

Fundamentals of Electronics

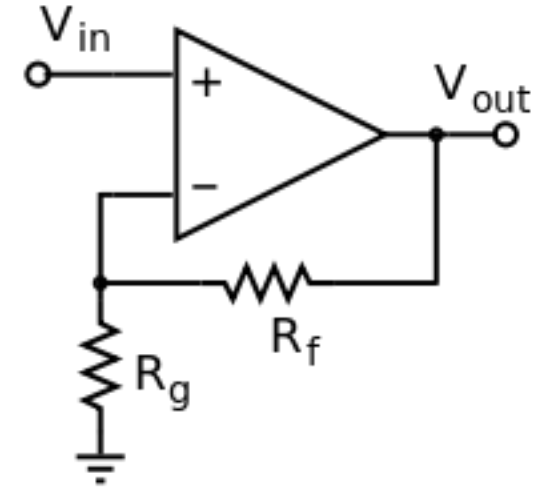
ECE 101



Op-Amp: Negative Feedback

Equilibrium?

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



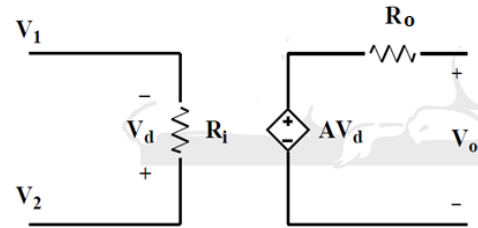
- When an op amp operates in linear (i.e., not saturated) mode, the difference in voltage between the non-inverting (+) and inverting (-) pins is negligibly small.
- The input impedance of the (+) and (-) pins is much larger than other resistances in the circuit.

Op-Amp analysis [Negative Feedback]

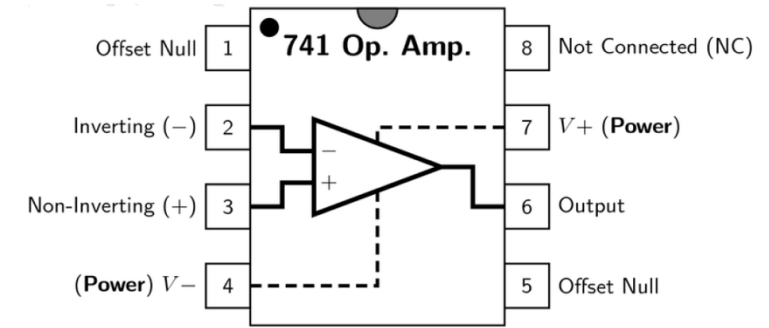
$$R_i = \infty \Omega$$

– Therefore, $i_1 = i_2 = 0A$

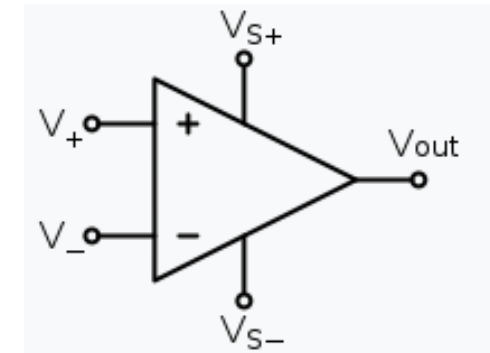
$$R_o = 0 \Omega$$



$$V_d = 0V \text{ and so } V_1 = V_2$$



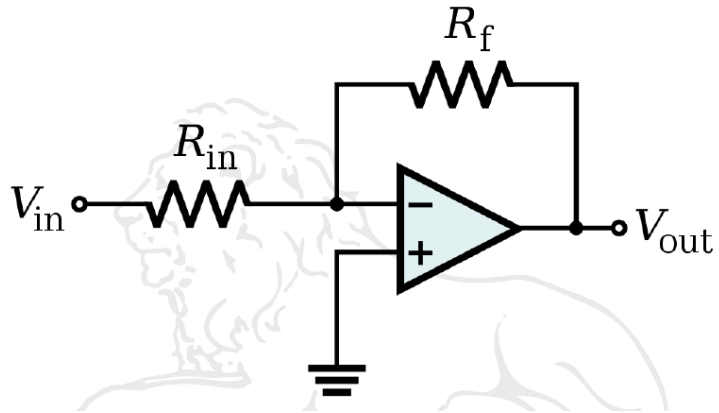
- The internal circuitry in the op-amp tries to force the voltage at the inverting input to be equal to the non-inverting input.
- **While analyzing an Op-Amp circuit [In negative feedback]**
 - No current flows into either input terminal
 - In negative feedback, voltage difference between the terminals is zero
 - Therefore, no current flows out of the output terminal



Op-Amp usages

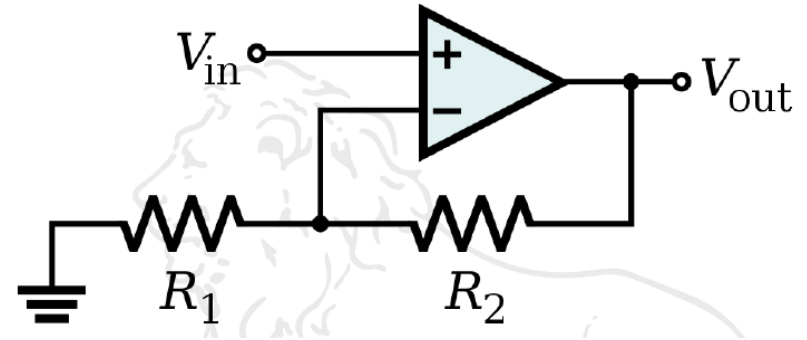
- While analyzing an Op-Amp circuit
 - Assume no current flows into either input terminal
 - Assume no current flows out of the output terminal
 - Virtual Ground

