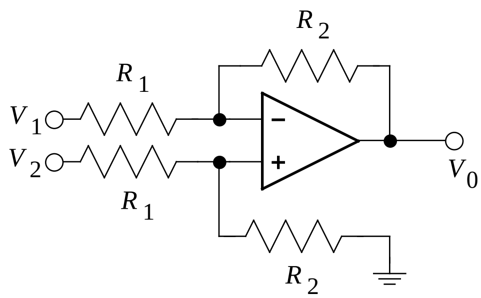
UNIVERSITY OF CALIFORNIA
Electrical Engineering and Computer Sciences

EECS 145L Electronic Transducer Lab
MIDTERM #1 (100 points maximum)

(closed book, calculators OK- note formulas on last page)
(You will not receive full credit if you do not show your work)

PROBLEM 1 (40 points)

Consider the differential amplifier circuit shown below:



Assume the following:

- The op-amp open loop gain is infinite

Do the following:

a. (20 points) derive the equation for the differential gain as a function of the resistor values R_1 and R_2

b. (20 points) derive the equation for the common mode gain as a function of the resistor values R_1 and R_2

PROBLEM 2 (60 points)

You have been given the assignment of designing an amplifier and filtering circuit that meets the following requirements:

- Differential input
- Operational temperature range 10°C to 30°c
- Differential gain 10^6 between 1 Hz and 1000 Hz, with an accuracy of 30%
- Differential gain <1 for frequencies >10,000 Hz
- Common mode gain < 10^{-2} for all frequencies
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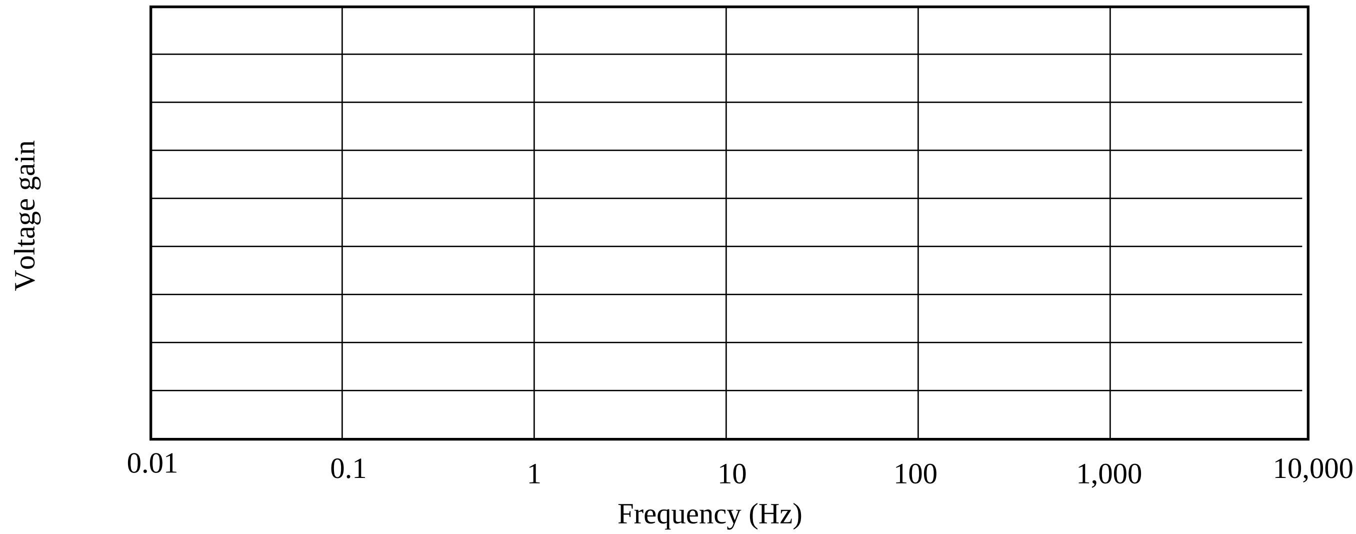
Assume the following

- Since you can't reliably get a differential gain >10^4 from a single instrumentation amplifier, your circuit will need additional amplification.
- The input offset voltage of the first instrumentation amplifier varies by 1 mV over the range from 10°C to 30°C, but the direction and magnitude of variation cannot be predicted because it differs from part to part (assume all other offset voltages are much less important and can be neglected)
- It is not possible to measure the temperature of the circuit

Do the following:

a. (30 points) Draw a sketch of your circuit, showing all necessary components.

b. (15 points) Sketch the differential gain vs. frequency for your circuit from 0.01 Hz to 10 kHz in the figure below



b. (5 points) What is the requirement for the common mode rejection ratio of the instrumentation amplifier in your circuit?

c. (5 points) If a 1 kΩ resistor is connected to one input and the other input is grounded, approximately how much Johnson noise does the resistor contribute to the output of the circuit?

c. (5 points) If both inputs are connected to ground through 1 kΩ resistors, approximately how much Johnson noise do the resistors contribute to the output of the circuit?

