EE 4770 Homework 1 Due: 5 February 1999

Problem 1: Design a circuit and an interface routine to convert temperature, $x \in [200\,\mathrm{K}, 300\,\mathrm{K}]$, to a floating point number $H(x) = x/\mathrm{K}$ to be written to variable `temp`. Temperature is to be measured using an *integrated temperature sensor*, a sensor with model function $H_\mathrm{t}(x) = x\frac{\mu\mathrm{A}}{\mathrm{K}}$. The circuit should use a 10 V, 16-bit ADC, $H_{\mathrm{ADC}(10\,\mathrm{V},16)}$. The full range of the ADC input does not have to be used (in this problem).

- Show a schematic of the circuit showing all component and supply values. (The symbol for an integrated temperature sensor is a current source.)
- Show pseudocode or C code for the interface routine.

Solution: Can use either an inverting amplifier or put the ITS in series with a resistor. The solution below uses the inverting amplifier, with the integrated temperature sensor connected to a $-10\,\mathrm{V}$ source.

Given: $H_\mathrm{t}(x) = x\frac{\mu\mathrm{A}}{\mathrm{K}}$. For inverting amplifier $H_\mathrm{c}(y) = yR_\mathrm{B}$. Choose R_B so that $0 \le H_\mathrm{c}(H_\mathrm{t}(x)) \le 10\,\mathrm{V}$ for $x \in [200\,\mathrm{K}, 300\,\mathrm{K}]$. Since voltage increases with temperature and the minimum voltage is positive, the relation can be satisfied by solving at the maximum temperature:

$$\begin{aligned} H_\mathrm{c}(H_\mathrm{t}(300\,\mathrm{K})) &= 10\,\mathrm{V} \\ R_\mathrm{B} 300\,\mathrm{K}\frac{\mu\mathrm{A}}{\mathrm{K}} &= 10\,\mathrm{V} \\ \Rightarrow R_\mathrm{B} &= 33.33\,\mathrm{k\Omega} \end{aligned}$$

For interface routine find H_f so that $H_\mathrm{f}(H_\mathrm{ADC}(H_\mathrm{c}(H_\mathrm{t}(x)))) = H(x)$. Let $r = H_\mathrm{ADC}(H_\mathrm{c}(H_\mathrm{t}(x)))$, the ADC output, and solve for x, the temperature.

$$r = \frac{2^{16}-1}{10\,\mathrm{V}} R_\mathrm{B} x \frac{\mu\mathrm{A}}{\mathrm{K}} \qquad \Rightarrow \qquad x = r\frac{\mathrm{K}}{\mu\mathrm{A}}\frac{10\,\mathrm{V}}{R_\mathrm{B}(2^{16}-1)}$$

The interface routine function is found by converting temperature, x, to the desired form, $H(x)$:

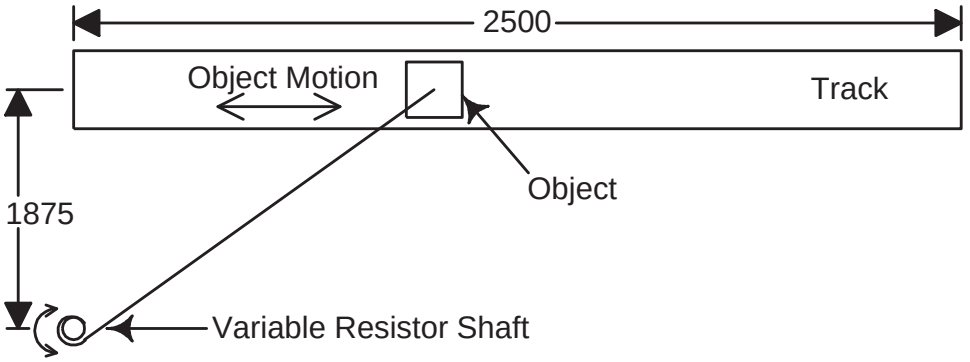
$$\begin{aligned} H_\mathrm{f}(r) &= H(x) \\ &= H\left(r\frac{\mathrm{K}}{\mu\mathrm{A}}\frac{10\,\mathrm{V}}{R_\mathrm{B}(2^{16}-1)}\right) \\ &= r\frac{\mathrm{K}}{\mu\mathrm{A}}\frac{10\,\mathrm{V}}{R_\mathrm{B}(2^{16}-1)}\frac{1}{\mathrm{K}} \\ &= \frac{r}{218.45} = 0.00457771r \end{aligned}$$

Interface routine code:

```
r = readInterface(); temp = r * 0.00457771;
```

Problem 2: Design a circuit and interface routine to convert $x \in [0, 2500\,\text{mm}]$, the position of the center of an object sliding along a track, to a floating point number $H(x) = x/\,\text{m}$ to be written to `dist`.

