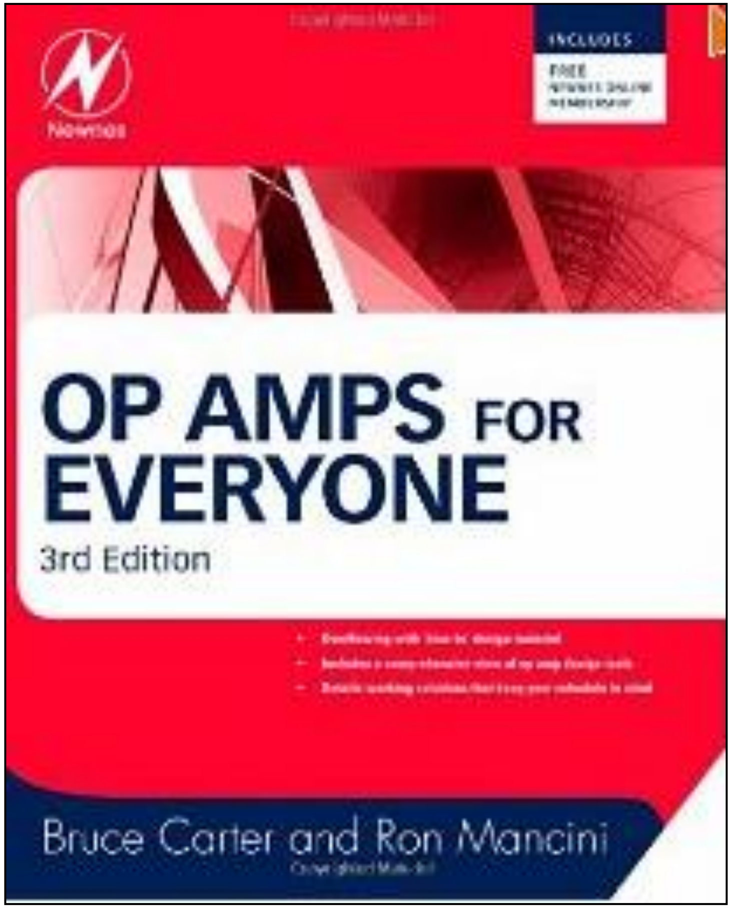
Laboratório 3
Filtros Ativos Passa-Alta

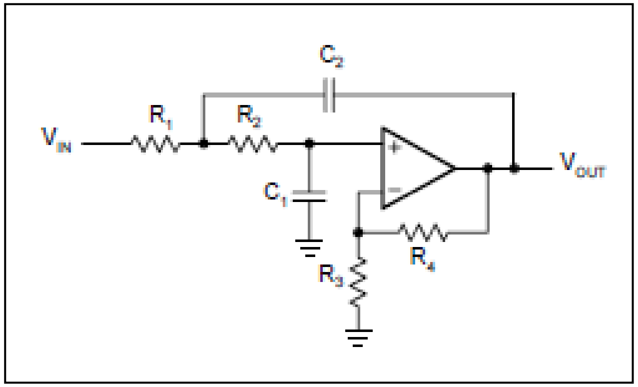
Referência

[OP AMPs for Everyone]

Newnes, 2009

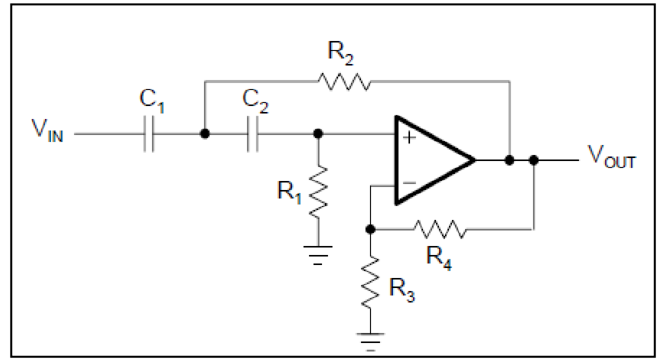


1 By replacing the resistors of a low-pass filter with capacitors, and its capacitors with resistors a high-pass filter is created



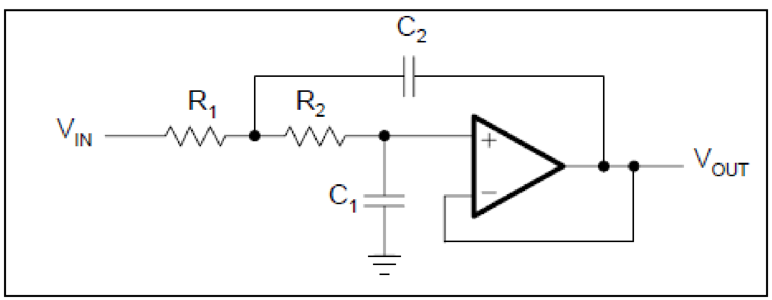
General Sallen-Key Low Pass Topology

(G≠1)



