Ideal Operational Amplifier Conditions

① Input Resistance $R_i \to \infty$ (gigaohms can be realized in practice)

② $A \to \infty$ A in excess of 10^6 can be realized

③ <u>Virtual</u> short ($v_i \to 0$). Note, however since $R_i \to \infty$ the current is very small

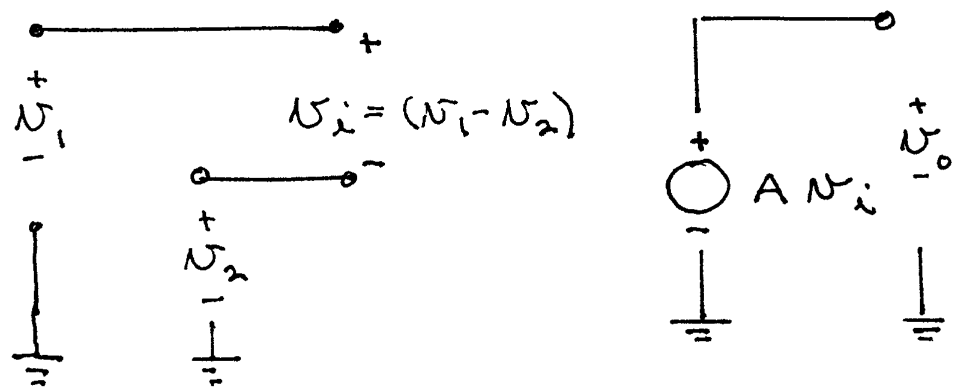
The argument for $v_i \to 0$

We showed that when $A \to \infty$

$$v_o / R_f = -i_s$$

so $$v_i = v_o / A = -i_s R_f / A \to 0$$ (Summing Point Constraint)

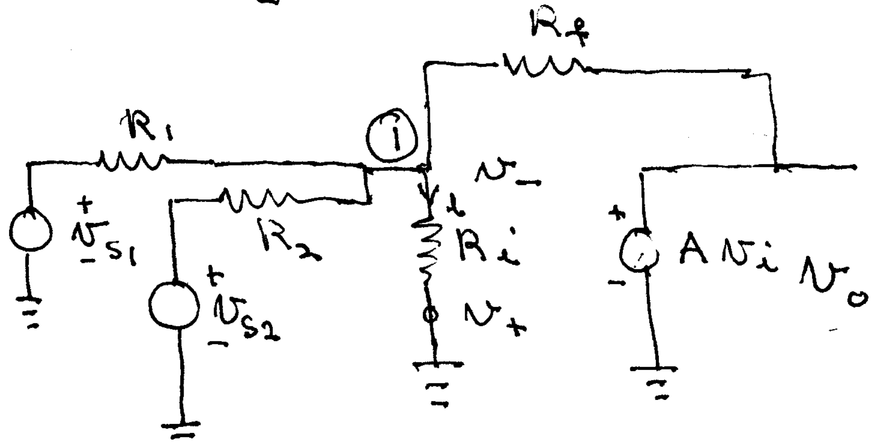
Results in <u>Ideal</u> <u>Op-Amp</u> picture of Fig 14.2