Inverting Amplifier



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

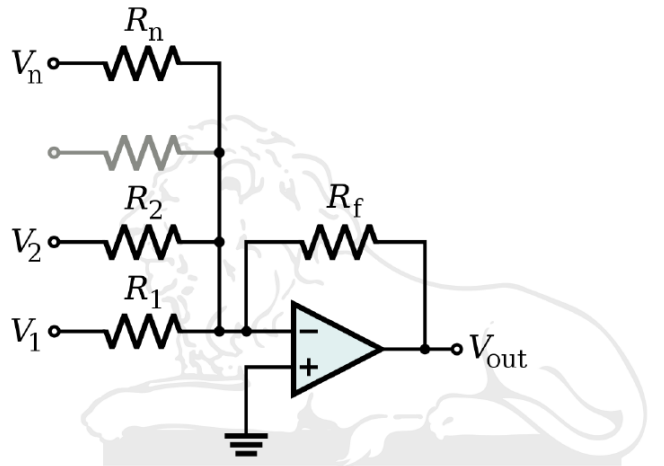
Non-inverting Amplifier



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

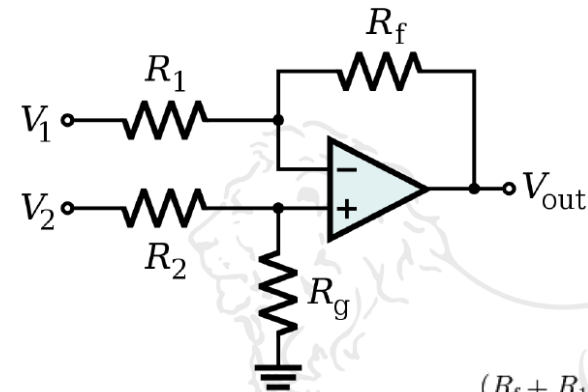
Op-Amp usages

Summing amplifier



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

Difference amplifier



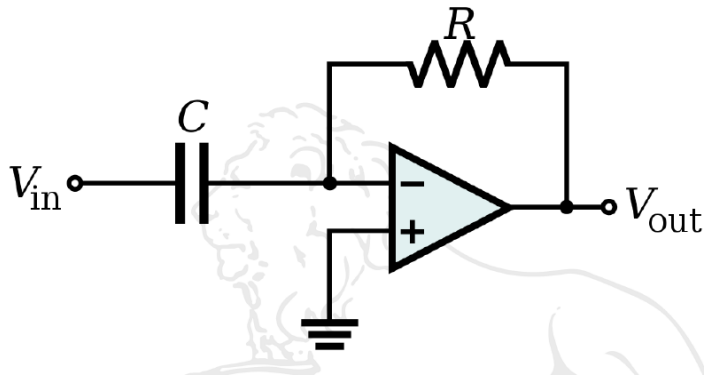
$$V_{out} = \frac{(R_f + R_1) R_g}{(R_g + R_2) R_1} V_2 - \frac{R_f}{R_1} V_1$$

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

Op-Amp usages

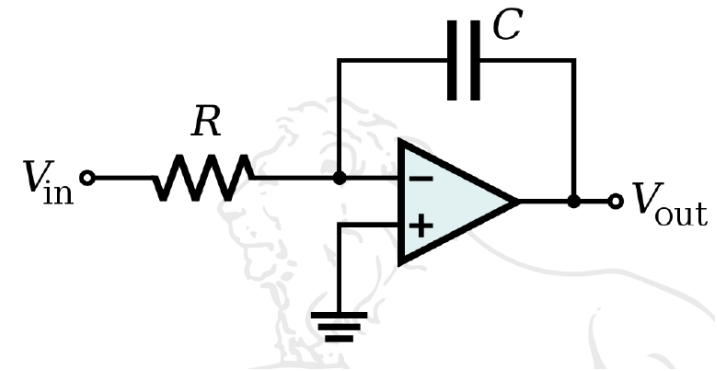
- While analyzing an Op-Amp circuit in negative feedback
 - Assume no current flows into either input terminal
 - Assume no current flows out of the output terminal

