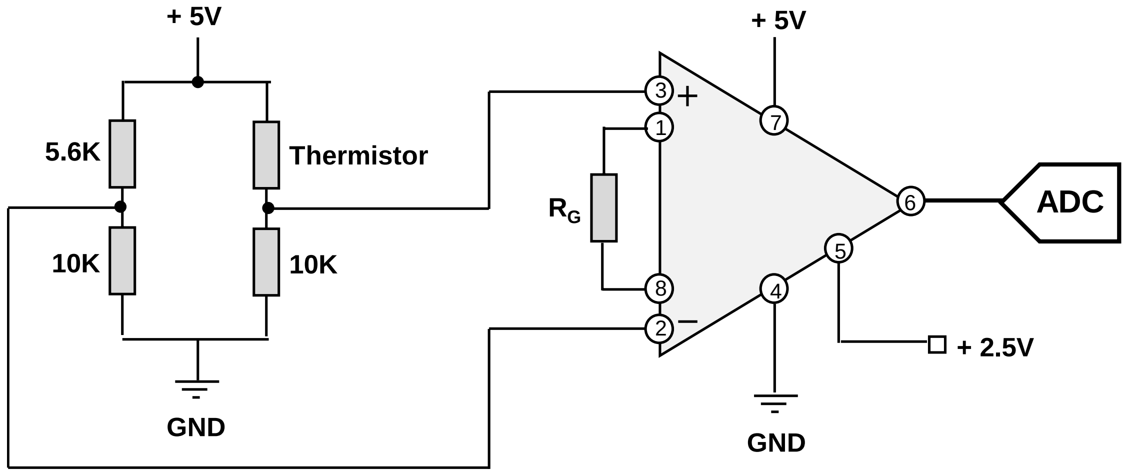
HW 2 – Temperature Measurement Systems
(12 problems for 100 pts)

Thermistor Circuit Design

You are asked to design a system to measure temperature from 30 °C up to 50°C. Consider the signal conditioning electronics shown in the figure. At T = 30°C, the thermistor resistance is R_T = 8.06 kohm and the tempco is α = -4.25%/°C. At T = 50°C, the thermistor has R_{TH} = 3.61 kohm and α = -3.8%/°C. The instrumentation amplifier is powered by +5 V and GND with an offset voltage of 2.5V. The amplifier output is fed to an 8-bit ADC operating from 0 to 5V.



- PROBLEM 1: Derive the equation for V_{MEAS} (the output of the instrumentation amplifier).

- PROBLEM 2: 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 problem, you must choose between an amplifier gain of 1, 1.5, 2, 2.5, 3, 3.5, 4. Which is the best choice? Show all work!

  Hint #1: Think about whether your maximum signal is limited by the amplifier or the ADC.

  Hint #2: You should get A_d = 3.

- PROBLEM 3: Suppose the output of the instrumentation amplifier has a noise voltage of 4 mV_{RMS}. What is the temperature sensitivity at T = 50°C? Hint: It should be around 0.18 °C.

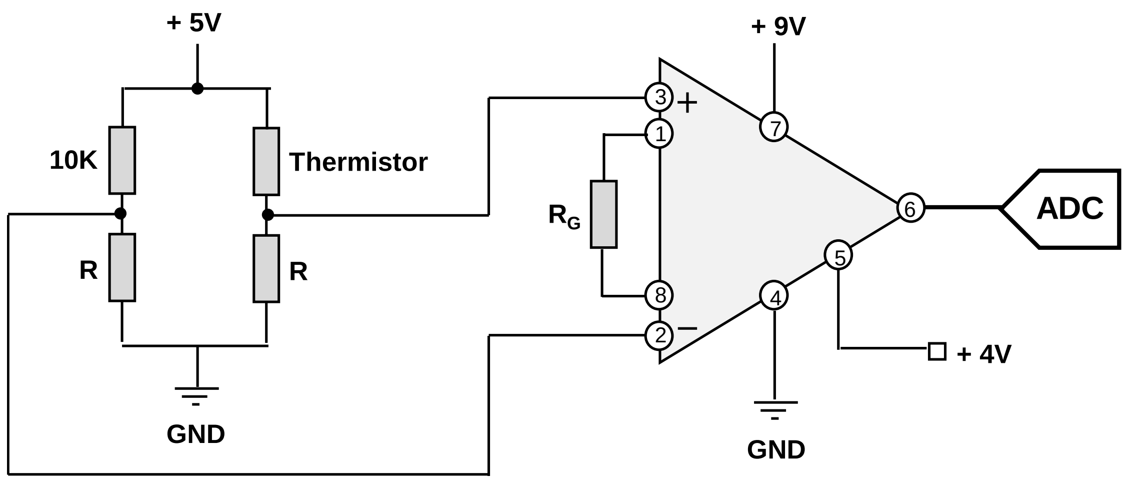
- PROBLEM 4: Suppose you replace the ADC with a 12-bit version operating from 0 to 5V. Re-compute the temperature sensitivity at T = 50°C. You can re-use your value of dV_{MEAS}/dT from Problem 3. Show all work!

