

Curs 12

2017/2018

Dispozitive și circuite de microunde pentru radiocomunicații

Documentatie

- RF-OPTO
 - <http://rf-opto.etti.tuiasi.ro>
- Fotografie
 - ~~de trimis prin email: rdamian@etti.tuiasi.ro~~
 - necesara la laborator/curs

Software

- ADS ~~2016~~2017
- EmPro ~~2015~~2017
- pe baza de IP din exterior



Date:

Grupa	5601 (2017/2018)
Specializarea	Master Retele de Comunicatii
Marca	857

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Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TMPAW			Tehnici moderne de proiectare a aplicatiilor web			
	N	29/05/2017	Nota finala	10	-	

Nume

Email

Cod de verificare

Trimite

Software

Advanced Design System Premier High-Frequency and High Speed Design Platform

2017

 **KEYSIGHT**
TECHNOLOGIES

Advanced Design System Premier High-Frequency and High Speed Design Platform

2016.01

 **KEYSIGHT**
TECHNOLOGIES

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Advanced Design System

Select a product license

You have more than one product license.

Description

▶ **ADS Inclusive**

▶ **GoldenGate All In**

Update Availability

Legend:  **License available**  License in use or not available

ADS Inclusive

▶ **License is available**

Number of licenses: 50

Used: 3

Version: 2018.07

Expires: 30-jul-

License Setup Wizard for Advanced Design System 2016.01

Specify Remote License Server

Enter the name of the network license server you wish to add or replace.

Advanced Design System 2016.01

Enter the network license server name (e.g., 27001 or host_name.t_number@host_name)

Network license server name

(e.g., 27001)

[What is a network license server?](#)

[How do I know which network license server to use?](#)

[How do I specify a network license server name?](#)

[Can I find out the network license server name from the license file?](#)

Examining your license server...



Cancel

Clear

Details

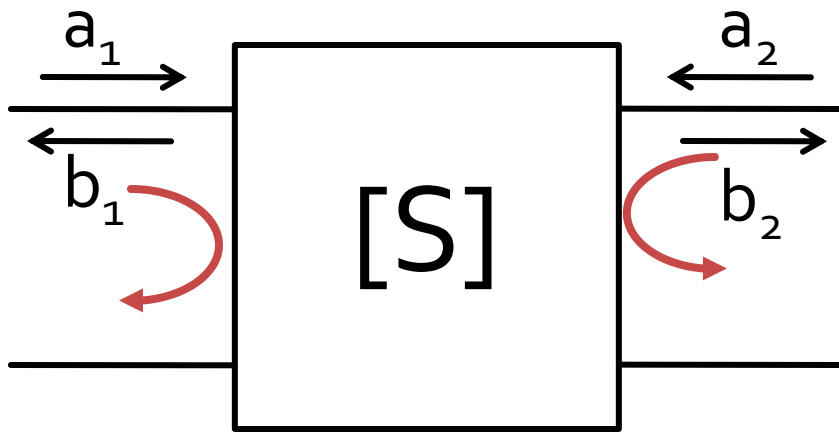
< Back

Next >

Exit

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

Matricea S (repartitie)

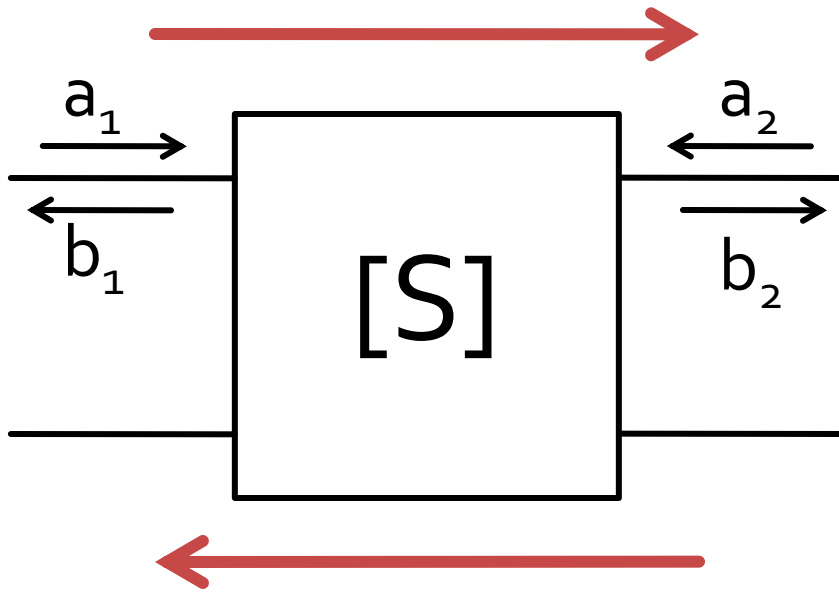


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

Matricea S (repartitie)

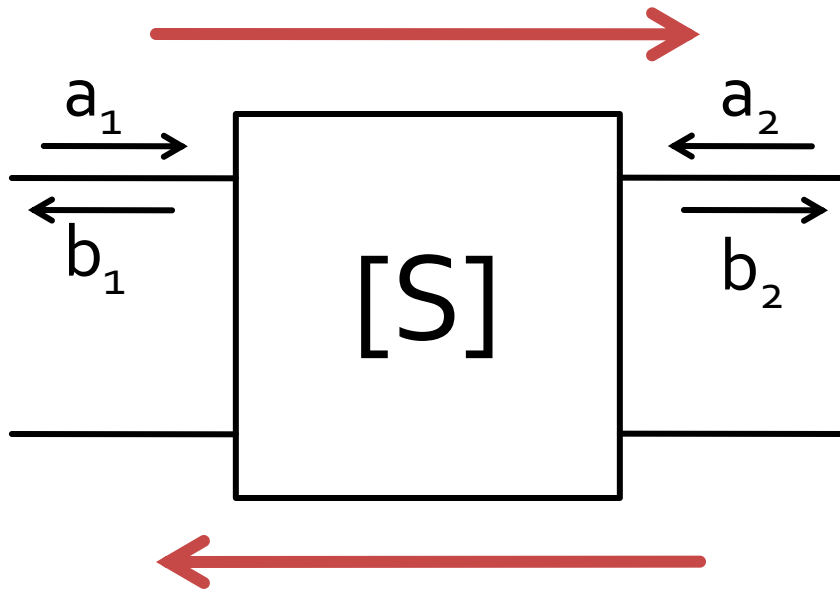


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

- 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

Adaptarea de impedanță

Diagrama Smith

Diagrama Smith

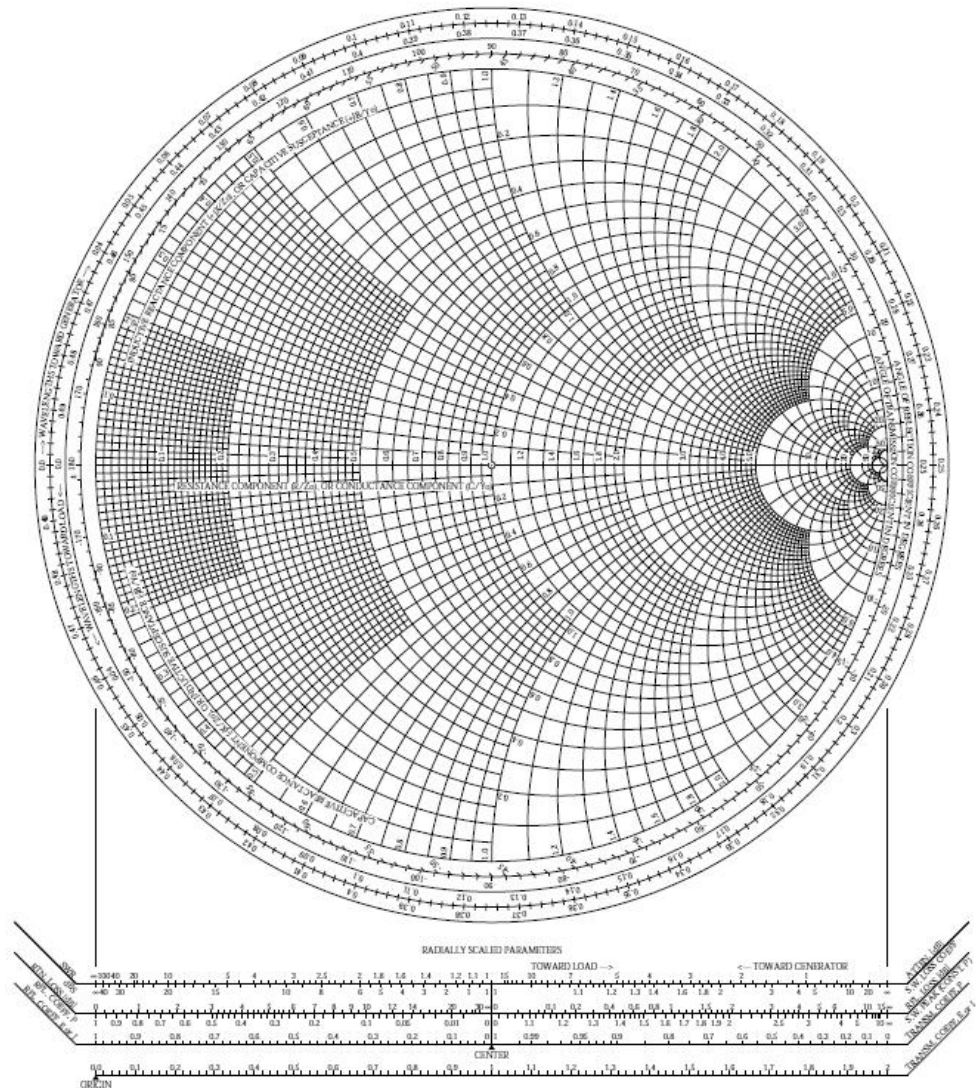
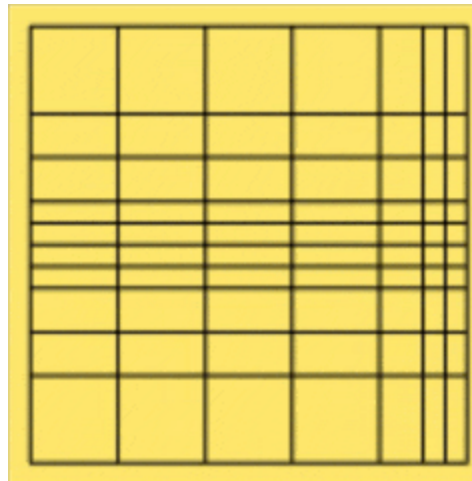
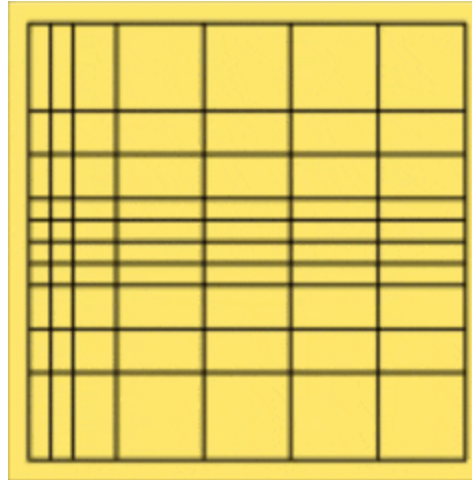
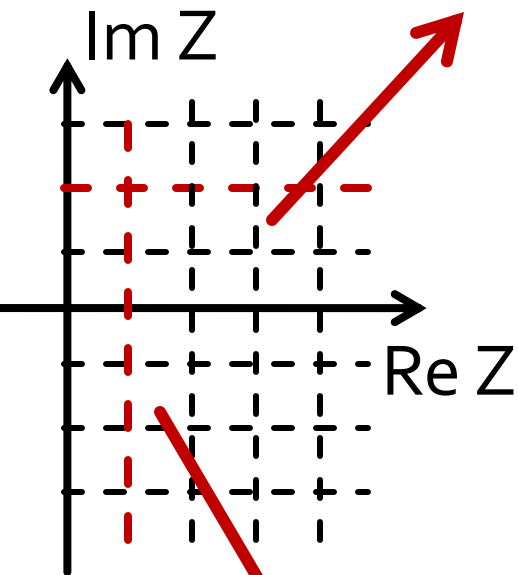


Diagrama Smith

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1}$$



$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{Y_0 - Y_L}{Y_0 + Y_L} = \frac{1 - y_L}{1 + y_L}$$

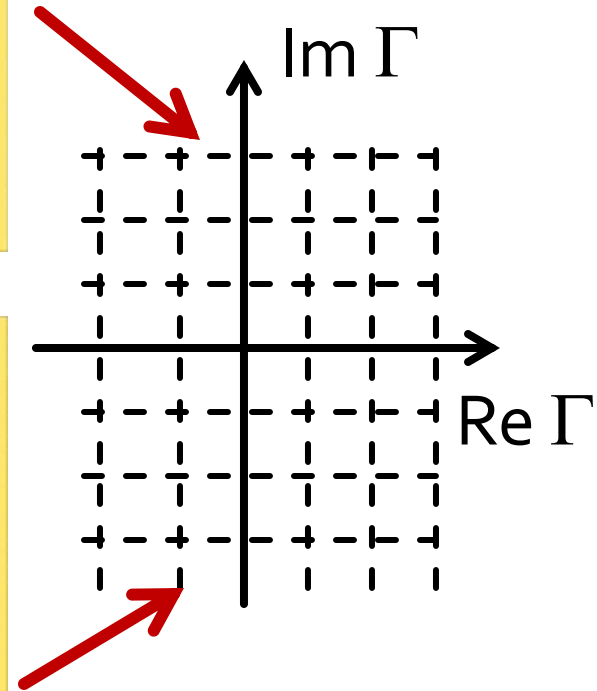
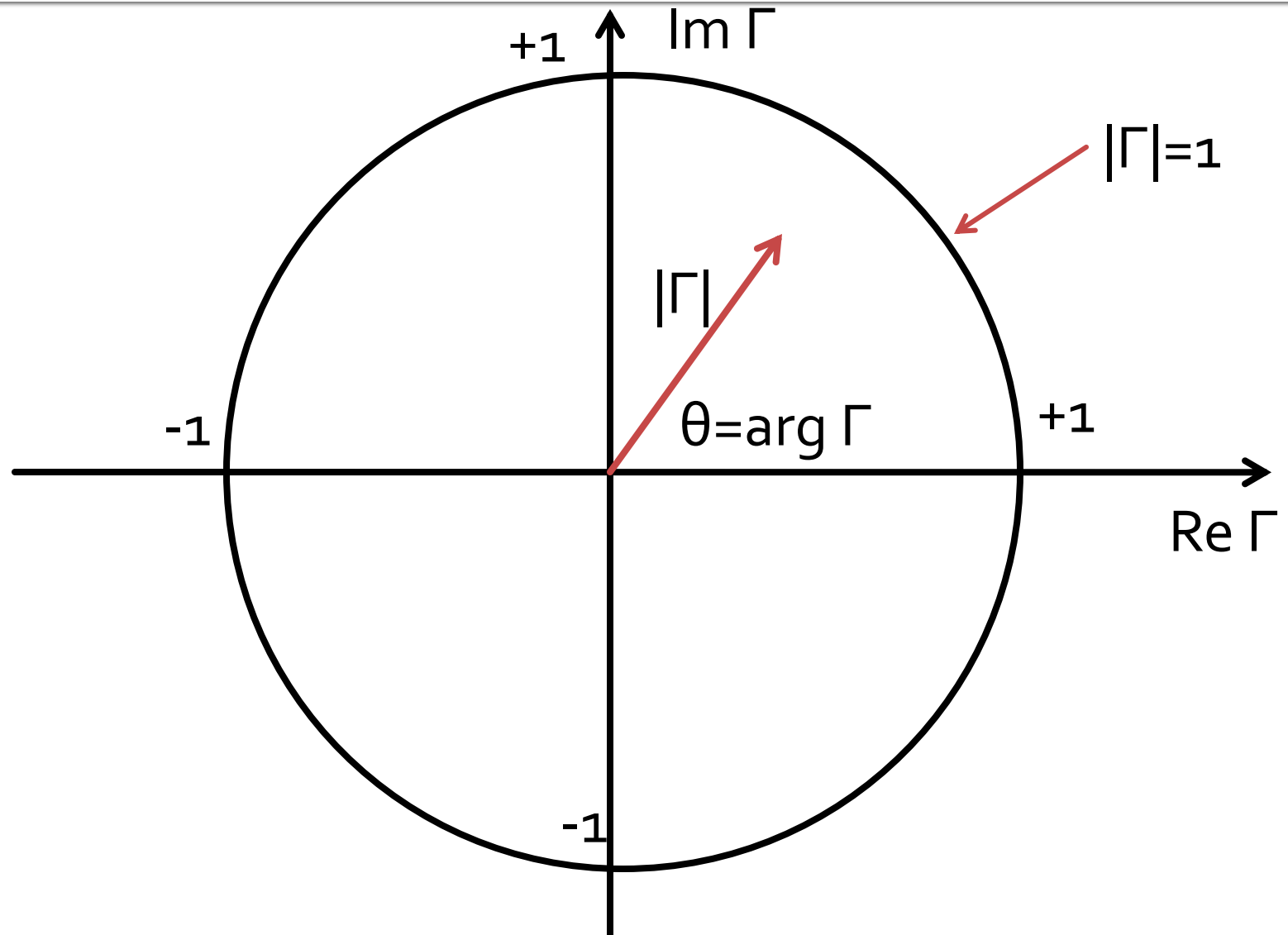


Diagrama Smith

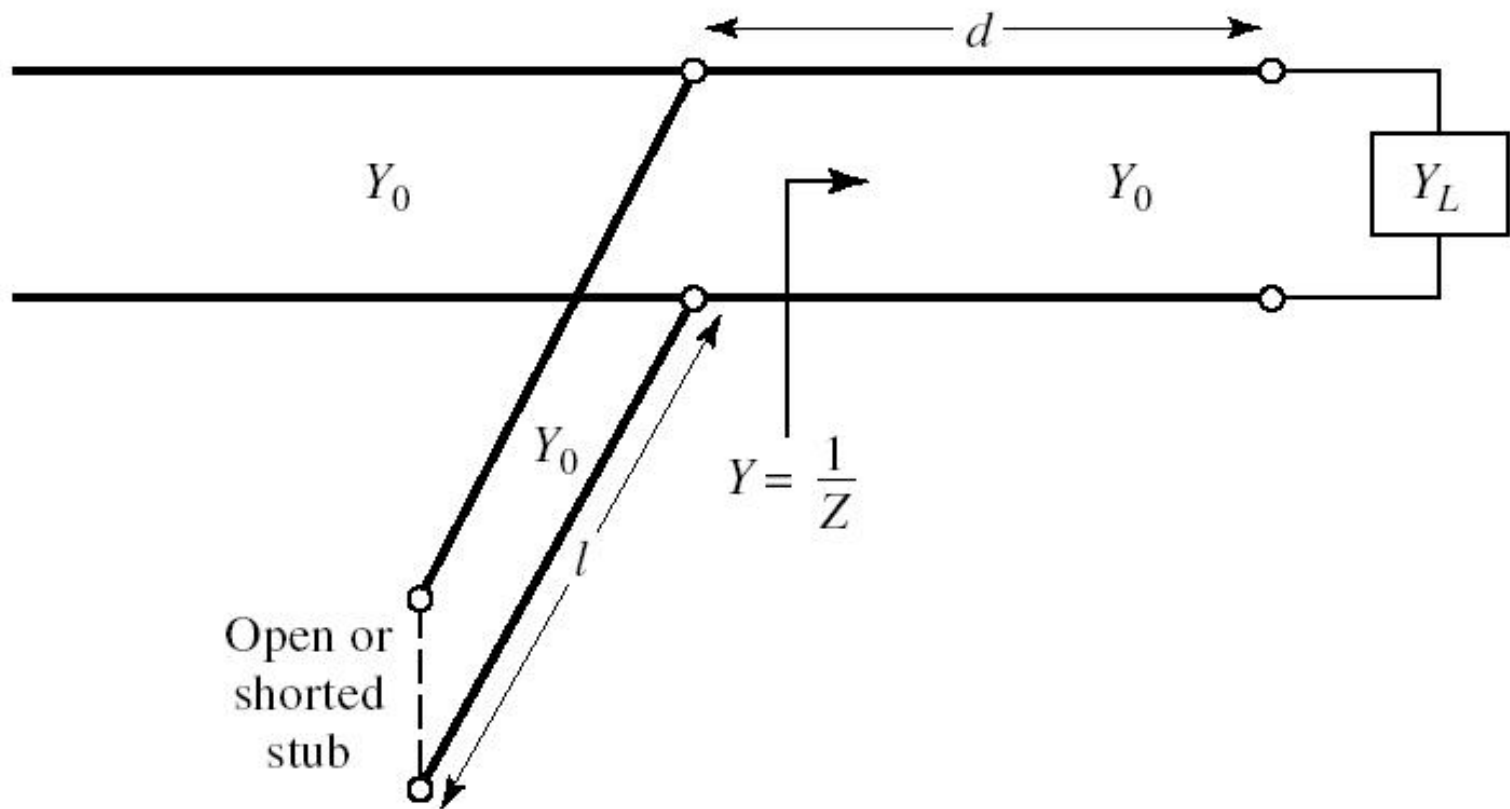


Adaptarea cu sectiuni de linii (stub)

Adaptarea de impedanță

Single stub tuning

- Shunt Stub (sectione de linie in paralel)



Calcul analitic (calcul efectiv)

$$\cos(\varphi + 2\theta) = -|\Gamma_S|$$

$$\Gamma_S = 0.593 \angle 46.85^\circ$$

$$\theta_{sp} = \beta \cdot l = \tan^{-1} \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}$$

$$|\Gamma_S| = 0.593; \quad \varphi = 46.85^\circ \quad \cos(\varphi + 2\theta) = -0.593 \Rightarrow (\varphi + 2\theta) = \pm 126.35^\circ$$

- **Semnul** (+/-) solutiei alese la ecuatia **liniei serie** impune **semnul** solutiei utilizate la ecuatia **stub-ului paralel**

- **solutia "cu +"** ↓

$$(46.85^\circ + 2\theta) = +126.35^\circ \quad \theta = +39.7^\circ \quad \text{Im } y_s = \frac{-2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = -1.472$$

$$\theta_{sp} = \tan^{-1}(\text{Im } y_s) = -55.8^\circ (+180^\circ) \rightarrow \theta_{sp} = 124.2^\circ$$

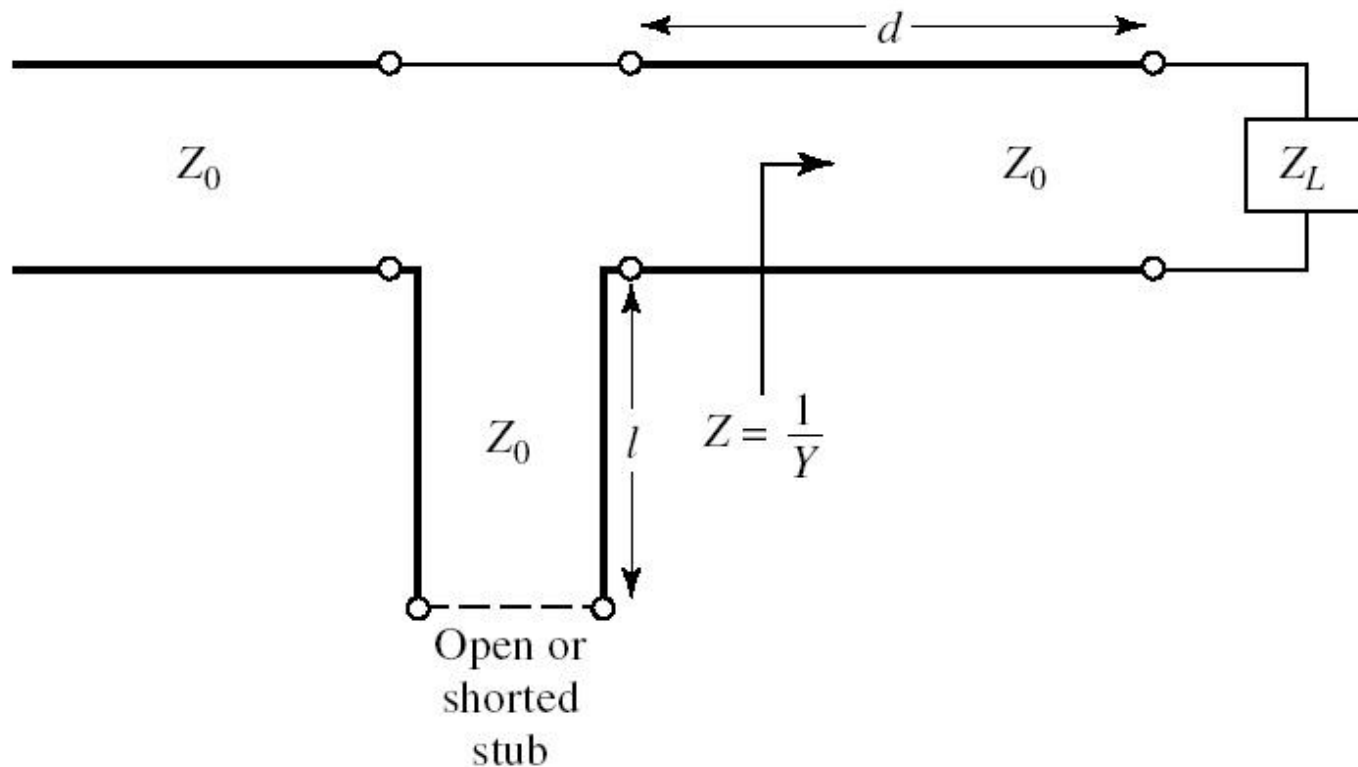
- **solutia "cu -"** ↓

$$(46.85^\circ + 2\theta) = -126.35^\circ \quad \theta = -86.6^\circ (+180^\circ) \rightarrow \theta = 93.4^\circ$$

$$\text{Im } y_s = \frac{+2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = +1.472 \quad \theta_{sp} = \tan^{-1}(\text{Im } y_s) = 55.8^\circ$$

Single stub tuning

- Series Stub (secțiune de linie în serie)
- tehnologic mai dificil de realizat la liniile monofilare (microstrip)



Calcul analitic (calcul efectiv)

$$\cos(\varphi + 2\theta) = |\Gamma_s|$$

$$\theta_{ss} = \beta \cdot l = \cot^{-1} \frac{\mp 2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}}$$

$$\Gamma_s = 0.555 \angle -29.92^\circ$$

$$|\Gamma_s| = 0.555; \quad \varphi = -29.92^\circ \quad \cos(\varphi + 2\theta) = 0.555 \Rightarrow (\varphi + 2\theta) = \pm 56.28^\circ$$

- **Semnul** (+/-) solutiei alese la ecuatia **liniei serie** impune **semnul** solutiei utilizate la ecuatia **stub-ului serie**

- **solutia "cu +"** ↓

$$(-29.92^\circ + 2\theta) = +56.28^\circ$$

$$\theta = 43.1^\circ$$

$$\text{Im } z_s = \frac{+2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}} = +1.335$$

$$\theta_{ss} = -\cot^{-1}(\text{Im } z_s) = -36.8^\circ (+180^\circ) \rightarrow \theta_{ss} = 143.2^\circ$$

- **solutia "cu -"** ↓

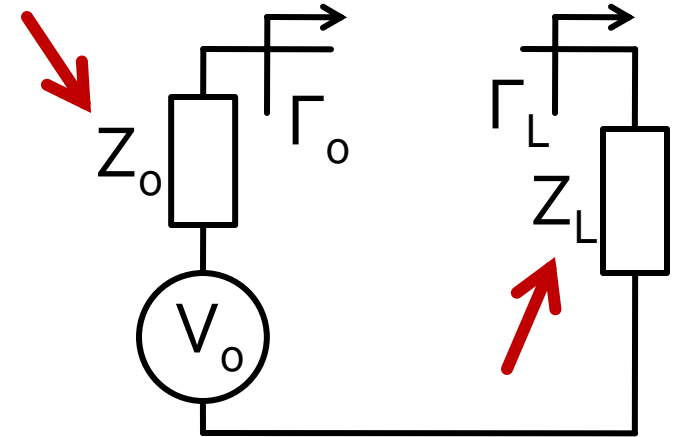
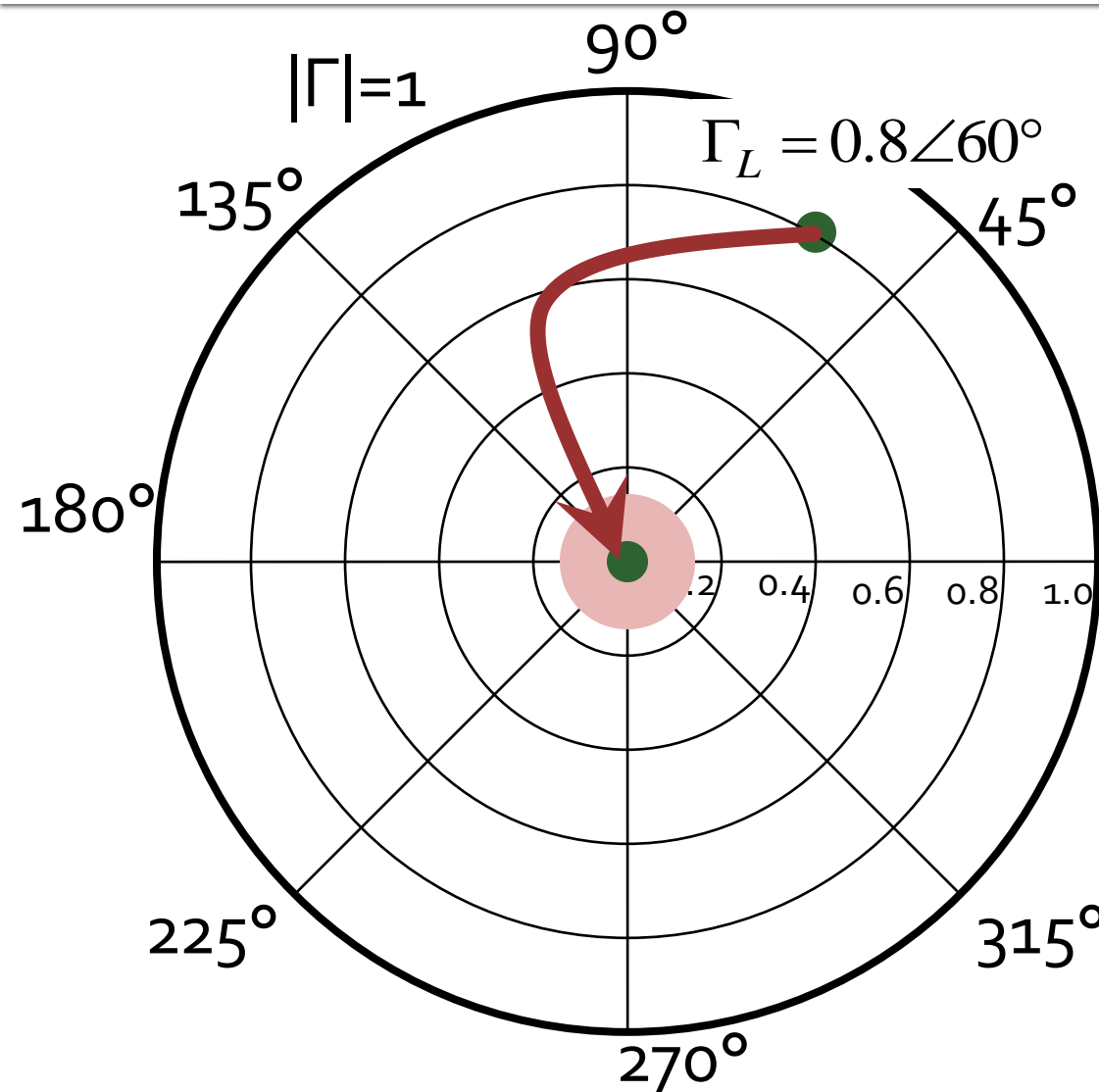
$$(-29.92^\circ + 2\theta) = -56.28^\circ$$

$$\theta = -13.2^\circ (+180^\circ) \rightarrow \theta = 166.8^\circ$$

$$\text{Im } z_s = \frac{-2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}} = -1.335$$

$$\theta_{ss} = -\cot^{-1}(\text{Im } z_s) = 36.8^\circ$$

Diagrama Smith, adaptare, $Z_L \neq Z_0$



Adaptare Z_L la Z_0 . Se raporteaza Z_L la Z_0

$$Z_L = 21.429\Omega + j \cdot 82.479\Omega$$

$$z_L = 0.429 + j \cdot 1.65$$

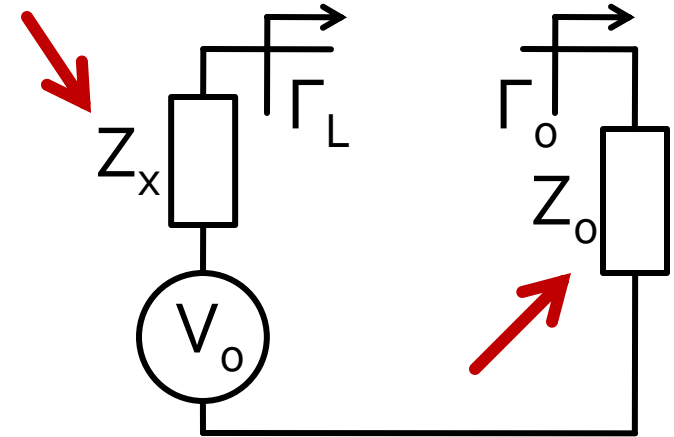
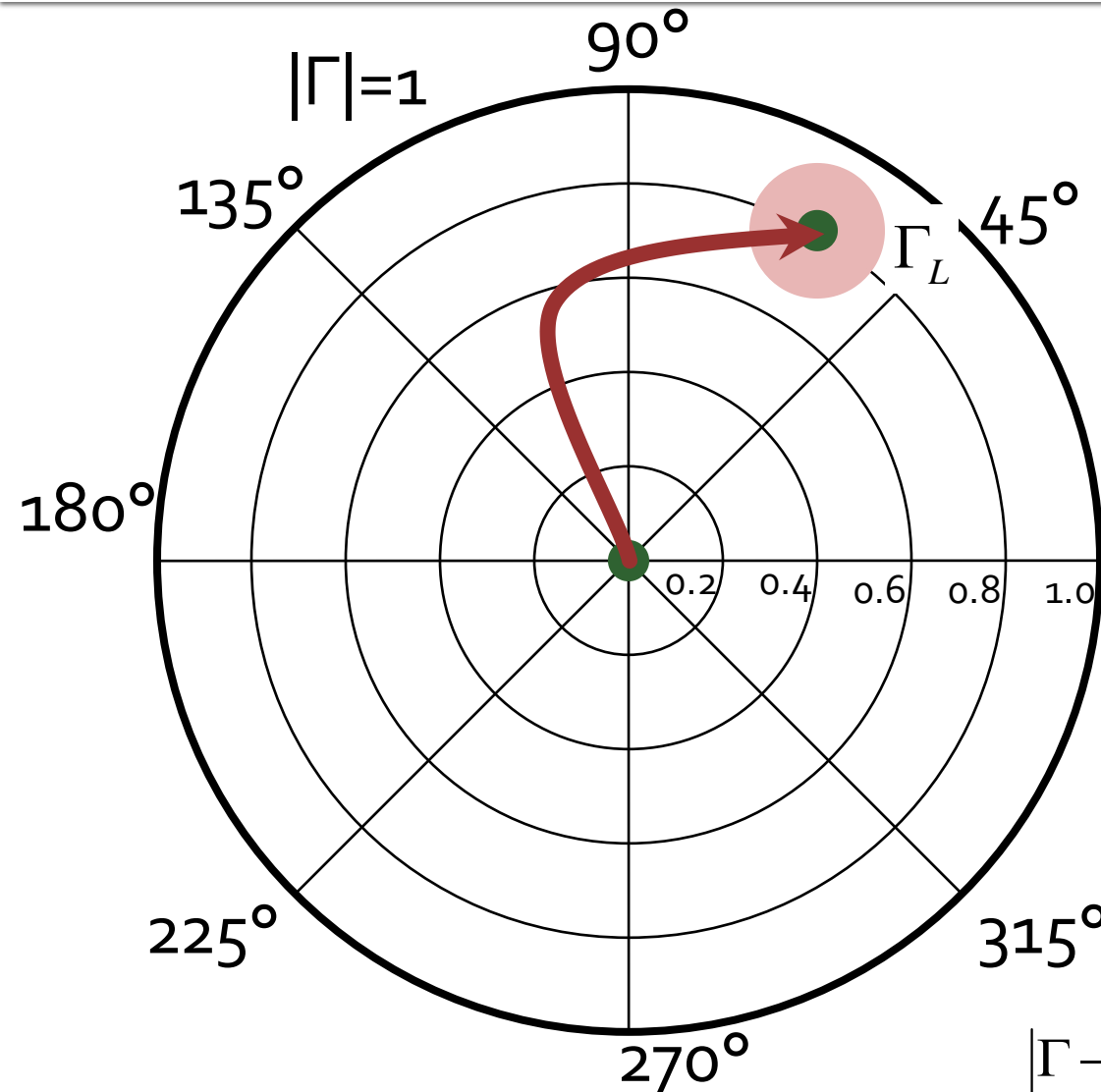
$$\Gamma_L = 0.8 \angle 60^\circ$$

Trebuie sa deplasez coeficientul de reflexie in zona in care pentru generator cu Z_0 am:

$\Gamma_0 = 0$ adaptare perfecta ●

$|\Gamma_0| \leq \Gamma_m$ adaptare "suficienta" ●

Diagrama Smith, adaptare, $Z_L = Z_o$



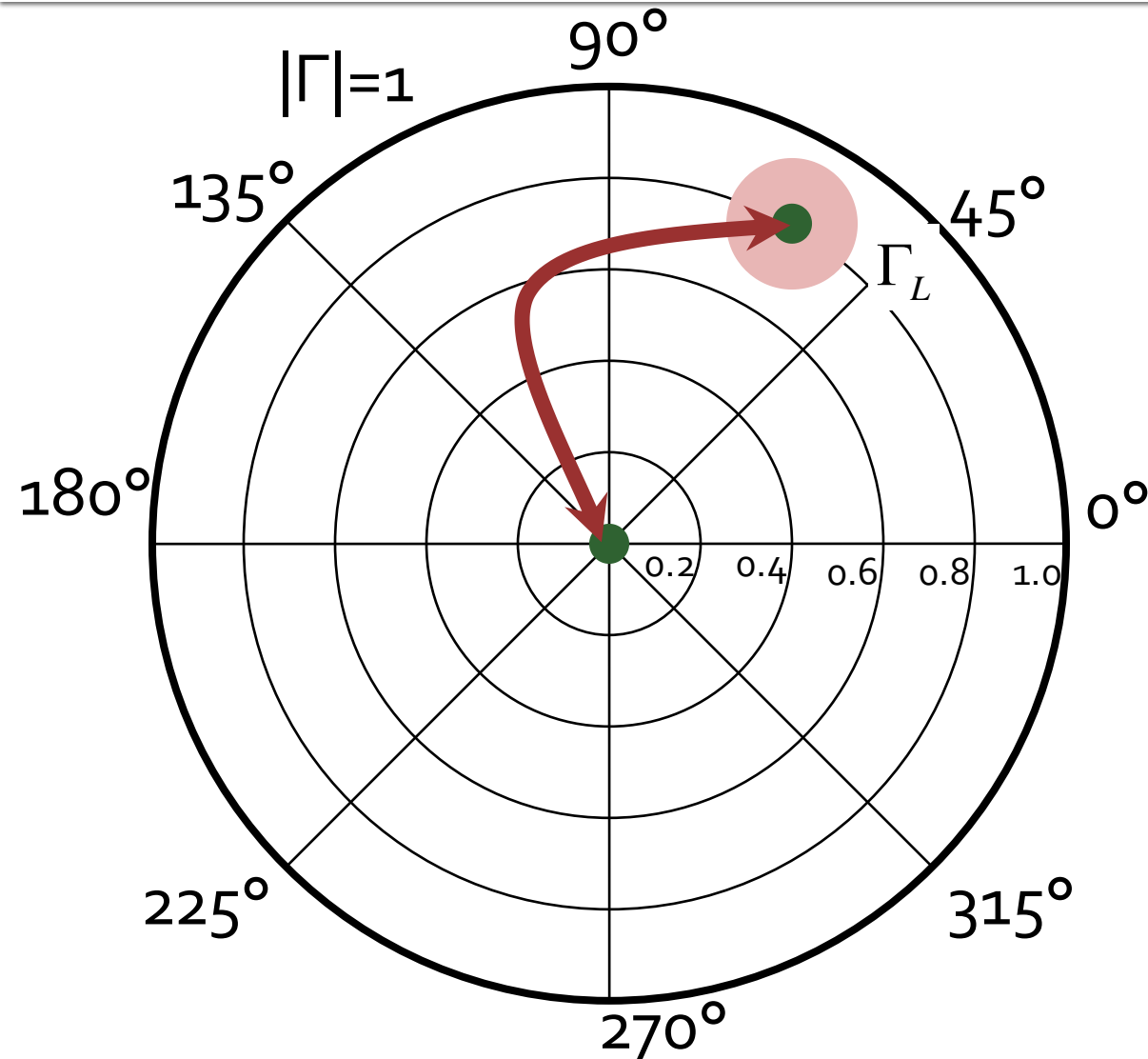
0° Sursa (de ex. tranzistorul) are Z_x și pentru funcționare corectă trebuie să vadă un coeficient de reflexie Γ_L spre sarcină cu Z_o .

