**Problem 2.14**
After the figure, change \( vo = 8 \ vin \) to \( vo = -8 \ vin \) and change the gain from 8 to \(-8\).

**Problem 2.43**
In Part (b), Equation (4), change \( R1 \) to \( R2 \). In Part (c), in the first equation after the figure, change \( vi \) to \(-vi\).
Exercise 2.1

(a) \( i_A = \frac{v_A}{R_A} \quad i_B = \frac{v_B}{R_B} \quad i_f = i_A + i_B = \frac{v_A}{R_A} + \frac{v_B}{R_B} \)

\( v_o = -R_f i_f = -\left( \frac{R_f}{R_A} v_A + \frac{R_f}{R_B} v_B \right) \)

(b) For the \( v_A \) source:

\( R_{inA} = \frac{v_A}{i_A} = R_A \)

(c) for the \( v_B \) source:

\( R_{inB} = \frac{v_B}{i_B} = R_B \)

(d) Because \( v_o \) is independent of \( R_L \), the output of the amplifier behaves as an ideal voltage source. Thus the output resistance is zero.
Exercise 2.2

(a)

\[ i_1 = \frac{v_{in}}{R_1} = 5 \text{ mA} \quad i_2 = i_1 = 5 \text{ mA} \]

\[ v_o = -R_2 i_2 = -50 \text{ V} \quad i_o = \frac{v_o}{R_L} = -50 \text{ mA} \]

\[ i_x = i_o - i_2 = -55 \text{ mA} \]

(b)

\[ v_{in} = 5 \]

\[ R_1 = R_2 = R_3 = R_4 = 1k\Omega \]

\[ i_1 = \frac{v_{in}}{R_1} = 5 \text{ mA} \quad i_2 = i_1 = 5 \text{ mA} \quad v_3 = R_2 i_2 = 5 \text{ V} \]

\[ i_3 = \frac{v_3}{R_3} = 5 \text{ mA} \quad i_4 = i_2 + i_3 = 10 \text{ mA} \]

\[ v_o = -R_4 i_4 - v_3 = -15 \text{ V} \]
Exercise 2.6

(a) \( v_1 = v_{in} \quad i_1 = \frac{v_{in}}{R_1} \quad v_2 = v_1 + R_2 i_1 \)

\[ v_2 = v_{in} + \frac{R_2}{R_1} \quad v_{in} = v_{in} - \frac{R_1 + R_2}{R_1} \]

\[ i_2 = \frac{v_2}{R_1} = v_{in} \frac{R_1 + R_2}{R_1^2} \]

\[ i_3 = i_1 + i_2 = v_{in} \frac{1}{R_1} + v_{in} \frac{R_1 + R_2}{R_1^2} \]

\[ i_3 = v_{in} \frac{2R_1 + R_2}{R_1^2} \]

\[ v_o = R_2 i_3 + v_2 = v_{in} \frac{R_1^2 + R_2^2 + 3R_1 R_2}{R_1^2} \]

\[ A_v = \frac{v_o}{v_{in}} = 1 + 3 \frac{R_2}{R_1} + \left(\frac{R_2}{R_1}\right)^2 \]

(b) \( A_v = 131 \)

(c) \( R_{in} = \frac{v_{in}}{i_{in}} = \frac{v_{in}}{0} = \infty \)

(d) \( v_o \) is independent of \( R_L \), therefore \( R_o = 0 \).
\[ A_{0CL} = \frac{A_{00L}}{1 + \beta A_{00L}} = \frac{0.9 \times 10^6}{1 + 0.1 \times 0.9 \times 10^6} = 9.99989 \]

The percentage change in gain is

\[ \frac{9.99989 - 9.99990}{9.99990} = -0.111 \times 10^{-3}\% \]

**Exercise 2.14**

The circuit is shown in Figure 2.29 in the text. The op amp limits at output voltages of ±12 V and currents of ±20 mA. The gain of the circuit is 4. The output current of the op amp is

\[ i_o = \frac{v_o}{R_1 + R_2} + \frac{v_o}{R_L} \quad (1) \]

(a) For a load resistance \( R_L = 1 \text{ k}\Omega \), clipping occurs for \( v_o = 12 \text{ V} \) (or \( v_s = 3 \text{ V} \)) because the current required for a 12-V output is 15 mA which is less than the current limit of the op amp.

(b) For a load resistance \( R_L = 200 \Omega \), clipping occurs for \( i_o = 20 \text{ mA} \). Using Equation (1), we find that this corresponds to an output voltage of \( v_o = 3.81 \text{ V} \) or an input voltage of 0.952 V.

**Exercise 2.15**

(a) \( f_{FP} = \frac{SR}{2\pi V_{omax}} = \frac{5 \times 10^6}{2\pi(4)} = 199 \text{ kHz} \)

(b) Clipping occurs when the output voltage limit occurs which is ±4 V.

