Department of Computer Science and Engineering (CSE)
BRAC University

CSE 251: Electronic Devices and Circuits
Fall 2023

Lecture 03: Operational Amplifier

→(i) Saturation Voltages
→(ii) Open-loop & Negative Feedback
→(iii) Some Useful Configurations

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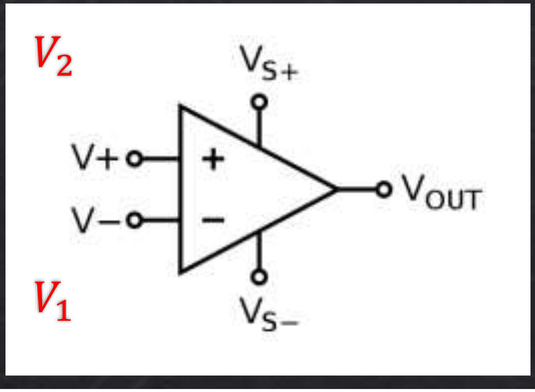
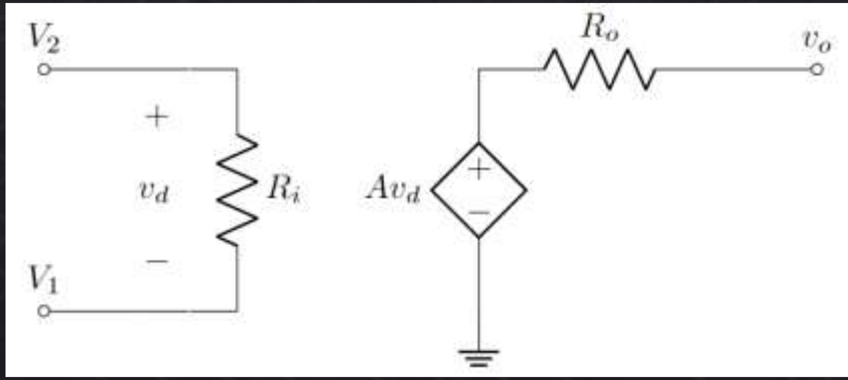
Operational Amplifier (Op-Amp)

- **Terminologies:**



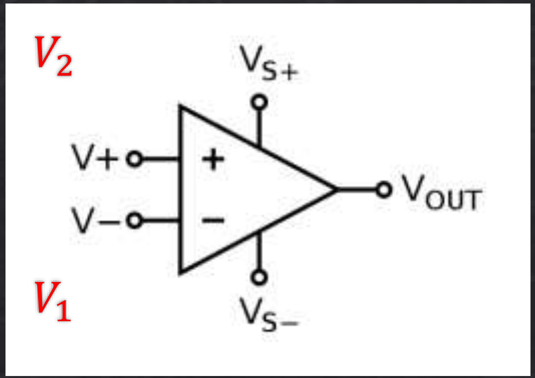


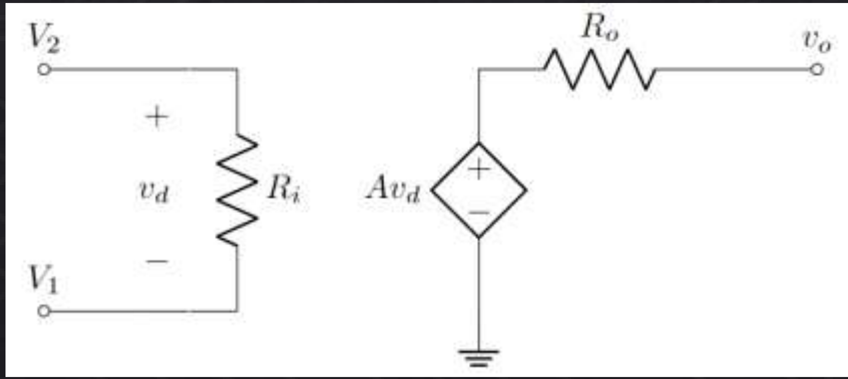
$V_1 = V_-$	Inverting Terminal
$V_2 = V_+$	Non-Inverting terminal
$v_d = V_2 - V_1$	Differential Input Voltage
A	Open Loop Gain (ideally ∞)
R_i	Input Resistance (ideally ∞)
R_o	Output Resistance
V_s^+, V_s^-	Positive & Negative Saturation Voltage

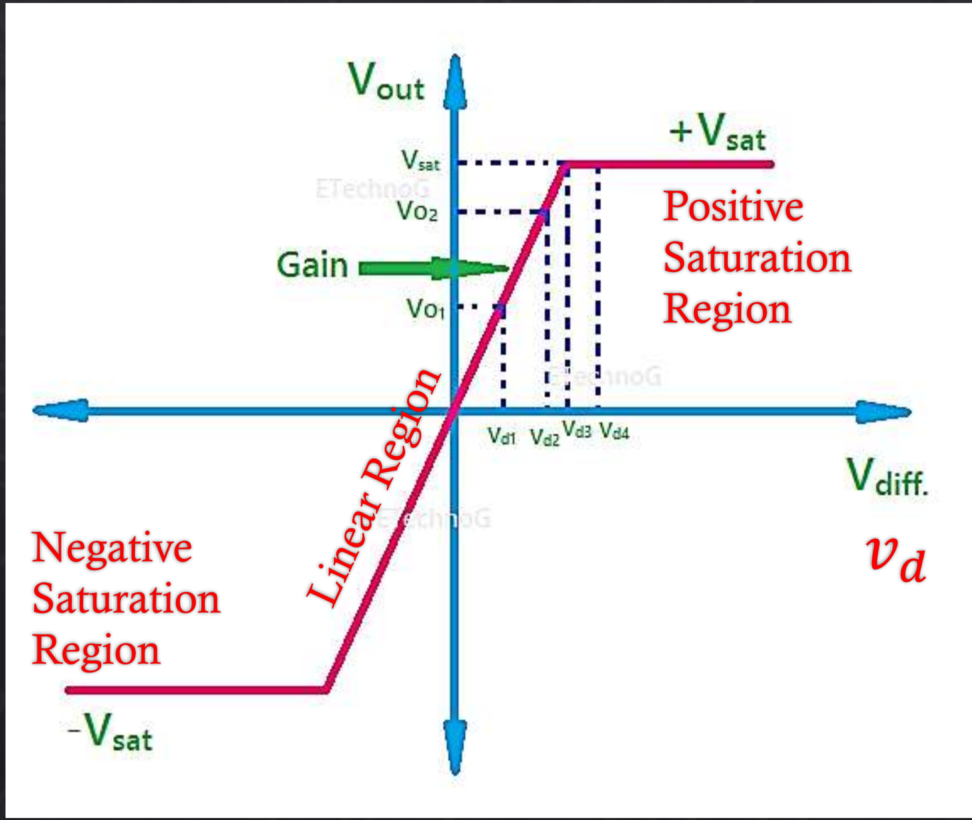
****Why are they named Saturation Voltage?****

