BASIC ELECTRONIC CIRCUITS

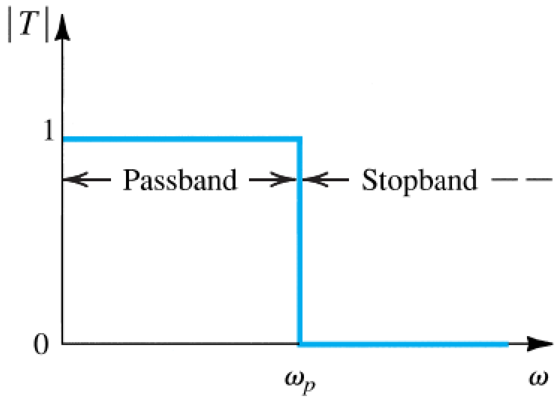
OP-AMP Applications: Active filters

contents

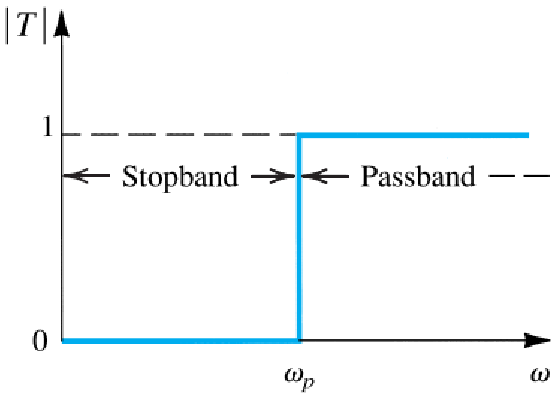
Filters

- Pass band: A frequency band over which the magnitude of transmission is unity
- Stop band: A frequency band over which the magnitude of the transmission is zero.
- Major filter types are: Low pass, High pass, Band pass and Band reject

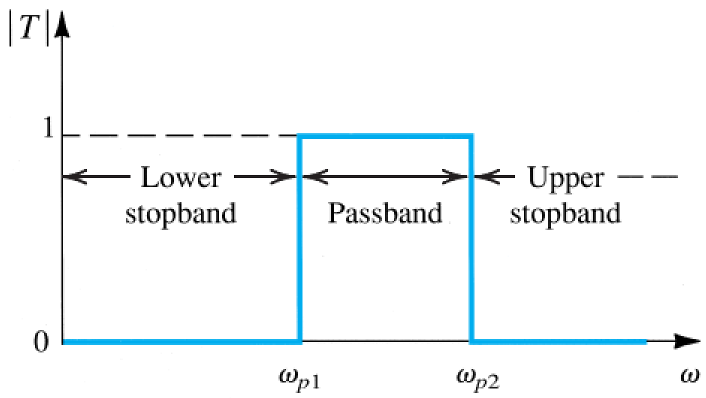
Brick-wall responses of the filter types



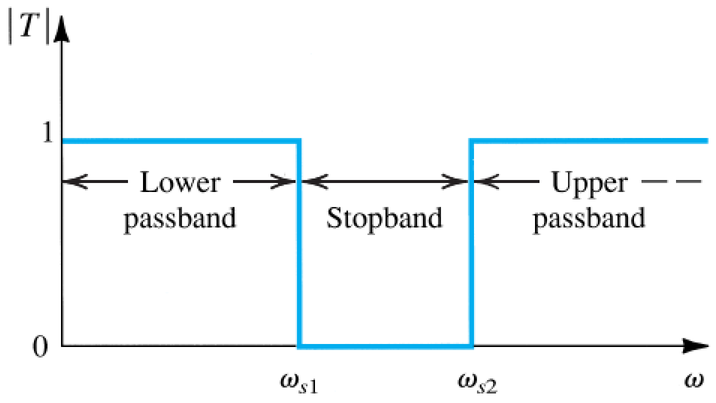
(a) Low-pass (LP)



(b) High-pass (HP)



(c) Bandpass (BP)



(d) Bandstop (BS)

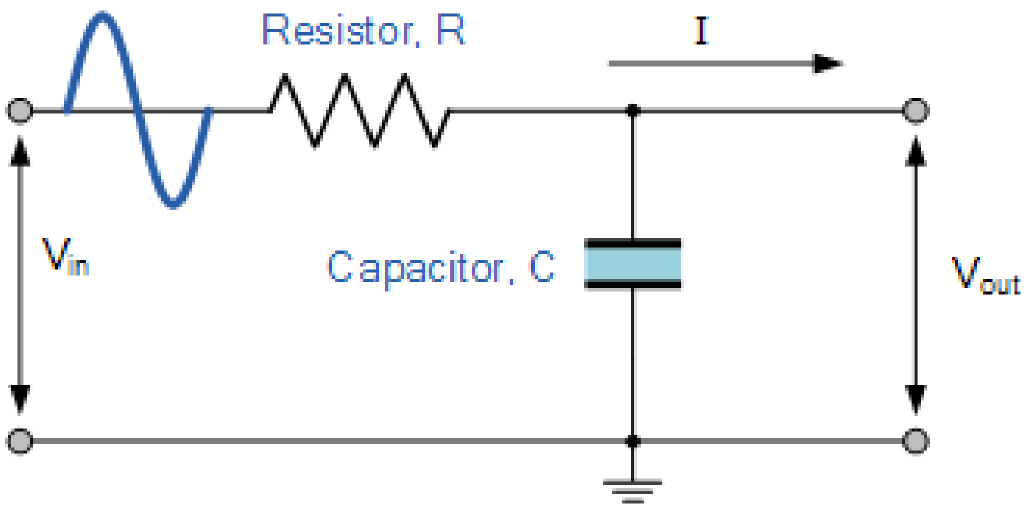
Passive Vs Active filters

- **Passive filters** are made up of passive components such as resistors, capacitors and inductors and have no amplifying elements (transistors, op-amps, etc) so have no signal gain, therefore their output level is always less than the input.

