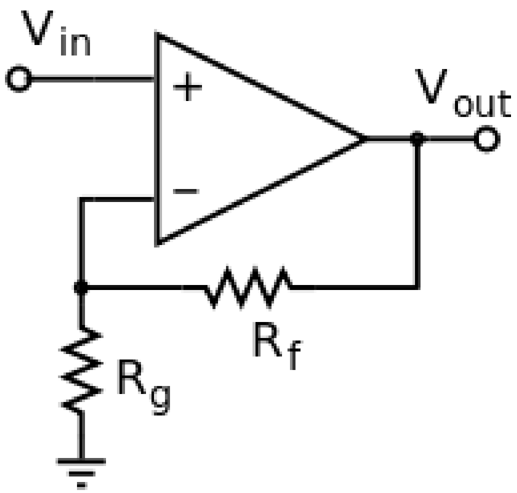
Fundamentals of Electronics

ECE 101

Op-Amp: Negative Feedback

Equilibrium?

What is: $A_{CL} = V_{out} / V_{in}$



- **When an op amp operates in linear (i.e., not saturated) mode, the difference in voltage between the non-inverting (+) and inverting (−) pins is <u>negligibly small</u>.**

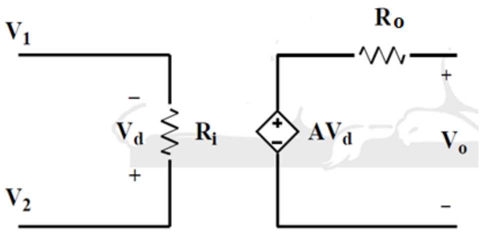
- **The input impedance of the (+) and (−) pins is much larger than other resistances in the circuit.**

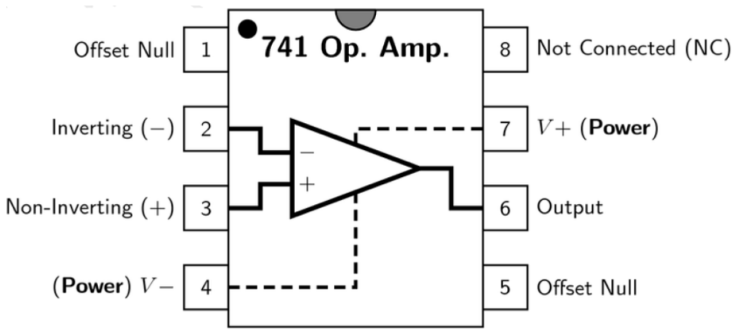
Op-Amp analysis [Negative Feedback]

$R_i = \infty\ \Omega$

– Therefore, $i_1 = i_2 = 0A$

$R_o = 0\ \Omega$

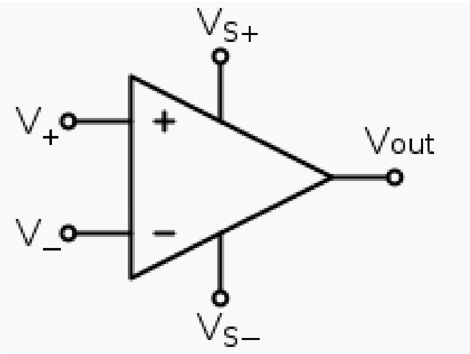




$V_d = 0V$ and so $V_1 = V_2$

- The internal circuitry in the op-amp tries to force the voltage at the inverting input to be equal to the non-inverting input.

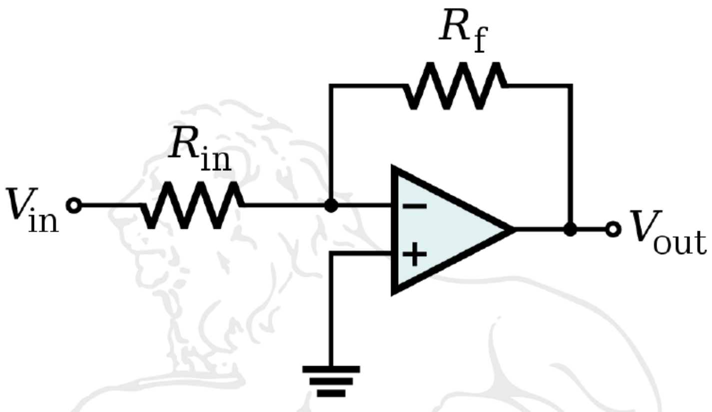
- **While analyzing an Op-Amp circuit [In negative feedback]**
  - **No current flows into either input terminal**
  - **In negative feedback, voltage difference between the terminals is zero**
  - **Therefore, no current flows out of the output terminal**



Op-Amp usages

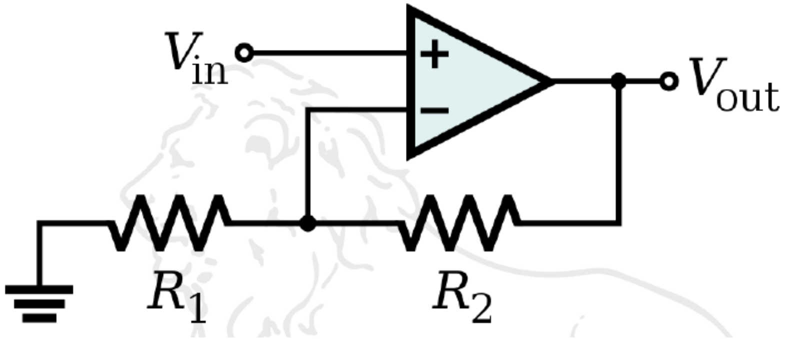
- While analyzing an Op-Amp circuit
  - Assume no current flows into either input terminal
  - Assume no current flows out of the output terminal
  - Virtual Ground

