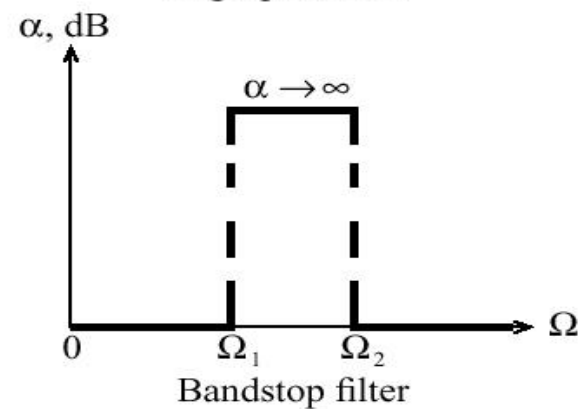
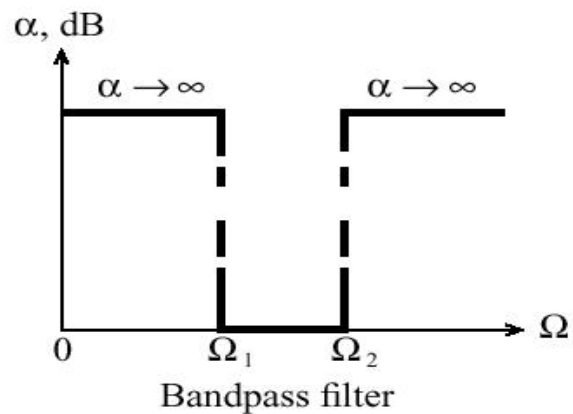
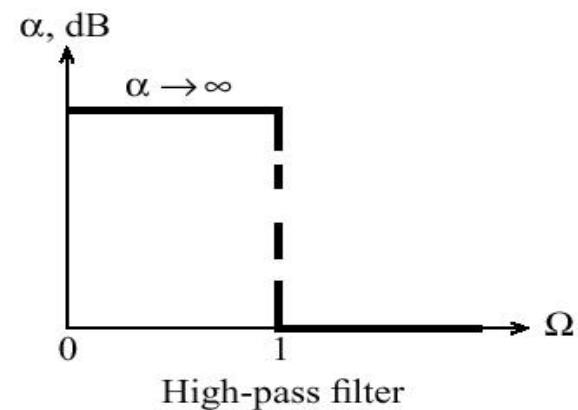
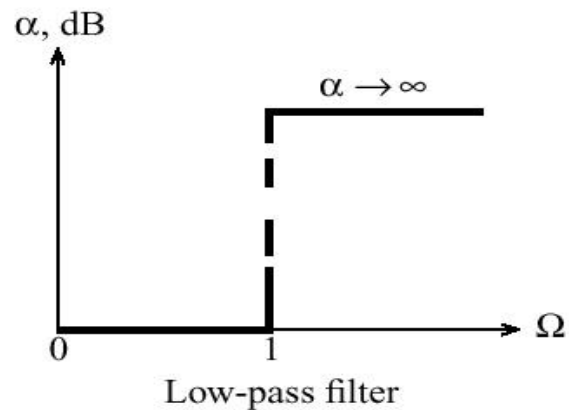
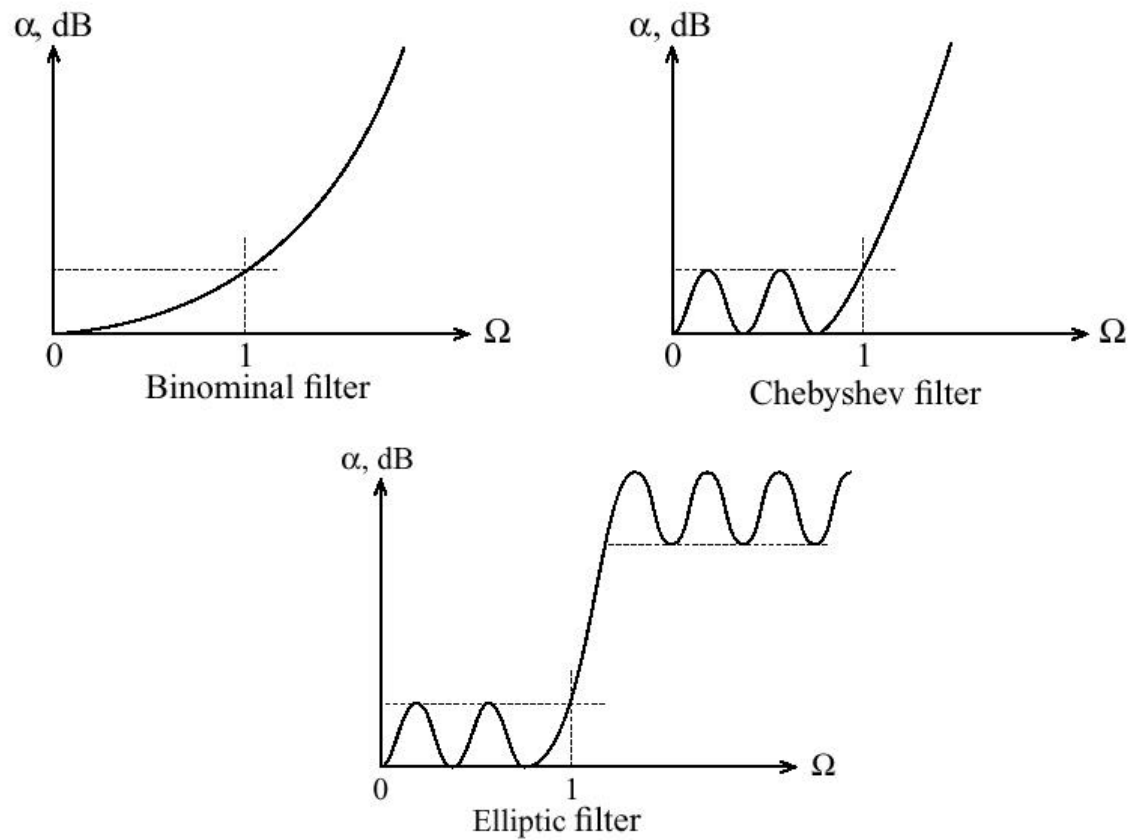


