Chapter 5, Solution 1.

(a) \( R_{\text{in}} = 1.5 \, \text{M}\Omega \)
(b) \( R_{\text{out}} = 60 \, \Omega \)
(c) \( A = 8 \times 10^4 \)

Therefore \( A_{\text{dB}} = 20 \log 8 \times 10^4 = 98.0 \, \text{dB} \)

Chapter 5, Solution 2.

\[
v_0 = A v_d = A(v_2 - v_1) = 10^5 (20-10) \times 10^{-6} = 0.1\text{V}
\]

Chapter 5, Solution 3.

\[
v_0 = A v_d = A(v_2 - v_1) = 2 \times 10^5 (30 + 20) \times 10^{-6} = 10\text{V}
\]

Chapter 5, Solution 4.

\[
v_2 - v_1 = \frac{v_0}{A} = \frac{-4}{2 \times 10^5} = -20\mu\text{V}
\]

If \( v_1 \) and \( v_2 \) are in mV, then

\[
v_2 - v_1 = -20 \, \text{mV} = 0.02
\]

\[
1 - v_1 = -0.02
\]

\[
v_1 = 1.02 \, \text{mV}
\]

Chapter 5, Solution 5.
\[-v_i + A v_d + (R_i - R_0) I = 0 \quad (1)\]

But \[v_d = R_i I,\]

\[-v_i + (R_i + R_0 + R_i A) I = 0\]

\[v_d = \frac{v_i R_i}{R_0 + (1 + A) R_i} \quad (2)\]

\[-A v_d - R_0 I + v_0 = 0\]

\[v_0 = A v_d + R_0 I = (R_0 + R_i A) I = \frac{(R_0 + R_i A) v_i}{R_0 + (1 + A) R_i}\]

\[\frac{v_0}{v_i} = \frac{R_0 + R_i A}{R_0 + (1 + A) R_i} = \frac{100 + 10^4 \times 10^5}{100 + (1 + 10^5)} \cdot 10^4\]

\[\cong \frac{10^9}{(1+10^5)} \cdot 10^4 = \frac{100,000}{100,001} = 0.9999990\]

Chapter 5, Solution 6.
\[(R_0 + R_i)R + v_i + AV_d = 0\]

But \[v_d = R_0I,\]

\[v_i + (R_0 + R_i + R_A)I = 0\]

\[I = \frac{-v_i}{R_0 + (1 + A)R_i}\] \quad (1)

\[-Av_d - R_0I + v_o = 0\]

\[v_o = Av_d + R_0I = (R_0 + R_A)I\]

Substituting for I in (1),

\[v_0 = -\left(\frac{R_0 + R_A}{R_0 + (1 + A)R_i}\right)v_i\]

\[= -\left(\frac{50 + 2\times10^6 \times 2\times10^5}{50 + (1 + 2\times10^5) \times 2\times10^6}\right)\times 10^{-3}\]

\[\approx -\frac{200,000 \times 2\times10^6}{200,001 \times 2\times10^6} \text{ mV}\]

\[v_0 = -0.999995 \text{ mV}\]

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 \(V_S = 1 \text{ mV}\), then \(V_0 = -10 \text{ mV}\)

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

Chapter 5, Solution 8.

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

\(v_a = v_b = 0\)

\[1 \text{ mA} = \frac{0 - v_0}{2k} \quad \rightarrow \quad v_0 = -2V\]

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

$$-v_a + 2 + v_0 = 0 \quad \Rightarrow \quad v_a = v_a - 2 = 1 - 2 = \boxed{1V}$$

**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,

$$1mA = \frac{4 - v_o}{2k} \quad \Rightarrow \quad v_0 = \boxed{2V}$$

(b)

Since $v_a = v_b = 3V$,

$$-v_b + 1 + v_o = 0 \quad \Rightarrow \quad v_o = v_b - 1 = \boxed{2V}$$

**Chapter 5, Solution 10.**

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

$$v_s = v_o \left( \frac{\frac{10}{10 + 10}}{2} \right) = v_o \Rightarrow \quad \frac{v_o}{v_s} = 2$$
Chapter 5, Solution 11.

\[ v_b = \frac{10}{10+5} = 2V \]

At node a,

\[ \frac{3 - v_a}{2} = \frac{v_a - v_o}{8} \Rightarrow 12 = 5v_a - v_o \]

But \( v_a = v_b = 2V \),

\[ 12 = 10 - v_o \Rightarrow v_o = -2V \]

\[ i_o = \frac{v_a - v_o + 0 - v_o}{8} = \frac{2 + 2}{8} = 0.5mA \]

\[ i_o = -1mA \]

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, \[ \frac{1.2 - v_a}{1} = \frac{v_a - v_o}{4}, \text{ but } v_a = v_b = \frac{2}{3} v_o \]

\[
4.8 - 4 \times \frac{2}{3} v_o = \frac{2}{3} v_o - v_o \quad \rightarrow \quad v_o = \frac{3 \times 4.8}{7} = 2.0570V
\]

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

\[ i_s = \frac{1.2 - v_a}{1} = -\frac{1.2}{7} \]

\[ p = v_s i_s = 1.2 \left( -\frac{1.2}{7} \right) = -205.7 \text{ mW} \]

Chapter 5, Solution 13.

