

- i) $v^+ = v^-$
 - ii) $i^+ = 0$
 - iii) $i^- = 0$
- Ideal
OP-AMP

$$v^+ = v_s - iR = v_s$$

KCL at node x

$$\frac{v_s}{10k} = \frac{v_o - v_s}{10k} \Rightarrow v_s = v_o - v_s \Rightarrow v_o = 2v_s$$

$$\text{or } \frac{v_o}{v_s} = 2$$

At node 1: KCL

$$i_1 = i_2 + i_3$$

$$\frac{9 - v_1}{4k} = \frac{v_1 - v_2}{4k} + \frac{v_1 - v_o}{8k}$$

$$\Rightarrow 18 = 5v_1 - v_o - 2v_2 \quad (1)$$

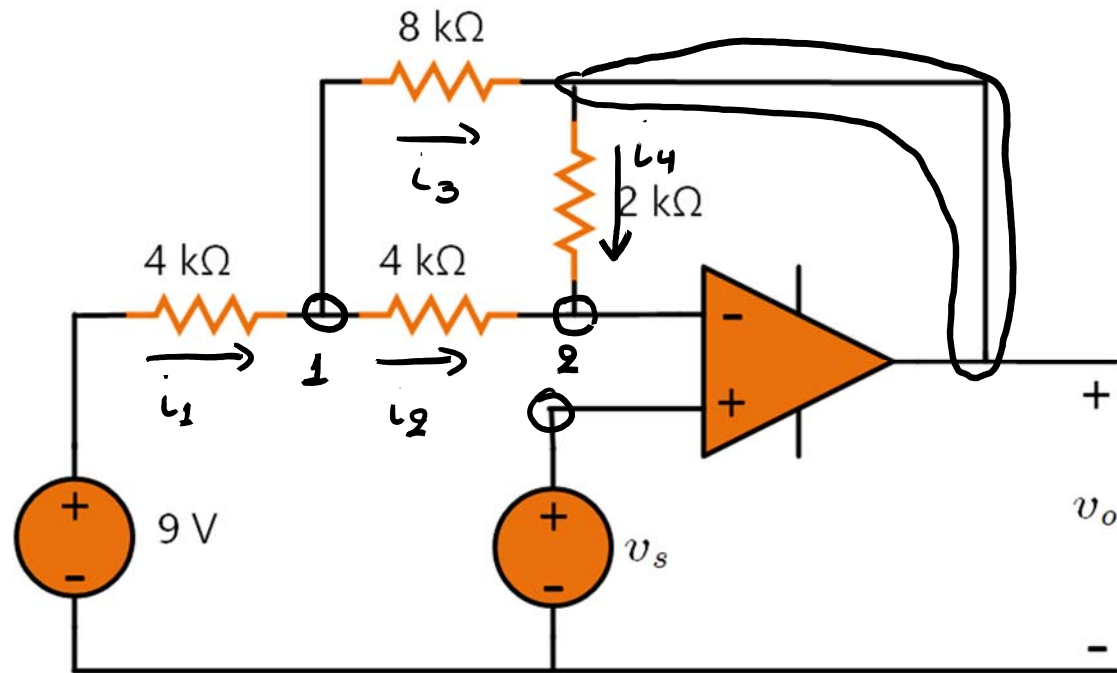
At node 2:

