

Curs 11-12

2016/2017

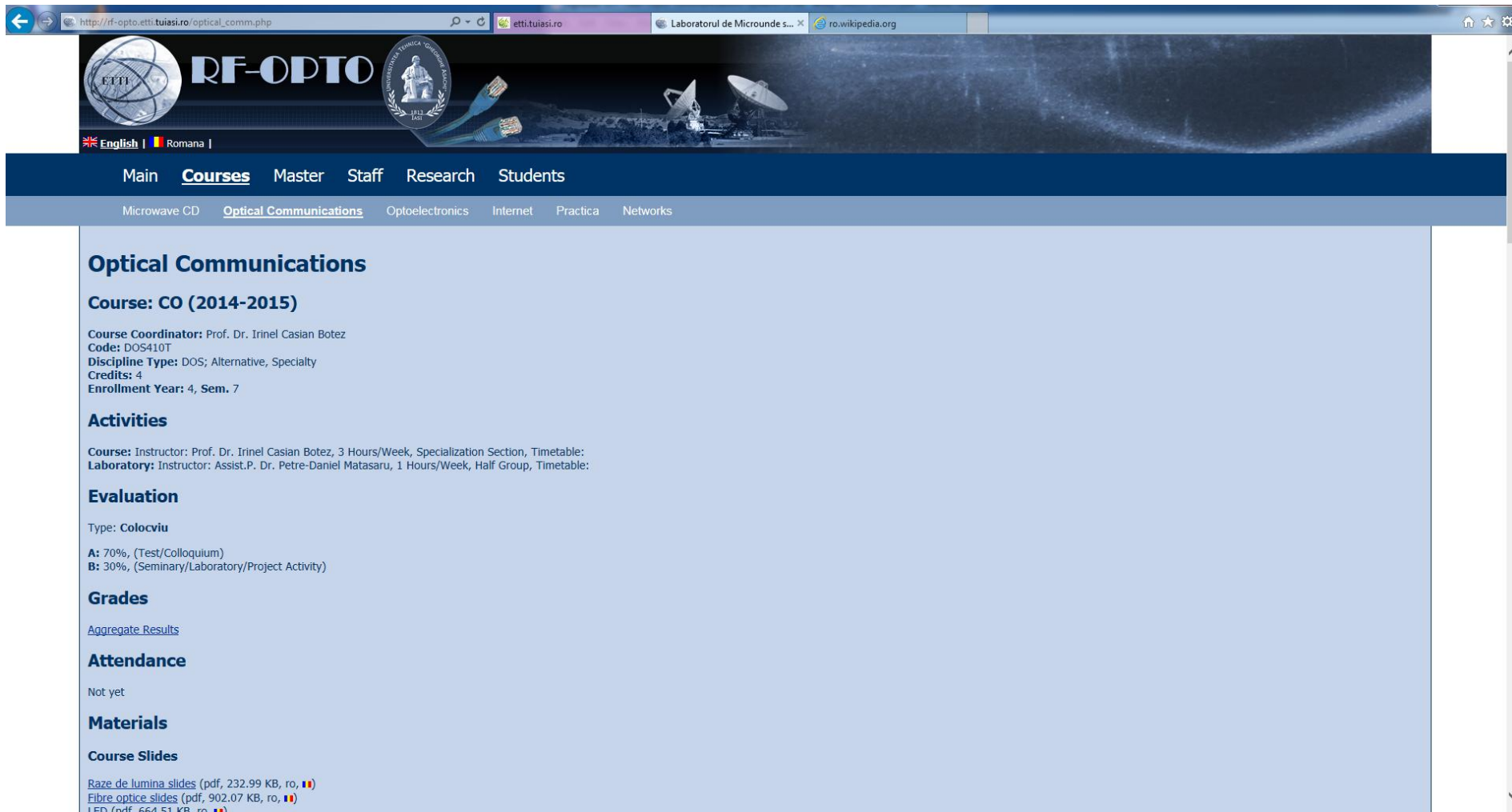
Dispozitive și circuite de microunde pentru radiocomunicații

Disciplina 2015/2016

- 2C/1L, **DCMR (CDM)**
- Minim 7 prezente (curs+laborator)
- Curs - **sl. Radu Damian**
 - Marti 18-20, P2
 - E – 50% din nota
 - probleme + (2p prez. curs)
 - 3prez.=+0.5p
 - toate materialele permise
- Laborator – **sl. Radu Damian**
 - Joi 8-14 impar II.13
 - L – 25% din nota
 - P – 25% din nota

Documentatie

■ <http://rf-opto.etti.tuiasi.ro>



The screenshot shows a web browser window with the URL http://rf-opto.etti.tuiasi.ro/optical_comm.php. The website has a dark blue header with a banner image featuring a globe, a person, and satellite dishes. The banner includes the text "RF-OPTO" and "ETTI". Below the banner is a navigation menu with links: Main, **Courses**, Master, Staff, Research, and Students. A secondary menu lists: Microwave CD, **Optical Communications**, Optoelectronics, Internet, Practica, and Networks. The main content area is titled "Optical Communications" and contains the following information:

Course: CO (2014-2015)

Course Coordinator: Prof. Dr. Irinel Casian Botez
Code: DOS410T
Discipline Type: DOS; Alternative, Specialty
Credits: 4
Enrollment Year: 4, Sem. 7

Activities

Course: Instructor: Prof. Dr. Irinel Casian Botez, 3 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assist.P. Dr. Petre-Daniel Matasaru, 1 Hours/Week, Half Group, Timetable:

Evaluation

Type: Colocviu

A: 70%, (Test/Colloquium)
B: 30%, (Seminary/Laboratory/Project Activity)

Grades




[Aggregate Results](#)

Attendance

Not yet

Materials

Course Slides

[Raze de lumina slides](#) (pdf, 232.99 KB, ro, 
[Fibre optic slides](#) (pdf, 902.07 KB, ro, 
[LED](#) (pdf, 664.51 KB, ro, 

Documentatie

- RF-OPTO
 - <http://rf-opto.etti.tuiasi.ro>
- Fotografie
 - de trimis prin email: rdamian@etti.tuiasi.ro
 - necesara la laborator/curs
 - ~~$\leq C_3 + 1p$~~
 - ~~$\leq C_5 + 0.5p$~~

Acces

■ Personalizat



Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

[Acceseaza ca acest student](#)

Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TW	Tehnologii Web					
	N	17/01/2014	Nota finala	10	-	
	A	17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	

Nume

Email

Cod de verificare

Trimite

Reprezentare logaritmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$-30 \text{ dBm} = 1 \mu\text{W}$$

$$-60 \text{ dBm} = 1 \text{ nW}$$

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

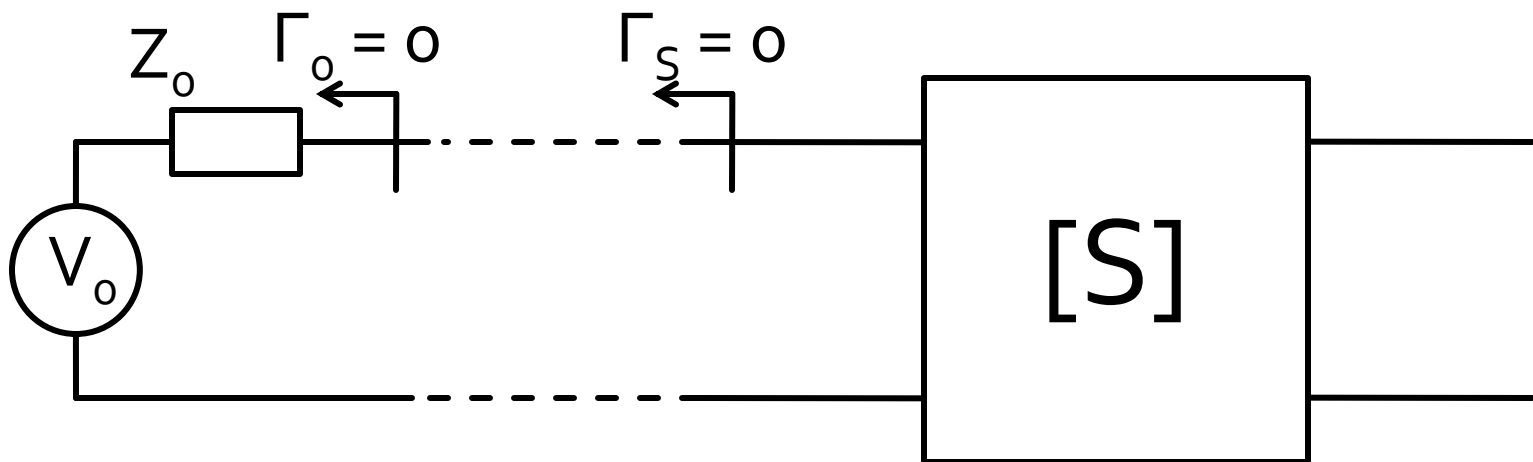
$$[\text{dBm/Hz}] + [\text{dB}] = [\text{dBm/Hz}]$$

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

Recapitulare

Adaptare – 1

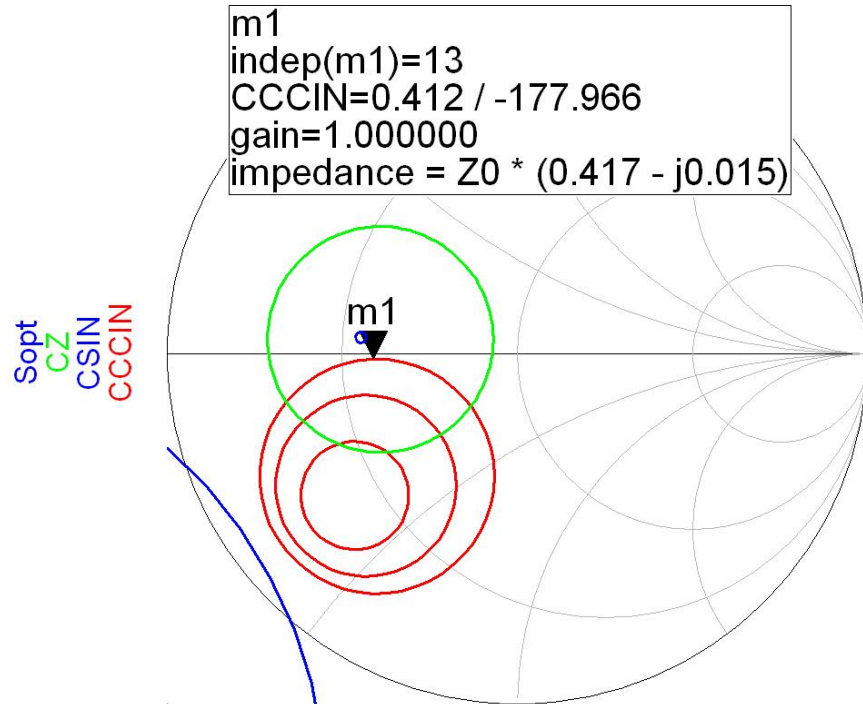
- Conectarea amplificatorului (tranzistorului) direct la sursa de semnal oferă un coeficient de reflexie la intrarea tranzistorului egal cu 0 (complex, $\Gamma_o = 0 + 0 \cdot j$)
 - de cele mai multe ori acest coeficient de reflexie nu oferă condiții optime de câștig și/sau zgomot



Adaptare – 2

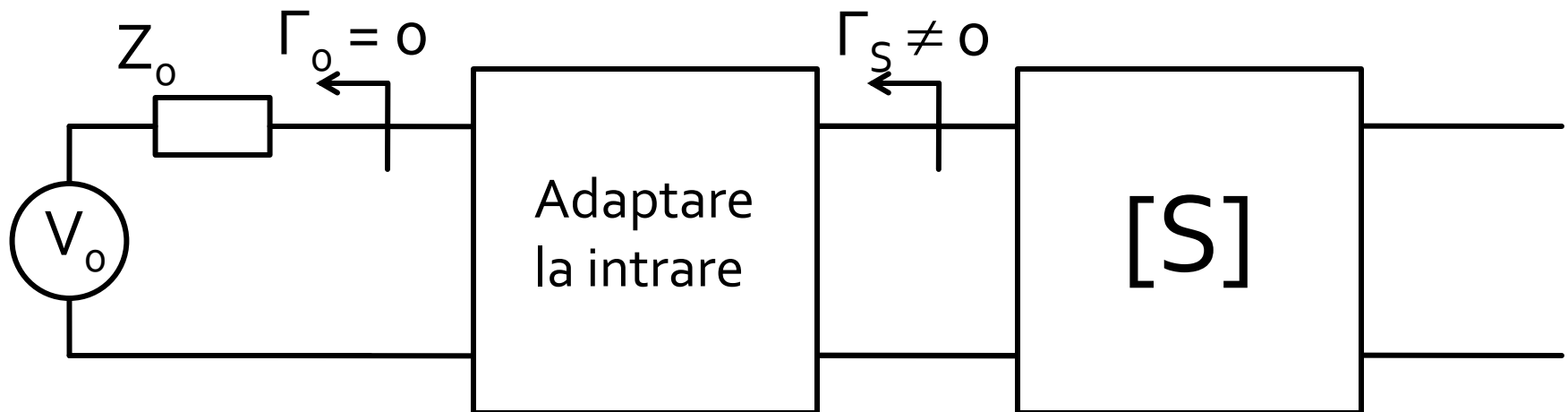
- Se deseneaza pe diagrama Smith cercurile de stabilitate/castig/zgomot, in functie de aplicatia
- Se alege punctul cu o pozitionare dorita relativ la aceste cercuri (de asemenea dependent de aplicatie)
- Se determina valoarea coeficientului de reflexie dorit la intrare Γ_s

$$\Gamma_s = 0.412 \angle -177.966^\circ$$



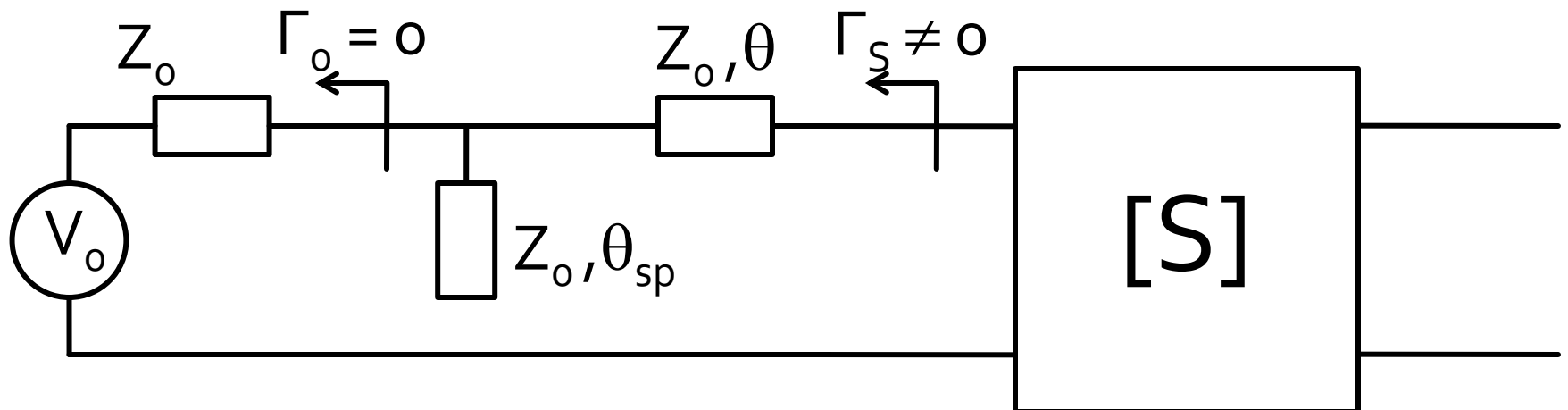
Adaptare – 3

- Se interpune rețeaua de adaptare la intrare care permite obținerea lui Γ_S determinat anterior



Adaptare – 4

- Varianta cea mai simpla de implementare, si pentru care exista relatii analitice de calcul consta in introducerea (in ordine, de la tranzistor spre sursa Z_o):
 - o sectiune de linie serie, cu impedanta caracteristica Z_o si lungime electrica θ
 - un stub paralel, lasat in gol la capat, realizat dintr-o linie cu impedanta caracteristica Z_o si lungime electrica θ_{sp}

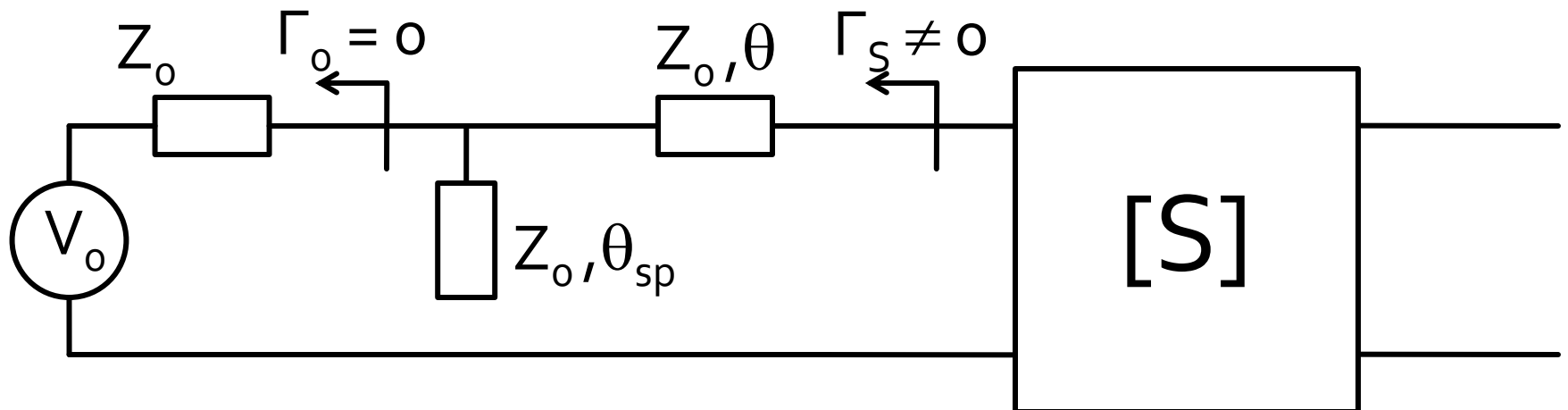


Adaptare – 5

- Relatiile de calcul depind numai de Γ_s (modul si faza)

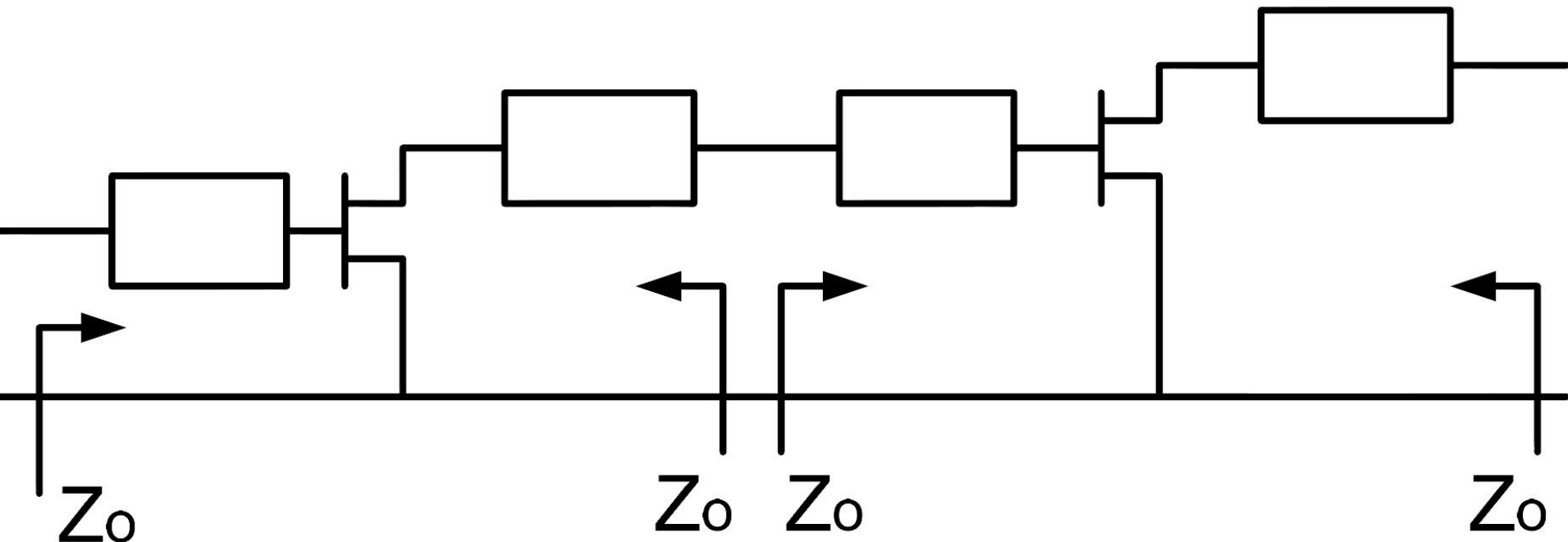
$$\cos(\varphi_s + 2\theta) = -|\Gamma_s| \quad \tan \theta_{sp} = \frac{\mp 2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}}$$

- Prima ecuatie are doua solutii, semnul solutiei alese impune semnul utilizat in a doua ecuatie



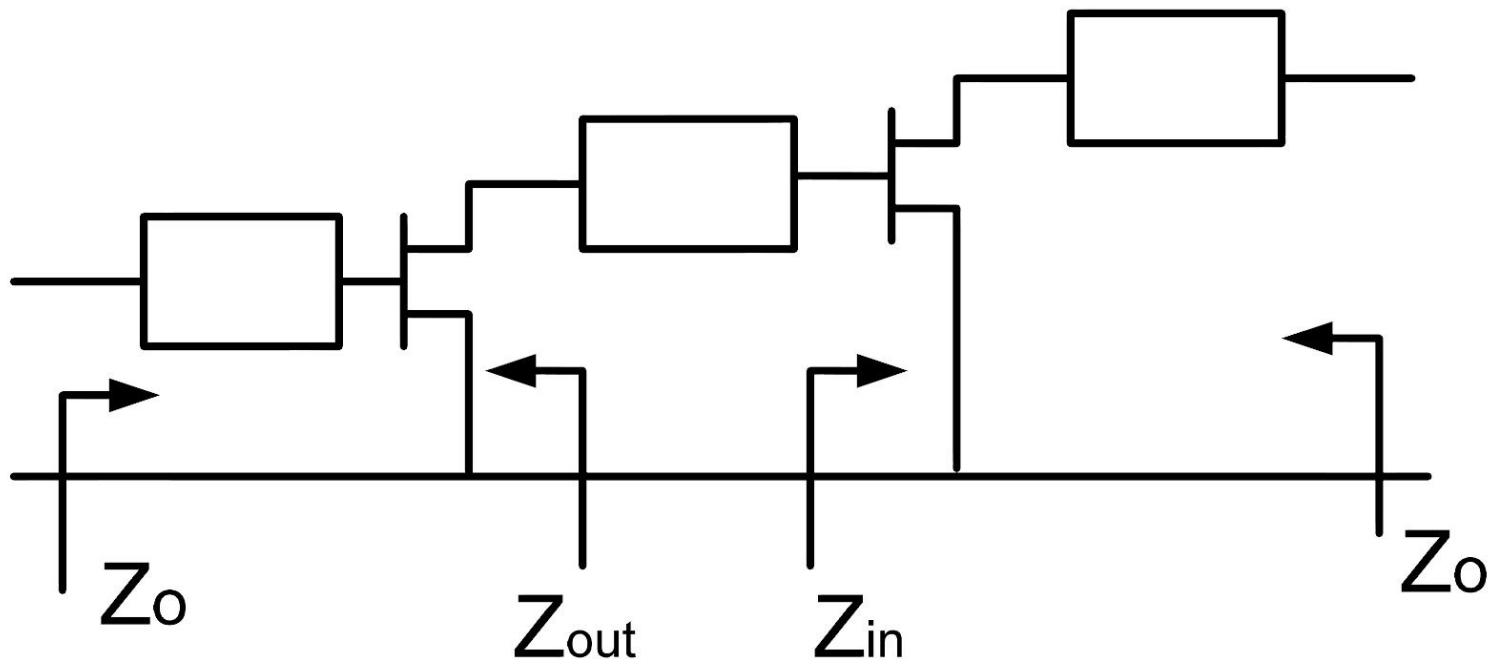
Amplificatoare in cascada

- Adaptarea inter-etaje se poate proiecta in doua moduri:
 - adaptarea fiecarui etaj spre un $\Gamma = 0$ intermediar

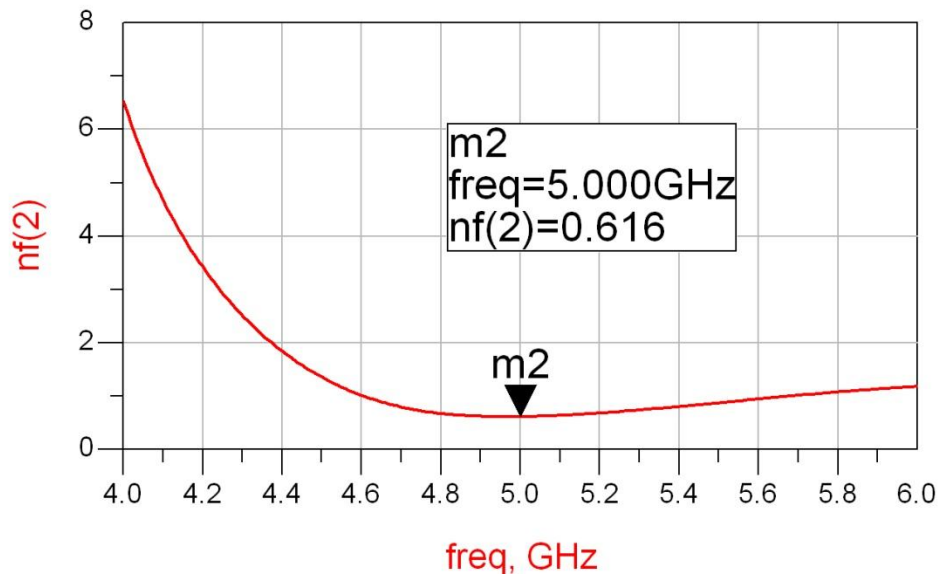
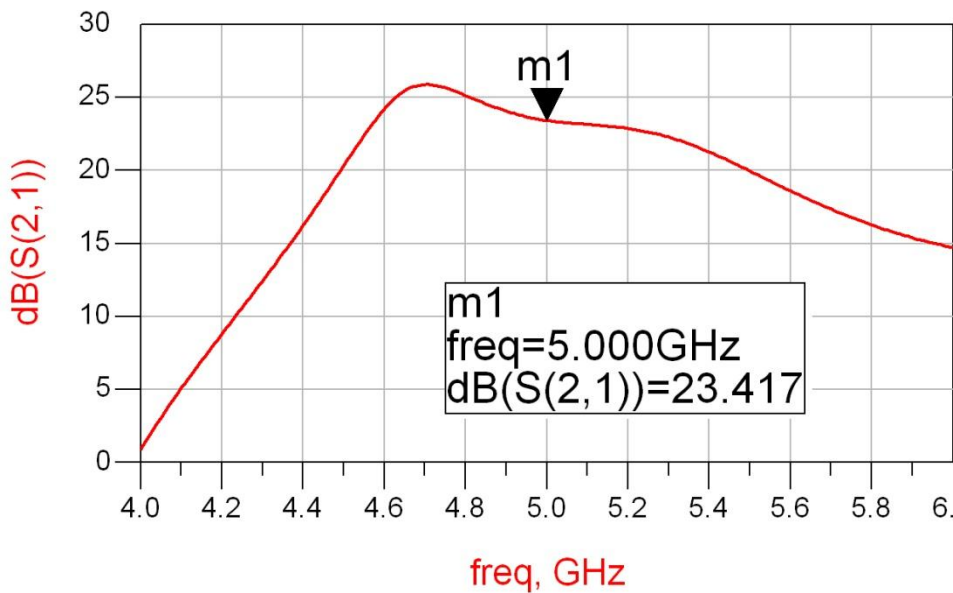
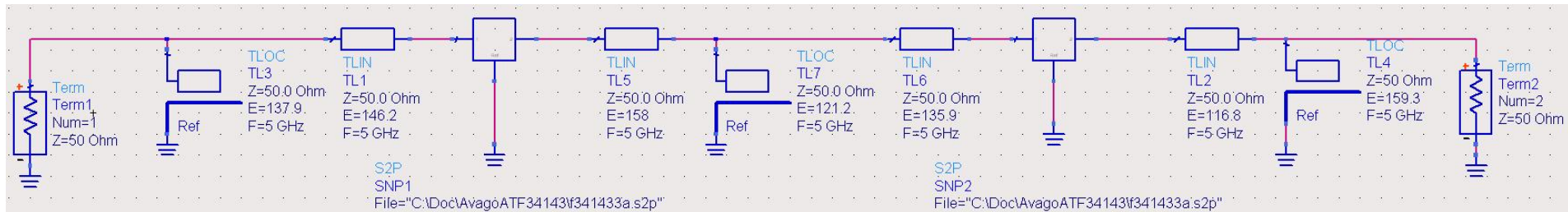


Amplificatoare in cascada

- Adaptarea inter-etaje se poate proiecta in doua moduri:
 - adaptarea unui etaj spre Γ necesar pentru celalalt



ADS 1



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

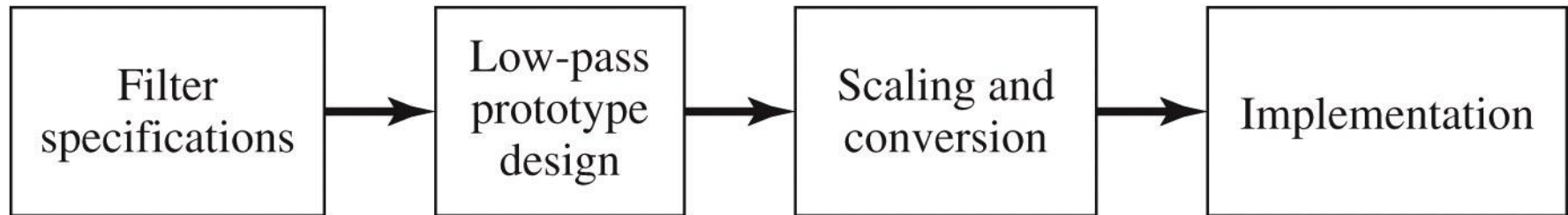


Figure 8.23

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Filtru prototip maxim plat

- Calculul elementelor filtrului

$$g_0 = 1$$

$$g_k = 2 \cdot \sin \left[\frac{(2 \cdot k - 1) \cdot \pi}{2 \cdot N} \right] , \quad k = 1, N$$

$$g_{N+1} = 1$$

Filtru prototip maxim plat

TABLE 8.3 Element Values for Maximally Flat Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10)

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

Source: Reprinted from G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, Artech House, Dedham, Mass., 1980, with permission.

