Microwave Engineering Filter Design by Insertion Loss Method

Tamer Abuelfadl

Electronics and Electrical Communications Department Faculty of Engineering Cairo University

ECE305B

1 / 13

- Characterization by power loss ration P_{LR} .
- Maximally flat Low-Pass Filter Prototype.
- Equal-Ripple Low-pass
- Filter Implementation.



Power Loss Ratio P_{LR}

$$P_{LR} = rac{ ext{Power availabe from source}}{ ext{Power delivered to load}} = rac{ ext{P_{inc}}}{ ext{P_{load}}} = rac{1}{1 - |\Gamma_{in}(\omega)|^2}$$

The network is assumed lossless

Insertion Loss (IL) in dB

$$IL = 10 \log P_{LR}$$

It can be shown that

$$P_{LR} = 1/|S_{21}|^2$$
, $IL = -20\log|S_{21}|$

• Maximally flat (Binomial or Butterworth) Low Pass Filter

$$P_{LR} = 1 + k^2 \left(\frac{\omega}{\omega_c}\right)^{2\Lambda}$$

- N is the filter order.
- ω_c is the pass band edge (cut-off frequency), passband extends from $\omega = 0$ to $\omega = \omega_c$. At the band edge, the power loss ratio $P_{LR} = 1 + k^2$. It is common to choose this as the -3 dB point, so have k = 1.
- Equal ripple (Chebyshev) Low pass Filter

$$P_{LR} = 1 + k^2 T_N^2 \left(\frac{\omega}{\omega_c}\right)$$

 $T_N(x)$ is the chebyshev polynomial, it oscillates between ± 1 for |x| < 1 and its magnitude exceeds 1 for |x| > 1.

• Other types of Low pass filters include: Elliptic filter and Linear phase filters. These types are not covered in this course.



The process of filter design by the insertion loss method



- Low pass prototype: It has cut-off $\omega_c = 1$ Hz, and source impedance $Z_o = 1 \Omega$.
- Scaling and conversion
 - Impedance scaling to scale to source with impedance R_0 .
 - Frequency scaling:
 - LPF is scaled to ω_c , $\omega \leftarrow \omega/\omega_c$.
 - HPF is scaled to $\omega_c, \qquad \omega \leftarrow -\omega_c/\omega.$

BPF is characterized with center frequency ω₀ and fractional bandwidth Δ = (ω₂ - ω₁)/ω₀, where ω₁ and ω₂ is the passband limits and ω₀ = √ω₁ω₂. the scaling is ω ← 1/Δ (ω/ω₀ - ω/ω)
BSF is scaled by ω ← Δ (ω/ω₀ - ω/ω)⁻¹

 Implementation: the filter can be realized either as lumped elements or as distributed elements (i.e stubs, coupled lines).

Low Pass Filter Prototype



Ladder circuits for low-pass filter prototypes and their element definitions. (a) Prototype beginning with a shunt element. (b) Prototype beginning with a series element.

Low Pass Filter Prototype



Tamer Abuelfadl (EEC, Cairo University)

Maximally Flat (Butterworth) Low Pass Filter Prototype

394 Chapter 8: Microwave Filters

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

N	81	g 2	83	84	85	86	87	8 8	g 9	810	1200
1	2.0000	1.0000						a na			
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	
0	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1 000
		Source: Re Networks, d	printed from	m G. L. Ma Ig Structure	tthaei, L. Y. s (Dedham,	oung, and E Mass.: Art	. M. T. Jon ech House,	es, Microwa 1980) with	we Filters, permission	Impedance-	Mancinen

Attenuation versus normalized frequency for maximally flat filter prototypes



Tamer Abuelfadl (EEC, Cairo University)

ECE305B 10 / 13

Equal Ripples (Chebyshev) Low Pass Filter Prototype

396 Chapter 8: Microwave Filters

TABLE 8.4 Element Values for Equal-Ripple Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, N = 0.5 dB and 3.0 dB ripple)

