5.1 The power dissipated by each resistor is

\[
\frac{V_{in}^2}{R} = \frac{25}{R} \quad \text{and} \quad \frac{V_{out}^2}{R_F} = \frac{[(GAIN)V_{in}^2]}{R_F} = \frac{25GAIN^2}{R_F}
\]

To be able to use 1/4 W resistors, the following must be true:

\[
\frac{25}{R} < 0.25 \quad \text{or} \quad R > 100\Omega
\]

\[
\frac{25GAIN^2}{R_F} < 0.25 \quad \text{or} \quad R_F > (GAIN^2)100\Omega
\]

(a) for GAIN=1, \( R_F > 100\Omega \)

(b) for GAIN=10, \( R_F > 10k\Omega \)

5.2

(a) \( V_+ = 1R_1 \)

\[V_o = \left(1 + \frac{R_3}{R_4}\right)V_+ = \left(1 + \frac{R_3}{R_4}\right)R_2I\]

(b) \( V_+ = V_- = V_o \)

\[I_1 = I_2 = \frac{V_+}{R_2} = \frac{V_o}{R_2}\]

\[V_+ + I_1R_1 = V_o + I_3R_3\]

so

\[I_3 = \frac{R_1}{R_3}I_1 = \frac{R_1}{R_2R_3}V_o\]

\[I = I_1 + I_3 = V_o\left(\frac{1}{R_2} + \frac{R_1}{R_2R_3}\right)\]

so

\[V_o = \frac{R_2R_3}{R_1 + R_2}I\]

5.3 With \( R_F \) replaced by a short, the op amp circuit becomes a buffer so the gain is 1.
5.4

(a) \( V_- = V_+ = \frac{R_2}{R_1 + R_2} V_1 = 5V \)

\( V_{out} = V_- + V_2 - I_3 R_3 \)

but \( I_3 = 0 \), so

\( V_{out} = V_- + V_2 = 10V \)

(b) same as (a)

5.5
\( V_+ = V_- = V_i \)

\( V_4 = \left( 1 + \frac{R_3}{R_2} \right) V_+ \)

\( I_4 = \frac{V_4}{R_4} = \frac{R_2 + R_3}{R_2 R_4} V_i \)

5.6 If \( V_A \) denotes the voltage at the output of the first op amp,

\( V_A = V_- = V_+ = 0V \)

and from Ohm’s Law, the current from voltage source \( V_1 \) is

\( I_1 = \frac{V_1 - V_A}{R} = \frac{V_1}{R} \)

If \( V_B \) denotes the voltage at the inverting input of the second op amp,

\( V_B = V_- = V_+ = V_2 \)

and from Ohm’s Law,

\( I_4 = \frac{V_B}{R} = \frac{V_2}{R} \) and \( I_2 = \frac{V_B - V_{out}}{R} = \frac{V_2 - V_{out}}{R} \)

where \( I_4 \) is the current through the vertical resistor and \( I_2 \) is the current through the feedback resistor of the second op amp. From this,

\( V_{out} = V_2 - I_2 R \)

Now applying Ohm’s Law to the resistor between the op amps gives

\( I_3 = \frac{V_A - V_B}{R} = \frac{V_2}{R} \)

where \( I_3 \) is the current through the resistor.
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From KCL, the current out of the first op amp is

\[ I_{out1} = I_3 - I_1 = -\frac{V_2}{R} - \frac{V_1}{R} = -\frac{1}{R}(V_1 + V_2) \]

The negative sign indicates that the current is actually into the op amp. From KCL,

\[ I_2 = I_3 - I_4 = -\frac{V_2}{R} - \frac{V_2}{R} = \left(\frac{2}{R}\right)V_2 \]

Therefore,

\[ V_{out} = V_2 - \left(\frac{2V_2}{R}\right)R = 3V_2 \]

5.7 \( V_o \neq V_1 \) because of positive feedback.

