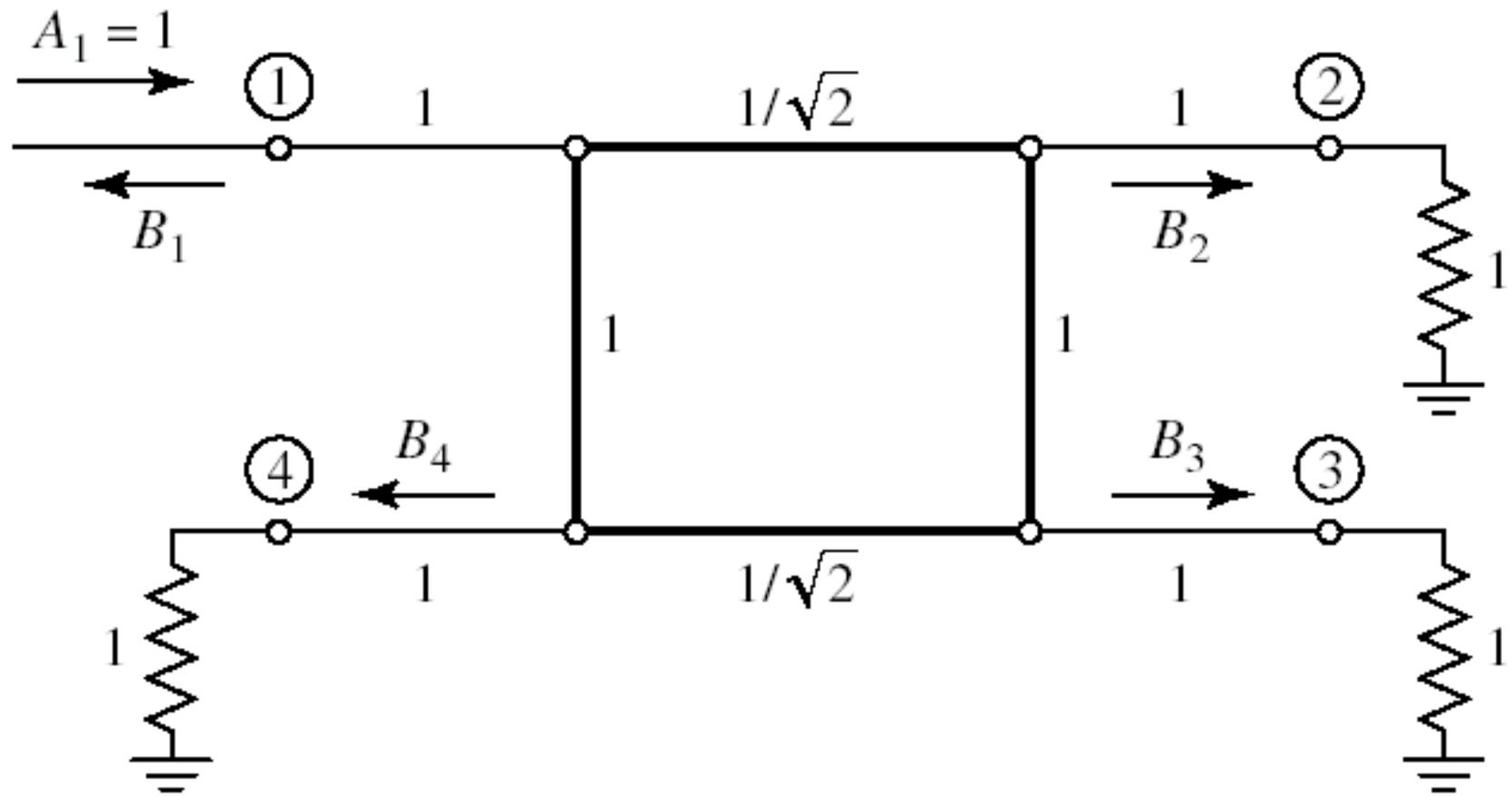


⇒

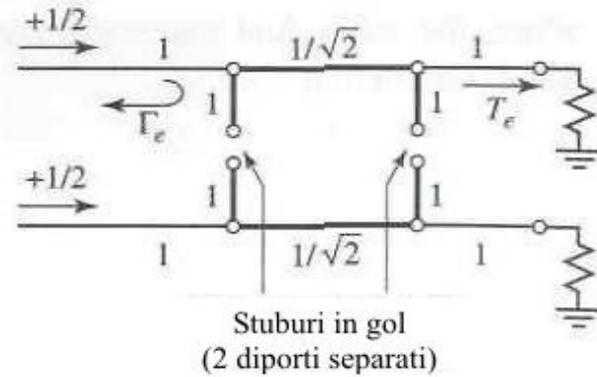
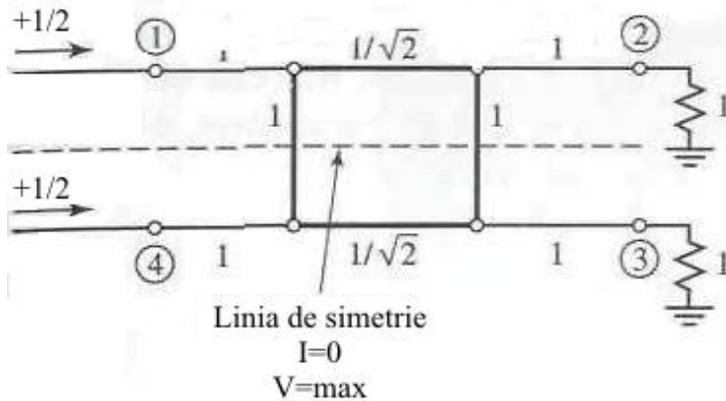


(b)

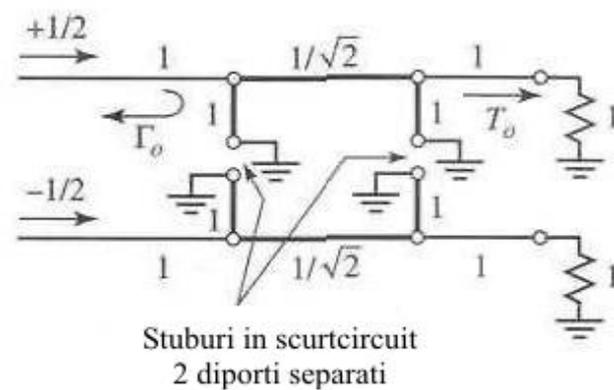
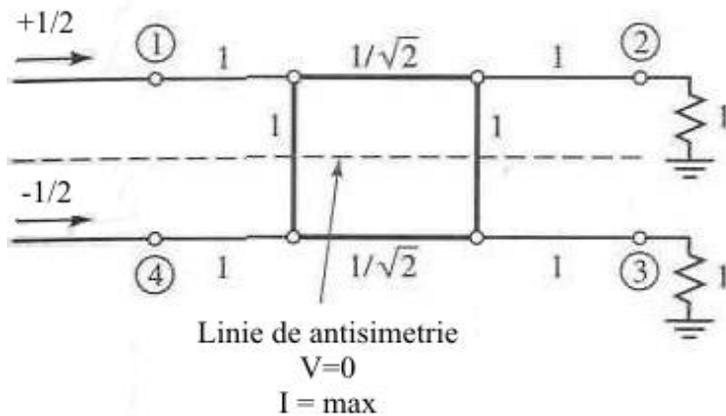
Analiza pe modul par-impair



Analiza pe modul par-impair



(a)



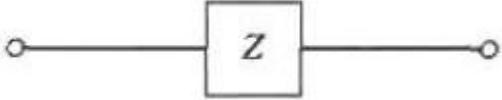
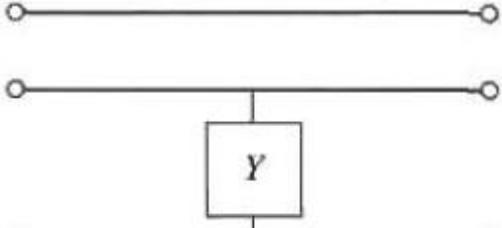
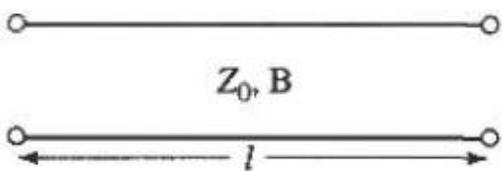
(b)