Transformari ale filtrului prototip


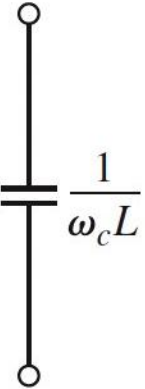
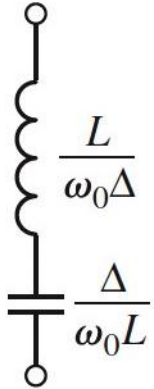
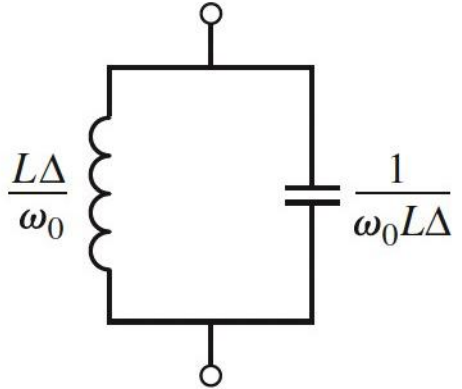
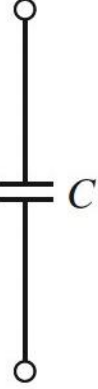
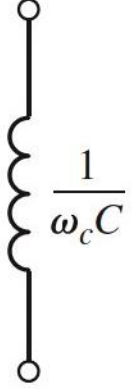
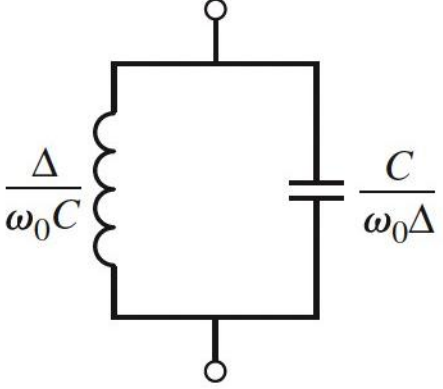
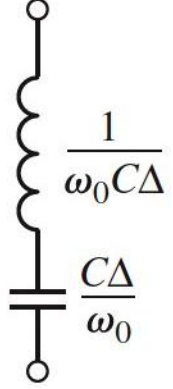
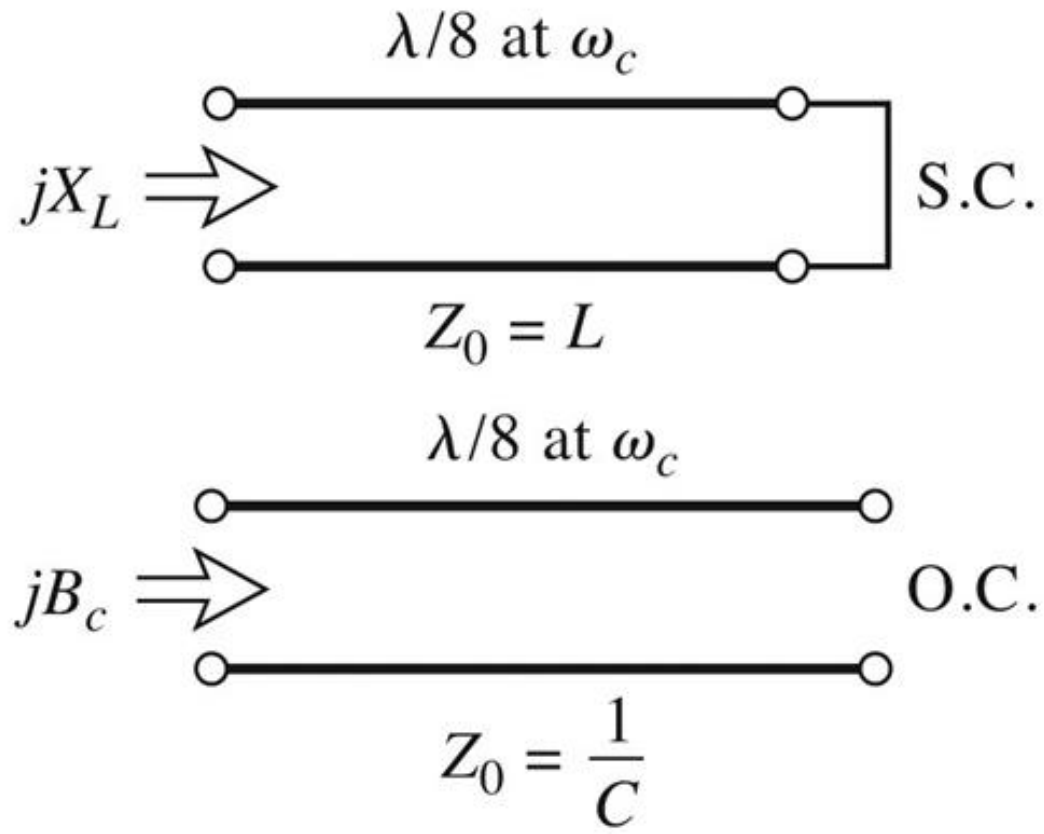
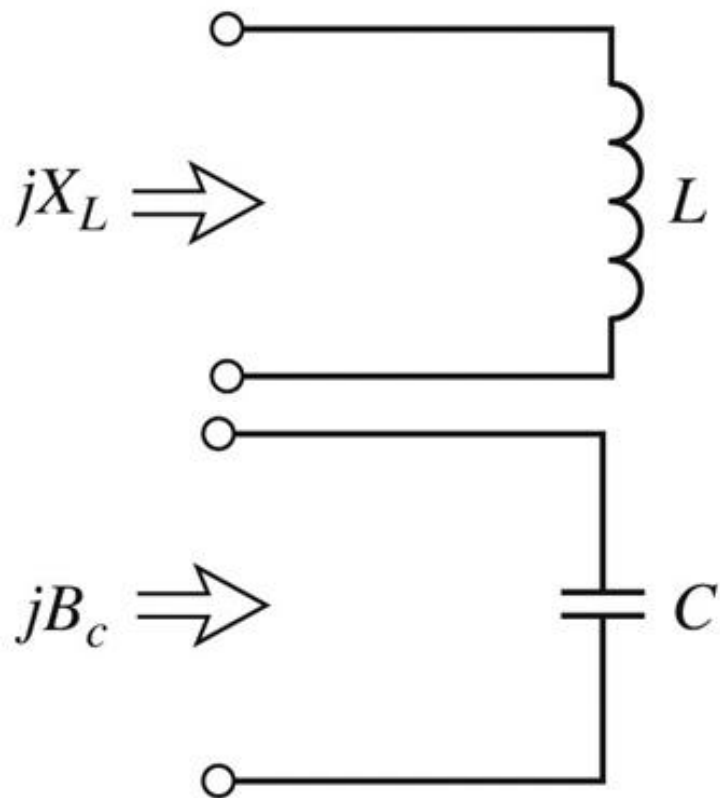
Low-pass	High-pass	Bandpass	Bandstop
			
			

Table 8.6

Implementarea filtrelor pentru microunde

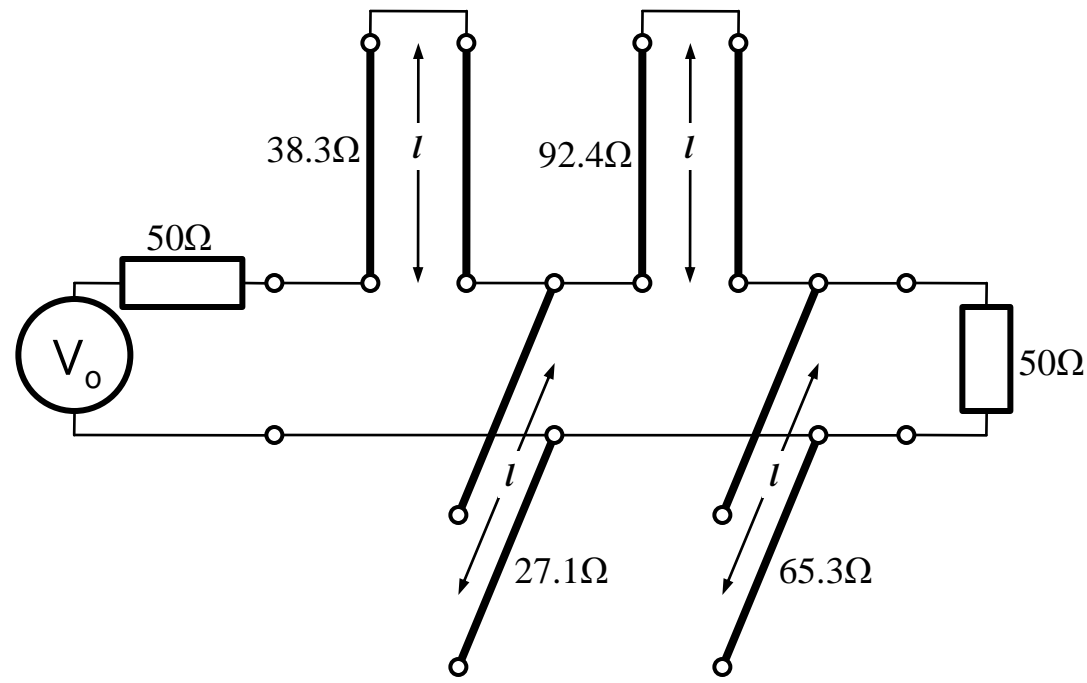
Transformarea Richards

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

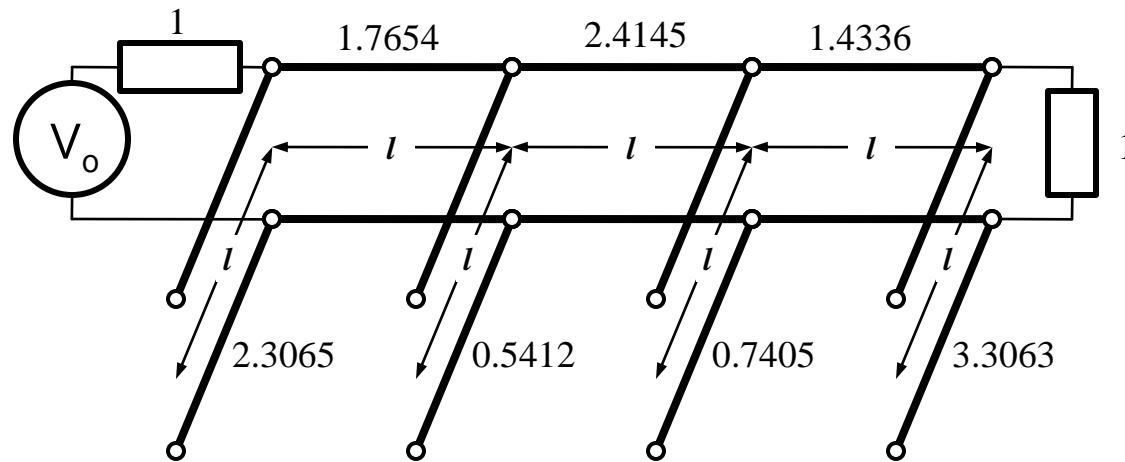


Identitatile Kuroda

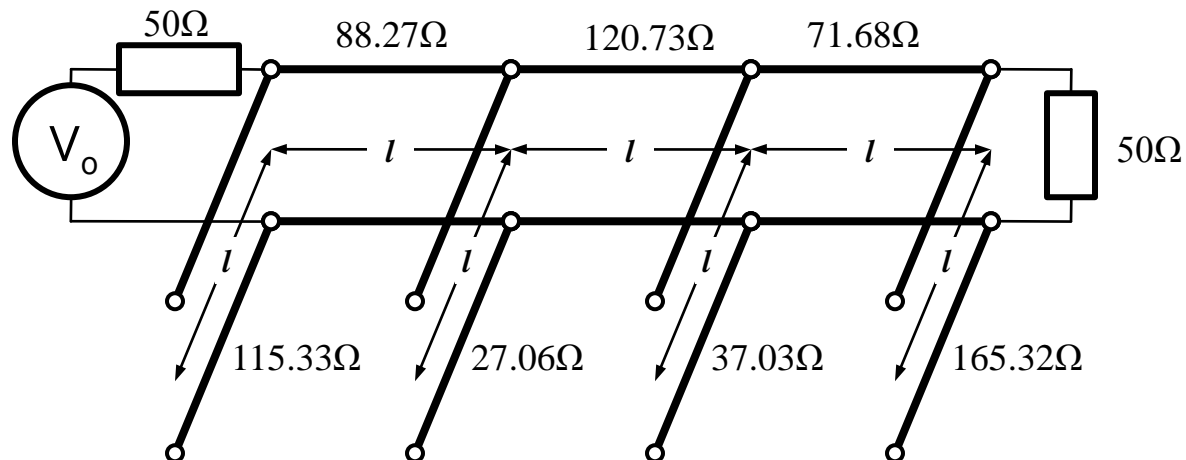
- Filtre implementate cu transformarea Richards au anumite dezavantaje in ceea ce priveste implementarea practica
- Identitatile/Transformarile Kuroda pot fi utilizate pentru a elimina o parte din aceste dezavantaje
- Se utilizeaza sectiuni de linie suplimentare pentru a obtine sisteme mai simplu de implementat in practica
- Liniile suplimentare se numesc elemente unitare si au lungimi de $\lambda/8$ la frecventa de taiere dorita (ωc) fiind comensurate cu celelalte sectiuni de linie



Exemplu



- Scalare la 50Ω

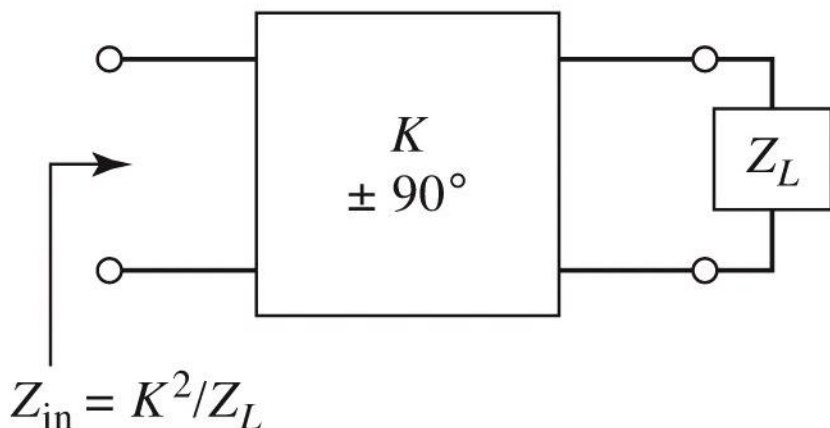


Inversoare de impedanta si admitanta

- 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

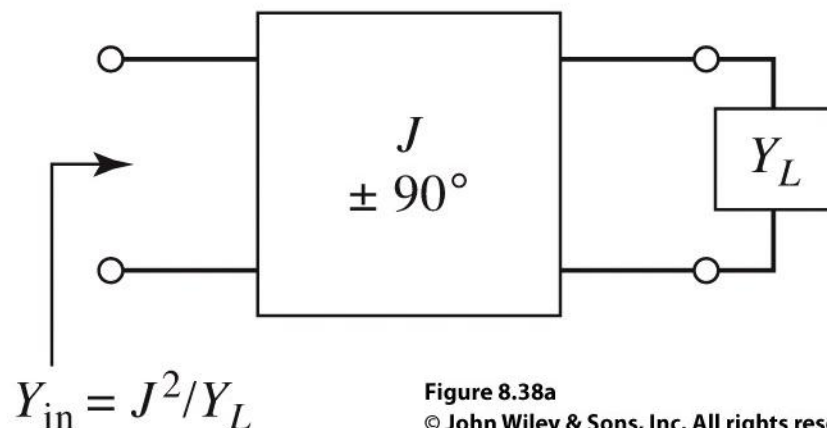
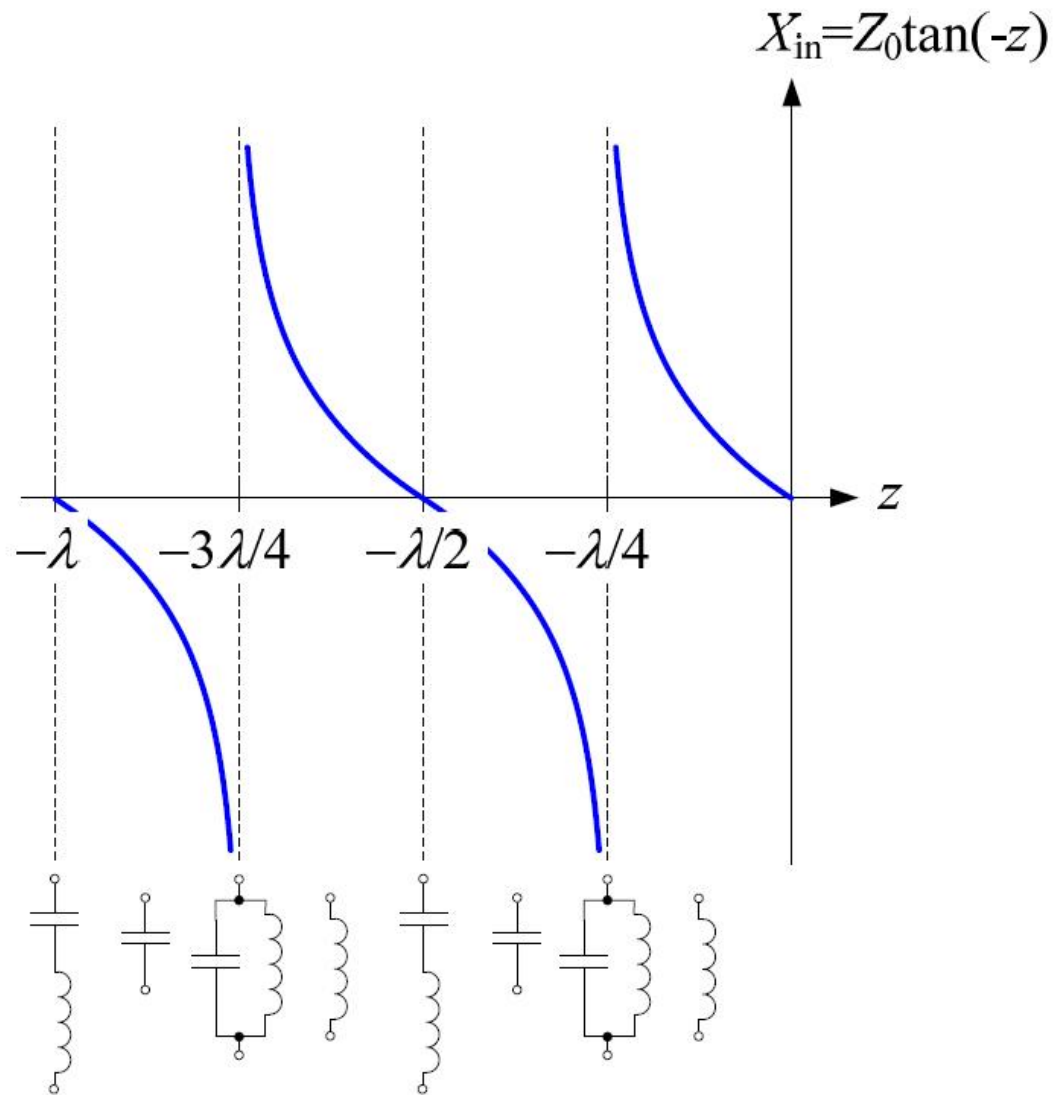


Figure 8.38a

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 $l = \lambda/4$)



Linii cuplate

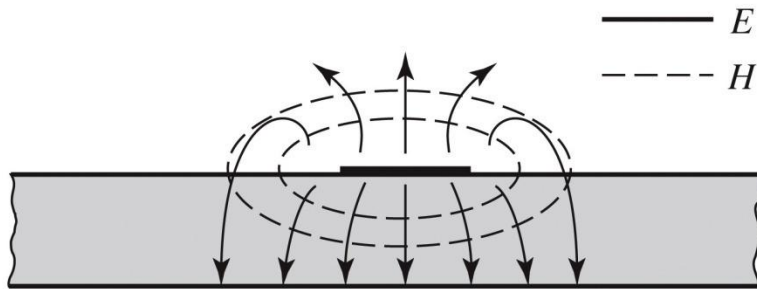
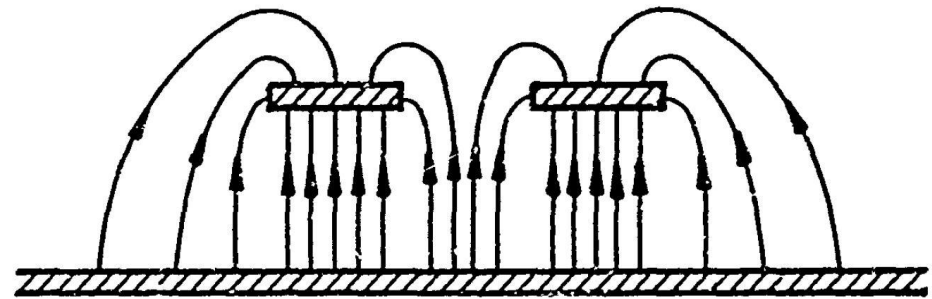
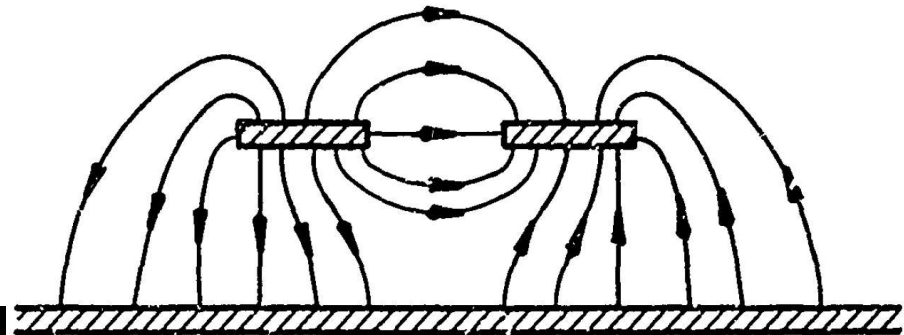


Figure 3.25b
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b) EVEN MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

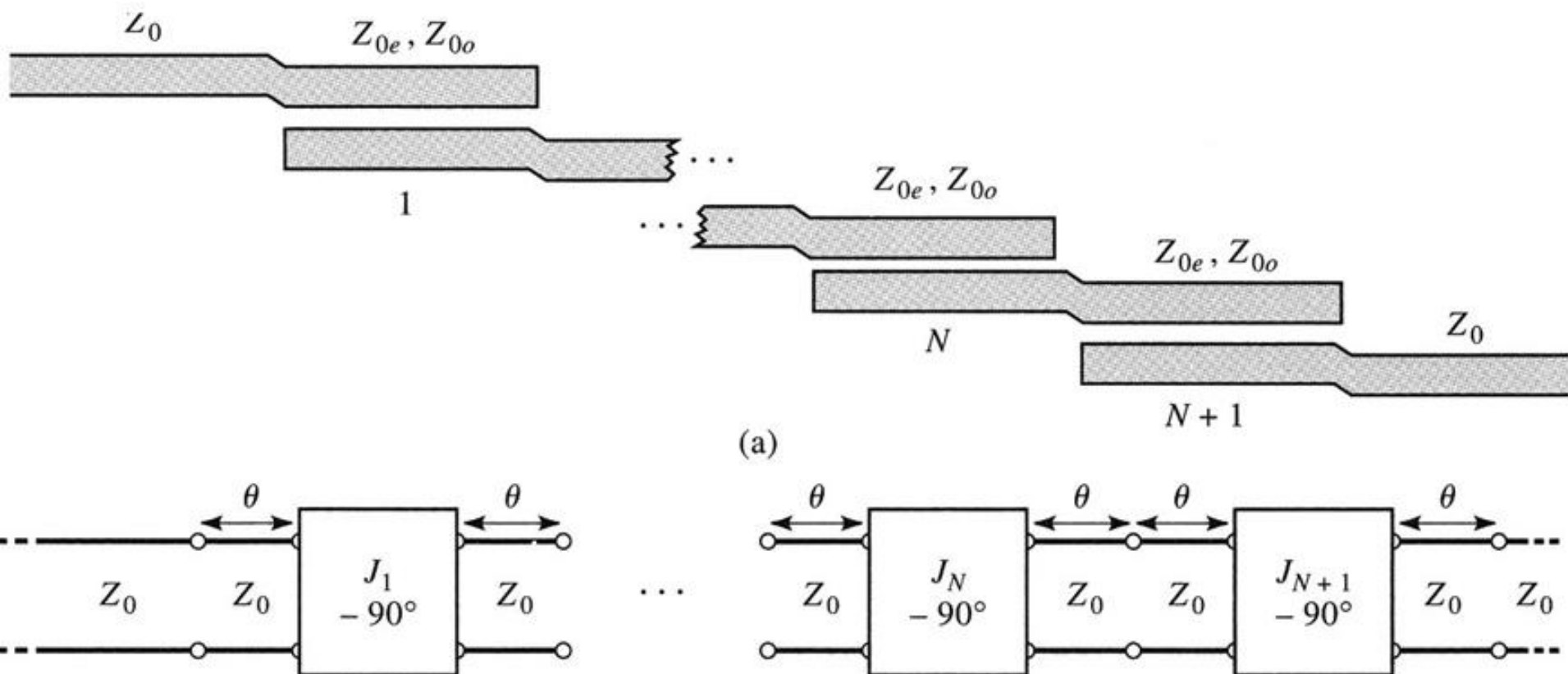


c) ODD MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

- 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

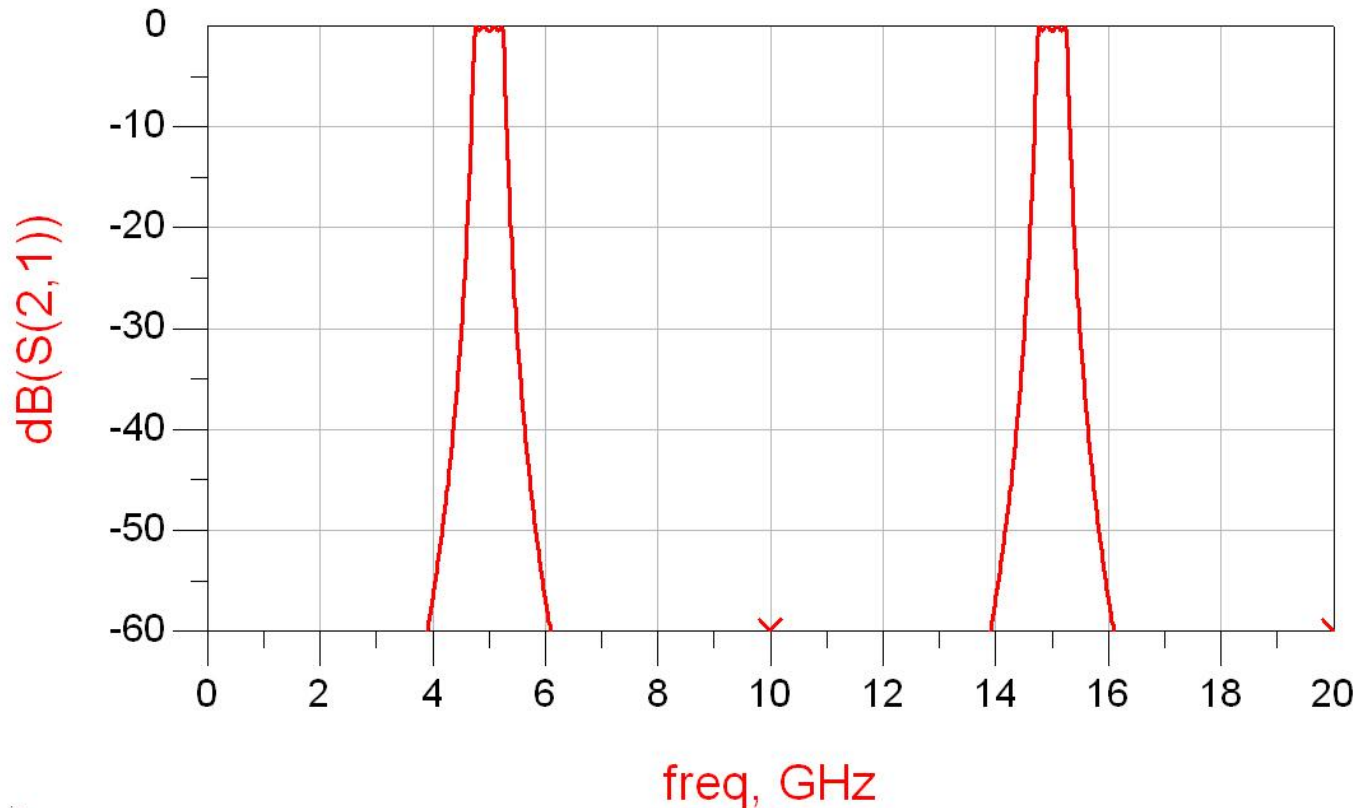
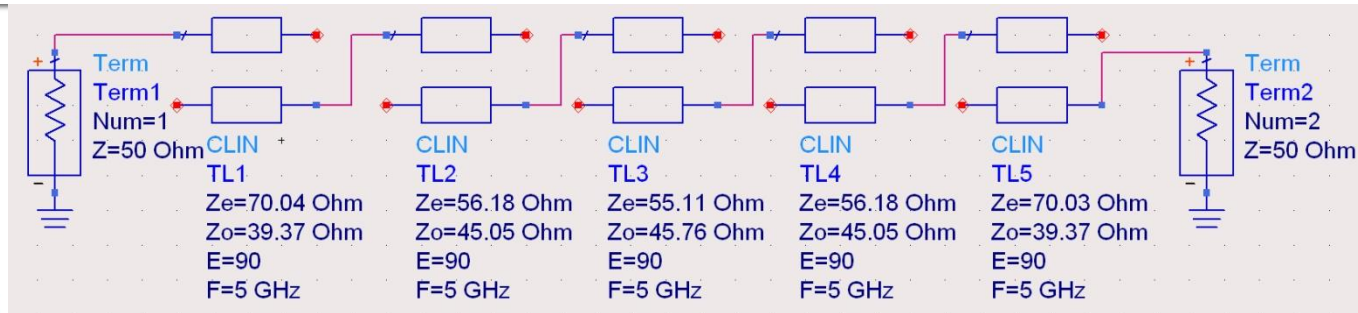