By voltage division,

\[ v_a = \frac{90}{100} (1) = 0.9V \]

\[ v_b = \frac{50}{150} v_o = \frac{v_o}{3} \]

But \( v_a = v_b \quad \rightarrow \quad \frac{v_o}{3} = 0.9 \quad \rightarrow \quad v_o = 2.7V \]

\[ i_o = i_1 + i_2 = \frac{v_o}{10k} + \frac{v_o}{150k} = 0.27mA + 0.018mA = 288 \mu A \]
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 \( 40 - 4v_1 = v_1 + 2v_1 - 2v_o \rightarrow 40 = 7v_1 - 2v_o \) \( (1) \)

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), \( 40 = -14v_o - 2v_o \rightarrow v_o = -2.5V \)

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

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

At the inverting terminal,

\[
i_s = \frac{0 - v_1}{R_1} \rightarrow v_1 = -i_s R_1\]

Combining (1) and (2) leads to

\[
i_s \left( 1 + \frac{R_1}{R_2} + \frac{R_1}{R_3} \right) = -\frac{v_o}{R_3} \rightarrow \frac{v_o}{i_s} = \left( \frac{R_1 + R_3 + \frac{R_1 R_3}{R_2}}{R_2} \right)
\]

(b) For this case,

\[
\frac{v_o}{i_s} = \left( 20 + 40 + \frac{20 \times 40}{25} \right) \Omega = -92 \Omega
\]
Let currents be in mA and resistances be in kΩ. At node a,
\[ \frac{0.5 - v_a}{5} = \frac{v_a - v_{oa}}{10} \quad \Rightarrow \quad 1 = 3v_a - v_{oa} \quad (1) \]

But
\[ v_a = v_b = \frac{8}{8+2}v_o \quad \Rightarrow \quad v_o = \frac{10}{8}v_a \quad (2) \]

Substituting (2) into (1) gives
\[ 1 = 3v_a - \frac{10}{8}v_a \quad \Rightarrow \quad v_a = \frac{8}{14} \]

Thus,
\[ i_x = \frac{0.5 - v_a}{5} = -1/70 \text{ mA} = -14.28 \mu\text{A} \]
\[ i_y = \frac{v_o - v_b + v_o - v_a}{2} = 0.6(v_o - v_a) = 0.6\left(\frac{10}{8}v_a - v_a\right) = 0.6 \times \frac{8}{14} \text{ mA} = 85.71 \mu\text{A} \]

Chapter 5, Solution 17.

(a) \[ G = \frac{v_o}{v_i} = \frac{-R_2}{R_1} = -\frac{12}{5} = -2.4 \]

(b) \[ \frac{v_o}{v_i} = \frac{-80}{5} = -16 \]

(c) \[ \frac{v_o}{v_i} = \frac{-2000}{5} = -400 \]
Chapter 5, Solution 18.

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

\[
10 \parallel 20 = \frac{20}{3} \text{k}\Omega
\]

\[
v_o = \frac{-1000}{50 + \frac{20}{3}} \cdot \frac{2v_i}{3} \quad \rightarrow \quad \frac{v_o}{v_i} = -\frac{200}{17} = -11.764
\]

Chapter 5, Solution 19.

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

\[
2\parallel 4 = \frac{4}{3}
\]
\[ v_o = -\frac{10k}{4x^\frac{4}{3}}(\frac{2}{3}) = -1.25V \]

\[ i_o = \frac{v_o}{5k} + \frac{v_o - 0}{10k} = -0.375mA \]

Chapter 5, Solution 20.

At node a,

\[ \frac{9 - v_a}{4} = \frac{v_a - v_o}{8} + \frac{v_a - v_b}{4} \quad \rightarrow \quad 18 = 5v_a - v_o - 2v_b \hspace{1cm} (1) \]

At node b,

\[ \frac{v_a - v_b}{4} = \frac{v_b - v_o}{2} \quad \rightarrow \quad v_a = 3v_b - 2v_o \hspace{1cm} (2) \]

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

\[ -18 = -10v_o - v_o \quad \rightarrow \quad v_o = -18/(11) = -1.6364V \]
Chapter 5, Solution 21.

