Laborator 3

2025/2026

Dispozitive şi circuite de microunde pentru radiocomunicații

Scurta teorie

Linie fara pierderi

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

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

- Puterea medie

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

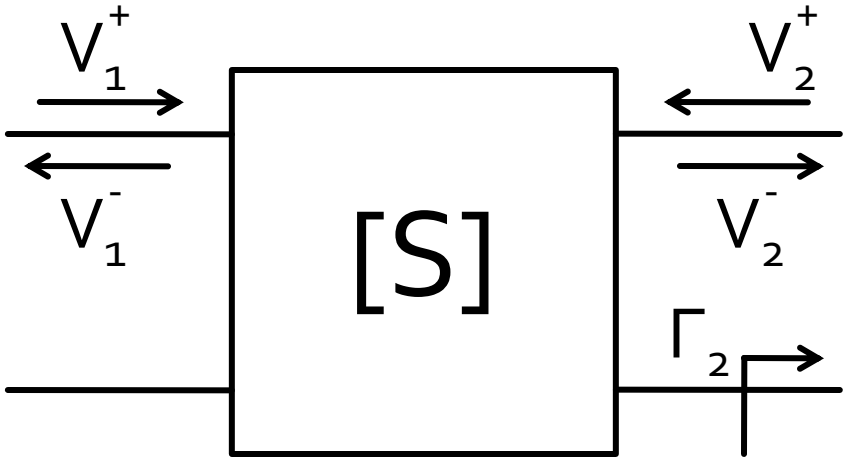
$$P_{avg} = \frac{1}{2} \cdot \frac{\left|V_0^+\right|^2}{Z_0} \cdot \left(1 - \left|\Gamma\right|^2\right)$$

- Puterea transmisa sarcinii = Puterea incidenta - Puterea "reflectata"
- Return Loss [dB]

$$\mathrm{RL} = -20 \cdot \log\left|\Gamma\right| \quad [\mathrm{dB}]$$

Matricea S (repartitie)

- Scattering parameters



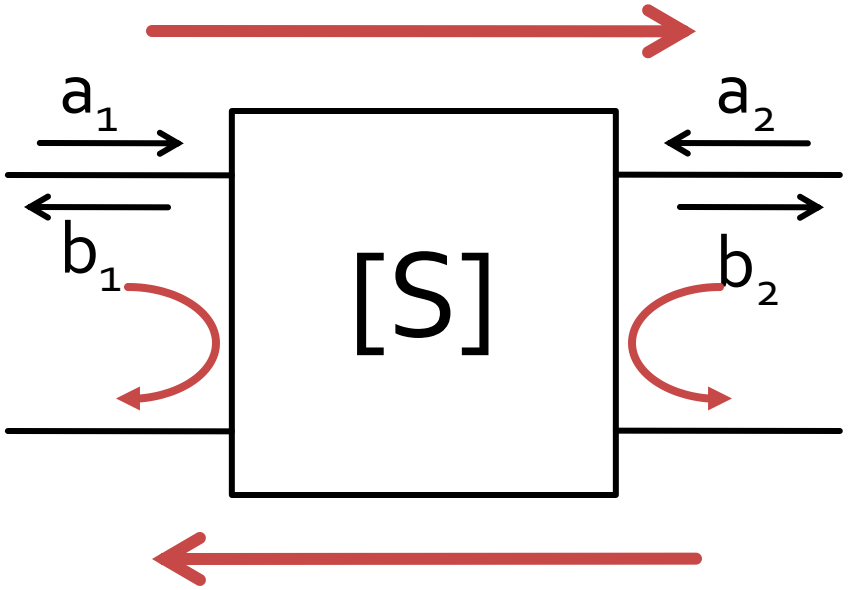
$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

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

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

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

Matricea S (repartitie)



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

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

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

Matricea S (repartitie)

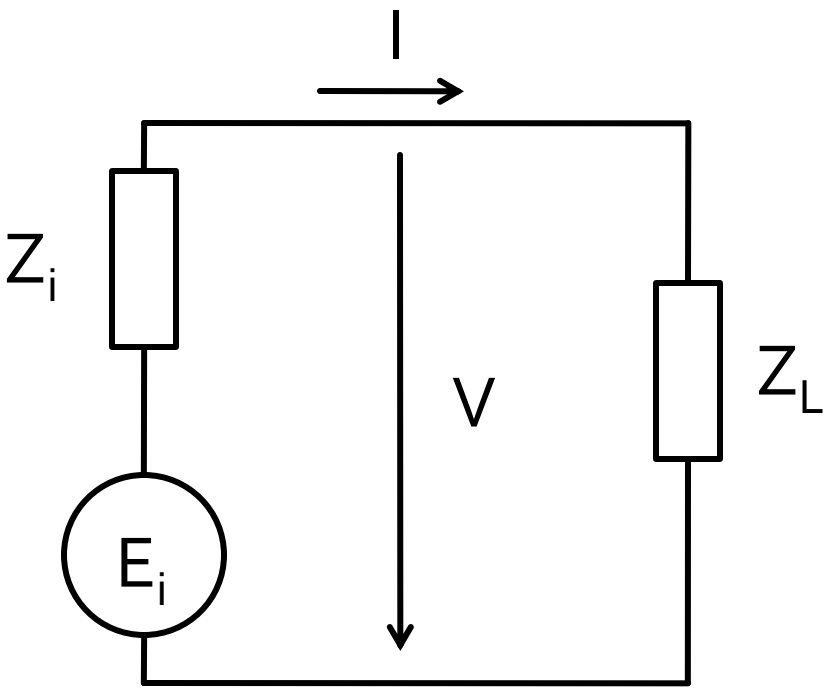
- Matricea S poate fi extinsa (generalizata) pentru multiporti (n-porturi)

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

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

Adaptare

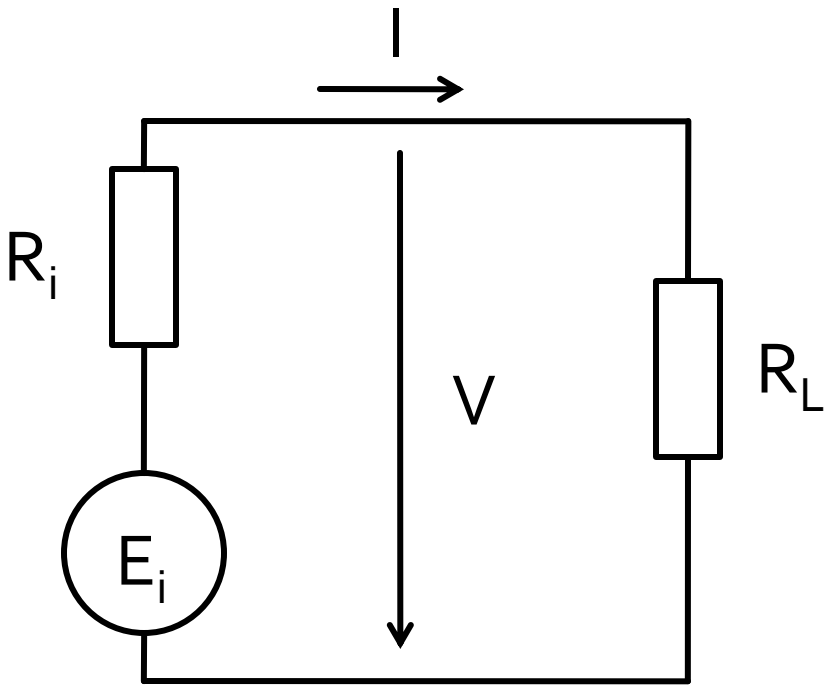
- Generator **adaptat** la sarcina ?



- valori impedanta ?
- reflexii ?

Adaptare, impedante reale

- Generator adaptat la sarcina



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

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

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

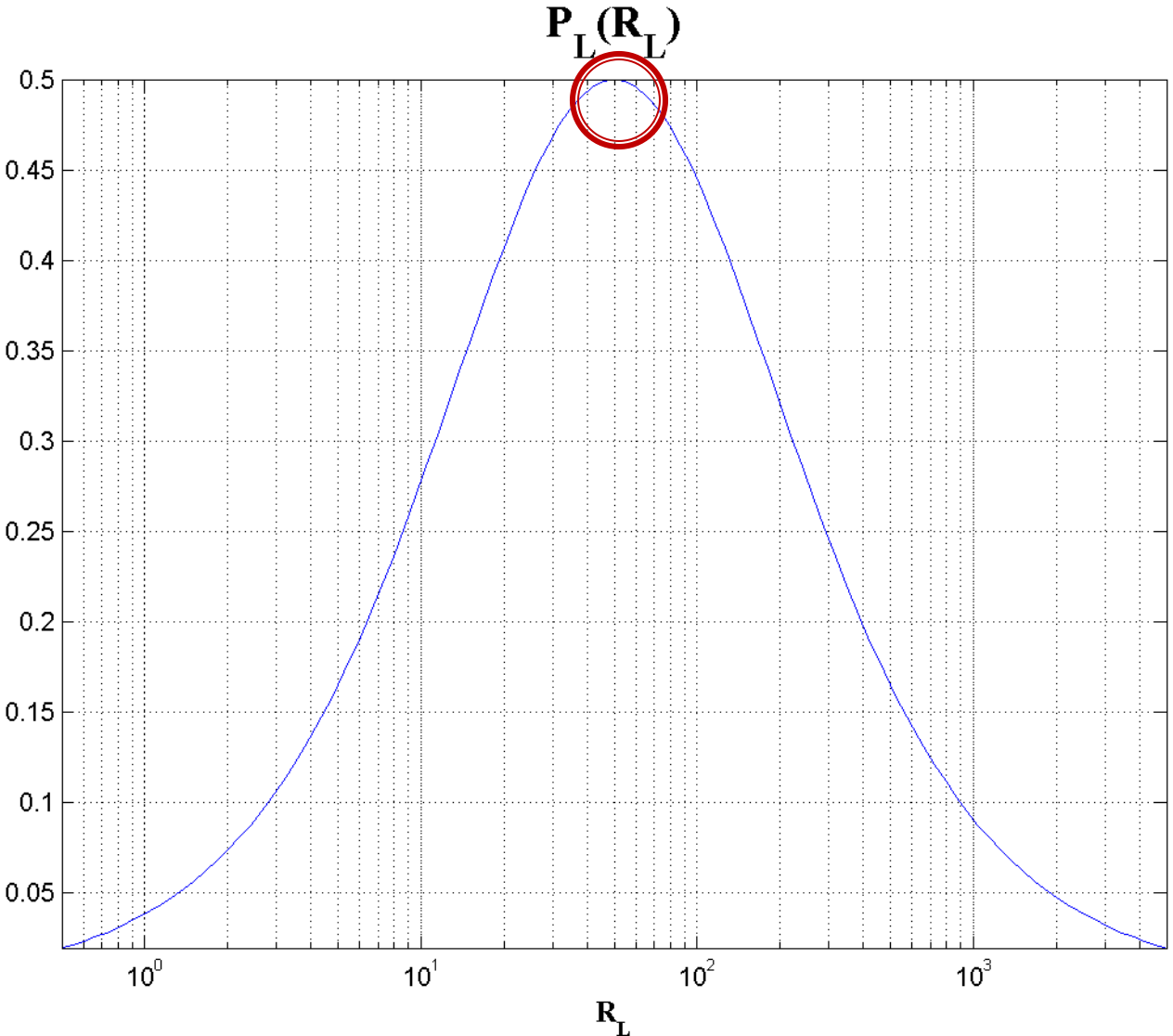
$$P_L = \frac{R_L \cdot E_i^2}{(R_i + R_L)^2}$$

Adaptare , impedante reale

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

- Putere pe sarcina
  - $R_i = 50\Omega$
  - $R_L = 0 \rightarrow P_L = 0$
  - $R_L = \infty \rightarrow P_L = 0$

