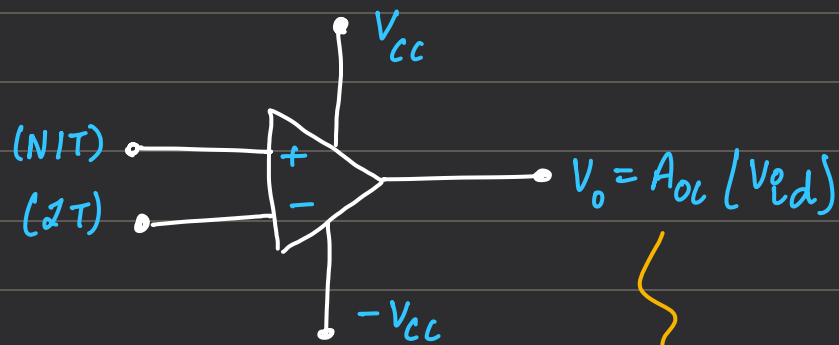


Operational Amplifier

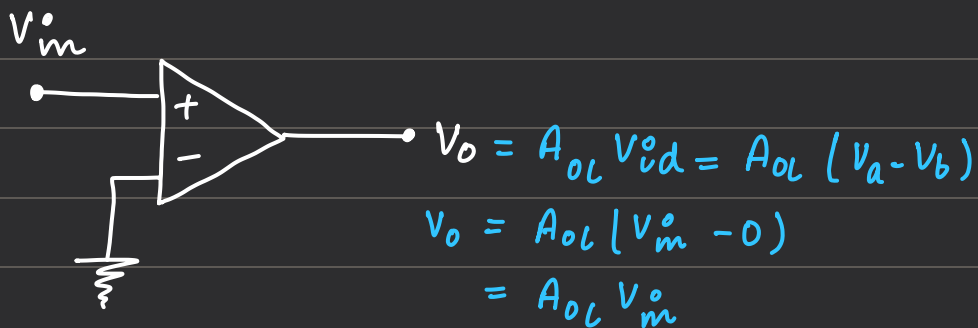


Open loop Gain

$$V_{id} = V_{NIT} - V_{IT}$$

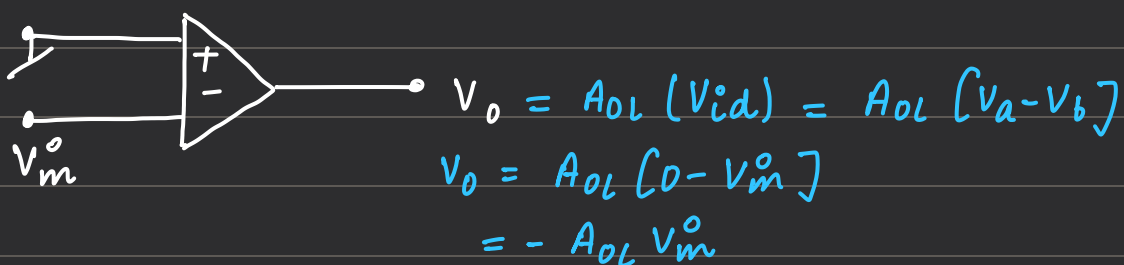
Differential i/p voltage

Example ①



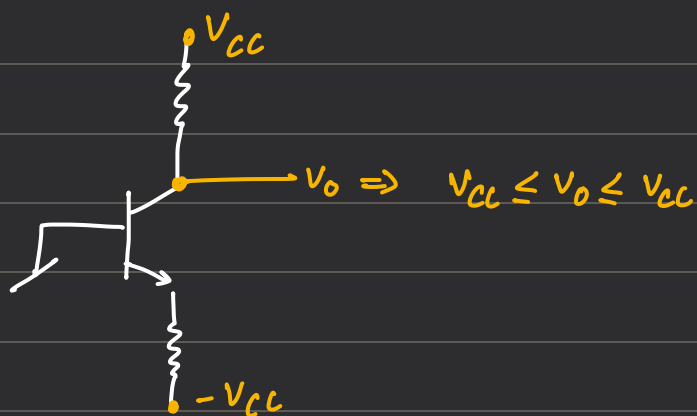