Inverting Amplifier



$$V_{out} = -\frac{R_f}{R_{in}} V_{in}$$

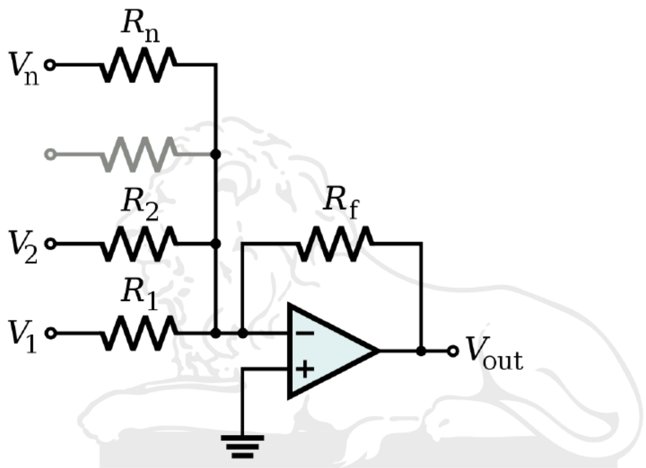
Non-inverting Amplifier



$$V_{out} = V_{in}\left(1 + \frac{R_2}{R_1}\right)$$

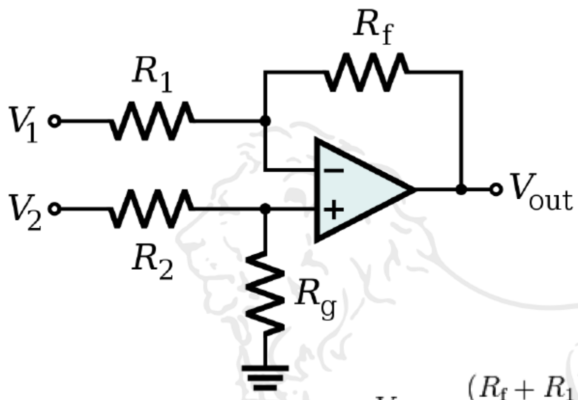
Op-Amp usages

Summing amplifier



$$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_n}{R_n}\right)$$

Difference amplifier



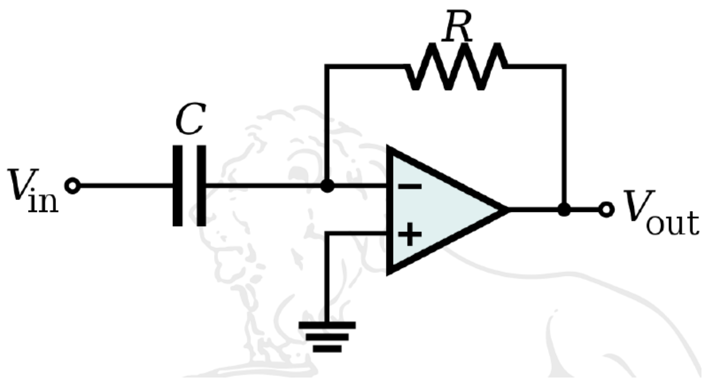
$$V_{out} = \frac{(R_f + R_1)\,R_g}{(R_g + R_2)\,R_1}V_2 - \frac{R_f}{R_1}V_1$$

If $R_1 = R_2$ and $R_f = R_g$: $V_{out} = \frac{R_f}{R_1}(V_2 - V_1)$

Op-Amp usages

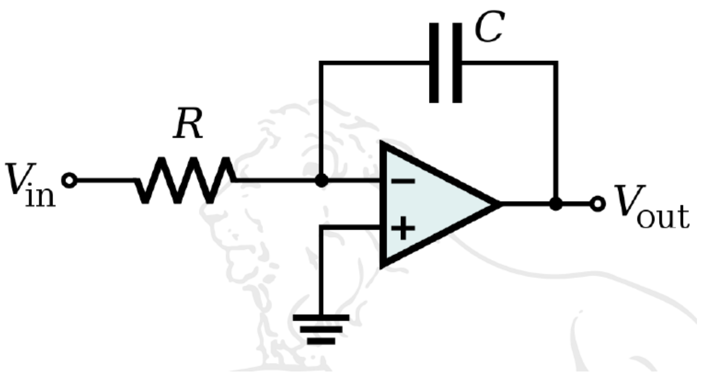
- While analyzing an Op-Amp circuit in negative feedback
  - Assume no current flows into either input terminal
  - Assume no current flows out of the output terminal

Differentiator



$$V_{out} = -RC \frac{dV_{in}}{dt}$$

Integrator

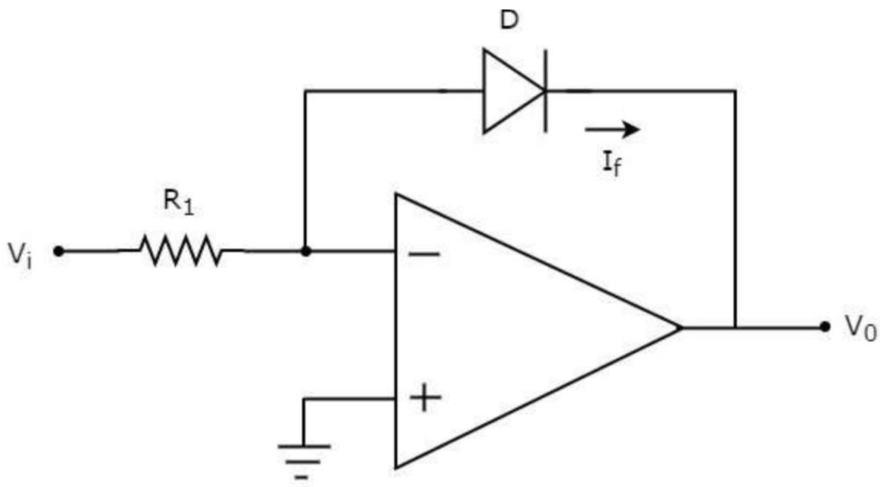


$$V_{out} = -\int_0^t \frac{V_{in}}{RC}\, dt + V_{initial}$$

Op-Amp usages

Log and Antilog Amplifiers

Log

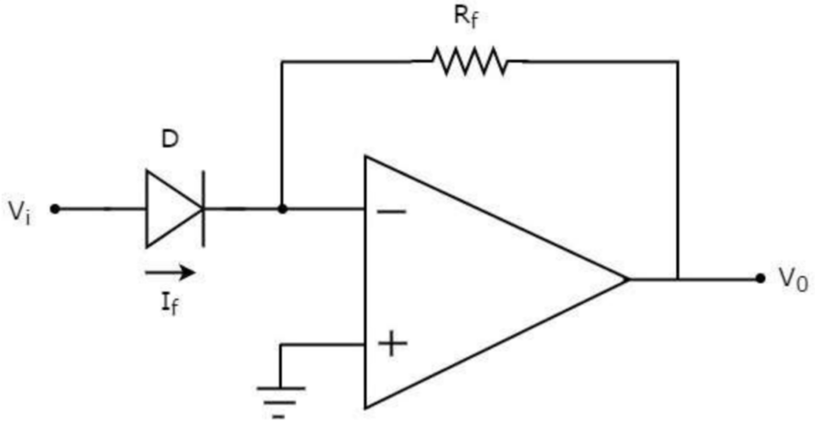


$$\frac{0 - V_i}{R_1} + I_f = 0 \qquad => I_f = \frac{V_i}{R_1}$$

$$I_f = I_s e^{\left(\frac{V_f}{nV_T}\right)} \qquad V_f = -V_0 \qquad I_f = I_s e^{\left(\frac{-V_0}{nV_T}\right)}$$

$$\frac{V_i}{R_1 I_s} = e^{\left(\frac{-V_0}{nV_T}\right)} \qquad \boxed{V_0 = -nV_T In\left(\frac{V_i}{R_1 I_s}\right)}$$

