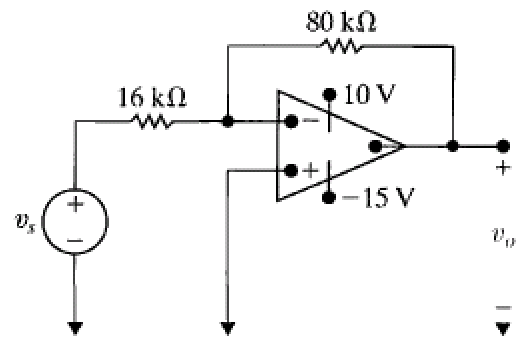
Mathcad Solutions to Assesment Problems from Nilsson and Riedel
Electric Circuits 9th edition, © 2012 R. Doering.
Chapter 5

AP 5.1 Assume that the op amp in the circuit shown is ideal.
a) Calculate v_0 for the following values of v_s: 0.4,2.0,3.5, -0.6, -1.6, and -2.4 V.
b) Specify the range of vs required to avoid amplifier saturation.



a) $$\text{Gain} := \frac{-80\text{k}\Omega}{16\text{k}\Omega} = -5$$

$$\text{Clamp}(v,H,L) := \begin{vmatrix} H & \text{if } v > H \\ L & \text{if } v < L \\ v & \text{otherwise} \end{vmatrix}$$

$$v_s := \begin{pmatrix} 0.4 \\ 2.0 \\ 3.5 \\ -0.6 \\ -1.6 \\ -2.4 \end{pmatrix} V \qquad v_o := \overrightarrow{\text{Clamp}(\text{Gain} \cdot v_s, 10V, -15V)} \qquad v_o = \begin{pmatrix} -2 \\ -10 \\ -15 \\ 3 \\ 8 \\ 10 \end{pmatrix} V$$

b) $$\frac{10}{\text{Gain}} \le v_s \le \frac{-15}{\text{Gain}} \text{ explicit}, \text{Gain} \rightarrow -2 \le v_s \land v_s \le 3$$

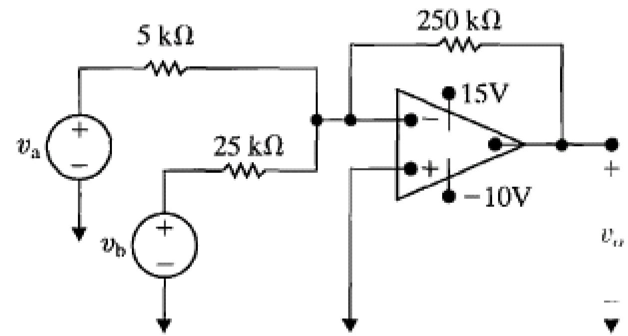
AP 5.2 The source voltage v_s in the circuit in Assessment Problem 5.1 is -640 mV. The 80 kΩ feedback resistor is replaced by a variable resistor R_x. What range of R_x allows the inverting amplifier to operate in its linear region?

$$v_s := -640\text{mV} \qquad \text{Gain}_{max} := \frac{10\text{V}}{v_s} = -15.625$$

$$R_{fmax} := -16\text{k}\Omega \cdot \text{Gain}_{max} = 250\,\text{k}\Omega$$

$$0 < R_x < 250\text{k}\Omega$$

AP 5.3 a) Find v_0 in the circuit shown if $v_a = 0.1$ V and $v_b = 0.25$ V.
b) If $v_b = 0.25$ V, how large can v_a be before the op amp saturates?
c) If $v_a = 0.10$ V, how large can v_b be before the op amp saturates?
d) Repeat (a), (b), and (c) with the polarity of v_b reversed.



a) $v_a := 0.1\text{V}$ $\quad v_b := 0.25\text{V}$

$$i := \frac{v_a}{5\text{k}\Omega} + \frac{v_b}{25\text{k}\Omega} \qquad v_o := -i \cdot 250\text{k}\Omega = -7.5\,\text{V}$$

b) $$v_{a\_max} := \frac{-10\text{V} + 10v_b}{-50} = 0.15\,\text{V}$$

c) $$v_{b\_max} := \frac{-10\text{V} + 50v_a}{-10} = 0.5\,\text{V}$$

d) $v_b := -0.25\text{V}$ $\quad i := \frac{v_a}{5\text{k}\Omega} + \frac{v_b}{25\text{k}\Omega}$ $\quad v_o := -i \cdot 250\text{k}\Omega = -2.5\,\text{V}$