Circuitul de adaptare mută punctul corespunzător coeficientului de reflexie în zona unde privind spre o sarcină cu Z_o ($\Gamma_o = 0$) se obține :

$\Gamma = \Gamma_L$ adaptare perfectă ●

$|\Gamma - \Gamma_L| \leq \Gamma_m$ adaptare "suficientă" ●

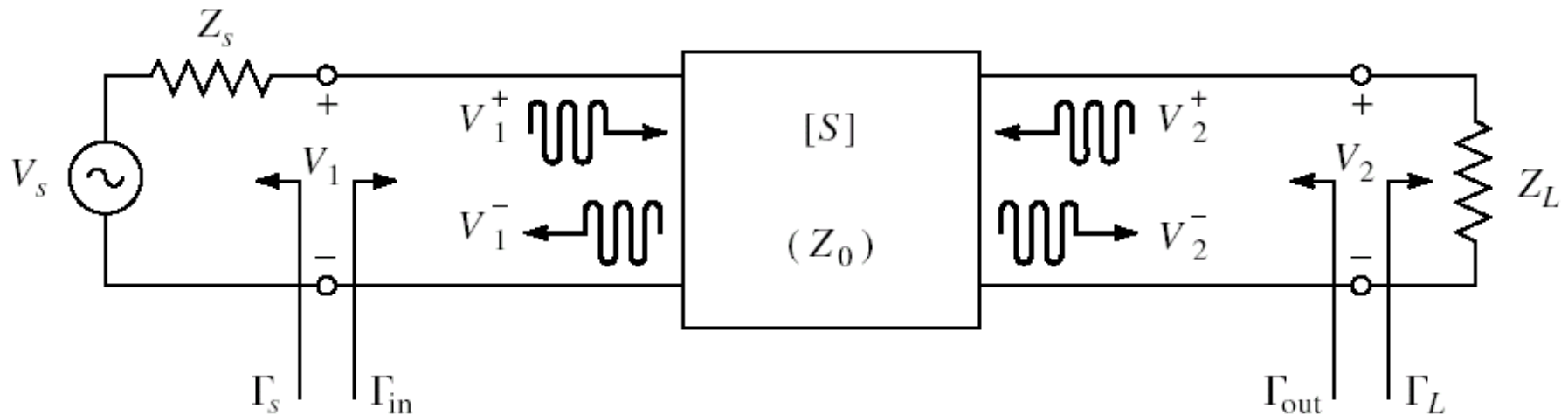
Diagrama Smith, adaptare, $Z_L = Z_o$, $Z_L = Z_o$



- Circuitele de adaptare care muta:
 - Γ_L in Γ_o
 - Γ_o in Γ_L
- sunt **identice**. Ele se diferentiaza doar prin **ordinea** in care se introduc elementele
- Ca urmare, in proiectarea/calculul circuitelor de adaptare se folosesc aceleasi:
 - **metode**
 - **formule de calcul**

Amplificatoare de microunde

Cuadripol Amplificator (diport)



- Caracterizare cu parametri S
- Normalizati la Z_0 (implicit 50Ω)
- Cataloage: parametri S pentru anumite polarizari

Catalogue

NE46100

VCE = 5 V, Ic = 50 mA

FREQUENCY (MHz)	S11		S21		S12		S22		K	MAG ² (dB)
	MAG	ANG	MAG	ANG	MAG	ANG	MAG	ANG		
100	0.778	-137	26.776	114	0.028	30	0.555	-102	0.16	29.8
200	0.815	-159	14.407	100	0.035	29	0.434	-135	0.36	26.2
500	0.826	-177	5.855	84	0.040	38	0.400	-162	0.75	21.7
800	0.827	176	3.682	76	0.052	43	0.402	-169	0.91	18.5
1000	0.826	173	2.963	71	0.058	47	0.405	-172	1.02	16.3
1200	0.825	170	2.441	66	0.064	47	0.412	-174	1.08	14.0
1400	0.820	167	2.111	61	0.069	47	0.413	-176	1.17	12.4
1600	0.828	165	1.863	57	0.078	54	0.426	-177	1.15	11.4
1800	0.827	162	1.671	53	0.087	50	0.432	-178	1.14	10.6
2000	0.828	159	1.484	49	0.093	50	0.431	-180	1.17	9.5
2500	0.822	153	1.218	39	0.11	48	0.462	177	1.18	7.8
3000	0.818	148	1.010	30	0.135	46	0.490	174	1.16	6.3
3500	0.824	142	0.876	21	0.147	44	0.507	170	1.16	5.3
4000	0.812	137	0.762	13	0.168	38	0.535	167	1.14	4.3

VCE = 5 V, Ic = 100 mA

100	0.778	-144	27.669	111	0.027	35	0.523	-114	0.27	30.2
200	0.820	-164	14.559	97	0.029	29	0.445	-144	0.42	27.0
500	0.832	-179	5.885	84	0.035	38	0.435	-166	0.81	22.2
800	0.833	175	3.691	76	0.048	45	0.435	-173	0.95	18.8
1000	0.831	172	2.980	71	0.056	51	0.437	-176	1.05	16.0
1200	0.836	169	2.464	67	0.061	52	0.432	-178	1.11	14.0
1400	0.829	166	2.121	61	0.072	53	0.447	-180	1.12	12.6
1600	0.831	164	1.867	58	0.080	54	0.445	179	1.14	11.4

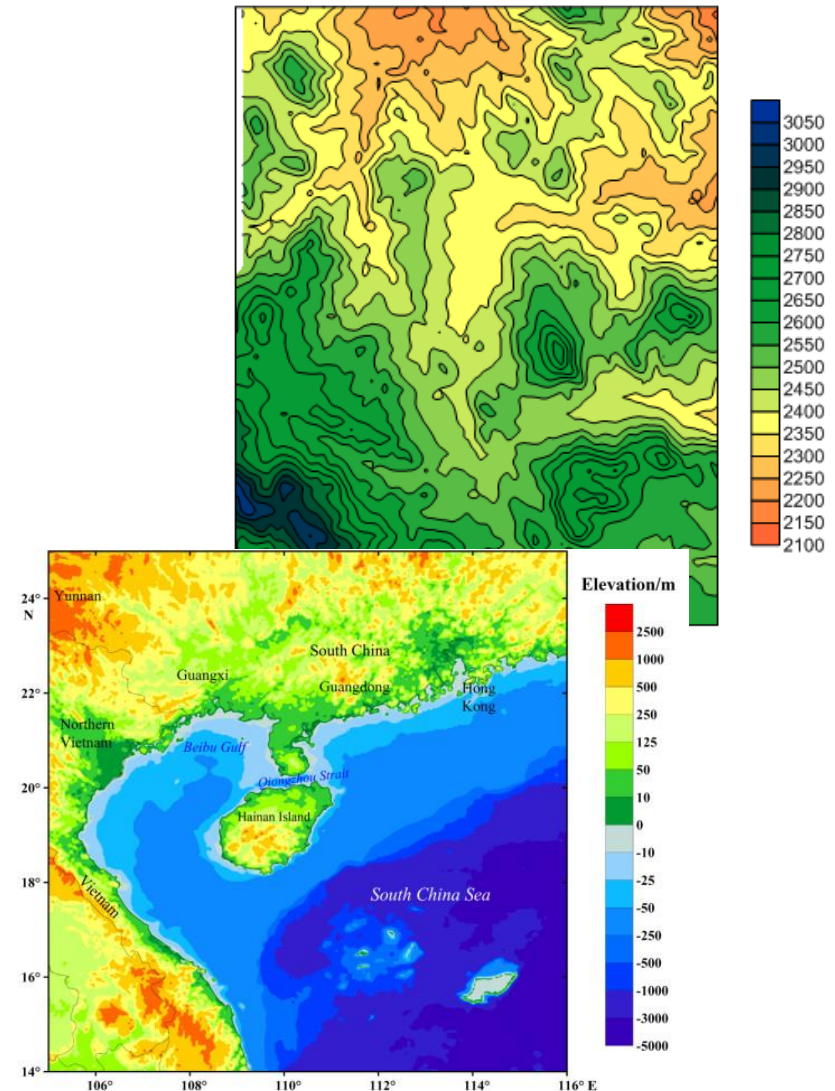
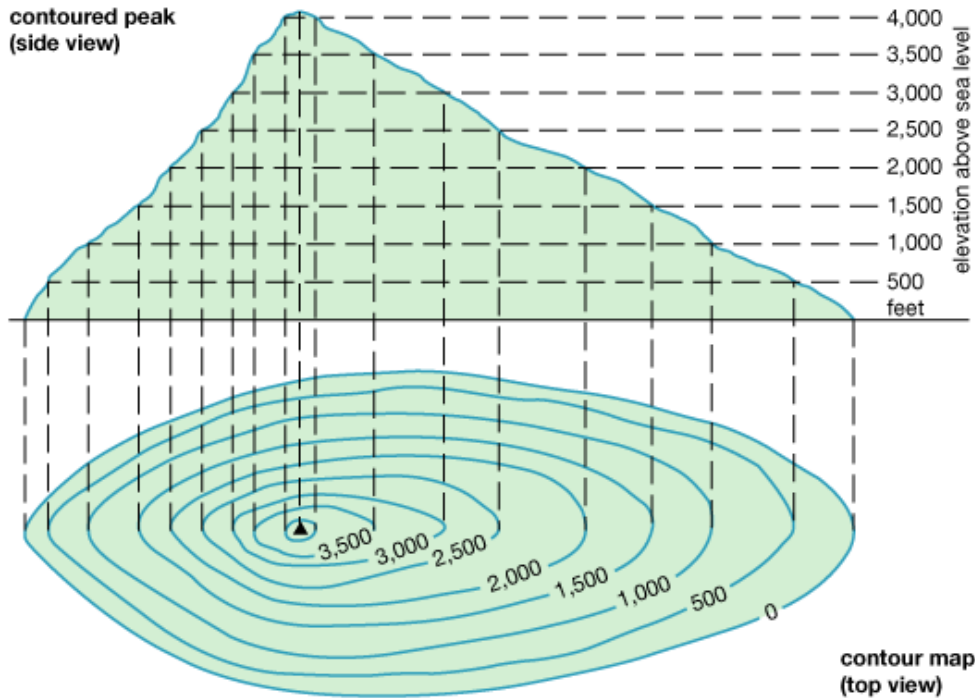
S2P - Touchstone

- Fisiere format Touchstone (*.s2p)

```
! SIEMENS Small Signal Semiconductors
! VDS = 3.5 V   ID = 15 mA
# GHz S MA R 50
! f      S11      S21      S12      S22
! GHz   MAG ANG   MAG ANG   MAG ANG   MAG ANG
1.000 0.9800 -18.0 2.230 157.0 0.0240 74.0 0.6900 -15.0
2.000 0.9500 -39.0 2.220 136.0 0.0450 57.0 0.6600 -30.0
3.000 0.8900 -64.0 2.210 110.0 0.0680 40.0 0.6100 -45.0
4.000 0.8200 -89.0 2.230 86.0 0.0850 23.0 0.5600 -62.0
5.000 0.7400 -115.0 2.190 61.0 0.0990 7.0 0.4900 -80.0
6.000 0.6500 -142.0 2.110 36.0 0.1070 -10.0 0.4100 -98.0
!
! f      Fmin  Gammaopt rn/50
! GHz   dB   MAG ANG  -
2.000   1.00 0.72 27 0.84
4.000   1.40 0.64 61 0.58
```

Contour map/lines

$$\begin{cases} F = f(x, y) & x, y \in \mathbf{R} \\ F = f(z) & z \in \mathbf{C} \end{cases}$$



Filtre pentru microunde

Metoda pierderilor de insertie

- Se aleg polinoamele pentru implementarea unui FTJ (prototip)
- Acest filtru poate fi convertit la alte functii, scalat in frecventa pentru a obtine alte tipuri de functii

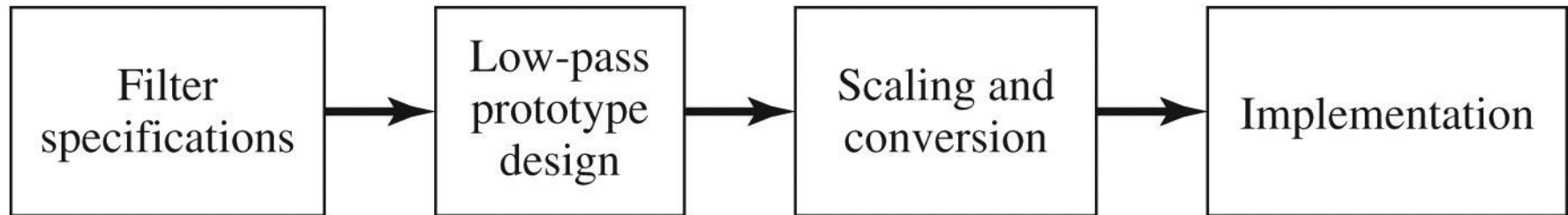


Figure 8.23

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Caracteristici de filtru trece jos prototip

- **Maxim plat** (Butterworth, binomial) ofera cea mai plata comportare in banda de trecere
- **Echiriplu** (Cebasev) ofera atenuare mai mare in banda de taiere cu dezavantajul existentei unor variatii (riplu) in banda de trecere
- **Filtre eliptice**, caracterizate de variatii (riplu) si in banda de taiere si in banda de trecere
- **Filtru cu raspuns liniar in faza**, ofera intarziere de grup de maxim plat, cu dezavantajul unei atenuari in putere mai mica, necesar in anumite aplicatii

Implementare filtre pentru microunde

- Implementarea cu elemente concentrate (L, C) este utilizabila mai ales in zona frecventelor ceva mai reduse (RF) datorita:
 - dificultatii de implementare a valorilor rezultante pentru componente
 - dificultatii de a asigura toleranta (foarte mica) necesara pentru componente

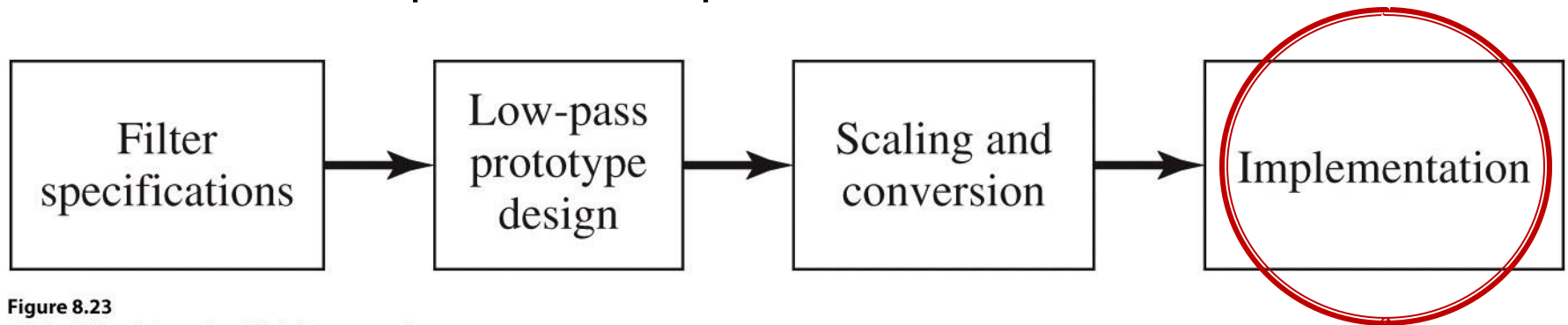
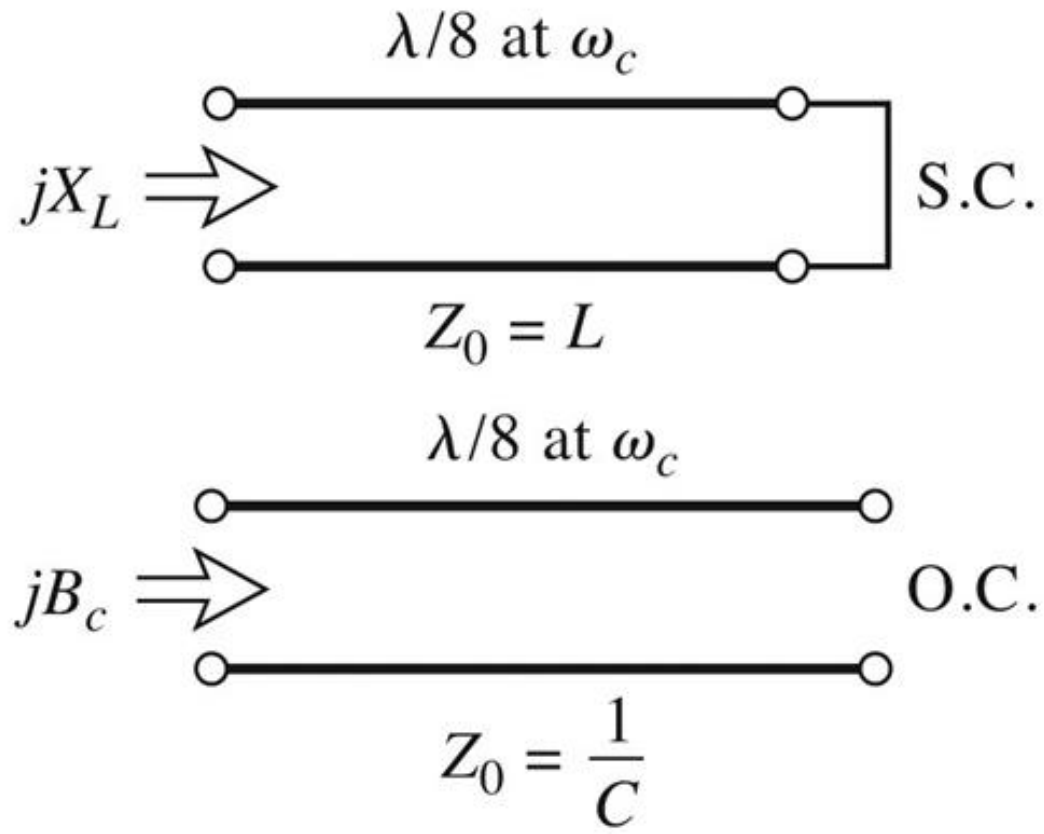
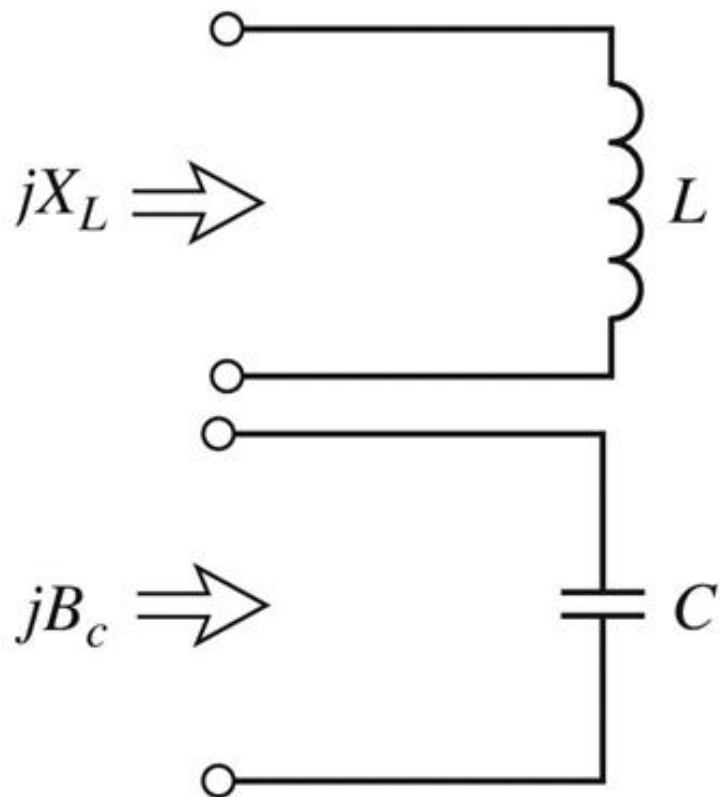


Figure 8.23

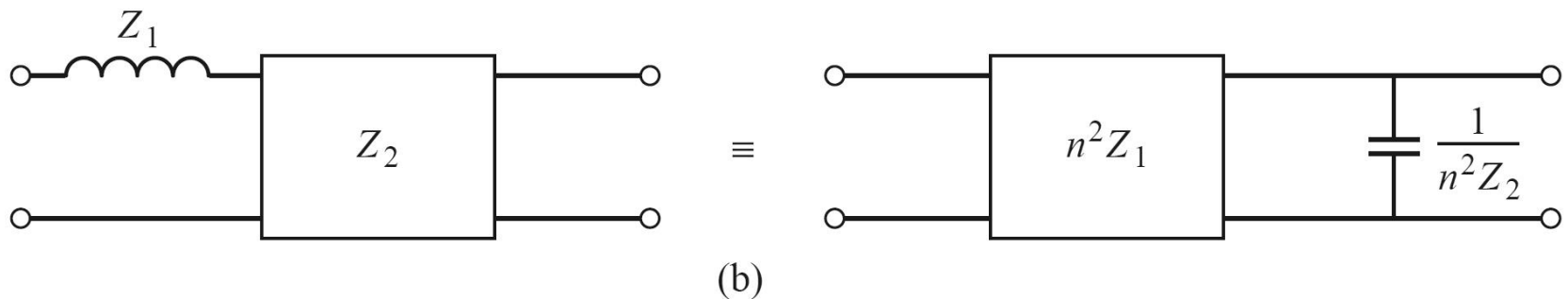
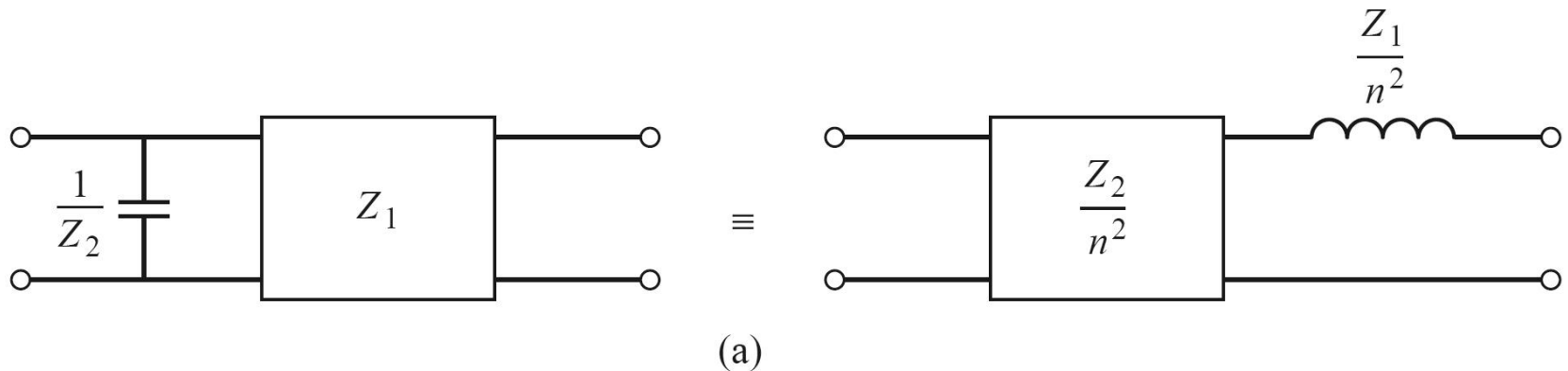
Transformarea Richards

- permite obtinerea cu sectiuni de linii a inductantelor si capacitatilor **dupa** scalarea prototipului pentru functia corespunzatoare (FTJ/FTS/FTB /FOB)



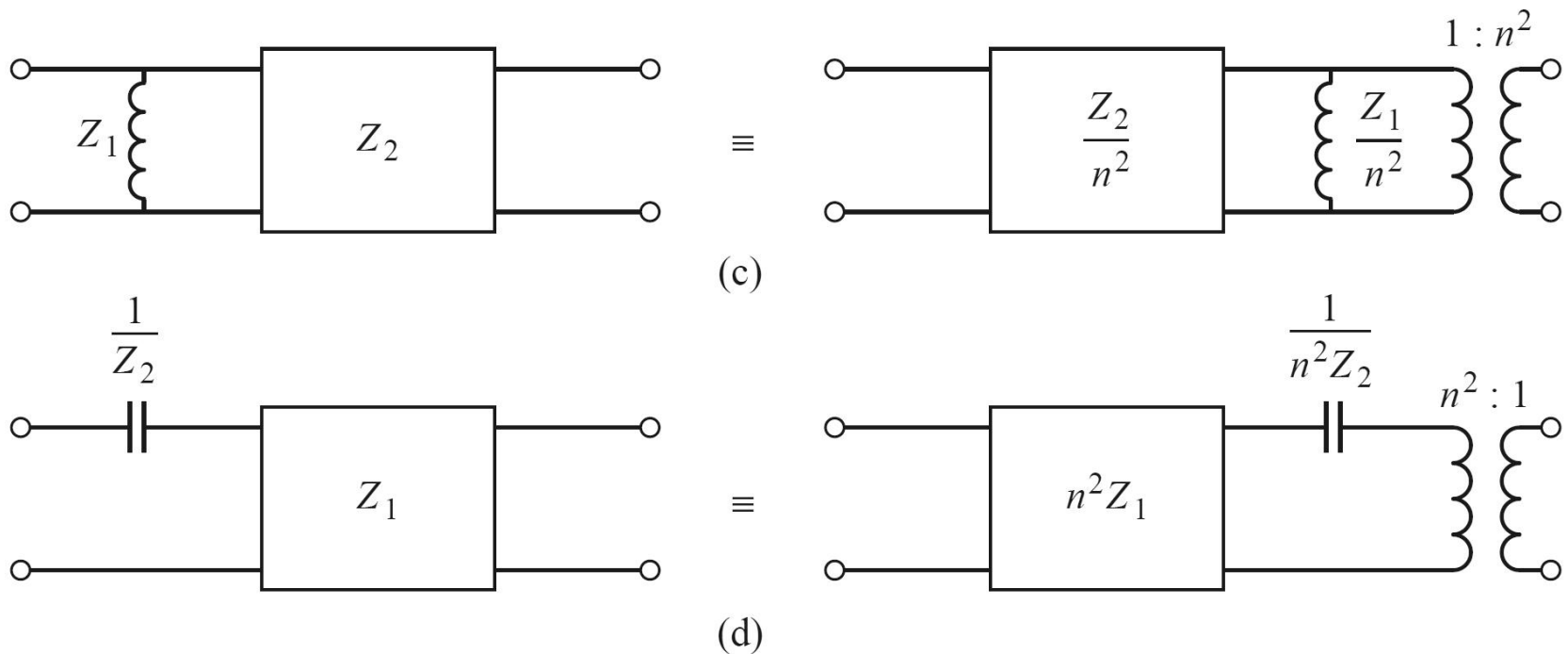
Identitățile Kuroda

- 4 echivalente de circuit



Identitatile Kuroda

- 4 echivalente de circuit

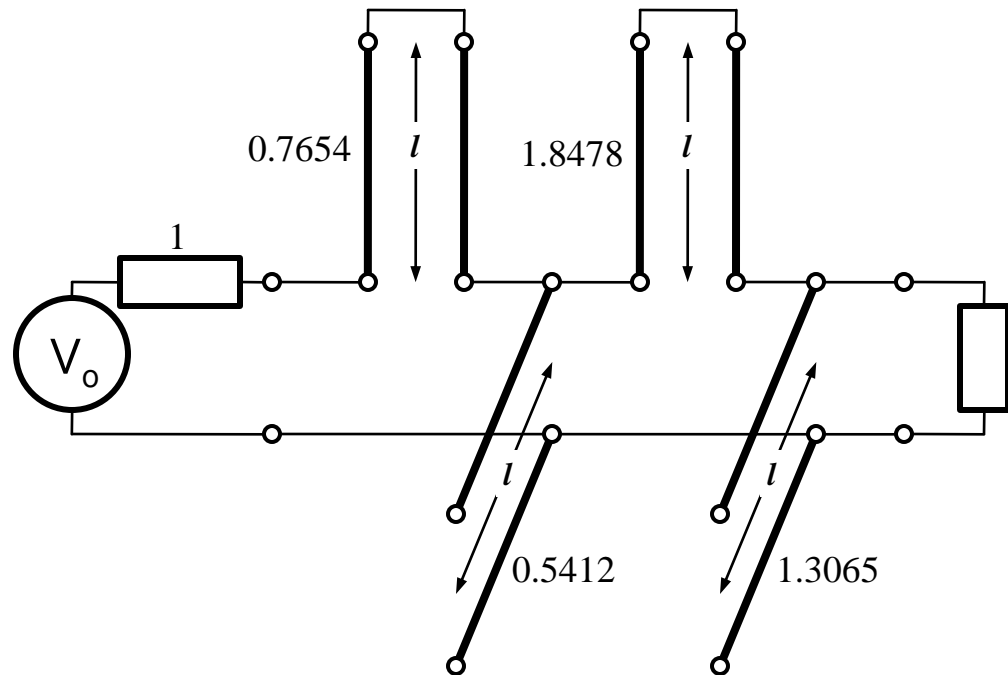


Exemplu

■ Se aplica transformarea Richards

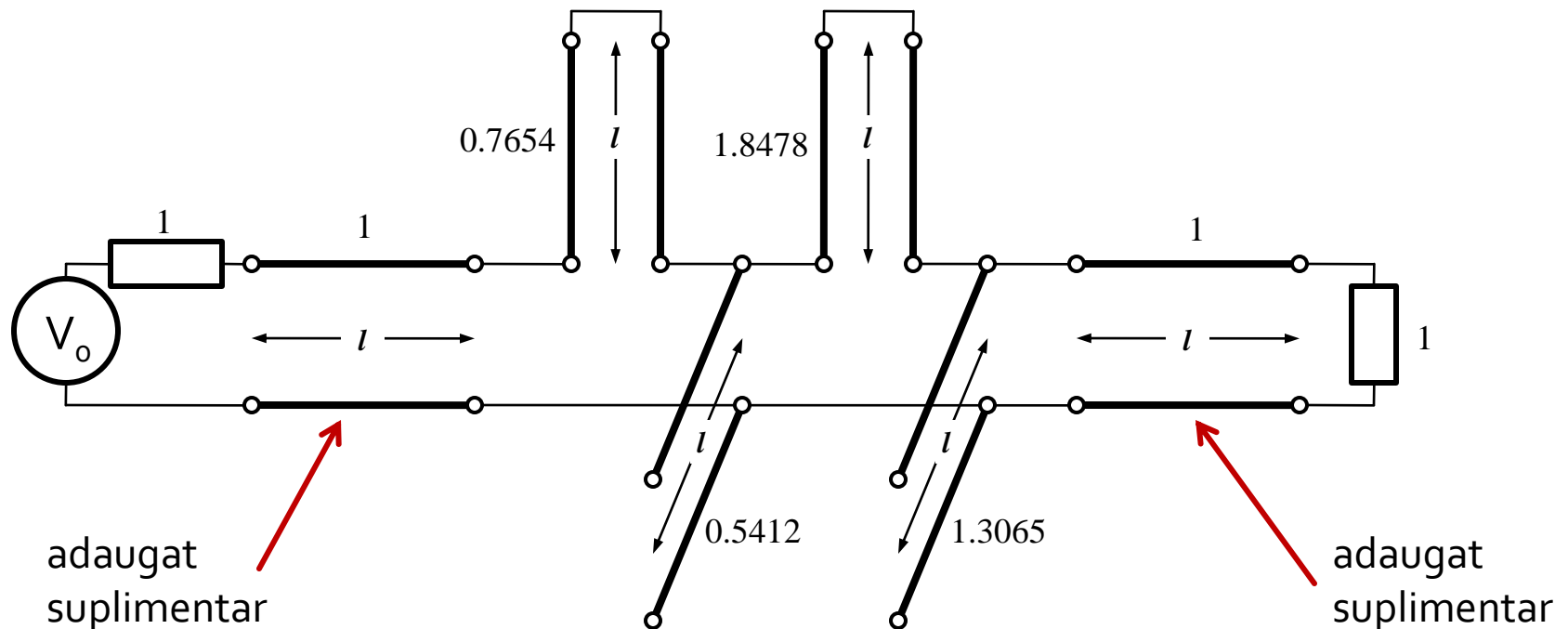
■ Probleme:

- stub-urile in serie sunt **extrem de dificil** de implementat in tehnologie microstrip
- cu tehnologia microstrip e preferabil sa avem stub-uri in gol (scurtcircuit necesita un **via-hole** spre planul de masa)
- cele 4 stub-uri sunt conectate in acelasi punct, o implementare care sa elimine/micsoreze **cuplajul** intre aceste linii e imposibila
- nu e cazul aici, dar pot aparea situatii cand impedantele raportate sunt mult diferite de 1. Majoritatea tehnologiilor sunt concepute pentru linii cu impedante caracteristice in jur de 50Ω



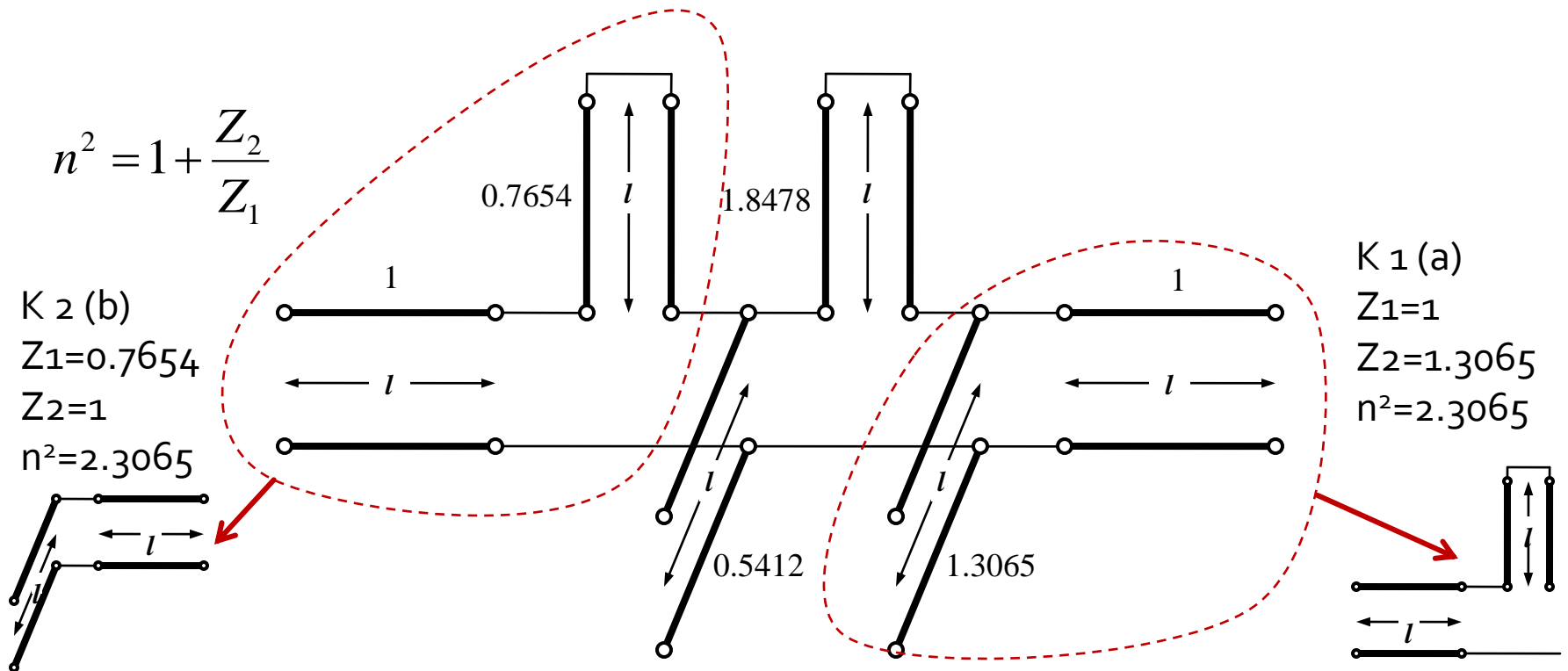
Exemplu

- Identitățile Kuroda se referă **intotdeauna** la o schema cu o secțiune de linie în serie:
 - se **adauga** elementele unitare ($z = 1, l = \lambda/8$) la fiecare capăt al circuitului (adaugarea nu modifică proprietățile filtrului acesta fiind adaptat la $z = 1$ la fiecare capăt)
 - se **aplica** una din identitățile Kuroda la fiecare capăt și se **continua**
 - un indicator al **opririi** procedurii este apariția unei secțiuni de linie între toate stub-urile obținute cu transformarea Richards