RF Filter Design – Basic Filter Types



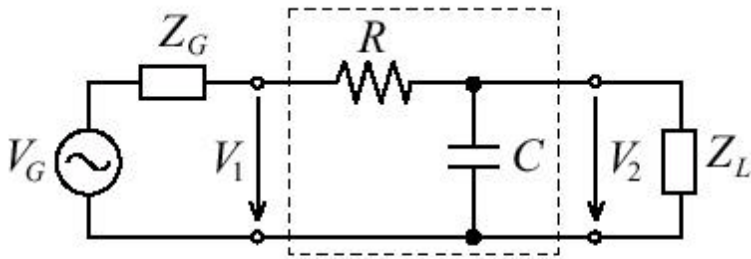
Filter Attenuation Profiles



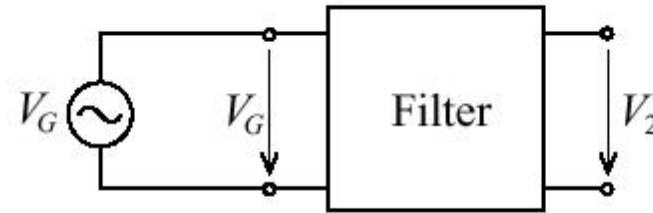
RF Filter Parameters

- Insertion Loss: $IL = 10 \log \frac{P_{in}}{P_L} = -10 \log (1 - |\Gamma_{in}|^2)$
- Ripple
- Bandwidth: $BW^{3dB} = f_u^{3dB} - f_L^{3dB}$
- Shape Factor: $SF = \frac{BW_{A_{min}}}{BW_{A_{max}}}$
- Rejection

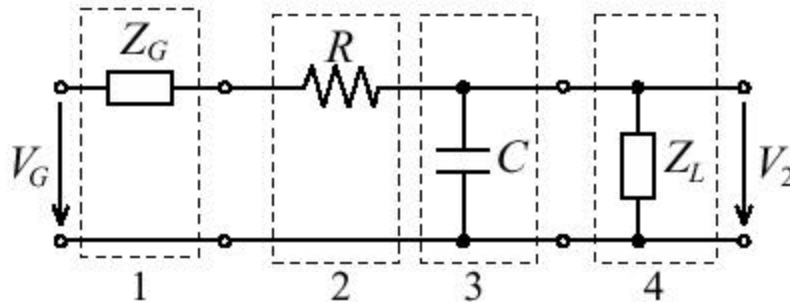
Low-Pass Filter



(a) Low-pass filter with load resistance.



