Laboratory Work 3
Active filter circuits design and simulation

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Summary

1. Filter approximation theory review
2. Laboratory work 3: ideal and real amplifier comparison
3. Active filter circuits design
4. Second Order Filters
5. Frequency Transformation
6. Step 1: check of scheme gain
7. Step 2: time domain simulation
8. Step 3: Step response (time domain simulation)
9. Step 4: frequency domain simulation)
10. Results and conclusions
11. Uploading report

The Butterworth Approximation

parameters that fully describe the filter transfer function

$\{H_o, H_C, H_S, \Omega_S\} \qquad (\Omega_C = 1)$

In terms of logarithmic gain

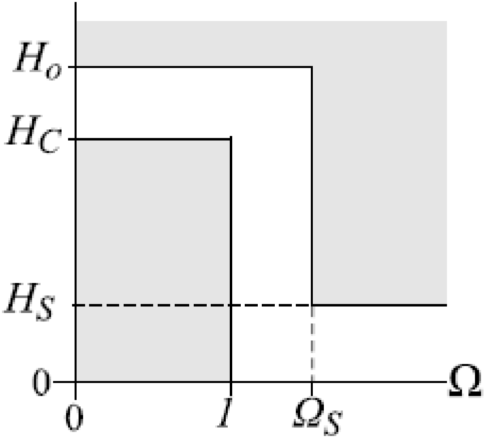
$\{\alpha_o, \alpha_{\max}, \alpha_{\min}, \Omega_S\} \qquad (\Omega_C = 1)$

If $H_0 = 1$, the filter requirements can be determined by three parameters

$\Omega_S \quad \text{and} \quad \{H_C, H_S\} \quad \text{or} \quad \{a_{\max}, \alpha_{\min}\}$

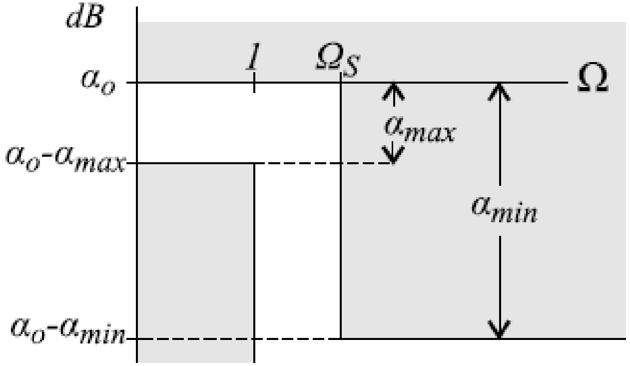
Plain gain

$G(\Omega) = |H(j\Omega)|$



Logarithmic gain

$G_{dB}(\Omega) = 20\log|H(j\Omega)|$



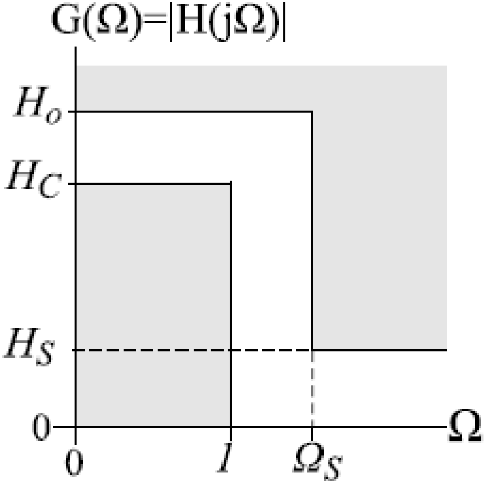
Butterworth proposed the monotonic function

$$G(\Omega) = \frac{H_o}{\sqrt{1 + \beta^2 \Omega^{2N}}}$$

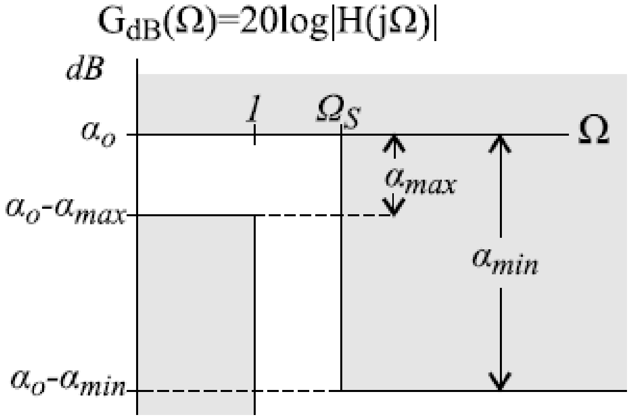
with N, the order of the approximation, a positive integer, and β a design parameter related to the passband tolerance.

The Butterworth Approximation

Plain gain



Logarithmic gain



$$G(\Omega) = \frac{H_o}{\sqrt{1+\beta^2\Omega^{2N}}}$$

For $\Omega = 0$

$$G(0) = H_o$$

$$G(1) = \frac{H_o}{\sqrt{1+\beta^2}} \geq H_C \quad \Leftrightarrow \quad \beta^2 \leq (H_o/H_C)^2 - 1$$

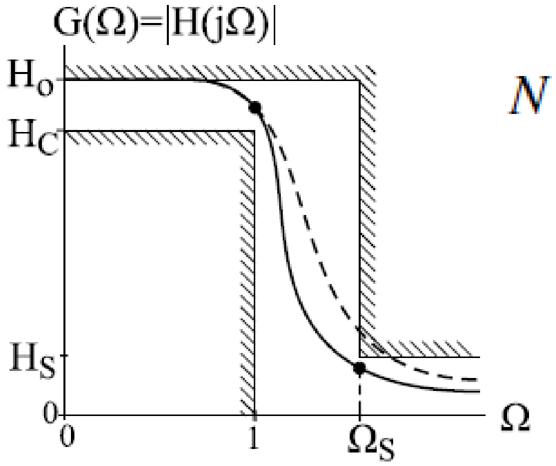
For $\beta = \beta_{max}$ the gain $G(1) = H_C$

$$\beta \leq \beta_{\max} = \sqrt{\left(\frac{H_o}{H_C}\right)^2 - 1} = \sqrt{10^{\frac{a_{\max}}{10}} - 1}$$

The Butterworth Approximation

$$G(\Omega) = \frac{H_o}{\sqrt{1+\beta^2\Omega^{2N}}}$$

$$G(\Omega_S) = \frac{H_o}{\sqrt{1+\beta^2\Omega_S^{2N}}} \le H_S$$

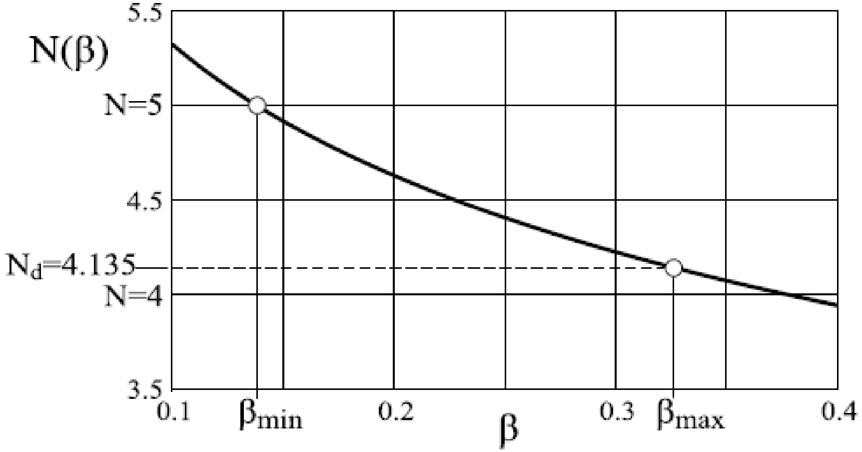


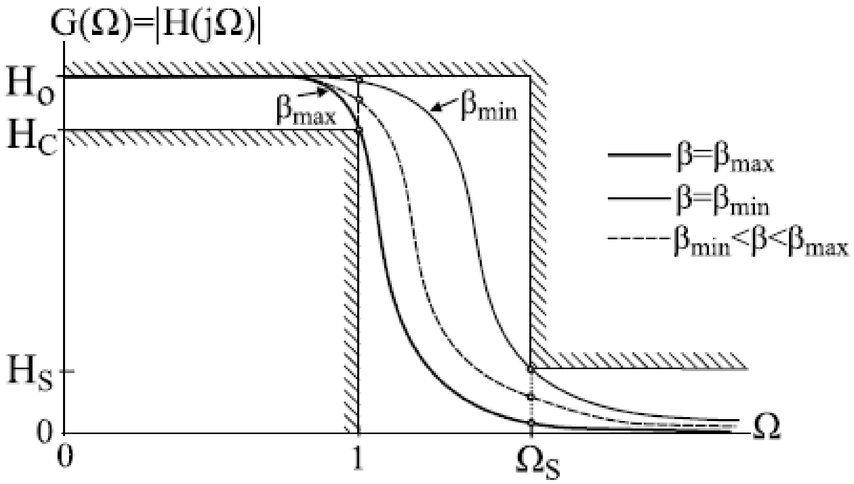
$$N \ge \frac{\log\left(\frac{(H_o/H_S)^2-1}{\beta^2}\right)}{2\log\Omega_S}$$

$$\boxed{N \ge N_d = \frac{\log\left(\frac{(H_o/H_S)^2-1}{\beta^2}\right)}{2\log\Omega_S}}$$

$$n_{f\,\min} = \frac{\log\left(\frac{\frac{H_o^2}{H_S^2}-1}{\frac{H_o^2}{H_C^2}-1}\right)}{2\log\Omega_S} = \frac{\log\left(\frac{10^{\frac{a_{\min}}{10}}-1}{10^{\frac{a_{\max}}{10}}-1}\right)}{2\log\Omega_S}$$

