Name Solution ____________________

# Real Time Computing Systems

# EE 4770

# Midterm Examination

17 March 1999, 8:40-9:30 CST

Problem 1 ________ (50 pts)

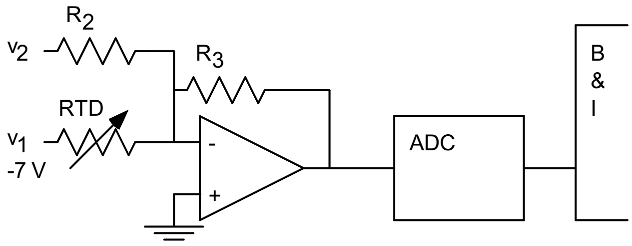
Problem 2 ________ (50 pts)

Alias ____________________ Exam Total ________ (100 pts)

*Good Luck!*

Problem 1: The partially designed circuit below is to be used to convert temperature $x \in [-20\,°\mathrm{C}, 40\,°\mathrm{C}]$ to a floating-point number $H(x) = x/\mathrm{K}$ to be written into variable `temp`. The circuit uses an RTD, its model function is $H_{t1}(x) = R_0(1+\alpha_1 x)$, where $R_0 = 100\,\Omega$ and $\alpha_1 = 0.00398/\,°\mathrm{C}$. The RTD is connected to a $-7\,\mathrm{V}$ source as shown. The ADC response is $H_{\mathrm{ADC}(10\,\mathrm{V},16\mathrm{b})}$.

(*a*) Complete the design (choose values for $v_2$, $R_2$ and $R_3$), so that the ADC input is in $[0.5\,\mathrm{V}, 9.5\,\mathrm{V}]$ over the range of temperatures to be measured. (20 pts)(For **reduced** credit [< 20 pts] make full use of the ADC dynamic range.)




First, find the voltage at the ADC input:

$$H_c(H_{t1}(x)) = -R_3\left(\frac{v_1}{H_{t1}(x)} + \frac{v_2}{R_2}\right)$$

Call the resistance at the minimum temperature $R_{\min}$ and the resistance at the maximum temperature $R_{\max}$. Using the boundaries of the temperature range

$$R_{\min} = H_{t1}(-20\,°\mathrm{C}) = 92.04\,\Omega \quad \text{and} \quad R_{\max} = H_{t1}(40\,°\mathrm{C}) = 115.92\,\Omega.$$

As stated in the problem, the ADC input should be a minimum of $0.5\,\mathrm{V}$ this occurs at the maximum temperature:

$$H_c(H_{t1}(40\,°\mathrm{C})) = 0.5\,\mathrm{V} = -R_3\left(\frac{v_1}{R_{\max}} + \frac{v_2}{R_2}\right).$$

Similarly the ADC input must be $9.5\,\mathrm{V}$ at $-20\,°\mathrm{C}$ or

$$H_c(H_{t1}(-20\,°\mathrm{C})) = 9.5\,\mathrm{V} = -R_3\left(\frac{v_1}{R_{\min}} + \frac{v_2}{R_2}\right).$$

The two equations can be combined by solving for $R_3$ in each and equating them:

$$\frac{-0.5\,\mathrm{V}}{\frac{v_1}{R_{\max}} + \frac{v_2}{R_2}} = \frac{-9.5\,\mathrm{V}}{\frac{v_1}{R_{\min}} + \frac{v_2}{R_2}}.$$

This equation could be solved for either $R_2$ or $v_2$; since it's harder to generate an arbitrary voltage solve for $R_2$ and set $v_2$ to a nice, convenient, readily available (presumably), 10 volts.

$$R_2 = \frac{9v_2}{0.5\frac{v_1}{R_{\min}} - 9.5\frac{v_1}{R_{\max}}} = 168.0\,\Omega.$$

With $R_2$ and $v_2$ a value for $R_3$ can easily be found:

$$R_3 = -\frac{0.5}{\frac{v_1}{R_{\max}} + \frac{v_2}{R_2}} = 574.4\,\Omega.$$

($b$) Write the interface routine. (20 pts)

```
double v1 = -7.0; /* Volts */
double v2 =  /* No need to copy in values from previous page. */
double R2 =
double R3 =
double vadc = 10.0; /* Volts */
double nadc = 65535; /* Quantization levels */
double al1 = 0.00398; /* / Degrees C */
double R0 = 100.0; /* Ohms */

int r = readInterface();
```

To write the interface routine $H_{\mathrm{f}}$ is needed, it is found from:

$$H_{\mathrm{f}}(H_{\mathrm{ADC}}(H_{\mathrm{c}}(H_{\mathrm{t1}}(x)))) = H(x).$$

First let $r = H_{\mathrm{ADC}}(H_{\mathrm{c}}(H_{\mathrm{t1}}(x)))$ and solve for $x$.

$$\begin{aligned} r &= H_{\mathrm{ADC}}(H_{\mathrm{c}}(H_{\mathrm{t1}}(x))) \\ &= -\frac{n_{\mathrm{adc}}}{v_{\mathrm{adc}}} R_3 \left( \frac{v_1}{R_0(1+\alpha_1 x)} + \frac{v_2}{R_2} \right) \end{aligned}$$

Solving for $x$ yields:

$$x = \left( \left( \left( r \frac{v_{\mathrm{adc}}}{n_{\mathrm{adc}} R_3} - \frac{v_2}{R_2} \right) \frac{1}{v_1} \right)^{-1} \frac{1}{R_0} - 1 \right) \frac{1}{\alpha_1}$$