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

\[
v_a = 3 \times 3 - 2v_0 = 9 - 2v_0
\]

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

\[
v_o = 21/(11) = 1.909V
\]

Chapter 5, Solution 22.

\[ A_v = -\frac{R_f}{R_i} = -15. \]

If \( R_i = 10k\Omega \), then \( R_f = 150 k\Omega \).

Chapter 5, Solution 23

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

\[
\frac{v_s - 0}{R_1} = \frac{0 + 0 - v_o}{R_2} \quad \Rightarrow \quad \frac{v_o}{v_s} = -\frac{R_f}{R_1}
\]

Chapter 5, Solution 24

We notice that \( v_1 = v_2 \). Applying KCL at node 1 gives

\[
\frac{v_1}{R_1} + \left( \frac{v_1 - v_s}{R_2} + \frac{v_1 - v_o}{R_f} \right) = 0 \quad \Rightarrow \quad \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_f} \right) v_1 - \frac{v_s}{R_2} - \frac{v_o}{R_f} = 0
\]
Applying KCL at node 2 gives

\[
\frac{v_1}{R_3} + \frac{v_1 - v_s}{R_4} = 0 \quad \rightarrow \quad v_1 = \frac{R_3}{R_3 + R_4} v_s
\]  \hspace{1cm} (2)

Substituting (2) into (1) yields

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

i.e.

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

Chapter 5, Solution 25.

\[v_o = \mathbf{2} \text{ V}\]

\[\begin{array}{c}
\mathbf{+} \\
\mathbf{+} \\
\mathbf{-} \\
\end{array}
\]

\[v_a \quad v_o
\]

\[-v_a + 3 + v_o = 0 \quad \text{which leads to } v_a = v_o + 3 = \mathbf{5} \text{ V}.
\]

Chapter 5, Solution 26

\[v_b = 0.4 = \frac{8}{8+2} v_o = 0.8 v_o \quad \rightarrow \quad v_o = 0.4 / 0.8 = 0.5 \text{ V}
\]

Hence,

\[i_o = \frac{v_o}{5k} = \frac{0.5}{5k} = 0.1 \text{ mA}
\]
Chapter 5, Solution 27.

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

$$v_a = \frac{2}{(8+2)} v_i = 0.2v_i$$

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

$$G = \frac{v_0}{v_i} = 10.2$$

(b) $v_i = \frac{v_0}{G} = \frac{15}{10.2} \cos 120 \pi t = 1.471 \cos 120 \pi t \text{V}$

Chapter 5, Solution 28.

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

But $v_1 = 0.4 \text{V}$,

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

Alternatively, viewed as a noninverting amplifier,

$$v_o = \left(1 + \frac{50}{10}\right)(0.4 \text{V}) = 2.4 \text{V}$$

$$i_o = \frac{v_o}{20k} = \frac{2.4}{20k} = 120 \mu \text{A}$$
Chapter 5, Solution 29

\[ v_a = \frac{R_2}{R_1 + R_2} v_i, \quad v_b = \frac{R_1}{R_1 + R_2} v_o \]

But \( v_a = v_b \quad \longrightarrow \quad \frac{R_2}{R_1 + R_2} v_i = \frac{R_1}{R_1 + R_2} v_o \)

Or

\[ \frac{v_o}{v_i} = \frac{R_2}{R_1} \]

Chapter 5, Solution 30.

The output of the voltage becomes

\[ v_o = v_i = 12 \]

\[ 30\Omega \parallel 20 = 12k\Omega \]

By voltage division,

\[ v_x = \frac{12}{12 + 60} (1.2) = 0.2V \]

\[ i_x = \frac{v_x}{20k} = \frac{0.2}{20k} = 10\mu A \]

\[ p = \frac{v_x^2}{R} = \frac{0.04}{20k} = 2\mu W \]
Chapter 5, Solution 31.

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

At node 1,

\[
\frac{12 - v_1}{3} = \frac{v_1 - v_o}{6} + \frac{v_1 - v_o}{12} \rightarrow 48 = 7v_1 - 3v_o \tag{1}
\]

At node 2,

\[
\frac{v_1 - v_o}{6} = \frac{v_o - 0}{6} = i_x \rightarrow v_1 = 2v_o \tag{2}
\]

From (1) and (2),

\[
v_o = \frac{48}{11}
\]

\[
i_x = \frac{v_o}{6k} = 0.7272 \text{mA}
\]

Chapter 5, Solution 32.