Exemplu

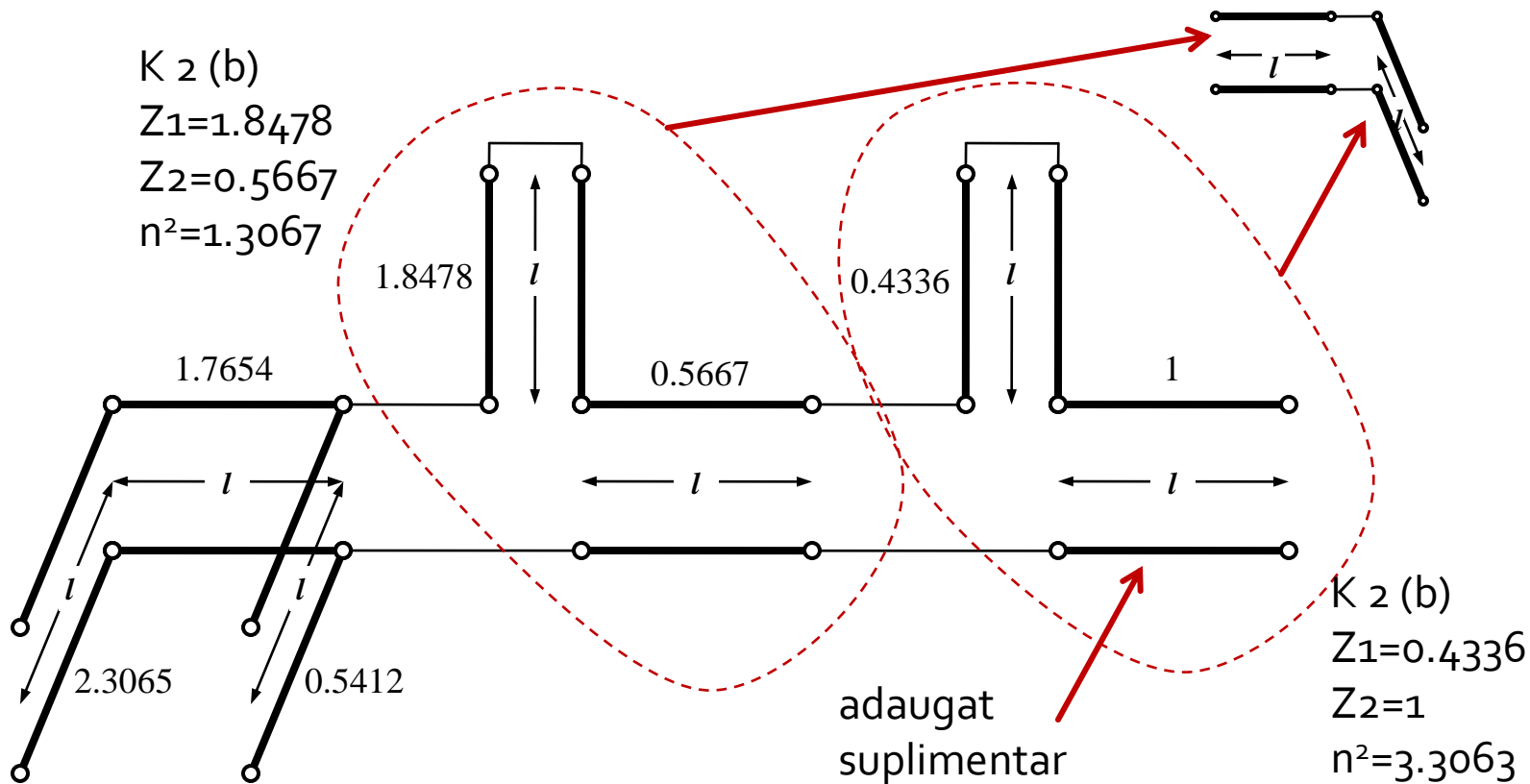
- Se aplica :
 - Kuroda 2 (L, Z cunoscut $\rightarrow C, Z$) in partea stanga
 - Kuroda 1 (C, Z cunoscut $\rightarrow L, Z$) in partea dreapta



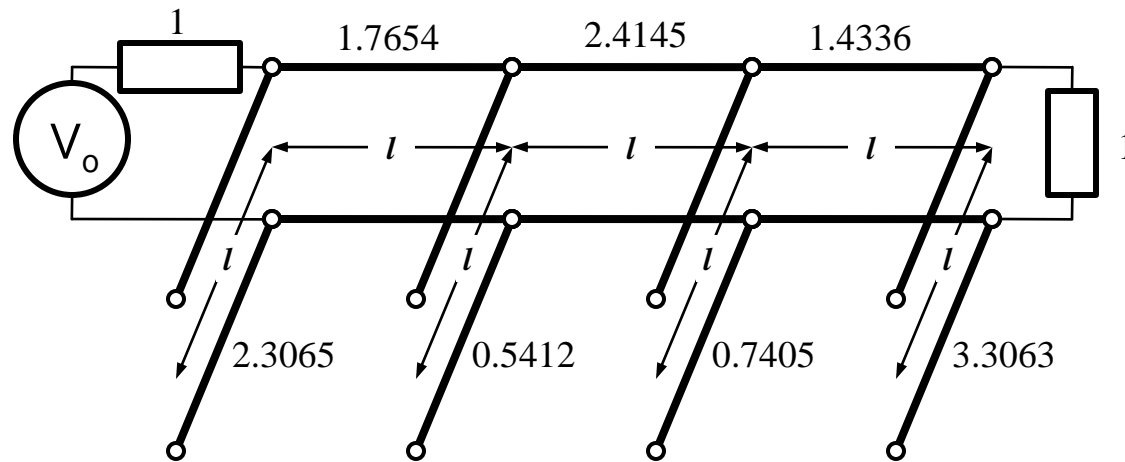
Exemplu

- Se mai adauga un element unitar in partea dreapta si se aplica Kuroda 2 de doua ori

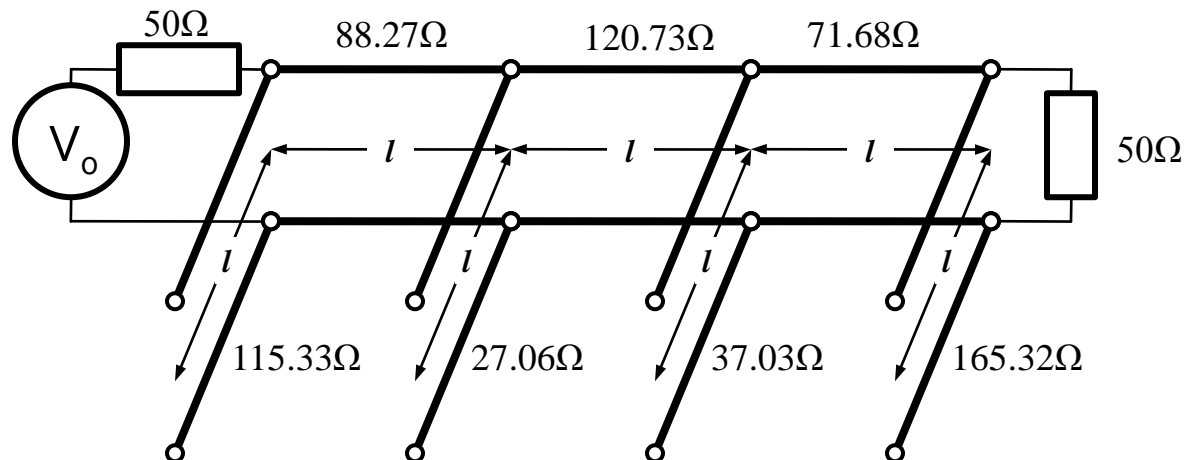
$$n^2 = 1 + \frac{Z_2}{Z_1}$$



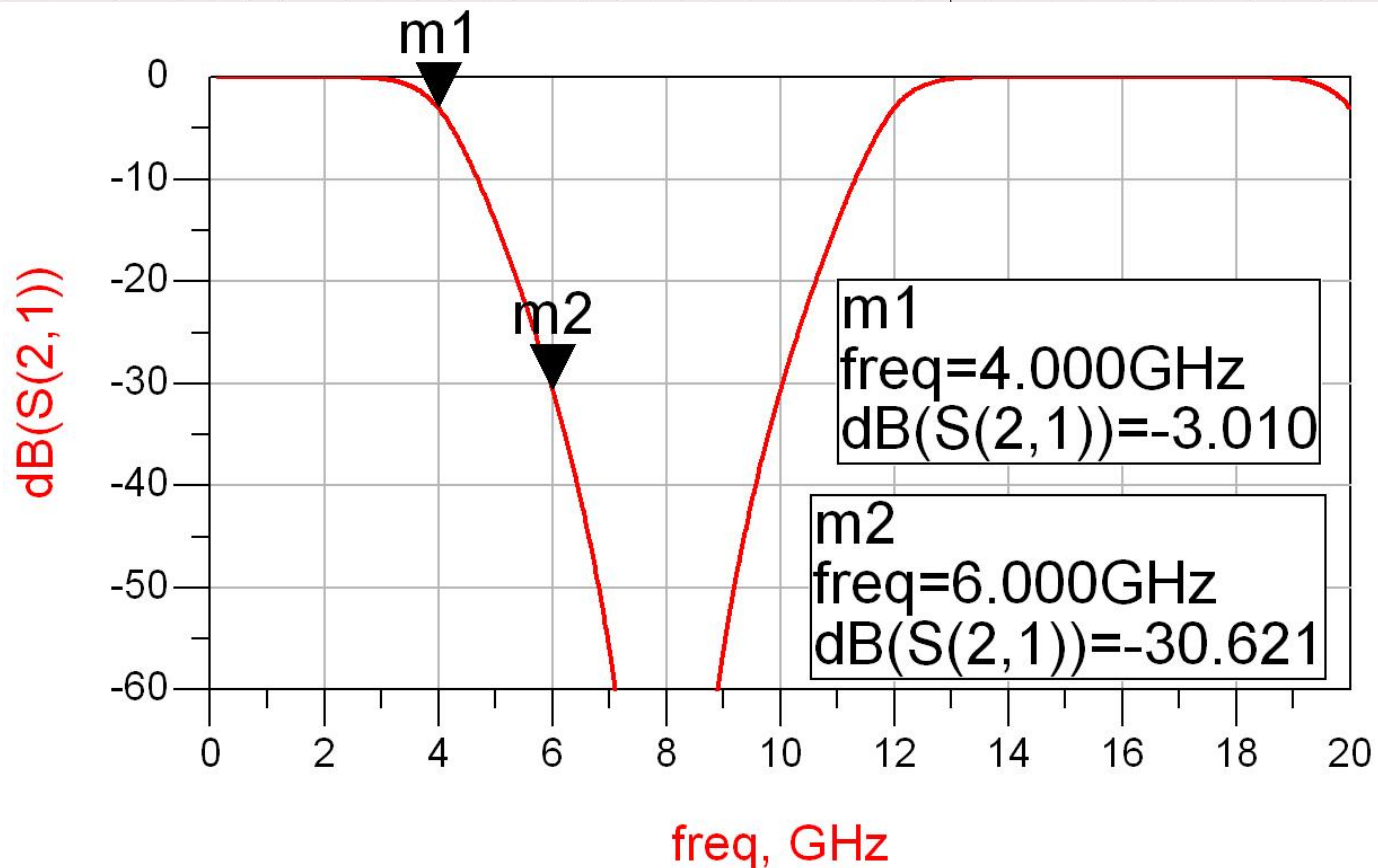
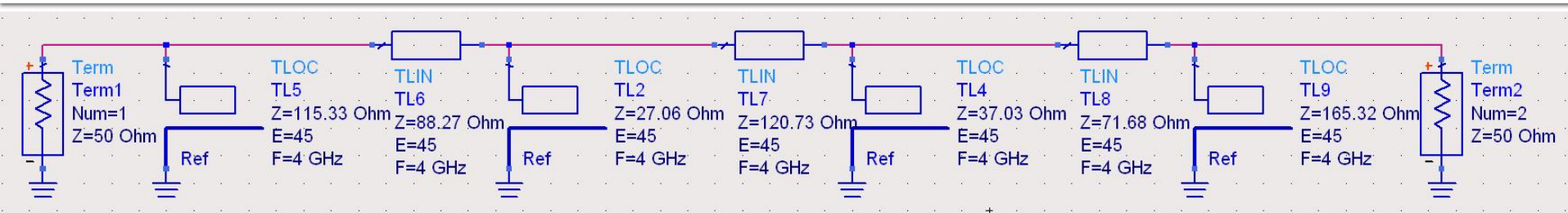
Exemplu



- Scalare la 50Ω



Identitatile Kuroda – ADS



Example

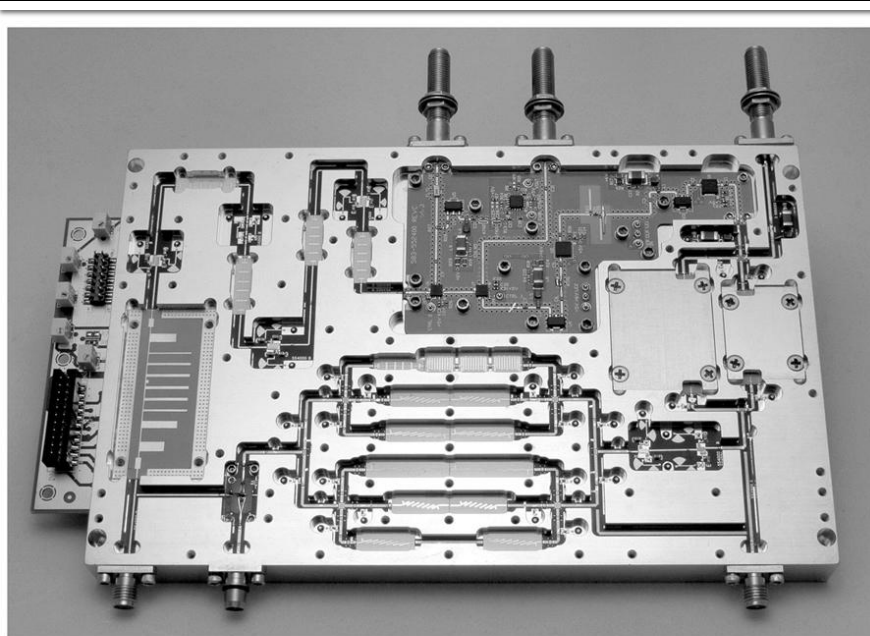
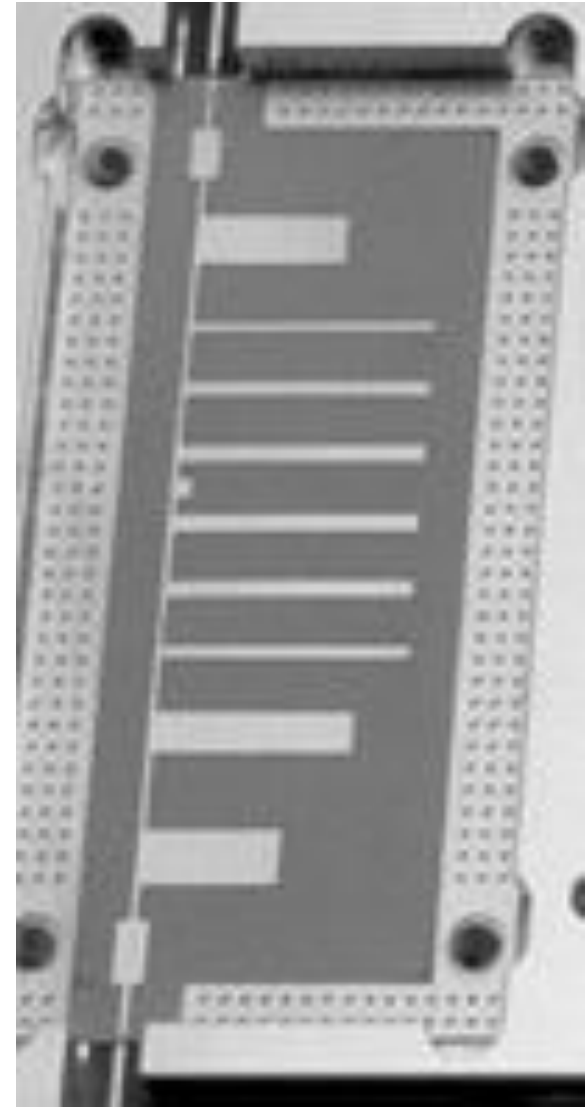
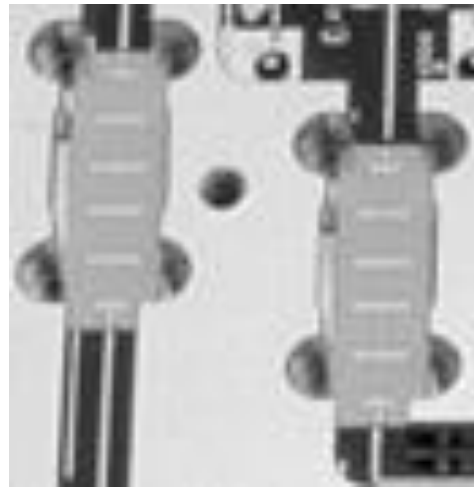
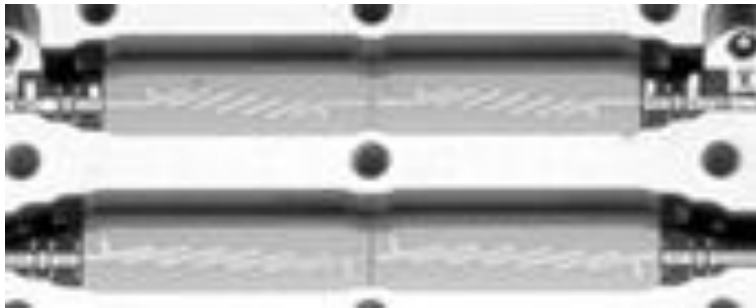


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.

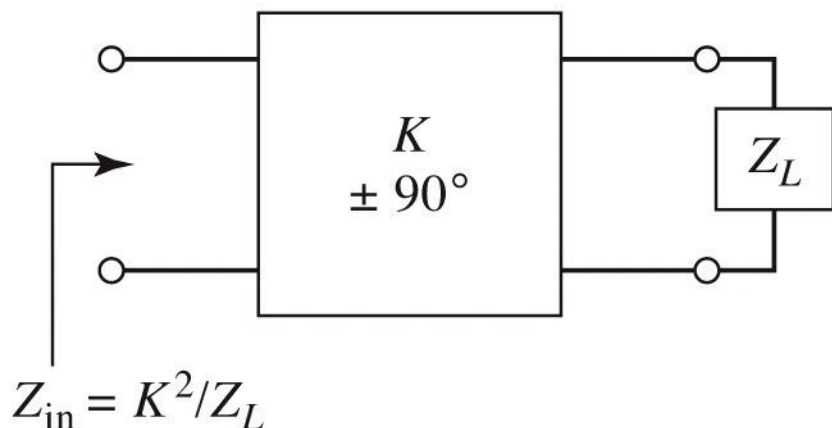


Inversoare de impedanta si admitanta

- Pentru situatiile in care implementarea cu Richards + Kuroda nu ofera solutii practice se folosesc structuri de circuit numite **inversoare de impedanta si admitanta**

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

Impedance inverters



$$Y_{in} = \frac{J^2}{Y_L}$$

Admittance inverters

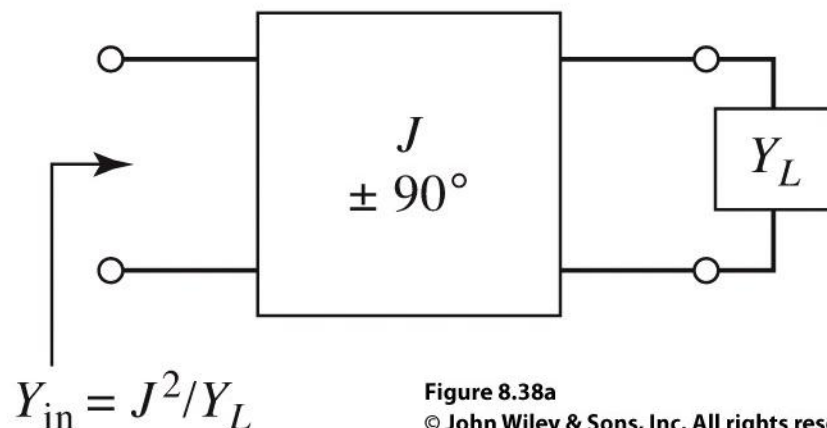
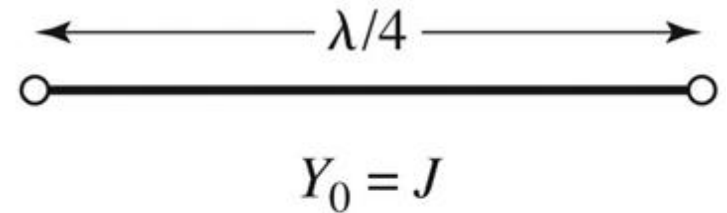
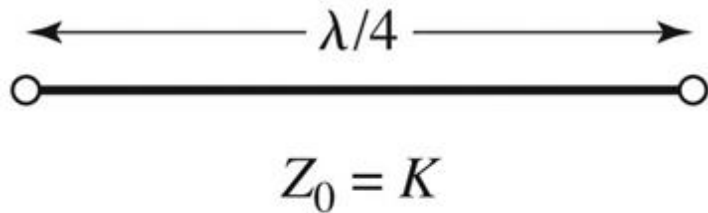


Figure 8.38a

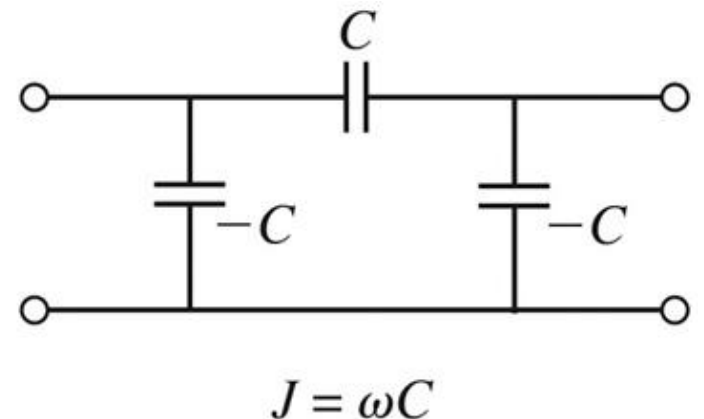
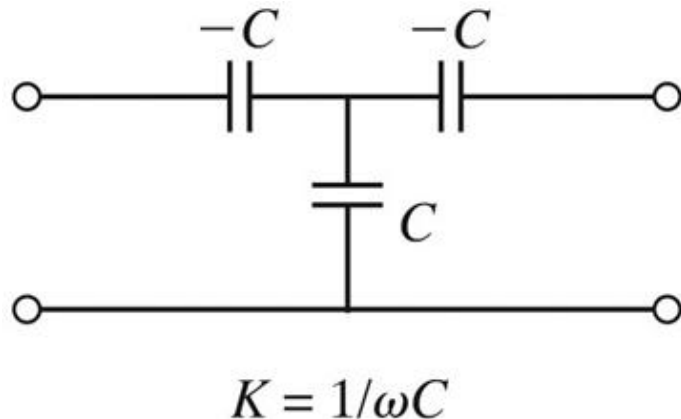
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Realizari practice de inversoare de impedanta/admitanta

- Cel mai uzual se foloseste transformatorul in sfert de lungime de unda

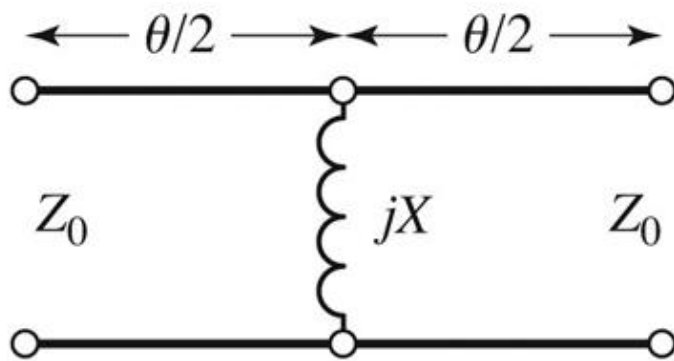


- Realizare cu elemente concentrate

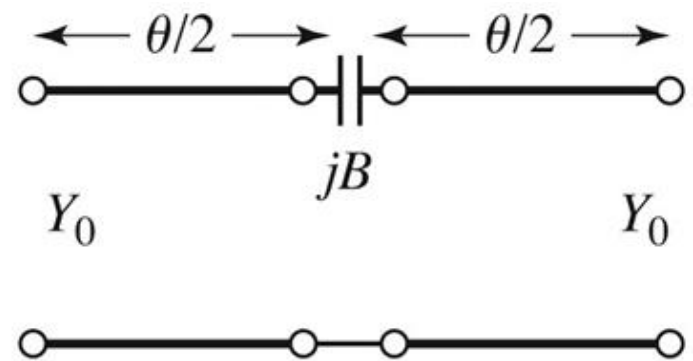


Realizari practice de inversoare de impedanta/admitanta

■ Realizare cu linii



$$K = Z_0 \cdot \tan \left| \frac{\theta}{2} \right|$$
$$X = \frac{K}{1 - \left(\frac{K}{Z_0} \right)^2}$$
$$\theta = -\tan^{-1} \frac{2 \cdot X}{Z_0}$$



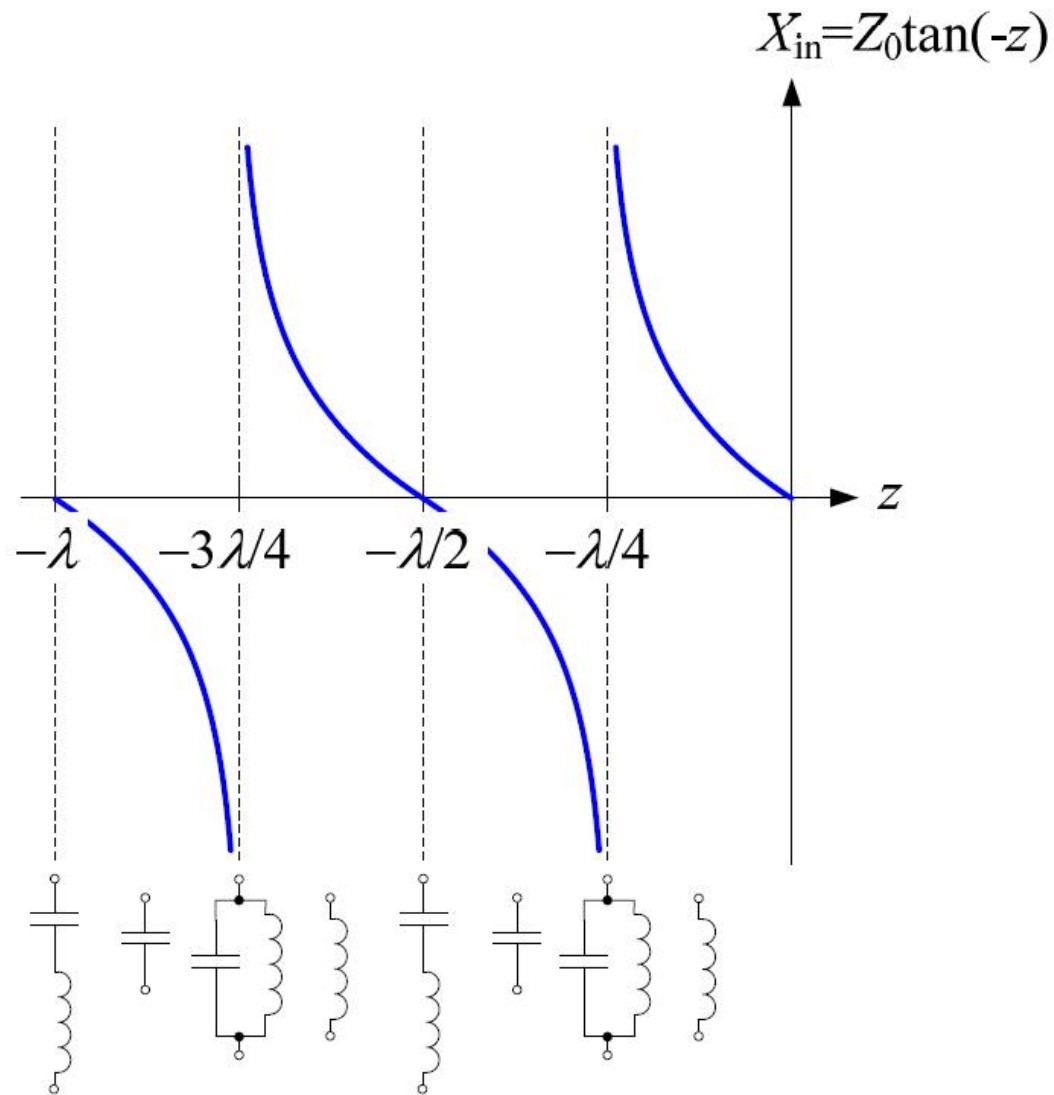
$$J = Y_0 \cdot \tan \left| \frac{\theta}{2} \right|$$
$$B = \frac{J}{1 - \left(\frac{J}{Y_0} \right)^2}$$
$$\theta = -\tan^{-1} \frac{2 \cdot B}{Y_0}$$

Red arrows from the θ terms in the equations above point to this expression:

$$\theta < 0$$

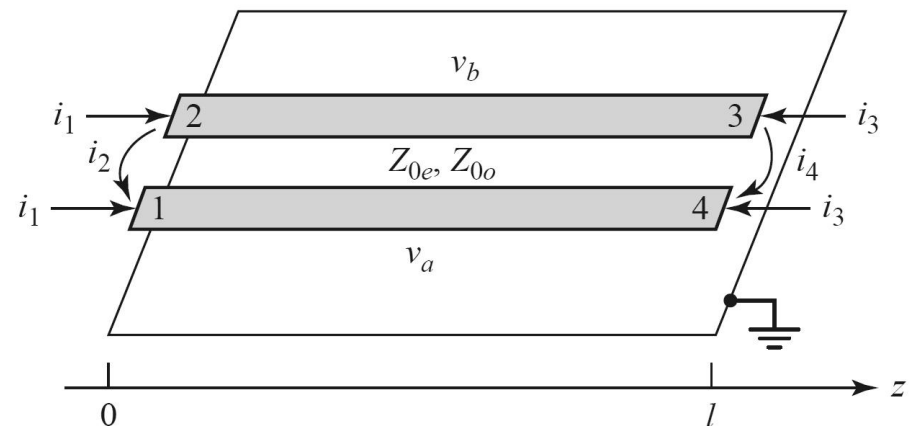
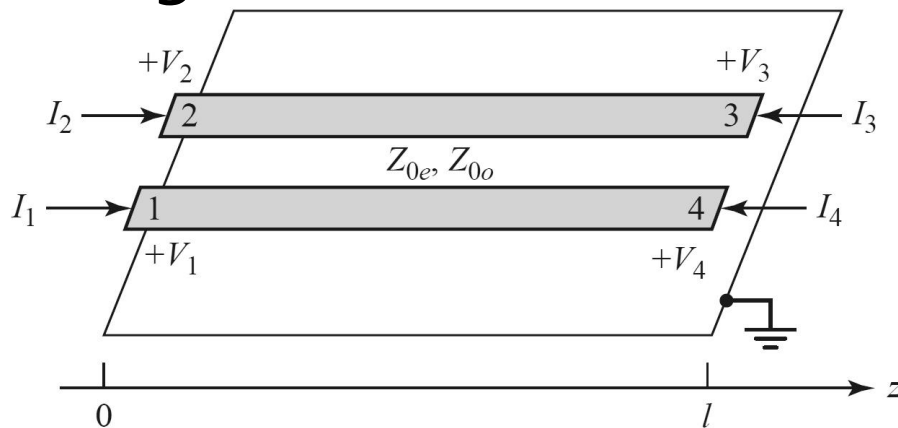
Linii ca rezonatoare

- Linie in scurtcircuit
- Pentru frecventa (ω_0) la care $l = \lambda/4$ se obtine un circuit rezonant LC paralel
 - linia are comportament capacitiv pentru frecvente mai mici ($l > \lambda/4$)
 - linia are comportament inductiv pentru frecvente mai mari ($l < \lambda/4$)
- Discutie similara pentru linia in gol (LC serie la frecventa la care $l = \lambda/4$)



Filtre cu linii cuplate

- Analiza sectiunilor de linii cuplate se face punand in evidenta comportarea pe modul par si pe modul impar
- Aceste moduri sunt caracterizate de impedantele caracteristice de mod par/impar a caror valoare va impune in functie de tehnologia utilizata geometria liniilor (latime/distanta dintre linii)



Linii cuplate

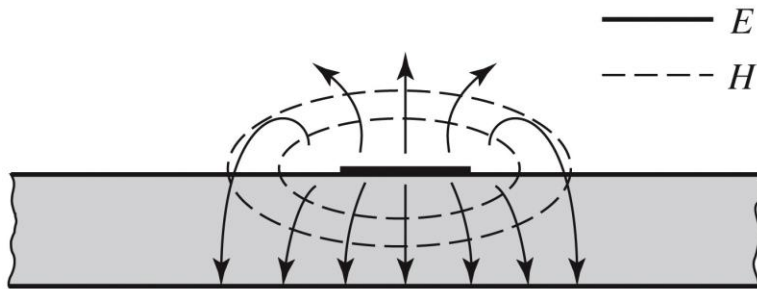
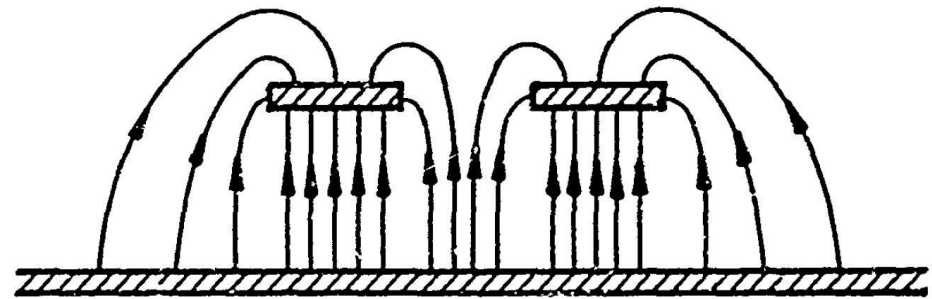
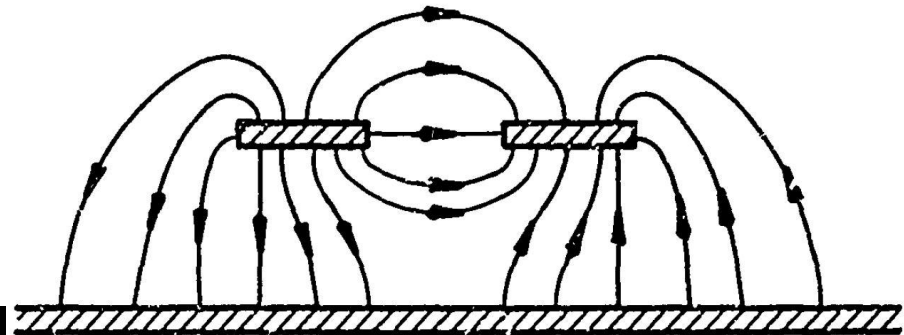


Figure 3.25b
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b) EVEN MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