Operational Amplifier (Op-Amp)

- **Saturation Voltages :**

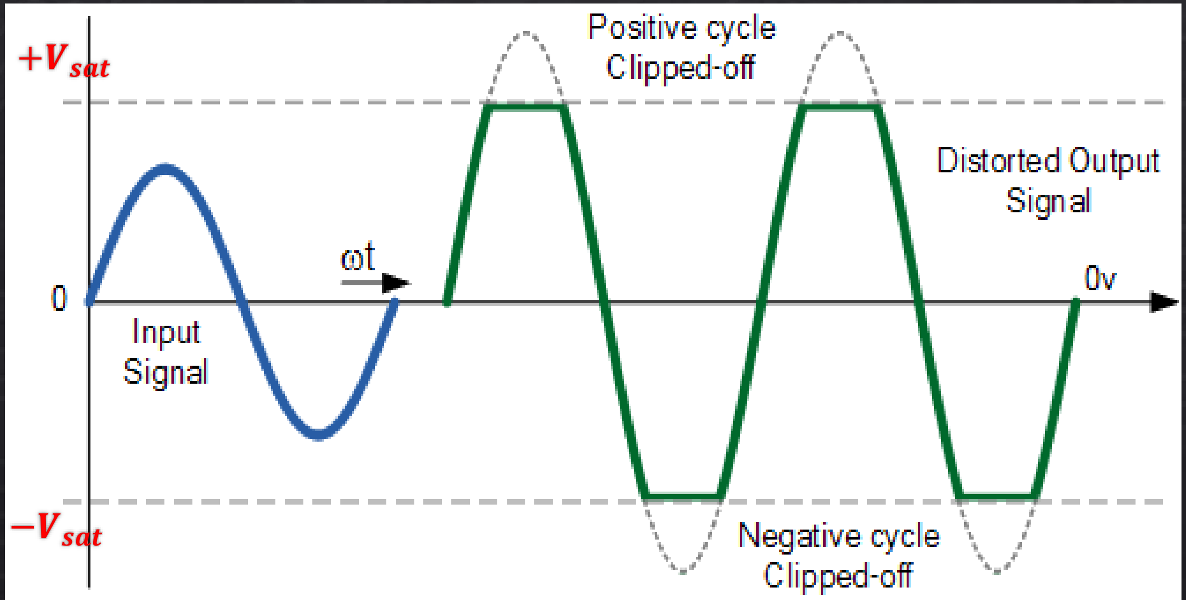


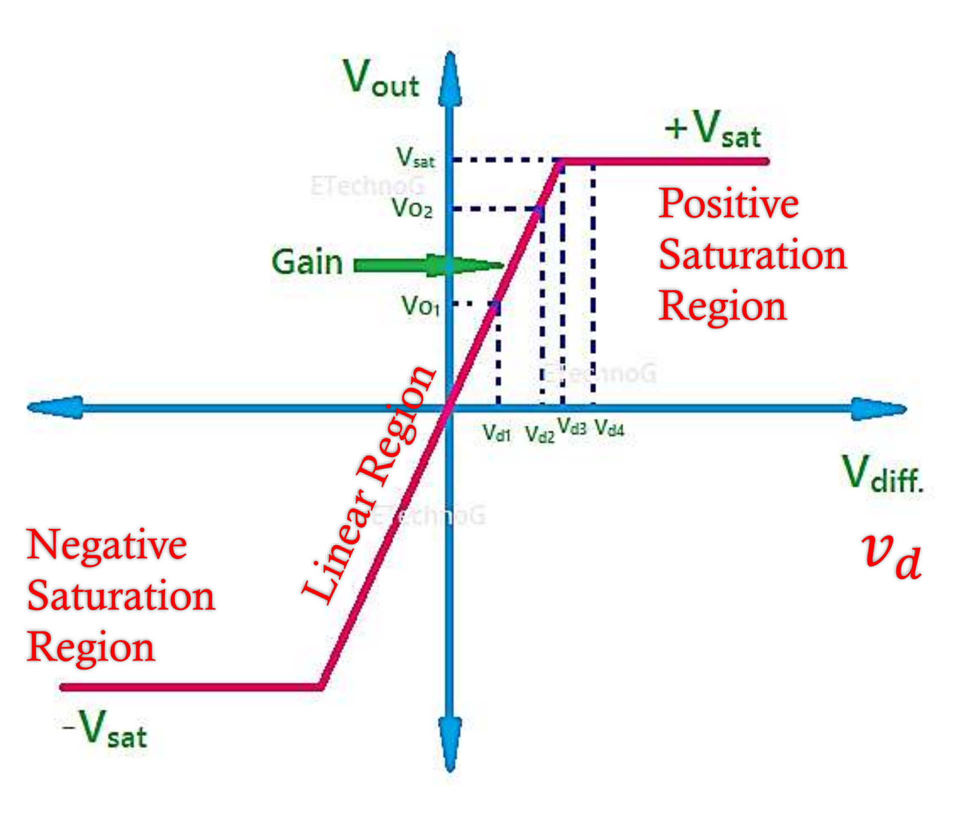




Operational Amplifier (Op-Amp)