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

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

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

$$b_4 = \frac{1}{2}\Gamma_e - \frac{1}{2}\Gamma_o$$

Circuit	ABCD Parameters	
	$A = 1$ $C = 0$	$B = Z$ $D = 1$
	$A = 1$ $C = Y$	$B = 0$ $D = 1$
	$A = \cos \beta l$ $C = jY_0 \sin \beta l$	$B = jZ_0 \sin \beta l$ $D = \cos \beta l$

Linie de transmisie cu impedanta de terminatie

$$\begin{aligned}
 Z_{in} &= Z_0 \frac{(Z_L + Z_0)e^{j\beta l} + (Z_L - Z_0)e^{-j\beta l}}{(Z_L + Z_0)e^{j\beta l} - (Z_L - Z_0)e^{-j\beta l}} \\
 &= Z_0 \frac{Z_L \cos \beta l + jZ_0 \sin \beta l}{Z_0 \cos \beta l + jZ_L \sin \beta l} \\
 &= Z_0 \frac{Z_L + jZ_0 \tan \beta l}{Z_0 + jZ_L \tan \beta l} .
 \end{aligned}$$

scurtcircuit

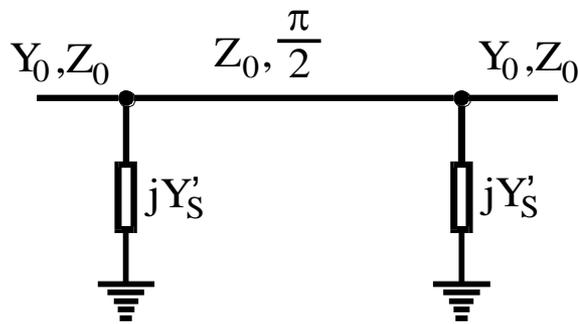
$$Z_{in} = jZ_0 \tan \beta l,$$

gol

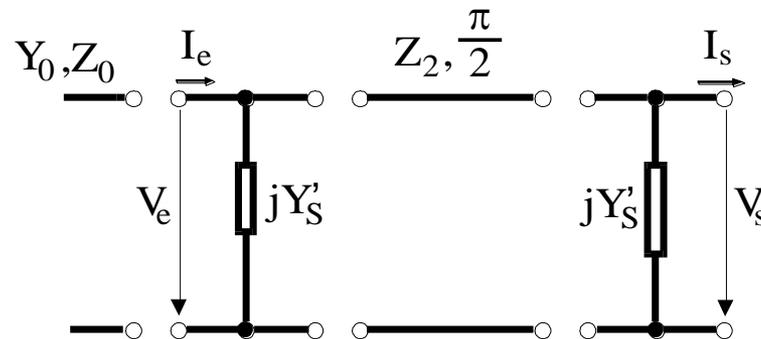
$$Z_{in} = -jZ_0 \cot \beta l,$$

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)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$b_3 = -C$$

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

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

Exemplu

Proiectați un cuplor în scară pe impedanța caracteristică de 50Ω , și reprezentați 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

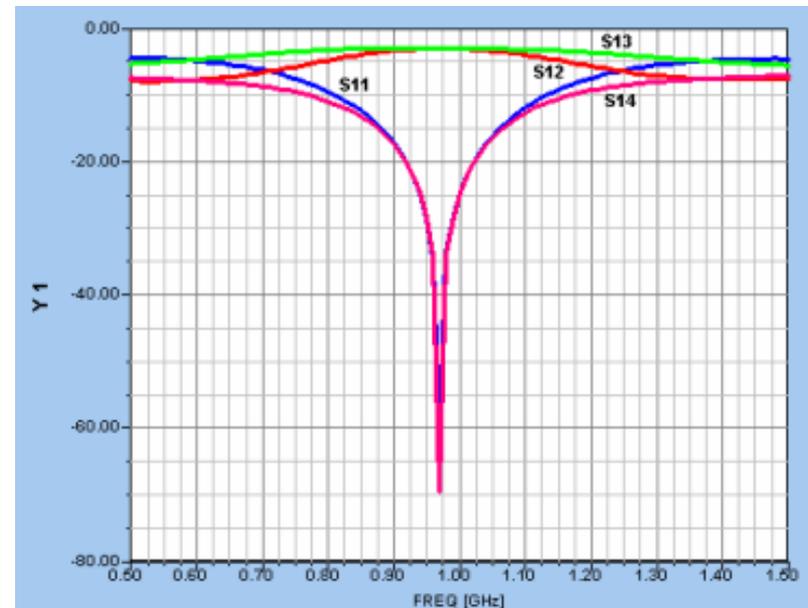
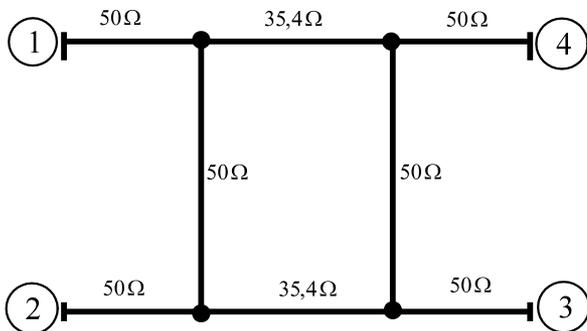
Un cuplor în scară cu $C = 3\text{dB}$, are $C = 1/\sqrt{2}$

