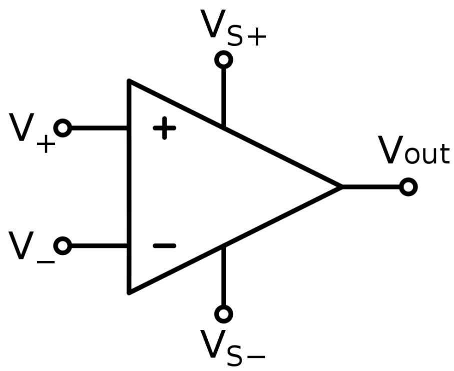
Lecture-3

Operational Amplifier



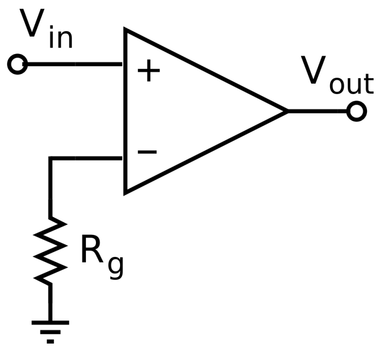
the amplifier's differential inputs consist of a non-inverting input(+) with voltage V_+ and an inverting input(-) with voltage V_-

ideally the op amp amplifies only the difference in voltage between the two and the output voltage of the op amp V_{out} is given by the equation

$$V_{out} = A_{OL}(V_+ - V_-)$$

where A_{OL} is the open-loop gain of the amplifier [1]

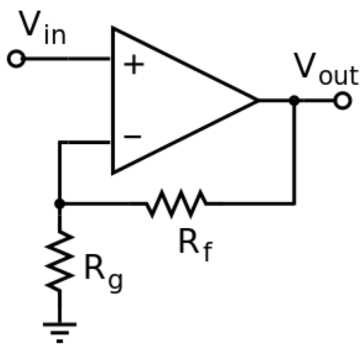
Open-loop Amplifier



Since the magnitude of A_{OL} is typically very large, the op amp without negative feedback will work as a comparator. [2]

$$V_{out} = \begin{cases} +\infty & V_{in} > 0 \\ -\infty & V_{in} < 0 \end{cases}$$

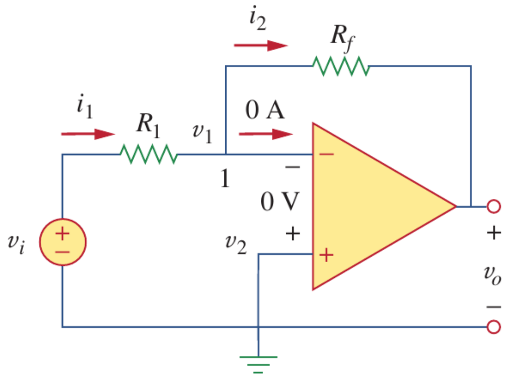
Closed-loop Amplifier



- $V_+ = V_-$: when an op amp operates in linear mode, the **difference in voltage** between the non-inverting (+) pin and the inverting (-) pin is **negligibly small**
- $I_{in} = 0$: the **input impedance** between (+) and (-) pins is **much larger** than other resistances in the circuit [3]

