

Dispozitive si Circuite de Microunde pentru Radiocomunicatii

Curs 3

DCMR

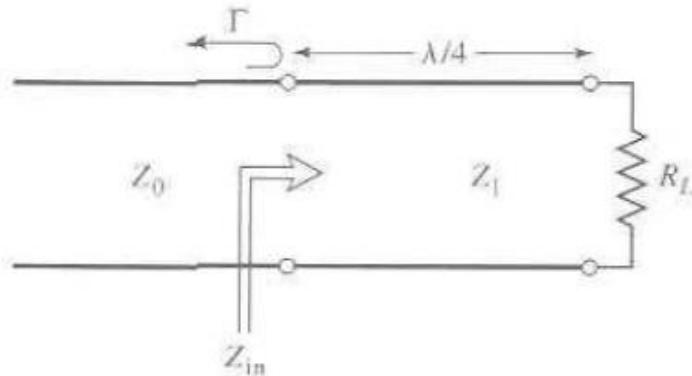
- ▶ Activitatea la laborator:
 - Ponderea: 15%
- ▶ Lucrări de specialitate (miniproiect):
 - Ponderea: 15%
- ▶ Evaluarea finală:
 - Ponderea în nota finală: 70%
 - Proba(ele): 5 probleme
 - condițiile de lucru (scris, 2 ore, orice material bibliografic autorizat)

Adaptarea de impedanță

Capitolul 1

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

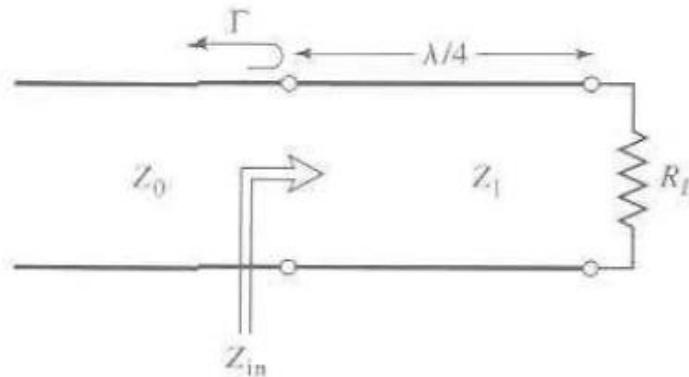


$$Z_{in} = Z_1 \frac{1 + \Gamma e^{-2j\beta l}}{1 - \Gamma e^{-2j\beta l}}$$

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

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

Transformatorul in sfert de lungime de unda



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

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

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

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

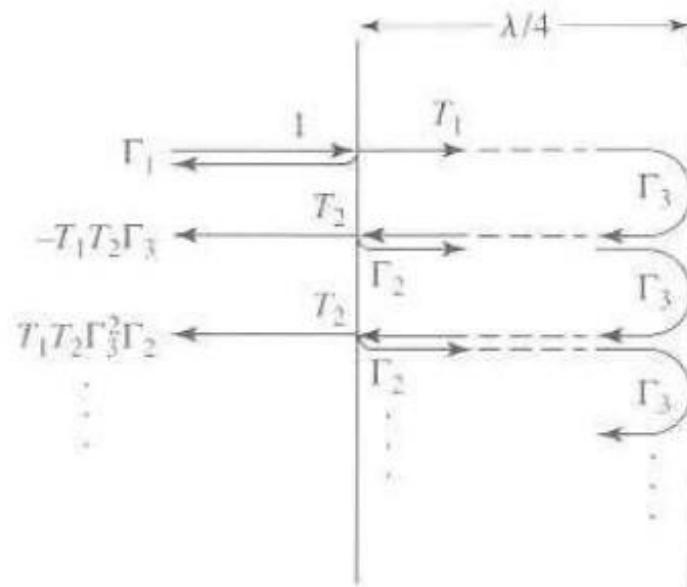
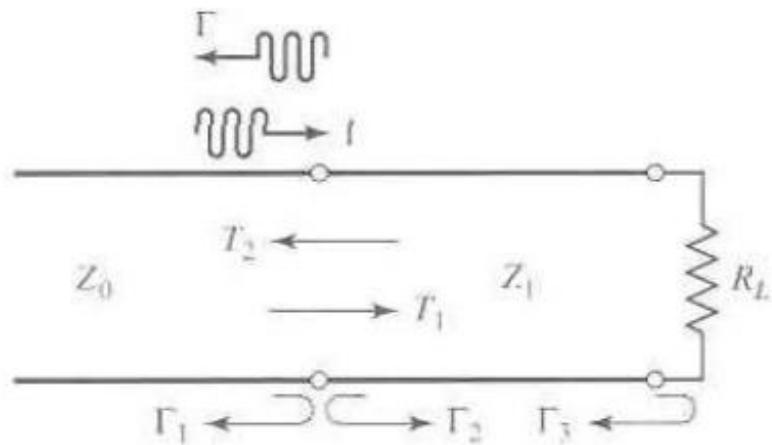
- ▶ Pe fider (Z_0) avem doar unda progresiva
- ▶ Pe linia in sfert de lungime de unda (Z_1) avem unda stationara