Equations, some of which you may need:

$R(T) = R(T_0)\exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$ $\quad I = I_0\, e^{-kLC}$ $\quad V_{\rm rms} = \sqrt{B\left[(D_1 G)^2 + (D_0)^2\right]}$

$V(t) = V_0 \sin(\omega t)$ $\quad \omega = 2\pi f$ $\quad V_0 = A(V_+ - V_-)$

$|G| = \dfrac{1}{\sqrt{1 + (f/f_c)^{2n}}}$ $\quad \tan\left(\dfrac{\varphi}{n}\right) = \dfrac{f}{f_c}$ $\quad f_c = \dfrac{1}{2\pi RC}$

$|G| = \dfrac{(f/f_c)^n}{\sqrt{1 + (f/f_c)^{2n}}}$

$x = e^{-\alpha t}\left[A\cos(\omega t) + B\sin(\omega t)\right] = Re^{-\alpha t}\cos(\omega t + \delta)$ $\quad V = q/C$

$v = v_0 + at \quad x = x_0 + v_0 t + 0.5\, at^2 \quad$ (constant a) $\quad g = 10 \text{ m s}^{-2}$

$I_{\rm rms} = \sqrt{2qI(F_2 - F_1)}$ $\quad q = 1.60 \times 10^{-19}$ Coulombs

$V_{\rm rms} = \sqrt{4kTR(F_2 - F_1)}$ $\quad k = 1.38 \times 10^{-23}$ Volt^2 sec ohm^{-1} °K^{-1}

$R_T = R_3 \dfrac{V_b R_1 - V_0(R_1 + R_2)}{V_b R_2 + V_0(R_1 + R_2)}$ $\quad V_0 = G_\pm(V_+ - V_-) + G_c(V_+ + V_-)2$

$N(x) = N(0)e^{-x\mu}$ $\quad$ "CMRR" $= \dfrac{G_\pm}{G_c}$ $\quad$ "CMR" $= 20\log_{10}\left(\dfrac{G_\pm}{G_c}\right)$

$R = \rho A/L$ $\quad \dfrac{\Delta R}{R} = G_s \dfrac{\Delta L}{L}$ $\quad V_0 = V_b\, G_s\left(\dfrac{\Delta L}{L}\right)$ $\quad \Delta x = \dfrac{\Delta V}{dV/dx}$

$V_T = V_{\rm BE2} - V_{\rm BE1} = \dfrac{kT}{q}\ln\left(\dfrac{I_1}{I_2}\right)$ $\quad k/q = 86.17\ \mu\text{V/K}$

$P_R = \sigma A T^4$ $\quad \sigma = 5.6696 \times 10^{-8}\ \text{W m}^{-2}\,\text{K}^4$

$E = hc/\lambda$ $\quad hc = 1240$ eV nm $\quad \lambda_{\max} = (2.8978 \times 10^6 \text{ nm K})/T$

$\eta = \dfrac{T_{n+2} - T_{n+1}}{T_{n+1} - T_n}$ $\quad T_{\rm equ} = T_{n+1} + \dfrac{T_{n+2} - T_{n+1}}{1 - \eta}$ $\quad T = T_2 - (T_2 - T_1)\, e^{-t/\tau}$

$Q = \pi I + I^2 R/2 + K_p(T_s - T_0) + K_a(T_a - T_0)$ $\quad T_{\rm equ} = \dfrac{\pi I + I^2 R/2 + K_p T_s + K_a T_a}{K_p + K_a}$

$\mu \approx \bar{a} = \frac{1}{m}\sum_{i=1}^{m} a_i$ $\quad \sigma_a^2 = \frac{1}{m-1}\sum_{i=1}^{m}(a_i - \bar{a})^2$ $\quad \sigma_{\bar{a}} = \dfrac{\sigma_a}{\sqrt{m}}$

$\sigma_f = \sqrt{\left(\dfrac{\partial f}{\partial a_1}\right)^2 \sigma_{a1}^2 + \left(\dfrac{\partial f}{\partial a_2}\right)^2 \sigma_{a2}^2 + \cdots + \left(\dfrac{\partial f}{\partial a_n}\right)^2 \sigma_{an}^2}$

Johnson noise = 129 μV for 1 MHz and 1 MΩ

Iron+Constantan - 52.6 μV/°C $\quad$ W+W(Rh) - 16.0 μV/°C