Operation Circuits

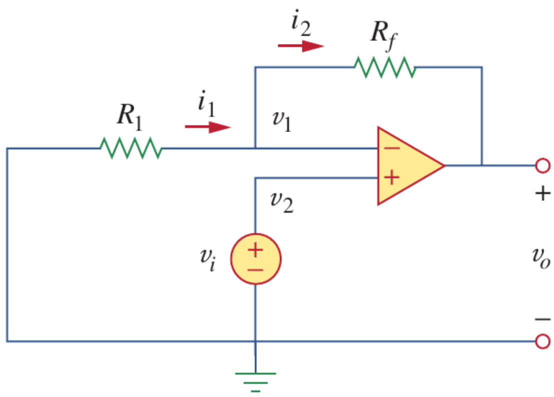
Inverting Amplifier



$$\frac{v_i - v_1}{R_1} = \frac{v_1 - v_0}{R_f}$$

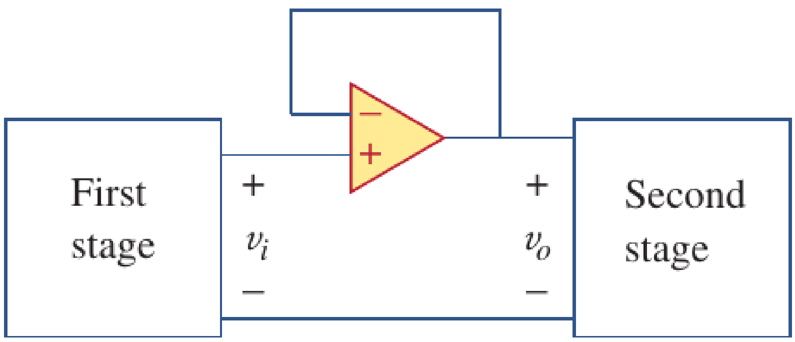
$$v_0 = -\frac{R_f}{R_1} v_i$$

Noninverting Amplifier



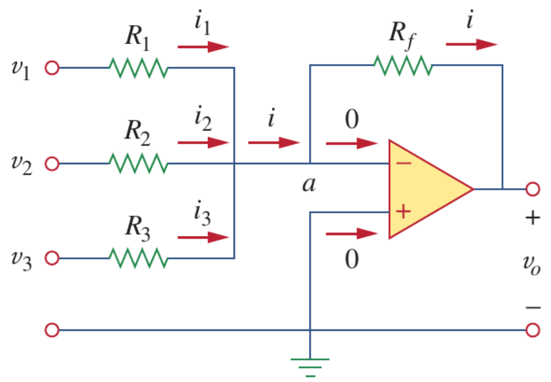
$$\frac{0 - v_i}{R_1} = \frac{v_i - v_0}{R_f}$$

$$v_0 = \left(1 + \frac{R_f}{R_1}\right) v_i$$



$$v_0 = v_i$$

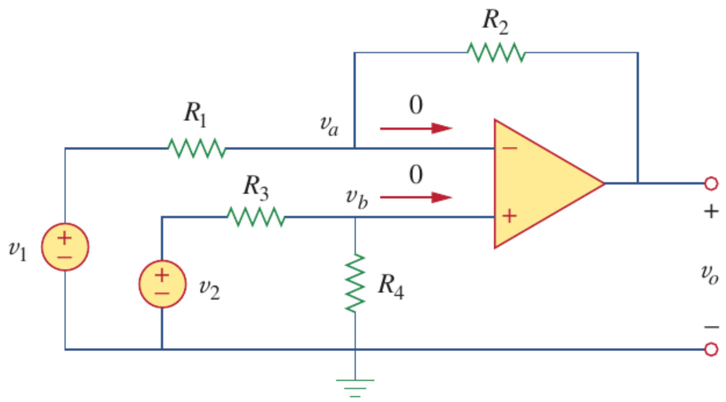
Summing Amplifier



$$\frac{0 - v_0}{R_f} = \frac{v_1 - 0}{R_1} + \frac{v_2 - 0}{R_2} + \frac{v_3 - 0}{R_3}$$