				0.5 di	3 Ripple					
81	82	83	g 4	85	86	g 7	g 8	89	810	21
0.6986	1.0000	a - 17 - 18	5							
1,4029	0.7071	1.9841								
1.5963	1.0967	1.5963	1.0000							
1.6703	1.1926	2.3661	0.8419	1.9841						
1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
1 7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
1 7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000	1 00 4 1		
1 7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841	1 0000	
1 7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	0.9942	1 000
1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.0042	1.500
				3.0 d	B Ripple					
81	82	83	84	85	86	87	88	89	g 10	ĝ1
1 9953	1.0000									
3 1013	0.5339	5.8095								
3 3487	0.7117	3.3487	1.0000							
3 4389	0.7483	4.3471	0.5920	5.8095						
3 4817	0.7618	4.5381	0.7618	3.4817	1.0000	κ				
3 5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095				
3 5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1.0000	7 000F		
3.5777	0.7745	4.6575	0.8089	4.6990	0.8018	4.4990	0.6073	5.8095	1 0000	
3.5210	0 7760	4.6692	0.8118	4.7272	0.8118	4.6692	0.7760	3.5340	1.0000	£ 00
	81 0.6986 1.4029 1.5963 1.7054 1.7254 1.7372 1.7451 1.7504 1.7543 81 1.9953 3.1013 3.3487 3.4887 3.4389 3.4817 3.5045 3.5182 3.5277 3.5340	g1 g2 0.6986 1.0000 1.4029 0.7071 1.5963 1.0967 1.6703 1.1926 1.7058 1.2296 1.7254 1.2479 1.7372 1.2583 1.7451 1.2647 1.7504 1.2690 1.7543 1.2721 g1 g2 1.9953 1.0000 3.1013 0.5339 3.4817 0.7143 3.4817 0.7618 3.52045 0.7685 3.5340 0.7745 3.5277 0.7745	g1 g2 g3 0.6986 1.000 1.4029 0.7071 1.9841 1.5963 1.0967 1.5963 1.5073 1.1926 2.3661 1.7058 1.2296 2.5408 2.3479 2.6664 1.7372 1.2583 2.6381 1.7372 2.6564 1.7372 1.2647 2.6564 2.6678 1.7543 1.2721 2.6754 1.7543 1.2721 2.6754 81 82 §3 1.9953 1.0000 3.1013 0.5339 5.8095 3.487 0.7117 3.3487 0.7618 4.5381 3.4817 0.7618 4.5381 3.5045 0.7685 4.6061 3.5122 0.7723 4.6385 3.5277 0.7745 4.6575 3.5340 0.7764 4.6597 3.5340 0.7764 4.6597	g_1 g_2 g_3 g_4 0.6986 1.0000 1.4029 0.7071 1.9841 1.5963 1.0967 1.5963 1.0000 1.6703 1.1926 2.3661 0.8419 1.7058 1.2296 2.5408 1.2326 1.7254 1.2479 2.6064 1.3137 1.7372 1.2583 2.6381 1.3444 1.7451 1.2647 2.6564 1.3590 1.7543 1.2721 2.6574 1.3673 1.7543 1.2721 2.6574 1.3673 1.7543 1.2721 2.6574 1.3673 1.7543 1.2721 2.6754 1.3673 1.7543 1.2721 2.6754 1.3673 3.1013 0.5339 5.8095 3.3487 1.0000 3.4817 0.7618 4.3581 0.7618 3.4817 0.7618 4.3581 0.7618 3.5425 0.7685 4.6661 0.7929 3.5182 <td< td=""><td>81 82 83 84 85 0.6986 1.0000 1.4029 0.7071 1.9841 1.5963 1.0967 1.5963 1.0000 1.6703 1.1926 2.3661 0.8419 1.9841 1.7058 1.2296 2.5408 1.2296 1.7058 1.7372 1.2583 2.6381 1.3137 2.4758 1.7372 1.2583 2.6381 1.3444 2.6381 1.7372 1.2583 2.6381 1.3590 2.6964 1.7541 1.2647 2.6564 1.3590 2.6984 1.7543 1.2721 2.6754 1.3570 2.7391 1.7543 1.2721 