The Butterworth Approximation





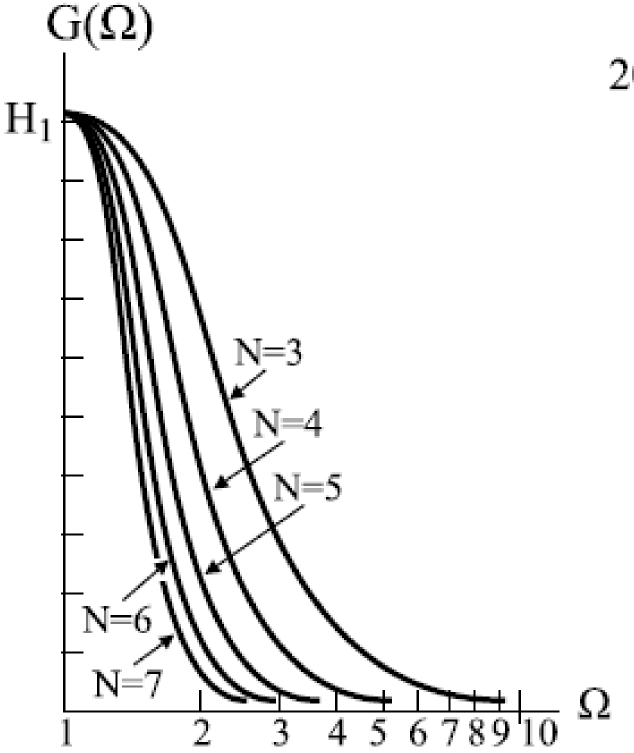
filter designed with normalized specifications

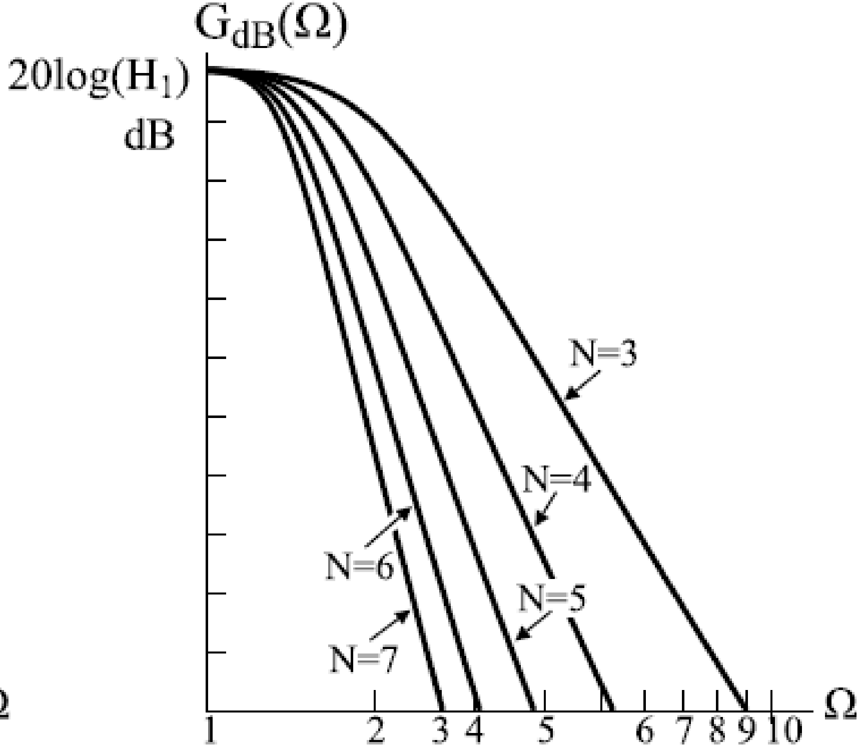
$H_o = 1$, $H_C = 0.95$, $H_S = 0.05$ and $\Omega_S = 2.7$

$$\beta_{\min} = \frac{\sqrt{\frac{H_o^2}{H_S^2} - 1}}{\Omega_S^N} \le \beta \le \sqrt{\frac{H_o^2}{H_C^2} - 1} = \beta_{\max}$$

$$\beta_{\min} = \frac{\sqrt{10^{\frac{\alpha_{\min}}{10}} - 1}}{\Omega_S^N} \le \beta \le \sqrt{10^{\frac{\alpha_{\max}}{10}} - 1} = \beta_{\max}$$

The Butterworth Approximation





The All-Pole Chebyshev Approximation

parameters that fully describe the filter transfer function

$$\{H_o, H_C, H_S, \Omega_S\} \qquad (\Omega_C = 1)$$

In terms of logarithmic gain

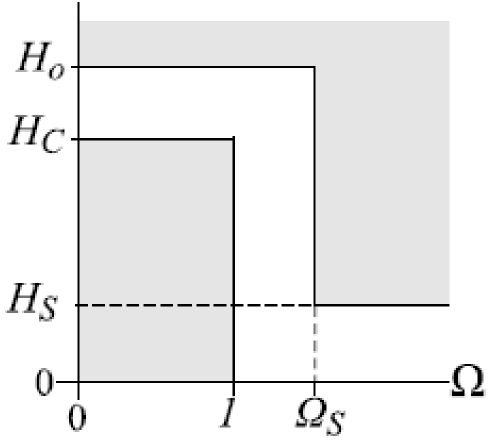
$$\{\alpha_o, \alpha_{\max}, \alpha_{\min}, \Omega_S\} \qquad (\Omega_C = 1)$$

If $H_0 = 1$, the filter requirements can be determined by three parameters

$$\Omega_S \quad \text{and} \quad \{H_C, H_S\} \quad \text{or} \quad \{a_{\max}, \alpha_{\min}\}$$

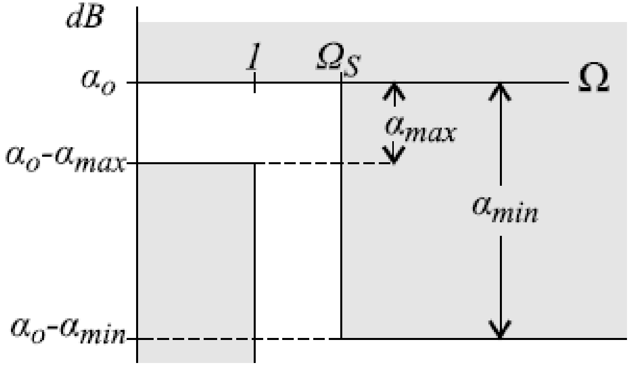
Plain gain

$G(\Omega)=|H(j\Omega)|$



Logarithmic gain

$G_{dB}(\Omega)=20\log|H(j\Omega)|$



Chebyshev approximation

$$G_{CH}(\Omega) = \frac{H_o}{\sqrt{1 + \varepsilon^2 C_N^2(\Omega)}}$$

The ripple factor ε and order N are so chosen to keep the response GCH(Ω) within the specifications.

The All-Pole Chebyshev Approximation

$$G_{CH}(\Omega) = \frac{H_o}{\sqrt{1+\varepsilon^2 C_N^2(\Omega)}}$$

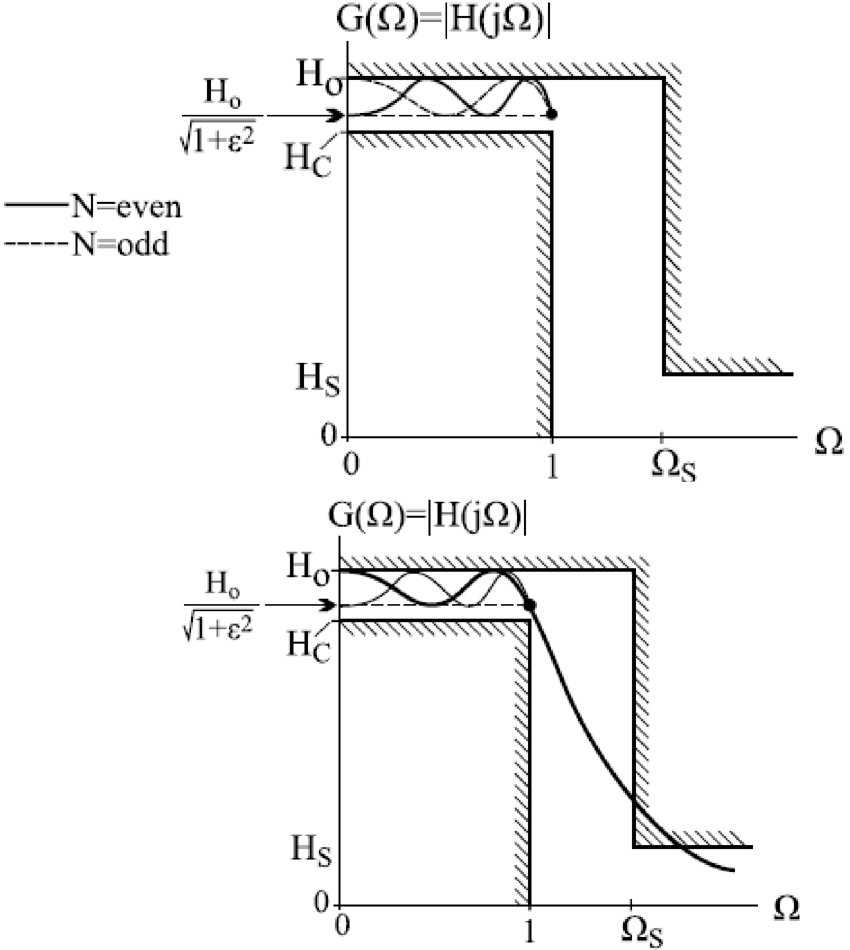
$$\varepsilon \le \sqrt{\frac{H_o^2}{H_C^2} - 1} = \sqrt{10^{\frac{\alpha_{\max}}{10}} - 1} = \varepsilon_{\max}$$

