Name Solution

Real Time Computing Systems

EE 4770

Midterm Examination

12 March 1997, 8:40-9:30 CST

Problem 1	______	(33 pts)
Problem 2	______	(34 pts)
Problem 3	______	(33 pts)
Exam Total	______	(100 pts)

Alias ______

Good Luck!

Problem 1: A circuit is to be designed to convert temperature $x \in [280\,\mathrm{K}, 300\,\mathrm{K}]$ to voltage $H(x) = (x - 280\,\mathrm{K})\frac{\mathrm{V}}{4\,\mathrm{K}}$ using a thermistor having model function $H_{t2}(x) = R_0 e^{\beta/x}$ with $\beta = 3000\,\mathrm{K}$ and $R_0 = 0.059\,\Omega$.

(a) Find a linear thermistor model appropriate to this problem using the method described in class. (In which the change in resistance with temperature (slope of model) matches H_{t2} at a particular point.) (8 pts)

Linear model: $H_{t4}(x) = R_\mathrm{M}(1 + \alpha(x - T_\mathrm{M}))$. As derived in class $\alpha = -\beta/T_\mathrm{M}^2$, where T_M is the middle of the temperature range to be measured ($[280\,\mathrm{K}, 300\,\mathrm{K}]$), so $T_\mathrm{M} = 290\,\mathrm{K}$, and R_M is the thermistor resistance at T_M, $R_\mathrm{M} = H_{t2}(T_\mathrm{M}) = R_0 e^{\beta/T_\mathrm{M}} = 1835\,\Omega$. Then $\alpha = -3000\,\mathrm{K}/(290\,\mathrm{K})^2 = -0.03567/uK$.

The complete model function is $\boxed{H_{t4}(x) = 1835\,\Omega\left(1 - \frac{0.03567}{\mathrm{K}}(x - 290\,\mathrm{K})\right).}$

(b) Find a linear thermistor model which matches H_{t2} at 280 K and 300 K. (7 pts)

Let R_{280} denote the thermistor resistance at 280 Kelvins, $R_{280} = H_{t2}(280\,\mathrm{K})$, and similarly $R_{300} = H_{t2}(300\,\mathrm{K})$. The linear model should pass through points $(280\,\mathrm{K}, R_{280})$ and $(300\,\mathrm{K}, R_{300})$. The equation of such a line is $H_{t5}(x) = R_{280} + (x - 280\,\mathrm{K})\frac{R_{300} - R_{280}}{300\,\mathrm{K} - 280\,\mathrm{K}}$. Using $R_{280} = 2655\,\Omega$ and $R_{300} = 1300\,\Omega$,

$\boxed{H_{t5}(x) = 2655\,\Omega + (x - 280\,\mathrm{K})\frac{-1355\,\Omega}{20\,\mathrm{K}}.}$

(c) Draw the schematic of a circuit that could be used to generate the voltage. Show the sign (but not the value of) of voltage sources used. Show, but do **not** solve, an equation or equations that can be used to find the component values. The equation should be in terms of the first linear model function requested above, and should not contain symbols H_c, H_t, or H. (That is, instead of $H(x)$ the equation might contain $(x - 280\,\mathrm{K})\frac{\mathrm{V}}{4\,\mathrm{K}}$.) If a gain/offset amplifier is used, the equation may be in terms of A_5 and O_5. (18 pts)

Use the gain/offset amplifier. The output is given by $v_o = A_5(H_{t4}(x) - O_5)$. Values for A_5 and O_5 are found by solving:

$$A_5(H_{t4}(280\,\mathrm{K}) - O_5) = 0\,\mathrm{V}$$
$$A_5(H_{t4}(300\,\mathrm{K}) - O_5) = 5\,\mathrm{V}$$

Both voltage sources must be negative.

Problem 2: An object slides along a straight track ten meters long. Mounted on the object is a lamp which radiates uniformly in all directions. Photodiodes with response $H_{t1}(E) = E \frac{50\,\mu\mathrm{A}}{\mathrm{mW}/\mathrm{cm}^2}$ are available (purchased at low cost from a pet shop). Only light directly radiated from the lamp will reach the photodiodes.

(a) Suppose the lamp has a radiant flux of $\Phi = 1.7\,\mathrm{W}$. Design a system to determine the location of the object and write the location, in meters, to variable `loc`. The solution should include the circuit and interface routine; all component and supply values must be specified. (15 pts)

Place the photodiode on the track's axis, $100\,\mathrm{mm}$ from one end. Use an inverting amplifier in a current-to-voltage configuration and a 5-volt, 16-bit ADC. The amplifier gain is chosen so that at maximum irradiance, ADC input is 5 volts: $H_c(H_t(E_{\max})) = RK_sE_{\max} = 5\,\mathrm{V}$. Maximum irradiance, based on a distance of $100\,\mathrm{mm}$ is $E_{\max} = \Phi/(4\pi(100\,\mathrm{mm})^2) = 13.53\,\mathrm{W}/\mathrm{m}^2$. Then $R = 5\,\mathrm{V}/(K_sE_{\max}) = 73.9\,\mathrm{k}\Omega$. The ADC output w, is

$$w = \frac{2^{16}-1}{5\,\mathrm{V}} \frac{\Phi}{4\pi d^2} K_s R,$$

where d is the distance between the object and the photodiode (including the extra $100\,\mathrm{mm}$). Solving,

$$d = \sqrt{\frac{2^{16}-1}{5\,\mathrm{V}} \frac{\Phi}{4\pi w} K_s R} = \frac{25.596}{\sqrt{w}}\,\mathrm{m}.$$

Let x be the distance from the end of the track near the photodiode, then $H(x) = (d - 100\,\mathrm{mm})/\,\mathrm{m}$ and we need to find $H_f(w) = H(x) = (d - 100\,\mathrm{mm})/\,\mathrm{m}$.