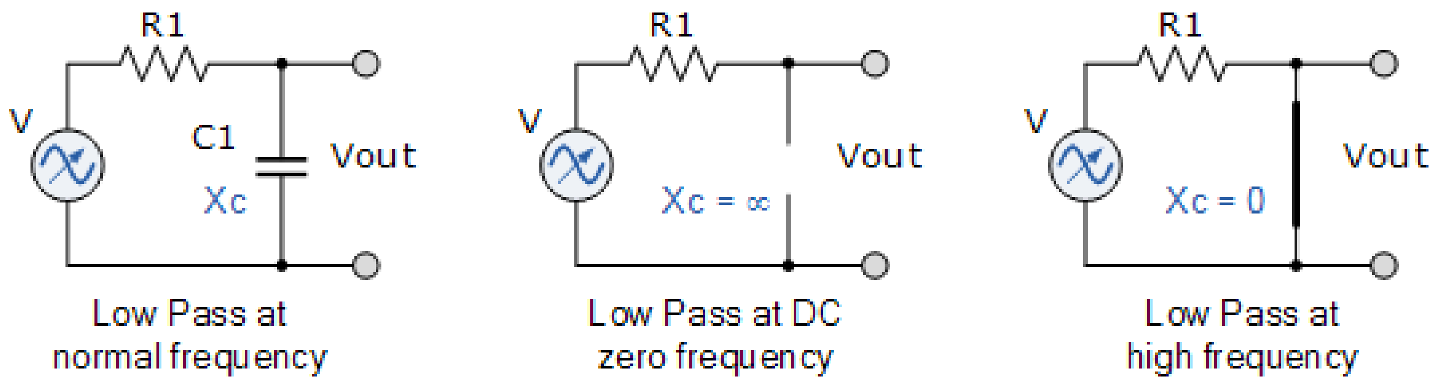
- **Active filters** contain amplifying devices to increase signal strength while passive do not contain amplifying devices to strengthen the signal

RC Low Pass Filter: Passive

- A Low Pass Filter is a circuit that can be designed to modify, reshape or reject all unwanted high frequencies of an electrical signal and accept or pass only those signals wanted by the circuits designer.



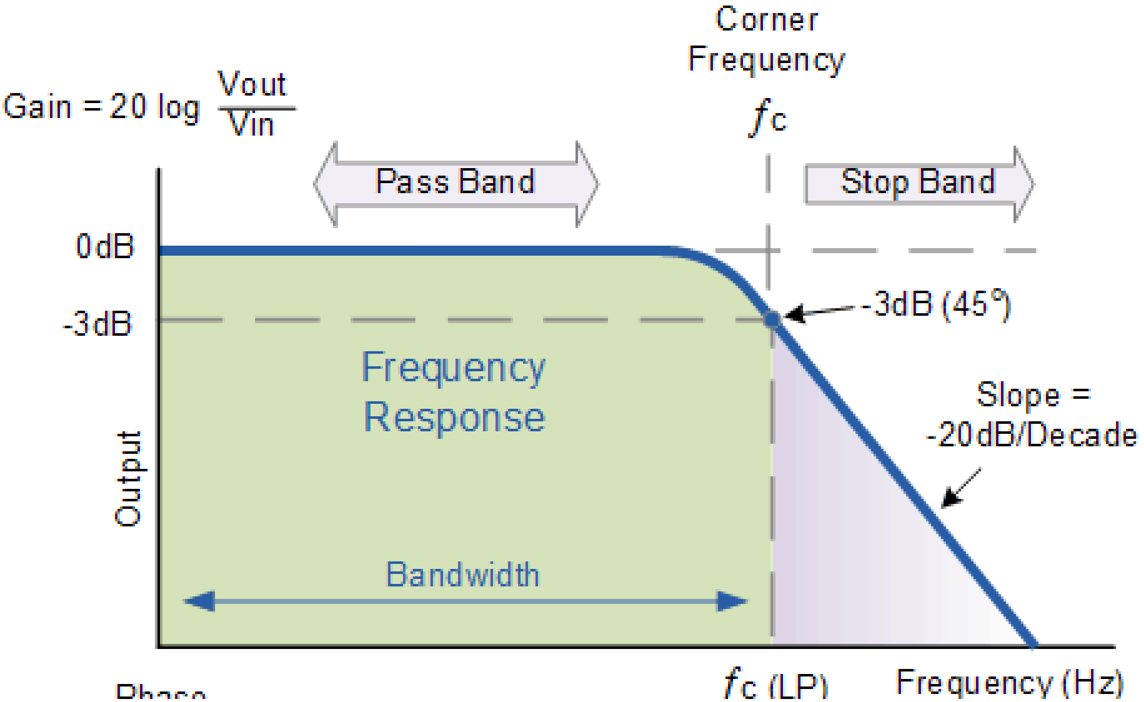
$$V_{out} = V_{in} \times \frac{X_C}{\sqrt{R^2 + X_C^2}} = V_{in} \frac{X_C}{Z}$$



- Xc – capacitive reactance, varies with applied frequency
- $X_c = 1/2\pi fC$
- Ex: A Low Pass Filter circuit consisting of a resistor of 4.7kΩ in series with a capacitor of 47nF is connected across a 10v sinusoidal supply. Calculate the output voltage (VOUT) at a frequency of 100Hz and again at frequency of 10kHz.

Frequency Response:

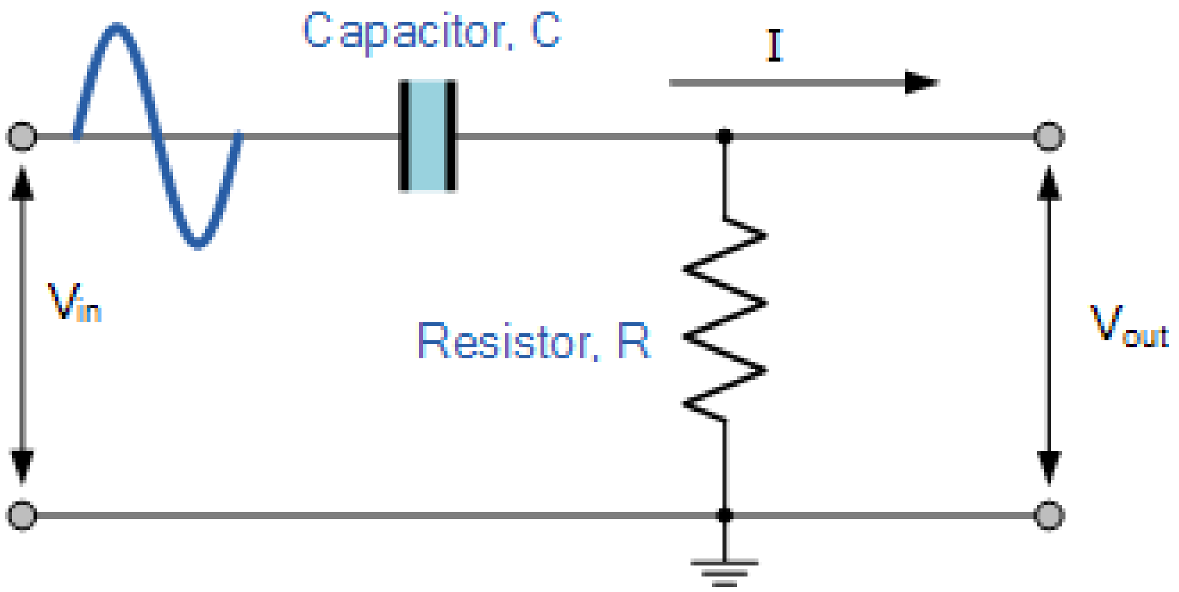
- This "Cut-off", "Corner" or "Breakpoint" frequency is defined as being the frequency point where the capacitive reactance and resistance are equal, R = Xc.

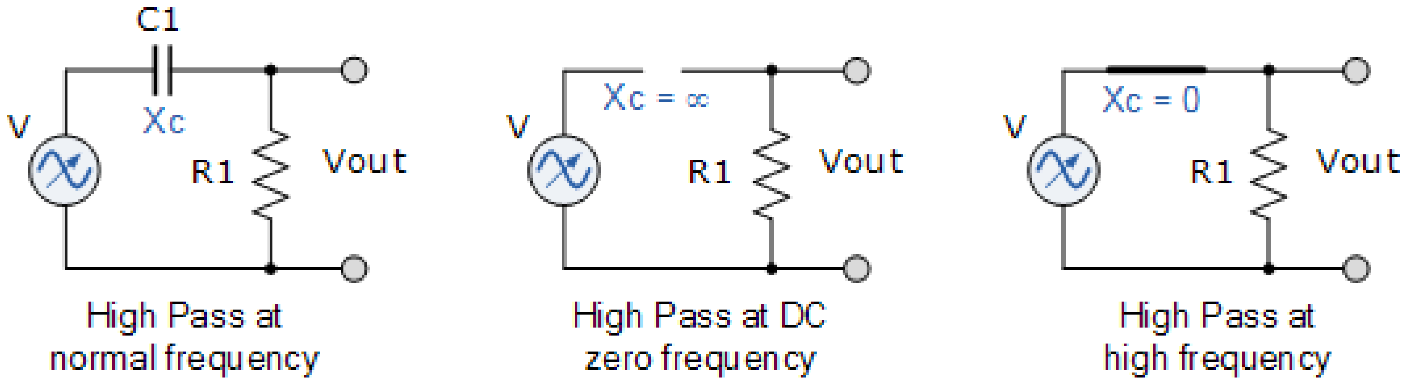


$$fc = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 4700 \times 47 \times 10^{-9}} = 720\text{Hz}$$

High pass filter

- A High Pass Filter is the exact opposite to the low pass filter circuit as the two components have been interchanged with the filters output signal now being taken from across the resistor.



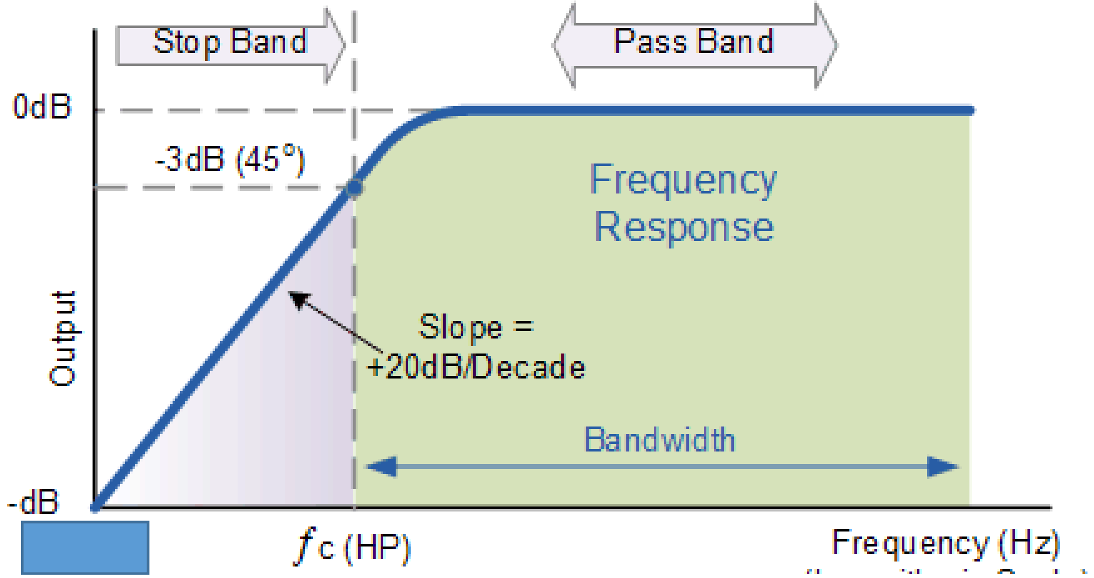


Frequency Response:

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

- Calculate the cut-off or "breakpoint" frequency (*fc*) for a simple passive high pass filter consisting of an 82pF capacitor connected in series with a 240kΩ resistor.