(b) Network with input/output voltages



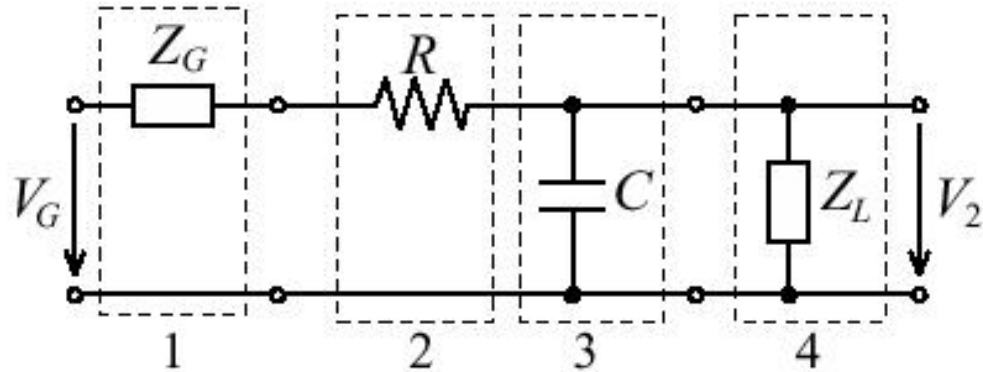
Cascading four ABCD-networks.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & R_G \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & R \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j\omega C & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/R_L & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 + (R + R_G) \left(j\omega C + \frac{1}{R_L} \right) & R_G + R_L \\ j\omega C + \frac{1}{R_L} & 1 \end{bmatrix}$$

RF Filter Parameters

Cascading four ABCD-networks.



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & R_G \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & R \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j\omega C & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/R_L & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 + (R + R_G) \left(j\omega C + \frac{1}{R_L} \right) & R_G + R_L \\ j\omega C + \frac{1}{R_L} & 1 \end{bmatrix}$$

Low-Pass Filter Frequency Response

- Frequency Response from the ABCD Definitions:

$$A = \left. \frac{v_1}{v_2} \right|_{i_2=0}$$

- So the **Transfer Function** is Simply:

$$\frac{1}{A} = H(\omega) = \frac{1}{1 + j\omega(R_G + R)C}$$

Low-Pass Filter Frequency Response

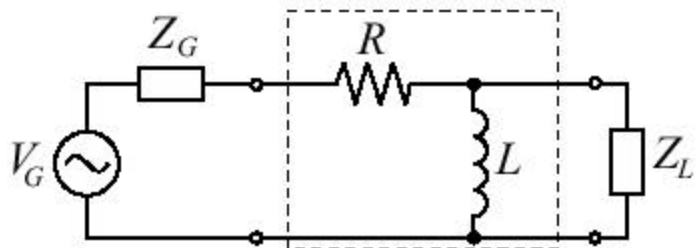
- Corresponding Phase is:

$$\mathbf{f}(\mathbf{w}) = \tan^{-1} \left(\frac{\text{Im}\{H(\mathbf{w})\}}{\text{Re}\{H(\mathbf{w})\}} \right)$$

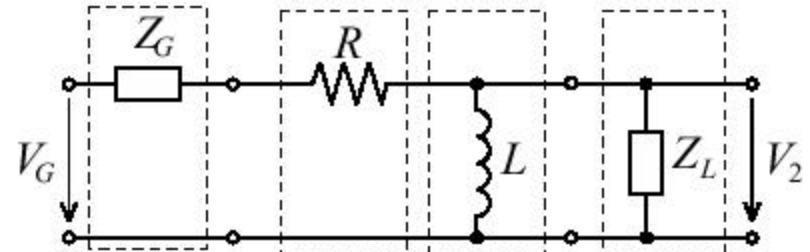
- Group Delay:

$$t_g = \frac{d\mathbf{f}(\mathbf{w})}{d\mathbf{w}}$$

High-Pass Filter



(a) High-pass filter with load resistance



(b) Network and input/output voltages

$$\begin{aligned} \begin{bmatrix} A & B \\ C & D \end{bmatrix} &= \begin{bmatrix} 1 & R_G \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & R \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{1}{j\omega L} & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \frac{1}{R_L} & 1 \end{bmatrix} \\ &= \begin{bmatrix} 1 + (R + R_G) \left(\frac{1}{j\omega L} + \frac{1}{R_L} \right) & R_G + R_L \\ \frac{1}{j\omega L} + \frac{1}{R_L} & 1 \end{bmatrix} \end{aligned}$$