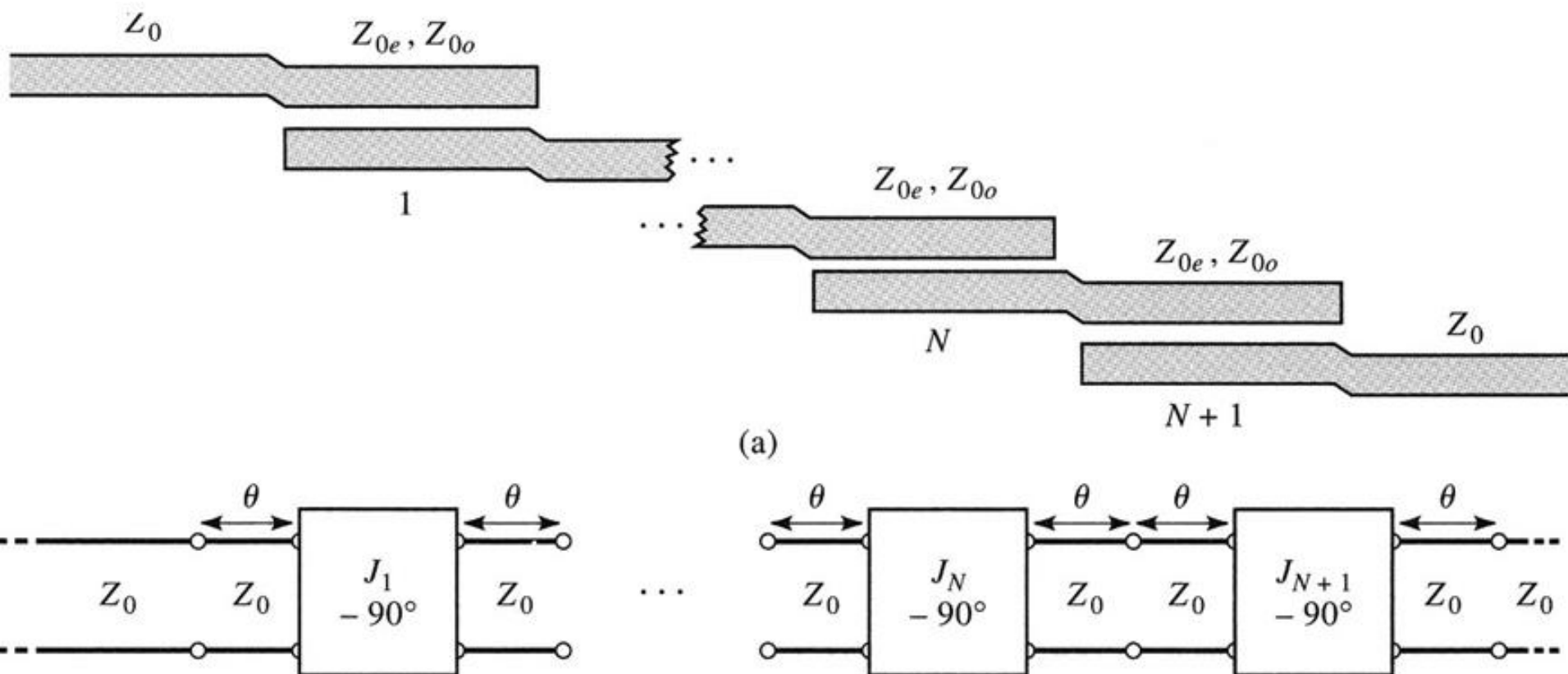


c) ODD MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

- Mod par – caracterizeaza semnalul de mod comun de pe cele doua linii
- Mod impar – caracterizeaza semnalul de mod diferential dintre cele doua linii

Filtre cu linii cuplate

- Un filtru cu $N+1$ sectiuni de linii cuplate



Example

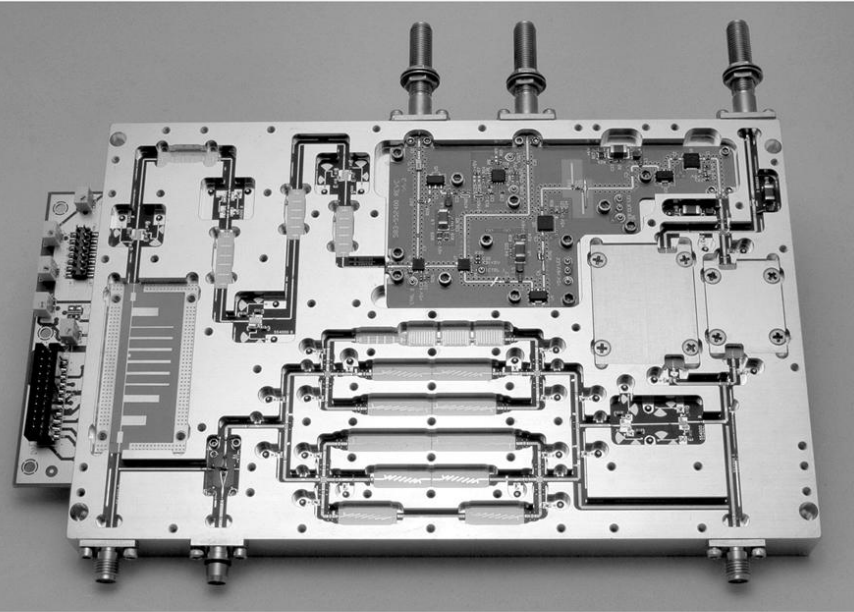
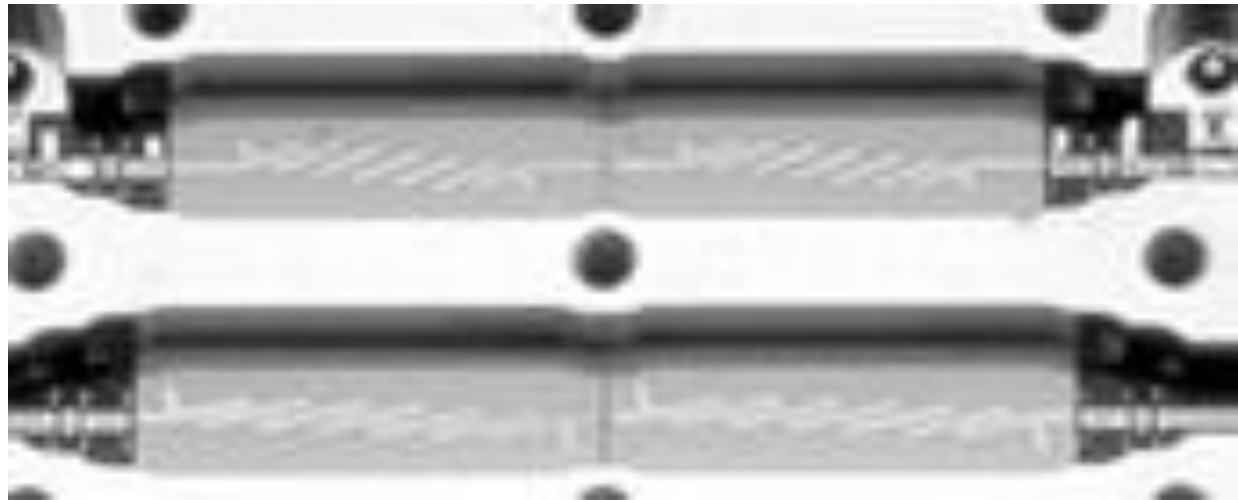
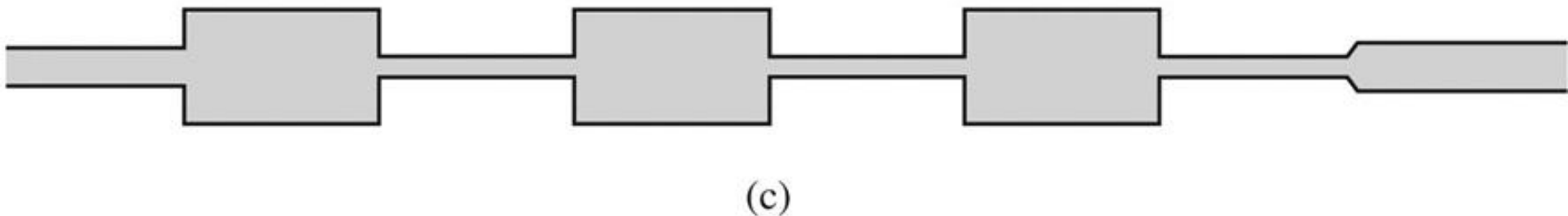
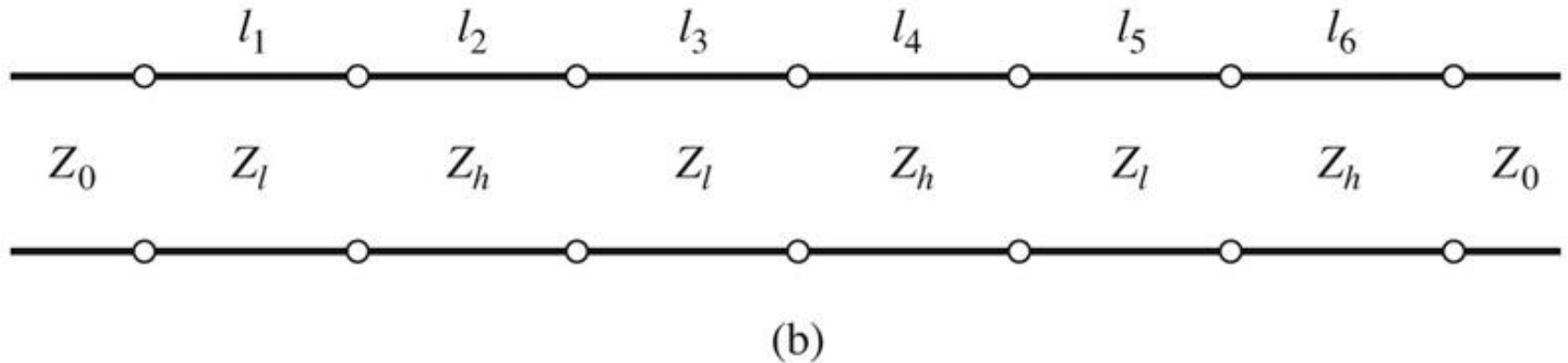


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.



Filtre cu variatii treapta a impedantei

- Nu toate liniile au aceeași lungime deci problema periodicității în frecvență a răspunsului este mai puțin importantă



Example

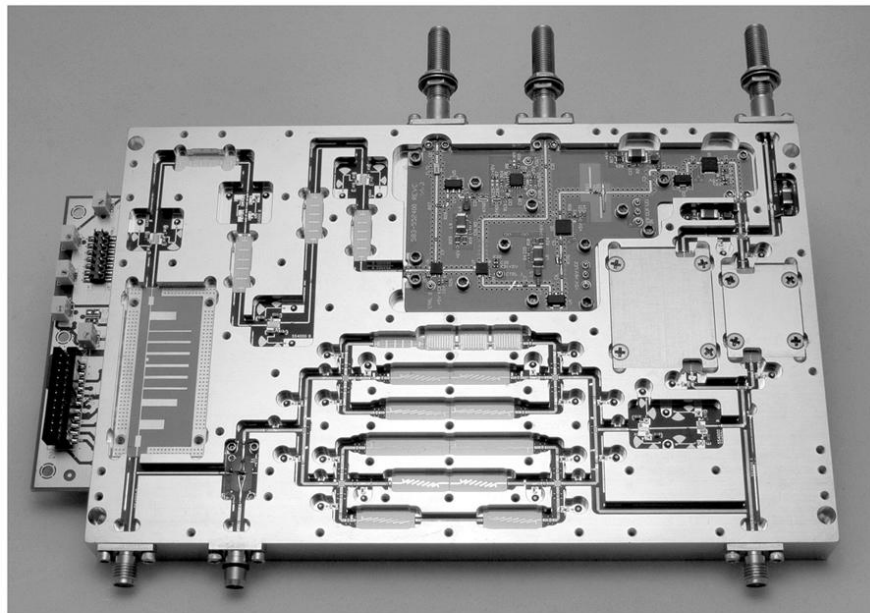
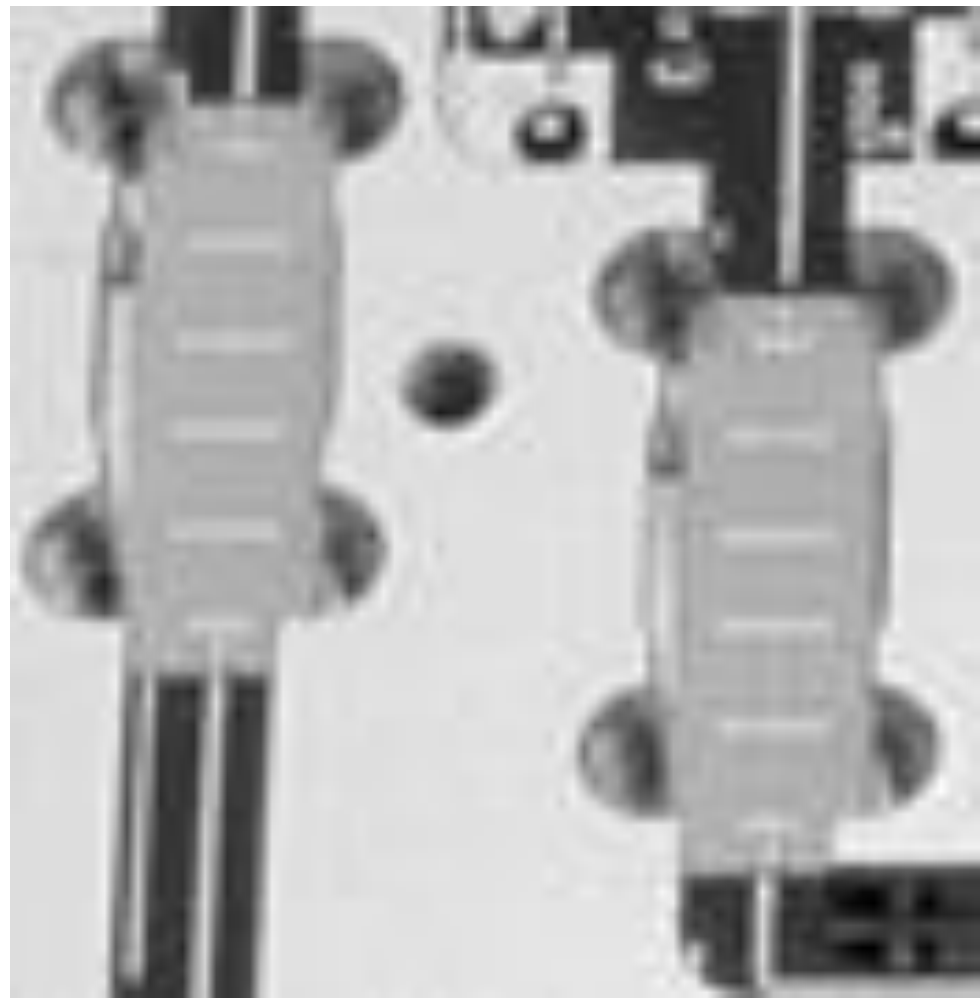


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.



Cuploare directionale si divizoare de putere

Cuploare/Divizoare

- Funcționalitatea dorită:
 - divizarea
 - combinarea
- puterii semnalului

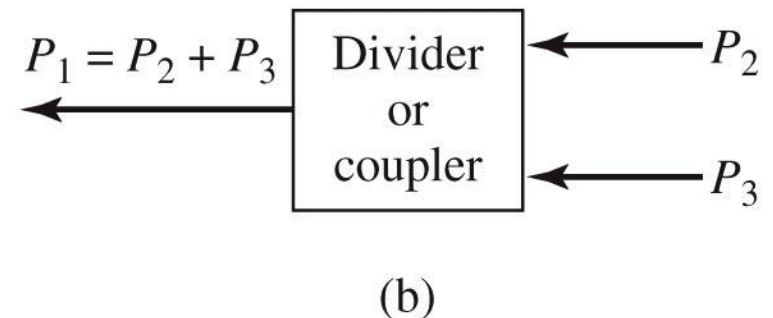
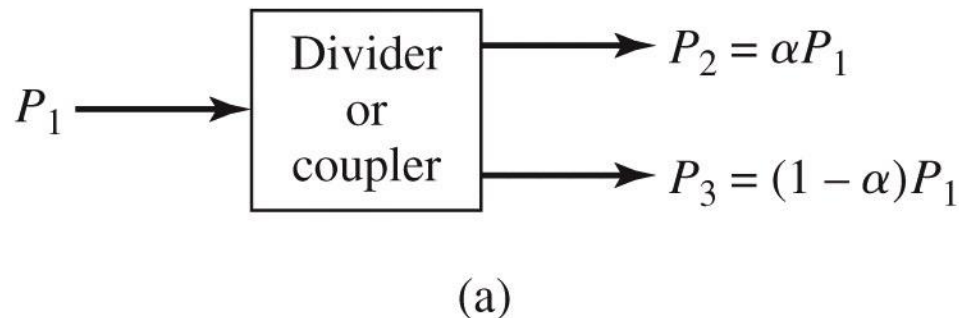


Figure 7.1
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Circuite cu trei porți

- numite si joncțiune in T
- caracterizate de o matrice \mathbf{S} 3x3

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

- 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 sa 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)
 - toată puterea introdusă pe un port se regăsește la celelalte porturi

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

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

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

Circuite cu trei porți

- circuit unitar (fără pierderi)

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

- 6 ecuatii / 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 solutie 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 posibilă
- Un circuit cu 3 porți **NU** poate fi simultan:
 - reciproc
 - fără pierderi
 - adaptat simultan la toate cele 3 porți
- Renunțarea la una din cele 3 condiții conduce la circuite realizabile

Circuit cu trei porți nereciproce

- de obicei cu materiale anizotrope, ferite
- **nereciproce**, 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 nereciproce

- doua solutii posibile
- circulatoare

- in sens orar direct

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

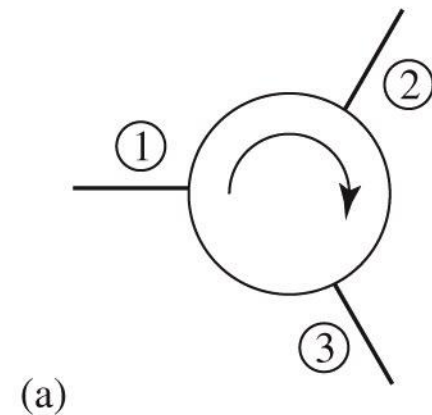
$$|S_{21}| = |S_{32}| = |S_{13}| = 1$$

- in sens orar invers

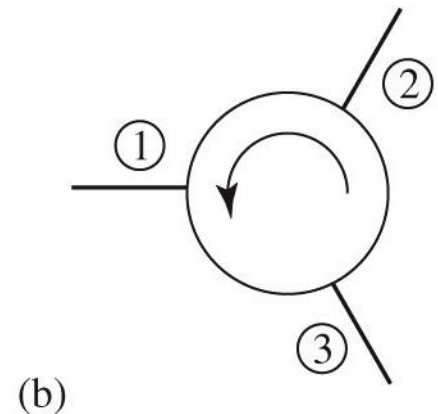
$$S_{21} = S_{32} = S_{13} = 0$$

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

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



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



Circuit cu trei porți neadaptat

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

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

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

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

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

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

$$|S_{13}| = |S_{23}|$$

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

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

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

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

Circuit cu trei porți neadaptat

- Un circuit cu 3 porți reciproc și fără pierderi

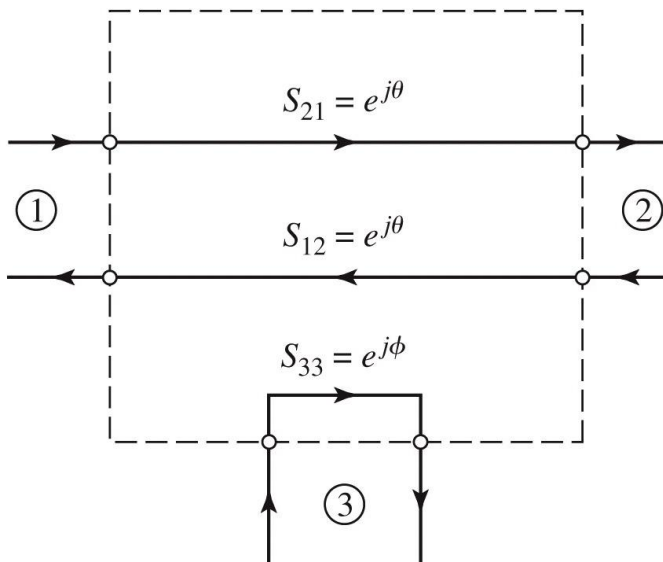
$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

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

$$S_{12} = e^{j\theta}$$

$$S_{33} = e^{j\phi}$$

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



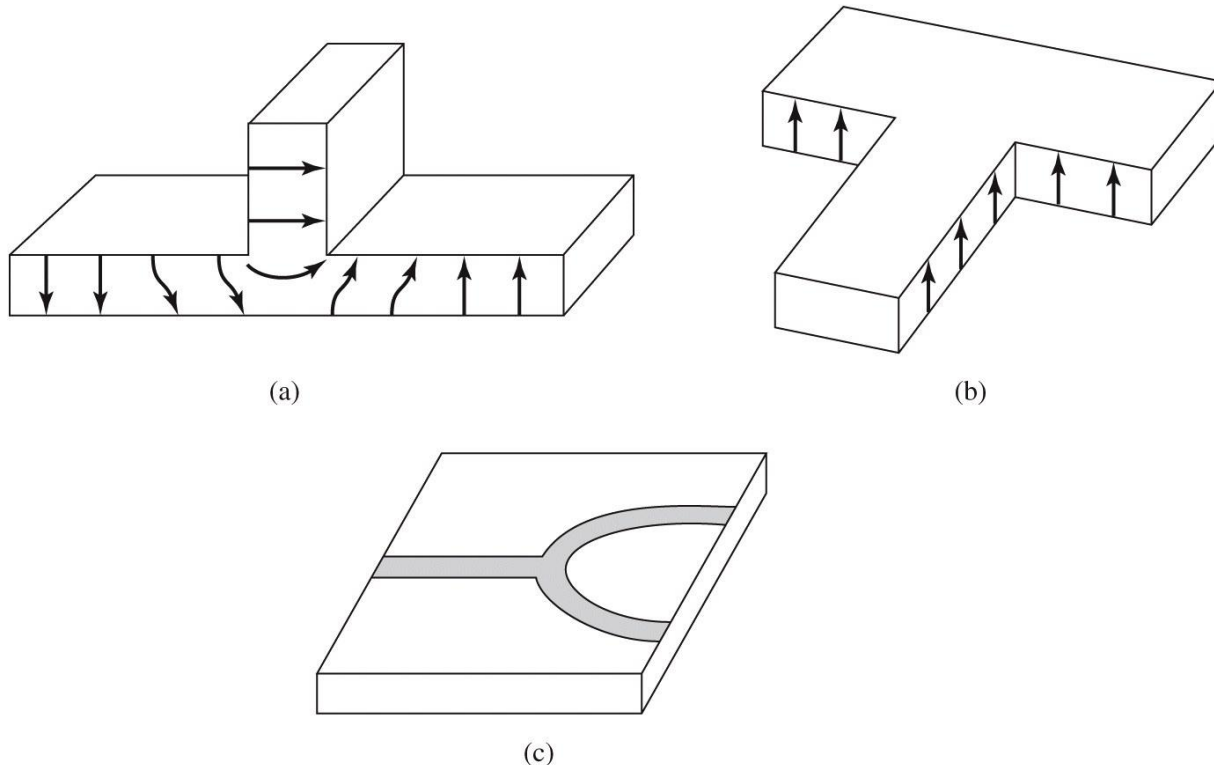
- Un circuit cu 3 porți reciproc și fără pierderi **degenerează** în două componente separate:

- o linie** fără pierderi, adaptată, între două dintre porturi
- al treilea **port** e **separat** și **dezadaptat**

Divizoare de putere

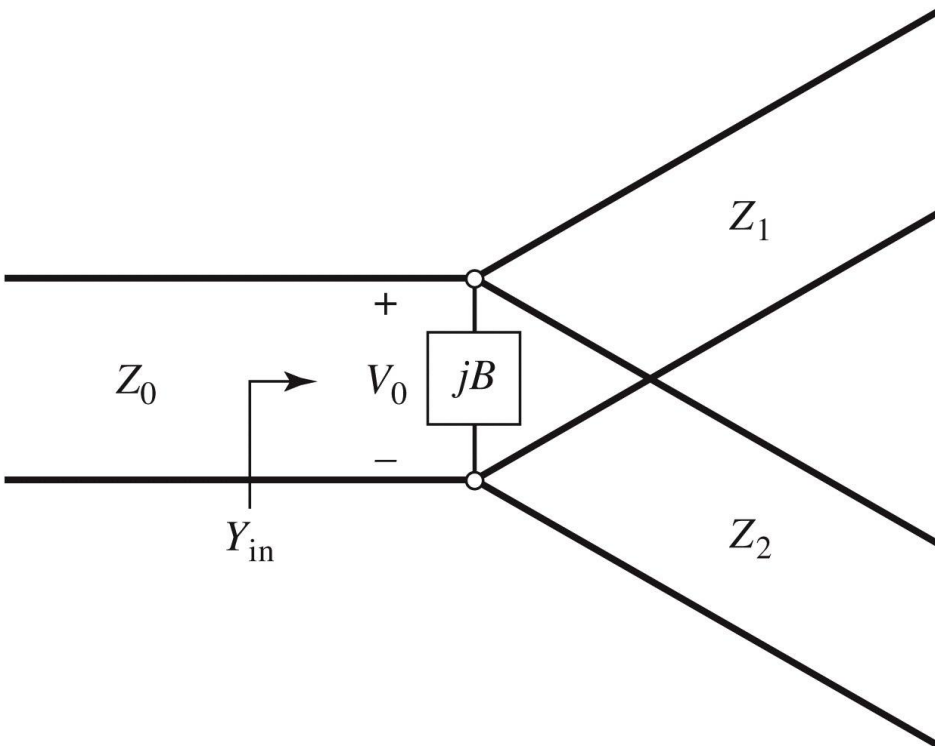
Divizarea de putere a jonctiunii in T

- consta in separarea unei linii incidente in doua linii separate
- se poate implementa in diverse tehnologii



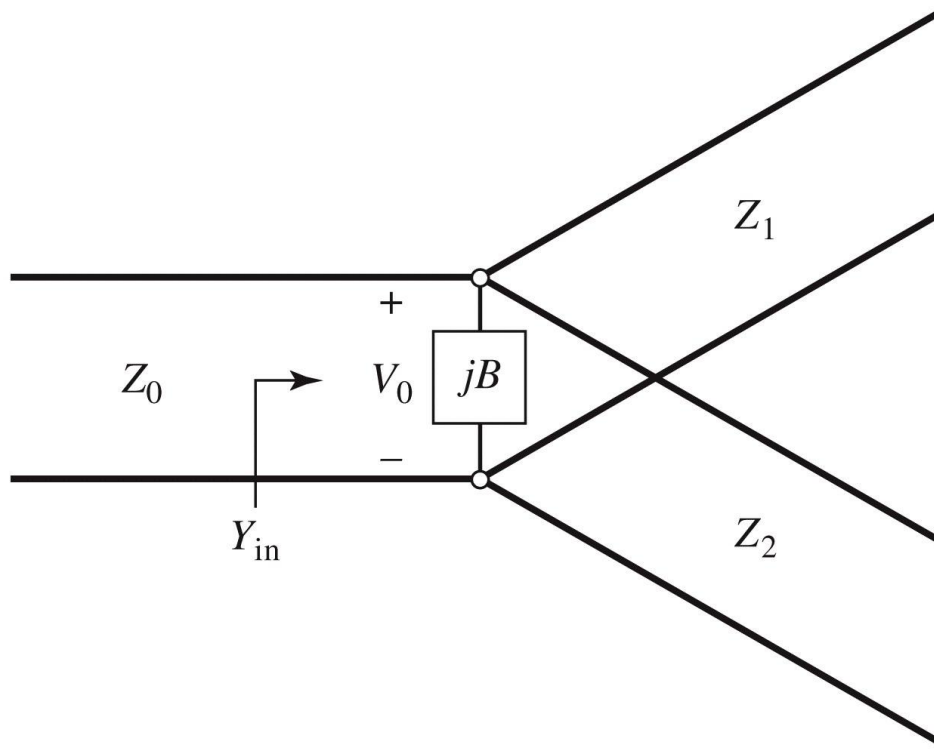
Divizarea de putere a jonctiunii in T

- dacă liniile sunt fără pierderi, diportul este reciproc, deci nu poate fi adaptat la toate porțile simultan



- la nivelul jonctiunii câmpurile sunt neuniforme, generând moduri de ordin superior localizate
- aceasta energie localizata poate fi modelata cu o reactanță concentrata 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, Cebîșev)

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, reglabila, cu efect macar intr-o banda ingusta de frecventa.

Divizarea de putere a jonctiunii in T

- daca V_0 e amplitudinea semnalului la jonctiune

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

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

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

deci:

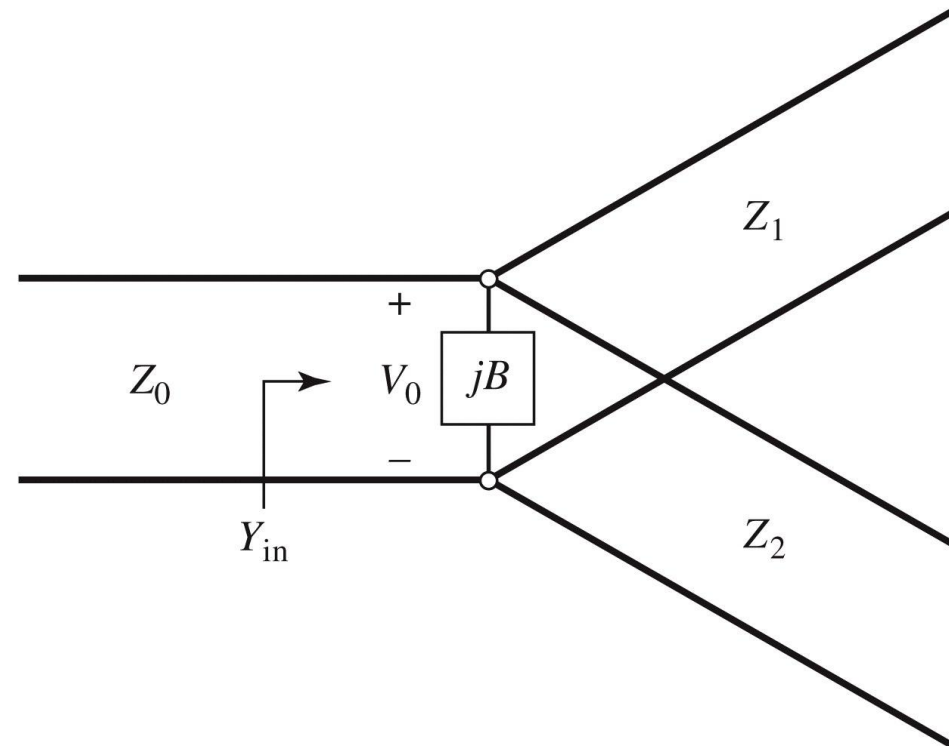
$$P_{in} = P_1 + P_2 \quad (\text{fara pierderi})$$

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

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

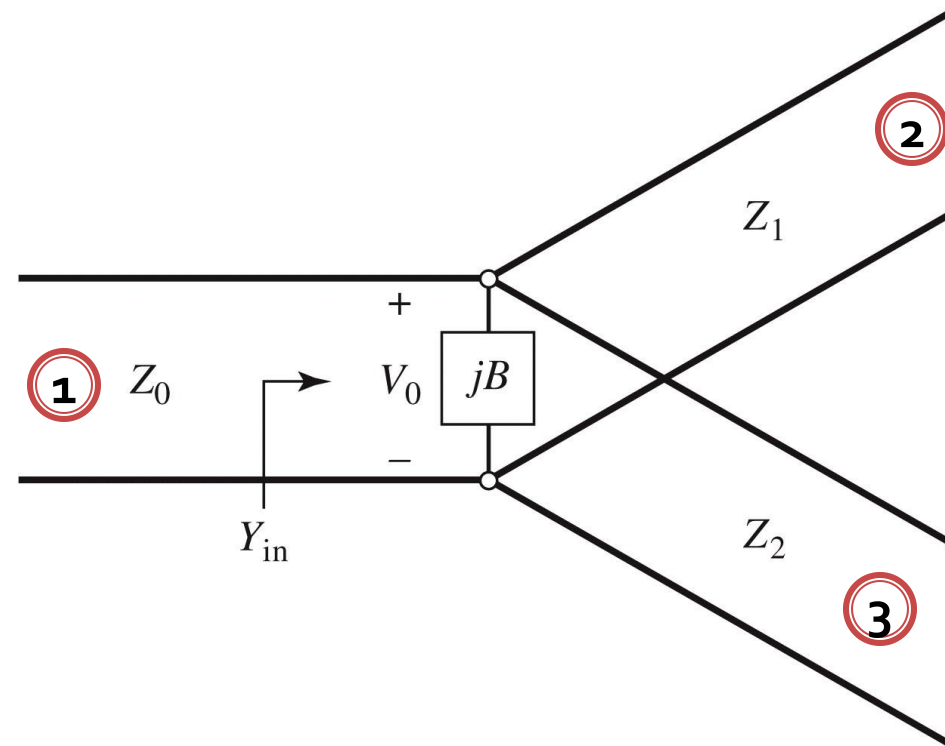
$$P_1 = P_{in} \cdot \frac{\alpha}{1 + \alpha} \quad P_2 = P_{in} \cdot \frac{1}{1 + \alpha}$$

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



Divizarea de putere a jonctiunii in T

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



$$P_2 = P_1 \cdot \frac{\alpha}{1 + \alpha} \quad S_{21} = S_{12} = \sqrt{\frac{\alpha}{1 + \alpha}}$$

$$P_3 = P_1 \cdot \frac{1}{1 + \alpha} \quad S_{31} = S_{13} = \sqrt{\frac{1}{1 + \alpha}}$$

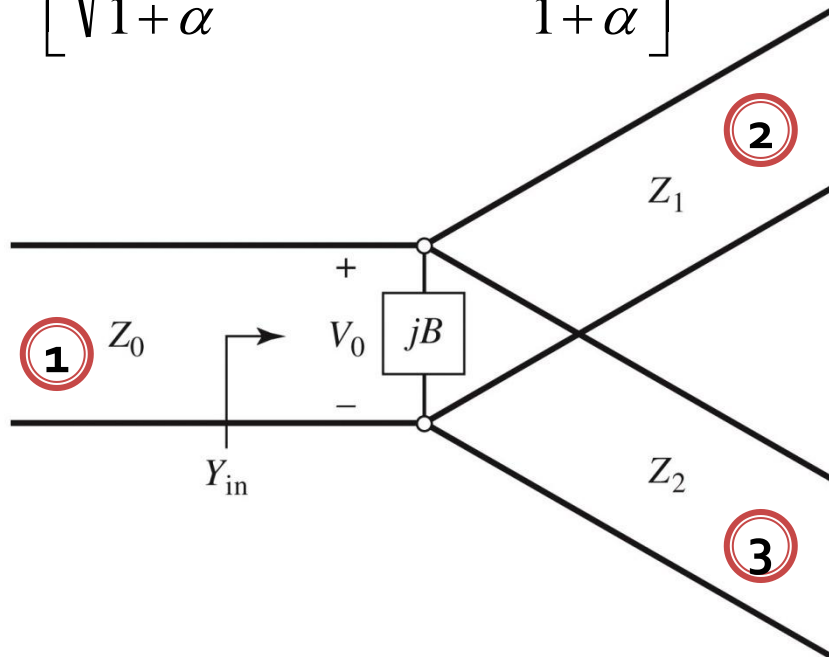
Coeficienti de reflexie la iesiri

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

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

Divizarea de putere a jonctiunii in T

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



Matrice unitara, coloanele 1 si 2

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

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

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

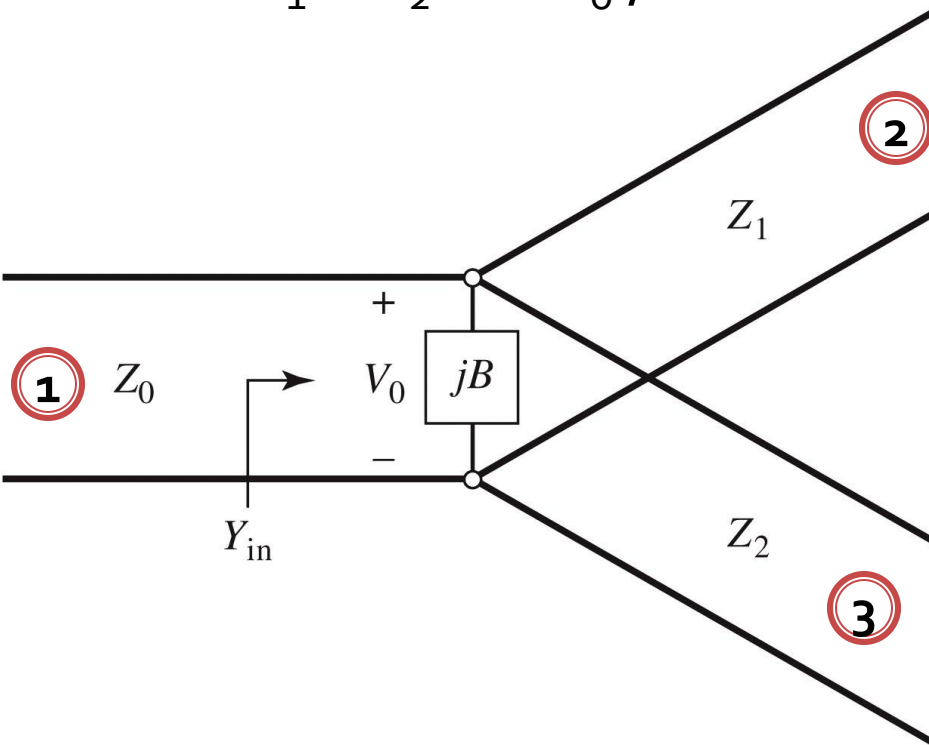
Divizarea de putere a jonctiunii in T

- 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 .