Differentiator



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

Integrator

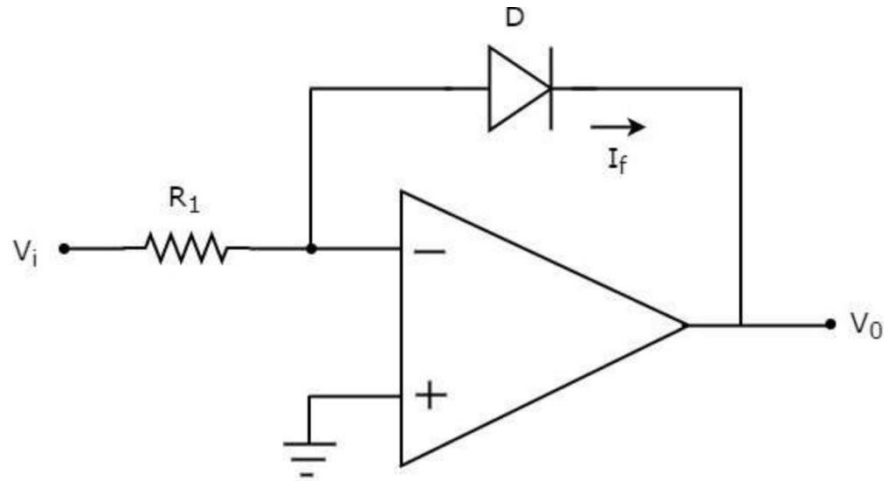


$$V_{\text{out}} = - \int_0^t \frac{V_{\text{in}}}{RC} dt + V_{\text{initial}}$$

Op-Amp usages

Log and Antilog Amplifiers

Log



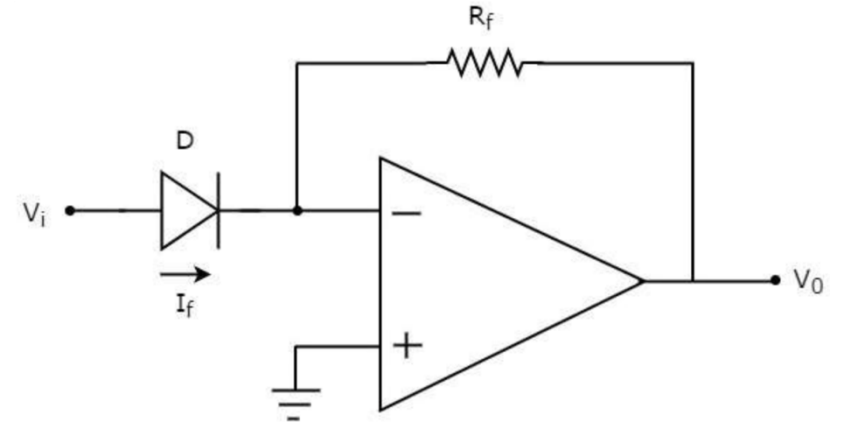
$$\frac{0 - V_i}{R_1} + I_f = 0 \quad \Rightarrow \quad I_f = \frac{V_i}{R_1}$$

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

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

$$V_0 = -nV_T \ln \left(\frac{V_i}{R_1 I_s} \right)$$

Antilog



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

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

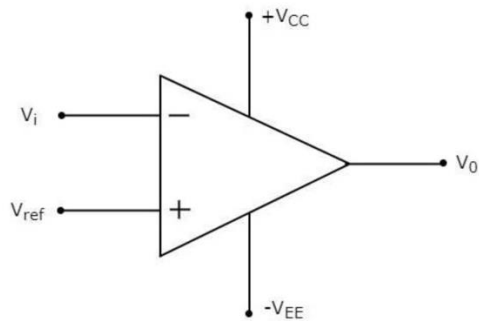
$$V_f = V_i$$

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

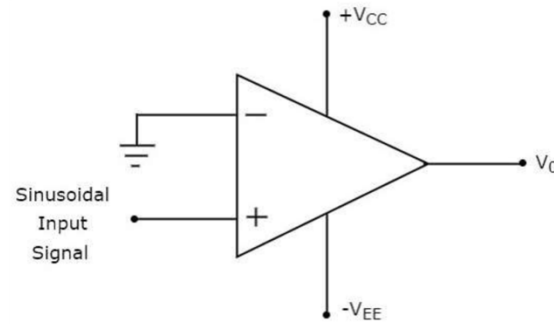
Op-Amp usages

Comparator

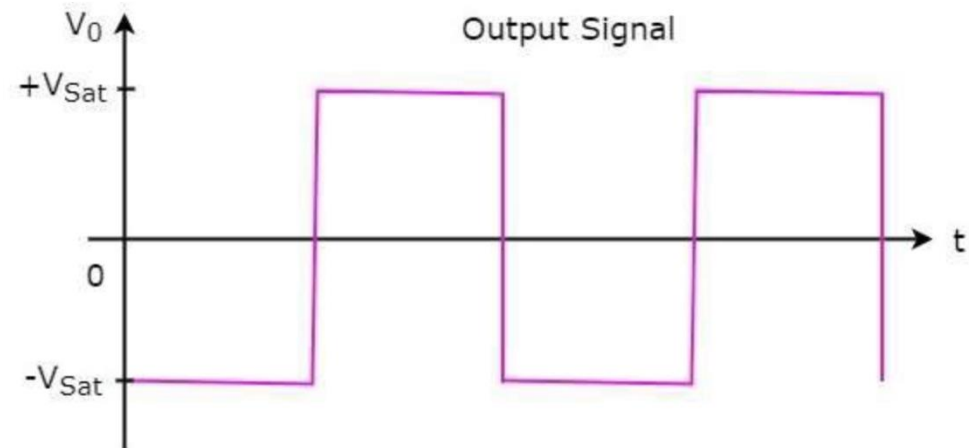
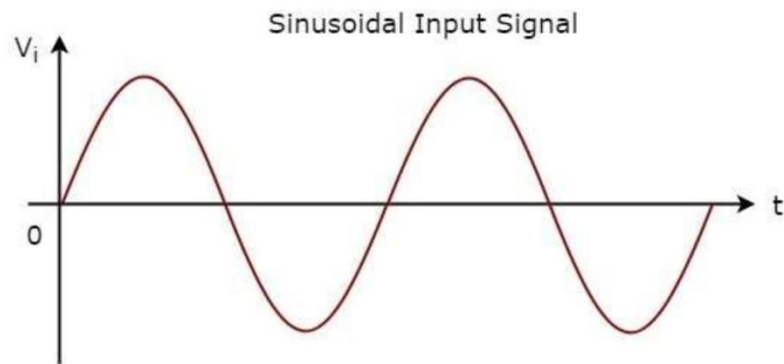
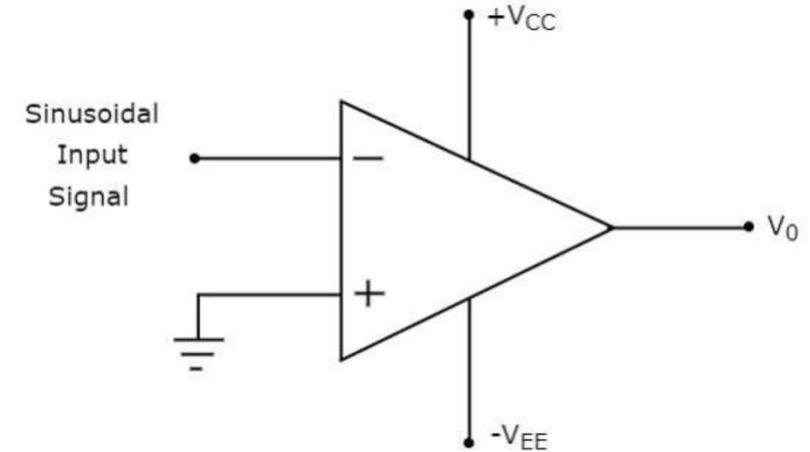
The output value of the comparator indicates which of the inputs is greater or lesser.



