EECS 145L Final Examination Solutions (Fall 2002)

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1a **Johnson noise** is produced by the thermal agitation of electrons in a resistor while shot noise arises from statistical fluctuations in the number of electrons per unit time

1b The **sensor** transduces a physical quantity into an electrical signal and the **actuator** transduces an electrical signal into a physical quantity

1c The **Thompson emf** is caused by a temperature gradient along the length of a conductor that causes the electrons to move to the colder end while the **Peltier emf** is produced when materials with two different electron mobilities are brought in contact and the electrons move to the material with the lower mobility.

1d The **thermocouple** consists of two dissimilar wires joined at their ends and converts a temperature difference into a potential while the **Peltier thermoelectric heat pump** consists of a doped semiconductor and converts a current into a temperature difference

1e The **EMG** is an electrical signal produced by skeletal muscle and has a random, noisy waveform while the **ECG** is an electrical signal produced by the heart muscle and consists of a periodic series of pulses.

1f A **beta ray** is a moving electron while an **x-ray** is an energetic photon (typically 1-100 keV).
[4 points off for not mentioning electron vs. photon]
[4 points off for not mentioning difference in penetrating power]

2a

$$V_0 = V_1\left(\frac{R_2+R_3}{R_3}\right)\left(\frac{1/j\omega C}{1/j\omega C+R_1}\right) = V_1\left(\frac{R_2+R_3}{R_3}\right)\left(\frac{1}{1+j\omega R_1 C}\right) = \left(\frac{R_2+R_3}{R_3}\right)\left(\frac{1-j\omega R_1 C}{1+(\omega R_1 C)^2}\right)$$

$$\left|\frac{V_0}{V_1}\right| = \left(\frac{R_2+R_3}{R_3}\right)\left(\frac{\sqrt{1+(\omega R_1 C)^2}}{1+(\omega R_1 C)^2}\right) == \left(\frac{R_2+R_3}{R_3}\right)\left(\frac{1}{\sqrt{1+(\omega R_1 C)^2}}\right)$$

2b At 0 Hz, Gain = 10, so R_2 = 9 kΩ and R_3 = 1 kΩ is suitable
Gain falls 3 dB to 7.07 at f = $1/(2\pi R_1 C)$ = 1 kHz, so R_1C = 0.159 ms
Choosing R_1 = 10 kΩ, we have C = 0.0159 µF = 15.9 nF

2c

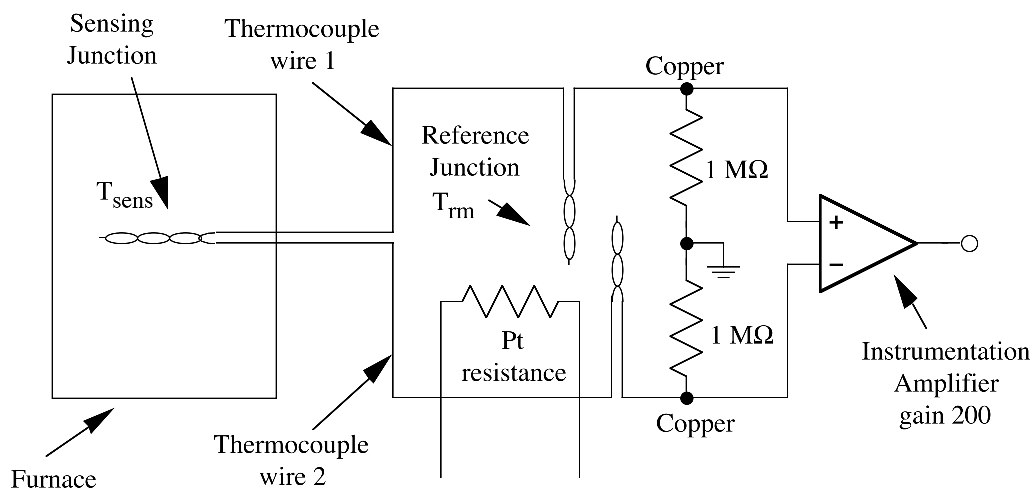
$$\frac{V_1}{R_1} = -V_0\left(1/R_2 + j\omega C\right)$$

