Chapter 5, Solution 1.

(a) R_{in} = **$\underline{1.5\ M\Omega}$**
(b) R_{out} = **$\underline{60\ \Omega}$**
(c) $A = 8x10^4$
Therefore $A_{dB} = 20 \log 8x10^4$ = **$\underline{98.0\ dB}$**

Chapter 5, Solution 2.

$$v_0 = Av_d = A(v_2 - v_1)$$
$$= 10^5\ (20\text{-}10) \times 10^{-6} = \underline{\mathbf{0.1V}}$$

Chapter 5, Solution 3.

$$v_0 = Av_d = A(v_2 - v_1)$$
$$= 2 \times 10^5\ (30 + 20) \times 10^{-6} = \underline{\mathbf{10V}}$$

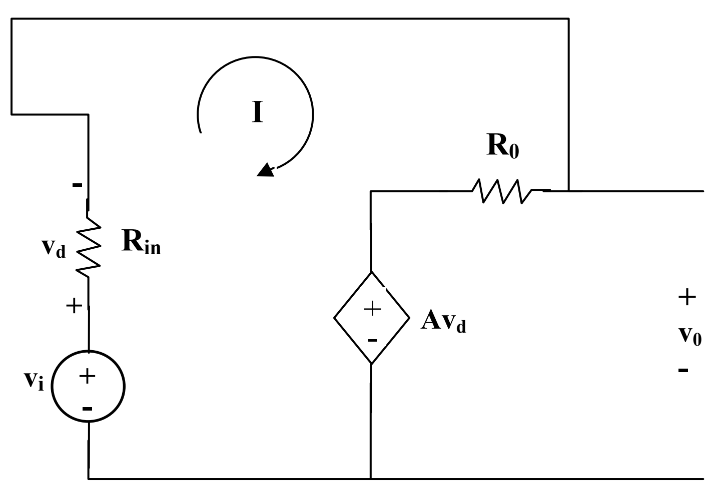
Chapter 5, Solution 4.

$$v_0 = Av_d = A(v_2 - v_1)$$
$$v_2 - v_1 = \frac{v_0}{A} = \frac{-4}{2x10^5} = -20\mu V$$

If v_1 and v_2 are in mV, then

$v_2 - v_1 = -20\ mV = 0.02$
$1 - v_1 = -0.02$
v_1 = **$\underline{1.02\ mV}$**

Chapter 5, Solution 5.



$$-v_i + Av_d + (R_i - R_0)\, I = 0 \qquad (1)$$

But $\quad v_d = R_iI,$

$$-v_i + (R_i + R_0 + R_iA)\, I = 0$$

$$v_d = \frac{v_iR_i}{R_0 + (1 + A)R_i} \qquad (2)$$

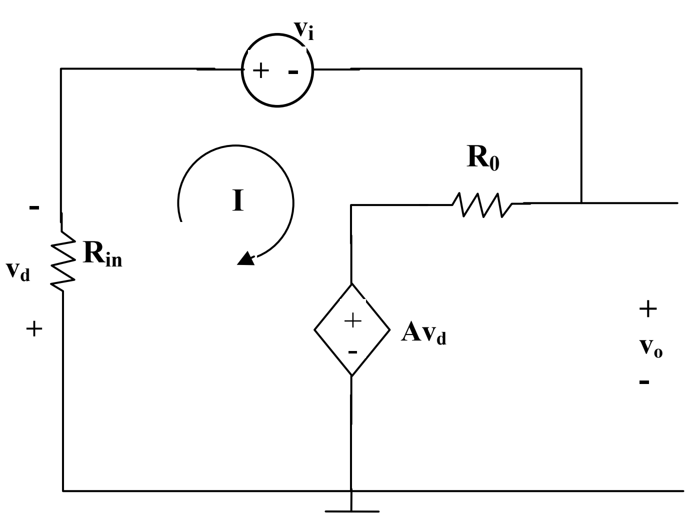
$$-Av_d - R_0I + v_0 = 0$$

$$v_0 = Av_d + R_0I = (R_0 + R_iA)I \quad = \frac{(R_0 + R_iA)v_i}{R_0 + (1 + A)R_i}$$

$$\frac{v_0}{v_i} = \frac{R_0 + R_iA}{R_0 + (1 + A)R_i} = \frac{100 + 10^4 x10^5}{100 + (1 + 10^5)} \cdot 10^4$$

$$\cong \frac{10^9}{\left(1 + 10^5\right)} \cdot 10^4 = \frac{100{,}000}{100{,}001} = \underline{\mathbf{0.9999990}}$$

Chapter 5, Solution 6.



$(R_0 + R_i)R + v_i + Av_d = 0$

But $v_d = R_iI$,

$v_i + (R_0 + R_i + R_iA)I = 0$

$$I = \frac{-v_i}{R_0 + (1+A)R_i} \qquad (1)$$

$-Av_d - R_0I + v_o = 0$

$v_o = Av_d + R_0I = (R_0 + R_iA)I$

Substituting for I in (1),

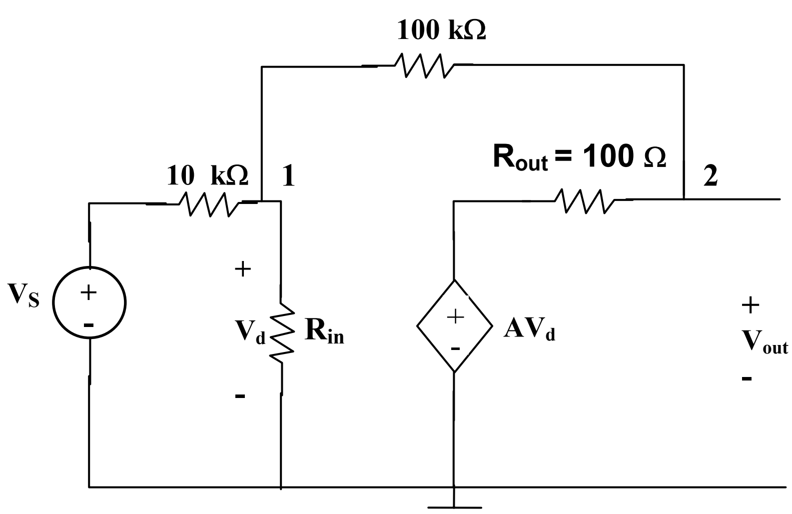
$$v_0 = -\left(\frac{R_0 + R_iA}{R_0 + (1+A)R_i}\right)v_i$$

$$= -\frac{\left(50 + 2x10^6 x2x10^5\right)\cdot 10^{-3}}{50 + \left(1 + 2x10^5\right)x2x10^6}$$

$$\cong \frac{-200{,}000x2x10^6}{200{,}001x2x10^6}\text{mV}$$

$v_0 =$ **-0.999995 mV**

Chapter 5, Solution 7.



At node 1, $(V_S - V_1)/10\text{ k} = [V_1/100\text{ k}] + [(V_1 - V_0)/100\text{ k}]$

$10\,V_S - 10\,V_1 = V_1 + V_1 - V_0$

which leads to $V_1 = (10V_S + V_0)/12$

At node 2, $(V_1 - V_0)/100\text{ k} = (V_0 - AV_d)/100$

But $V_d = V_1$ and $A = 100{,}000$,

$V_1 - V_0 = 1000\,(V_0 - 100{,}000V_1)$

$0 = 1001V_0 - 100{,}000{,}001[(10V_S + V_0)/12]$

$0 = -83{,}333{,}334.17\,V_S - 8{,}332{,}333.42\,V_0$

which gives us $(V_0/V_S) = -10$ (for all practical purposes)

If $V_S = 1$ mV, then $V_0 =$ **-10 mV**

Since $V_0 = A\,V_d = 100{,}000\,V_d$, then $V_d = (V_0/10^5)$ V = **-100 nV**

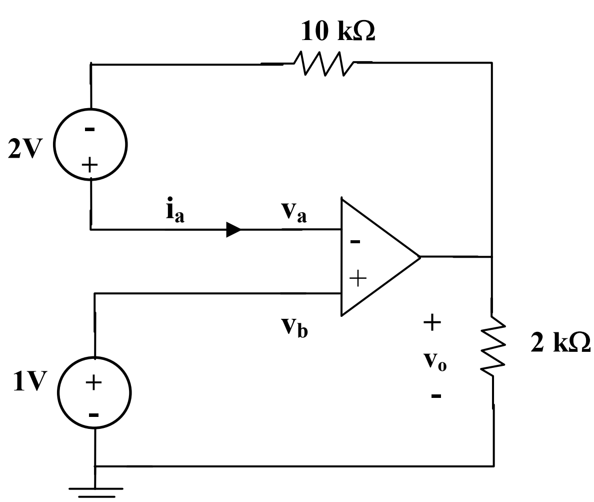
Chapter 5, Solution 8.

(a) If v_a and v_b are the voltages at the inverting and noninverting terminals of the op amp.

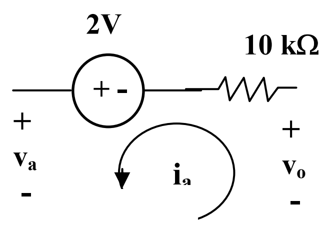
$v_a = v_b = 0$

$$1\text{mA} = \frac{0 - v_0}{2k} \longrightarrow v_0 = \mathbf{-2V}$$

(b)



(a)



(b)

Since $v_a = v_b = 1V$ and $i_a = 0$, no current flows through the 10 kΩ resistor. From Fig. (b),

$$-v_a + 2 + v_0 = 0 \longrightarrow v_a = v_a - 2 = 1 - 2 = \underline{\mathbf{-1V}}$$

Chapter 5, Solution 9.

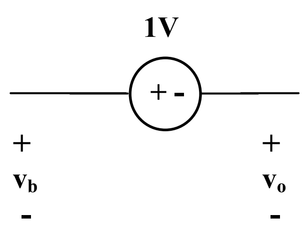
(a) Let v_a and v_b be respectively the voltages at the inverting and noninverting terminals of the op amp

$$v_a = v_b = 4V$$

At the inverting terminal,

$$1mA = \frac{4 - v_0}{2k} \longrightarrow v_0 = \underline{\mathbf{2V}}$$

(b)



Since $v_a = v_b = 3V$,

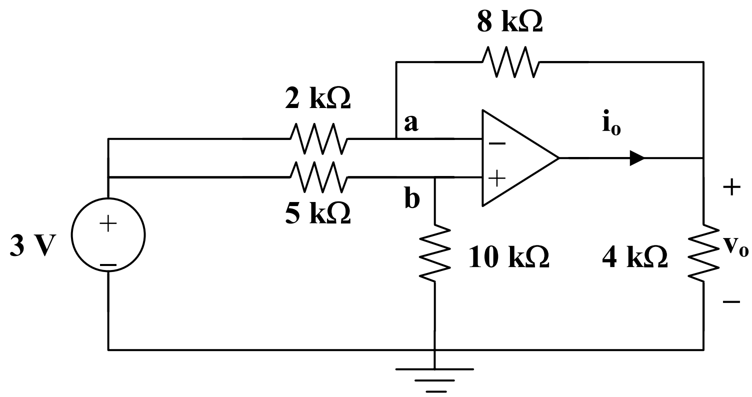
$$-v_b + 1 + v_o = 0 \longrightarrow v_o = v_b - 1 = \underline{\mathbf{2V}}$$

Chapter 5, Solution 10.

Since no current enters the op amp, the voltage at the input of the op amp is v_s. Hence

$$v_s = v_o\left(\frac{10}{10+10}\right) = \frac{v_o}{2} \longrightarrow \frac{v_o}{v_s} = \underline{\mathbf{2}}$$

Chapter 5, Solution 11.



$$v_b = \frac{10}{10+5}(3) = 2V$$

At node a,

$$\frac{3 - v_a}{2} = \frac{v_a - v_o}{8} \longrightarrow 12 = 5v_a - v_o$$

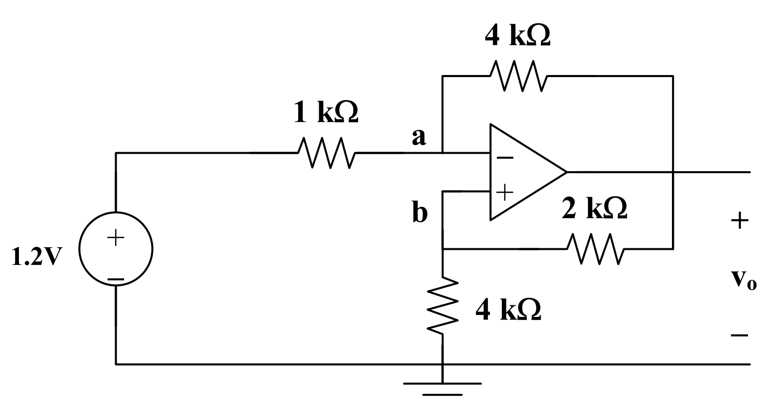
But $v_a = v_b = 2V$,

$$12 = 10 - v_o \longrightarrow v_o = \underline{\mathbf{-2V}}$$

$$-i_o = \frac{v_a - v_o}{8} + \frac{0 - v_o}{4} = \frac{2+2}{8} + \frac{2}{4} = 1mA$$

$$i_o = \underline{\mathbf{-1mA}}$$

Chapter 5, Solution 12.



At node b, $v_b = \frac{4}{4+2}v_o = \frac{2}{3}v_o = \frac{2}{3}v_o$

At node a, $\frac{1.2 - v_a}{1} = \frac{v_a - v_o}{4}$, but $v_a = v_b = \frac{2}{3}v_o$

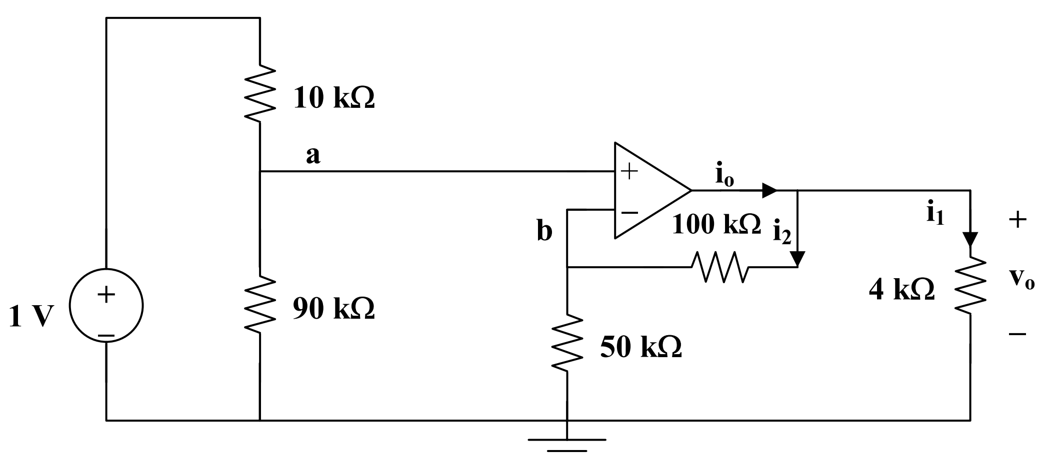
$$4.8 - 4 \text{ x } \frac{2}{3}v_o = \frac{2}{3}v_o - v_o \longrightarrow v_o = \frac{3x4.8}{7} = 2.0570\text{V}$$

$$v_a = v_b = \frac{2}{3}v_o = \frac{9.6}{7}$$

$$i_s = \frac{1.2 - v_a}{1} = \frac{-1.2}{7}$$

$$p = v_s i_s = 1.2\left(\frac{-1.2}{7}\right) = \underline{\mathbf{-205.7\ mW}}$$

Chapter 5, Solution 13.