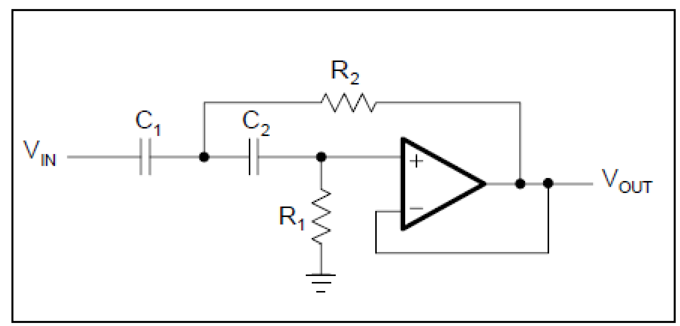
General Sallen-Key High Pass Topology

(G≠1)



Unit Gain Sallen-Key Low Pass Topology

(G=1)



Unit Gain Sallen-Key High Pass Topology

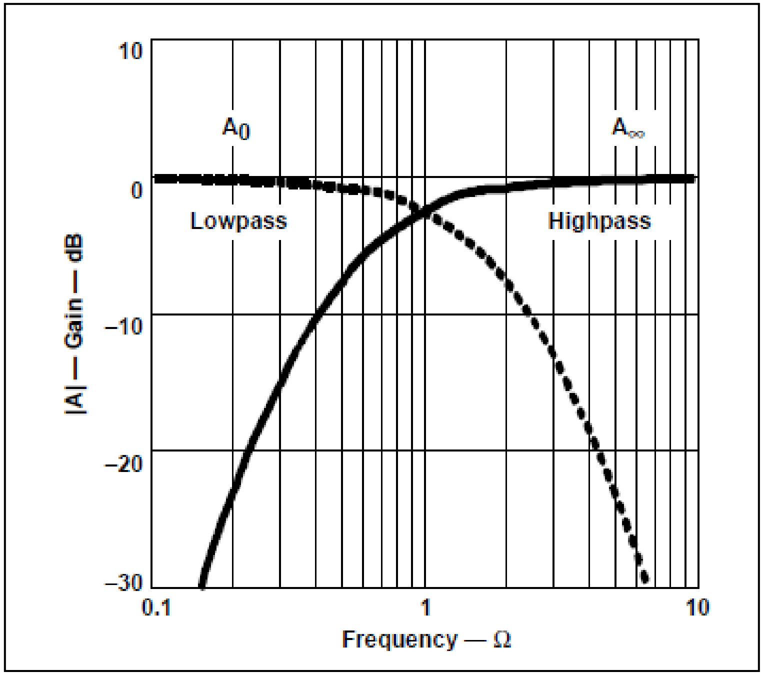
(G=1)

2 To plot the gain response of a high-pass filter mirror the gain response of a low-pass filter **replacing Ω with 1/Ω** and **s with 1/s**

$$A(s) = \frac{A_0}{\prod_i \left(1 + a_i s + b_i s^2\right)}$$

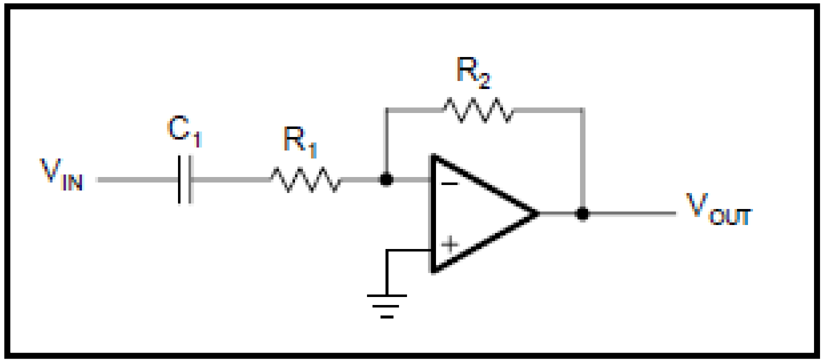
→

$$A(s) = \frac{A_\infty}{\prod_i \left(1 + \frac{a_i}{s} + \frac{b_i}{s^2}\right)}$$