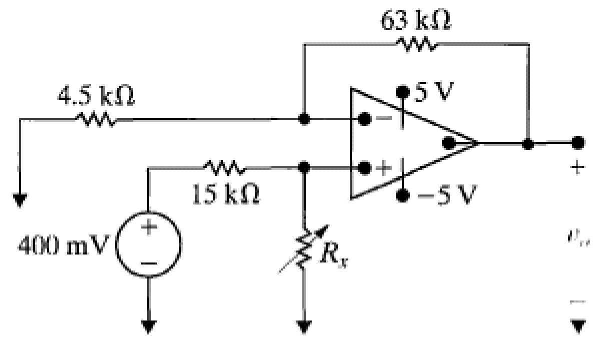
$$v_{a\_max} := \frac{-10\text{V} + 10v_b}{-50} = 0.25\,\text{V}$$

$$v_{b\_min} := \frac{15\text{V} + 50v_a}{-10} = -2\,\text{V}$$

AP 5.4 Assume that the op amp in the circuit shown is ideal.

a) Find the output voltage when the variable resistor is set to 60 kΩ.

b) How large can R_x be before the amplifier saturates?



a) $v_s := 400mV$ $R_x := 60k\Omega$

$$v_p := v_s \cdot \frac{R_x}{R_x + 15k\Omega} = 0.32\,V \qquad v_n := v_p \qquad v_o := v_o$$

$$i := \frac{v_n}{4.5k\Omega} \qquad \frac{v_o - v_n}{63k\Omega} = i \text{ solve}, v_o \rightarrow 4.8 \cdot V$$

b) $v_{sat} := 5V$

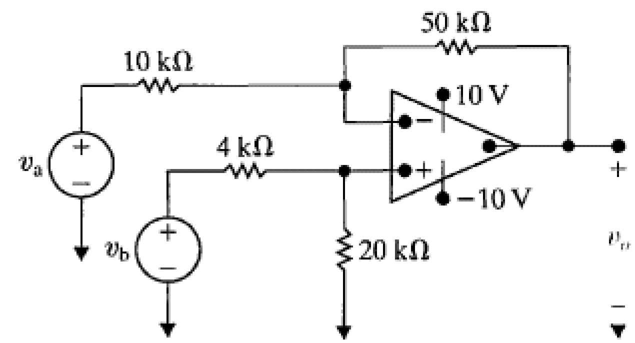
$$v_n := 5V \cdot \frac{4.5}{63 + 4.5} = \frac{1}{3}\,V \qquad R_x := R_x$$

$$v_p := v_n \qquad v_p = v_s \cdot \frac{R_x}{R_x + 15k\Omega} \left| \begin{matrix} \text{solve}, R_x \\ \text{float}, 3 \end{matrix} \right. \rightarrow -\frac{5.0e15 \cdot V \cdot k\Omega}{(3.33e14 \cdot V + -4.0e17 \cdot mV)^{1.0}}$$

$$R_x := -\frac{4.9999999999999995e15 \cdot V \cdot k\Omega}{(3.3333333333333333e14 \cdot V - 4.0e17 \cdot mV)^{1.0}} = 75\,k\Omega$$

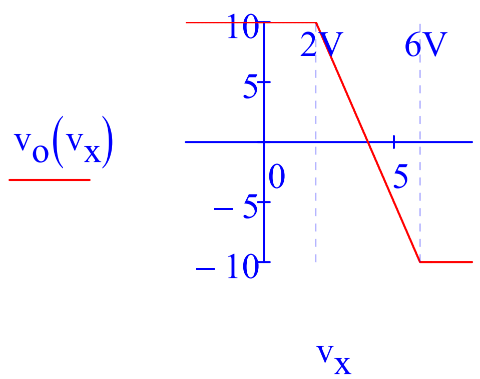
AP 5.5 a) In the difference amplifier shown, v_b = 4.0 V. What range of values for v_a will result in linear operation?