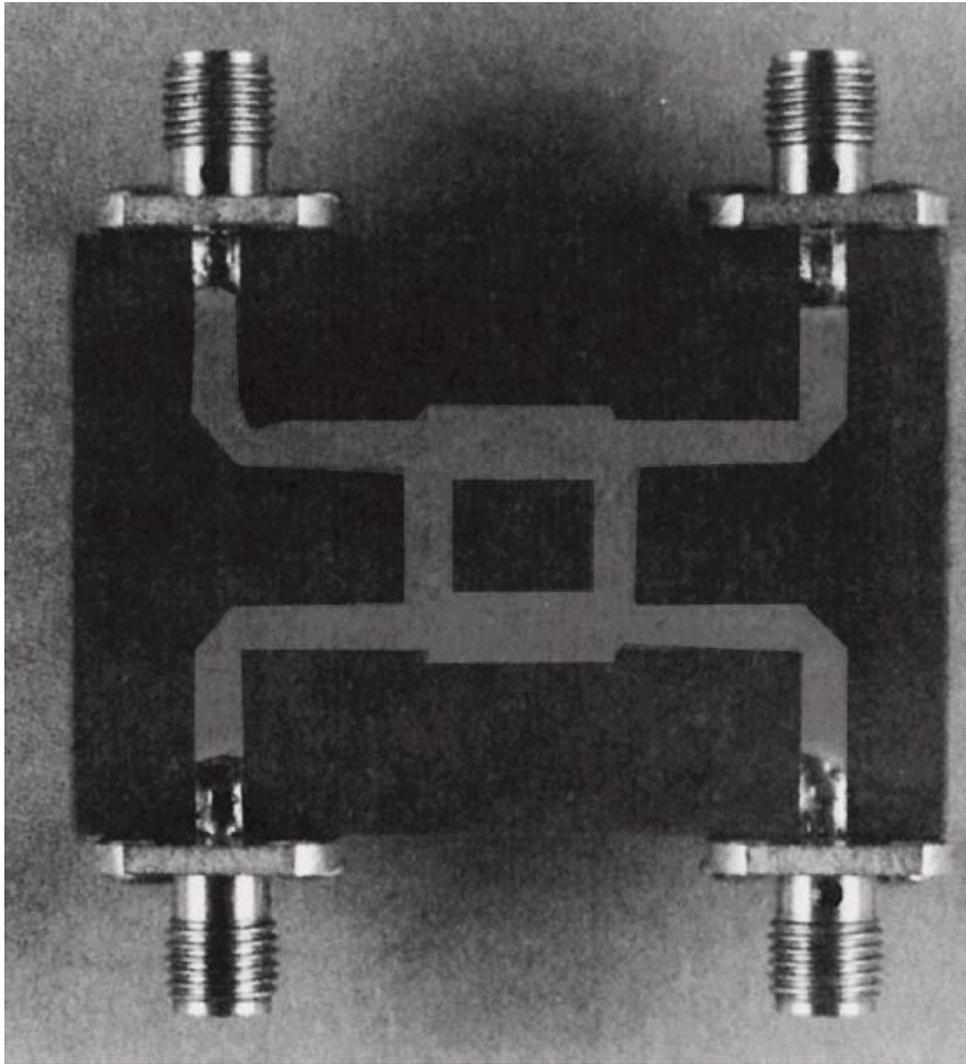
. Atunci $y_2 = \sqrt{2}$ și $y_1 = 1$

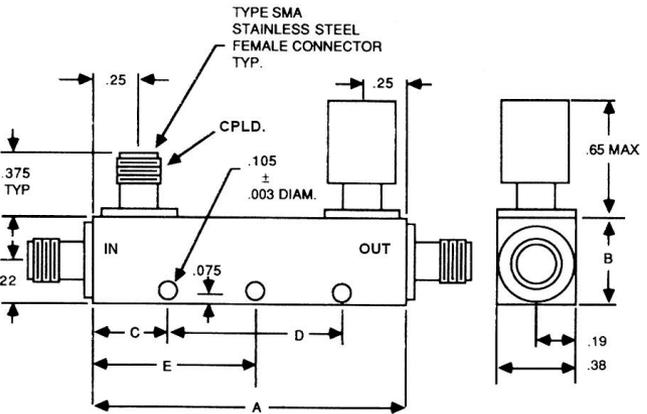
. Astfel matricea S din relația (&.47) devine cea din relația (&.38). În plus, pentru $Z_0 = 50\Omega$

, impedanțele caracteristice ale liniilor cuplorului vor fi:

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

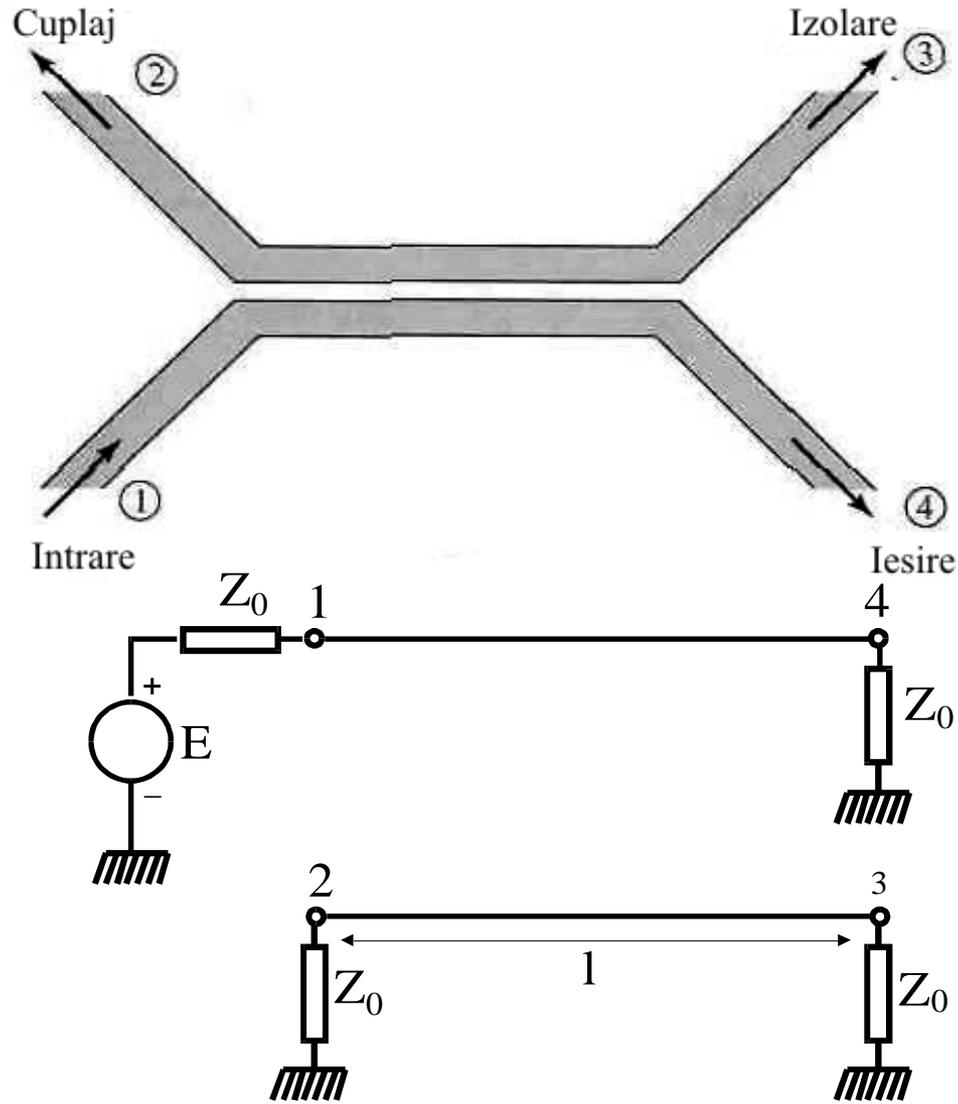




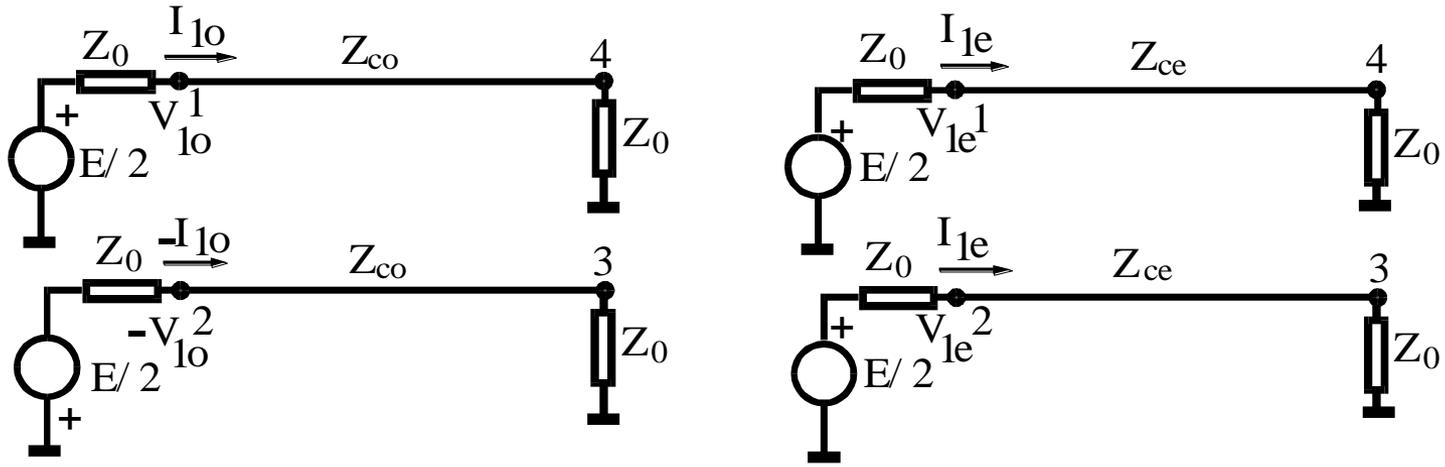


Model No.	Frequency Range (Ghz)	Coupling † (dB)	Freq. Sens. (dB)	Insertion Loss (dB)		Directivity (dB min.)	VSWR max.	
				Excl. Cpld Pwr	True		Primary Line	Secondary Line
MDC6223-6	0.5-1.0	6 ±1.00	±0.60	0.20	1.80	25	1.15	1.15
MDC6223-10	0.5-1.0	10 ±1.25	±0.75	0.20	0.80	25	1.10	1.10
MDC6223-20	0.5-1.0	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