High Pass Filters
First Order Topology

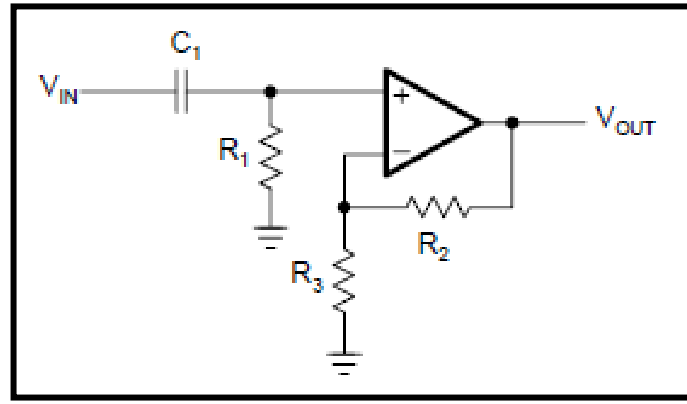
Inverting



$$A(s) = -\frac{-\frac{R_2}{R_1}}{1 + \frac{1}{\omega_c R_1 C_1} \cdot \frac{1}{s}}$$

$$A_\infty = -\frac{R_2}{R_1}$$

Noninverting

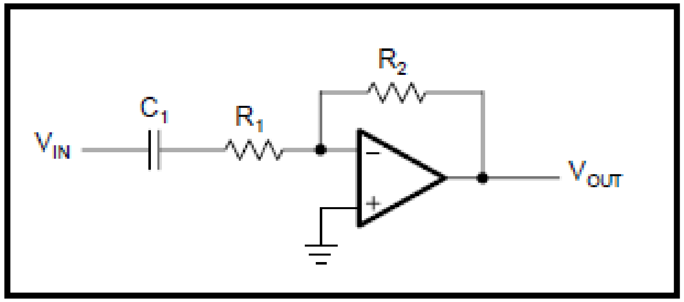


$$A(s) = \frac{1 + \frac{R_2}{R_3}}{1 + \frac{1}{\omega_c R_1 C_1} \cdot \frac{1}{s}}$$