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

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

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

Verificare

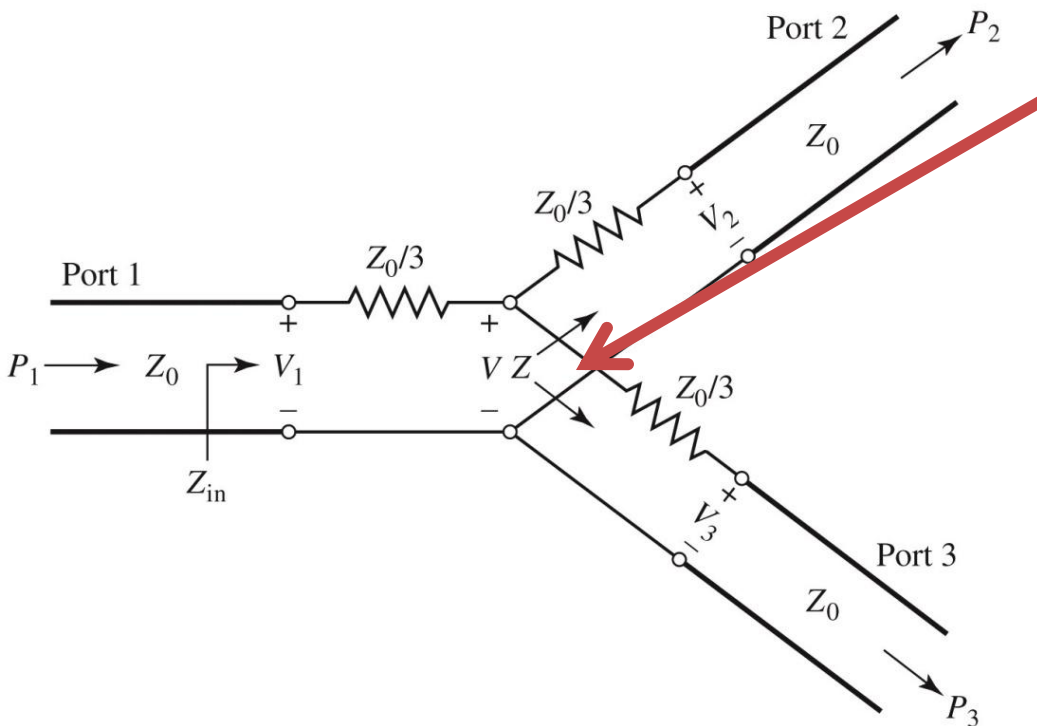
$$Z_{in} = 40\Omega \parallel 120\Omega = 30\Omega$$

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

$$Z_c^1 = \sqrt{Z_1 \cdot Z_L} = \sqrt{120\Omega \cdot 30\Omega} = 60\Omega \quad Z_c^2 = \sqrt{Z_2 \cdot Z_L} = \sqrt{40\Omega \cdot 30\Omega} = 34.64\Omega$$

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

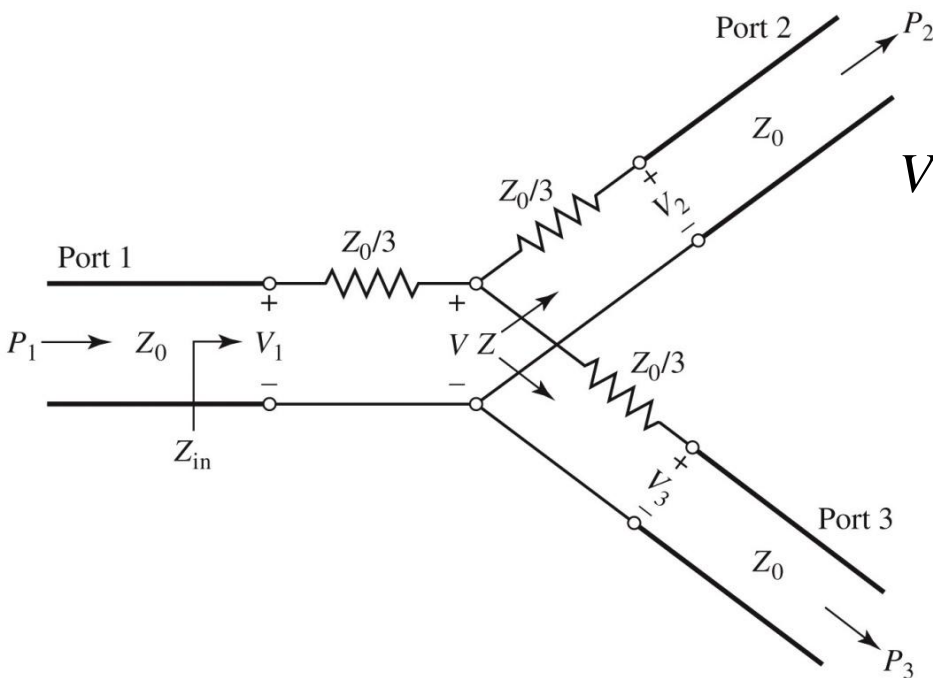
$$Z_{in} = \frac{Z_0}{3} + \frac{1}{2} \cdot \frac{4Z_0}{3} = Z_0$$

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 simetrica)
 - 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 iesire se obtin tot prin divizare:

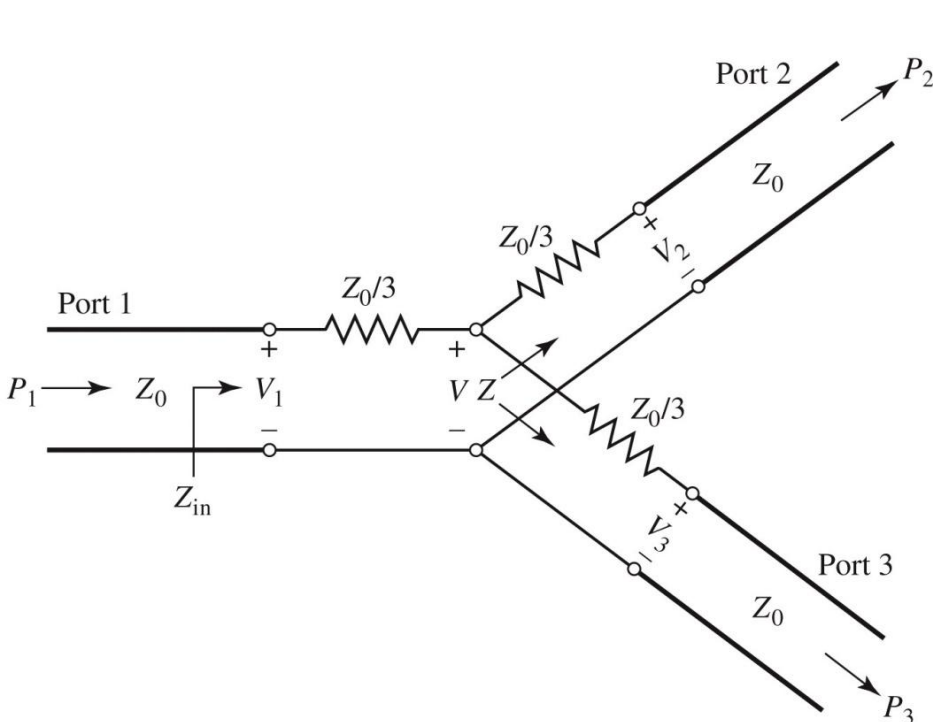
$$V_2 = V_3 = V \cdot \frac{Z_0}{Z_0 + Z_0/3} = \frac{3}{4} \cdot V = \frac{1}{2} \cdot V_1$$

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

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 simetrica) $S_{21} = S_{31} = S_{23} = \frac{1}{2}$
 - adaptat la toate cele porti $S_{11} = S_{22} = S_{33} = 0$



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

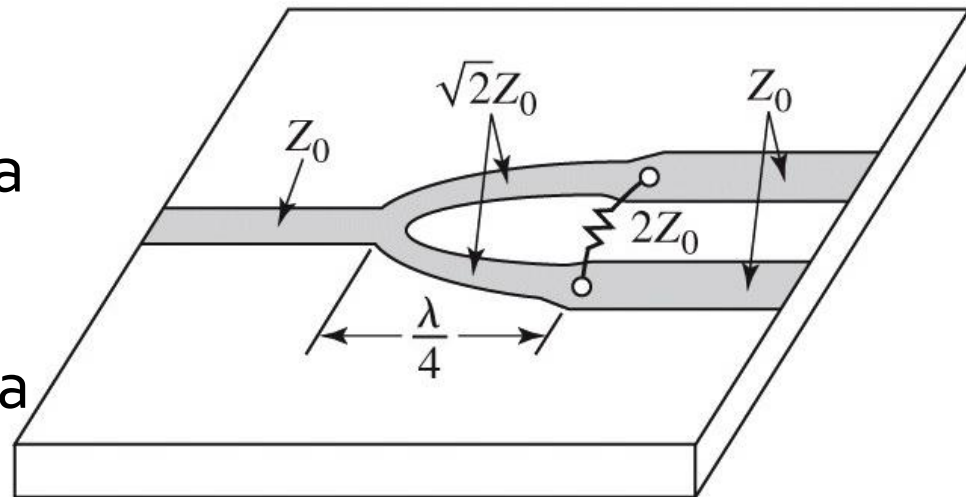
Puteri:
$$P_{in} = \frac{1}{2} \cdot \frac{V_1^2}{Z_0}$$

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

Jumatate din putere se disipa pe cei 3 rezistori

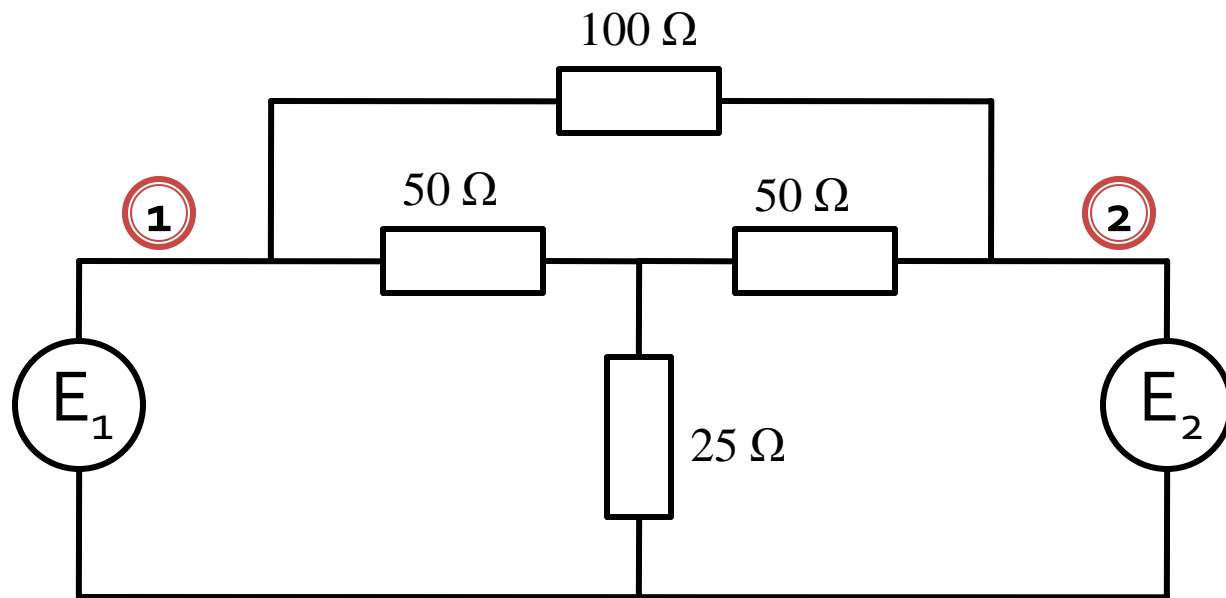
Divizorul de putere Wilkinson

- Divizoarele de putere anterioare au un dezavantaj major, nu exista **izolare** între cele doua porturi de iesire $S_{23} = S_{32} \neq 0$
 - acest deziderat e important in anumite aplicatii
- Divizorul Wilkinson este introdus pentru rezolvarea acestui impediment
 - o proprietate utila suplimentara este ca "pare" fara pierderi daca porturile de iesire sunt adaptate
 - numai energia reflectata din iesiri este disipata



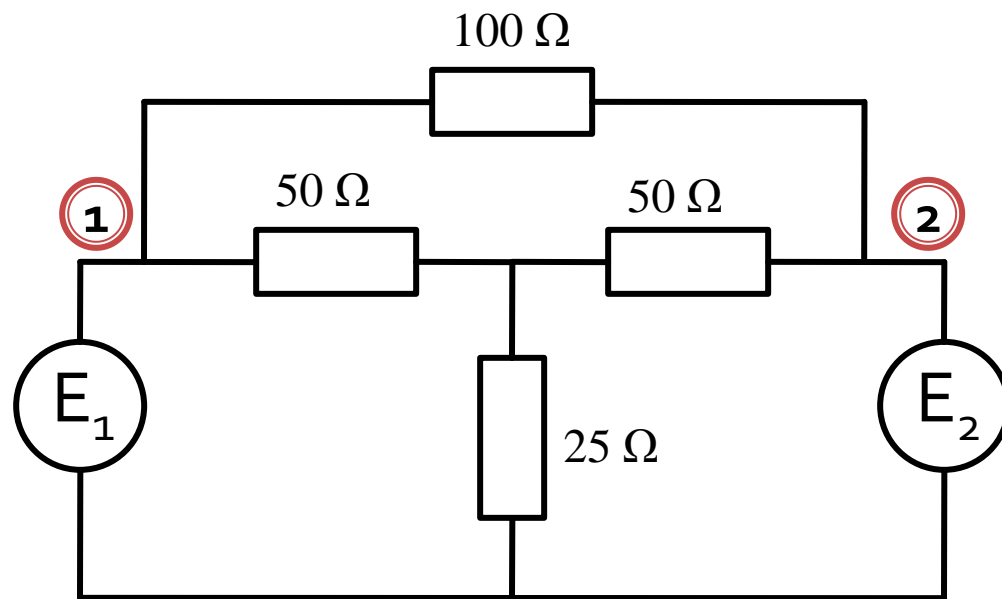
Analiza pe mod par/impar (even/odd)

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



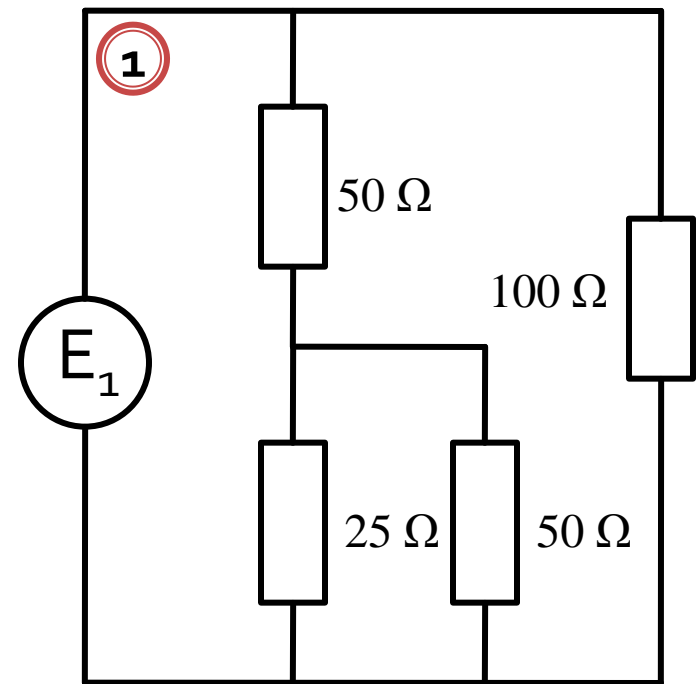
Analiza pe mod par/impar (even/odd)

- presupunem ca doresc Y_{11} $Y_{11} = \frac{I_1}{V_1} \Big|_{V_2=0}$
- $E_2 = 0$



$$R_{ech} = 100\Omega \parallel (50\Omega + 25\Omega \parallel 50\Omega) =$$

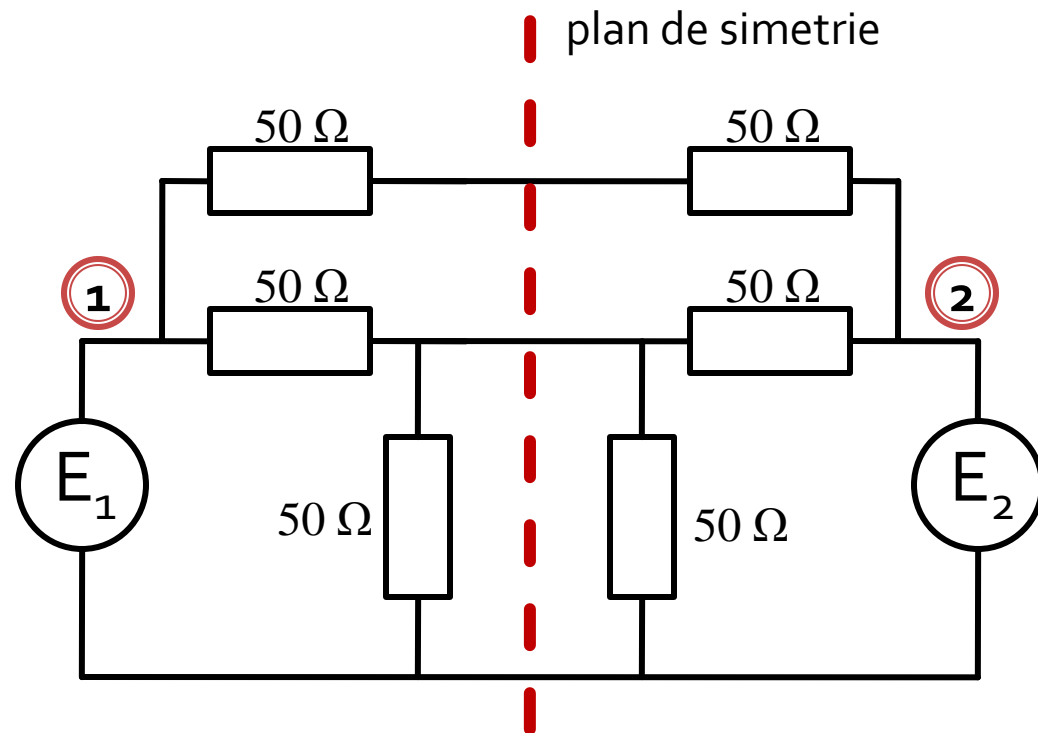
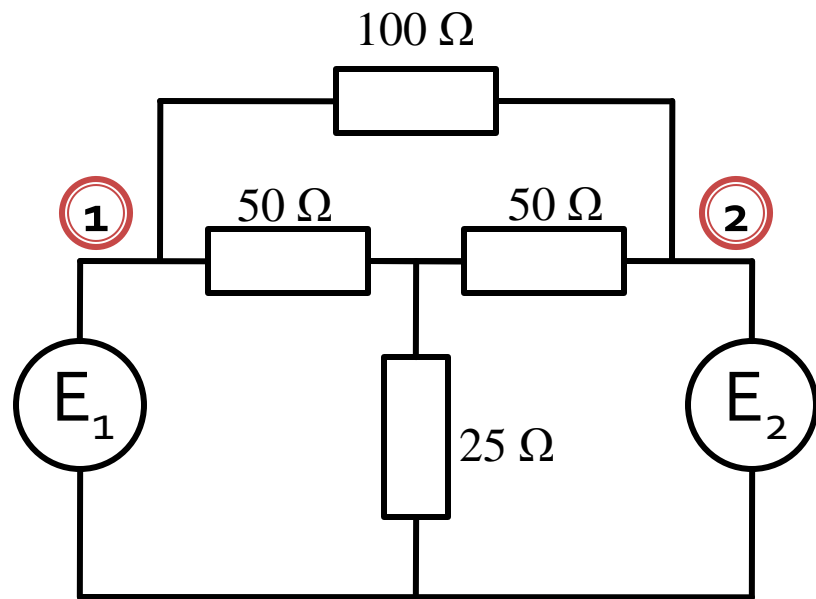
$$= 100\Omega \parallel (50\Omega + 16.67\Omega) = 100\Omega \parallel 66.67\Omega = 40\Omega$$



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

Analiza pe mod par/impar (even/odd)

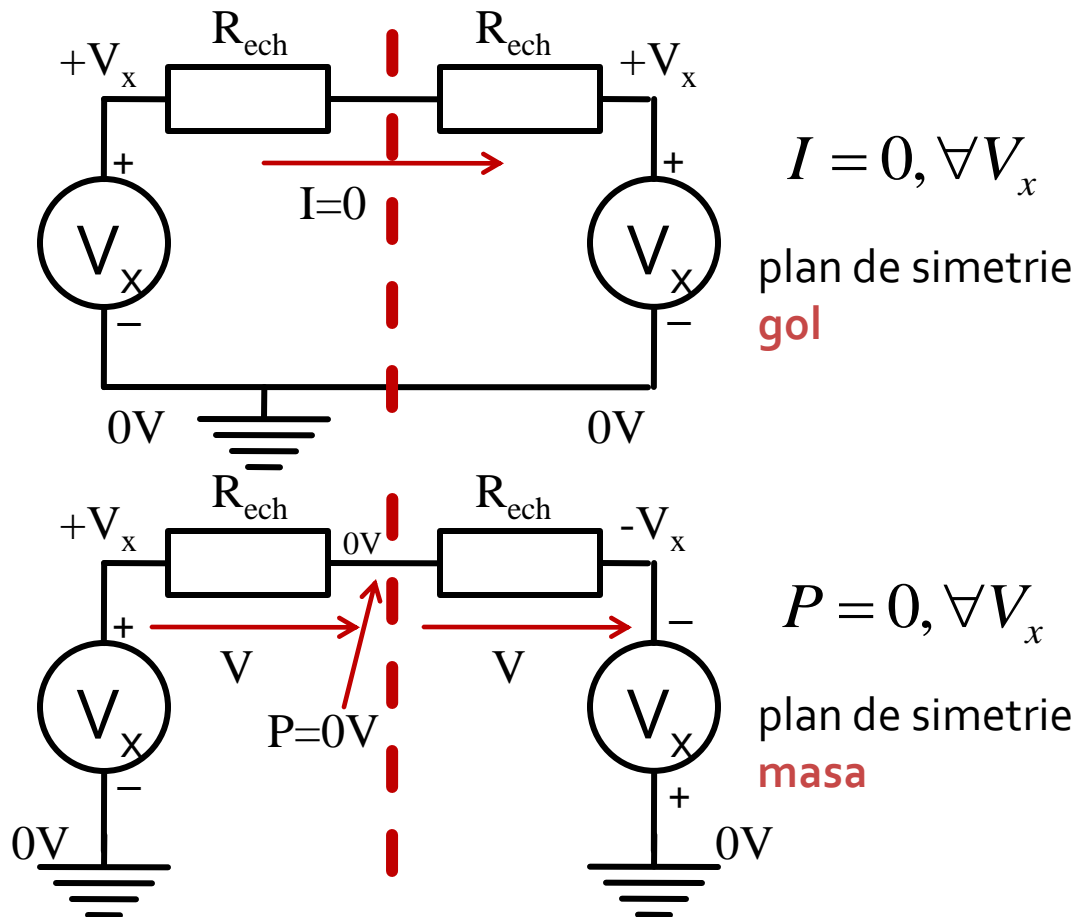
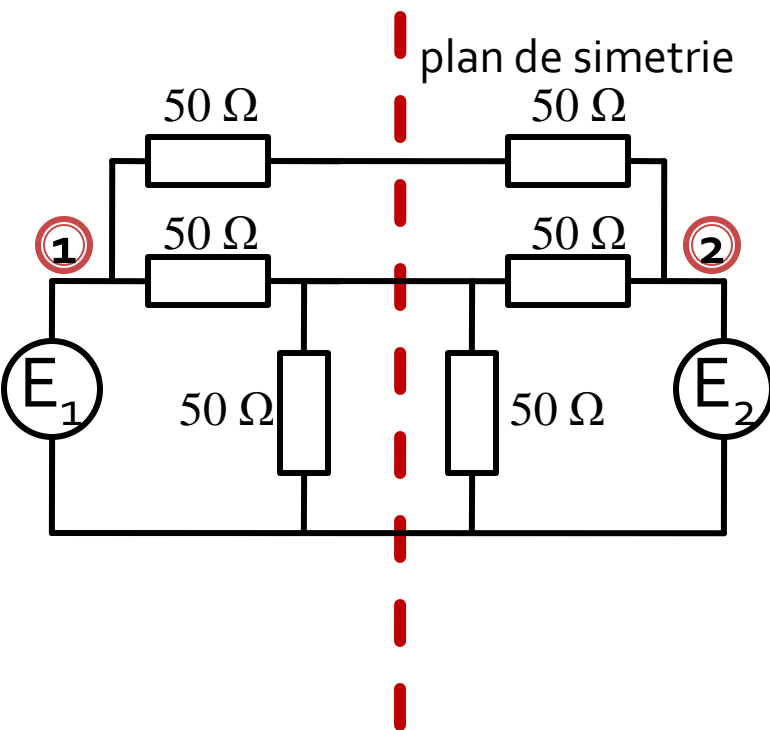
- analiza pe mod par/impar beneficiaza de existenta in circuit a unor plane de simetrie
 - initiale
 - create



Analiza pe mod par/impar (even/odd)

- la atacul porturilor cu surse simetrice/antisimetrice planele de simetrie se transforma in

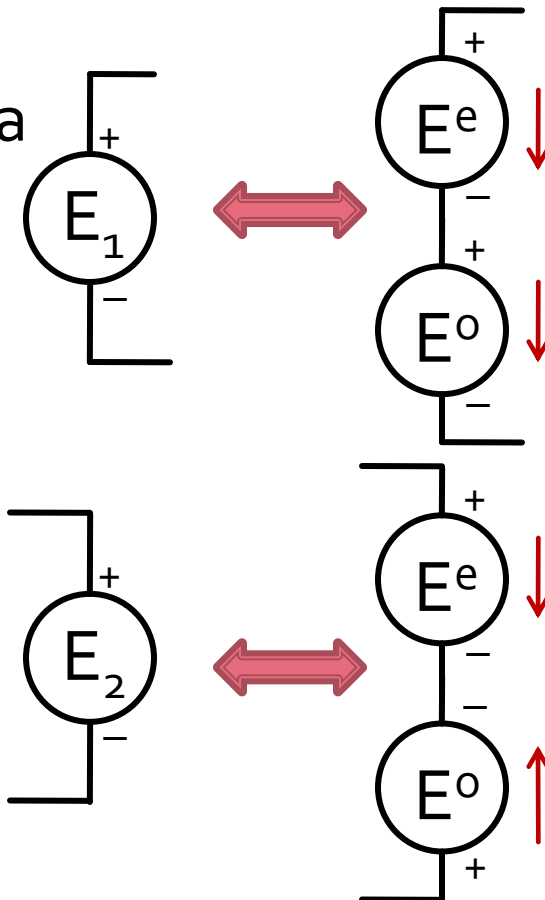
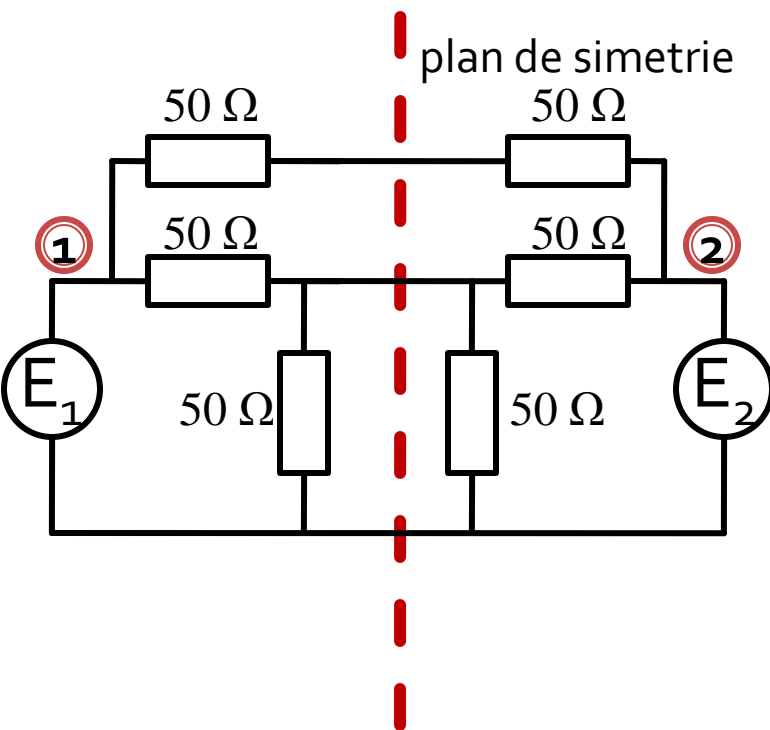
- gol virtual
- masa virtuala



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

$$\text{Efect} (\text{Sursa1} + \text{Sursa2}) = \text{Efect} (\text{Sursa1}) + \text{Efect} (\text{Sursa2})$$

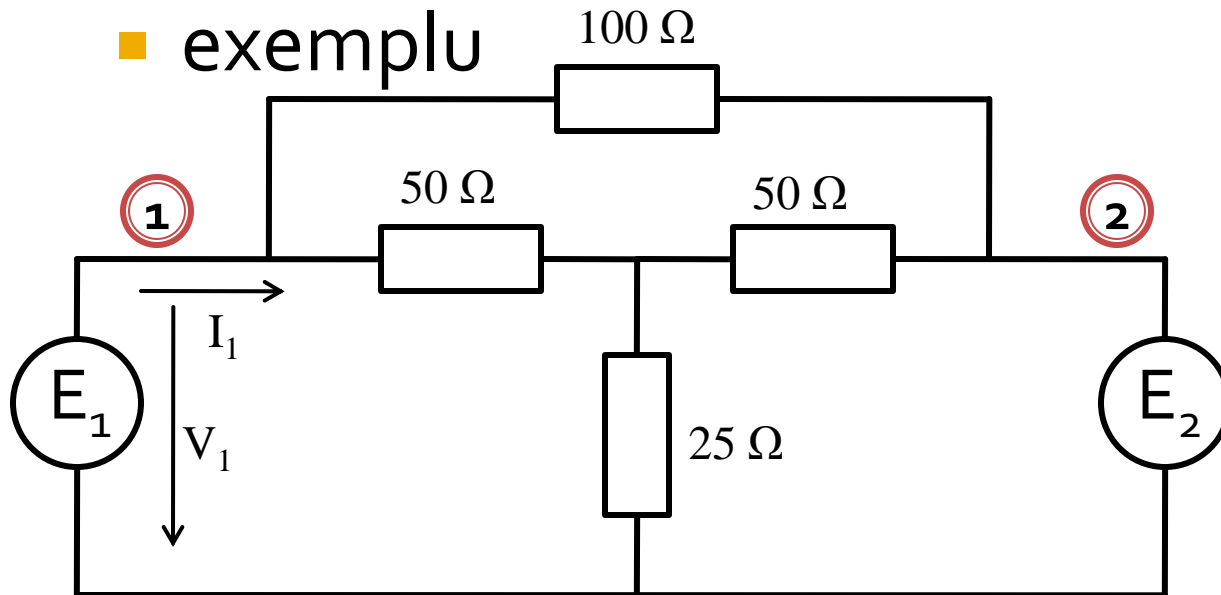
$$\text{Efect} (\text{PAR} + \text{IMPAR}) = \text{Efect} (\text{PAR}) + \text{Efect} (\text{IMPAR})$$



Putem beneficia de avantajele simetriilor!!

Analiza pe mod par/impar (even/odd)

■ exemplu

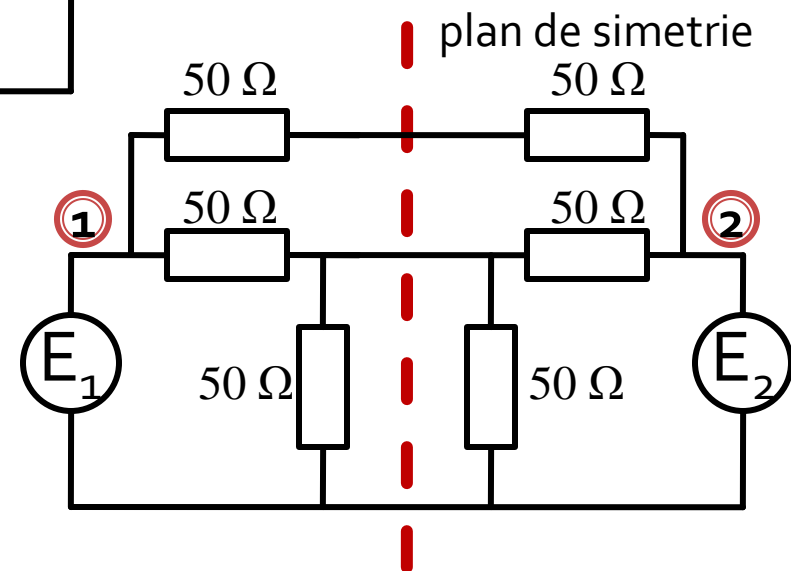


$$Y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2=0}$$

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

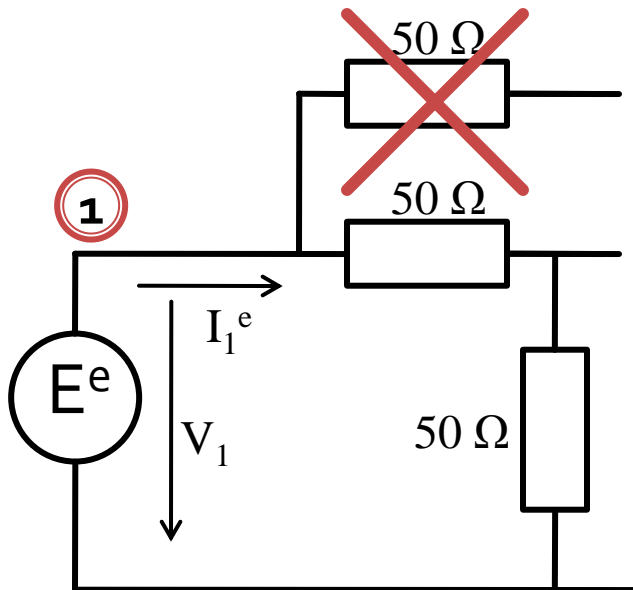
$$E^e = \frac{E_1}{2}$$

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



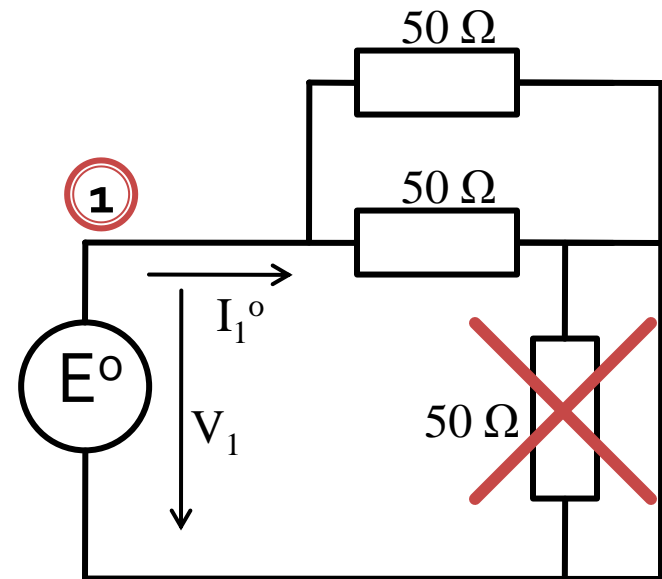
Analiza pe mod par/impar (even/odd)

- analiza pe mod par/impar



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

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

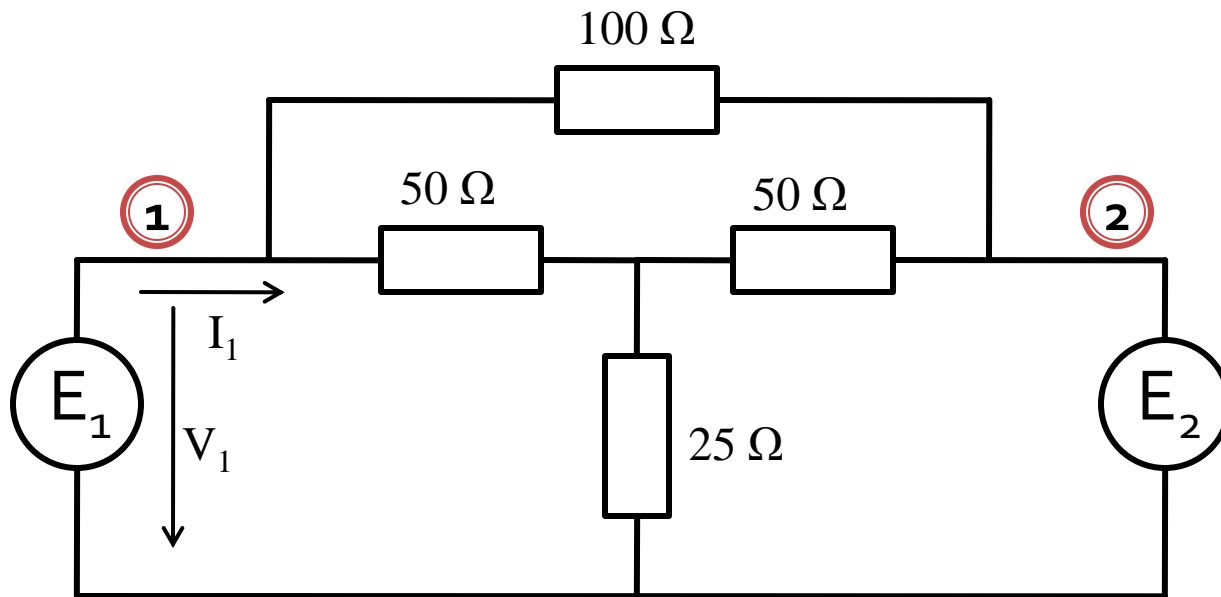


$$R_{ech}^o = 50\ \Omega \parallel 50\ \Omega = 25\ \Omega$$

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

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)

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

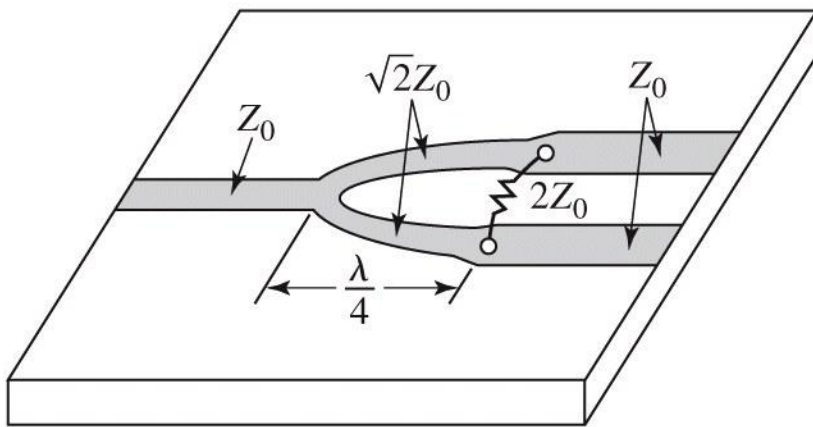
$$\text{Efect} (\text{PAR} + \text{IMPAR}) = \text{Efect} (\text{PAR}) + \text{Efect} (\text{IMPAR})$$



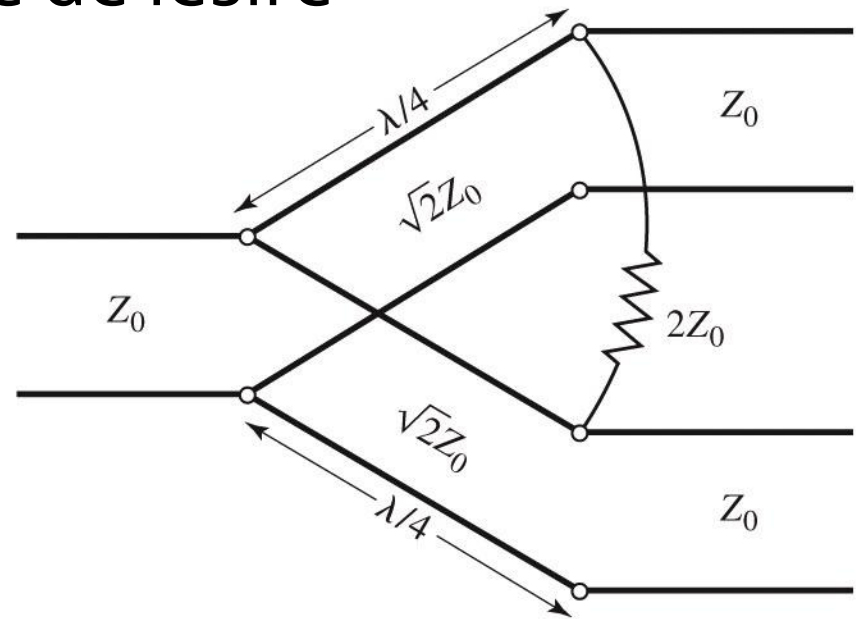
Putem beneficia de avantajele simetriilor!!