Exemplu

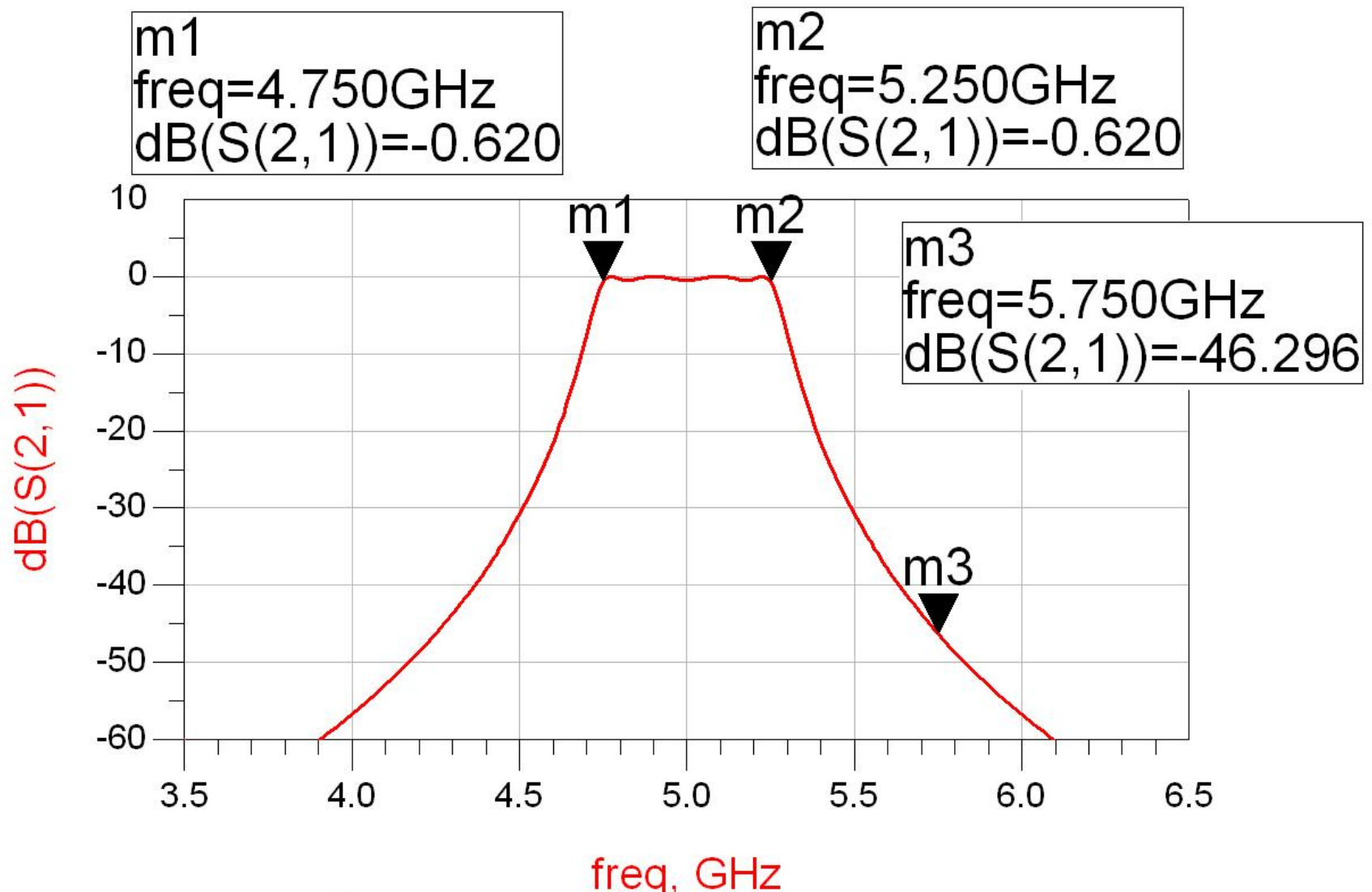
- Similar cu o tema de proiect
- Continuarea amplificatorului C₁₁
- Filtru trece banda de ordinul 4, $f_0 = 5\text{GHz}$, banda 10 %
- Tabel echiriplu 0.5dB sau relatii de calcul:

n	g	$Z_0 J_n$	Z_{0e}	Z_{0o}
1	1.6703	0.306664	70.04	39.37
2	1.1926	0.111295	56.18	45.05
3	2.3661	0.09351	55.11	45.76
4	0.8419	0.111294	56.18	45.05
5	1.9841	0.306653	70.03	39.37

ADS – FTB coupled line



ADS – FTB coupled line



Continuare

Supliment Mini Proiect

Implementare cu linii microstrip

- linii microstrip
 - strat dielectric
 - metalizare totala (plan de masa)
 - trasee care fixeaza
 - impedanta caracteristica
 - lungime fizica/electrica

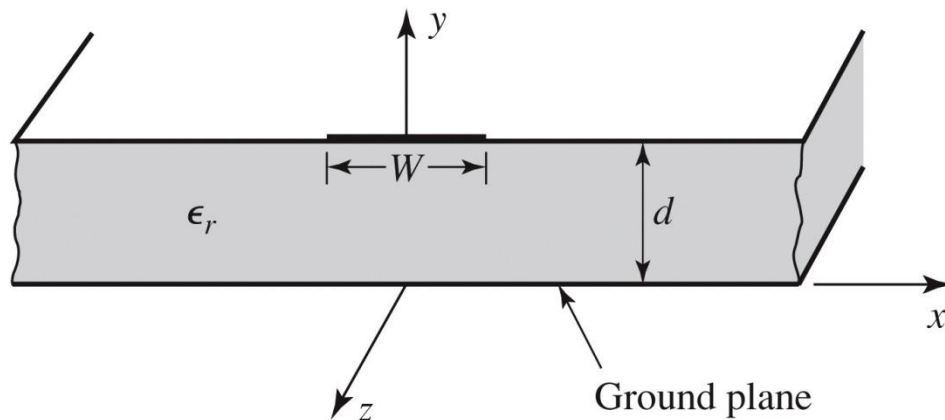


Figure 3.25a
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Implementare cu linii microstrip

- Linie quasi TEM

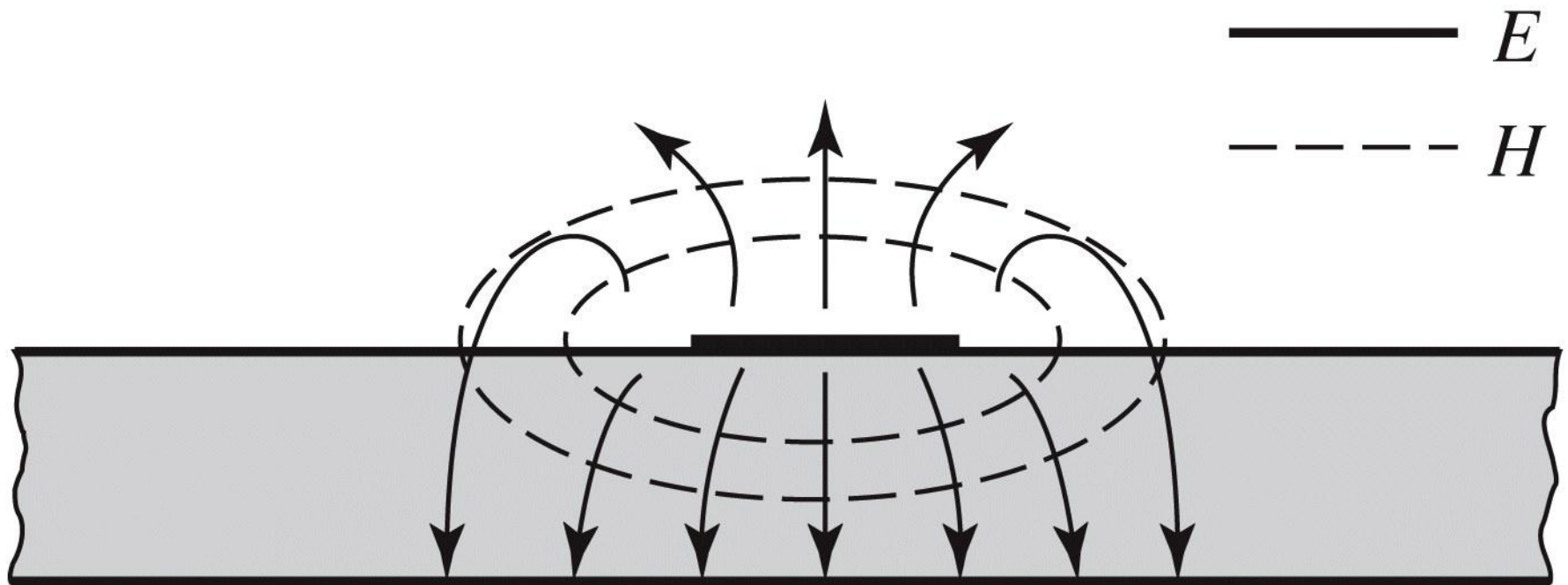


Figure 3.25b

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Implementare cu linii microstrip

- Se echivaleaza linia cu o linie cu dielectric omogen echivalent

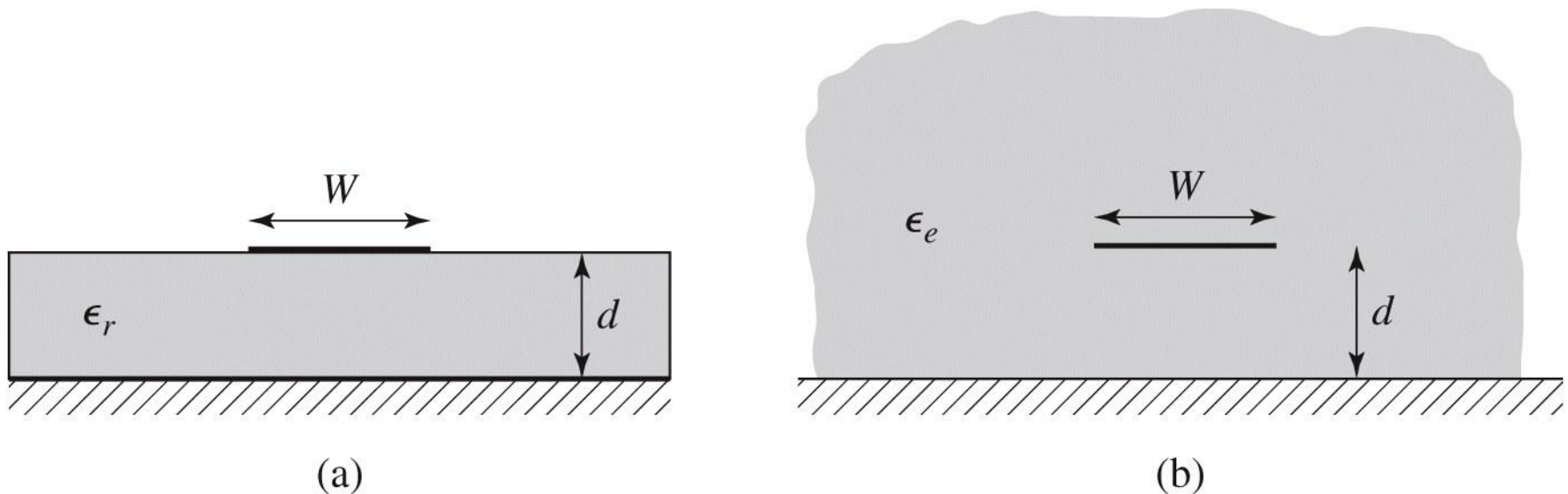
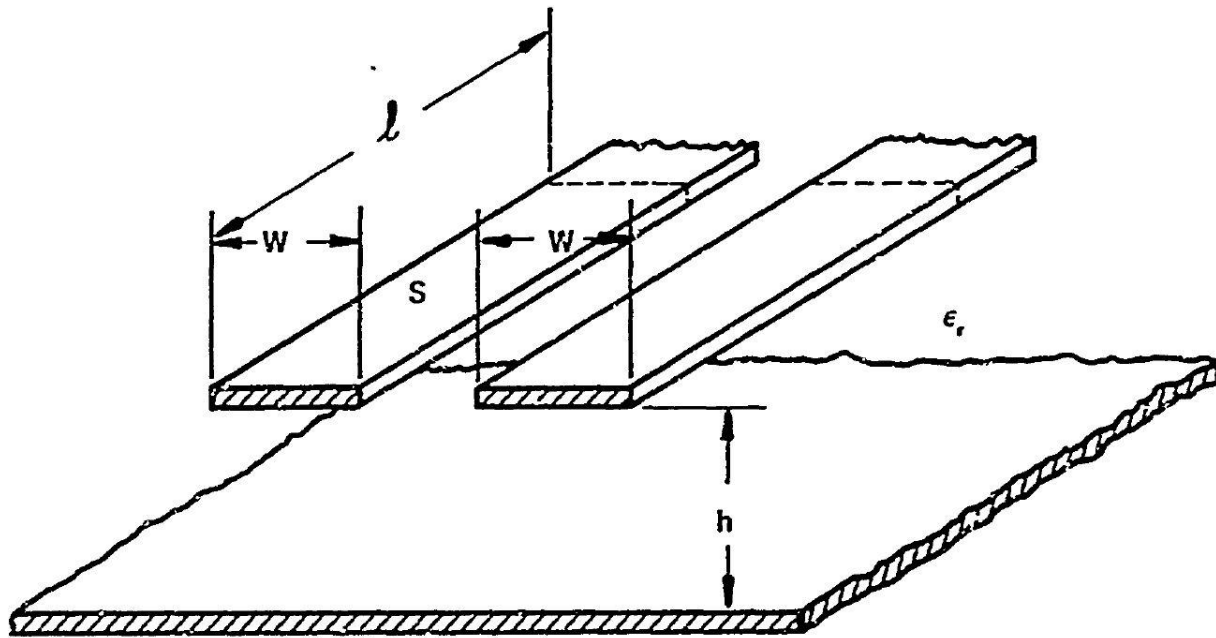


Figure 3.26
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Implementare cu linii microstrip

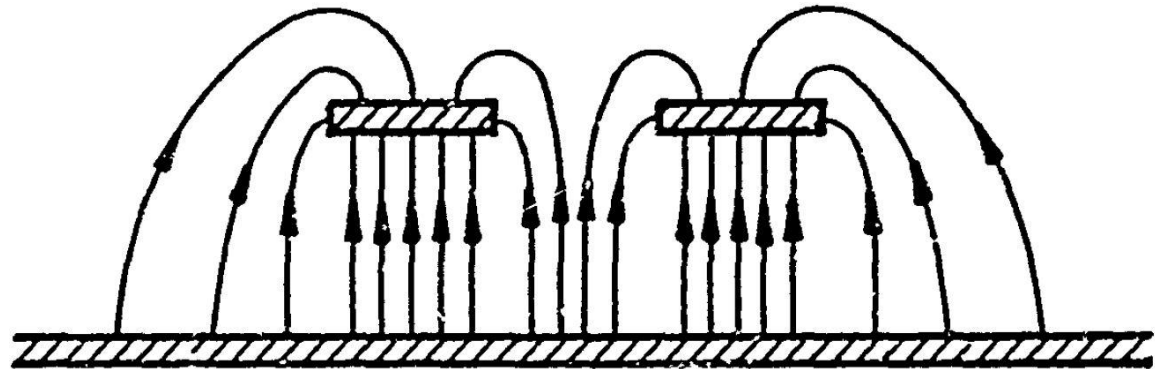
- ~ Aproximativ TEM



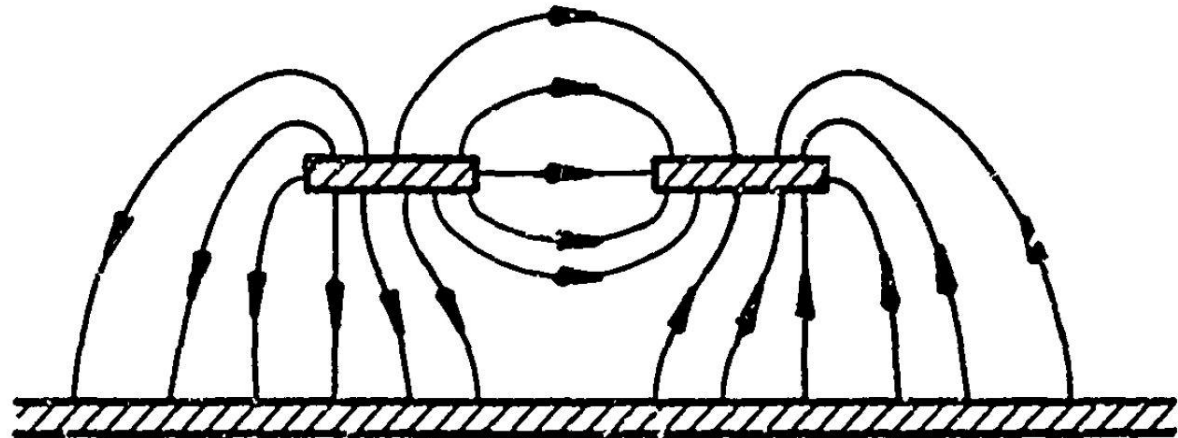
a) COUPLED STRIP GEOMETRY

Implementare cu linii microstrip

- ~ Aproximativ TEM



b) EVEN MODE ELECTRIC FIELD PATTERN (SCHEMATIC)



c) ODD MODE ELECTRIC FIELD PATTERN (SCHEMATIC)

Calcul

■ Calcul empiric

$$v_p = \frac{c}{\sqrt{\epsilon_e}},$$

$$\beta = k_0 \sqrt{\epsilon_e},$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12d/W}}.$$

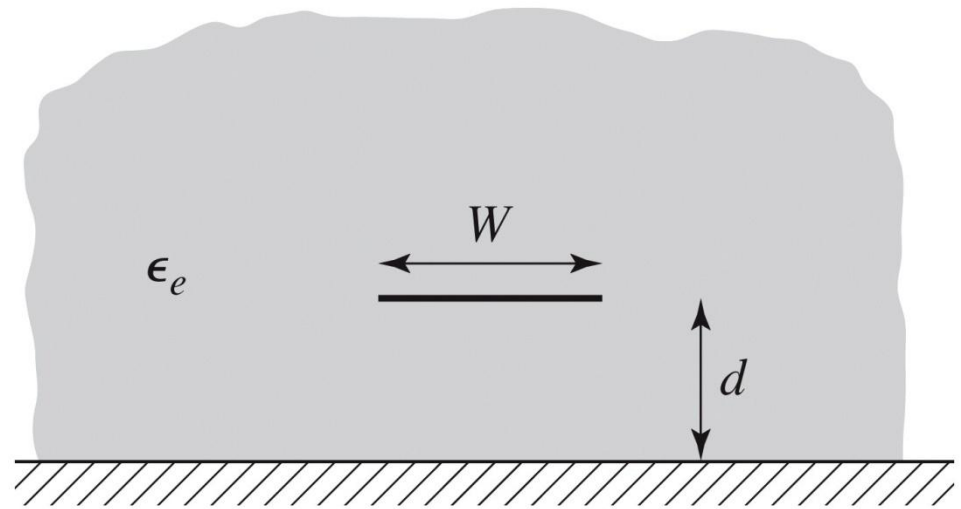


Figure 3.26b
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$$Z_0 = \begin{cases} \frac{60}{\sqrt{\epsilon_e}} \ln \left(\frac{8d}{W} + \frac{W}{4d} \right) & \text{for } W/d \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_e} [W/d + 1.393 + 0.667 \ln (W/d + 1.444)]} & \text{for } W/d \geq 1. \end{cases}$$

Calcul

■ Calcul empiric

$$A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left(0.23 + \frac{0.11}{\epsilon_r} \right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

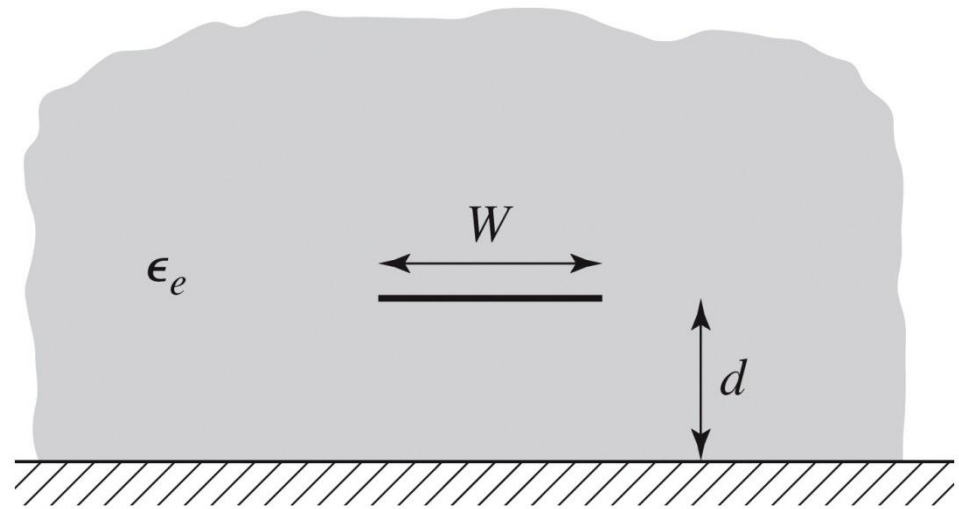
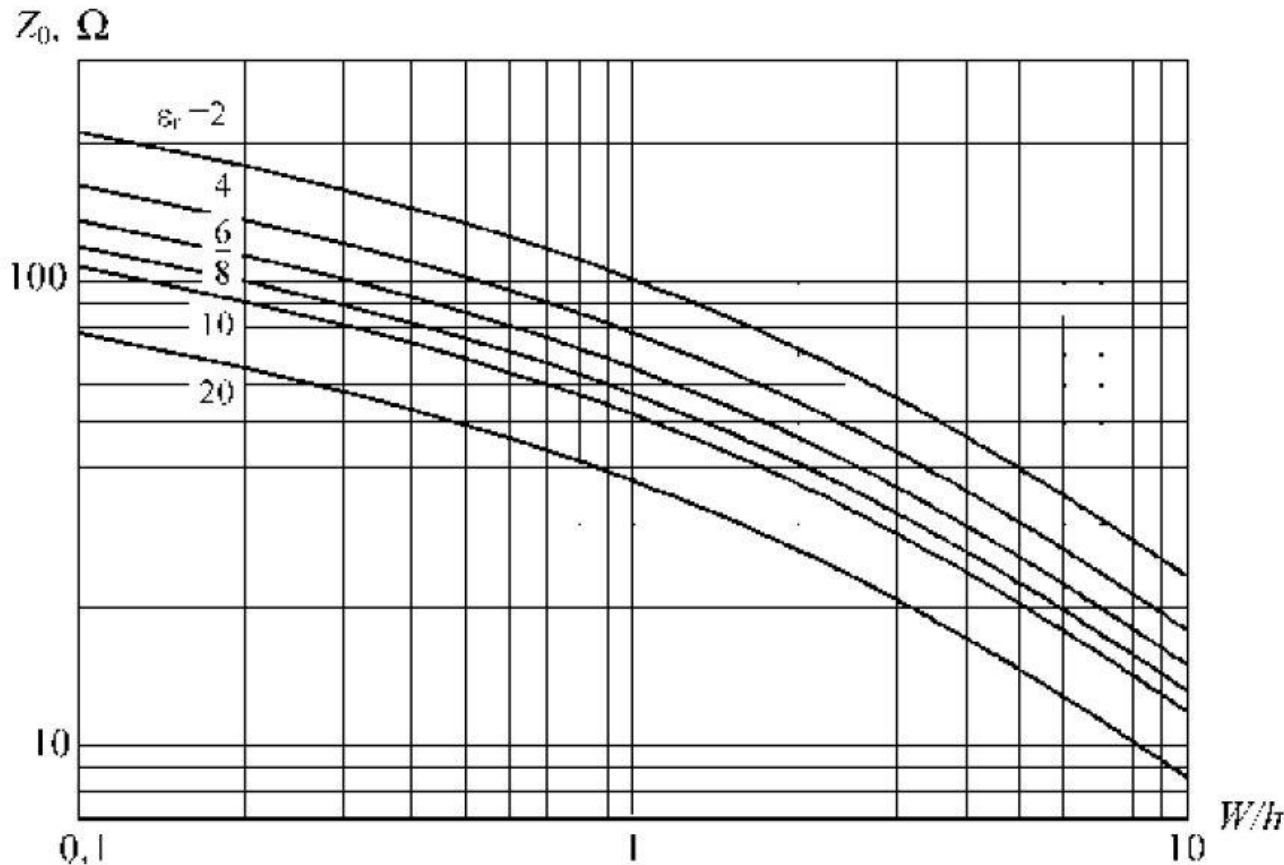


Figure 3.26b
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$$\frac{W}{d} = \begin{cases} \frac{8e^A}{e^{2A} - 2} & \text{for } W/d < 2 \\ \frac{2}{\pi} \left[B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left\{ \ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r} \right\} \right] & \text{for } W/d > 2, \end{cases}$$

Impedanta caracteristica

- Pentru impedante mari e nevoie de latimi mici ale traseelor
- Pentru impedante mici e nevoie de latimi mari ale traseelor



$$k_0 = \frac{2\pi f}{c}$$
$$\beta \ell = \sqrt{\epsilon_e} k_0 \ell,$$

Microstrip standardizare

- Standardizare
 - dimensiuni in **mil**
 - 1 mil = 10^{-3} inch
 - 1 inch = 2.54 cm
- Inaltimea conductoarelor
 - in functie de greutatea cuprului
 - uncii / picioare pătrate (oz/ft²)
 - 10z=28.35g și 1ft=30.48cm

Greutatea cuprului depus		Grosimea stratului	
oz/ft ²	g/ft ²	inch	mm
0.5	14.175	0.0007	0.0178
1.0	28.35	0.0014	0.0356
2.0	56.7	0.0028	0.0712

Microstrip standardizare

- Tipic inaltimea straturilor de dielectric de asemenea standardizat in mil

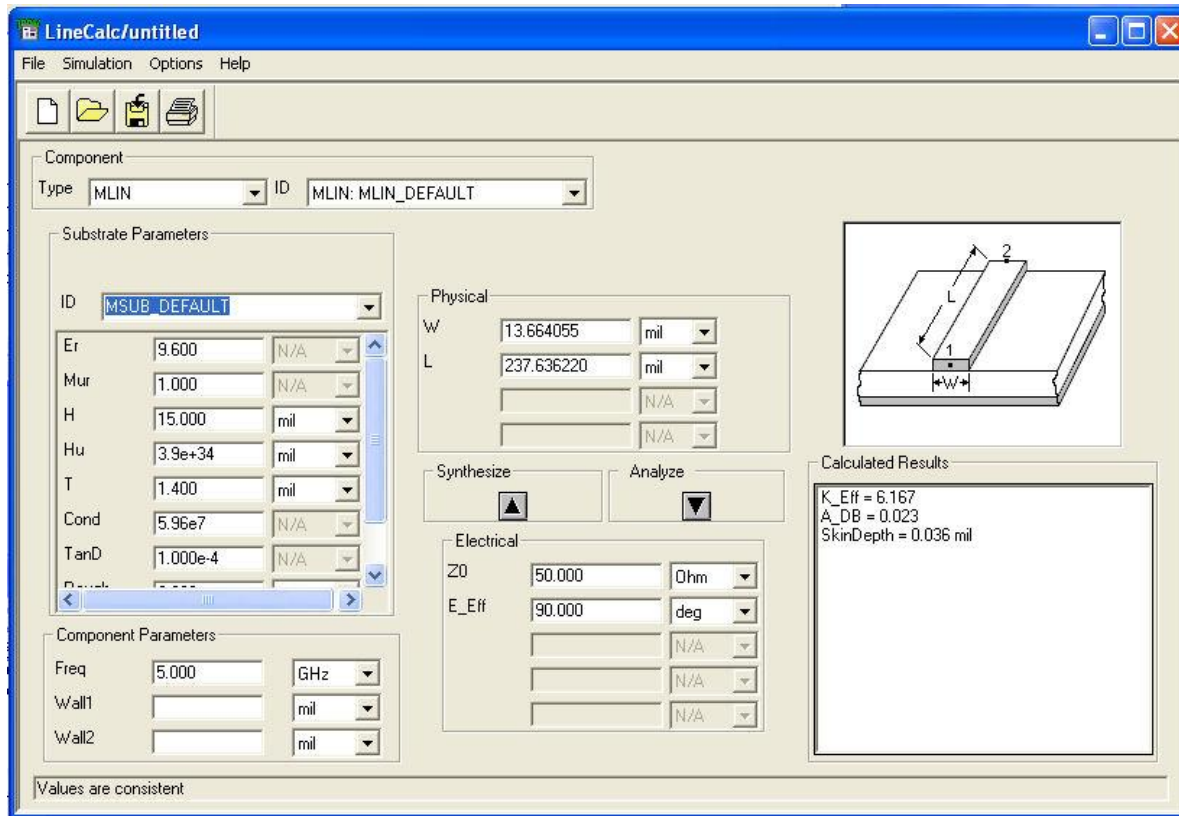
Standard Thickness
RO4003C: 0.008" (0.203mm), 0.012 (0.305mm), 0.016" (0.406mm), 0.020" (0.508mm) 0.032" (0.813mm), 0.060" (1.524mm) RO4350B: *0.004" (0.101mm), 0.0066" (0.168mm) 0.010" (0.254mm), 0.0133 (0.338mm), 0.0166 (0.422mm), 0.020" (0.508mm) 0.030" (0.762mm), 0.060" (1.524mm)

Microstrip, materiale substrat

	Constanta dielectrică relativă	Factorul de pierderi dielectrice	Conductivitate termică	Coeficient liniar de expansiune	Coeficient de temperatură a lui ϵ_r
Material	-	-	W/cm/K	ppm/K	ppm/K
Al_2O_3 (99.5%)	9.8	0.0001	0.37	6.3	+136
Al_2O_3 (96%)	9.4	0.001	0.35	6.4	-
Safir	9.4;11.6	0.0001	0.42	6.0	+110-+140
Sticlă cuarț	3.78	0.0001	0.017	0.55	+13
Sticlă Corning 7059	5.75	0.0036	0.012	4.6	-
BeO Ceramic (98%)	6.3	0.006	2.1	6.1	+107
TiO_2	85	0.004	0.05	7.5	-575
Tetratitanat de Ba (BaTi_4O_9)	37	0.0005	0.02	9.4	-26
Zirconat	20-40	0.002	-	5.0	-130-+100
GaAs	12.9	0.002	0.46	5.7	-
Si	11.9	0.015	1.45	4.2	-
Ferită	9-16	0.001	-	-	-

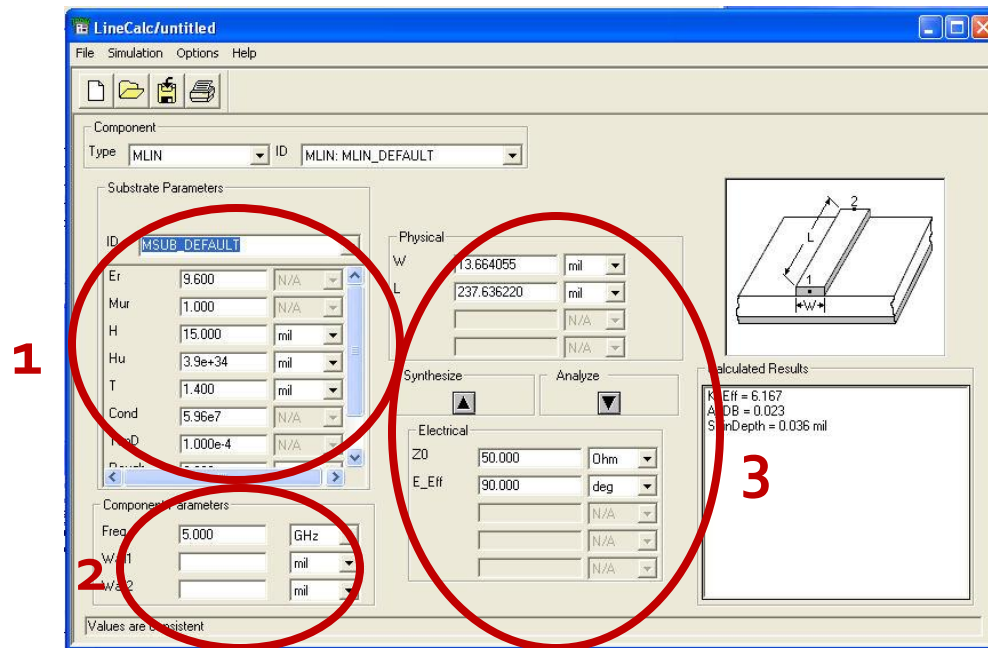
ADS linecalc

- In scheme:
 - >Tools>LineCalc>Start
 - Pentru linii Microstrip >Tools>LineCalc>Send to Linecalc