For $\varepsilon \le \varepsilon_{max}$

$$H_0 \ge G_{CH}(\Omega) \ge \frac{H_0}{\sqrt{1+\varepsilon^2}} \ge H_C$$

For $\Omega = 1$

$$G_{CH}(1) = \frac{H_0}{\sqrt{1+\varepsilon^2}} \ge H_C$$



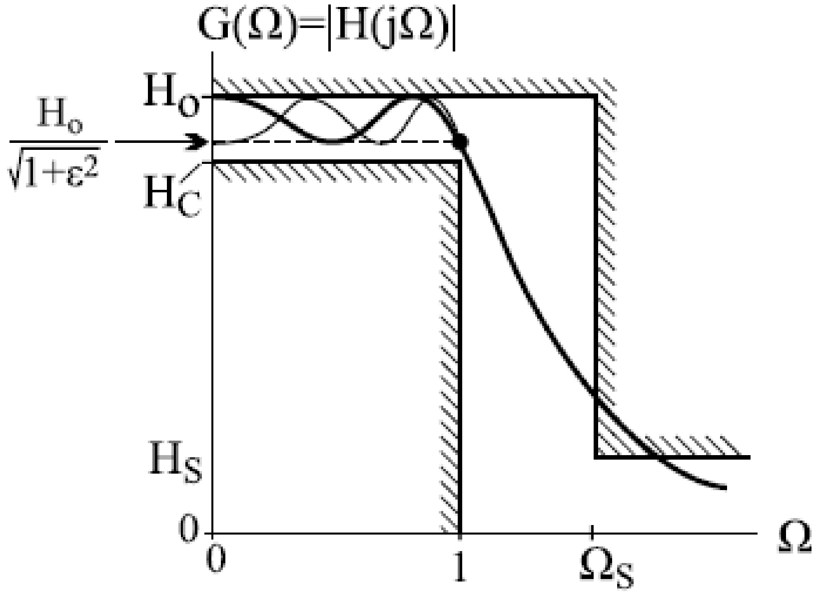
The All-Pole Chebyshev Approximation

$$G_{CH}(\Omega_s) = \frac{H_o}{\sqrt{1+\varepsilon^2 C_N^2(\Omega_S)}} \le H_S$$

$$\Leftrightarrow \quad C_N^2(\Omega_S) \ge \frac{(H_o/H_S)^2 - 1}{\varepsilon^2}$$

$$\Leftrightarrow \quad N \cosh^{-1}(\Omega_S) \ge \cosh^{-1}\sqrt{\frac{(H_o/H_S)^2 - 1}{\varepsilon^2}}$$

for N: $$N \ge N_d = \frac{\cosh^{-1}\left(\sqrt{\frac{(H_o/H_S)^2-1}{\varepsilon^2}}\right)}{\cosh^{-1}(\Omega_S)}$$

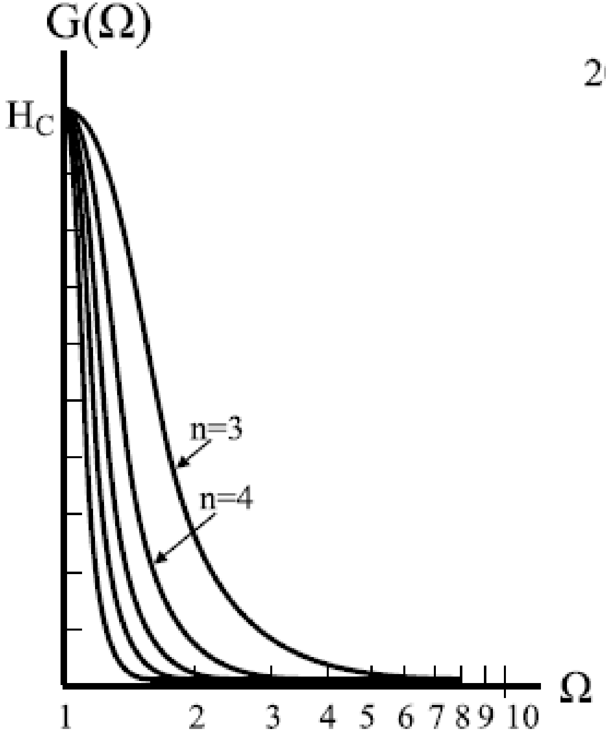


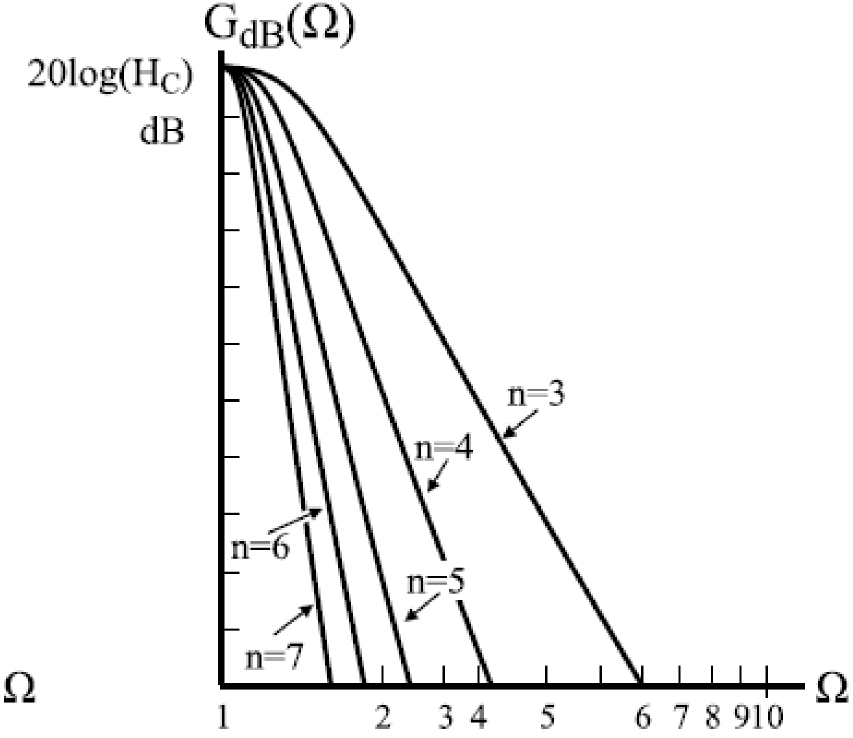
$$N \ge N_d = \frac{\cosh^{-1}\left(\sqrt{\frac{(H_o/H_S)^2-1}{\varepsilon^2_{\max}}}\right)}{\cosh^{-1}(\Omega_S)} = \frac{\cosh^{-1}\left(\sqrt{\frac{(H_o/H_S)^2-1}{(H_o/H_C)^2-1}}\right)}{\cosh^{-1}(\Omega_S)}$$

logarithmic gain specifications

$$N \ge N_d = \frac{\cosh^{-1}\left(\sqrt{\frac{10^{\frac{\alpha_{\min}}{10}}-1}{10^{\frac{\alpha_{\max}}{10}}-1}}\right)}{\cosh^{-1}(\Omega_S)}$$