Example Op-Amp Circuits

Summing Amplifier

Equivalent Circuit



Equivalent Circuit

a) Find v_o

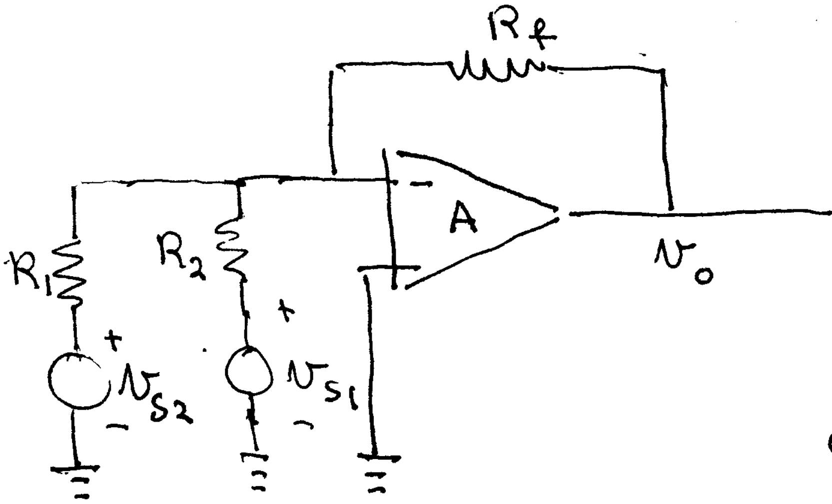
b) Take Limit as $A \to \infty$

$R_i \to \infty$

$v_+ \to v_-$

$i \to 0$

Then



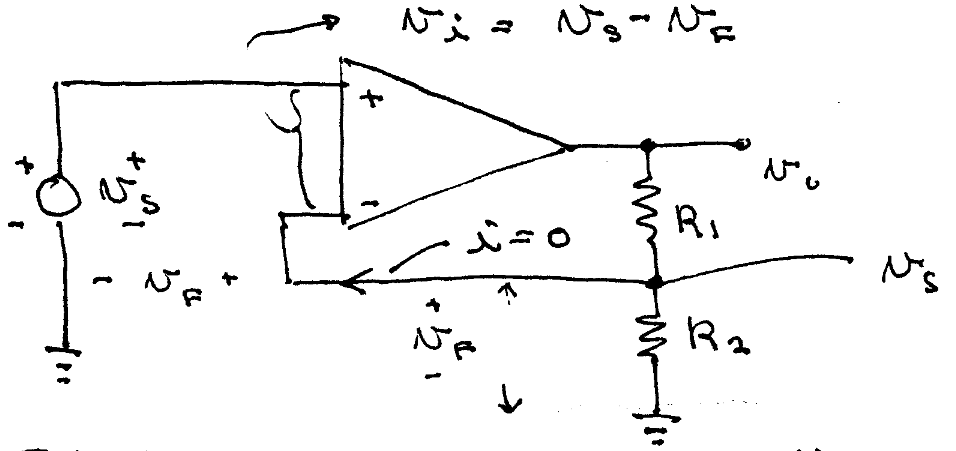
Summing Circuit

KCL at 1

$$\frac{v_{S1}}{R_1} + \frac{v_{S2}}{R_2} = -\frac{v_o}{R_f}$$

or $$v_o = -R_f\left(\frac{v_{S1}}{R_1} + \frac{v_{S2}}{R_2}\right)$$

Non inverting Amplifier



Ideal Op Amp $v_- = v_+ = v_s$

But $v_s = \dfrac{R_2}{R_1+R_2} v_o$

$\therefore \; v_o = \left(\dfrac{R_1+R_2}{R_2}\right) v_s$

Feed back Equations.

$$v_i = v_s - v_F$$

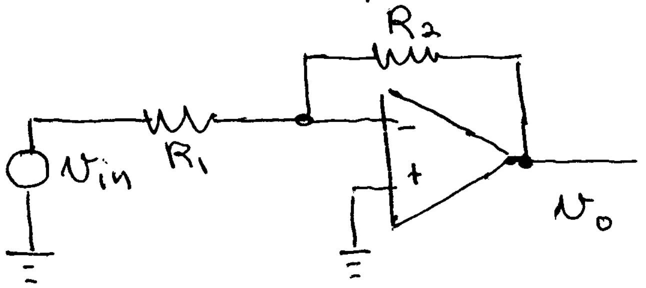
$$v_o = A \, v_i$$

$$v_F = v_s = \frac{R_2}{R_2+R_1} v_o = F \, v_o$$

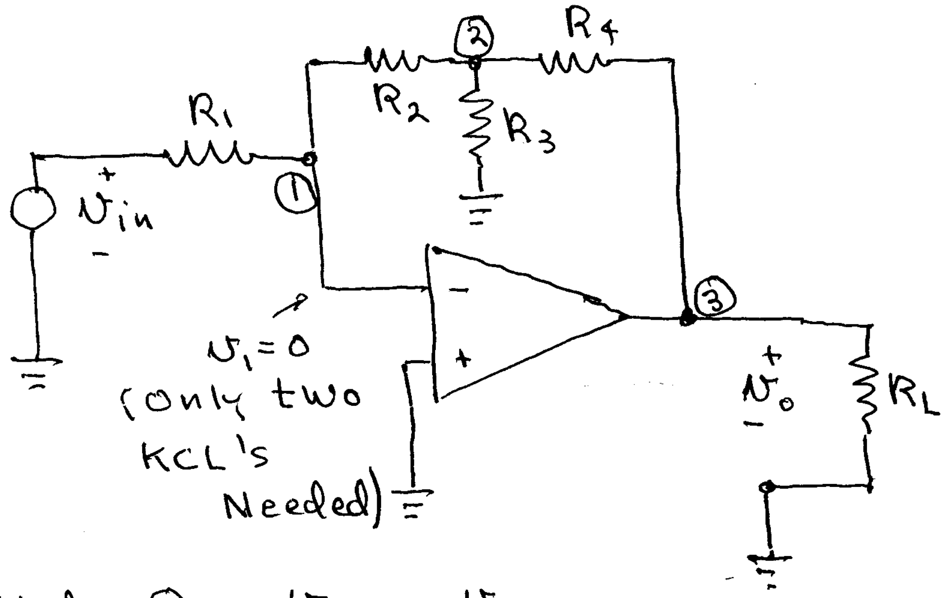
$$\therefore \; v_o = A \, v_i = A \, (v_s - v_F)$$
$$= A \, (v_s - F v_o)$$

$\therefore \; v_o = \dfrac{A \, v_s}{1 + AF}$ negative feed back.

