Quick Recap

RLC $\rightarrow$ total response

$$v(t) = v_f(t) + v_n(t)$$

$$= V_{ss} + \underbrace{v_T(t)}$$

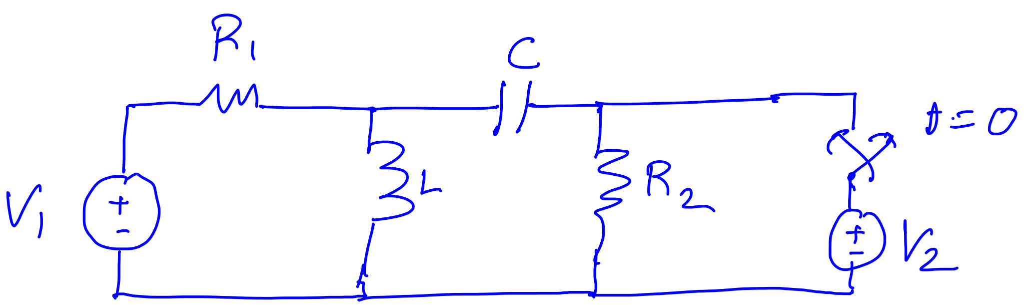
$\rightarrow A_1 e^{s_1 t} + A_2 e^{s_2 t}$

$\rightarrow A_1 t e^{st} + A_2 e^{st}$

$\rightarrow e^{-\alpha t}(A_d \sin\omega_d t + B_d \cos\omega_d t)$

$I_L(t) = I_L(t^+) \qquad (V_L(t) \neq \infty)$

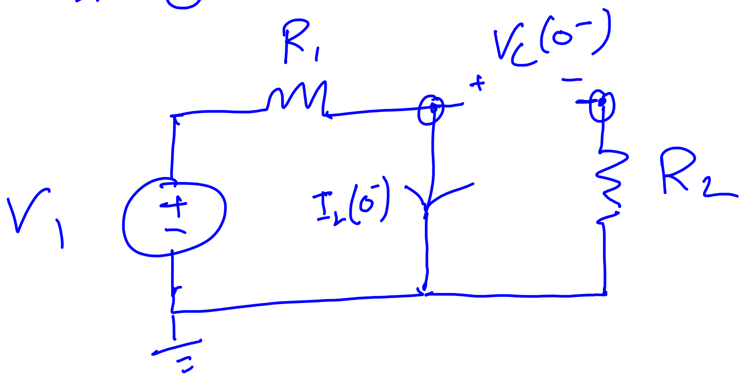
$V_C(t^-) = V_C(t^+) \qquad (I_C(t) \neq \infty)$



$I_L(0^-) = ?$

$V_C(0^-) = ?$

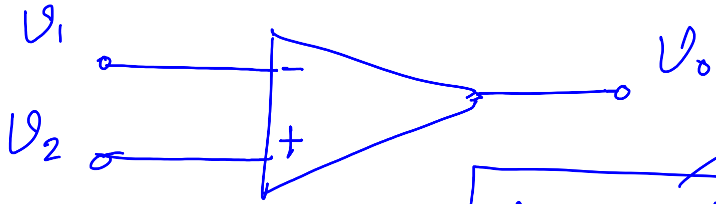
at $t = 0^-$



$$I_L(0^-) = \frac{V_1}{R_1}$$

$$V_C(0^-) = 0$$

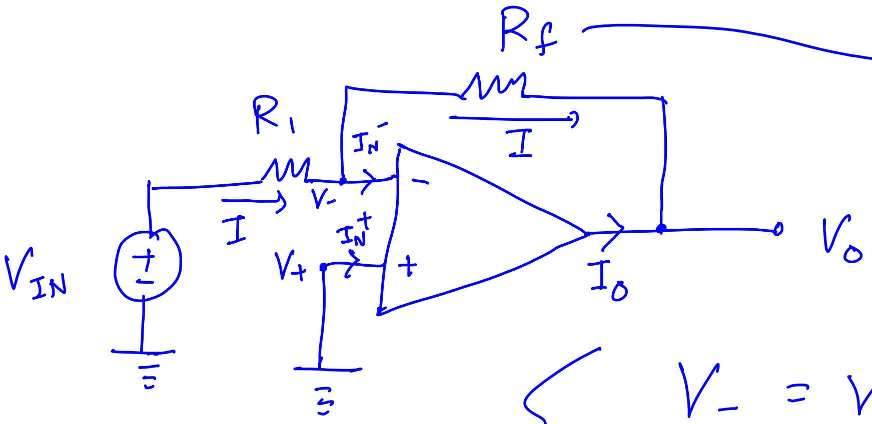
open-loop OpAmp



$$\boxed{v_o = A(v_2 - v_1)}$$

open-loop gain

closed-loop OpAmp



R_f → feedback resistance

Ideal OpAmp
$$\left\{ \begin{array}{l} V_- = V_+ \quad \text{(virtual short)} \\ I_N^- = I_N^+ = 0 \end{array} \right.$$