Interface routine: `w = readInterface(); distance = 25.5964 * pow(w,-0.5) - 0.1;`

(b) Unlike the first part, suppose that the radiant flux of the lamp is not known. Like the first part, the position is unknown. Using only photodiodes, design a system to convert the radiant flux, $x \in [0, 1.7\,\mathrm{W}]$, into a floating-point number $H(x) = x/\mathrm{W}$, to be written to variable `phi`. *Hint: use two photodiodes.* (19 pts)

Place photodiodes at both sides, each $100\,\mathrm{mm}$ from its end of the track. Let d_1 denote the distance from one photodiode and d_2 the distance from the other. Clearly,

$$E_1 = \frac{\Phi}{4\pi d_1^2} \quad \text{and} \quad E_2 = \frac{\Phi}{4\pi d_2^2}.$$

Because the photodiodes are placed at known positions, $d_1 + d_2 = 100\,\mathrm{mm} + 1\,\mathrm{m} + 100\,\mathrm{mm} = L$, where L is the distance between the photodiodes. Using this to eliminate d_2 in the second equation yields $E_2 = \frac{\Phi}{4\pi(L-d_1)^2}$. Solving for d_1 in the first displayed equation and substituting in the second yields:

$$E_2 = \frac{\Phi}{4\pi\left(L - \sqrt{\frac{\Phi}{4\pi E_1}}\right)^2}.$$

By setting $\phi = \sqrt{\Phi}$ and collecting ϕ terms the equation can be rewritten:

$$\phi^2\left(\frac{1}{4\pi}\left(\frac{E_2}{E_1} - 1\right)\right) + \phi\left(-\frac{2L}{\sqrt{4\pi E_1}}\right) + L^2 E_2 = 0$$

Thus, Φ can be found in terms of the irradiances. The interface routine:

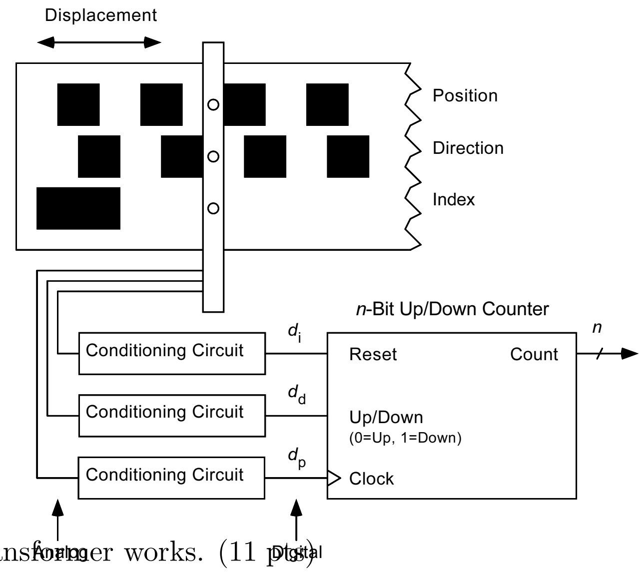
```
e1 = readInterface(1) * 0.000206455;
e2 = readInterface(2) * 0.000206455;
a = (e2/(e1*4.0*M_PI)-1.0/(4.0*M_PI));
b = -20.4 * pow( 4.0 * M_PI * e1, -0.5);
c = 104.04 * e2;
Phi = ( -b + pow( b*b - 4*a*c, 0.5) ) / (2 * a);
```

(In the C math library, `pow(x,y)` is x^y and `M_PI` $= \pi$.)

Problem 3: Answer each question below.

(*a*) Show how marks are placed on a two-way relative coded displacement transducer and explain how these are used to determine direction. (11 pts)

Three rows of marks are placed as shown, called position, direction, and index. Each row is read by a transducer. When a 0-to-1 (no-mark-to-mark) transition is detected at the position sensor the state of the direction sensor is checked. If its zero motion is forward (card moving to the left), if one motion is backward.



(*b*) Explain how a linear variable differential transformer works. (11 pts)

An LVDT is a transformer with three windings, a primary and two secondaries, and a movable core. The core is linked to the object being measured. The secondaries are connected to oppose each other, so if the core is centered (as in an ordinary transformer) the secondary voltages exactly cancel. At other positions the voltage at one secondary is stronger than the other, the phase can be used to determine which secondary is stronger. Displacement is determined by measuring the secondary voltage and phase.

(*c*) Explain the difference between practical and thermodynamic temperature scales. Why are practical temperature scales periodically revised? (11 pts)

In a practical scale temperature is defined in terms of the best transducers that could be built at the time the scale was defined. (Roughly, the temperature is whatever the transducer says it is.) In the thermodynamic scale temperature is defined in terms of particle translational energy (motion). Practical scales are revised every few decades to incorporate the most accurate and reproducible contemporary transducers.