(c) The output current is given by

\[ i_o = \frac{v_o}{R_1 + R_2} + \frac{v_o}{R_L} \]

Substituting \( i_o = 10 \text{ mA} \) and the resistor values, we find \( v_{omax} = 0.9995 \text{ V} \).
Problem 2.8

Positive feedback is a problem when we have a fire in a building. When a fire first starts heat is created which vaporizes additional fuel increasing the size of the fire. Usually positive feedback is self limiting. In the case of a building fire, the fire dies out when the building is totally consumed.

When our children behave well we give them positive feedback encouraging them to continue their good behavior.

Problem 2.9

\[ A_v = -\frac{R_2}{R_1} \]

\[ R_{in} = R_1 \]

\[ R_o = 0 \]

Problem 2.10

\[ v_o = -1k\Omega \times 2mA \]

\[ = -2V \]
(b) \[ v_o = -3 \times 2 + 5 = -1 \text{V} \]

(c) \[ v_o = -1 \times 4 = 3 \text{V} \]

(d) \[ v_o = 0 \]

\[ 2 \text{mA} \]
Problem 2.11

Notice that $A_v = -R_2/R_1 = -10$. For $v_o = 12$ V, we have $v_{in} = v_o/A_v = 12/(-10) = -1.2$ V and $v_x = v_o/(-A_{OL}) = 12/(-10^4) = -1.2$ mV. Thus $v_x$ is 1000 times less than $v_{in}$, and $v_x$ can be assumed to be zero with sufficient accuracy for most applications. Thus we are justified in using the summing-point constraint for this circuit.

Problem 2.12

(a)
\[ V_x = V_{in} - R_1 I_{in} \]  

(2)

Using Equation (2) to substitute for \( V_x \) in Equation (1) and solving for the input impedance, we find

\[ Z_{in} = \frac{V_{in}}{I_{in}} = R_1 + \frac{R_2}{1 + A_{OL}} \]

Evaluating for \( R_1 = 1 \, k\Omega, \, R_2 = 10 \, k\Omega, \) and \( A_{OL} = 10^4 \), we find

\[ Z_{in} = 1001 \, \Omega \]

The input impedance assuming infinite \( A_{OL} \) is

\[ Z_{in} = R_1 = 1000 \, \Omega \]

The percentage difference between the two answers is 0.1%

**Problem 2.14**

Starting from the input and working toward the output we can determine the voltages and currents shown below:

Eventually we determine that \( v_o = 8v_{in} \) so we have a closed loop voltage gain of 8.
Problem 2.28

(a) This circuit has negative feedback. For an ideal op amp we have $v_o(t) = v_{in}(t)$.

(b) This circuit has positive feedback. The summing-point constraint does not apply. Instead either $v_o = +5 \text{ V}$ or $v_o = -5 \text{ V}$.

Notice that $v = v_o - v_{in}$. If $v > 0$, $v_o = +5 \text{ V}$. On the other hand if $v < 0$, $v_o = -5 \text{ V}$. 

---
\[ v_i = -v_x \quad i_x = \frac{v_x}{R_{in}} + \frac{v_x - A_{OL}v_i}{R_o} \quad z_o = \frac{v_x}{i_x} = \frac{1}{\frac{1}{R_{in}} + \frac{1 + A_{OL}}{R_o}} \]

Evaluating we find \( z_o = 2.5 \times 10^{-4} \) \( \Omega \) compared to \( z_o = 0 \) for an ideal op amp.

**Problem 2.43**

(a) Refer to Figure P2.43 in the text. Writing current equations at the input terminal of the op amp and at the output terminal we have:

\[ \frac{v_s + v_i}{R_1} + \frac{v_o + v_i}{R_2} + \frac{v_i}{R_{in}} = 0 \quad (1) \]

\[ \frac{v_o + v_i}{R_2} + \frac{v_o - A_{OL}v_i}{R_o} = 0 \quad (2) \]

Now we solve Equation (1) for \( v_i \), substitute into Equation (2), and use algebra to obtain:

\[ A_{VS} = \frac{v_o}{v_s} = \frac{-R_2}{R_1 \left[ 1 + \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{in}} \right) \frac{R_o R_2 + R_2^2}{A_{OL} R_2 - R_o} \right]} \]

Evaluating we find \( A_{VS} = -9.9989 \) compared to \( A_{VS} = -10 \) for an ideal op amp.
(b) From the circuit we can write:

\[
v_s = R_1 i_s - v_i \tag{3}
\]

\[
v_i + (R_1 + R_o) \left( \frac{v_i}{R_{in}} + i_s \right) + A_{OL} v_i = 0 \tag{4}
\]

Now we solve Equation (3) for \( v_i \), substitute into Equation (4), and use algebra to obtain:

\[
Z_{in} = \frac{v_s}{i_s} = R_1 + \frac{R_2 + R_o}{1 + A_{OL} + \frac{R_2 + R_o}{R_{in}}}
\]

Evaluating we find \( Z_{in} = 1.0001 \text{ k}\Omega \) compared to \( Z_{in} = 1.0000 \text{ k}\Omega \) for an ideal op amp.

