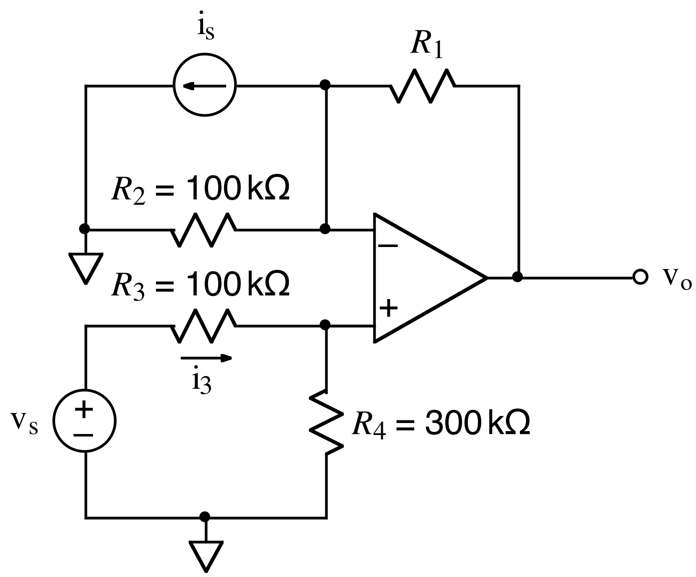
Ex:



a) The above circuit operates in linear mode. Derive a symbolic expression for v_o. The expression must contain not more than the parameters i_s, v_s, R_1, R_2, R_3, and R_4.

b) If $i_s = 0$ A, find the value of R_1 that will yield an output voltage of $v_o = 1$ V when $v_s = 1$ V.

c) Using the value of R_1 from part (b), find the value of i_s that will yield $v_o = 1$ V when $v_s = 0$ V.

d) Using the value of R_1 from part (b), calculate the input resistance, $R_{in} = v_s/i_3$, seen by the v_s source.

Sol'n: a) We use superposition and turn on one independent source at a time.

Case I: v_s on, i_s off

i) Find v_+: Use v-divider
(+ input of op-amp) $v_+ = v_s \dfrac{R_4}{R_3 + R_4}$

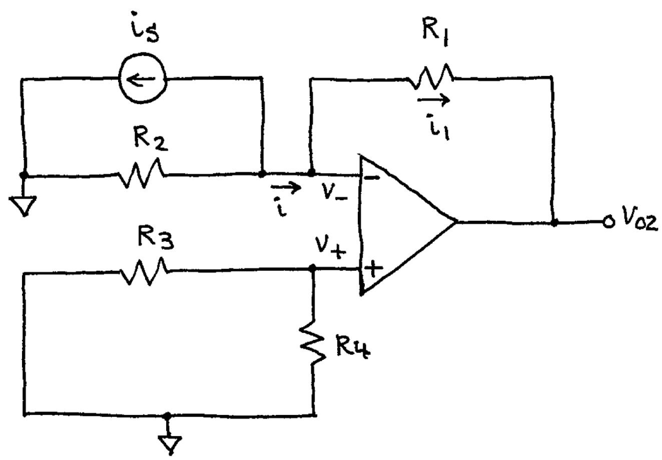
ii) Set $v_- = v_+ = v_s \dfrac{R_4}{R_3 + R_4}$

or $\quad -v_{o1} = -v_-\left(\frac{R_1}{R_2} + 1\right)$

or $\quad v_{o1} = v_-\left(1 + \frac{R_1}{R_2}\right)$

or $\quad v_{o1} = v_s \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_1}{R_2}\right)$