- **Saturation Voltages :**





The dotted line shows what the output should have been

The green line shows what we actually get

Operational Amplifier (Op-Amp)

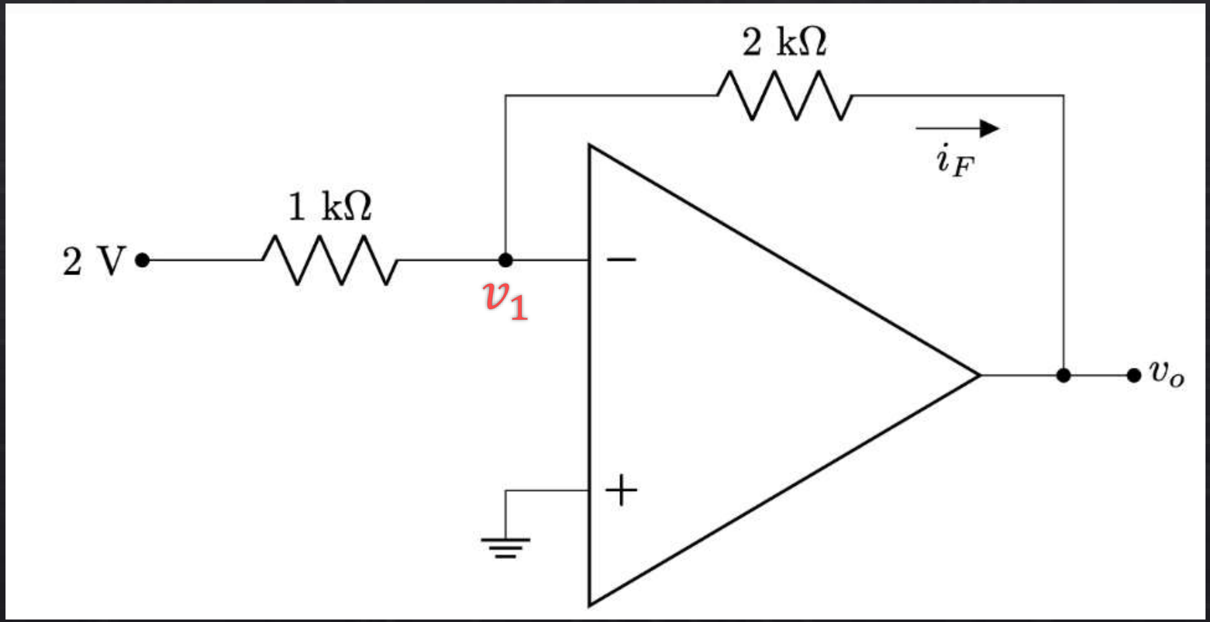
- **A non-ideal Op-Amp circuit example:**

Given,

$$R_i = 250k\Omega$$
$$R_0 = 0.1\ k\Omega$$
$$A = 1.8 \times 10^5$$

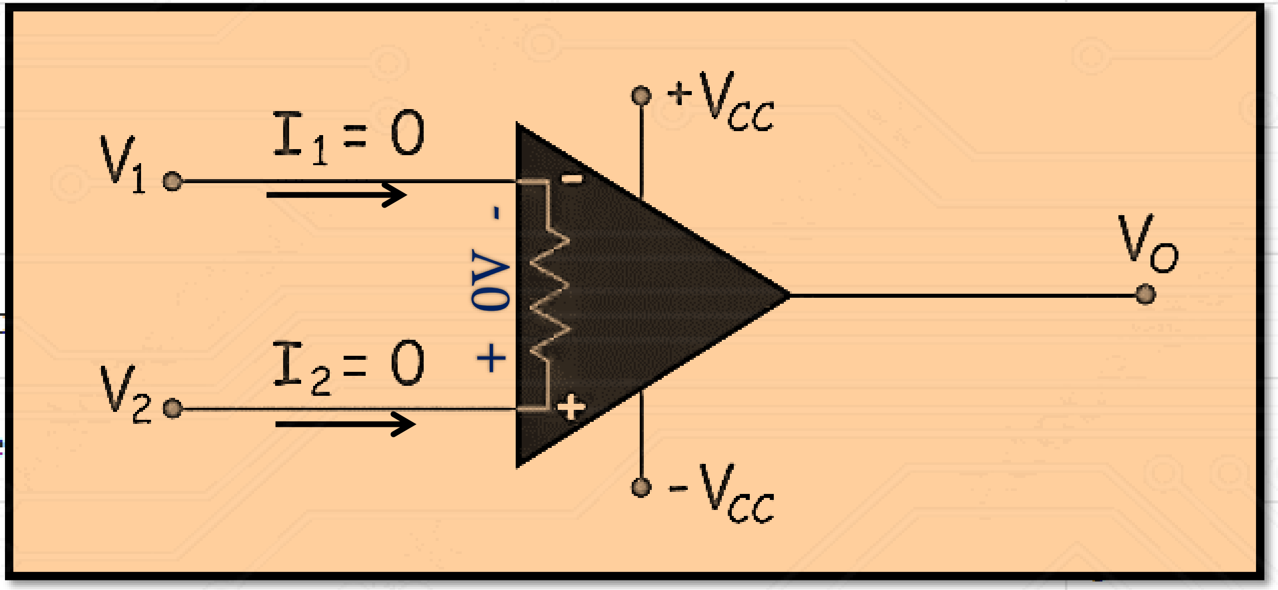
Find i_F and v_0. Also, what do you think should be reasonable saturation voltages for this circuit?