- PROBLEM 5: If the self-heating produces a temperature rise less than ΔT_{MIN}, then we can ignore self-heating. Is this the case when using the 8-bit ADC? Assuming a dissipation factor of 7 mW/°C and evaluate the self-heating induced temperature rise at T = 30 °C. Show all work!

Another Thermistor Circuit Design

You are asked to design a temperature measurement system that operates from 0 °C to +100 °C. You decide to use a thermistor R_T in a quarter bridge powered by +5V, as shown in the figure below. The instrumentation amplifier has a differential gain A_d = 2 and is powered by +9V and GND. The amplifier output is limited to within 1V of the power supplies (just like in Problem 2). The voltage reference is V_{REF} = +4V. The ADC has 12 bits over a 0 to 10V range. The system noise voltage is 10 mV_{RMS}. The thermistor properties are the following:

- T = 100 °C: R_T = 677 ohm α = -2.94 %/°C
- T = 25 °C: R_T = 10,000 ohm α = -4.38 %/°C
- T = 0 °C: R_T = 32,554 ohm α = -5.09 %/°C

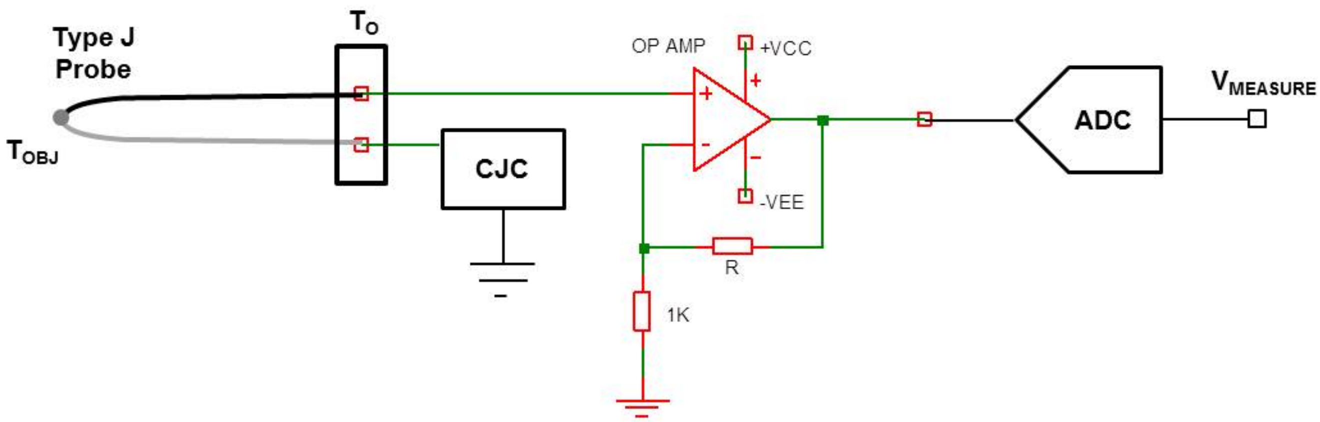


- PROBLEM 6: You have available R = 10 kohm and R = 20 kohm. Do either of these resistors ensure an operating range of 0 to +100 °C?. Show all work!

- PROBLEM 7: Compute the temperature sensitivity at T = 0°C and 100 °C. Show all work!

- PROBLEM 8: Suppose we can ignore self-heating if the temperature rise is less than ΔT_{MIN} at T = 0 °C. Is this the case? Assume a dissipation factor δ = 5 mW/ºC. Show all work!

Thermocouple System



- PROBLEM 9: Suppose T_O = 30°C. What is the appropriate voltage produced by the cold junction compensation? Express your answer in mV. To make things easier, just use the standard Seebeck coefficients from the Lecture 4 notes (see course website). Technically, those values are only for 0°C, but for this course we'll assume ΔS does not change with temperature.

- PROBLEM 10: What gain G is necessary to produce a measured voltage V_{MEAS} = (10 mV/°C)*T_{OBJ}? Hint: See page 4.6 of the lecture notes to guide your thoughts. Hint #2: You should get G ≈ 196.

- PROBLEM 11: The op amp in the above figure is configured as a non-inverting amplifier (just like Lecture 4). What value of "R" is necessary to achieve a gain G that is close to your answer in PROBLEM 10? Choose a standard 1% resistor value and compute the actual gain of your amplifier based on this value. For this problem, it does not matter if your actual gain is slightly higher or lower than the ideal value from Problem 10.

  NOTE: The pdf on the course website only lists 1% resistor values from 10.0 to 97.6 ohms. Just multiply all values by 10000 if you need resistors between 100 kohm and 976 kohm.

- PROBLEM 12: Suppose the ADC has 10 bits over a +/- 5V range and the noise voltage is 3 mV_{RMS}. Compute the highest temperature T_{MAX} that can be measured as well as the temperature sensitivity ΔT_{MIN}. To make things easier, assume the Seebeck coefficient remains constant throughout the temperature range. Also remember to use the actual gain of your amplifier (see Problem 11). Hint: T_{MAX} should be near 500 °C and ΔT_{MIN} should be around 1 °C.