Inverting comparator

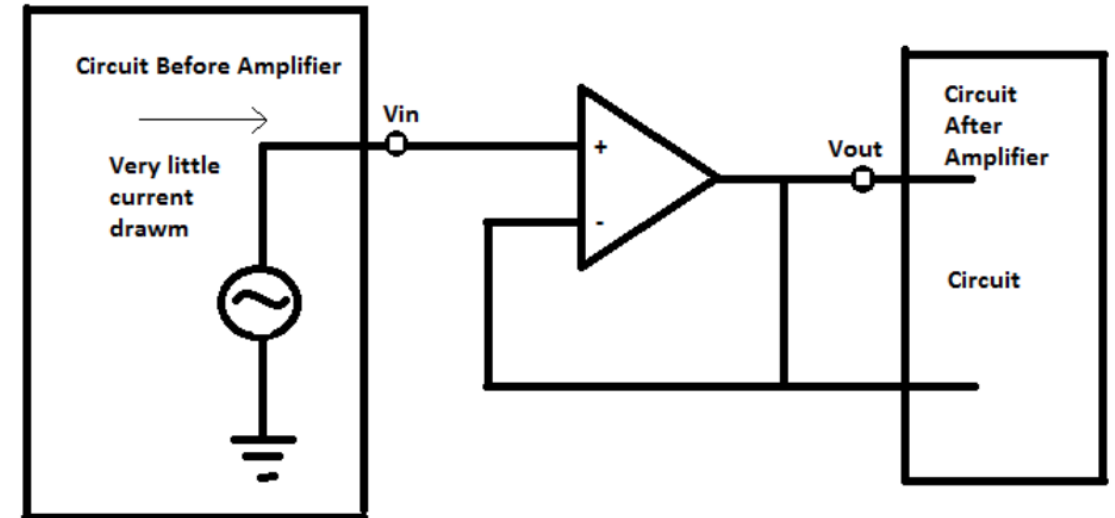
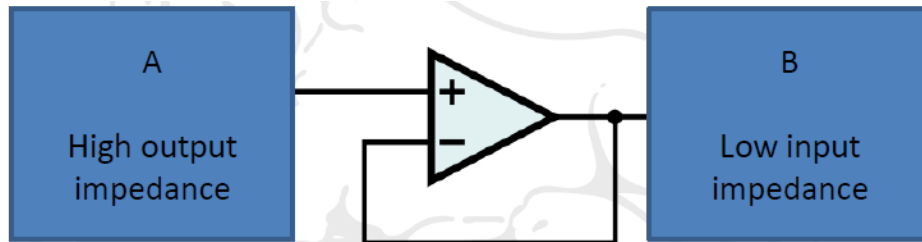
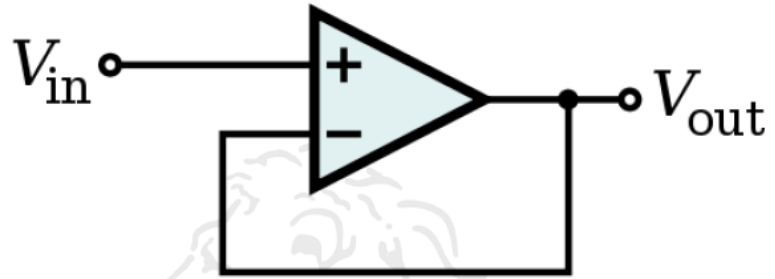


