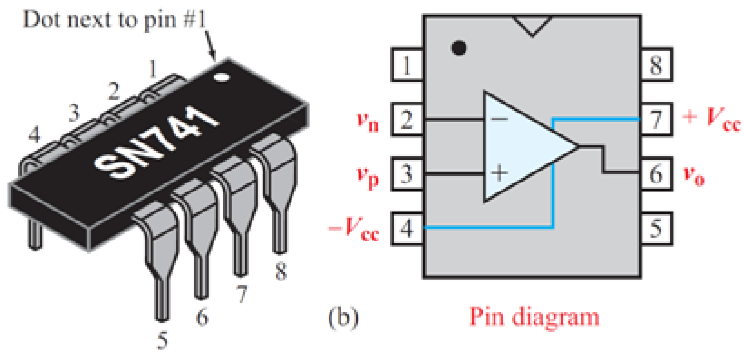
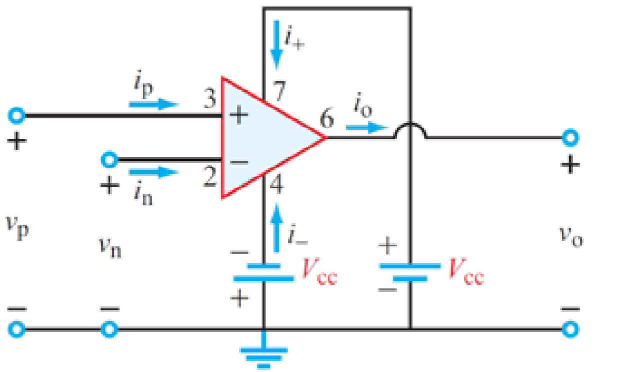
CHAPTER 4

Operational Amplifier "Op Amp"

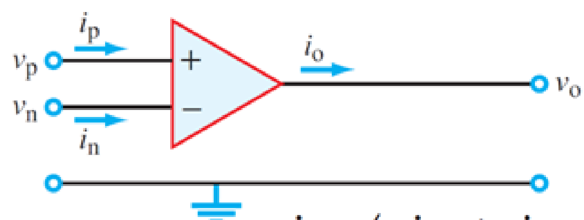
- Two input terminals, positive (non- inverting) and negative (inverting)
- One output
- Power supply $+V_{cc}$ and $-V_{cc}$



Op Amp showing power supply



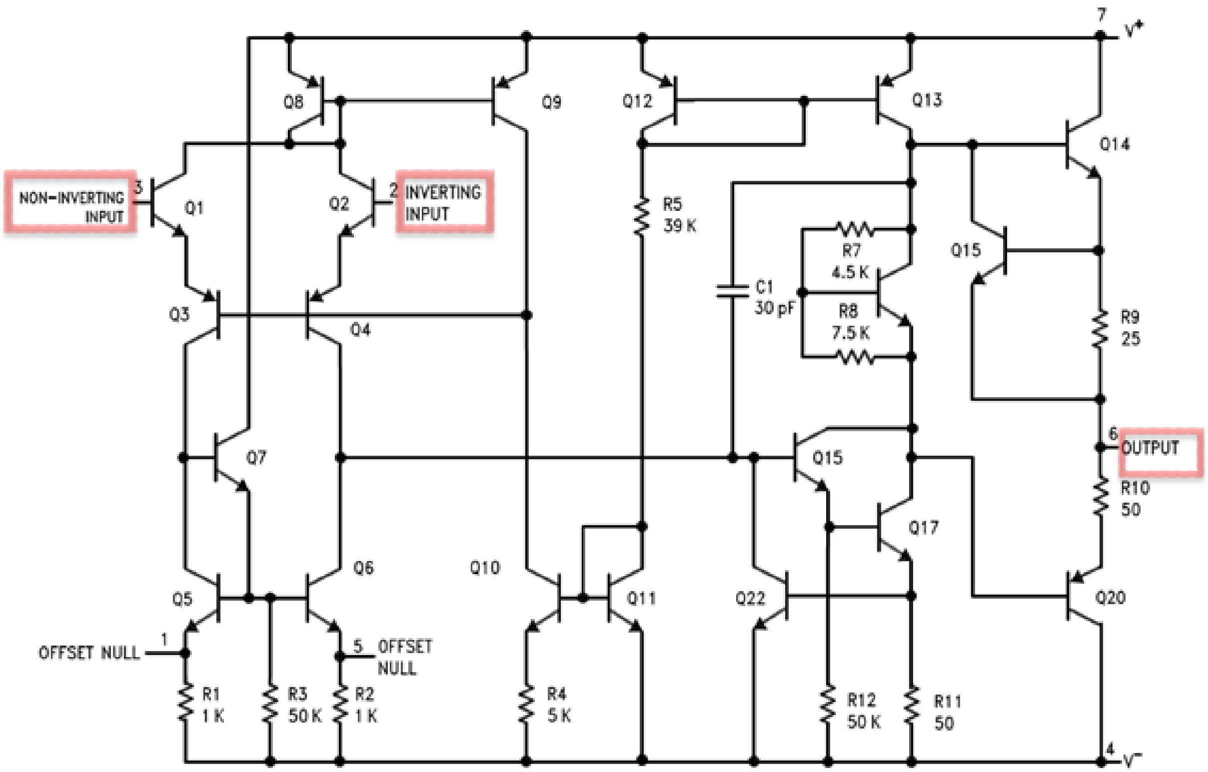
Op Amp with power supply not shown (which is how we usually display op amp circuits)