Transformatorul în sfert de lungime de undă

► Punct de vedere fizic

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

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



Caracteristica de frecventa

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

not
 $t = \tan(\beta l)$

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

$$Z_L = R_L(\text{real})$$
$$Z_1 = \sqrt{Z_0 R_L}$$

$$|\Gamma| = \frac{|Z_L - Z_0|}{[(Z_L + Z_0)^2 + 4t^2 Z_0 Z_L]^{1/2}}$$

$$= \frac{1}{\{(Z_L + Z_0/Z_L - Z_0)^2 + [4t^2 Z_0 Z_L/(Z_L - Z_0)^2]\}^{1/2}}$$
$$= \frac{1}{\{1 + [4Z_0 Z_L/(Z_L - Z_0)^2] + [4Z_0 Z_L t^2/(Z_L - Z_0)^2]\}^{1/2}}$$
$$= \frac{1}{\{1 + [4Z_0 Z_L/(Z_L - Z_0)^2] \sec^2 \theta\}^{1/2}},$$

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

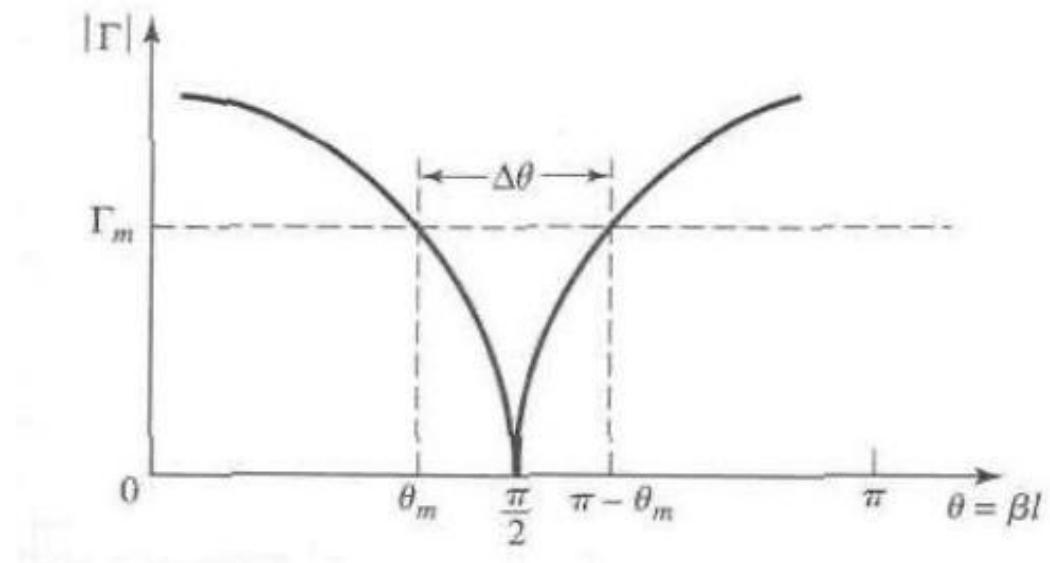
$$\sec^2 \theta = 1 + \tan^2 \theta = 1 + t^2$$