Antilog



$$-\frac{V_0}{R_f} = I_f \qquad I_f = I_s e^{\left(\frac{V_f}{nV_T}\right)}$$

$$V_0 = -R_f I_s e^{\left(\frac{V_f}{nV_T}\right)}$$

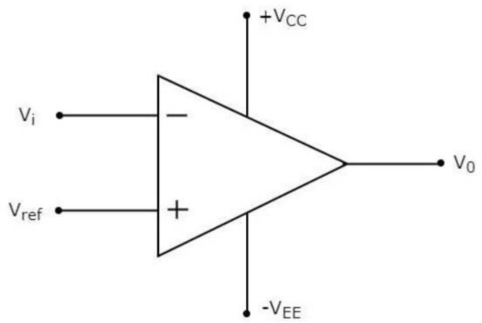
$$V_f = V_i$$

$$V_0 = -R_f I_s e^{\left(\frac{V_i}{nV_T}\right)}$$

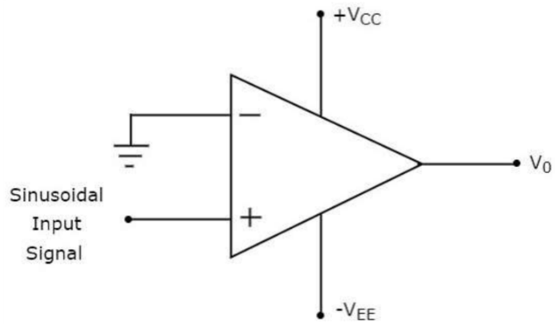
Op-Amp usages

Comparator

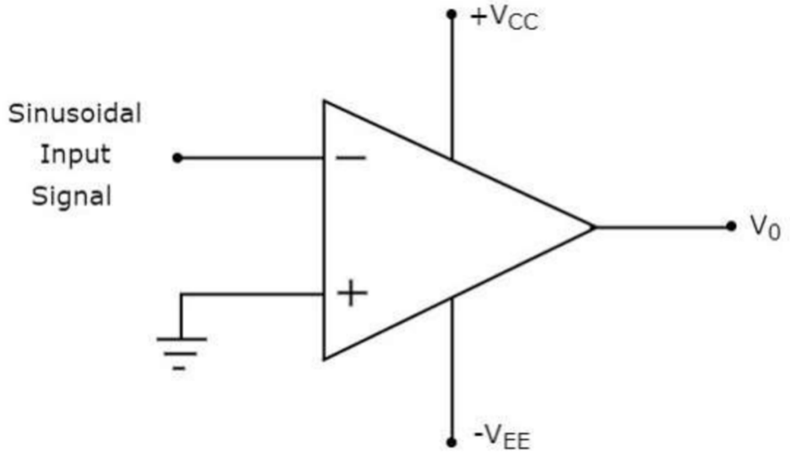
The output value of the comparator indicates which of the inputs is greater or lesser.