Differential Amplifier - Examples



$$\frac{v_o}{R_2} = -\frac{v_{in}}{R_1}$$

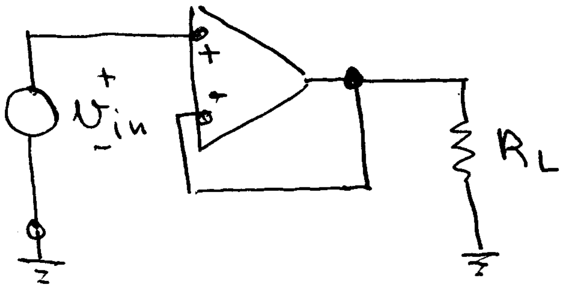


Node ① $\quad \dfrac{v_{in}}{R_1} + \dfrac{v_2}{R_2} = 0$

② $\quad v_2\left(\dfrac{1}{R_3} + \dfrac{1}{R_2} + \dfrac{1}{R_4}\right) - \dfrac{v_o}{R_4} = 0$

Thus $\quad -\dfrac{R_2}{R_1}\left(\dfrac{1}{R_3} + \dfrac{1}{R_2} + \dfrac{1}{R_4}\right) = \dfrac{v_o}{R_4}$

Voltage Follower

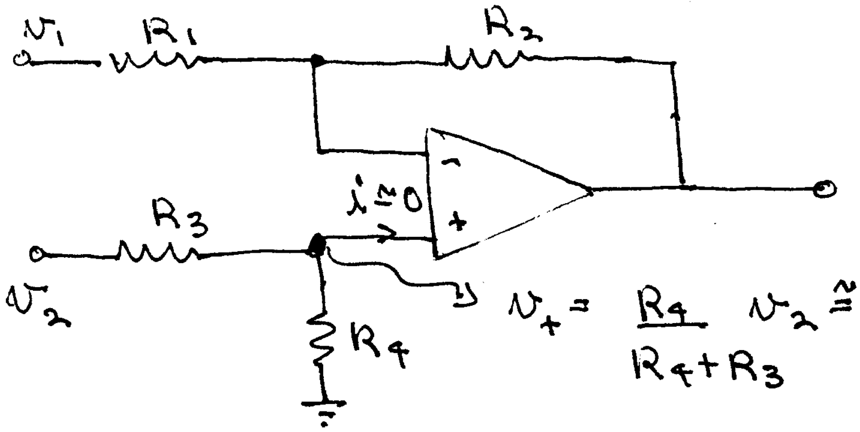


v_- forced to be v_o

But $v_- = v_{in}$

Thus $v_o = v_{in}$

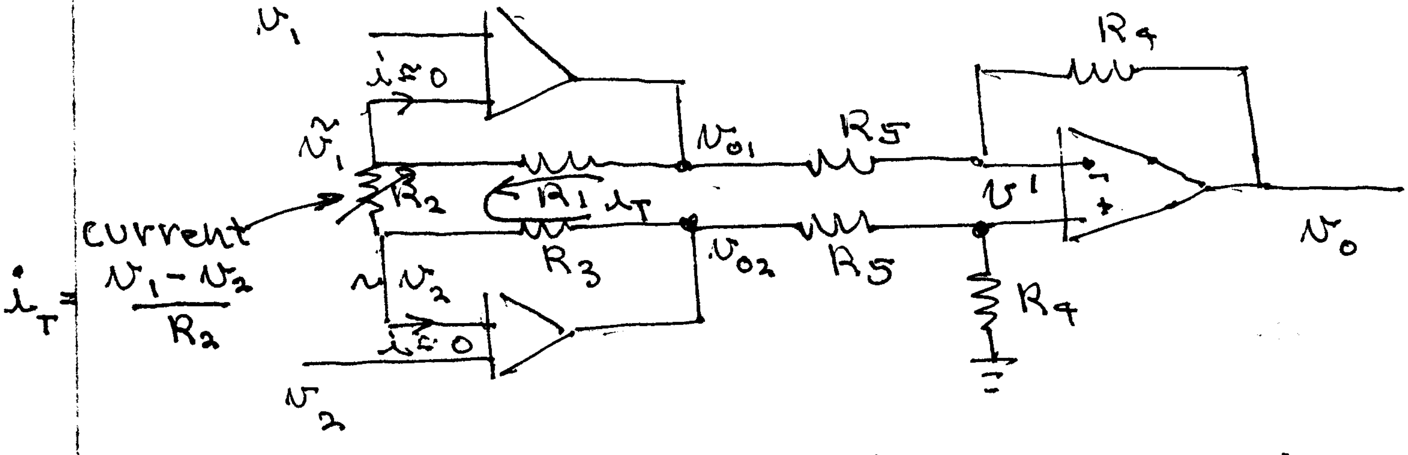
Subtracting Amplifier.



