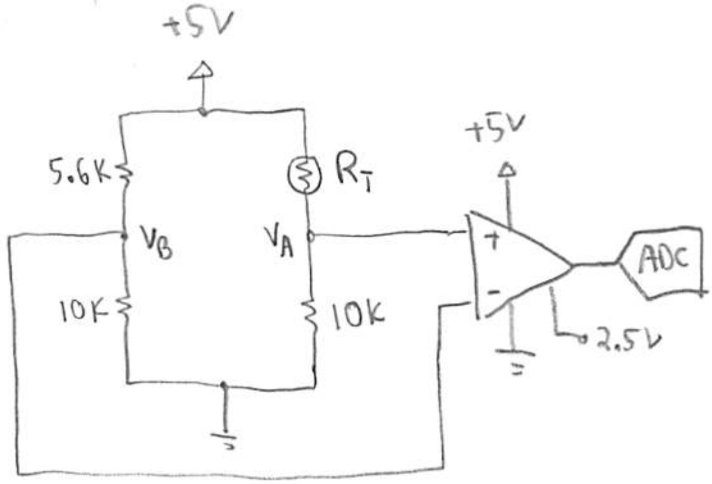
BME 386
HW2 Solns

12 problems
Total = 100 pts



1) $$V_A = 5 \frac{10K}{10K + R_T}$$

+8

$$V_B = 5 \frac{10K}{10K + 5.6K}$$

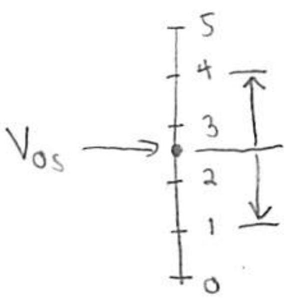
$$\Delta V = 5\left(\frac{10K}{10K + R_T} - \frac{10K}{15.6K} \right)$$

$$= 5\left(\frac{10K}{10K + R_T} - 0.641 \right) \rightarrow \boxed{V_{MEAS} = 2.5 + A_d \cdot 5\left(\frac{10K}{10K + R_T} - .641 \right)}$$

2) What limits V_{MEAS}?

+10

	Amplifier	ADC
Max	4V	5V
Min	1V	0V



$\boxed{\text{Choose } A_d = 3}$

- Want Max $V_{MEAS} < 4V$

$T_{MAX} = 50^\circ C$

$$\rightarrow 2.5 + A_d\, \underbrace{5\left(\frac{10K}{10K + 3.61K} - .641 \right)}_{0.469} < 4V$$

$$\Rightarrow A_d < \underline{\underline{3.2}}$$

Limiting factor (smaller value)

- Want Min $V_{MEAS} > 1V$

$T_{MIN} = 30^\circ C$

$$\rightarrow 2.5 + A_d\, \underbrace{5\left(\frac{10K}{10K + 8.06K} - .641 \right)}_{-0.436} > 1V$$

$$\Rightarrow A_d < \underline{\underline{3.44}}$$

3) $\Delta T_{MIN} = \dfrac{\Delta V_{MIN}}{\dfrac{\partial V_{MEAS}}{\partial T}}$ $\leftarrow$ $V_N = 4\ mV$ This is ΔV_{MIN}

(+10)

$\Delta V_{ADC} = \dfrac{5V}{2^8 - 1} = .0196V = 19.6mV$

$$V_{MEAS} = 2.5 + A_d \cdot 5\left(\frac{10K}{10K + R_T} - .641\right)$$

$$\frac{\partial V_{Meas}}{\partial R_T} = -A_d 5 \frac{10K}{(10K + R_T)^2}$$

$$\text{So, } \frac{\partial V_{Meas}}{\partial T} = \frac{\partial V_{Meas}}{\partial R_T} \alpha R_T = -3 \cdot 5V \frac{10K}{(10K + 3.61K)^2}\left(-.038 \tfrac{1}{°C}\right)(3.61K)$$

$$= +0.111\ V/°C$$

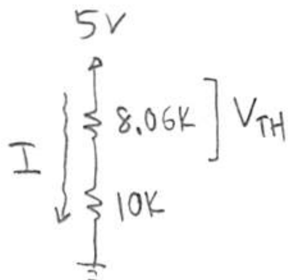
$$\rightarrow \Delta T_{MIN} = \frac{.0196V}{.111\ V/°C} = \boxed{0.18°C}$$

