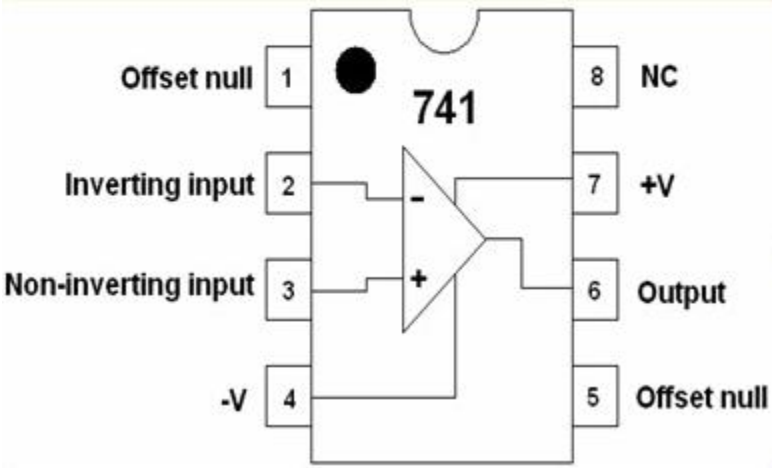
ECE 131 (Basic Electronics and Electrical Engineering)

Unit 5

Fundamentals of Filters and Operational Amplifier



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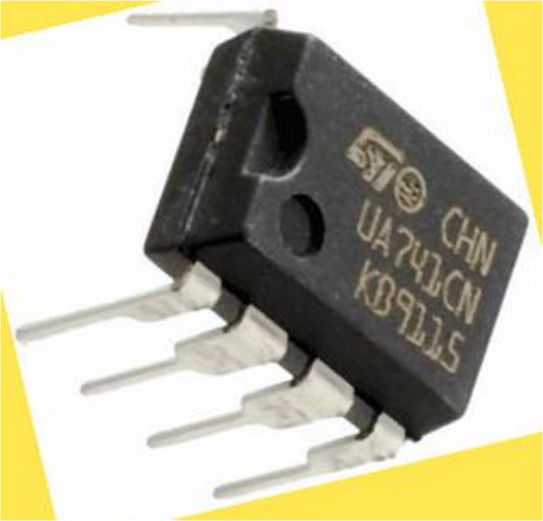

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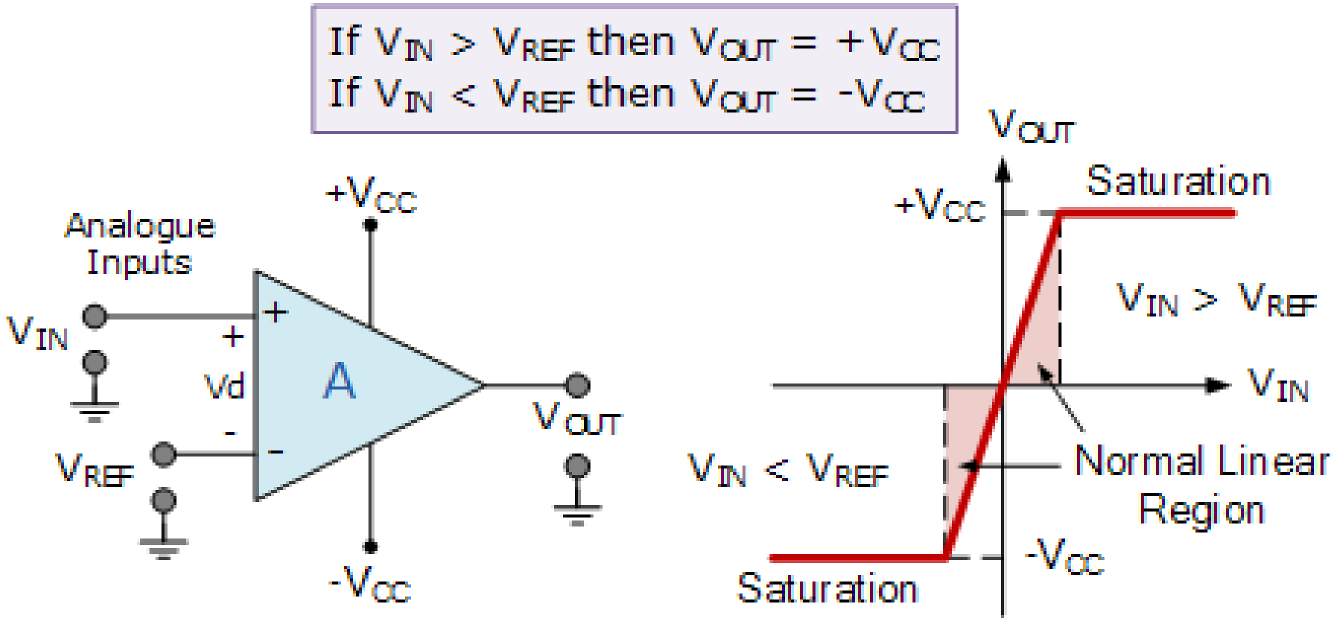
Applications of an Op Amp

1. Adder
2. Subtractor or Difference Amplifier
3. Integrator
4. Differentiator
5. Comparator
6. Filters

Op Amp as Comparator

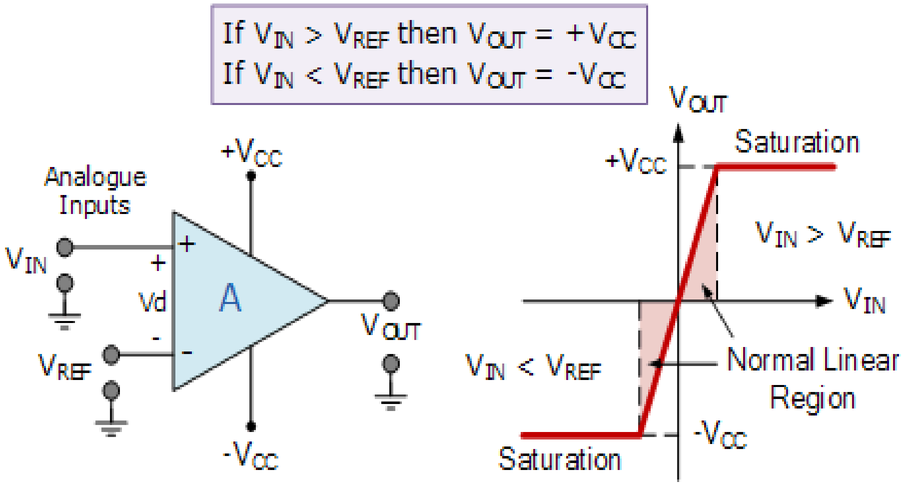
- The Op-amp comparator compares one analog voltage level with another analog voltage level, or some preset reference voltage, V_{REF} and produces an output signal based on this voltage comparison.
- In other words, the op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the largest of the two.



- Determines if one signal is bigger than another
- No negative feedback, infinite gain and circuit saturates
- Saturation: output is most positive or most negative value

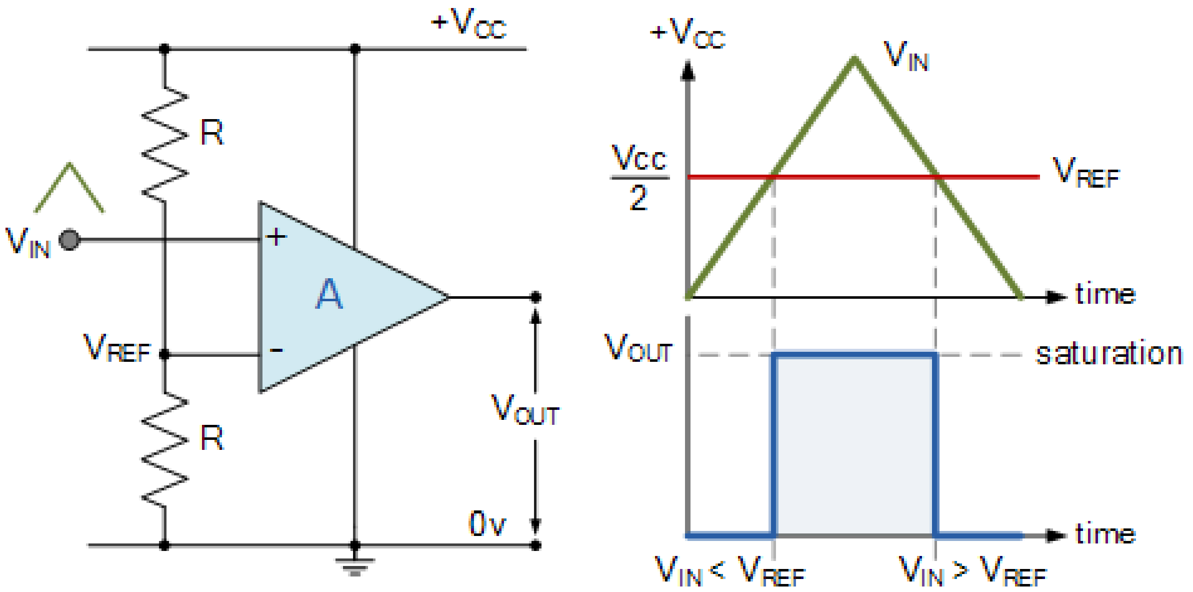
Op Amp as Comparator

- With reference to the op-amp comparator circuit above, lets first assume that V_{IN} is less than the DC voltage level at V_{REF} (V_{IN} < V_{REF}). As the non-inverting (positive) input of the comparator is less than the inverting (negative) input, the output will be LOW and at the negative supply voltage, -V_{CC} resulting in a negative saturation of the output.
- If we now increase the input voltage, V_{IN} so that its value is greater than the reference voltage V_{REF} on the inverting input, the output voltage rapidly switches HIGH towards the positive supply voltage, $+V_{CC}$ resulting in a positive saturation of the output.



