Homework #11

Operational Amplifiers – *100 points*

DUE @ Beginning of Class: Tuesday, December 5

1) E-Book, problem 9.2 (12 points)

2) E-Book, problem 9.6 (10 points)

3) E-Book, problem 9.7 (14 points)

4) E-Book, problem 9.19 (14 points)

5) E-Book, problem 9.25 (20 points)

6) E-Book, problem D9.35 (10 points)

7) E-Book, problem D9.60 (20 points)

1) E-Book, problem 9.2 (12 points)

9.2 The op-amp in the circuit shown in Figure P9.2 is ideal except it has a finite open-loop gain. (a) If $A_{od} = 10^4$ and $v_O = -2$ V, determine v_I. (b) If $v_I = 2$ V and $v_O = 1$ V, determine A_{od}.

a) Since the input is on (2):

$$v_2 = \frac{v_o}{A_{od}} = \frac{-2\,V}{10^4} = 2\times10^{-4}\,V$$

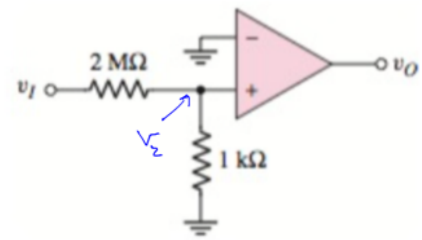


Figure P9.2

voltage divider:

$$v_2 = \left(\frac{1k\Omega}{1k\Omega + 2000k\Omega}\right) v_I$$

$$2\times10^{-4}\,V = \left(\frac{1}{2001}\,k\Omega\right) v_I \Rightarrow \boxed{v_I = -0.4\,V}$$ **8**

b) $$v_2 = \left(\frac{1}{2001}\,k\Omega\right) v_I = 0.9995\times10^{-3}\,V$$

$$v_o = 1V = A_{od} v_2 = A_{od}\left(0.9995\times10^{-3}\,V\right) \Rightarrow \boxed{A_{od} = 1000.5}$$ **4**

2) E-Book, problem 9.6 (10 points)

9.6 Assume the op-amps in Figure P9.6 are ideal. Find the voltage gain $A_v = v_O/v_I$ and the input resistance R_i of each circuit.