$$\text{Gain (dB)} = 20\log\frac{Vout}{Vin}$$



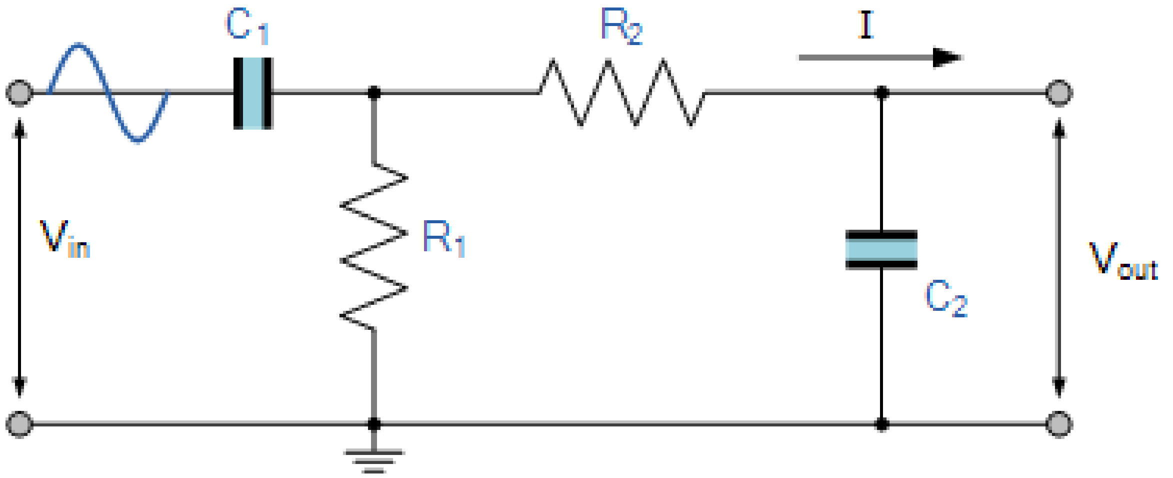
$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{R}{\sqrt{R^2 + Xc^2}} = \frac{R}{Z}$$

$$\text{at low } f: \; Xc \to \infty, \quad Vout = 0$$

$$\text{at high } f: \; Xc \to 0, \quad Vout = Vin$$

Band pass filter

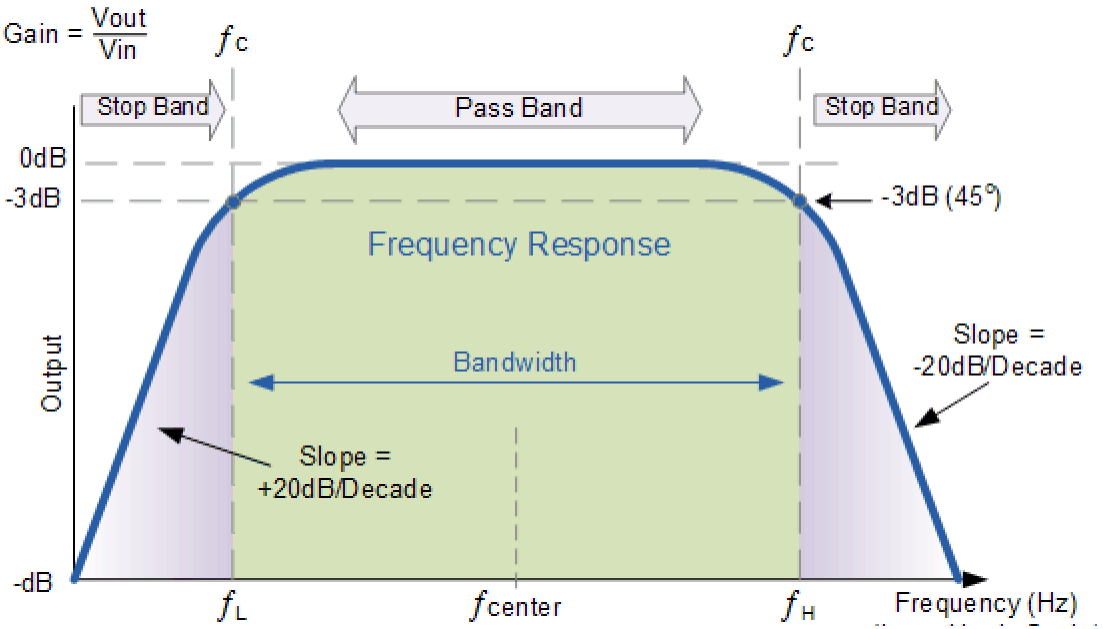
- Passive Band Pass Filters can be made by connecting together a low pass filter with a high pass filter



Frequency Response:

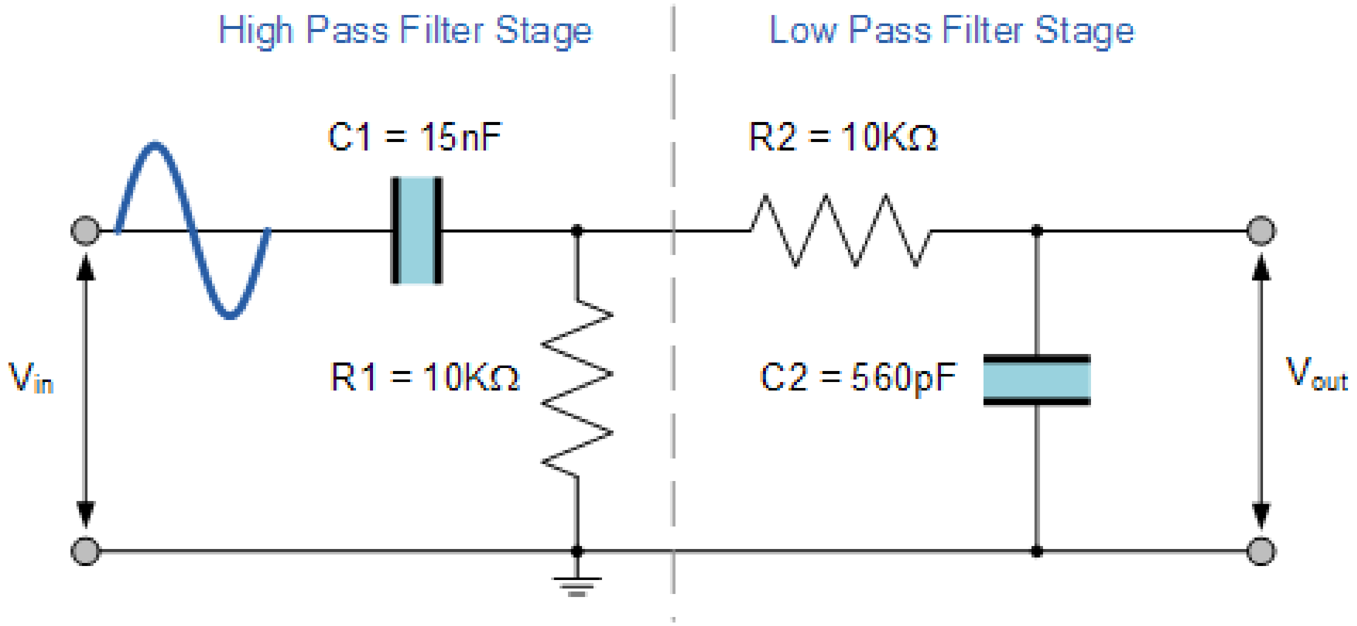
- fL – cur off frequency of the high pass stage
- fH – cutoff frequency of the low pass stage