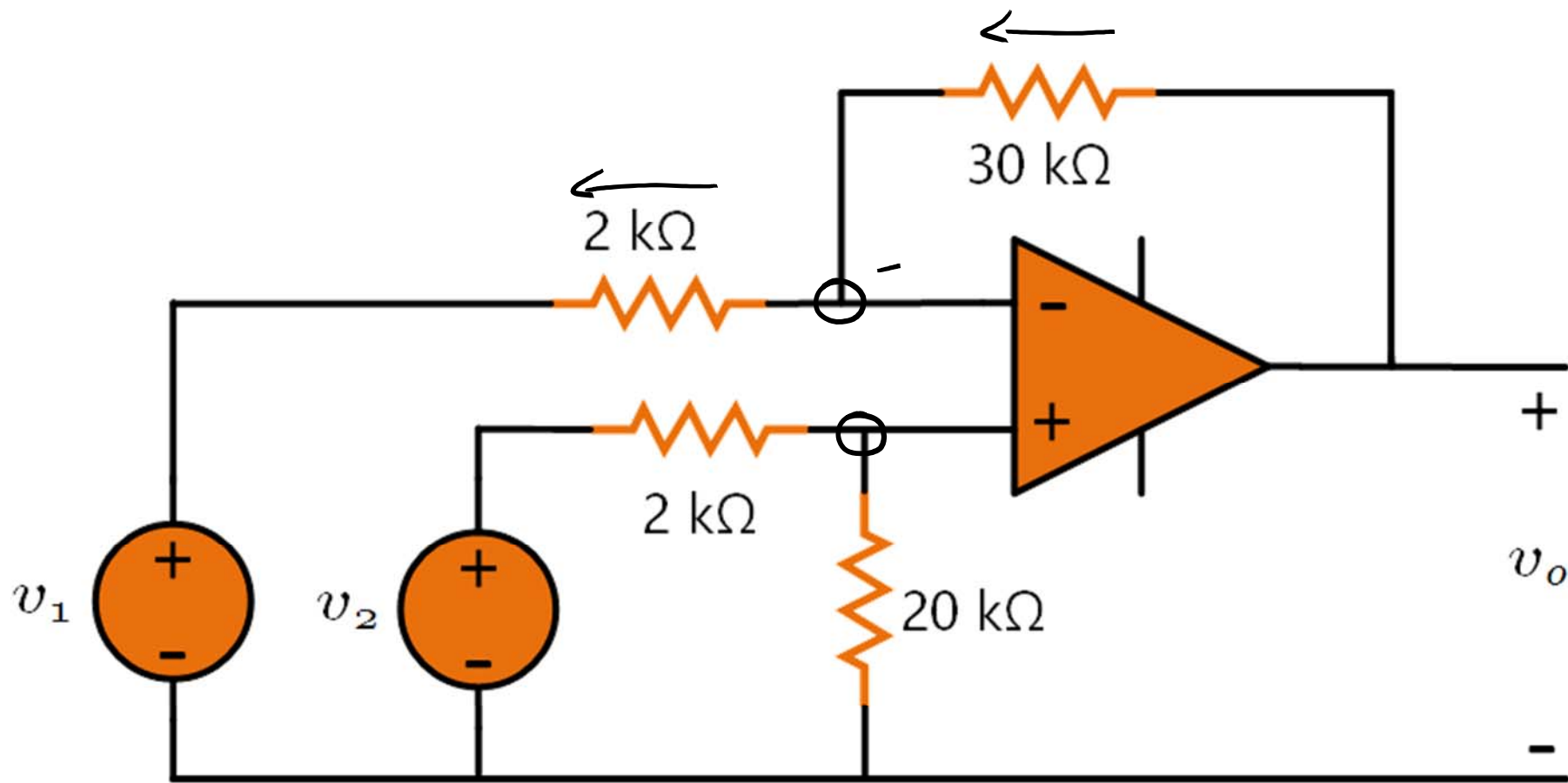
$$i_2 + i_4 = 0 \Rightarrow \frac{v_1 - v_2}{4k} + \frac{v_o - v_2}{2k} = 0 \Rightarrow v_1 = 3v_2 - 2v_o \quad (2)$$

$$v^+ = v^- \Rightarrow v_2 = v_s \quad (3)$$

when $v_s = 5V$ $v_1 = 15 - 2v_o$

$$18 = 75 - 10v_o - v_o - 2 \cdot 5 \Rightarrow -11v_o = -47 \Rightarrow v_o = \frac{47}{11}$$