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"

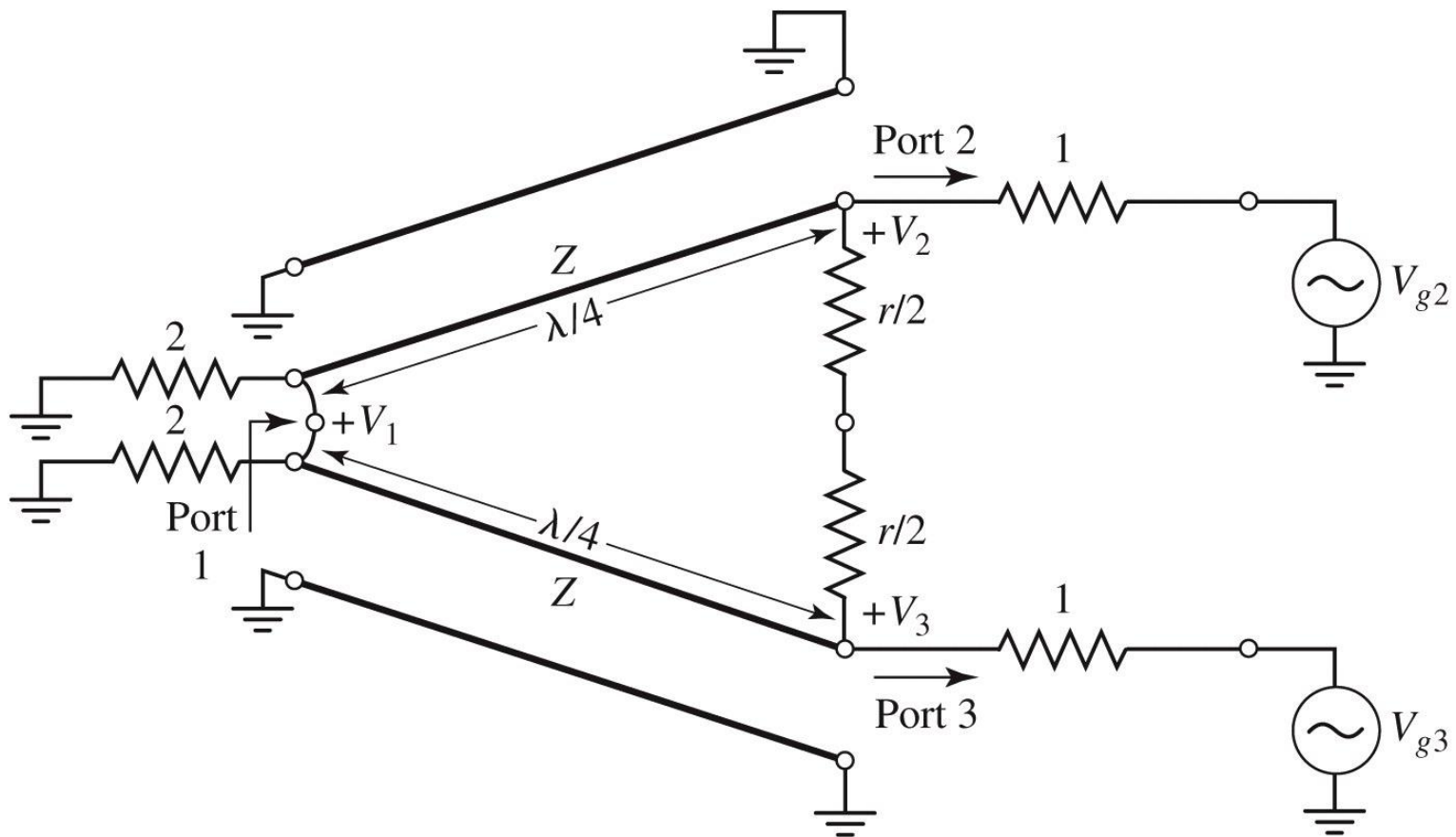
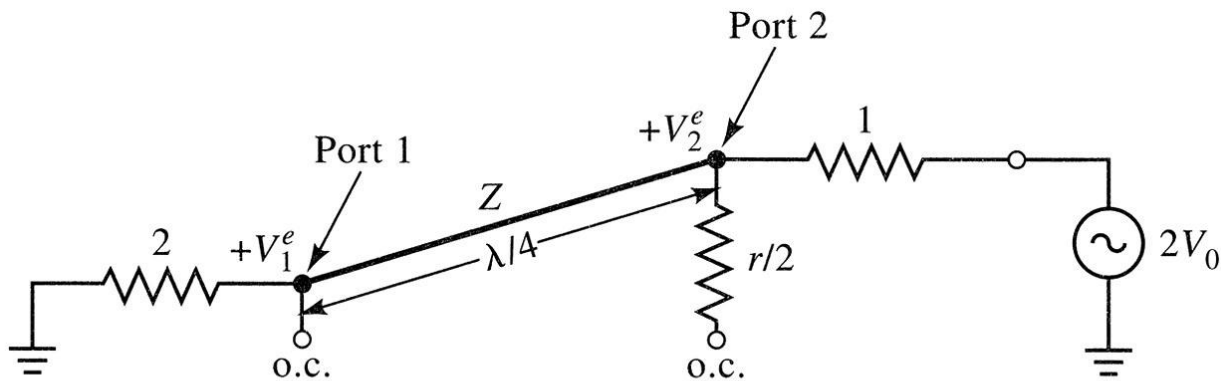


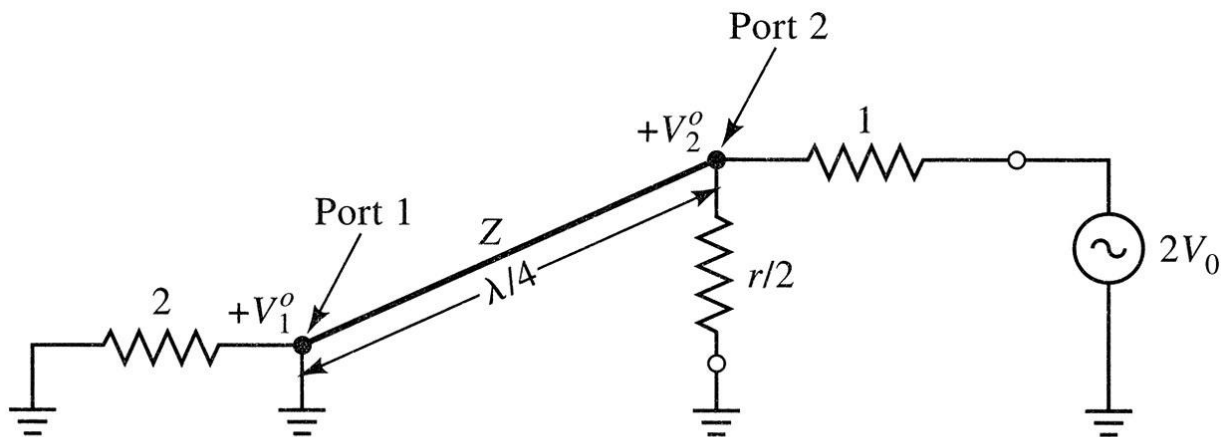
Figure 7.9

Divizorul de putere Wilkinson

- analiza pe mod par si impar



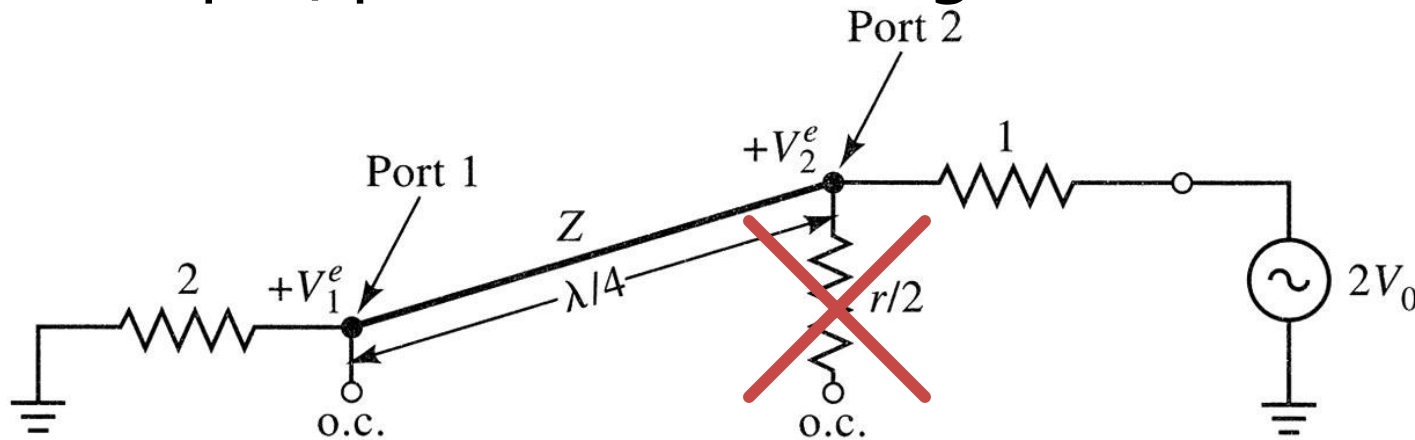
(a)



(b)

Divizorul de putere Wilkinson

- mod par, plan de simetrie gol



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

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

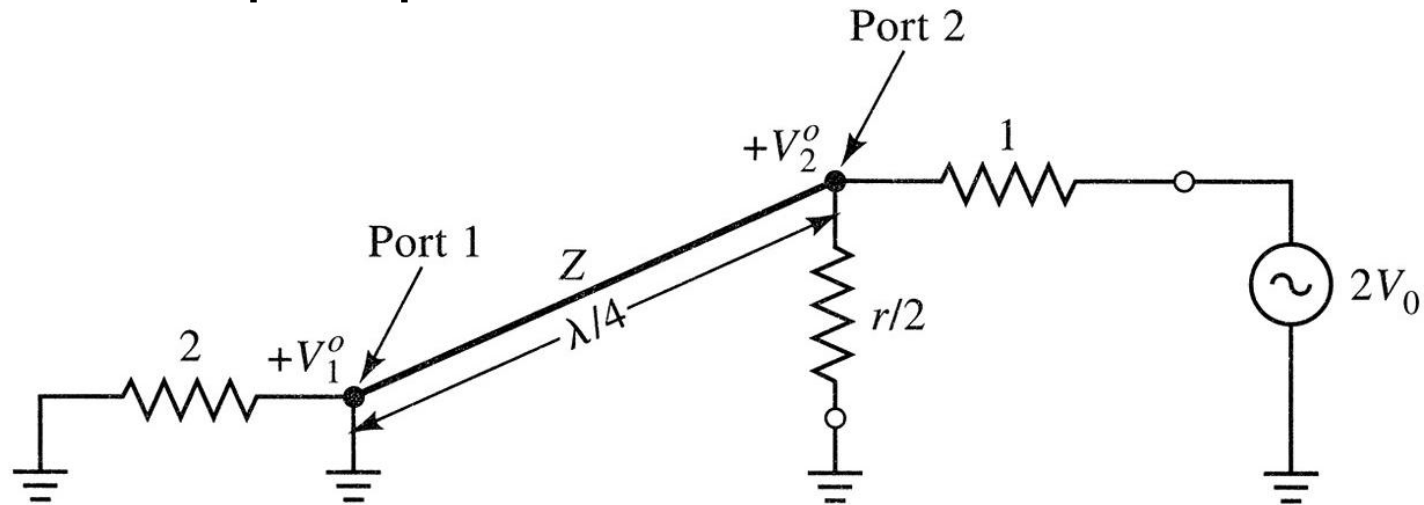
$$V_2^e = V(-\lambda/4) = jV^+ \cdot (1 - \Gamma) = V_0 \quad V_1^e = V(0) = V^+ \cdot (1 + \Gamma) = jV_0 \cdot \frac{\Gamma + 1}{\Gamma - 1}$$

$Z_{in2}^e = 1$

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



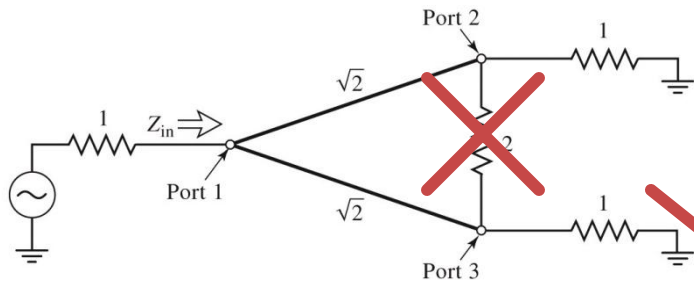
linia in $\lambda/4$ este scurtcircuitata la capat
 impedanta vazuta dinspre portul 2 este ∞ $Z_{in2}^o = r/2$ daca $r = 2$ portul 2 este adaptat

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

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

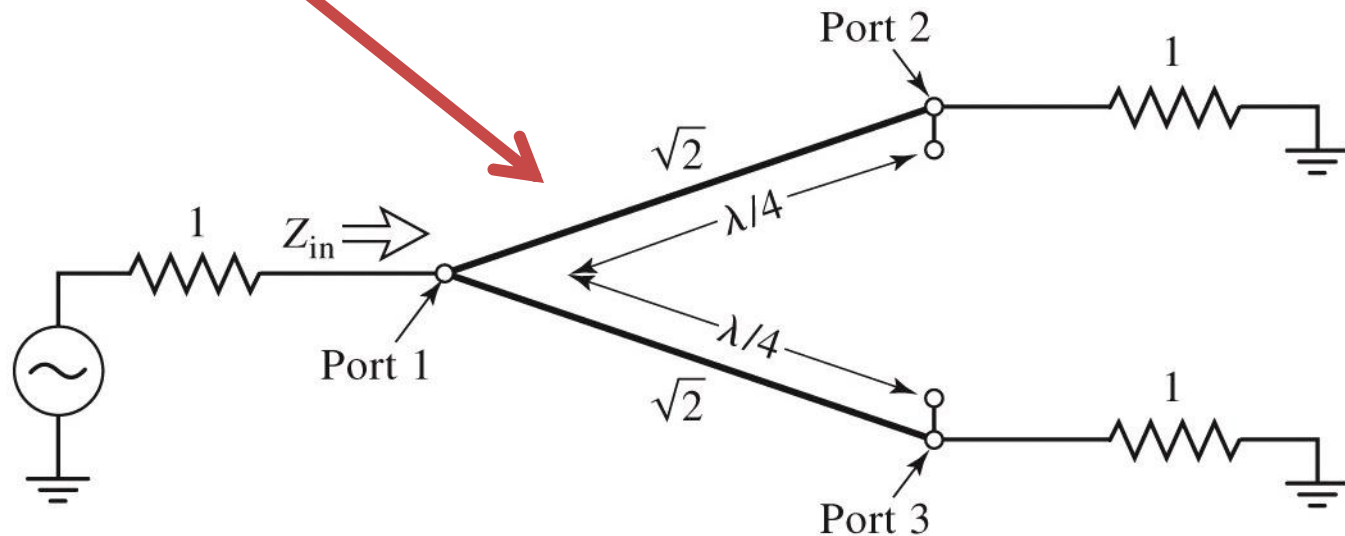
Divizorul de putere Wilkinson

- 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

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

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

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

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

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

Divizorul de putere Wilkinson

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

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

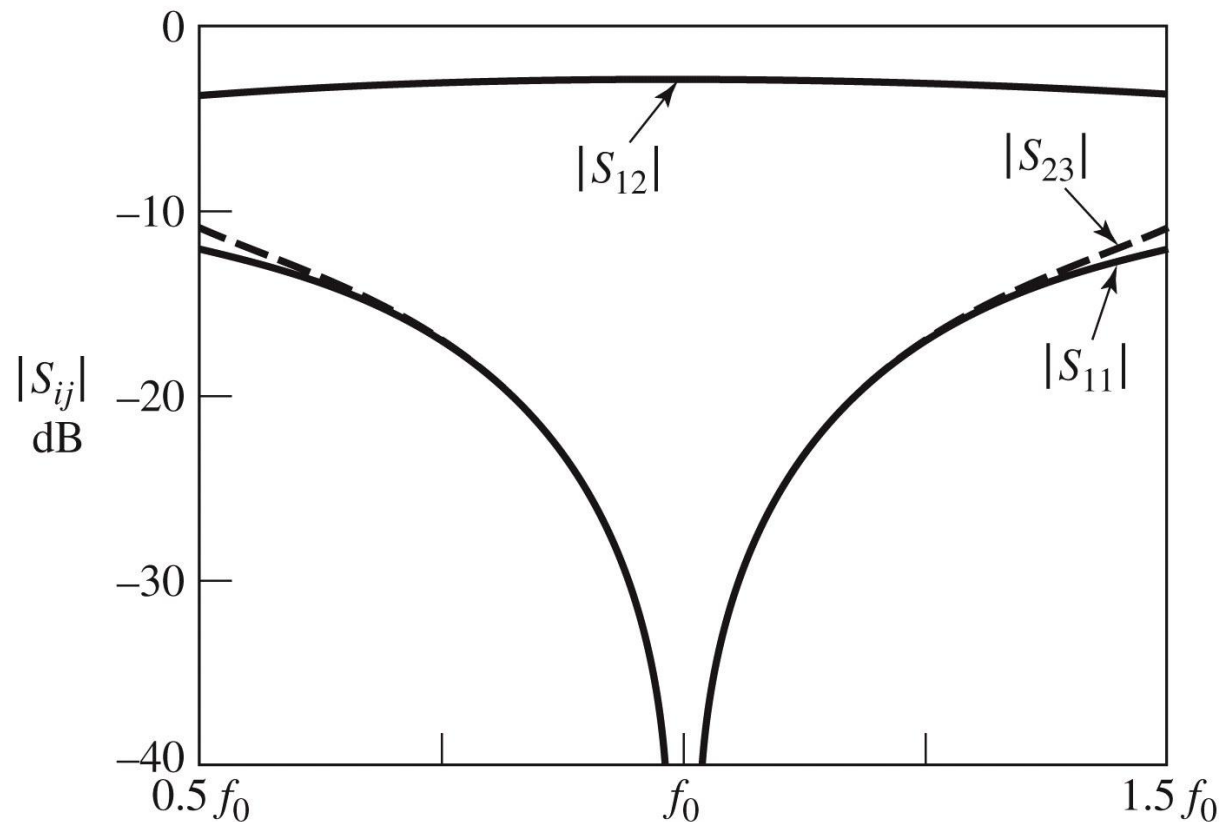


Figure 7.12
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Divizorul de putere Wilkinson

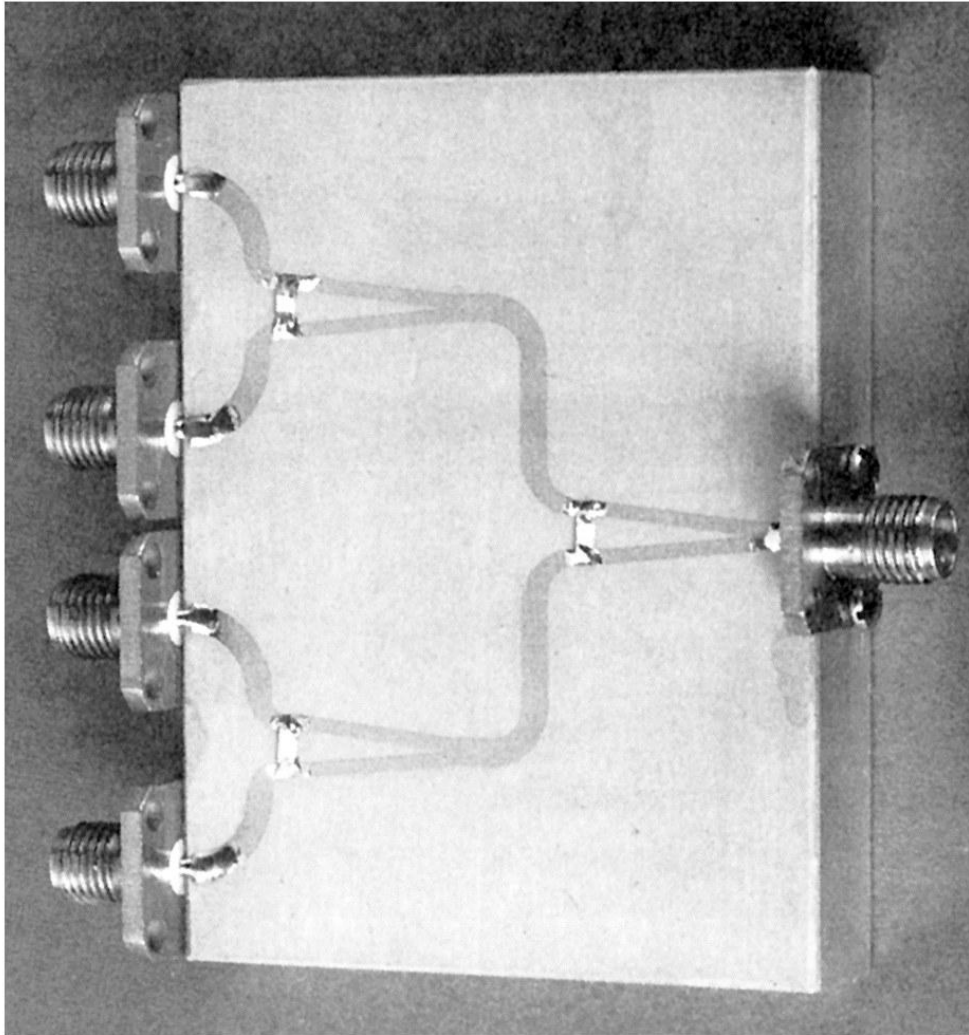
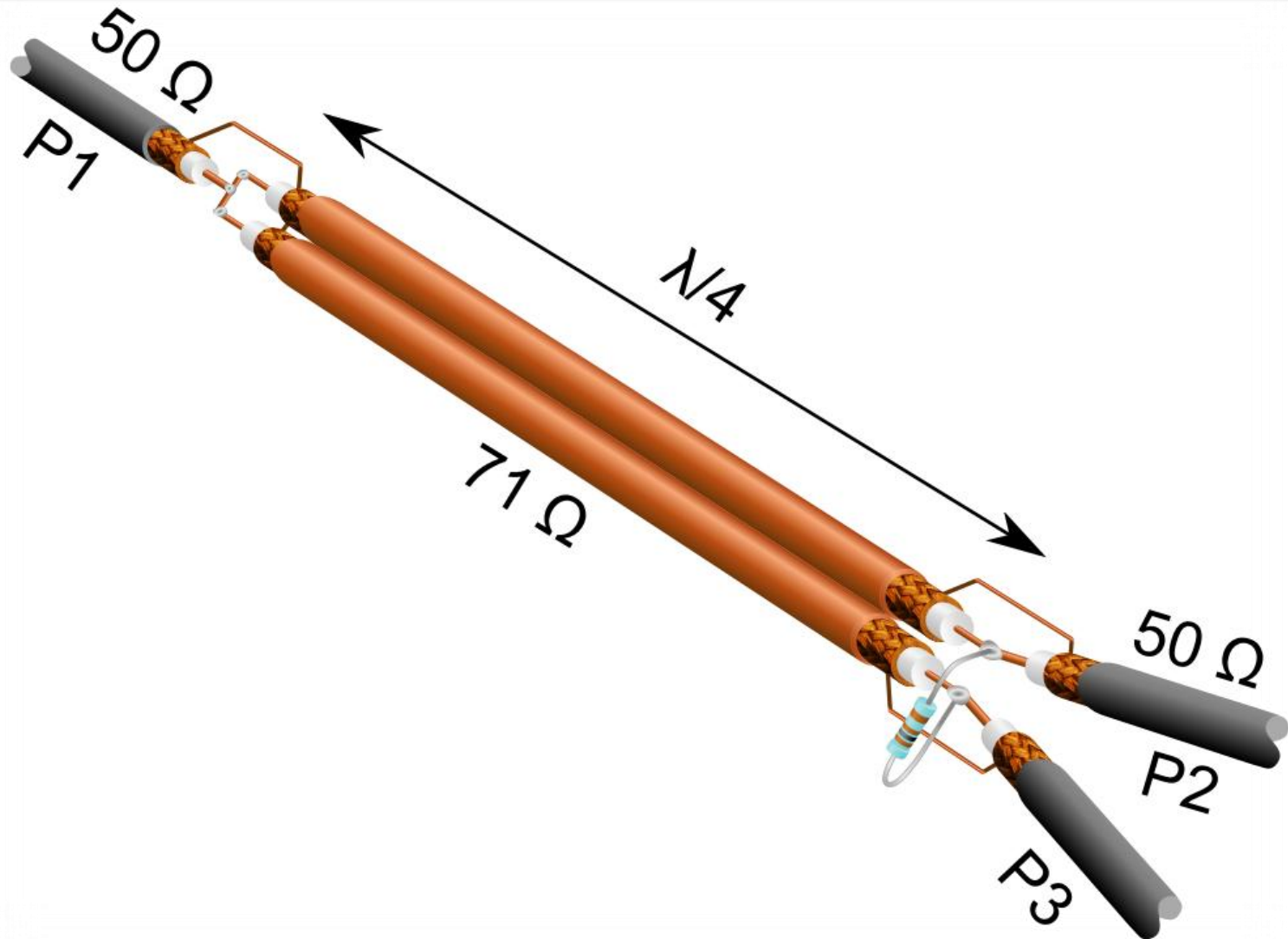


Figure 7.15
Courtesy of M. D. Abouzahra, MIT Lincoln Laboratory, Lexington, Mass.

Divizorul de putere Wilkinson



Cuploare directionale

Circuite cu patru porți

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

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

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

Circuite cu patru porți

- circuit reciproc

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

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

- adaptat simultan la toate portile

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

- matricea S devine:

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

Circuite cu patru porți

- reciproc, adaptat, matricea S :

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

- circuit unitar (fără pierderi)
 - toată puterea introdusă pe un port se regăsește la celelalte porturi

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

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

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

Circuite cu patru porți

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

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

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

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

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

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

- o soluție: $S_{14} = S_{23} = 0$
- cuplorul rezulta **directional**

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

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

$$|S_{13}|^2 + |S_{34}|^2 = 1 \quad \rightarrow \quad |S_{12}| = |S_{34}|$$

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

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

Circuite cu patru porți

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

β – coeficientul de cuplaj în tensiune

■ Alegem referintele de faza

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

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

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

- Cealalta solutie posibila pentru ecuatiile anterioare ofera fie aceeași solutie (cu alta referinta de faza) fie un caz degenerat

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

Circuite cu patru porți

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

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

Circuite cu patru porți

- 2 cazuri mai des intalnite in practica

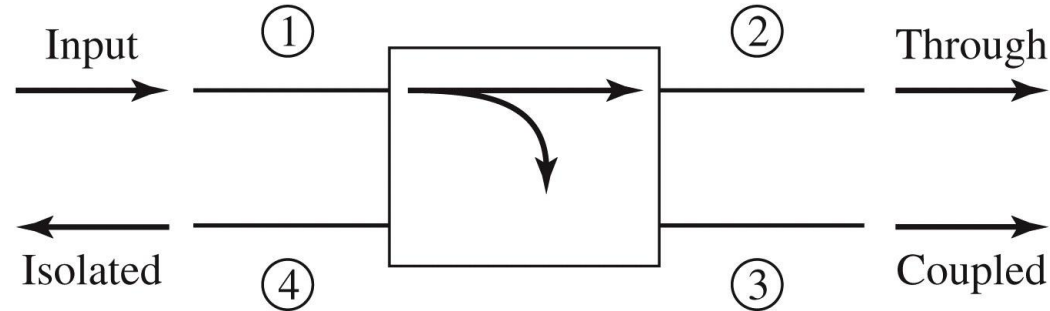
- cuplor simetric $\theta = \phi = \pi/2$

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

- cuplor asimetric $\theta = 0, \phi = \pi$

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

Cuplor 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

Cuplorul hibrid este cuplorul directional de 3 dB

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

Cuplor hibrid in cuadratura

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

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

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°)

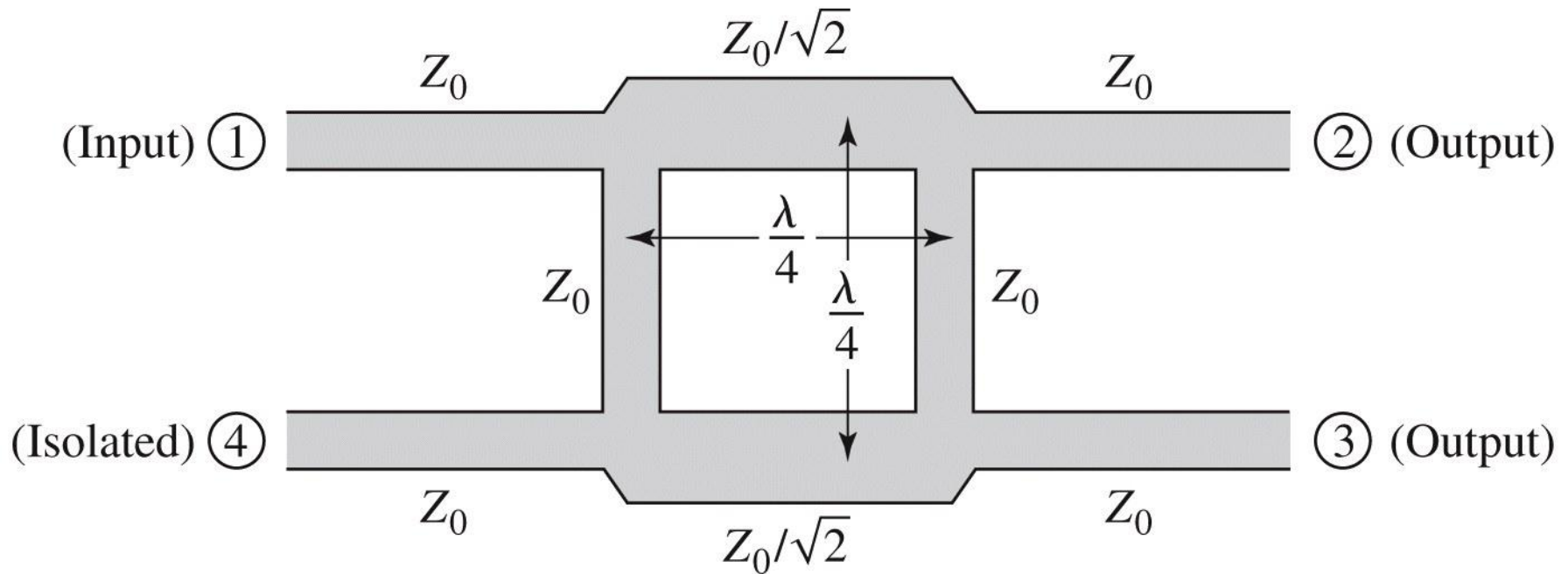
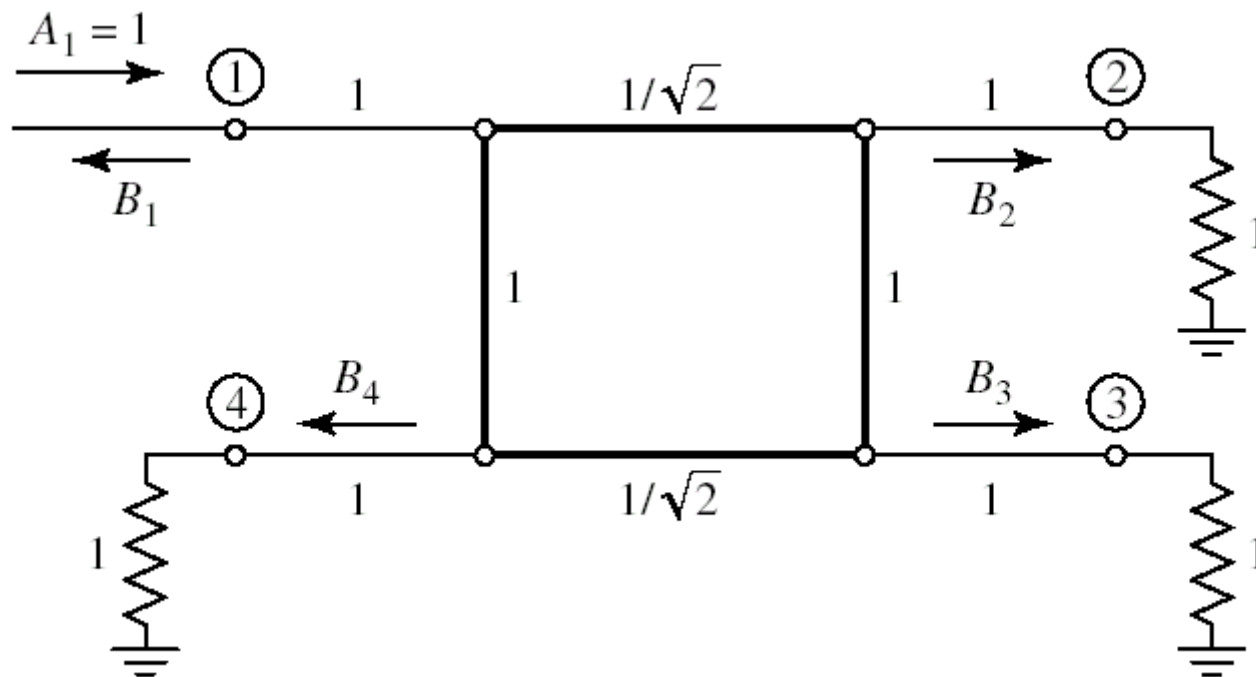


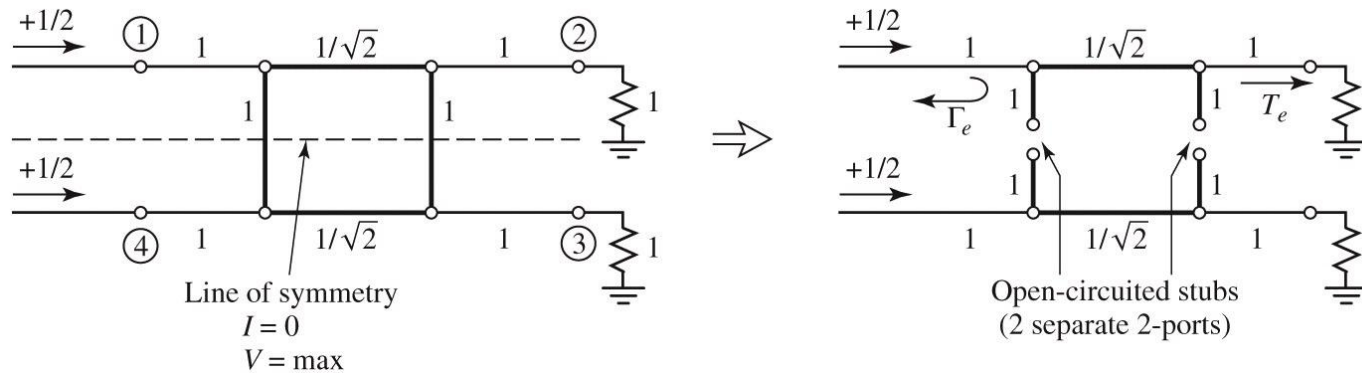
Figure 7.21
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$$[S] = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}$$

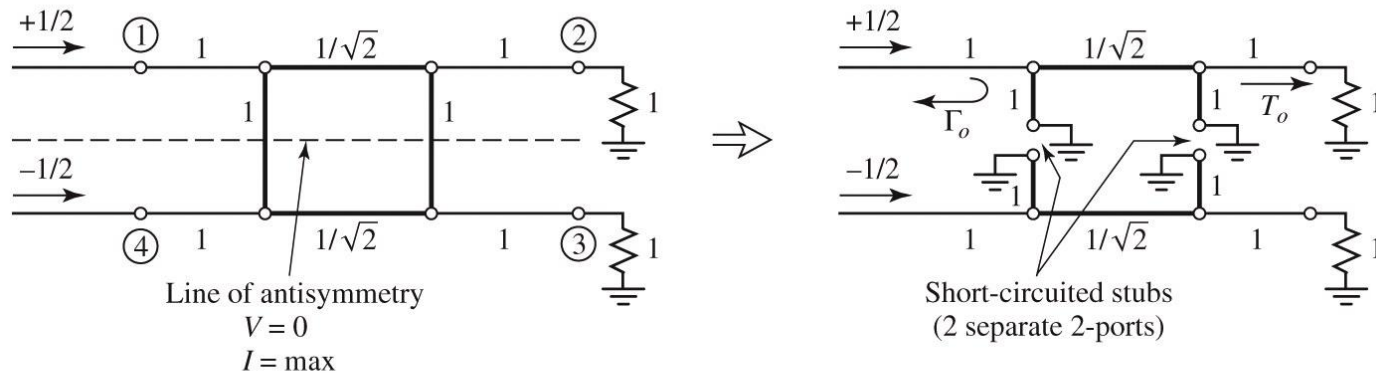
Analiza pe modul par-impar



Analiza pe modul par-impair



(a)