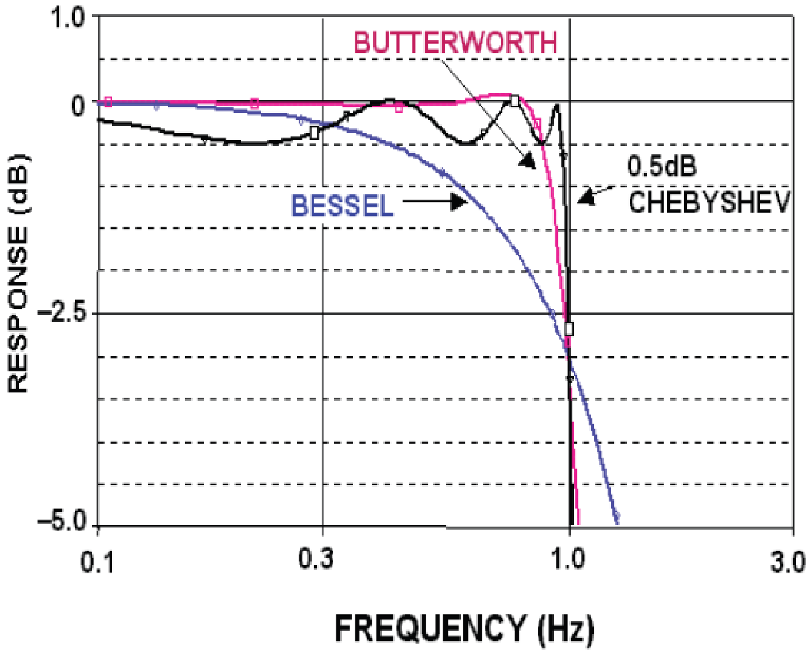
The All-Pole Chebyshev Approximation

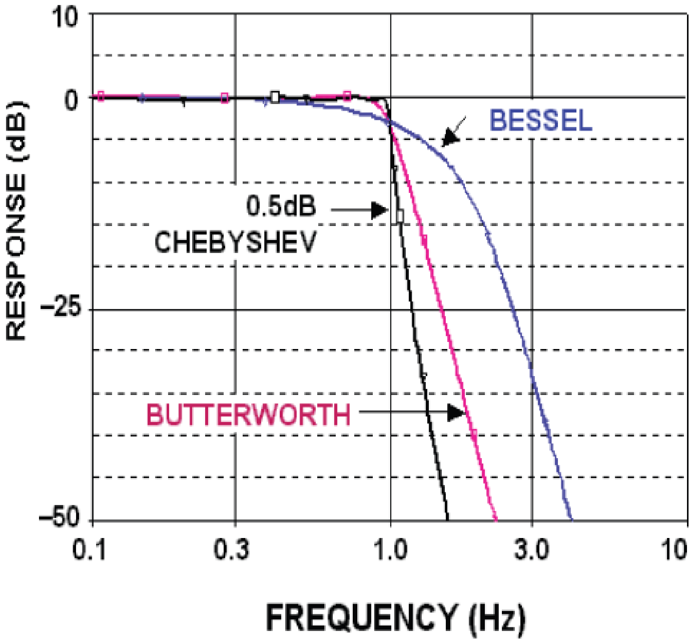




Comparison of All-Pole Responses

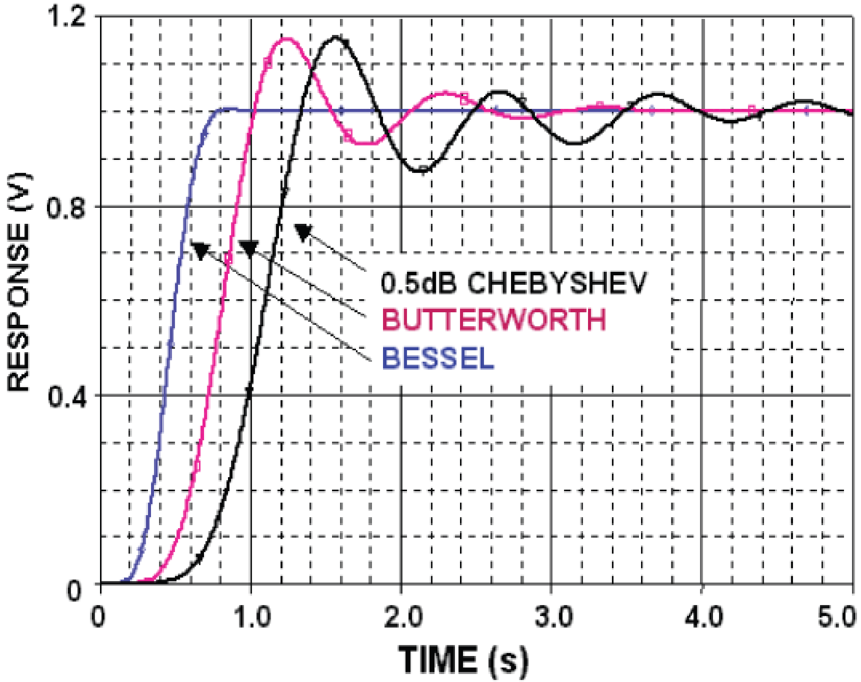
Comparison of Amplitude Response

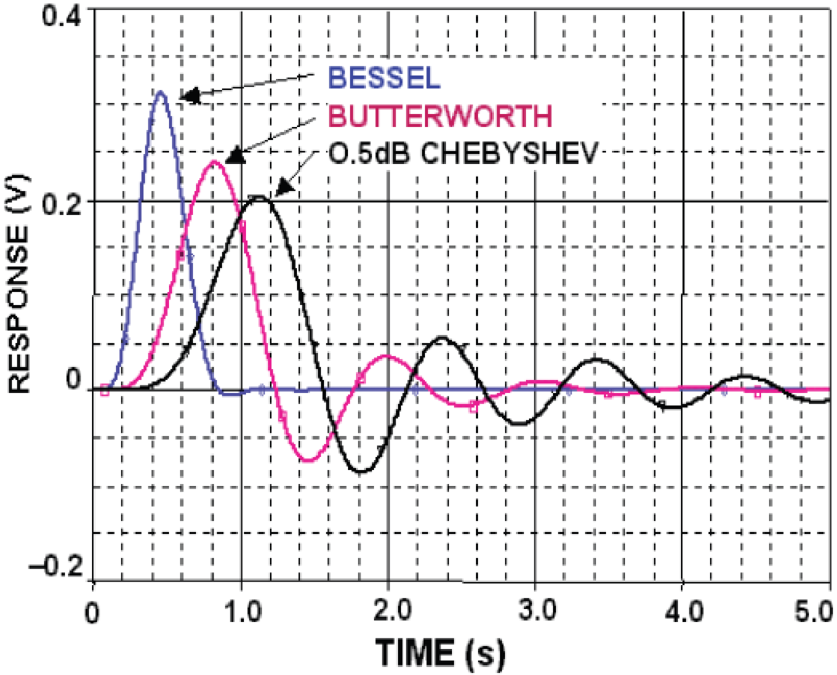




Comparison of All-Pole Responses

Comparison of Step and Impulse Responses





Butterworth VS Chebyshev

	Butterworth Filter	Chebyshev Filter
Order of Filter	The order of the Butterworth filter is higher than the Chebyshev filter for the same desired specifications.	The order of the Chebyshev filter is less compared to the Butterworth filter for the same desired specifications.
Hardware	It requires more hardware.	It requires less hardware.
Ripple	There is no ripple in passband and stopband of frequency response.	There is either ripple in passband or stopband.
Poles	All poles lie on a circle having a radius of the cutoff frequency.	All poles lie on ellipse having major axis R, ξ, minor axis r.
Transition band	The Butterworth filter has a wider transition band compared to the Chebyshev filter.	The Chebyshev filter has a narrow transition band compared to the Butterworth filter.
Types	It doesn’t have any types.	It has two types; type-1 and type-2.
Cutoff Frequency	The cutoff frequency of this filter is not equal to the passband frequency.	The cutoff frequency of this filter is equal to the passband frequency.

Laboratory Work 3
Active filter circuits design and simulation

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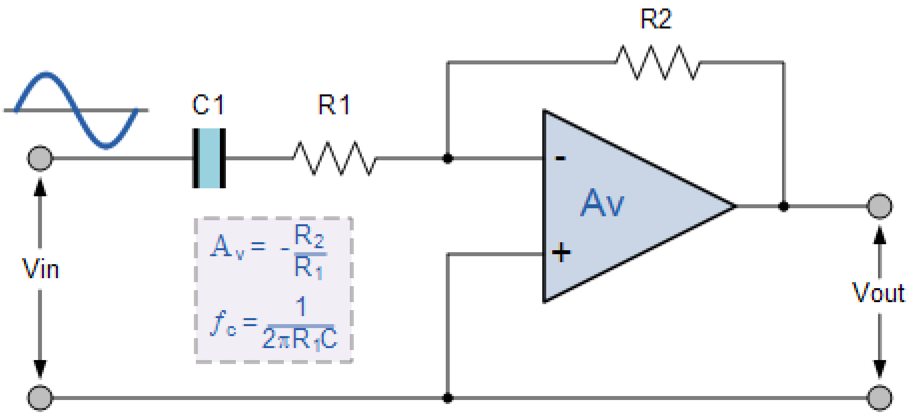
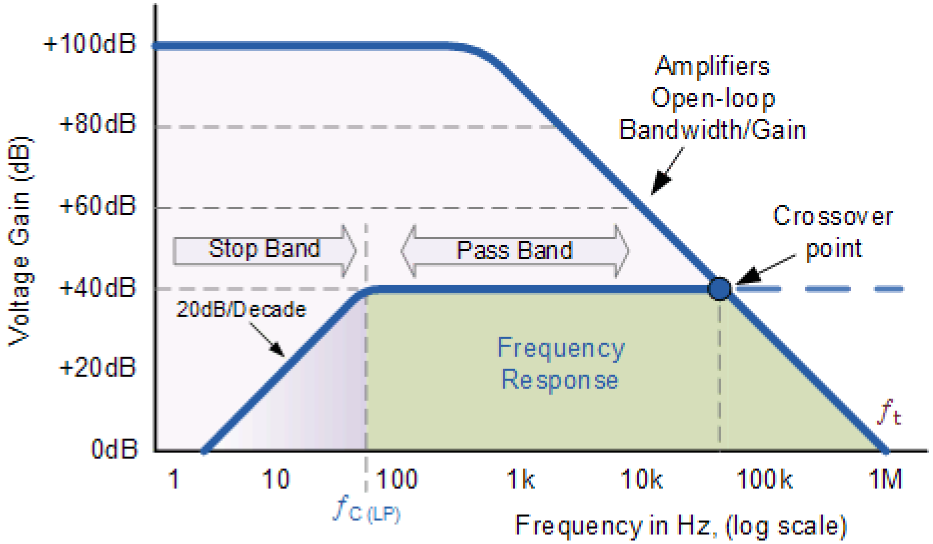
Active High Pass Filter

First-order Filter





Second Order Filters

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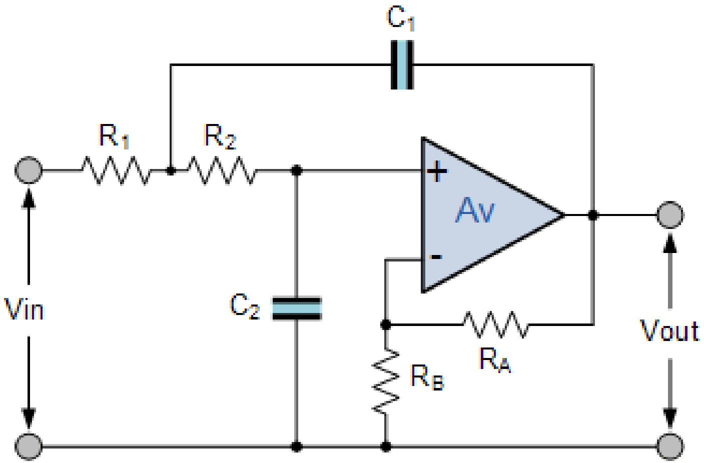
Second Order Low Pass Filter



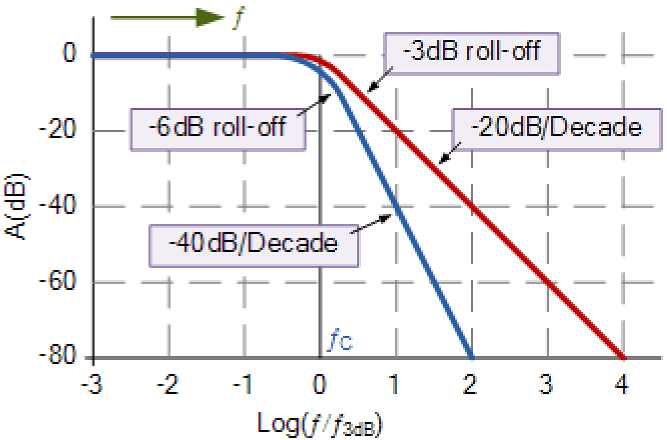
$$\text{Gain }(A_V) = 1 + \frac{R_A}{R_B}$$

If Resistor and Capacitor values are different:

$$f_C = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

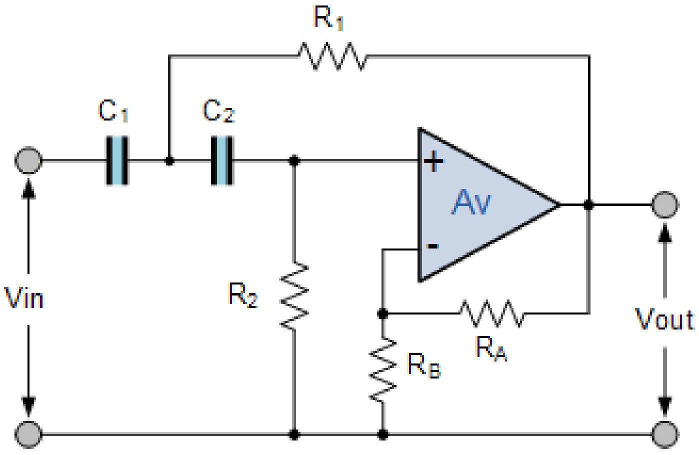
If Resistor and Capacitor values are the same:

$$f_C = \frac{1}{2\pi RC}$$



Second Order High Pass Filter

ITMO



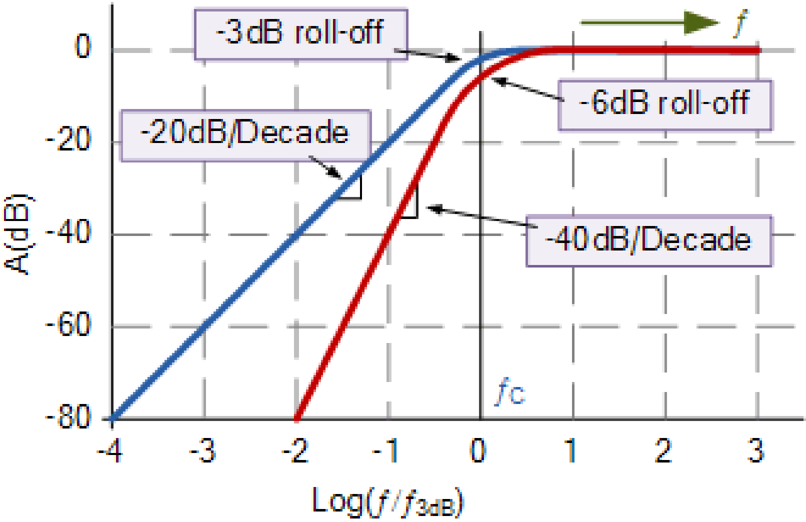
$$\text{Gain (Av)} = 1 + \frac{R_A}{R_B}$$