* O/P has a 0° phase shift

Example ②

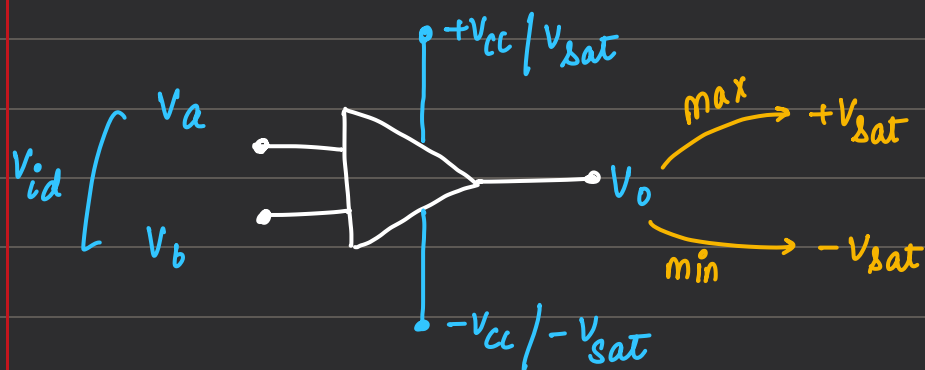


* o/p has a 180° phase shift

Example ③

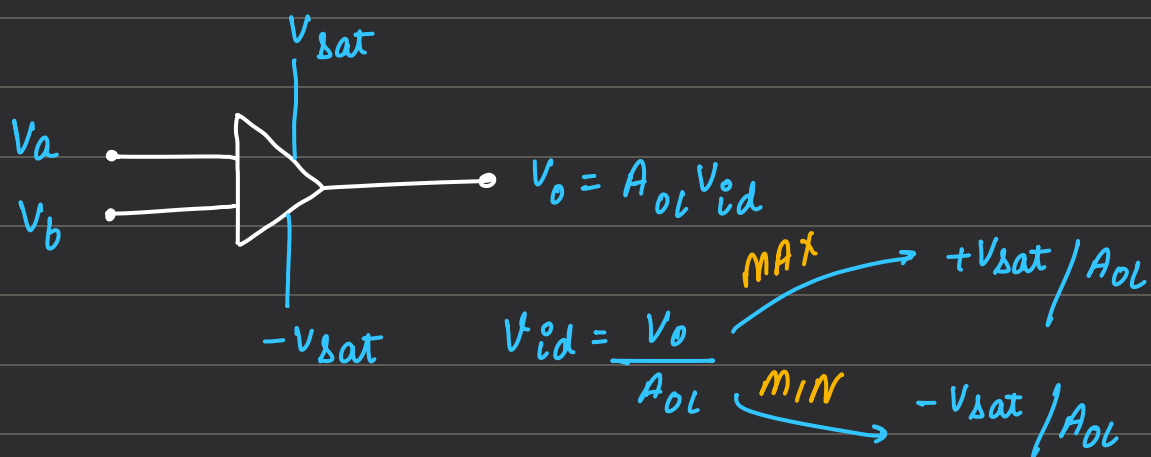


Sum only



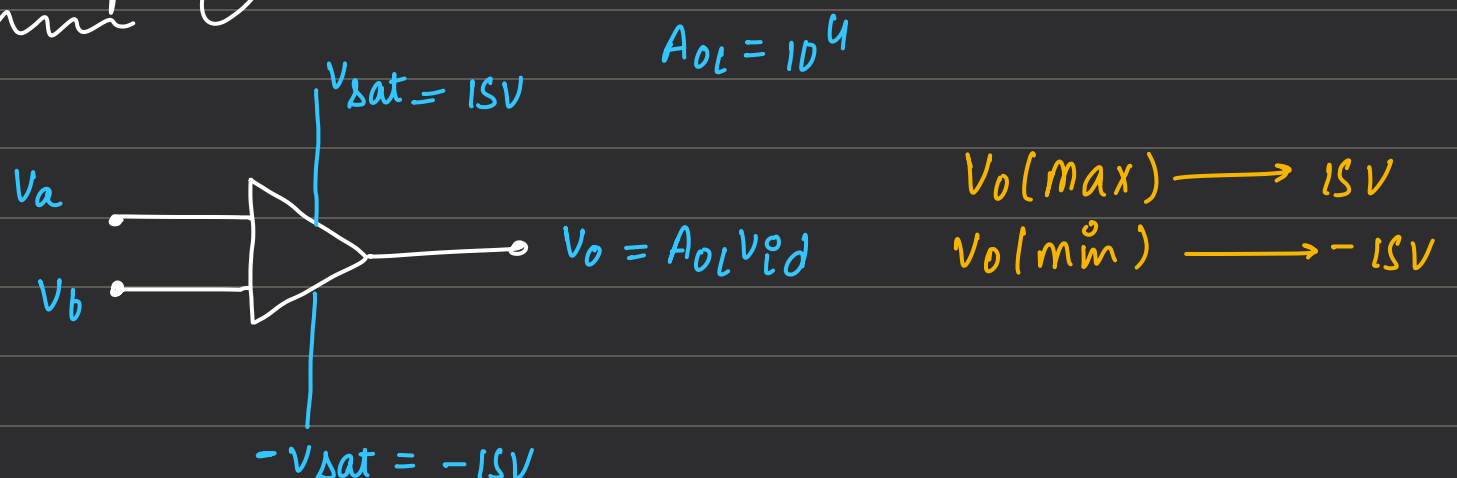
$$-V_{sat} \leq V_o \leq V_{sat}$$

Example (4)