By voltage division,

$$v_a = \frac{90}{100}(1) = 0.9\text{V}$$

$$v_b = \frac{50}{150}v_o = \frac{v_o}{3}$$

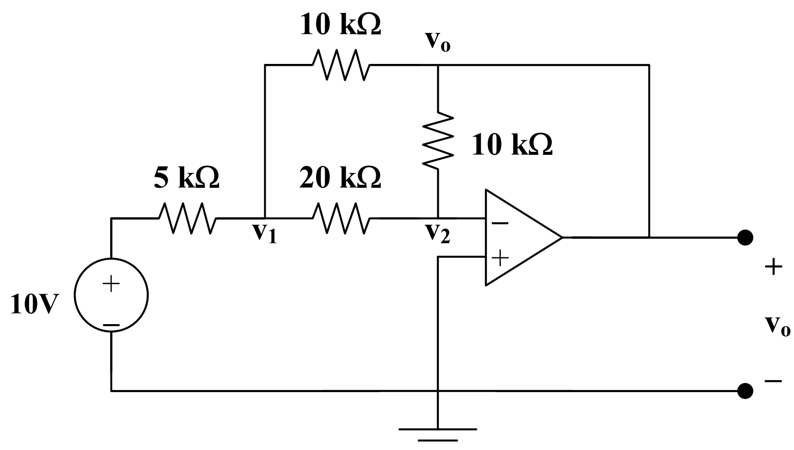
But $v_a = v_b \longrightarrow \frac{v_0}{3} = 0.9 \longrightarrow v_o = \underline{\mathbf{2.7V}}$

$$i_o = i_1 + i_2 = \frac{v_o}{10k} + \frac{v_o}{150k} = 0.27\text{mA} + 0.018\text{mA} = \underline{\mathbf{288\ \mu A}}$$

Chapter 5, Solution 14.

Transform the current source as shown below. At node 1,

$$\frac{10 - v_1}{5} = \frac{v_1 - v_2}{20} + \frac{v_1 - v_o}{10}$$



But $v_2 = 0$. Hence $40 - 4v_1 = v_1 + 2v_1 - 2v_o \longrightarrow 40 = 7v_1 - 2v_o$ (1)

At node 2, $\frac{v_1 - v_2}{20} = \frac{v_2 - v_o}{10}$, $v_2 = 0$ or $v_1 = -2v_o$ (2)

From (1) and (2), $40 = -14v_o - 2v_o \longrightarrow v_o = \underline{\mathbf{-2.5V}}$

Chapter 5, Solution 15

(a) Let v_1 be the voltage at the node where the three resistors meet. Applying KCL at this node gives

$$i_s = \frac{v_1}{R_2} + \frac{v_1 - v_o}{R_3} = v_1\left(\frac{1}{R_2} + \frac{1}{R_3}\right) - \frac{v_o}{R_3} \qquad (1)$$

At the inverting terminal,

$$i_s = \frac{0 - v_1}{R_1} \longrightarrow v_1 = -i_s R_1 \qquad (2)$$

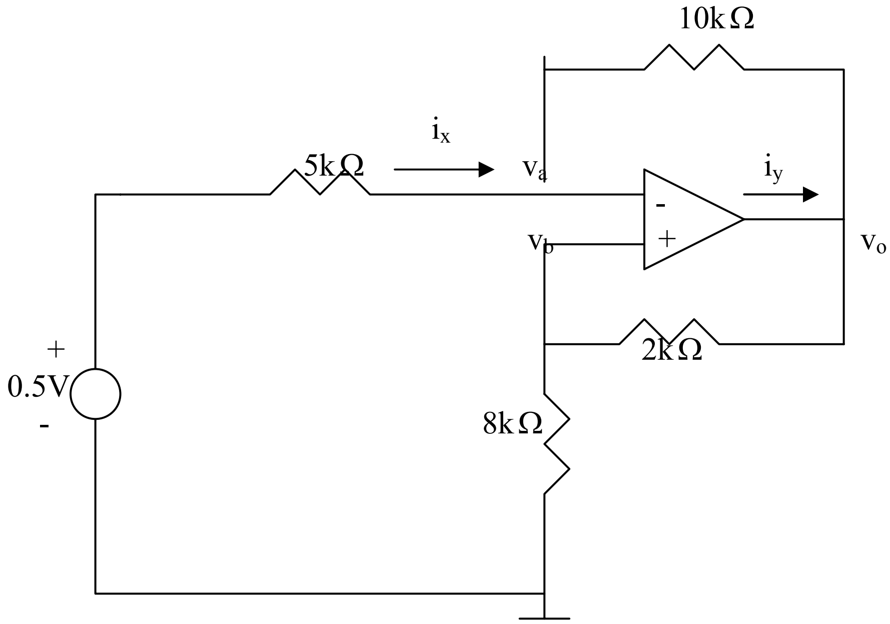
Combining (1) and (2) leads to

$$i_s\left(1 + \frac{R_1}{R_2} + \frac{R_1}{R_3}\right) = -\frac{v_o}{R_3} \longrightarrow \underline{\frac{v_o}{i_s} = -\left(R_1 + R_3 + \frac{R_1 R_3}{R_2}\right)}$$

(b) For this case,

$$\frac{v_o}{i_s} = -\left(20 + 40 + \frac{20x40}{25}\right)\text{k}\Omega = \underline{-92\text{ k}\Omega}$$

Chapter 5, Solution 16



Let currents be in mA and resistances be in kΩ. At node a,

$$\frac{0.5 - v_a}{5} = \frac{v_a - v_o}{10} \longrightarrow 1 = 3v_a - v_o \qquad (1)$$

But

$$v_a = v_b = \frac{8}{8+2}v_o \longrightarrow v_o = \frac{10}{8}v_a \qquad (2)$$

Substituting (2) into (1) gives

$$1 = 3v_a - \frac{10}{8}v_a \longrightarrow v_a = \frac{8}{14}$$

Thus,

$$i_x = \frac{0.5 - v_a}{5} = -1/70 \text{ mA} = \underline{-14.28\ \mu\text{A}}$$

$$i_y = \frac{v_o - v_b}{2} + \frac{v_o - v_a}{10} = 0.6(v_o - v_a) = 0.6(\frac{10}{8}v_a - v_a) = \frac{0.6}{4}x\frac{8}{14} \text{ mA} = \underline{85.71\ \mu\text{A}}$$

Chapter 5, Solution 17.

(a) $G = \frac{v_o}{v_i} = -\frac{R_2}{R_1} = -\frac{12}{5} = \underline{\mathbf{-2.4}}$

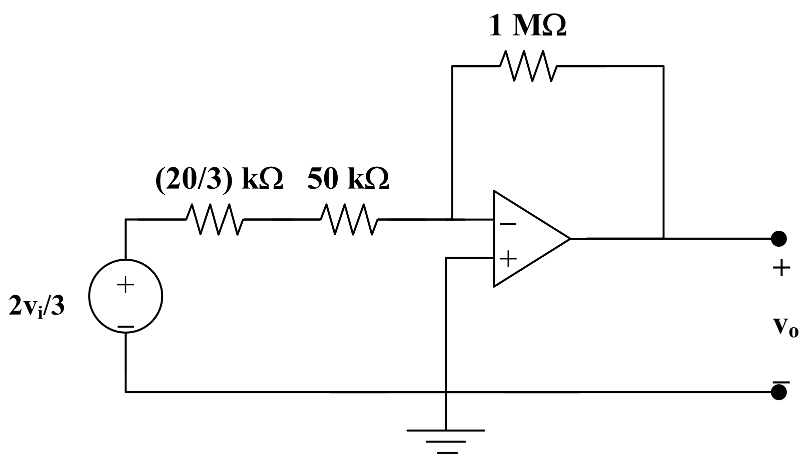
(b) $\frac{v_o}{v_i} = -\frac{80}{5} = \underline{\mathbf{-16}}$

(c) $\frac{v_o}{v_i} = -\frac{2000}{5} = \underline{\mathbf{-400}}$

Chapter 5, Solution 18.

Converting the voltage source to current source and back to a voltage source, we have the circuit shown below:

$$10\|20 = \frac{20}{3}\ \text{k}\Omega$$

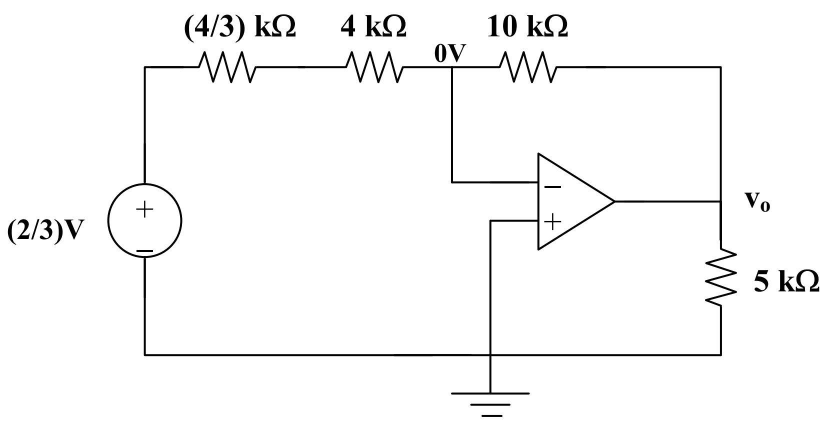


$$v_o = -\frac{1000}{50+\frac{20}{3}}\cdot\frac{2v_i}{3} \longrightarrow \frac{v_o}{v_1} = -\frac{200}{17} = \underline{\mathbf{-11.764}}$$

Chapter 5, Solution 19.

We convert the current source and back to a voltage source.

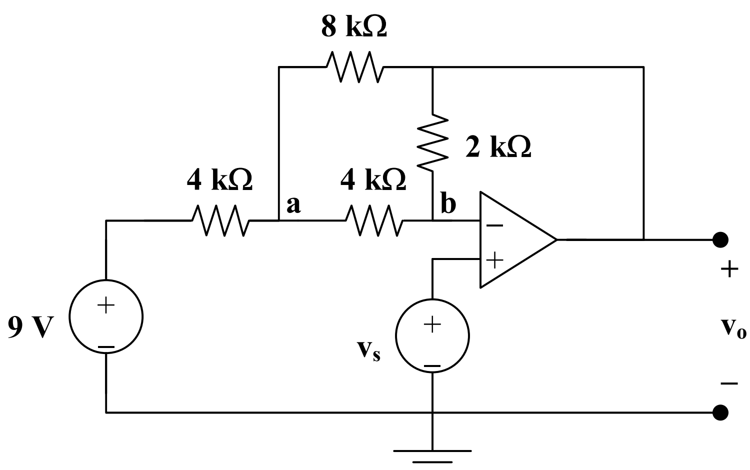
$$2\|4 = \frac{4}{3}$$



$$v_o = -\frac{10k}{\left(4x\frac{4}{3}\right)k}\left(\frac{2}{3}\right) = -1.25V$$

$$i_o = \frac{v_o}{5k} + \frac{v_o - 0}{10k} = \underline{\mathbf{-0.375mA}}$$

Chapter 5, Solution 20.



At node a,

$$\frac{9 - v_a}{4} = \frac{v_a - v_o}{8} + \frac{v_a - v_b}{4} \longrightarrow 18 = 5v_a - v_o - 2v_b \qquad (1)$$

At node b,

$$\frac{v_a - v_b}{4} = \frac{v_b - v_o}{2} \longrightarrow v_a = 3v_b - 2v_o \qquad (2)$$

But $v_b = v_s = 0$; (2) becomes $v_a = -2v_o$ and (1) becomes

$$-18 = -10v_o - v_o \longrightarrow v_o = -18/(11) = \underline{\mathbf{-1.6364V}}$$

Chapter 5, Solution 21.

Eqs. (1) and (2) remain the same. When $v_b = v_s = 3V$, eq. (2) becomes

$$v_a = 3 \times 3 - 2v_0 = 9 - 2v_o$$

Substituting this into (1), $18 = 5\,(9\text{-}2v_o) - v_o - 6$ leads to

$$v_o = 21/(11) = \underline{\mathbf{1.909V}}$$

Chapter 5, Solution 22.