Non-inverting comparator

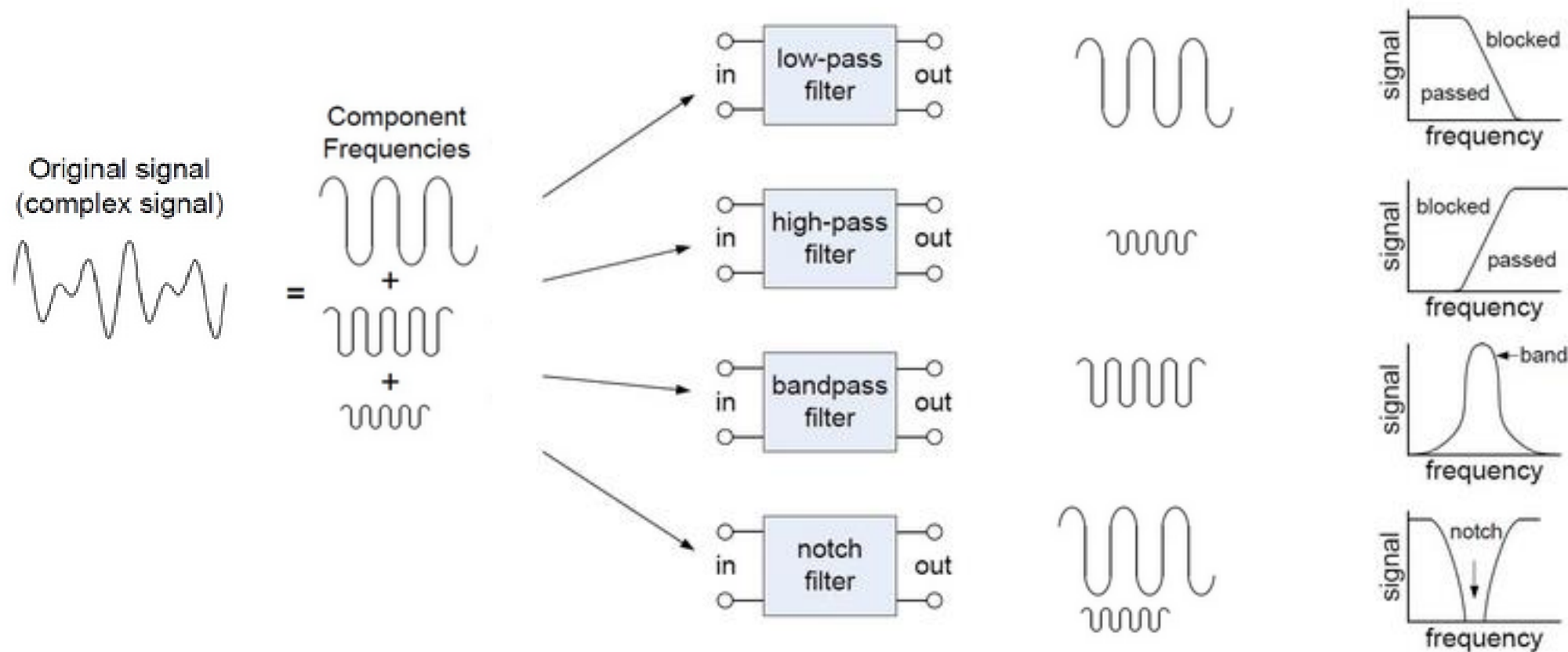


Op-Amp usages

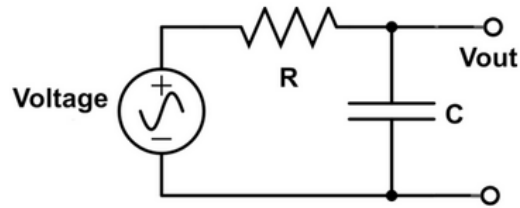
Buffer/Voltage follower or Isolation Amplifier



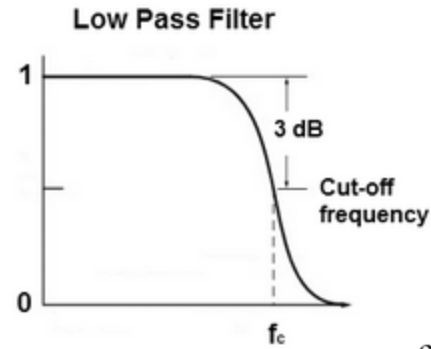
Electronic Filters



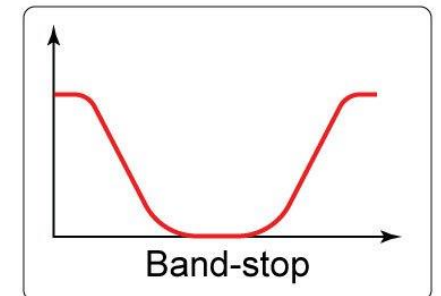
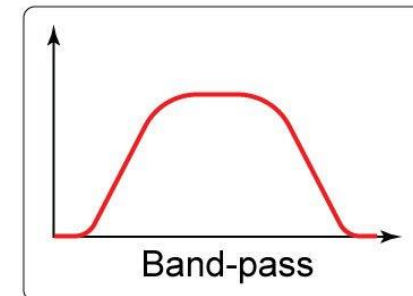
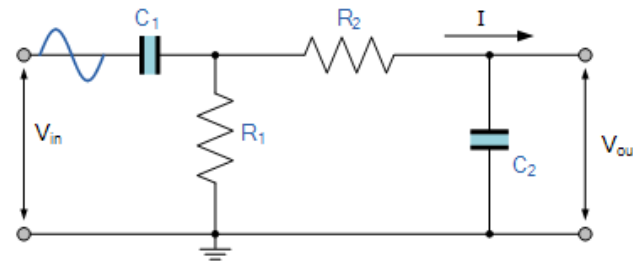
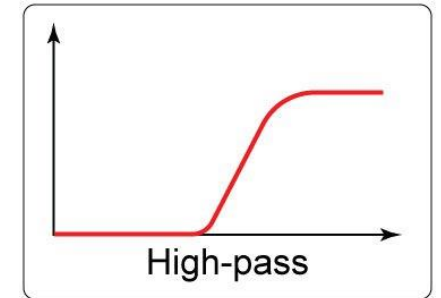
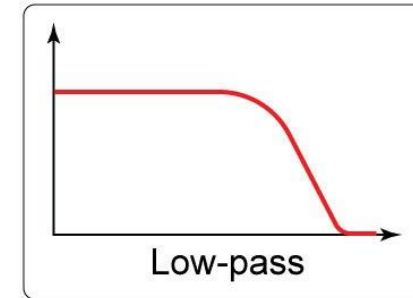
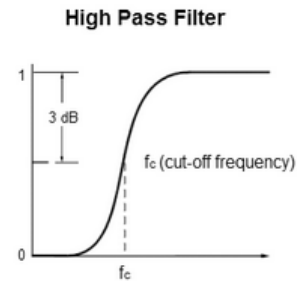
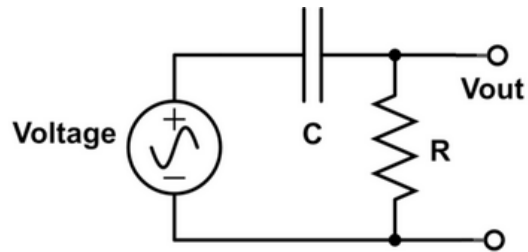
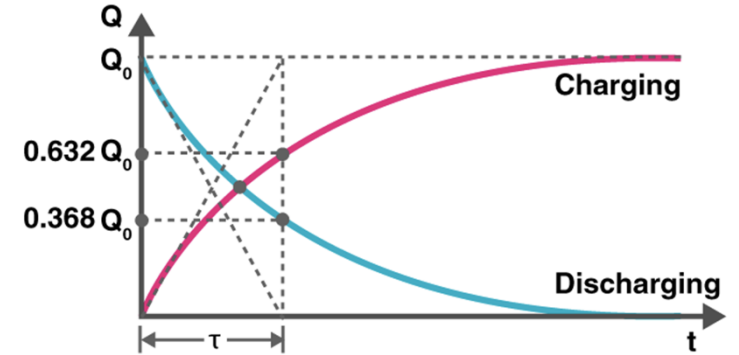
Filter circuits