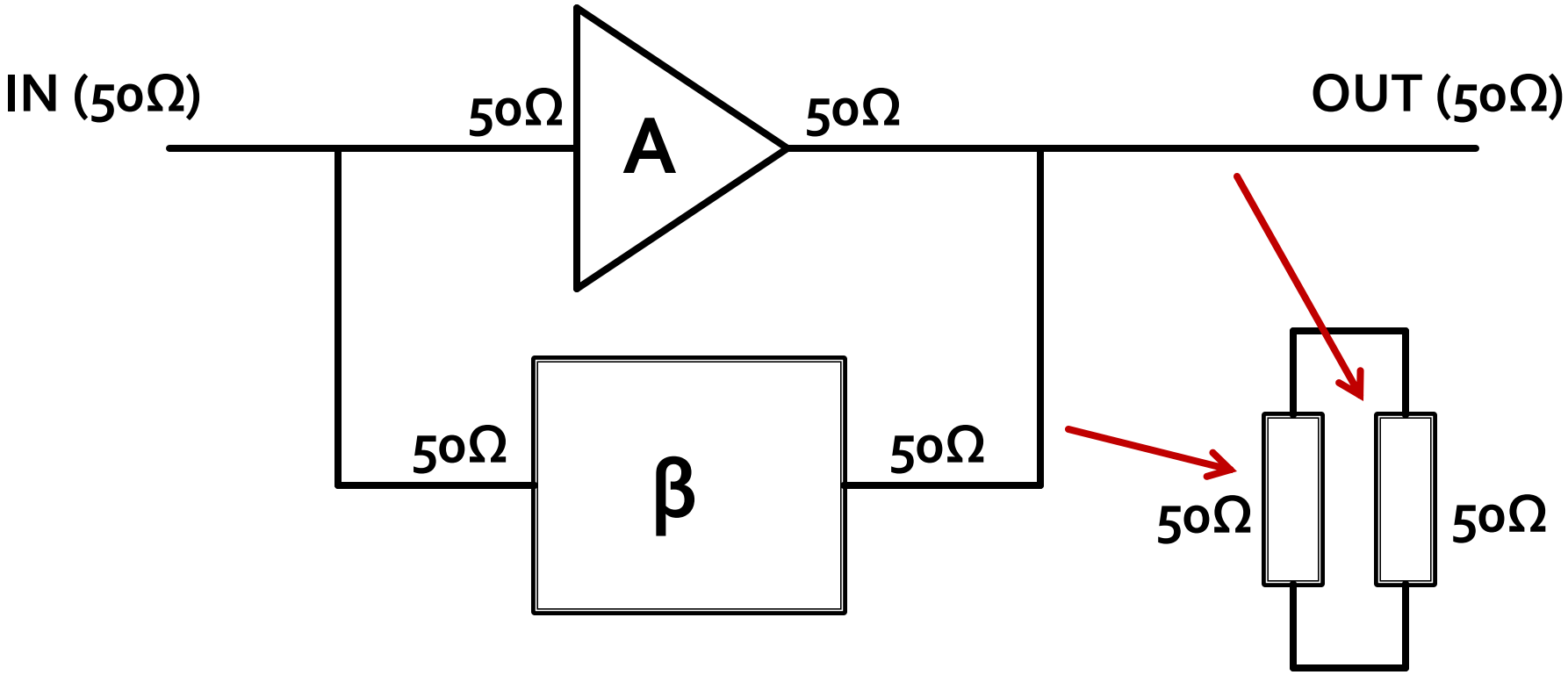
Adaptare , impedante reale



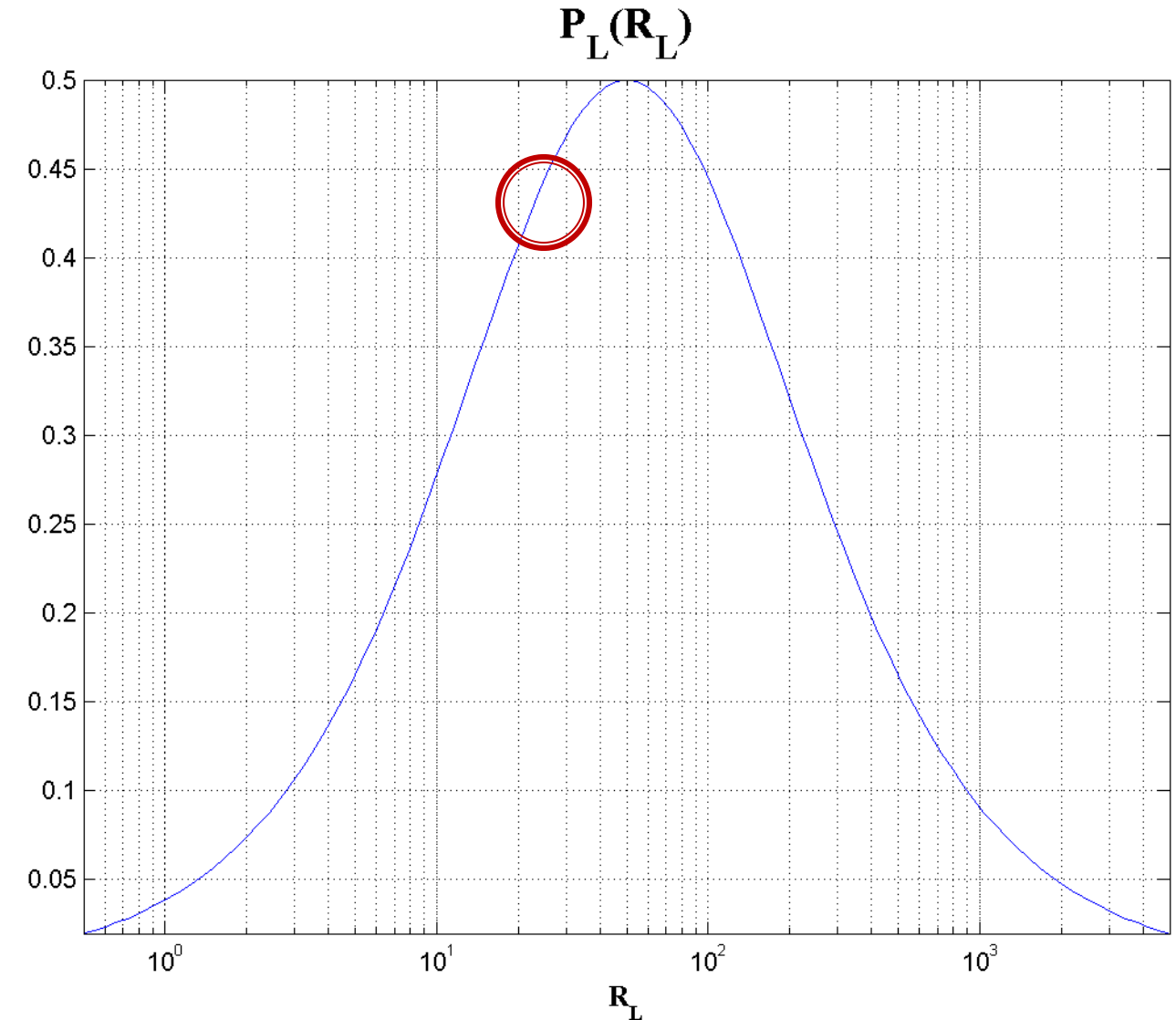
- Pmax
- $R_i = R_L$
- 50Ω

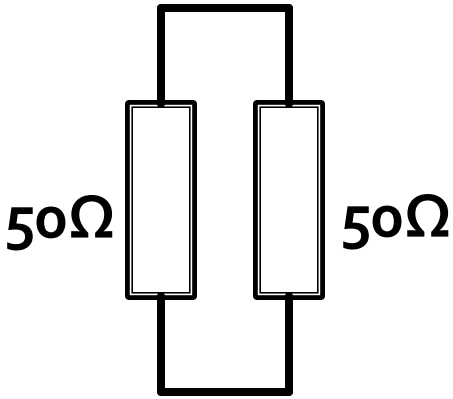
Adaptare

- amplificator cu reactie



Adaptare , impedante reale

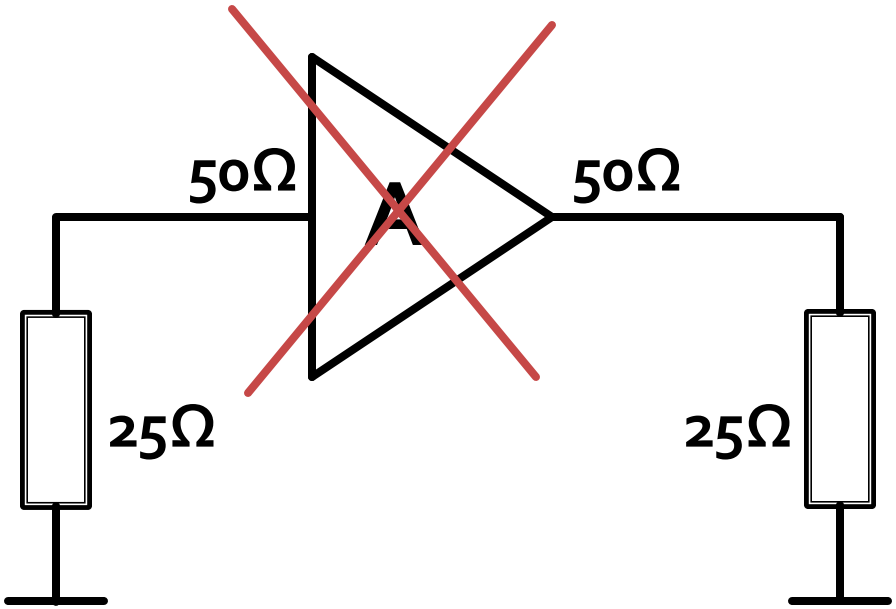




- 50Ω
- 50Ω||50Ω = 25Ω

Adaptare

- amplificator cu reactie



Cuploare directionale si divizoare de putere

Cuploare/Divizoare

- Funcționalitatea dorită:
  - divizarea
  - combinarea
- puterii semnalului

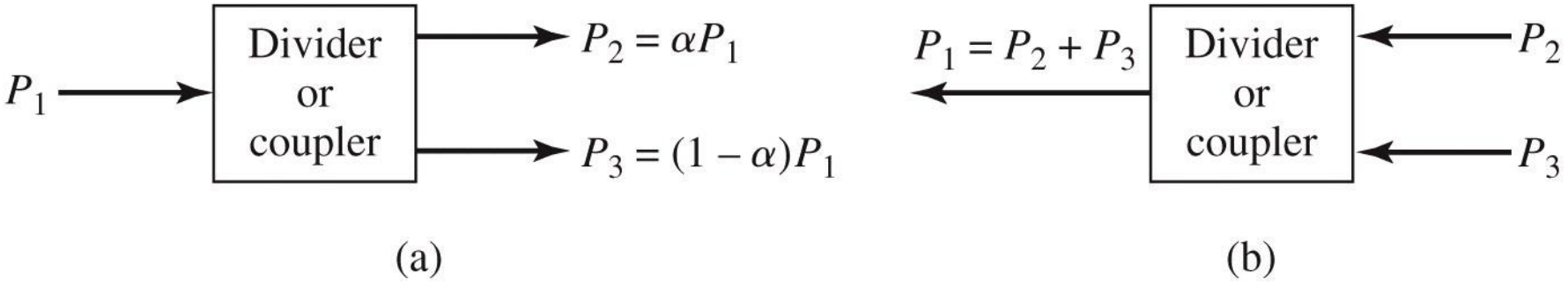


Figure 7.1

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Circuite cu trei porți

- numite si joncțiune in T
- caracterizate de o matrice **S** 3x3

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

- 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

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

- 6 ecuații / 3 necunoscute
  - **nici o soluție posibila**
- Un circuit cu 3 porți **NU** poate fi simultan:
  - reciproc
  - fara pierderi
  - adaptat simultan la toate cele 3 porți

Circuite cu patru porți

- caracterizate de o matrice **S** 4x4

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

- 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 sa obținem circuitul **adaptat simultan la toate porțile**
  - evitarea unor pierderi externe de putere

Circuite cu patru porți

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

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

Cuplor directional

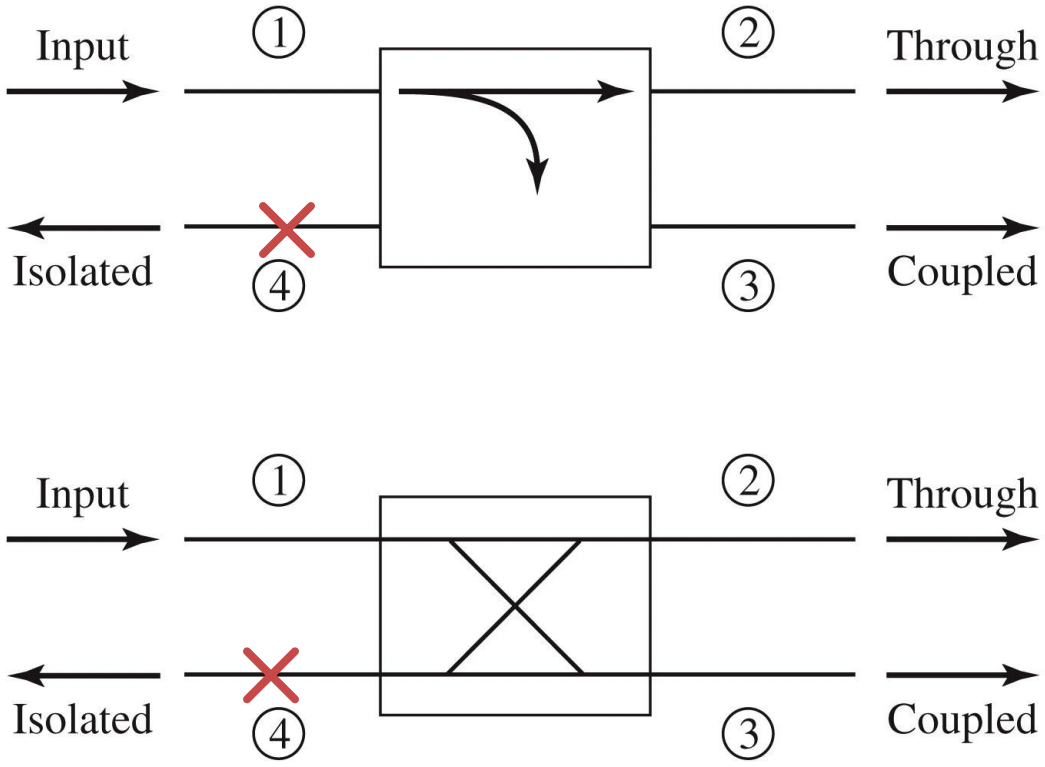


Figure 7.4
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$$|S_{12}|^2 = \alpha^2 = 1 - \beta^2$$