$A_v = -R_f/R_i = -15.$

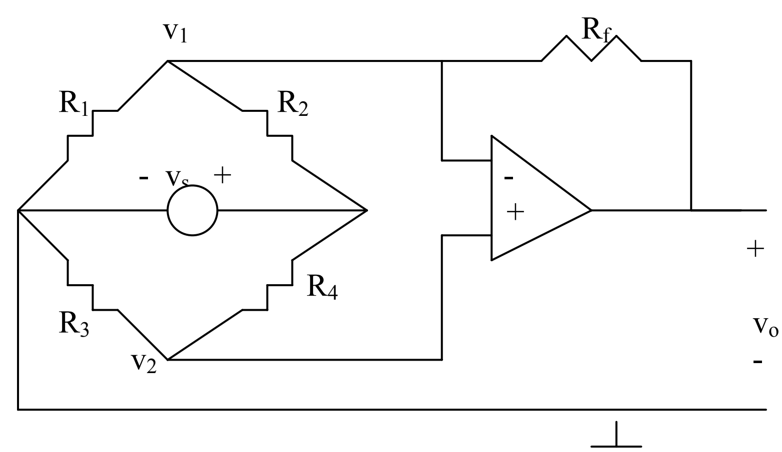
If $R_i = 10\text{k}\Omega$, then $R_f = \underline{\mathbf{150\ k\Omega.}}$

Chapter 5, Solution 23

At the inverting terminal, v=0 so that KCL gives

$$\frac{v_s - 0}{R_1} = \frac{0}{R_2} + \frac{0 - v_o}{R_f} \quad \longrightarrow \quad \underline{\frac{v_o}{v_s} = -\frac{R_f}{R_1}}$$

Chapter 5, Solution 24



We notice that $v_1 = v_2$. Applying KCL at node 1 gives

$$\frac{v_1}{R_1} + \frac{(v_1 - v_s)}{R_2} + \frac{v_1 - v_o}{R_f} = 0 \quad \longrightarrow \quad \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_f}\right)v_1 - \frac{v_s}{R_2} = \frac{v_o}{R_f} \qquad (1)$$

Applying KCL at node 2 gives

$$\frac{v_1}{R_3} + \frac{v_1 - v_s}{R_4} = 0 \qquad \longrightarrow \qquad v_1 = \frac{R_3}{R_3 + R_4} v_s \qquad (2)$$

Substituting (2) into (1) yields

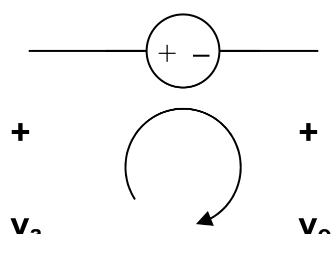
$$v_o = R_f \left[\left(\frac{R_3}{R_1} + \frac{R_3}{R_f} - \frac{R_4}{R_2} \right) \left(\frac{R_3}{R_3 + R_4} \right) - \frac{1}{R_2} \right] v_s$$

i.e.

$$\underline{k = R_f \left[\left(\frac{R_3}{R_1} + \frac{R_3}{R_f} - \frac{R_4}{R_2} \right) \left(\frac{R_3}{R_3 + R_4} \right) - \frac{1}{R_2} \right]}$$

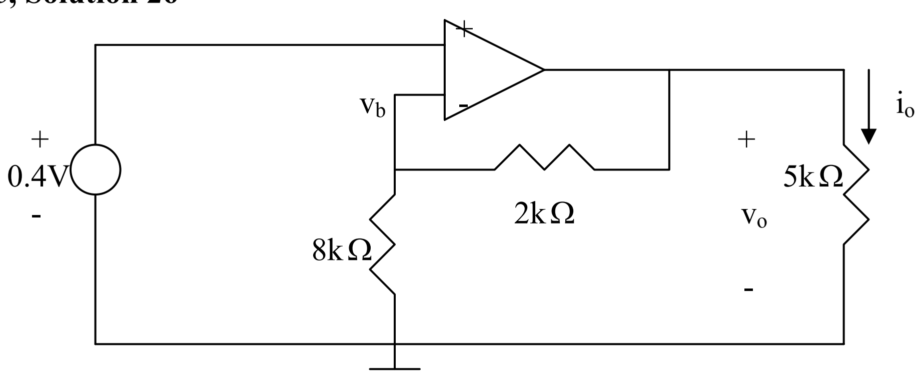
Chapter 5, Solution 25.

v_o = **2 V**



$-v_a + 3 + v_o = 0$ which leads to $v_a = v_o + 3 = \underline{\mathbf{5\ V}}$.

Chapter 5, Solution 26



$$v_b = 0.4 = \frac{8}{8+2} v_o = 0.8 v_o \qquad \longrightarrow \qquad v_o = 0.4/0.8 = 0.5\,\text{V}$$

Hence,

$$i_o = \frac{v_o}{5k} = \frac{0.5}{5k} = \underline{0.1\,\text{mA}}$$

Chapter 5, Solution 27.

(a) Let v_a be the voltage at the noninverting terminal.

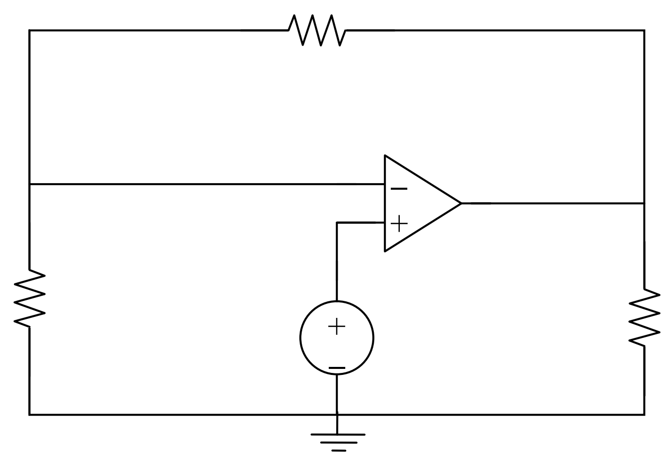
$v_a = 2/(8+2)\ v_i = 0.2v_i$

$$v_0 = \left(1 + \frac{1000}{20}\right)v_a = 10.2v_i$$

$G = v_0/(v_i) = \underline{\mathbf{10.2}}$

(b) $v_i = v_0/(G) = 15/(10.2) \cos 120\pi t = \underline{\mathbf{1.471 \cos 120\pi t\ V}}$

Chapter 5, Solution 28.



At node 1, $\frac{0 - v_1}{10k} = \frac{v_1 - v_o}{50k}$

But $v_1 = 0.4V$,

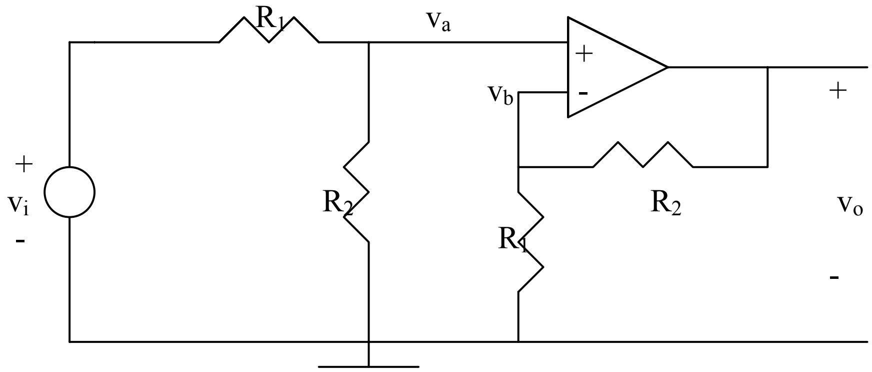
$-5v_1 = v_1 - v_o$, leads to $v_o = 6v_1 = \underline{\mathbf{2.4V}}$

Alternatively, viewed as a noninverting amplifier,

$v_o = (1 + (50/10))\ (0.4V) = \underline{\mathbf{2.4V}}$

$i_o = v_o/(20k) = 2.4/(20k) = \underline{\mathbf{120\ \mu A}}$

Chapter 5, Solution 29



$$v_a = \frac{R_2}{R_1 + R_2} v_i, \qquad v_b = \frac{R_1}{R_1 + R_2} v_o$$

But $v_a = v_b$ $\longrightarrow$ $\frac{R_2}{R_1 + R_2} v_i = \frac{R_1}{R_1 + R_2} v_o$

Or

$$\underline{\frac{v_o}{v_i} = \frac{R_2}{R_1}}$$

Chapter 5, Solution 30.

The output of the voltage becomes

$v_o = v_i = 12$

$30 \| 20 = 12\text{k}\Omega$

By voltage division,

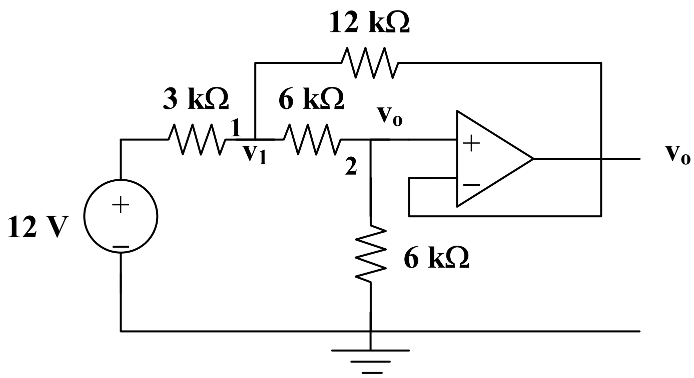
$$v_x = \frac{12}{12 + 60}(1.2) = 0.2\text{V}$$

$$i_x = \frac{v_x}{20\text{k}} = \frac{0.2}{20\text{k}} = \underline{\mathbf{10\mu A}}$$

$$p = \frac{v_x^2}{R} = \frac{0.04}{20\text{k}} = \underline{\mathbf{2\mu W}}$$

Chapter 5, Solution 31.

After converting the current source to a voltage source, the circuit is as shown below:



At node 1,

$$\frac{12 - v_1}{3} = \frac{v_1 - v_o}{6} + \frac{v_1 - v_o}{12} \longrightarrow 48 = 7v_1 - 3v_o \qquad (1)$$

At node 2,

$$\frac{v_1 - v_o}{6} = \frac{v_o - 0}{6} = i_x \longrightarrow v_1 = 2v_o \qquad (2)$$

From (1) and (2),

$$v_o = \frac{48}{11}$$

$$i_x = \frac{v_o}{6k} = \underline{\mathbf{0.7272mA}}$$

Chapter 5, Solution 32.

Let v_x = the voltage at the output of the op amp. The given circuit is a non-inverting amplifier.

$$v_x = \left(1 + \frac{50}{10}\right)(4 \text{ mV}) = 24 \text{ mV}$$

$$60 \| 30 = 20k\Omega$$

By voltage division,

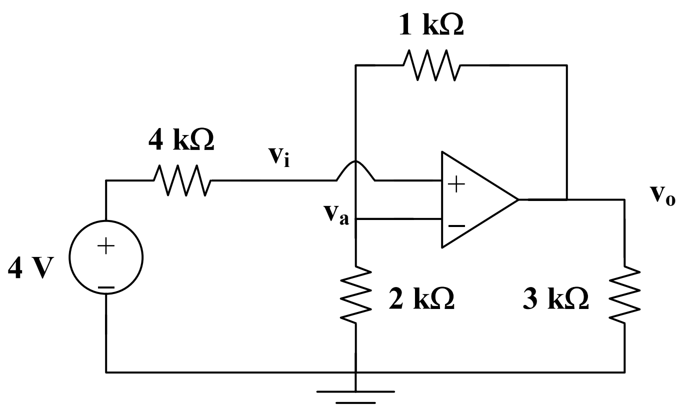
$$v_o = \frac{20}{20+20} v_o = \frac{v_o}{2} = 12\text{mV}$$

$$i_x = \frac{v_x}{(20+20)k} = \frac{24\text{mV}}{40k} = \underline{\mathbf{600nA}}$$

$$p = \frac{v_o^2}{R} = \frac{144x10^{-6}}{60x10^3} = \underline{\mathbf{204nW}}$$

Chapter 5, Solution 33.

After transforming the current source, the current is as shown below:



This is a noninverting amplifier.

$$v_o = \left(1 + \frac{1}{2}\right) v_i = \frac{3}{2} v_i$$

Since the current entering the op amp is 0, the source resistor has a OV potential drop. Hence v_i = 4V.

$$v_o = \frac{3}{2}(4) = 6\text{V}$$

Power dissipated by the 3kΩ resistor is

$$\frac{v_o^2}{R} = \frac{36}{3k} = \underline{\mathbf{12mW}}$$

$$i_x = \frac{v_a - v_o}{R} = \frac{4-6}{1k} = \underline{\mathbf{-2mA}}$$

Chapter 5, Solution 34

$$\frac{v_1 - v_{in}}{R_1} + \frac{v_1 - v_{in}}{R_2} = 0 \qquad (1)$$

but

$$v_a = \frac{R_3}{R_3 + R_4} v_o \qquad (2)$$

Combining (1) and (2),

$$v_1 - v_a + \frac{R_1}{R_2} v_2 - \frac{R_1}{R_2} v_a = 0$$

$$v_a\left(1 + \frac{R_1}{R_2}\right) = v_1 + \frac{R_1}{R_2} v_2$$

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

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

$$\underline{v_O = \frac{R_3 + R_4}{R_3(R_1 + R_2)}(v_1 R_2 + v_2)}$$

Chapter 5, Solution 35.

$$A_v = \frac{v_o}{v_i} = 1 + \frac{R_f}{R_i} = 10 \longrightarrow R_f = 9R_i$$

If R_i = **<u>10kΩ</u>**, R_f = **<u>90kΩ</u>**

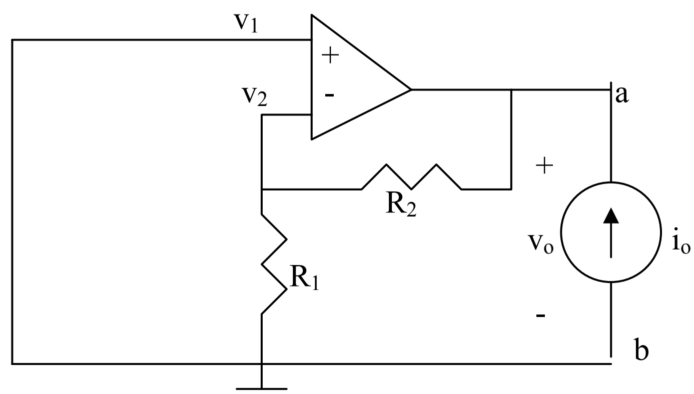
Chapter 5, Solution 36

$$V_{Th} = V_{ab}$$

But $v_s = \frac{R_1}{R_1 + R_2} V_{ab}$. Thus,

$$V_{Th} = V_{ab} = \frac{R_1 + R_2}{R_1} v_s = \underline{(1 + \frac{R_2}{R_1}) v_s}$$

To get R_{Th}, apply a current source I_o at terminals a-b as shown below.