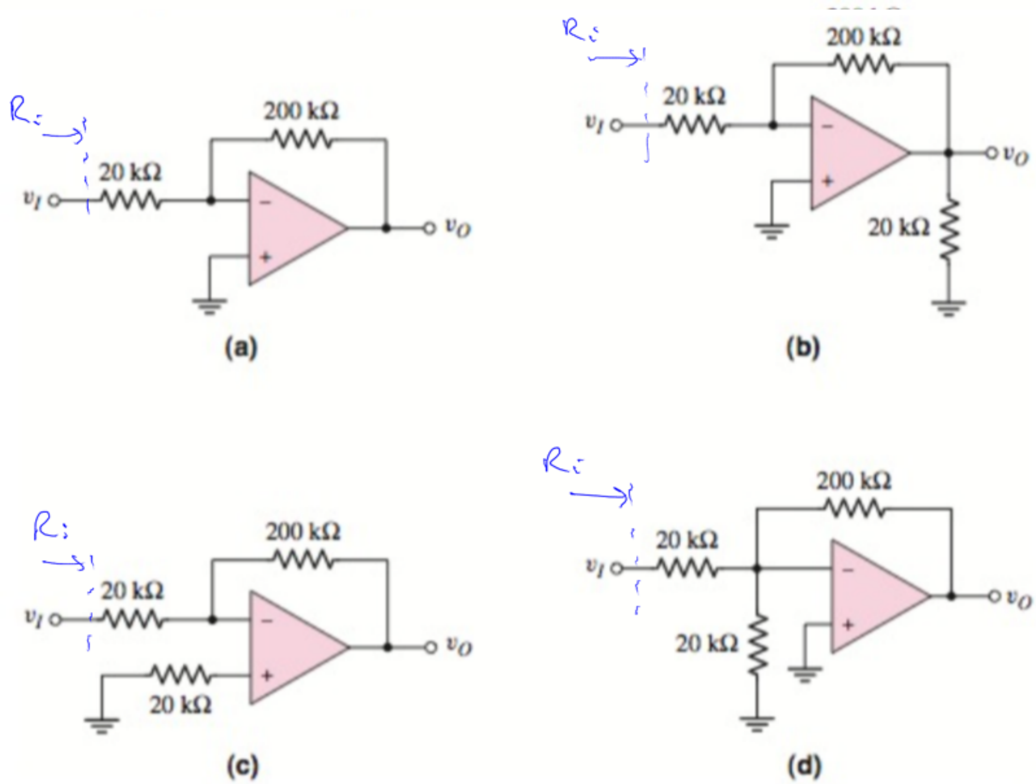


Figure P9.6

Each one of these is a negative feedback, inverting op-amp having the same $R_i = 20k\Omega$ and gain, $A_v = -\frac{R_2}{R_1} = -\frac{200k\Omega}{20k\Omega} = -10$

2 pts for each part

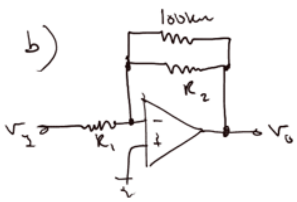
3) E-Book, problem 9.7 (14 points)

9.7 Consider an ideal inverting op-amp with $R_2 = 100\,\text{k}\Omega$ and $R_1 = 10\,\text{k}\Omega$. (a) Determine the ideal voltage gain and input resistance R_i. (b) Repeat part (a) for a second $100\,\text{k}\Omega$ resistor connected in parallel with R_2. (c) Repeat part (a) for a second $10\,\text{k}\Omega$ resistance connected in series with R_1.

a) $A_v = -\frac{R_2}{R_1} = -\frac{100\,\text{k}\Omega}{10\,\text{k}\Omega} = \boxed{-10}$ **2**

$R_i = R_1 = \boxed{10\,\text{k}\Omega}$ **2**

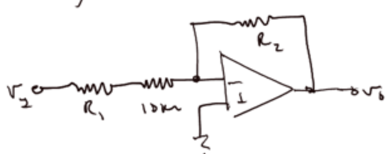
b)



$A_v = \frac{-R_2 \| 100\,\text{k}\Omega}{R_1} = -\frac{100\,\text{k}\Omega \| 100\,\text{k}\Omega}{10\,\text{k}\Omega} = \boxed{-5}$ **3**

$R_i = R_1 = \boxed{10\,\text{k}\Omega}$ **3**

c)



$A_v = -\frac{R_2}{R_1 + 10\,\text{k}\Omega} = -\frac{100\,\text{k}\Omega}{10\,\text{k}\Omega + 10\,\text{k}\Omega} = \boxed{-5}$ **2**

$R_i = 10\,\text{k}\Omega + 10\,\text{k}\Omega = \boxed{20\,\text{k}\Omega}$ **2**

4) E-Book, problem 9.19 (14 points)

9.19 Consider the circuit shown in Figure P9.19. (a) Determine the ideal output voltage v_O if $v_I = -0.40$ V. (b) Determine the actual output voltage if the open-loop gain of the op-amp is $A_{od} = 5 \times 10^3$. (c) Determine the required value of A_{od} in order that the actual voltage gain be within 0.2 percent of the ideal value.

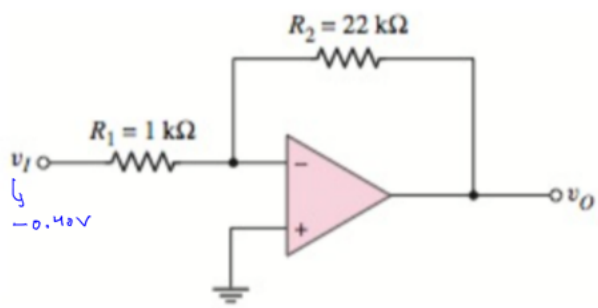


Figure P9.19

a) $v_o = -\frac{R_2}{R_1} v_I = -\left(\frac{22\,k\Omega}{1\,k\Omega}\right)(-0.40V) = \boxed{8.8\,V}$ **4**

b) since finite open-loop gain:

$$A_v = -\frac{R_2}{R_1}\left(\frac{1}{1 + \frac{1}{A_{od}}\left(1 + \frac{R_2}{R_1}\right)}\right) = -(22)\left(\frac{1}{1 + \frac{1}{(5\times10^3)}(1+22)}\right) = \boxed{-21.9}$$ **4**

c) within 0.2% of ideal would be:

$$A_v = -\left(\frac{22\,k\Omega}{1\,k\Omega}\right)(0.998) = -21.956$$

$$-21.956 = -(22)\left(\frac{1}{1 + \frac{1}{A_{od}}(23)}\right) \Rightarrow \boxed{A_{od} = 1.148 \times 10^4}$$ **6**

5) E-Book, problem 9.25 (20 points)

9.25 For the op-amp circuit shown in Figure P9.25, determine the gain $A_v = v_O/v_I$. Compare this result to the gain of the circuit shown in Figure 9.12, assuming all resistor values are equal.

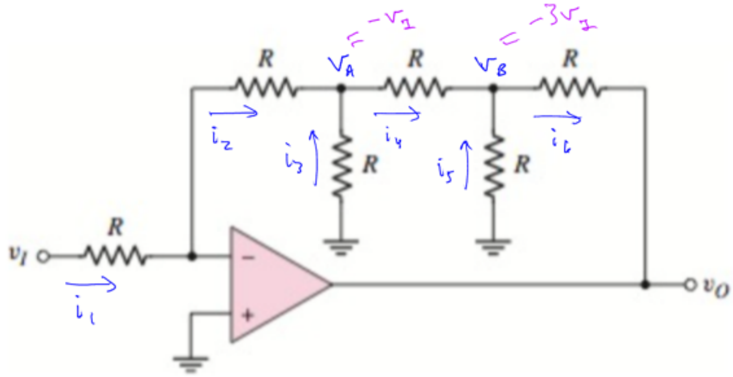


Figure P9.25

$$i_1 = \frac{v_I}{R} = i_2$$

$$v_A = -i_2 R = -\left(\frac{v_I}{R}\right) R = -v_I$$

$$i_3 = -\frac{v_A}{R} = \frac{v_I}{R}$$

$$i_4 = i_2 + i_3 = -\frac{v_A}{R} - \frac{v_A}{R} = -\frac{2v_A}{R} = \frac{2v_I}{R}$$

$$v_B = v_A - i_4 R = -v_I - \left(\frac{2v_I}{R}\right) R = -3v_I$$

$$i_5 = -\frac{v_B}{R} = -\frac{(-3v_I)}{R} = \frac{3v_I}{R}$$

$$i_6 = i_4 + i_5 = \frac{2v_I}{R} + \frac{3v_I}{R} = \frac{5v_I}{R}$$

$$v_o = v_B - i_6 R = -3v_I - \left(\frac{5v_I}{R}\right) R \Longrightarrow \frac{v_o}{v_I} = \boxed{A_v = -8}$$

6

8

From Fig. 9.12, $\boxed{A_v = -3}$, so the additional T-branch increased A_v.

6

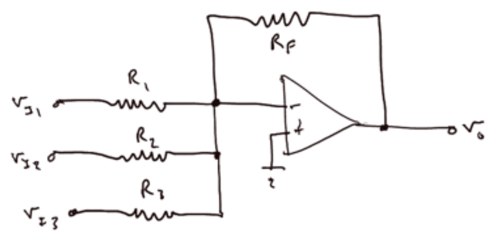
6) E-Book, problem D9.35 (10 points)

D9.35 (a) Design an ideal summing op-amp circuit to provide an output voltage of $v_O = -2[(v_{I1}/4) + 2v_{I2} + v_{I3}]$. The largest resistor value is to be 250 kΩ. (b) Using the results of part (a), determine the range in output voltage and the maximum current in R_F if the input voltages are in the ranges $-2 \le v_{I1} \le +2$ V, $0 \le v_{I2} \le 0.5$ V, and $-1 \le v_{I3} \le 0$ V.

