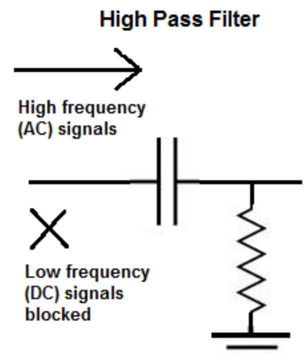
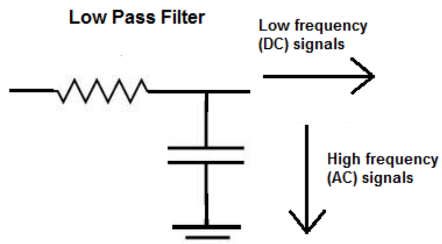
Coupling Capacitors and Decoupling Capacitors:

- *Coupling Capacitors*
  - Block DC signals, AC signals pass through
  - Connected in series with incoming signal
  - A theoretical 'extreme' (passive) high pass filter (all frequencies except DC) where the resistor value is very small >> 0.
    - If the resistor value was zero, all of the signal would just go to ground; impractical in reality
  - Used in AC amplifiers to stop signals from interfering with DC bias of transistors



- *Decoupling Capacitors* (AKA Bypass Capacitors)
  - Block AC signals, DC signals pass through
  - Connected in parallel to incoming signal
  - A theoretical 'extreme' (passive) low pass filter (only DC signal passes through) where the R value is very small
  - Used to smooth signals
    - Absorbs any excess (AC or rapidly changing) voltage and will shoot it into ground
    - Will provide voltage if the incoming signal drops off temporarily

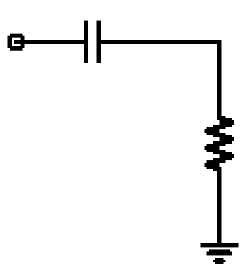


Passive vs. Active Filters

Passive filters work better in low frequency applications (< 100 kHz) and for circuits where you do not want an external power source or require signal amplification. Active filters use chips/OP-AMPS, which require a positive and negative supply, to amplify the signal and/or buffer it (recall voltage/current buffer circuits).

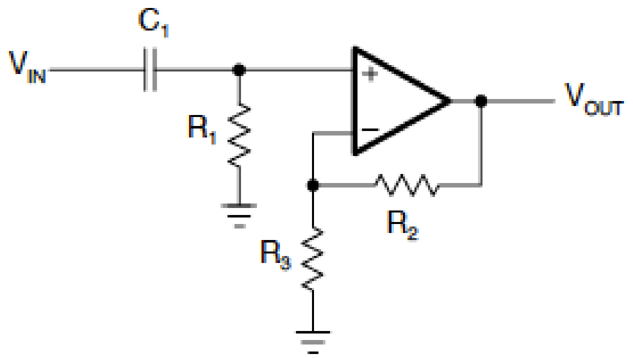
High Pass and Low Pass Filters

- Just coupling/decoupling capacitors with the addition of one or more resistors
- You must modify the capacitor and resistor values in order to get the desired cut-off frequency (f_c) of your circuit. The equation depends on the kind of filter you wish to build.
- *High Pass Filters*
  - Remove low frequency signals, allow high frequency signals to pass through
  - Passive, first order HPF



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

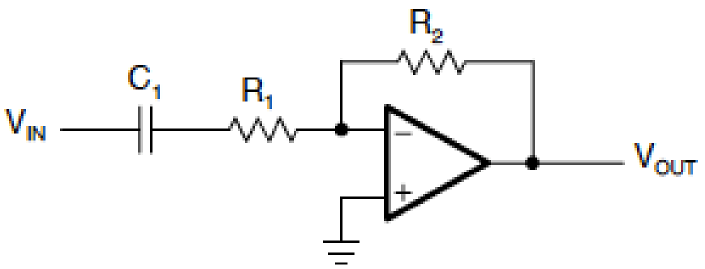
- Active, first-order, non-inverting HPF with amplification



$$G = 1 + \frac{R_2}{R_3}$$

$$f_H = \frac{1}{2\pi R_1 C_1}$$

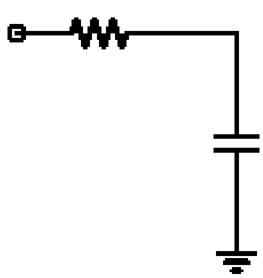
- Active, first order, inverting HPF with amplification



$$G = -\frac{R_2}{R_1}$$

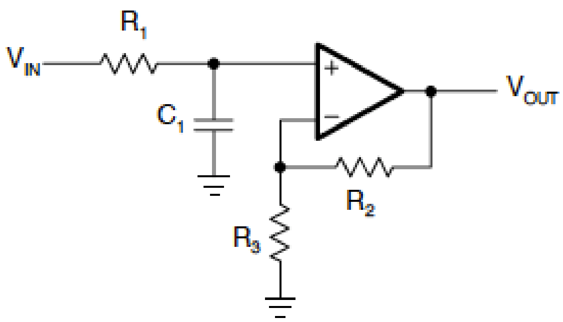
$$f_H = \frac{1}{2\pi R_1 C_1}$$

- *Low Pass Filters*
  - Remove high frequency signals, allow low frequency signals to pass through
  - Passive, first order LPF