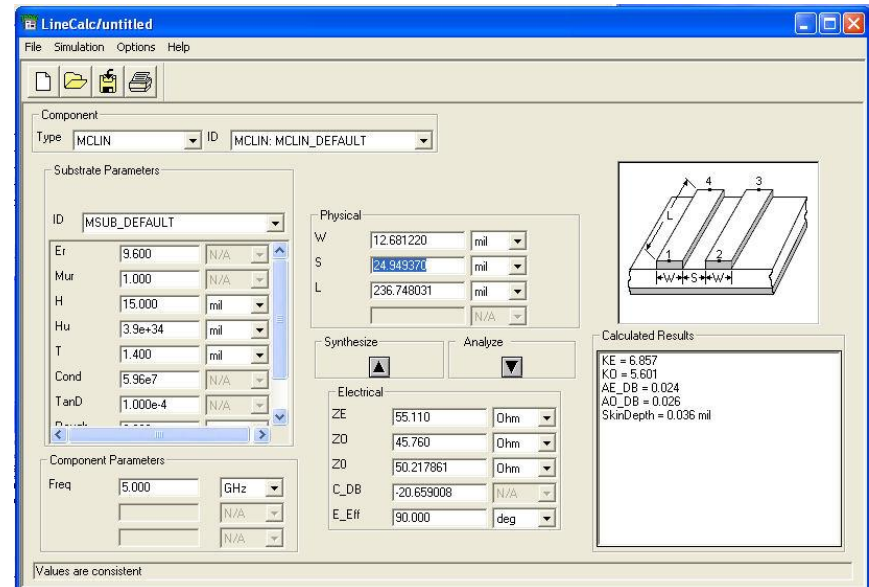
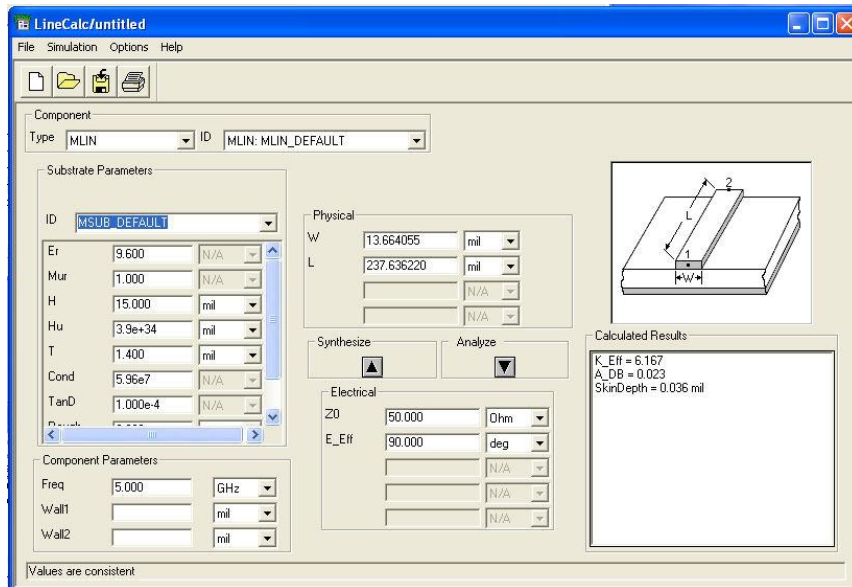
ADS linecalc

- 1. Definire (receptie din schema) substrat
- 2. Introducere frecventa
- 3. Introducere date de intrare
 - Analiza: $W, L \rightarrow Z_0, E$ sau $Z_e, Z_0, E / la f$ [GHz]
 - Sinteza: $Z_0, E \rightarrow W, L / la f$ [GHz]



ADS linecalc

- Se poate utiliza pentru:
 - linii microstrip MLIN: $W, L \Leftrightarrow Z_0, E$
 - linii cuplate microstrip MCLIN: $W, L \Leftrightarrow Z_e, Z_0, E$



ADS linecalc

LineCalc/untitled

File Simulation Options Help

Component

Type: MCLIN ID: MCLIN: MCLIN_DEFAULT

Substrate Parameters

ID: MSUB_DEFAULT

Er	9.600	N/A
Mur	1.000	N/A
H	15.000	mil
Hu	3.9e+34	mil
T	1.400	mil
Cond	5.96e7	N/A
TanD	1.000e-4	N/A

Physical

W	12.681220	mil
S	24.949370	mil
L	236.748031	mil

Synthesize Analyze

Electrical

ZE	55.110	Ohm
ZO	45.760	Ohm
Z0	50.217861	Ohm
C_DB	-20.659008	N/A
E_Eff	90.000	deg

Diagram showing a cross-section of a microstrip line with dimensions W, S, and L, and numbered points 1, 2, 3, 4.

Calculated Results

KE = 6.857
KO = 5.601
AE_DB = 0.024
AO_DB = 0.026
SkinDepth = 0.036 mil

Values are consistent

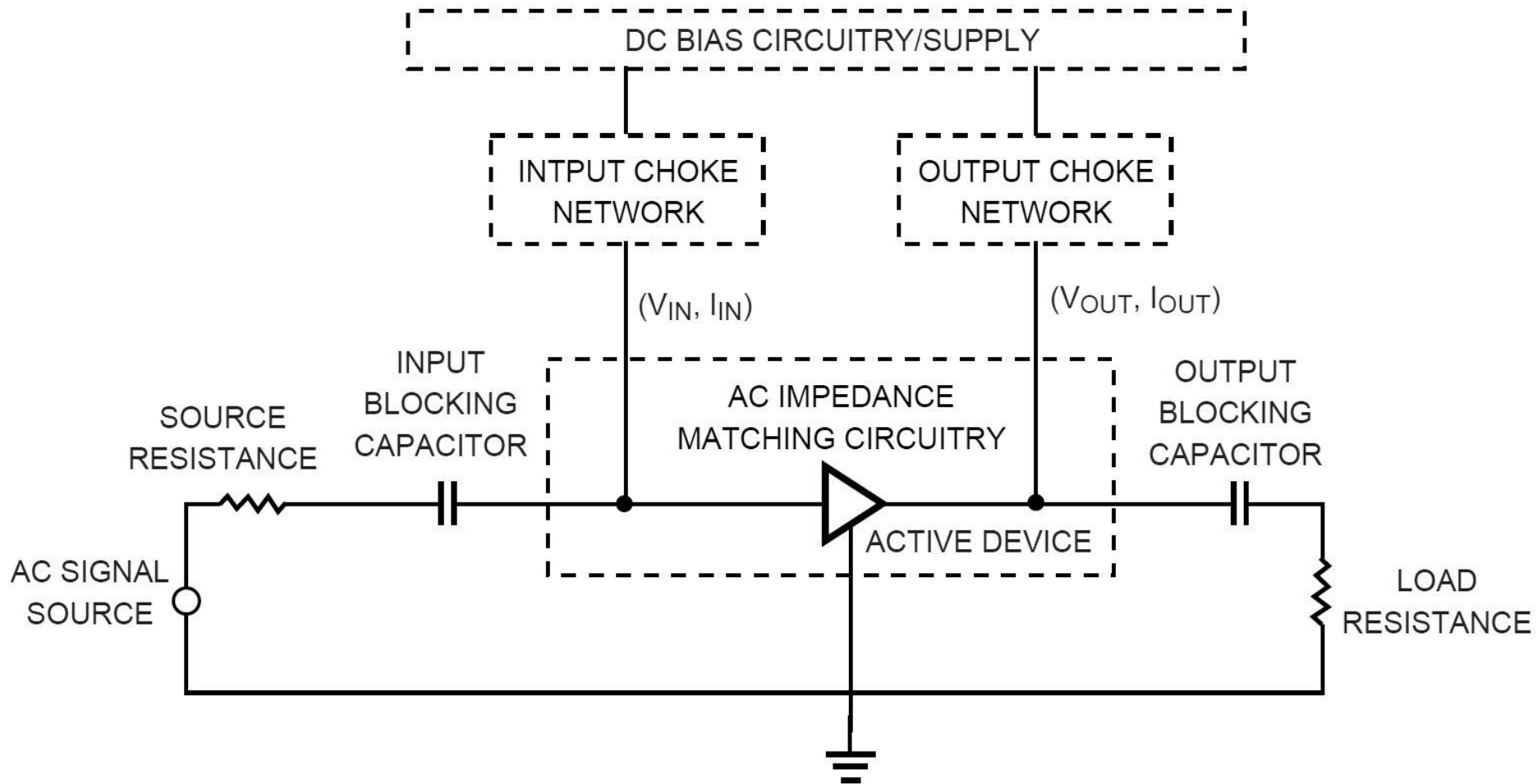
Linii de transmisie

- <http://rf-opto.etti.tuiasi.ro>
- linii de transmisie Rogers
 - relatii dependente de
 - t , inaltimea metalizarilor
 - f , frecventa
 - relatii pentru
 - microstrip
 - strip
 - linii cuplate

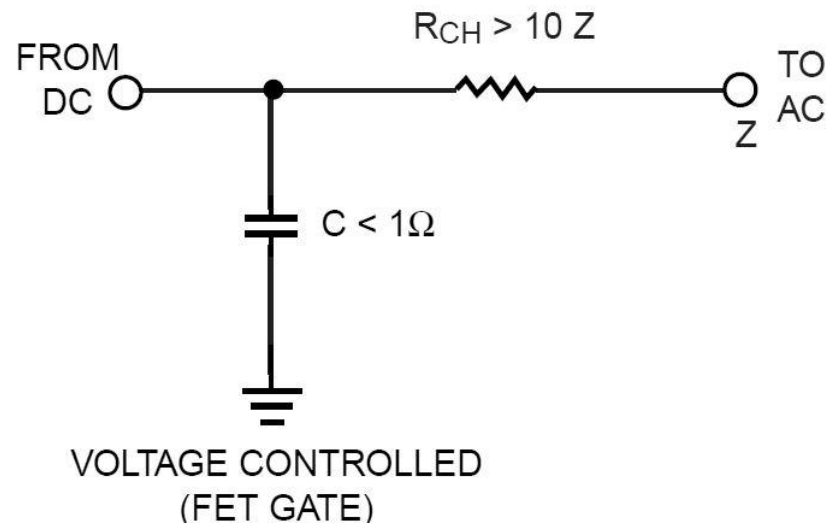
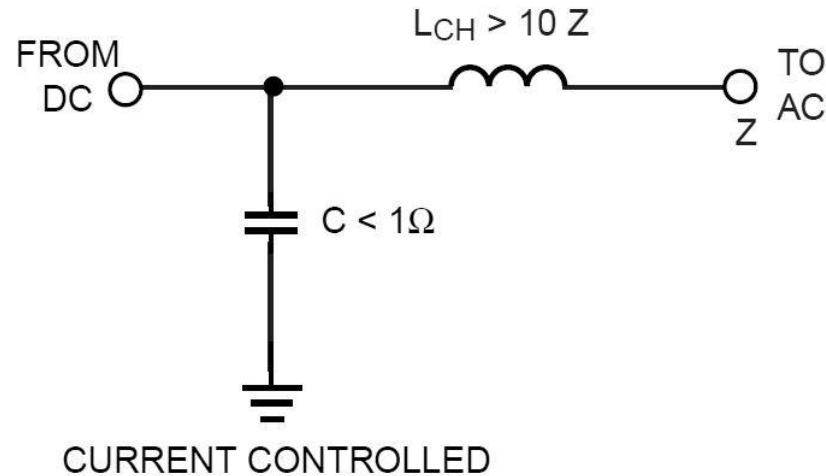
Polarizare

- <http://rf-opto.etti.tuiasi.ro>
- note de aplicatii importante Agilent
 - decuplarea circuit de semnal/circuit de polarizare
 - detalii de implementare a circuitelor de polarizare pentru tranzistoarele cu microunde
- Appcad contine instrumente pentru calculul schemelor de polarizare

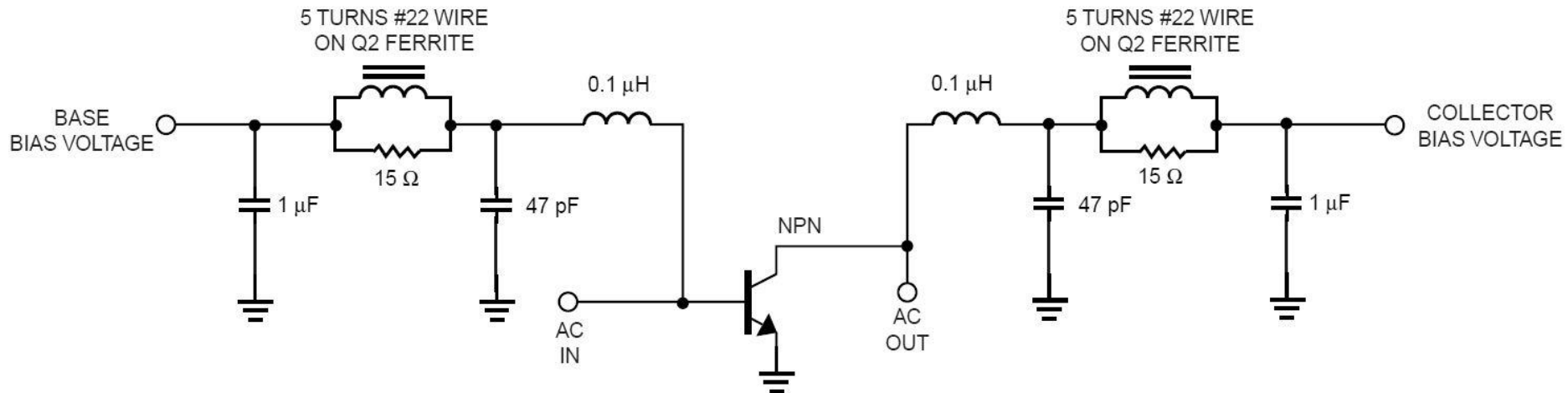
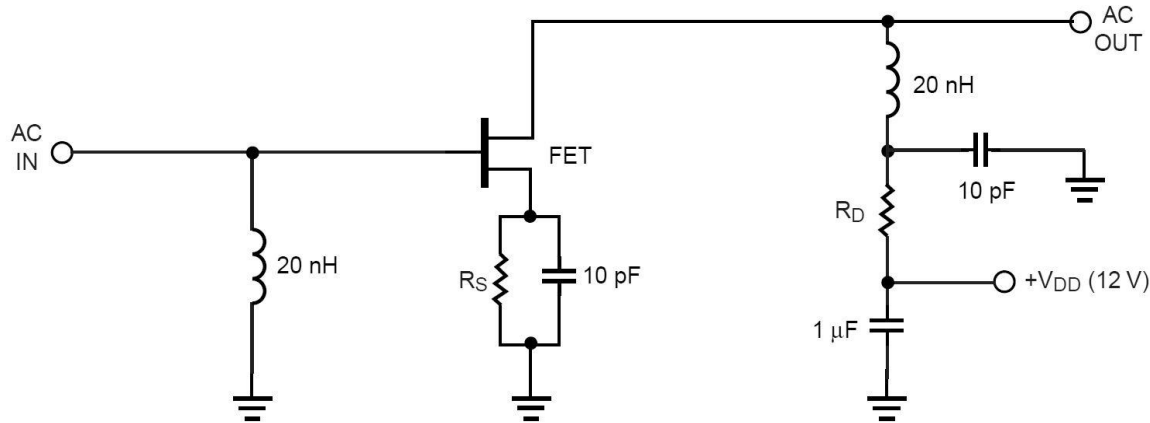
Polarizare



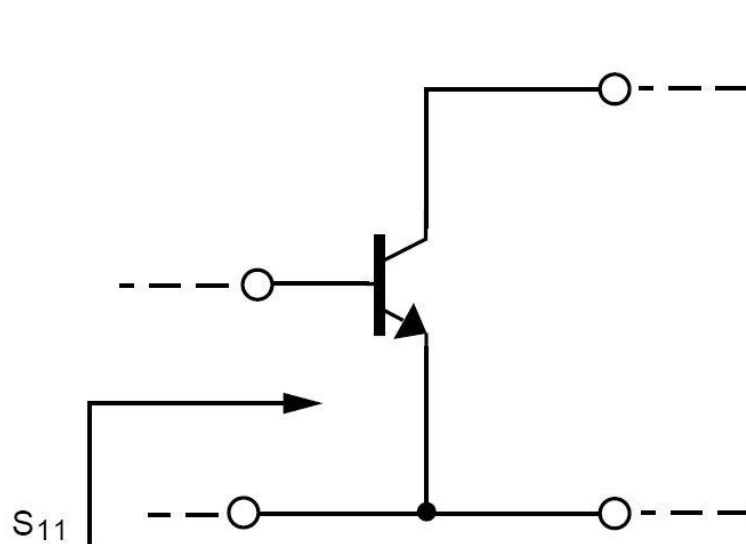
Polarizare, soc tipic



Polarizare, scheme/valori tipice

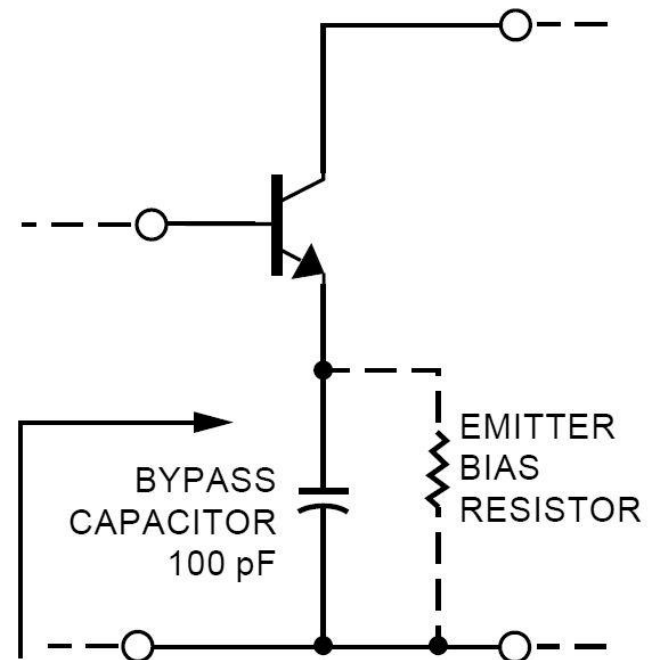


Polarizare, problema elementelor conectate in E/S



$$S_{11} \text{ (AT 4 GHz)} = 0.52 \angle 154^\circ$$

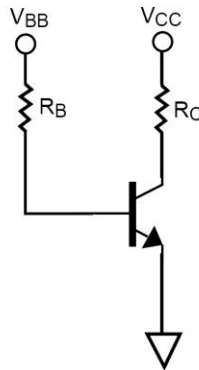
$$S_{11} \text{ (AT 0.1 GHz)} = 0.901 \angle -14.9^\circ$$



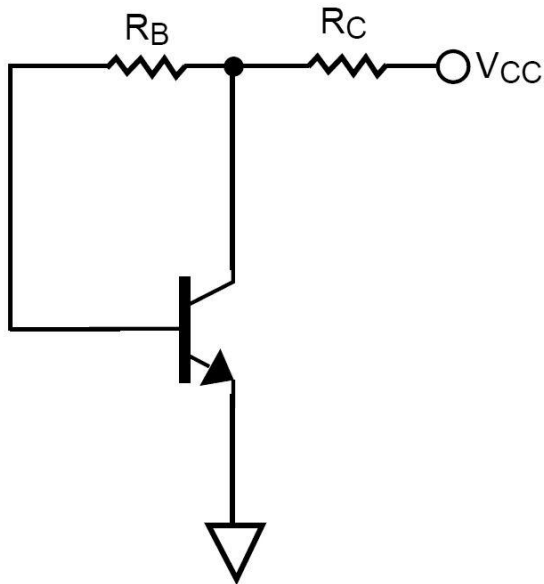
$$S'_{11} \text{ (AT 4 GHz)} = 0.52 \angle 154^\circ \text{ UNCHANGED AT 4 GHz}$$

$$S'_{11} \text{ (AT 0.1 GHz)} = 1.066 \angle -8.5^\circ \quad |S_{11}| > 1 \text{ AT 0.1 GHz}$$

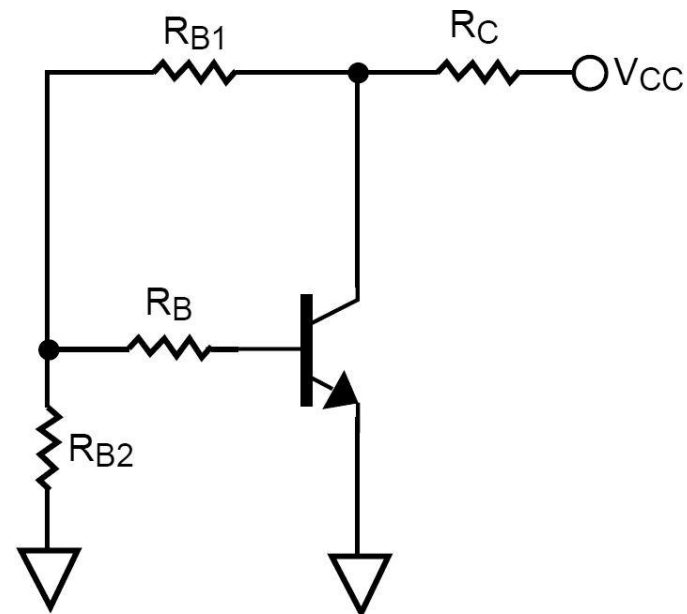
Polarizare TB scheme de polarizare



NON-STABILIZED



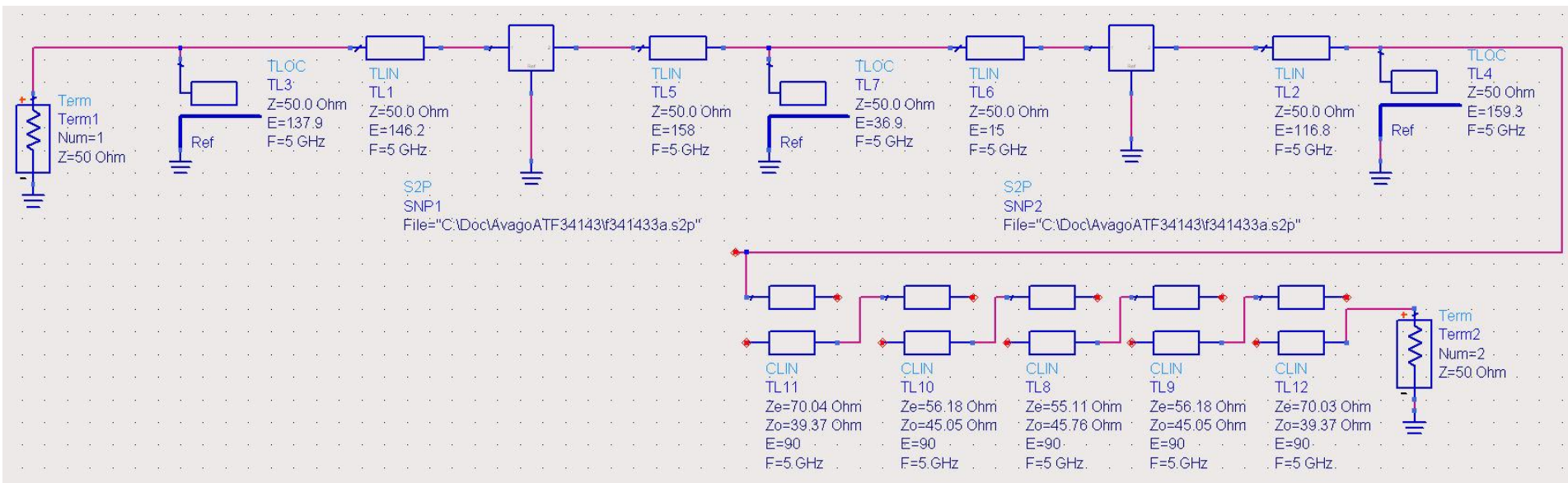
VOLTAGE FEEDBACK



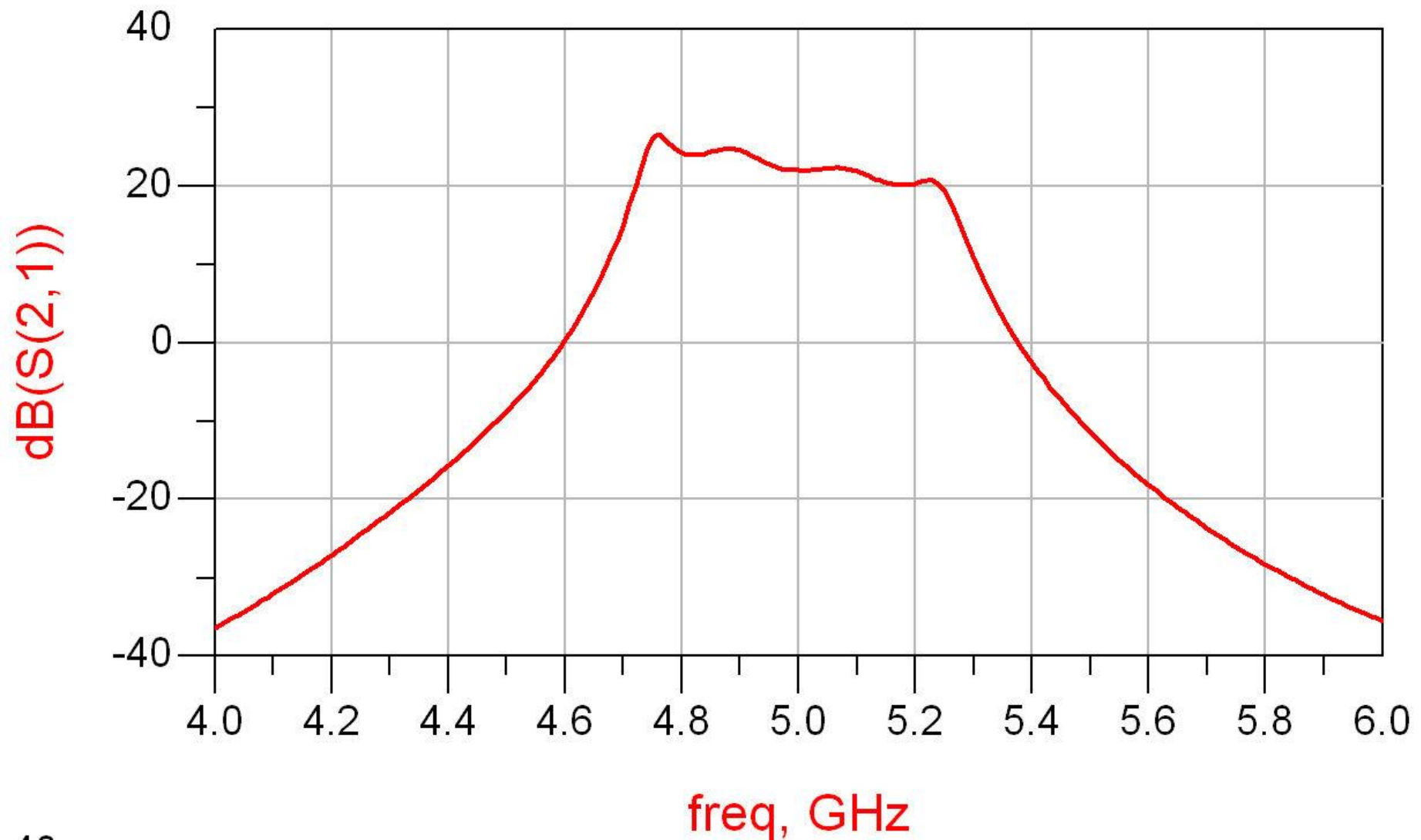
VOLTAGE FEEDBACK AND CONSTANT
BASE CURRENT SOURCE

Exemplu proiect

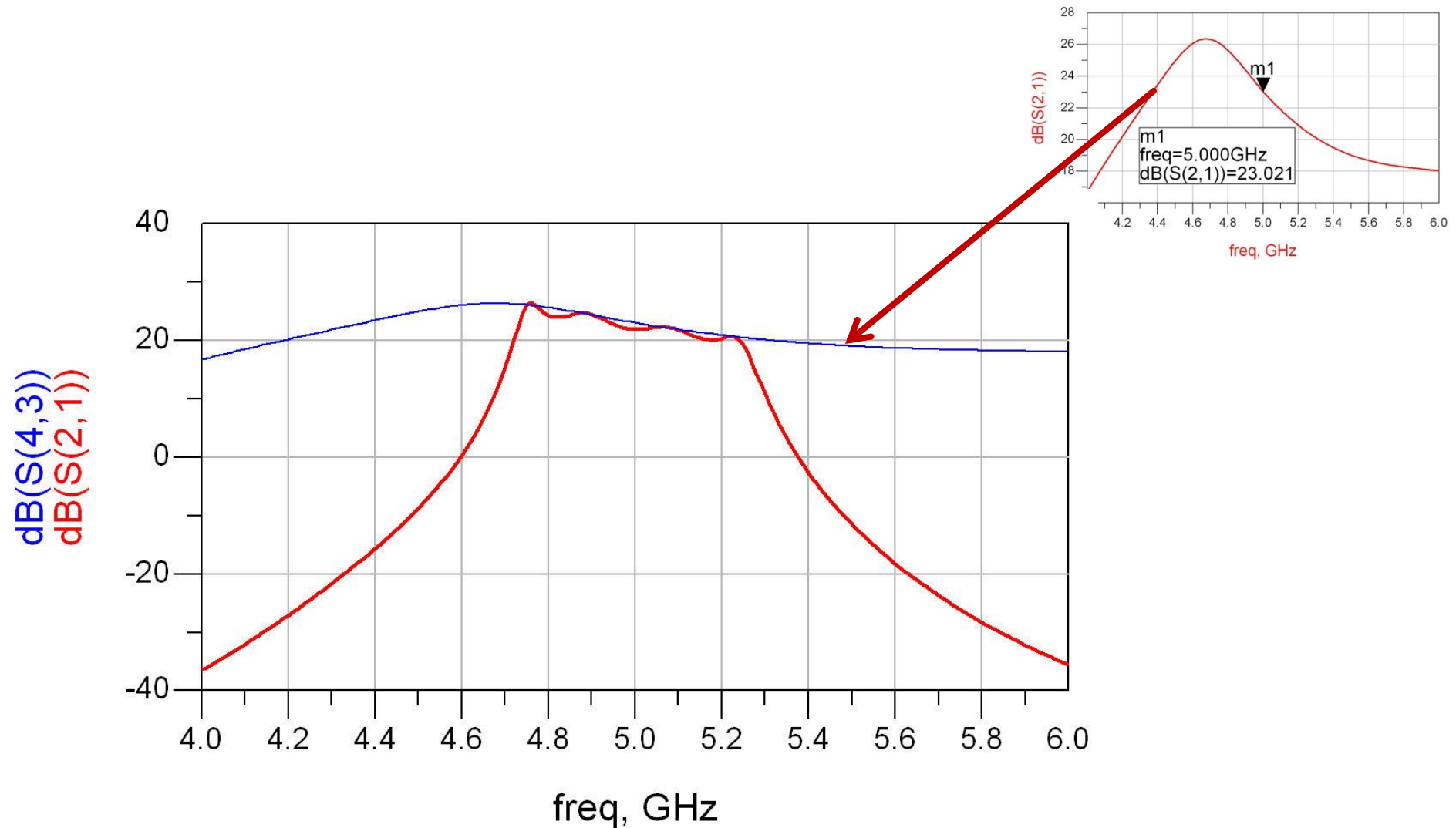
- Unirea celor doua scheme
 - C11 – amplificator (var 4/S36-37)
 - ~~C13~~ – filtre