Finally, $H_{\mathrm{f}}(r) = H(x)$, where $H(x) = x/\,\mathrm{K}$ (from the problem statement). This last step is just a conversion from Celsius to Kelvins. If the values are assigned to the variables above so that all units cancel (volts and ohms, not millivolts or $\mathrm{k}\Omega$) then the interface routine is 273.15 plus the value of $x$ above written in C:

```
temp = 273.15 + ( v1 / ( r * vadc / (nadc*R3) - v2/R2 ) / R0 - 1.0 ) / al1;
```

($c$) Determine the precision of the temperature measurement. The answer may be given as a formula using $H_{\mathrm{f}}(r)$, the mapping from ADC output to temperature in Kelvins. (10 pts)

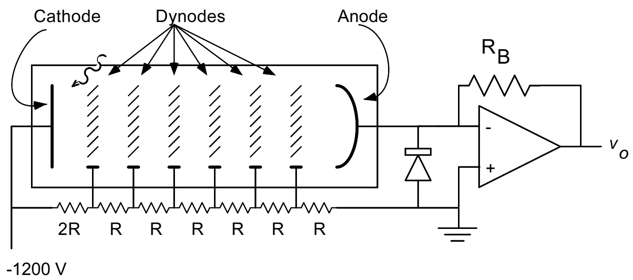
The precision is $\max_{0<r<2^{16}} |H_{\mathrm{f}}(r) - H_{\mathrm{f}}(r-1)|$ but that answer is not quite good enough because it doesn't give a value of $r$ without first trying all possible values. If the response is linear any $r$ will do. The transducer response, $H_{\mathrm{t1}}(x)$, is linear, but the conditioning circuit response is not. (The conditioning circuit response would be linear if the RTD were placed in the $R_3$ position.) A given change in RTD resistance results in a smaller change in ADC input voltage when the RTD resistance is high. Put another way, $|\frac{d}{dx} H_{\mathrm{c}}(H_{\mathrm{t1}}(x))|$ is smaller at higher temperatures. Based on the solution to the first part, higher temperatures result in lower ADC input voltages, and at the highest temperature the input voltage is $0.5\,\mathrm{V}$.

Let $r_{\min} = 0.5 \frac{2^{16}-1}{10\,\mathrm{V}}$. Then the precision is $H_{\mathrm{f}}(r_{\min}) - H_{\mathrm{f}}(r_{\min}+1)$.

Problem 2: Answer each question below.

(*a*) Describe how a photomultiplier works and how it is connected to a conditioning circuit. Name an advantage and disadvantage over a photodiode. (10 pts)

A photon strikes the cathode liberating electrons. A bias voltage accelerates electrons towards dynodes which block their path. When an electron strikes a dynode it liberates more than one electron which, due to the bias voltage, accelerates towards the next dynode. Several dynodes are placed between the cathode and the anode, the current leaves the device at the anode.



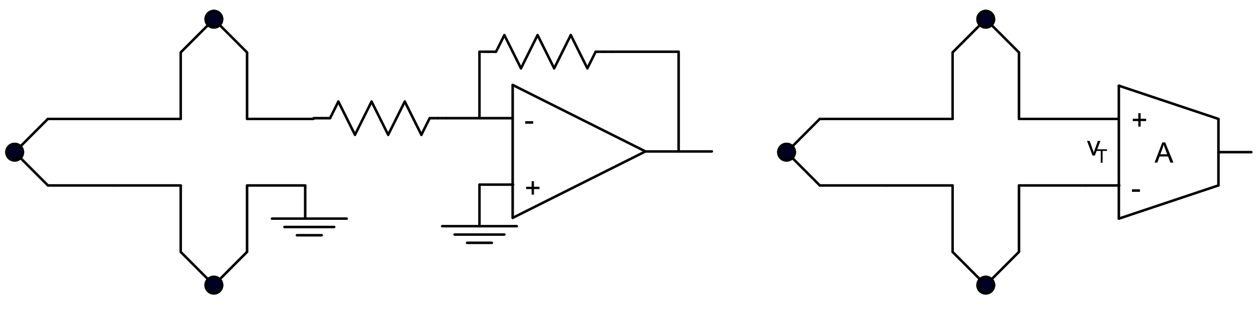

Advantage: sensitivity. Disadvantage: high bias voltage, cost, fragility.

(*b*) A programmer has the option of writing a program that runs as multiple tasks or writing it to run as one multithreaded task. Name two advantages of writing it as a single multithreaded task. (10 pts)

As a multithreaded task the different tasks can communicate via shared memory which is more efficient than reading and writing a common file.

Context switches between different threads in a multithreaded task is faster than context switches between different tasks.

(*c*) Describe a problem with the circuit on the left that does not occur with the circuit on the right. Explain how the circuit on the right avoids the problem. (10 pts)




The differential inputs to the instrumentation amplifier cancel noise, this noise is not canceled with the single input used in the inverting amplifier.

(*d*) Explain how a magnetic reluctance proximity sensor works. Under what conditions could it be used to measure the speed of a single object? (10 pts)

An object passes between a gap in a magnetic core. The magnetic reluctance of the object is different than that of the air or other medium that normally fills the gap. As the object enters the gap the field lines strengthen and as it leaves they weaken. The change in magnetic field strength induces a voltage in the winding which is detected by the conditioning circuit.

A magnetic reluctance sensor could measure speed of the magnetic reluctance and size of the object within the gap were known.

(*e*) Why is a gray code used in absolute coded displacement transducers? (10 pts)

Because there is only a single bit change from one position to the next and so the problem of not-quite-simultaneous changes in mark-reading transducer outputs when multiple bits change (as from 0111 to 1000) does not occur.