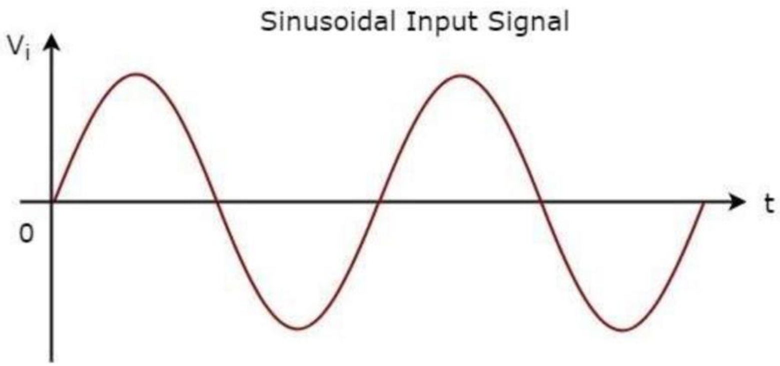


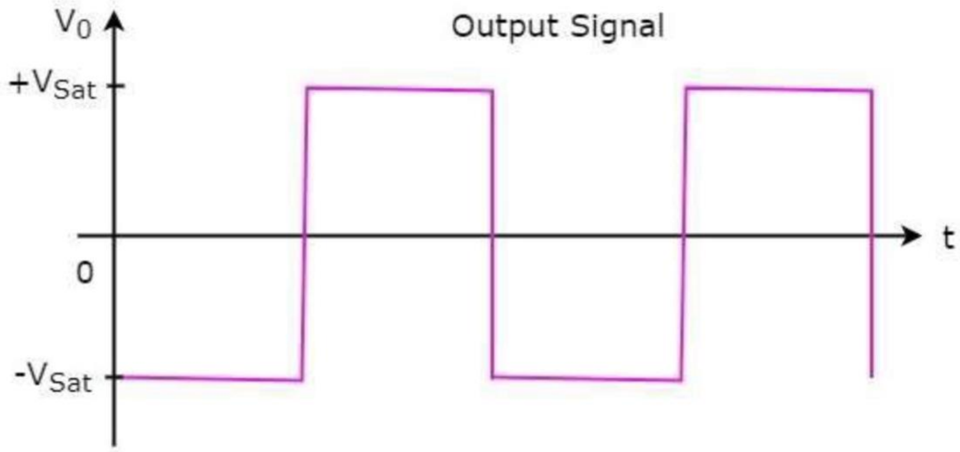
Inverting comparator



Non-inverting comparator

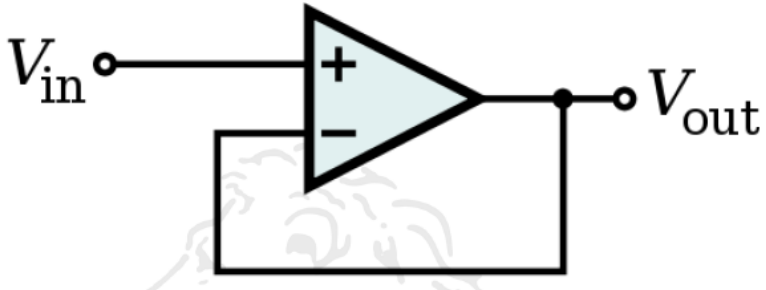


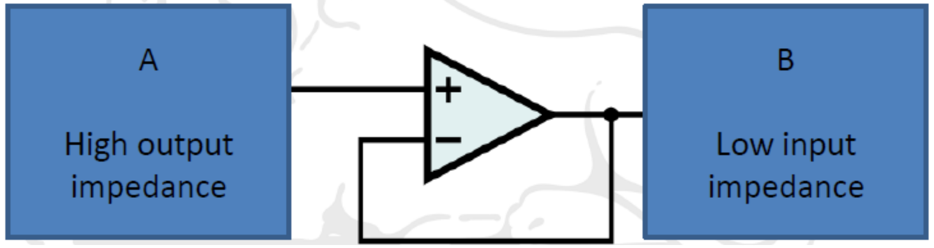


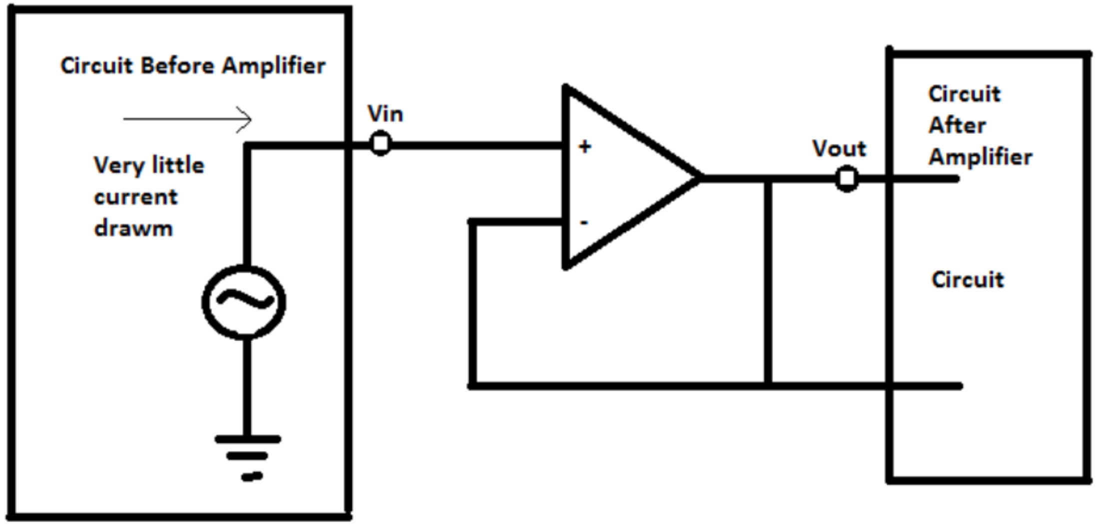


Op-Amp usages

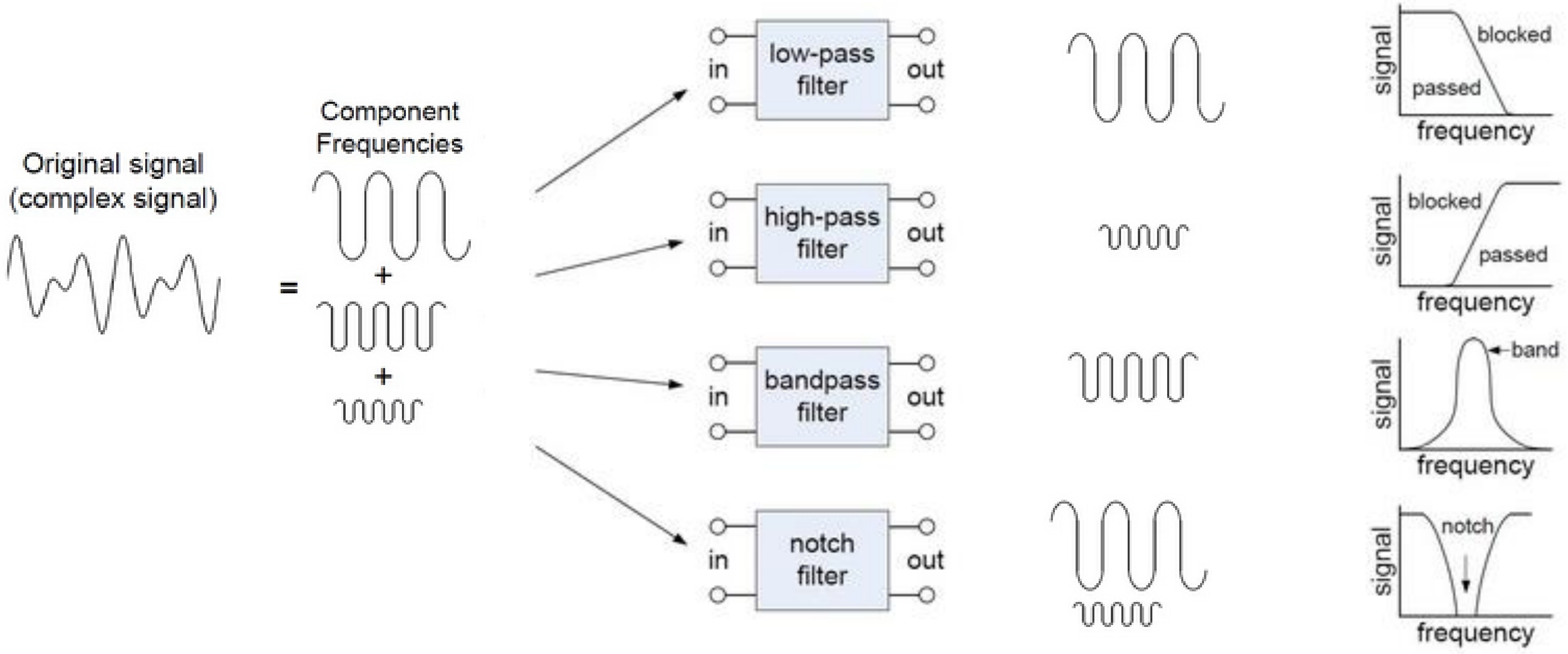
Buffer/Voltage follower or Isolation Amplifier