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

Cuplaj

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

Directivitate

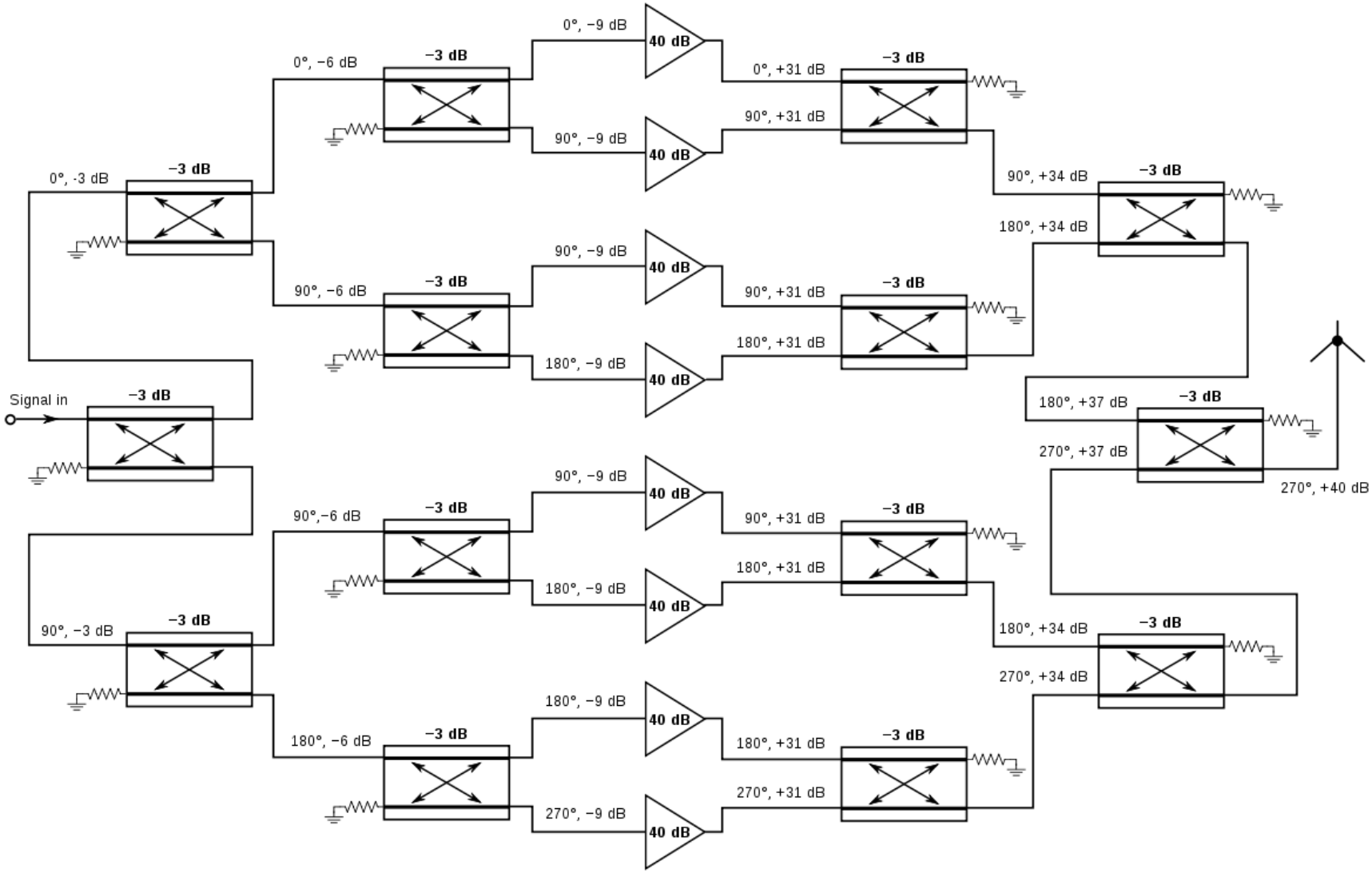
$$D = 10\log\frac{P_3}{P_4} = 20\cdot\log\left(\frac{\beta}{|S_{14}|}\right)[\text{dB}]$$

Izolare

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

$$I = D + C\ ,\ \ dB$$

Amplificatoare echilibrate



Cuplorul hibrid în cuadratură (90°)

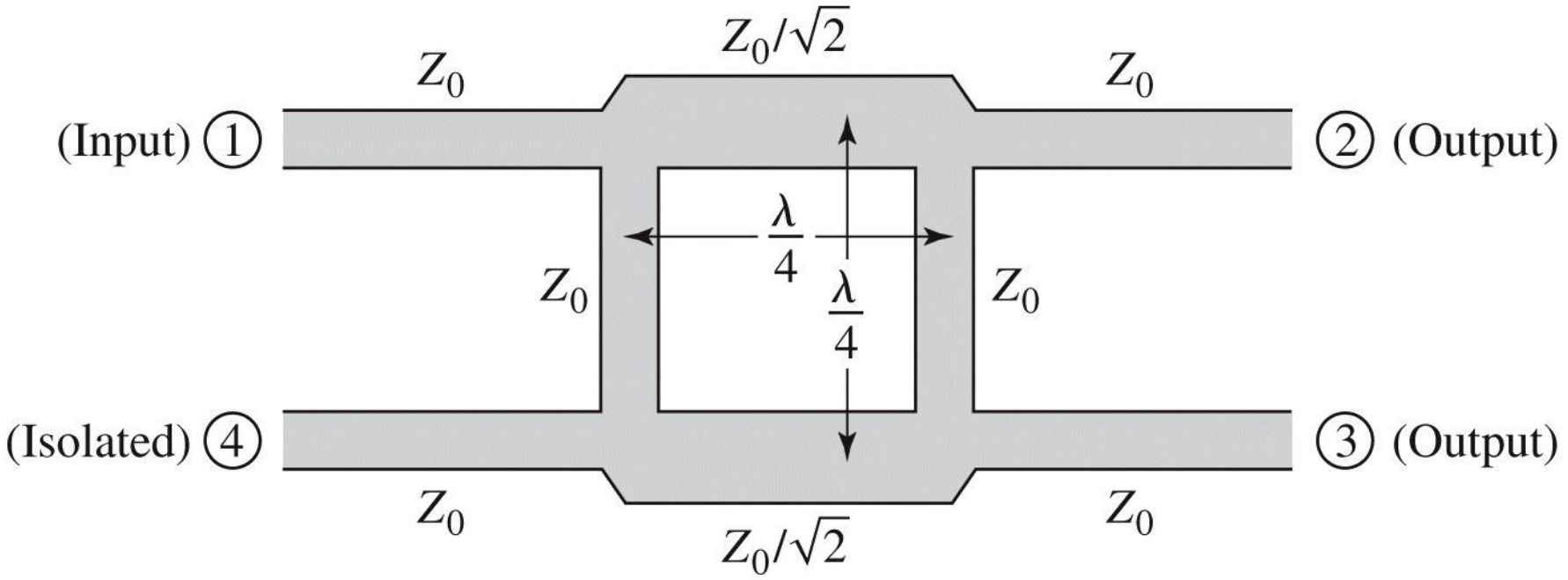
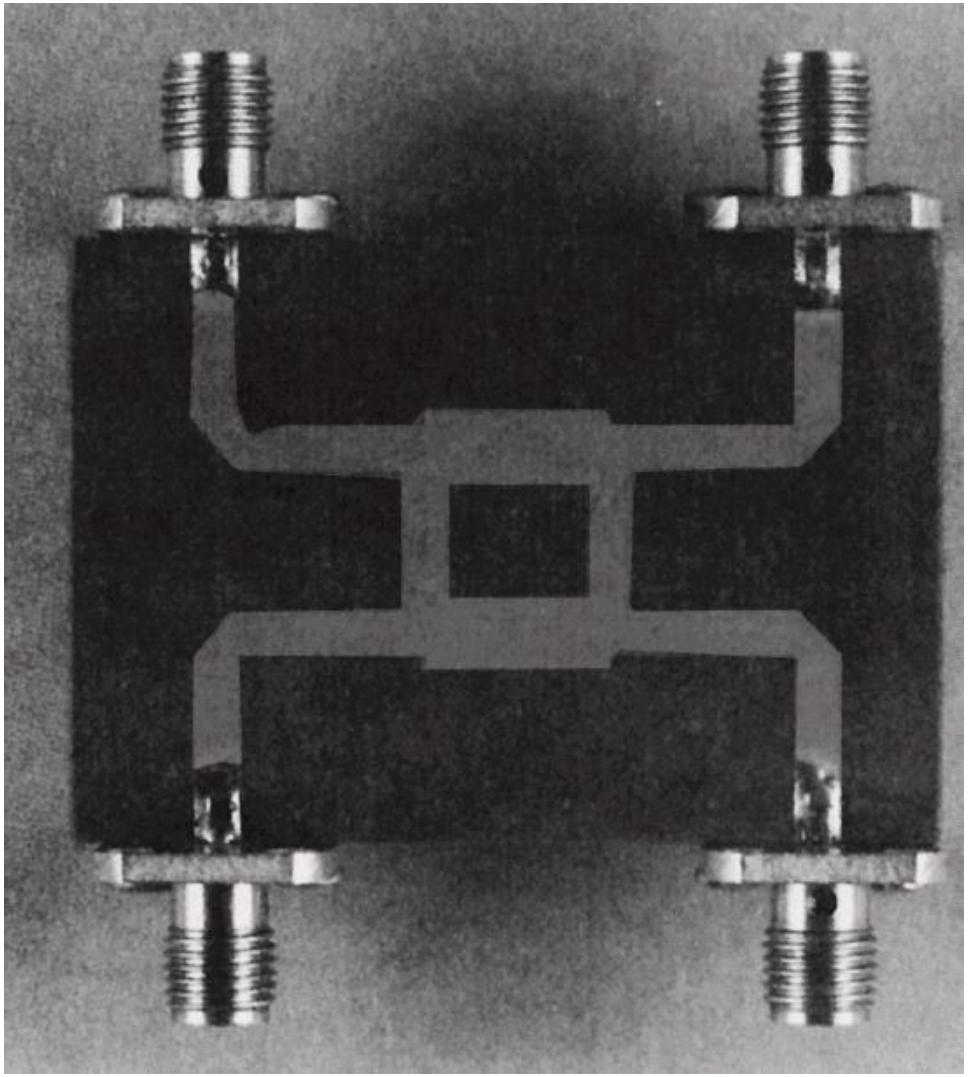


Figure 7.21
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$$[S] = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}$$



Cuplorul in cuadratura

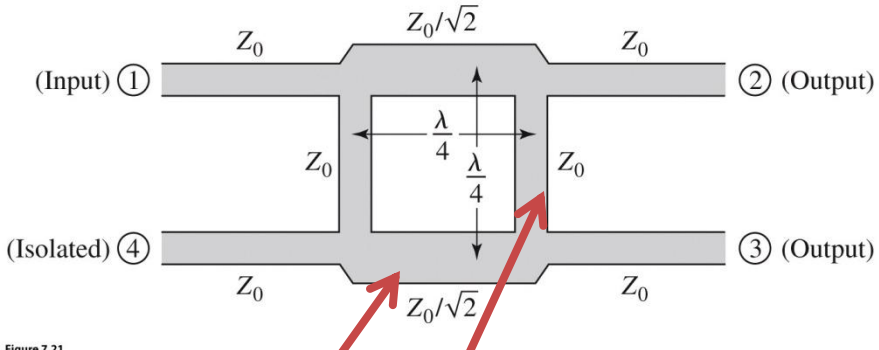


Figure 7.21
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$$y_2^2 = 1 + y_1^2$$

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

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

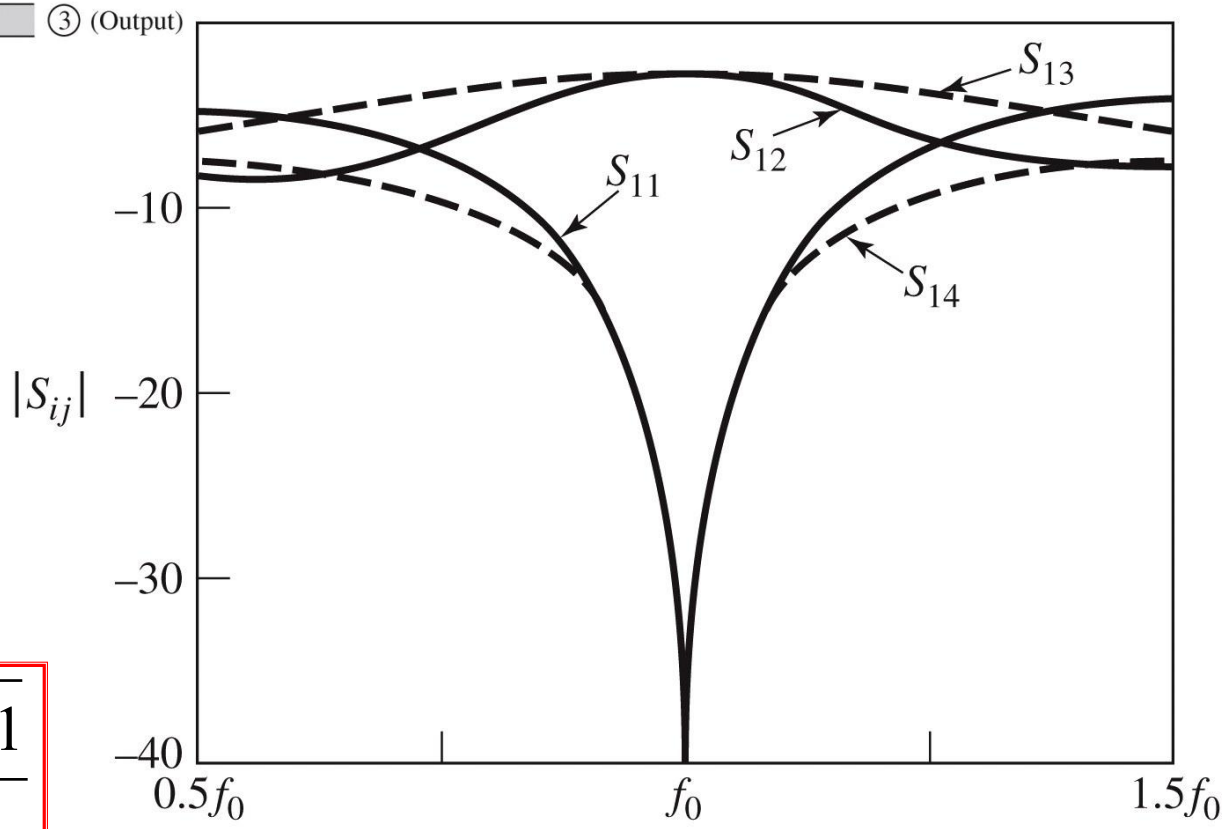
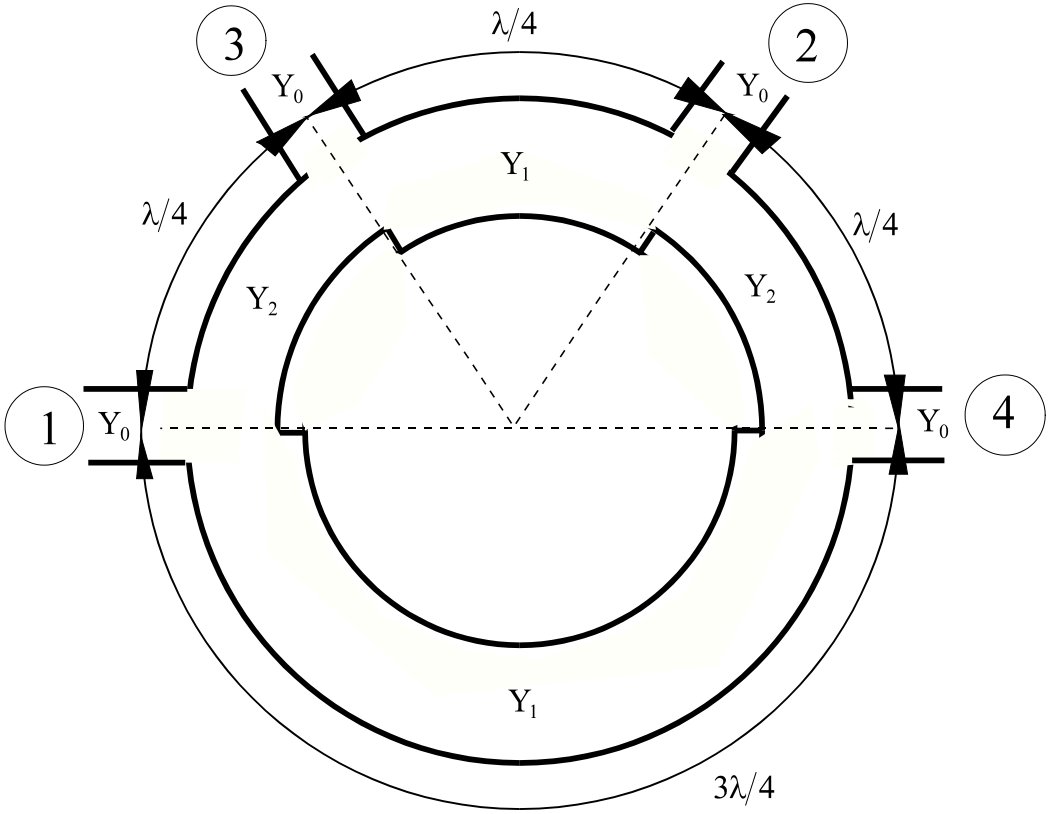