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

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

\[
60 \parallel 30 = 20k\Omega
\]
By voltage division,

\[ v_o = \frac{20}{20 + 20} \cdot \frac{v_o}{2} = 12 \text{mV} \]

\[ i_x = \frac{v_x}{(20 + 20)k} = \frac{24 \text{mV}}{40k} = 600 \text{nA} \]

\[ p = \frac{v_o^2}{R} = \frac{144 \times 10^{-6}}{60 \times 10^3} = 204 \text{nW} \]

**Chapter 5, Solution 33.**

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

![Noninverting Amplifier Diagram]

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 \( v_i = 4 \text{V} \).

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

Power dissipated by the 3kΩ resistor is

\[ \frac{v_o^2}{R} = \frac{36}{3k} = 12 \text{mW} \]

\[ i_x = \frac{v_a - v_o}{R} = \frac{4 - 6}{1k} = -2 \text{mA} \]
Chapter 5, Solution 34

\[ \frac{v_1 - v_{\text{in}}}{R_1} + \frac{v_1 - v_{\text{in}}}{R_2} = 0 \]  

(1)

but

\[ v_a = \frac{R_3}{R_3 + R_4} v_o \]  

(2)

Combining (1) and (2),

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

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

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

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

\[ v_o = \frac{R_3 + R_4}{R_3 (R_1 + R_2)} (v_1 R_2 + v_2) \]

Chapter 5, Solution 35.

\[ A_v = \frac{v_o}{v_i} = 1 + \frac{R_f}{R_i} = 10 \quad \rightarrow \quad R_f = 9R_i \]

If \( R_i = 10k\Omega \), \( R_f = 90k\Omega \)
Chapter 5, Solution 36

\[ V_{Th} = V_{ab} \]

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

\[ V_{Th} = V_{ab} = \frac{R_1 + R_2}{R_1} v_s = (1 + \frac{R_2}{R_1})v_s \]

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

\[ R_{Th} = \frac{v_o}{i_o} = 0 \]

Chapter 5, Solution 37.

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

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

\[ v_o = -3V \]
Chapter 5, Solution 38.

\[ v_o = \left[ \frac{R_f}{R_1} v_1 + \frac{R_f}{R_2} v_2 + \frac{R_f}{R_3} v_3 + \frac{R_f}{R_4} v_4 \right] \]
\[ = \left[ \frac{50}{25} (10) + \frac{50}{20} (-20) + \frac{50}{10} (50) + \frac{50}{50} (-100) \right] \]
\[ = -120 \text{mV} \]

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,

\[ v_o = -16.5 = -9 - 2.5v_2 \quad \rightarrow \quad v_2 = 3 \text{ V} \]

Chapter 5, Solution 40

Applying KCL at node a,

\[ \frac{v_1 - v_a}{R_1} + \frac{v_2 - v_a}{R_2} + \frac{v_3 - v_a}{R_3} = 0 \quad \rightarrow \quad \frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_3}{R_3} = v_o \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) \quad (1) \]
But

\[ v_a = v_b = \frac{R}{R + R_f} v_o \]  \hspace{1cm} (2)

Substituting (2) into (1) gives

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

or

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

Chapter 5, Solution 41.

\[ R_f/R_1 = 1/(4) \rightarrow R_1 = 4R_f = 40k\Omega \]

The averaging amplifier is as shown below:

![Averaging Amplifier Diagram]

Chapter 5, Solution 42

\[ R_f = \frac{1}{3} R_1 = 10k\Omega \]
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

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

\[ \frac{R_f}{R_i} = \frac{1}{4} \rightarrow R_f = \frac{R_i}{4} = \frac{12}{4} = 3k\Omega \]

Chapter 5, Solution 44.

At node b,

\[ \frac{v_b - v_1}{R_1} + \frac{v_b - v_2}{R_2} = 0 \rightarrow v_b = \frac{v_1 + v_2}{\frac{R_1}{1} + \frac{1}{R_2}} \]

(1)

At node a,

\[ \frac{0 - v_a}{R_3} = \frac{v_a - v_o}{R_4} \rightarrow v_a = \frac{v_o}{1 + \frac{R_4}{R_3}} \]

(2)

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

\[ \frac{v_o}{1 + \frac{R_4}{R_3}} = \frac{R_2 v_1 + R_1 v_1}{R_1 + R_2} \]

or

\[ v_o = \frac{(R_3 + R_4)}{R_3(R_1 + R_2)} (R_2 v_1 + R_1 v_1) \]
Chapter 5, Solution 45.

This can be achieved as follows:

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

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

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 (\(R<100k\Omega\)).