If Resistor and Capacitor values are different:

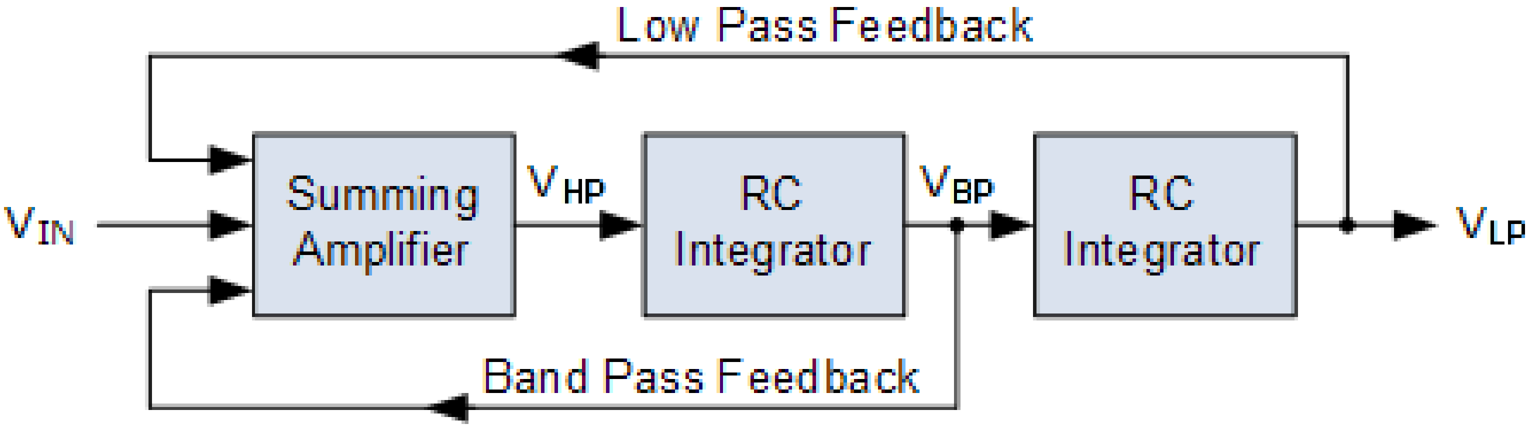
$$f_C = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

If Resistor and Capacitor values are the same:

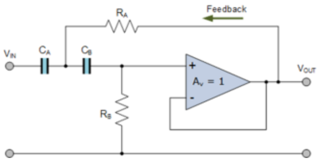
$$f_C = \frac{1}{2\pi RC}$$

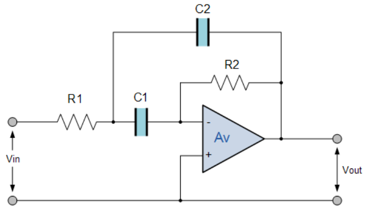


State Variable Filter



Sallen-Key Filter VS Multiple Feedback Filter





Sallen-Key	Multiple Feedback
Non-inverting	Inverting
Very precise DC-gain of 1	Any gain is dependent on the resistor precision
Less components for gain = 1	Less components for gain > 1 or < 1
Op-amp input capacitance must possibly be taken into account	Op-amp input capacitance has almost no effect
Resistive load for sources even in high-pass filters	Capacitive loads can become very high for sources in high-pass filters

Frequency Transformation

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Typical values of low-pass filter parameters

$$H_{LP}(f) := \frac{K}{b_1 \cdot \left(\left(\frac{2 \cdot \pi \cdot f \cdot i}{\omega_p}\right)^2\right) + a_1 \cdot \frac{(2 \cdot \pi \cdot f \cdot i)}{\omega_p} + 1}$$

Butterworth

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,4142	1,0000	1,000	0,71
3	1	1,0000	0,0000	1,000	–
	2	1,0000	1,0000	1,272	1,00
4	1	1,8478	1,0000	0,719	0,54
	2	0,7654	1,0000	1,390	1,31
5	1	1,0000	0,0000	1,000	–
	2	1,6180	1,0000	0,859	0,62
	3	0,6180	1,0000	1,448	1,62
6	1	1,9319	1,0000	0,676	0,52
	2	1,4142	1,0000	1,000	0,71
	3	0,5176	1,0000	1,479	1,93
7	1	1,0000	0,0000	1,000	–
	2	1,8019	1,0000	0,745	0,55
	3	1,2470	1,0000	1,117	0,80
	4	0,4450	1,0000	1,499	2,25
8	1	1,9616	1,0000	0,661	0,51
	2	1,6629	1,0000	0,829	0,60
	3	1,1111	1,0000	1,206	0,90
	4	0,3902	1,0000	1,512	2,56
9	1	1,0000	0,0000	1,000	–
	2	1,8794	1,0000	0,703	0,53
	3	1,5321	1,0000	0,917	0,65
	4	1,0000	1,0000	1,272	1,00
	5	0,3473	1,0000	1,521	2,88
10	1	1,9754	1,0000	0,655	0,51
	2	1,7820	1,0000	0,756	0,56
	3	1,4142	1,0000	1,000	0,71
	4	0,9080	1,0000	1,322	1,10
	5	0,3129	1,0000	1,527	3,20

Chebyshev

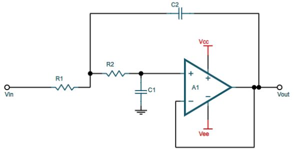
n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,0650	1,9305	1,000	1,30
3	1	3,3496	0,0000	0,299	–
	2	0,3559	1,1923	1,396	3,07
4	1	2,1853	5,5339	0,557	1,08
	2	0,1964	1,2009	1,410	5,58
5	1	5,6334	0,0000	0,178	–
	2	0,7620	2,6530	0,917	2,14
	3	0,1172	1,0686	1,500	8,82
6	1	3,2721	11,6773	0,379	1,04
	2	0,4077	1,9873	1,086	3,46
	3	0,0815	1,0861	1,489	12,78
7	1	7,9064	0,0000	0,126	–
	2	1,1159	4,8963	0,670	1,98
	3	0,2515	1,5944	1,222	5,02
	4	0,0582	1,0348	1,527	17,46
8	1	4,3583	20,2948	0,286	1,03
	2	0,5791	3,1808	0,855	3,08
	3	0,1765	1,4507	1,285	6,83
	4	0,0448	1,0478	1,517	22,87
9	1	10,1759	0,0000	0,098	–
	2	1,4585	7,8971	0,526	1,93
	3	0,3561	2,3651	1,001	4,32
	4	0,1294	1,3165	1,351	8,87
	5	0,0348	1,0210	1,537	29,00
10	1	5,4449	31,3788	0,230	1,03
	2	0,7414	4,7363	0,699	2,94
	3	0,2479	1,9952	1,094	5,70
	4	0,1008	1,2638	1,380	11,15
	5	0,0283	1,0304	1,530	35,85

Bessel

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,3617	0,6180	1,000	0,58
3	1	0,7560	0,0000	1,323	–
	2	0,9996	0,4772	1,414	0,69
4	1	1,3397	0,4889	0,978	0,52
	2	0,7743	0,3890	1,797	0,81
5	1	0,6656	0,0000	1,502	–
	2	1,1402	0,4128	1,184	0,56
	3	0,6216	0,3245	2,138	0,92
6	1	1,2217	0,3887	1,063	0,51
	2	0,9686	0,3505	1,431	0,61
	3	0,5131	0,2756	2,447	1,02
7	1	0,5937	0,0000	1,684	–
	2	1,0944	0,3395	1,207	0,53
	3	0,8304	0,3011	1,695	0,66
	4	0,4332	0,2381	2,731	1,13
8	1	1,1112	0,3162	1,164	0,51
	2	0,9754	0,2979	1,381	0,56
	3	0,7202	0,2621	1,963	0,71
	4	0,3728	0,2087	2,992	1,23
9	1	0,5386	0,0000	1,857	–
	2	1,0244	0,2834	1,277	0,52
	3	0,8710	0,2636	1,574	0,59
	4	0,6320	0,2311	2,226	0,76
	5	0,3257	0,1854	3,237	1,32
10	1	1,0215	0,2650	1,264	0,50
	2	0,9393	0,2549	1,412	0,54
	3	0,7815	0,2351	1,780	0,62
	4	0,5604	0,2059	2,479	0,81
	5	0,2883	0,1665	3,466	1,42

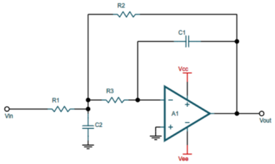
Typical values of low-pass filter parameters

Lowpass Filter



Sallen-Key

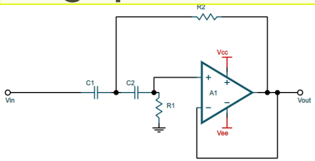
$$H_{LP\_SK}(f) := \frac{K}{(2\cdot\pi\cdot f\cdot i)^2\cdot R_{1LP}\cdot R_{2LP}\cdot C_{1LP}\cdot C_{2LP} + C_{2LP}\cdot\left(R_{1LP}+R_{2LP}\right)\cdot(2\cdot\pi\cdot f\cdot i)+1}$$