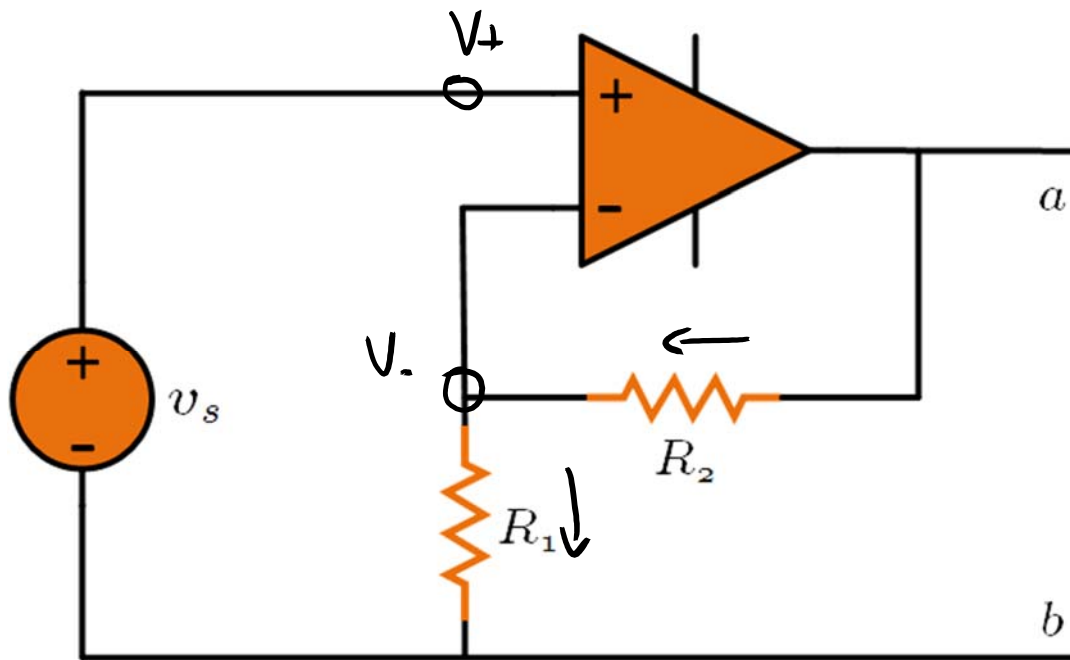




$$V_+ = \frac{20}{20+2} \cdot V_2 = \frac{20}{22} V_2 \quad (1)$$

$$\text{At } (-) \text{ node, KCL: } \frac{V_o - V_-}{30k} = \frac{V_- - V_1}{2k} \Rightarrow V_o - V_- = 15V_- - 15V_1$$

$$\Rightarrow V_o = 16V_- - 15V_1 = \frac{16 \cdot 20}{22} \cdot V_2 - 15V_1$$



$$V_{th} = V_{ob}$$

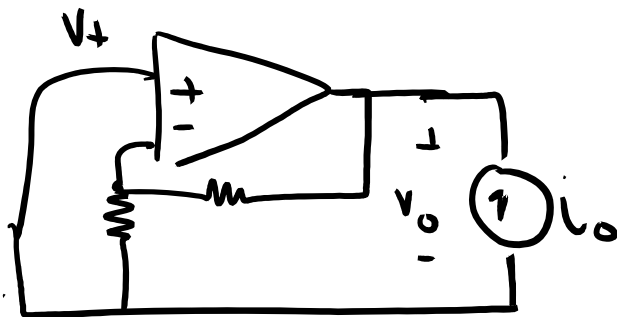
$$V_+ = V_- = V_s$$

$$\frac{V_{ob}}{R_1 + R_2} = \frac{V_s}{R_1} \Rightarrow V_{ob} = \frac{R_1 + R_2}{R_1} \cdot V_s$$

