Homework 1

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1. We can set up and calculate:

$$v_i = v_s \frac{R_i}{R_s + R_i} = 5\frac{10^6}{10^6 + 10^5} = 4.545[\mathrm{V}_{rms}]$$

Given that the open-circuit voltage gain is unity, we may write:

$$v_o = 4.545[\mathrm{V}_{pp}]\frac{50}{100 + 50}$$

$$\boxed{\therefore v_o = 1.515[\mathrm{V}_{rms}]}$$

Power can then be determined using the $50[\Omega]$ load:

$$P_L = \frac{v_o^2}{R} = \frac{1.515^2}{50}$$

$$\boxed{\therefore P_L = 45.9[\mathrm{mW}]}$$

With a direct signal source connection, we can use voltage division to find:

$$v_L = v_s \frac{R_L}{R_L + R_s} = 5\frac{50}{50 + 10^5}$$

$$\boxed{\therefore v_L = 2.5[\mathrm{mV}]}$$

The power can then be found using:

$$P_L = \frac{(2.5 \cdot 10^{-3})^2}{50}$$

$$\boxed{\therefore P_L = .125[\mu\mathrm{W}]}$$

With the implementation of an amplifier, we see that the power is significantly increased. Similarly, the voltage delivered is also significantly increased. Thus, the use of an amplifier can greatly help with power delivery.

2. • For $A - B$ cascade:

The input impedance can be found to be:

$$\boxed{R_i = R_{i1} = 3[\text{k}\Omega]}$$

The output impedance can be found to be:

$$\boxed{R_o = R_{o2} = 20[\Omega]}$$

We may then proceed to find the gain using individual gains as steps:

$$A_{v1} = \frac{V_{o1}}{V_i} = \frac{100V_i\left[\frac{10^6}{10^6+400}\right]}{V_i}$$

$$A_{v1} = 99.96 = 20\log(99.96) = 39.97[\text{dB}]$$

$$A_{v2} = \frac{V_{o2}}{V_{o1}} = \frac{500V_{o1}}{V_{o1}}$$

$$A_{v2} = 500 = 20\log(500) = 53.979[\text{dB}]$$

We then multiply to find the overall gain:

$$A_{voc} = A_{v1}A_{v2} = (500)(99.96)$$

$$\boxed{A_{voc} = 49.98 \cdot 10^3 = 93.976[\text{dB}]}$$

• For $B - A$ cascade:

The input impedance can be found to be:

$$\boxed{R_i = R_{i2} = 1[\text{M}\Omega]}$$

The output impedance can be found to be:

$$\boxed{R_o = R_{o1} = 400[\Omega]}$$

We may then proceed to find the gain using individual gains as steps:

$$A_{v2} = \frac{V_{o2}}{V_i} = \frac{500V_i\left[\frac{3000}{3000+20}\right]}{V_i}$$

$$A_{v2} = 496.69 = 20\log(496.69) = 53.92[\text{dB}]$$

$$A_{v1} = \frac{V_{o1}}{V_{o2}} = \frac{100V_{o2}}{V_{o2}}$$

$$A_{v1} = 100 = 20\log(100) = 40[\text{dB}]$$

We then multiply to find the overall gain:

$$A_{voc} = A_{v1}A_{v2} = (100)(496.69)$$

$$\boxed{A_{voc} = 49.669 \cdot 10^3 = 93.922[\text{dB}]}$$

3. We begin by finding A_{vs}, the voltage gain from source to output:

$$A_{vs} = \frac{V_o}{V_s}$$

$$i_i = \frac{V_s}{R_{i1} + R_s} = \frac{V_s}{55000}$$

$$V_{moc} = \frac{10}{55}V_s$$

$$V_{i2} = \frac{V_{moc}R_{i2}}{R_{i2} + R_{o1}} = \left(\frac{10}{55}V_s\right)\left(\frac{10^6}{10^6 + 200}\right)$$

$$V_{i2} = .1818V_s$$

$$i_{msc} = (.02)(.1818V_s) = (3.6356 \cdot 10^{-3})V_s$$

$$|V_o| = (i_{msc})\frac{R_{o2}R_L}{R_{o2} + R_L} = (3.6356 \cdot 10^{-3})V_s\left(\frac{(10^5)(10^3)}{10^5 + 10^3}\right)$$

$$|V_o| = 3.5996V_s[\text{V}]$$

First, because the current is travelling in a direction opposing i_o, we flip the sign, and then find the gain:

$$V_o = -3.5996V_s[\text{V}]$$

$$\boxed{A_{vs} = -\frac{3.5996V_s}{V_s} = -3.5996}$$

Using V_{i1}, from above, we can find the loaded voltage gain:

$$\boxed{A_v = -\frac{3.5996V_s}{(50/55)V_s} = -3.9596}$$

Using i_i, from above, we can find the overall current gain:

$$i_o = \frac{V_o}{1000} = -.0035996V_s$$

$$\boxed{A_i = -\frac{.0035996V_s}{(1/55000)V_s} = -197.98}$$

Finally, we get the power gain:

$$A_p = (3.9596)(197.98) = 783.91$$

4. For the operational amplifier:

(a) We can find that the voltage gain is:

$$\boxed{A_v = \frac{7.5}{.02} = 375 = 51.48[\text{VdB}]}$$

We can find that the current gain is:

$$\boxed{A_i = \frac{(7.5/.5) \cdot 10^{-3}}{10^{-6}} = 15000 = 83.522[\text{dB}]}$$

Combining the two together, the power gain is:

$$\boxed{A_p = (375)(15000) = 5.625 \cdot 10^6 = 67.501[\text{dB}]}$$

Finally, the input resistance is defined as:

$$\boxed{R_i = \frac{.02}{10^6} = 20[\text{k}\Omega]}$$

(b) The power delivered to the amplifier may be found as:

$$\boxed{P_s = 2(12)(.01) = .24[\text{W}]}$$

To find the efficiency, we must first find the output power:

$$P_o = \frac{1}{1000}(7.5)^2 = 56.25[\text{mW}]$$

Thus, we find the efficiency to be:

$$\eta = \frac{P_o}{P_s} \cdot 100 = \frac{56.25}{2.40}$$

$$\boxed{\eta = 23.44\%}$$

(c) The max voltage may be calculated as follows:

$$V_{max} = \frac{V_{dc}}{A_v} = \frac{12}{375}$$

$$\boxed{V_{max} = 32[\text{mV}]}$$

5. (a) We begin by finding the impedance of the capacitor:

$$C_L = \frac{1}{j\omega C} = \frac{10^7}{s}$$

From here, we begin to solve the circuit:

$$V_i = \frac{150V_s}{200} = .75V_s$$
$$i_i = .075V_s$$

Here, we solve for the equivalent impedance:

$$R_{eq} = \left(\frac{(15000)(5000)}{20000}\right) = 3750[\Omega]$$
$$Z_{eq} = \left(\frac{(3750)(10^7/s)}{3750 + (10^7/s)}\right)[\Omega]$$
$$Z_{eq} = \frac{10^7}{s + 2666.67}[\Omega]$$

We now multiply by the current to find V_o:

$$Z_{eq}i_i = \left(\frac{10^7}{s + 2666.67}\right)(.075V_s)$$
$$V_o = \frac{75 \cdot 10^4 V_s}{s + 2666.67}$$

This finally gives us:

$$A_{vs}(s) = \frac{75 \cdot 10^4}{s + 2666.67}$$
$$\boxed{A_{vs}(j\omega) = \frac{75 \cdot 10^4}{j\omega + 2666.67}}$$

(b) The 3dB frequency may be found using the magnitude of the transfer function:

$$|A_{vs}(j\omega)| = \frac{1}{\sqrt{2}}$$
$$|\frac{750000}{\sqrt{\omega^2 + 2666.67^2}}| = \frac{1}{\sqrt{2}}$$
$$\omega^2 + 2666.67^2 = 1.125 \cdot 10^{12}$$
$$\omega^2 = 1.125 \cdot 10^{12}$$
$$\omega \approx 1.0607 \cdot 10^6 \left[\frac{\text{rad}}{\text{s}}\right]$$

Finally, this yields:

$$f = \frac{\omega}{2\pi}$$
$$\boxed{f_c = 1.688 \cdot 10^5[\text{Hz}]}$$

(c) The gain-bandwidth is found as follows:

$$G_{BW} = \frac{750000}{\sqrt{(1.0607 \cdot 10^6)^2 + 2666.67^2}}(1.0607 \cdot 10^6)$$

$$\boxed{G_{BW} = 749998}$$

6. The voltage gain for the first operational amplifer can be found according to the zero current flow into the terminals is zero:

$$A_1 = \frac{v_{o1}}{v_i} = -\frac{4R}{R}$$

$$\boxed{A_1 = -4}$$

We repeat the same process for the second op-amp:

$$A_2 = \frac{v_{o2}}{v_i} = -\frac{4R}{R}$$

$$\boxed{A_2 = -4}$$

Thus, thanks to the summing-point constraint, we see both voltages are inverted, and the gains are 4.