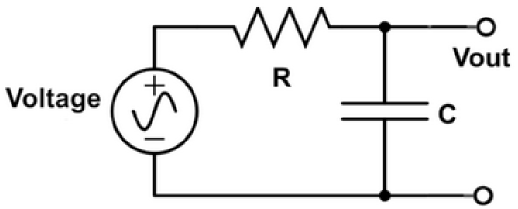




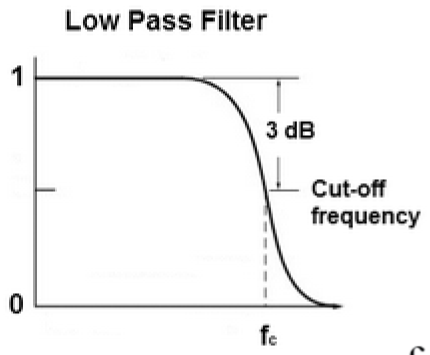
Electronic Filters

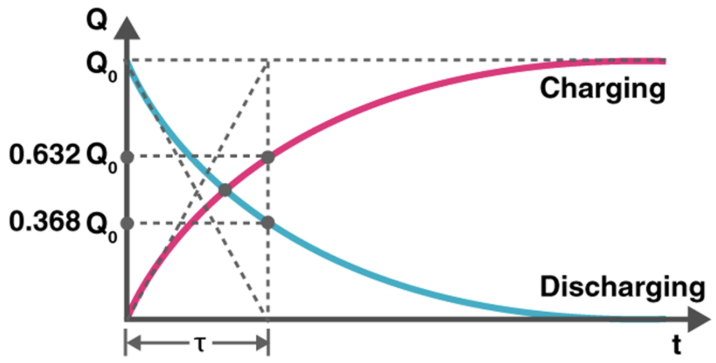


Filter circuits

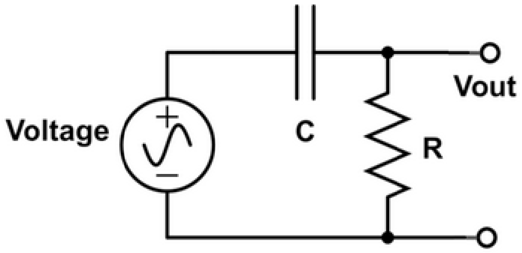


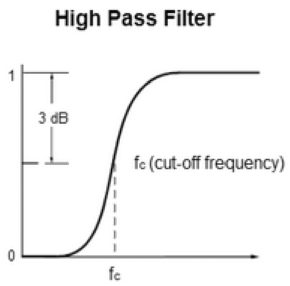
$$X_c = \frac{1}{2\pi f C}$$

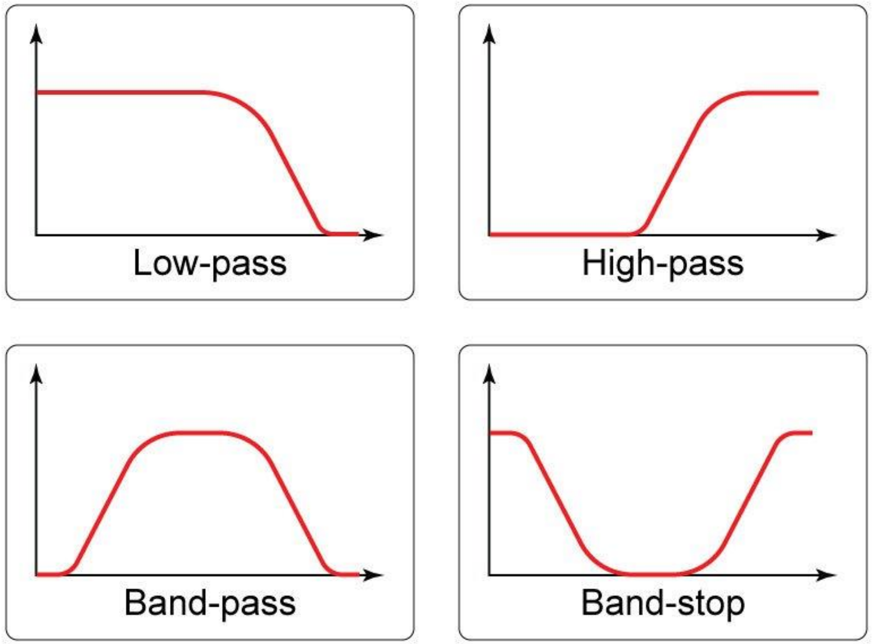


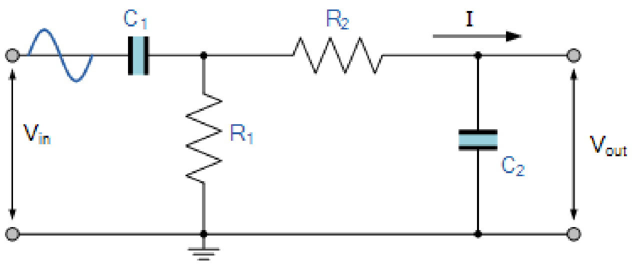


$$f_{\text{cutoff}} = \frac{1}{2\pi RC}$$





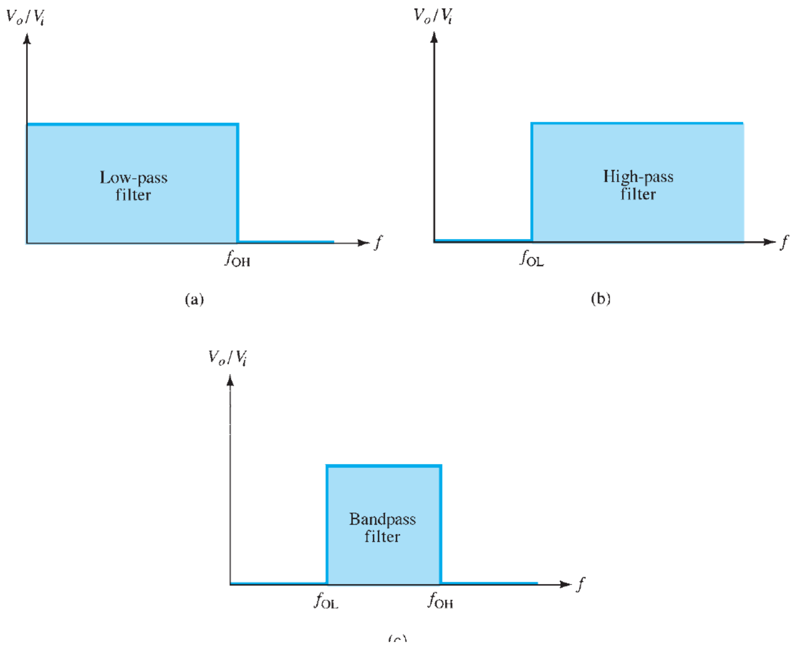