$$v_1 = 2.3329 \times 10^{-4} V, v_0 = -3.9993V$$
$$i_F = 1.99965\ mA$$



Ideal Op-Amp

Characteristic	Value
Open Loop Gain	
Input Resistance	
Output Resistanc	
Bandwith of Ope	
Offset Voltage	



Ideal Op-Amp

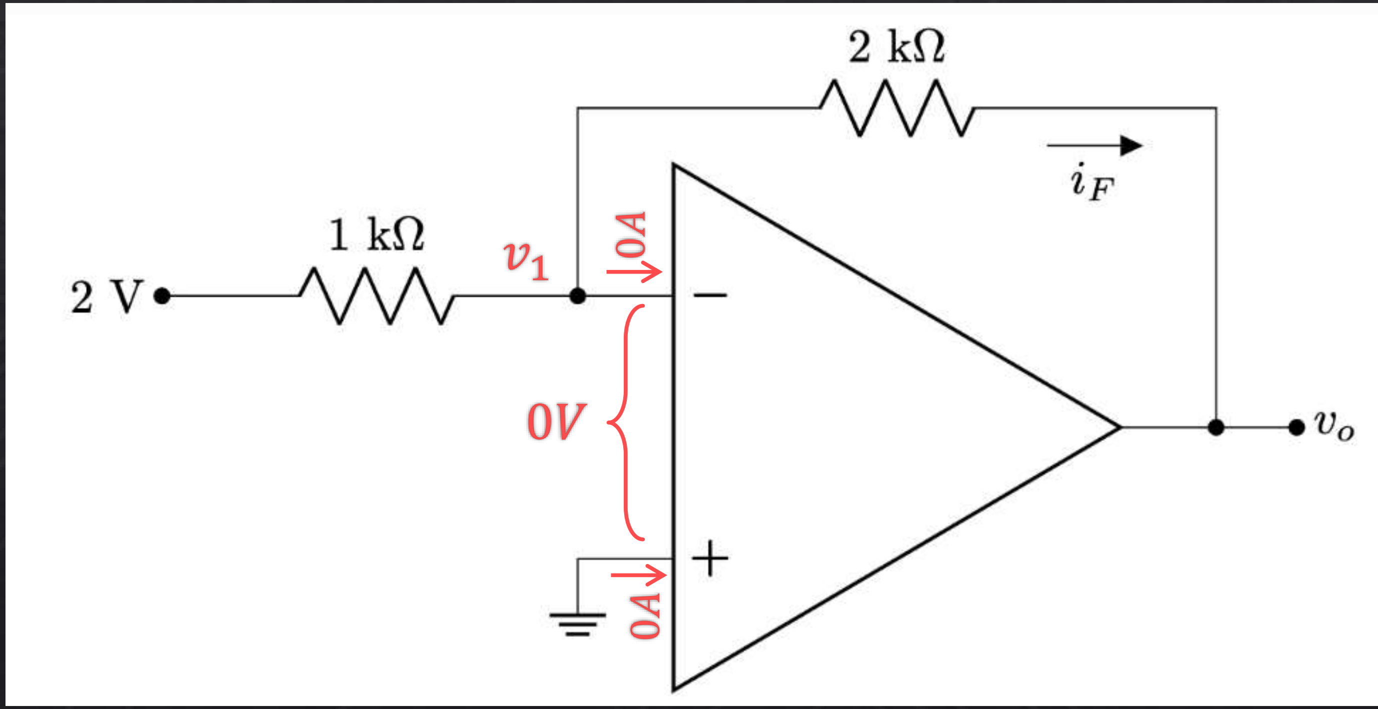
- **An Ideal Op-Amp circuit example:**

[Same example]