$$\frac{V_0}{V_1} = \frac{-1}{R_1(1/R_2+j\omega C)} = \frac{-R_2}{R_1}\left(\frac{1}{1+j\omega R_2 C}\right) = \frac{-R_2}{R_1}\left(\frac{1-j\omega R_2 C}{1+(\omega R_2 C)^2}\right)$$

$$\left|\frac{V_0}{V_1}\right| = \left(\frac{R_2}{R_1}\right)\left(\frac{\sqrt{1+(\omega R_2 C)^2}}{1+(\omega R_2 C)^2}\right) = \frac{(R_2/R_1)}{\sqrt{1+(\omega R_2 C)^2}}$$

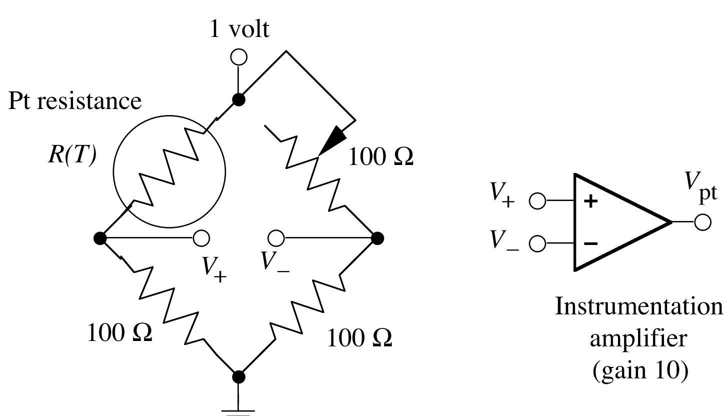
2d At 0 Hz, Gain = 10, so R_1 = 10 kΩ and R_2 = 100 kΩ is suitable
Gain falls 3 dB to 7.07 at f = $1/(2\pi R_2 C)$ = 1 kHz, so R_2C = 0.159 ms
Since R_2 = 100 kΩ, we have C = 0.00159 μF = 1.59 nF

3a



[6 points off for no instrumentation amplifier]

3b



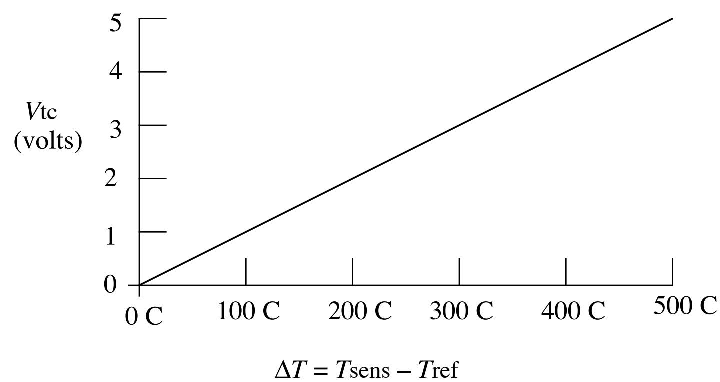
[6 points off for no instrumentation amplifier]

$$V_+ - V_- = \frac{100}{100 + 100(1+0.004T)} - \frac{100}{200} = \frac{1}{2+0.004T} - \frac{1}{2}$$

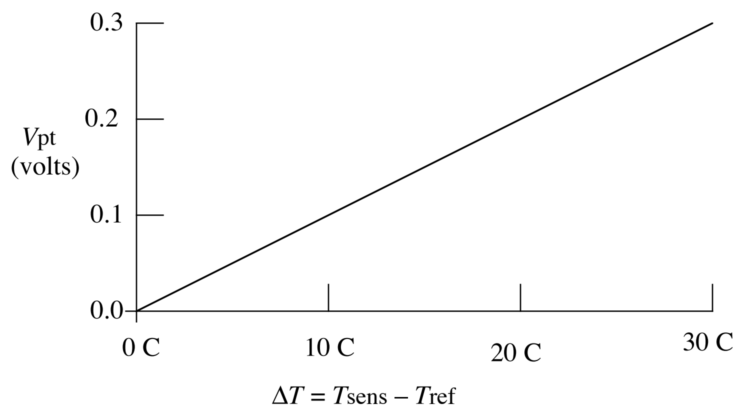
$$= \frac{0.5}{1+0.002T} - \frac{0.5}{1}0.5 \approx 0.5(1-0.002T) - 0.5 = 0.001T\text{(volts)}$$

The bridge sensitivity is 1 mV /C° and a gain of 10 is needed to increase the sensitivity to 10 mV/C°.

