PreLab 2 – Thermistor Measurement System
(9 problems for 30 pts)

INTRODUCTION

In this lab, you will develop a temperature measurement system. A system block diagram is shown in Fig. 1. Here's how it works:

1) The thermistor (in a quarter bridge) converts temperature to a voltage signal.
2) The instrumentation amplifier increases the signal amplitude.
3) The amplifier output is recorded by the Arduino and sent to a computer.
4) The computer processes the data (using MATLAB) to produce a plot of temperature versus time.

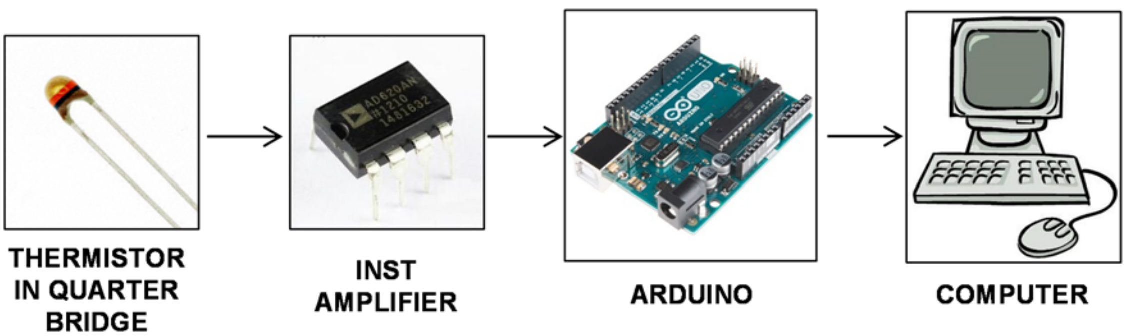

Fig. 1: Overall temperature measurement system.

PART 1: SYSTEM DESIGN

In Lab2, we want to build a temperature measurement system that operates between T = 10 °C and +35°C. Consider the signal conditioning electronics shown in Fig. 2. The bridge consists of a 10 kohm thermistor and three 10.0 kohm resistors (1% tolerance). The quarter bridge and amplifier are powered by +5 V and GND. The AD620 has a reference $V_{REF} \approx 2.5V$ provided by the voltage divider at pin 5.

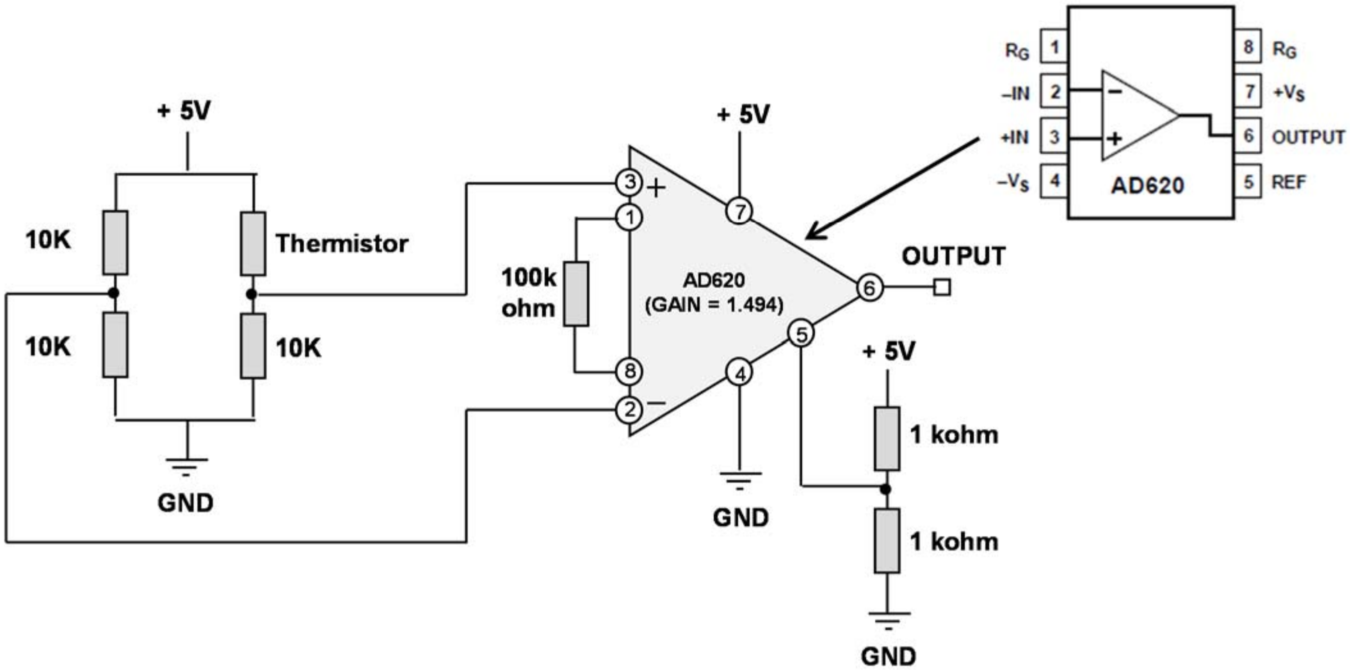

Fig. 2: Signal conditioning electronics for the thermistor. Vref = 2.5V is applied to pin 5 of the AD620 chip.