![Diagram](image)

Chapter 5, Solution 46.

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

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.

![Diagram](image)
Chapter 5, Solution 47.

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

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

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

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, \((10 + 30)\,i_1 = 5\quad \rightarrow \quad i_1 = 5/(40) = 0.125\,\mu A\)

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

But, \( 10i + v_1 - 5 = 0 \quad \rightarrow \quad v_1 = 5 - 10i = 3.75\,mV\)
\( 60i + v_2 + 5 = 0 \quad \rightarrow \quad v_2 = -5 - 60i = -2\,mV\)

As a difference amplifier,

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

\( = 23\,mV \)
Chapter 5, Solution 49.

\[ R_1 = R_3 = 10k\Omega, \quad R_2/(R_1) = 2 \]

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

Verify:

\[
\begin{align*}
  v_o &= \frac{R_2}{R_1} \frac{1 + R_1/R_2}{1 + R_3/R_4} v_2 - \frac{R_2}{R_1} v_1 \\
  &= 2 \frac{1 + 0.5}{1 + 0.5} v_2 - 2v_1 = 2(v_2 - v_1)
\end{align*}
\]

Thus, \( R_1 = R_3 = 10k\Omega, \quad R_2 = R_4 = 20k\Omega \)

Chapter 5, Solution 50.

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

![Difference Amplifier Diagram]

\[ v_o = \frac{R_2}{R_1} (v_2 - v_1) = 2(v_2 - v_1), \quad \text{i.e.} \frac{R_2}{R_1} = 2 \]

If \( R_1 = 10k\Omega \) then \( R_2 = 20k\Omega \)

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

\[
\begin{align*}
v_o &= 2v_1 - 2v_2 \\
   &= \left[ -\frac{R}{R/2}(-v_1) + \frac{R}{R/2}v_2 \right] \\
   &= \left[ -\frac{R}{R_1}(-v_1) + \frac{R}{R_2}v_2 \right]
\end{align*}
\]

i.e. \( R_f = R, \quad R_1 = R/2 = R_2 \)
We need an inverter to invert $v_1$ and a summer, as shown below. We may let $R = 10k\Omega$.

![Inverter and Summer Circuit](attachment:image.png)

Chapter 5, Solution 51.

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

![Cascaded Circuits](attachment:image.png)

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 $R = 10 \, \text{k}\Omega$.

![Summing Amplifier Diagram]

Chapter 5, Solution 53.

(a)

At node a, $v$

$$v_a = v_b$$

At node b,

$$v_b = \frac{R_2}{R_1 + R_2} v_2$$

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

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

(b)

At node A,
\[ \frac{v_i - v_A}{R_1/2} + \frac{v_B - v_A}{R_g} = \frac{v_A - v_a}{R_1/2} \]

or
\[ v_1 - v_A + \frac{R_1}{2R_g} (v_B - v_A) = v_A - v_a \]  \hspace{1cm} (1)

At node B,
\[ \frac{v_2 - v_B}{R_1/2} = \frac{v_B - v_A}{R_1/2} + \frac{v_B - v_b}{R_g} \]

or
\[ v_2 - v_B = \frac{R_1}{2R_g} (v_B - v_A) = v_B - v_b \]  \hspace{1cm} (2)

Subtracting (1) from (2),
\[ v_2 - v_i - v_B + v_A = -\frac{2R_1}{2R_g} (v_B - v_A) = v_B - v_A - v_b + v_a \]

Since, \( v_a = v_b \),
\[ \frac{v_2 - v_i}{2} = \left(1 + \frac{R_1}{2R_g}\right) (v_B - v_A) = \frac{v_i}{2} \]
or \( v_B - v_A = \frac{v_i}{2} \cdot \frac{1}{1 + \frac{R_1}{2R_g}} \) (3)

But for the difference amplifier,

\[
v_o = \frac{R_2}{R_1/2} (v_B - v_A)
\]

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

Equating (3) and (4),

\[
\frac{R_1}{2R_2} v_o = \frac{v_i}{2} \cdot \frac{1}{1 + \frac{R_1}{2R_g}}
\]

\[
\frac{v_o}{v_i} = \frac{R_2}{R_1} \cdot \frac{1}{1 + \frac{R_1}{2R_g}}
\]

(c) At node a,

\[
\frac{v_1 - v_a}{R_1} = \frac{v_a - v_A}{R_2/2}
\]

\[
v_1 - v_a = \frac{2R_1}{R_2} v_a - \frac{2R_1}{R_2} v_A
\]

At node b,

\[
v_2 - v_b = \frac{2R_1}{R_2} v_b - \frac{2R_1}{R_2} v_B
\]