2.6754 1.3673 2.7239 1.7543 1.2721 2.6754 1.3673 2.7239 1.7543 1.2000 2.6754 1.3673 2.7239 3.1013 0.5339 5.8095 3.4817 0.5920 5.8095 3.4810 0.7117 3.4847 0.5920 5</td><td>81 82 83 84 85 86 0.6986 1.0000 1.4029 0.7071 1.9841 1.5963 1.0007 1.5963 1.0000 1.5763 1.0000 1.5763 1.0000 1.7543 1.2276 2.3661 0.8419 1.9841 1.7058 1.2296 2.3661 0.8419 1.9841 1.7254 1.2479 2.6064 1.3137 2.4758 0.8696 1.7254 1.2479 2.6054 1.3137 2.4758 0.8696 1.7372 1.2583 2.6381 1.3444 2.6381 1.3533 1.7541 1.2647 2.6564 1.3570 2.6964 1.3387 1.7543 1.2269 2.6678 1.3673 2.7239 1.3673 1.7543 1.2269 2.6678 1.3572 2.7392 1.3673 1.7543 1.2269 2.6754 1.3070 2.7239 1.3673 1.7543 1.22647 3.4817 1.0000 3.0 dB Ripple \$1 \$2<td>g1 g2 g3 g4 g5 g6 g7 0.6986 1.0000 1.9241 1.5963 1.0967 1.5963 1.0000 1.6703 1.9267 1.5963 1.0000 1.9841 1.7563 1.0967 1.5963 1.0000 1.7758 1.2296 1.7058 1.0000 1.6703 1.9262 2.5408 1.2296 1.7058 1.0000 1.7254 1.2479 2.6064 1.3137 2.4758 0.8696 1.9841 1.7254 1.2647 2.6664 1.3137 2.4758 0.8696 1.9841 1.7372 1.2583 2.6381 1.3444 2.6381 1.3482 2.6373 2.6678 1.754 1.2647 2.6664 1.3590 2.6964 1.3389 2.5933 1.7543 1.2721 2.6754 1.3725 2.7392 1.3806 2.7231 1.7543 1.2721 2.6754 1.3705 2.7392 1.3806 2.7231 3.1013 0.5339</td><td>B1 B2 B3 B4 B3 B6 B7 B1 0.6986 1.0000 1.9841 1.5963 1.0967 1.5963 1.0000 1.1926 2.3661 0.8419 1.9841 1.5963 1.0967 1.5963 1.0000 1.7524 1.2479 2.6664 1.3137 2.4758 0.8696 1.9841 1.7254 1.2479 2.6664 1.3137 2.4758 0.8696 1.9841 1.7372 1.2583 2.6381 1.3444 2.6381 1.3372 1.0000 1.7451 1.2647 2.6664 1.3590 2.6964 1.3593 2.6078 1.2670 1.7541 1.2647 2.6678 1.3670 2.7239 1.3673 2.6678 1.2560 1.7543 1.2721 2.6754 1.3725 2.7392 1.3603 2.7231 1.3485 1.7543 1.2721 2.6754 1.3702 5.0055 3.4817 0.7117 3.4817 1.0000 3.4389 0.7113</td><td>$\begin{array}{c ccccccccccccccccccccccccccccccccccc$</td><td>$\begin{array}{c c c c c c c c c c c c c c c c c c c$</td></td></td<>	81 82 83 84 85 0.6986 1.0000 1.4029 0.7071 1.9841 1.5963 1.0967 1.5963 1.0000 1.6703 1.1926 2.3661 0.8419 1.9841 1.7058 1.2296 2.5408 1.2296 1.7058 1.7372 1.2583 2.6381 1.3137 2.4758 1.7372 1.2583 2.6381 1.3444 2.6381 1.7372 1.2583 2.6381 1.3590 2.6964 1.7541 1.2647 2.6564 1.3590 2.6984 1.7543 1.2721 2.6754 1.3570 2.7391 1.7543 1.2721 2.6754 1.3673 2.7239 1.7543 1.2721 2.6754 1.3673 2.7239 1.7543 1.2000 2.6754 1.3673 2.7239 3.1013 0.5339 5.8095 3.4817 0.5920 5.8095 3.4810 0.7117 3.4847 0.5920 5	81 82 83 84 85 86 0.6986 1.0000 1.4029 0.7071 1.9841 1.5963 1.0007 1.5963 1.0000 1.5763 1.0000 1.5763 1.0000 1.7543 1.2276 2.3661 0.8419 1.9841 1.7058 1.2296 2.3661 0.8419 1.9841 1.7254 1.2479 2.6064 1.3137 2.4758 0.8696 1.7254 1.2479 2.6054 1.3137 2.4758 0.8696 1.7372 1.2583 2.6381 1.3444 2.6381 1.3533 1.7541 1.2647 2.6564 1.3570 2.6964 1.3387 1.7543 1.2269 2.6678 1.3673 2.7239 