Caracteristica de frecventa

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

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

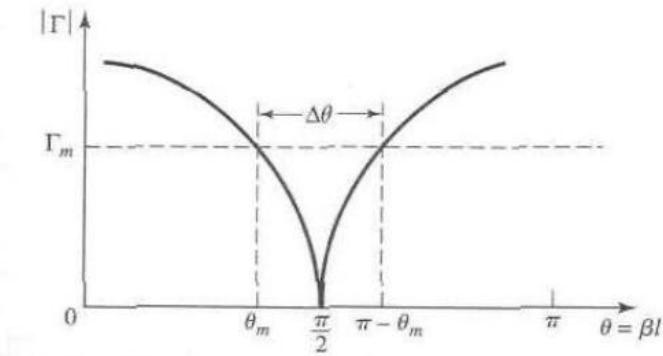
$$|\Gamma| \simeq \frac{|Z_L - Z_0|}{2\sqrt{Z_0 Z_L}} |\cos \theta|,$$



Caracteristica de frecventa

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

$$\frac{1}{\Gamma_m^2} = 1 + \left(\frac{2\sqrt{Z_0 Z_L}}{Z_L - Z_0} \sec \theta_m \right)^2,$$
$$\cos \theta_m = \frac{\Gamma_m}{\sqrt{1 - \Gamma_m^2}} \frac{2\sqrt{Z_0 Z_L}}{|Z_L - Z_0|}.$$
$$\Delta\theta = 2 \left(\frac{\pi}{2} - \theta_m \right),$$



- ▶ linii TEM

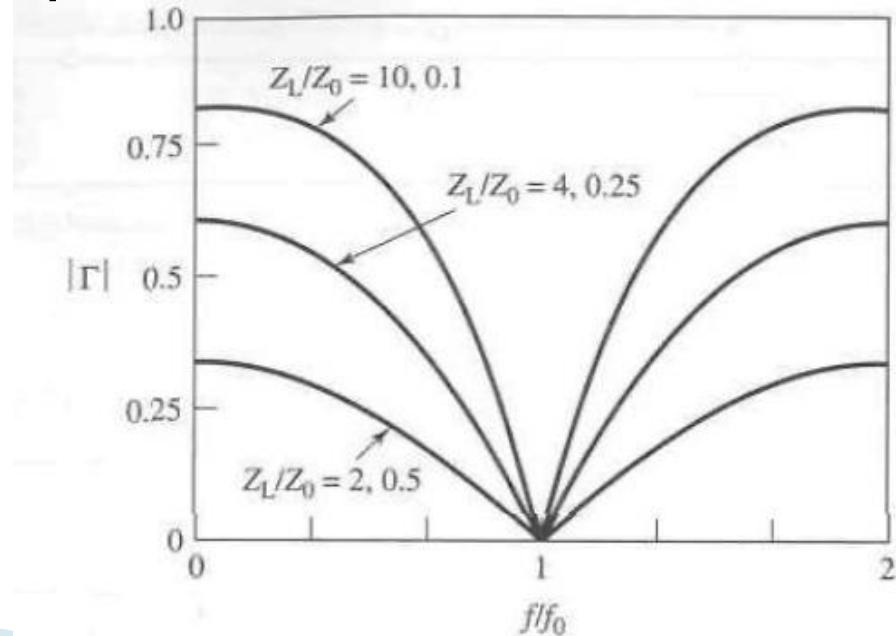
$$\theta = \beta \ell = \frac{2\pi f}{v_p} \frac{v_p}{4f_0} = \frac{\pi f}{2f_0}, \quad f_m = \frac{2\theta_m f_0}{\pi},$$