b) Repeat (a) with the 20 kΩ resistor decreased to 8 kΩ.



a) $v_b := 4.0V$

$v_o(v_a) := \text{Clamp}(5v_b - 5v_a, 10V, -10V)$



$$-\left(\frac{10V}{5} - v_b\right) = 2\,V$$

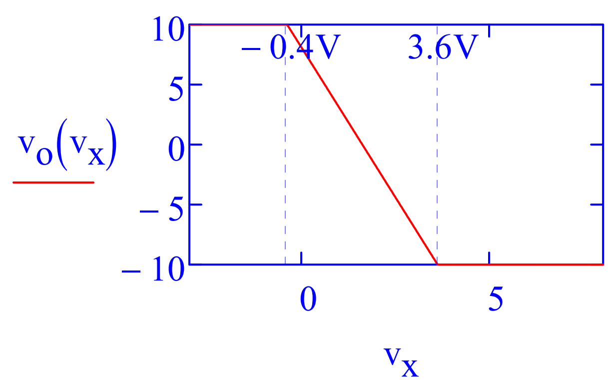
$$-\left(\frac{-10V}{5} - v_b\right) = 6\,V$$

$2V < V_a < 6V$

$v_o(v_a) := \text{Clamp}(2v_b - 5v_a, 10V, -10V)$

$$-\left(\frac{10V - v_b \cdot 2}{5}\right) = -0.4\,V$$

$$-\frac{-10V - v_b \cdot 2}{5} = 3.6\,V$$



b) $-0.4V < V_a < 3.6V$

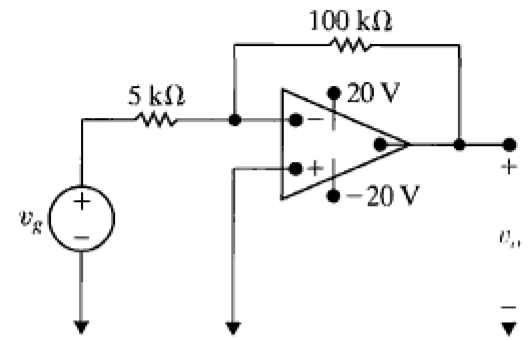
AP 5.6 The inverting amplifier in the circuit shown has an input resistance of 500 kΩ, an output resistance of 5 kΩ, and an open-loop gain of 300,000. Assume that the amplifier is operating in its linear region.

a) Calculate the voltage gain (v_o/v_g) of the amplifier.

b) Calculate the value of v_n in microvolts when v_g= 1V.

c) Calculate the resistance seen by the signal source (v_g).

d) Repeat (a)-(c) using the ideal model for the op amp.



$v_g := 1V \qquad A_{OL} := 300000 \qquad v_i := -20V \qquad v_n := 0V \qquad v_o := 0V$

given $\quad \dfrac{v_g - v_n}{5k\Omega} + \dfrac{v_i - v_n}{100k\Omega + 5k\Omega} + \dfrac{-v_n}{500k\Omega} = 0 \qquad v_i = A_{OL} \cdot -v_n \qquad v_o = v_i - 5k\Omega \cdot \left(\dfrac{v_i - v_n}{100k\Omega + 5k\Omega}\right)$

$$\begin{pmatrix} v_i \\ v_n \\ v_o \end{pmatrix} := \text{find}(v_i, v_n, v_o) = \begin{pmatrix} -20.9984 \times 10^{0} \\ 69.9948 \times 10^{-6} \\ -19.9985 \times 10^{0} \end{pmatrix} V$$

a) gain is $\dfrac{v_o}{v_g} = -19.9985$ $\qquad$ b) $v_n = 69.995\ \mu V$

c) $R_{in} := \dfrac{v_g}{\dfrac{v_g - v_n}{5k\Omega}} = 5000.35\ \Omega$ $\qquad$ or $\qquad R_{in} := 5k\Omega + \left[\dfrac{(100k\Omega + 5k\Omega)}{A_{OL}}\right] \parallel (500k\Omega) = 5000.35\ \Omega$

d) gain is $\frac{-100}{5} = -20$ $v_n := 0V$ $R_{in} := 5k\Omega$

While these answers match the books answers... part b) is WRONG!