$$\frac{v_1 - 2}{1} + \frac{v_1 - v_0}{2} + 0 = 0$$

$$\Rightarrow \frac{0 - 2}{1} + \frac{0 - v_0}{2} + 0 = 0$$

$$\Rightarrow v_0 = -4V$$



Ideal Op-Amp

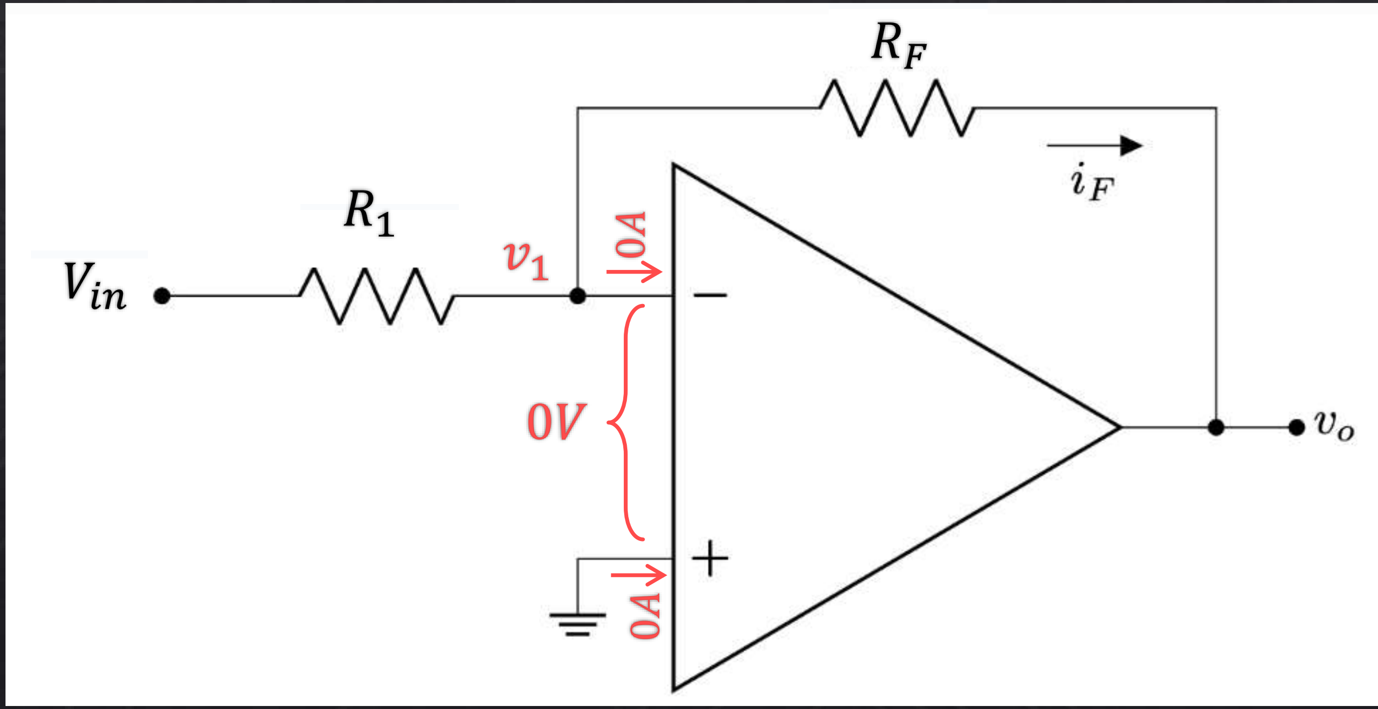
- **An Inverting Amplifier:**

$$\frac{v_1 - V_{in}}{R_1} + \frac{v_1 - v_0}{R_F} + 0 = 0$$

$$\Rightarrow \frac{0 - V_{in}}{R_1} + \frac{0 - v_0}{R_F} + 0 = 0$$

$$\Rightarrow v_0 = -\frac{R_F}{R_1} V_{in}$$

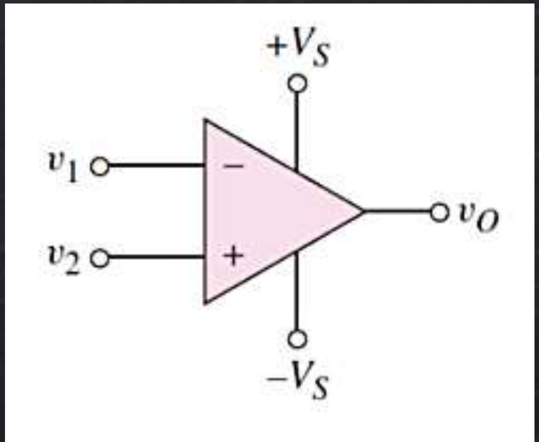
More about this..later on!!