Multiple Feedback

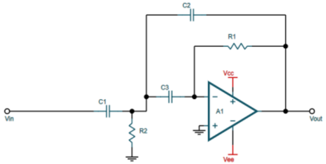
$$H_{LP\_MF}(f) := \frac{\dfrac{R_{2LP}}{R_{1LP}}}{(2\cdot\pi\cdot f\cdot i)^2\cdot R_{2LP}\cdot R_{3LP}\cdot C_{1LP}\cdot C_{2LP} + C_{1LP}\cdot\left(R_{2LP}+R_{3LP}+\dfrac{R_{2LP}\cdot R_{3LP}}{R_{1LP}}\right)\cdot(2\cdot\pi\cdot f\cdot i)+1}$$

Highpass Filter



Sallen-Key

$$H_{HP\_SK}(f) := \frac{K}{\dfrac{1}{(2\cdot\pi\cdot f\cdot i)^2\cdot R_{1HP}\cdot R_{2HP}\cdot C_{1HP}\cdot C_{2HP}} + \dfrac{R_{2HP}\cdot\left(C_{1HP}+C_{2HP}\right)+(1-K)\cdot R_{1HP}\cdot C_{2HP}}{R_{1HP}\cdot R_{2HP}\cdot C_{1HP}\cdot C_{2HP}\cdot 2\cdot\pi\cdot f\cdot i}+1}$$



Multiple Feedback

$$H_{HP\_MF}(f) := \frac{(2\cdot\pi\cdot f\cdot i)^2\cdot R_{1HP}\cdot R_{2HP}\cdot C_{1HP}\cdot C_{3HP}}{(2\cdot\pi\cdot f\cdot i)^2\cdot R_{1HP}\cdot R_{2HP}\cdot C_{2HP}\cdot C_{3HP} + R_{2HP}\cdot\left(C_{1HP}+C_{2HP}+C_{3HP}\right)\cdot(2\cdot\pi\cdot f\cdot i)+1}$$

Frequency Transformation

Type of Transformation	Frequency transform
The Lowpass to Highpass (LP-HP) Frequency Transformation	$s \Leftrightarrow \dfrac{1}{s}$ $H_{HP}(s) = H_{LP}\left(\dfrac{1}{s}\right)$
The Lowpass to Bandpass (LP-BP) Frequency Transformation	$s \Leftrightarrow \dfrac{s^2+\omega_0^2}{sBW}$ $H_{BP}(s) = H_{LP}\left(\dfrac{s^2+\omega_0^2}{sBW}\right)$
The Lowpass to Band-Reject (LP-BR) Frequency Transformation	$s \Leftrightarrow \dfrac{sBW}{s^2+\omega_0^2}$ $H_{BR}(s) = H_{LP}\left(\dfrac{sBW}{s^2+\omega_0^2}\right)$

Typical values of High-pass filter parameters

$$H_{HP}(f) := \frac{K}{\dfrac{b_1}{\left(\left(\dfrac{2 \cdot \pi \cdot f \cdot i}{\omega_p}\right)\right)^2} + \dfrac{a_1}{\dfrac{(2 \cdot \pi \cdot f \cdot i)}{\omega_p}} + 1}$$

Butterworth

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,4142	1,0000	1,000	0,71
3	1	1,0000	0,0000	1,000	–
	2	1,0000	1,0000	1,272	1,00
4	1	1,8478	1,0000	0,719	0,54
	2	0,7654	1,0000	1,390	1,31
5	1	1,0000	0,0000	1,000	–
	2	1,6180	1,0000	0,859	0,62
	3	0,6180	1,0000	1,448	1,62
6	1	1,9319	1,0000	0,676	0,52
	2	1,4142	1,0000	1,000	0,71
	3	0,5176	1,0000	1,479	1,93
7	1	1,0000	0,0000	1,000	–
	2	1,8019	1,0000	0,745	0,55
	3	1,2470	1,0000	1,117	0,80
	4	0,4450	1,0000	1,499	2,25
8	1	1,9616	1,0000	0,661	0,51
	2	1,6629	1,0000	0,829	0,60
	3	1,1111	1,0000	1,206	0,90
	4	0,3902	1,0000	1,512	2,56
9	1	1,0000	0,0000	1,000	–
	2	1,8794	1,0000	0,703	0,53
	3	1,5321	1,0000	0,917	0,65
	4	1,0000	1,0000	1,272	1,00
	5	0,3473	1,0000	1,521	2,88
10	1	1,9754	1,0000	0,655	0,51
	2	1,7820	1,0000	0,756	0,56
	3	1,4142	1,0000	1,000	0,71
	4	0,9080	1,0000	1,322	1,10
	5	0,3129	1,0000	1,527	3,20

Chebyshev

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,0650	1,9305	1,000	1,30
3	1	3,3496	0,0000	0,299	–
	2	0,3559	1,1923	1,396	3,07
4	1	2,1853	5,5339	0,557	1,08
	2	0,1964	1,2009	1,410	5,58
5	1	5,6334	0,0000	0,178	–
	2	0,7620	2,6530	0,917	2,14
	3	0,1172	1,0686	1,500	8,82
6	1	3,2721	11,6773	0,379	1,04
	2	0,4077	1,9873	1,086	3,46
	3	0,0815	1,0861	1,489	12,78
7	1	7,9064	0,0000	0,126	–
	2	1,1159	4,8963	0,670	1,98
	3	0,2515	1,5944	1,222	5,02
	4	0,0582	1,0348	1,527	17,46
8	1	4,3583	20,2948	0,286	1,03
	2	0,5791	3,1808	0,855	3,08
	3	0,1765	1,4507	1,285	6,83
	4	0,0448	1,0478	1,517	22,87
9	1	10,1759	0,0000	0,098	–
	2	1,4585	7,8971	0,526	1,93
	3	0,3561	2,3651	1,001	4,32
	4	0,1294	1,3165	1,351	8,87
	5	0,0348	1,0210	1,537	29,00
10	1	5,4449	31,3788	0,230	1,03
	2	0,7414	4,7363	0,699	2,94
	3	0,2479	1,9952	1,094	5,70
	4	0,1008	1,2638	1,380	11,15
	5	0,0283	1,0304	1,530	35,85

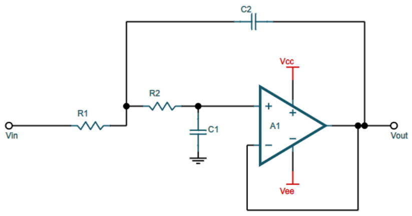
Bessel

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,3617	0,6180	1,000	0,58
3	1	0,7560	0,0000	1,323	–
	2	0,9996	0,4772	1,414	0,69
4	1	1,3397	0,4889	0,978	0,52
	2	0,7743	0,3890	1,797	0,81
5	1	0,6656	0,0000	1,502	–
	2	1,1402	0,4128	1,184	0,56
	3	0,6216	0,3245	2,138	0,92
6	1	1,2217	0,3887	1,063	0,51
	2	0,9686	0,3505	1,431	0,61
	3	0,5131	0,2756	2,447	1,02
7	1	0,5937	0,0000	1,684	–
	2	1,0944	0,3395	1,207	0,53
	3	0,8304	0,3011	1,695	0,66
	4	0,4332	0,2381	2,731	1,13
8	1	1,1112	0,3162	1,164	0,51
	2	0,9754	0,2979	1,381	0,56
	3	0,7202	0,2621	1,963	0,71
	4	0,3728	0,2087	2,992	1,23
9	1	0,5386	0,0000	1,857	–
	2	1,0244	0,2834	1,277	0,52
	3	0,8710	0,2636	1,574	0,59
	4	0,6320	0,2311	2,226	0,76
	5	0,3257	0,1854	3,237	1,32
10	1	1,0215	0,2650	1,264	0,50
	2	0,9393	0,2549	1,412	0,54
	3	0,7815	0,2351	1,780	0,62
	4	0,5604	0,2059	2,479	0,81
	5	0,2883	0,1665	3,466	1,42

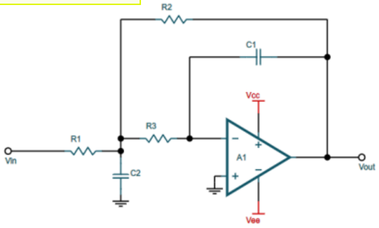
Typical values of low-pass filter parameters

Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency , [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	Lowpass Highpass	Vcc	Vee	$\lvert K_{NI} \rvert$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%

Lowpass Filter

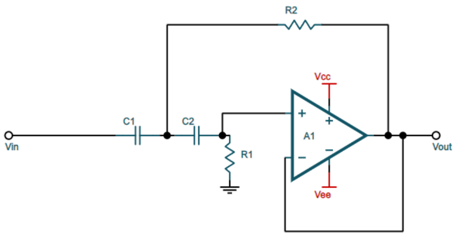


Sallen-Key

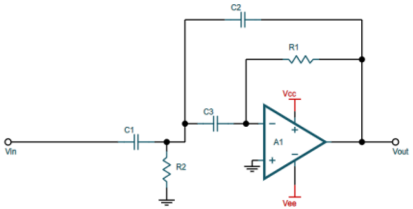


Multiple Feedback

Highpass Filter



Sallen-Key

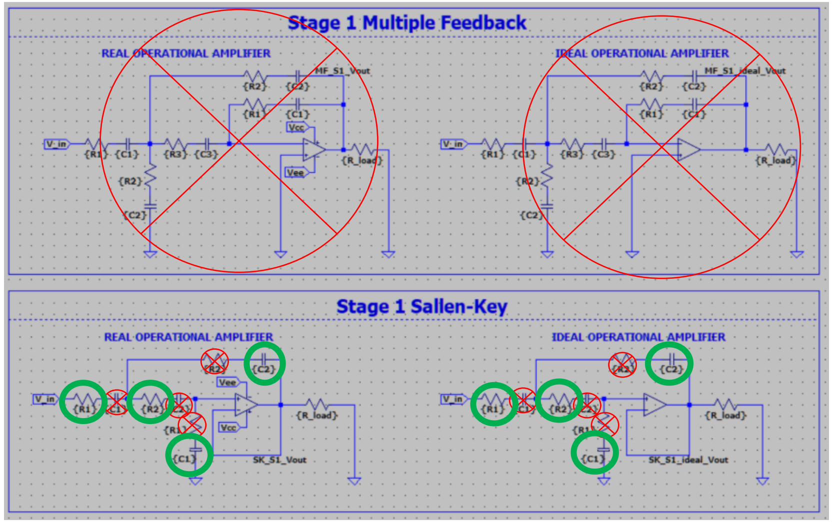


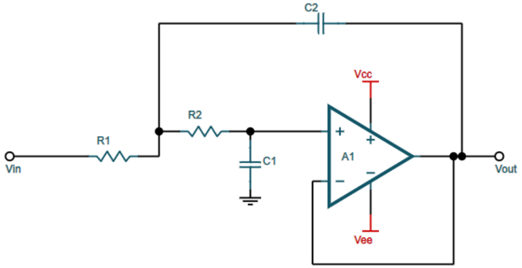
Multiple Feedback

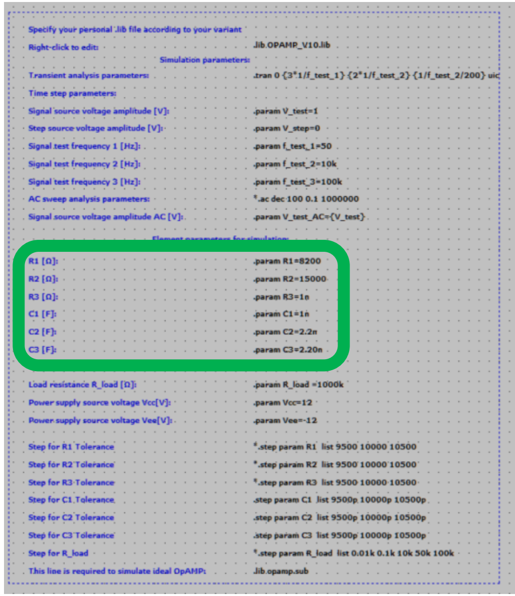
Collect the scheme

Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency , [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	Lowpass Highpass	Vcc	Vee	$\|K_{NI}\|$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%