$$i_o \neq i_p + i_n$$

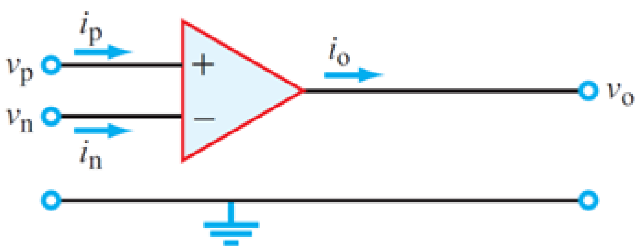
Inside The Op-Amp (741)

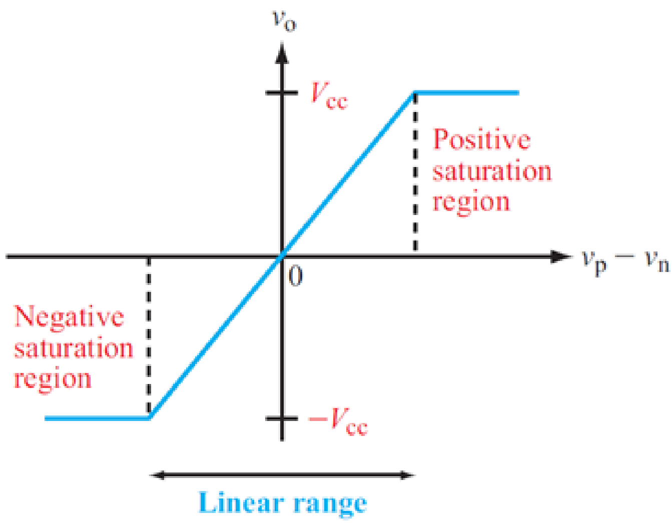
Schematic Diagram



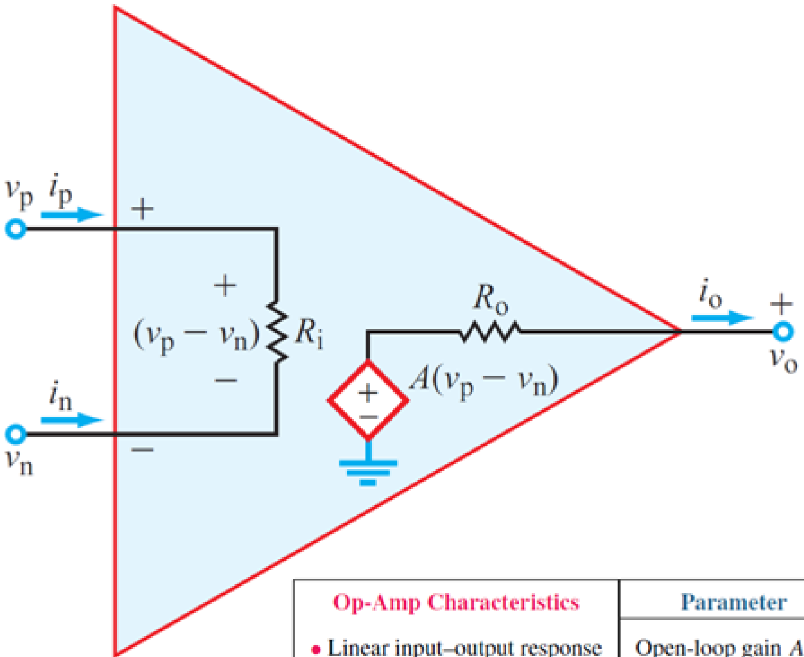
Gain

- Key important aspect of op amp: high voltage gain
- Output $v_o = A(v_p - v_n)$ op-amp gain (or open-loop gain) – different from circuit gain G
- Linear response