* If V_{id} goes out of limit then the o/p gets saturated

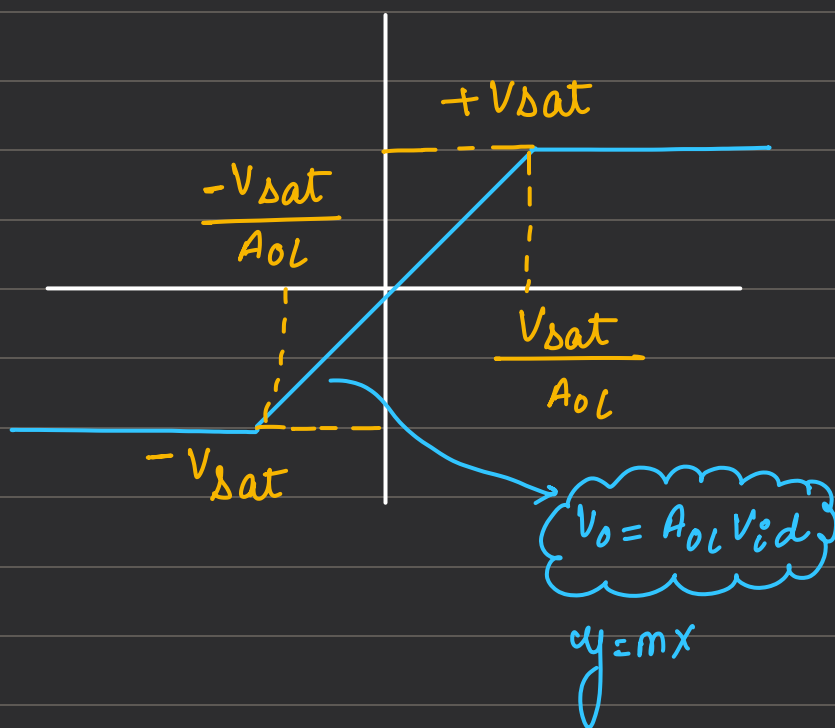
Example (5)



* Always check for limits since if limits are exceeded the o/p values may be clipped.

$$-\frac{V_{sat}}{A_{OL}} \leq V_{id} \leq \frac{V_{sat}}{A_{OL}}$$

Transfer Char.