- Bandwidth = $f_H - f_L$.

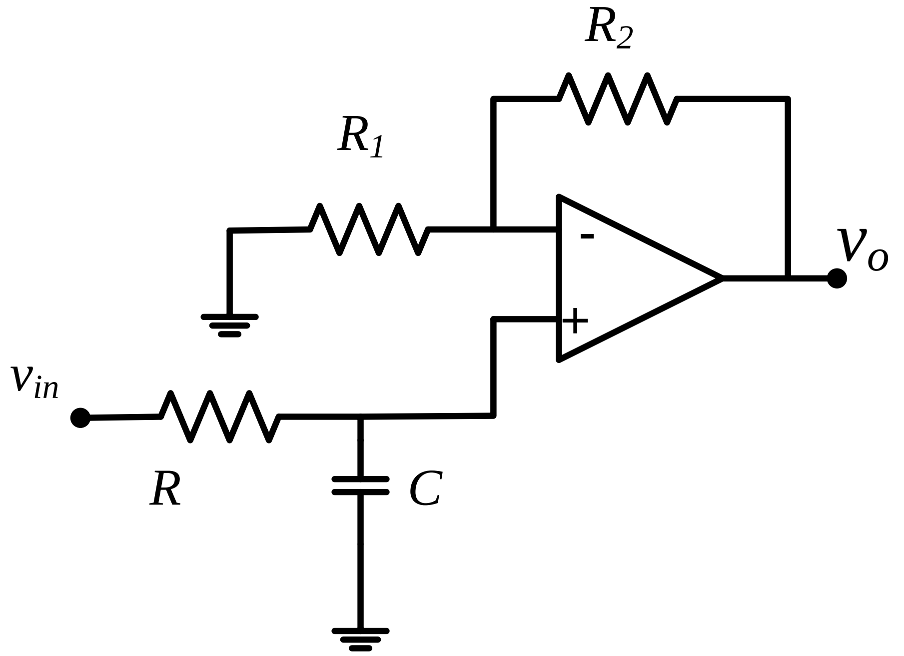


$$fr = \sqrt{f_L \; x \; f_H}$$

- Ex: A second-order band pass filter is to be constructed using RC components that will only allow a range of frequencies to pass above 1kHz (1,000Hz) and below 30kHz (30,000Hz). Assuming that both the resistors have values of 10kΩ, calculate the values of the two capacitors required.



Low Pass Active Filter



- Non inverting configuration
- Pass band gain 'G' $G = \left(1 + \frac{R_2}{R_1}\right)$
- At low freq. f < fc: $v_o \cong G v_{in}$
- At the cut-off freq. f = fc: $v_o \cong \frac{G}{\sqrt{2}} v_{in}$
- At high freq. f > fc: $v_o < G v_{in}$

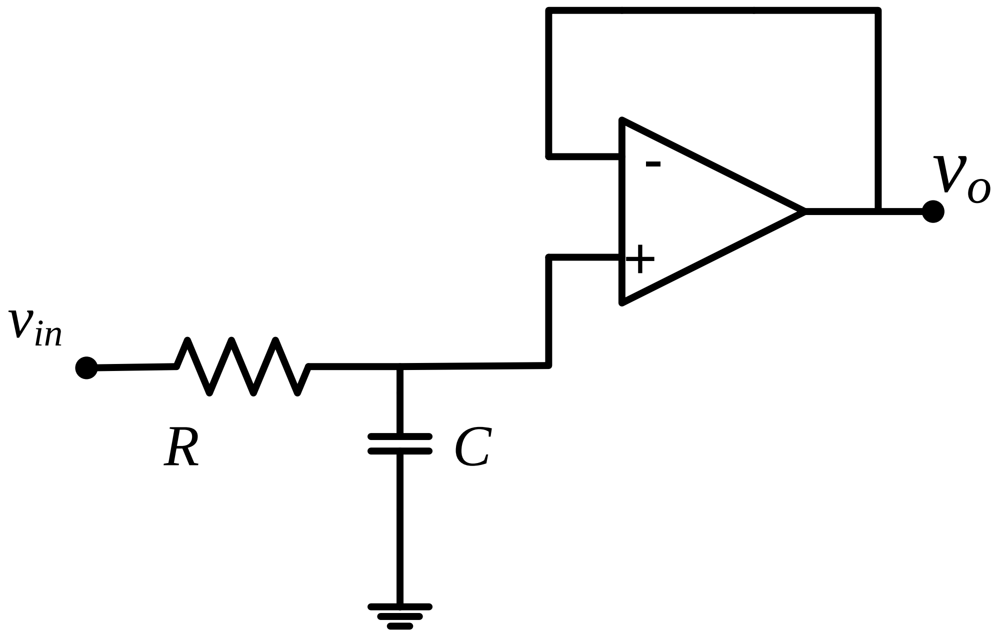
$$v_o = \frac{\left(1 + \frac{R_2}{R_1}\right)}{\sqrt{1 + \left(\frac{f}{f_c}\right)^2}} v_{in}$$