$$\frac{V_{IN}}{R_1} = \frac{-V_o}{R_f} \Rightarrow V_o = -\frac{R_f}{R_1} V_{IN}$$

$$I + I_o = 0 \Rightarrow I_o = -I = -\frac{V_{IN}}{R_1}$$

$I_{IN} = 0$, however, $I_o \neq 0$. This is possible because of the power supplies ($+V_{cc}$, $-V_{cc}$). OpAmp is an active element.

Equivalent circuit of OpAmp ✓

Fundamental questions

$$\frac{0}{0} = ?$$

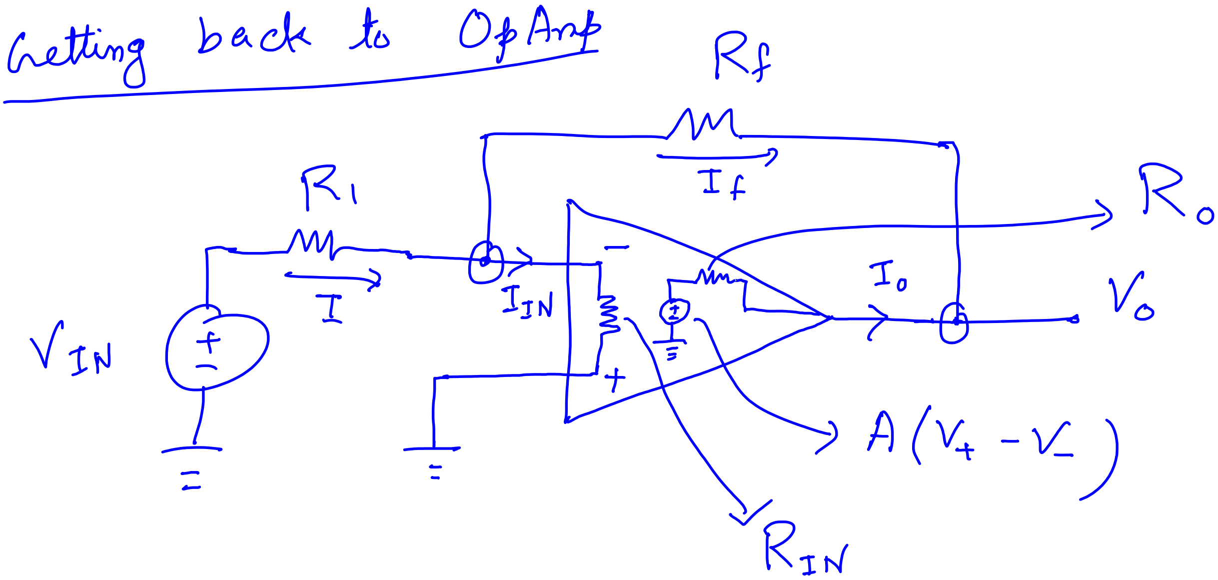
$$\infty \times 0 = ?$$

$$\frac{0}{0} = m \Rightarrow 0 = m \times 0$$

any real number

$$\underset{t \to \infty}{Lt} \frac{e^{-pt}}{e^{-qt}} \left\{ \begin{array}{ll} = 0 & \text{if } p > q \\ = \infty & \text{if } p < q \\ = 1 & \text{if } p = q \end{array} \right.$$

Getting back to OpAmp



Ideal Op Amp

$$\left. \begin{array}{l} A = \infty \\ R_{IN} = \infty \\ R_o = 0 \end{array} \right\}$$

$$I = I_f + I_{IN} \quad \text{—— (I)}$$

$$I_f + I_o = 0 \quad \text{—— (II)}$$

$$\frac{V_{IN} - V^-}{R_1} = \frac{V^- - V_o}{R_f} + \frac{V^-}{R_{IN}} \quad \text{———} \quad (1)$$

$$\frac{V^- - V_o}{R_f} + \frac{A(V^+ - V^-) - V_o}{R_o} = 0 \quad \text{———} \quad (11)$$