$$\Rightarrow \text{slope } \theta: A_{OL} = \tan \theta$$

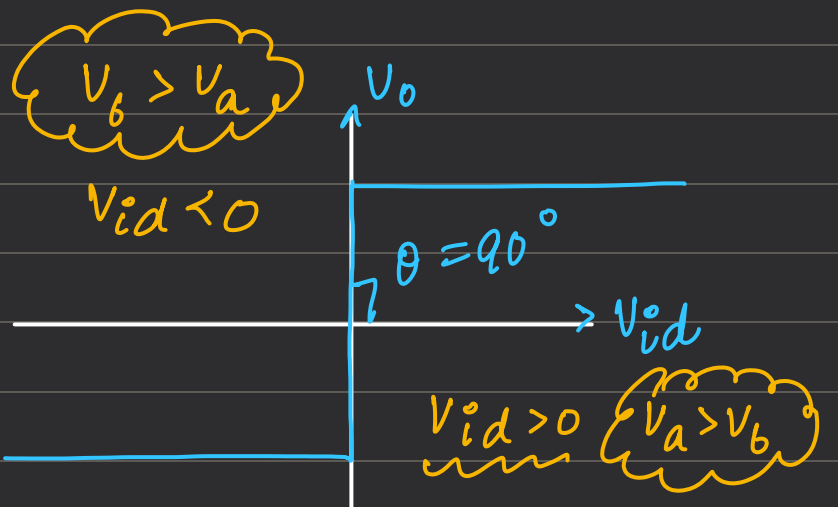
Since $A_{OL} \gg \gg$

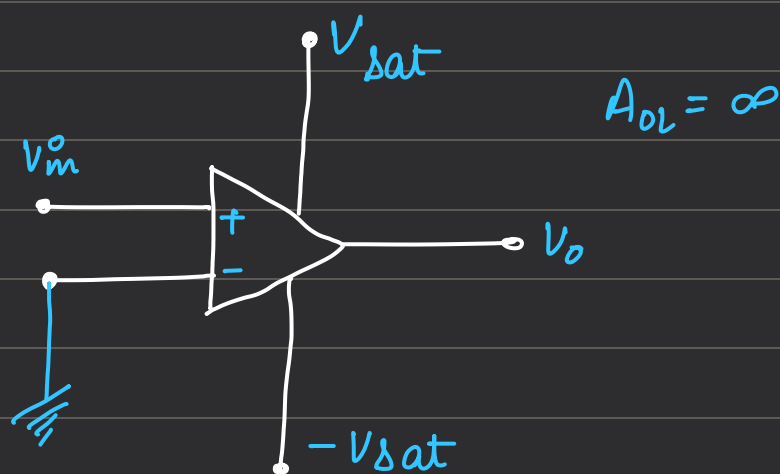
$$\therefore \theta \simeq 90^\circ \Rightarrow \text{Approaches } 90^\circ$$

Thus in case of ideal op-amp:

$$A_{OL} \rightarrow \infty$$

$$\theta = \tan^{-1}(\infty) = 90^\circ$$



Example (6)