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

At node A,

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

\[
v_a - v_A + \frac{R_2}{2R_g} (v_B - v_A) = v_A - v_o
\] (4)
At node B,
\[ \frac{v_b - v_B}{R/2} - \frac{v_B - v_A}{R_g} = \frac{v_B - 0}{R/2} \]
\[ v_b - v_B - \frac{R_2}{2R_g} (v_B - v_A) = v_B \]  \hspace{1cm} (5)
Subtracting (5) from (4),
\[ v_B - v_A + \frac{R_2}{R_g} (v_B - v_A) = v_A - v_B - v_o \]
\[ 2 (v_B - v_A) \left( 1 + \frac{R_2}{2R_g} \right) = -v_o \]  \hspace{1cm} (6)
Combining (3) and (6),
\[ \frac{-R_2}{R_1} v_i \left( 1 + \frac{R_2}{2R_g} \right) = -v_o \]
\[ \frac{v_o}{v_i} = \frac{R_2}{R_1} \left( 1 + \frac{R_2}{2R_g} \right) \]

Chapter 5, Solution 54.

(a) \[ A_0 = A_1 A_2 A_3 = (-30)(-12.5)(0.8) = 300 \]
(b) \[ A = A_1 A_2 A_3 A_4 = A_0 A_4 = 300 A_4 \]
But \[ 20 \log_{10} A = 60 \] \[ \log_{10} A = 3 \]
\[ A = 10^3 = 1000 \]
\[ A_4 = \frac{A}{300} = 3.333 \]

Chapter 5, Solution 55.

Let \[ A_1 = k, \ A_2 = k, \text{ and } A_3 = k/(4) \]
\[ A = A_1 A_2 A_3 = k^3/(4) \]
\[ 20 \log_{10} A = 42 \]
\[ \log_{10} A = 2.1 \rightarrow A = 10^{2.1} = 125.89 \]
\[ k^3 = 4A = 503.57 \]
\[ k = \sqrt[3]{503.57} = 7.956 \]
Thus \[ A_1 = A_2 = 7.956, \ A_3 = 1.989 \]
Chapter 5, Solution 56.

There is a cascading system of two inverting amplifiers.

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

\[ i_o = \frac{v_s}{2k} = 3v_s \text{mA} \]

(a) When \( v_s = 12\text{V} \), \( i_o = 36\text{mA} \)

(b) When \( v_s = 10 \cos 377t \text{V} \), \( i_o = 30 \cos 377t \text{mA} \)

Chapter 5, Solution 57

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

\[ v_o = \frac{R_2}{R_1} (v_2 - v_1) = \frac{100}{50} \left(1 + \frac{1}{4}\right) = 10 \text{mA} \]

The second stage is a non-inverter.

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

Which leads to,

\[ R = 120 \text{ k}\Omega \]

Chapter 5, Solution 58.

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

\[ v_1 = \frac{3}{3 + 1} (0.6) = 0.45 \text{V} \]

Thus

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

\[ i_o = \frac{0 - v_o}{4k} = 0.7875\text{mA} \]
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

\[ \frac{v_o}{v_s} = -\frac{2}{1.5} = -1.333 \]

Chapter 5, Solution 60.

Transform the current source as shown below:

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

\[ v_1 = \frac{-10}{5} (5i_s) - \frac{10}{4} v_o = -10i_s - 2.5v_o \quad (1) \]

By voltage division,
\[ v_1 = \frac{3}{3+3} v_o = \frac{1}{2} v_o \] 

(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),

\[ 0.5v_o = -10i_s - 2.5v_o \quad \rightarrow \quad 3v_o = 10i_s \]

\[ v_o = -2i_o = -\frac{10i_s}{3} \quad \rightarrow \quad \frac{i_o}{i_s} = \frac{5}{3} = 1.667 \]

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.

\[ v_{01} = -\frac{R_2}{R_1} v_1 \]

\[ v_o = -\frac{R_2}{R_5} v_{01} - \frac{R_4}{R_3} v_2 \]

\[ v_1 = \frac{R_2 R_4}{R_1 R_5} v_1 - \frac{R_4}{R_3} v_2 \]

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

\[ v_1 = -\frac{R_2}{R_i} v_i - \frac{R_2}{R_f} v_o \] 

(1)

The second stage is a follower. By voltage division
\[ v_o = v_2 = \frac{R_4}{R_3 + R_4} v_1 \quad \rightarrow \quad v_1 = \frac{R_3 + R_4}{R_4} v_o \quad (2) \]