1.3673 1.7543 1.2269 2.6678 1.3572 2.7392 1.3673 1.7543 1.2269 2.6754 1.3070 2.7239 1.3673 1.7543 1.22647 3.4817 1.0000 3.0 dB Ripple \$1 \$2 <td>g1 g2 g3 g4 g5 g6 g7 0.6986 1.0000 1.9241 1.5963 1.0967 1.5963 1.0000 1.6703 1.9267 1.5963 1.0000 1.9841 1.7563 1.0967 1.5963 1.0000 1.7758 1.2296 1.7058 1.0000 1.6703 1.9262 2.5408 1.2296 1.7058 1.0000 1.7254 1.2479 2.6064 1.3137 2.4758 0.8696 1.9841 1.7254 1.2647 2.6664 1.3137 2.4758 0.8696 1.9841 1.7372 1.2583 2.6381 1.3444 2.6381 1.3482 2.6373 2.6678 1.754 1.2647 2.6664 1.3590 2.6964 1.3389 2.5933 1.7543 1.2721 2.6754 1.3725 2.7392 1.3806 2.7231 1.7543 1.2721 2.6754 1.3705 2.7392 1.3806 2.7231 3.1013 0.5339</td> <td>B1 B2 B3 B4 B3 B6 B7 B1 0.6986 1.0000 1.9841 1.5963 1.0967 1.5963 1.0000 1.1926 2.3661 0.8419 1.9841 1.5963 1.0967 1.5963 1.0000 1.7524 1.2479 2.6664 1.3137 2.4758 0.8696 1.9841 1.7254 1.2479 2.6664 1.3137 2.4758 0.8696 1.9841 1.7372 1.2583 2.6381 1.3444 2.6381 1.3372 1.0000 1.7451 1.2647 2.6664 1.3590 2.6964 1.3593 2.6078 1.2670 1.7541 1.2647 2.6678 1.3670 2.7239 1.3673 2.6678 1.2560 1.7543 1.2721 2.6754 1.3725 2.7392 1.3603 2.7231 1.3485 1.7543 1.2721 2.6754 1.3702 5.0055 3.4817 0.7117 3.4817 1.0000 3.4389 0.7113</td> <td>$\begin{array}{c ccccccccccccccccccccccccccccccccccc$</td> <td>$\begin{array}{c c c c c c c c c c c c c c c c c c c$</td>	g1 g2 g3 g4 g5 g6 g7 0.6986 1.0000 1.9241 1.5963 1.0967 1.5963 1.0000 1.6703 1.9267 1.5963 1.0000 1.9841 1.7563 1.0967 1.5963 1.0000 1.7758 1.2296 1.7058 1.0000 1.6703 1.9262 2.5408 1.2296 1.7058 1.0000 1.7254 1.2479 2.6064 1.3137 2.4758 0.8696 1.9841 1.7254 1.2647 2.6664 1.3137 2.4758 0.8696 1.9841 1.7372 1.2583 2.6381 1.3444 2.6381 1.3482 2.6373 2.6678 1.754 1.2647 2.6664 1.3590 2.6964 1.3389 2.5933 1.7543 1.2721 2.6754 1.3725 2.7392 1.3806 2.7231 1.7543 1.2721 2.6754 1.3705 2.7392 1.3806 2.7231 3.1013 0.5339	B1 B2 B3 B4 B3 B6 B7 B1 0.6986 1.0000 1.9841 1.5963 1.0967 1.5963 1.0000 1.1926 2.3661 0.8419 1.9841 1.5963 1.0967 1.5963 1.0000 1.7524 1.2479 2.6664 1.3137 2.4758 0.8696 1.9841 1.7254 1.2479 2.6664 1.3137 2.4758 0.8696 1.9841 1.7372 1.2583 2.6381 1.3444 2.6381 1.3372 1.0000 1.7451 1.2647 2.6664 1.3590 2.6964 1.3593 2.6078 1.2670 1.7541 1.2647 2.6678 1.3670 2.7239 1.3673 2.6678 1.2560 1.7543 1.2721 2.6754 1.3725 2.7392 1.3603 2.7231 1.3485 1.7543 1.2721 2.6754 1.3702 5.0055 3.4817 0.7117 3.4817 1.0000 3.4389 0.7113	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	$ \begin{array}{c c c c c c c c c c c c c c c c c c c $

Tamer Abuelfadl (EEC, Cairo University)

ECE305B

11 / 13

Attenuation versus normalized frequency for equal ripples (Chebyshev) filter prototypes (0.5 dB ripples)



ECE305B 12 / 13

Attenuation versus normalized frequency for equal ripples (Chebyshev) filter prototypes (3 dB ripples)