Cuplorul prin proximitate

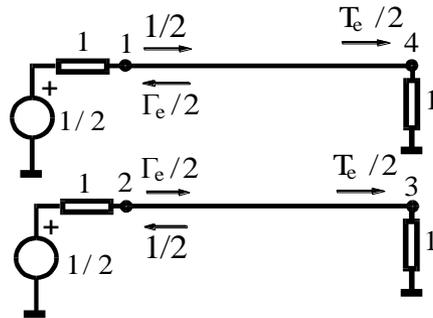


Adaptarea cuplorului prin proximitate

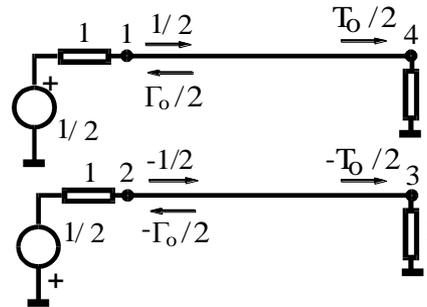


$$\begin{cases} Z_{ce} Z_{co} = Z_0^2 \\ \theta_e = \theta_o \end{cases}$$

Directivitatea și coeficientul de cuplaj ale cuplorului prin proximitate



modul par



modul impar

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

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

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

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

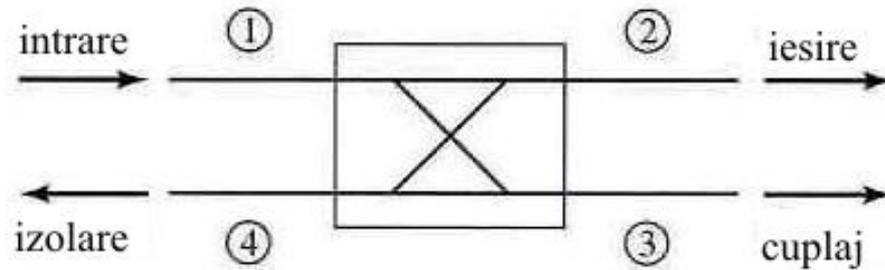
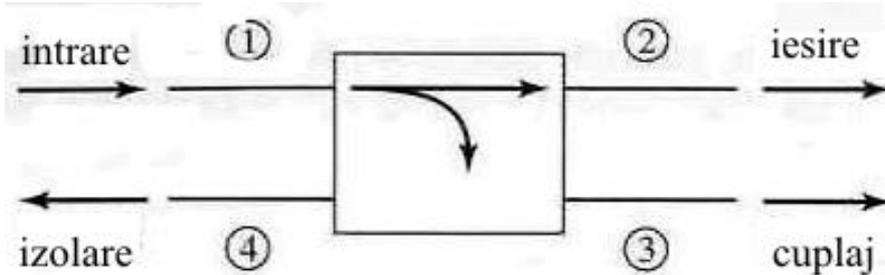
$$b_4 = \frac{1}{2}(T_e + T_o) = \frac{\sqrt{1-C^2}}{\cos(\theta)\sqrt{1-C^2} + j\sin(\theta)}$$

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

$$\theta = \pi/2$$

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

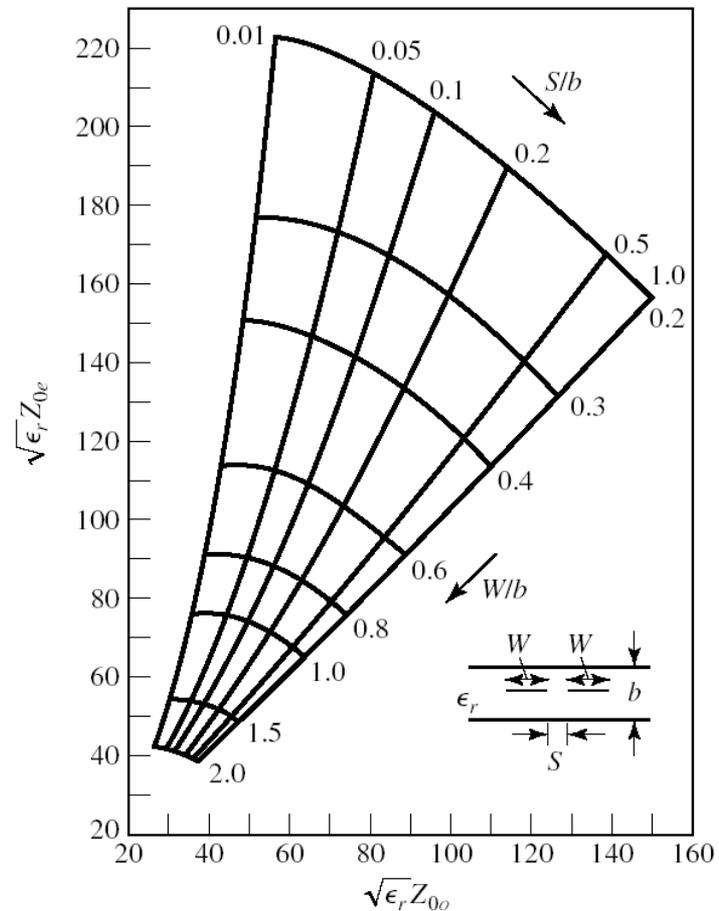
Cuplor prin proximitate



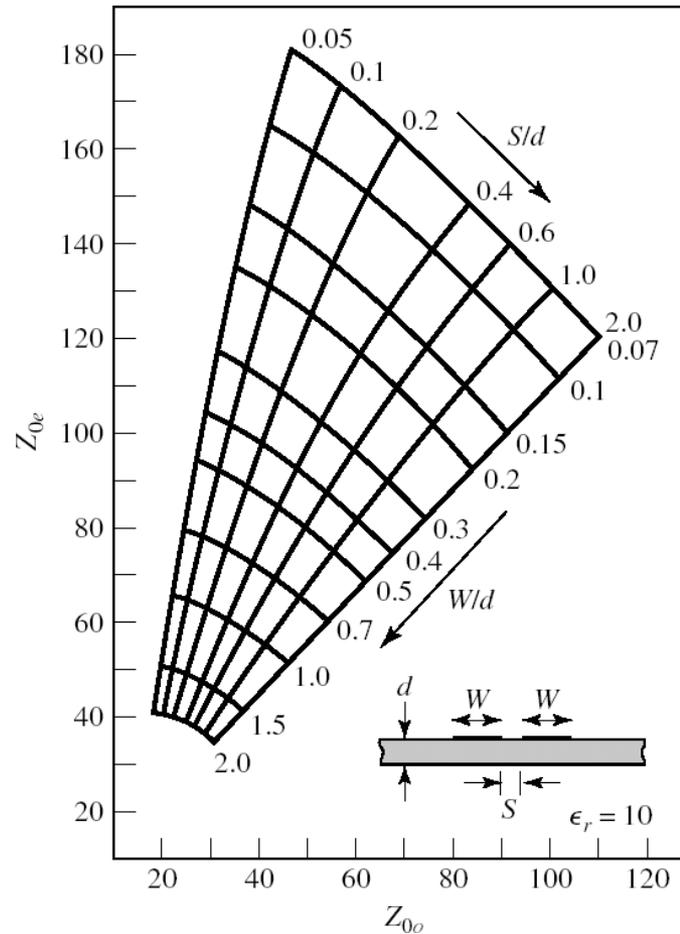
$$[S] = -j \cdot \begin{bmatrix} 0 & \sqrt{1-C^2} & jC & 0 \\ \sqrt{1-C^2} & 0 & 0 & jC \\ jC & 0 & 0 & \sqrt{1-C^2} \\ 0 & jC & \sqrt{1-C^2} & 0 \end{bmatrix}$$

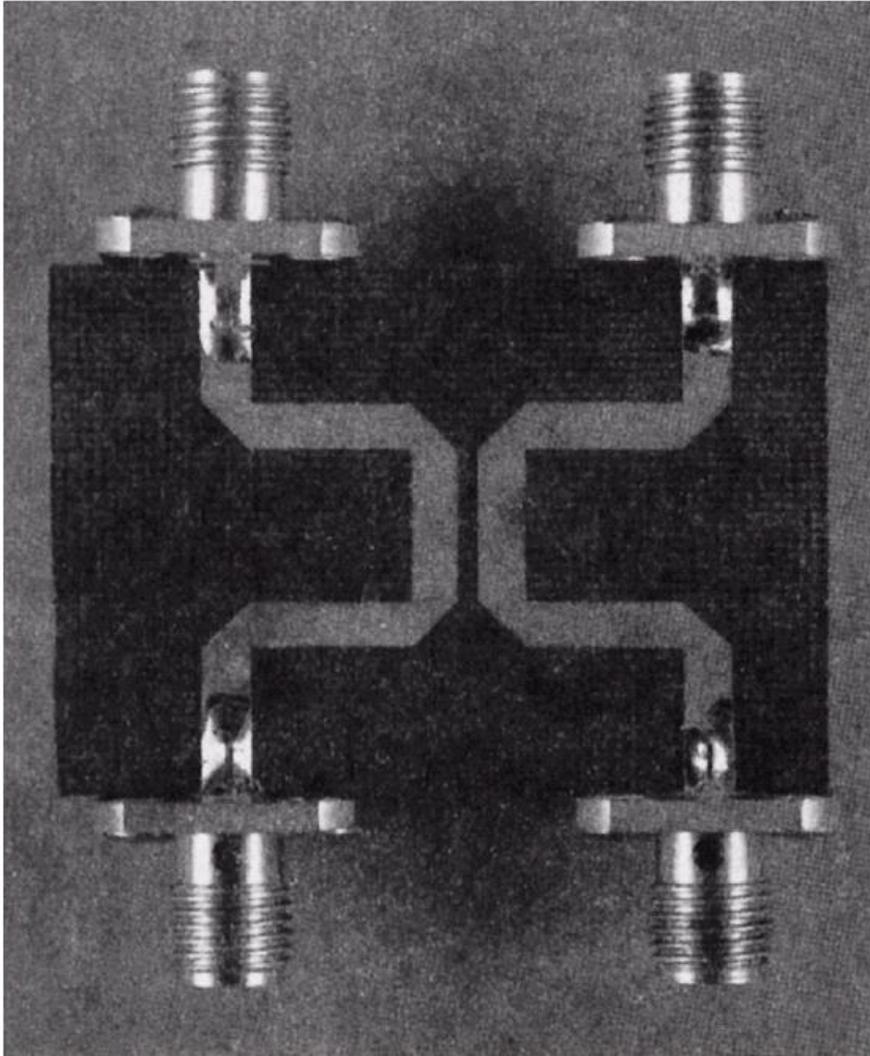
$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix}$$