Figure 7.25
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Cuplorul in inel



Cuplor în inel

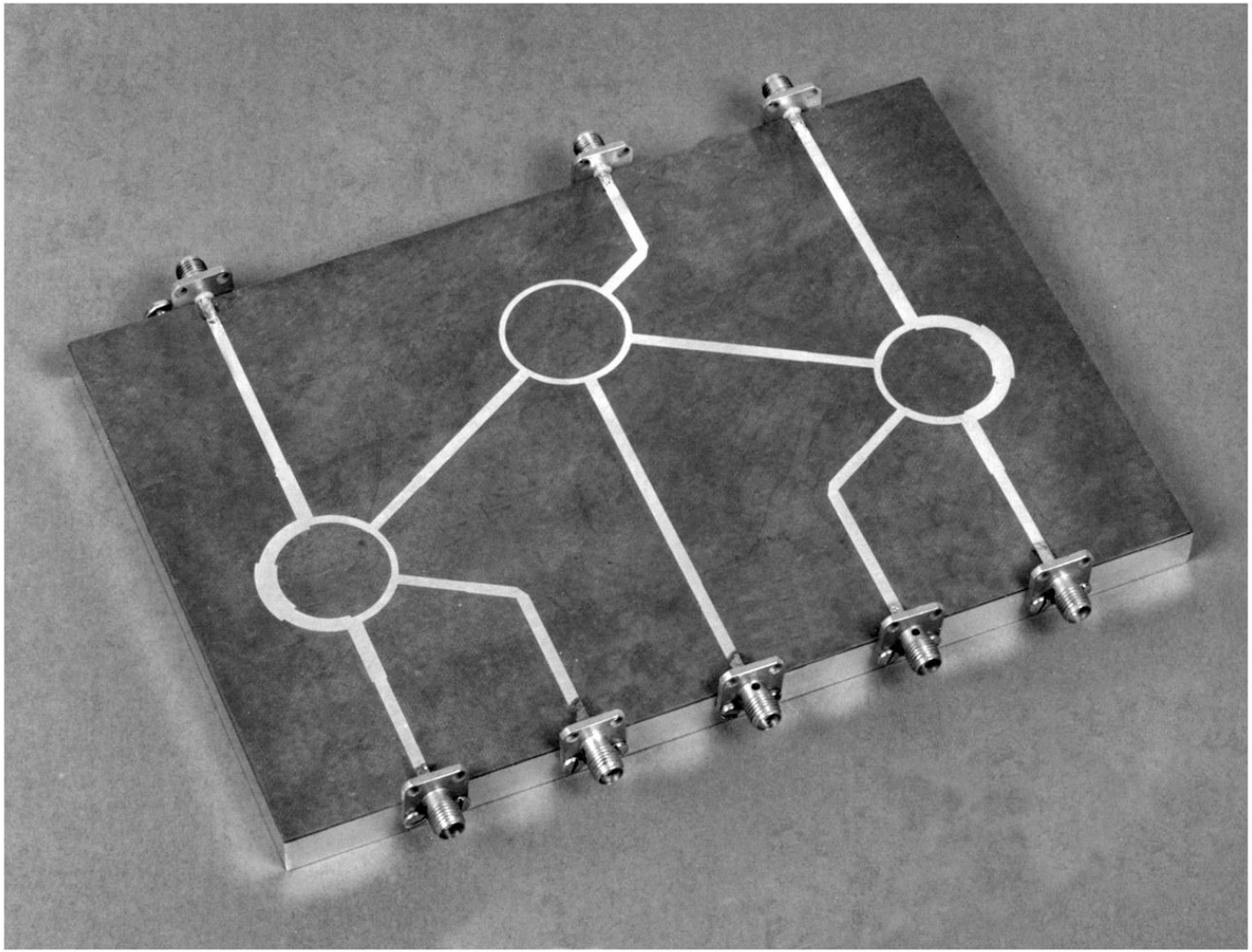
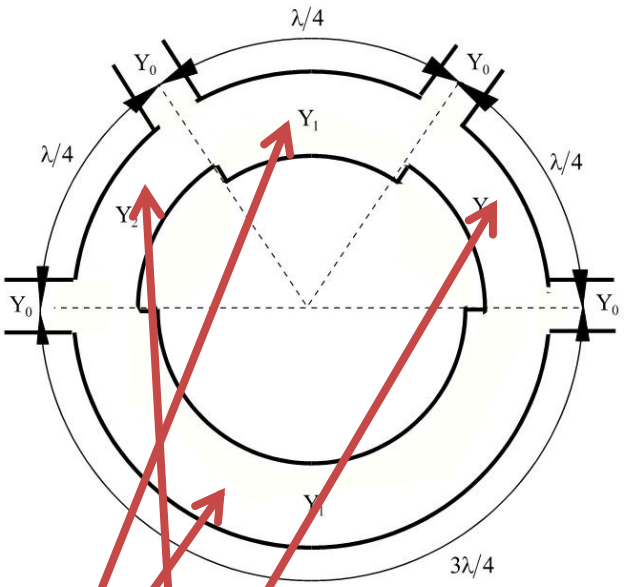


Figure 7.43
Courtesy of M. D. Abouzahra, MIT Lincoln Laboratory, Lexington, Mass.

Cuplorul în inel



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

$$|\beta| = y_1$$

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

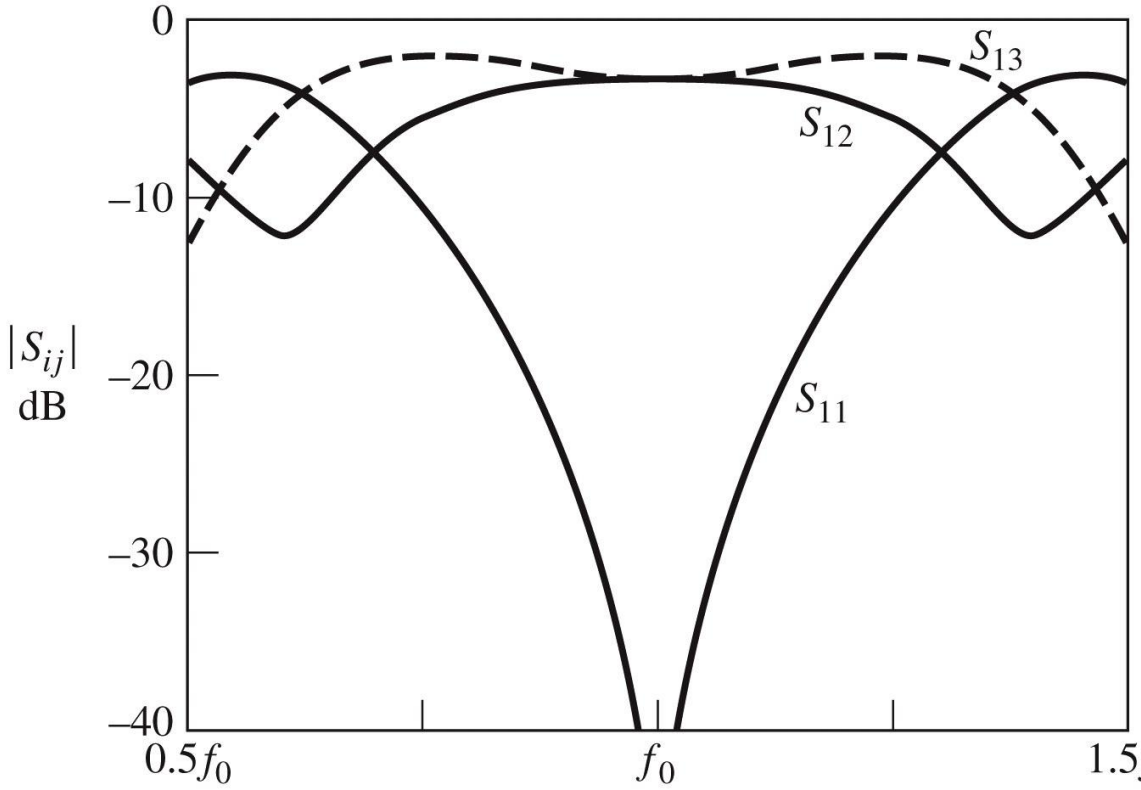
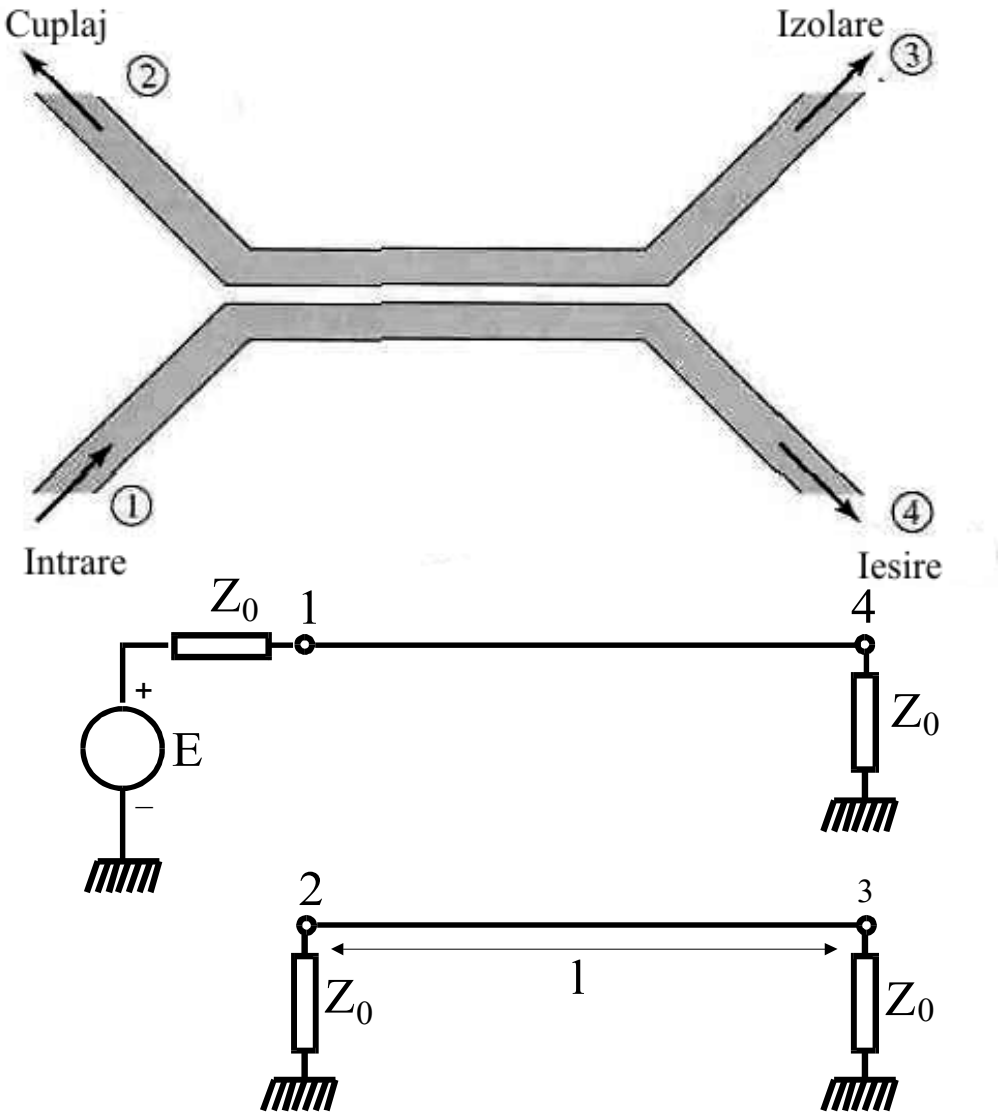