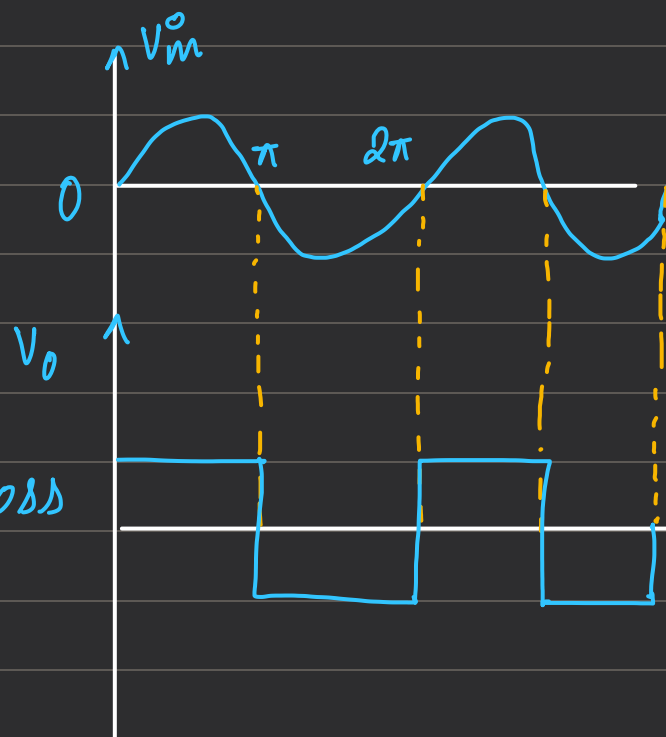
$$V_o = A_{OL} V_{id}$$

$$V_{id} = \frac{V_o}{A_{OL}} \rightarrow \begin{aligned} & \frac{+V_{sat}}{A_{OL}} = \frac{+()}{\infty} = +0 \\ & \frac{-V_{sat}}{A_{OL}} = \frac{-()}{\infty} = -0 \end{aligned}$$

$$V_{id} > 0 \Rightarrow V_o = +V_{sat}$$

$$V_{id} < 0 \Rightarrow V_o = -V_{sat}$$

$$V_{id} = V_m - 0 = V_m$$



* This circuit is called 0-cross detector

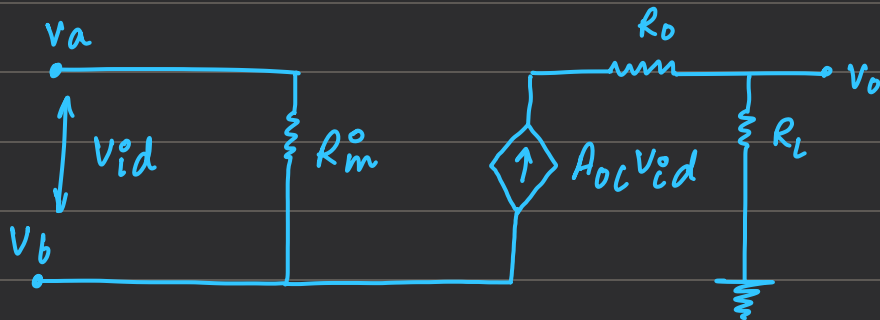
* It is also a comparator

Char. of Ideal Op-Amp

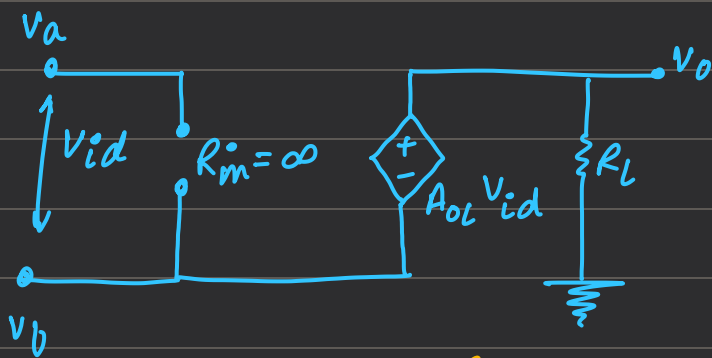
- ① ∞ i/p impedance
- ② 0 o/p impedance
- ③ ∞ open loop gain
- ④ ∞ Bandwidth
- ⑤ ∞ CMRR

Feedback $\rightarrow +ve$ (increases gain)
 $\rightarrow -ve$ (\downarrow gain)

Eq. Circuit of Ideal Op-Amp

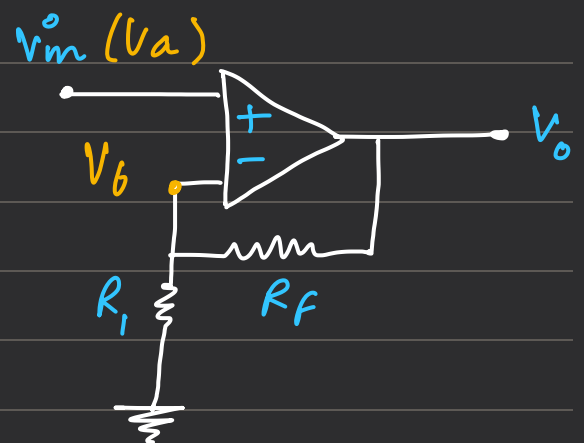
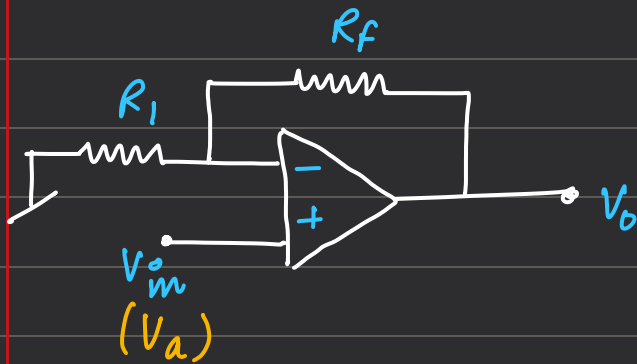