$$v_0 = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3\right)$$

Difference Amplifier

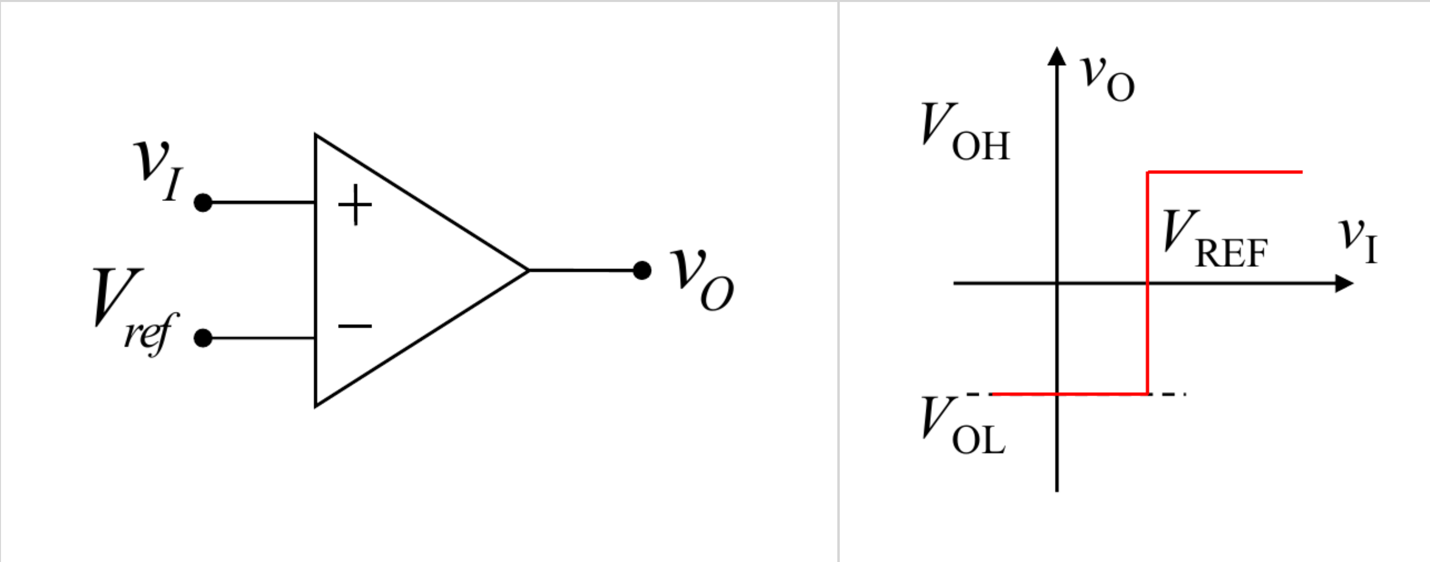


$$\begin{cases} \frac{v_1 - v_a}{R_1} = \frac{v_a - v_0}{R_2} \\ v_a = v_b = \frac{R_4}{R_3 + R_4} v_2 \end{cases} \implies v_0 = \frac{R_2(1 + R_1/R_2)}{R_1(1 + R_3/R_4)} v_2 - \frac{R_2}{R_1} v_1$$

Comparator Circuit

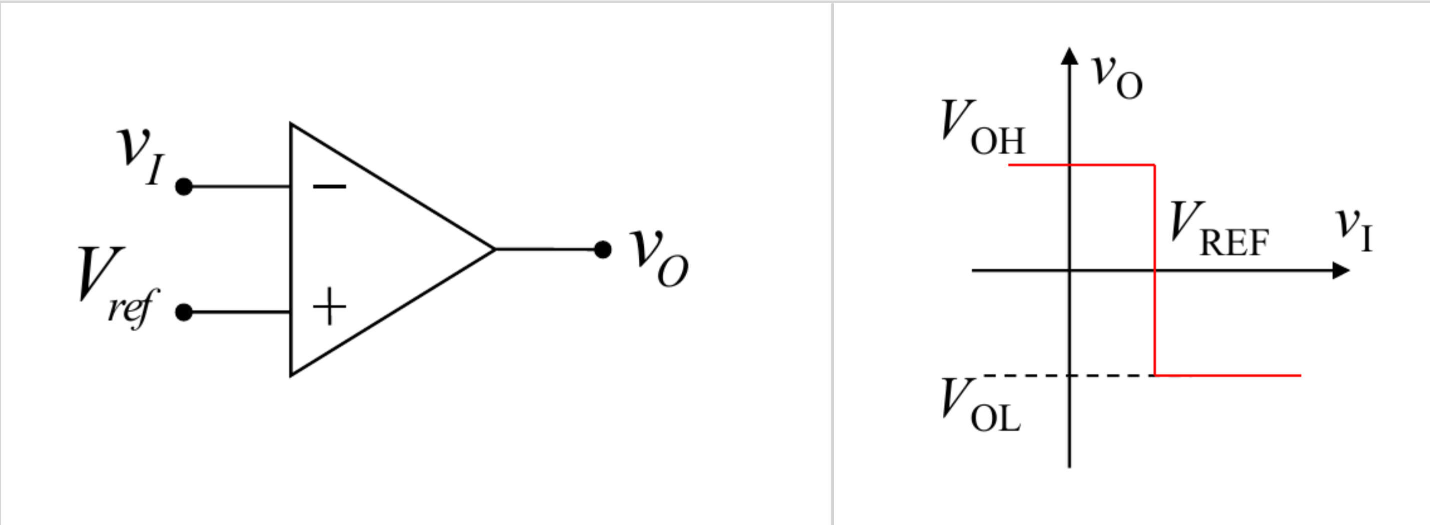
If we use operation amplifier as the comparator, there come two teo cases

Noninverting Op-Amp



$$V_O = \begin{cases} +V_{\text{SAT}} & V_i > V_{\text{ref}} \\ -V_{\text{SAT}} & V_i < V_{\text{ref}} \end{cases}$$