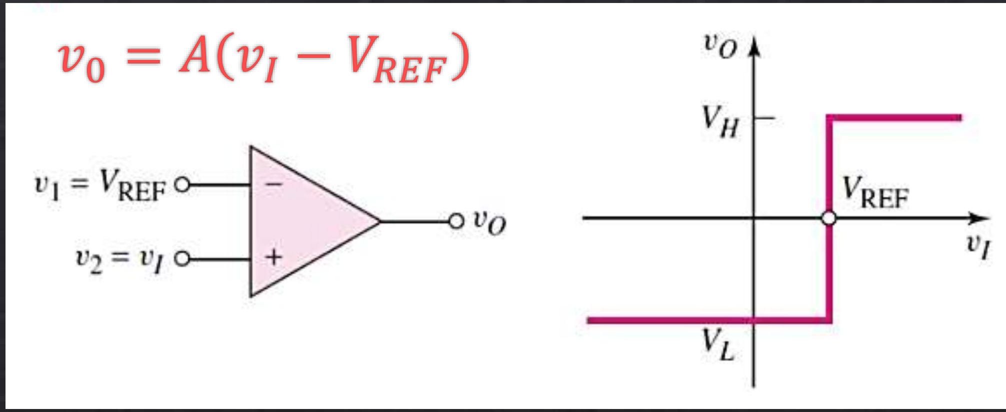


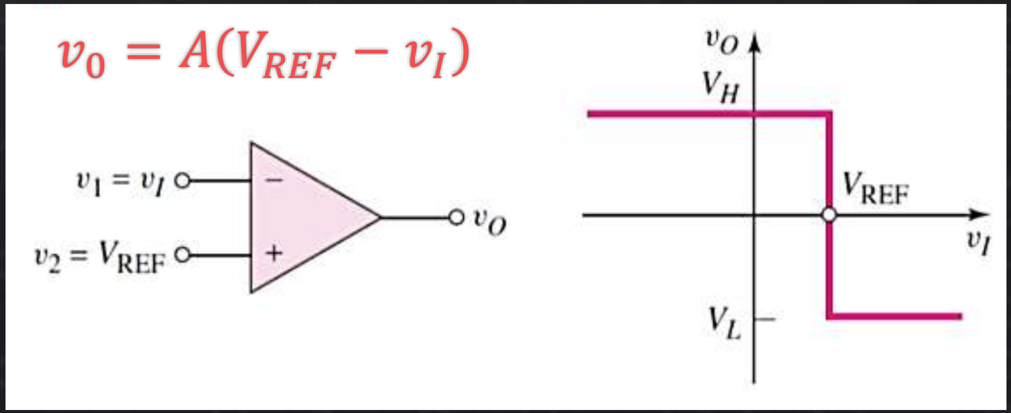
Open Loop vs Negative Feedback

1. **Open-Loop:**

Comparator





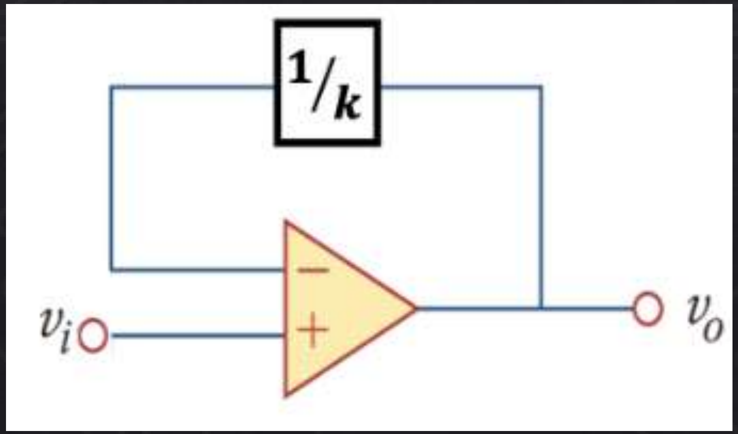


Application: Smoke/Fire detector [Link], Temp. control switch in AC, Water Level detection [Link] etc.

Open Loop vs Negative Feedback

2. Negative Feedback:

- The gain (A) of an ideal op-amp is infinity, practically extremely large.
- The power supply ($+V_s$ and $-V_s$) limits the op-amp's output.
- We require a method to have a finite gain. That is what negative feedback does.
- Negative feedback: feeding back **a portion** of ***output*** to inverting ***input***
- Idea – the output will become stable due to a self-correcting mechanism



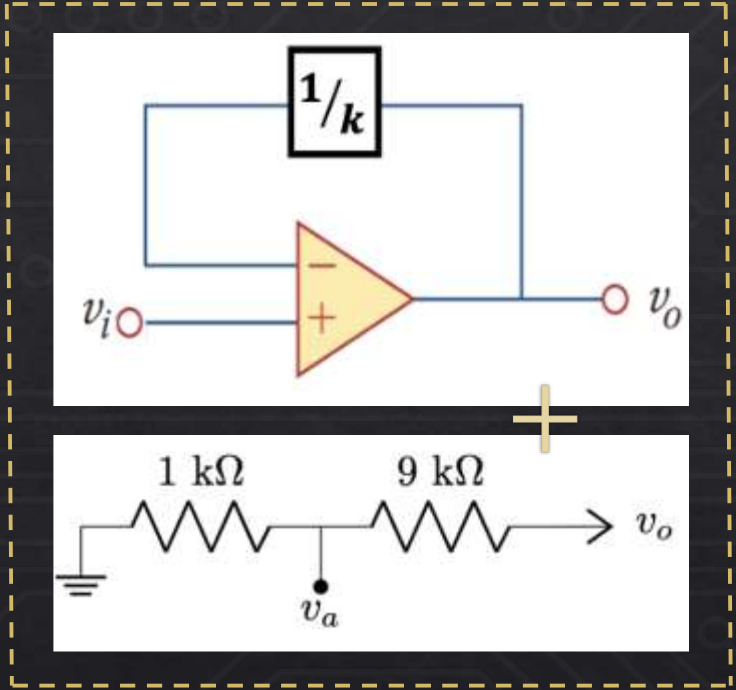
Show that,

$v_0 = kv_i$

Open Loop vs Negative Feedback

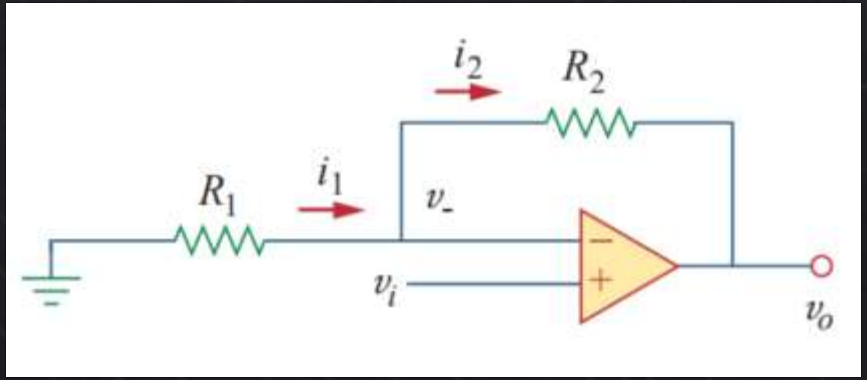
2. Negative Feedback:

- $k = 10$ means we are feeding $1/10^{\text{th}}$ of the output to the negative input terminal.
- But how to get $1/k$ output-to-input ratio through a circuit?



