Problem 1

Need to produce $6.2 \times 10^{19}$ photons/sec per input volt, which requires an input current of $6.2 \times 10^{19}$ electrons/sec per volt which is $10 \, \text{A}$ per volt. So resistor should be $R = \frac{V}{I} = \frac{1\, \text{V}}{10\, \text{A}} = 0.1 \, \Omega$.

![Diagram](image)

[5 points off for $R = 1 \, \Omega$
[7 points off for $R = 10 \, \Omega$

Problem 2

$V_+ - V_- = V_b \left( \frac{R}{2R} \right) = V_b \left( \frac{R(2R + \Delta R) - 2R^2}{(2R)(2R + \Delta R)} \right) = V_b \left( \frac{\Delta R}{4R} \right) = V_b \left( \frac{G_s \Delta L}{4L} \right)

For $G_s = 2$, $\Delta L/L = 0.001$, and amplifier gain $A$, $V_b = A \, V_b (0.0005)$

$A = 2000/V_b$

For $V_b = 1 \, \text{V}$, $A = 2000$.

For $V_b = 2 \, \text{V}$, $A = 1000$.

[5 points off for gain 20]
[3 points off for $V_b = 1$ and gain 1000]
[5 points off for $V_b = 1$ and gain 500]
Problem 3

\[ R \times \text{gain} = 10^9 \Omega \text{ for } 1 \text{ V per nA} \]

For \( R = 1 \text{ M}\Omega \), gain = 1000

6.2 x 10^9 photons/sec produces 6.2 x 10^9 electrons/sec or 1 nA.

The correct solution has an \( RA \) product = 10^9. Since the PIN diode cannot produce more than 0.6 V an amplifier is needed. Another consideration is that the amplifier leakage currents should be well below 1 nA.

[15 points off for \( RA = 0.1 \) or 1 \( \Omega \)]

[10 points off for \( R = 10^9 \Omega \) and a buffer amplifier since a PIN photodiode cannot produce more than 0.6 V]

Problem 4

Note: Slide 187 of the class lectures and slide 33 of the design tip review lecture says:

To optimize sensitivity at \( T \), choose \( R_3 = R_T \)
Select \( R_1 \) and \( R_2 \) to set temperature where \( V_0 = 0 \)

\[ R_T = \exp\left(\frac{2730}{273}\right) = 22,026 \Omega \text{ at } 0°C \]
\[ R_T = \exp\left(\frac{2730}{293}\right) = 11,130 \Omega \text{ at } 20°C \]
\[ R_T = \exp\left(\frac{2730}{313}\right) = 6,127 \Omega \text{ at } 40°C \]

For maximum sensitivity at 20 °C, want \( R_3 = 11,130 \Omega \)
For zero bridge output at 0°C, choose \( R_2 = 11,130 \Omega, R_1 = 22,026 \Omega \)

Use a differential amplifier with gain \( G \) to produce 4 volts at 40°C
Midterm #2 Solutions – EECS 145L Fall 2013

\[ V_0 = GV_b \left( \frac{R_3}{R_3 + R_T} \right) = GV_b \left( \frac{11,130}{11,130 + 6,127} \right) = GV_b \left( \frac{0.645 - 0.336}{0.309} \right) = GV_b 0.309 = 4 \text{ volts} \]

\[ GV_b = 4/0.309 \text{ volts} = 12.9 \text{ volts} \]

[5 points off for \( V_b > 5 \text{V} \), because this will cause excessive self-heating]
[5 points off if the output is not 0V at 0°C]
[5 points off if the output is not 4V at 40°C]

An alternative solution was to set all three resistors to 11,130Ω, in which case
At 0°C \( V+ - V- = 0.356 \text{V} -0.5 = -0.164 \text{V} \)
At 40°C \( V+ - V- = 0.645 \text{V} -0.5 = +0.145 \text{V} \)
For 0V at 0°C need to shift upward by 0.164V using a summing amplifier.
This summing amplifier would also provide the gain of \( 4/(0.164+0.145) = 12.9 \) needed to produce 4V at 40°C

Problem 5
The electronic ice point was covered in lecture slides 195-196 and review slide 35.

\[ V_{\text{thermocouple}} = (T_{\text{sense}} - T_{\text{ref}})/100\text{°C} \]
\[ V_{\text{thermistor}} = T_{\text{ref}}/10\text{°C} \]
\[ V_{\text{thermocouple}} + 0.1 \times V_{\text{thermistor}} = T_{\text{sense}}/100\text{°C} \]

The last inverter can be eliminated by reversing the thermistor bridge and thermocouple connections.

Thermistor output was 1 V per 10°C
Thermocouple output is 1 V per 100°C
Need to add voltages with thermistor gain reduced by a factor of ten.

[3 points off if the output was not connected to the thermistor]
[3 points off if the output was not connected to the thermocouple]
**Midterm #2 Solutions – EECS 145L Fall 2013**

[5 points off if the two signals were not summed to get an output that was proportional to the sense temperature]
[3 points off if the thermistor did not contribute 1V per 100°C to the output]
[3 points off if the thermocouple did not contribute 1V per 100°C to the output]
[3 points off for adding a voltage that converts between K and °C; both problems 4 and 5 were in °C]

**145L midterm #2 grade distribution:**

<table>
<thead>
<tr>
<th>Problem</th>
<th>Maximum Score</th>
<th>Average Score</th>
<th>Minimum Score</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.2 (3.8 rms) (20 max)</td>
<td>40-49</td>
<td>1</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>50-59</td>
<td>1</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>18.0 (4.5 rms) (20 max)</td>
<td>60-69</td>
<td>5</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>70-79</td>
<td>4</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>14.6 (7.0 rms) (20 max)</td>
<td>80-89</td>
<td>6</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>90-94</td>
<td>1</td>
<td>A+</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10.4 (4.6 rms) (20 max)</td>
<td>95-100</td>
<td>0</td>
<td>A+</td>
</tr>
<tr>
<td>5</td>
<td>13.9 (3.8 rms) (20 max)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NOTE: LETTER GRADES ARE APPROXIMATE*