a) $$v_o = -\left(\frac{R_F}{R_1}v_{I1} + \frac{R_F}{R_2}v_{I2} + \frac{R_F}{R_3}v_{I3}\right)$$

$$= -2\left(\frac{v_{I1}}{4} + 2v_{I2} + v_{I3}\right)$$

$$= -\frac{1}{2}v_{I1} - 4v_{I2} - 2v_{I3}$$



$$\Rightarrow \frac{R_F}{R_1} = \frac{1}{2}, \quad \frac{R_F}{R_2} = 4, \quad \frac{R_F}{R_3} = 2;$$

$\boxed{R_1 = 250\,k\Omega}$, $\boxed{R_F = 125\,k\Omega}$, $\boxed{R_2 = 31.25\,k\Omega}$, $\boxed{R_3 = 62.5\,k\Omega}$

2 each

b) For $v_{I1} = -2V$, $v_{I2} = 0V$, $v_{I3} = -1V$

$$v_o = -\tfrac{1}{2}(-2) - 4(0) - 2(-1) = 3V$$

For $v_{I1} = 2V$, $v_{I2} = 0.5V$, $v_{I3} = 0$

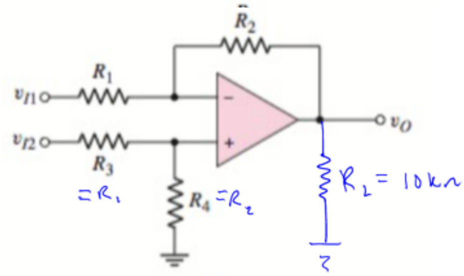
$$v_o = -\tfrac{1}{2}(2) - 4(0.5) - 2(0) = -3V$$

Then : $\boxed{-3V \le v_o \le 3V}$ **1**

$$|i_F|_{max} = \frac{|v_o|_{max}}{R_F} = \frac{3V}{125k\Omega} = \boxed{24\mu A}$$ **1**

7) E-Book, problem D9.60 (20 points)

D9.60 Consider the op-amp difference amplifier in Figure 9.24(a). Let $R_1 = R_3$ and $R_2 = R_4$. A load resistor $R_L = 10\,\text{k}\Omega$ is connected from the output terminal to ground. (a) Design the circuit such that the difference voltage gain is $A_d = 15$ and the minimum difference input resistance is $30\,\text{k}\Omega$. (b) If the load current is $i_L = 0.25\,\text{mA}$, what is the differential input voltage $(v_{I2} - v_{I1})$? (c) If $v_{I1} = 1.5\,\text{V}$ and $v_{I2} = 1.2\,\text{V}$, determine i_L. (d) If $i_L = 0.5\,\text{mA}$ when $v_{I2} = 2.0\,\text{V}$, determine v_{I1}.



(a)

a) $A_d = 15$, $R_{id} = 30\,\text{k}\Omega$

$R_{id} = R_1 + R_3 = 30\,\text{k}\Omega$

$\rightarrow \boxed{R_1 = R_3 = 15\,\text{k}\Omega}$ **4**

$\dfrac{R_2}{R_1} = \dfrac{R_4}{R_3} = 15 \Rightarrow \boxed{R_2 = R_4 = 225\,\text{k}\Omega}$ **4**

b) $v_o = i_L R_L = (0.25\,\text{mA})(10\,\text{k}\Omega) = 2.5\,\text{V} = \dfrac{R_2}{R_1}(v_{I2} - v_{I1})$

$v_{I2} - v_{I1} = \dfrac{2.5}{15} = \boxed{0.167\,\text{V}}$ **4**

c) $v_o = \dfrac{R_2}{R_1}(v_{I2} - v_{I1}) = (15)(1.2 - 1.5) = -4.5\,\text{V}$

$i_L = \dfrac{v_o}{R_L} = \dfrac{-4.5\,\text{V}}{10\,\text{k}\Omega} = \boxed{-0.45\,\text{mA}}$ **4**

d) $v_o = (0.5)(10\,\text{k}\Omega) = 5\,\text{V}$

$v_{I2} - v_{I1} = \dfrac{5\,\text{V}}{15} = 0.333\,\text{V}$

$v_{I1} = 2 - 0.333\,\text{V} = \boxed{1.667\,\text{V}}$ **4**