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

$$\text{DC Gain} = \left(1 + \frac{R_2}{R_1}\right)$$

Low Pass Active Filter:

- Unit gain (Voltage follower)

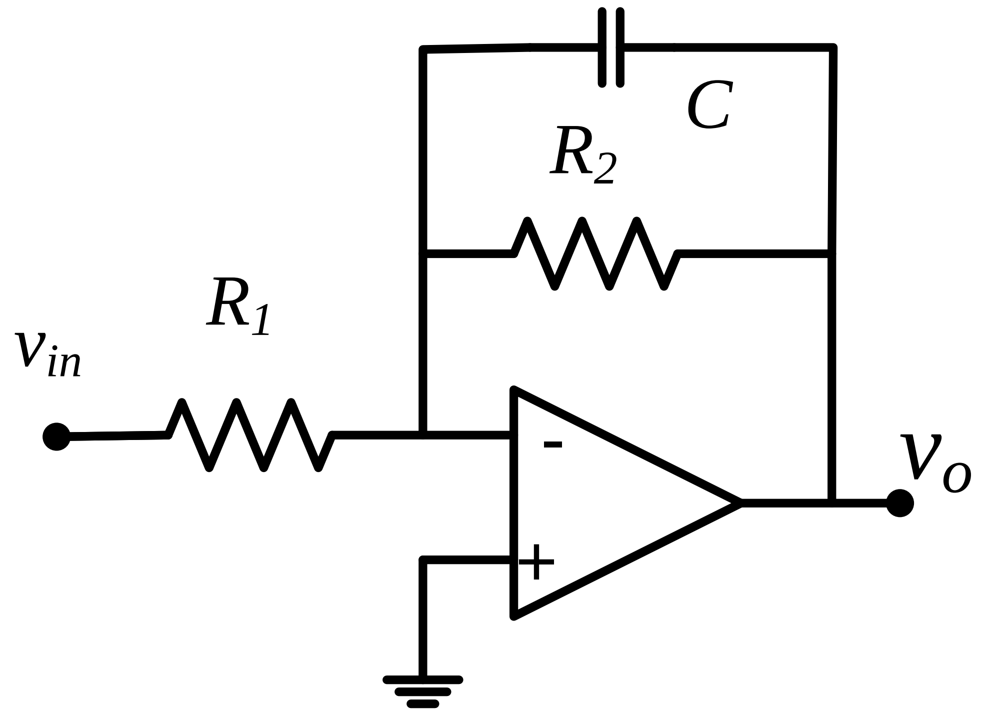


Example:

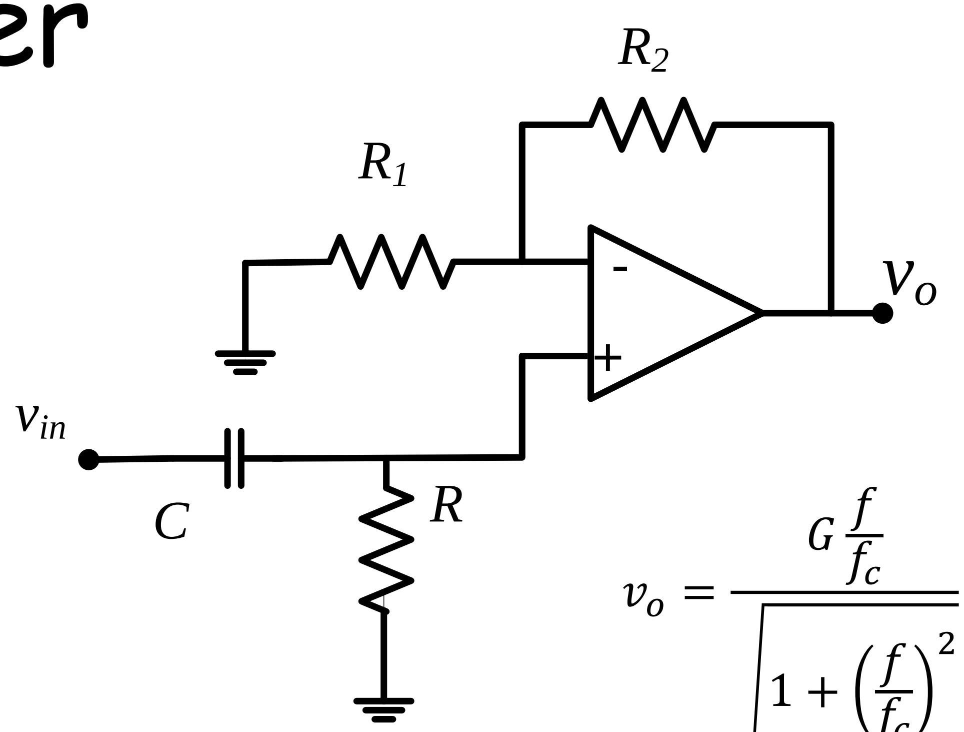
- Design a non-inverting active low pass filter circuit that has a gain of ten at low frequencies, a high frequency cut-off or corner frequency of 159Hz and an input impedance of 10KΩ. Assume that the resistance in feed-in path is 1 KΩ. Determine the voltage gain at 100 Hz, 10kHz.
- Ans: R_2 = 9KΩ; C = 100 nF

Low Pass Active Filter: Inverting configuration

- DC gain = -R2/R1
- Integrator (in time domain)



Active High Pass Filter



- Noninverting configuration
- Pass band gain $G = \left(1 + \frac{R_2}{R_1}\right)$