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 $\epsilon_r = 10$.





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 permitivitate electrică relativă de 2.56, pe o impedanță de 50 Ω , la frecvența de 3 GHz. Reprezentați cuplajul și directivitatea între 1 și 5 GHz.

Soluție

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

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

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

TRL - Edge-coupled Symmetric Stripline (CPL)1

File Edit View Structure Window Help

Edge-coupled Symmetric Stripline (CPL)1

Dimensions

W 1.14072

S 0.51747

P 15.6142

Electrical

Z0 50

K 20

E 90

Zo 45.2267

Ze 55.2771

Units

Dimension mm

Frequency GHz

Impedance Ohm

Electrical Length Deg

Resistivity uOhm*cm

Frequency 3 Analysis Auto Calculate Off ! Reset All ! Synthesis 3

Substrate

Required

B 1.58 ER 2.56

Optional

TAND 0

Metallization

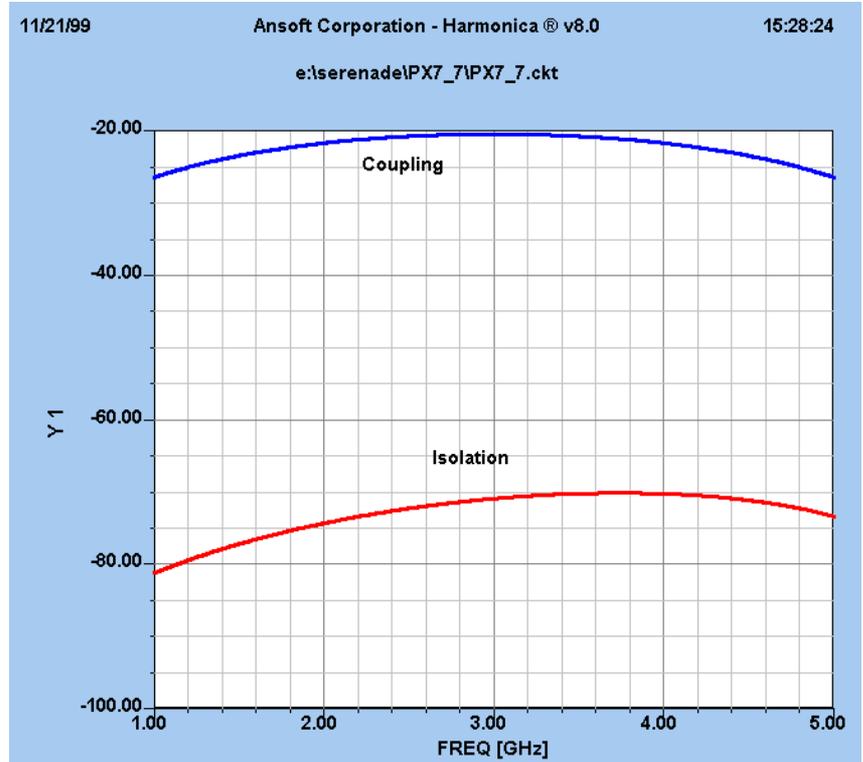
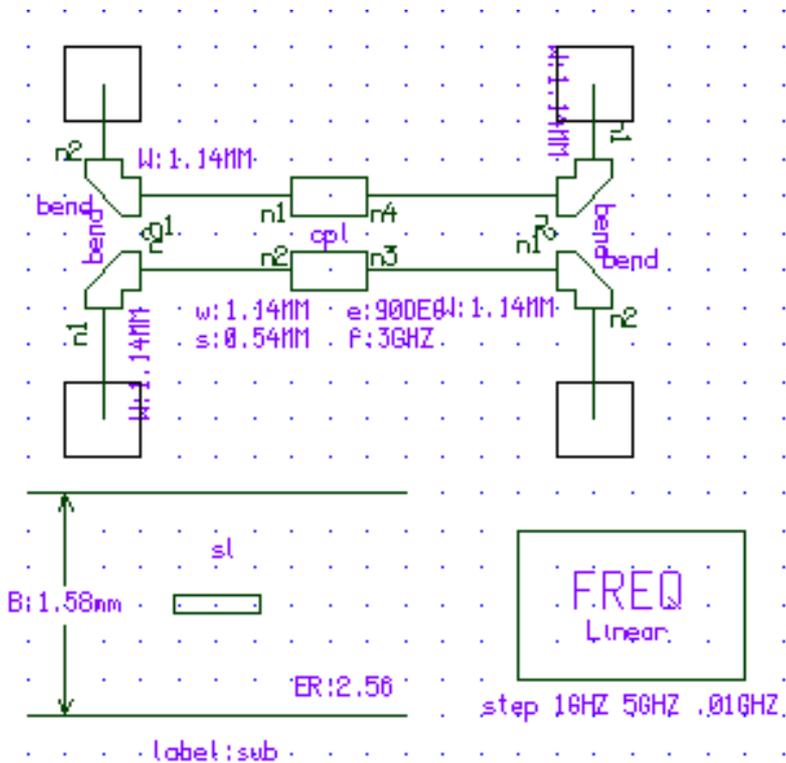
Layers	Metal Name	Code	Resistivity	Thickness	
Bottom	*None*				Reset
Middle	*None*				Reset
Top	*None*				Reset

RGH 0 Add new metal

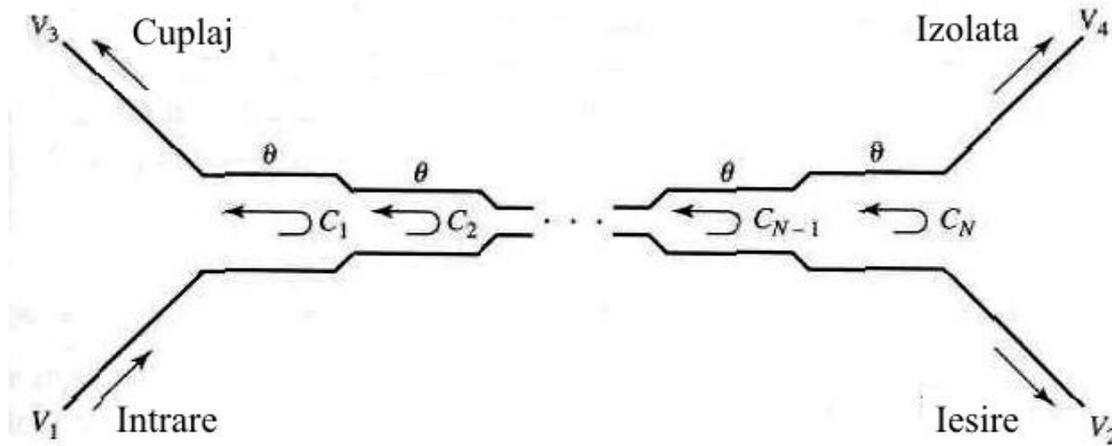
For Help, press F1

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

Simulare



Cuplor 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 cuplor cu trei secțiuni, avînd 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