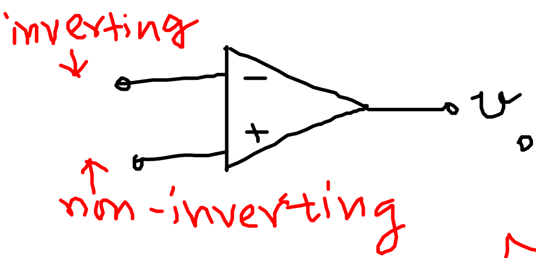


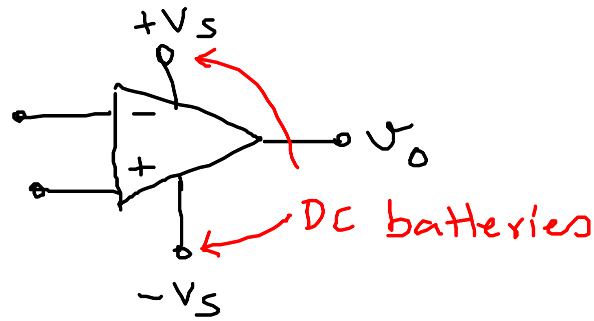


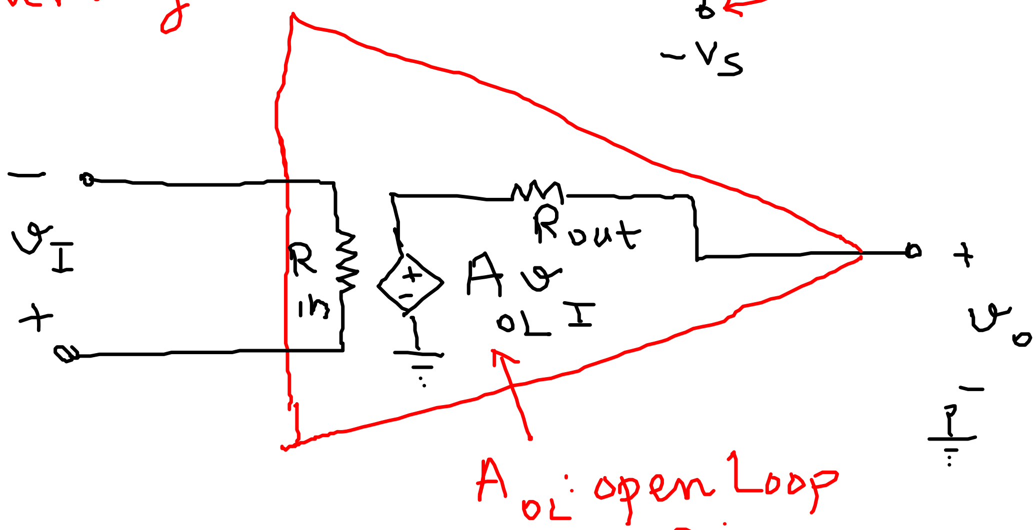
Equivalent Circuit



Op-Amp Characteristics	Parameter	Typical Range	Ideal Op Amp
• Linear input–output response	Open-loop gain A	10^4 to 10^8 (V/V)	∞
• High input resistance	Input resistance R_i	10^6 to 10^{13} Ω	∞ Ω
• Low output resistance	Output resistance R_o	1 to 100 Ω	0 Ω
• Very high gain	Supply voltage V_{cc}	5 to 24 V	As specified by manufacturer