Figure 7.46
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Cuplorul prin proximitate



Linii cuplate

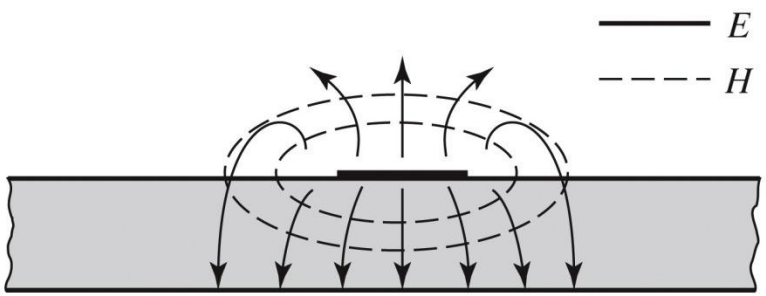
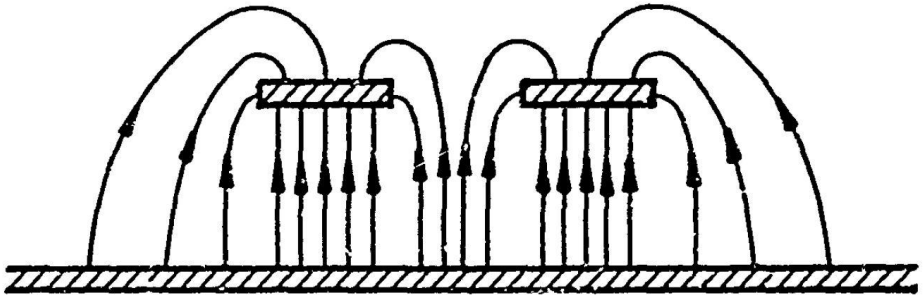
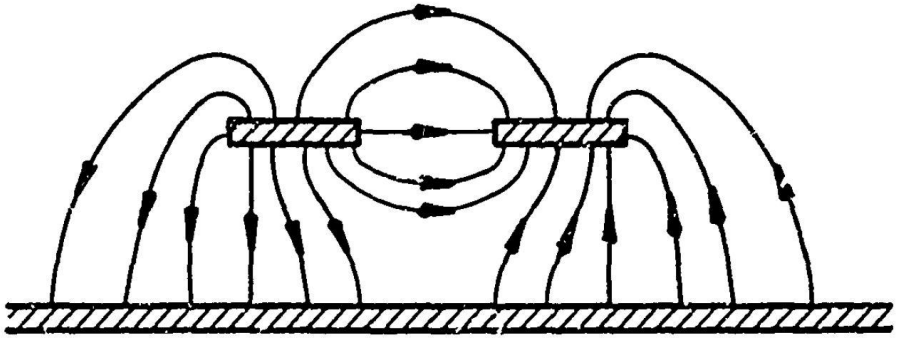


Figure 3.25b
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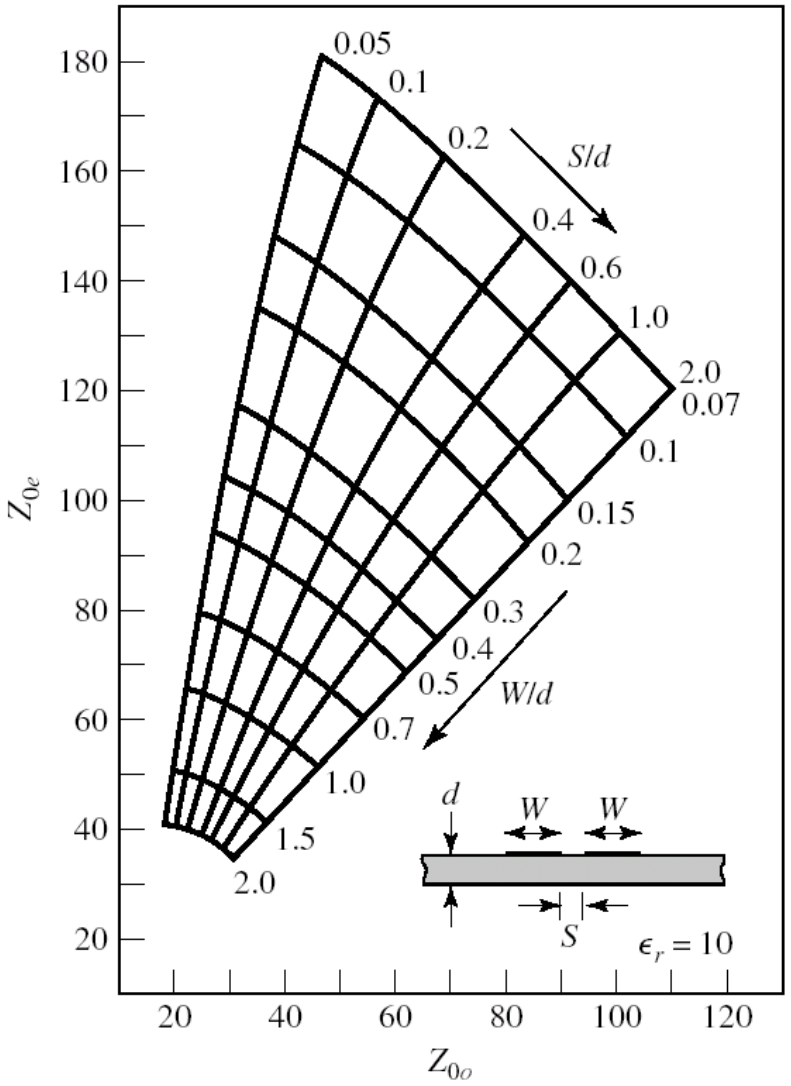
b) EVEN MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

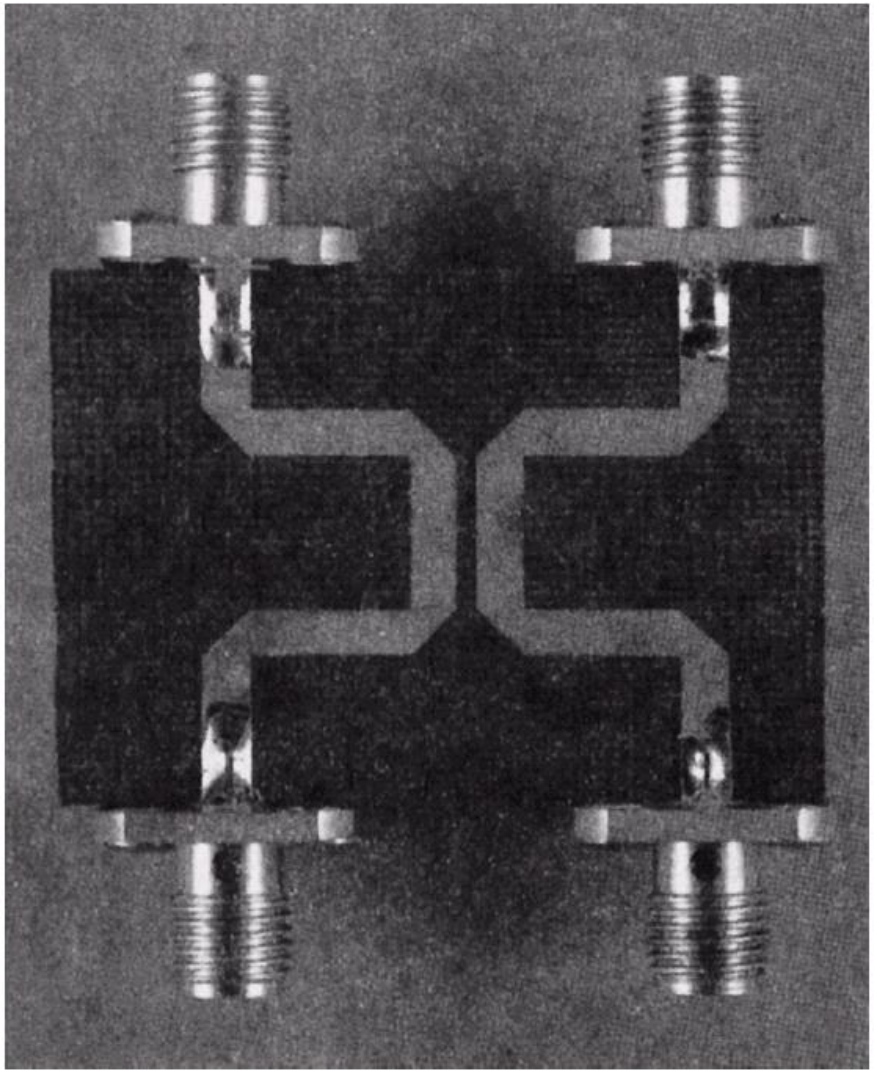
- Mod par – caracterizeaza semnalul de mod comun de pe cele doua linii
- Mod impar – caracterizeaza semnalul de mod diferential dintre cele doua linii
- Fiecare din cele doua moduri e caracterizat de impedante caracteristice **diferite**



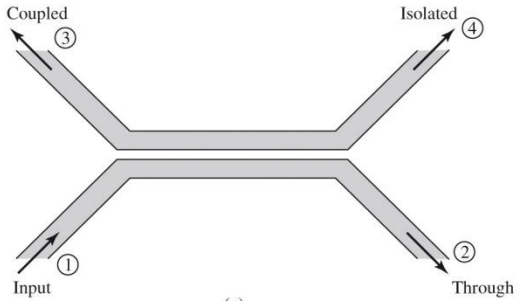
c) ODD MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

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





Cuplor prin proximitate



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

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

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

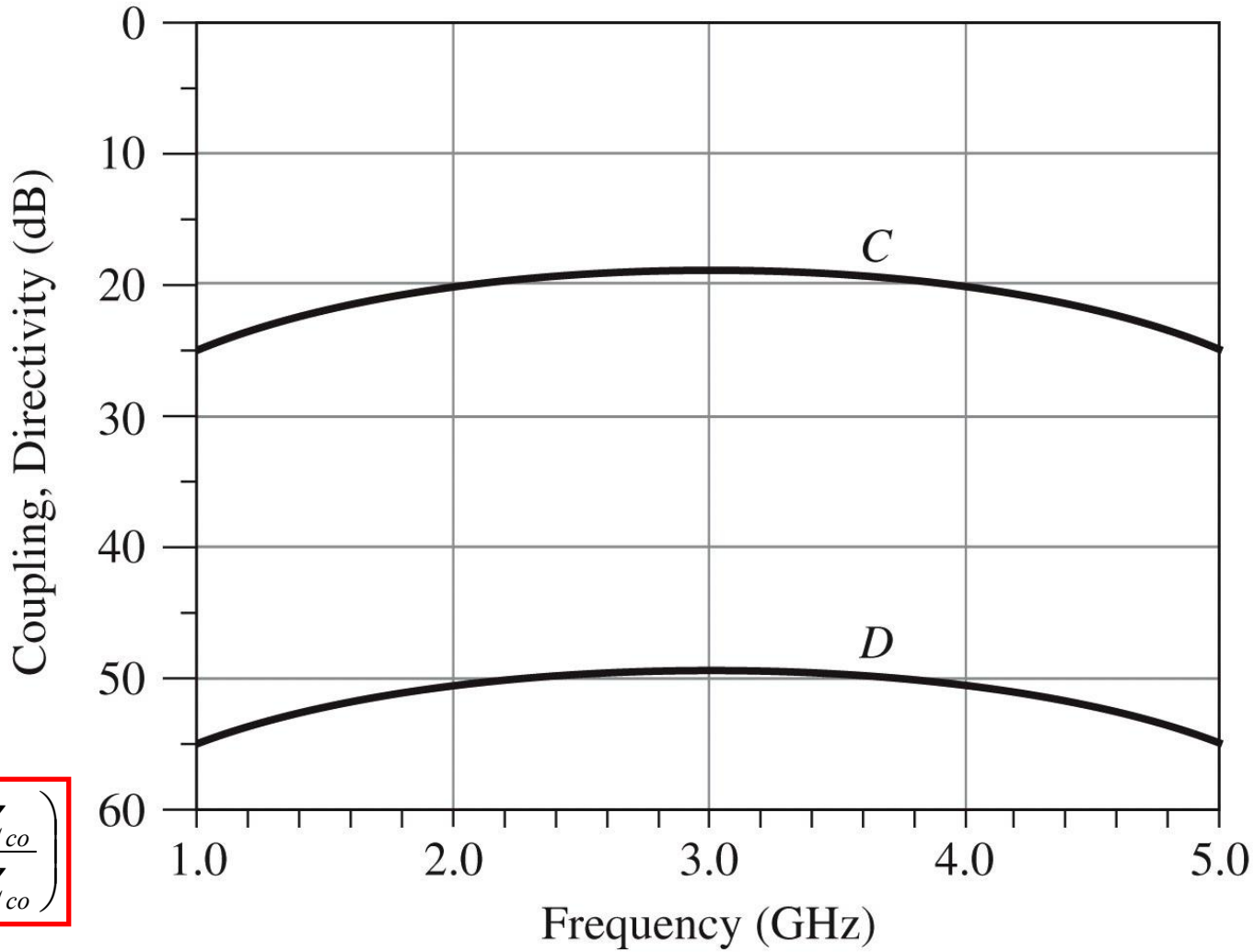


Figure 7.34

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Mod de lucru

Pas o

- Se scrie de mana de 100 de ori pe o foaie de hartie:
- **Promit solemn sa citesc SI textul si sa nu sar din poza in poza**
- ☺

Pas 1

- Se calculeaza caracteristicile cuploarelor
- Spre deosebire de laboratorul 2 **NU** va fi necesar reglaj
  - daca nu se obtine comportamentul dorit se verifica si se refac calculele
  - orice incercare de compensare a calculelor prin reglaj e **inutila** (precizia necesara prea mare)