High-Pass Filter Frequency Response

- Frequency Response from the ABCD Definitions:

$$A = \left. \frac{v_1}{v_2} \right|_{i_2=0}$$

- So the **Transfer Function** is Simply:

$$\frac{1}{A} = H(\omega) = \frac{1}{1 + (R_G + R) \left(\frac{1}{j\omega L} + \frac{1}{R_L} \right)}$$

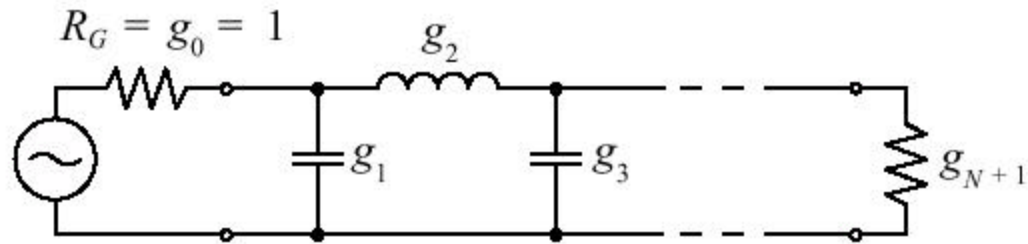
High-Pass Filter Frequency Response

- For $\omega \rightarrow \infty$:

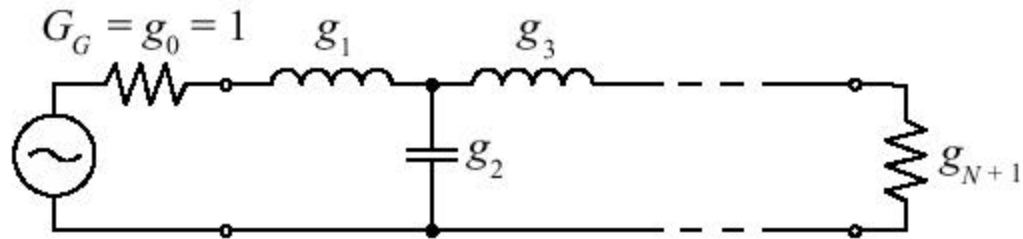
$$\frac{V_2}{V_G} = \frac{1}{1 + \frac{(R + R_G)}{R_L}} = \frac{R_L}{R_L + R_G + R}$$

- Inductive Influence Can Be Neglected

Low-Pass Filter Realizations



(a)