Op Amp Comparator Circuit Application in Non Sinusoidal Waveform Generation

- In this non-inverting configuration, the reference voltage is connected to the inverting input of the operational amplifier with the input signal connected to the non-inverting input. To keep things simple, we have assumed that the two resistors forming the potential divider network are equal and: R_1 = R_2 = R. This will produce a fixed reference voltage which is one half that of the supply voltage, that is $V_{CC}/2$, while the input voltage is variable from zero to the supply voltage.
- When V_{IN} is greater than V_{REF}, the op-amp comparators output will saturate towards the positive supply rail, V_{CC}. When V_{IN} is less than V_{REF} the op-amp comparators output will change state and **saturate at the negative supply rail, 0 V** as shown.



Filters

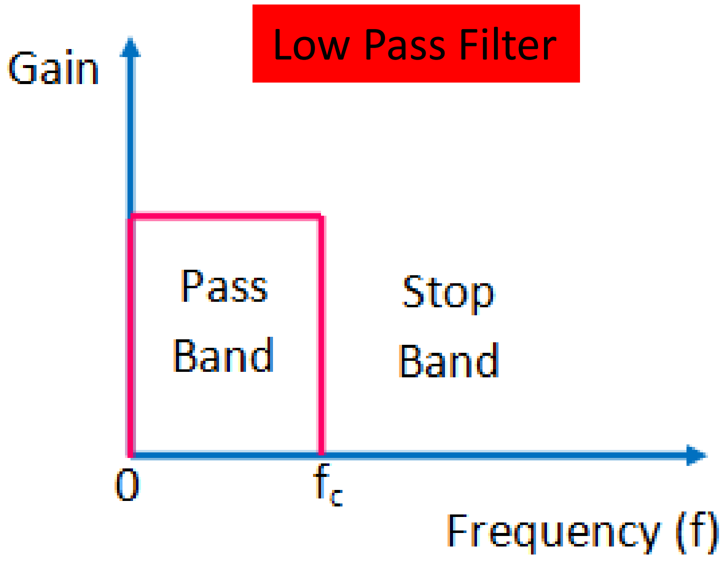
- A filter is a circuit capable of passing (or amplifying) certain frequencies while attenuating other frequencies. Thus, a filter can extract important frequencies from signals that also contain undesirable or irrelevant frequencies.
- Filters can be placed in one of two categories: ***passive*** or ***active***.
- **Passive filters** include only passive components—resistors, capacitors, and inductors.
- In contrast, **active filters** use **active components, such as op-amps**, in addition to resistors and capacitors, but not inductors.

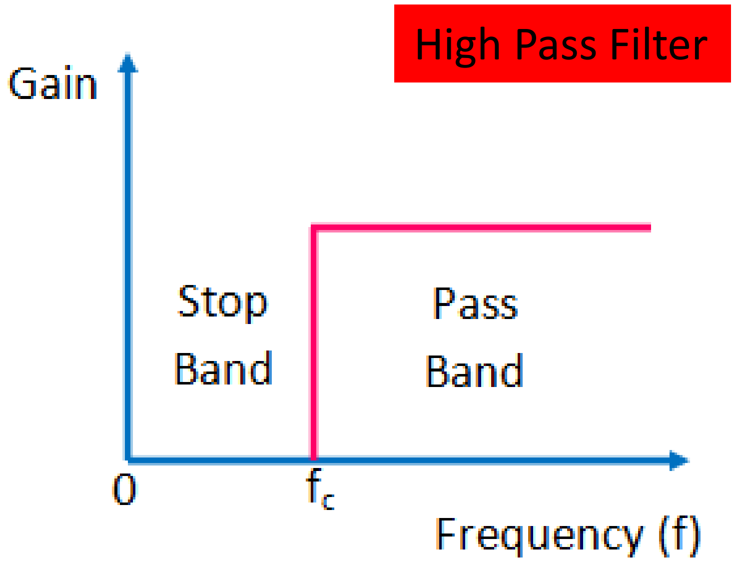
Types of Filters

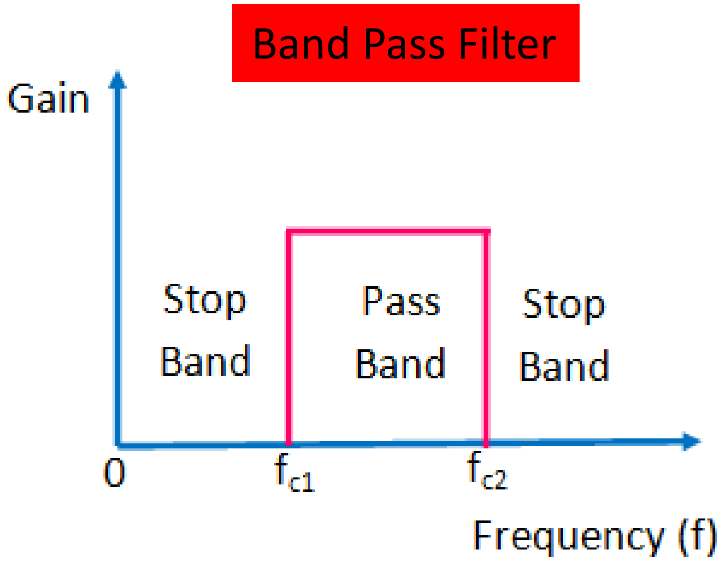
- Depending upon the frequency of operation, filters can be classified as:

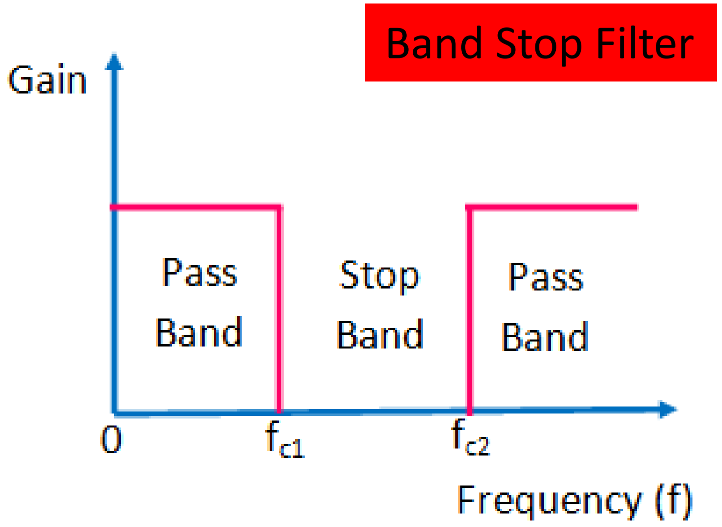
1. **Low Pass Filter** : The low pass filter only allows low frequency signals from 0 Hz to its cut-off frequency, ƒc point to pass while blocking any higher frequency signals.
2. **High Pass Filter** : The high pass filter only allows high frequency signals from its cut-off frequency, ƒc point and higher to infinity to pass through while blocking those any lower.
3. **Band Pass Filter :** The band pass filter allows signals falling within a certain frequency band set up between two points to pass through while blocking both the lower and higher frequencies either side of this frequency band.
4. **Band Stop Filter :** The band stop filter blocks signals falling within a certain frequency band set up between two points while allowing both the lower and higher frequencies either side of this frequency band.