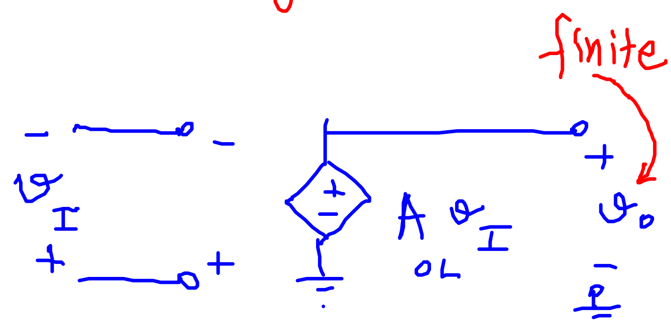


ideal op_amp

$R_{in} \to \infty$

$R_{out} \to 0$

$A_{OL} \to \infty$



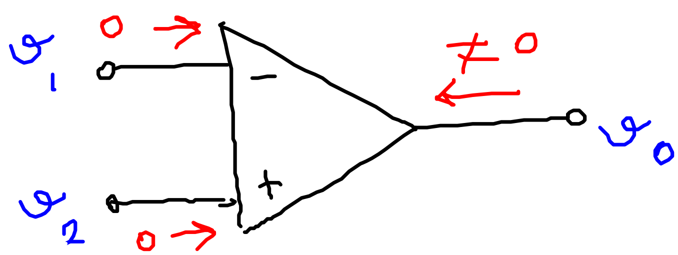
$$v_o = A_{OL} v_I$$

$$\text{finite} = \infty \cdot v_I$$

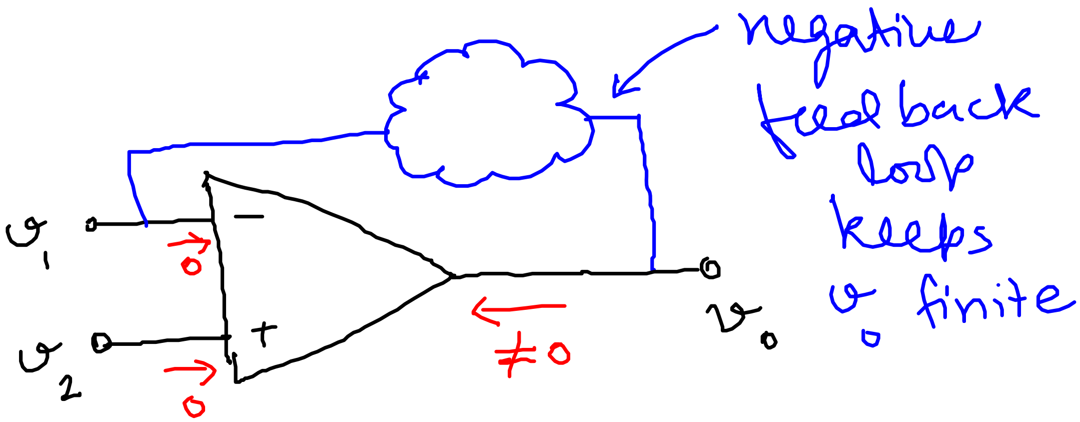
$$v_I \to 0$$

$\therefore$ if v_o = finite

then $v_I = 0$ (virtual short)

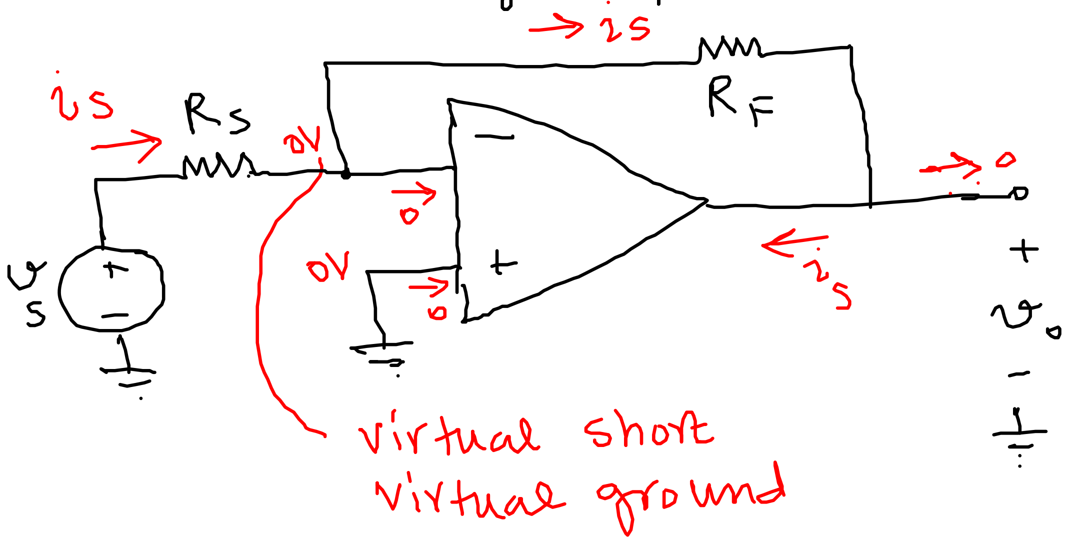


$v_1 = v_2$ (virtual short)



$v_1 = v_2$

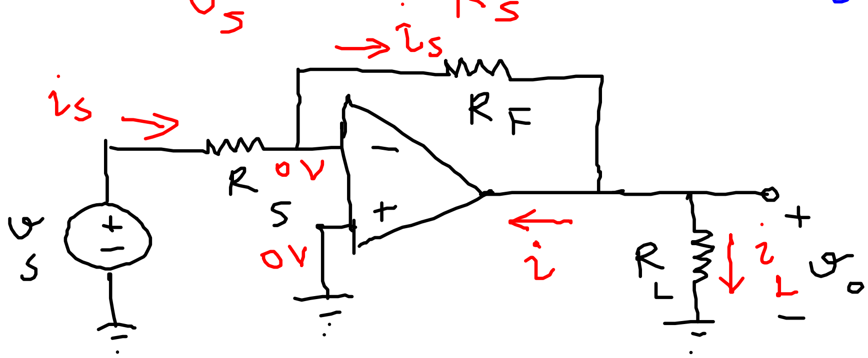
The inverting Amp:



closed loop gain $\frac{v_o}{v_S} = ?$

$$\frac{v_S - 0V}{R_S} = \frac{0V - v_o}{R_F}$$

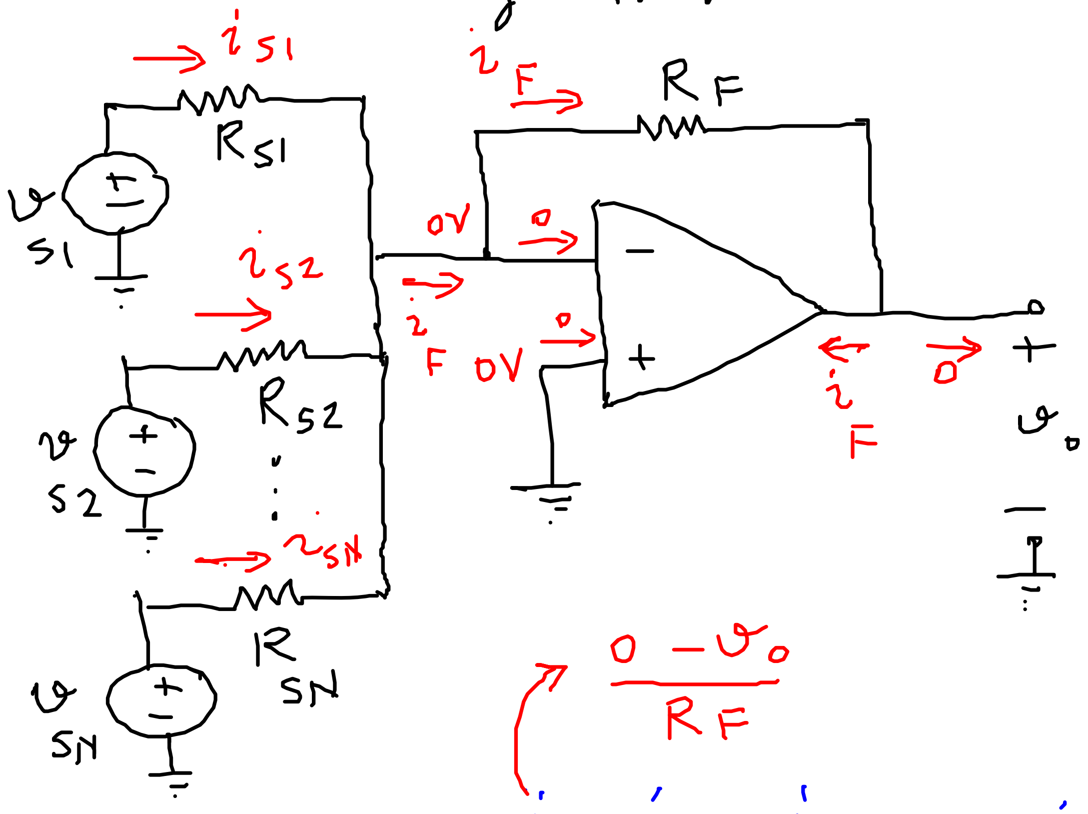
$$\frac{v_o}{v_S} = -\frac{R_F}{R_S} \qquad i_S = \frac{v_S - 0}{R_S} = \frac{v_S}{R_S}$$



$$\frac{v_S - 0V}{R_S} = \frac{0V - v_o}{R_F} \Rightarrow \frac{v_o}{v_S} = -\frac{R_F}{R_S}$$

$$i_S = \frac{v_S - 0}{R_S} = \frac{v_S}{R_S} \qquad i_L = \frac{v_o}{R_L} = -\frac{1}{R_L}\frac{R_F}{R_S}v_S$$

Summing Amp



$$\frac{0 - v_o}{R_F}$$

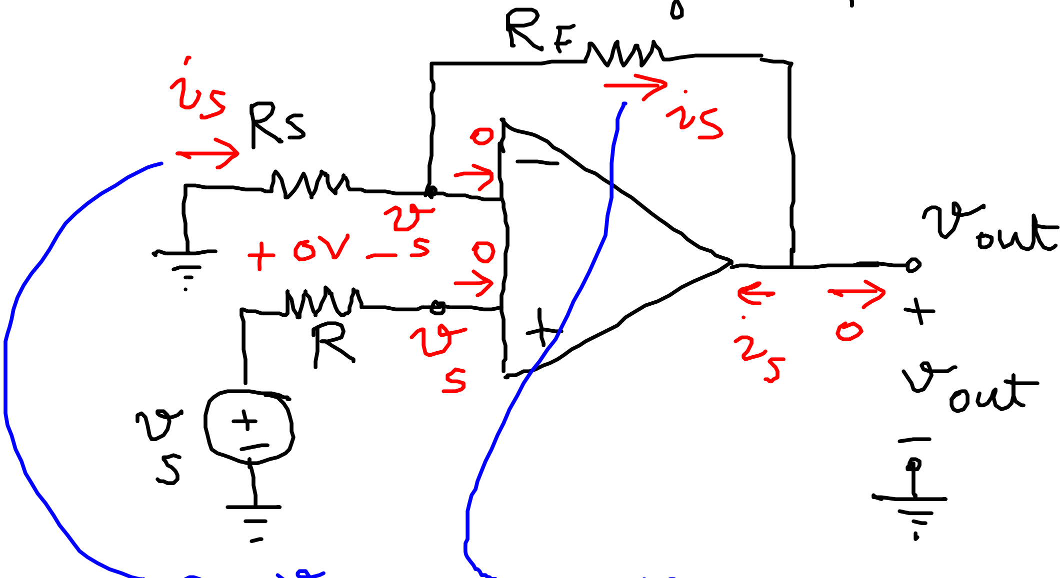
$$i_F = i_{S1} + i_{S2} + \cdots + i_{SN}$$

$$\frac{v_{S1} - 0}{R_{S1}} \qquad \frac{v_{S2} - 0}{R_{S2}} \qquad \frac{v_{SN} - 0}{R_{SN}}$$

$$-\frac{v_o}{R_F} = \frac{v_{S1}}{R_{S1}} + \frac{v_{S2}}{R_{S2}} + \cdots + \frac{v_{SN}}{R_{SN}}$$

$$v_o = -R_F\left[\frac{v_{S1}}{R_{S1}} + \frac{v_{S2}}{R_{S2}} + \cdots + \frac{v_{SN}}{R_{SN}}\right]$$