$$X_c = \frac{1}{2\pi fC}$$

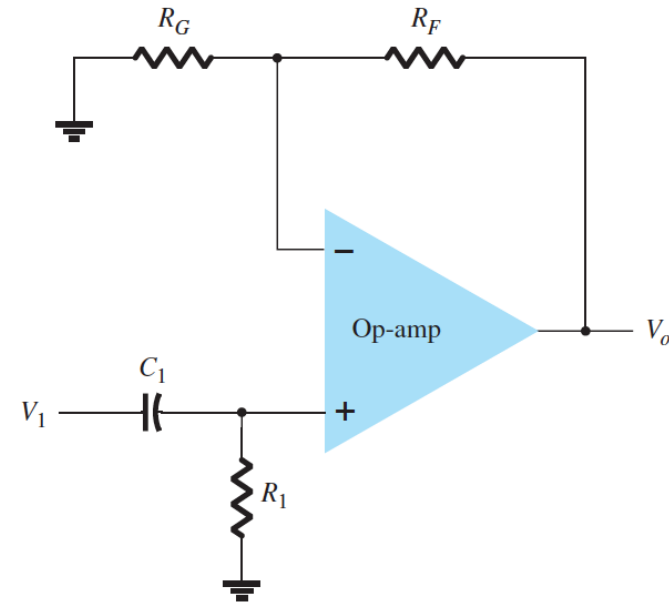
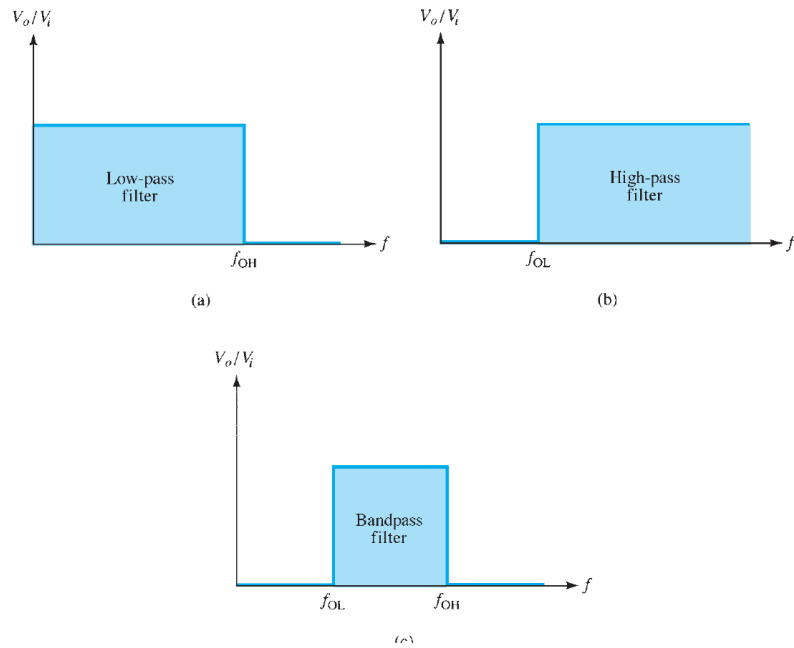


$$f_{\text{cutoff}} = \frac{1}{2\pi RC}$$



Op-Amp usages

Op-Amp based active filters



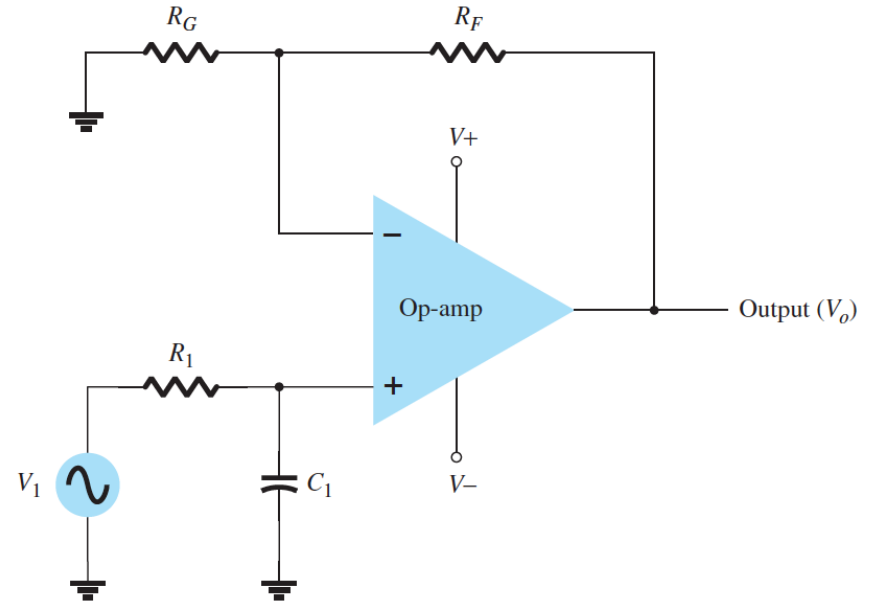
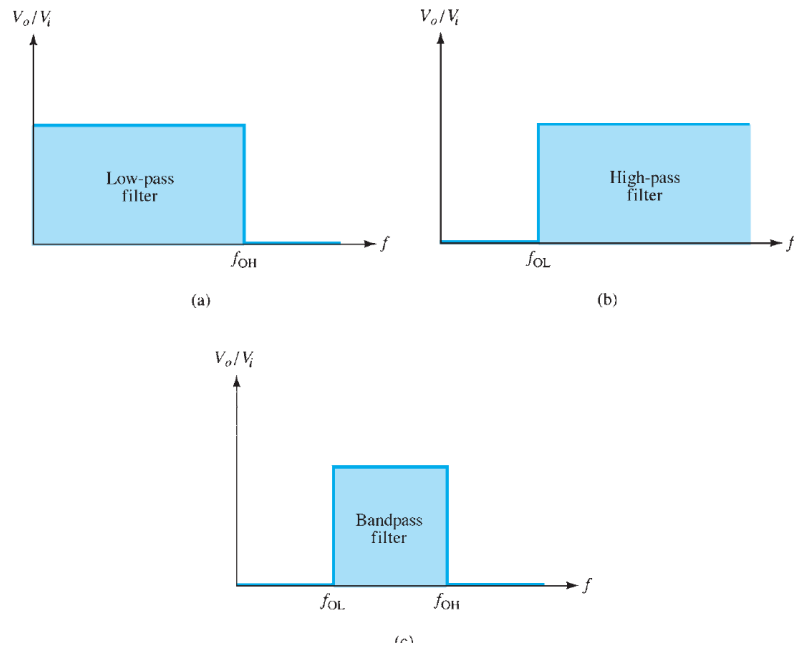
High Pass Filter (LPF)