$$V_{th} = \frac{R_1 + R_2}{R_1} \cdot V_s$$

R_{th} → disable voltage source

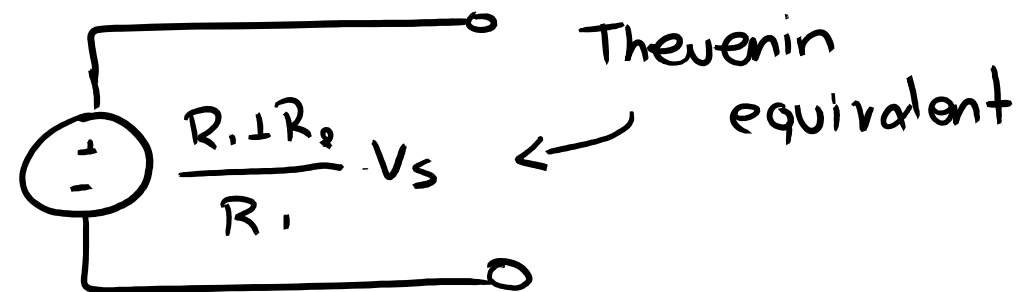
add current source in terminals a-b



$$V_+ = 0 \Rightarrow V_o = 0$$

$$V_- = 0$$

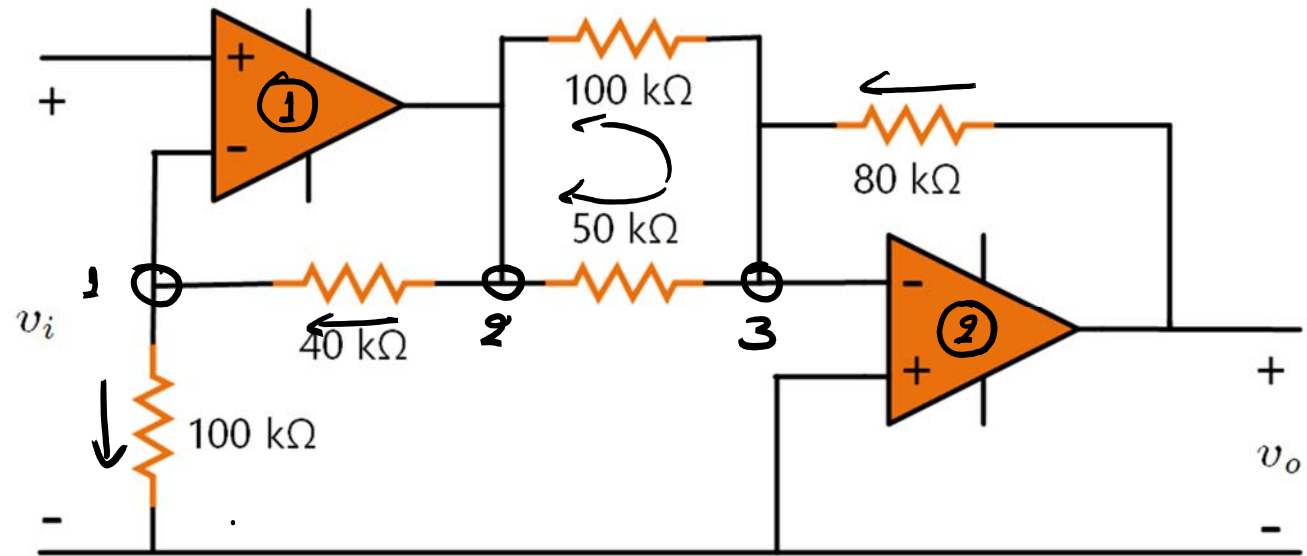
$$R_{th} = \frac{0}{I_o} = 0$$



KCL at node 1
(OPAMP 1)

$$\frac{V_i}{100k} = \frac{V_2 - V_i}{40k}$$

$$\Rightarrow V_2 = \frac{3.5}{2.5} V_i = 1.4 V_i$$



OPAMP 2 $V_+ = V_- \Rightarrow V_3 = 0$

KCL at node 3

$$\frac{V_o - 0}{80k} = \frac{0 - V_2}{50k} + \frac{0 - V_2}{100k} \Rightarrow V_o = -3 \cdot \frac{8}{10} V_2 \Rightarrow V_o = -\frac{3 \cdot 8 \cdot 1.4}{10} V_i$$

$$\Rightarrow V_o = -3.34 V_i$$

$$\underline{\underline{V_o/V_i = -3.34}}$$