Since the noninverting terminal is connected to ground, $v_1 = v_2 = 0$, i.e. no current passes through R_1 and consequently R_2. Thus, v_o=0 and

$$\underline{R_{Th} = \frac{v_o}{i_o} = 0}$$

Chapter 5, Solution 37.

$$v_o = -\left[\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \frac{R_f}{R_3} v_3\right]$$

$$= -\left[\frac{30}{10}(1) + \frac{30}{20}(2) + \frac{30}{30}(-3)\right]$$

v_o = **<u>-3V</u>**

Chapter 5, Solution 38.

$$v_o = -\left[\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3 + \frac{R_f}{R_4}v_4\right]$$

$$= -\left[\frac{50}{25}(10) + \frac{50}{20}(-20) + \frac{50}{10}(50) + \frac{50}{50}(-100)\right]$$

$= \underline{\textbf{-120mV}}$

Chapter 5, Solution 39

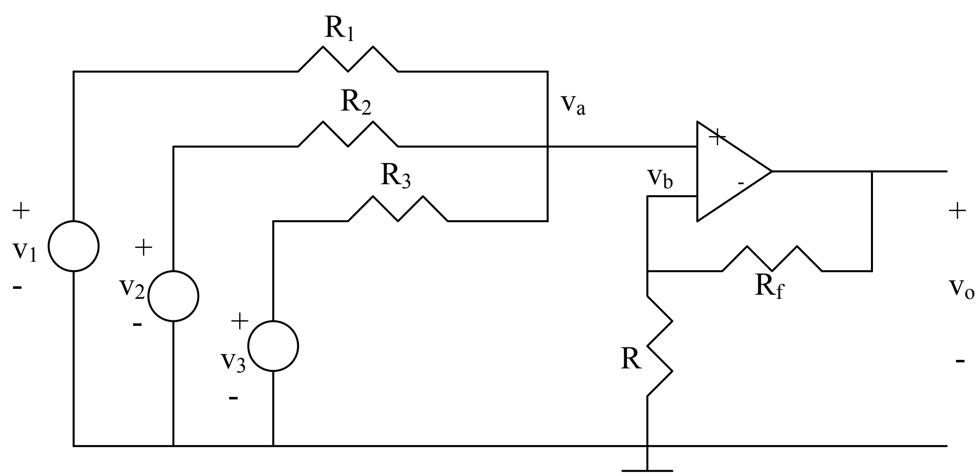
This is a summing amplifier.

$$v_o = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3\right) = -\left(\frac{50}{10}(2) + \frac{50}{20}v_2 + \frac{50}{50}(-1)\right) = -9 - 2.5v_2$$

Thus,

$v_o = -16.5 = -9 - 2.5v_2 \longrightarrow \underline{\quad v_2 = 3\text{ V}}$

Chapter 5, Solution 40



Applying KCL at node a,

$$\frac{v_1 - v_a}{R_1} + \frac{v_2 - v_a}{R_2} + \frac{v_3 - v_a}{R_3} = 0 \longrightarrow \frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} = v_a\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) \quad (1)$$

But

$$v_a = v_b = \frac{R}{R + R_f} v_o \qquad (2)$$

Substituting (2) into (1)gives

$$\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} = \frac{Rv_o}{R + R_f}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

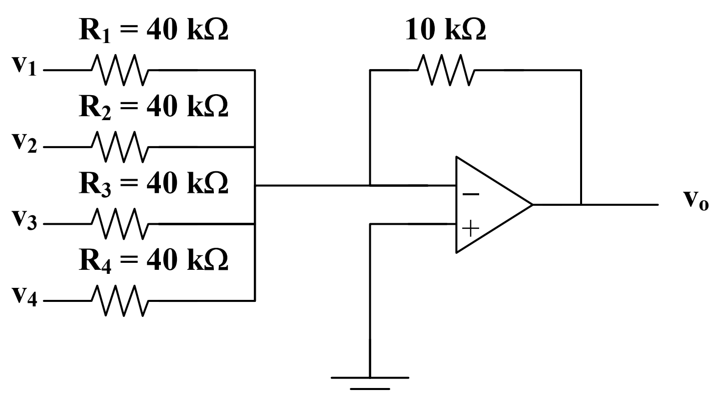
or

$$\underline{v_o = \frac{R + R_f}{R} \left(\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3}\right) / \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

Chapter 5, Solution 41.

$R_f/R_i = 1/(4) \longrightarrow R_i = 4R_f = 40k\Omega$

The averaging amplifier is as shown below:



Chapter 5, Solution 42

$$R_f = \frac{1}{3} R_1 = \underline{10\,k\Omega}$$

Chapter 5, Solution 43.

In order for

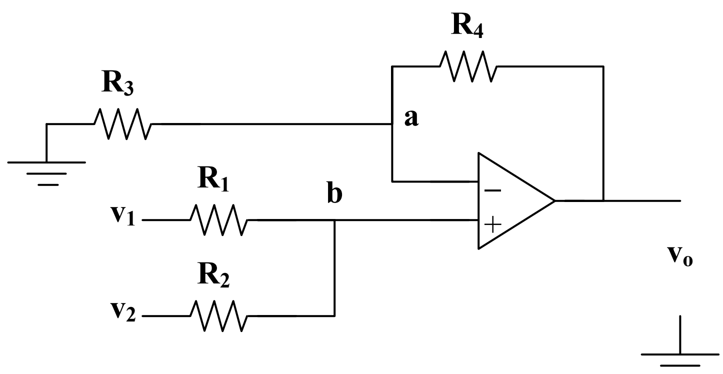
$$v_o = \left(\frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \frac{R_f}{R_3} v_3 + \frac{R_f}{R_4} v_4 \right)$$

to become

$$v_o = -\frac{1}{4}(v_1 + v_2 + v_3 + v_4)$$

$$\frac{R_f}{R_i} = \frac{1}{4} \longrightarrow R_f = \frac{R_i}{4} = \frac{12}{4} = \underline{\mathbf{3k\Omega}}$$

Chapter 5, Solution 44.



At node b, $\frac{v_b - v_1}{R_1} + \frac{v_b - v_2}{R_2} = 0 \longrightarrow v_b = \dfrac{\frac{v_1}{R_1} + \frac{v_2}{R_2}}{\frac{1}{R_1} + \frac{1}{R_2}}$ (1)

At node a, $\frac{0 - v_a}{R_3} = \frac{v_a - v_o}{R_4} \longrightarrow v_a = \frac{v_o}{1 + R_4 / R_3}$ (2)

But $v_a = v_b$. We set (1) and (2) equal.

$$\frac{v_o}{1 + R_4 / R_3} = \frac{R_2 v_1 + R_1 v_1}{R_1 + R_2}$$

or

$$\underline{v_o = \frac{(R_3 + R_4)}{R_3(R_1 + R_2)}(R_2 v_1 + R_1 v_1)}$$

Chapter 5, Solution 45.

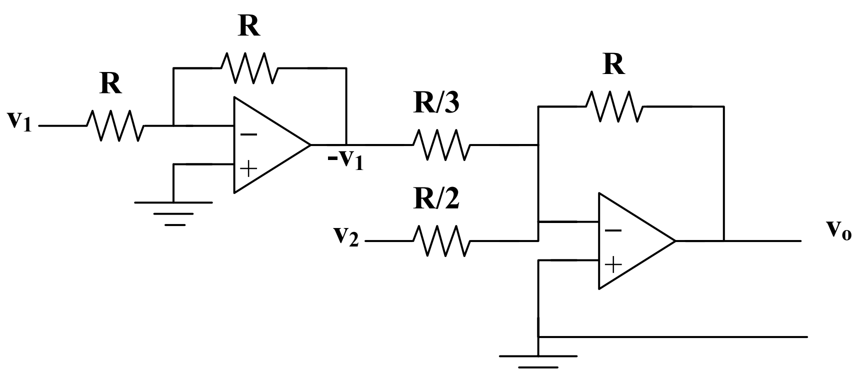
This can be achieved as follows:

$$v_o = -\left[\frac{R}{R/3}(-v_1) + \frac{R}{R/2}v_2\right]$$

$$= -\left[\frac{R_f}{R_1}(-v_1) + \frac{R_f}{R_2}v_2\right]$$

i.e. $R_f = R$, $R_1 = R/3$, and $R_2 = R/2$

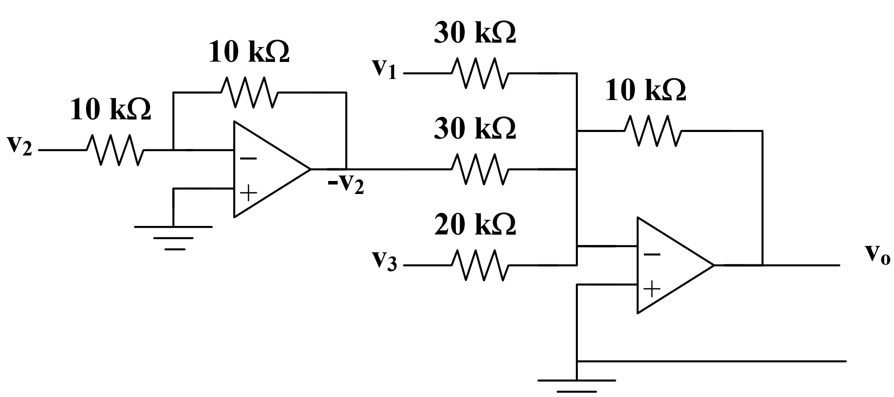
Thus we need an inverter to invert v_1, and a summer, as shown below ($R<100k\Omega$).



Chapter 5, Solution 46.

$$-v_o = \frac{v_1}{3} + \frac{1}{3}(-v_2) + \frac{1}{2}v_3 = \frac{R_f}{R_1}v_1 + \frac{R_x}{R_2}(-v_2) + \frac{R_f}{R_3}v_3$$

i.e. $R_3 = 2R_f$, $R_1 = R_2 = 3R_f$. To get $-v_2$, we need an inverter with $R_f = R_i$. If $R_f = 10k\Omega$, a solution is given below.



Chapter 5, Solution 47.

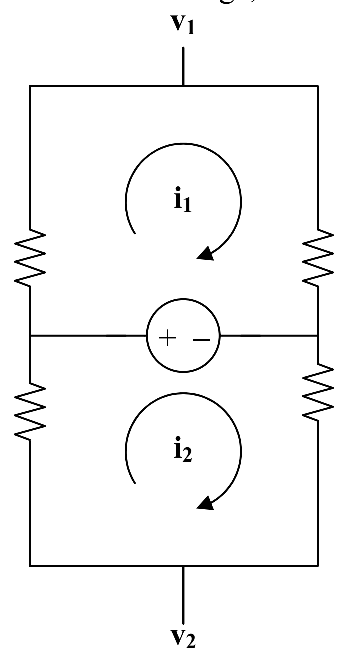
If a is the inverting terminal at the op amp and b is the noninverting terminal, then,

$$v_b = \frac{3}{3+1}(8) = 6V, v_a = v_b = 6V \quad \text{and at node a,} \frac{10 - v_a}{2} = \frac{v_a - v_o}{4}$$

which leads to $v_o =$ **–2 V** and $i_o = \frac{v_o}{5k} - \frac{(v_a - v_o)}{4k} = -0.4 - 2 \text{ mA} =$ **–2.4 mA**

Chapter 5, Solution 48.

Since the op amp draws no current from the bridge, the bridge may be treated separately as follows:



For loop 1, $(10 + 30)\, i_1 = 5 \longrightarrow i_1 = 5/(40) = 0.125\mu A$

For loop 2, $(40 + 60)\, i_2 = -5 \longrightarrow i_2 = -0.05\mu A$

But, $10i + v_1 - 5 = 0 \longrightarrow v_1 = 5 - 10i = 3.75mV$

$60i + v_2 + 5 = 0 \longrightarrow v_2 = -5 - 60i = -2mV$

As a difference amplifier,

$$v_o = \frac{R_2}{R_1}(v_2 - v_1) = \frac{80}{20}[3.75 - (-2)]mV$$

= **23mV**

Chapter 5, Solution 49.

$R_1 = R_3 = 10k\Omega$, $R_2/(R_1) = 2$

i.e. $R_2 = 2R_1 = 20k\Omega = R_4$

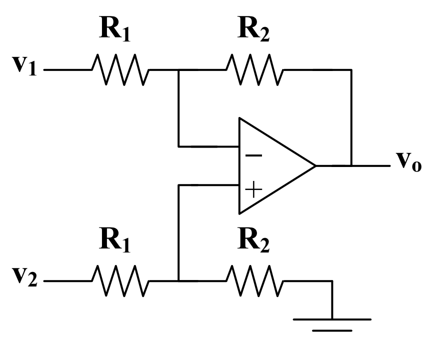
Verify: $$v_o = \frac{R_2}{R_1}\frac{1+R_1/R_2}{1+R_3/R_4}v_2 - \frac{R_2}{R_1}v_1$$

$$= 2\frac{(1+0.5)}{1+0.5}v_2 - 2v_1 = 2(v_2 - v_1)$$

Thus, $R_1 = R_3 =$ **<u>10kΩ</u>**, $R_2 = R_4 =$ **<u>20kΩ</u>**

Chapter 5, Solution 50.

(a) We use a difference amplifier, as shown below:



$$v_o = \frac{R_2}{R_1}(v_2 - v_1) = 2(v_2 - v_1),\ \text{i.e. } R_2/R_1 = 2$$

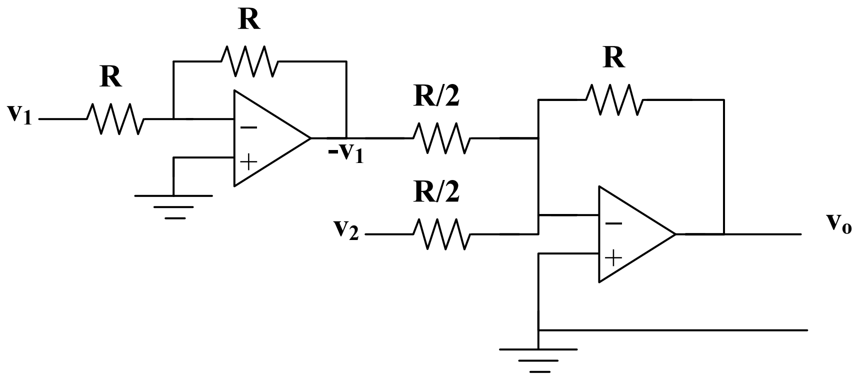
If R_1 = **<u>10 kΩ</u>** then R_2 = **<u>20kΩ</u>**

(b) We may apply the idea in Prob. 5.35.

$$v_0 = 2v_1 - 2v_2$$
$$= -\left[\frac{R}{R/2}(-v_1) + \frac{R}{R/2}v_2\right]$$
$$= -\left[\frac{R_f}{R_1}(-v_1) + \frac{R_f}{R_2}v_2\right]$$

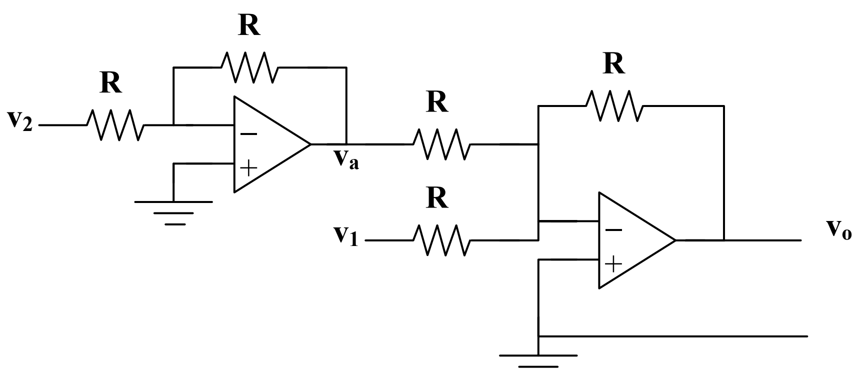
i.e. $R_f = R$, $R_1 = R/2 = R_2$

We need an inverter to invert v_1 and a summer, as shown below. We may let R = 10kΩ.