$$A_\infty = 1 + \frac{R_2}{R_3}$$

Designing
High Pass Filters
First Order Topology

Inverting

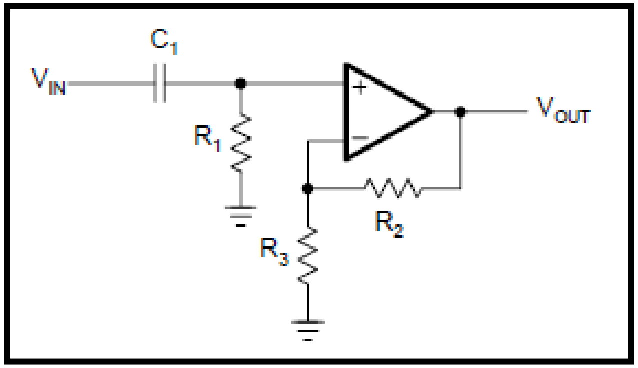


1 Specify f_C, A_∞, C_1

2 $$R_1 = \frac{1}{2\pi f_C a_1 C_1}$$

3 $$R_2 = -R_1 A_\infty$$

Noninverting



1 Specify f_C, A_∞, C_1

2 $$R_1 = \frac{1}{2\pi f_C a_1 C_1}$$

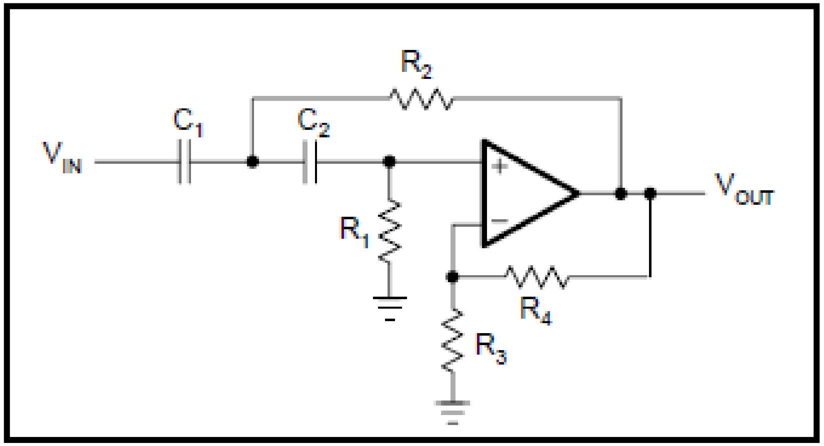
3 $$R_2 = R_3(A_\infty - 1)$$

Pick R_2 and detemine R_3

High Pass Filters
Second Order Topology

Sallen-Key Topology

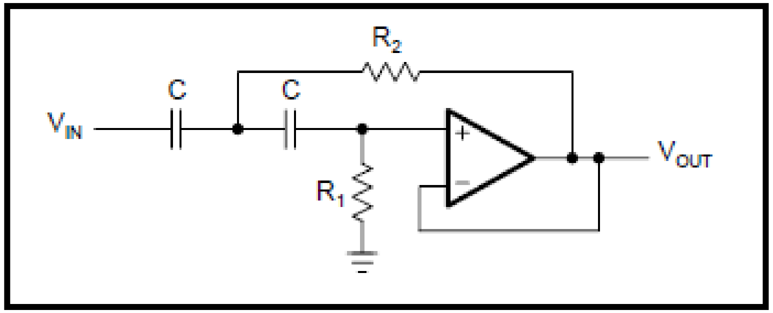
General Sallen-Key Topology



$$A(s) = \frac{\alpha}{1 + \frac{R_2(C_1+C_2)+R_1C_2(1-\alpha)}{\omega_c R_1 R_2 C_1 C_2}\cdot\frac{1}{s} + \frac{1}{\omega_c^2 R_1 R_2 C_1 C_2}\cdot\frac{1}{s^2}}$$

$$\alpha = 1 + \frac{R_4}{R_3}$$

Unit Gain Sallen-Key Topology

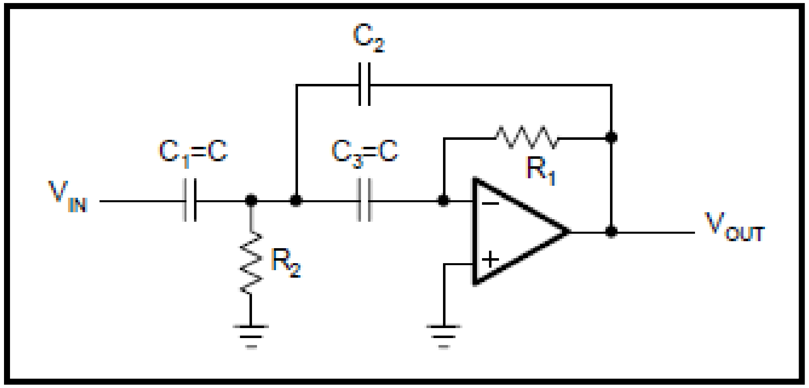


$$A(s) = \frac{1}{1 + \frac{2}{\omega_c R_1 C}\cdot\frac{1}{s} + \frac{1}{\omega_c^2 R_1 R_2 C^2}\cdot\frac{1}{s^2}}$$

$$\alpha = 1$$

Multiple Feedbak Topology

The MFB topology is commonly used in filters that have high Qs and require a high gain

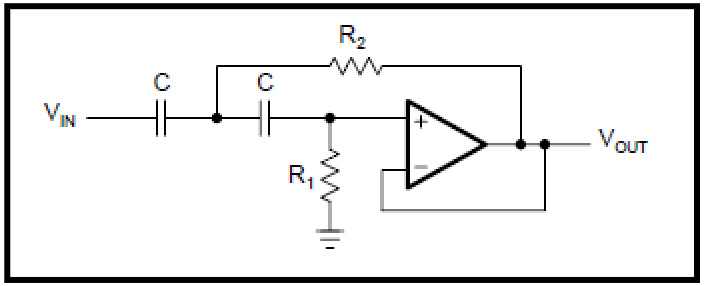


$$A(s) = -\frac{\frac{C}{C_2}}{1 + \frac{2C + C_2}{\omega_c R_1 C C_2} \cdot \frac{1}{s} + \frac{2C + C_2}{\omega_c R_1 C C_2} \cdot \frac{1}{s^2}}$$

$$A_\infty = \frac{C}{C_2}$$

Designing
High Pass Filters
Second Order Topology

Sallen-Key Topology (unit gain)



$$A(s) = \frac{1}{1 + \frac{2}{\omega_c R_1 C} \cdot \frac{1}{s} + \frac{1}{\omega_c{}^2 R_1 R_2 C^2} \cdot \frac{1}{s^2}}$$