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

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

Op-Amp usages

Op-Amp based active filters



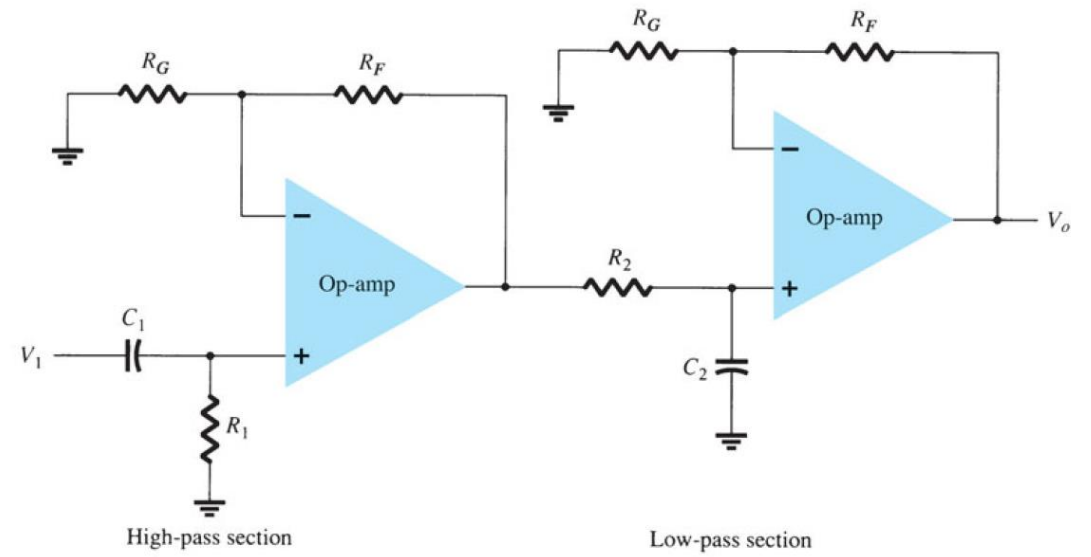
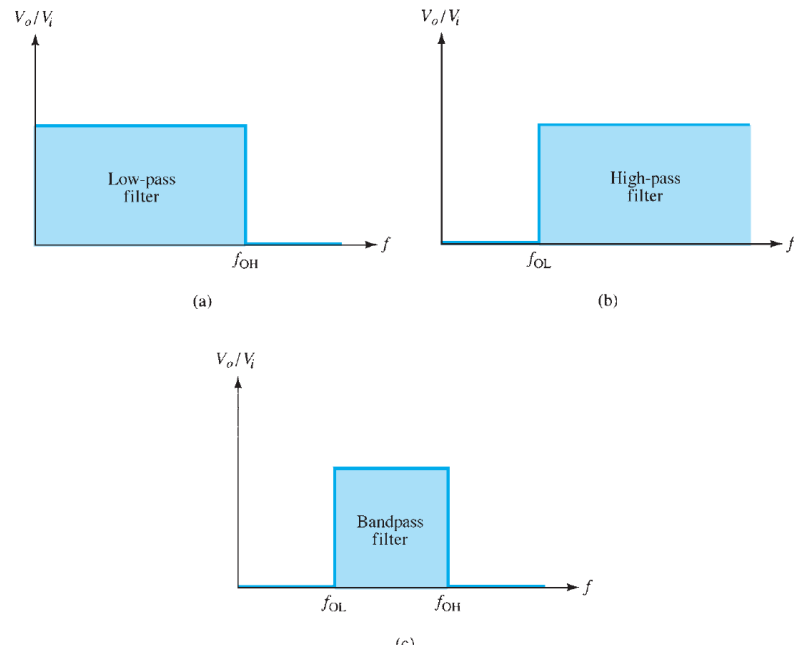
Low Pass Filter (LPF)