4) $\Delta V_{ADC} = \dfrac{5V}{2^{12} - 1} = 1.22mV < V_N = 4mV$ $\leftarrow \Delta V_{MIN}$

(+6)

$$\text{So, } \Delta T_{MIN} = \frac{.004V}{.111\ V/°C} = \boxed{.036\ °C}$$

5) At $T = 30°C$, $R_T = 8.06k\Omega$



(+8)

$$P = I V_{TH} = I^2 (8.06K) = \left(\frac{5V}{18.06K}\right)^2 (8.06K) = \underline{\underline{0.618mW}}$$

$$\delta T = \frac{.618mW}{7\ mW/°C} = \boxed{.088°C}$$

30°C $\rightarrow$ $\dfrac{\partial V_{Meas}}{\partial T} = -3 \cdot 5V \cdot \dfrac{10K}{(10K + 8.06K)^2}(-.0425\ 1/°C)(8.06K) = 0.158\ V/°C$

8-bit ADC $\rightarrow$ $\Delta T_{MIN} = \dfrac{.0196V}{.158\ V/°C} = \boxed{0.124°C}$

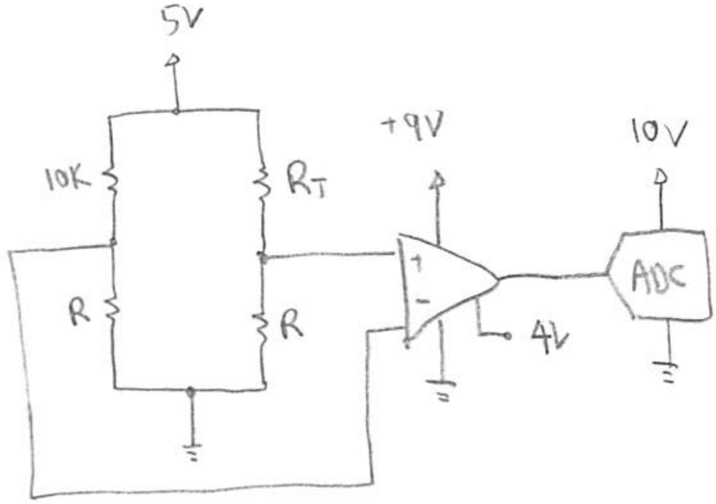
$\delta T_{self} < \Delta T_{MIN}$ ✓
YES, we can ignore self heating!

6) +10

$\Delta V = V_A - V_B$

$= 5 \frac{R}{R+R_T} - 5 \frac{R}{R+10K}$

$= 5\left(\frac{R}{R+R_T} - \frac{R}{R+10K} \right)$



$V_{MEAS} = 4 + A_d \Delta V = 4 + 2 \times 5 \times \left(\frac{R}{R+R_T} - \frac{R}{R+10K} \right)$

- When $T\uparrow$, then $R_T \downarrow$, so $V_{MEAS} \uparrow$

At $T = 100°C$, $V_{MEAS} < 8V$ (limited by amplifier)

$\text{Max } V_{MEAS} = 4 + 10\left(\frac{R}{R + .677K} - \frac{R}{R+10K} \right) < 8V$

R = 10K :

$\text{Max } V_{MEAS} = 4 + 10\left(\frac{10K}{10.677K} - \frac{10K}{20K} \right) = 8.37V$ X (Too high)

R = 20K :

$\text{Max } V_{MEAS} = 4 + 10\left(\frac{20K}{20.677K} - \frac{20K}{30K} \right) = 7V$ ✓

- When $T\downarrow$, then $R_T \uparrow$, so $V_{MEAS} \downarrow$

At $T = 0°C$, $V_{MEAS} > 1V$ (limited by amplifier)

$\text{Min } V_{MEAS} = 4 + 10\left(\frac{R}{R + 32.554K} - \frac{R}{R+10K} \right)$

$R = 10K$: $\quad 4 + 10\left(\frac{10K}{42{,}554K} - \frac{10K}{20K}\right) = 1.35V$ ✓

$R = 20K$: $\quad 4 + 10\left(\frac{20K}{52{,}554K} - \frac{20K}{30K}\right) = 1.14V$ ✓