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

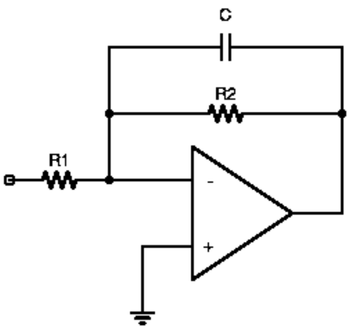
  - Active, first-order, non-inverting LPF with amplification



$$G = 1 + \frac{R_2}{R_3}$$

$$f_L = \frac{1}{2\pi R_1 C_1}$$

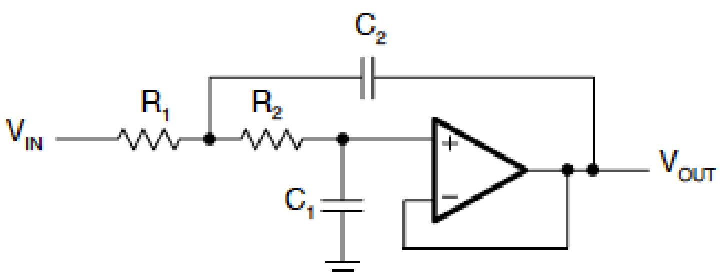
- Active, first order, inverting LPF with amplification



$$G = -\frac{R_2}{R_1}$$

$$f_L = \frac{1}{2\pi R_1 C_1}$$

- Active, second-order LPF
  - Circuit schematic for Sallen-Key topology with unity gain



$$R_1, R_2 = \frac{a_1 C_2 \pm \sqrt{(a_1 C_2)^2 - 4b_1 C_1 C_2}}{4\pi f_c C_1 C_2}$$

$$\text{where } C_2 \geq C_1 \frac{4b_1}{{a_1}^2}$$

Coefficients for Second-Order Filters

	Butterworth	*3 dB Chebyshev*
a_1	1.4142	1.065
b_1	1	1.9305
Q	0.71	1.3
R_4/R_3	0.568	0.234

Notes:

- An inverting amplifier shifts the phase of the input signal by 180 degrees, which is the same as flipping the signal along its x-axis (inverting it).
- Increasing the order of the circuit increases the slope of the cut-off. This can also be modified using different types of filters:

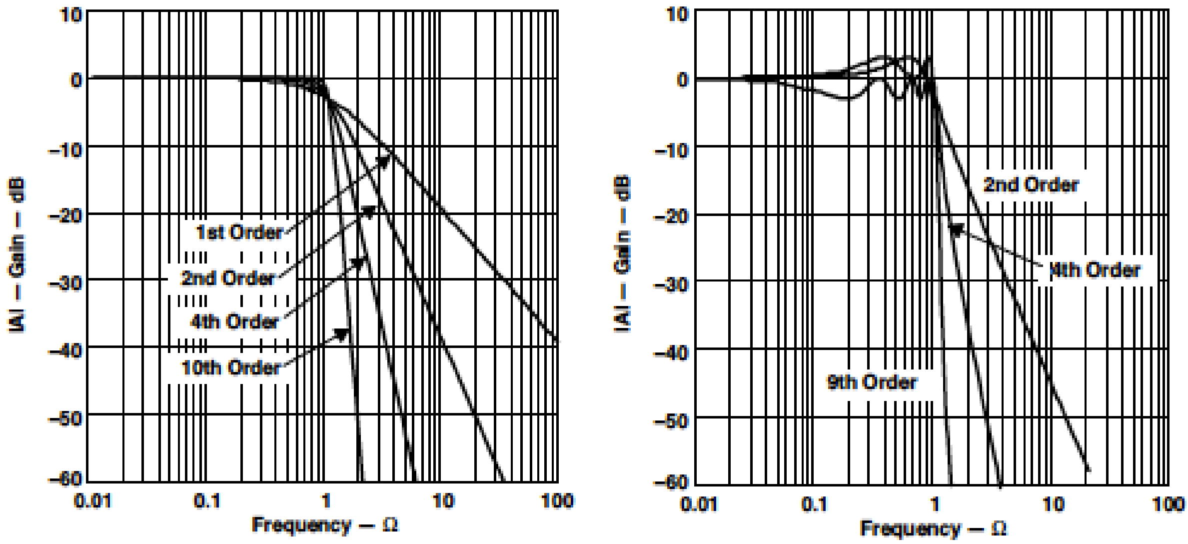


Figure: Amplitude response of a Butterworth and Chebyshev LPF

- Butterworth
  - Provides maximum pass band flatness. This allow for a clean, consistent signal to pass through.
  - In Fig. X, the higher the order, the longer the pass band at the same cut-off frequency and the steeper the cut-off.
- Chebyshev
  - Provides a steeper slop at the cut-off, but inconsistent signal amplitude at the pass band.
  - In Fig. X, the higher the order, the more ripples in pass band at the same cut-off frequency and the steeper the cut-off.
  - Each ripple equals one second-order filter stage. I.e. two ripples means it's a fourth-order filter.
    - Filters with an even order create ripples above the 0 dB line and filters with an odd order create ripples below the 0 dB line.

- To easily create a higher order filter you just cascade lower order filters.

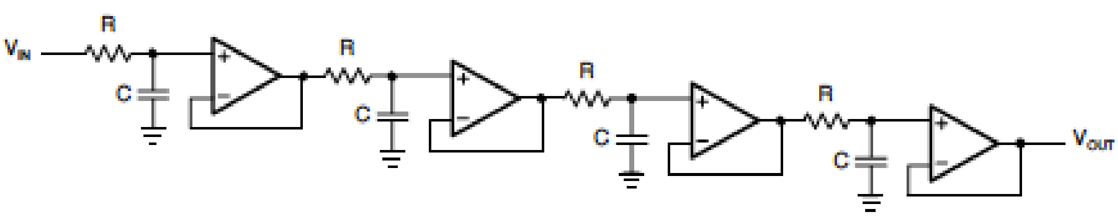


Figure: A fourth-order low pass filter circuit, non-inverting, unity gain