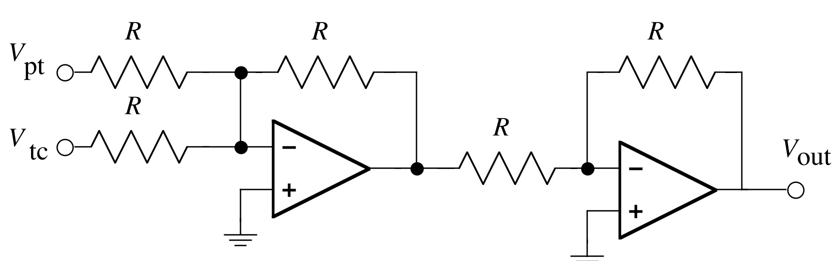
3c



3d



3e



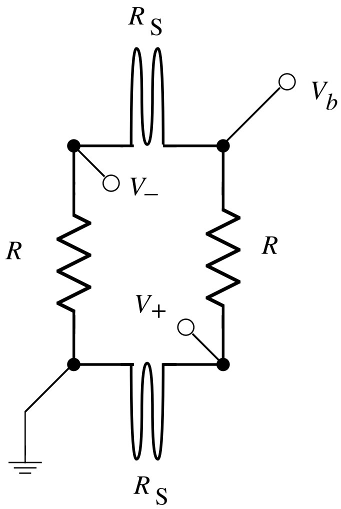
$$V_{out} = V_{tc} + V_{pt}$$

R = 1 kΩ would be suitable

[3 points off for subtracting V_{tc} and V_{pt} rather than adding.]

[1 point off for $V_{out} = -V_{pt} - V_{tc}$]

4a



4b $R = 100\ \Omega$

$R_S = R + \Delta R$

$V+ - V- = V_b\ [\ (R + \Delta R)/(\Delta R + 2R) - (R)/(\Delta R + 2R)] =$

$V_b\ (\Delta R)\ /(\Delta R{+}200) \approx V_b\ \Delta R/(2R)$

4c Voltage across each strain gauge $\approx V_b\ /2$ (since $\Delta R << R$)

Power = $(V_b\ /2)^2/100\ \Omega < 0.25$ W

want highest V_b for sensitivity but power limits $V_b < 10$ volts (5 volts was accepted)

[6 points off for "does not matter"]

[4 points off for 1V and not considering max power]

4d $\Delta T = 1$ °C means $\Delta L/L = 23$ ppm and $\Delta R/R = 46$ ppm.

$V_+ - V_- =$ (10 volts)(23 ppm) = 230 μV/°C

(115 μV/°C for 5 V bias)

4e noise is 10 μV at 1 MHz- $\Delta T = 1/23$ C° = 43×10^{-3} °C

noise is 10 nV at 1 Hz $\Delta T = 1/23{,}000$ C° = 43×10^{-6} °C

145LFinal Examination score distribution:

70-79	0	80-89	1	90-99	0
100-109	0	110-119	0	120-129	0
130-139	1	140-149	1	150-159	4
160-169	1	170-179	3	180-189	5
190-199	7	200	1		

19 undergraduates: average = 173.4, rms = 26.0
5 other students (1 graduate , 2 extension, 2 exchange) : average = 176.0, rms = 21.0

145L Course Grade Distribution

Grade	Undergraduate Scores	Other Scores
A+	974	982
A	950, 952. 960, 972	
A–	918, 923, 923, 927, 938, 940	913, 923, 932
B+	901, 907	895
B	869, 873, 881	
B–	835, 844	
C+		
C		
C–		
D+		
D		
D–		
F	463	
Maximum	1000	1000
Average	892.0	929.0
rms	111.5	32.7