(b)

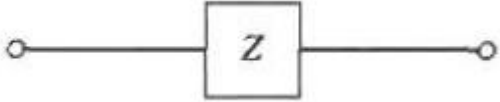
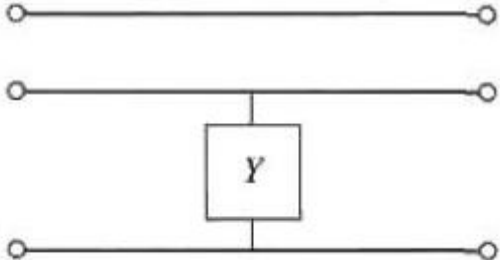
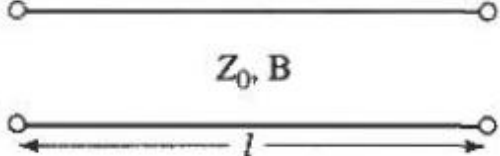
Figure 7.23
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$$b_1 = \frac{1}{2} \Gamma_e + \frac{1}{2} \Gamma_o$$

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

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

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

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

Linie de transmisie cu impedanta de terminatie

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

scurtcircuit

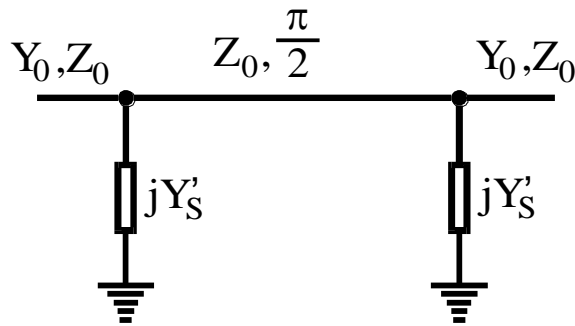
$$Z_{\text{in}} = jZ_0 \tan \beta\ell,$$

gol

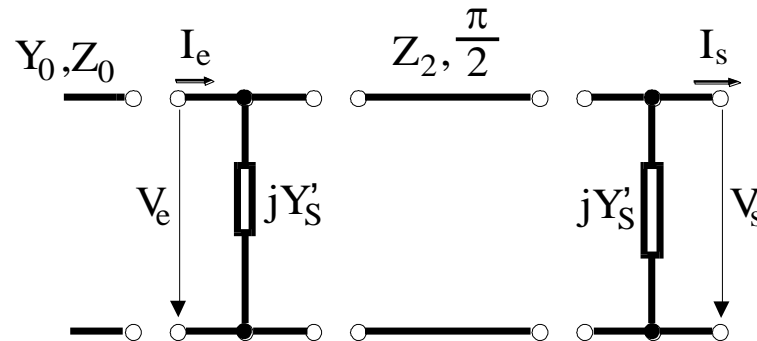
$$Z_{\text{in}} = -jZ_0 \cot \beta\ell,$$

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)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$b_3 = -C$$

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

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

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

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

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

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

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

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

Cuplorul in cuadratura

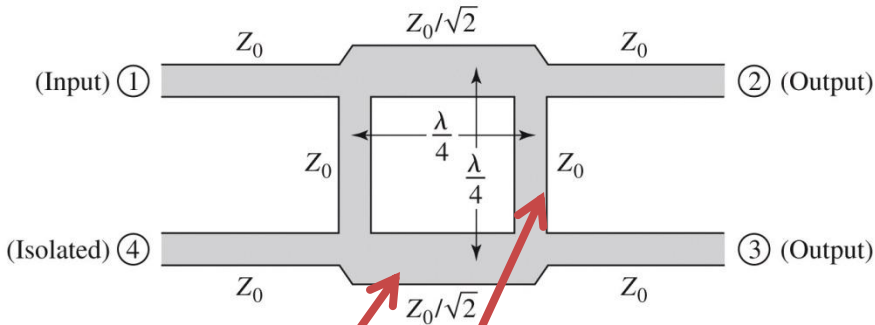


Figure 7.21
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$$y_2^2 = 1 + y_1^2$$

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

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

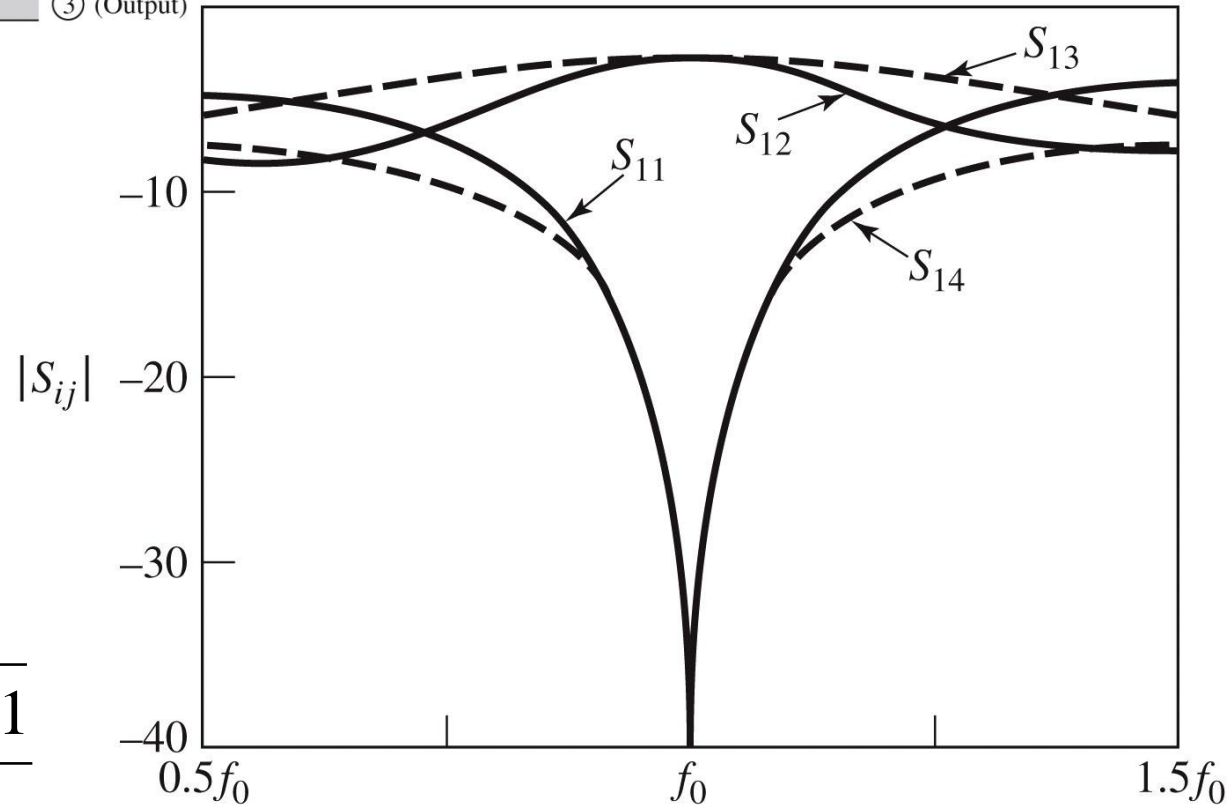


Figure 7.25
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Exemplu

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

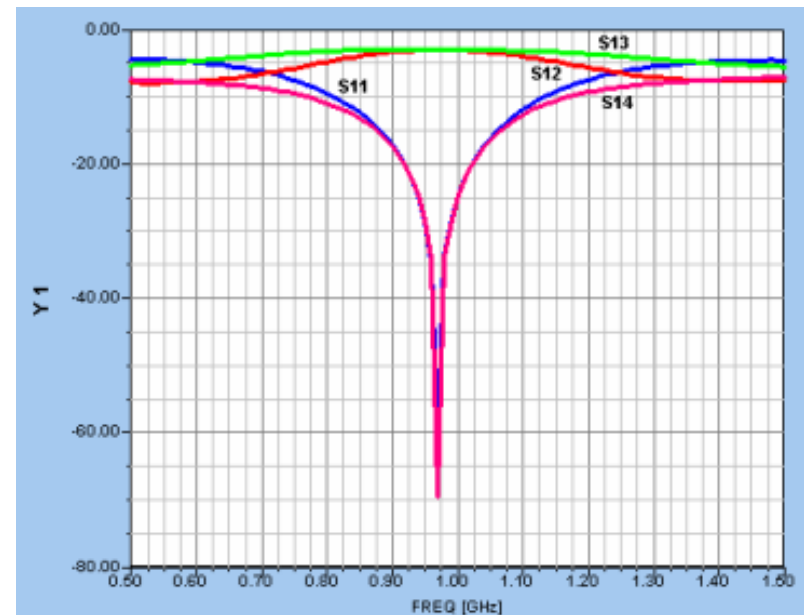
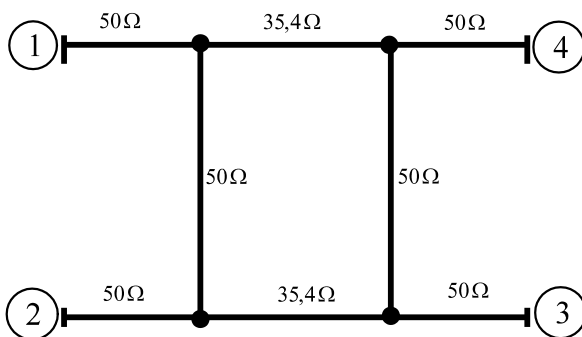
Un cuplor în scară cu $C = 3\text{dB}$, are $C = 1/\sqrt{2}$

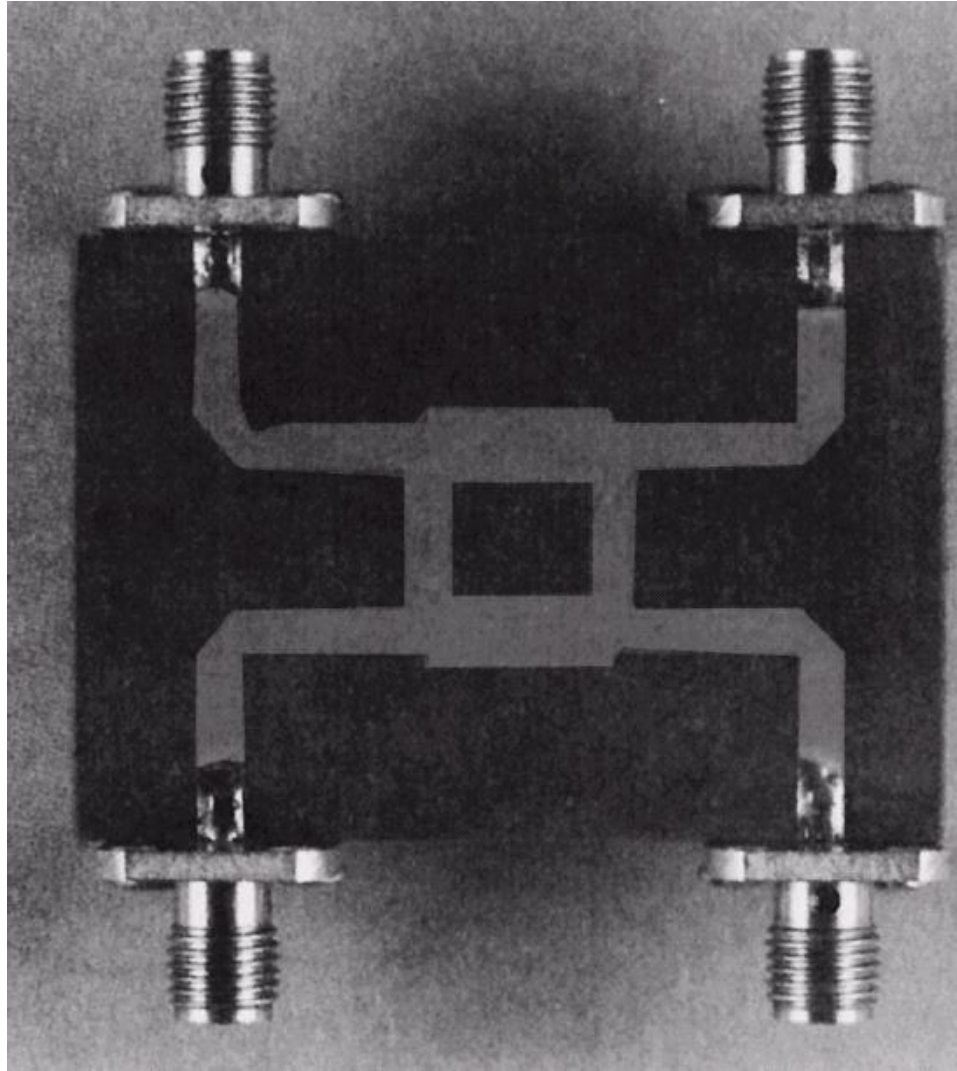
. Atunci $y_2 = \sqrt{2}$ și $y_1 = 1$

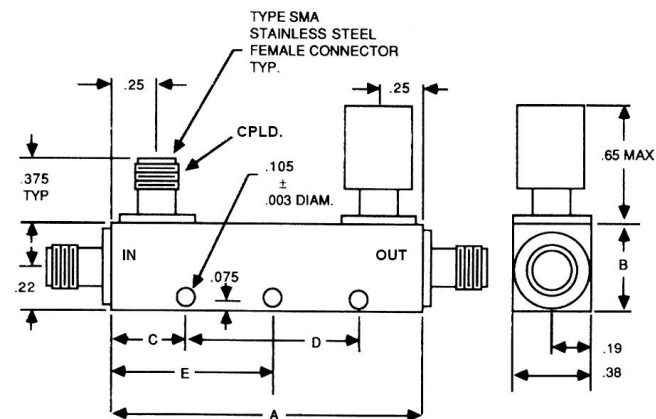
. Astfel matricea S din relația (&.47) devine cea din relația (&.38). În plus, pentru $Z_0 = 50\Omega$

, impedanțele caracteristice ale liniilor cuplorului vor fi:

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

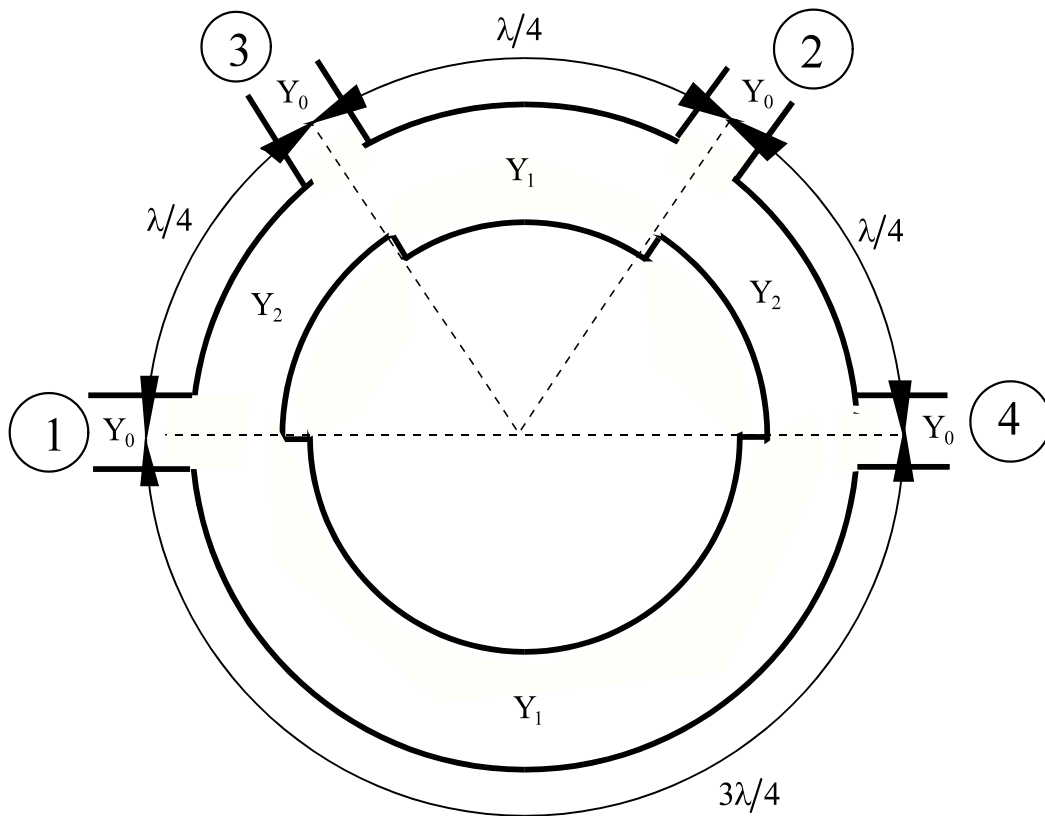




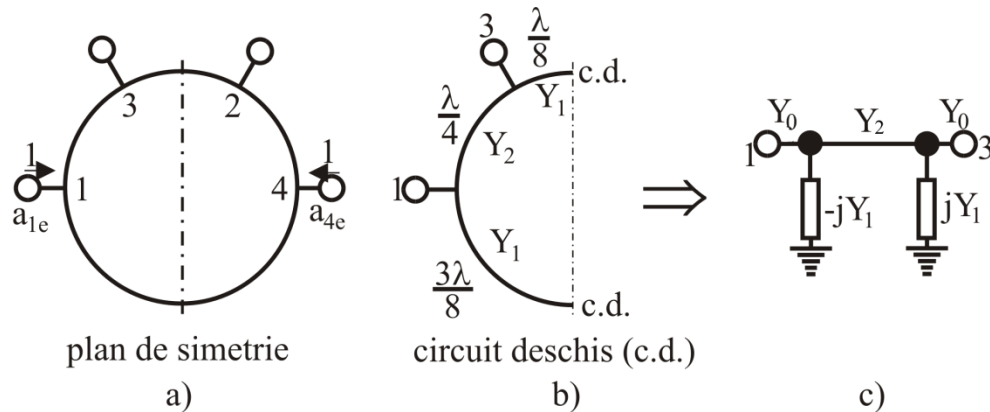


Model No.	Frequency Range (Ghz)	Coupling † (dB)	Freq. Sens. (dB)	Insertion Loss (dB)		Directivity (dB min.)	VSWR max.	
				Excl. Cpld Pwr	True		Primary Line	Secondary Line
MDC6223-6	0.5-1.0	6 ±1.00	±0.60	0.20	1.80	25	1.15	1.15
MDC6223-10	0.5-1.0	10 ±1.25	±0.75	0.20	0.80	25	1.10	1.10
MDC6223-20	0.5-1.0	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
MDC6227-30	7.0-12.4	30 ±1.00	±0.50	0.30	0.20	17	1.30	1.30

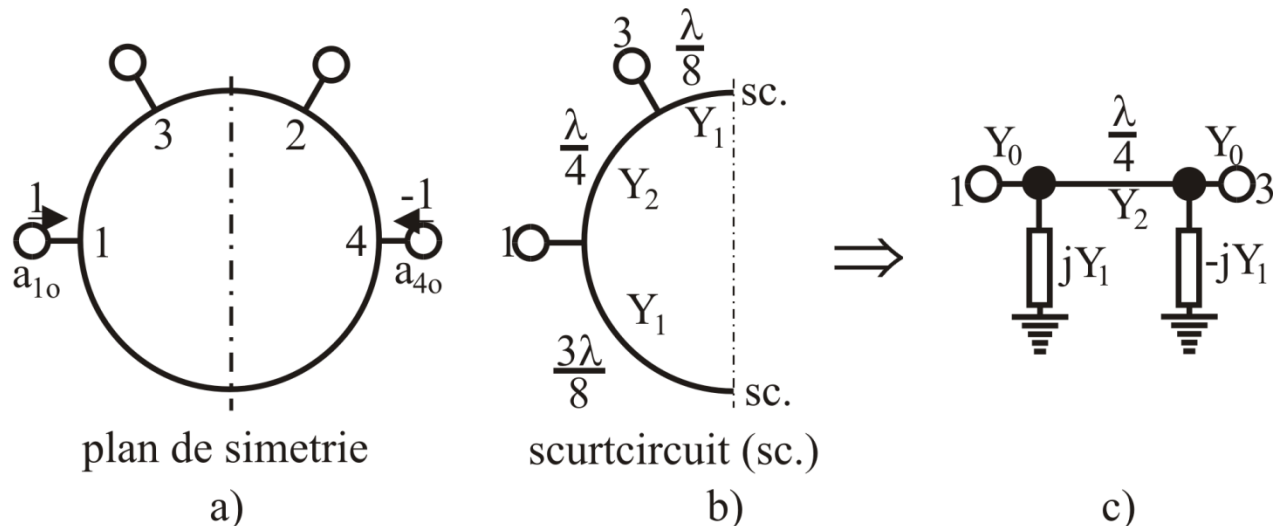
Cuplorul in inel



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:

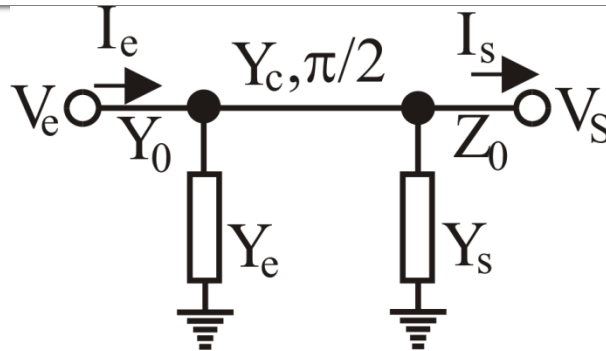
$$y_e = -jy_1$$

$$y_s = jy_1$$

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

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

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



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:

$$y_e = jy_1$$

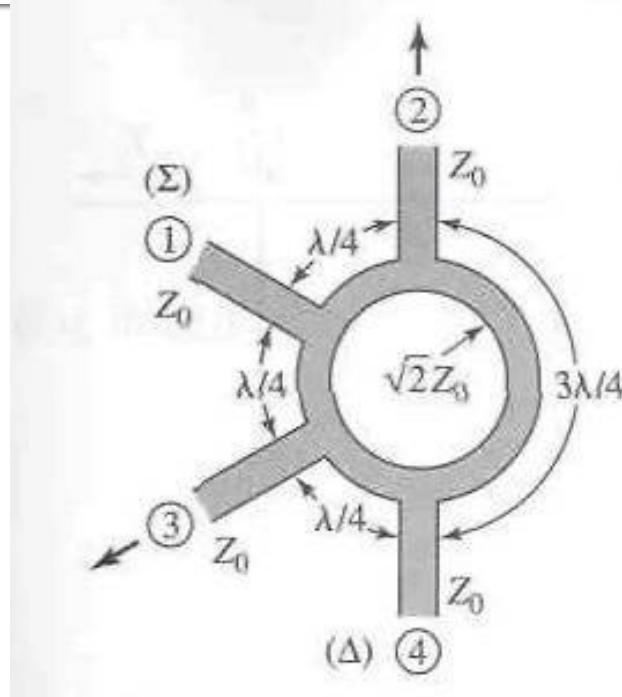
$$y_s = -jy_1$$

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

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

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

Cuplorul in inel



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

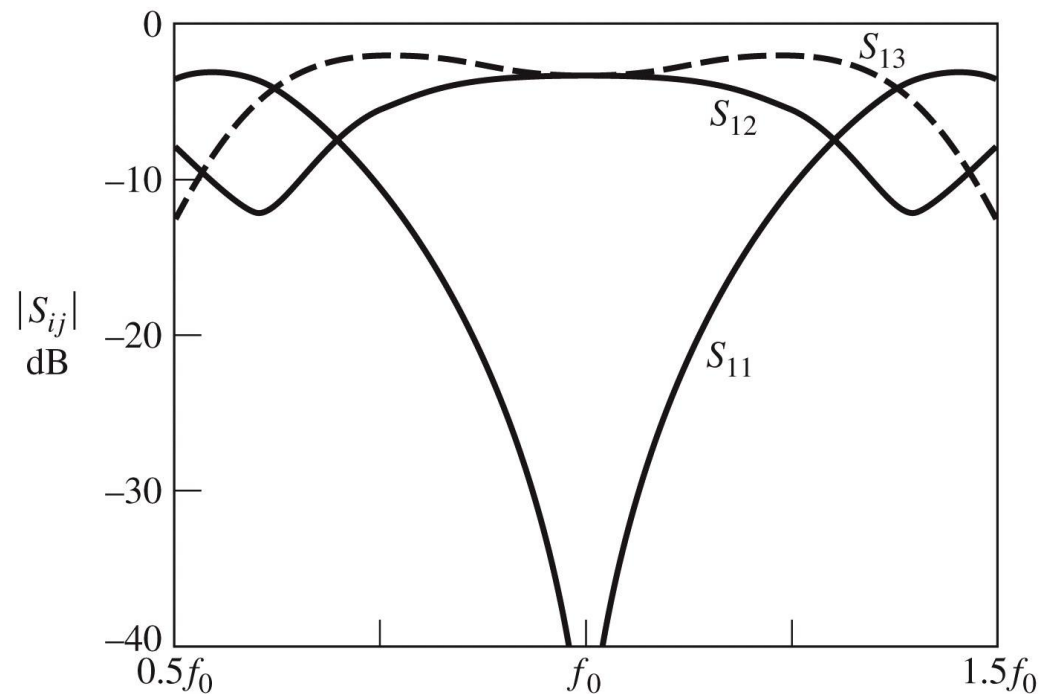
$$C(dB) = -20 \log(\beta) = -20 \log(y_1)$$

Proiectarea și performanța unui cuplor în inel

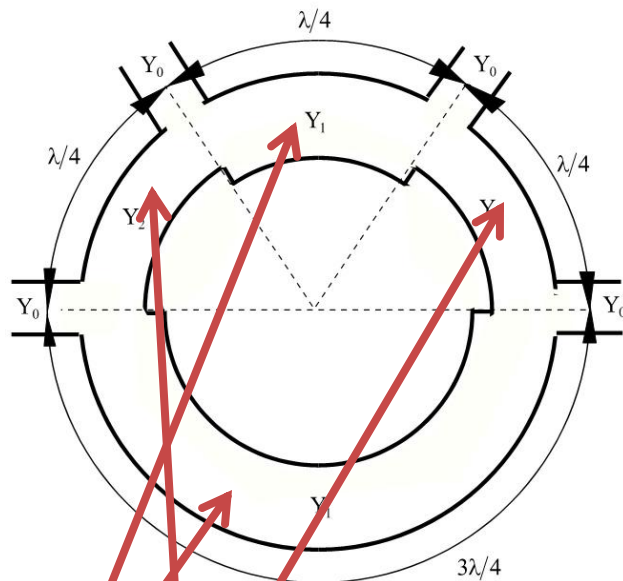
Proiectați un cuplor în inel hibrid (3dB) pe impedanța de $50\ \Omega$ și reprezentați mărimea parametrilor S între 0.5 și 1.5 din frecvența centrală.

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

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



Cuplorul în inel



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

$$|\beta| = y_1$$

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

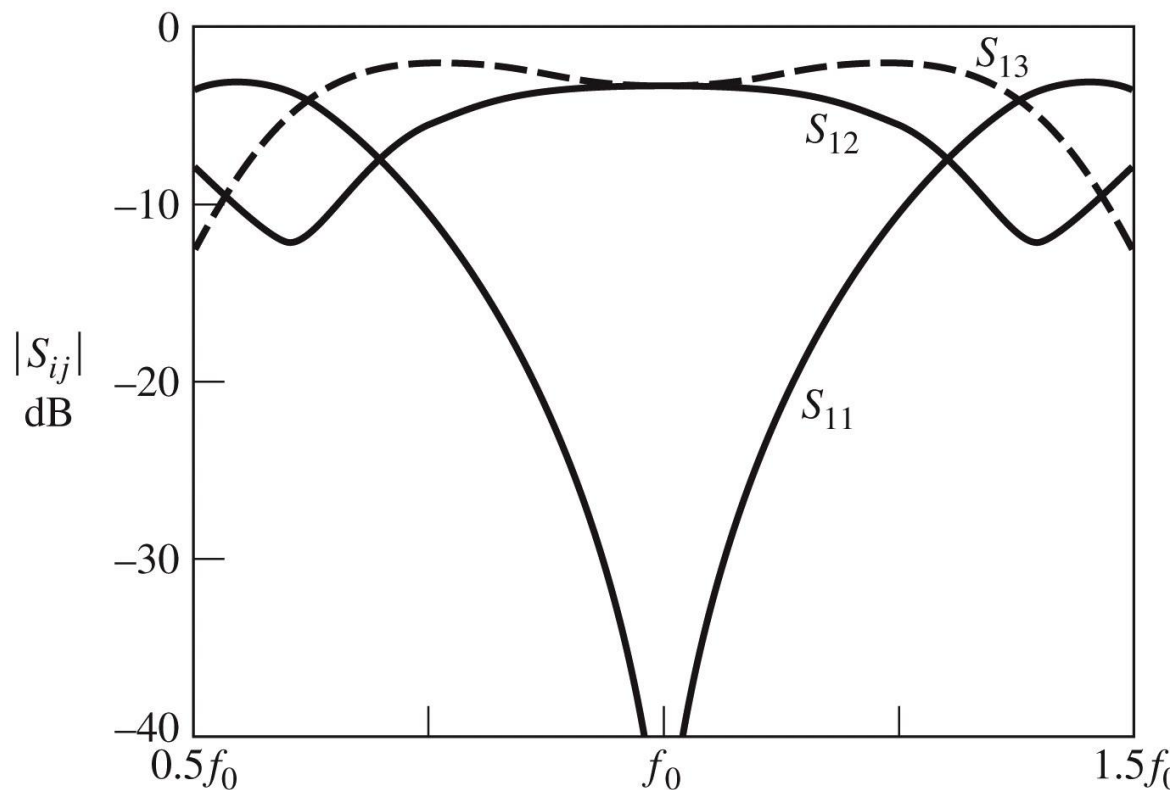


Figure 7.46
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Cuplor în inel

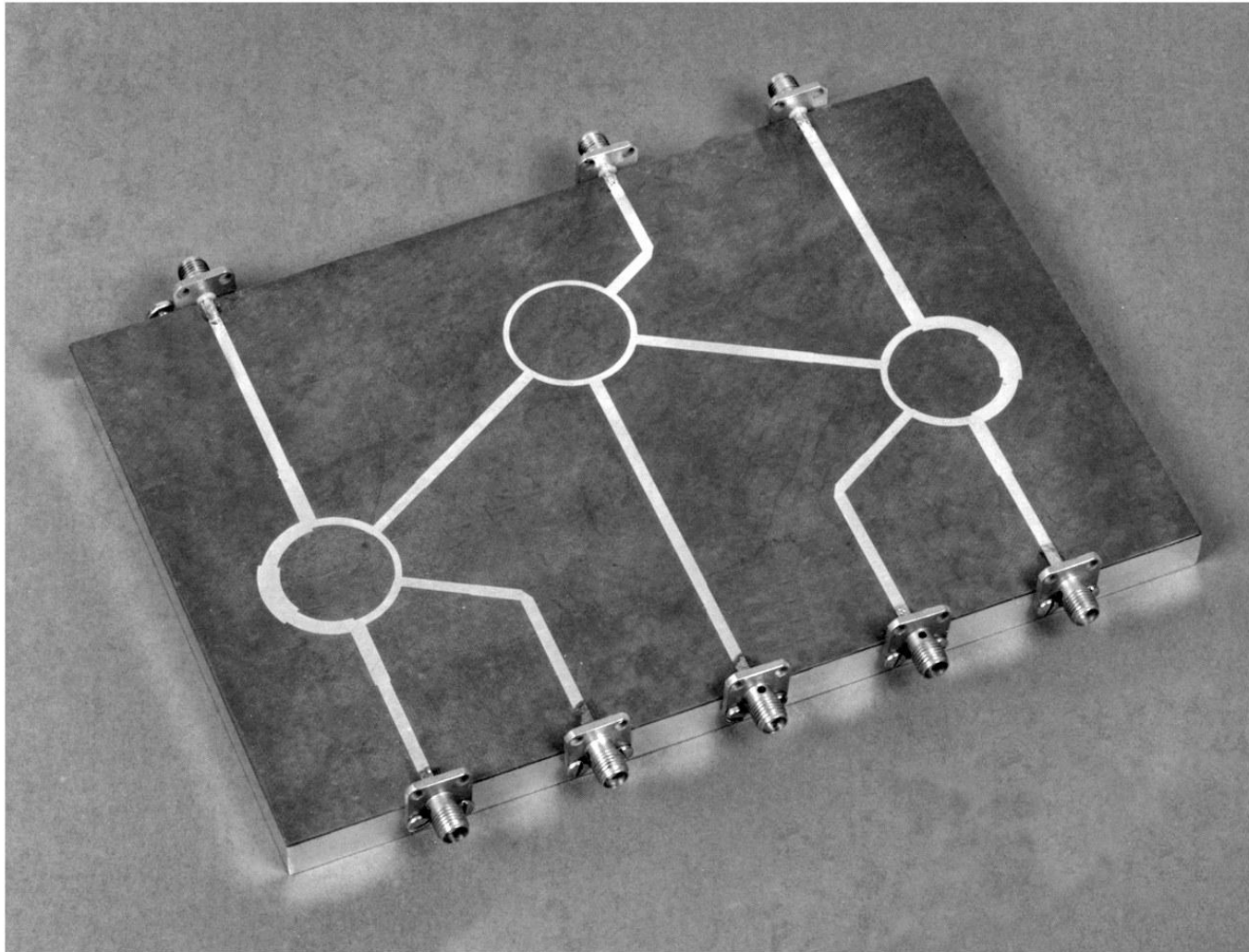
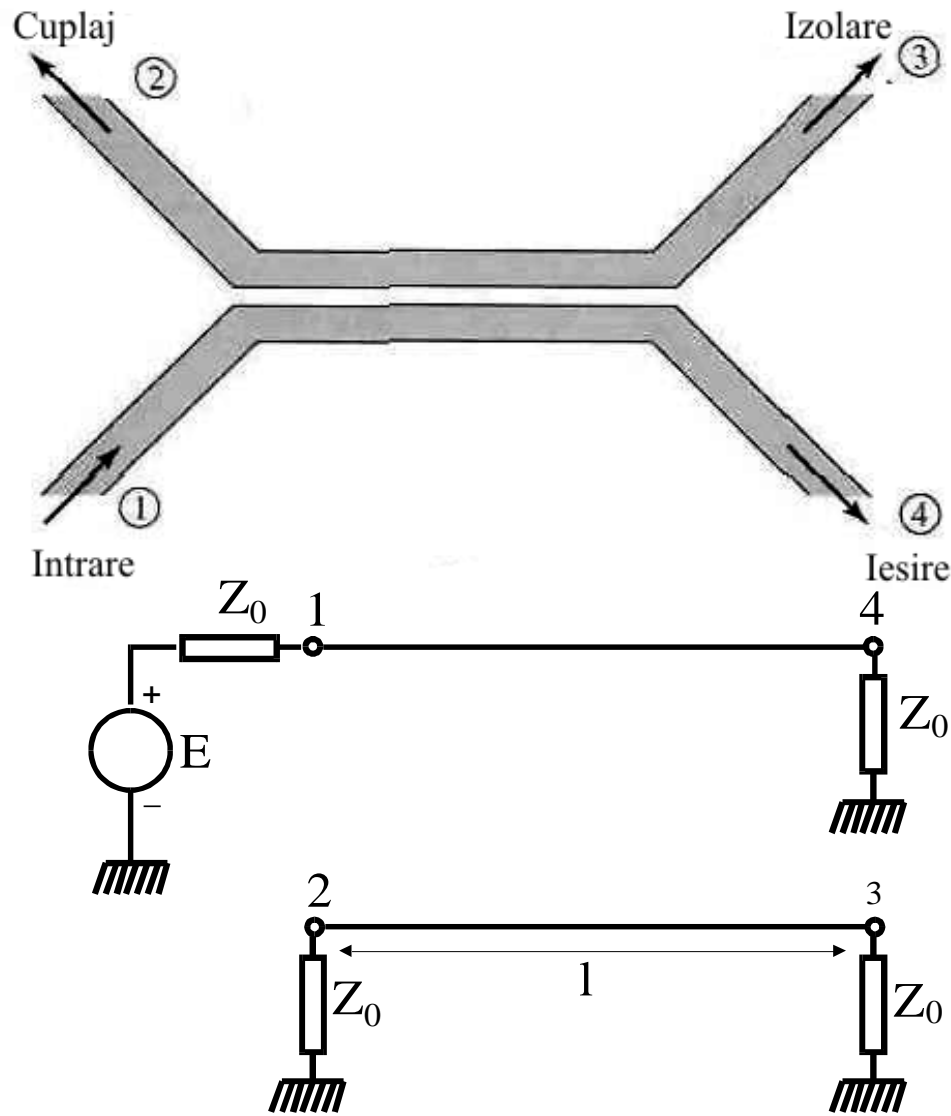


Figure 7.43
Courtesy of M. D. Abouzahra, MIT Lincoln Laboratory, Lexington, Mass.