Chapter 5, Solution 51.

We achieve this by cascading an inverting amplifier and two-input inverting summer as shown below:



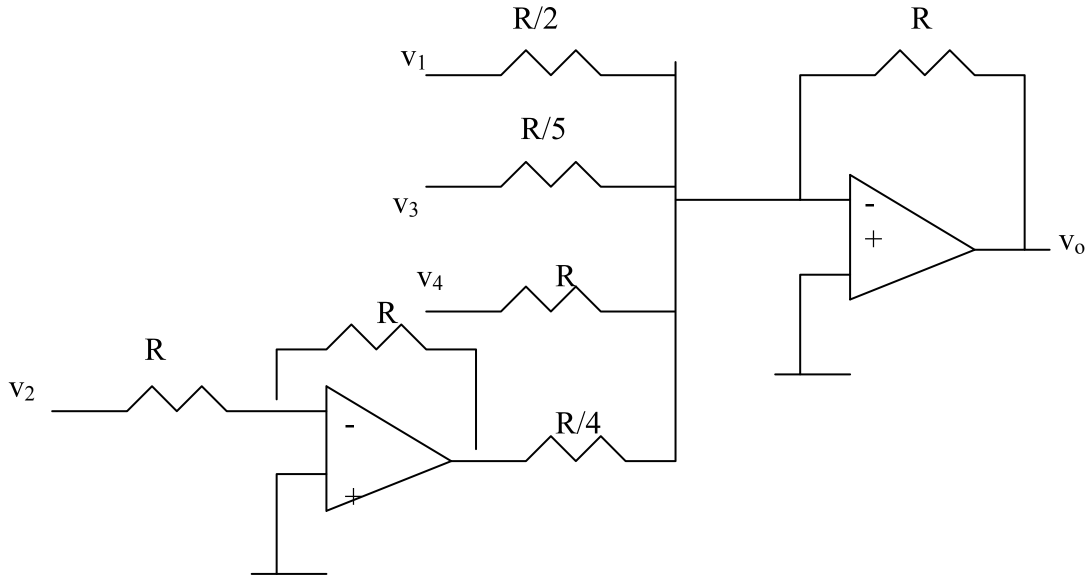
Verify: $v_o = -v_a - v_1$

But $v_a = -v_2$. Hence

$v_o = v_2 - v_1$.

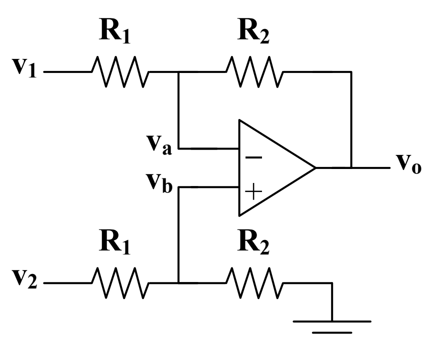
Chapter 5, Solution 52

A summing amplifier shown below will achieve the objective. An inverter is inserted to invert v_2. Let $R = 10\ k\Omega$.



Chapter 5, Solution 53.

(a)



At node a, v

$$\longrightarrow \quad = \quad + \qquad (1)$$

At node b, $$v_b = \frac{R_2}{R_1 + R_2} v_2 \qquad (2)$$

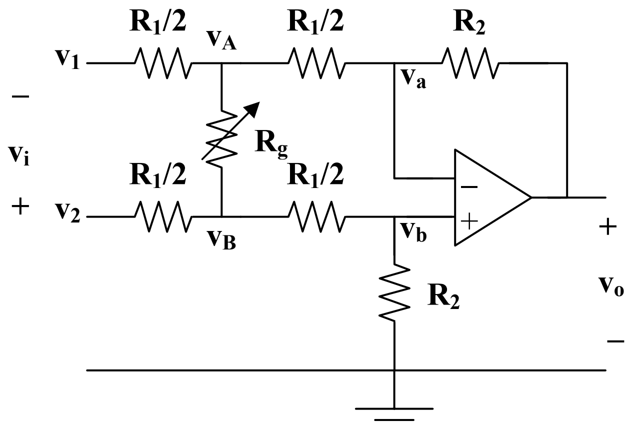
But $v_a = v_b$. Setting (1) and (2) equal gives

$$\frac{R_2}{R_1 + R_2} v_2 = \frac{R_2 v_1 + R_1 v_o}{R_1 + R_2}$$

$$v_2 - v_1 = \frac{R_1}{R_2} v_o = v_i$$

$$\frac{v_o}{v_i} = \underline{\frac{R_2}{R_1}}$$

(b)



At node A, $\quad \dfrac{v_1 - v_A}{R_1/2} + \dfrac{v_B - v_A}{R_g} = \dfrac{v_A - v_a}{R_1/2}$

or $\quad v_1 - v_A + \dfrac{R_1}{2R_g}(v_B - v_A) = v_A - v_a \qquad (1)$

At node B, $\quad \dfrac{v_2 - v_B}{R_1/2} = \dfrac{v_B - v_A}{R_1/2} + \dfrac{v_B - v_b}{R_g}$

or $\quad v_2 - v_B - \dfrac{R_1}{2R_g}(v_B - v_A) = v_B - v_b \qquad (2)$

Subtracting (1) from (2),

$$v_2 - v_1 - v_B + v_A - \frac{2R_1}{2R_g}(v_B - v_A) = v_B - v_A - v_b + v_a$$

Since, $v_a = v_b$,

$$\frac{v_2 - v_1}{2} = \left(1 + \frac{R_1}{2R_g}\right)(v_B - v_A) = \frac{v_i}{2}$$

or $$v_B - v_A = \frac{v_i}{2} \cdot \frac{1}{1 + \dfrac{R_1}{2R_g}} \quad (3)$$

But for the difference amplifier,

$$v_o = \frac{R_2}{R_1/2}\left(v_B - v_A\right)$$

or $$v_B - v_A = \frac{R_1}{2R_2} v_o \quad (4)$$

Equating (3) and (4), $$\frac{R_1}{2R_2} v_o = \frac{v_i}{2} \cdot \frac{1}{1 + \dfrac{R_1}{2R_g}}$$

$$\underline{\frac{v_o}{v_i} = \frac{R_2}{R_1} \cdot \frac{1}{1 + \dfrac{R_1}{2R_g}}}$$

(c) At node a, $$\frac{v_1 - v_a}{R_1} = \frac{v_a - v_A}{R_2/2}$$

$$v_1 - v_a = \frac{2R_1}{R_2} v_a - \frac{2R_1}{R_2} v_A \quad (1)$$

At node b, $$v_2 - v_b = \frac{2R_1}{R_2} v_b - \frac{2R_1}{R_2} v_B \quad (2)$$

Since $v_a = v_b$, we subtract (1) from (2),

$$v_2 - v_1 = \frac{-2R_1}{R_2}(v_B - v_A) = \frac{v_i}{2}$$

or $$v_B - v_A = \frac{-R_2}{2R_1} v_i \quad (3)$$

At node A,

$$\frac{v_a - v_A}{R_2/2} + \frac{v_B - v_A}{R_g} = \frac{v_A - v_o}{R/2}$$

$$v_a - v_A + \frac{R_2}{2R_g}\left(v_B - v_A\right) = v_A - v_o \quad (4)$$

At node B, $\frac{v_b - v_B}{R/2} - \frac{v_B - v_A}{R_g} = \frac{v_B - 0}{R/2}$

$$v_b - v_B - \frac{R_2}{2R_g}(v_B - v_A) = v_B \qquad (5)$$

Subtracting (5) from (4),

$$v_B - v_A + \frac{R_2}{R_g}(v_B - v_A) = v_A - v_B - v_o$$

$$2(v_B - v_A)\left(1 + \frac{R_2}{2R_g}\right) = -v_o \qquad (6)$$

Combining (3) and (6),

$$\frac{-R_2}{R_1} v_i \left(1 + \frac{R_2}{2R_g}\right) = -v_o$$

$$\underline{\frac{v_o}{v_i} = \frac{R_2}{R_1}\left(1 + \frac{R_2}{2R_g}\right)}$$

Chapter 5, Solution 54.

(a) $A_0 = A_1A_2A_3 = (-30)(-12.5)(0.8) = 300$
(b) $A = A_1A_2A_3A_4 = A_0A_4 = 300A_4$

But $20\text{Log}_{10}A = 60\text{dB} \longrightarrow \text{Log}_{10}A = 3$

$A = 10^3 = 1000$
$A_4 = A/(300) = \underline{\mathbf{3.333}}$

Chapter 5, Solution 55.

Let $A_1 = k$, $A_2 = k$, and $A_3 = k/(4)$
$A = A_1A_2A_3 = k^3/(4)$
$20\text{Log}_{10}A = 42$
$\text{Log}_{10}A = 2.1 \longrightarrow A = 10^{2.1} = 125.89$
$k^3 = 4A = 503.57$
$k = \sqrt[3]{503.57} = 7.956$

Thus $A_1 = A_2 = \underline{\mathbf{7.956}}$, $A_3 = \underline{\mathbf{1.989}}$

Chapter 5, Solution 56.

There is a cascading system of two inverting amplifiers.

$$v_o = \frac{-12}{4}\left(\frac{-12}{6}\right)v_s = 6v_s$$

$$i_o = \frac{v_s}{2k} = 3v_s mA$$

(a) When v_s = 12V, i_o = **<u>36mA</u>**
(b) When v_s = 10 cos 377t V, i_o = **<u>30 cos 377t mA</u>**

Chapter 5, Solution 57

The first stage is a difference amplifier. Since $R_1/R_2 = R_3/R_4$,

$$v_o' = \frac{R_2}{R_1}(v_2 - v_1) = \frac{100}{50}(1+4) = 10\,mA$$

The second stage is a non-inverter.

$$v_o = \left(1 + \frac{R}{40}\right)v_o' = \left(1 + \frac{R}{40}\right)10\,mA = 40\,mV(\text{given})$$

Which leads to,

R = **<u>120 kΩ</u>**

Chapter 5, Solution 58.

By voltage division, the input to the voltage follower is:

$$v_1 = \frac{3}{3+1}(0.6) = 0.45V$$

Thus

$$v_o = \frac{-10}{2}v_1 - \frac{10}{5}v_1 = -7v_1 = -3.15$$

$$i_o = \frac{0 - v_o}{4k} = \ \mathbf{\underline{0.7875mA}}$$

Chapter 5, Solution 59.

Let a be the node between the two op amps.

$v_a = v_o$

The first stage is a summer

$$v_a = \frac{-10}{5} v_s - \frac{10}{20} v_o = v_o$$

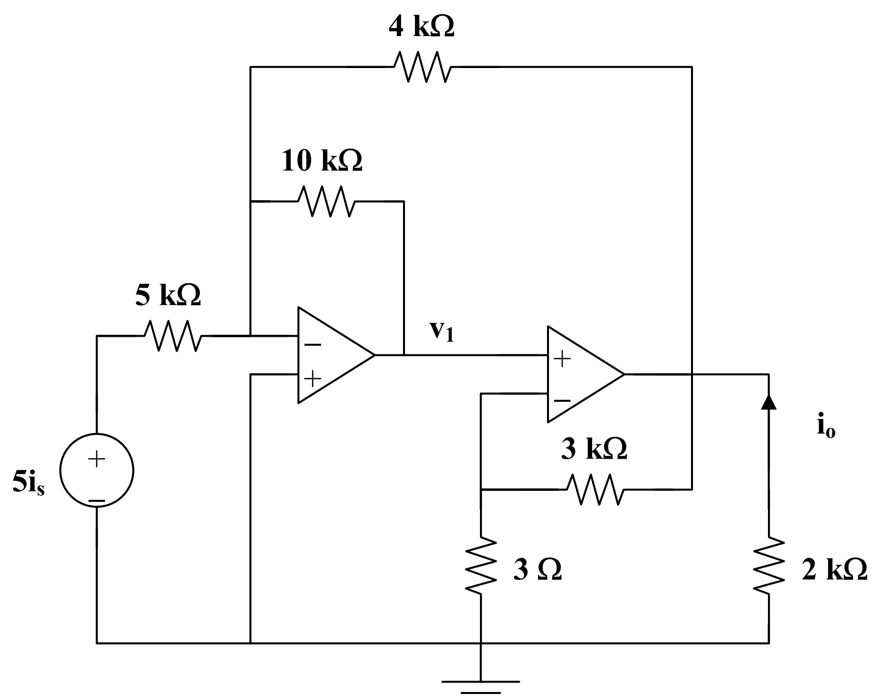
$$1.5v_s = -2v_s$$

or

$$\frac{v_o}{v_s} = \frac{-2}{1.5} = \underline{\mathbf{-1.333}}$$

Chapter 5, Solution 60.

Transform the current source as shown below:



Assume all currents are in mA. The first stage is a summer

$$v_1 = \frac{-10}{5}(5i_s) - \frac{10}{4} v_o = -10i_s - 2.5v_o \qquad (1)$$

By voltage division,

$$v_1 = \frac{3}{3+3} v_o = \frac{1}{2} v_o \qquad (2)$$

Alternatively, we notice that the second stage is a non-inverter.

$$v_o = \left(\frac{1}{3+3}\right) v_1 = 2v_1$$

From (1) and (2),

$$0.5v_o = -10i_s - 2.5v_o \longrightarrow 3v_o = 10i_s$$

$$v_o = -2i_o = -\frac{10i_s}{3} \longrightarrow \frac{i_o}{i_s} = \frac{5}{3} = \underline{\mathbf{1.667}}$$

Chapter 5, Solution 61.

Let v_{01} be the voltage at the left end of R_5. The first stage is an inverter, while the second stage is a summer.

$$v_{01} = -\frac{R_2}{R_1} v_1$$

$$v_0 = -\frac{R_4}{R_5} v_{01} - \frac{R_4}{R_3} v_2$$

$$v_1 = \underline{\frac{R_2 R_4}{R_1 R_5} v_1 - \frac{R_4}{R_3} v_2}$$

Chapter 5, Solution 62.

