Microwave Engineering

Filter Design by Insertion Loss Method

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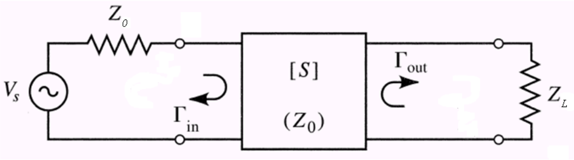
Filter Design by Insertion Loss Method.

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

Filter Design by the Insertion Loss Method



Power Loss Ratio P_{LR}

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

The network is assumed lossless

Insertion Loss (IL) in dB

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

It can be shown that

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

Filter Design by the Insertion Loss Method

- Maximally flat (Binomial or Butterworth) Low Pass Filter

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

  - 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 $k = 1$.

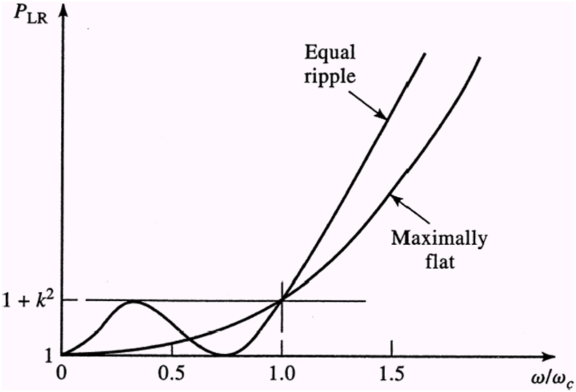
- Equal ripple (Chebyshev) Low pass Filter

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

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

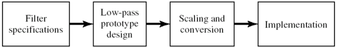
- Other types of Low pass filters include: Elliptic filter and Linear phase filters. These types are not covered in this course.

Filter Design by the Insertion Loss Method

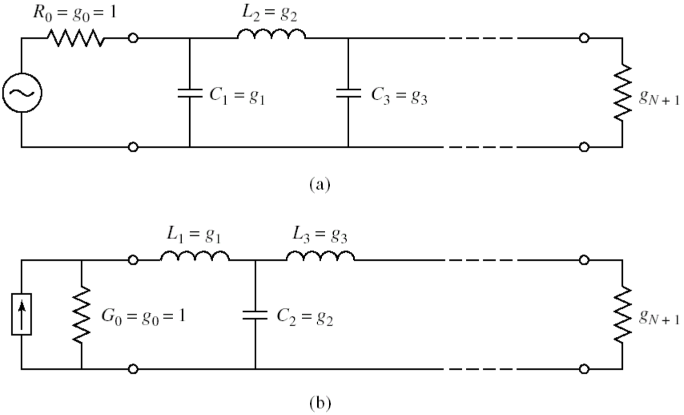


Filter Design by the Insertion Loss Method

The process of filter design by the insertion loss method

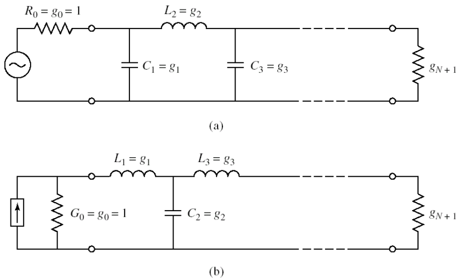


- Low pass prototype: It has cut-off $\omega_c = 1$ Hz, and source impedance $Z_o = 1\ \Omega$.
- Scaling and conversion
  - Impedance scaling to scale to source with impedance R_0.
  - Frequency scaling:
    - LPF is scaled to ω_c, $\quad \omega \leftarrow \omega/\omega_c$.
    - HPF is scaled to ω_c, $\quad \omega \leftarrow -\omega_c/\omega$.
    - BPF is characterized with center frequency ω_0 and fractional bandwidth $\Delta = (\omega_2 - \omega_1)/\omega_0$, where ω_1 and ω_2 is the passband limits and $\omega_0 = \sqrt{\omega_1 \omega_2}$. the scaling is $\omega \leftarrow \frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$
    - BSF is scaled by $\omega \leftarrow \Delta\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)^{-1}$
- Implementation: the filter can be realized either as lumped elements or as distributed elements (i.e stubs, coupled lines).



