Homework 2

Michael Brodskiy

Professor: M. Onabajo

September 22, 2024

1. We may begin to write KCL equations for the circuit. Let us call the voltage at the negative (upper) terminal V^-, the voltage at the bottom terminal V^+, and the voltages on the nodes V_1 and V_2. With this, we get:

$$\frac{V^- - V_{in}}{R} + \frac{V^- - V_1}{R} = 0$$
$$V^- = 0$$
$$V_{in} = -V_1$$

We write the next KCL:

$$\frac{V_1 - V^-}{R} + \frac{V_1}{R} + \frac{V_1 - V_2}{R} = 0$$
$$\frac{2V_1}{R} + \frac{V_1 - V_2}{R} = 0$$
$$V_2 = -3V_1$$

And finally the last KCL:

$$\frac{V_2 - V_1}{R} + \frac{V_2}{R} + \frac{V_2 - V_o}{R} = 0$$
$$3V_2 - V_1 = V_o$$

Combining with our first two KCL equations, we get:

$$-8V_{in} = V_o$$
$$\boxed{\frac{V_o}{V_{in}} = -8}$$

2. (a) We begin by writing:

$$V_s - 1000I_s - 1000000I = 0$$
$$V_s = 1000I_s + 1000000I$$

Where:

$$v_i = 1000000I$$

Using KVL, we find:

$$v_i - 10000(I_s - I) - 25(I_s - I) - 100000v_i = 0$$
$$-10000(I_s - I) - 25(I_s - I) \approx 100000v_i$$
$$-10025(I_s - I) \approx 100000v_i$$
$$v_i \approx -.10025(I_s - I)$$

Since we know $v_i = 1000000I$, we can write:

$$100000I = -.10025(I_s - I)$$
$$-(9.975 \cdot 10^6)I = I_s - I$$
$$-(9.975 \cdot 10^6)I = I_s$$

We can substitute this back into our first equation to find:

$$V_s = -9.974 \cdot 10^6 I$$

Then we can once again use KVL to write:

$$v_o - 25(I_s - I) - 10^{11}I = 0$$
$$v_o = 25I_s - 10^{11}I$$
$$v_o = 9.975 \cdot 10^{10}I$$

Therefore, we may say that:

$$\boxed{\frac{v_o}{V_s} \approx -10001}$$

We can tell that the finite gain is approximately one-tenth of the ideal op-amp gain.

(b) To find the impedance, we can use our equations from part (a) to write:

$$Z_{in} =$$

(c)

3. (a) We begin by calculating the impedance from the capacitor:

$$z_c = -\frac{j}{\omega C}$$

We can tell that the output voltage is:

$$V_o = A_{OL} V^-$$

From here, we apply KCL:

$$j\omega C(V^- - V_i) + \frac{V^- - V_o}{R} = 0$$

And substitute from the equation above:

$$j\omega RC(V^- - V_i) + V^- - A_{OL}V^- = 0$$
$$j\omega RCV_i = j\omega RCV^- + V^- - A_{OL}V^-$$

This gives us the input voltage:

$$V_i = V^- + \frac{V^- - A_{OL}V^-}{j\omega RC}$$
$$V_i = \frac{j\omega RCV^- + V^- - A_{OL}V^-}{j\omega RC}$$
$$V_i = \frac{V^-(j\omega RC + 1 - A_{OL})}{j\omega RC}$$

We then take the ratio of the output to input and find the closed loop voltage gain:

$$A_{CL} = \frac{V_o}{V_i}$$
$$\boxed{A_{CL}(j\omega) = \frac{j\omega RCA_{OL}}{1 + j\omega RC - A_{OL}}}$$