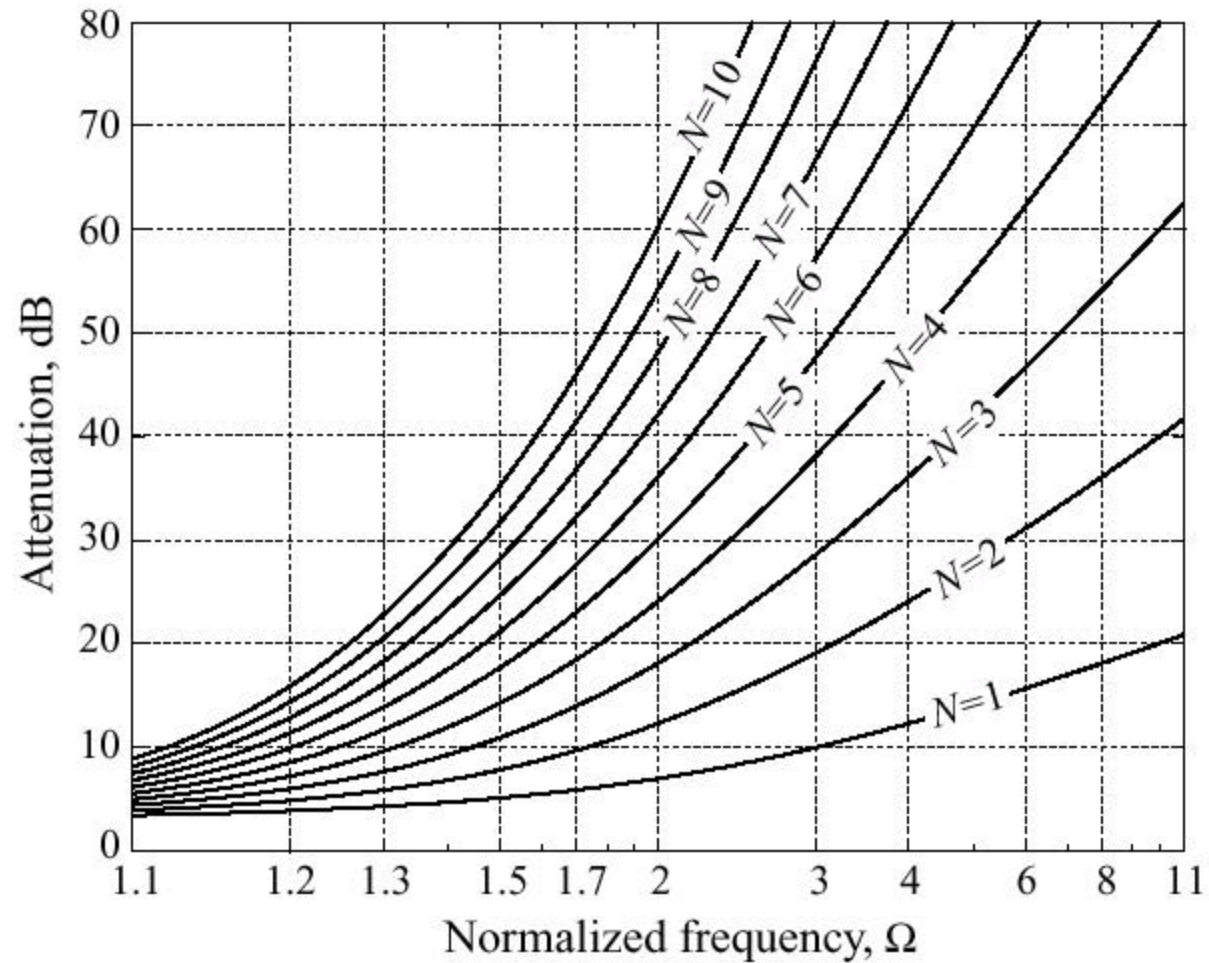


(b)