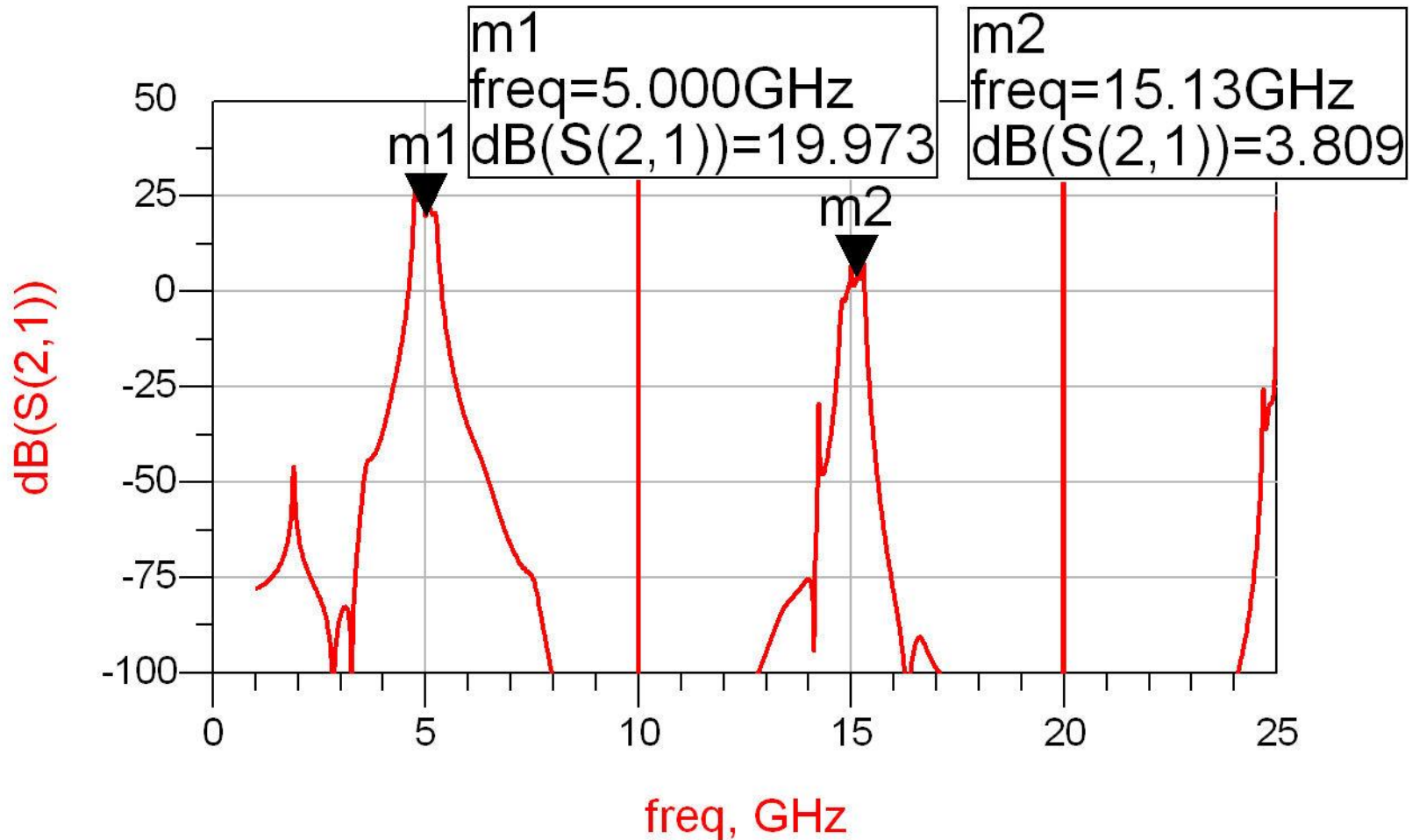
Rezultat (dezechilibrat)



Rezultat (dezechilibrat)

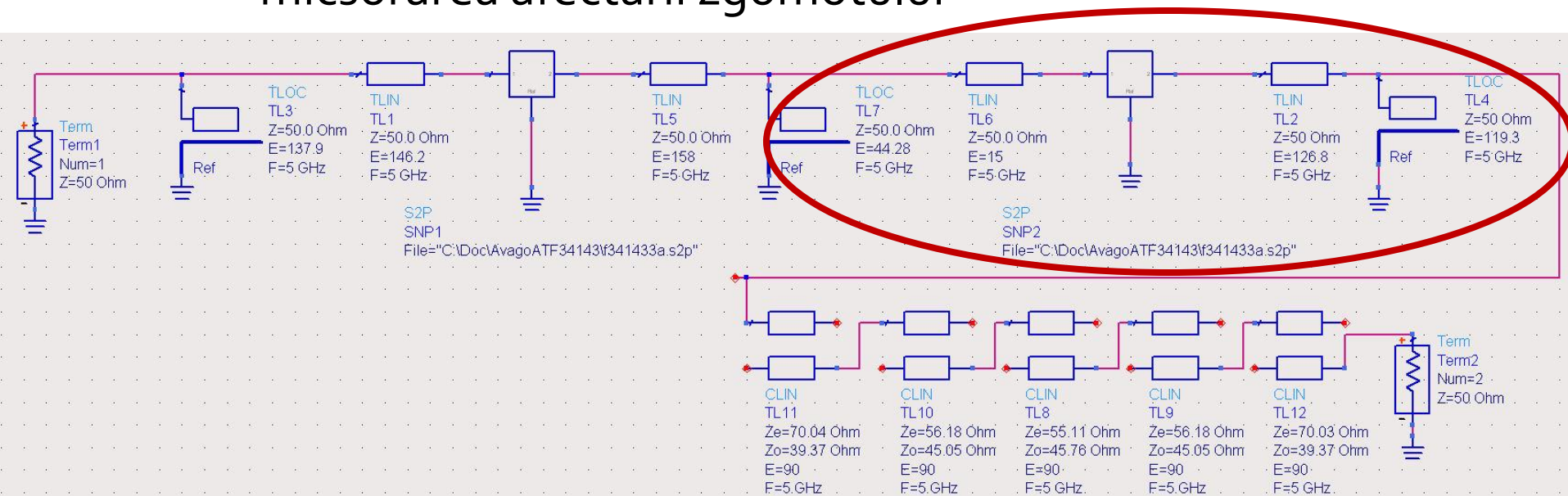


Rezultat (periodic in frecventa)

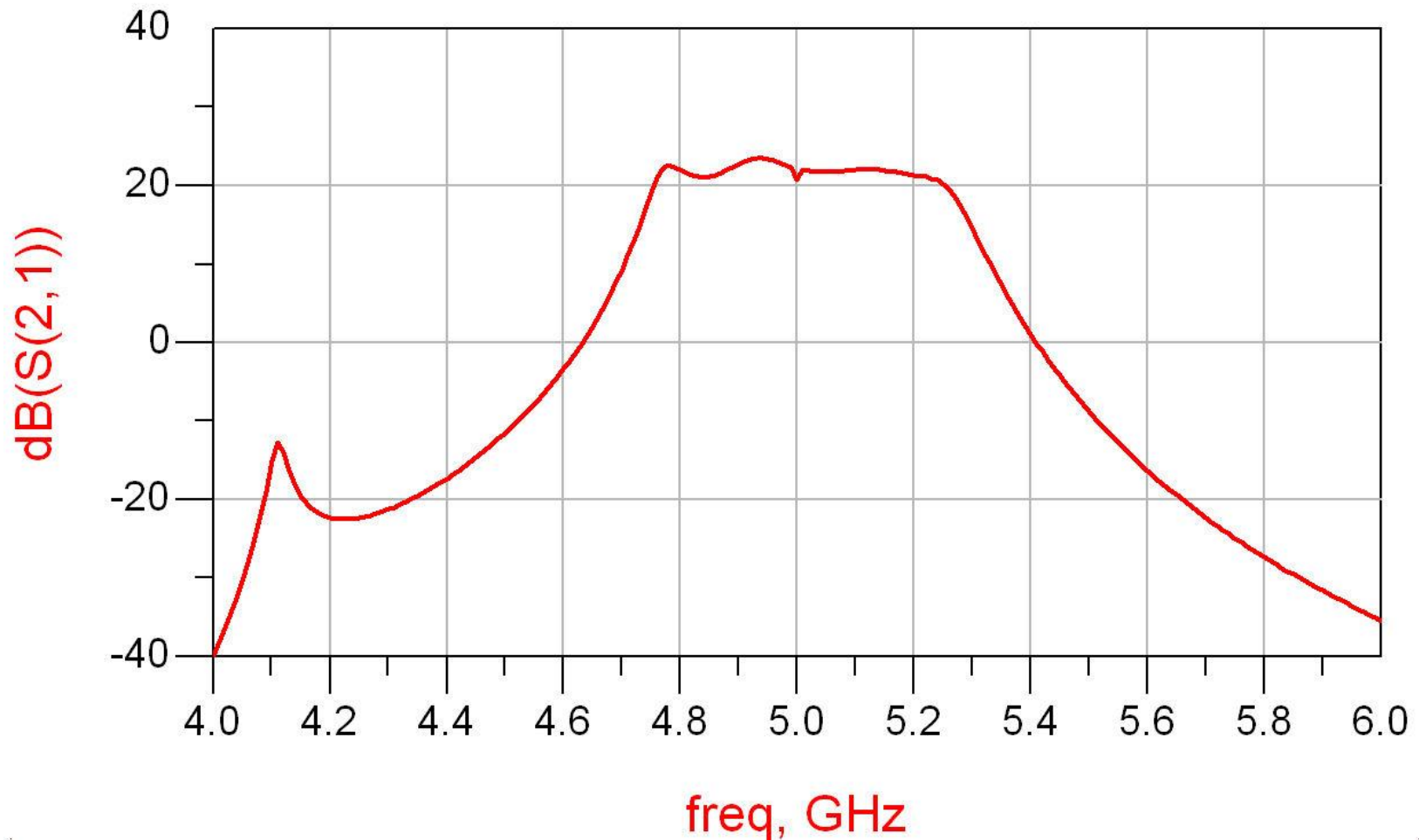


Reglaj -> echilibrare

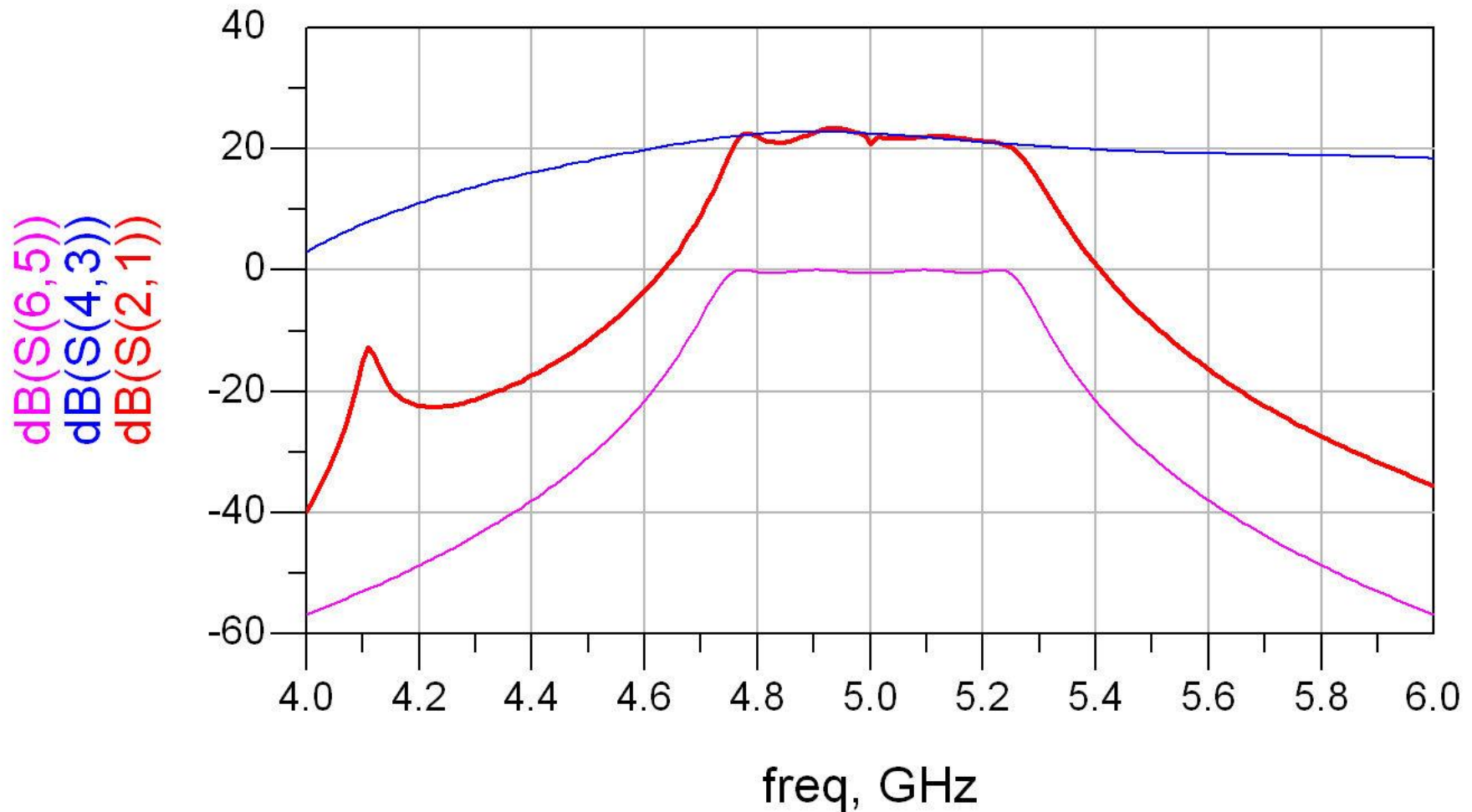
- scopul: echilibrarea caracteristicii amplificatorului (maxim la frecventa centrala)
- se prefera reglarea lungimii liniilor de la iesirea amplificatorului
 - micsorarea afectarii zgomotului



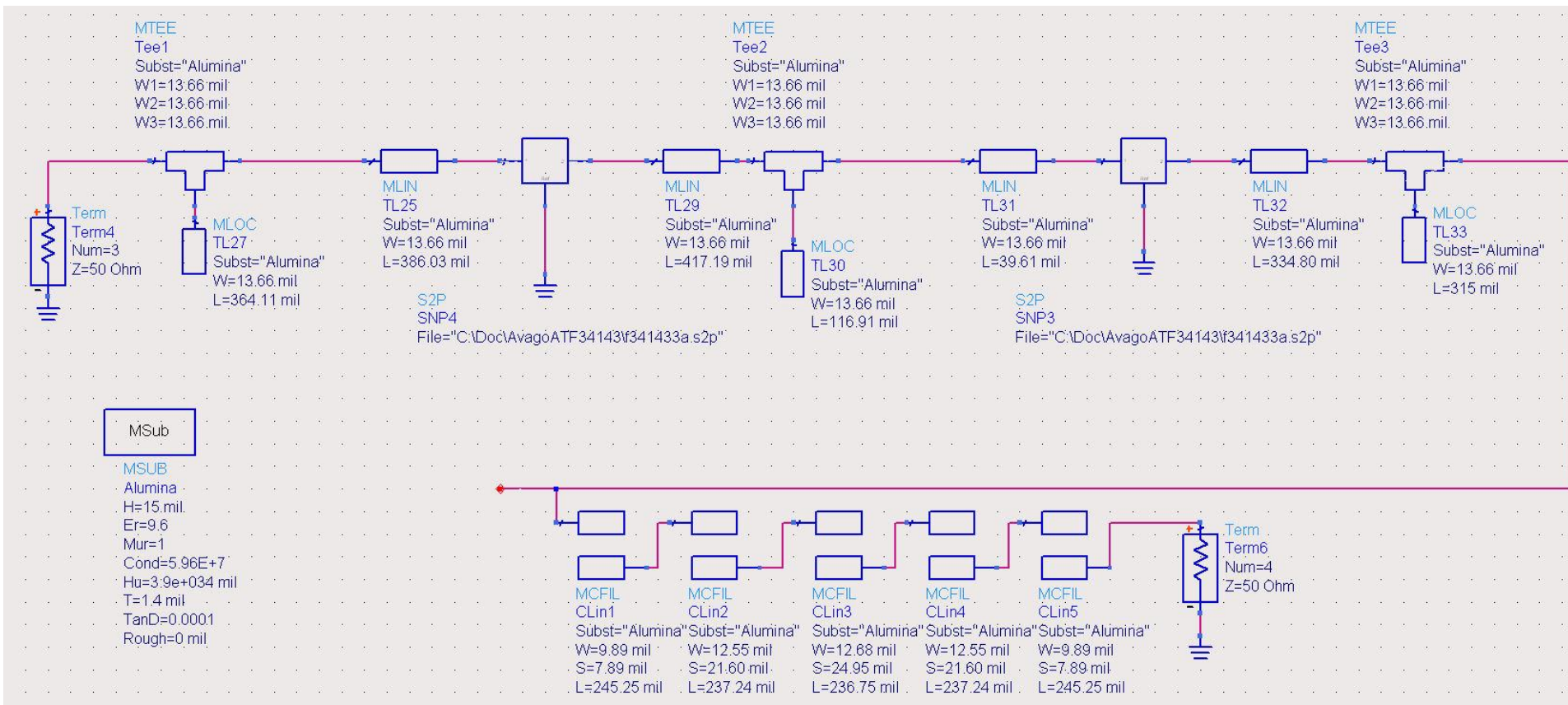
Reglaj -> echilibrare, efect



Amplificator, Filtru, Total

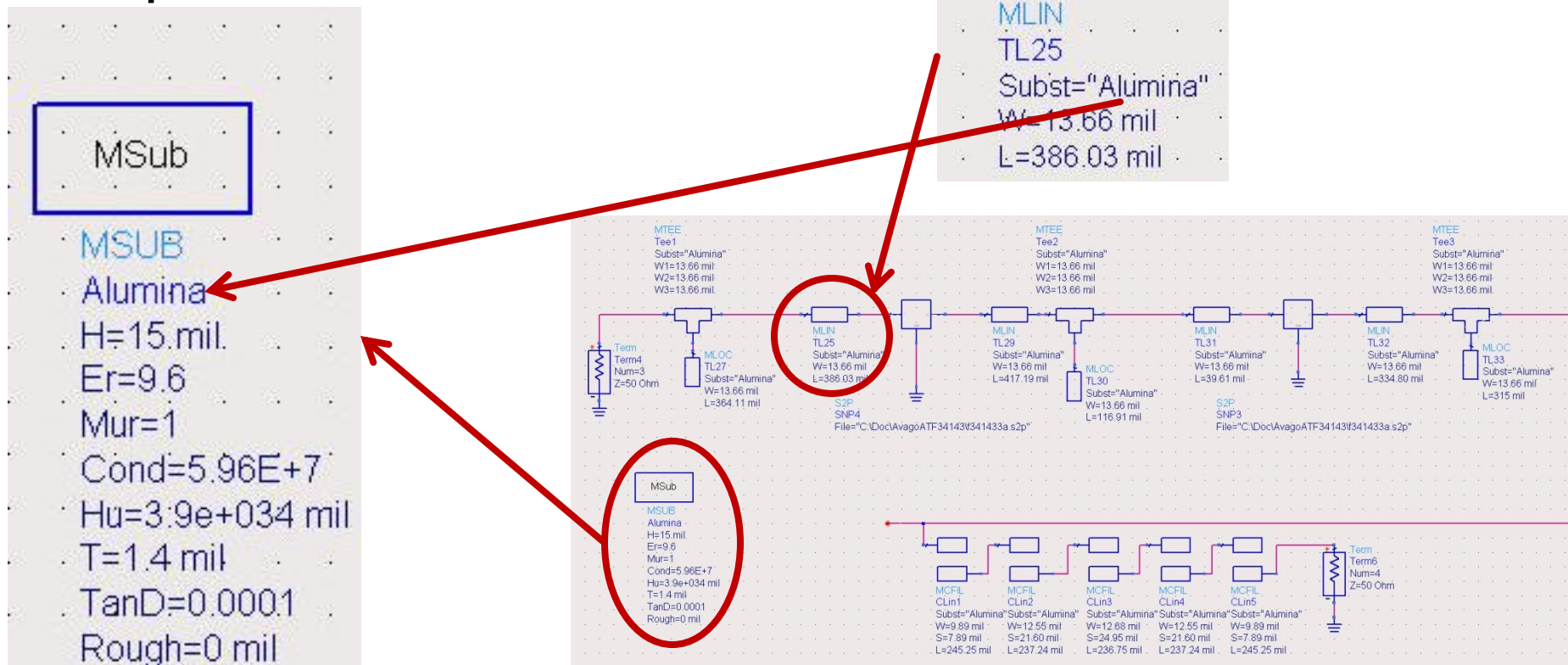


Implementare cu linii microstrip



Implementare cu linii microstrip

- Se introduce modelul de substrat
- Liniile/liniile cuplate se calculeaza cu Linecalc pentru acelasi substrat

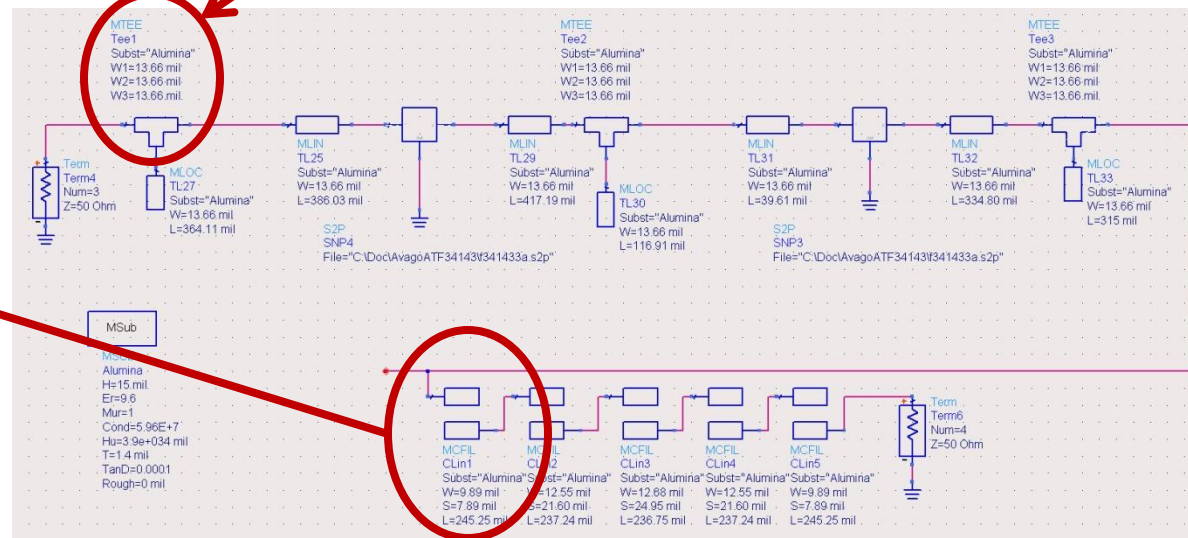
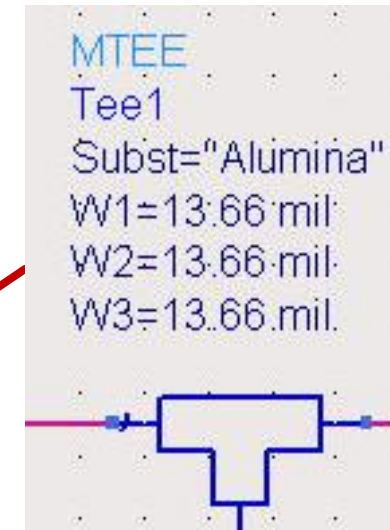


Implementare cu linii microstrip

- Se folosesc componente din paleta Transmission Lines – Microstrip
 - MSUB - substrat
 - MLIN – linie serie
 - MLOC – stub paralel in gol
 - MTEE – modelare conexiune cu stub in paralel
 - MCFIL – sectiune de filtru cu linii cuplate
(alternativa mai precisa decat MCLIN – se tine cont de faptul ca doua sectiuni succesive sunt in fizic alaturate)

Implementare cu linii microstrip

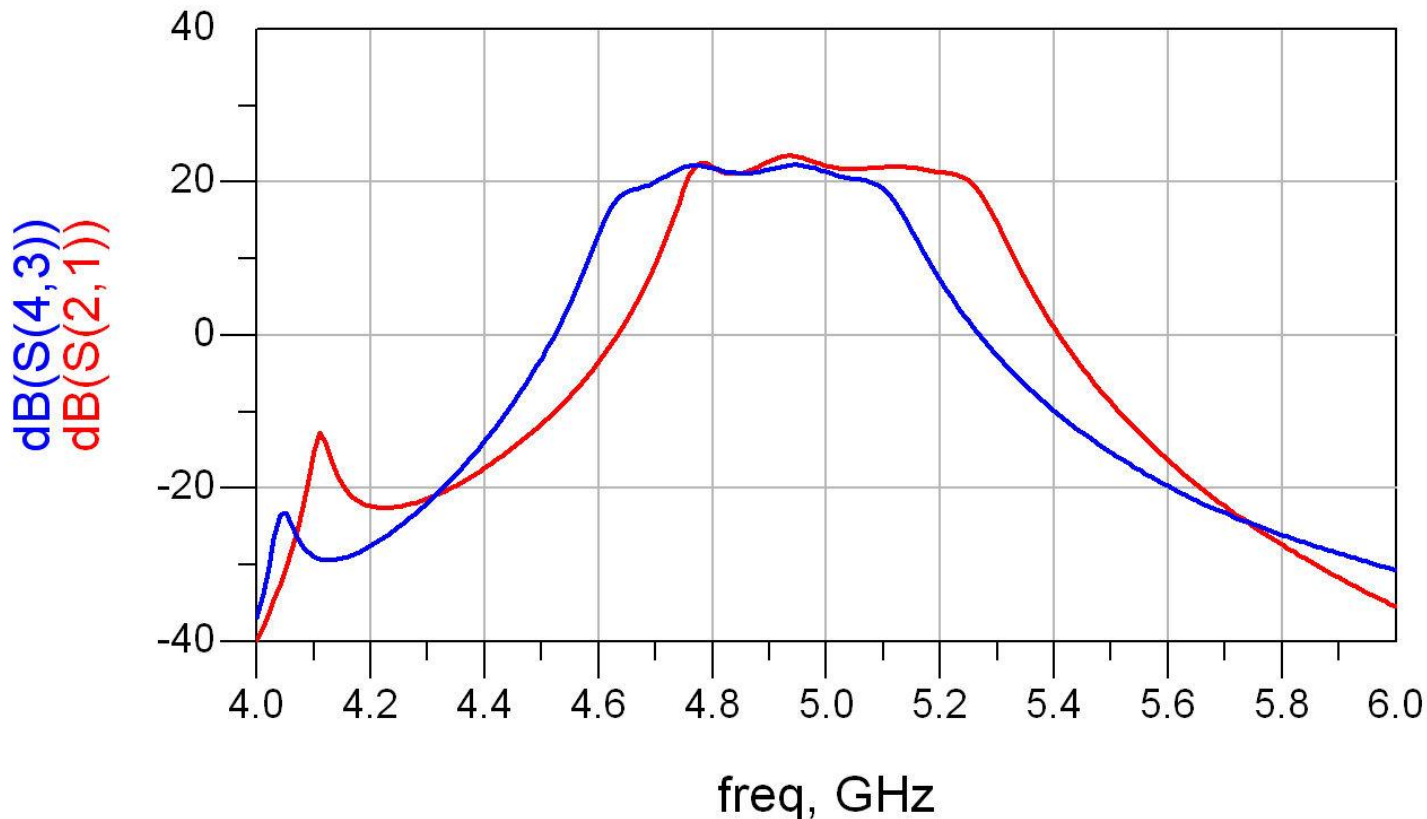
- E necesara atentie la completarea parametrilor pentru MTEE si MCFIL prin verificarea in schema a latimii liniilor conectate la fiecare terminal



Implementare cu linii microstrip

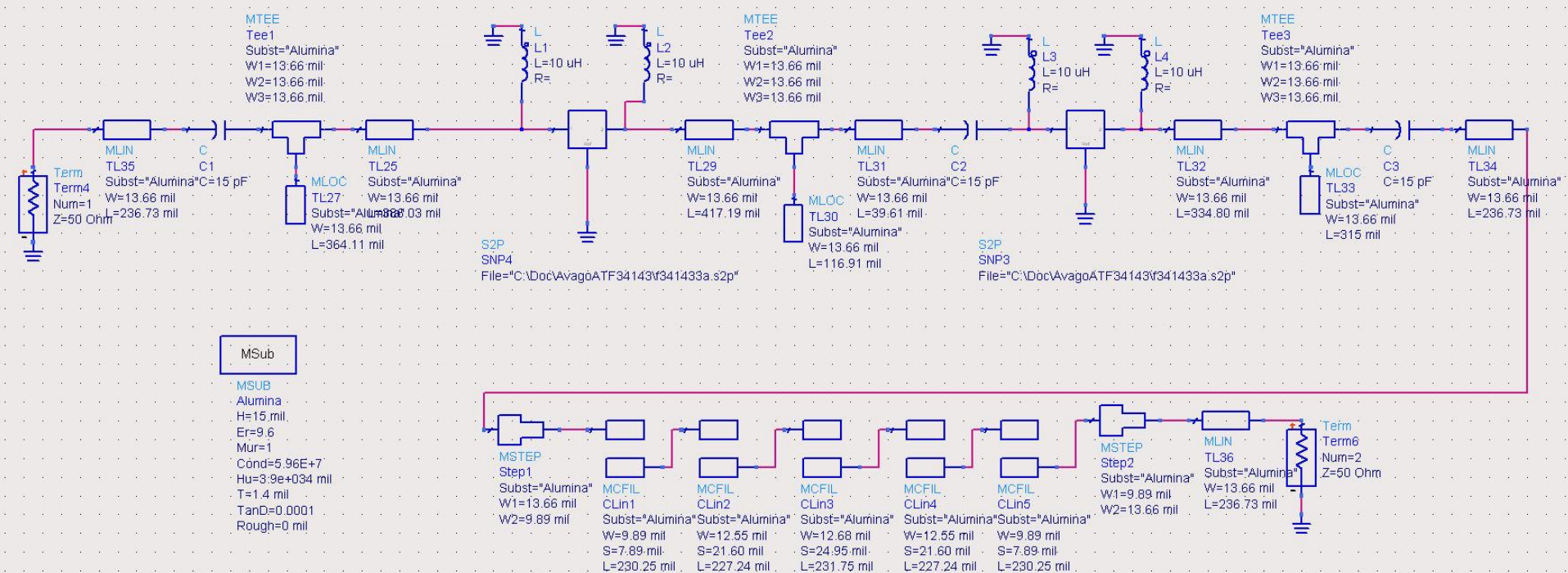
Rezultat

- Se constata o deplasare a benzii obtinute (albastru) spre frecvente mai mici fata de modelele ideale (rosu)
 - datorat diferentei MCFIL / MCLIN