The non-inverting amp

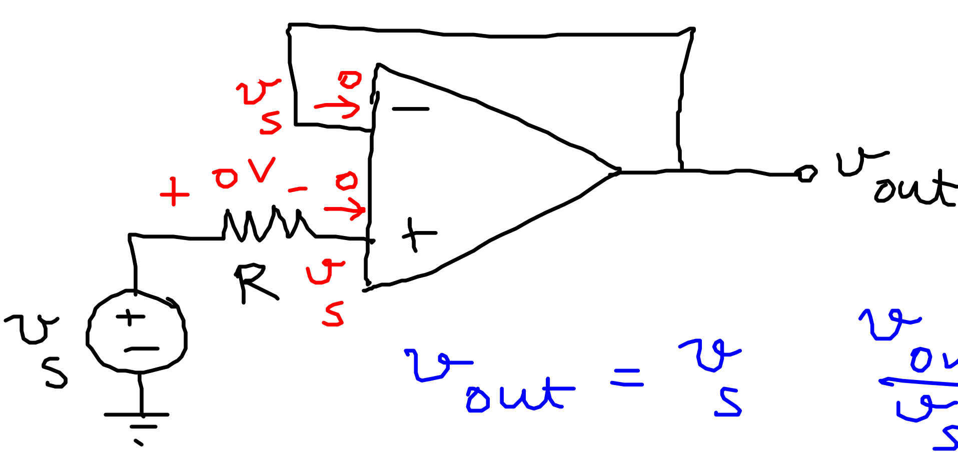


$$\frac{0 - v_s}{R_s} = \frac{v_s - v_{out}}{R_F}$$

$$\frac{v_{out}}{v_s} = 1 + \frac{R_F}{R_s}$$

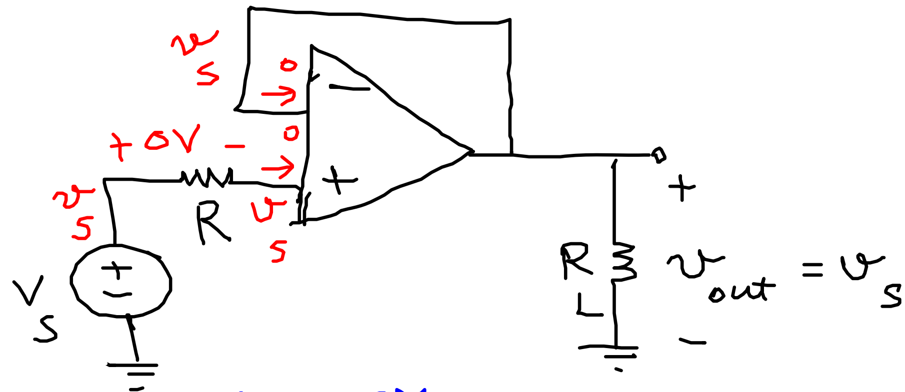
Voltage Follower

$R_s \to \infty$, $R_F = 0$



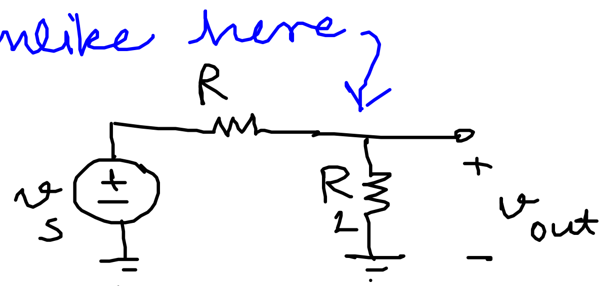
$v_{out} = v_s$ $\quad \frac{v_{out}}{v_s} = 1$