Let v_1 = output of the first op amp
v_2 = output of the second op amp

The first stage is a summer

$$v_1 = -\frac{R_2}{R_1} v_i - \frac{R_2}{R_f} v_o \qquad (1)$$

The second stage is a follower. By voltage division

$$v_o = v_2 = \frac{R_4}{R_3 + R_4} v_1 \longrightarrow v_1 = \frac{R_3 + R_4}{R_4} v_o \qquad (2)$$

From (1) and (2),

$$\left(1 + \frac{R_3}{R_4}\right) v_o = -\frac{R_2}{R_1} v_i - \frac{R_2}{R_f} v_o$$

$$\left(1 + \frac{R_3}{R_4} + \frac{R_2}{R_f}\right) v_o = -\frac{R_2}{R_1} v_i$$

$$\frac{v_o}{v_i} = -\frac{R_2}{R_1} \cdot \frac{1}{1 + \frac{R_3}{R_4} + \frac{R_2}{R_4}}$$

$$= \underline{\frac{-R_2 R_4}{R_1 (R_2 + R_3 + R_4)}}$$

Chapter 5, Solution 63.

The two op amps are summer. Let v_1 be the output of the first op amp. For the first stage,

$$v_1 = -\frac{R_2}{R_1} v_i - \frac{R_2}{R_3} v_o \qquad (1)$$

For the second stage,

$$v_o = -\frac{R_4}{R_5} v_1 - \frac{R_4}{R_o} v_i \qquad (2)$$

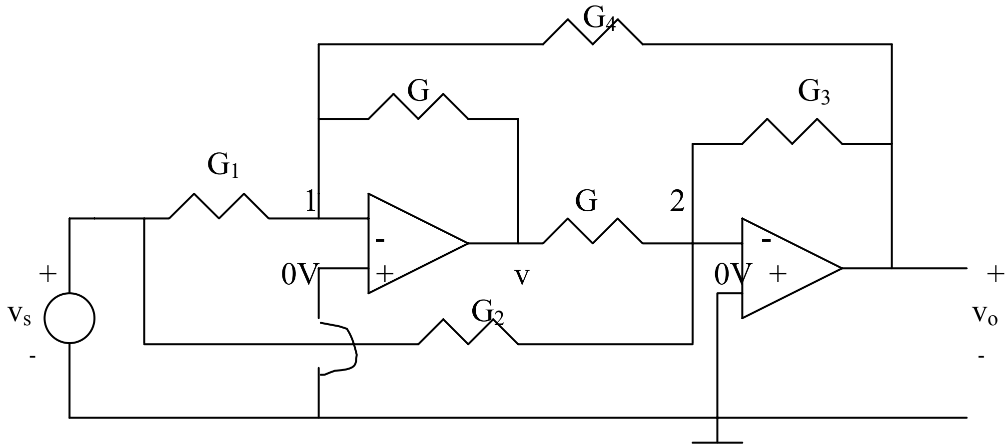
Combining (1) and (2),

$$v_o = \frac{R_4}{R_5}\left(\frac{R_2}{R_1}\right) v_i + \frac{R_4}{R_5}\left(\frac{R_2}{R_3}\right) v_o - \frac{R_4}{R_6} v_i$$

$$v_o \left(1 - \frac{R_2 R_4}{R_3 R_5}\right) = \left(\frac{R_2 R_4}{R_1 R_5} - \frac{R_4}{R_6}\right) v_i$$

$$\frac{v_o}{v_i} = \underline{\frac{\frac{R_2 R_4}{R_1 R_3} - \frac{R_4}{R_6}}{1 - \frac{R_2 R_4}{R_3 R_5}}}$$

Chapter 5, Solution 64



At node 1, $v_1=0$ so that KCL gives

$$G_1 v_s + G_4 v_o = -Gv \qquad (1)$$

At node 2,

$$G_2 v_s + G_3 v_o = -Gv \qquad (2)$$

From (1) and (2),

$$G_1 v_s + G_4 v_o = G_2 v_s + G_3 v_o \longrightarrow (G_1 - G_2)v_s = (G_3 - G_4)v_o$$

or

$$\underline{\frac{v_o}{v_s} = \frac{G_1 - G_2}{G_3 - G_4}}$$

Chapter 5, Solution 65

The output of the first op amp (to the left) is 6 mV. The second op amp is an inverter so that its output is

$$v_o' = -\frac{30}{10}(6\text{mV}) = \text{-18 mV}$$

The third op amp is a noninverter so that

$$v_o' = \frac{40}{40+8}v_o \longrightarrow v_o = \frac{48}{40}v_o' = \underline{-21.6\text{ mV}}$$

Chapter 5, Solution 66.

$$v_o = \frac{-110}{25}(6) - \frac{100}{20}\left(-\frac{40}{20}\right)(4) - \frac{100}{10}(2)$$
$$= -24 + 40 - 20 = \underline{\mathbf{-4V}}$$

Chapter 5, Solution 67.

$$v_o = -\frac{80}{40}\left(-\frac{80}{20}\right)(0.5) - \frac{80}{20}(0.2)$$
$$= 3.2 - 0.8 = \underline{\mathbf{2.4V}}$$

Chapter 5, Solution 68.

If $R_q = \infty$, the first stage is an inverter.

$$V_a = -\frac{15}{5}(10) = -30\text{mV}$$

when V_a is the output of the first op amp.

The second stage is a noninverting amplifier.

$$v_o = \left(1 + \frac{6}{2}\right)v_a = (1+3)(-30) = \underline{\mathbf{-120mV}}$$

Chapter 5, Solution 69.

In this case, the first stage is a summer

$$v_a = -\frac{15}{5}(10) - \frac{15}{10}v_o = -30 - 1.5v_o$$

For the second stage,

$$v_o = \left(1 + \frac{6}{2}\right)v_a = 4v_a = 4(-30 - 1.5v_o)$$

$$7v_o = -120 \longrightarrow v_o = -\frac{120}{7} = \underline{\mathbf{-17.143mV}}$$

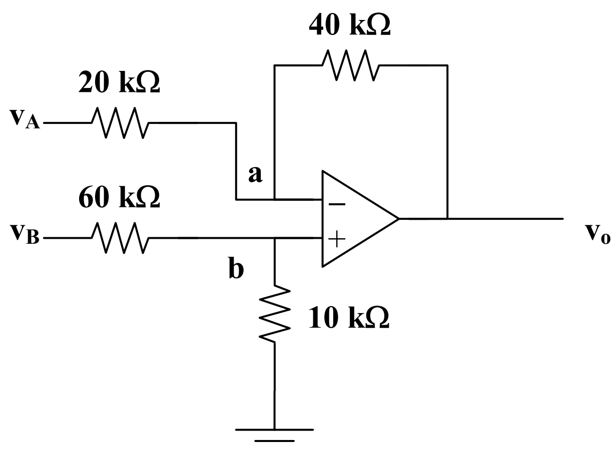
Chapter 5, Solution 70.

The output of amplifier A is

$$v_A = -\frac{30}{10}(10) - \frac{30}{10}(2) = -9$$

The output of amplifier B is

$$v_B = -\frac{20}{10}(3) - \frac{20}{10}(4) = -14$$



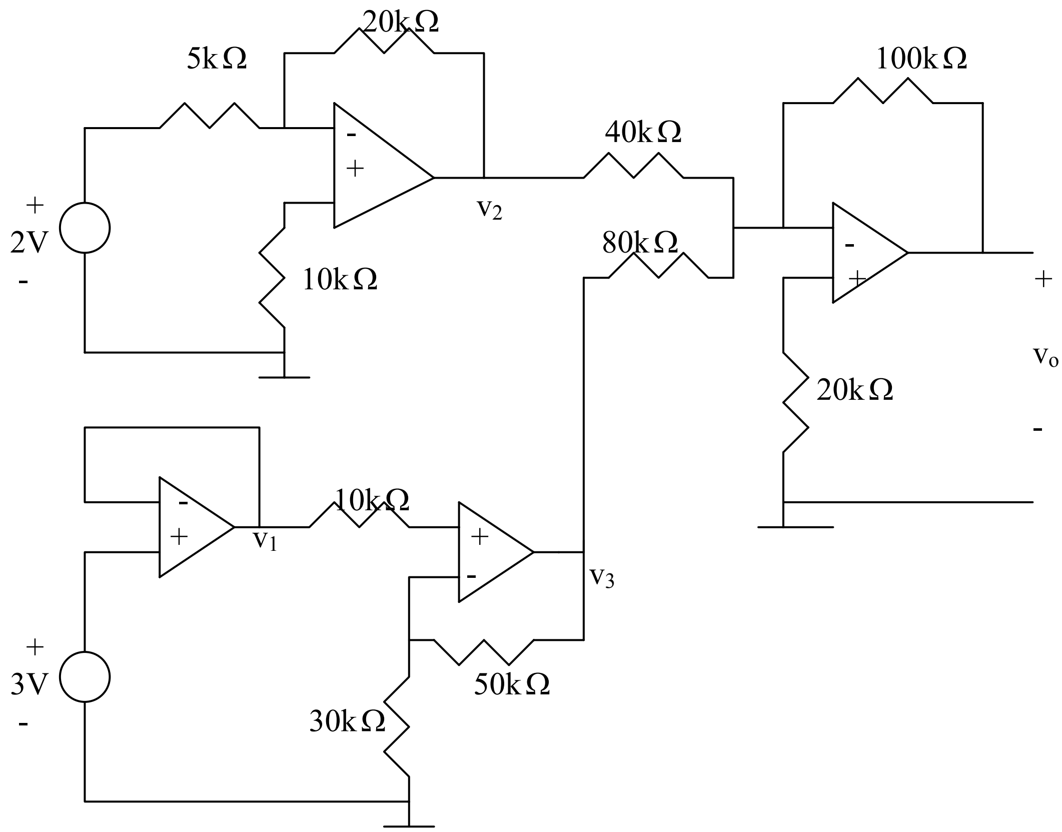
$$v_b = \frac{60}{60+10}(-14) = -2V$$

At node a, $\frac{v_A - v_a}{20} = \frac{v_a - v_o}{40}$

But $v_a = v_b = -2V$, $2(-9+2) = -2-v_o$

Therefore, $v_o = \underline{\mathbf{12V}}$

Chapter 5, Solution 71



$$v_1 = 3, \qquad v_2 = -\frac{20}{5}(2) = -8, \qquad v_3 = (1+\frac{50}{30})v_1 = 8$$

$$v_o = -\left(\frac{100}{40}v_2 + \frac{100}{80}v_3\right) = -(-20+10) = \underline{10\text{ V}}$$

Chapter 5, Solution 72.

Since no current flows into the input terminals of ideal op amp, there is no voltage drop across the 20 kΩ resistor. As a voltage summer, the output of the first op amp is

$$v_{01} = 0.4$$

The second stage is an inverter

$$v_2 = -\frac{150}{100} v_{01}$$
$$= -2.5(0.4) = \underline{\textbf{-1V}}$$

Chapter 5, Solution 73.

The first stage is an inverter. The output is

$$v_{01} = -\frac{50}{10}(-1.8) = -9V$$

The second stage is

$$v_2 = v_{01} = \underline{\textbf{-9V}}$$

Chapter 5, Solution 74.

Let v_1 = output of the first op amp
v_2 = input of the second op amp.

The two sub-circuits are inverting amplifiers

$$v_1 = -\frac{100}{10}(0.6) = -6V$$

$$v_2 = -\frac{32}{1.6}(0.4) = -8V$$

$$i_o = \frac{v_1 - v_2}{20k} = -\frac{-6+8}{20k} = \underline{\textbf{100 μA}}$$

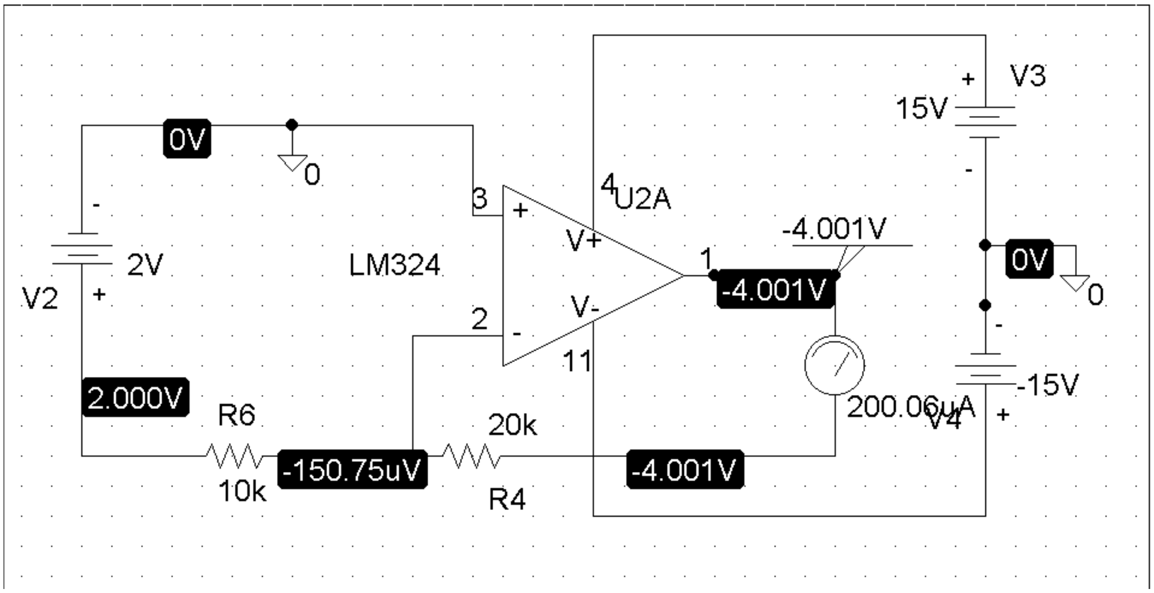
Chapter 5, Solution 75.

The schematic is shown below. Pseudo-components VIEWPOINT and IPROBE are involved as shown to measure v_o and i respectively. Once the circuit is saved, we click <u>Analysis | Simulate</u>. The values of v and i are displayed on the pseudo-components as:

$$i = \underline{\mathbf{200\ \mu A}}$$

$$(v_o/v_s) = -4/2 = -2$$

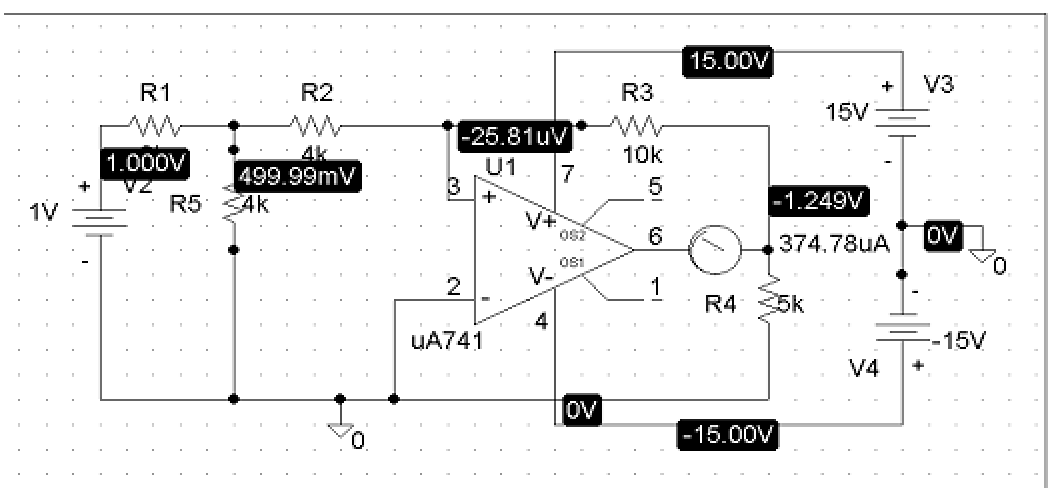
The results are slightly different than those obtained in Example 5.11.