$$v_0 = kv_i$$

$$v_a = \frac{1}{9+1}v_0 = \frac{v_0}{10}$$

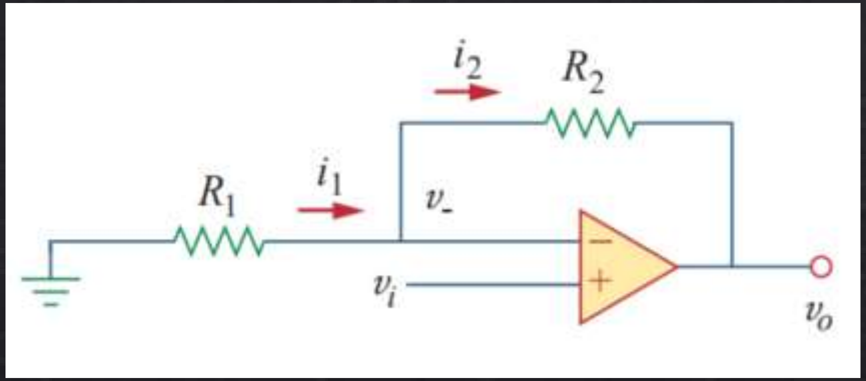


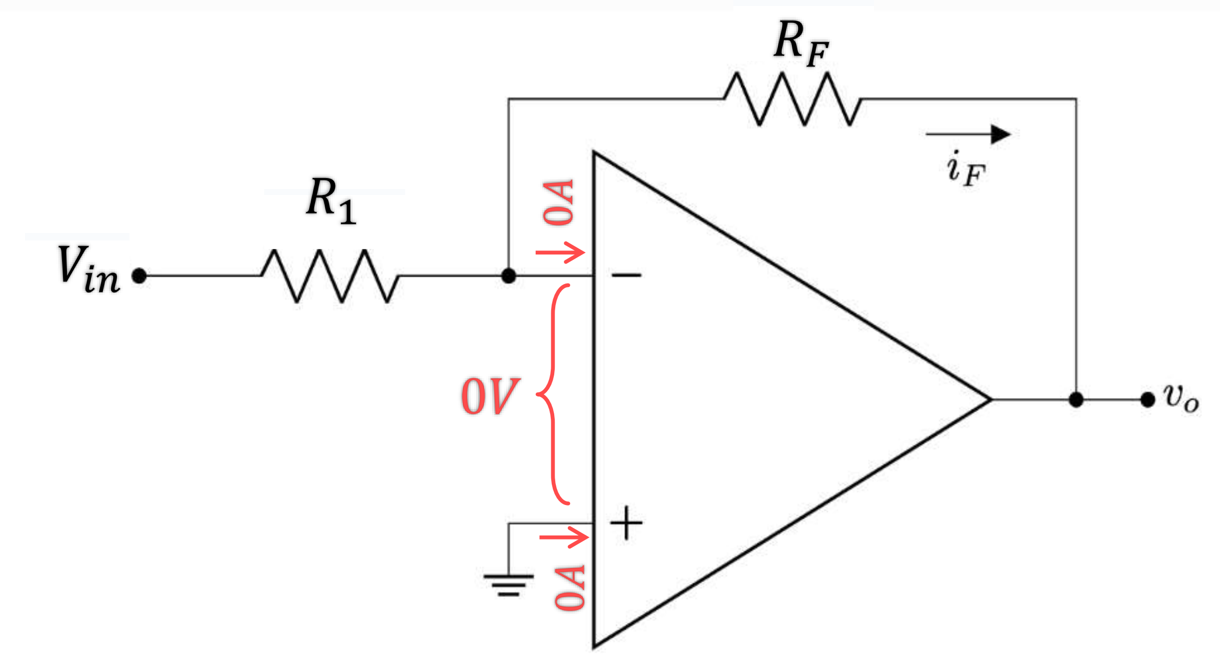
Does this look familiar?

Open Loop vs Negative Feedback

2. **Negative Feedback:**

The Inverting Amplifier





Inverting Amplifier (Config-1)

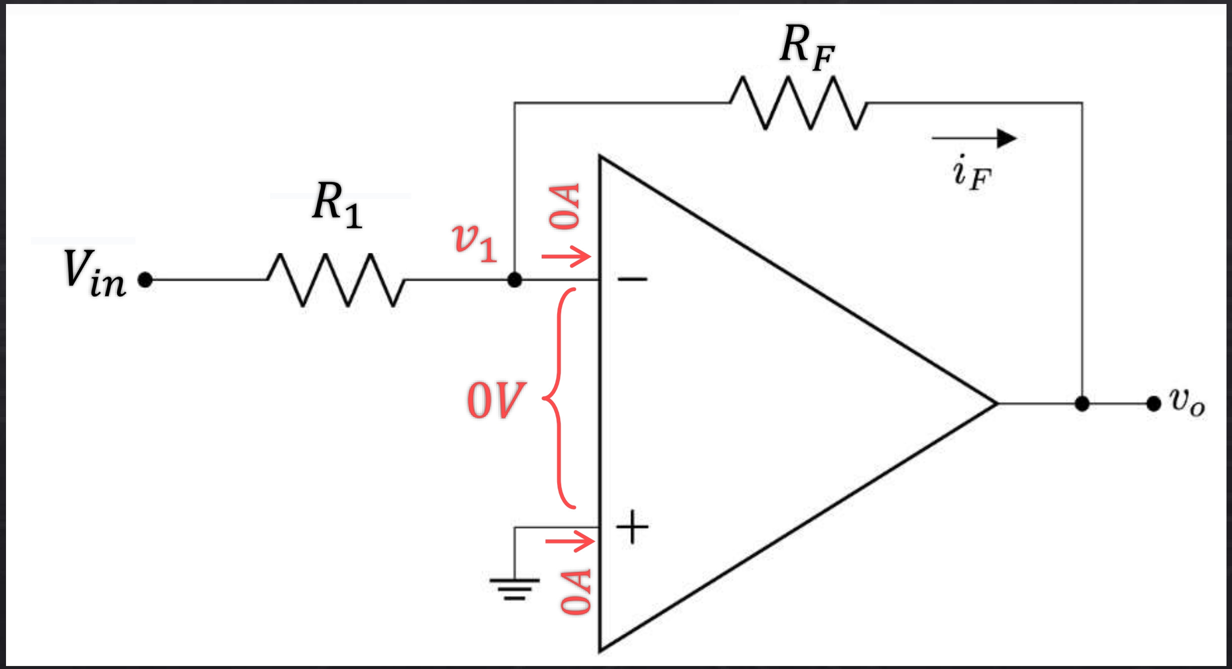
⟐ Circuit Configuration & Gain:

$$\frac{v_1 - V_{in}}{R_1} + \frac{v_1 - v_0}{R_F} + 0 = 0$$

$$\Rightarrow \frac{0 - V_{in}}{R_1} + \frac{0 - v_0}{R_F} + 0 = 0$$

$$\Rightarrow \boldsymbol{v_0 = -\frac{R_F}{R_1} V_{in}}$$

$$\boldsymbol{Gain = -\frac{R_F}{R_1}}$$



Non-Inverting Amplifier (Config-2)

