Name ____

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 (30 points)

You have a cylindrical water tank that is 1 m high and holds 3 m^3 of water when filled to the top.

Your task is to design a system with the following requirements:

1 The system can sense the volume of water in the tank and produce an analog output voltage of 0.000 V when the tank is empty and 3.000 V when the tank is full.

2 The analog output can drive a 1 kΩ load.

You have the following components available:

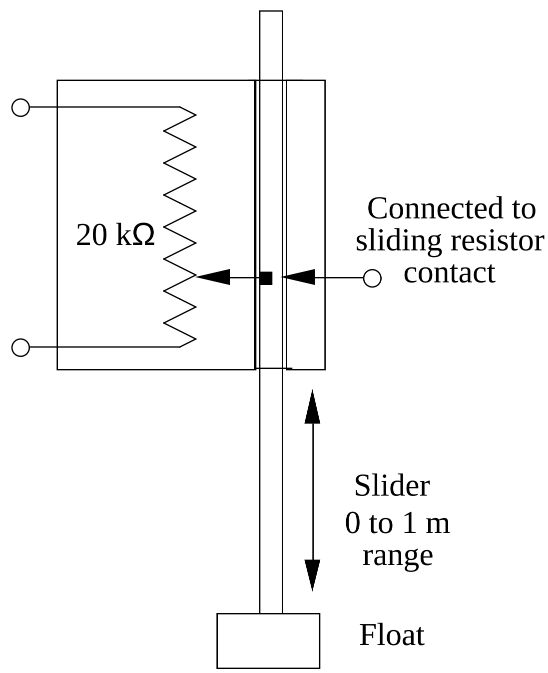
1 The level sensor shown at the right. Assume (1) that the level sensor is fixed in position and that the float remains in contact with the top surface of the water, (2) that the slider contact is at the bottom of the resistor when the tank is empty and at the top when the tank is full, (3) that the 20 kΩ resistor has a perfectly linear response function.

2 Several Op-amps (assume ideal).

3 A selection of precision resistors (1% rms uncertainty) from 100 Ω to 10 kΩ.

4 A power supply that produces three outputs: –12.000 V, 0.000 V, and +12.000 V (assume the output voltages are exact)

Note: no other power supplies are allowed.



Do the following:

a. (20 points) Sketch a block diagram of your circuit in enough detail so that a skilled technician can build it and understand how it meets the design objectives. Show all resistors (More space provided on next page)

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b. (10 points) Combine the rms uncertainties of your resistor values to determine the overall rms uncertainty in the output voltage.

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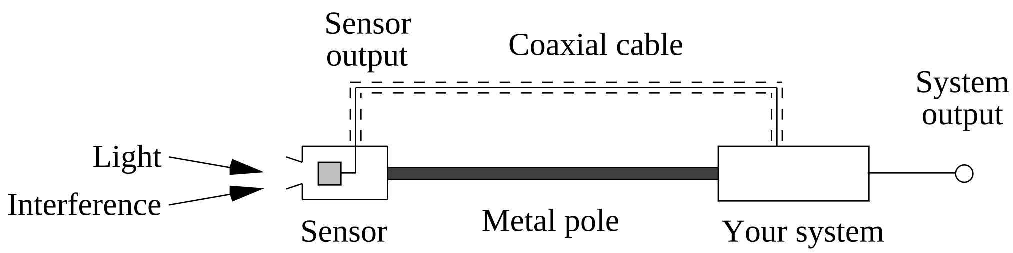
PROBLEM 2 (70 points)

You have a light sensor at the end of a long metal pole that produces a signal in the 100 Hz to 100 kHz frequency range. The sensor also receives 60 Hz interference from nearby power lines and 1 MHz interference from a nearby radio station. In addition, the sensor output also has an additive component that depends on temperature.



Design two systems that each meet the following requirements:

- Amplifies a 1 mV sensor output signal in the 100 Hz to 100 kHz frequency range to produce a 10 V system output with an accuracy of 1%.
- All unwanted signals (0 Hz to 1 MHz) must contribute less than 0.1 V to the system output.