- PROBLEM 1: Show that the resistor bridge voltage is given by:

$$\Delta V = \left(\frac{10kohm}{10kohm+R_T} - 0.5\right) \times V_S \qquad \text{Eq.(1)}$$

where R_T is the thermistor resistance and V_S is the power supply.

- PROBLEM 2: The thermistor datasheet has a table of thermistor resistance values versus temperature. The table has values for a variety of thermistors. We are using a 10 kohm thermistor, which means the resistance is 10 kohm at T = 25 °C. What is the thermistor resistance $R_{T,HOT}$ at T_{HOT} = 35 °C? What is the thermistor resistance $R_{T,COLD}$ and T_{COLD} = 10 °C? Express your answer in kohms.

- PROBLEM 3: Based on your answers to Problem 1 and 2, show that ΔV_{HOT} = 0.524V and ΔV_{COLD} = -0.826V.

How to choose the amplifier gain A_d?

- We always want our measured voltage V_{MEAS} to be within the allowable measurement range. In other words, we must make sure that $V_{MEAS,MIN} < V_{MEAS} < V_{MEAS,MAX}$.

- Depending on the system, $V_{MEAS,MIN}$ and $V_{MEAS,MAX}$ are determined by either the amplifier or the ADC. We already know the Arduino can measure from 0 to 5V. What limitations are imposed by the amplifier?

- Most instrumentation amplifiers have a limited output voltage range. If an amplifier is powered by $+V_S$ and GND, the highest output is typically V_S - 1 while the lowest output is typically +1V. For example, an amplifier powered by +9V and GND has a maximum output of 8V and a minimum output of 1V. **For this lab, the amplifier is powered by +5V and GND.**

- PROBLEM 4: Keeping in mind that $V_{MEAS} = V_{REF} + A_d\Delta V$, determine the maximum allowable amplifier gain such that $V_{MEAS} < V_{MEAS,MAX}$ at T_{MAX} = 35 °C. Do a similar calculation for T_{MIN} = 10 °C, except you now want $V_{MEAS} > V_{MEAS,MIN}$. The SMALLER gain value is the correct choice for the maximum usable amplifier gain for the entire temperature range.

- PROBLEM 5: You must choose between A_d = 1, 1.5, 2 2.5, and 3. Choose one, compute the closest 5% resistor value, and then compute the actual gain based on your choice of resistor.

  Hint #1: Remember that the AD620 gain is determined by: $A_d = 1 + \frac{49400}{R_G}$

  Hint #2: You should get 100 kohm.

OK, now we need to convert the measured voltage to a temperature value! This is actually a two step process. First, we convert the measured voltage V_{MEAS} to the thermistor resistance R_T. Second, use the Steinhart-Hart equation to convert R_T into a temperature.

- PROBLEM 6: Derive the following expression that converts V_{MEAS} into R_T:

$$R_T = (10\ kohm)(0.5 - \beta)/(0.5 + \beta) \qquad \text{where} \quad \beta = (V_{MEAS} - V_{REF})/(A_d V_S) \qquad \text{Eq. (2)}$$

- PROBLEM 7: Suppose the instrumentation amplifier has a gain of Ad = 1.5, and that your measured voltage is V_{MEAS} = 1.5V. Use the Extended Steinhart-Hart Equation to determine the thermistor temperature in °C. The extended Steinhart-Hart equation is given below (T is in Kelvin):

$$T = \frac{1}{A + B\ln\left(\frac{R_T}{R_{25}}\right) + C\left(\ln\left(\frac{R_T}{R_{25}}\right)\right)^2 + D\left(\ln\left(\frac{R_T}{R_{25}}\right)\right)^3} \qquad \text{Eq. (3)}$$

  where A = 3.354016 E-3, B = 2.569850 E-4, C = 2.620131 E-6, and D = 6.383091 E-8. You will need to convert your answer from the above equation (in Kelvin) to °C. You will use Eq. (2) and Eq. (3) in your MATLAB program.

Hint: Your final answer should be close to 13°C.

PART 2: OTHER SYSTEM SPECIFICATIONS

- PROBLEM 8: Suppose your measurement system has a noise voltage of 2 $mV_{RMS.}$ The Arduino ADC has 10 bits from 0 to 5V. What is the temperature sensitivity at T = 10°C? Consult the thermistor data sheet to find the tempco value, which is listed as "TCR" in the table. Hint: ΔT_{MIN} should be around 0.06 °C.

- PROBLEM 9: Assuming the thermistor is left in the open air at T = 25°C, the thermistor temperature should also be T = 25°C. Let the 10k thermistor have a dissipation factor of 7 mW/°C. Let us adopt the criterion that self-heating can be ignored if it produces a temperature rise less than the sensitivity ΔT_{MIN} of your measurement system at T = 25°C. Can we ignore self-heating? Show all work! Hint: ΔT_{SELF} should be around 0.09 °C.

  NOTE: You will find that ΔT_{SELF} is only slightly higher than ΔT_{MIN}. Technically, this means we cannot ignore self-heating. Realistically, it is OK to ignore self-heating if the desired temperature sensitivity is much bigger (e.g. desired ΔT_{MIN} = 0.5 °C) than the actual ΔT_{MIN} of your system.

(End of PreLab2)