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

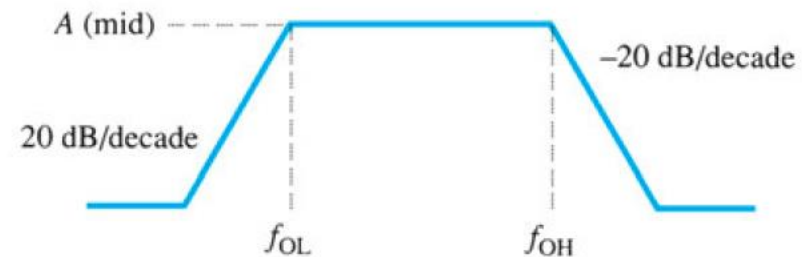
$$f_{OH} = \frac{1}{2\pi R_1 C_1}$$

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

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

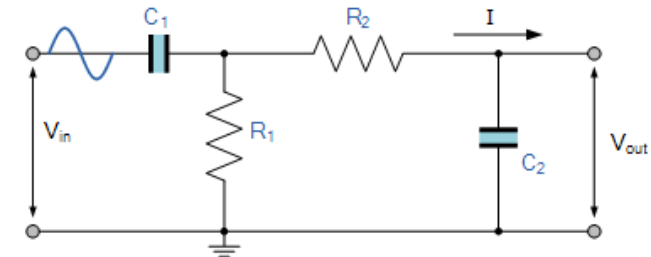
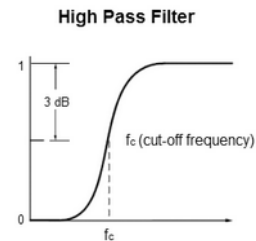
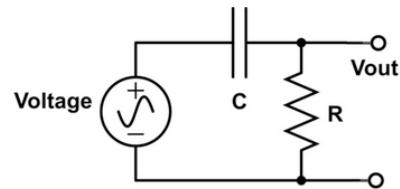
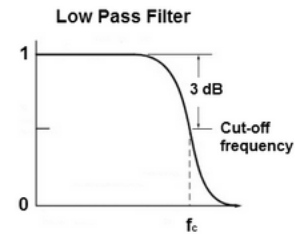
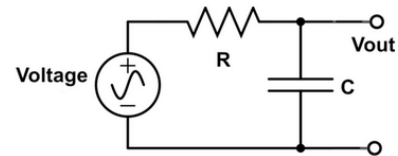
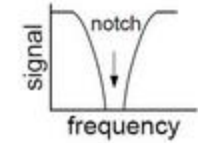
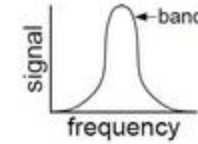
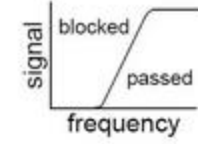
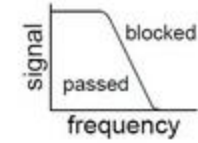
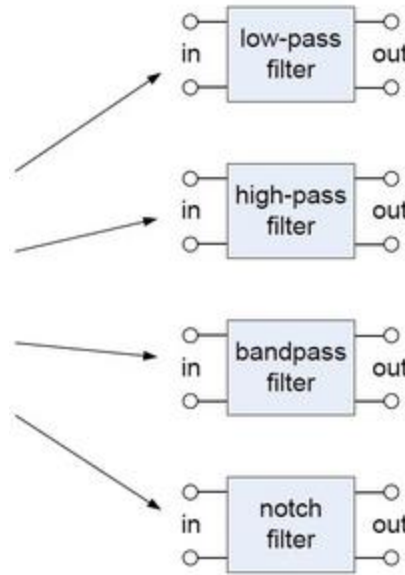
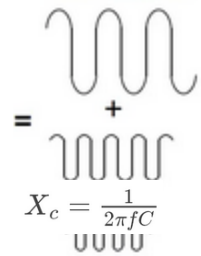
Oscillator = Amplifier + Filter (Frequency Selection) + Positive feedback

Electronic Filters

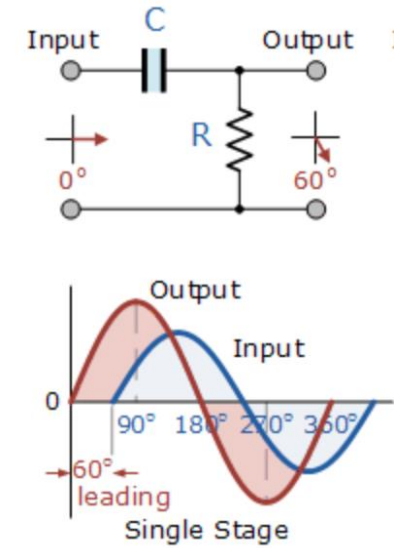
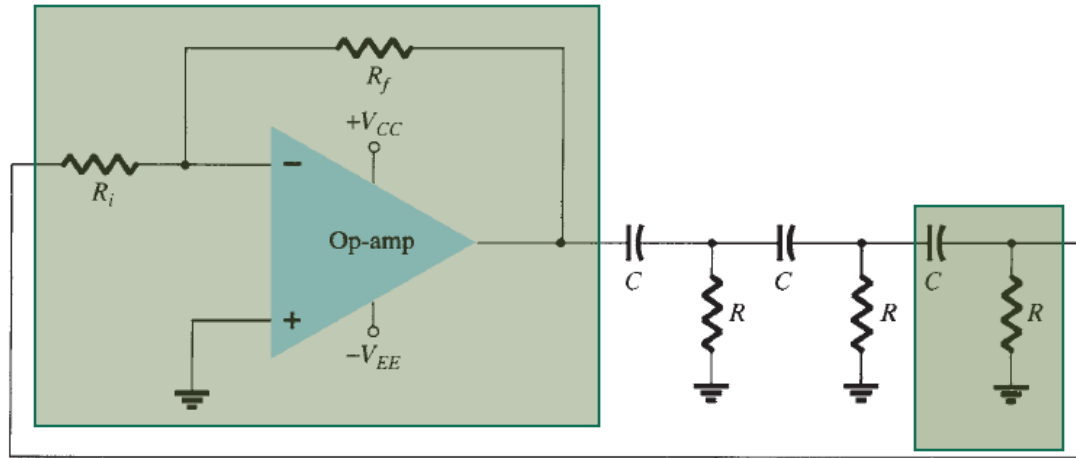
Original signal
(complex signal)



Component
Frequencies



An oscillator circuit



Oscillator = Amplifier + Filter + Positive feedback

Thank you