(b) With an ideal op-amp, we know $A_{OL} \to \infty$. Thus, we may refactor our finding from (a) to write:

$$A_{CL}(j\omega) = \frac{j\omega RC}{(1/A_{OL})(1 + j\omega RC) - 1}$$

We know that, as $A_{OL} \to \infty$, $1/A_{OL} \to 0$, which gives us:

$$A^i_{CL}(j\omega) = -j\omega RC$$

This gives us a magnitude of:

$$\boxed{|A^i_{CL}(j\omega)| = \omega RC}$$

(c) Using our equation from part (a), we may write:

$$A_{CL} = \frac{j(1000\pi)(10000)(20 \cdot 10^{-6})(10^4)}{1 + j(1000\pi)(10000)(20 \cdot 10^{-6}) - 10^4}$$

$$A_{CL} = \frac{j(1000\pi)(100)(20)}{1 + j(10\pi)(20) - 10^4}$$

$$A_{CL} = \frac{(2 \cdot 10^6)\pi j}{j(200\pi) - 9999}$$

$$A_{CL} = 39.331 - 625.910j$$

Now we find the magnitude:

$$|A_{CL}| = \sqrt{39.331^2 + 625.910^2}$$

$$|A_{CL}| = 627.14$$

Now we use the input amplitude to get the output amplitude:

$$|V_o| = |A_{CL}||V_i|$$

$$|V_o| = (627.14)(5 \cdot 10^{-3})$$

$$\boxed{|V_o| = 3.1357[\mathrm{V}]}$$

4. (a) To start, it is given that the output voltage is:

$$V_o = .1[\mathrm{V}]$$

Offset voltage can be found using the equation:

$$V_{IO} = \left(1 + \frac{R_2}{R_1}\right)^{-1} V_o$$

$$V_{IO} = \left(1 + \frac{100}{10}\right)^{-1} (.1)$$

$$V_{IO} = (11)^{-1} (.1)$$

$$\boxed{V_{IO} = .00909[\mathrm{V}]}$$

(b) The input bias current may be written as:

$$I_B = \frac{I_B^+ + I_B^-}{2}$$

Using KVL, we may write:

$$V_o - V^- = I_B^- R_2$$

Since the DC input voltage is zero, we know:

$$V^- = V^+ = 0$$

Therefore, we get:

$$V_o = I_B^- R_2$$

and since the terminals are balanced:

$$I_B^- = I_B^+$$

Which gives us:

$$I_B^- = \frac{V_o}{R_2}$$

$$I_B^- = \frac{.1}{100000}$$

$$\boxed{I_B = I_B^- = I_B^+ = 1 \cdot 10^{-6}[\mathrm{A}]}$$

(c) We need to place a compensating resistor on the positive terminal to ground in order to cancel the effects. This gives us:

$$V^+ = -I_B^+ R_c$$

Applying KCL, we find:

$$I_B^- = -\frac{V^-}{R_1} + \frac{V_o - V^-}{R_2}$$

$$I_B^- = -V^{\left[10^{-4} + 10^{-5}\right]}$$

$$I_B^- = .00011 I_B^+ R_c$$

Since the two bias currents equal each other, we get:

$$1 = .00011 R_c$$

$$\boxed{R_c = 9090.9[\Omega]}$$

(d) The maximum offset current may be found using:

$$I_o = \frac{V_o}{R_2 + R_c}$$

Using our known values, we substitute:

$$I_o = \frac{.1}{10^5 + 9090.9}$$

$$\boxed{I_o = 9.167 \cdot 10^{-7}[\mathrm{A}]}$$

5. (a) The slew rate may be defined as:

$$SR = \frac{dV_o}{dt}$$

Since we know a sinusoidal input will generate an output of the form $V_o = |V|\sin(\omega t)$, we can write:

$$\frac{dV_o}{dt} = |V|\omega\cos(\omega t)$$

From this, we may determine that the maximum slew rate is:

$$SR = |V|\omega$$

$$SR = |V|2\pi f$$

$$SR = (4)(2)(\pi)(10^6)$$

$$\boxed{SR = 2.51 \cdot 10^7 \left[\frac{\mathrm{V}}{\mathrm{s}}\right]}$$

(b)

(c)

6. (a)

(b)

(c)

(d)

(e)