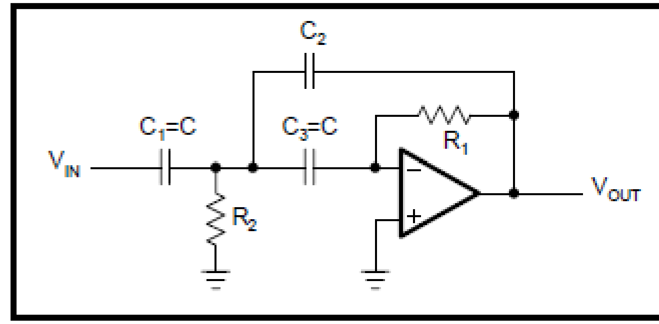
1 Get the filter coefficients

2 Specify C

3 $$R_1 = \frac{1}{\pi f_c C a_1}$$

4 $$R_2 = \frac{a_1}{4\pi f_c C b_1}$$

Multiple Feedbak Topology



$$A(s) = -\frac{\frac{C}{C_2}}{1 + \frac{2C + C_2}{\omega_c R_1 C C_2} \cdot \frac{1}{s} + \frac{2C + C_2}{\omega_c R_1 C C_2} \cdot \frac{1}{s^2}}$$

$$A_\infty = \frac{C}{C_2}$$

1 Get the filter coefficients

2 Pick C and C_2

3 $$R_1 = \frac{1 - 2A_\infty}{2\pi f_c \cdot C \cdot a_1}$$

4 $$R_2 = \frac{a_1}{2\pi f_c \cdot b_1 C_2 (1 - 2A_\infty)}$$

Designing
High Pass Filters
Higher Order Topology

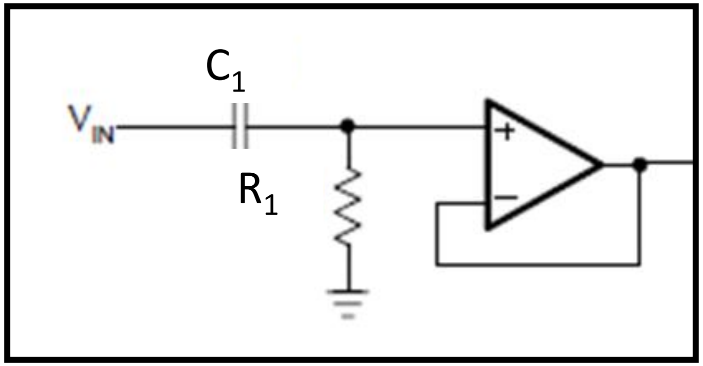
Exemple 1:
Design a third-order Sallen-Key unity-gain Bessel high-pass filter with the corner frequency f_C = 1 kHz.

1 Get the Bessel coefficients

Table 16–4. Bessel Coefficients

n	i	a_i	b_i	$k_i = f_{Ci} / f_C$	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

First Filter: first order non-inverting with unit gain

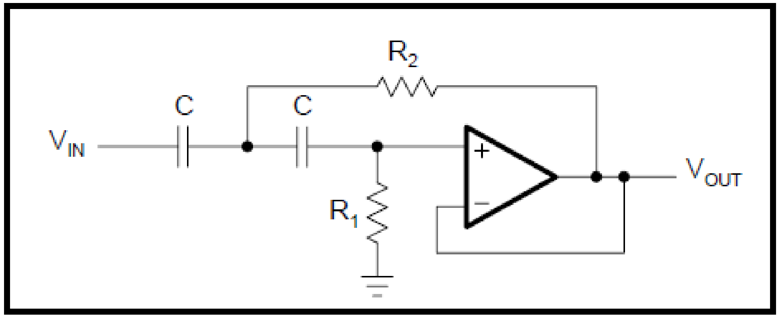


2 Bessel coefficientes: $a_1 = 0.756$, $b_1 = 0$

3 Pick C_1 → $C_1 = 100nF$

4 Get R_1 → $R_1 = \frac{1}{2\pi f_c a_1 C_1} = \frac{1}{2\pi \cdot 10^3 Hz \cdot 0.756 \cdot 100 \cdot 10^{-9} F} = 2.105\ k\Omega$

Second Filter: second order SK with unit gain



5 Bessel coefficientes: $a_2 = 0.996$, $b_2 = 0.4772$

6 Pick C → C = 100nF

7 $$R_1 = \frac{1}{\pi f_c C a_1} \rightarrow R_1 = \frac{1}{\pi f_c C a_1} = \frac{1}{\pi \cdot 10^3 \cdot 100 \cdot 10^{-9} \cdot 0.756} = 3.18\ k\Omega$$

8 $$R_2 = \frac{a_2}{4\pi f_c C a_2} \rightarrow R_2 = \frac{a_1}{4\pi f_c C b_1} = \frac{0.9996}{4\pi \cdot 10^3 \cdot 100 \cdot 10^{-9} \cdot 0.4772} = 1.67\ k\Omega$$

Third-order Sallen Key unity-gain Bessel high-pass filter with the corner frequency f_C = 1 kHz.