Cuplorul prin proximitate



Linii cuplate

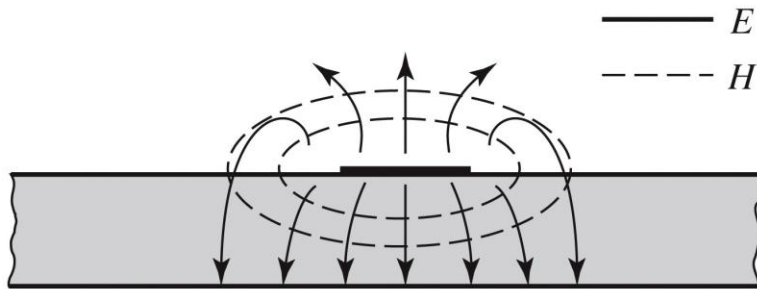
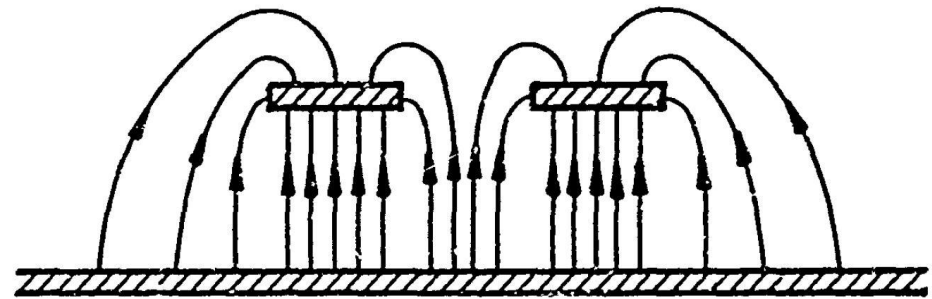
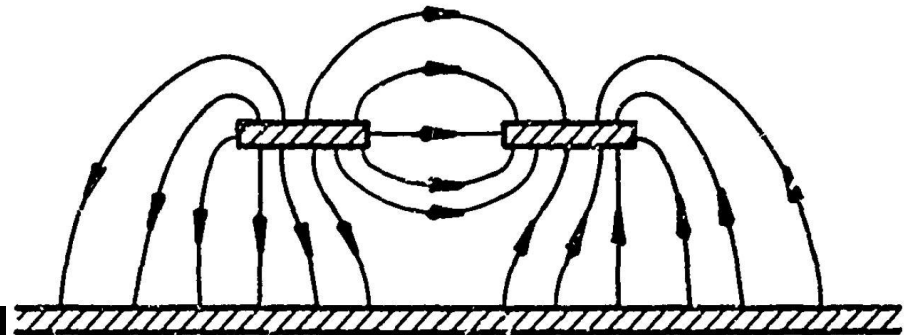


Figure 3.25b
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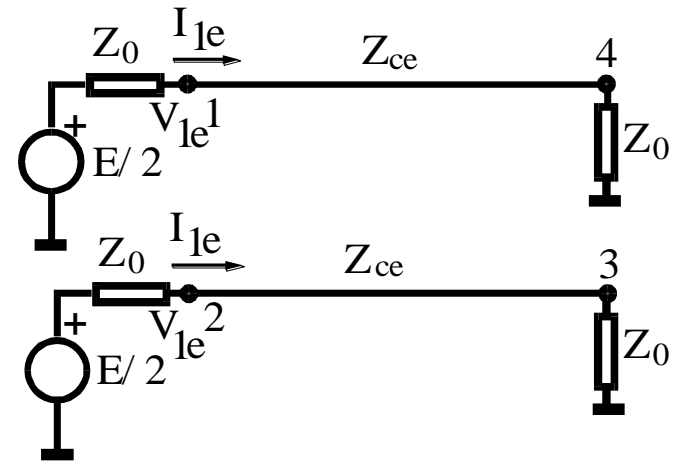
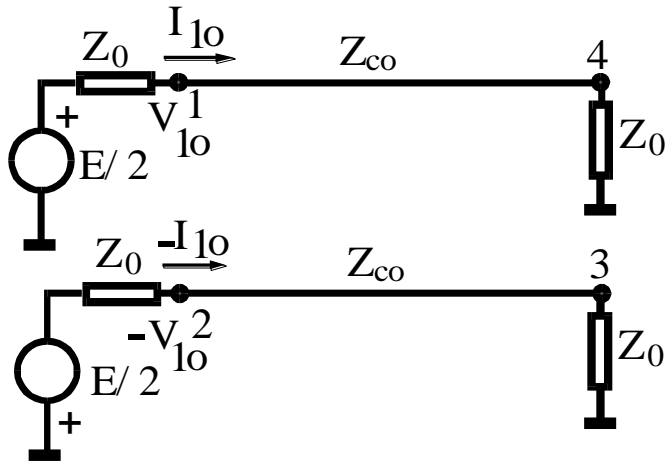
b) EVEN MODE ELECTRIC FIELD PATTERN (SCHEMATIC)



c) ODD MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

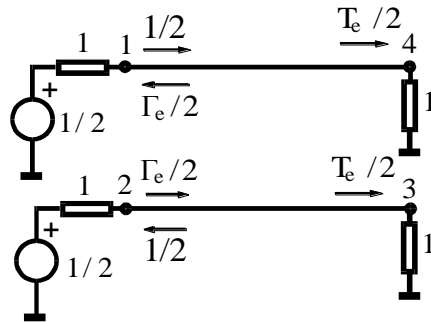
- Mod par – caracterizeaza semnalul de mod comun de pe cele doua linii
- Mod impar – caracterizeaza semnalul de mod diferential dintre cele doua linii

Adaptarea cuplorului prin proximitate

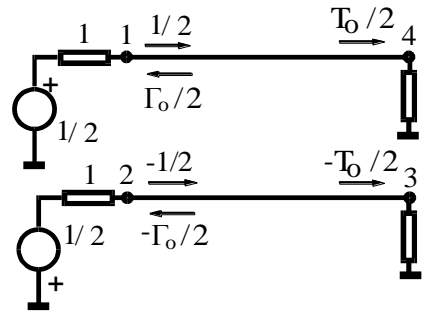


$$\begin{cases} Z_{ce} Z_{co} = Z_0^2 \\ \theta_e = \theta_o \end{cases}$$

Directivitatea și coeficientul de cuplaj ale cuplurii prin proximitate



modul par



modul impar

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

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

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

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

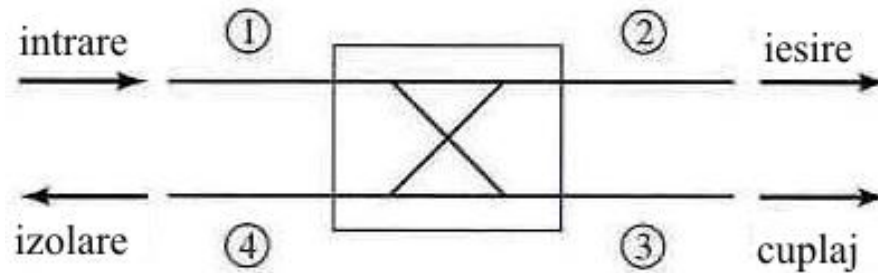
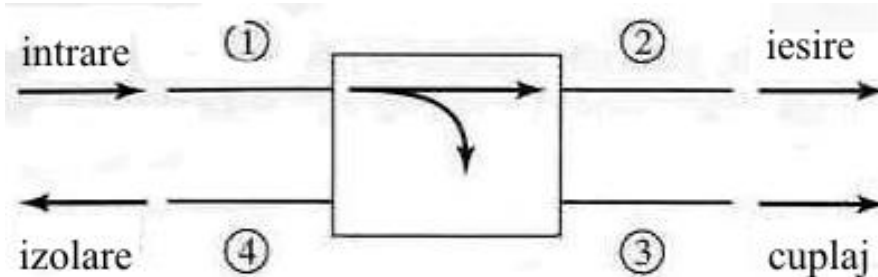
$$b_4 = \frac{1}{2}(T_e + T_o) = \frac{\sqrt{1-C^2}}{\cos(\theta)\sqrt{1-C^2} + j\sin(\theta)}$$

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

$$\theta = \pi/2$$

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

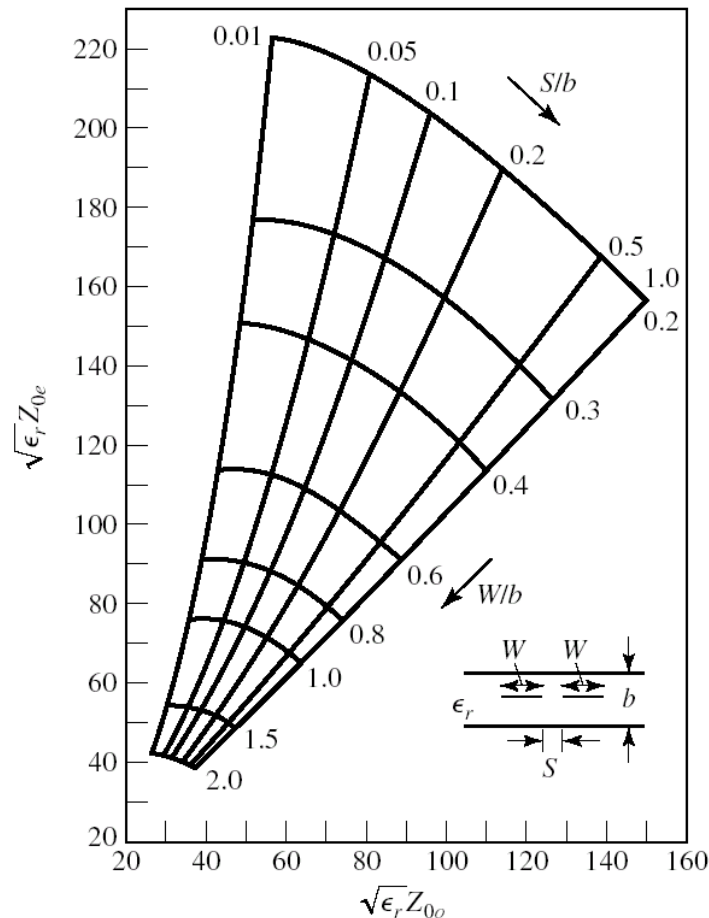
Cuplor prin proximitate



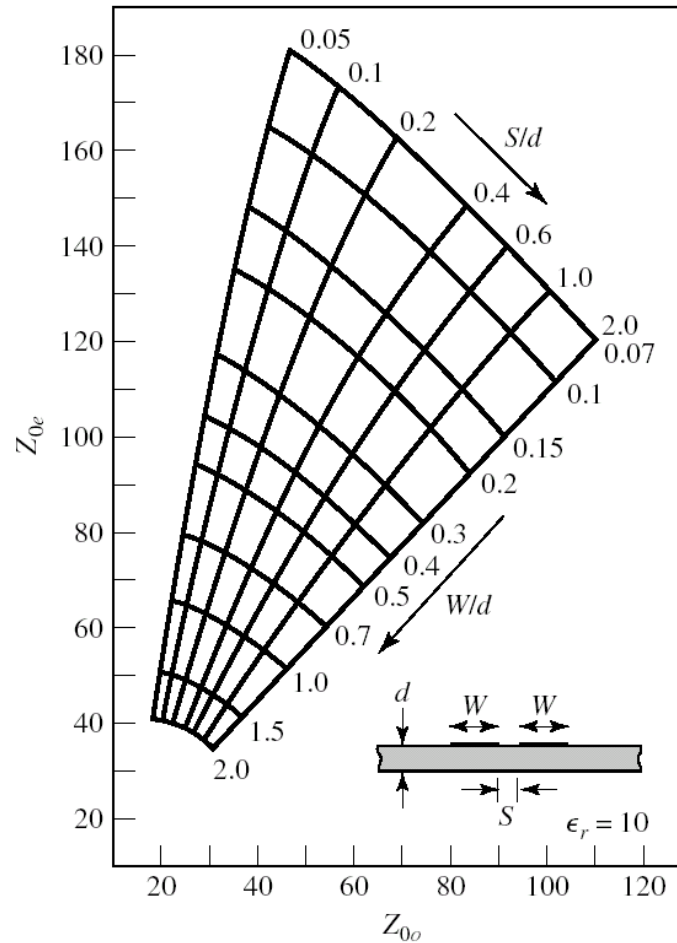
$$[S] = -j \cdot \begin{bmatrix} 0 & \sqrt{1-C^2} & jC & 0 \\ \sqrt{1-C^2} & 0 & 0 & jC \\ jC & 0 & 0 & \sqrt{1-C^2} \\ 0 & jC & \sqrt{1-C^2} & 0 \end{bmatrix}$$

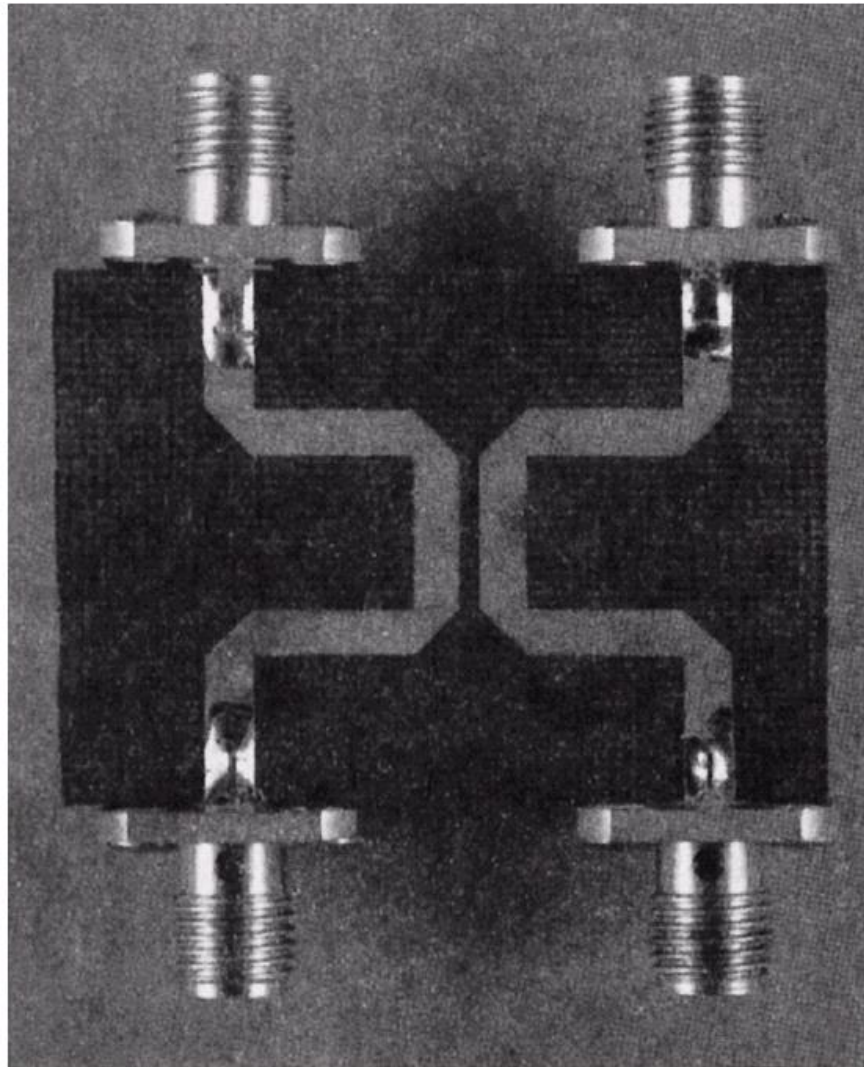
$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & j & 0 \\ 1 & 0 & 0 & j \\ j & 0 & 0 & 1 \\ 0 & j & 1 & 0 \end{bmatrix}$$

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

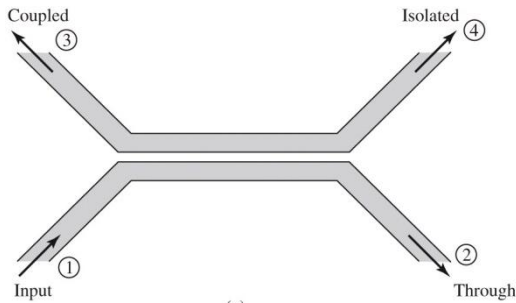


Even- and odd-mode characteristic impedance design data for coupled microstrip lines on a substrate with $\epsilon_r = 10$.





Cuplor prin proximitate



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

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

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

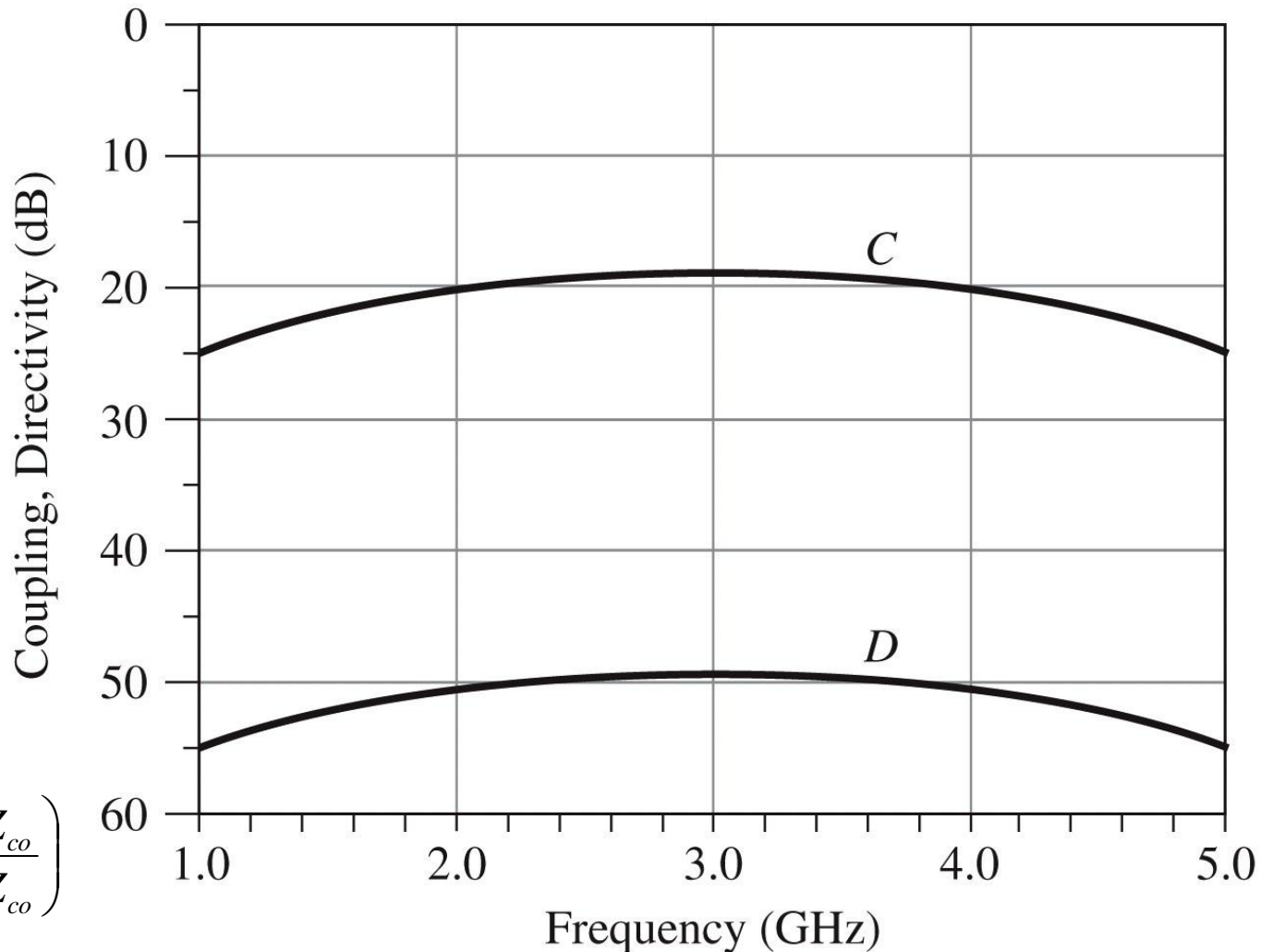


Figure 7.34

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 $50\ \Omega$, 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

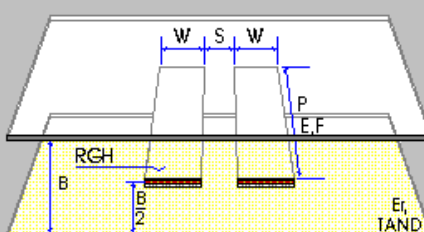
Metallization

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

RGH 0 Add new metal

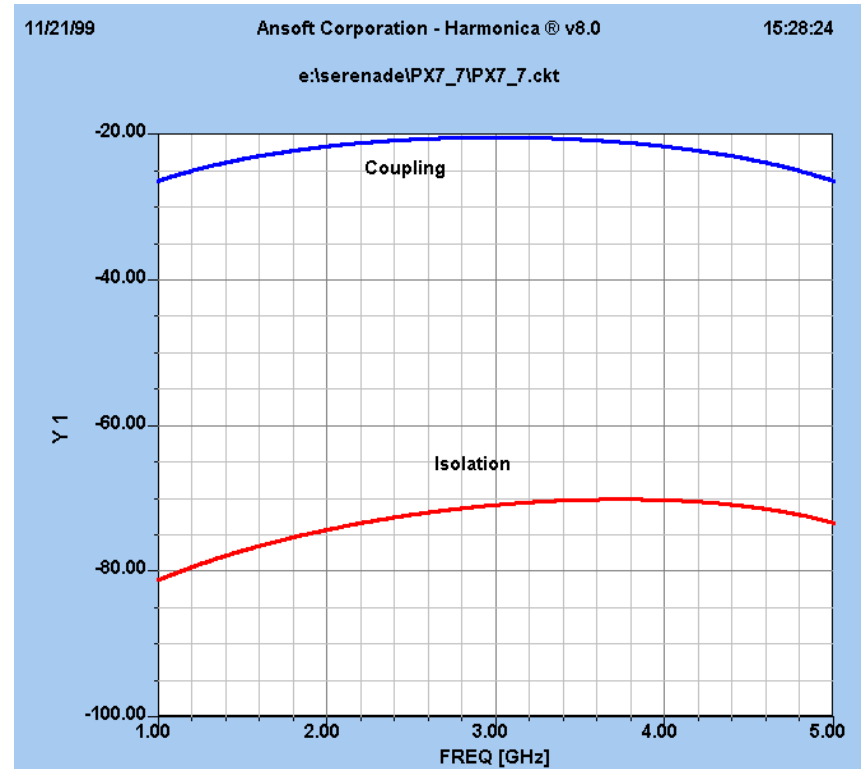
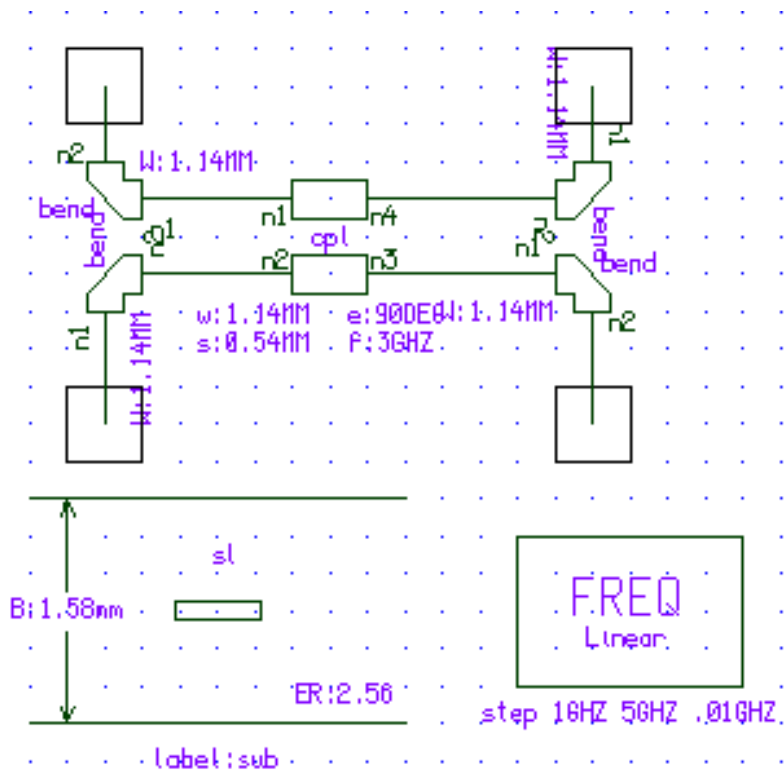
For Help, press F1

NUM

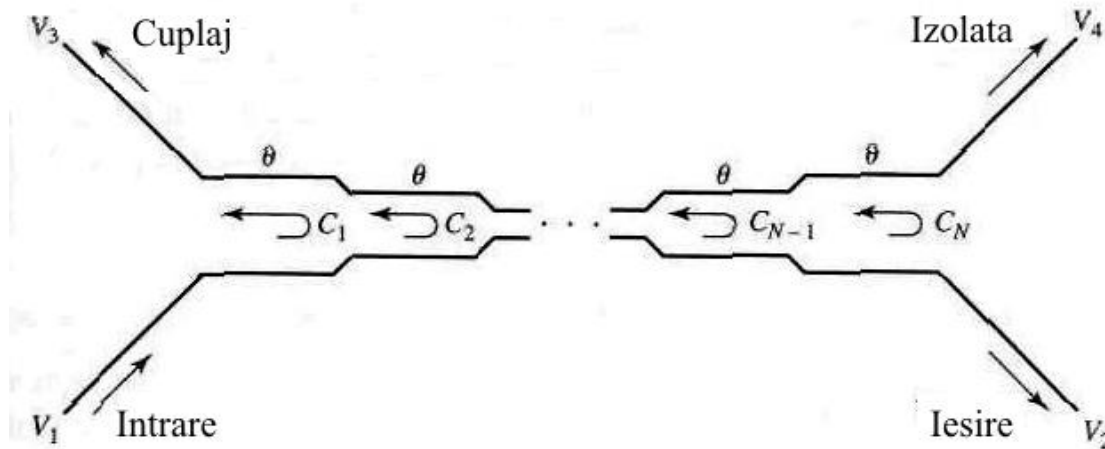


$$Z_{ce} = Z_0 \sqrt{\frac{1+C}{1-C}}, Z_{co} = Z_0 \sqrt{\frac{1-C}{1+C}}$$

Simulare



Cuplor prin proximitate cu mai multe secțiuni



$$C \ll 1$$

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

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

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

Exemplu

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

Solutie

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

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

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

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

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

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

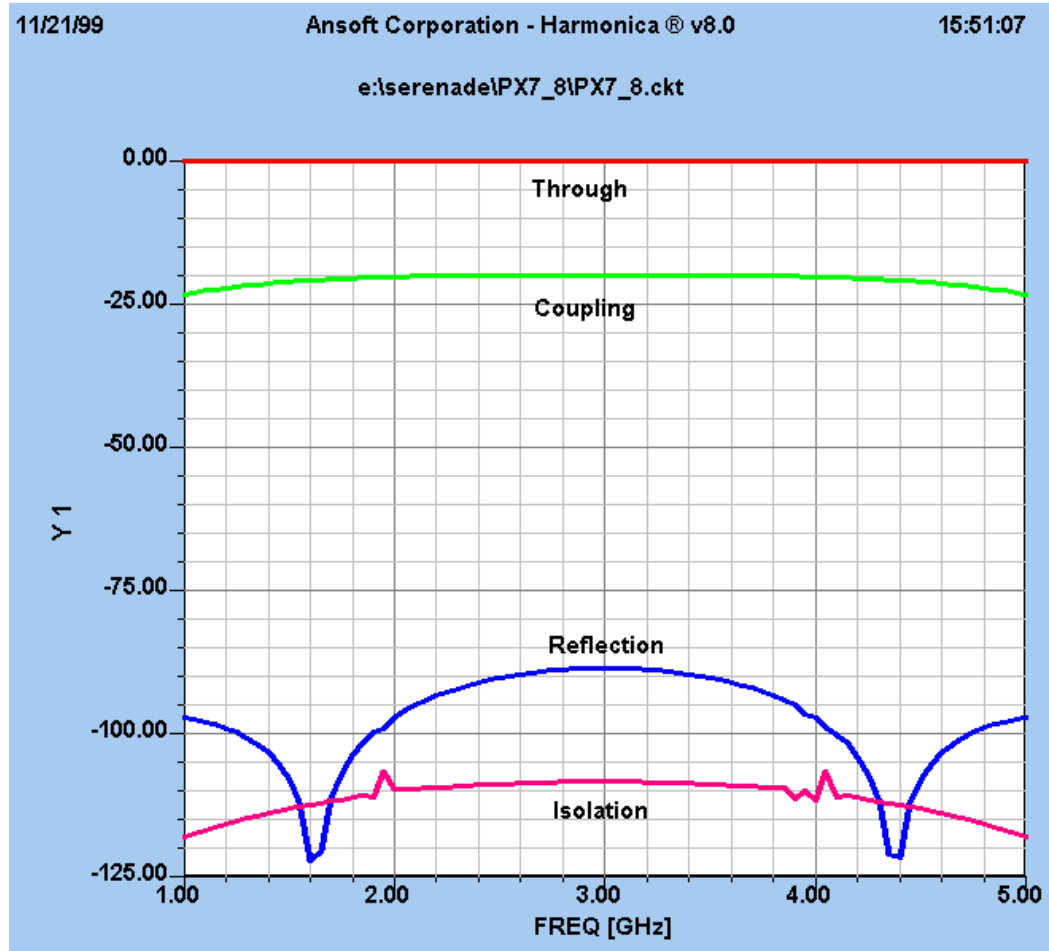
$$Z_{0e}^1 = Z_{0e}^3 = 50 \sqrt{\frac{1.0125}{0.9875}} = 50.63 \Omega$$

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

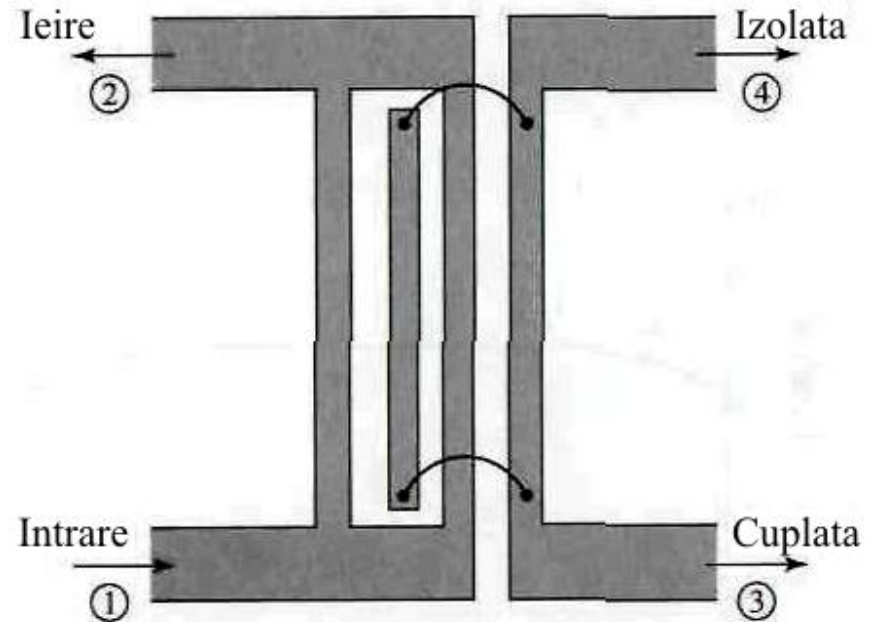
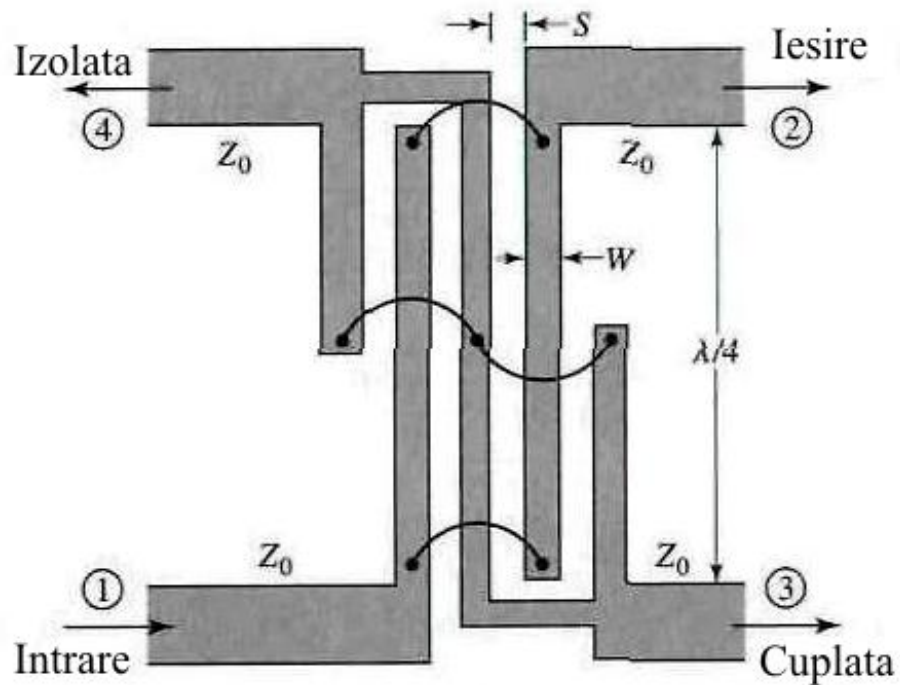
$$Z_{0e}^2 = 50 \sqrt{\frac{1.125}{0.875}} = 56.69 \Omega$$

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

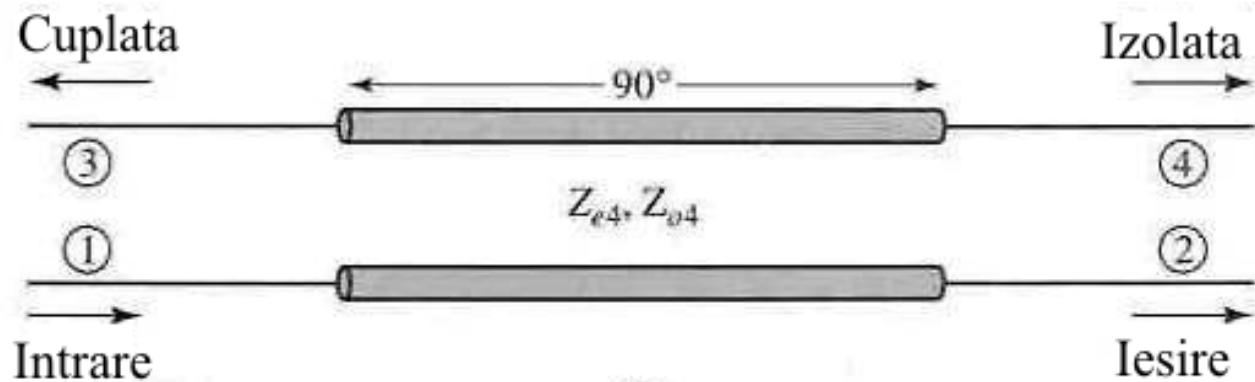
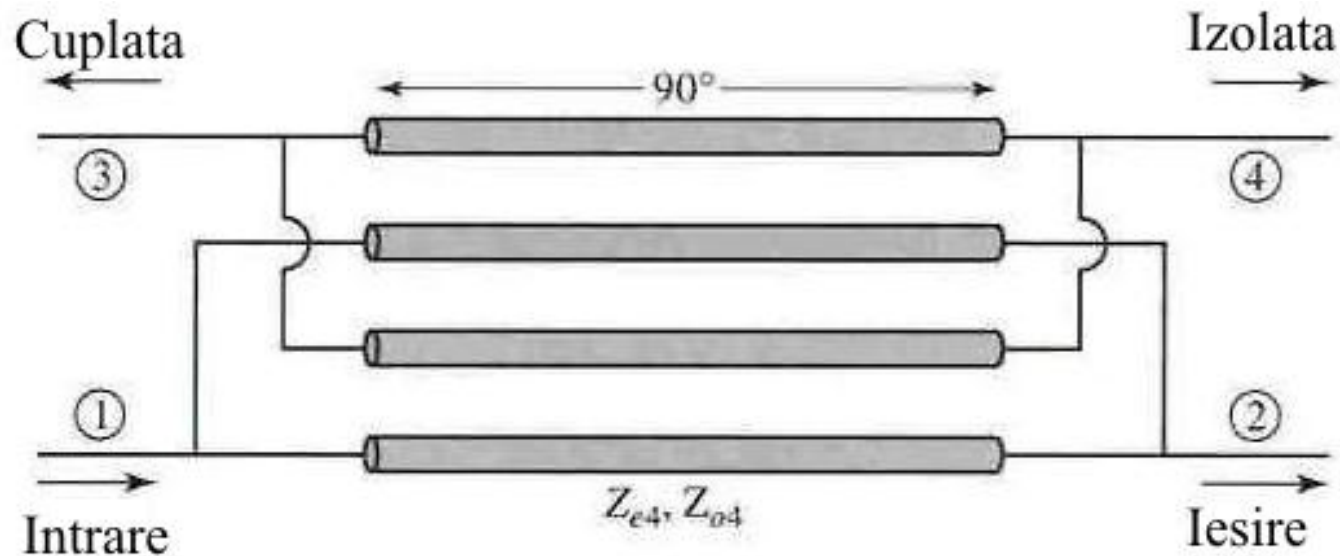
Simulare



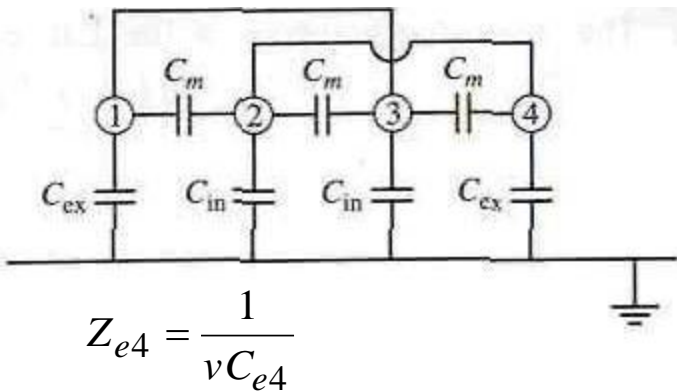
Cuplorul Lange



Cuplor Lange



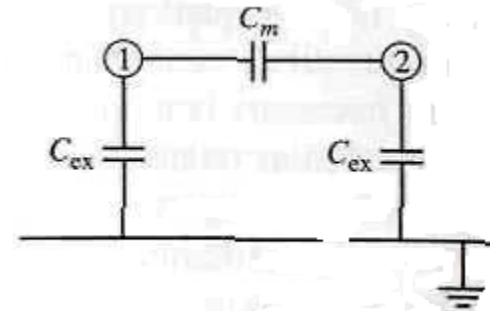
Modelul de circuit



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

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

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



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

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

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

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

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

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

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

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

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

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

Contact

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- rdamian@etti.tuiasi.ro