Types of Filters

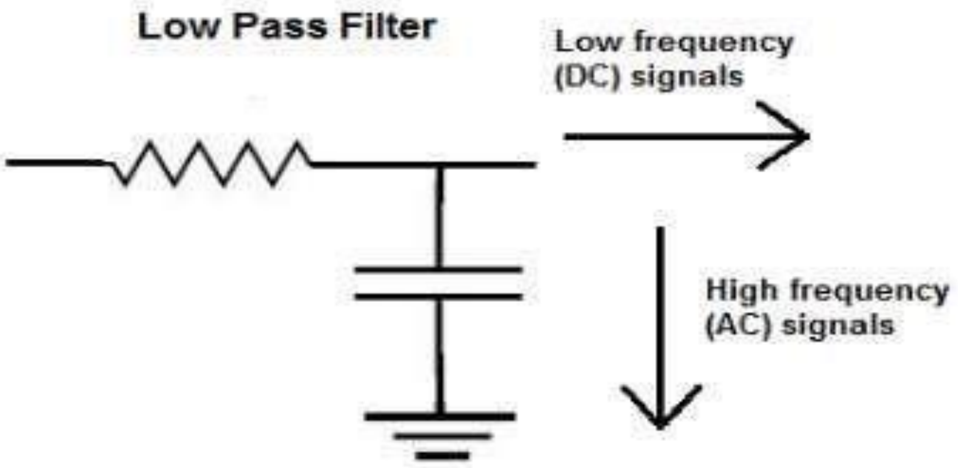




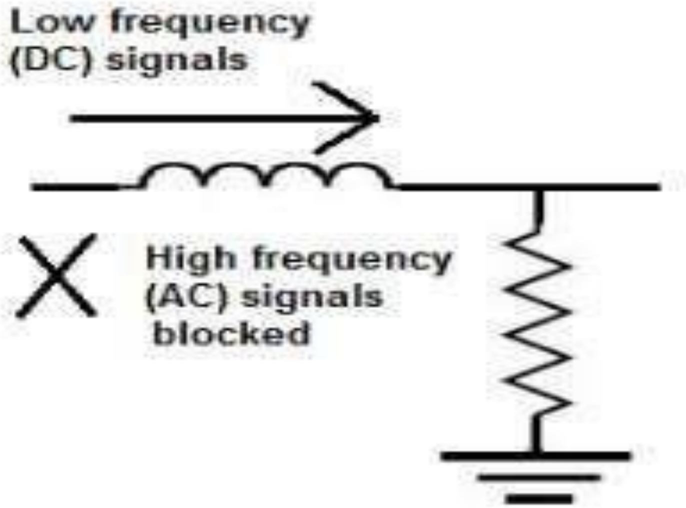




Low Pass Filter



RC low-pass filter

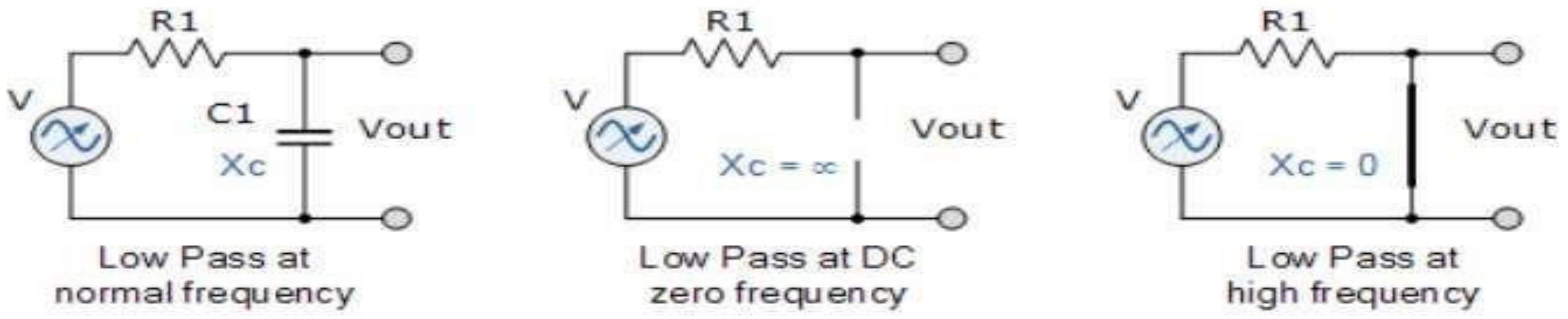


RL low-pass filter

- RC low pass filter works based on the principle of *capacitive reactance*, while RL low pass filter works on the principle of *inductive reactance*

http://www.learningaboutelectronics.com/Articles/Low-pass-filter.php

Capacitive Reactance

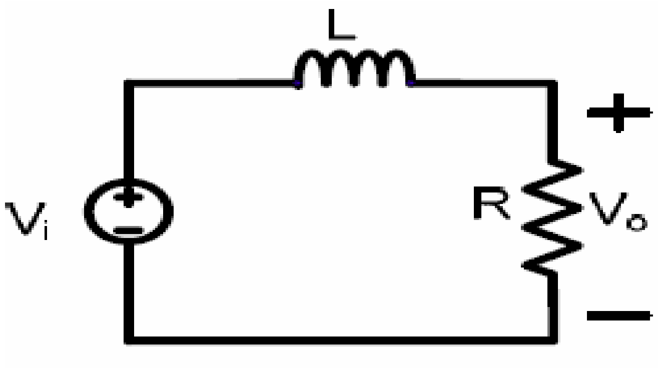


- *Capacitive Reactance (Xc)* varies with the applied frequency.
  - As the frequency applied to the capacitor increases, its effect is to decrease its reactance (measured in ohms).
  - Likewise as the frequency across the capacitor decreases its reactance value increases.

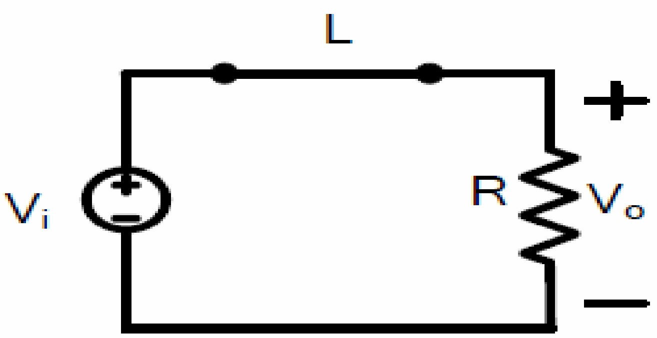
$$(X_c = {}^{1}\!/_{2\pi f c})\ \text{ohms}$$

http://www.electronics-tutorials.ws/filter/filter_1.html

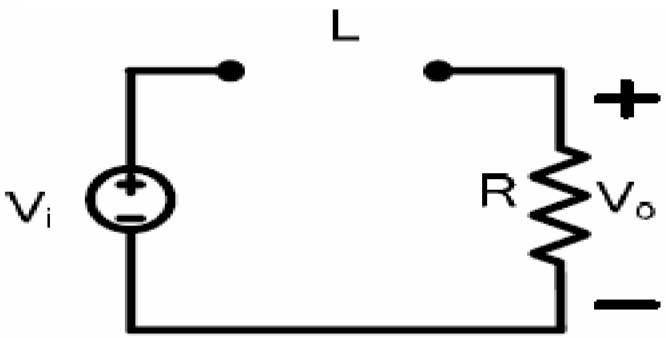
Inductive Reactance



RL low-pass filter



RL low-pass filter at low frequencies
$\omega = 0$



RL low-pass filter at high frequencies
$\omega = \infty$

- *Inductive Reactance (X_L)* varies with the applied frequency.
  - To high frequency signals, inductors offer high resistance thus blocks high frequencies
  - As frequencies decrease, the inductor offers low resistance so low frequencies pass

$$X_L = 2\pi f L \text{ ohms}$$

http://faculty.kfupm.edu.sa/ee/malek/EE205/pdfslides-205/Lecture%2028_ee205.pdf

Low Pass Filter

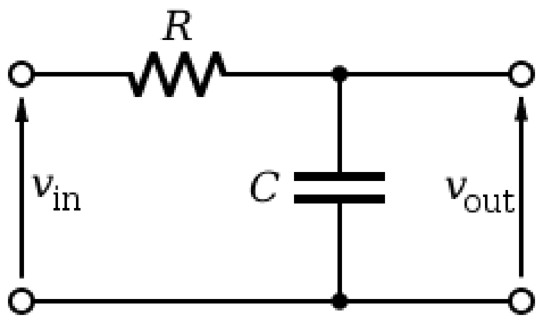
- *First Order Circuit*

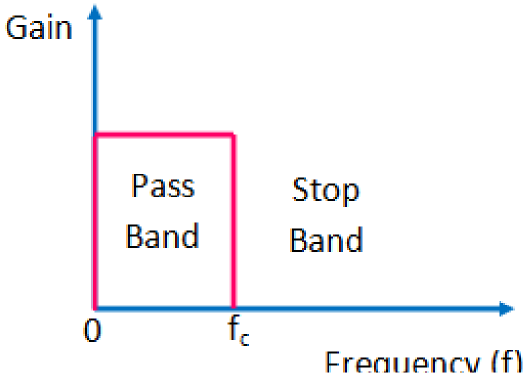
$$\frac{V_{out}}{V_{in}} = \frac{X_C}{X_C + R}$$

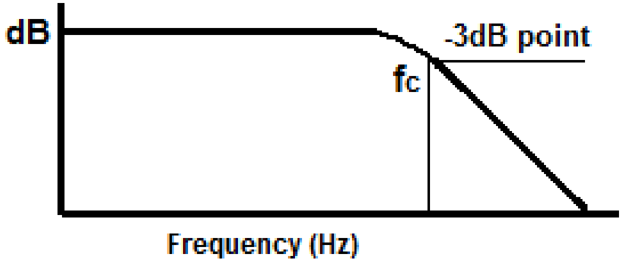
And, cut-off frequency:

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

- All low-pass filters are rated at a certain cutoff frequency. That is, the frequency above which the output voltage falls below 70.7% of the input voltage.