Chapter 5, Solution 76.

The schematic is shown below. IPROBE is inserted to measure i_o. Upon simulation, the value of i_o is displayed on IPROBE as

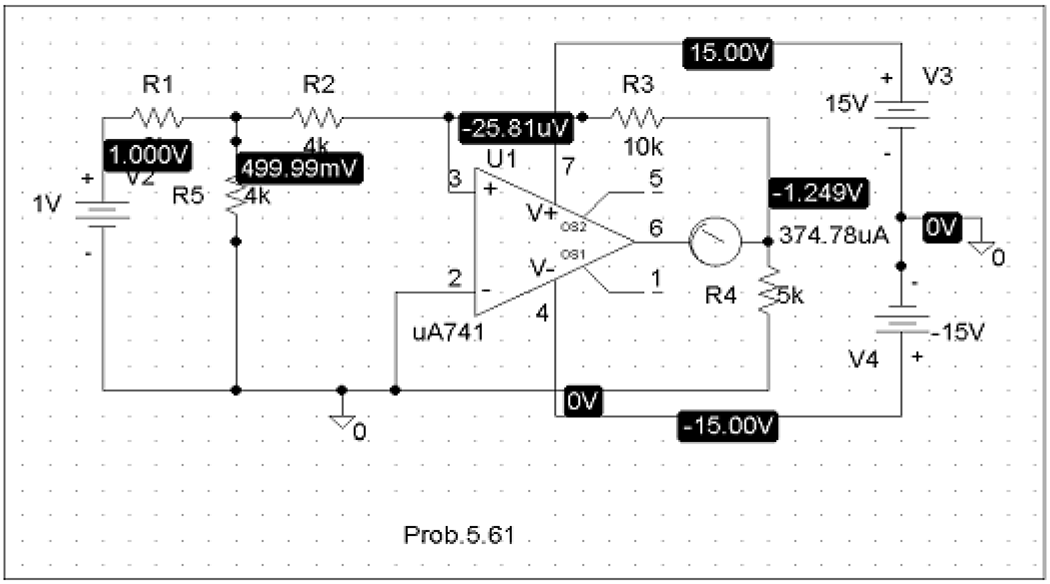
$$i_o = \underline{\mathbf{-374.78\ \mu A}}$$



Chapter 5, Solution 77.

The schematic is shown below. IPROBE is inserted to measure i_o. Upon simulation, the value of i_o is displayed on IPROBE as

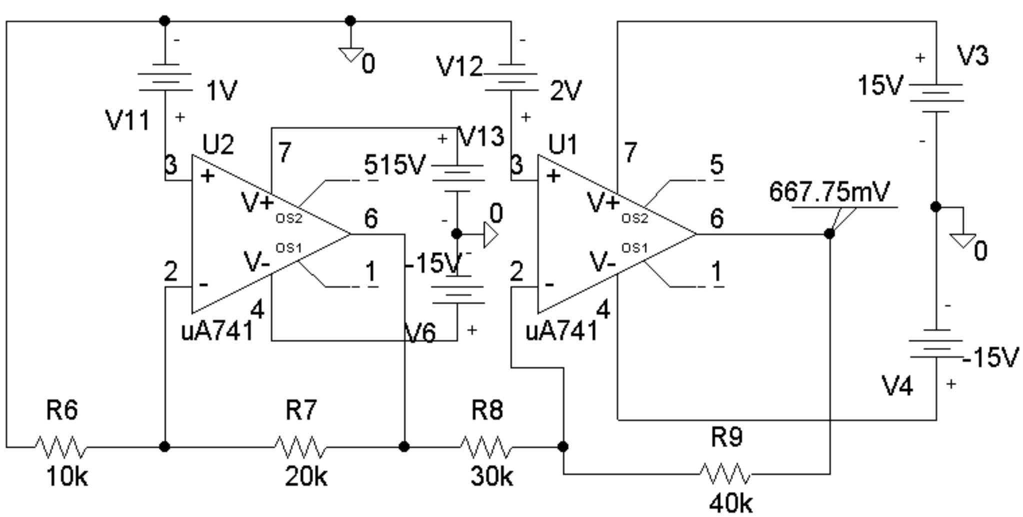
$$i_o = \underline{\mathbf{-374.78\ \mu A}}$$



Chapter 5, Solution 78.

The circuit is constructed as shown below. We insert a VIEWPOINT to display v_o. Upon simulating the circuit, we obtain,

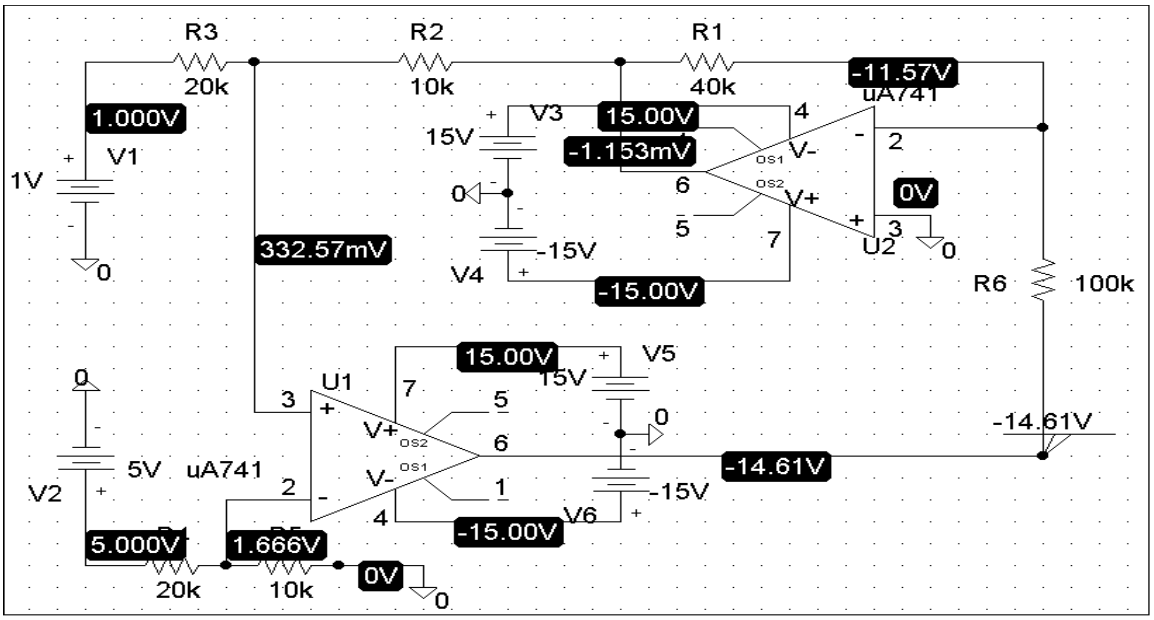
$$v_o = \underline{\mathbf{667.75\ mV}}$$



Chapter 5, Solution 79.

The schematic is shown below. A pseudo-component VIEWPOINT is inserted to display v_o. After saving and simulating the circuit, we obtain,

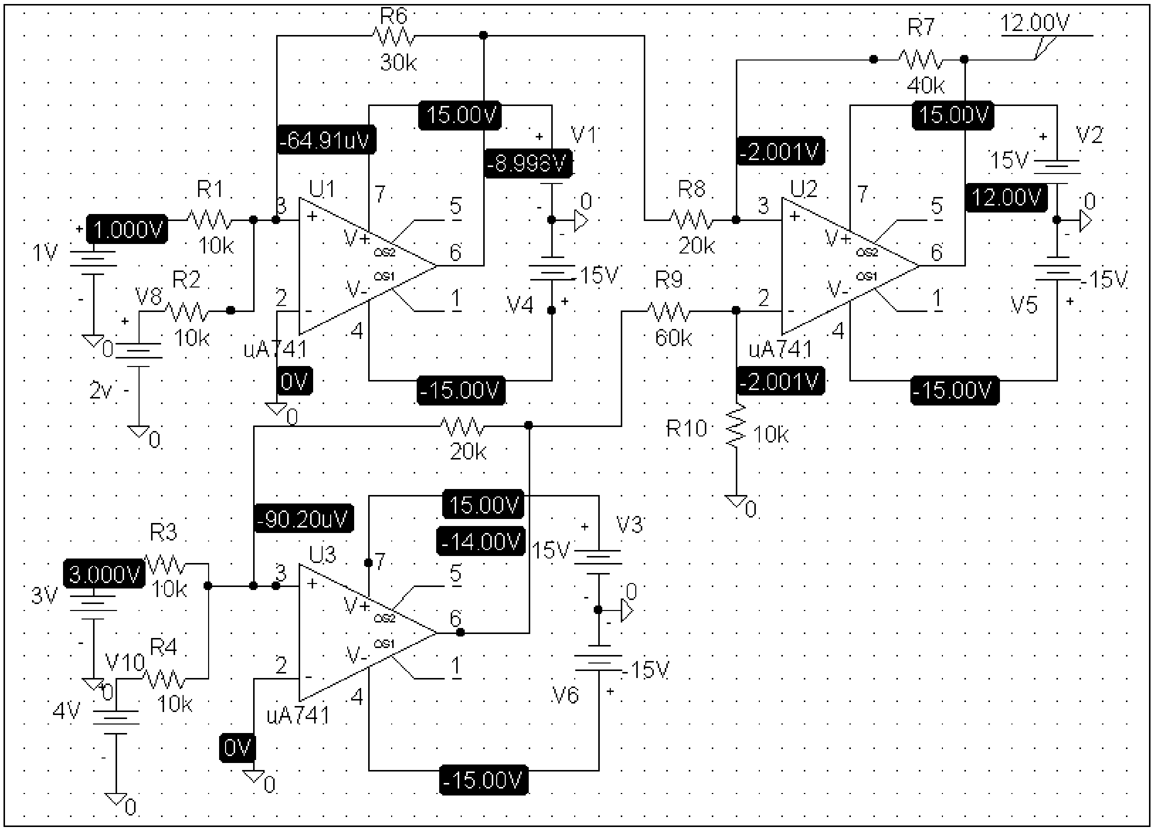
$$v_o = \underline{\mathbf{-14.61\ V}}$$



Chapter 5, Solution 80.

The schematic is shown below. VIEWPOINT is inserted to display v_o. After simulation, we obtain,

$$v_o = \underline{\mathbf{12\ V}}$$

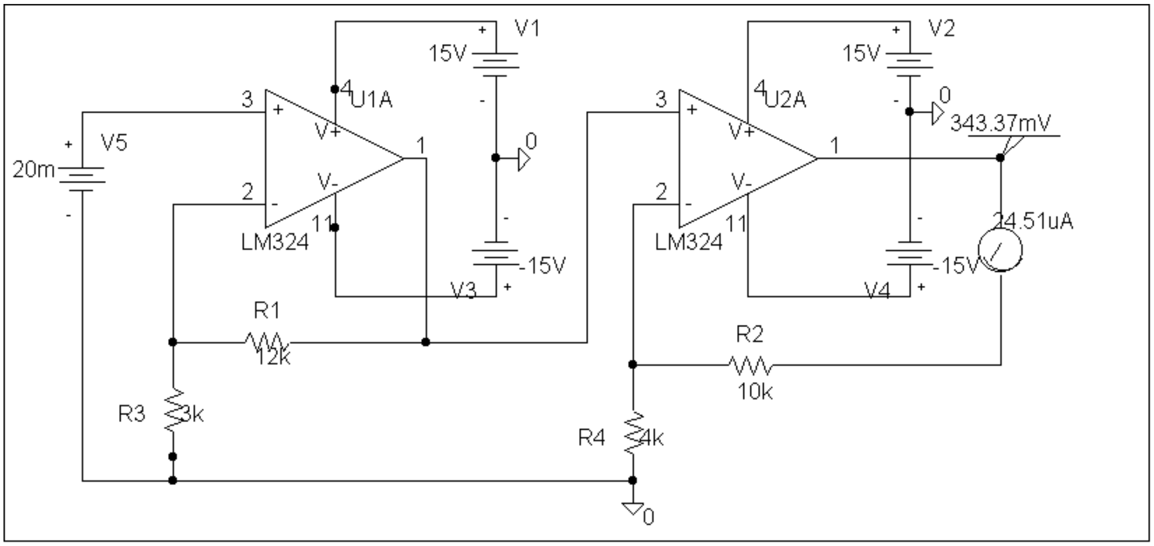


Chapter 5, Solution 81.

The schematic is shown below. We insert one VIEWPOINT and one IPROBE to measure v_o and i_o respectively. Upon saving and simulating the circuit, we obtain,

$$v_o = \underline{\mathbf{343.37\ mV}}$$

$$i_o = \underline{\mathbf{24.51\ \mu A}}$$



Chapter 5, Solution 82.

The maximum voltage level corresponds to

$$11111 = 2^5 - 1 = 31$$

Hence, each bit is worth $(7.75/31) = \underline{\mathbf{250\ mV}}$

Chapter 5, Solution 83.

