AP 5.2 From Assessment Problem 5.1

$$v_o = (-R_f/R_i)v_s = (-R_x/16{,}000)v_s$$
$$= (-R_x/16{,}000)(-0.640) = 0.64R_x/16{,}000 = 4\times10^{-5}R_x$$

Use the negative power supply value to determine one limit on the value of R_x:

$4\times10^{-5}R_x = -15$ so $R_x = -15/4\times10^{-5} = -375\,\text{k}\Omega$

Since we cannot have negative resistor values, the lower limit for R_x is 0. Now use the positive power supply value to determine the upper limit on the value of R_x:

$4\times10^{-5}R_x = 10$ so $R_x = 10/4\times10^{-5} = 250\,\text{k}\Omega$

Therefore,

$0 \leq R_x \leq 250\,\text{k}\Omega$

AP 5.4 **[a]** Write a node voltage equation at v_n; remember that for an ideal op amp, the current into the op amp at the inputs is zero:

$$\frac{v_n}{4500} + \frac{v_n - v_o}{63{,}000} = 0$$

Solve for v_o in terms of v_n by multiplying both sides by 63,000 and collecting terms:

$$14v_n + v_n - v_o = 0 \qquad \text{so} \qquad v_o = 15v_n$$

Now use voltage division to calculate v_p. We can use voltage division because the op amp is ideal, so no current flows into the non-inverting input terminal and the 400 mV divides between the 15 kΩ resistor and the R_x resistor:

$$v_p = \frac{R_x}{15{,}000 + R_x}(0.400)$$

Now substitute the value $R_x = 60$ kΩ:

$$v_p = \frac{60{,}000}{15{,}000 + 60{,}000}(0.400) = 0.32 \text{ V}$$

Finally, remember that for an ideal op amp, $v_n = v_p$, so substitute the value of v_p into the equation for v_0

$$v_o = 15v_n = 15v_p = 15(0.32) = 4.8 \text{ V}$$

[b] Substitute the expression for v_p into the equation for v_o and set the resulting equation equal to the positive power supply value:

$$v_o = 15\left(\frac{0.4R_x}{15{,}000 + R_x}\right) = 5$$

$$15(0.4R_x) = 5(15{,}000 + R_x) \quad \text{so} \quad R_x = 75\,\text{k}\Omega$$

AP 5.5 **[a]** Since this is a difference amplifier, we can use the expression for the output voltage in terms of the input voltages and the resistor values given in Eq. 5.22:

$$v_o = \frac{20(60)}{10(24)}v_\mathrm{b} - \frac{50}{10}v_\mathrm{a}$$

Simplify this expression and substitute in the value for v_b:

$$v_o = 5(v_\mathrm{b} - v_\mathrm{a}) = 20 - 5v_\mathrm{a}$$

Set this expression for v_o to the positive power supply value:

$$20 - 5v_\mathrm{a} = 10 \text{ V} \quad \text{so} \quad v_\mathrm{a} = 2 \text{ V}$$

Now set the expression for v_o to the negative power supply value:

$$20 - 5v_\mathrm{a} = -10 \text{ V} \quad \text{so} \quad v_\mathrm{a} = 6 \text{ V}$$

Therefore $\quad 2 \le v_\mathrm{a} \le 6 \text{ V}$

[b] Begin as before by substituting the appropriate values into Eq. 5.22:

$$v_o = \frac{8(60)}{10(12)}v_\mathrm{b} - 5v_\mathrm{a} = 4v_\mathrm{b} - 5v_\mathrm{a}$$

Now substitute the value for v_b:

$$v_o = 4(4) - 5v_\mathrm{a} = 16 - 5v_\mathrm{a}$$

Set this expression for v_o to the positive power supply value:

$$16 - 5v_\mathrm{a} = 10 \text{ V} \quad \text{so} \quad v_\mathrm{a} = 1.2 \text{ V}$$

Now set the expression for v_o to the negative power supply value:

$$16 - 5v_\mathrm{a} = -10 \text{ V} \quad \text{so} \quad v_\mathrm{a} = 5.2 \text{ V}$$

Therefore $\quad 1.2 \le v_\mathrm{a} \le 5.2 \text{ V}$

P 5.7 **[a]** The circuit shown is a non-inverting amplifier.

[b] We assume the op amp to be ideal, so $v_n = v_p = 3$V. Write a KCL equation at v_n:

$$\frac{3}{40{,}000} + \frac{3 - v_o}{80{,}000} = 0$$

Solving,

$v_o = 9$ V.

P 5.16 **[a]** This circuit is an example of an inverting summing amplifier.

[b] $v_o = -\frac{220}{33}v_\mathrm{a} - \frac{220}{22}v_\mathrm{b} - \frac{220}{80}v_\mathrm{c} = -8 + 15 - 11 = -4\ \mathrm{V}$

[c] $v_o = -19 - 10v_\mathrm{b} = \pm 6$

$$\therefore \quad v_\mathrm{b} = -1.3\ \mathrm{V} \quad \text{when} \quad v_o = -6\ \mathrm{V};$$

$$v_\mathrm{b} = -2.5\ \mathrm{V} \quad \text{when} \quad v_o = 6\ \mathrm{V}$$

$$\therefore \quad -2.5\ \mathrm{V} \leq v_\mathrm{b} \leq -1.3\ \mathrm{V}$$

P 5.20 **[a]** $v_p = v_s, \qquad v_n = \frac{R_1 v_o}{R_1 + R_2}, \qquad v_n = v_p$

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

[b] $v_o = v_s$

[c] Because $v_o = v_s$, thus the output voltage follows the signal voltage.