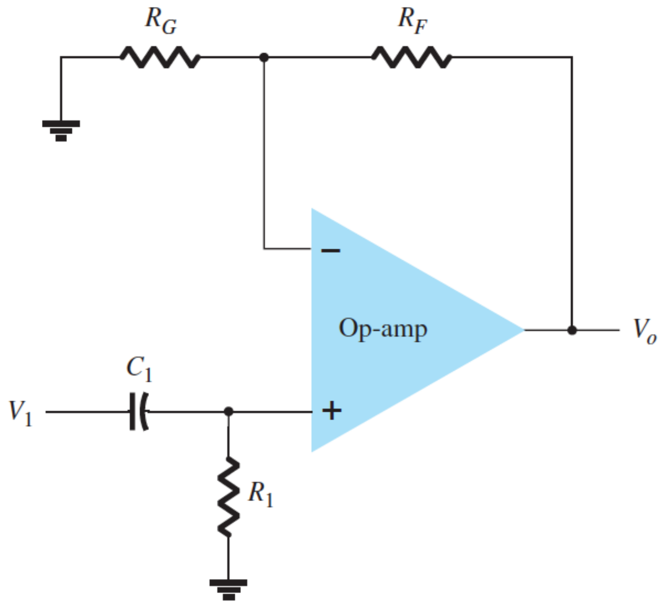


https://www.robomart.com/blog/rc-filter-circuits-introduction/

Op-Amp usages

Op-Amp based active filters





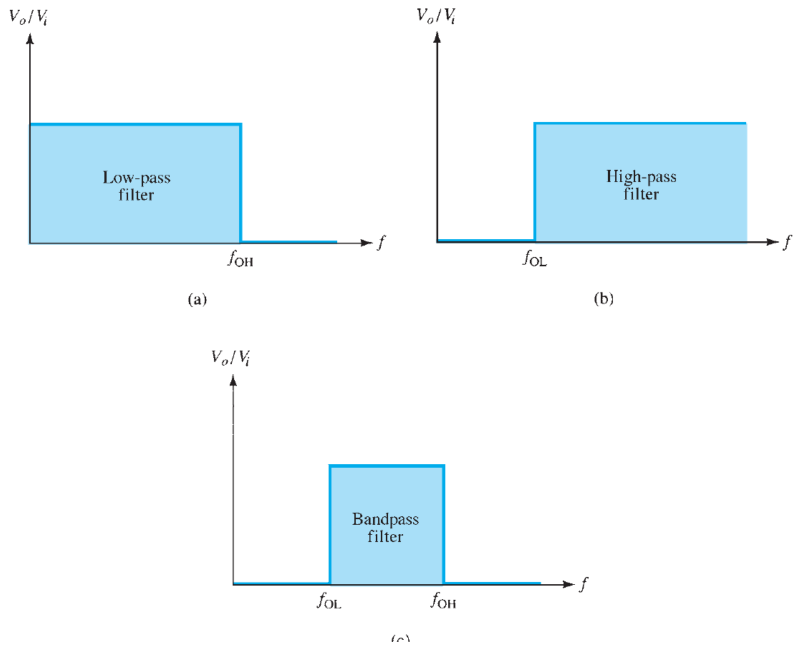
High Pass Filter (LPF)

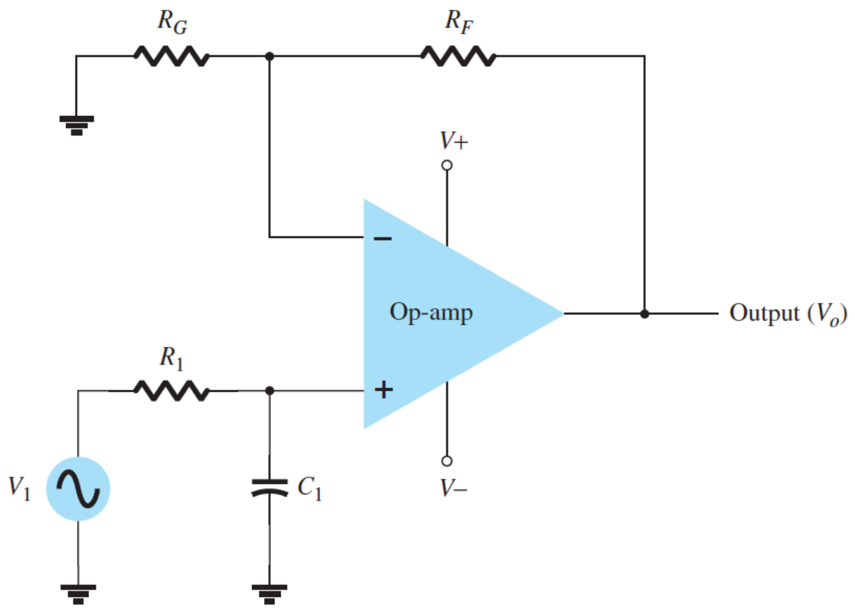
$$A_v = 1 + \frac{R_F}{R_G}$$

$$f_{OL} = \frac{1}{2\pi R_1 C_1}$$

Op-Amp usages

Op-Amp based active filters





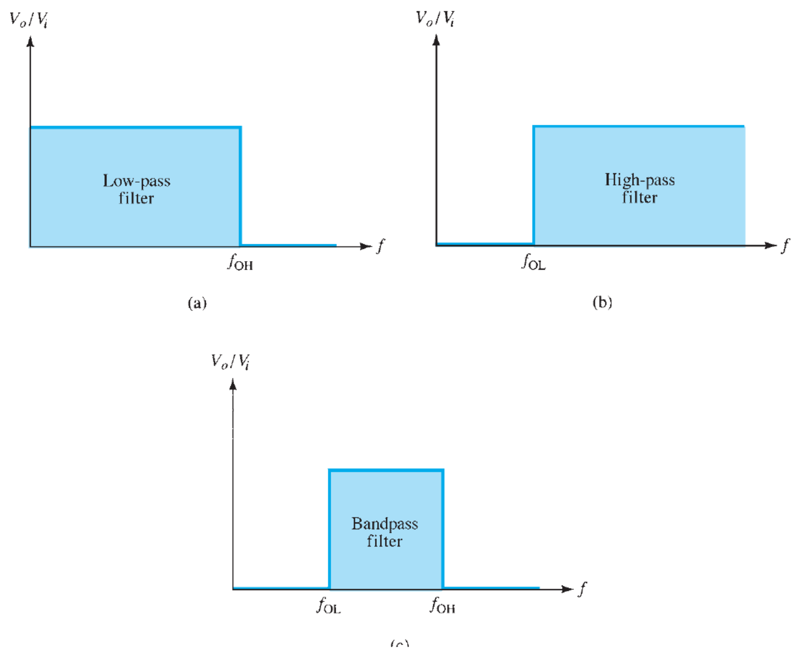
Low Pass Filter (LPF)