Case II: v_s off, i_s on

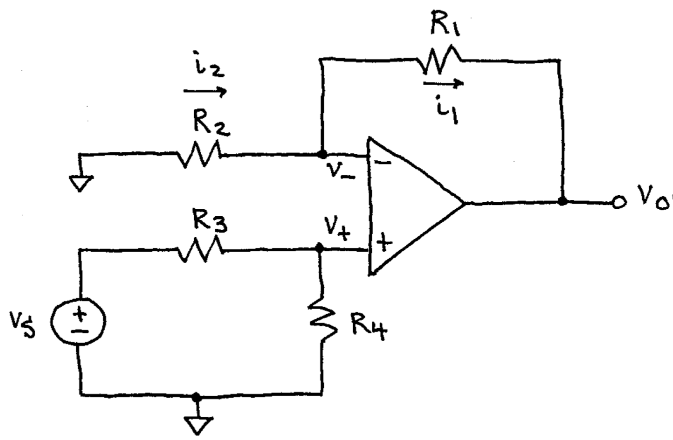


i) Find v_+: $v_+ = 0\text{V}$ since no current in R_3 or R_4

ii) Set $v_- = v_+ = 0\text{V}$

iii) Calculate i flowing toward − input from left. (Note how circuit is drawn to show i as total current on left side.)

$$i = -i_s + \cancelto{0}{\frac{\overset{0\text{V}}{\overset{\shortparallel}{v_-}} - 0\text{V}}{R_2}} = -i_s$$



iii) Calculate current i_2 flowing toward − input from the left. Use node votage v_-.

$$i_2 = \frac{0V - v_-}{R_2} = -\frac{v_S}{R_2}\frac{R_4}{R_3+R_4}$$

iv) Calculate current i_1 flowing in feedback. Use node voltage v_-.

$$i_1 = \frac{v_- - v_{o1}}{R_1} = \frac{v_S \frac{R_4}{R_3+R_4} - v_{o1}}{R_1}$$

v) Since no current flows into the op-amp, set $i_1 = i_2$ and solve for v_{o1}.

$$\frac{v_- - v_{o1}}{R_1} = \frac{-v_-}{R_2}$$

or $v_- - v_{o1} = -v_- \dfrac{R_1}{R_2}$

iv) Calculate i_1 flowing in feedback.

$$i_1 = \frac{v_- - v_{o2}}{R_1} = -\frac{v_{o2}}{R_1}$$

v) Since no current flows into op-amp, set $i = i_1$. Then solve for v_{o2}.

$$i = -i_s = \frac{-v_{o2}}{R_1} = i_1$$

$$\text{or} \quad v_{o2} = i_s R_1$$

Sum v_{o1} and v_{o2} to find v_o:

$$v_o = v_{o1} + v_{o2} = v_s \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_1}{R_2}\right) + i_s R_1$$

b) $i_s = 0\,A$ and $v_o = 1\,V$ for $v_s = 1V$:

$$v_o = 1V = v_s \frac{R_4}{R_3 + R_4}\left(1 + \frac{R_1}{R_2}\right)$$

$$1V = 1V \frac{300\,k\Omega}{100\,k\Omega + 300\,k\Omega}\left(1 + \frac{R_1}{100\,k\Omega}\right)$$

$$\text{or} \quad 1 = \frac{3}{4}\left(1 + \frac{R_1}{100\,k\Omega}\right)$$

$$\text{or} \quad 1 + \frac{R_1}{100\,k\Omega} = \frac{4}{3} \quad \text{or} \quad \frac{R_1}{100\,k\Omega} = \frac{1}{3}$$

or $\quad R_1 = \dfrac{100\,k\Omega}{3} \approx 33\,k\Omega$

c) $\quad v_o = 1\,V$ and $v_s = 0\,V$ with $R_1 = \dfrac{100\,k\Omega}{3}$:

$$v_o = 1\,V = i_s R_1 = i_s \frac{100\,k\Omega}{3}$$

or $\quad i_s = 1\,V \cdot \dfrac{3}{100\,k\Omega} = 30\,\mu A$

d) $$R_{in} = \frac{v_s}{i_3} = \frac{\cancel{v_s}}{\dfrac{\cancel{v_s}}{R_3 + R_4}} = R_3 + R_4$$

$$R_{in} = 100\,k\Omega + 300\,k\Omega = 400\,k\Omega$$