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

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 $\text{SWR} < 1.5$

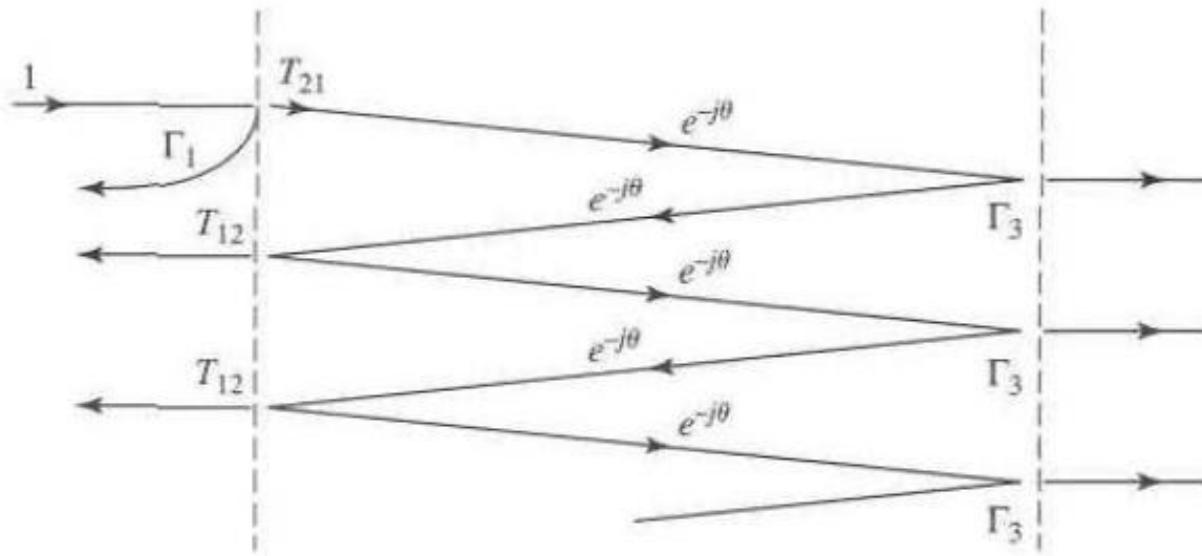
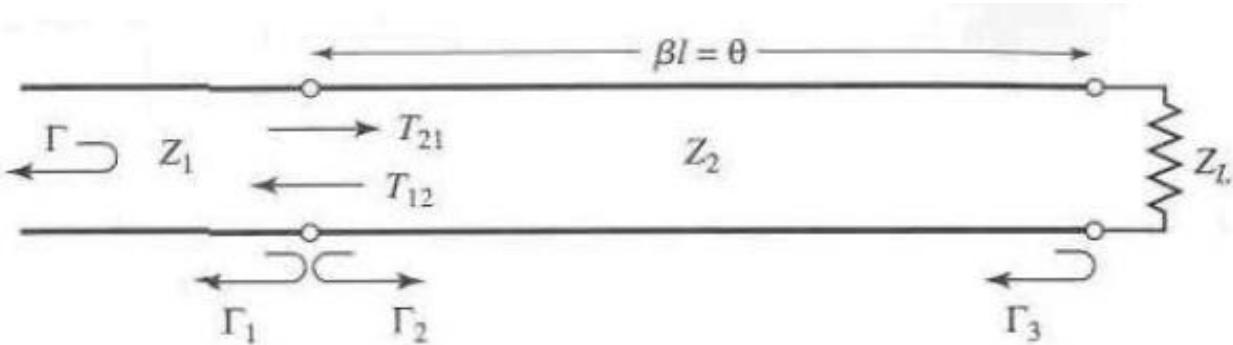
$$Z_1 = \sqrt{Z_0 Z_L} = \sqrt{(50)(10)} = 22.36\ \Omega, \quad \Gamma_m = \frac{\text{SWR} - 1}{\text{SWR} + 1} = \frac{1.5 - 1}{1.5 + 1} = 0.2.$$

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

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

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

$$\Gamma_2 = -\Gamma_1,$$

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

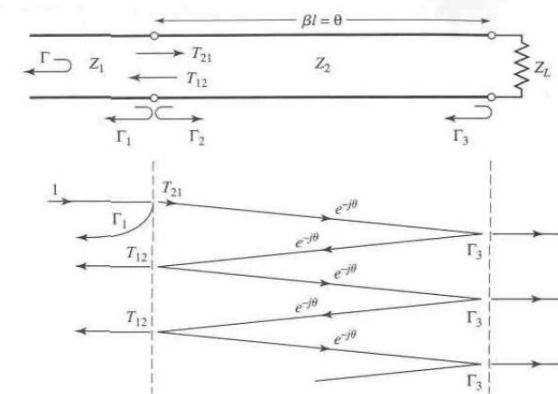
$$T_{21} = 1 + \Gamma_1 = \frac{2Z_2}{Z_1 + Z_2},$$