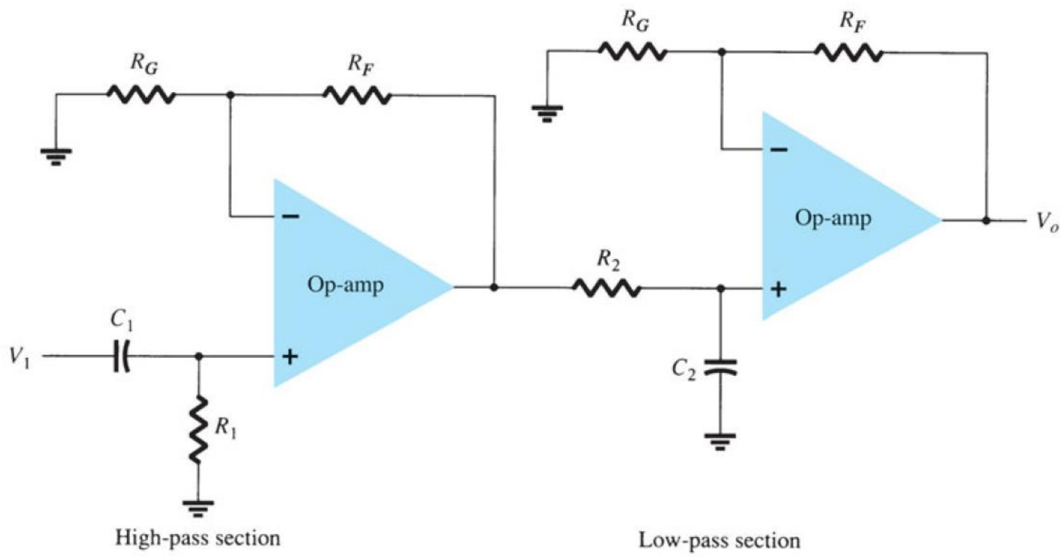
$$A_v = 1 + \frac{R_F}{R_G}$$

$$f_{OH} = \frac{1}{2\pi R_1 C_1}$$

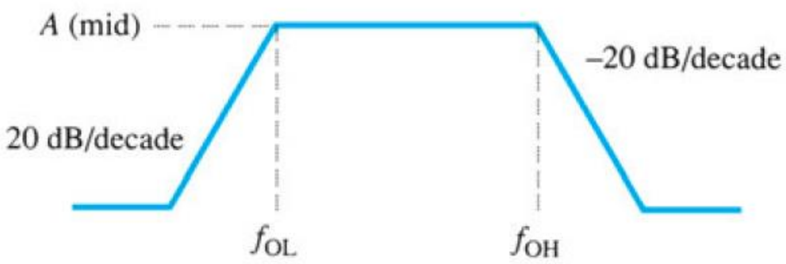
Op-Amp usages

Op-Amp based active filters





Band Pass Filter (LPF)



$$f_{OL} = \frac{1}{2\pi R_1 C_1}$$

$$f_{OH} = \frac{1}{2\pi R_2 C_2}$$

OpAmp and Oscillators

Oscillators

- Oscillation: an effect that repeatedly and regularly fluctuates about the mean value
- Oscillator: circuit that produces oscillation
- Oscillators are signal generators
- **Oscillator is an electronic circuit that generates a periodic waveform on its output without an external signal source.**
    - **Except the DC input**
- It is used to convert dc to ac – in a way.
- Largely two types of oscillators:
    - Harmonic oscillators: produces a sinusoidal wave
    - Relaxation oscillators: produces non-sinusoidal wave like square wave or sawtooth wave

Mechanism of an oscillator

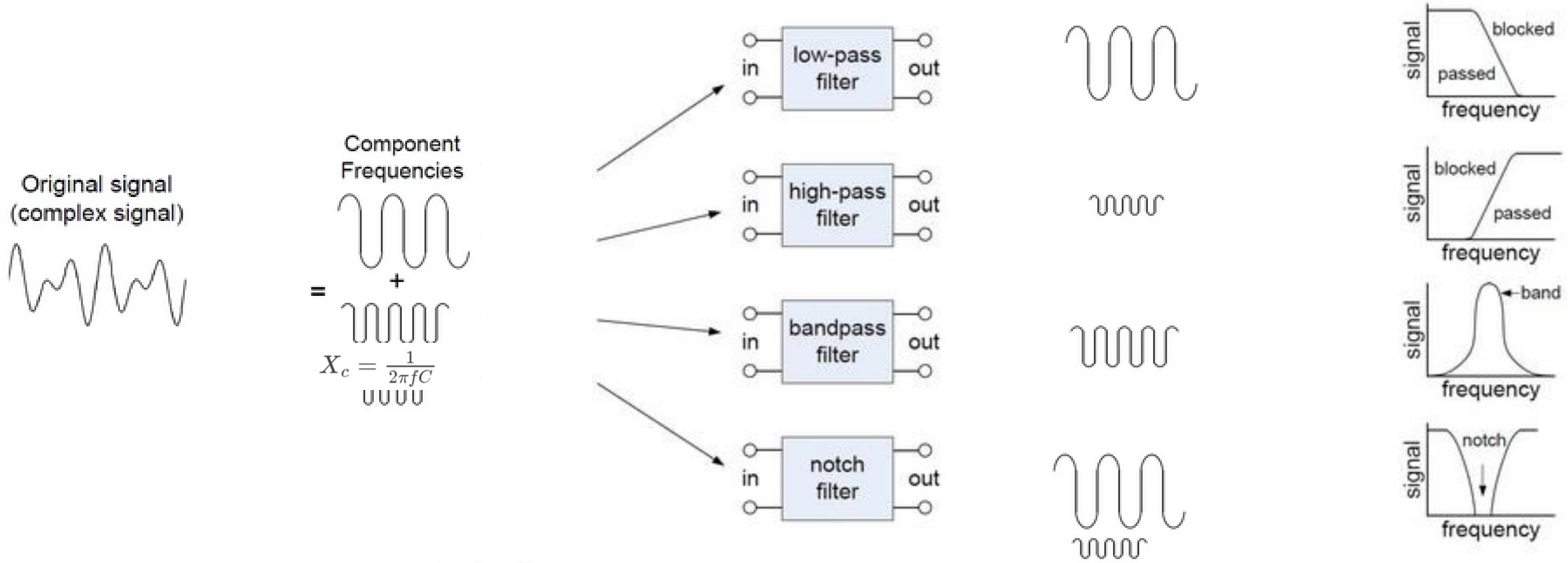
- Let’s consider the case of harmonic oscillator
- The basic form of a harmonic oscillator is an **electronic amplifier** with the **output** attached to a **narrow-band electronic filter**
- The output of the filter attached to the input of the amplifier
- When the power supply to the amplifier is first switched on, the amplifier's output consists only of noise

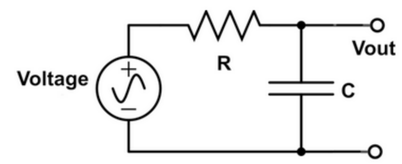
Noise is an unwanted disturbance in an electrical signal consisting of various frequencies.