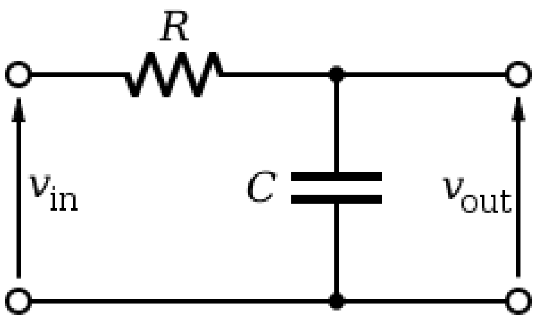
https://www.electronics-tutorials.ws/filter/filter_2.html

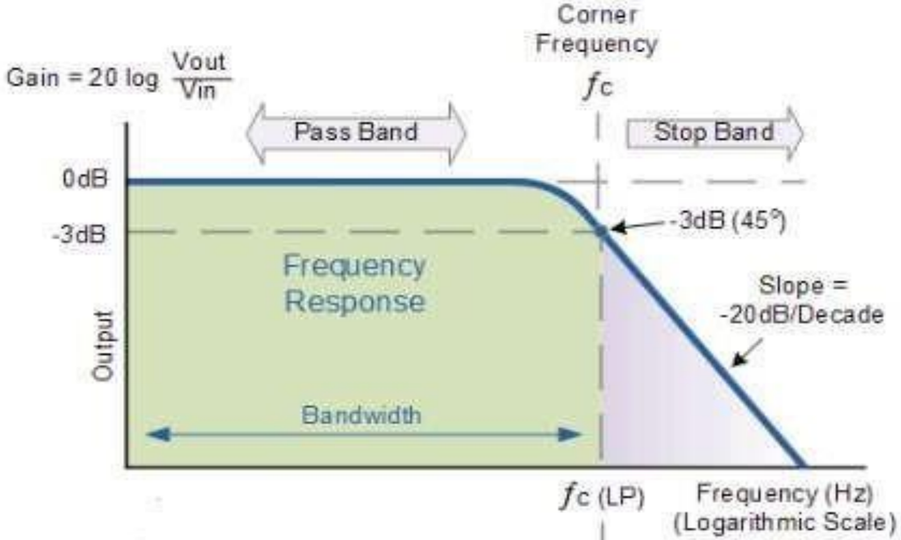
Explanation Slide

RC Potential Divider

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

$$\frac{V_{out}}{V_{in}} = \frac{X_C}{X_C + R}$$





Roll off is also called the **attenuation rate**, roll-off is the rate of change of amplitude with frequency in a filter. The faster the roll-off, or the higher the attenuation rate, the more selective the filter is, i.e., the better able it is to differentiate between two closely spaced signals, one desired and the other not.

Explanation

QUICK QUIZ (POLL)

What are filters created by using resistors and capacitors or inductors are called?

a) Active filters
b) Passive filters
c) Continuous filters
d) Differential filters

QUICK QUIZ (POLL)

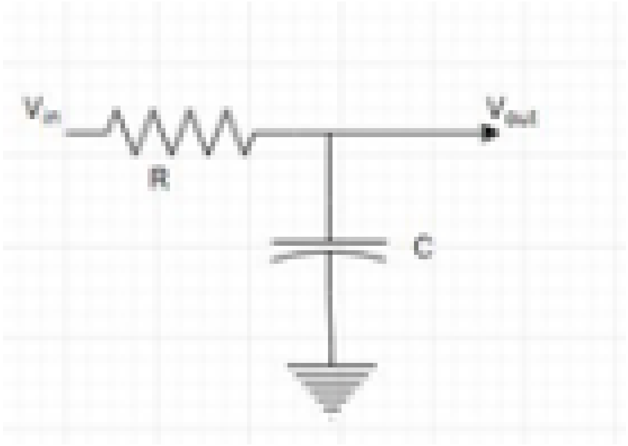
What is the type of filter shown in the figure?

a) Low pass filter

b) High pass filter

c) Band pass filter

d) All pass filter



QUICK QUIZ (POLL)

Find the cut off frequency for an RC low pass filter of R=8.2KΩ and C=0.0033μF?

a) 6KHz

b) 5.88KHz

c) 4.26KHz

d) 7.91KHz

High Pass Filter

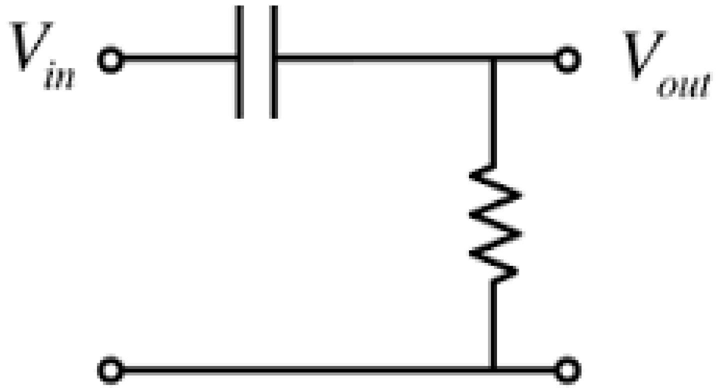
- *First Order Circuit*

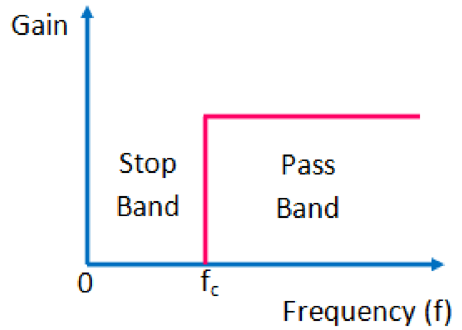
$$\frac{V_{out}}{V_{in}} = \frac{R}{X_C + R}$$

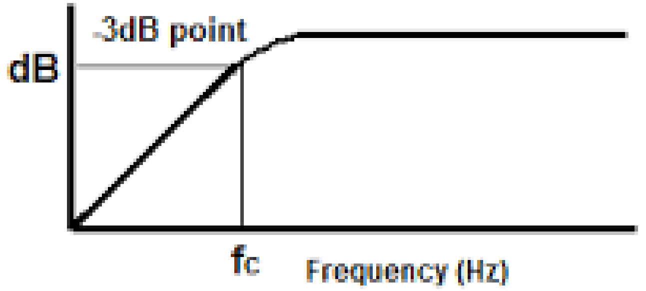
And, cut-off frequency:

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

- All low-pass filters are rated at a certain cutoff frequency. That is, the frequency above which the output voltage falls below 70.7% of the input voltage.

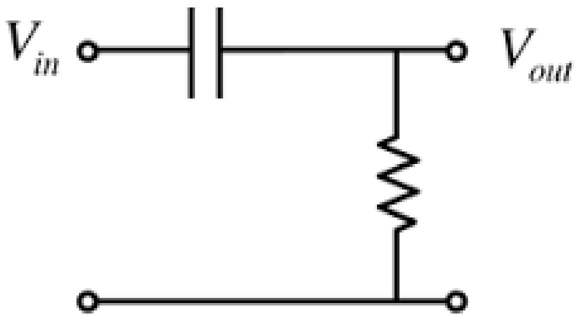






Explanation Slide

$$\frac{V_{out}}{V_{in}} = \frac{R}{X_C + R}$$



QUICK QUIZ (POLL)

What is the value of resistor for a high pass RC filter to produce a cutoff frequency of3.4KHz if C = 0.047µF?