Lowpass Filter

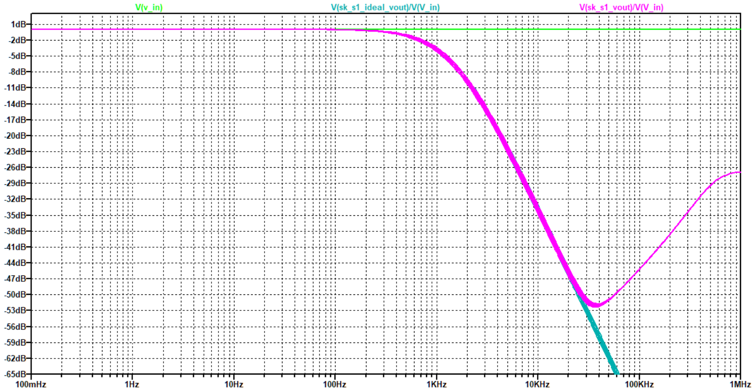


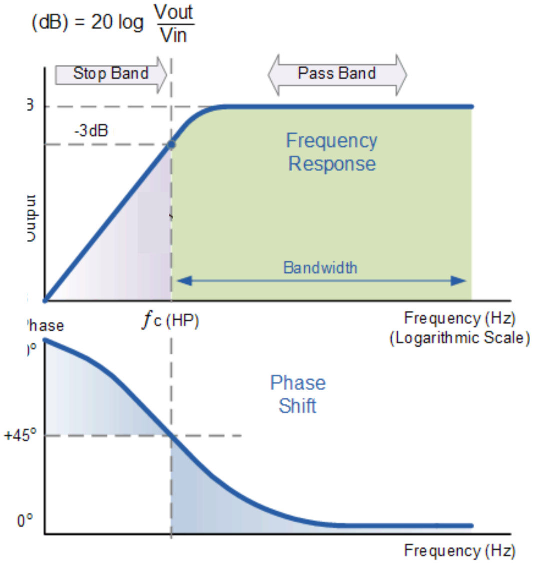


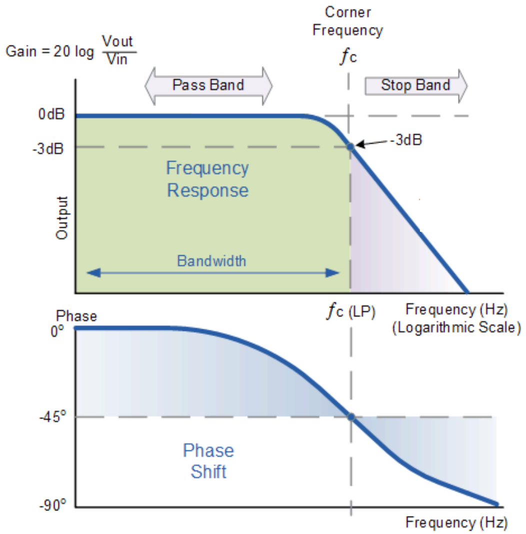


Define the filter passband

Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency, [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	Lowpass Highpass	Vcc	Vee	$\|K_{NI}\|$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%







Define the filter approximation

Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency, [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	Lowpass Highpass	Vcc	Vee	$\lvert K_{NI}\rvert$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%

Butterworth

n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,4142	1,0000	1,000	0,71

Chebyshev

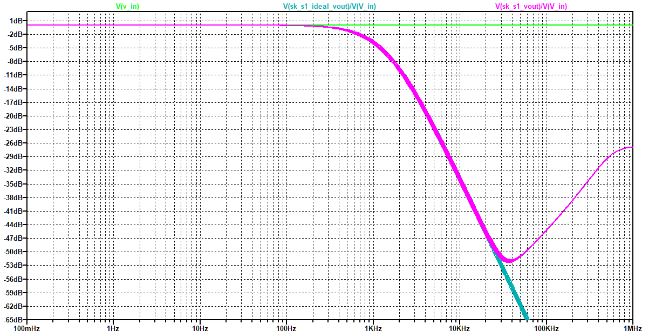
n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,0650	1,9305	1,000	1,30

Bessel

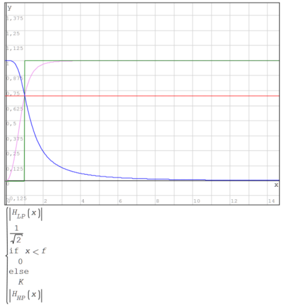
n	i	a_i	b_i	f_{gi}/f_g	Q_i
1	1	1,0000	0,0000	1,000	–
2	1	1,3617	0,6180	1,000	0,58

$$H_{LP}(f) := \frac{K}{b_1 \cdot \left(\left(\frac{2 \cdot \pi \cdot f \cdot i}{\omega_p}\right)^2\right) + a_1 \cdot \frac{(2 \cdot \pi \cdot f \cdot i)}{\omega_p} + 1}$$

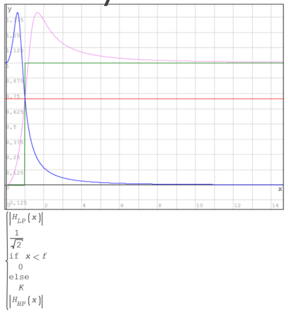
$$H_{HP}(f) := \frac{K}{\frac{b_1}{\left(\left(\frac{2 \cdot \pi \cdot f \cdot i}{\omega_p}\right)^2\right)} + \frac{a_1}{\frac{(2 \cdot \pi \cdot f \cdot i)}{\omega_p}} + 1}$$



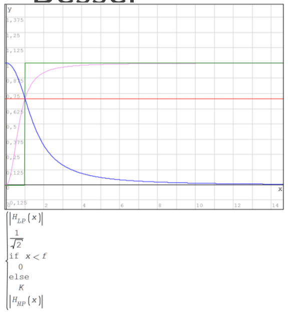
Butterworth



Chebyshev

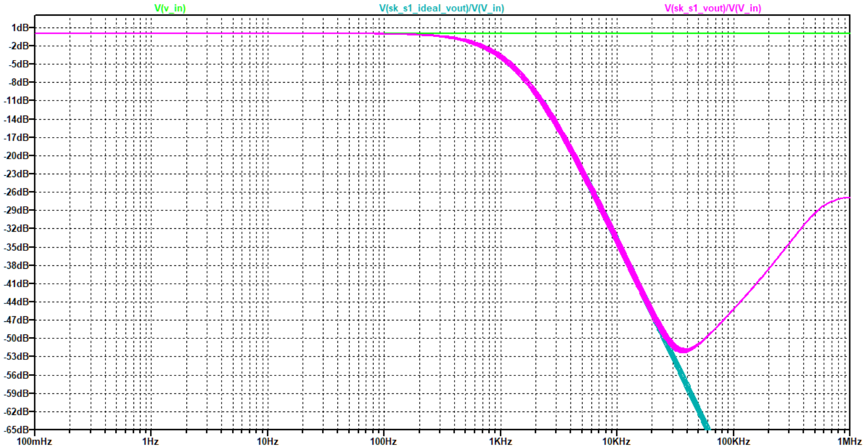


Bessel

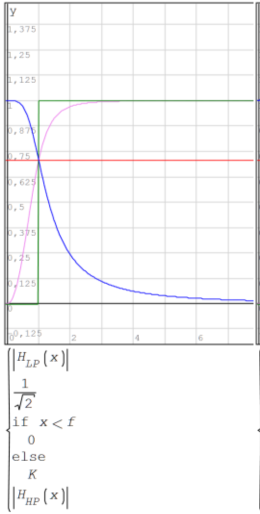


Define the filter approximation

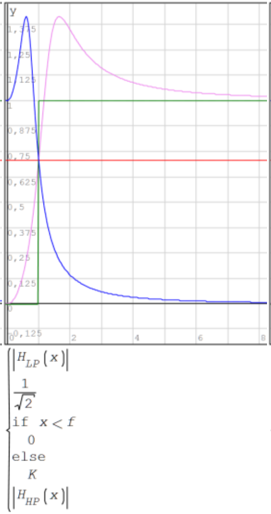
Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency , [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	Lowpass Highpass	Vcc	Vee	$\|K_{NI}\|$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%