From (1) and (2),

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

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

\[ v_o = -\frac{R_2}{R_1} + \frac{1}{1 + \frac{R_3 + R_2}{R_4 + R_4}} \]

\[ v_o = -\frac{R_2 R_4}{R_1 (R_2 + R_3 + R_4)} \]

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,

\[ v_1 = -\frac{R_2}{R_1} v_i - \frac{R_2}{R_3} v_o \quad (1) \]

For the second stage,

\[ v_o = -\frac{R_4}{R_5} v_1 - \frac{R_4}{R_o} v_i \quad (2) \]

Combining (1) and (2),

\[ v_o = \frac{R_4}{R_5} \left(\frac{R_2}{R_1}\right) v_1 + \frac{R_4}{R_5} \left(\frac{R_2}{R_3}\right) v_o - \frac{R_4}{R_6} v_i \]

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

\[ v_o = \frac{\frac{R_2 R_4}{R_1 R_5} - \frac{R_4}{R_6}}{1 - \frac{R_2 R_4}{R_3 R_5}} \]
Chapter 5, Solution 64

At node 1, \( v_1 = 0 \) so that KCL gives

\[
G_1 v_s + G_4 v_o = -Gv
\]  \hspace{1cm} (1)

At node 2,

\[
G_2 v_s + G_3 v_o = -Gv
\]  \hspace{1cm} (2)

From (1) and (2),

\[
G_1 v_s + G_4 v_o = G_2 v_s + G_3 v_o \quad \Rightarrow \quad (G_1 - G_2) v_s = (G_3 - G_4) v_o
\]

or

\[
v_o = \frac{G_1 - G_2}{G_3 - G_4}
v_s
\]

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

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

The third op amp is a noninverter so that

\[
v_o = \frac{40}{40 + 8} v_o' \quad \Rightarrow \quad v_o = \frac{48}{40} v_o' = -21.6 \text{ mV}
\]
Chapter 5, Solution 66.

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

Chapter 5, Solution 67.

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

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.

\[ v_o = \left(1 + \frac{6}{2}\right)v_a = (1 + 3)(-30) = -120\text{mV} \]

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,

\[ v_o = \left(1 + \frac{6}{2}\right)v_a = 4v_a = 4(-30 - 1.5v_o) \]
\[ 7v_o = -120 \quad \rightarrow \quad v_o = -\frac{120}{7} = -17.143\text{mV} \]
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

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

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

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

Therefore, \( v_o = 12V \)
\[ v_1 = 3, \quad v_2 = -\frac{20}{5} (2) = -8, \quad v_3 = (1 + \frac{50}{30})v_1 = 8 \]

\[ v_o = \left( -\frac{100}{40} v_2 + \frac{100}{80} v_3 \right) = (-20 + 10) = 10 \text{ V} \]
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
\[ v_2 = -\frac{150}{100} v_{01} = -2.5(0.4) = -1V \]

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
\[ v_2 = v_{01} = 9V \]

Chapter 5, Solution 74.

Let \( v_1 \) = output of the first op amp
\[ v_2 = \text{input of the second op amp.} \]

The two sub-circuits are inverting amplifiers
\[ v_1 = -\frac{100}{10}(0.6) = -6V \]
\[ v_2 = -\frac{32}{1.6}(0.4) = -8V \]
\[ i_o = \frac{v_1 - v_2}{20k} = -\frac{6 + 8}{20k} = 100 \mu A \]

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 Analysis | Simulate. The values of \( v \) and \( i \) are displayed on the pseudo-components as:
\[ i = 200 \mu A \]

\[ \left( v_o/v_i \right) = -4/2 = -2 \]

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

\[ i_o = -374.78 \mu A \]
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

$$i_o = -374.78 \mu A$$

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,

$$v_o = 667.75 \text{ mV}$$
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,

$$v_o = -14.61 \text{ V}$$

Chapter 5, Solution 80.

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

$$v_o = 12 \text{ V}$$
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,

$v_o = 343.37 \text{ mV}$

$i_o = 24.51 \mu\text{A}$
Chapter 5, Solution 82.

The maximum voltage level corresponds to

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

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

Chapter 5, Solution 83.

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

$$-v_o = (R_f/R_1)v_1 + \cdots + (R_f/R_6)v_6$$

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

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

(c) This corresponds to $[1 \ 1 \ 1 \ 1 \ 1 \ 1]$

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

\[
2R + R + 2R + 2R + 2R + 2R + 2R + R = 0
\]

For the first case, let \( v_2 = v_3 = v_4 = 0 \), and \( i_1 = 1 \text{A} \).

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

Second case, let \( v_1 = v_3 = v_4 = 0 \), and \( i_2 = 1 \text{A} \).