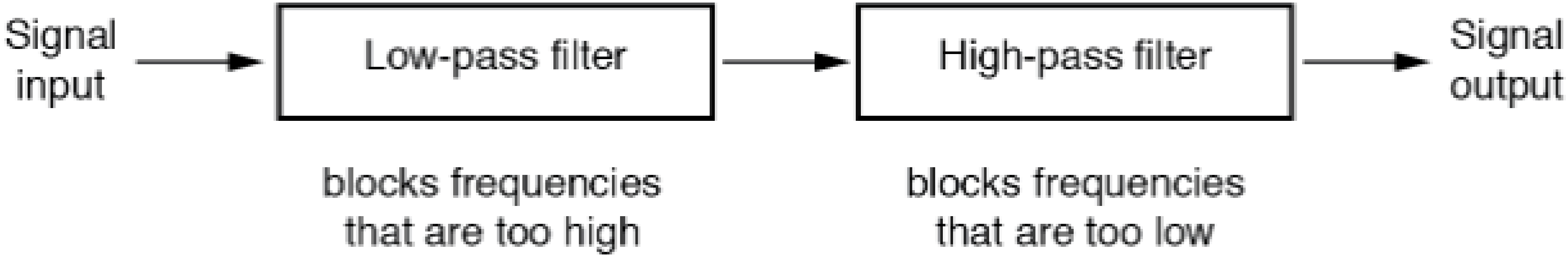
a) 654Ω

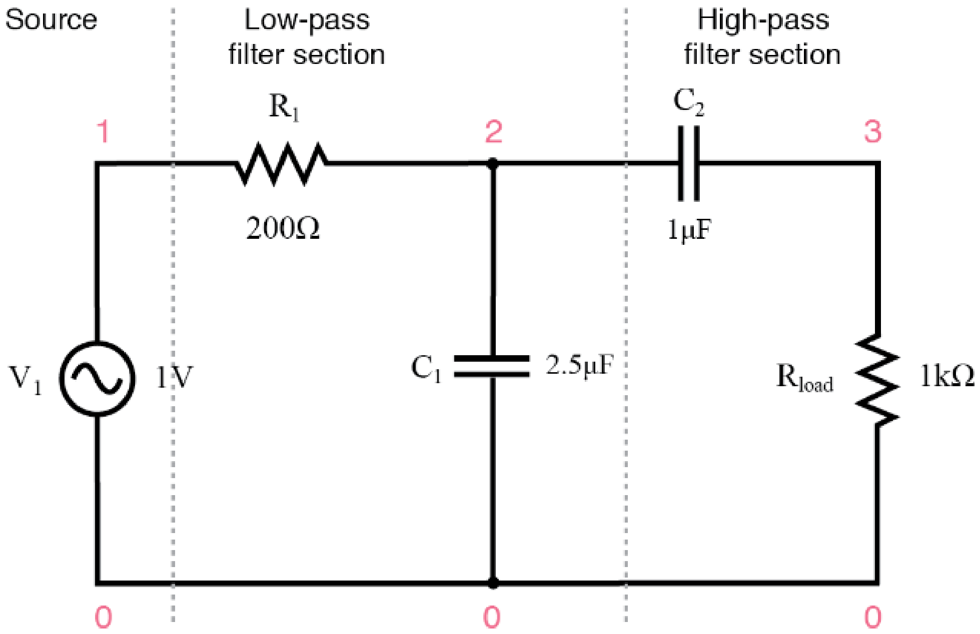
b) 1000Ω

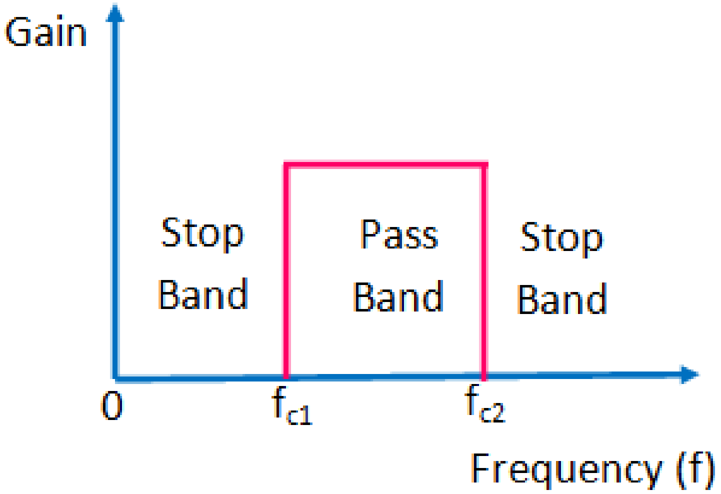
c) 996Ω

d) 752Ω

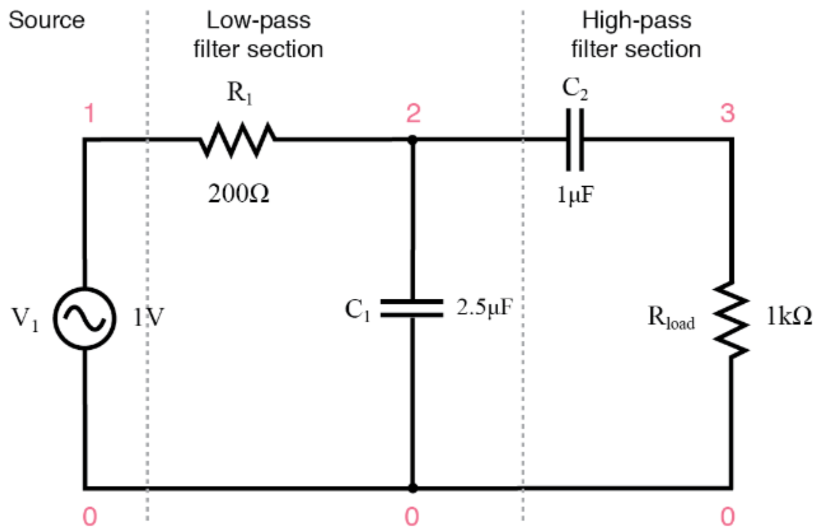
Band Pass Filter

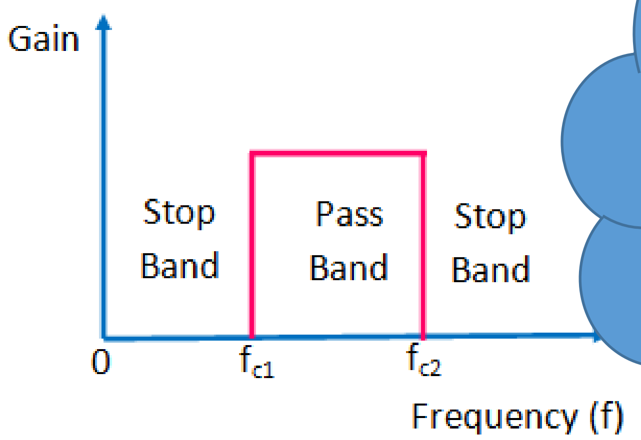




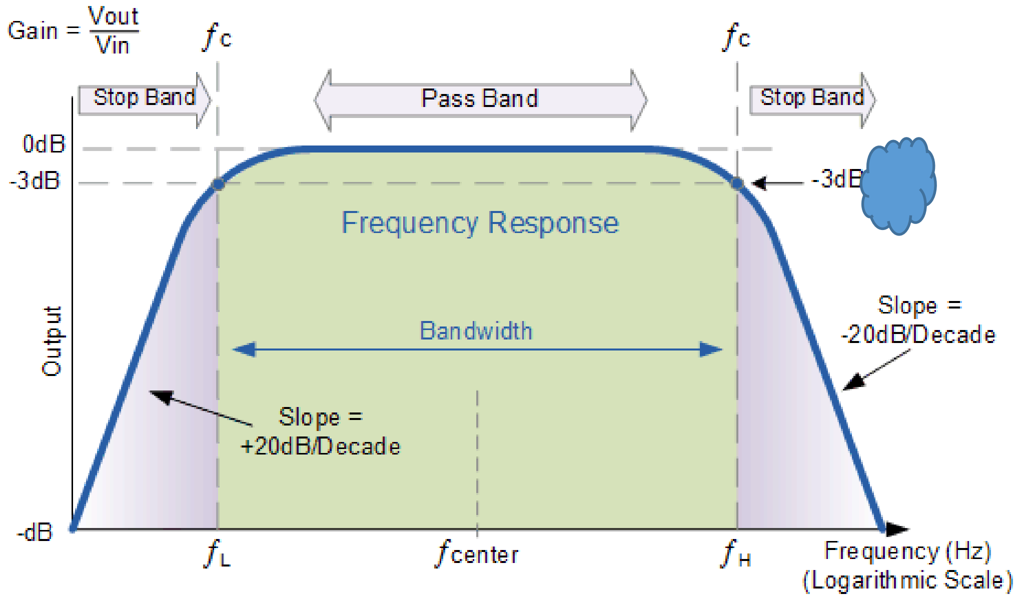


Band Pass Filter





Bandwidth: The frequency range, in Hertz, between the lower and upper -3dB cut-off points of the RC combination is know as the filters **"Bandwidth"**.



- A ***band-pass*** **filter works to screen out frequencies that are too low or too high, giving easy passage only to frequencies within a certain range.**
- **Band-pass filters can be made by stacking a low-pass filter on the end of a high-pass filter, or vice versa.**

QUICK QUIZ (POLL)

Given the lower and higher cut-off frequency of a band-pass filter are 2.5kHz and 10kHz. Determine its bandwidth.