$\left(\frac{0}{0}\right)$

$\underline{\underline{V^+ = 0}}$

since $R_{IN} = \infty$

$$\Rightarrow \quad \frac{V_{IN} - V^-}{R_1} = \frac{V^- - V_o}{R_f}$$

since $R_o = 0$ $\Rightarrow$ $\boxed{A(V^+ - V^-) = V_o}$

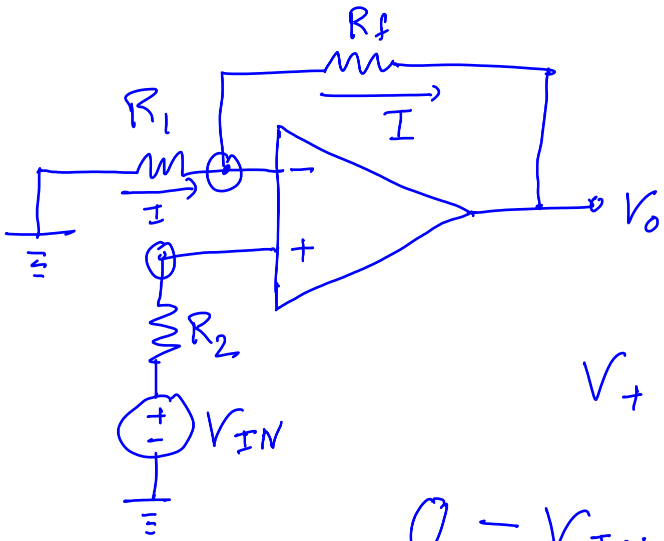
$$A(V^+ - V^-) = V_o$$

$$A(0 - V^-) = V_o$$

since $A = \infty$ $\Rightarrow$ $V^- = 0$ and V_o is finite.

$$\Rightarrow \quad V^+ = V^- = 0$$

$$I_{IN} = 0$$



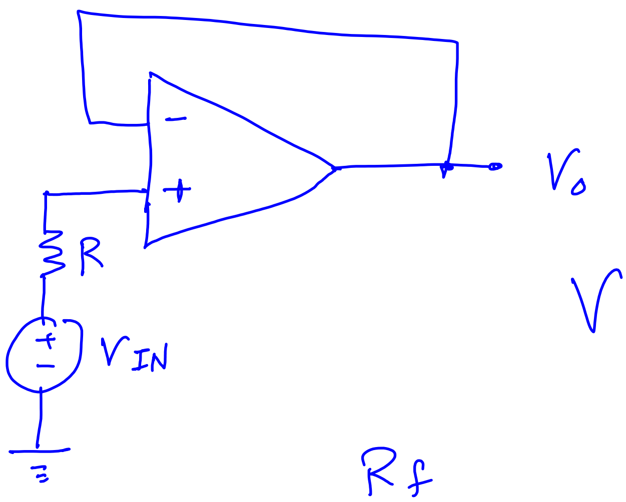
$$V_+ = V_- = V_{IN}$$

$$\frac{0 - V_{IN}}{R_1} = \frac{V_{IN} - V_o}{R_f}$$

$$\Rightarrow \quad \frac{V_o}{R_f} = \left(\frac{1}{R_1} + \frac{1}{R_f}\right) V_{IN}$$

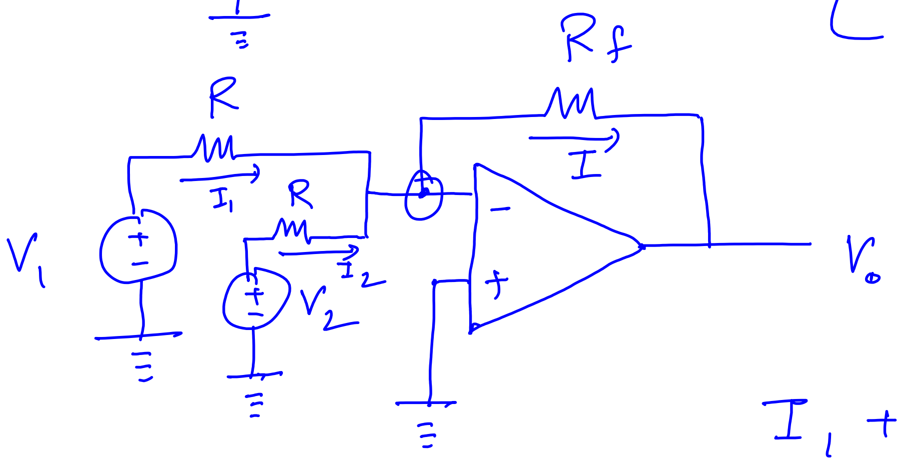
$$\Rightarrow \quad V_o = \left(1 + \frac{R_f}{R_1}\right) V_{IN}$$