Inverting Op-Amp

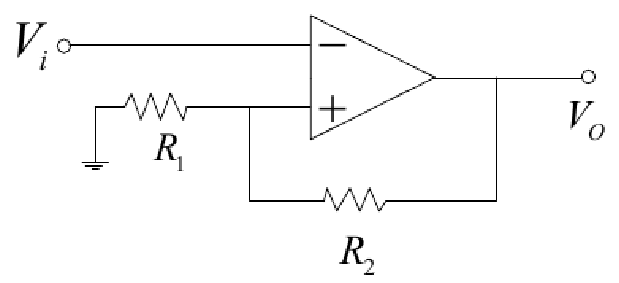


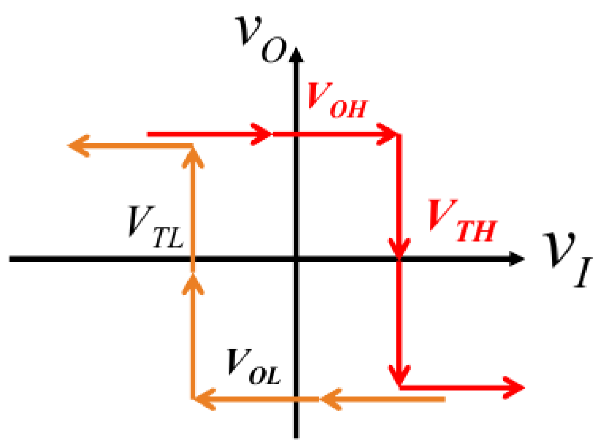
$$V_O = \begin{cases} -V_{\text{SAT}} & V_i > V_{\text{ref}} \\ +V_{\text{SAT}} & V_i < V_{\text{ref}} \end{cases}$$

Schmitt Trigger

similarly, there two cases for the Schmitt Trigger

Basic Inverting Schmitt Trigger





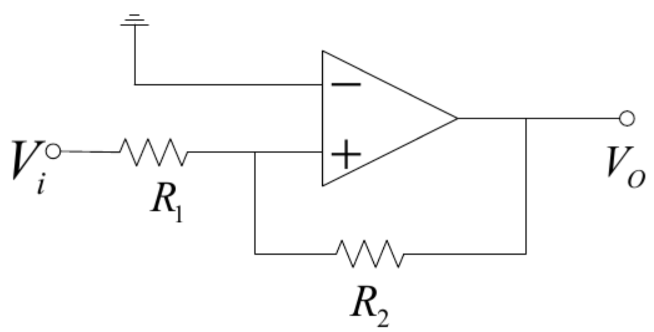
- output voltage is high

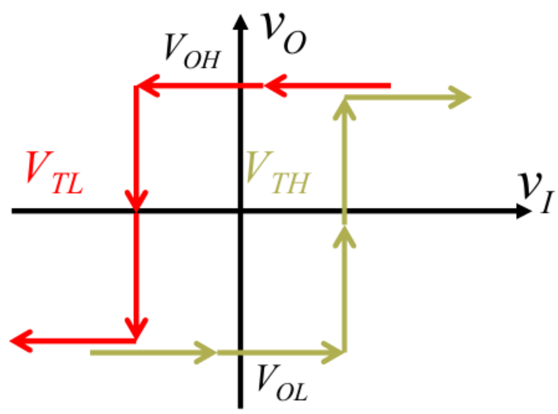
$$V_O = \begin{cases} V_{OH} & V_I < \frac{R_1}{R_1+R_2} V_{OH} \\ V_{OL} & V_I > \frac{R_1}{R_1+R_2} V_{OH} \end{cases}$$

- output voltage is low

$$V_O = \begin{cases} V_{OL} & V_I > \frac{R_1}{R_1+R_2} V_{OL} \\ V_{OH} & V_I < \frac{R_1}{R_1+R_2} V_{OL} \end{cases}$$

Noninverting Schmitt Trigger





- output voltage is high

$$V_O = \begin{cases} V_{OH} & V_I > -\frac{R_1}{R_2} V_{OH} \\ V_{OL} & V_I < -\frac{R_1}{R_2} V_{OH} \end{cases}$$

- output voltage is low

$$V_O = \begin{cases} V_{OL} & V_I < -\frac{R_1}{R_2} V_{OL} \\ V_{OH} & V_I > -\frac{R_1}{R_2} V_{OL} \end{cases}$$

Reference

- [1] Operational amplifier - 1 Operation - Wikipedia
- [2] Operational amplifier - 1.1 Open-loop amplifier - Wikipedia
- [2] Operational amplifier - 1.2 Closed-loop amplifier - Wikipedia