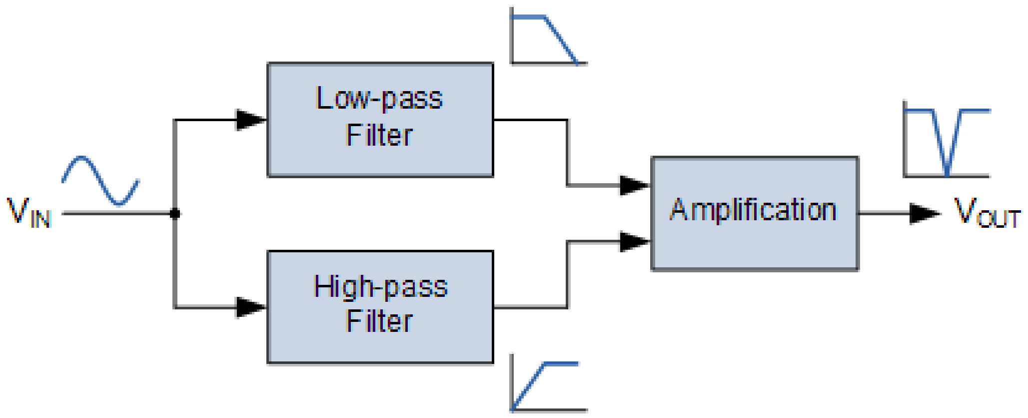
a) 750 Hz

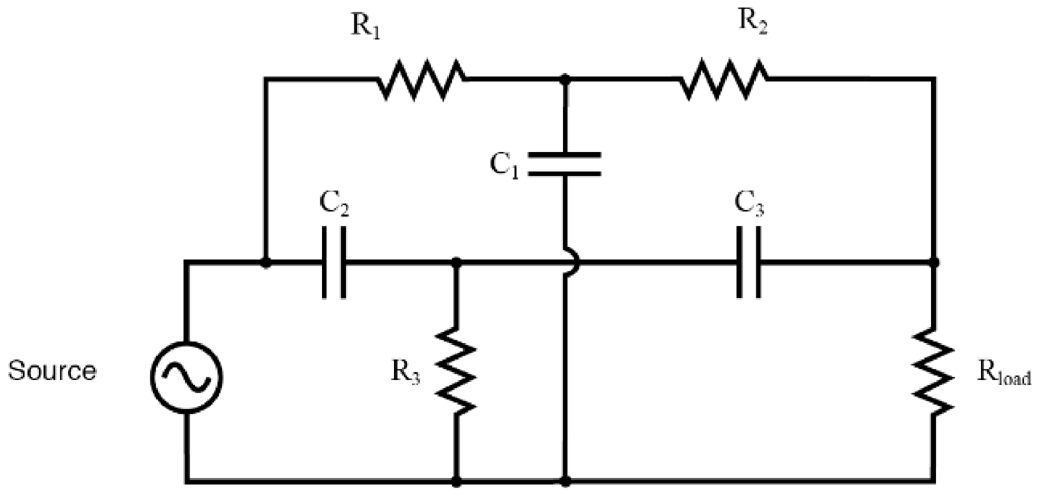
b) 7500 Hz

c) 75000 Hz

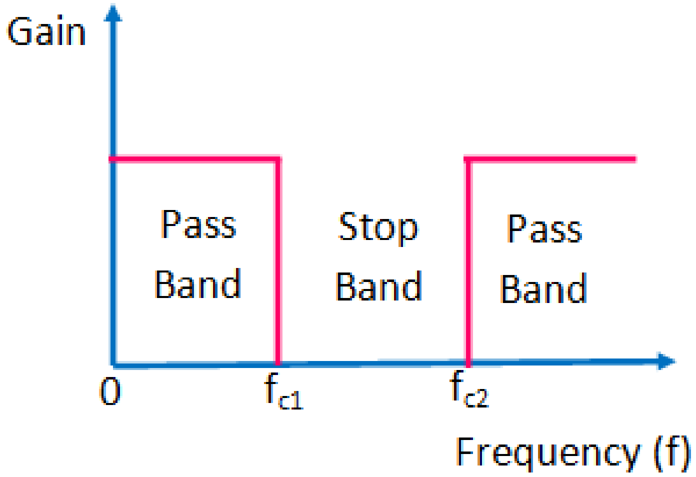
d) None of the mentioned

Band Stop Filter

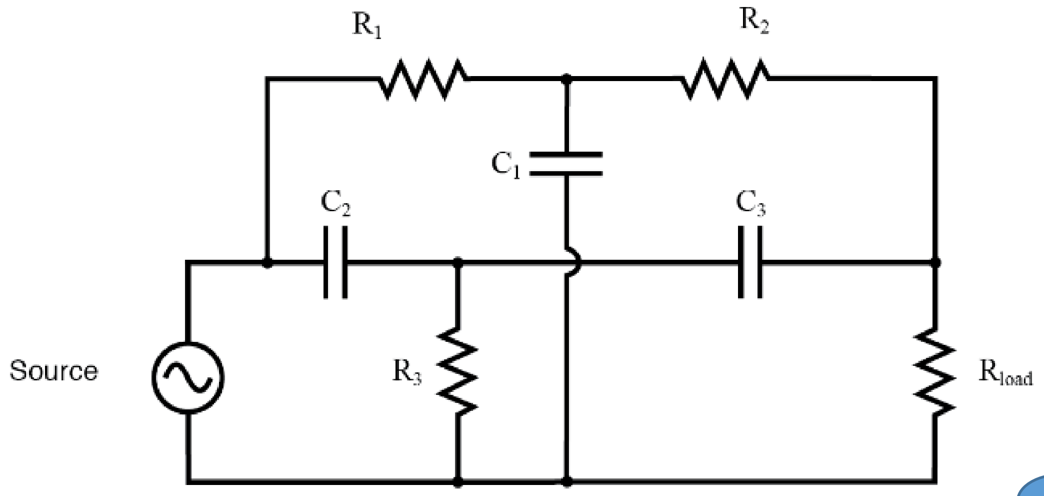




"Twin-T" band-stop filter.



Band Stop Filter

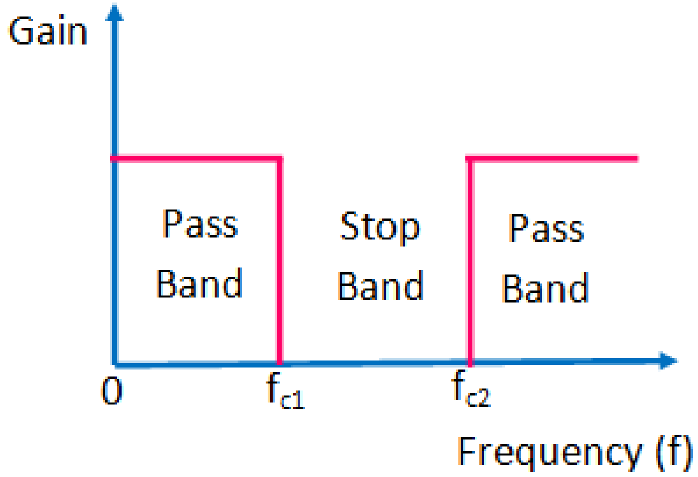


"Twin-T" band-stop filter.

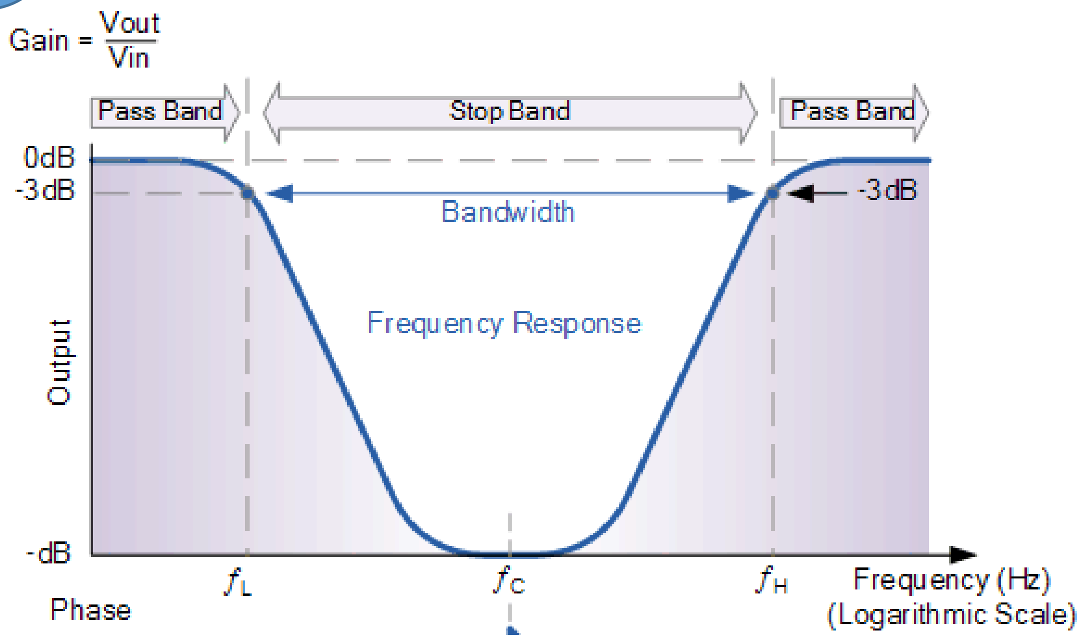
$$f_c = \frac{1}{2\pi RC}$$

$$f_c = \sqrt{f_L f_H}$$

Maximum attenuation



- ❑ **Also known as band-elimination, band-reject, or notch filters.**
- ❑ **Band-stop filters can be made by placing a low-pass filter in parallel with a high-pass filter. Commonly, both the low-pass and high-pass filter sections are of the "T" configuration, giving the name "Twin-T" to the band-stop combination.**
- ❑ **The frequency of maximum attenuation is called the notch frequency.**



QUICK QUIZ (POLL)

The attenuation rate is also called?

a) Roll off
b) Roll in
c) Envelope delay
d) Ripple

Limitations of Passive Filters

1. The amplitude of the output signal is less than that of the input signal, i.e., the gain is never greater than unity.
2. The load impedance affects the filters characteristics.

- With passive filter circuits containing multiple stages, this loss in signal amplitude called "Attenuation" can become quiet severe. One way of restoring or controlling this loss of signal is by using amplification through the use of **Active Filters**.
- As their name implies, **Active Filters** contain active components such as **operational amplifiers, transistors or FETs** within their circuit design. They draw their power from an external power source and use it to boost or amplify the output signal.