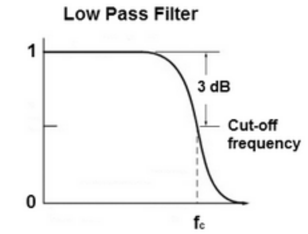
- The noise travels around the loop, being filtered and re-amplified until it increasingly resembles the desired signal.

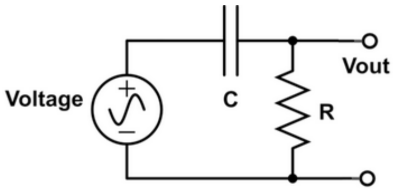
Oscillator = Amplifier + Filter (Frequency Selection) + Positive feedback

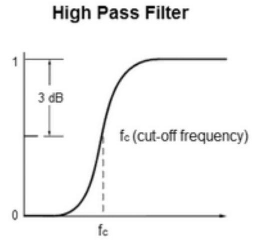
Electronic Filters

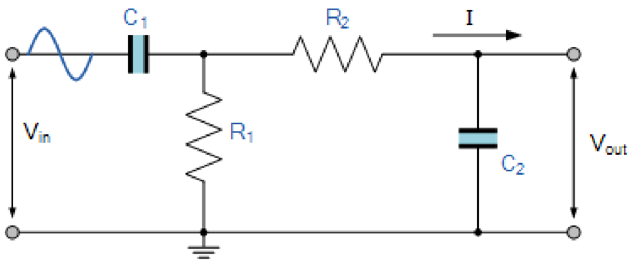












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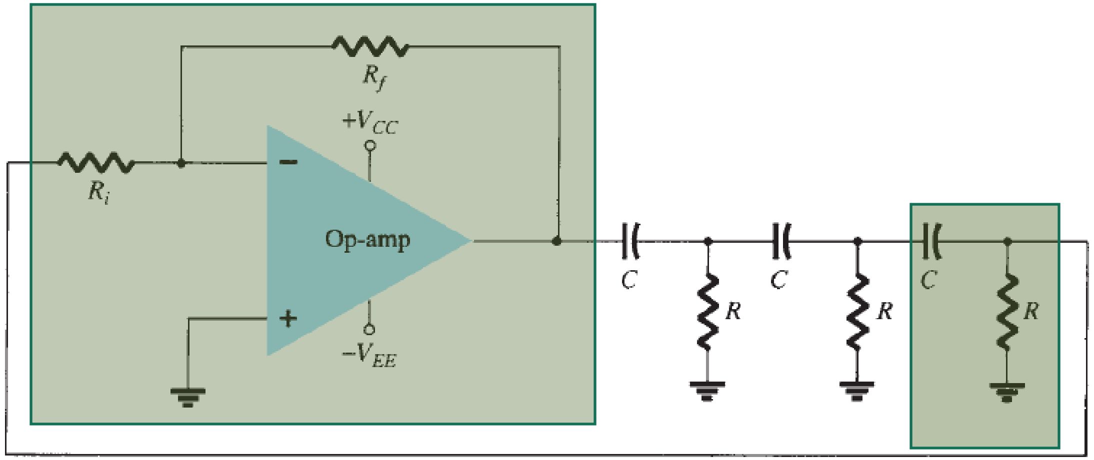
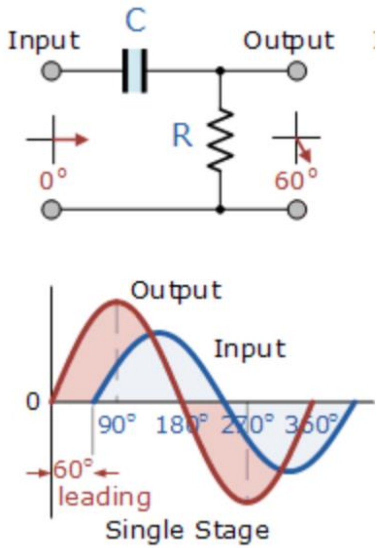
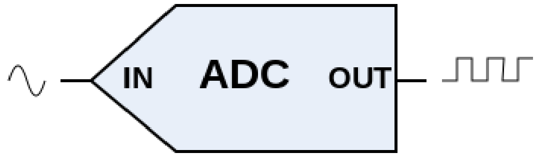
An oscillator circuit



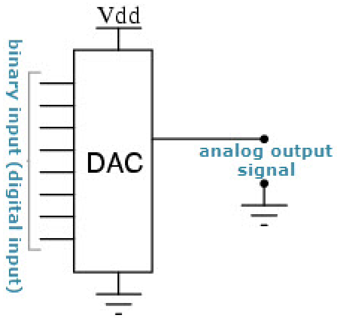


Oscillator = Amplifier + Filter + Positive feedback

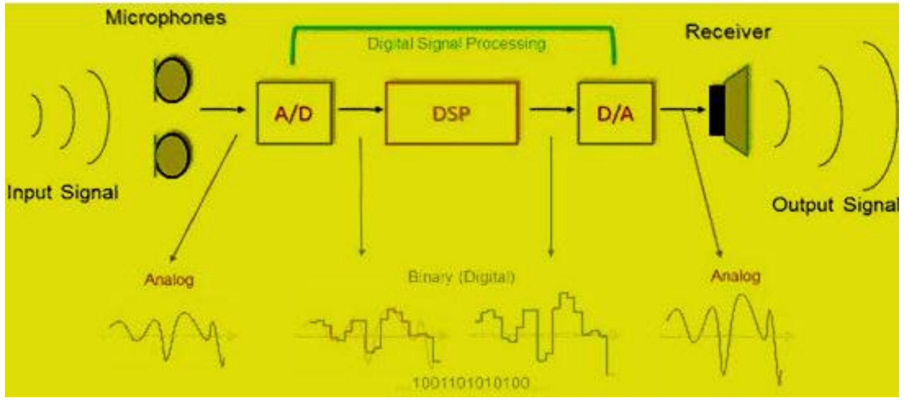
A-D and D-A converters



Analog to digital converter



Digital to analog converter



Audio Signal Processing

Thank you