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

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

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

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

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

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

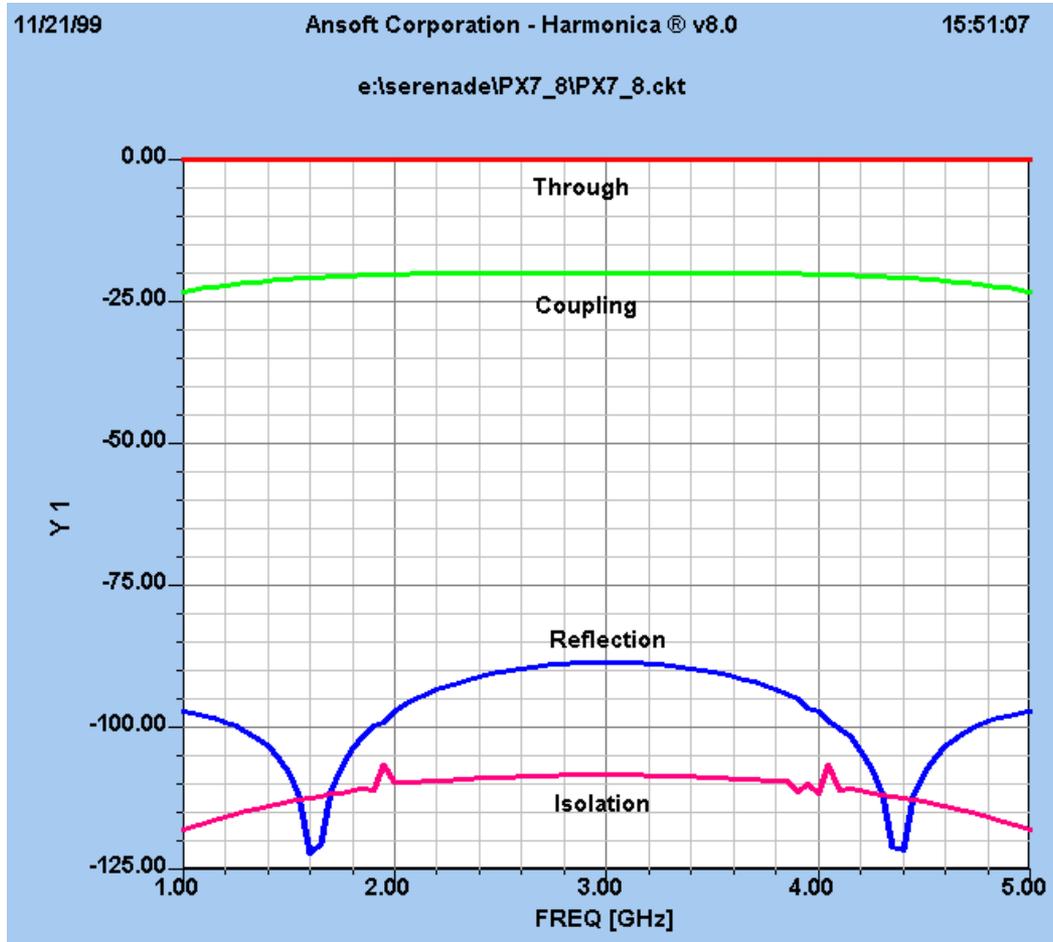
$$Z_{0e}^1 = Z_{0e}^3 = 50 \sqrt{\frac{1.0125}{0.9875}} = 50.63 \Omega$$

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

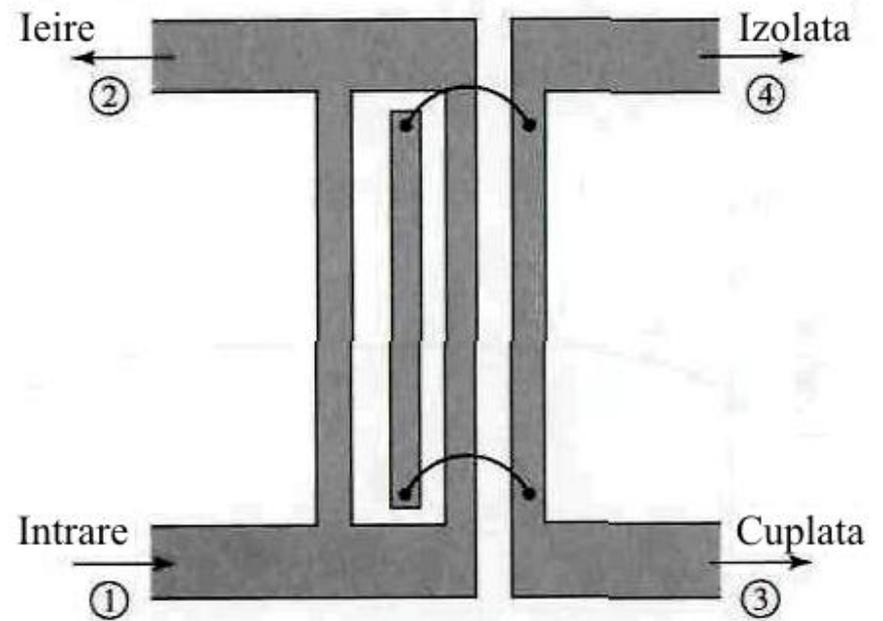
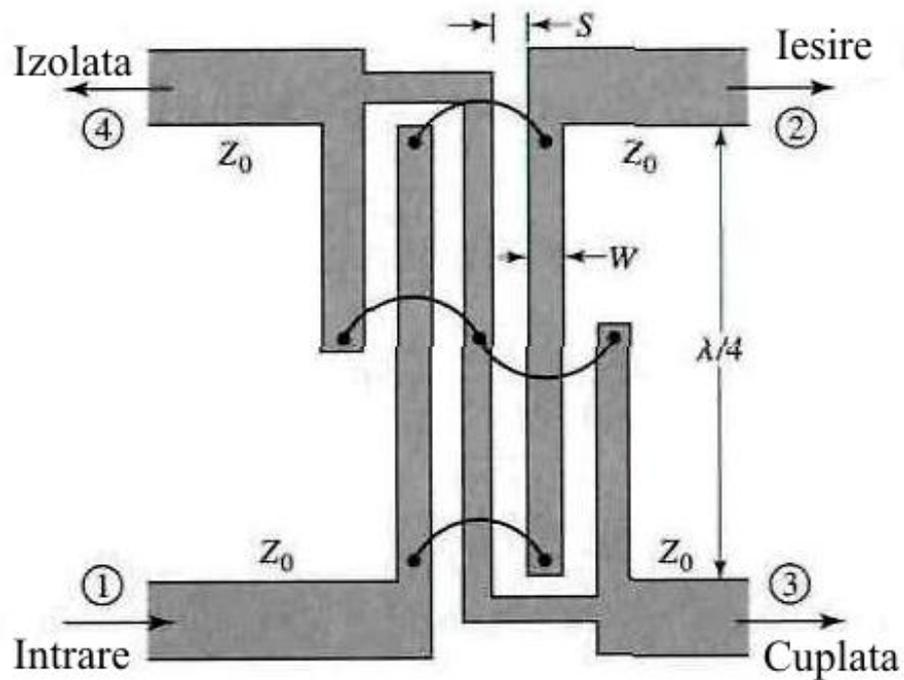
$$Z_{0e}^2 = 50 \sqrt{\frac{1.125}{0.875}} = 56.69 \Omega$$