Pas 1

- Se remarca faptul ca toate exemplele din referat sunt pentru cuploare de **3dB** (1/2 : 1/2)
- In mod particular

$$\beta = 10^{-3/20} = \frac{1}{\sqrt{2}} = 0.7071$$

- Deoarece valorile primite nu sunt 3dB (~~**3dB**~~) in relatii nu va aparea 2 sau $\sqrt{2}$ ci va trebui calculat

$$\beta = 10^{-C[dB]/20} = \cdots$$

Pas 2

- Se deseneaza schema (identica cu cea din referat, cu exceptia valorilor numerice)
  - **ATENTIE!** Pentru primele doua cuploare relatiile ofera admitantele raportate ale liniilor (y_1 si y_2) in timp ce schema trebuie sa primeasca impedantele caracteristice

$$Z = \frac{Z_0}{y} \rightarrow \begin{cases} Z_1 = \dfrac{50\Omega}{y_1} \\ Z_2 = \dfrac{50\Omega}{y_2} \end{cases}$$

  - **ATENTIE!** Pentru primele doua cuploare impedantele liniilor sunt egale doua cate doua (pe diagonala) din aceasta cauza se calculeaza 2 valori si se introduc 4 linii de transmisie (2 Z1 si 2 Z2)

Pas 3

- Se alege o poarta ca poarta de intrare si se reprezinta puterea de iesire pe toate portile (inclusiv cea aleasa ca intrare) cu intrare de semnal pe poarta aleasa anterior
  - daca aleg de exemplu **Term2** – poarta numarul **2** ca intrare voi reprezenta dB(S(1,**2**)), dB(S(2,**2**)), dB(S(3,**2**)), dB(S(4,**2**)) pentru a afisa iesirile de putere pe toate cele 4 porti la introducere de semnal pe poarta 2

Pas 4

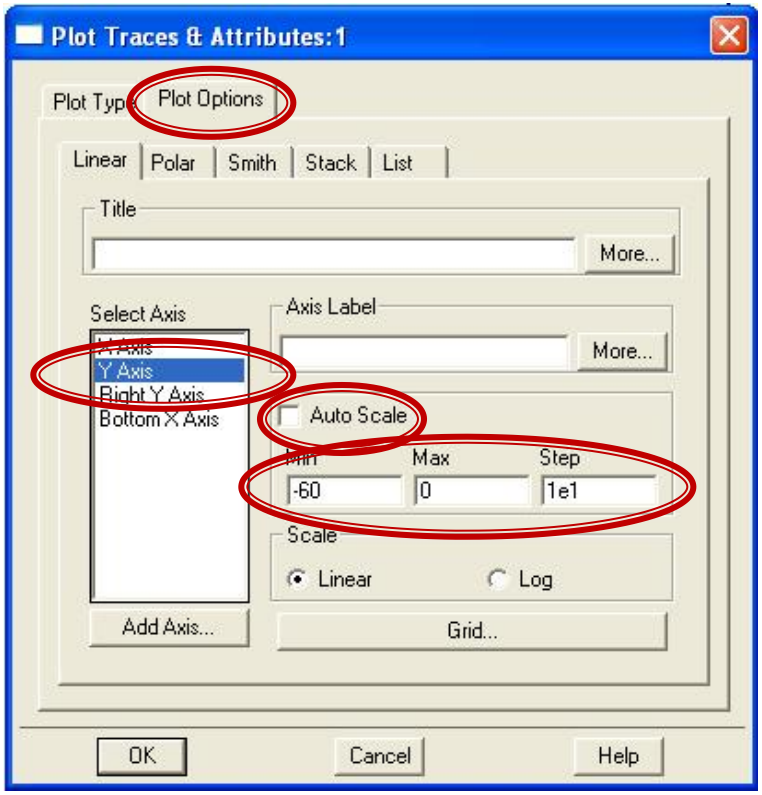
- Daca rezultatele nu sunt cele dorite se alege o alta poarta ca intrare si se repeta afisarea
  - rezultate dorite: la frecventa din tema pe 2 porti se obtin valori ridicate (0 ÷ -10dB in functie de tema) si pe celelalte 2 porti se obtin valori scazute (<-60dB)
  - cuploarele pot fi rotite in general asa ca pot functiona ca si cuploare cu considerarea intrarii in mai multe pozitii

Pas 5

- Daca este necesar **se schimba scala** axei y pentru grafic
- Scala este logaritmica (dB) ca urmare, in functie de precizia cu care au fost facute calculele se pot obtine valori nepractice a caror afisare este inutila
- Valorile suficiente sunt de obicei Min=-60, Max=0, Step=10 (se reaminteste ca $10^{-60/10}=0.000001$ precizie de cele mai multe ori mai mult decat suficienta)
  - pentru cuplorul prin proximitate e posibil sa fie necesar Min mai mic (ca in exemplul din referat ~-110dB sau se afiseaza pe doua grafice diferite)

Pas 5

- Pentru schimbarea scalei: dublu click pe grafic, tab Plot Options, Y Axis, Auto Scale, Min/Max/Step

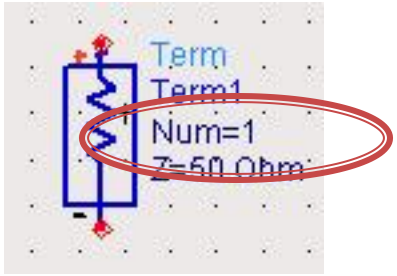


Pas 6

- Pentru upload pe server se obtin 2 imagini, cu schema si cu rezultatele obtinute (print screen sau desenare pe hartie si scanare/foto)

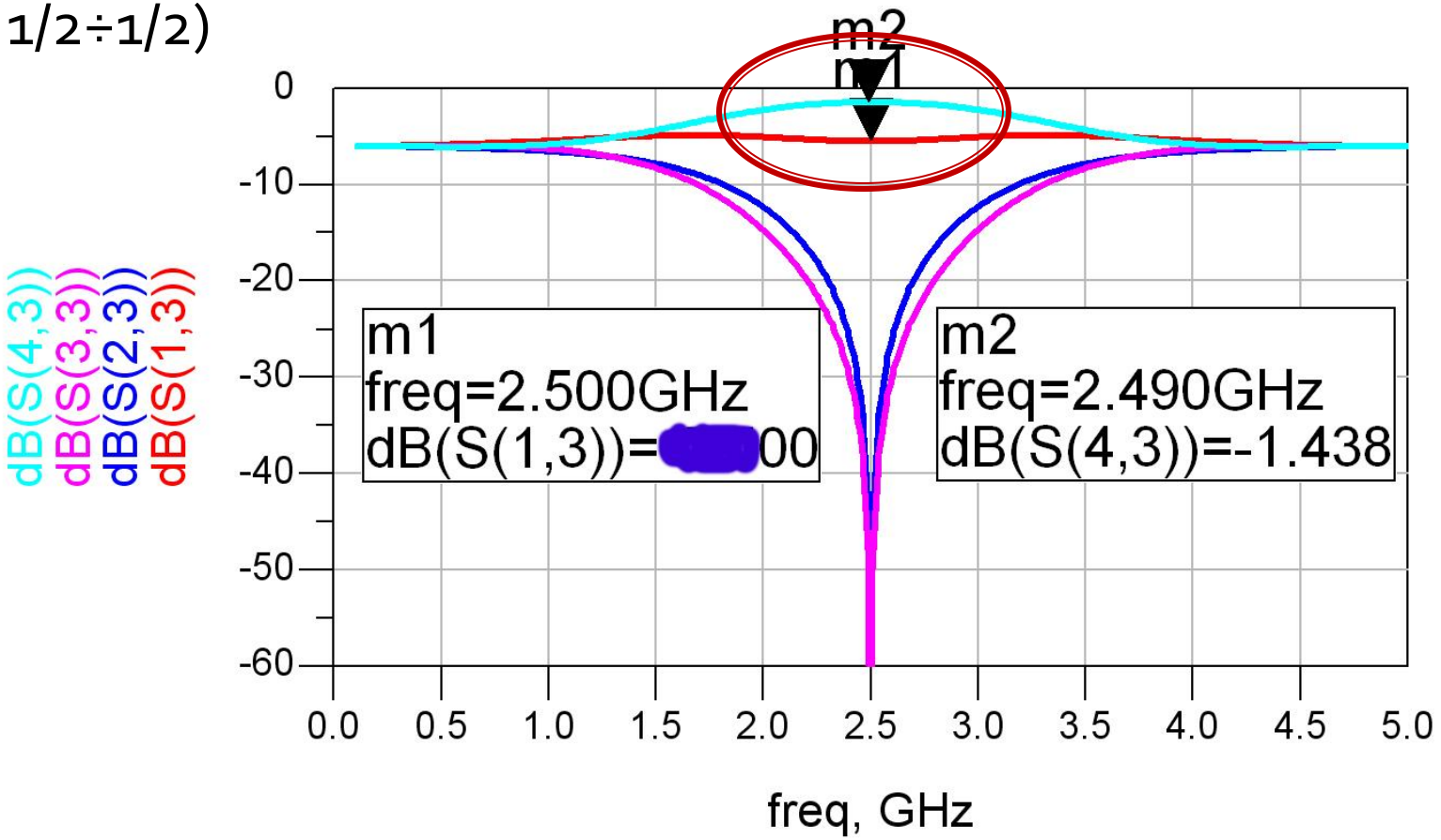
Pas 7

- Se identifica corect portile/porturile din rezultate (identificarea trebuie indicata pe server)
- Textul care trebuie introdus trebuie sa fie de tipul: "3 - intrare, 4 - iesire, 1 - cuplata, 2 - izolata"
- Indicele portului e cel care apare la **Num = …**



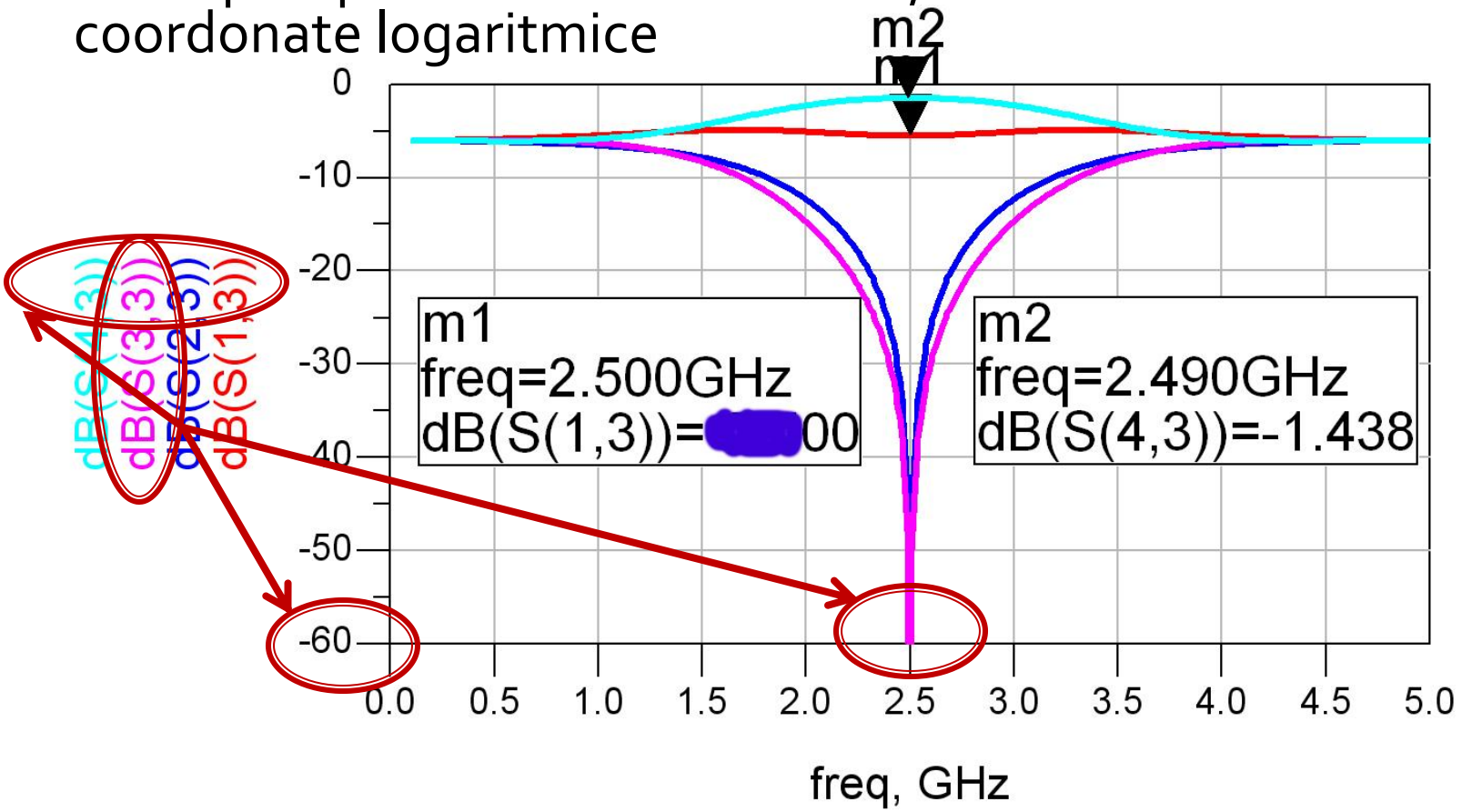
Pas 7

- Se remarca faptul ca cele doua curbe care au valori mai mari nu se mai ating (cuploarele nu mai sunt de 3dB adica 1/2÷1/2)