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 \( i_3 = 1 \text{A} \).

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 \( i_3 = 1 \text{A} \).
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 \([v_1 \ v_2 \ v_3 \ v_4] = [1 \ 0 \ 11],\)

\[
|v_o| = 0.6[1 + 0.25 + 0.125] = 825 \text{ mV}
\]

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

\[
|v_o| = 0.6[0.5 + 0.125] = 375 \text{ mV}
\]

Chapter 5, Solution 85.

\[ A_v = 1 + (2R/R_f) = 1 + 20,000/100 = 201 \]

Chapter 5, Solution 86.

\[ v_o = A(v_2 - v_1) = 200(v_2 - v_1) \]

(a) \[ v_o = 200(0.386 - 0.402) = -3.2 \text{ V} \]

(b) \[ v_o = 200(1.011 - 1.002) = 1.8 \text{ V} \]

Chapter 5, Solution 87.

The output, \( v_a \), of the first op amp is,

\[ v_a = (1 + (R_2/R_1))v_1 \] \hspace{1cm} (1)

Also,

\[ v_o = (-R_4/R_3)v_a + (1 + (R_4/R_3))v_2 \] \hspace{1cm} (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,

\[ v_o = (1 + (R_4/R_3))v_2 - (R_4/R_3 + (R_2R_4/R_1R_3))v_1 \]

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 \( v_i \).

\[ v_a = (3/5)v_i, \ v_b = (2/3)v_i \]

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

\[ (v_o/v_i) = A_v = -220/15 = -14.667 \]
Chapter 5, Solution 89.

If we use an inverter, \( R = 2 \text{ k ohms} \),

\[
\frac{v_o}{v_i} = -\frac{R_2}{R_1} = -6
\]

\[R = 6R = 12 \text{ k ohms}\]

Hence the op amp circuit is as shown below.

![Circuit Diagram for Chapter 5, Solution 89.]

Chapter 5, Solution 90.

Transforming the current source to a voltage source produces the circuit below,

At node b,

\[v_b = \frac{2}{(2 + 4)}v_o = \frac{v_o}{3}\]

![Circuit Diagram for Chapter 5, Solution 90.]

At node a,

\[(5i_s - v_a)/5 = (v_a - v_o)/20\]

But \(v_a = v_b = v_o/3\).

\[20i_s - (4/3)v_o = (1/3)v_o - v_o, \text{ or } i_s = v_o/30\]

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

\[i_o/i_s = (v_o/6)/(v_o/30) = 5\]
Chapter 5, Solution 91.

\[ i_o = i_1 + i_2 \quad (1) \]

But
\[ i_1 = i_s \quad (2) \]

R₁ and R₂ have the same voltage, \( v_o \), across them.

\[ R_1 i_1 = R_2 i_2, \] which leads to \[ i_2 = (R_1/R_2)i_1 \quad (3) \]

Substituting (2) and (3) into (1) gives,
\[ i_o = i_s(1 + R_1/R_2) \]
\[ i_o/i_s = 1 + (R_1/R_2) = 1 + 8/1 = 9 \]

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,
\[ v_o = v_1 - v_2 = 3v_i + 2.5v_i = 5.5v_i \]
\[ v_o/v_i = 5.5 \]
At node a, \( \frac{v_i - v_a}{R_1} = \frac{v_a - v_o}{R_3} \)
\[ v_i - v_a = (R_1/R_2)(v_a - v_o) \]
\[ v_i + (R_1/R_3)v_o = (1 + R_1/R_3)v_a \quad (1) \]

But \( v_a = v_b = v_L \). Hence, (1) becomes
\[ v_i = (1 + R_1/R_3)v_L - (R_1/R_3)v_o \quad (2) \]

\[ i_o = v_o/(R_4 + R_2||R_L), \quad i_L = (R_L/(R_2 + R_L))i_o = (R_2/(R_2 + R_1))(v_o/(R_4 + R_2||R_L)) \]

Or, \[ v_o = i_L[(R_2 + R_L)(R_4 + R_2||R_L)/R_2] \quad (3) \]

But, \[ v_L = i_L R_L \quad (4) \]

Substituting (3) and (4) into (2),
\[ v_i = (1 + R_1/R_3) i_L r_L - R_1[(R_2 + R_L)/(R_2 R_3)](R_4 + R_2||R_L)i_L \]
\[ = [((R_3 + R_1)/R_3)R_L - R_1((R_2 + R_1)/(R_2 R_3))R_4 + (R_2 R_1/(R_2 + R_L))]i_L \]
\[ = (1/A)i_L \]
Thus,

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