Low-Pass Butterworth Filter Coefficients

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

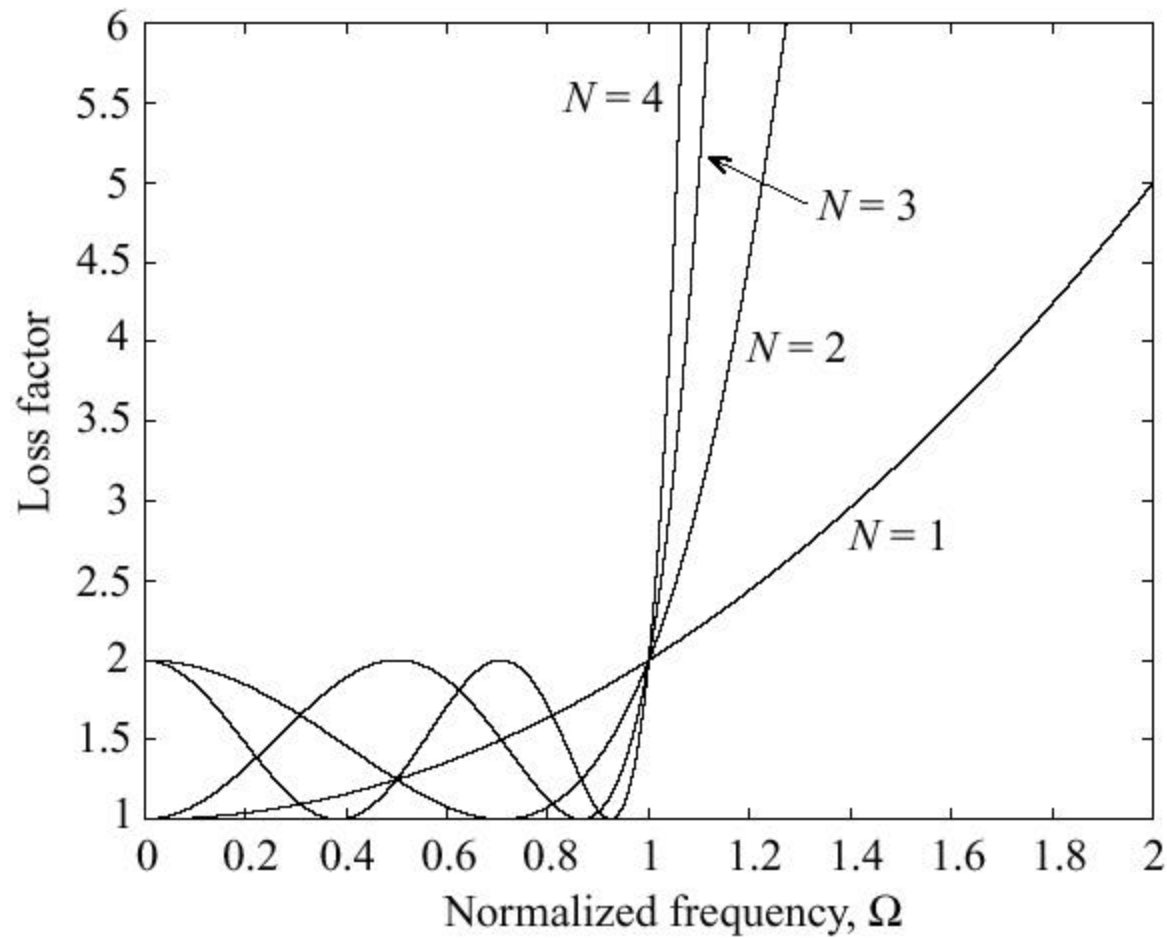
Low-Pass Butterworth Filter Attenuation



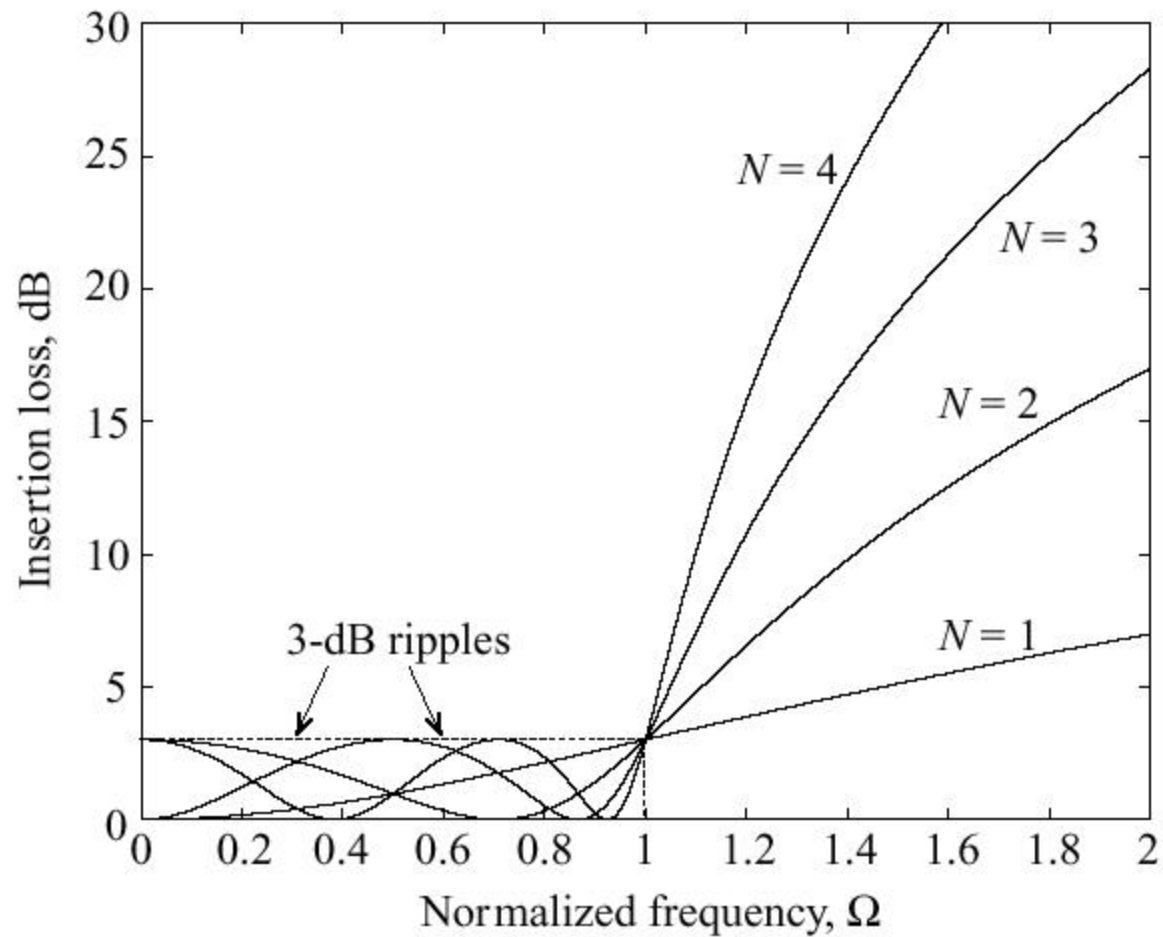
Low-Pass Linear-Phase Filter Coefficients