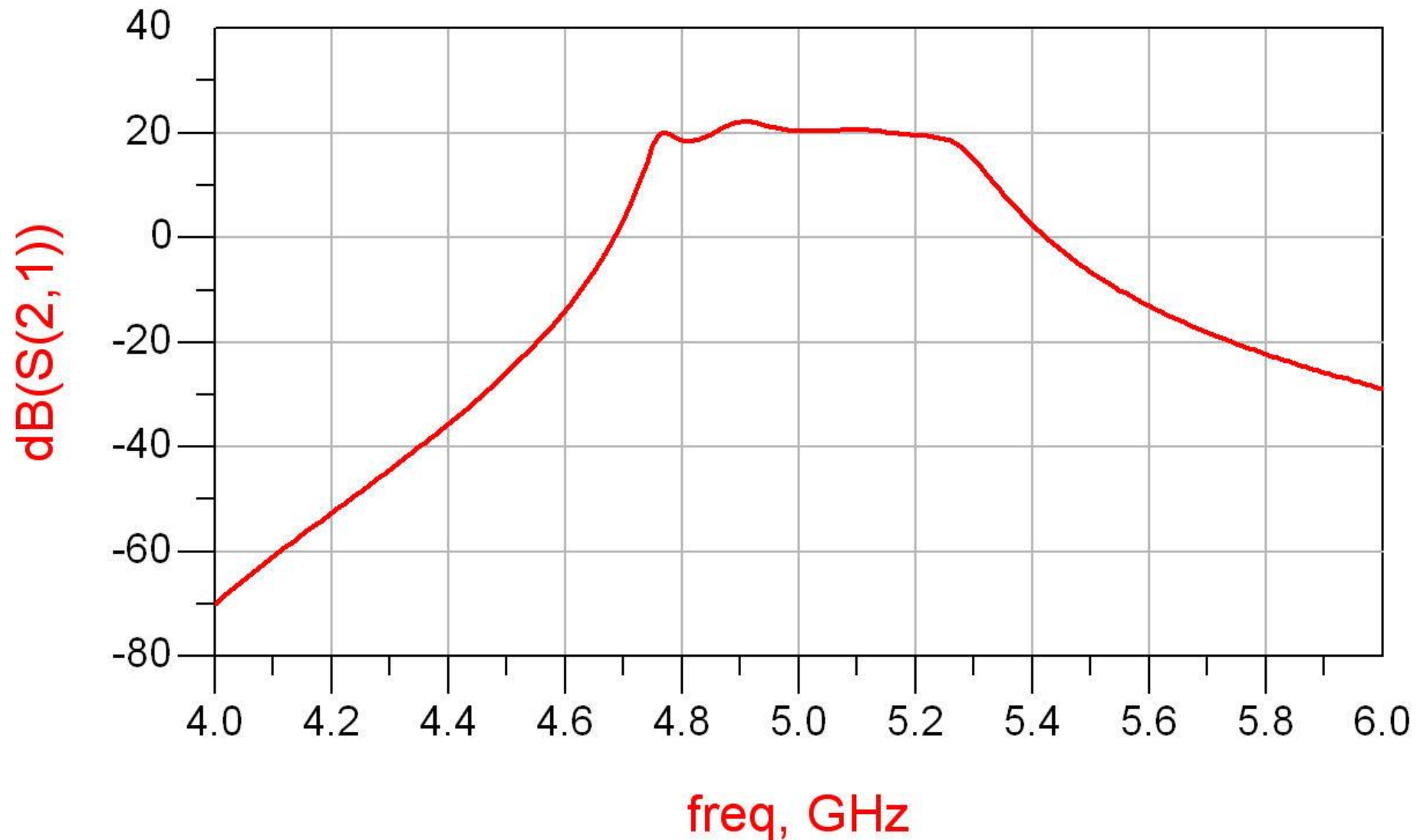


Introducere elemente de polarizare

- Reglaj de lungimi la elementele filtrului pentru reglarea frecventelor in jurul $f_0 = 5\text{GHz}$
- Introducere L (soc RF) si C (decuplare)

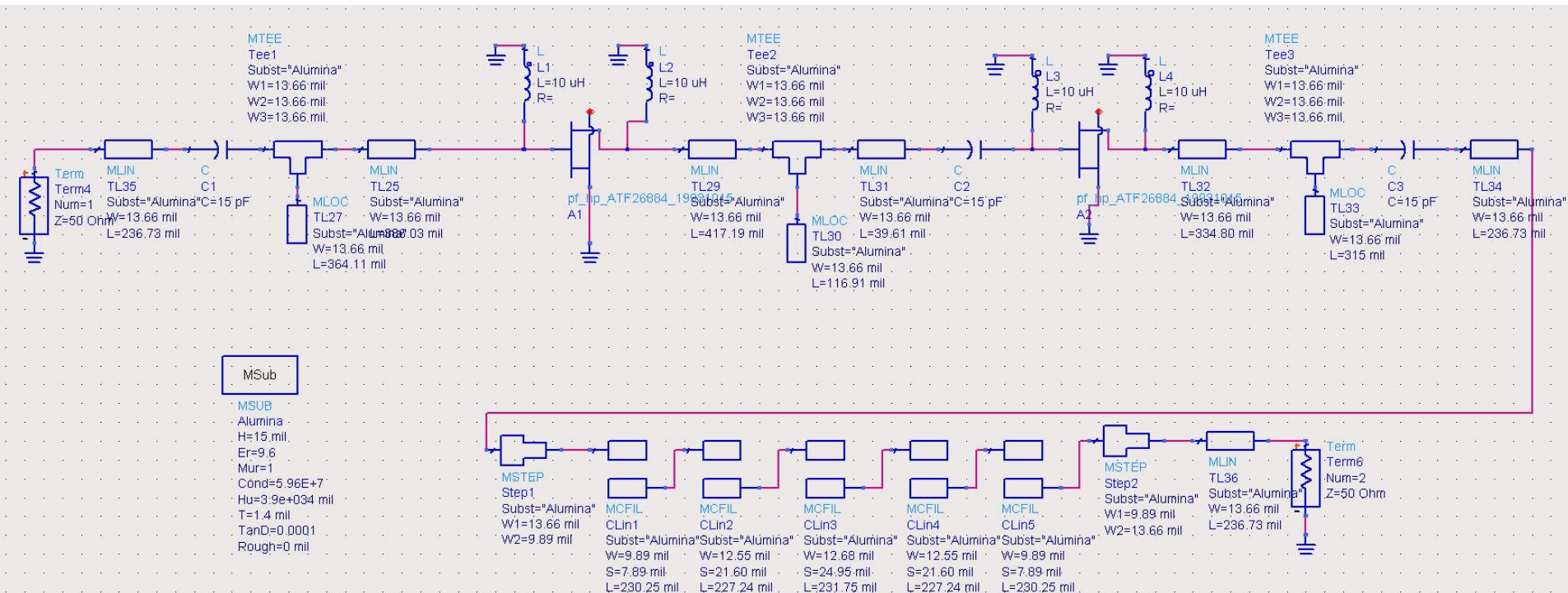


Rezultat final (Castig)

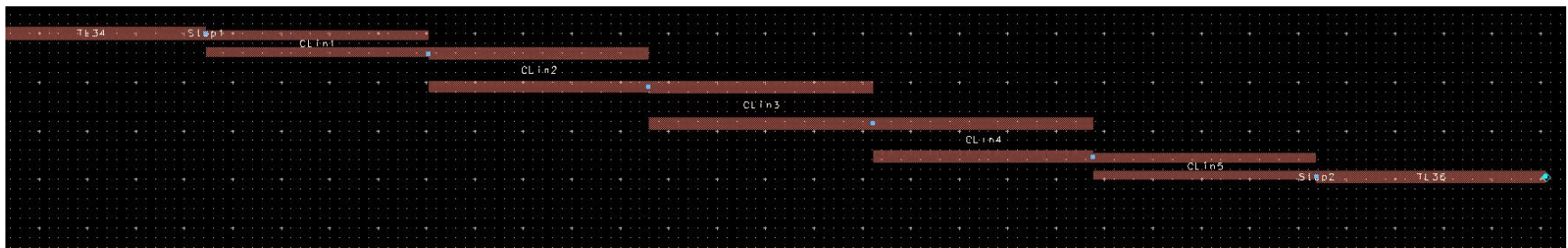
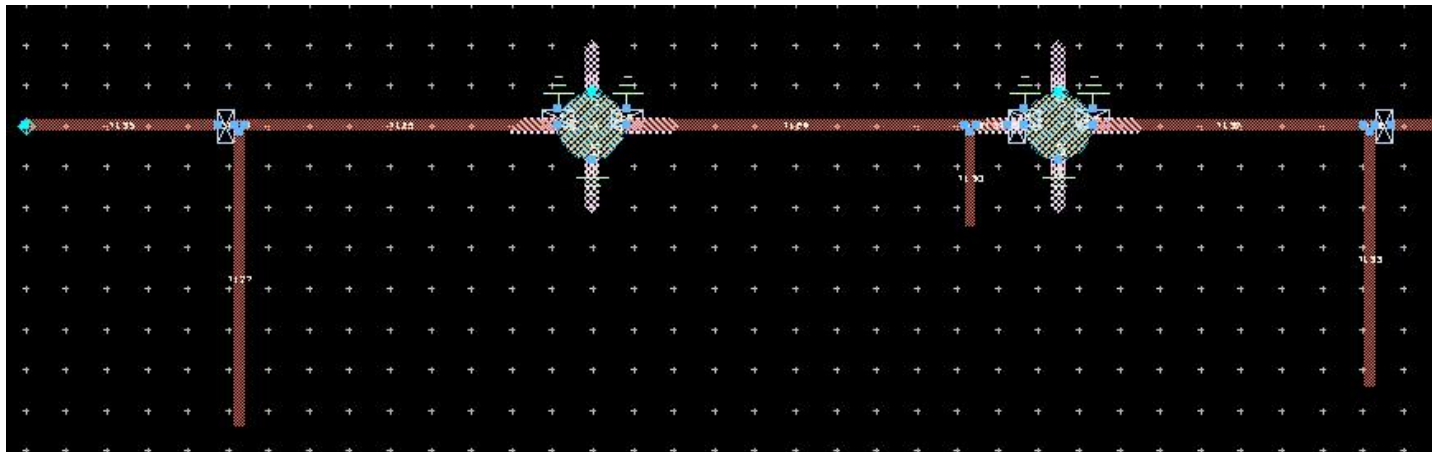
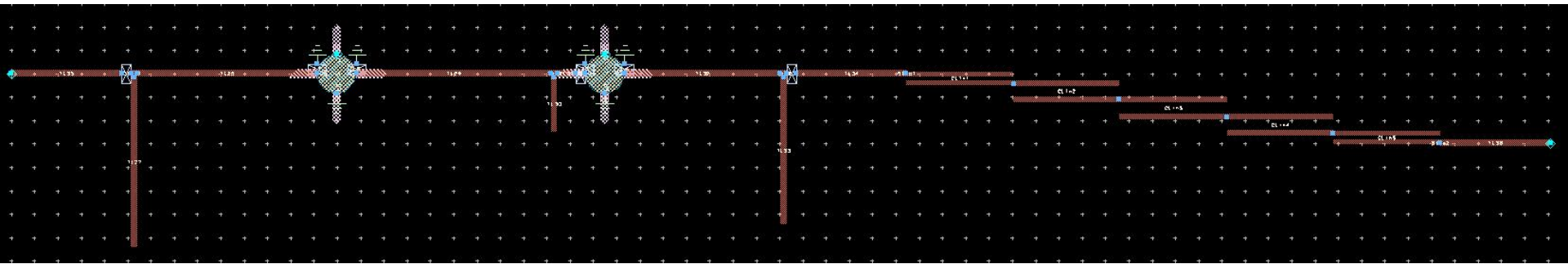


Layout (Exemplu)

- Inlocuirea (fictiva) a tranzistoarelor si elementelor concentrate (LC) cu elemente pentru care ADS are informatii despre capsule



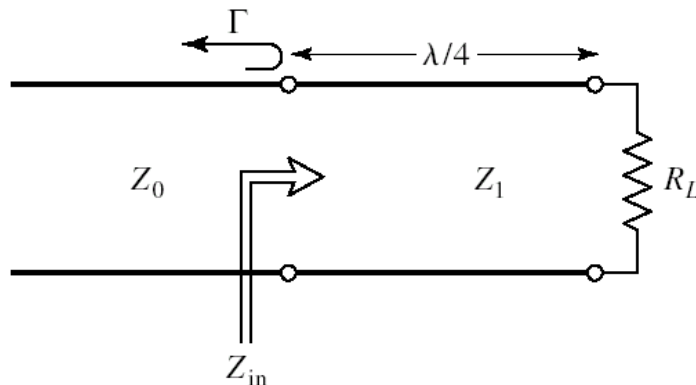
Layout (Exemplu)



Adaptarea de impedanță

Transformatorul in sfert de lungime de unda

- Feed line – linie de intrare cu impedanta caracteristica Z_0
- Sarcina cu impedanta R_L
- Dorim adaptarea sarcinei la fider cu o linie de lungime $\lambda/4$ si impedanta caracteristica Z_1

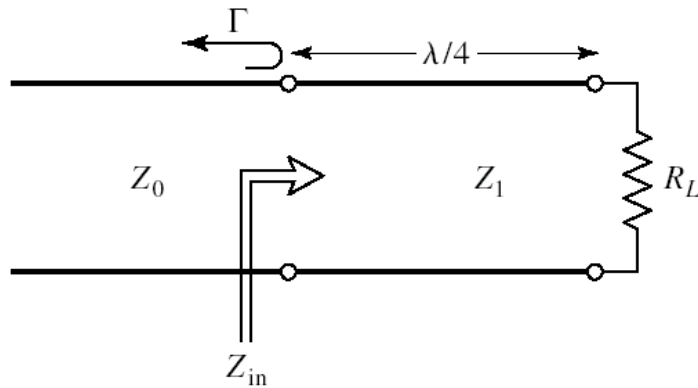


$$Z_{in} = Z_1 \frac{1 + \Gamma e^{-2j\beta l}}{1 - \Gamma e^{-2j\beta l}}$$

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

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

Transformatorul in sfert de lungime de unda



$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

$$\beta \cdot l = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4} = \frac{\pi}{2}$$

$$Z_{in} = \frac{Z_1^2}{R_L}$$

$$\Gamma_{in} = \frac{Z_1^2 - Z_0 \cdot R_L}{Z_1^2 + Z_0 \cdot R_L} \quad \Gamma_{in} = 0 \quad Z_1 = \sqrt{Z_0 R_L}$$

- Pe fider (Z_0) avem doar unda progresiva
- Pe linia in sfert de lungime de unda (Z_1) avem unda stationara

Transformatorul in sfert de lungime de unda

■ Punct de vedere fizic

$$\Gamma = \Gamma_1 - T_1 T_2 \Gamma_3 + T_1 T_2 \Gamma_2 \Gamma_3^2 - T_1 T_2 \Gamma_2^2 \Gamma_3^3 + \dots$$

$$= \Gamma_1 - T_1 T_2 \Gamma_3 \sum_{n=0}^{\infty} (-\Gamma_2 \Gamma_3)^n.$$

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

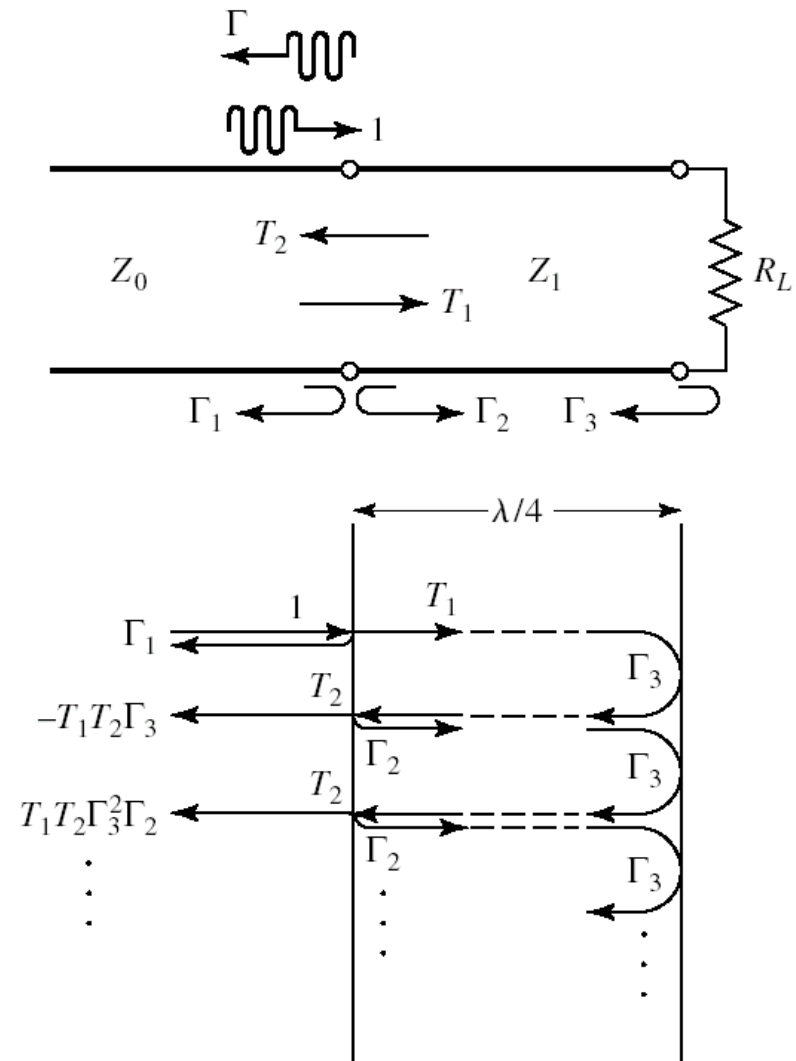
$$\Gamma_2 = \frac{Z_0 - Z_1}{Z_0 + Z_1} = -\Gamma_1,$$

$$\Gamma_3 = \frac{R_L - Z_1}{R_L + Z_1},$$

$$T_1 = \frac{2Z_1}{Z_1 + Z_0},$$

$$T_2 = \frac{2Z_0}{Z_1 + Z_0}.$$

$$\left. \begin{array}{l} T_1 = \frac{2Z_1}{Z_1 + Z_0} \\ T_2 = \frac{2Z_0}{Z_1 + Z_0} \end{array} \right\} T = 1 - \Gamma$$



Transformatorul in sfert de lungime de unda

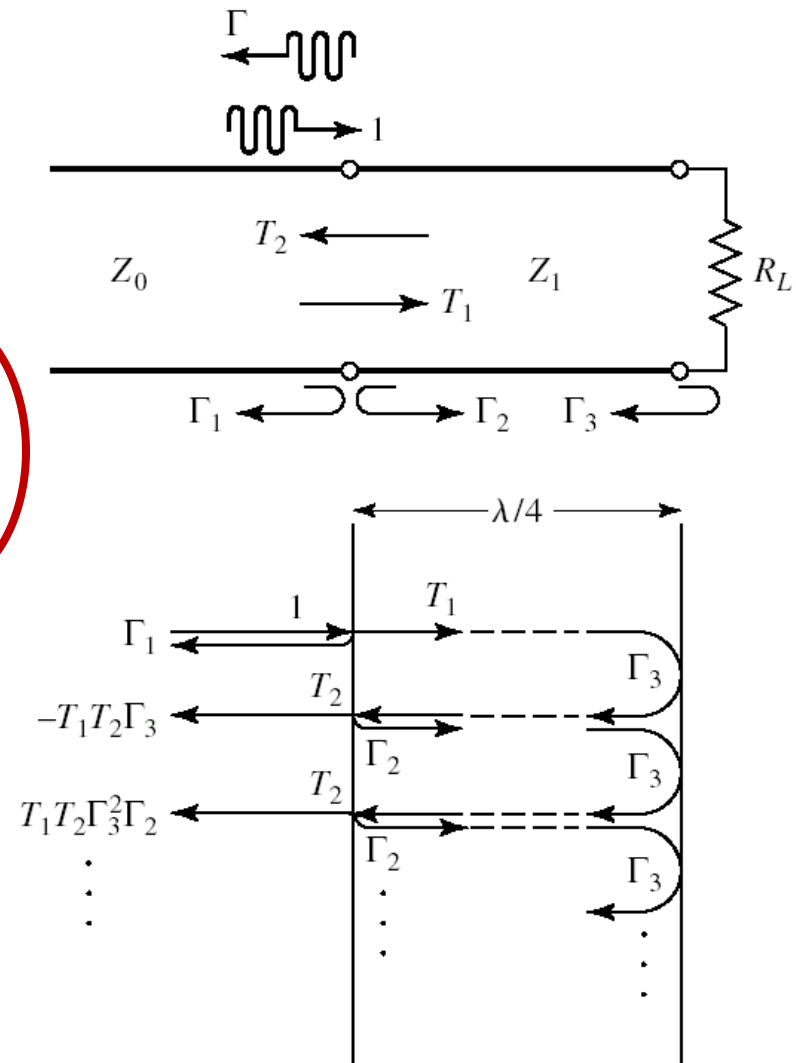
■ Punct de vedere fizic

$$\sum_{n=0}^{\infty} x^n = \frac{1}{1-x}, \quad \text{for } |x| < 1,$$

$$\Gamma = \Gamma_1 - \frac{T_1 T_2 \Gamma_3}{1 + \Gamma_2 \Gamma_3} = \frac{\Gamma_1 + \Gamma_1 \Gamma_2 \Gamma_3 - T_1 T_2 \Gamma_3}{1 + \Gamma_2 \Gamma_3}.$$

$$\Gamma_1 - \Gamma_3(\Gamma_1^2 + T_1 T_2) = \frac{2(Z_1^2 - Z_0 R_L)}{(Z_1 + Z_0)(R_L + Z_1)},$$

$$\Gamma = 0 \leftrightarrow Z_1^2 - Z_0 \cdot R_L = 0$$



Caracteristica de frecventa

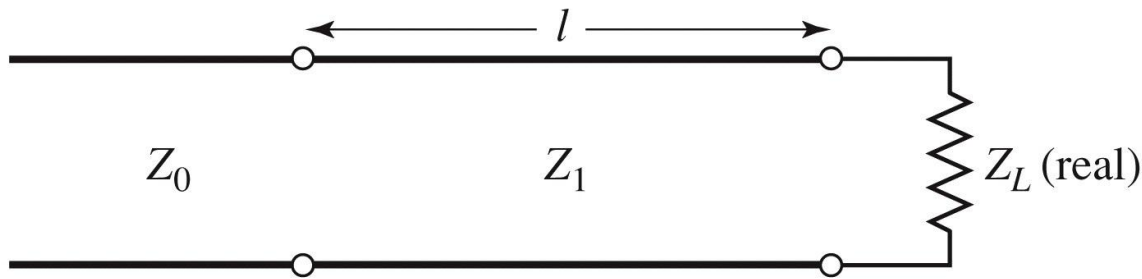


Figure 5.10
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$$Z_1 = \sqrt{Z_0 \cdot Z_L}$$

■ **(doar)** la frecventa f_0

$$l = \frac{\lambda_0}{4} \quad \beta_0 \cdot l = \frac{2\pi}{\lambda_0} \cdot \frac{\lambda_0}{4} = \frac{\pi}{2}$$

$$Z_{in} = Z_1 \cdot \frac{Z_L + j \cdot Z_1 \cdot \tan(\beta \cdot l)}{Z_1 + j \cdot Z_L \cdot \tan(\beta \cdot l)}$$

$$\theta = \beta \cdot l \quad t = \tan(\beta \cdot l)$$

$$Z_{in} = Z_1 \cdot \frac{Z_L + j \cdot Z_1 \cdot t}{Z_1 + j \cdot Z_L \cdot t}$$

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = \frac{Z_1(Z_L - Z_0) + jt(Z_1^2 - Z_0 Z_L)}{Z_1(Z_L + Z_0) + jt(Z_1^2 + Z_0 Z_L)}$$

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0 + j2t\sqrt{Z_0 Z_L}}$$

Caracteristica de frecventa

- calitatea adaptarii \equiv coeficient de reflexie in putere

$$\begin{aligned} |\Gamma| &= \frac{|Z_L - Z_0|}{[(Z_L + Z_0)^2 + 4t^2 Z_0 Z_L]^{1/2}} \\ &= \frac{1}{\{(Z_L + Z_0)^2 / (Z_L - Z_0)^2 + [4t^2 Z_0 Z_L / (Z_L - Z_0)^2]\}^{1/2}} \\ &= \frac{1}{\{1 + [4Z_0 Z_L / (Z_L - Z_0)^2] + [4Z_0 Z_L t^2 / (Z_L - Z_0)^2]\}^{1/2}} \\ &= \frac{1}{\{1 + [4Z_0 Z_L / (Z_L - Z_0)^2] \sec^2 \theta\}^{1/2}}, \end{aligned}$$

$$\sec \theta = \frac{1}{\cos \theta} \rightarrow$$

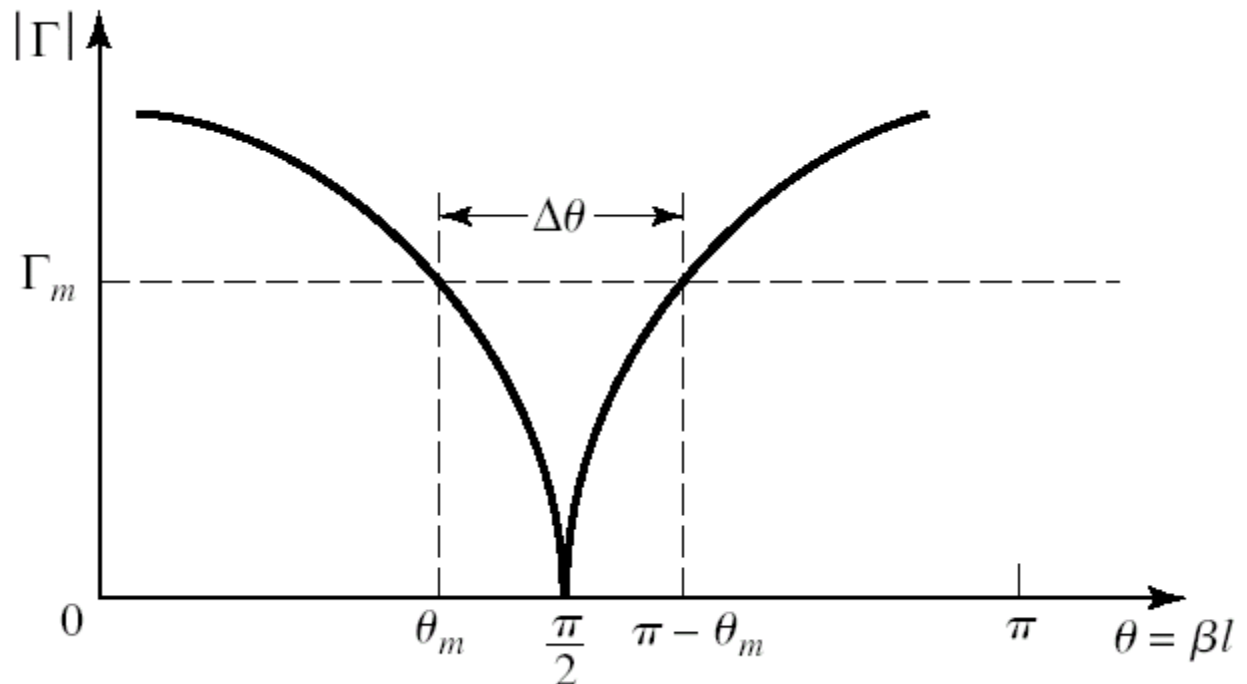
$$\sec^2 \theta = 1 + \tan^2 \theta = 1 + t^2$$

Caracteristica de frecventa

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

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

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



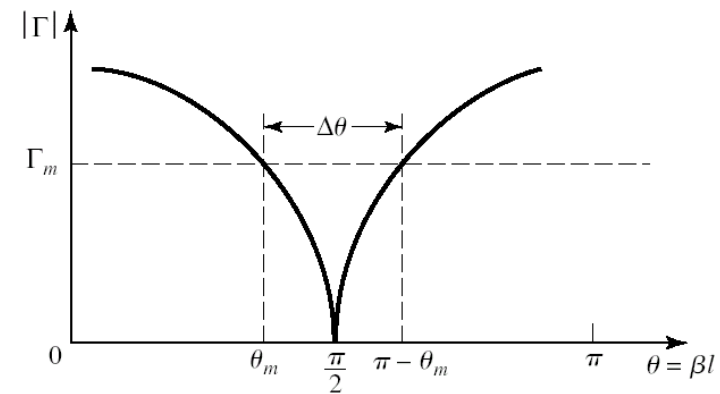
Caracteristica de frecventa

- Definim un maxim acceptat pentru coeficientul de reflexie Γ_m care va defini banda adaptarii, θ_m

$$\frac{1}{\Gamma_m^2} = 1 + \left(\frac{2\sqrt{Z_0 Z_L}}{Z_L - Z_0} \sec \theta_m \right)^2,$$

$$\cos \theta_m = \frac{\Gamma_m}{\sqrt{1 - \Gamma_m^2}} \frac{2\sqrt{Z_0 Z_L}}{|Z_L - Z_0|}.$$

$$\Delta\theta = 2 \left(\frac{\pi}{2} - \theta_m \right)$$



- in linii TEM

$$\theta = \beta \cdot l = \beta \cdot \frac{\lambda_0}{4} = \frac{2\pi \cdot f}{v_f} \cdot \frac{1}{4} \cdot \frac{v_f}{f_0} = \frac{\pi \cdot f}{2f_0}$$