5.8 Applying Ohm’s Law to both resistors gives

\[ I_1 = \frac{V_1}{R_1} \quad \text{and} \quad I_2 = \frac{V_2}{R_2} \]

From KCL,

\[ I_F = I_1 + I_2 \]

Since \( V_o + I_F R_F = 0 \),

\[ V_o = -R_F \left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) \]

For \( R_1 = R_2 = R_F = R \),

\[ V_o = -(V_1 + V_2) \]

5.9 Applying Ohm’s Law to both resistors gives

\[ I_1 = \frac{V_1 - V_3}{R_1} \quad \text{and} \quad I_2 = \frac{V_2 - V_3}{R_2} \]

From KCL,

\[ I_F = I_1 + I_2 \]

Since \( V_o + I_F R_F = V_3 \),

\[ V_o = V_3 - R_F \left(\frac{V_1 - V_3}{R_1} + \frac{V_2 - V_3}{R_2}\right) \]
For $R_1 = R_2 = R_F = R$,

$$V_o = V_3 - (V_1 - V_3 + V_2 - V_3) = 3V_3 - (V_1 + V_2)$$

5.10 From voltage division,

$$V_o = V_3 = \left( \frac{R_F}{R_F + R_2} \right) V_2$$

From Ohm’s Law,

$$I_1 = \frac{(V_1 - V_o)}{R_1}$$

The output voltage can be found with:

$$V_o = V_3 - I_1 R_F = \left( \frac{R_F}{R_F + R_2} \right) V_2 - \frac{\left( V_1 - \left( \frac{R_F}{R_F + R_2} \right) V_2 \right)}{R_1} R_F$$

Simplifying gives

$$V_o = \frac{R_1 V_2 - (V_1 (R_F + R_2) - R_F V_2)}{R_1 (R_F + R_2) / R_F}$$

For $R_1 = R_2 = R$,

$$V_o = \frac{R_F}{R} (V_2 - V_1)$$

5.11 $V_{out_in} = \left( 1 + \frac{R_F}{R} \right) V_{in}$ and $V_{out_ref} = \left( \frac{R_F}{R} \right) V_{ref}$

$$V_{out} = V_{out_in} + V_{out_ref} = \left( 1 + \frac{R_F}{R} \right) V_{in} - \left( \frac{R_F}{R} \right) V_{ref}$$

5.12 Using superposition,

$$V_{o_1} = \frac{R_4}{R_3} V_3$$

$$V_{o_2} = \left( 1 + \frac{R_4}{R_3} \right) \frac{R_5}{R_3 + R_5} V_4$$
\[
V_0 = V_{o1} + V_{o2} = -\frac{R_4}{R_3}V_3 + \left(1 + \frac{R_4}{R_3}\right)\frac{R_5}{R_3 + R_5}V_4
\]

5.13 \(V_+ = V_- = 0\)

\[V_i = L\frac{dI_L}{dt}\text{ so } I_L = \frac{1}{L}\int V_i dt\]

\[V_o = V_- + I_R R\]

but \(I_R = I_L\), so \(V_o = \frac{R}{L}\int V_i dt\)

5.14

(a) \(V_o = -\left(\frac{R_F}{R}\right)V_i = -2V_i\)

(b) \(V_o = -\frac{1}{RC}\int V_i dt = \int V_i dt\)

(c) \(V_o = -\frac{R_F}{R}(V_1 + V_2) = -4V_i\)

(d) \(V_- = V_+ = 0\ V\)

From Ohm’s Law,
\[I_1 = \frac{V_1}{5k} = \frac{V_i}{5k}\text{ and } I_2 = \frac{V_2}{10k} = \frac{V_i}{10k}\]

From KCL,
\[I_F = I_1 + I_2 = V_i\left(\frac{1}{5k} + \frac{1}{10k}\right)\]

but from Ohm’s Law,
\[I_F = \frac{0 - V_o}{5k}\]

so
\[V_o = -5kI_F = -V_i\left(1 + \frac{1}{2}\right) = -\frac{3}{2}V_i\]
5.15

The limit on the feedback resistor current is:

\[ I_F = \frac{V_{\text{out}}}{R_F} = \frac{10V}{R_F} < 10mA \]

Therefore,

\[ R_F > \frac{10V}{10mA} = 1k\Omega \]

5.16

5.17 The limit on the feedback resistor current is:

\[ I_F = \frac{V_{\text{out}}}{R_F} = \frac{10V}{R_F} < 10mA \]

Therefore,

\[ R_F > \frac{10V}{10mA} = 1k\Omega \]

5.18 closed loop gain \[ \frac{R_F}{R} = 10 \]

so the fall-off frequency is \(10^5\)Hz.