* Practical Op-Amp



* Ideal Op-Amp

Negative Feedback



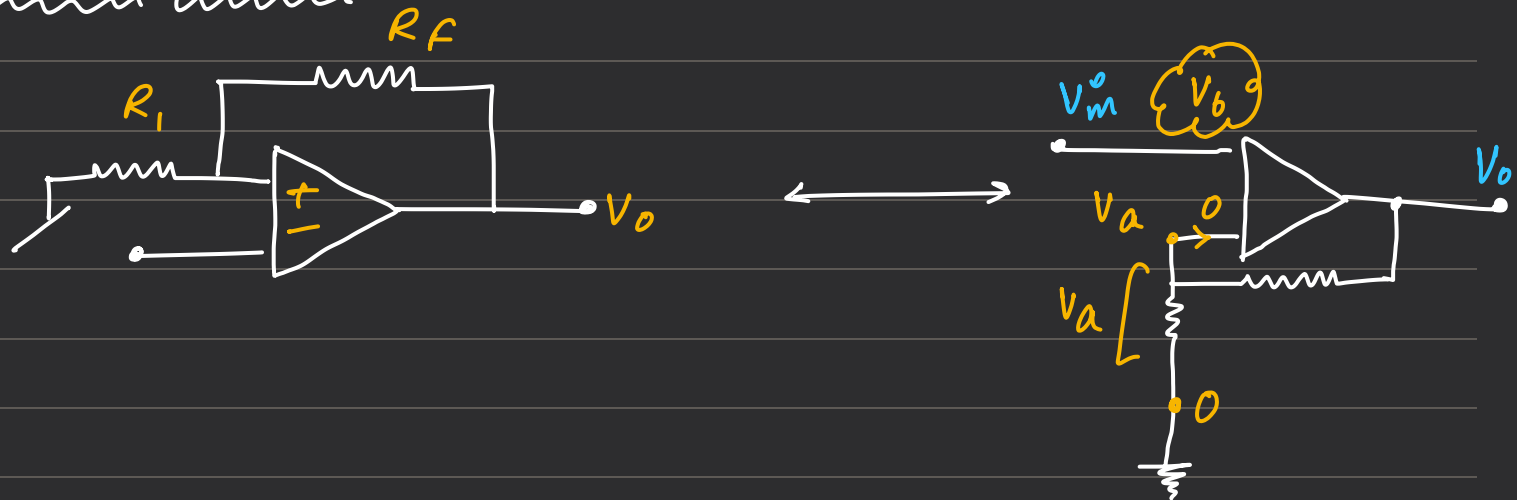
$$\begin{aligned} V_o &= A_{OL} V_{id} \\ &= A_{OL} (V_a - V_b) \\ &= A_{OL} (V_m - V_b) \end{aligned}$$

$$V_b = \frac{V_o R_1}{R_1 + R_2}$$

$V_o \uparrow \longrightarrow V_b \uparrow \longrightarrow V_o \downarrow$ minus feedback

$V_o \downarrow \longrightarrow V_b \downarrow \longrightarrow V_o \uparrow$ minus feedback

Positive feedback



$$\begin{aligned} V_o &= A_{ol} V_{id} \\ &= A_{ol} (V_a - V_b) \\ &= A_{ol} (V_a - V_m) \end{aligned}$$