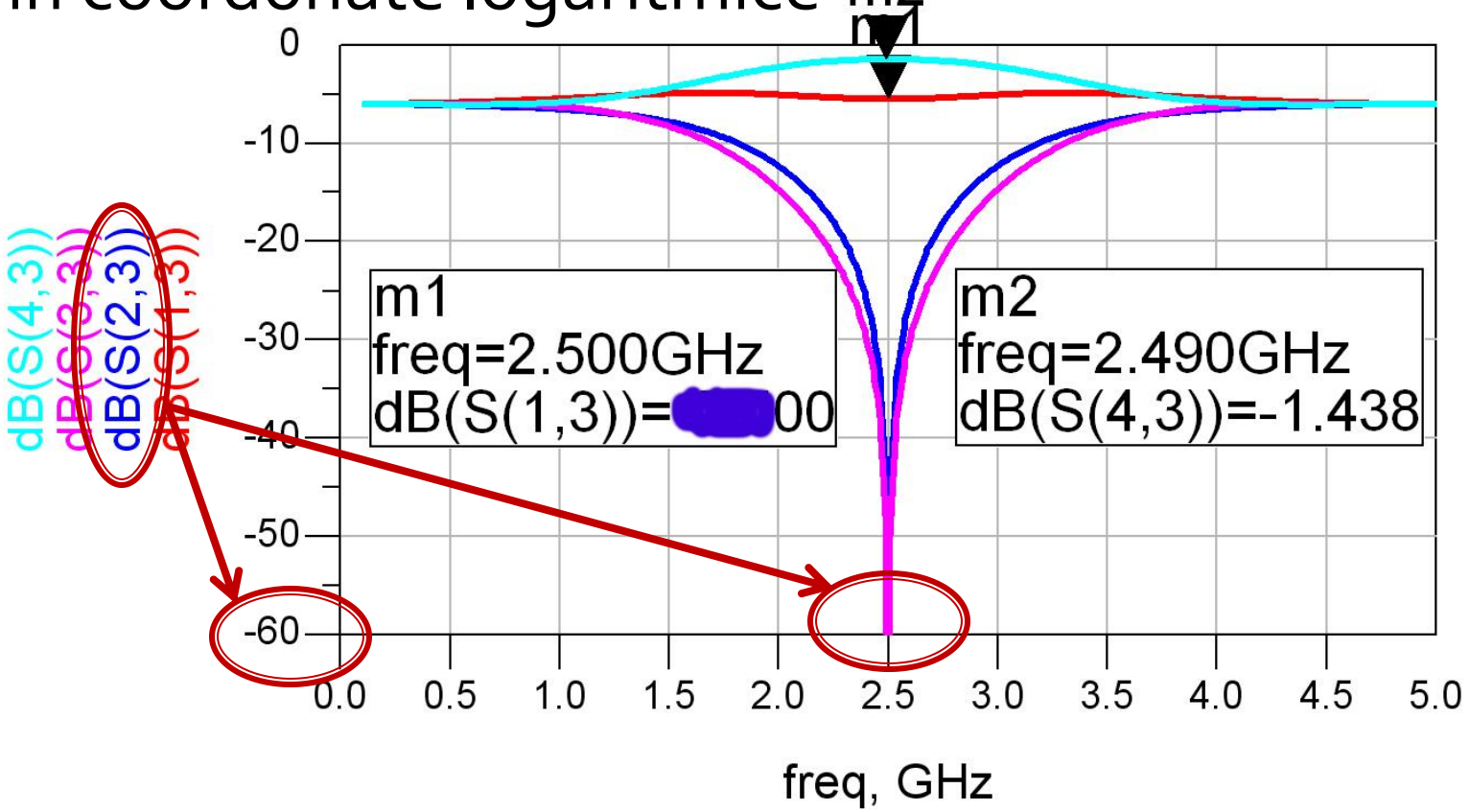
Pas 7

- **intrarea** se recunoaste prin faptul ca e al doilea indice, comun, din rezultatele afisate si S(x,x) (S(3,3) in exemplu) este aproape **o** la frecventa dorita, adica –Xo÷XoodB in coordonate logaritmice



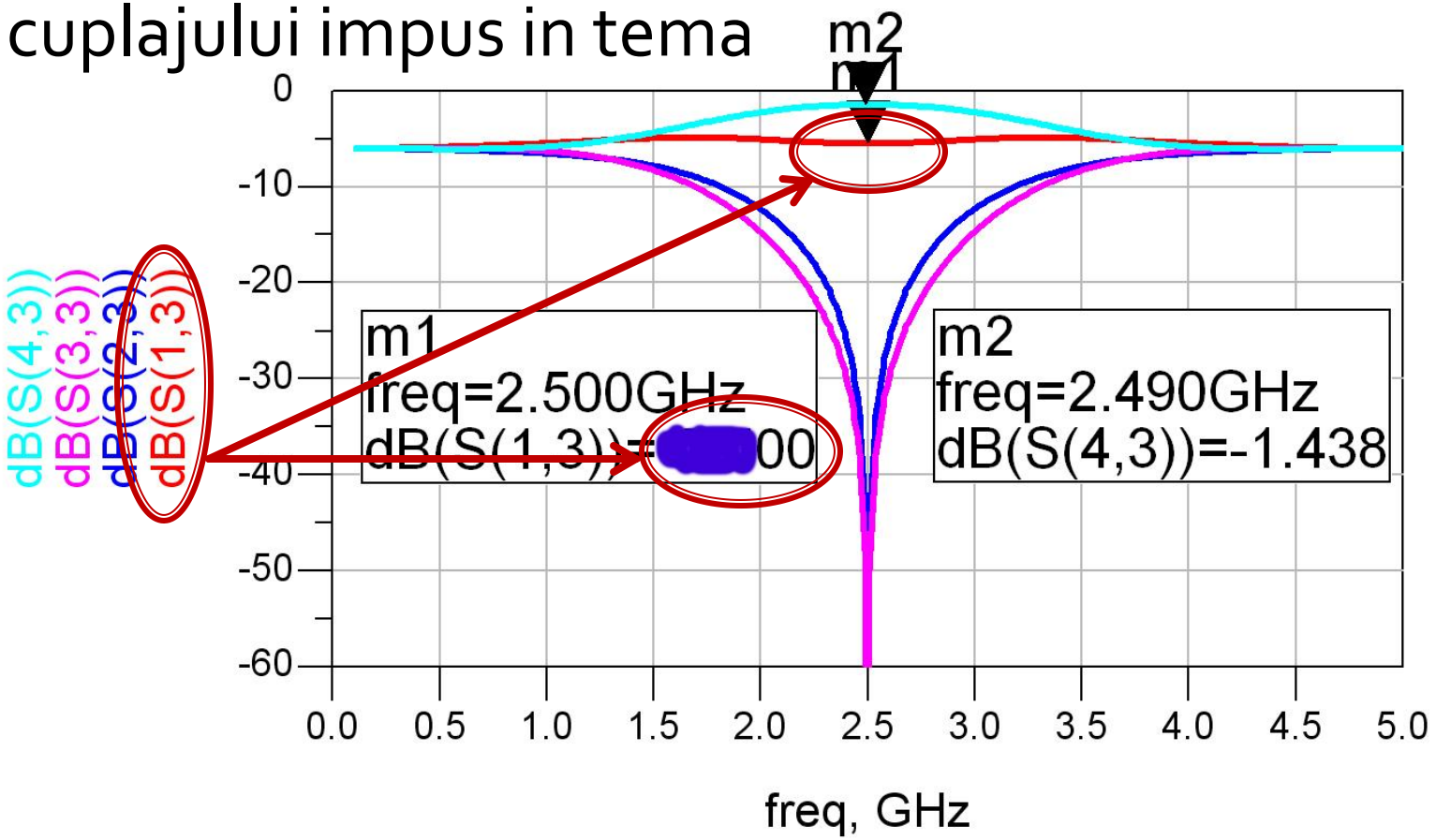
Pas 7

- **poarta izolata** este celalta curba care este aproape **o** la frecventa dorita, adica –Xo÷XoodB in coordonate logaritmice



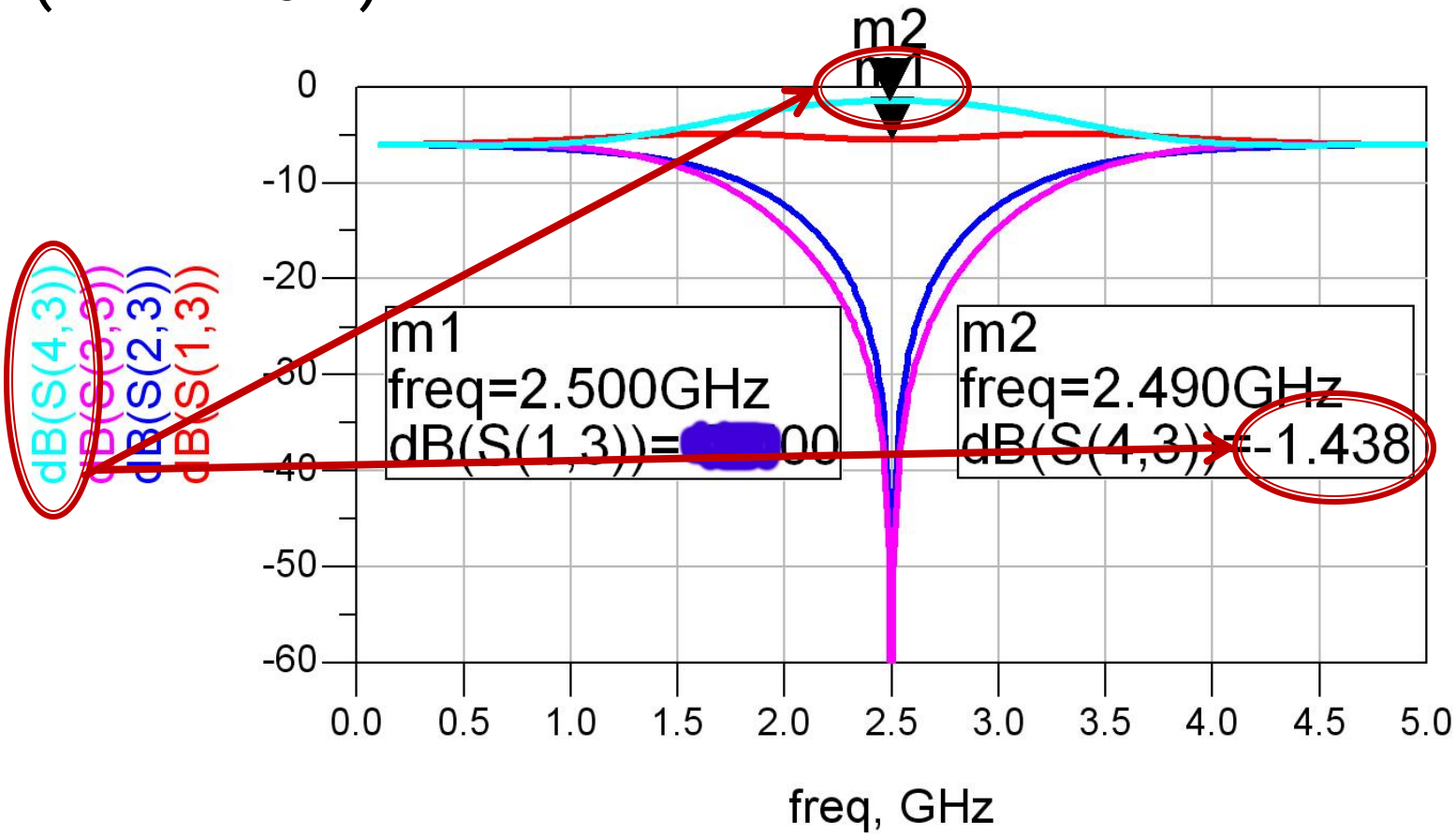
Pas 7

- **poarta cuplata** este curba la care un marker va indica la frecventa dorita exact valoarea cuplajului impus in tema



Pas 7

- **poarta de iesire** ultima curba care ramane (~-1÷-2dB)



Pas 8

- Se salveaza schema cu un alt nume (Save As)
  - schema pentru celelate cuploare este aproape aceeasi, o mare parte din componente se pot pastra

Pas 9 - 23

- **Se repeta** pasii 1-8 anteriori pentru celelalte doua cuploare dar se utilizeaza alte relatii si se modifica schema dupa necesitati

Pas 21

- Se completeaza **cu atentie** in "examenul" Laborator 3 de pe server-ul rf-opto valorile obtinute. Pentru fiecare din cele 3 cuploare vor fi necesare:
  - **rezultate calcule** (y_1/y_2 sau Z_{ce}/Z_{co})
  - **imagine** cu schema (**cu valorile componentelor inteligibile**)
  - **imagine** cu rezultatele (**cu text inteligibil**)
  - **text** cu identificarea portilor/porturilor