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

$$\Gamma = \Gamma_1 + \frac{T_{12}T_{21}\Gamma_3 e^{-2j\theta}}{1 - \Gamma_2\Gamma_3 e^{-2j\theta}}.$$

Discontinuitati mici
intre impedante

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



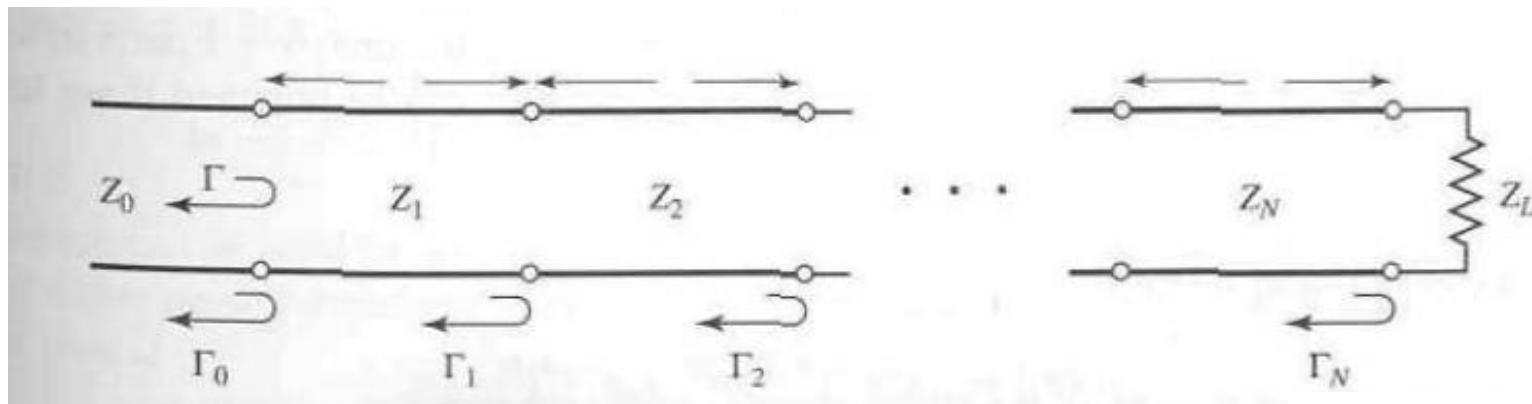
$$\begin{aligned} \Gamma &= \Gamma_1 + T_{12}T_{21}\Gamma_3 e^{-2j\theta} + T_{12}T_{21}\Gamma_3^2\Gamma_2 e^{-4j\theta} + \dots \\ &= \Gamma_1 + T_{12}T_{21}\Gamma_3 e^{-2j\theta} \sum_{n=0}^{\infty} \Gamma_2^n \Gamma_3^n e^{-2jn\theta}. \end{aligned}$$

$$|\Gamma_2| < 1, |\Gamma_3| < 1$$

$$\sum_{n=0}^{\infty} x^n = \frac{1}{1-x},$$

$$\Gamma \simeq \Gamma_1 + \Gamma_3 e^{-2j\theta}.$$

Transformatoare cu mai multe sectiuni



- ▶ Presupunem ca toate impedantele cresc sau descrez uniform
- ▶ Toti coeficientii de reflexie vor fi reali si de acelasi semn

$$\Gamma_0 = \frac{Z_1 - Z_0}{Z_1 + Z_0},$$

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

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

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

Transformatoare cu mai multe sectiuni

- ▶ Transformatorul este simetric

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

- ▶ Aceasta **nu** implica faptul ca impedantele sunt egale

$$\Gamma(\theta) = e^{-jN\theta} \{ \Gamma_0 [e^{jN\theta} + e^{-jN\theta}] + \Gamma_1 [e^{j(N-2)\theta} + e^{-j(N-2)\theta}] + \dots \}.$$

$$\begin{aligned}\Gamma(\theta) &= 2e^{-jN\theta} \left[\Gamma_0 \cos N\theta + \Gamma_1 \cos(N-2)\theta + \dots + \Gamma_n \cos(N-2n)\theta \right. \\ &\quad \left. + \dots + \frac{1}{2} \Gamma_{N/2} \right], \quad \text{for } N \text{ even,}\end{aligned}$$

$$\begin{aligned}\Gamma(\theta) &= 2e^{-jN\theta} [\Gamma_0 \cos N\theta + \Gamma_1 \cos(N-2)\theta + \dots + \Gamma_n \cos(N-2n)\theta \\ &\quad + \dots + \Gamma_{(N-1)/2} \cos \theta], \quad \text{for } N \text{ odd.}\end{aligned}$$