Limitations of Passive Filters

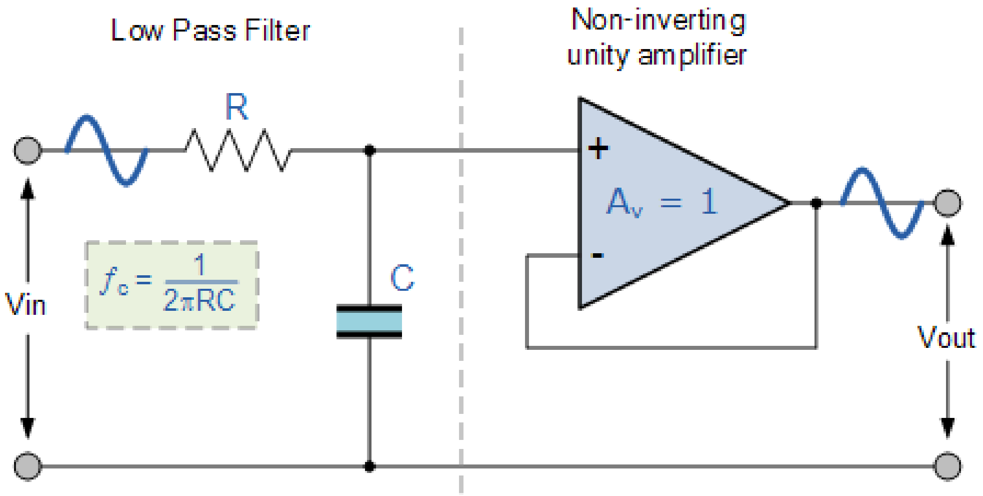
- An active filter generally uses an operational amplifier (op-amp) within its design and in the Operational Amplifier tutorial we saw that an Op-amp has a high input impedance, a low output impedance and a voltage gain determined by the resistor network within its feedback loop.
- Active filters are generally much easier to design than passive filters, they produce good performance characteristics, very good accuracy with a steep roll-off and low noise when used with a good circuit design.

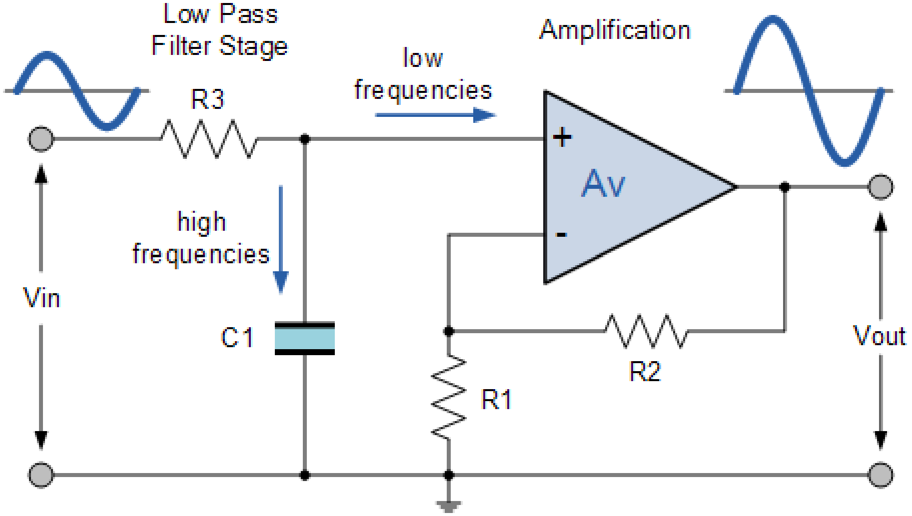
Explanation Slide

Active Low Pass Filter

- The only difference this time is that it uses an op-amp for amplification and gain control.

How much amplification ???





QUICK QUIZ (POLL)

The gain of the first order low pass filter

a) Increases at the rate 20dB/decade

b) Increases at the rate 40dB/decade

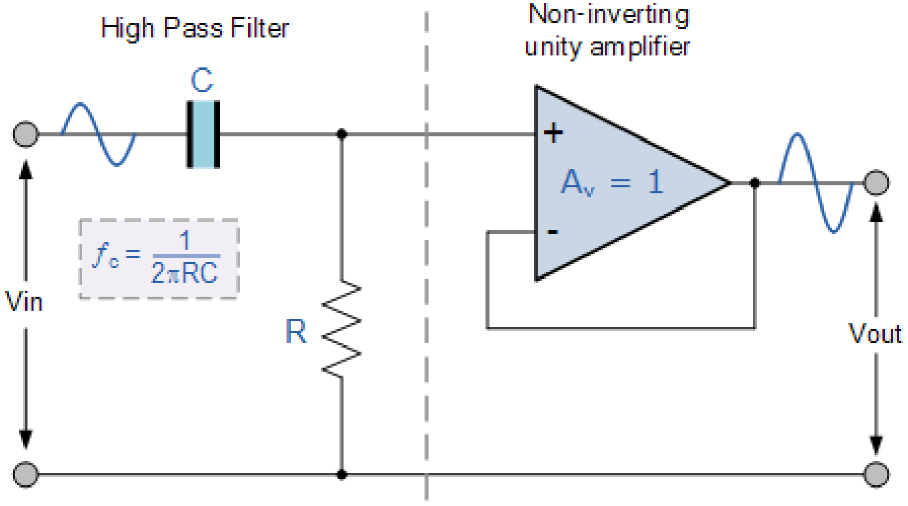
c) Decreases at the rate 20dB/decade

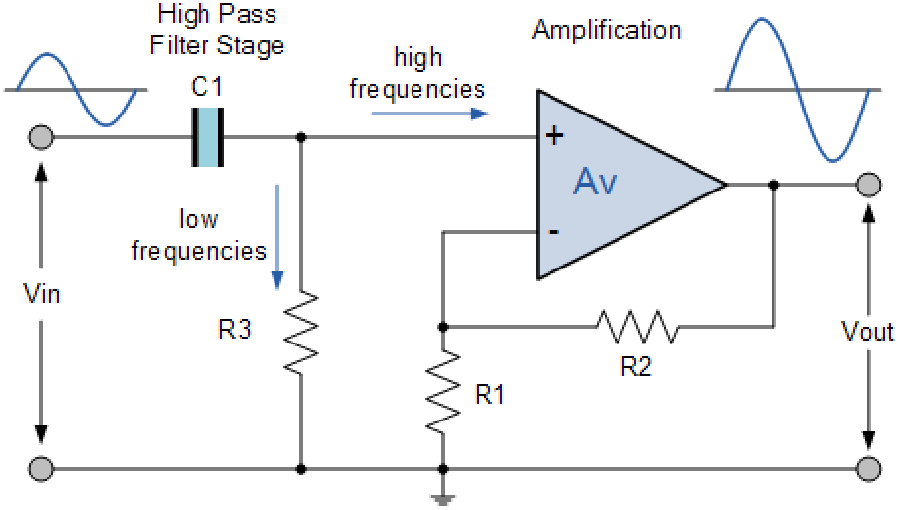
d) Decreases at the rate 40dB/decade

Active High Pass Filter

- The only difference this time is that it uses an op-amp for amplification and gain control.

Cut off frequency?