The internal Voltage, v_i, is lower than the power supply voltage -20V.

so the equations should be modified to:

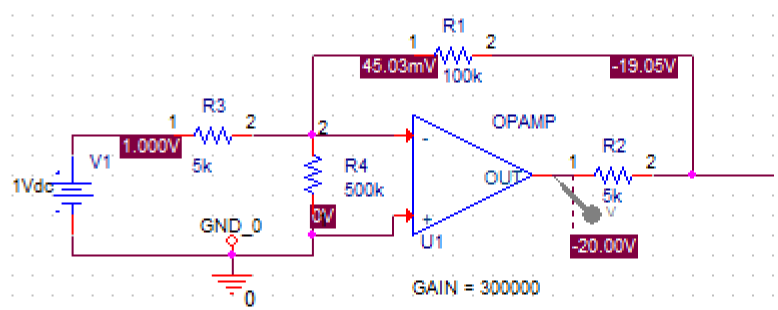
Given $\frac{v_g - v_n}{5k\Omega} + \frac{v_i - v_n}{100k\Omega + 5k\Omega} + \frac{-v_n}{500k\Omega} = 0$ $v_i = \text{Clamp}(A_{OL} \cdot -v_n, 20V, -20V)$

$$v_o = v_i - 5k\Omega \cdot \left(\frac{v_i - v_n}{100k\Omega + 5k\Omega}\right)$$

$$\begin{pmatrix} v_i \\ v_n \\ v_o \end{pmatrix} := \text{Find}(v_i, v_n, v_o) = \begin{pmatrix} -20 \times 10^{0} \\ 45.0248 \times 10^{-3} \\ -19.0455 \times 10^{0} \end{pmatrix} V$$

so $v_n = 45.025\,mV$

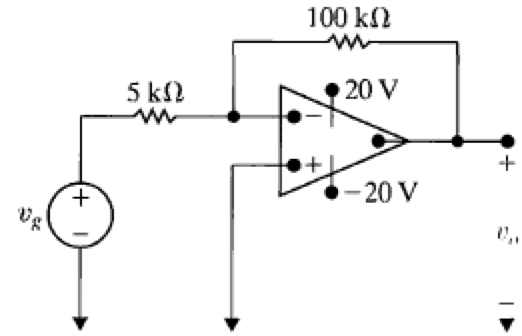
PSpice Solution to part b:



Alternative Matrix Solutions

using voltage nodes:

$$G := \begin{pmatrix} \frac{1}{5k\Omega} + \frac{1}{100k\Omega} + \frac{1}{500k\Omega} & 0 & \frac{-1}{100k\Omega} \\ A_{OL} \cdot S & S & 0 \\ \frac{-1}{100k\Omega} & \frac{-1}{5k\Omega} & \frac{1}{5k\Omega} + \frac{1}{100k\Omega} \end{pmatrix} \quad \begin{pmatrix} v_n \\ v_i \\ v_o \end{pmatrix} \quad i := \begin{pmatrix} \frac{v_g}{5k\Omega} \\ 0 \\ 0 \end{pmatrix}$$



$$v := G^{-1} \cdot i \qquad v = \begin{pmatrix} 69.9948 \times 10^{-6} \\ -20.9984 \times 10^{0} \\ -19.9985 \times 10^{0} \end{pmatrix} V$$

using current mesh:

$$cm := \begin{pmatrix} 5k\Omega + 500k\Omega & -500k\Omega \\ -500k\Omega - A_{OL} \cdot 500k\Omega & 500k\Omega + 100k\Omega + 5k\Omega + A_{OL} \cdot 500k\Omega \end{pmatrix} \qquad v := \begin{pmatrix} v_g \\ 0 \end{pmatrix}$$

$$i := cm^{-1} \cdot v \qquad i = \begin{pmatrix} 199.986001036 \\ 199.985861047 \end{pmatrix} \mu A$$

$$v_n := 500k\Omega \cdot (i_0 - i_1) = 69.9948\ \mu V$$

$$v_o := A_{OL} \cdot -v_n + 5k\Omega \cdot i_1 = -19.9985\ V$$