The center of the object is connected to a cable which winds around the shaft of a variable resistor placed 1875 mm below the track at the zero position (see the diagram). The shaft is spring loaded so the cable is always wound tightly. The shaft will turn exactly one revolution for each ten centimeters of cable unwound. The circuit should use a 10 V, 16-bit ADC, $H_{\text{ADC}(10\,\text{V},16)}$. Try to use the full range of the ADC input by efficient use of the variable resistor.



- As part of the design determine the number of turns from minimum to maximum position, and choose a maximum resistance.
- Find a model function for the variable resistor (rotation to resistance) and find the mapping from object position to shaft rotation.
- Show a schematic of the circuit showing all component and supply values.
- Show pseudocode or C code for the interface routine.

Solution: First determine the relationship between object position and the distance from the object to the variable resistor, d. Noting the right triangle, $d = H_{\text{a}}(x) = \sqrt{1875\,\text{mm}^2 + x^2}$. The distance d is linearly related to shaft rotation, denoted θ. To make full use of the variable resistor the cable will be attached so that $\theta = 0$ when $x = 0$. The change in d from $x = 0$ to $x = 2500\,\text{mm}$ is $H_{\text{a}}(2500\,\text{mm}) - H_{\text{a}}(0\,\text{mm}) = 3125\,\text{mm} - 1875\,\text{mm} = 1250\,\text{mm}$. At one rotation per 100 mm, the maximum number of rotations is 12.5. The mapping from object position to shaft rotation is

$$\theta = H_{\text{b}}(x) = (H_{\text{a}}(x) - 1875\,\text{mm})\frac{360^\circ}{100\,\text{mm}} = (\sqrt{(1875\,\text{mm})^2 + x^2} - 1875\,\text{mm})\frac{360^\circ}{100\,\text{mm}}.$$

The choice of maximum resistance is based on what the conditioning circuit can easily handle, choose $100\,\text{k}\Omega$. Since the variable resistor linearly converts rotation to resistance its model is

$$H_{\text{vr}}(\theta) = \theta\frac{100\,\text{k}\Omega}{12.5 \times 360^\circ}.$$

An inverting amplifier will be used to convert variable resistance to voltage, with the variable resistor in the R_{B} position.

To find H_f in

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

solve for x in the ADC output,

$$\begin{aligned} r &= H_\mathrm{ADC}(H_\mathrm{c}(H_\mathrm{vr}(H_\mathrm{b}(x)))) \\ &= \frac{2^{16}-1}{10\,\mathrm{V}} \frac{10\,\mathrm{V}}{100\,\mathrm{k\Omega}} \frac{100\,\mathrm{k\Omega}}{12.5 \times 360^\circ} \frac{360^\circ}{100\,\mathrm{mm}} \left(\sqrt{(1875\,\mathrm{mm})^2 + x^2} - 1875\,\mathrm{mm} \right) \end{aligned}$$

yielding

$$x = \sqrt{\left(\frac{r}{2^{16}-1} 12.5 \times 100\,\mathrm{mm} + 1875\,\mathrm{mm} \right)^2 - (1875\,\mathrm{mm})^2}$$

$$\begin{aligned} H_\mathrm{f}(r) = H(x) &= \sqrt{\left(\frac{r}{2^{16}-1} 12.5 \times 100\,\mathrm{mm} + 1875\,\mathrm{mm} \right)^2 - (1875\,\mathrm{mm})^2} \frac{1}{1000\,\mathrm{mm}} \\ &= \sqrt{\left(\frac{r}{2^{16}-1} 12.5 \frac{1}{10} + 1.875 \right)^2 - 1.875^2} \end{aligned}$$

Rendered as code:

```
r = readInterface();
temp = 1.875 + r * 0.0000190738;
dist = pow( temp * temp - 3.51562, 0.5 );
```