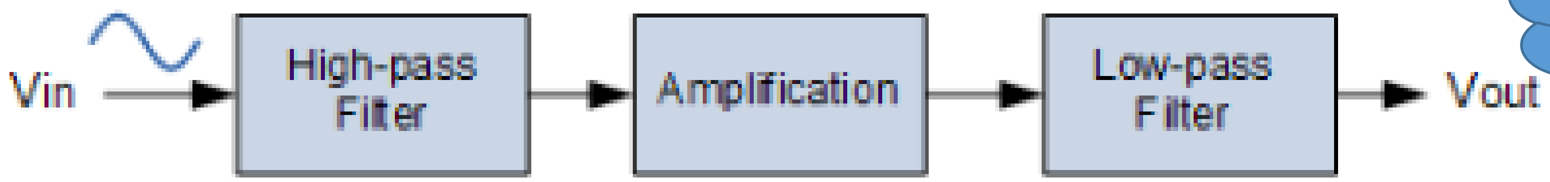


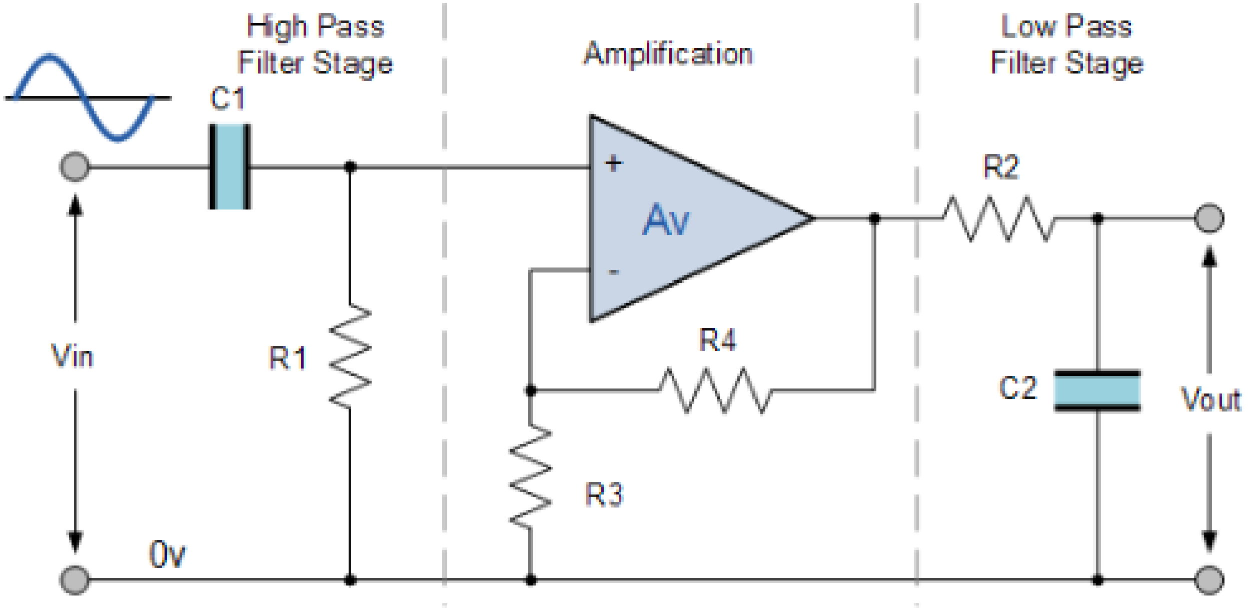


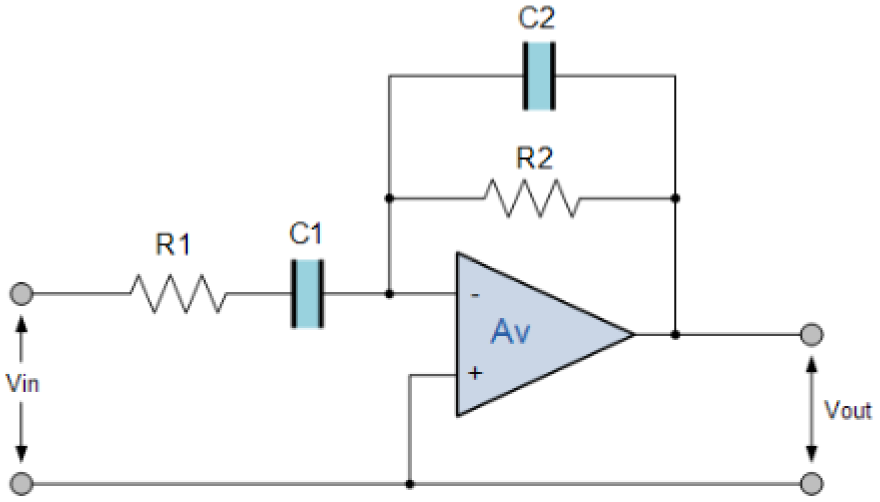
Active Band Pass Filter

- Simple **Active Band Pass Filter** can be easily made by cascading together a single Low Pass Filter with a single High Pass Filter as shown.

Input Impedance Of Op-amp ?

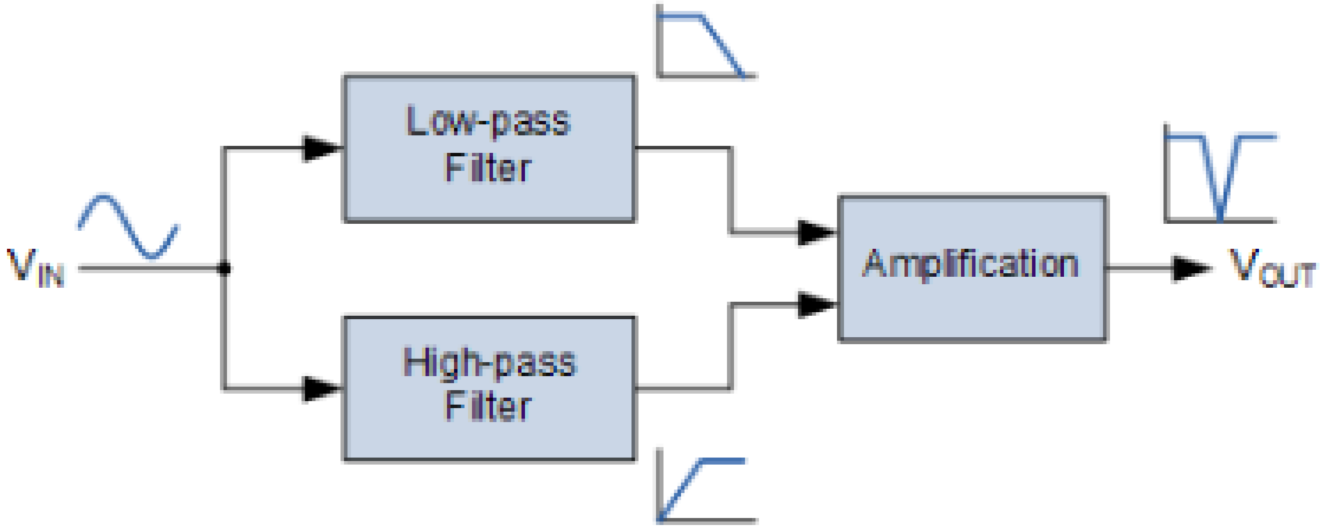




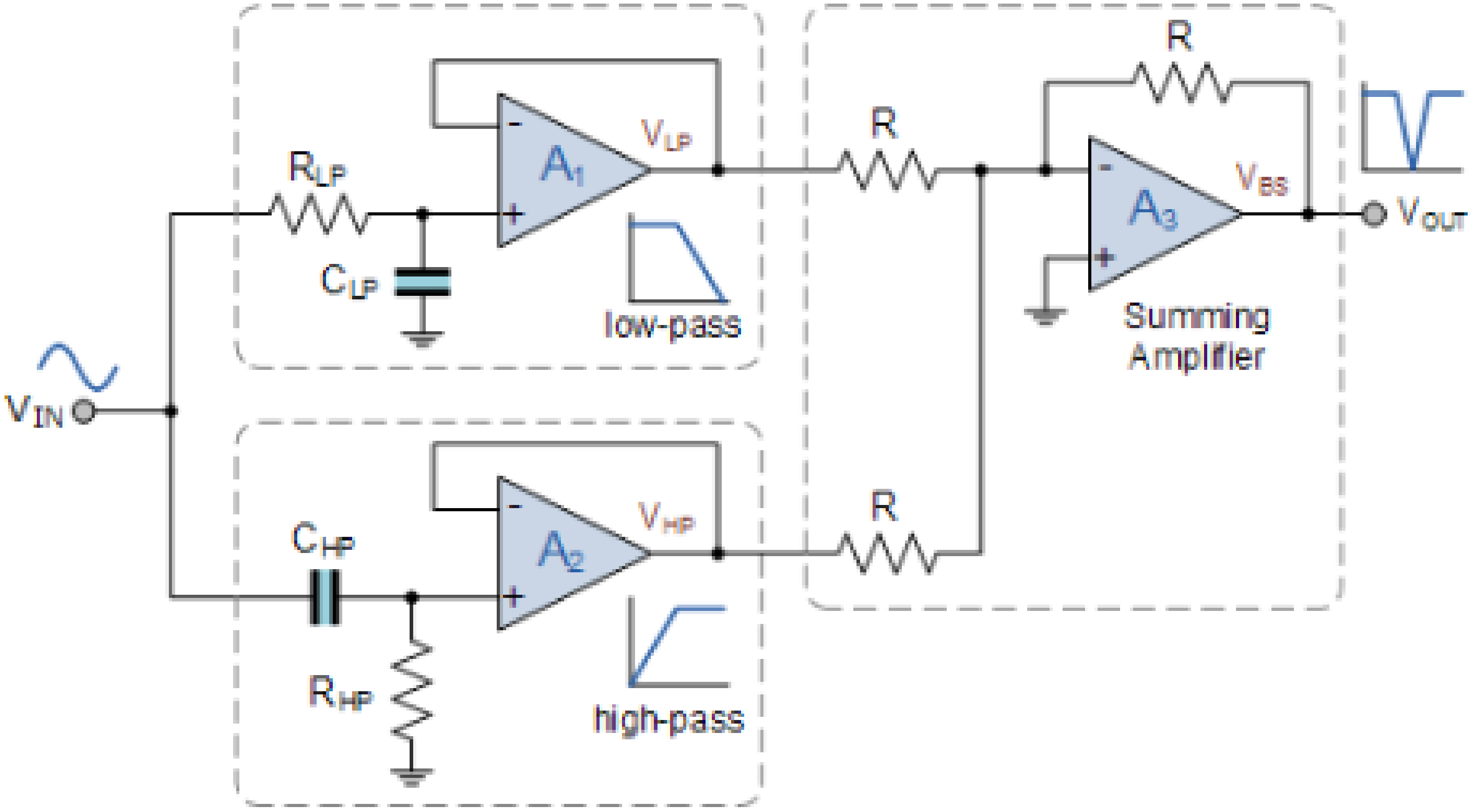


Active Band Stop Filter

- The band stop filter, also known as a band reject filter, passes all frequencies with the exception of those within a specified stop band which are greatly attenuated.
- The use of operational amplifiers within the band stop filter design also allows us to introduce voltage gain into the basic filter circuit.



Active Band Stop Filter



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