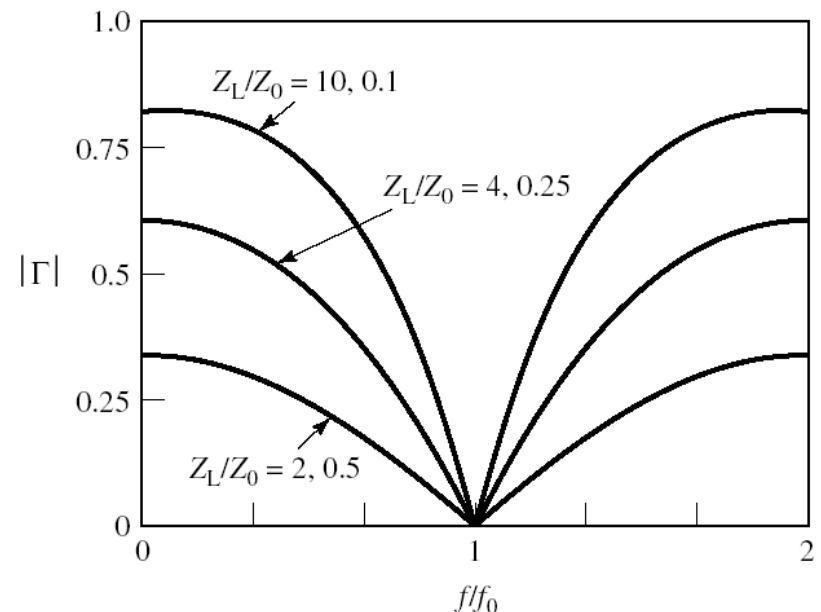
$$f_m = \frac{2 \cdot \theta_m \cdot f_0}{\pi}$$

$$\frac{\Delta f}{f_0} = \frac{2 \cdot (f_0 - f_m)}{f_0} = 2 - \frac{4 \cdot \theta_m}{\pi} = 2 - \frac{4}{\pi} \cdot \cos^{-1} \left[\frac{\Gamma_m}{\sqrt{1 - \Gamma_m^2}} \cdot \frac{2\sqrt{Z_0 \cdot Z_L}}{|Z_L - Z_0|} \right]$$

Caracteristica de frecventa

- Pentru linii non TEM constanta de propagare nu depinde liniar de frecventa, dar in practica influenta este minora in banda ingusta
- Sunt neglijate reactantele introduse de discontinuitati ($Z_0 \rightarrow Z_1$). Compensarea se face printr-o mica modificare a lungimii liniei
- Banda depinde de dezadaptarea initiala

cu cat dezadaptarea este mai mica
cu atat banda se obtine mai larga



Exemplu

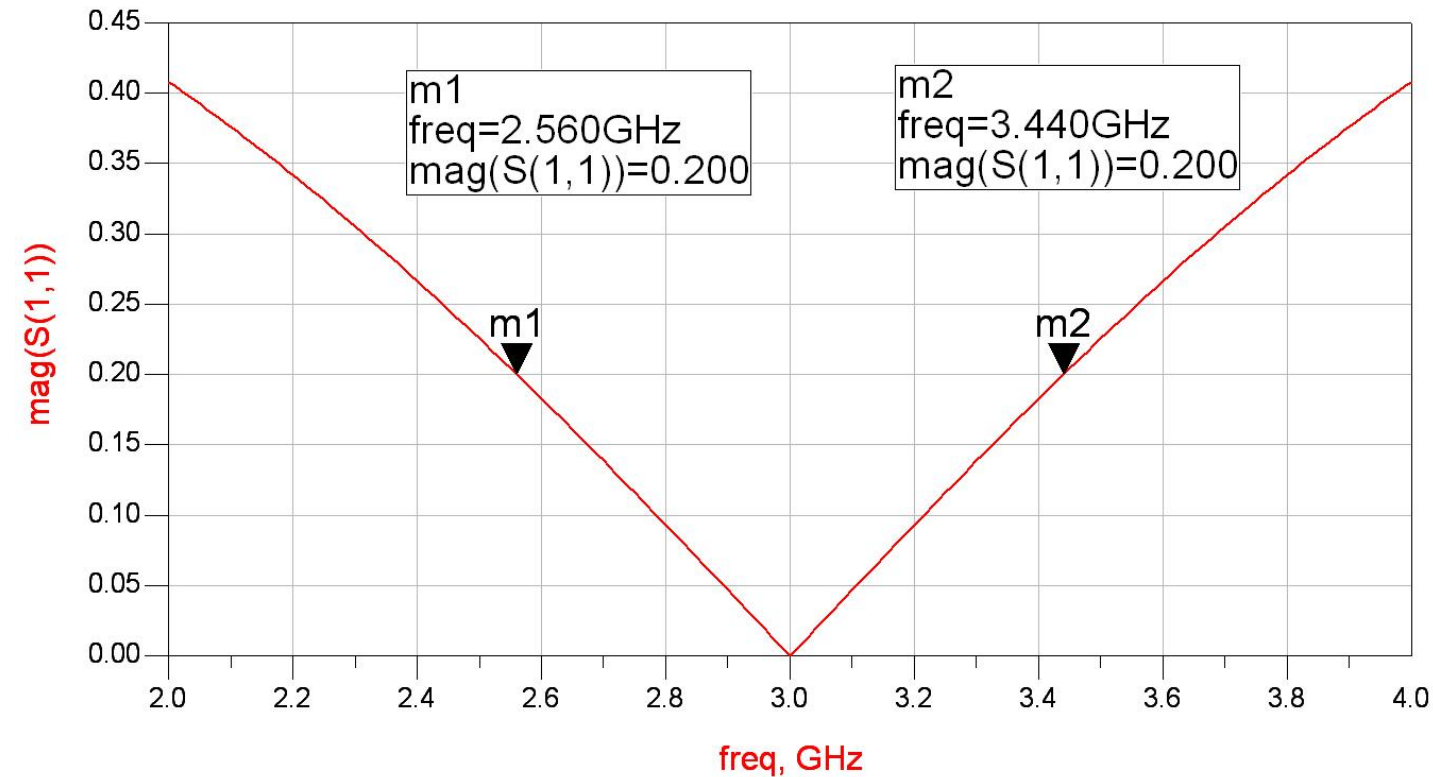
- Transformator de adaptare cu o singura sectiune ($\lambda/4$) pentru a adapta o sarcina de 10Ω la o linie de 50Ω la frecventa $f_0=3\text{GHz}$
 - banda pentru $\text{SWR}<1.5$

$$Z_1 = \sqrt{Z_0 Z_L} = \sqrt{(50)(10)} = 22.36 \Omega, \quad \Gamma_m = \frac{\text{SWR} - 1}{\text{SWR} + 1} = \frac{1.5 - 1}{1.5 + 1} = 0.2.$$

$$\begin{aligned} \frac{\Delta f}{f_0} &= 2 - \frac{4}{\pi} \cos^{-1} \left[\frac{\Gamma_m}{\sqrt{1 - \Gamma_m^2}} \frac{2\sqrt{Z_0 Z_L}}{|Z_L - Z_0|} \right] \\ &= 2 - \frac{4}{\pi} \cos^{-1} \left[\frac{0.2}{\sqrt{1 - (0.2)^2}} \frac{2\sqrt{(50)(10)}}{|10 - 50|} \right] \\ &= 0.29, \text{ or } 29\%. \end{aligned}$$

Simulare

■ simulare ADS

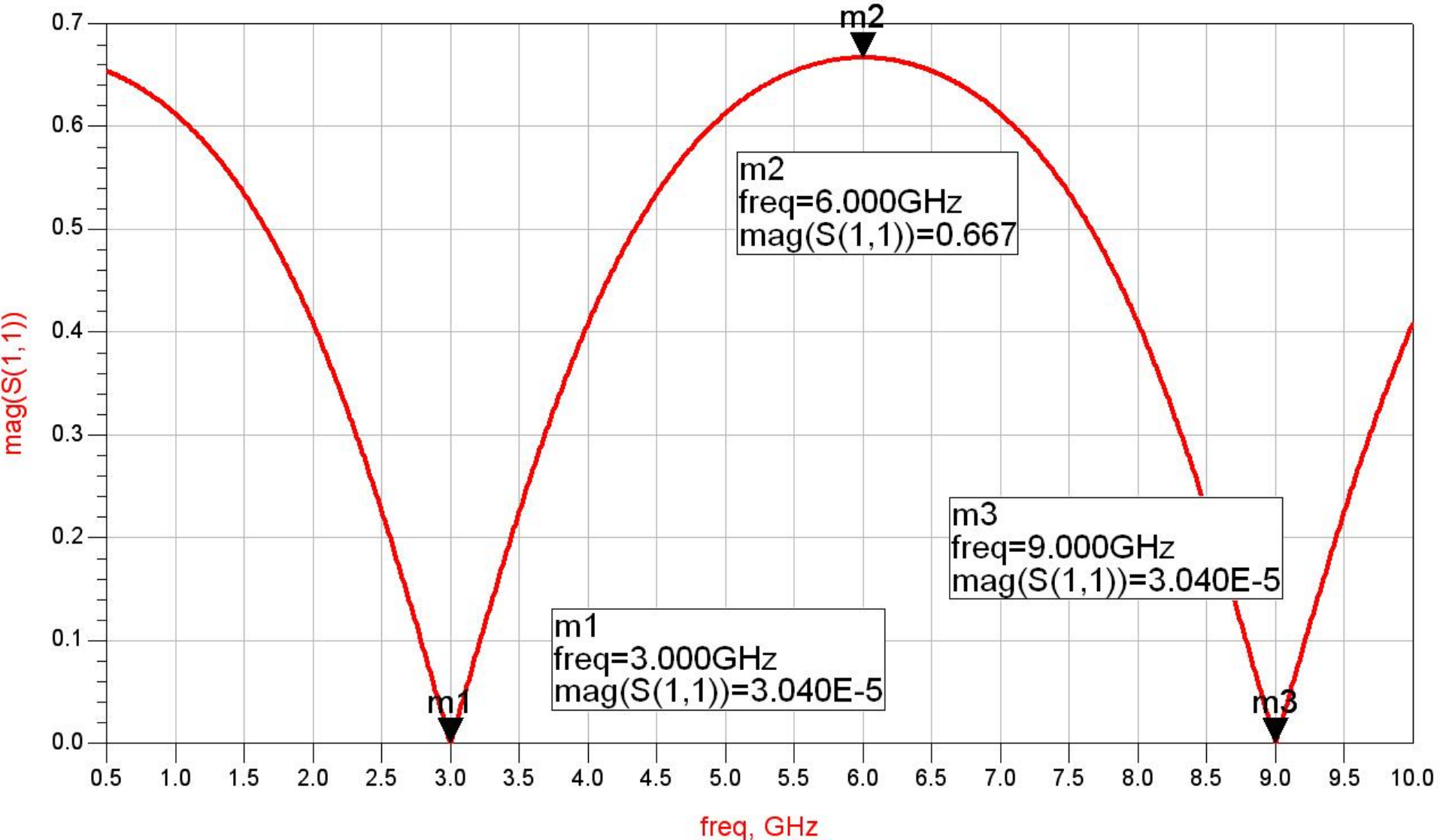


$$\Delta f = 0.88\text{GHz}$$

$$|\Gamma(3\text{GHz})| = 3 \cdot 10^{-5}$$

$$\frac{\Delta f}{f_0} = \frac{0.88}{3} = 0.2933$$

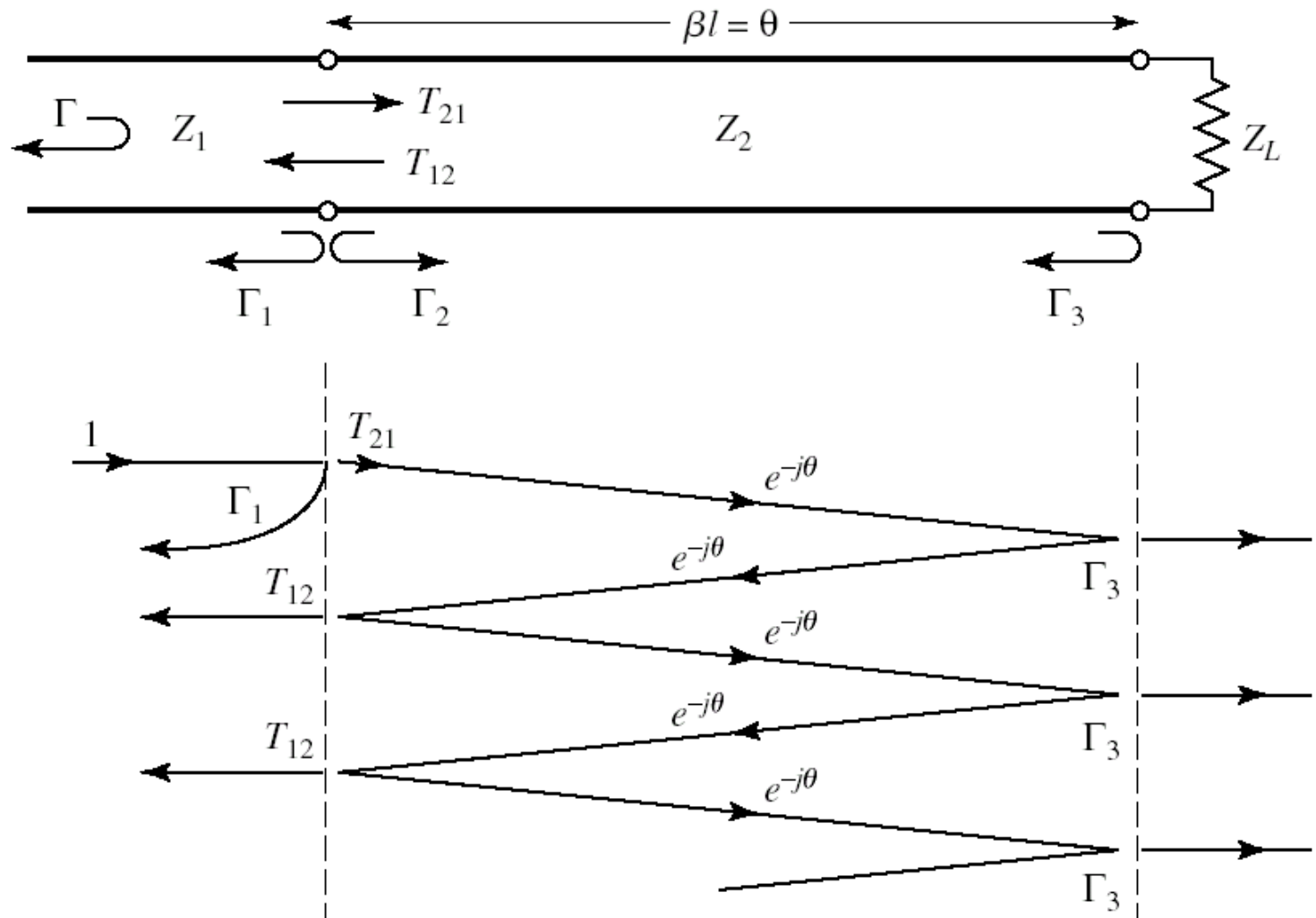
Simulare banda larga



Transformatoare de impedanta multisectiune

- Transformatorul in sfert de lungime de unda permite adaptarea oricarei impedante reale cu orice impedanta a fiderului (liniei).
- Daca banda necesara este mai mare decat cea oferita de transformatorul in sfert de lungime de unda se folosesc transformatoare multisectiune
 - caracteristica binomiala
 - tip Cebîșev

Teoria reflexiilor mici



Teoria reflexiilor mici

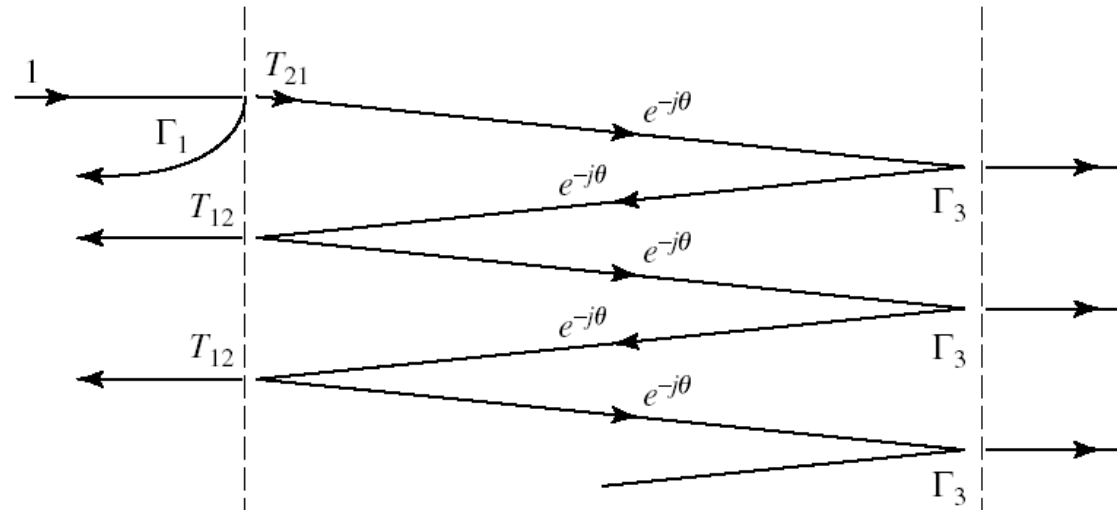
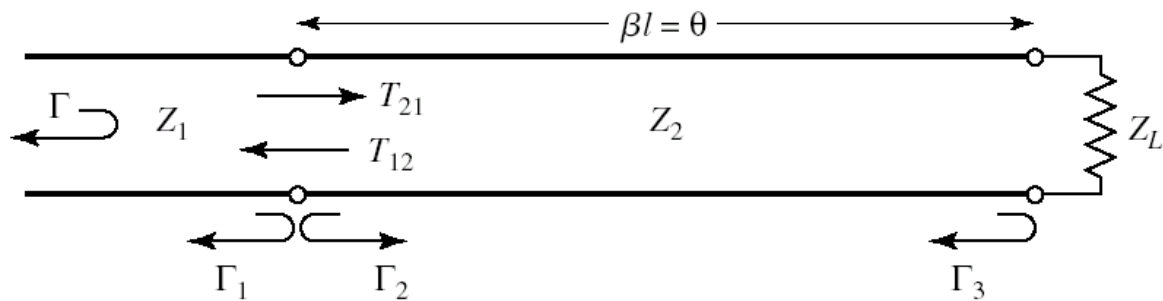
$$\Gamma_1 = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$\Gamma_2 = -\Gamma_1$$

$$\Gamma_3 = \frac{Z_L - Z_2}{Z_L + Z_2}$$

$$T_{21} = 1 + \Gamma_1 = \frac{2 \cdot Z_2}{Z_1 + Z_2}$$

$$T_{12} = 1 + \Gamma_2 = \frac{2 \cdot Z_1}{Z_1 + Z_2}$$



$$\Gamma = \Gamma_1 + T_{12} \cdot T_{21} \cdot \Gamma_3 \cdot e^{-2j\theta} + T_{12} \cdot T_{21} \cdot \Gamma_3^2 \cdot \Gamma_2 \cdot e^{-4j\theta} + T_{12} \cdot T_{21} \cdot \Gamma_3^3 \cdot \Gamma_2^2 \cdot e^{-6j\theta} + \dots$$

$$\Gamma = \Gamma_1 + T_{12} \cdot T_{21} \cdot \Gamma_3 \cdot e^{-2j\theta} \sum_{n=0}^{\infty} \Gamma_3^n \cdot \Gamma_2^n \cdot e^{-2jn\theta}$$

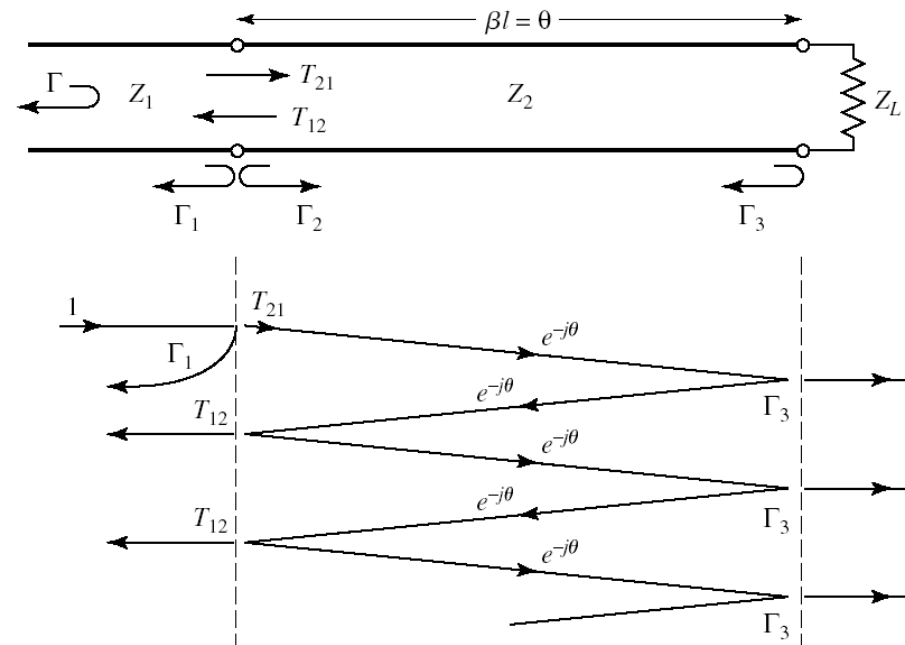
Teoria reflexiilor mici

$$\Gamma = \Gamma_1 + T_{12} \cdot T_{21} \cdot \Gamma_3 \cdot e^{-2j\theta} \sum_{n=0}^{\infty} \Gamma_3^n \cdot \Gamma_2^n \cdot e^{-2jn\theta}$$

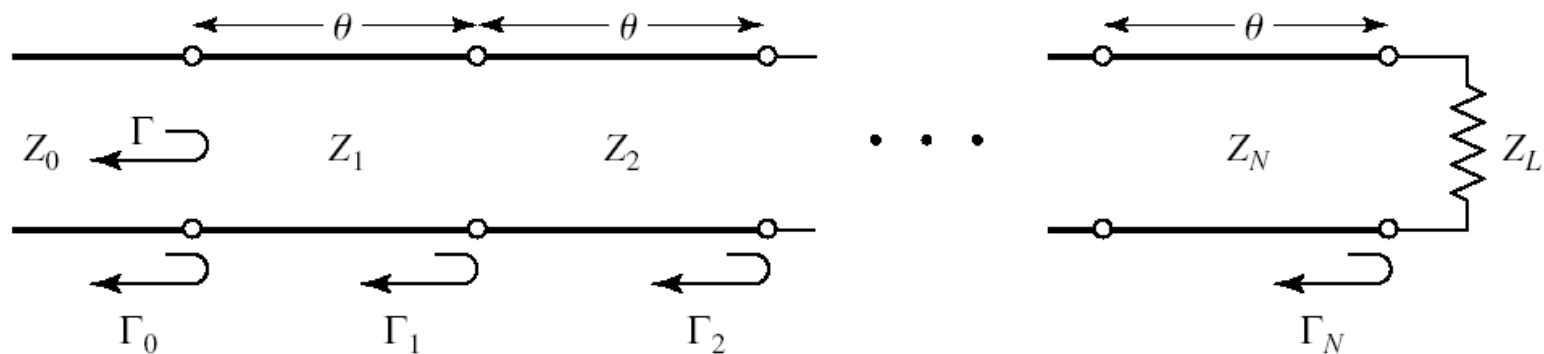
$$\sum_{n=0}^{\infty} x^n = \frac{1}{1-x} \quad |x| < 1$$

$$\Gamma = \frac{\Gamma_1 + \Gamma_3 \cdot e^{-2j\theta}}{1 + \Gamma_1 \cdot \Gamma_3 \cdot e^{-2j\theta}}$$

$$\Gamma \cong \Gamma_1 + \Gamma_3 \cdot e^{-2j\theta}$$



Transformatoare cu mai multe sectiuni



- Presupunem ca toate impedantele **cresc sau descreasc uniform**

- Toti coeficientii de reflexie vor fi reali si de acelasi semn

- Anterior $\Gamma \cong \Gamma_1 + \Gamma_3 \cdot e^{-2j\theta} \Rightarrow$

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

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

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

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

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

Transformatoare cu mai multe sectiuni

- Realizez transformatorul **simetric**
- Aceasta **nu** implica faptul ca impedantele sunt egale

$$\Gamma_0 = \Gamma_N, \Gamma_1 = \Gamma_{N-1}, \Gamma_2 = \Gamma_{N-2} \cdots$$

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

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

$$\Gamma(\theta) = 2e^{-jN\theta} \cdot [\Gamma_0 \cdot \cos N\theta + \Gamma_1 \cdot \cos(N-2)\theta + \cdots \Gamma_n \cdot \cos(N-2n)\theta + \cdots]$$

ultimul termen:

$$\cdots \frac{1}{2} \cdot \Gamma_{N/2} \quad n \text{ par}$$

$$\cdots \Gamma_{(N-1)/2} \cdot \cos \theta \quad n \text{ impar}$$

Transformatoare cu mai multe sectiuni

- Coeficient de reflexie

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

$$e^{-2j\theta} \equiv x$$

$$f(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + \dots + a_N \cdot x^N$$

- aleg coeficientii astfel incat sa obtin o variatie dorita (a polinomului)

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

- Raspunsul acestui transformator este de tip maxim plat in jurul frecventei de adaptare
- Pentru N sectiuni se anuleaza primele N-1 derivate ale functiei $|\Gamma(\theta)|$

$$f(x) = A \cdot (1+x)^N$$

$$\Gamma(\theta) = A \cdot (1 + e^{-2j\theta})^N$$

$$|\Gamma(\theta)| = |A| \cdot |e^{-j\theta}|^N \cdot |e^{j\theta} + e^{-j\theta}|^N = 2^N \cdot |A| \cdot |\cos \theta|^N$$

$$\left| \Gamma\left(\frac{\pi}{2}\right) \right| = 0; \quad \frac{d^n}{d\theta^n} |\Gamma(\theta)| \Big|_{\theta=\frac{\pi}{2}} = 0 \quad n = \overline{1, N-1} \quad l = \frac{\lambda}{4} \Rightarrow \theta = \beta \cdot l = \frac{\pi}{2}$$

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

- $A, \theta \rightarrow 0$, liniile de lungime 0, dispar

$$\Gamma(0) = 2^N \cdot A = \frac{Z_L - Z_0}{Z_L + Z_0} \quad A = 2^{-N} \cdot \frac{Z_L - Z_0}{Z_L + Z_0}$$

- dezvoltarea binomului

$$f(x) = (1+x)^N = C_N^0 + C_N^1 \cdot x + \dots + C_N^n \cdot x^n + \dots + C_N^N \cdot x^N$$

$$C_N^n = \frac{N!}{(N-n)!n!}$$

- Coeficientii de reflexie

$$\Gamma(\theta) = A \cdot (1 + e^{-2j\theta})^N \quad \Gamma(\theta) = \Gamma_0 + \Gamma_1 \cdot e^{-2j\theta} + \Gamma_2 \cdot e^{-4j\theta} + \dots + \Gamma_N \cdot e^{-2jN\theta}$$

$$\Gamma_n = A \cdot C_N^n$$

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

■ Proiectare

$$\Gamma_n = A \cdot C_N^n$$

$$\Gamma_n = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n} \cong \frac{1}{2} \ln \frac{Z_{n+1}}{Z_n} \qquad \ln x \cong 2 \cdot \frac{x-1}{x+1} \quad x \cong 1$$

$$\ln \frac{Z_{n+1}}{Z_n} \cong 2 \cdot \Gamma_n = 2 \cdot A \cdot C_N^n = 2 \cdot 2^{-N} \cdot \frac{Z_L - Z_0}{Z_L + Z_0} \cong 2^{-N} \cdot C_N^n \cdot \ln \frac{Z_L}{Z_0}$$

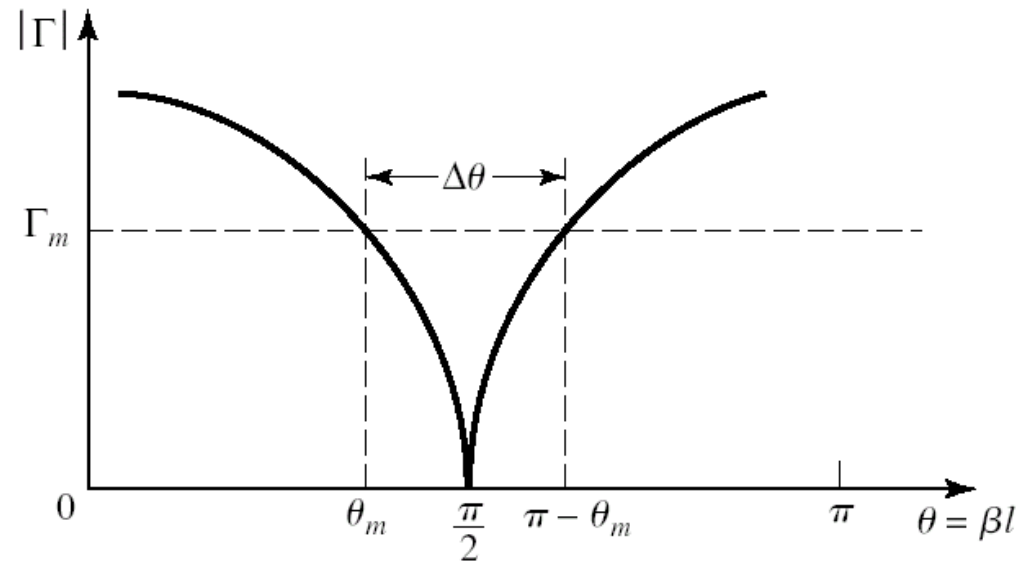
$$\ln Z_{n+1} \cong \ln Z_n + 2^{-N} \cdot C_N^n \cdot \ln \frac{Z_L}{Z_0}$$