$\Rightarrow$ Choose $\boxed{R = 20K}$

7) +10

$\Delta V_{MIN} \rightarrow V_N = 10\,mV$

$$\Delta T_{MIN} = \frac{\Delta V_{MIN}}{\frac{\partial V_{MEAS}}{\partial T}} = \frac{V_{n,rms}}{\frac{\partial V_{MEAS}}{\partial R_T}\alpha R_T}$$

$$\Delta V_{ADC} = \frac{10V}{2^{12}-1} = 2.44\,mV$$

$$V_{MEAS} = 4 + 10\left(\frac{20K}{20K + R_T} - \frac{2}{3}\right)$$

$$\frac{\partial V_{MEAS}}{\partial R_T} = -10\,\frac{20K}{(20K + R_T)^2}$$

$0°C$ $\quad \Rightarrow \frac{\partial V_{MEAS}}{\partial T} = -10V\,\frac{20K}{(20K + 32.554K)^2}\left(-.0509/°C\right)(32.554K)$

$$= 0.12\ V/°C$$

$$\Rightarrow \Delta T_{MIN} = \frac{.010V}{0.12\ V/°C} = \boxed{0.083°C}$$

$100°C$ $\quad \Rightarrow \frac{\partial V_{MEAS}}{\partial T} = -10V\,\frac{20K}{(20K + .677K)^2}\left(-.0294/°C\right)(.677K)$

$$= .0093\ V/°C$$

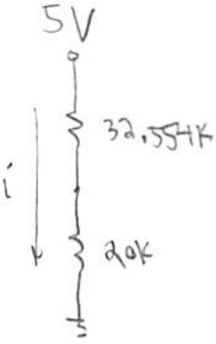
$$\Rightarrow \Delta T_{MIN} = \frac{.010V}{.0093\ V/°C} = \boxed{1.08°C}$$

8) (+8)

$$P = I^2 R_T$$

$$= \left(\frac{5V}{32.554K + 20K} \right)^2 (32.554K)$$

$$= 0.295\ mW$$



$$\delta T = \frac{.295\ mW}{5\ mW/^\circ C} = \underline{\underline{0.059\ ^\circ C}} < .083^\circ C\ \checkmark$$

$\boxed{\text{YES, we can ignore self-heating!}}$

9) (+6)

$$\underbrace{\text{Compensating voltage}}_{V_{CJC}} = \Delta S \times T_o = (51\ \mu V/^\circ C)(30^\circ C) = 1530\ \mu V$$

$$= \boxed{1.53\ mV}$$

10) (+8)

$$V_{MEAS} = G \times (V_{CJC} + \Delta S \times T_o) = \underbrace{G \times \Delta S}_{10\ mV/^\circ C} \times T_{obj}$$

$\Delta S \times (T_{obj} - T_o)$

$$\text{Want } G = \frac{10\ mV/^\circ C}{.051\ mV/^\circ C} = \boxed{196.1}$$

NOTE: This is not max gain. The problem only asked for a gain that produces 10 mV/°C

11) (+8)

$$G = 1 + \frac{R}{1K} = 196.1$$

(Closest 1% value)

$$R = 195.1k \Rightarrow \text{Choose } \boxed{R = 196K}$$

$$\text{Actual gain} = 1 + \frac{196K}{1} = \boxed{197}$$

NOTE: OK to choose R = 191K
→ G = 192

12)

+8

$V_{MEAS} = G \, \Delta S \, T_{obj}$

If max $V_{MEAS} = 5V$, what is corresponding T_{obj}?

$$\text{Max } T_{obj} = \frac{5V}{197 \times (51 \times 10^{-6} \, V/°C)} = \boxed{497.7°C}$$

NOTE: If $G = 192$, then $T_{MAX} = 510.6°C$

$V_N = 3 \, mV$

$$\Delta T_{MIN} = \frac{\Delta V_{MIN}}{\frac{\partial V_{MEAS}}{\partial T}} = \frac{\Delta V_{ADC}}{A \, \Delta S}$$

$$\Delta V_{ADC} = \frac{10V}{2^{10}-1} = \underline{\underline{9.8 \, mV}}$$

(bigger)

$$= \frac{.0098V}{197 \times 51 \times 10^{-6} V/°C} = \boxed{0.98°C}$$

NOTE: If $G = 192$, then $\Delta T_{MIN} = 1.00°C$