5.40 The inverting amplifier in the circuit in Fig. P5.40 has an input resistance of 400 kΩ, an output resistance of 2 kΩ, and an open-loop gain of 500,000. Assume that the amplifier is operating in its linear region.

a) Calculate the voltage gain \( \left( \frac{v_o}{v_i} \right) \) of the amplifier.

b) Calculate the value of \( v_i \) in microvolts when \( v_o = 50 \text{ mV} \).

c) Calculate the resistance seen by the signal source \( (v_i) \).

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

\[ \text{Figure P5.40} \]
[b] \[ N_1 = \begin{vmatrix} v_g & -2.5 \\ 3.52 \times 10^6 v_g & 57 \end{vmatrix} = 8,800,057 v_g \]

\[ v_n = \frac{N_1}{\Delta} = 0.9995 v_g; \quad v_n = 999.5 \text{ mV} \]

\[ v_p = (11/15)(1000) + (4/15)(999.5) = 999.87 \text{ mV} \]

[c] \[ v_p - v_n = 367.94 \mu \text{V} \]

[d] \[ i_g = \frac{(1000 - 999.87) \times 10^{-3}}{160 \times 10^3} = 836.22 \text{ pA} \]

[e] \[ \frac{v_g}{8} + \frac{v_g - v_o}{240} = 0, \quad \text{since } v_n = v_p = v_g \]

\[ \therefore v_o = 31 v_g, \quad \frac{v_o}{v_g} = 31 \]

\[ v_n = v_p = 1 \text{ V}; \quad v_p - v_n = 0 \text{ V}; \quad i_p = 0 \text{ A} \]

P 5.40 [a]

![Diagram of electrical circuit]

\[ \frac{v_n}{400} + \frac{v_n - v_g}{8} + \frac{v_n - v_o}{320} = 0 \]

\[ \therefore 41.8 v_n - v_o = 40 v_g \]

\[ \frac{v_o - 500,000 (-v_n)}{2} + \frac{v_o - v_n}{320} = 0 \]

\[ \therefore 80 \times 10^6 v_n + 161 v_o = 0 \]

\[ \Delta = \begin{vmatrix} 41.8 & -1 \\ 80 \times 10^6 & 161 \end{vmatrix} = 80,006,729.8 \]

\[ N_o = \begin{vmatrix} 41.8 & 40 v_g \\ 80 \times 10^6 & 0 \end{vmatrix} = -32 \times 10^8 v_g \]

\[ v_o = \frac{N_o}{\Delta} = -39.997 v_g; \quad \text{so } \frac{v_o}{v_g} = -39.997 \]
CHAPTER 5. The Operational Amplifier

[b] \[ N_1 = \begin{vmatrix} 40v_g & -1 \\ 0 & 161 \end{vmatrix} = 6440v_g \]

\[ v_n = \frac{N_1}{\Delta} = 8.05 \times 10^{-5}v_g \]

\[ v_g = 50 \text{ mV}, \quad v_n = 4.02 \mu \text{ V} \]

[c] \[ i_g = \frac{v_g - v_n}{8} = \frac{v_g - 8.05 \times 10^{-5}v_g}{8} \]

\[ R_g = \frac{v_g}{i_g} = \frac{v_g}{v_g - 8.05 \times 10^{-5}v_g} \cdot (8000) = 8000.644\Omega \]

[d] \[ \frac{v_o}{v_g} = -40; \quad v_n = 0 \text{ V}; \quad R_g = 8000 \Omega \]

P 5.41 [a] From the solution of Problem 5.40 we have \[ 41.8v_n - v_o = 40v_g \]

At the output we now have \[ \frac{v_o + 50 \times 10^4v_n}{2} + \frac{v_o - v_n}{320} + \frac{v_o}{0.5} = 0 \]

or \[ 80 \times 10^6v_n + 801v_o = 0 \]

\[ \Delta = \begin{vmatrix} 41.8 & -1 \\ 80 \times 10^6 & 801 \end{vmatrix} = 80,033,481.8 \]

\[ N_o = \begin{vmatrix} 41.8 & 40v_g \\ 80 \times 10^6 & 0 \end{vmatrix} = -32 \times 10^8v_g \]

\[ v_o = \frac{N_o}{\Delta} = -39.98v_g; \quad \frac{v_o}{v_g} = -39.98 \]

[b] \[ N_1 = \begin{vmatrix} 40v_g & -1 \\ 0 & 801 \end{vmatrix} = 32,040v_g; \quad v_n = \frac{N_1}{\Delta} = 4.003 \times 10^{-4}v_g \]

When \[ v_g = 50 \text{ mV}, \quad v_n = 20.017 \mu \text{ V} \]

[c] \[ R_g = \frac{v_g}{i_g}, \quad i_g = \frac{v_g - v_n}{8000} = \frac{v_g - 4.003 \times 10^{-4}v_g}{8000} = 8003.2 \Omega \]

[d] \[ \frac{v_o}{v_g} = -40; \quad v_n = 0 \text{ V}; \quad R_g = 8000 \Omega \]

P 5.42 \[ v_p = \frac{-3(50)}{200} = -0.75 \text{ V} = v_n \]

\[ \frac{-0.75 + 3}{5} + \frac{-0.75 - v_o}{R_f} = 0 \]