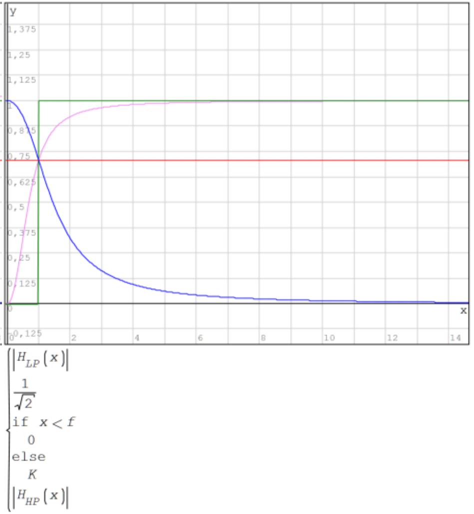
Butterworth



Chebyshev

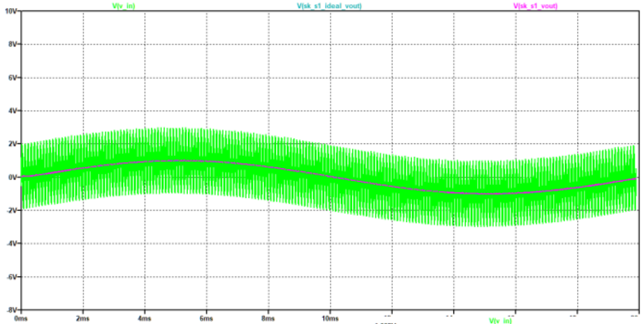


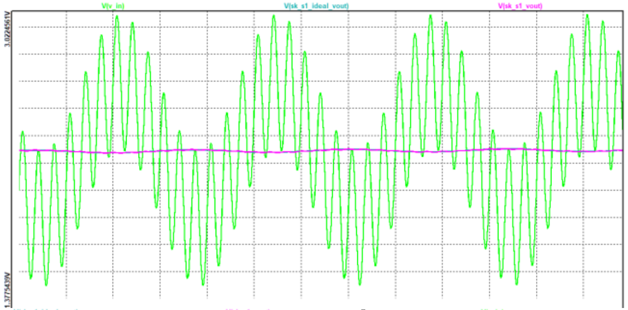
Bessel

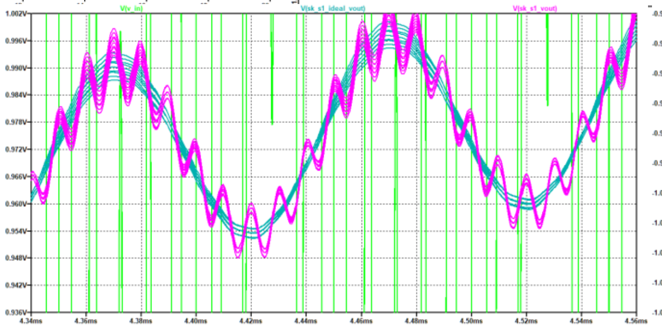


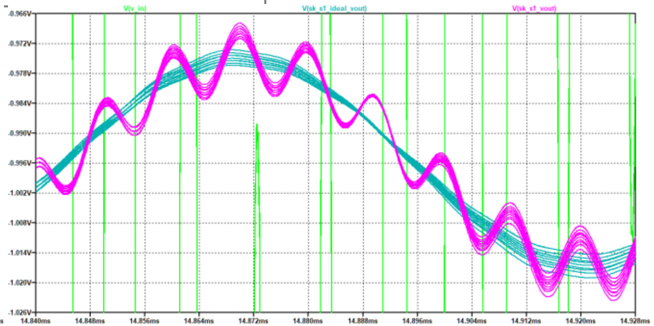
Define the filter approximation

Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency , [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	**Lowpass Highpass**	Vcc	Vee	$\|K_{NI}\|$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%



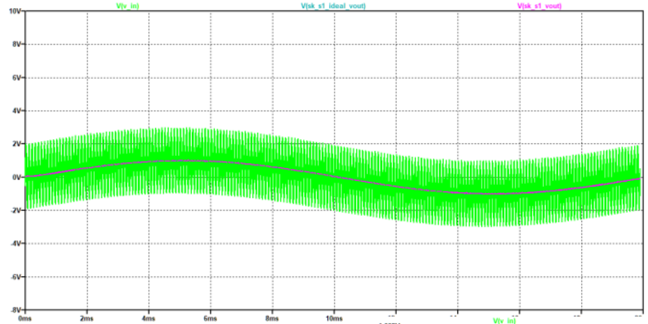


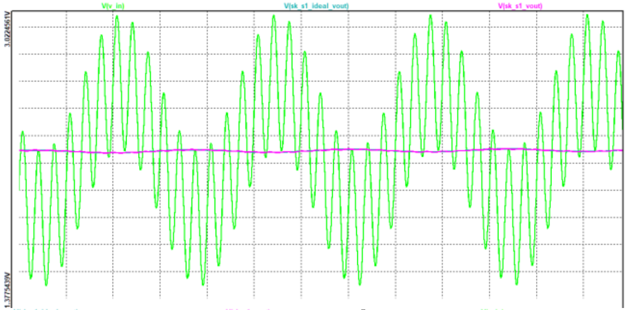


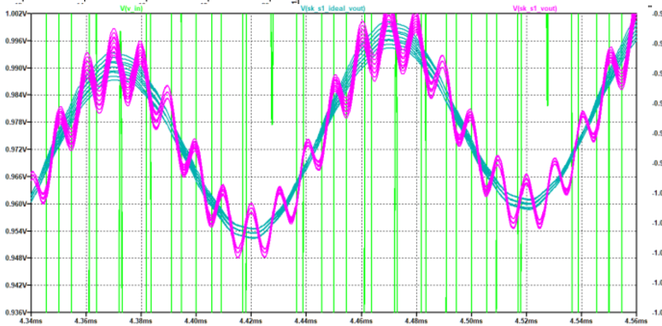


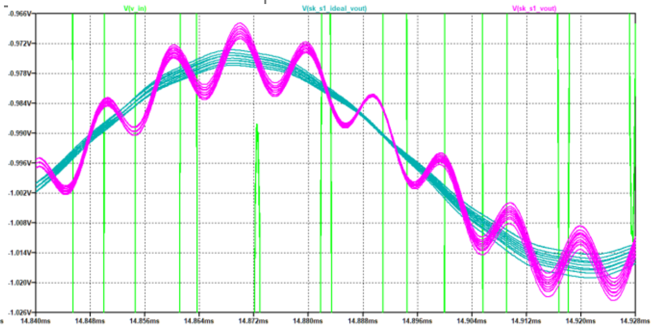
Define the filter approximation

Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency , [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	**Lowpass Highpass**	Vcc	Vee	$\lvert K_{NI} \rvert$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%



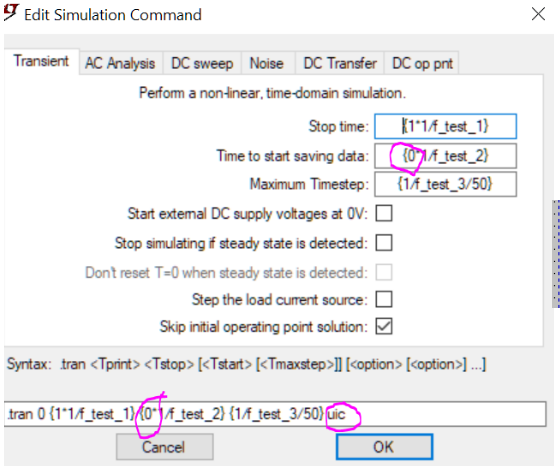






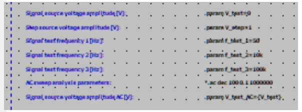
Define the step response

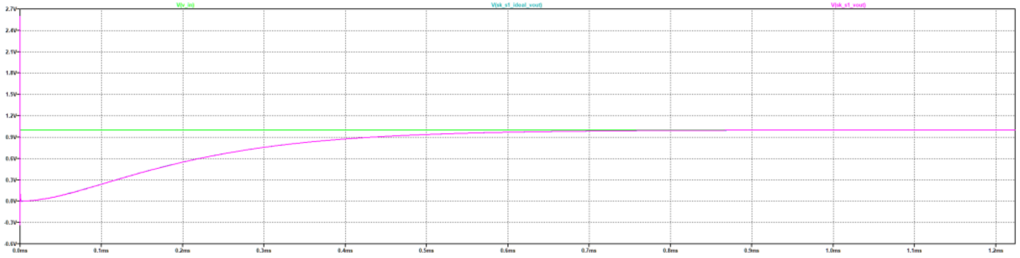
Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency, [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	Lowpass Highpass	Vcc	Vee	$\lvert K_{NI} \rvert$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%

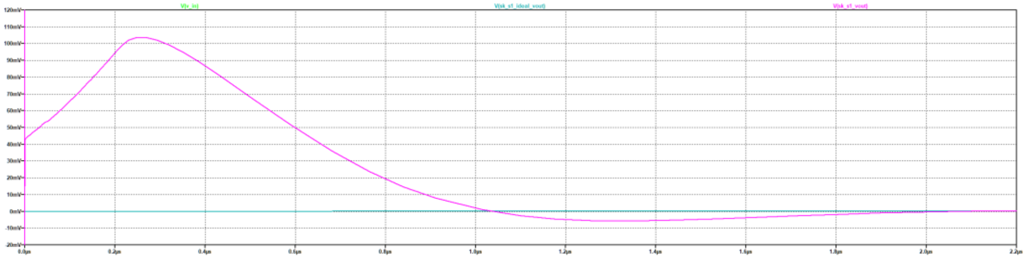


V_step=1

V_test=0







Conclusions

Filter scheme	Filter type	Voltage source power supply [V]		Required absolute gain of amplifier (sign of the gain is not considered)	Source voltage frequency, [Hz]	Source voltage frequency , [Hz]	Source voltage frequency, [Hz]	Source voltage amplitude, [V]	Load resistance, [Ω]	Filter resistance, [Ω]				Filter capacitance, [Ω]			
Sallen-Key Multiple Feedback	Lowpass Highpass	Vcc	Vee	$\lvert K_{NI} \rvert$	f_{test_1}	f_{test_2}	f_{test_3}	$V_{testAC}=V_{test}$	R_{Load}	R_1	R_2	R_3	Resistor tolerance	C_1	C_2	C_3	Capacitor tolerance
Sallen-Key	Lowpass	6	-6	1,000	50	1000	100000	2,000	1000000	8200	15000	-	5%	1e-9	2,20E-09	-	20%
Multiple Feedback	Highpass	6	-6	1,000	60	1200	120000	2,000	1000000	3300	820	-	5%	1,50E-08	1,50E-08	2,20E-08	20%

Conclusions should contain:

- Which filter type were used?
- What was the bandwidth?
- What was the maximum/minimum gain relation in the passband?

Lab 3 submission form

https://forms.yandex.com/cloud/637a65df5d2a068973e26fba/

https://clck.ru/32jqcy

1st deadline: 02.12.2022 23:59 (GMT +8)

Thanks for your attention!