**Problem Set #2 Solutions.**

**2.10 Plan:** Here we need to analyse the given OPAMP circuits using basic summing point criteria.

(a) \[ V_o = -1 \, k \Omega \times 2 \, mA \]

(b) \[ V_o = -2 \, mA \times 3 \, k \Omega + 5 \, V \]

(c) \[ V_o = -1 + 2 \]

(d) \[ V_o = 0 \]

(e) \[ V_o = -2 + 5 \]

**Inference:** Here we observe the effects of connecting a source voltage at the i/p terminals and the corresponding o/p voltage.
Ex 2.28 Plan: Here we analyse the clipping action of the opamp.

(a) This circuit has negative feedback. For an ideal opamp, we have \( V_o(t) = V_{in}(t) \).

(b) This circuit has positive feedback. The saturation point constraint does not apply. Instead, either \( V_o = +5V \) or \( V_o = -5V \).

Observe that \( V = V_o - V_{in} \). If \( V > 0 \), \( V_o = +5V \). On the other hand if \( V < 0 \), \( V_o = -5V \).

Influence: As observed from the figure, clipping action occurs at \( \pm 5V \) even if the supply voltage exceeds this limit.
Solution Plan: Here we investigate all the parameters of a voltage follower circuit.

a) Please refer to the fig P.2.42 in the text.

\[ V_o = R_i i_s + R_o i_s + A_o l (R_i i_s) \]
\[ V_o = R_i i_s + A_o l R_i i_s \]
\[ A_v = \frac{V_o}{V_i} = \frac{R_o + A_o l R_i}{R_i + R_o + A_o l R_i} \]
\[ A_v = \frac{25 + 10^5 \times 10^6}{10^6 + 25 + 10^5 \times 10^6} \]
\[ A_v = 0.999 \]

The gain would be ideally 1.00 for an ideal OPAMP.

b) \[ Z_i = \frac{V_i}{i_s} = R_i + R_o + A_o l R_i \]
\[ Z_i = 10^2 \Omega \]

In comparison we would have \( Z_i \approx 0 \) for ideal OPAMP.

c) \[ V_i = V_x \quad i_x = \frac{V_x}{R_i} + V_x - A_o l V_i \]
\[ Z_o = \frac{V_x}{i_x} = \frac{1}{R_i + \frac{1}{R_o} + A_o l} \]

Evaluating \( Z_o = 2.5 \times 10^{-4} \Omega \) compared to \( Z_o = 0 \) for ideal case.

Inference: The values indicate the behavior of a practical voltage follower to an ideal case.
Plan: Here we investigate and analyze an inverting amplifier parameters.

a) Please refer to figure P2.43 in the text.

Writing current equations at the i/p terminals of opamp and at the o/p terminal

\[ \frac{V_s + V_i}{R_1} + \frac{V_o + V_i}{R_2} + \frac{V_i}{R_{in}} = 0 \quad - (i) \]

\[ \frac{V_o + V_i}{R_2} + V_o - A_{ol} V_i \frac{V_i}{R_0} = 0 \quad - (ii) \]

We solve eq. (i) and substitute it in eq. (ii) to obtain.

\[ Av_o = \frac{V_o}{V_s} \]

\[ Av_o = \frac{-R_2}{R_1 \left[ 1 + \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{in}} \right) \frac{R_0 R_2 + R_2^2}{A_{ol} R_2 - R_0} \right]} \]

Evaluating we obtain \( Av_o = -9.99 \) compared to \( Av_o = -10 \) for an ideal opamp.

b) From the circuit, we can write

\[ V_s = R_1 i_s - V_i \quad - (iii) \]

\[ V_i + (R_1 + R_0) \left( \frac{V_i}{R_{in}} + i_s \right) + A_{ol} V_i = 0 \quad - (iv) \]

We solve eq. (iii) for \( V_i \) and substitute in (iv) to obtain.

\[ Z_{in} = \frac{V_s}{i_s} \]

\[ Z_{in} = R_1 + \frac{R_2 + R_0}{1 + A_{ol} + \frac{R_2 + R_0}{R_{in}}} \]

Evaluating we find \( Z_{in} = 1k \Omega \) as compared to \( Z_{in} = 1k \Omega \) for ideal case.
c) 

\[ V_i = \frac{R_{in} R_1}{R_2 + R_{in} R_1} \] 
\[ i_x = \frac{V_x}{R_2 + R_{in} R_1} + \frac{V_x - A_{ov} V_i}{R_o} \] 

\[ Z_0 = \frac{V_x}{i_x} \]

\[ Z_0 = \frac{1}{\frac{1}{R_2 + R_{in} R_1} + \frac{1}{R_o} \left( 1 + A_{ov} (R_{in} R_1) \right)} \]

Evaluating, we find \( Z_0 = 2.75 \text{m}\Omega \) compared to \( Z_0 = 0.5 \Omega \) for ideal case

Inference: Here we see the parameter specifications of an inverting amplifier. The evaluated values agree with the ideal values.
3.9 PLAN: Here we need to analyze the given circuit using graphical load line methods.

a) 
\[ V = 4 \text{ V} \]
\[ i = 1.5i + V \]  \( (i \text{ is in mA}) \)

\[ i \]
\[ V \]
\[ 2.67 \]
\[ 2 \]
\[ V = 0.8 \text{ V} \]
\[ i = 2.13 \text{ mA} \]

\[ V_x = V \approx 0.8 \text{ V} \]
\[ I_x = i \approx 2.13 \text{ mA} \]

b) 
\[ V = 400i_x + V_x \]  \( (i_x \text{ is in mA}) \)

Part (c) 
\[ i_x = 1.15 \text{ mA} \]
\[ V_x = 0.21 \text{ V} \]
\[ i_x = 1.65 \text{ mA} \]
\[ V_x = 0.33 \text{ V} \]

Part (b) 
\[ i_x = 1.65 \text{ mA} \]
\[ V_x = V_x + 200i_x \approx 0.66 \text{ V} \]
c) Thevenin Eq

\[ 0.5 = 250 i_x + v_x \]  
(Refer to load line on previous page)

\[ i_C = i_x = 1.15 \text{mA} \]
\[ v_C = 0.5 - v_x = 0.29 \text{V} \]

Inference: The load line analysis can be a pretty useful method of analyzing circuits as seen from the above problem.

3.17 Plan: Given the state of the diode, we can find and analyze various voltages in the circuit.

a) D_1 is ON, D_2 is ON, D_3 is OFF

Using voltage divider we find that \( V = 7.5 \text{V} \) and \( I = 0 \text{A} \)

b) \( \text{Vin} \ D_1 \ D_2 \ D_3 \ D_4 \ V(V) \ I(\text{mA}) \)

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Plotting \( V/V_{\text{in}} \)
Inference: Here we observe the effects of a HWR during positive and negative cycles of operation.