⟐ Circuit Configuration & Gain:

$$\frac{v_1 - 0}{R_1} + \frac{v_1 - v_0}{R_F} + 0 = 0$$

$$\Rightarrow \frac{V_{in}}{R_1} + \frac{V_{in} - v_0}{R_F} = 0$$

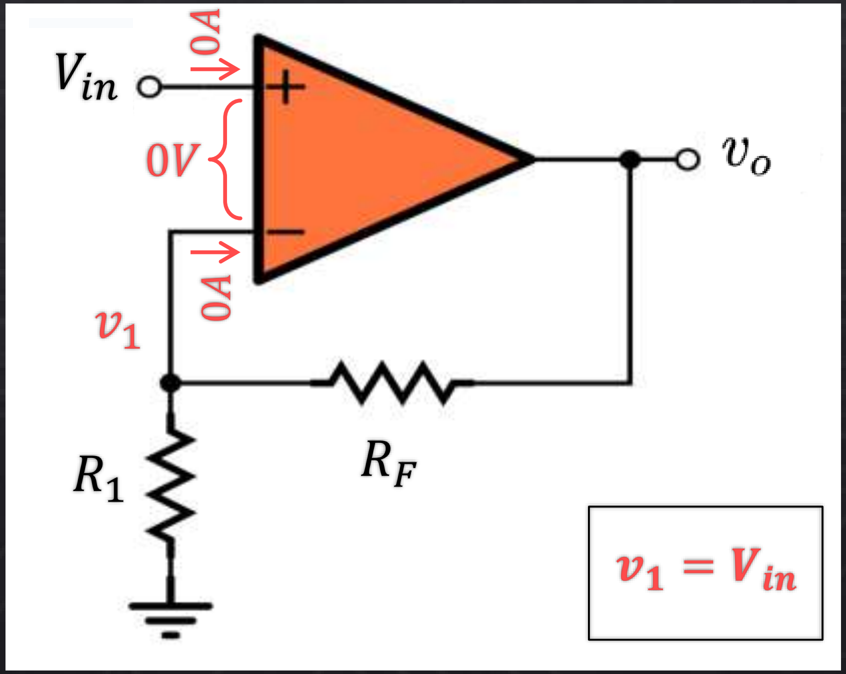
$$\Rightarrow V_{in}R_F + V_{in}R_1 - v_0R_1 = 0$$

$$\Rightarrow V_{in}(R_F + R_1) = v_0R_1$$

$$\Rightarrow v_0 = V_{in}\frac{(R_1 + R_F)}{R_1}$$

$$\Rightarrow v_0 = \left(1 + \frac{R_F}{R_1}\right)V_{in}$$

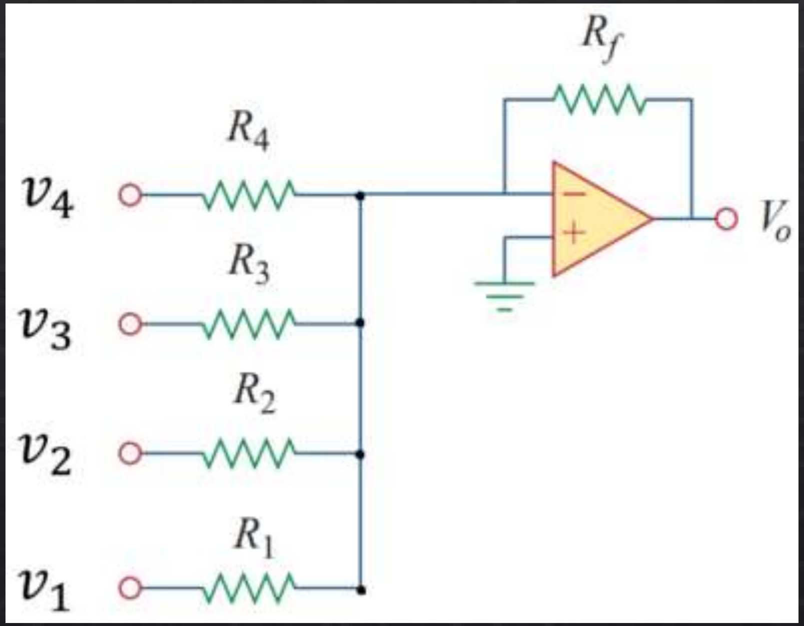
$$\boldsymbol{Gain} = \left(\mathbf{1} + \frac{\boldsymbol{R_F}}{\boldsymbol{R_1}}\right)$$



Inverting Adder (Config-3)

◈ **Circuit Configuration & Gain:**

>> Use ***Superposition Principle***



$$v_0 = \left(-\frac{R_f}{R_1}v_1 - \frac{R_f}{R_2}v_2 - \frac{R_f}{R_3}v_3 - \frac{R_f}{R_4}v_4\right)$$

$$\Rightarrow v_0 = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3 + \frac{R_f}{R_4}v_4\right)$$