Greseli frecvente

Greseli 1

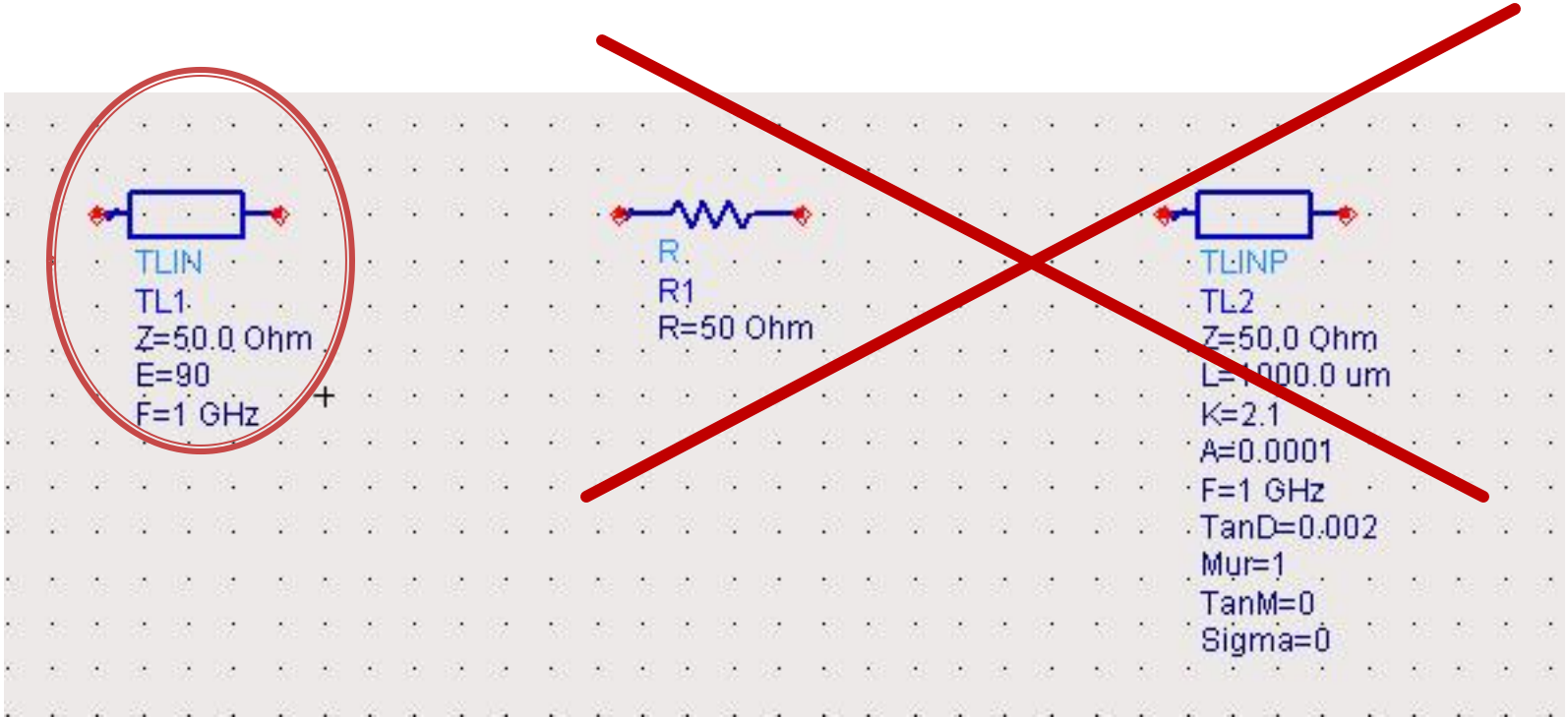
- Greseli la calcul (**! frecvent**)
  - din cauza functiilor de radical, ridicare la putere, e nevoie sa se utilizeze **5-6 zecimale exacte** in calcul pentru ca propagarea erorilor sa nu modifice rezultatul
  - pentru primele 2 cuploare se obtine dintr-o ecuatie direct una din valori (y_2/y_1), iar din a doua ecuatie se poate calcula cealalta valoare (y_1/y_2)
  - pentru cuplorul prin proximitate se obtine un sistem de 2 ecuatii cu doua necunoscute, singura posibilitate este de rezolvare **ca sistem**

Greseli 2

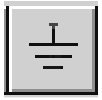
- Greseli de interpretare a relatiilor (**! frecvent**)
  - Exemplele din referat sunt pentru cuploare la 3 dB (pentru ca acestea se intalnesc cel mai frecvent in practica). Aceste cuploare duc la aparitia unor valori egale cu 2, $\sqrt{2}$, sau la situatii particulare tip $y_1 = 1$, $Z_1 = 50\Omega$, $y_1 = y_2$
  - Pentru valorile din tema personala acest lucru **nu** se mai intampla, calculele trebuie facute cu relatiile originale

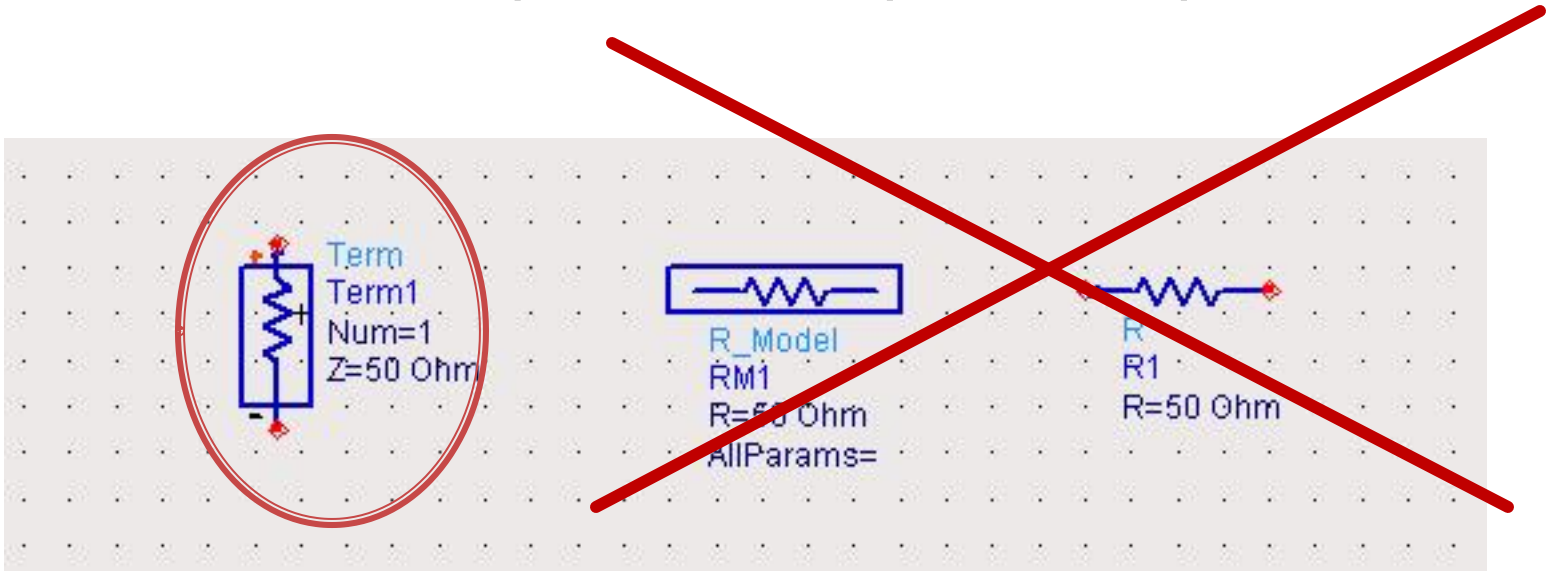
Greseli 3

- In schema in loc de linii de transmisie ideale (**TLIN**) se introduc rezistente sau alte elemente (linii microstrip, fizice etc.)



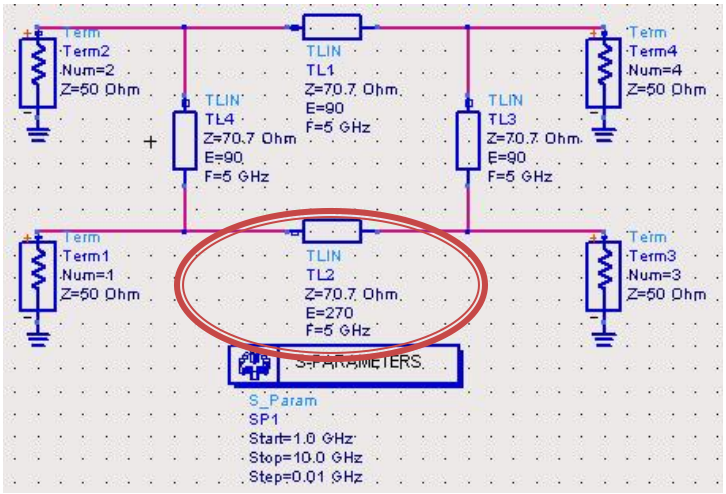
Greseli 4

- Se uita introducerea **masei** la terminatori,  rezultand un circuit flotant care nu poate fi simulat
- In schema in loc de terminatie/port (**TERM – paleta Simulation S-param**) se introduce R_model sau R (paleta Lumped Components)



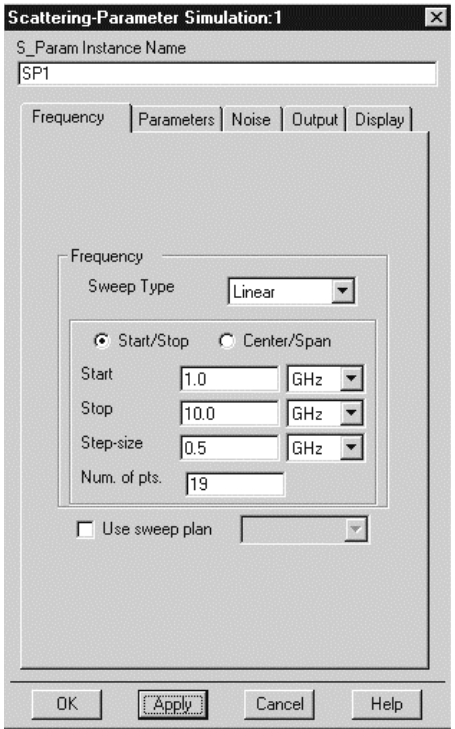
Greseli 5

- Se uita sa se modifice frecventa de lucru primita in tema la toate liniile de transmisie (**TLIN, CLIN**)
- Se greseste lungimea electrica (**! frecvent**)
  - aproape toate liniile trebuie sa ramana cu E=90
  - singura exceptie e linia mai lunga de la **cuplorul in inel (E=270)**



Greseli 6

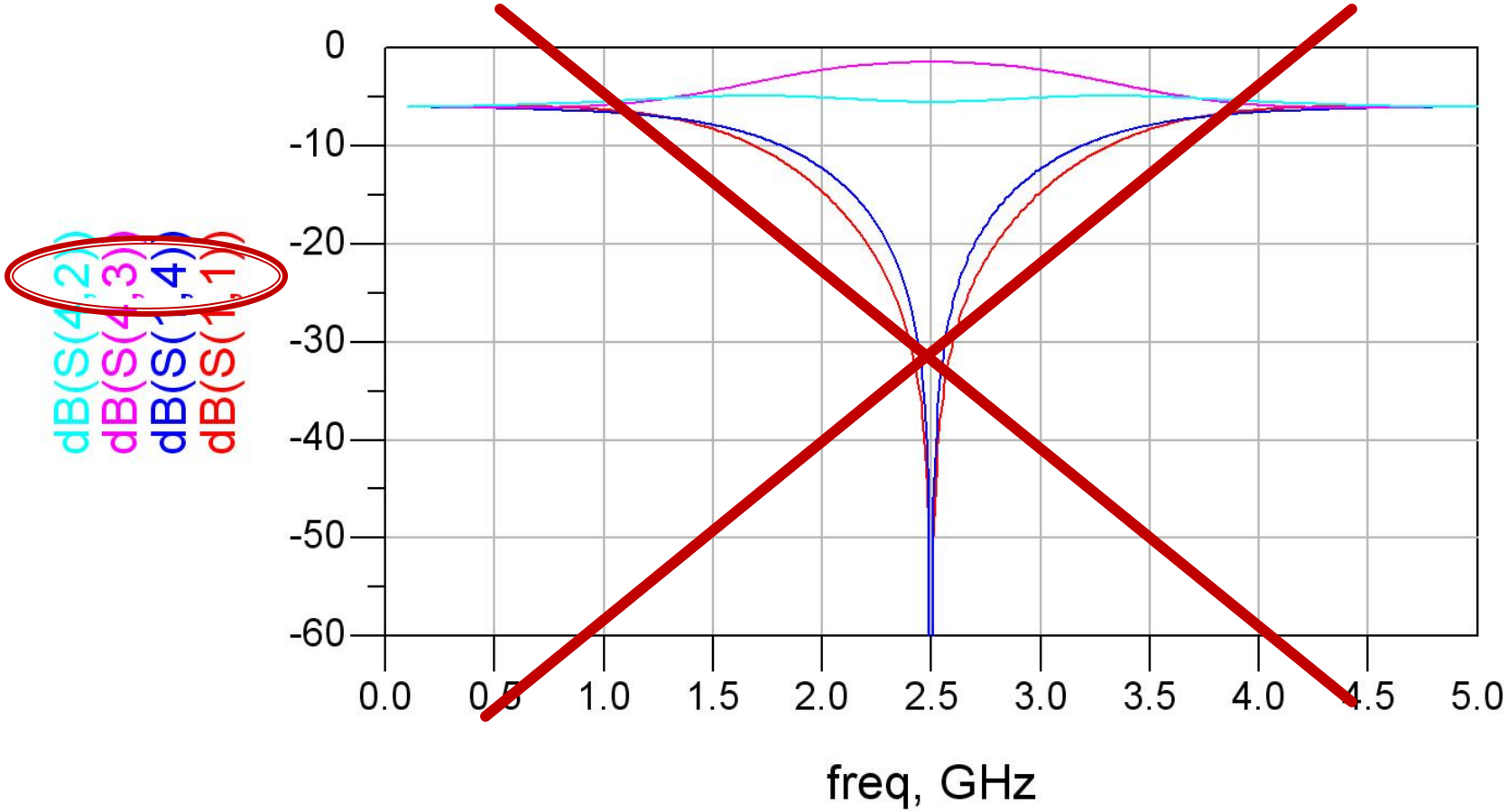
- Se uita sa se modifice parametrii de simulare
  - deseori ramane **Start/Stop/Step size**: **1GHz/10GHz/1GHz** cu efecte total neplacute



- trebuie modificat **Start/Stop/Step size**: **fo-Δf/fo+Δf/(0.05GHz sau 0.01GHz)**
- unde Δf se ia de o parte si de alta a frecventei fo impusa in tema in asa fel incat sa permita observarea benzii, daca din rezultate se observa ca Δf e prea mic, se modifica si se repeta simularea

Greseli 7

- La alegerea marimilor de afisat se adauga marimi eronate (se reprezinta marimi pentru introducere de semnal pe mai multe porti), e important ca **al doilea indice** sa fie **acelasi**



Contact

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