note: $v_{out} = v_s$ Independent of R_L



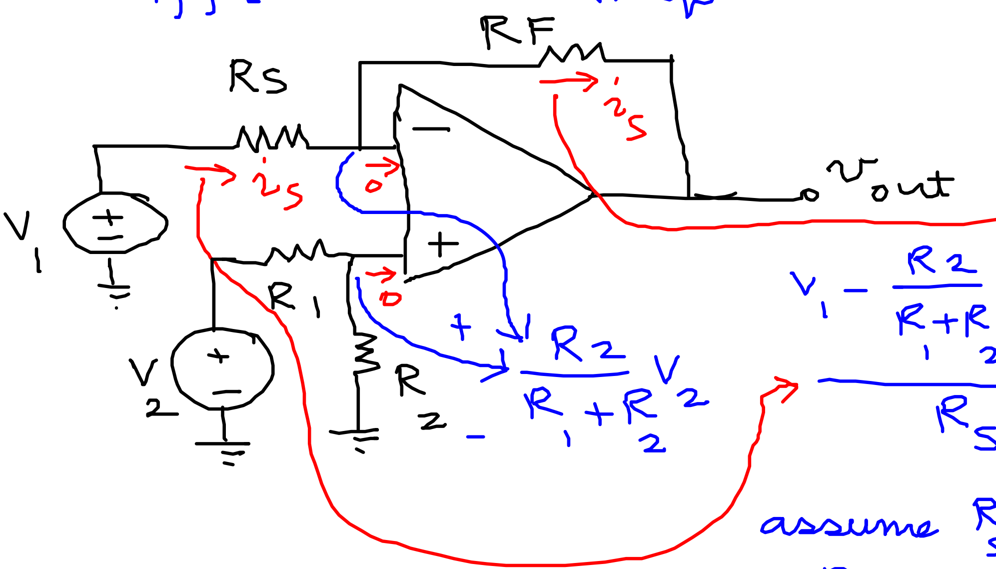
$$v_s = v_{out}$$

unlike here,



$$v_{out} = \frac{R_L}{R+R_L} v_s$$

Differential Amp

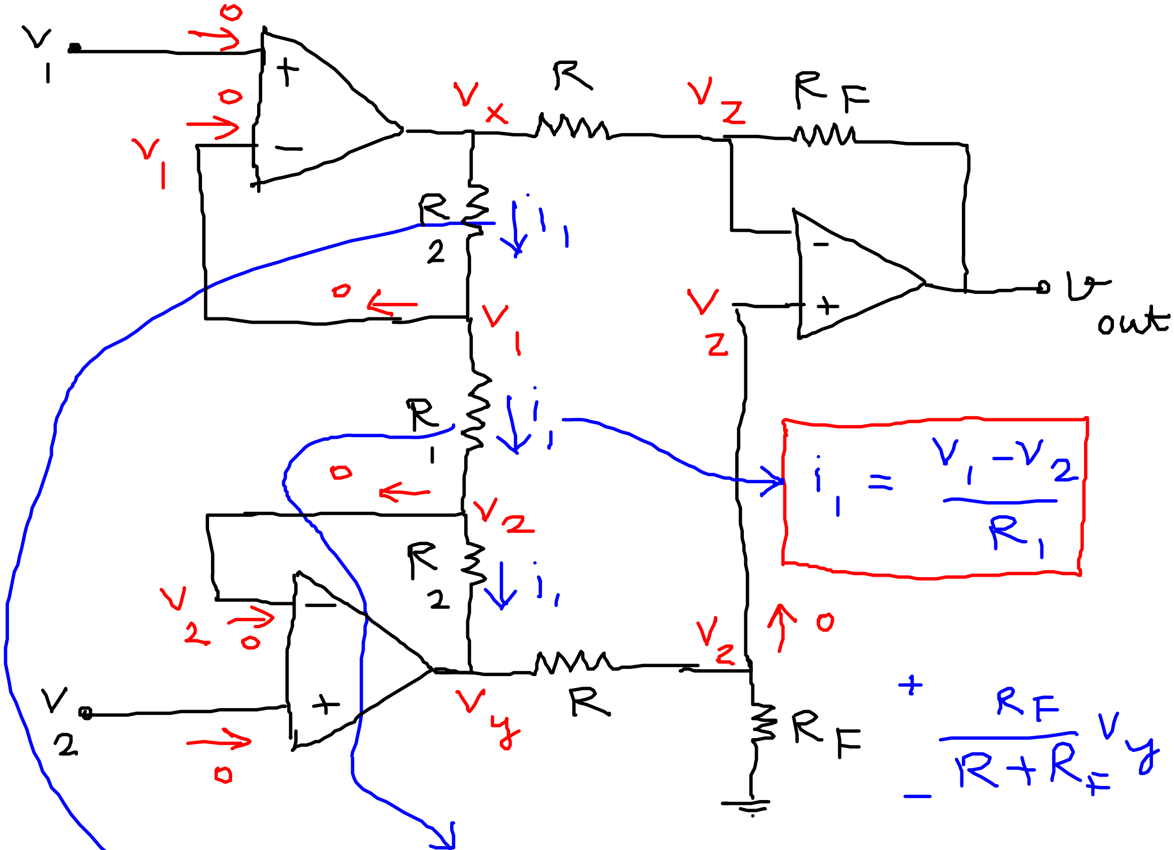


$$+ \quad \frac{R_2}{R_1+R_2} V_2 \quad -$$

$$\frac{V_1 - \frac{R_2}{R_1+R_2} V_2}{R_S} = \frac{\frac{R_2}{R_1+R_2} V_2 - V_{out}}{R_F}$$

assume $R_S = R_1$, $R_F = R_2$

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



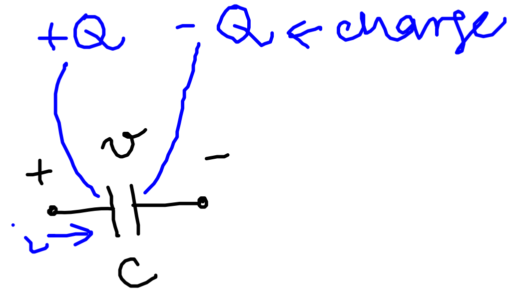
$$\boxed{i_1 = \frac{V_1 - V_2}{R_1}}$$

$$\frac{V_x - V_1}{R_2} = \frac{V_1 - V_2}{R_1} \qquad \frac{V_1 - V_2}{R_1} = \frac{V_2 - V_y}{R_2}$$