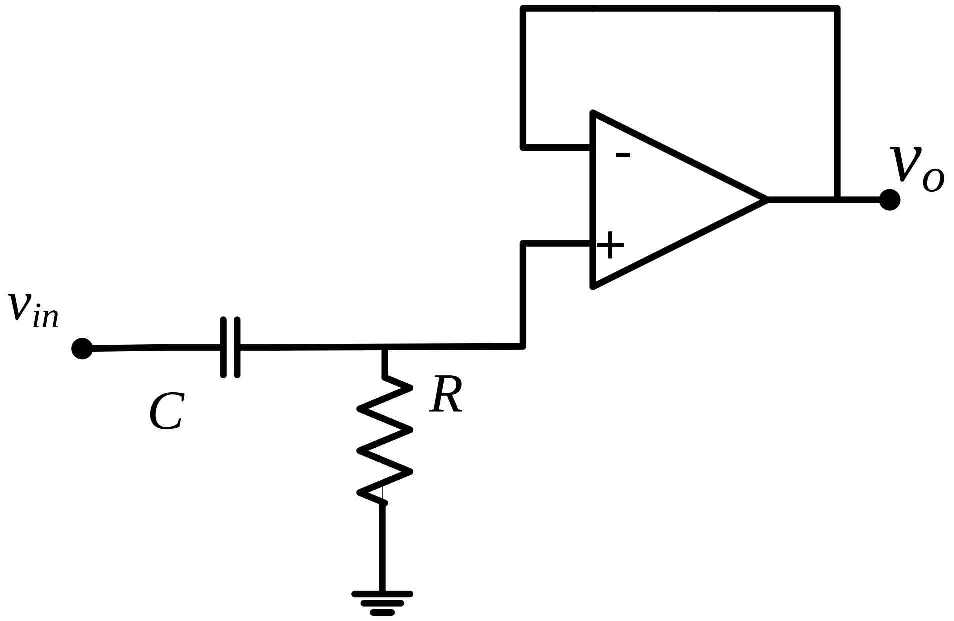
$$v_o = \frac{G\frac{f}{f_c}}{\sqrt{1+\left(\frac{f}{f_c}\right)^2}} v_{in}$$

- At low freq. f < fc: $v_o < G v_{in}$
- At the cut-off freq. f = fc: $v_o \cong \frac{G}{\sqrt{2}} v_{in}$
- At high freq. f > fc: $v_o \cong G v_{in}$

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

High Pass Active Filter

- Unit gain

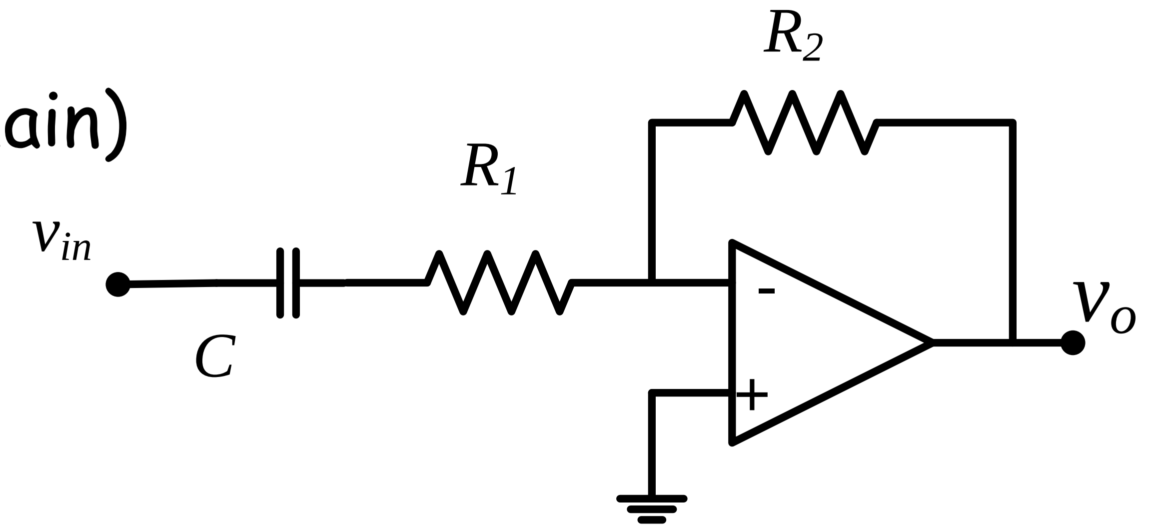


Example:

- A first order active high pass filter has a pass band gain of two and a cut-off corner frequency of 1kHz. If the input capacitor has a value of 10nF, calculate the value of the cut-off frequency determining resistor and if the feed in resistor is 10 KΩ determine feedback resistance.
- Also determine the gain at 10 Hz, 100 Hz, 1KHz and 10 kHz.

High Pass Active Filter

- Inverting configuration
- Differentiator (time domain)