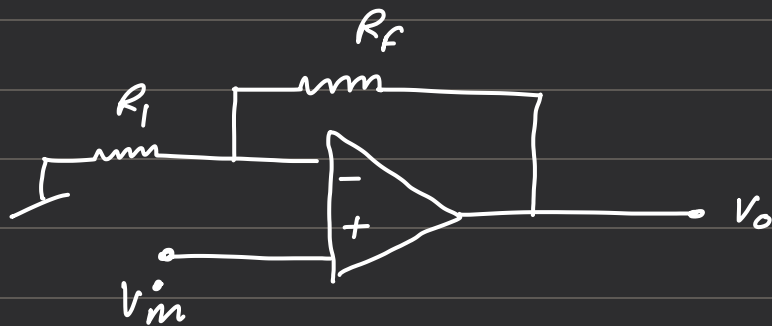
$$V_a = V_o \left(\frac{R_1}{R_1 + R_F} \right)$$

$V_o \uparrow \longrightarrow V_a \uparrow \longrightarrow V_o \uparrow$
 LOOP $\rightarrow \infty$

$V_o \downarrow \longrightarrow V_a \downarrow \longrightarrow V_o \downarrow$
 LOOP $\rightarrow \infty$

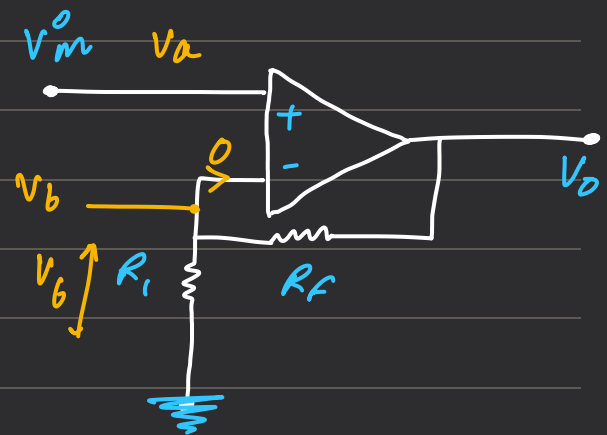
plus feedback

=> NON-Buffering Amp.



we need to find $v_o/v_{in}^o (A_{CL}) = ?$

$$\begin{aligned} V_o &= A_{OL} (V_{id}) \\ &= A_{OL} (V_a - V_b) \\ &= A_{OL} (V_{in}^o - V_b) \end{aligned}$$



$$V_b = \frac{V_o R_i}{R_i + R_f}$$

$$V_b = \frac{V_a - V_o}{A_{OL}}$$

$$\frac{V_o R_i}{R_i + R_f} = \frac{V_{in}^o - V_o}{A_{OL}}$$

$$\frac{R_i}{R_i + R_f} = \frac{V_{in}^o}{V_o} - \frac{1}{A_{OL}}$$

$$\frac{V_{in}^o}{V_o} = \frac{R_i}{R_i + R_f} + \frac{1}{A_{OL}}$$

$$= \frac{R_i A_{OL} + R_i + R_f}{A_{OL} (R_i + R_f)}$$

$$\frac{V_o}{V_{in}^o} = \frac{A_{OL} (R_i + R_f)}{R_i A_{OL} + R_i + R_f}$$

$$= \frac{A_{OL} R_i \left[1 + \frac{R_f}{R_i} \right]}{R_i A_{OL} \left[1 + \frac{1}{A_{OL}} \left(1 + \frac{R_f}{R_i} \right) \right]}$$

★★

$$\frac{V_o}{V_{in}} = \frac{1 + R_f/R_i}{1 + \frac{1}{A_{OL}} \left(1 + \frac{R_f}{R_i} \right)}$$

$$\text{If } A_{OL} \rightarrow \infty$$

$$\frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_i} \longrightarrow \text{Ideal OP-Amp}$$

Approx. Method

$$\text{If } A_{OL} \rightarrow \infty$$

$$V_b = V_a - \frac{V_o}{A_{OL}}$$

$$\Rightarrow V_b = V_a - 0$$

$$\Rightarrow V_b = V_a \longrightarrow \text{Case of Virtual Short}$$