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

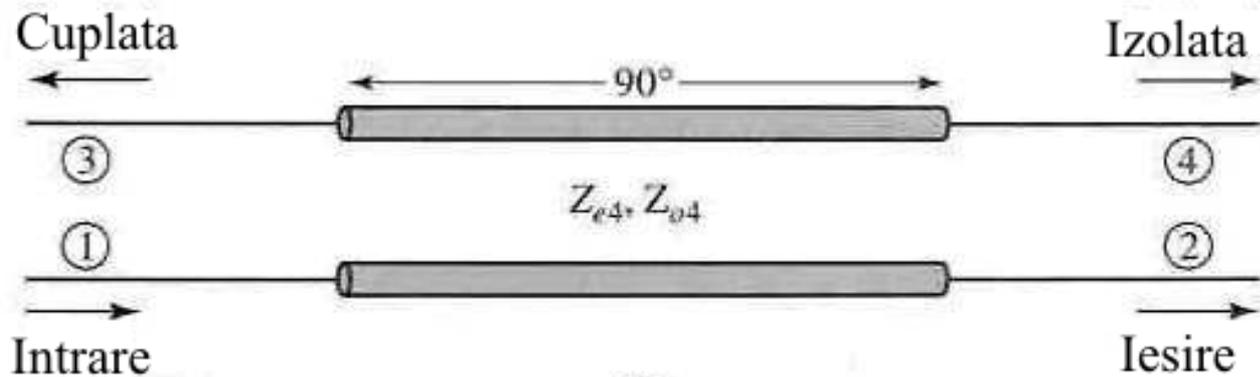
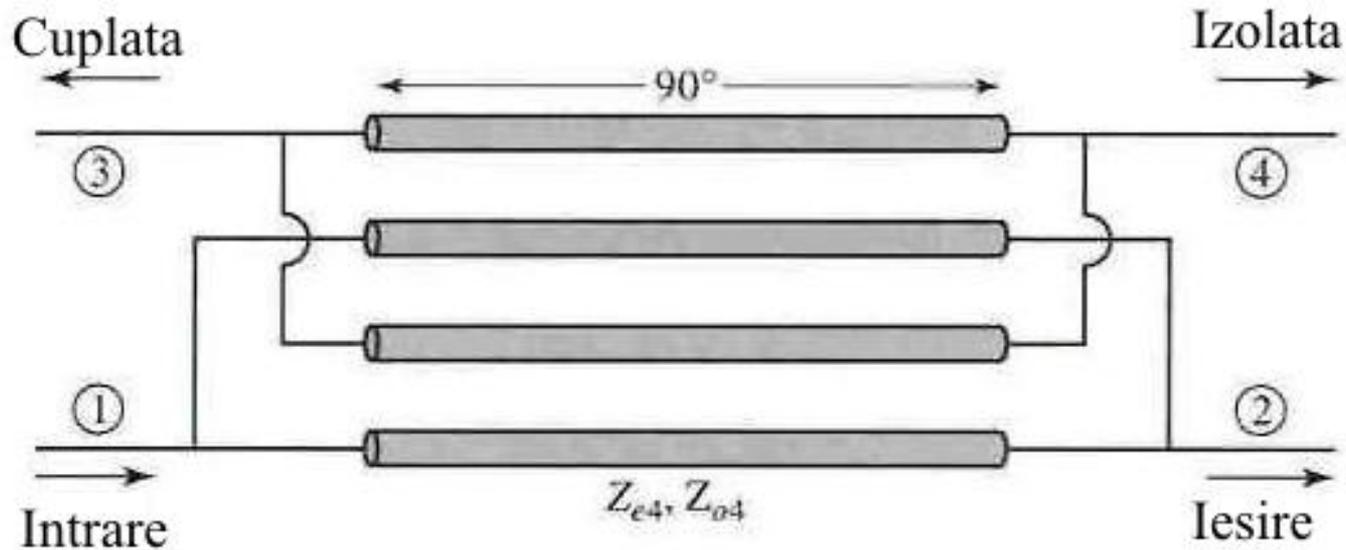
Simulare



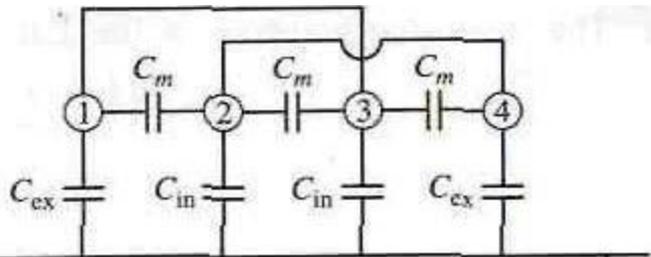
Cuplorul Lange



Cuplor Lange



Modelul de circuit



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

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

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

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

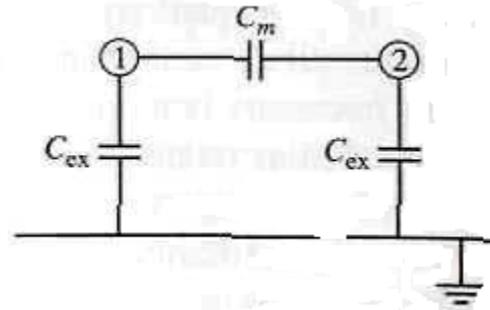
$$Z_{o4} = \frac{1}{vC_{o4}}$$

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

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

$$Z_{e4} = Z_{0e} \frac{Z_{0e} + Z_{0o}}{3Z_{0o} + Z_{0e}}$$

$$Z_{o4} = Z_{0o} \frac{Z_{0e} + Z_{0o}}{3Z_{0e} + Z_{0o}}$$



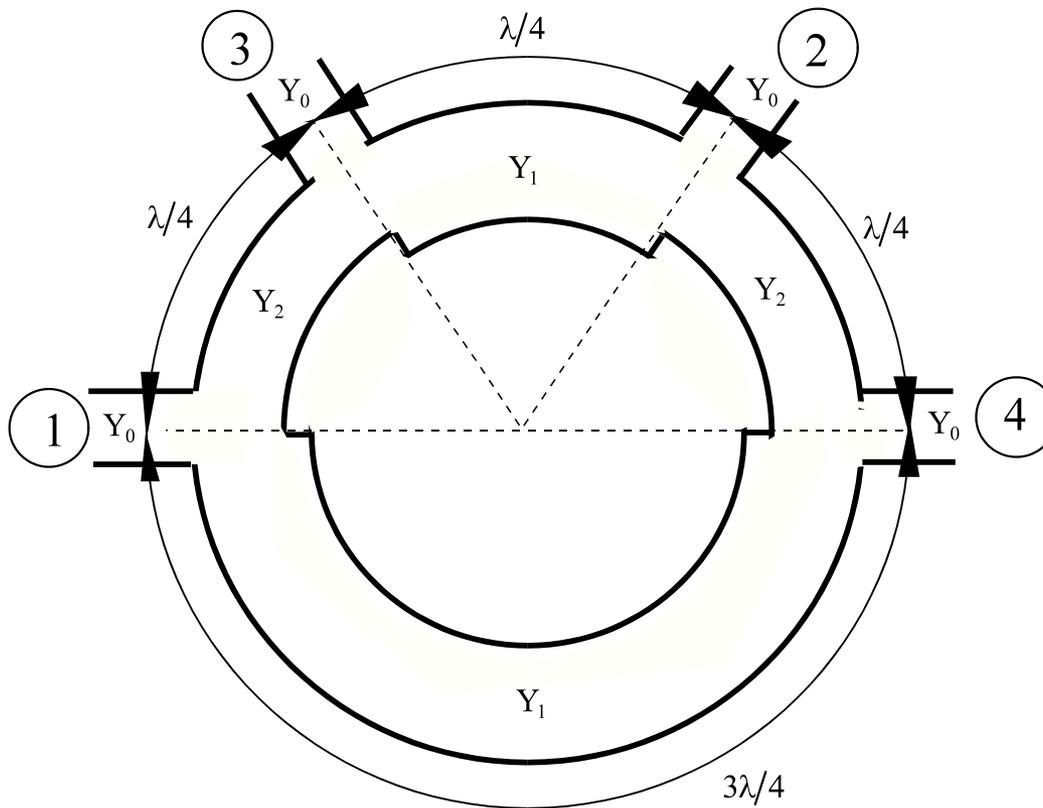
$$C_o = C_{ex} + 2C_m$$

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

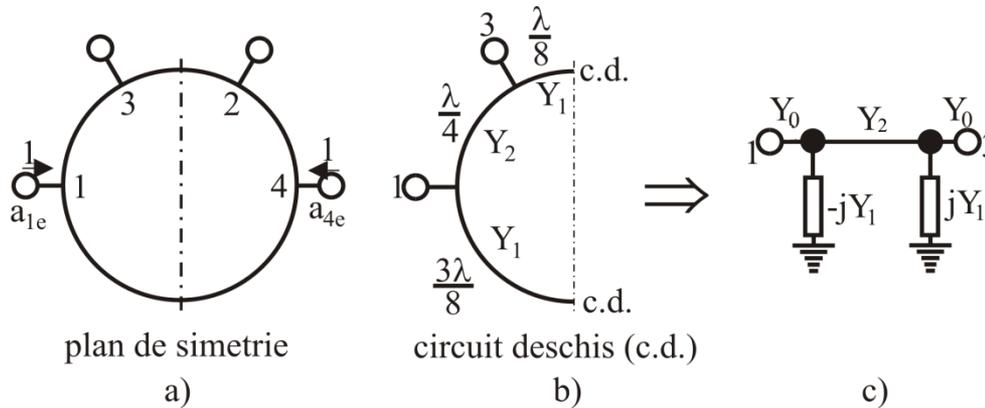
$$C = \frac{Z_{e4} - Z_{o4}}{Z_{0e} + Z_{0o}} = \frac{3(Z_{0e}^2 - Z_{0o}^2)}{4C(3 + \sqrt{9 - 8C}) + 2C\sqrt{(1-C)/(1+C)}} \frac{Z_{0e} + Z_{0o}}{Z_{0e} + Z_{0o}}$$