(non-inverting amplifier)



$$V_o = V_{IN}$$

(Buffer)



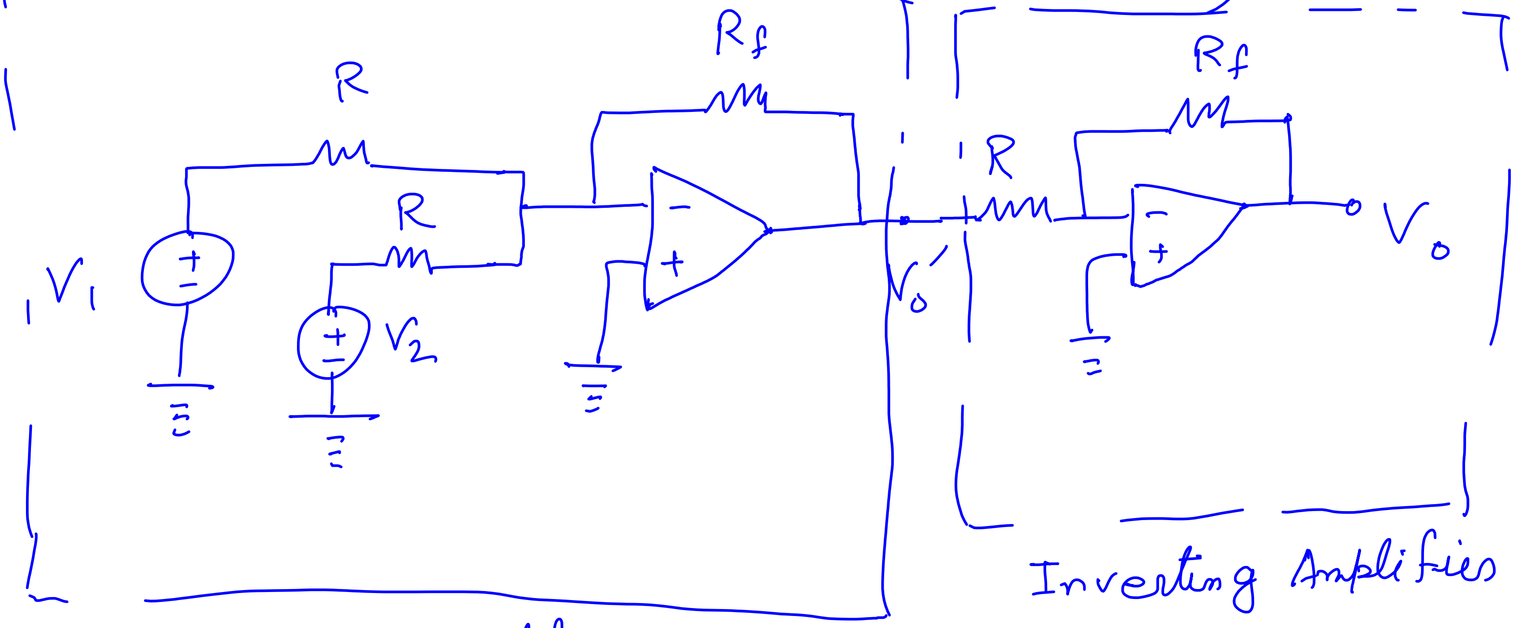
$$I_1 + I_2 = I$$

$$(V^+ = V^- = 0)$$

$$\frac{V_1}{R} + \frac{V_2}{R} = -\frac{V_o}{R_f}$$

$$V_o = -\frac{R_f}{R}(V_1 + V_2)$$

(Addition)



Inverting Adder

$$V_o' = -\frac{R_f}{R}(V_1 + V_2)$$

$$V_o = -\frac{R_f}{R} V_o' = +\frac{R_f^2}{R^2}(V_1 + V_2)$$