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	1.5774	0.4226	1.0000								
3	1.2550	0.5528	0.1922	1.0000							
4	1.0598	0.5116	0.3181	0.1104	1.0000						
5	0.9303	0.4577	0.3312	0.2090	0.0718	1.0000					
6	0.8377	0.4116	0.3158	0.2364	0.1480	0.0505	1.0000				
7	0.7677	0.3744	0.2944	0.2378	0.1778	0.1104	0.0375	1.0000			
8	0.7125	0.3446	0.2735	0.2297	0.1867	0.1387	0.0855	0.0289	1.0000		
9	0.6678	0.3203	0.2547	0.2184	0.1859	0.1506	0.1111	0.0682	0.0230	1.0000	
10	0.6305	0.3002	0.2384	0.2066	0.1808	0.1539	0.1240	0.0911	0.0557	0.0187	1.0000

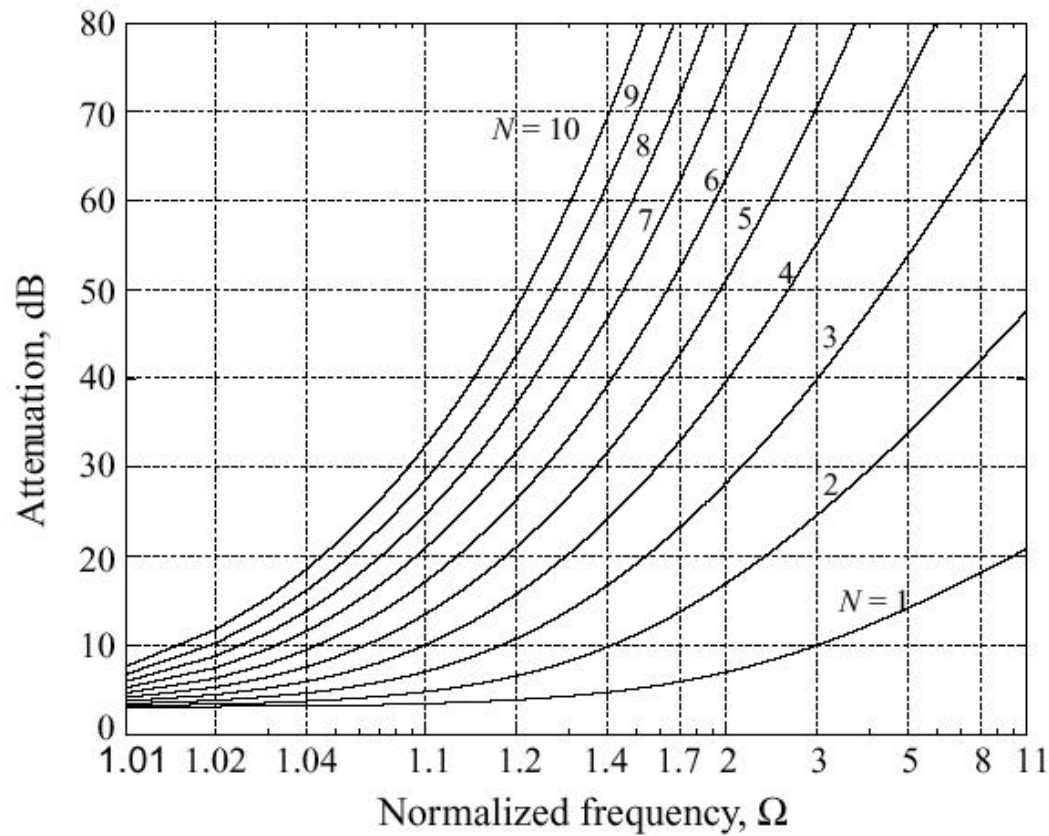
Chebyshev-Type Filters



Chebyshev-Type Filters

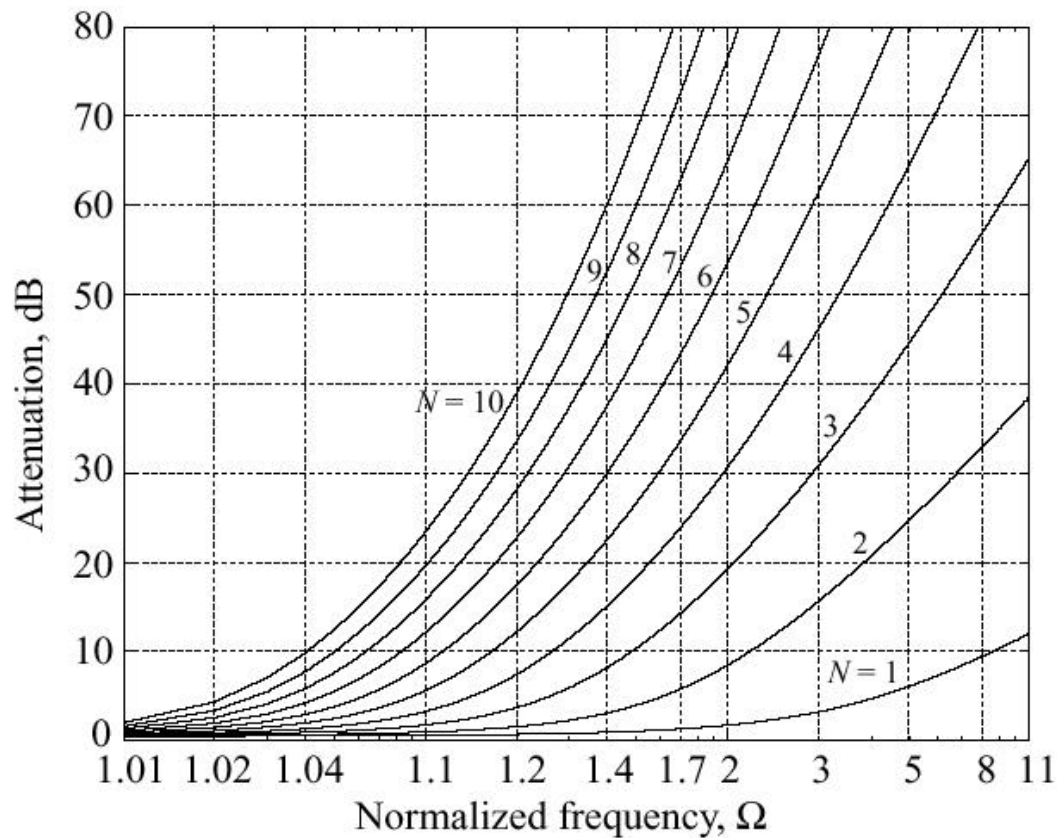


Chebyshev-Type Filter Response



Response for 3 dB ripple Chebyshev LPF

Chebyshev-Type Filter Response



Response for 0.5 dB ripple Chebyshev LPF

Low-Pass Chebyshev Filter Coefficients – 3 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	3.5384	0.7771	4.6768	0.8136	4.7425	0.8164	4.7260	0.8051	4.5142	0.6091	5.8095

Low-Pass Chebyshev Filter Coefficients – 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	2.7939	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	1.9841

Standard Low-Pass Filter Design

- The normalized inductors and capacitors (g_1, g_2, \dots, g_N) are denormalized using:

$$C = \frac{C_n}{2\pi f_C R} \quad \text{and} \quad L = \frac{L_n R}{2\pi f_C}$$

where C_n , L_n , are the g_n normalized values from the tables