$$v_+ = \frac{R_4}{R_4+R_3} v_2 \cong v_-$$

$$\therefore \frac{v_1}{R_1} - \frac{R_4}{R_1(R_4+R_3)} v_2 = -\frac{v_o}{R_2}$$

Sensor Circuit (sense when $v_1 \neq v_2$)



$$\left.\begin{aligned} \therefore v_{01} &= v_1 + i_T R_1 \\ v_{02} &= v_2 - i_T R_3 \end{aligned}\right\rangle \quad \begin{aligned} (v_{02} - v_{01}) &= v_2 - v_1 + i_T (R_3 + R_1) \\ &= (v_2 - v_1)\left(1 + \frac{R_3 + R_1}{R_2}\right) \end{aligned}$$

$$\frac{v_o - v'}{R_4} = -\frac{v_{01} - v'}{R_5} \ ;$$

$$v' = \frac{R_4}{R_4 + R_5} v_{02}$$

$$\frac{v_o}{R_4} + \frac{v_{o1}}{R_5} = \frac{R_4}{R_4+R_5} v_{o2} \left(\frac{1}{R_4} + \frac{1}{R_5}\right)$$

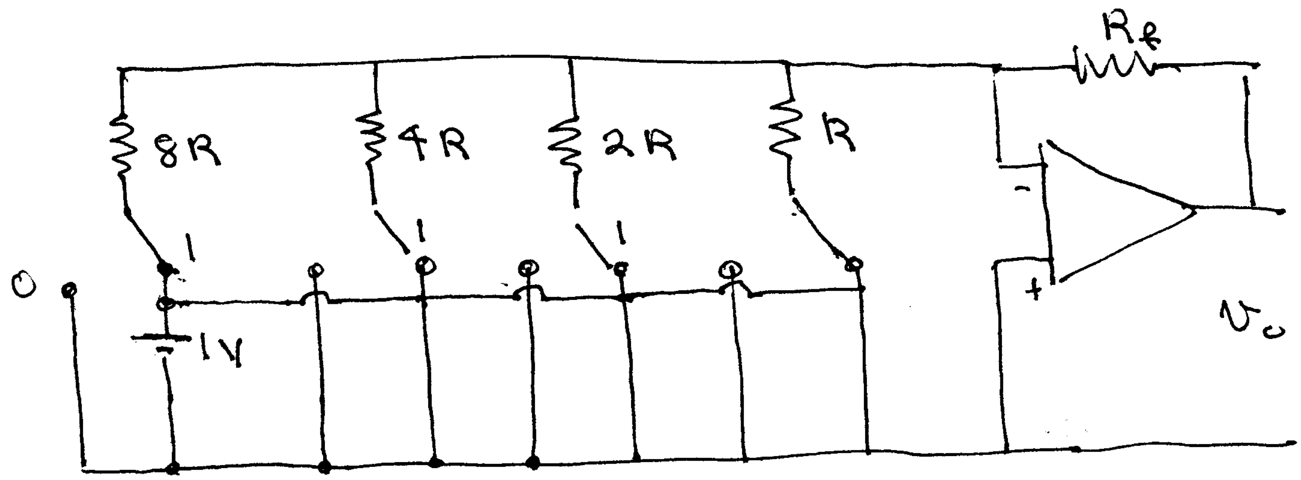
$$= \cancel{R_4}\, v_{o2} \frac{(R_4+R_5)}{\cancel{R_4} R_5}$$

$$\therefore v_o = -\frac{R_4}{R_5}(v_{o2} - v_{o1})$$

$$v_o = -\frac{R_4}{R_5}\left(1 + \frac{R_3+R_1}{R_2}\right)(v_2 - v_1)$$

Set $R_4 = R_5 = R_3 = R_1$ R_2 is gain control,

Simple DAC



$$v_o = -\frac{R_f}{R}\left(V_1 + \frac{1}{2}V_2 + \frac{1}{4}V_3 + \frac{1}{8}V_4\right)$$

$$= -\frac{R_f}{8R}(8V_1 + 4V_2 + 2V_3 + V_4)$$