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 $|\Gamma(\theta)|$

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

$$\begin{aligned} |\Gamma(\theta)| &= |A| |e^{-j\theta}|^N |e^{j\theta} + e^{-j\theta}|^N \\ &= 2^N |A| |\cos \theta|^N \end{aligned}$$

$$\left| \Gamma\left(\frac{\pi}{2}\right) \right| = 0; \quad \frac{d^n}{d\theta^n} |\Gamma(\theta)| \Big|_{\theta=\frac{\pi}{2}} = 0$$

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

$$\Gamma(\theta) = A(1 + e^{-2j\theta})^N = A \sum_{n=0}^N C_n^N e^{-2jn\theta},$$

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

$$\Gamma(\theta) = A \sum_{n=0}^N C_n^N e^{-2jn\theta} = \Gamma_0 + \Gamma_1 e^{-2j\theta} + \Gamma_2 e^{-4j\theta} + \dots + \Gamma_N e^{-2jN\theta}.$$

Transformatoare cu mai multe sectiuni cu caracteristica binomiala

$$\Gamma(\theta) = A \sum_{n=0}^N C_n^N e^{-2jn\theta} = \Gamma_0 + \Gamma_1 e^{-2j\theta} + \Gamma_2 e^{-4j\theta} + \dots + \Gamma_N e^{-2jN\theta}.$$

$$\Gamma_n = AC_n^N. \quad \Gamma_n = \frac{Z_{n+1} - Z_n}{Z_{n+1} + Z_n} \simeq \frac{1}{2} \ln \frac{Z_{n+1}}{Z_n}, \quad \ln x \simeq 2(x-1)/(x+1).$$

$$\ln \frac{Z_{n+1}}{Z_n} \simeq 2\Gamma_n = 2AC_n^N = 2(2^{-N}) \frac{Z_L - Z_0}{Z_L + Z_0} C_n^N \simeq 2^{-N} C_n^N \ln \frac{Z_L}{Z_0},$$

$$\Gamma_m = 2^N |A| \cos^N \theta_m,$$

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

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

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 o N sectiuni pentru a adapta o sarcina de 50Ω la o linie de 100Ω la frecventa $f_0=3\text{GHz}$

$$N = 3, Z_L = 50 \Omega, Z_0 = 100 \Omega$$

$$A = 2^{-N} \frac{Z_L - Z_0}{Z_L + Z_0} \simeq \frac{1}{2^{N+1}} \ln \frac{Z_L}{Z_0} = -0.0433.$$

$$\begin{aligned}\frac{\Delta f}{f_0} &= 2 - \frac{4}{\pi} \cos^{-1} \left[\frac{1}{2} \left(\frac{\Gamma_m}{|A|} \right)^{1/N} \right] \\ &= 2 - \frac{4}{\pi} \cos^{-1} \left[\frac{1}{2} \left(\frac{0.05}{0.0433} \right)^{1/3} \right] = 0.70, \text{ or } 70\%.\end{aligned}$$