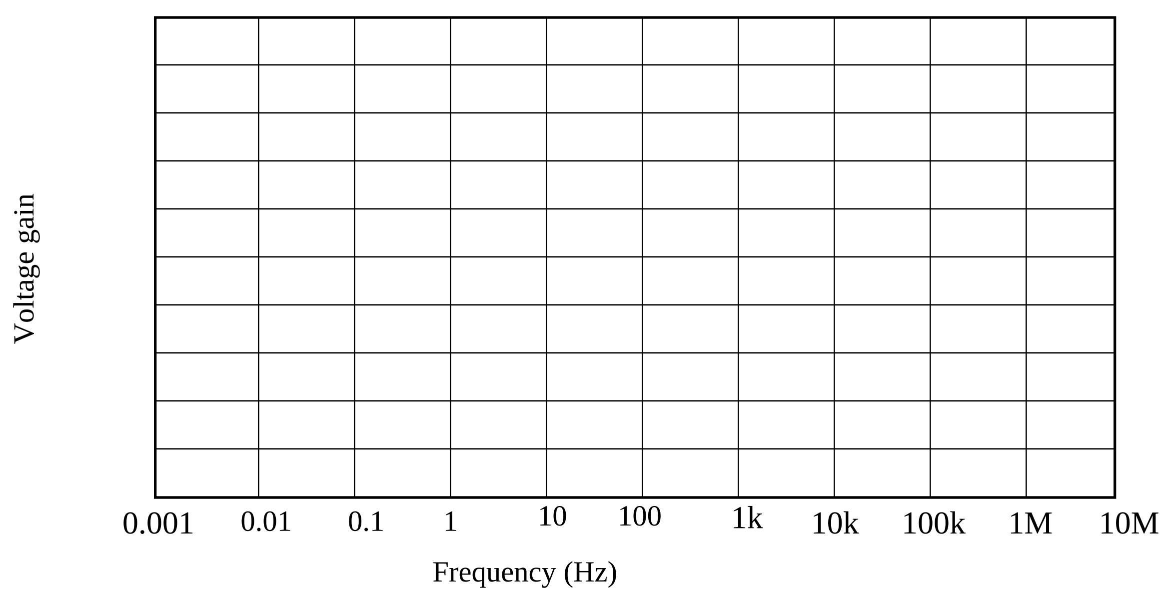
Assume the following

- The unwanted 60 Hz background produces a sensor output of ±1 mV
- The unwanted 1 MHz background produces a sensor output of ±10 mV
- The maximum temperature variation produces an unwanted sensor output from –10 mV to + 10 mV (assume a maximum frequency of 0.1 Hz)
- The sensor output is connected to the input of your circuit with a coaxial cable that effectively shields the internal signal wire from external interference.

Do the following:

a. **System 1** (25 points) Sketch the design of a system **that uses analog filtering** to accomplish the design objectives. Specify general characteristics such as number of stages and corner frequencies, but you do not need to show individual resistors and capacitors. Show sufficient detail that a skilled technician can build it and understand how it meets the design objectives. (more space provided on next page)

b. **System 1** (10 points) Sketch the voltage gain of your system from 0.001 Hz to 10 MHz in the figure below



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c. **System 2** (25 points) Sketch the design of a system **that uses an identical sensor and differential amplification by an instrumentation amplifier**. Show sufficient detail that a skilled technician can build it and understand how it meets the design objectives.

d. **System 2** (10 points) What are the Common Mode Rejection requirements of the instrumentation amplifier at 0 Hz, 60 Hz, and 1 MHz? Which would be the most difficult and why?

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Equations, some of which you may need:

$$V_{\text{rms}} = \sqrt{B\left[(D_1 G)^2 + (D_0)^2\right]}$$

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

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

$\|G\| =$	0.999	0.99	0.9	0.707	0.01	0.001	0.0001
(n= 2) f/fc =	0.212	0.377	0.696	1.000	10.000	31.623	100.000
(n= 3) f/fc =	0.355	0.522	0.785	1.000	4.642	10.000	21.544
(n= 4) f/fc =	0.460	0.614	0.834	1.000	3.162	5.623	10.000
(n= 6) f/fc =	0.596	0.723	0.886	1.000	2.154	3.162	4.642
(n= 8) f/fc =	0.678	0.784	0.913	1.000	1.778	2.371	3.162
(n= 10) f/fc =	0.733	0.823	0.930	1.000	1.585	1.995	2.512
(n= 12) f/fc =	0.772	0.850	0.941	1.000	1.468	1.778	2.154

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

$\|G\| =$	0.999	0.99	0.9	0.707	0.01	0.001	0.0001
(n= 1) f/fc =	20.	7.0	2.06	1.000	0.01	0.001	0.001
(n= 2) f/fc =	5.0	2.65	1.44	1.000	0.10	0.032	0.01

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

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

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

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

$V_0 = G_\pm(V_+ - V_-) + G_c(V_+ + V_-)2$

"CMRR" $= \dfrac{G_\pm}{G_c}$ $\quad$ "CMR" $= 20\log_{10}\left(\dfrac{G_\pm}{G_c}\right)$

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

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

$f = k(a+b) \quad \sigma_f^2 = k^2\left(\sigma_a^2 + \sigma_b^2\right)$ $\quad f = kab \quad \sigma_f^2 / f^2 = \sigma_a^2 / a^2 + \sigma_b^2 / b^2$

Johnson noise = 129 μV for 1 MHz and 1 MΩ