(c)
Evaluating we find $Z_o = 2.75 \text{ m} \Omega$ compared to $Z_o = 0$ for an ideal op amp.

**Problem 2.44**

Equation 2.39 states:

$$ f_t = A_{OCL} f_{BCL} = A_{OOL} f_{BOL} $$

Solving for $f_{BCL}$ we have

$$ f_{BCL} = \frac{f_t}{A_{OCL}} $$

For $A_{OCL} = 10$ we find $f_{BCL} = 1.5 \text{ MHz}$. For $A_{OCL} = 100$, we have $f_{BCL} = 150 \text{ kHz}$.

**Problem 2.45**

![Graph showing dB vs. frequency](image_url)
Figure 2.54 page 112

Show \( v_0 = \left(1 + \frac{R_2}{R_1}\right)(v_1 - v_2) \)

\[
\begin{align*}
\text{at node 2:} & \quad \frac{v_2 - v_1}{2R_1} + \frac{v_2 - v_3}{R_2} = 0 (1) \implies N_3 = -\frac{R_2 v_1 + (R_2 + 2R_1) v_2}{2R_1} \\
\text{at node 4:} & \quad \frac{v_4 - v_2}{2R_1} + \frac{v_4 - v_4}{R_2} = 0 (2) \implies V_4 = \frac{(R_2 + 2R_1) v_1 - R_2 v_3}{2R_1} \\
\text{at node 5:} & \quad \frac{v_5 - v_3}{R} + \frac{v_5 - v_0}{R} = 0 (3) \implies V_0 = \frac{2v_5 - v_3}{2} \\
\text{at node 6:} & \quad \frac{v_5 - v_0}{R} + \frac{v_5 - v_5}{R} = 0 (4) \implies V_5 = \frac{v_5}{2} \\
\end{align*}
\]

From (5), (6), \( v_0 \) is:

\[
\begin{align*}
V_0 &= \frac{(R_2 + 2R_1) v_1 - R_2 v_2 + R_2 v_1 - (R_2 + 2R_1) v_2}{2R_1} \\
&= \frac{(2R_2 + 2R_1) v_1 - (2R_2 + 2R_1) v_2}{2R_1} \\
&= \frac{2R_2 + 2R_1}{2R_1} \cdot (v_1 - v_2) = \left(1 + \frac{R_2}{R_1}\right)(v_1 - v_2)
\end{align*}
\]
\[ i_0 = -\frac{v_{in}}{R_2} \]

* at node 1: \[ \frac{v_1 - v_{in}}{R_1} + \frac{v_1 - v_0}{R_4} = 0 \] (1) \[ \Rightarrow v_1 = \frac{R_4 v_{in} + R_4 v_0}{R_1 + R_4} \] (3)

* at node 2: \[ \frac{v_1}{R_2} + i_0 + \frac{v_1 - v_0}{R_3} = 0 \] (2) \[ \Rightarrow i_0 = -v_1 \left( \frac{1}{R_2} + \frac{1}{R_3} \right) + \frac{v_0}{R_3} \] (4)

From (3) and (4) \[ i_0 = - \frac{(R_4 v_{in} + R_4 v_0)}{R_1 + R_4} \left( \frac{R_2 + R_3}{R_2 R_3} \right) + \frac{v_0}{R_3} \]

\[ i_0 = v_0 \left( \frac{1}{R_3} - \frac{R_1}{R_2 + R_4} \right) - \frac{v_{in} R_4}{R_1 + R_4 + \frac{R_2 R_3}{R_2 + R_3}} \]

We have \[ \frac{R_3}{R_2} = \frac{R_4}{R_1} \] \[ \Rightarrow R_1 R_3 = R_2 R_4 \]

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

\[ \Rightarrow A = \frac{1}{R_3} \cdot [1 - 1] = 0 \] (6)

\[ B = \frac{R_4}{R_1 + R_4} \cdot \frac{R_2 + R_3}{R_2 R_3} = \frac{1}{R_2} \left[ \frac{R_4 R_2 + R_4 R_3}{R_1 R_3 + R_1 R_4 + R_2 R_3} \right] = 1 \left[ \frac{R_1 R_2 + R_1 R_3}{R_1 R_3 + R_4 R_3} \right] \]

\[ \Rightarrow B = \frac{1}{R_2} \cdot 1 = \frac{1}{R_2} \] (7)

From (5), (6) and (7) \[ i_0 = -\frac{1}{R_2} v_{in} \]