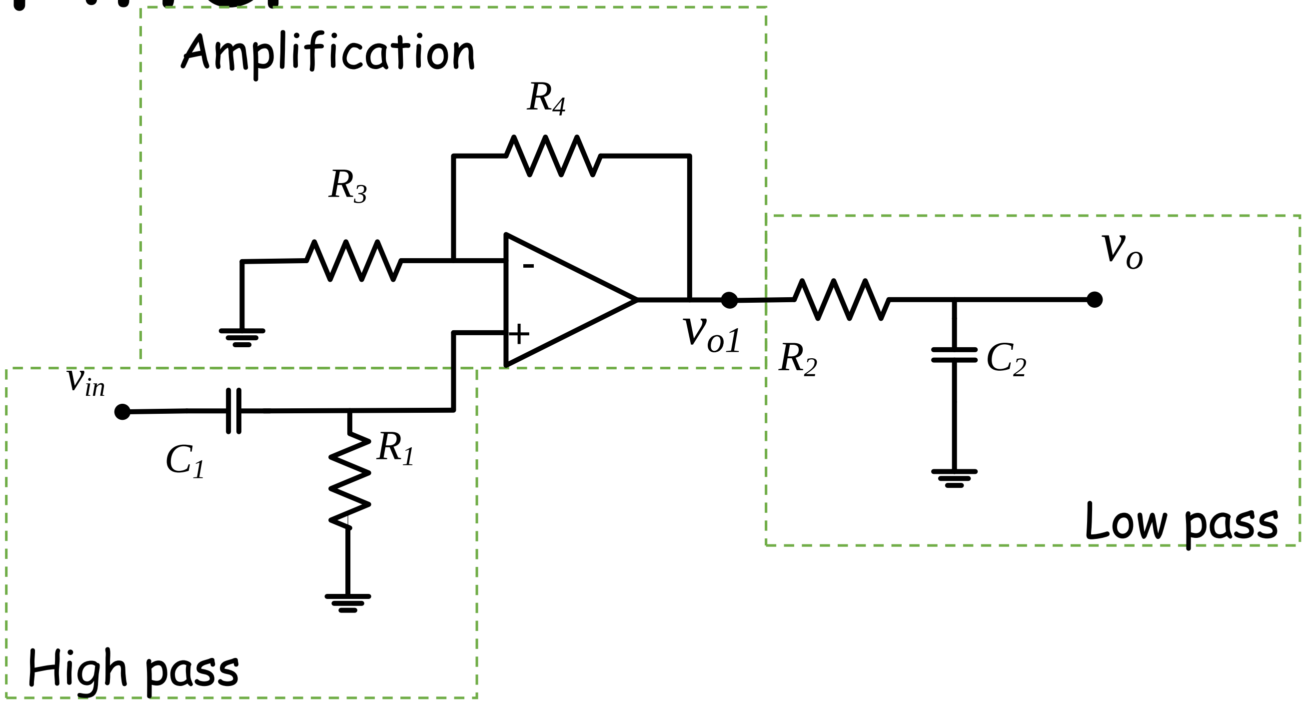
Band pass Active Filter

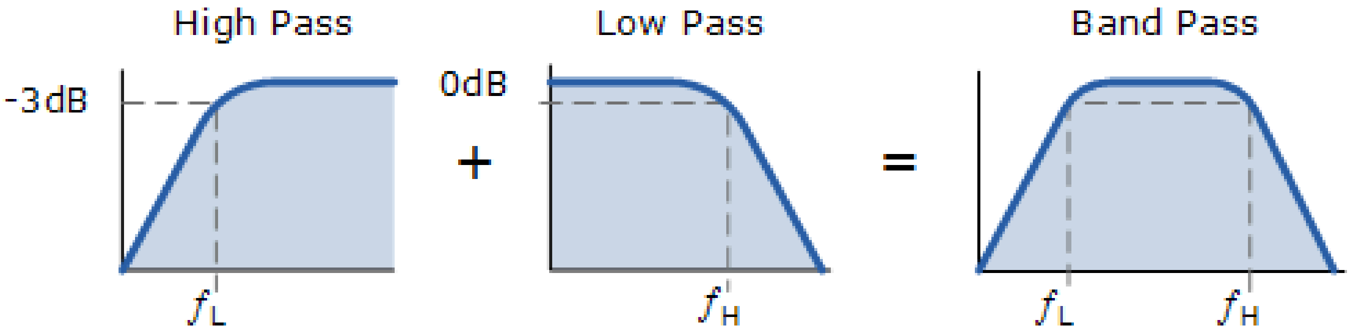
- Non inverting configuration

$$v_o = \frac{\left(1+\frac{R_4}{R_3}\right)}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}} \frac{\frac{f}{f_L}}{\sqrt{1+\left(\frac{f}{f_L}\right)^2}} v_{in}$$

$$f_L = \frac{1}{2\pi R_1 C_1} \qquad f_H = \frac{1}{2\pi R_2 C_2}$$

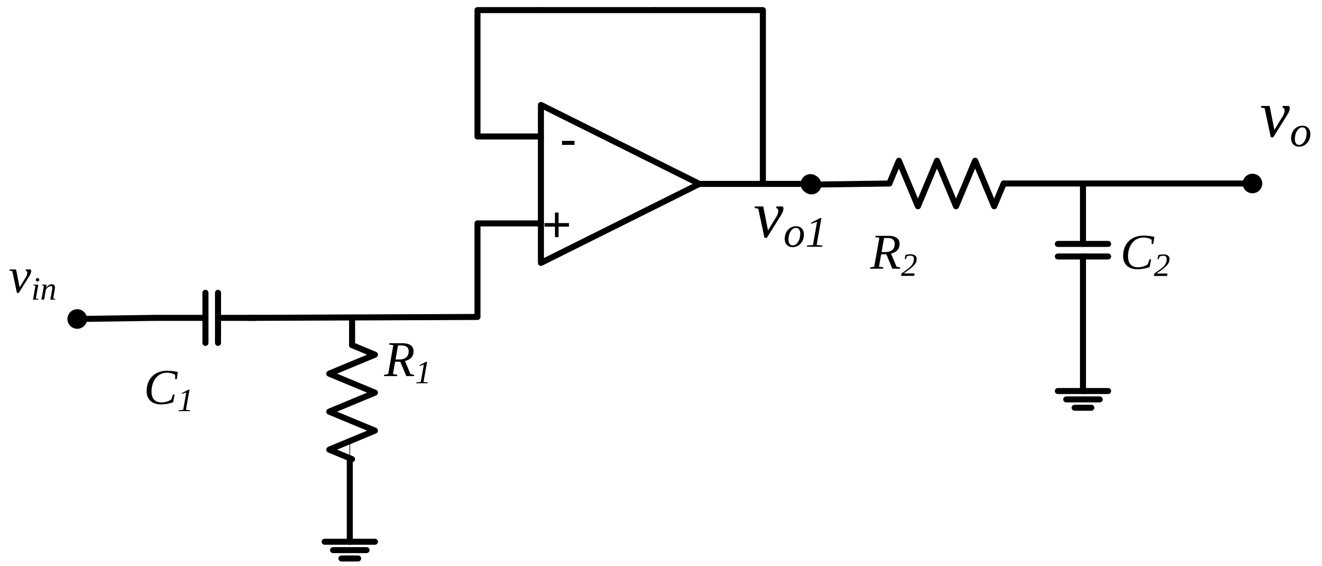
$$f_r = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$





Band pass active filter

- Unit Gain (Voltage follower)



Band Pass Active Filter

- Inverting Configuration