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

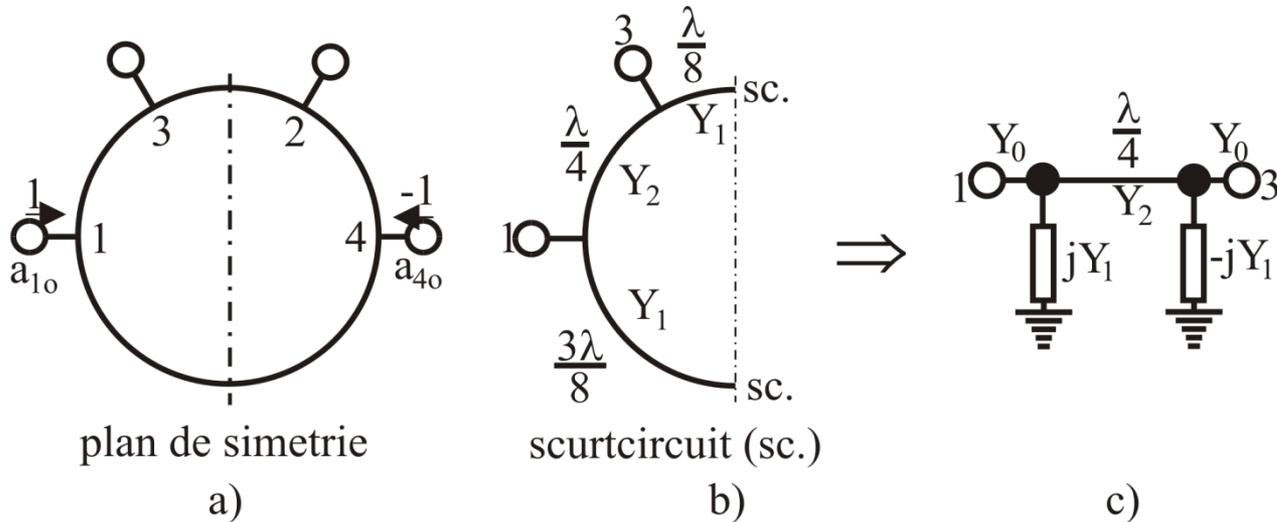
Cuplorul in inel



Analiza cuplorului in inel



Modul par



Modul impar

Analiza cuplorului in inel

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

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

Pentru modul par:

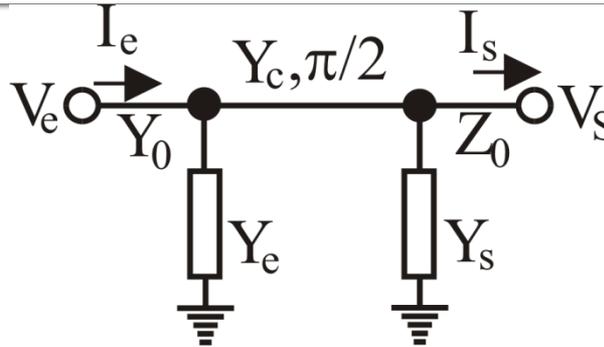
$$y_e = -jy_1$$

$$y_s = jy_1$$

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

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

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



Conditia de adaptare

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

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

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

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

Pe modul impar:

$$y_e = jy_1$$

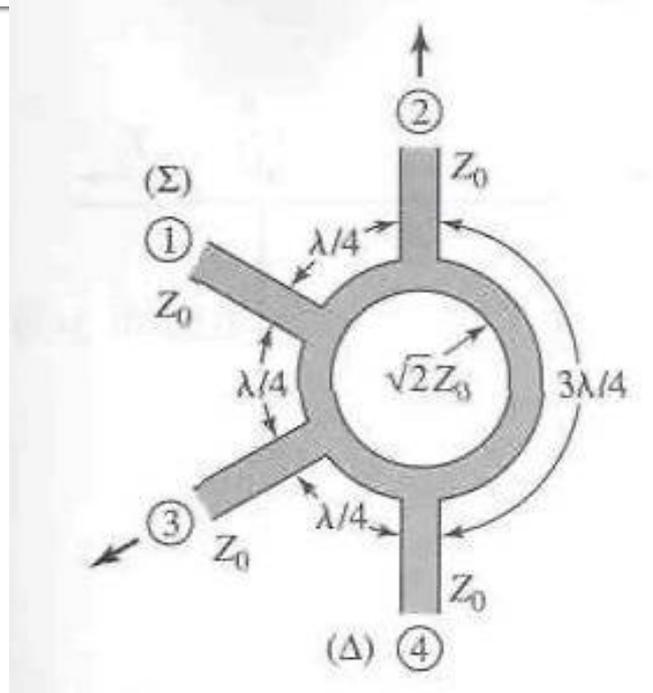
$$y_s = -jy_1$$

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

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

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

Cuplorul in inel



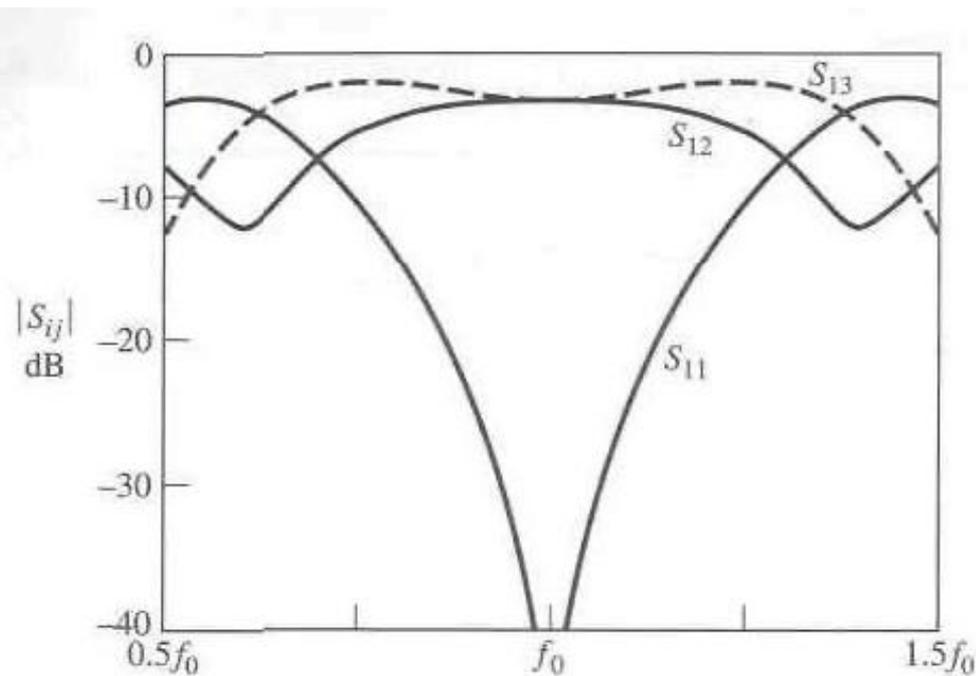
$$[S] = \begin{bmatrix} 0 & -jy_2 & -jy_1 & 0 \\ -jy_2 & 0 & 0 & jy_1 \\ -jy_1 & 0 & 0 & -jy_2 \\ 0 & jy_1 & -jy_2 & 0 \end{bmatrix} = -j \begin{bmatrix} 0 & \alpha & \beta & 0 \\ \alpha & 0 & 0 & -\beta \\ \beta & 0 & 0 & \alpha \\ 0 & -\beta & \alpha & 0 \end{bmatrix}$$

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

Proiectarea și performanța unui cuplor în inel

Proiectați un cuplor în inel pe impedanța de 50Ω și reprezentați mărimea parametrilor S între 0.5 și 1.5 din frecvența centrală.

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



Contact

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