Exemplu

$$C_0^3 = \frac{3!}{3!0!} = 1,$$

$$C_1^3 = \frac{3!}{2!1!} = 3,$$

$$C_2^3 = \frac{3!}{1!2!} = 3.$$

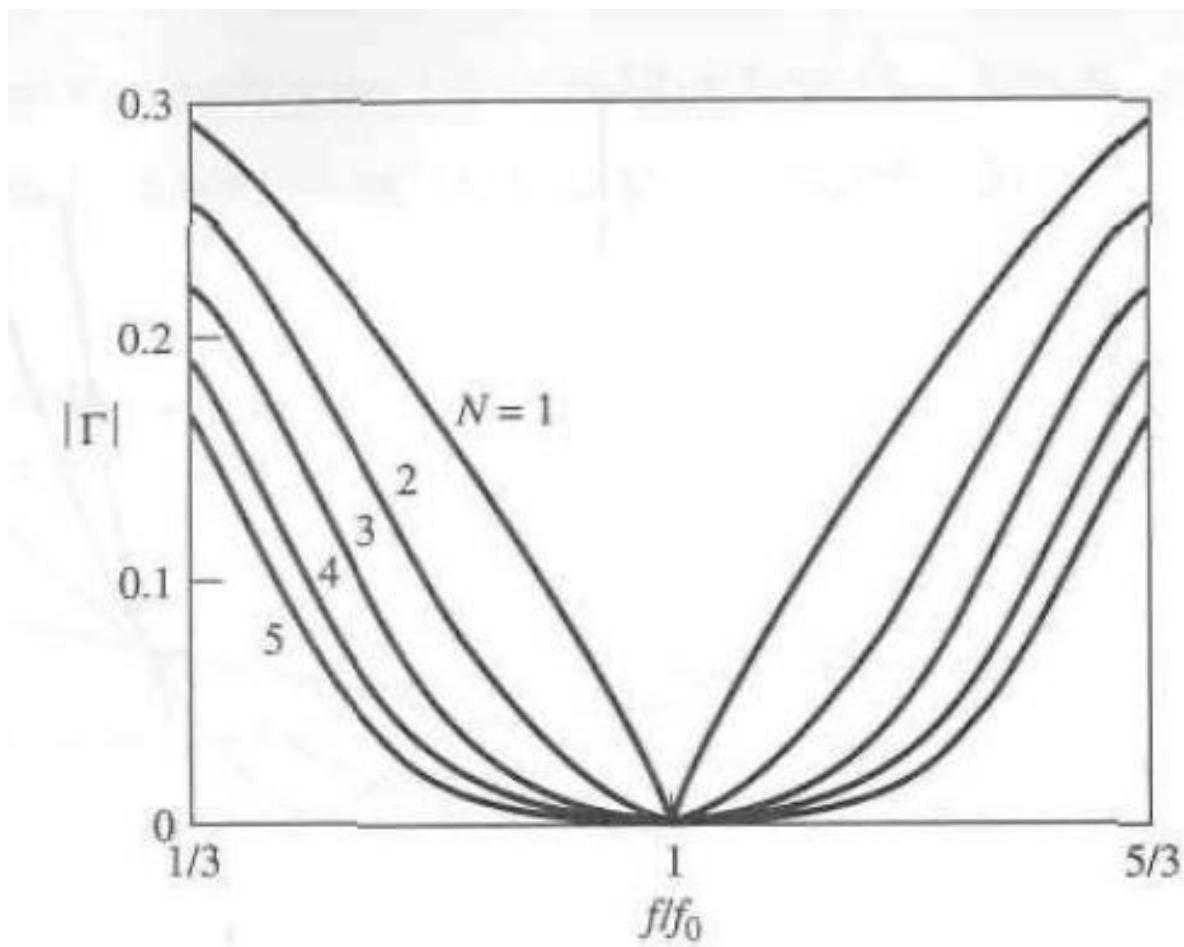
$$\begin{aligned} n = 0: \quad & \ln Z_1 = \ln Z_0 + 2^{-N} C_0^3 \ln \frac{Z_L}{Z_0} \\ & = \ln 100 + 2^{-3}(1) \ln \frac{50}{100} = 4.518, \\ & Z_1 = 91.7 \text{ } \Omega; \end{aligned}$$

$$\begin{aligned} n = 1: \quad & \ln Z_2 = \ln Z_1 + 2^{-N} C_1^3 \ln \frac{Z_L}{Z_0} \\ & = \ln 91.7 + 2^{-3}(3) \ln \frac{50}{100} = 4.26, \end{aligned}$$

$$Z_2 = 70.7 \text{ } \Omega;$$

$$\begin{aligned} n = 2: \quad & \ln Z_3 = \ln Z_2 + 2^{-N} C_2^3 \ln \frac{Z_L}{Z_0} \\ & = \ln 70.7 + 2^{-3}(3) \ln \frac{50}{100} = 4.00, \\ & Z_3 = 54.5 \text{ } \Omega. \end{aligned}$$

Exemplu



Transformatoare cu mai multe sectiuni de tip Cebîșev

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