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

- Banda, Γ_m maxim tolerat

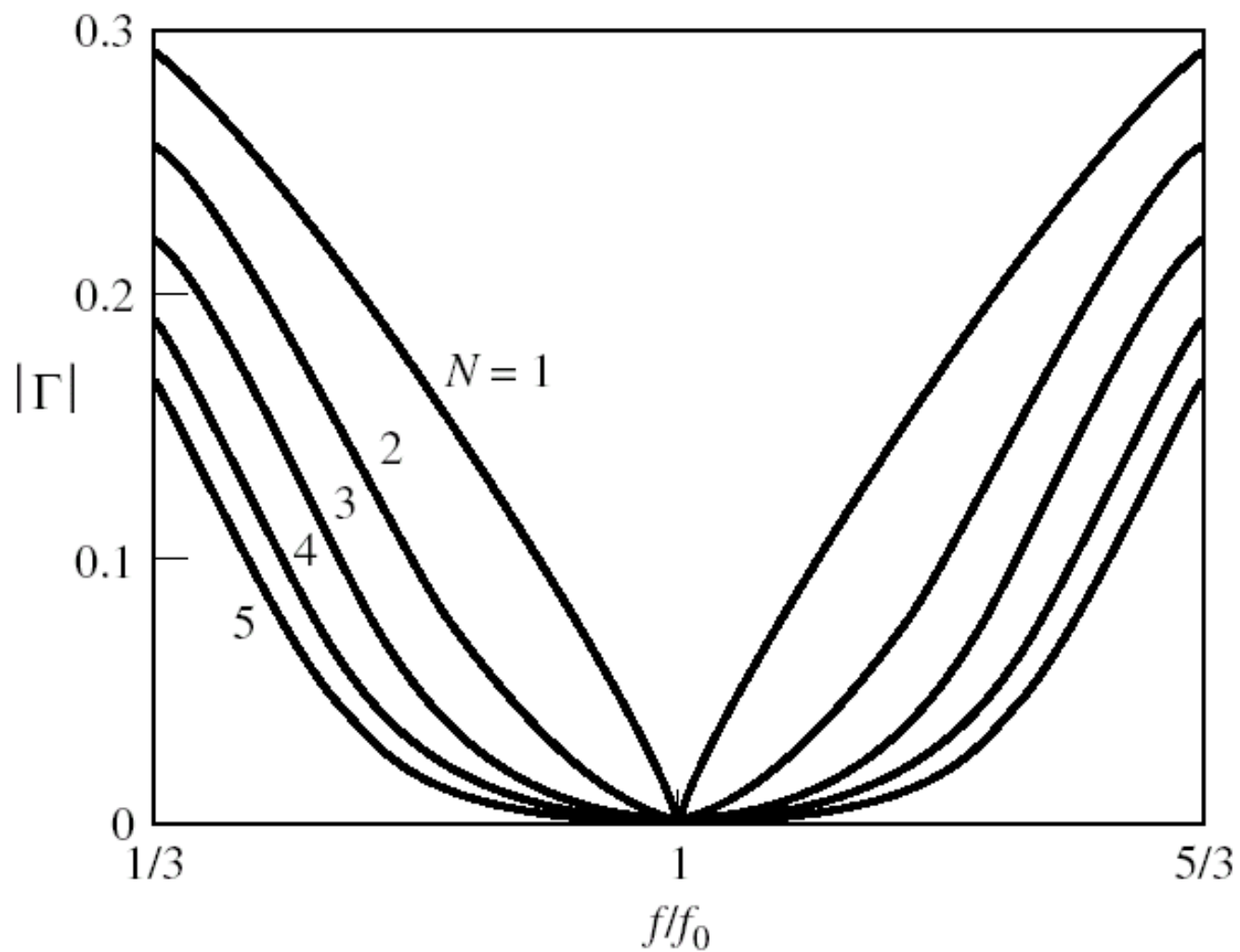
$$\Gamma_m = |\Gamma(\theta_m)| = 2^N \cdot |A| \cdot |\cos \theta_m|^N$$

$$\theta_m = \cos^{-1} \left[\frac{1}{2} \left(\frac{\Gamma_m}{|A|} \right)^{\frac{1}{N}} \right]$$



$$\frac{\Delta f}{f_0} = \frac{2(f_0 - f_m)}{f_0} = 2 - \frac{4\theta_m}{\pi} = 2 - \frac{4}{\pi} \cdot \cos^{-1} \left[\frac{1}{2} \left(\frac{\Gamma_m}{|A|} \right)^{\frac{1}{N}} \right]$$

Banda



Transformatoare cu mai multe sectiuni cu caracteristica binomiala rezultate exacte

Z_L/Z_0	$N = 2$		$N = 3$			$N = 4$			
	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.1067	1.3554	1.0520	1.2247	1.4259	1.0257	1.1351	1.3215	1.4624
2.0	1.1892	1.6818	1.0907	1.4142	1.8337	1.0444	1.2421	1.6102	1.9150
3.0	1.3161	2.2795	1.1479	1.7321	2.6135	1.0718	1.4105	2.1269	2.7990
4.0	1.4142	2.8285	1.1907	2.0000	3.3594	1.0919	1.5442	2.5903	3.6633
6.0	1.5651	3.8336	1.2544	2.4495	4.7832	1.1215	1.7553	3.4182	5.3500
8.0	1.6818	4.7568	1.3022	2.8284	6.1434	1.1436	1.9232	4.1597	6.9955
10.0	1.7783	5.6233	1.3409	3.1623	7.4577	1.1613	2.0651	4.8424	8.6110

Z_L/Z_0	$N = 5$					$N = 6$					
	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_5/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_5/Z_0	Z_6/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.0128	1.0790	1.2247	1.3902	1.4810	1.0064	1.0454	1.1496	1.3048	1.4349	1.4905
2.0	1.0220	1.1391	1.4142	1.7558	1.9569	1.0110	1.0790	1.2693	1.5757	1.8536	1.9782
3.0	1.0354	1.2300	1.7321	2.4390	2.8974	1.0176	1.1288	1.4599	2.0549	2.6577	2.9481
4.0	1.0452	1.2995	2.0000	3.0781	3.8270	1.0225	1.1661	1.6129	2.4800	3.4302	3.9120
6.0	1.0596	1.4055	2.4495	4.2689	5.6625	1.0296	1.2219	1.8573	3.2305	4.9104	5.8275
8.0	1.0703	1.4870	2.8284	5.3800	7.4745	1.0349	1.2640	2.0539	3.8950	6.3291	7.7302
10.0	1.0789	1.5541	3.1623	6.4346	9.2687	1.0392	1.2982	2.2215	4.5015	7.7030	9.6228

Exemplu

- Transformator de adaptare cu 3 sectiuni pentru a adapta o sarcina de 30Ω la o linie de 100Ω la frecventa $f_0=3\text{GHz}$, $\Gamma_m=0.1$
 - $N = 3$

$$Z_L = 30\Omega \quad Z_0 = 100\Omega$$

$$A = 2^{-N} \frac{Z_L - Z_0}{Z_L + Z_0} \approx \frac{1}{2^{N+1}} \ln \frac{Z_L}{Z_0} = -0.07525$$

$$C_3^0 = \frac{3!}{3! \cdot 0!} = 1 \quad C_3^1 = \frac{3!}{2! \cdot 1!} = 3 \quad C_3^2 = \frac{3!}{1! \cdot 2!} = 3$$

Exemplu

$$n = 0$$

$$\ln Z_1 = \ln Z_0 + 2^{-N} C_3^0 \ln \frac{Z_L}{Z_0} = \ln 100 + 2^{-3} \cdot 1 \cdot \ln \frac{30}{100} = 4.455$$

$$Z_1 = 86.03 \Omega$$

$$n = 1$$

$$\ln Z_2 = \ln Z_1 + 2^{-N} C_3^1 \ln \frac{Z_L}{Z_0} = \ln 86.03 + 2^{-3} \cdot 3 \cdot \ln \frac{30}{100} = 4.003$$

$$Z_2 = 54.77 \Omega$$

$$n = 2$$

$$\ln Z_3 = \ln Z_2 + 2^{-N} C_3^2 \ln \frac{Z_L}{Z_0} = \ln 54.77 + 2^{-3} \cdot 3 \cdot \ln \frac{30}{100} = 3.552$$

$$Z_3 = 34.87 \Omega$$

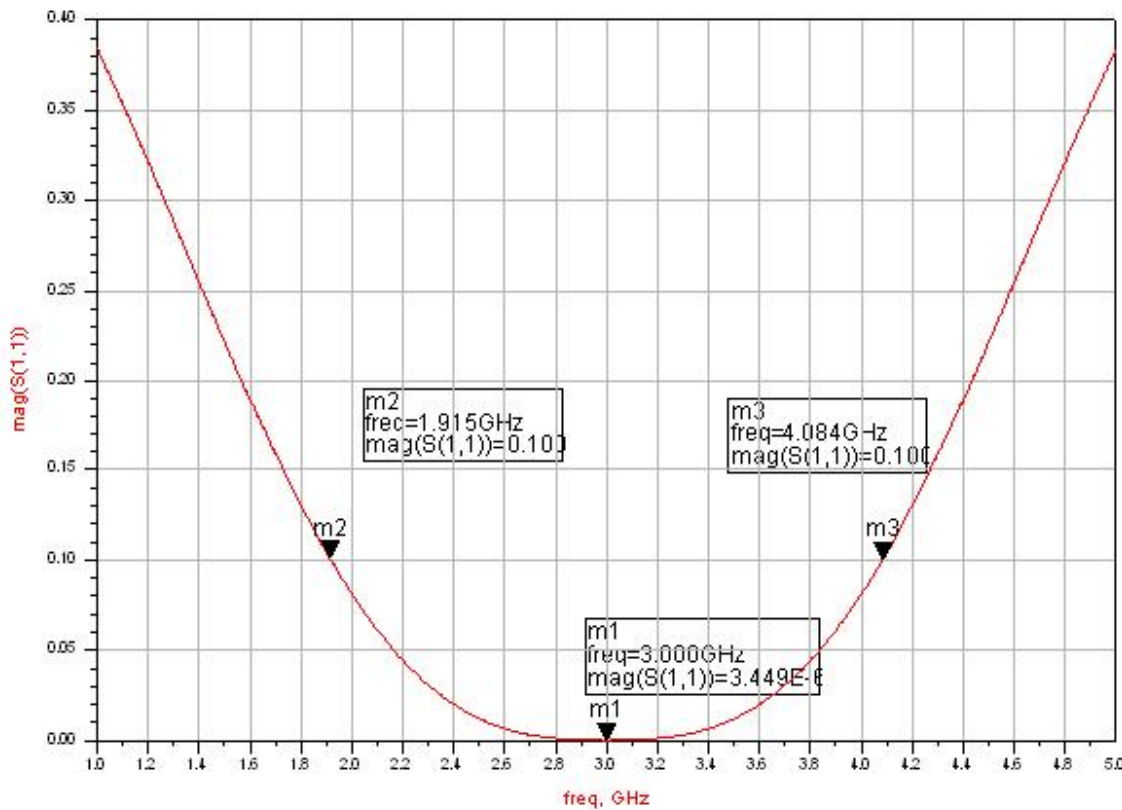
Exemplu

$$\frac{\Delta f}{f_0} = 2 - \frac{4}{\pi} \arccos \left[\frac{1}{2} \left(\frac{\Gamma_m}{|A|} \right)^{1/N} \right] = 2 - \frac{4}{\pi} \arccos \left[\frac{1}{2} \left(\frac{0.1}{0.07525} \right)^{1/3} \right] = 0.74$$

$$\Delta f = 2.22 \text{GHz}$$

Simulare

■ Similar Lab. 1



$$\Delta f = 2.169\text{GHz}$$

$$|\Gamma(3\text{GHz})| = 3.5 \cdot 10^{-6}$$

Transformatoare cu mai multe sectiuni de tip Cebîșev

- Raspunsul acestui transformator este de tip echiriplu in jurul frecventei de adaptare
- mareste banda in detrimentul riplului in banda de adaptare
- Se egaleaza functia $\Gamma(\theta)$ cu un polinom Cebîșev

Polinoame Cebîşev

$$T_1(x) = x$$

$$T_2(x) = 2x^2 - 1$$

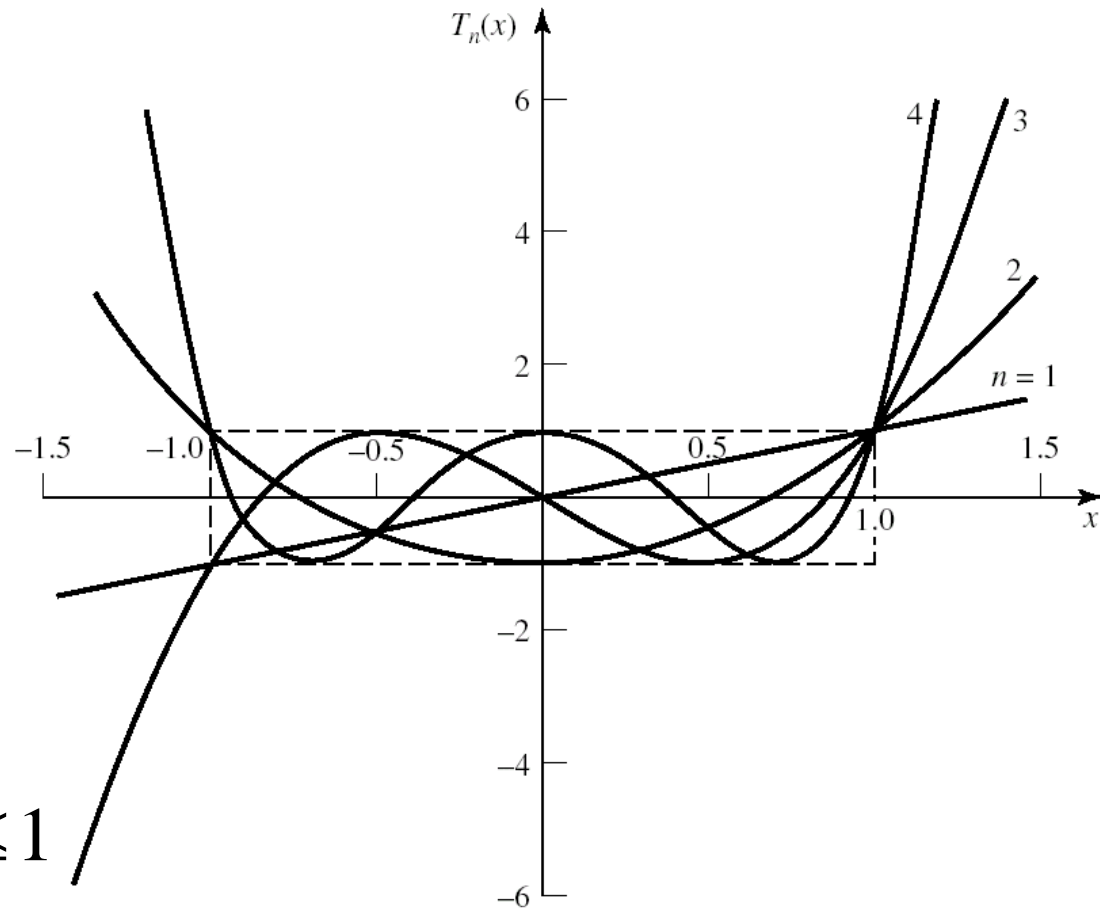
$$T_3(x) = 4x^3 - 3x$$

$$T_4(x) = 8x^4 - 8x^2 + 1$$

■ Echiriplu

$$-1 \leq x \leq 1 \Rightarrow |T_n(x)| \leq 1$$

$$T_n(x) = 2xT_{n-1}(x) - T_{n-2}(x)$$



Polinoame Cebîşev

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

$$e^{-2j\theta} \equiv x$$

$$f(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + \dots + a_N \cdot x^N$$

$$\Gamma(\theta) = 2e^{-jN\theta} \cdot [\Gamma_0 \cdot \cos N\theta + \Gamma_1 \cdot \cos(N-2)\theta + \dots + \Gamma_n \cdot \cos(N-2n)\theta + \dots]$$

ultimul termen:

$$\dots \frac{1}{2} \cdot \Gamma_{N/2} \quad n \text{ par}$$
$$\dots \Gamma_{(N-1)/2} \cdot \cos \theta \quad n \text{ impar}$$

$$x = \cos \theta \qquad T_n(\cos \theta) = \cos(n\theta)$$

$$T_n(x) = \cos(n \arccos(x)) \quad |x| < 1 \qquad T_n(x) = \cosh(n \cosh^{-1}(x)) \quad |x| > 1$$

Transformatoare cu mai multe sectiuni de tip Cebîșev

- Schimbare de variabila

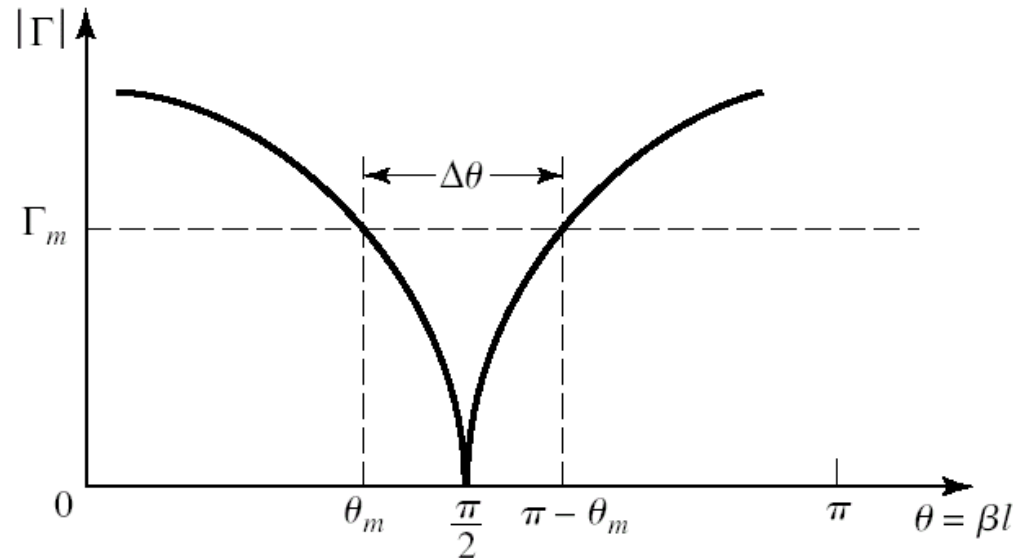
$$\theta = \theta_m \rightarrow x = 1$$

$$\theta = \pi - \theta_m \rightarrow x = -1$$

$$x \equiv \frac{\cos \theta}{\cos \theta_m}$$

$$\sec \theta = \frac{1}{\cos \theta}$$

$$x = \sec \theta_m \cos \theta$$



Transformatoare cu mai multe sectiuni de tip Cebîșev

$$T_1(\sec \theta_m \cos \theta) = \sec \theta_m \cos \theta$$

$$T_2(\sec \theta_m \cos \theta) = \sec^2 \theta_m (1 + \cos 2\theta) - 1$$

$$T_3(\sec \theta_m \cos \theta) = \sec^3 \theta_m (\cos 3\theta + 3 \cos \theta) - 3 \sec \theta_m \cos \theta$$

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

- Cautam coeficientii pentru a obtine un polinom Cebîșev

$$\Gamma(\theta) = 2e^{-jN\theta} \cdot [\Gamma_0 \cdot \cos N\theta + \Gamma_1 \cdot \cos(N-2)\theta + \dots \Gamma_n \cdot \cos(N-2n)\theta + \dots]$$

$$\Gamma(\theta) = A \cdot e^{-jN\theta} \cdot T_N(\sec \theta_m \cos \theta)$$

$$\begin{aligned} \text{ultimul termen:} \quad & \dots \frac{1}{2} \cdot \Gamma_{N/2} \quad n \text{ par} \\ & \dots \Gamma_{(N-1)/2} \cdot \cos \theta \quad n \text{ impar} \end{aligned}$$

Transformatoare cu mai multe sectiuni de tip Cebîșev

- $A, \theta \rightarrow 0$, liniile de lungime 0, dispar

$$\Gamma(0) = \frac{Z_L - Z_0}{Z_L + Z_0} = A \cdot T_N(\sec \theta_m) \quad A = \frac{Z_L - Z_0}{Z_L + Z_0} \cdot \frac{1}{T_N(\sec \theta_m)} \quad \Gamma_m = |A|$$

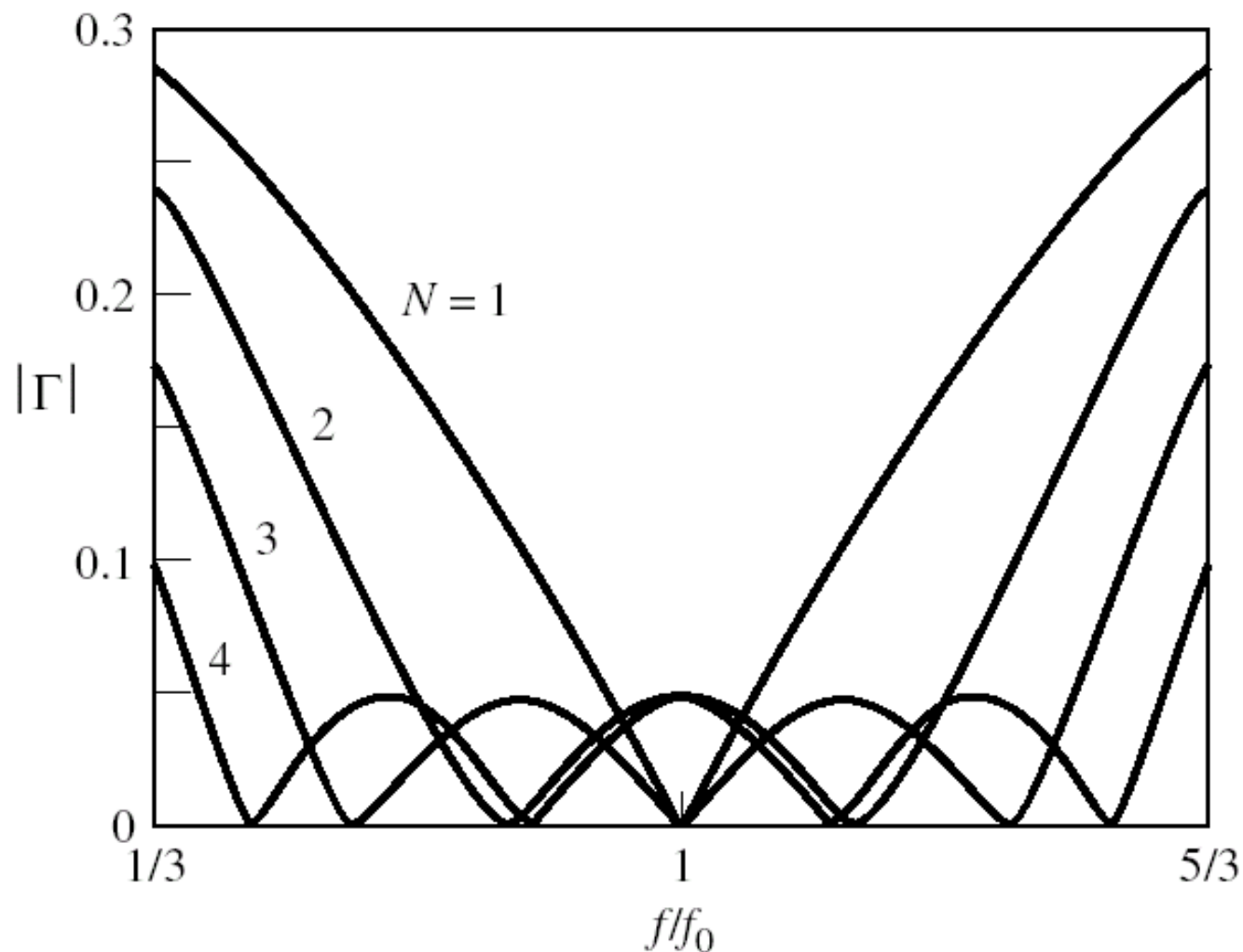
$$T_N(\sec \theta_m) = \frac{1}{\Gamma_m} \left| \frac{Z_L - Z_0}{Z_L + Z_0} \right| \cong \frac{1}{2\Gamma_m} \left| \ln \frac{Z_L}{Z_0} \right|$$

$$T_n(x) = \cosh(n \cosh^{-1}(x))$$

$$\sec \theta_m = \cosh \left[\frac{1}{N} \cosh^{-1} \left(\frac{1}{\Gamma_m} \left| \frac{Z_L - Z_0}{Z_L + Z_0} \right| \right) \right] \cong \cosh \left[\frac{1}{N} \cosh^{-1} \left(\left| \frac{\ln(Z_L/Z_0)}{2\Gamma_m} \right| \right) \right]$$

$$\frac{\Delta f}{f_0} = \frac{2(f_0 - f_m)}{f_0} = 2 - \frac{4\theta_m}{\pi}$$

Transformatoare cu mai multe sectiuni de tip Cebîșev



Transformatoare cu mai multe sectiuni de tip Cebîșev

Z_L/Z_0	$N = 2$				$N = 3$					
	$\Gamma_m = 0.05$		$\Gamma_m = 0.20$		$\Gamma_m = 0.05$			$\Gamma_m = 0.20$		
	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.1347	1.3219	1.2247	1.2247	1.1029	1.2247	1.3601	1.2247	1.2247	1.2247
2.0	1.2193	1.6402	1.3161	1.5197	1.1475	1.4142	1.7429	1.2855	1.4142	1.5558
3.0	1.3494	2.2232	1.4565	2.0598	1.2171	1.7321	2.4649	1.3743	1.7321	2.1829
4.0	1.4500	2.7585	1.5651	2.5558	1.2662	2.0000	3.1591	1.4333	2.0000	2.7908
6.0	1.6047	3.7389	1.7321	3.4641	1.3383	2.4495	4.4833	1.5193	2.4495	3.9492
8.0	1.7244	4.6393	1.8612	4.2983	1.3944	2.8284	5.7372	1.5766	2.8284	5.0742
10.0	1.8233	5.4845	1.9680	5.0813	1.4385	3.1623	6.9517	1.6415	3.1623	6.0920

$N = 4$

Z_L/Z_0	$\Gamma_m = 0.05$				$\Gamma_m = 0.20$			
	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0
1.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1.5	1.0892	1.1742	1.2775	1.3772	1.2247	1.2247	1.2247	1.2247
2.0	1.1201	1.2979	1.5409	1.7855	1.2727	1.3634	1.4669	1.5715
3.0	1.1586	1.4876	2.0167	2.5893	1.4879	1.5819	1.8965	2.0163
4.0	1.1906	1.6414	2.4369	3.3597	1.3692	1.7490	2.2870	2.9214
6.0	1.2290	1.8773	3.1961	4.8820	1.4415	2.0231	2.9657	4.1623
8.0	1.2583	2.0657	3.8728	6.3578	1.4914	2.2428	3.5670	5.3641
10.0	1.2832	2.2268	4.4907	7.7930	1.5163	2.4210	4.1305	6.5950

Exemplu

- Transformator de adaptare cu 3 sectiuni pentru a adapta o sarcina de 30Ω la o linie de 100Ω la frecventa $f_0=3\text{GHz}$, $\Gamma_m=0.1$

- $N = 3 \quad Z_L = 30\Omega \quad Z_0 = 100\Omega$

$$\Gamma(\theta) = 2e^{-j3\theta} [\Gamma_0 \cos 3\theta + \Gamma_1 \cos \theta] = Ae^{-j3\theta} T_3(\sec \theta_m \cos \theta)$$

$$|A| = \Gamma_m = 0.1 \quad A = \frac{Z_L - Z_0}{Z_L + Z_0} \cdot \frac{1}{T_N(\sec \theta_m)} \quad Z_L < Z_0 \rightarrow A < 0 \quad A = -0.1$$

$$\sec \theta_m = \cosh \left[\frac{1}{N} \cdot \cosh^{-1} \left(\left| \frac{\ln Z_L / Z_0}{2\Gamma_m} \right| \right) \right] = \cosh \left[\frac{1}{3} \cdot \cosh^{-1} \left(\left| \frac{\ln(30/100)}{2 \cdot 0.1} \right| \right) \right] = 1.362$$

$$\theta_m = \arccos \left(\frac{1}{\sec \theta_m} \right) = 0.746 \text{ rad} = 42.76^\circ$$

Exemplu

$$2[\Gamma_0 \cos 3\theta + \Gamma_1 \cos \theta] = A \sec^3 \theta_m (\cos 3\theta + 3 \cos \theta) - 3A \sec \theta_m \cos \theta$$

$$\cos 3\theta \quad 2\Gamma_0 = A \sec^3 \theta_m \quad \Gamma_0 = -0.1263$$

$$\cos \theta \quad 2\Gamma_1 = 3A(\sec^3 \theta_m - \sec \theta_m) \quad \Gamma_1 = -0.1747$$

$$\text{simetrie:} \quad \Gamma_3 = \Gamma_0; \quad \Gamma_2 = \Gamma_1$$

Exemplu

$$n = 0$$

$$\ln Z_1 = \ln Z_0 + 2 \cdot \Gamma_0 = \ln 100 - 2 \cdot 0.1263 = 4.353 \quad \Gamma_0 = -0.1263$$

$$Z_1 = 77.68\Omega \quad \Gamma_1 = -0.1747$$

$$n = 1$$

$$\ln Z_2 = \ln Z_1 + 2 \cdot \Gamma_1 = \ln 77.68 - 2 \cdot 0.1747 = 4.003$$

$$Z_2 = 54.77\Omega$$

$$n = 2$$

$$\ln Z_3 = \ln Z_2 + 2 \cdot \Gamma_2 = \ln 54.77 - 2 \cdot 0.1747 = 3.654$$

$$Z_3 = 38.62\Omega$$

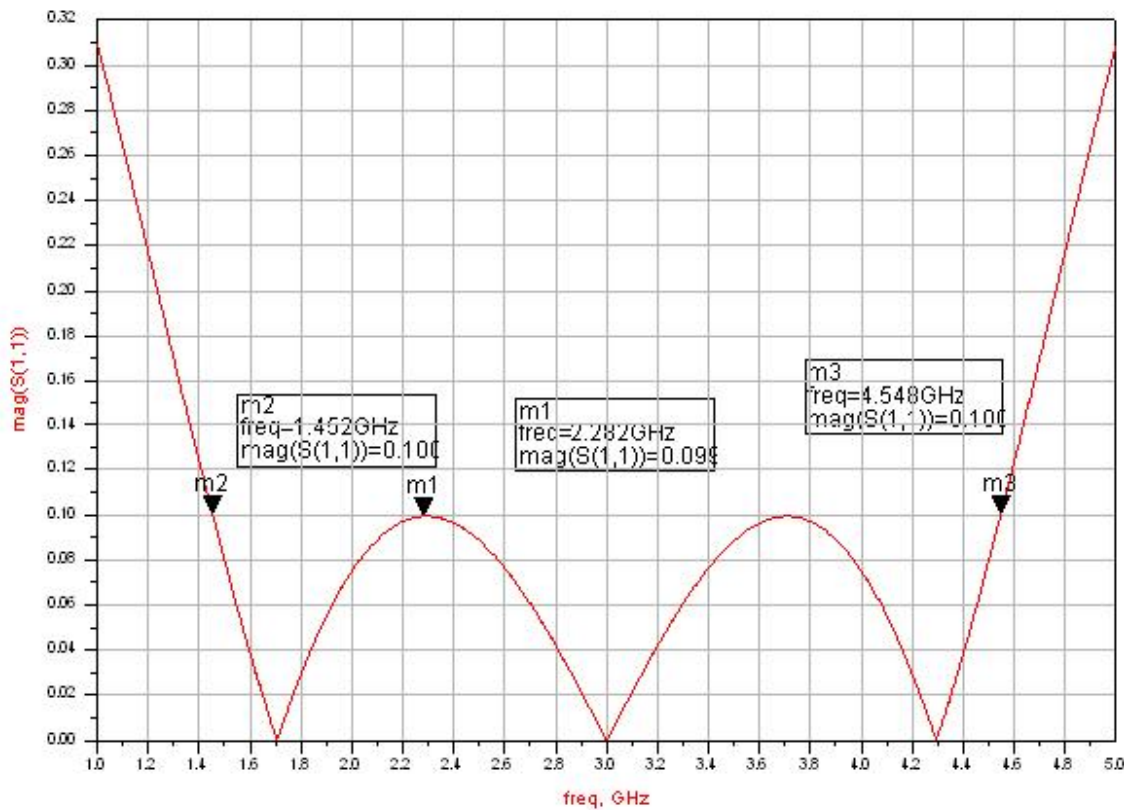
Exemplu

$$\frac{\Delta f}{f_0} = \frac{2(f_0 - f_m)}{f_0} = 2 - \frac{4\theta_m}{\pi} = 2 - \frac{4 \cdot 42.76^\circ}{180^\circ} = 1.045$$

$$\Delta f = 3.15 \text{GHz}$$

Simulare

■ Similar Lab. 1



$$\Delta f = 3.096 \text{ GHz}$$

$$|\Gamma(3 \text{ GHz})| = 4.17 \cdot 10^{-5}$$

$$|\Gamma(2.282 \text{ GHz})| = 0.09925$$

Contact

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