$$\boxed{V_x = \left(1 + \frac{R_2}{R_1}\right)V_1 - \frac{R_2}{R_1} V_2} \qquad \boxed{V_y = \left(1 + \frac{R_2}{R_1}\right)V_2 - \frac{R_2}{R_1} V_1}$$

$$\boxed{V_z = \frac{R_F}{R+R_F} V_y}$$

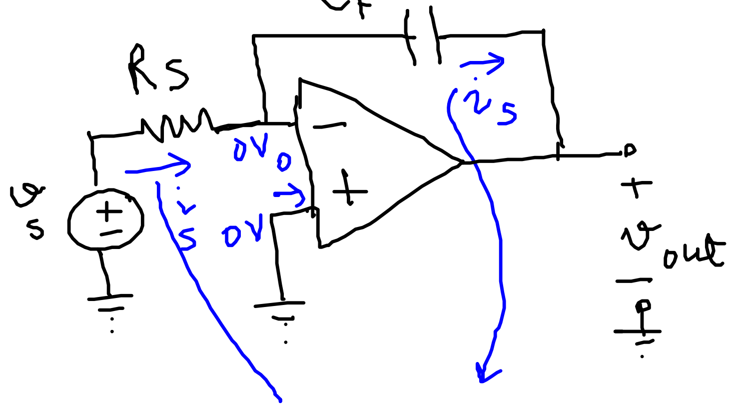
$$\frac{V_{out} - V_z}{R_F} = \frac{V_z - V_x}{R} \qquad \boxed{V_{out} = \frac{R_F}{R}\left(1 + \frac{2R_2}{R_1}\right)(V_2 - V_1)}$$



$$i = C\frac{dv}{dt}$$

$$C = \frac{Q}{v}$$

Ideal Integrator

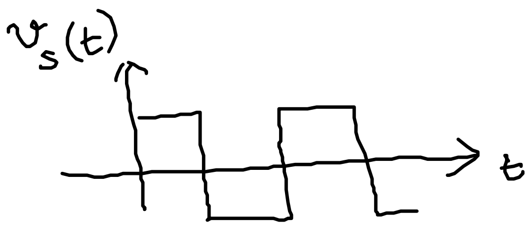


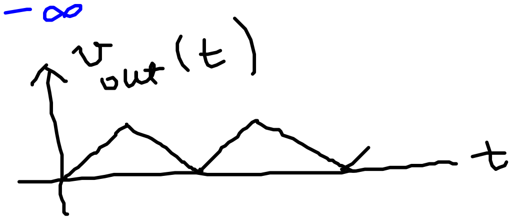
$$\frac{v_S - 0}{R_S} = C_F\frac{d}{dt}\left[0 - v_{out}(t)\right]$$

$$v_S(t) = -R_S C_F \frac{dv_{out}(t)}{dt}$$

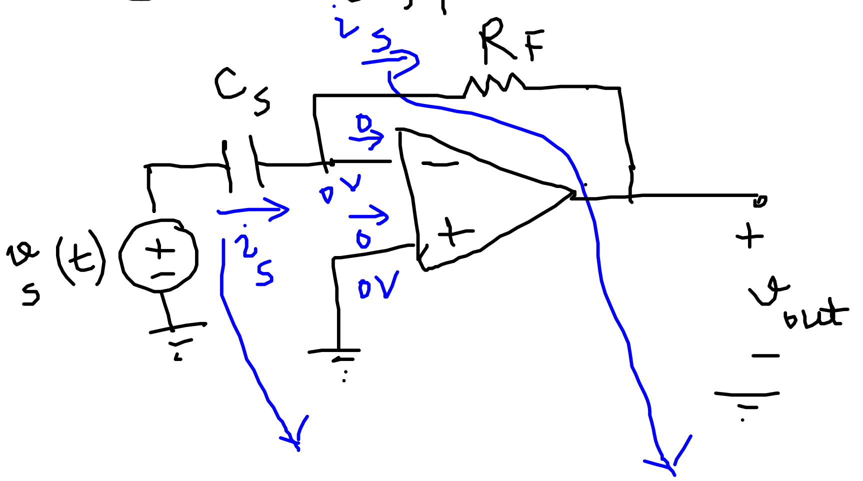
$$\int_{-\infty}^{t} v_S(t')\,dt' = -R_S C_F \int_{-\infty}^{t} \frac{dv_{out}(t')}{dt'}\,dt'$$

$$v_{out}(t) = -\frac{1}{R_S C_F}\int_{-\infty}^{t} v_S(t')\,dt'$$





Ideal Differentiator



$$C_S \frac{d}{dt}\left[v_S(t) - 0\right] = \frac{0 - v_{out}}{R_F}$$

$$v_{out}(t) = -R_F C_S \frac{d}{dt} v_S(t)$$