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



$$g_0 = \begin{cases} \text{generator resistance (Figure a)} \\ \text{generator conductance (Figure b)} \end{cases}$$

$$\underset{(k=1 \text{ to } N)}{g_k} = \begin{cases} \text{inductance for series inductor} \\ \text{capacitance for shunt capacitors} \end{cases}$$

$$g_{N+1} = \begin{cases} \text{load resistance if } g_N \text{ is a shunt capacitor} \\ \text{load conductance if } g_N \text{ is a sseries inductor} \end{cases}$$

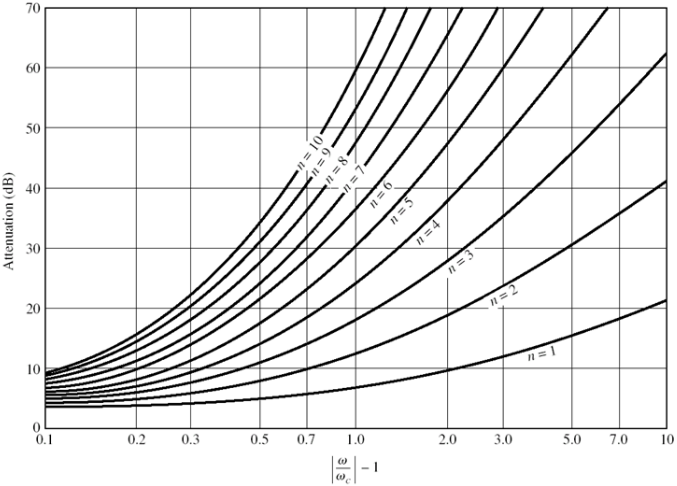
Maximally Flat (Butterworth) Low Pass Filter Prototype

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

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	[illegible]
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	[illegible]

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

Attenuation versus normalized frequency for maximally flat filter prototypes



Equal Ripples (Chebyshev) Low Pass Filter Prototype

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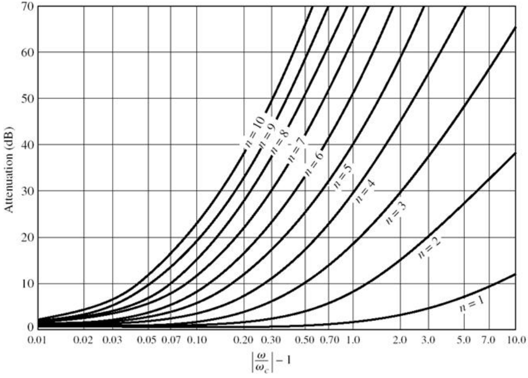
TABLE 8.4 Element Values for Equal-Ripple Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N =$ [illegible] 0.5 dB and 3.0 dB ripple)

0.5 dB Ripple											
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7239	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	[illegible]

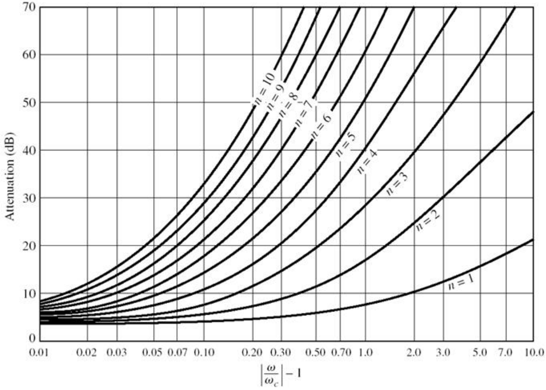
3.0 dB Ripple											
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	1.9953	1.0000									
2	3.1013	0.5339	5.8095								
3	3.3487	0.7117	3.3487	1.0000							
4	3.4389	0.7483	4.3471	0.5920	5.8095						
5	3.4817	0.7618	4.5381	0.7618	3.4817	1.0000					
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095				
7	3.5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1.0000			
8	3.5277	0.7745	4.6575	0.8089	4.6990	0.8018	4.4990	0.6073	5.8095		
9	3.5340	0.7760	4.6692	0.8118	4.7272	0.8118	4.6692	0.7760	3.5340	1.0000	
10						[illegible]	[illegible]	[illegible]	4.5142	0.6091	[illegible]

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



(a)

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



(b)