The result depends on your design. Hence, let R_G = 10 k ohms, R_1 = 10 k ohms, R_2 = 20 k ohms, R_3 = 40 k ohms, R_4 = 80 k ohms, R_5 = 160 k ohms, R_6 = 320 k ohms, then,

$$-v_o = (R_f/R_1)v_1 + \text{---------} + (R_f/R_6)v_6$$

$$= v_1 + 0.5v_2 + 0.25v_3 + 0.125v_4 + 0.0625v_5 + 0.03125v_6$$

(a) $|v_o| = 1.1875 = 1 + 0.125 + 0.0625 = 1 + (1/8) + (1/16)$ which implies,

$[v_1\ v_2\ v_3\ v_4\ v_5\ v_6]$ = **[100110]**

(b) $|v_o| = 0 + (1/2) + (1/4) + 0 + (1/16) + (1/32) = (27/32) = \underline{\mathbf{843.75\ mV}}$

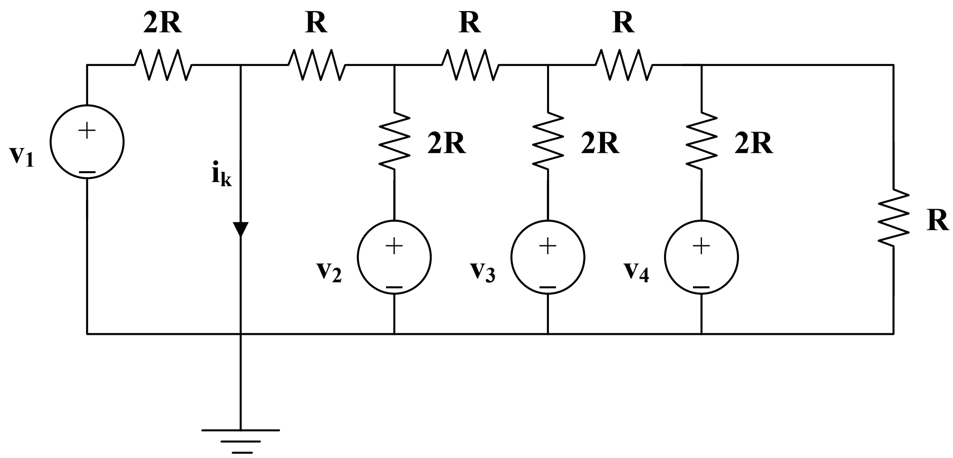
(c) This corresponds to [1 1 1 1 1 1].

$|v_o| = 1 + (1/2) + (1/4) + (1/8) + (1/16) + (1/32) = 63/32 = \underline{\mathbf{1.96875\ V}}$

Chapter 5, Solution 84.

For (a), the process of the proof is time consuming and the results are only approximate, but close enough for the applications where this device is used.

(a) The easiest way to solve this problem is to use superposition and to solve for each term letting all of the corresponding voltages be equal to zero. Also, starting with each current contribution (i_k) equal to one amp and working backwards is easiest.



For the first case, let $v_2 = v_3 = v_4 = 0$, and $i_1 = 1A$.

Therefore, $v_1 = 2R$ volts or $i_1 = v_1/(2R)$.

Second case, let $v_1 = v_3 = v_4 = 0$, and $i_2 = 1A$.

Therefore, $v_2 = 85R/21$ volts or $i_2 = 21v_2/(85R)$. Clearly this is not ($1/4^{th}$), so where is the difference? $(21/85) = 0.247$ which is a really good approximation for 0.25. Since this is a practical electronic circuit, the result is good enough for all practical purposes.

Now for the third case, let $v_1 = v_2 = v_4 = 0$, and $i_3 = 1A$.

Therefore, $v_3 = 8.5R$ volts or $i_3 = v_3/(8.5R)$. Clearly this is not ($1/8^{th}$), so where is the difference? $(1/8.5) = 0.11765$ which is a really good approximation for 0.125. Since this is a practical electronic circuit, the result is good enough for all practical purposes.

Finally, for the fourth case, let $v_1 = v_2 = v_4 = 0$, and $i_3 = 1A$.

Therefore, $v_4 = 16.25R$ volts or $i_4 = v_4/(16.25R)$. Clearly this is not $(1/16^{th})$, so where is the difference? $(1/16.25) = 0.06154$ which is a really good approximation for 0.0625. Since this is a practical electronic circuit, the result is good enough for all practical purposes.

Please note that a goal of a lot of electronic design is to come up with practical circuits that are economical to design and build yet give the desired results.

(b) If $R_f = 12$ k ohms and $R = 10$ k ohms,

$$-v_o = (12/20)[v_1 + (v_2/2) + (v_3/4) + (v_4/8)]$$

$$= 0.6[v_1 + 0.5v_2 + 0.25v_3 + 0.125v_4]$$

For $[v_1\ v_2\ v_3\ v_4] = [1\ 0\ 1 1]$,

$$|v_o| = 0.6[1 + 0.25 + 0.125] = \underline{\mathbf{825\ mV}}$$

For $[v_1\ v_2\ v_3\ v_4] = [0\ 1\ 0\ 1]$,

$$|v_o| = 0.6[0.5 + 0.125] = \underline{\mathbf{375\ mV}}$$

Chapter 5, Solution 85.

$$A_v = 1 + (2R/R_g) = 1 + 20{,}000/100 = \underline{\mathbf{201}}$$

Chapter 5, Solution 86.

$$v_o = A(v_2 - v_1) = 200(v_2 - v_1)$$

(a) $v_o = 200(0.386 - 0.402) = \underline{\mathbf{-3.2\ V}}$

(b) $v_o = 200(1.011 - 1.002) = \underline{\mathbf{1.8\ V}}$

Chapter 5, Solution 87.

The output, v_a, of the first op amp is,

$$v_a = (1 + (R_2/R_1))v_1 \quad (1)$$

Also,

$$v_o = (-R_4/R_3)v_a + (1 + (R_4/R_3))v_2 \quad (2)$$

Substituting (1) into (2),

$$v_o = (-R_4/R_3)(1 + (R_2/R_1))v_1 + (1 + (R_4/R_3))v_2$$

Or, $$v_o = \underline{\mathbf{(1 + (R_4/R_3))v_2 - (R_4/R_3 + (R_2R_4/R_1R_3))v_1}}$$

If $R_4 = R_1$ and $R_3 = R_2$, then,

$$v_o = (1 + (R_4/R_3))(v_2 - v_1)$$

which is a subtractor with a gain of $(1 + (R_4/R_3))$.

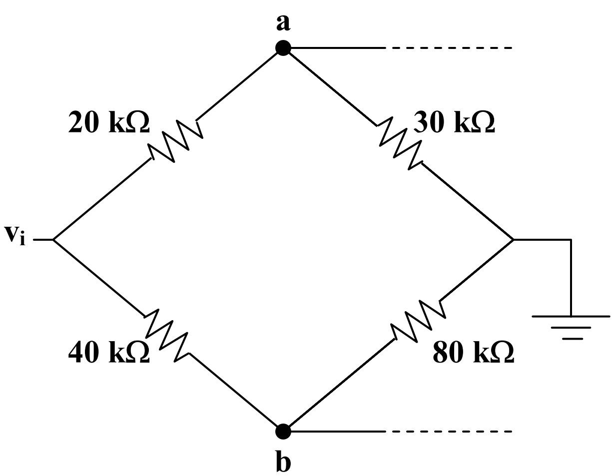
Chapter 5, Solution 88.

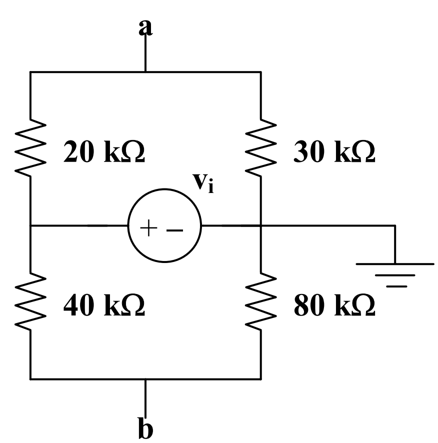
We need to find V_{Th} at terminals a – b, from this,

$$v_o = (R_2/R_1)(1 + 2(R_3/R_4))V_{Th} = (500/25)(1 + 2(10/2))V_{Th}$$

$$= 220V_{Th}$$

Now we use Fig. (b) to find V_{Th} in terms of v_i.





(a) **(b)**

$$v_a = (3/5)v_i, \quad v_b = (2/3)v_i$$

$$V_{Th} = v_b - v_a \ (1/15)v_i$$

$$(v_o/v_i) = A_v = -220/15 = \underline{\mathbf{-14.667}}$$

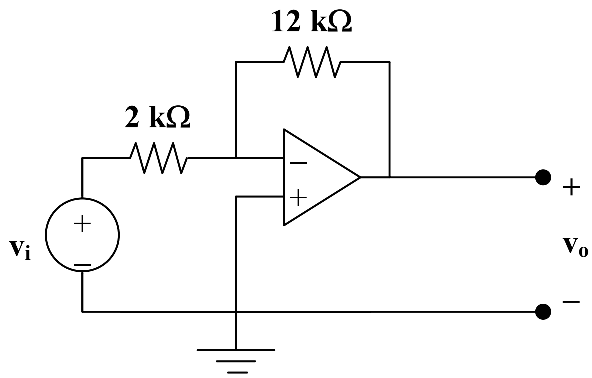
Chapter 5, Solution 89.

If we use an inverter, R = 2 k ohms,

$$(v_o/v_i) = -R_2/R_1 = -6$$

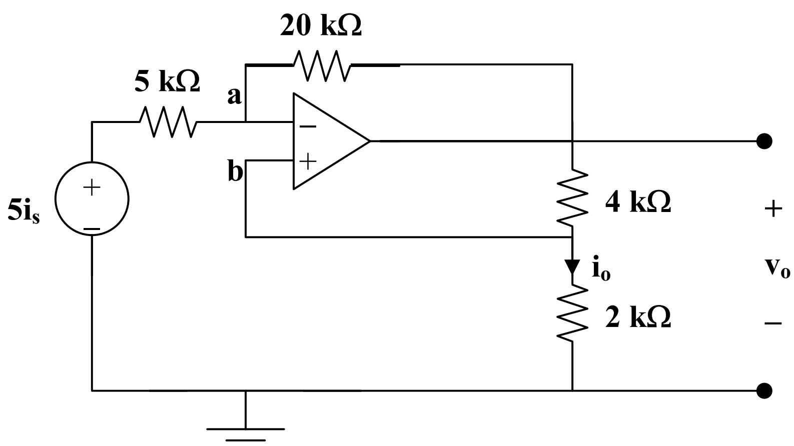
$$R = 6R = 12 \text{ k ohms}$$

Hence the op amp circuit is as shown below.



Chapter 5, Solution 90.

Transforming the current source to a voltage source produces the circuit below,
At node b, $v_b = (2/(2 + 4))v_o = v_o/3$



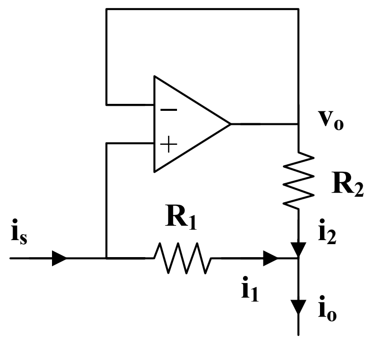
At node a, $(5i_s – v_a)/5 = (v_a – v_o)/20$

But $v_a = v_b = v_o/3$. $20i_s – (4/3)v_o = (1/3)v_o – v_o$, or $i_s = v_o/30$

$i_o = [(2/(2 + 4))/2]v_o = v_o/6$

$i_o/i_s = (v_o/6)/(v_o/30) = \underline{\mathbf{5}}$

Chapter 5, Solution 91.



$$i_o = i_1 + i_2 \qquad (1)$$

But $$i_1 = i_s \qquad (2)$$

R_1 and R_2 have the same voltage, v_o, across them.

$$R_1 i_1 = R_2 i_2, \text{ which leads to } i_2 = (R_1/R_2)i_1 \qquad (3)$$

Substituting (2) and (3) into (1) gives,

$$i_o = i_s(1 + R_1/R_2)$$

$$i_o/i_s = 1 + (R_1/R_2) = 1 + 8/1 = \underline{\mathbf{9}}$$

Chapter 5, Solution 92

The top op amp circuit is a non-inverter, while the lower one is an inverter. The output at the top op amp is

$$v_1 = (1 + 60/30)v_i = 3v_i$$

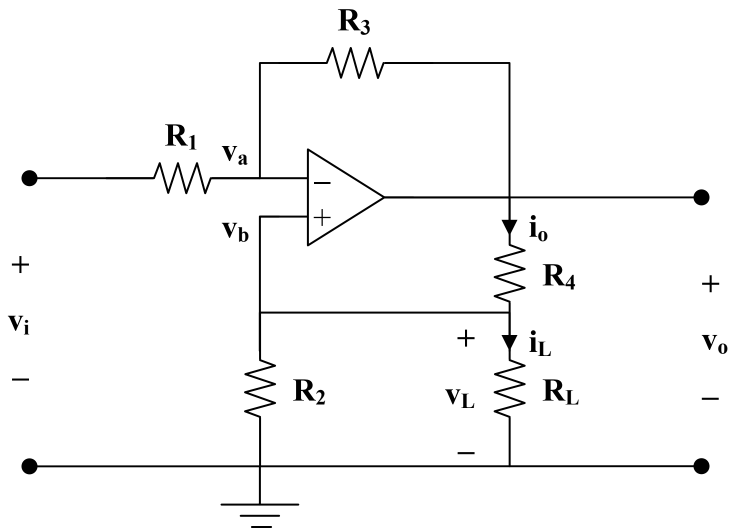
while the output of the lower op amp is

$$v_2 = -(50/20)v_i = -2.5v_i$$

Hence, $$v_o = v_1 - v_2 = 3v_i + 2.5v_i = 5.5v_i$$

$$v_o/v_i = \underline{\mathbf{5.5}}$$

Chapter 5, Solution 93.



At node a, $(v_i - v_a)/R_1 = (v_a - v_o)/R_3$

$v_i - v_a = (R_1/R_2)(v_a - v_o)$

$$v_i + (R_1/R_3)v_o = (1 + R_1/R_3)v_a \quad (1)$$

But $v_a = v_b = v_L$. Hence, (1) becomes

$$v_i = (1 + R_1/R_3)v_L - (R_1/R_3)v_o \quad (2)$$

$i_o = v_o/(R_4 + R_2||R_L)$, $i_L = (R_L/(R_2 + R_L))i_o = (R_2/(R_2 + R_L))(v_o/(R_4 + R_2||R_L))$

Or, $v_o = i_L[(R_2 + R_L)(R_4 + R_2||R_L)/R_2$ (3)

But, $v_L = i_L R_L$ (4)

Substituting (3) and (4) into (2),

$$v_i = (1 + R_1/R_3)\, i_L R_L - R_1[(R_2 + R_L)/(R_2R_3)](R_4 + R_2||R_L)i_L$$

$$= [((R_3 + R_1)/R_3)R_L - R_1((R_2 + R_L)/(R_2R_3)(R_4 + (R_2R_L/(R_2 + R_L))]i_L$$

$$= (1/A)i_L$$

Thus,

$$A = \frac{\mathbf{1}}{\left(\mathbf{1}+\frac{\mathbf{R_1}}{\mathbf{R_3}}\right)\mathbf{R_L} - \mathbf{R_1}\left(\frac{\mathbf{R_2}+\mathbf{R_L}}{\mathbf{R_2}\mathbf{R_3}}\right)\left(\mathbf{R_4}+\frac{\mathbf{R_2}\mathbf{R_L}}{\mathbf{R_2}+\mathbf{R_L}}\right)}$$