EE313 Project (v4)

Project parts are to be done individually and independently. Write the following statement at the beginning of each project report and sign it:

"I affirm that I have not given or received any unauthorized help on this report and that this work is my own."

Still, if you prefer to work in groups, the grade will be equally divided by the number of group members!

Thermocouple instrumentation amplifier controlled heater

For type-K (yellow wire:+, red wire: −) thermocouple as the input, design a single-supply thermocouple amplifier that generates a voltage proportional to the temperature at the output. A heater (a ¼ W resistance of between 220Ω and 390Ω) is aimed to be kept at T_S=30+mod(BilkentID,40) °C above the room temperature. The thermocouple is in contact with the heater resistance. The 18V voltage source feeds the heater resistance through an electronic switch (either ON or OFF). The switch should turn ON when the temperature of the heater resistance is lower than the aimed temperature and turn OFF when it is above (an ON/OFF controller). For visual feedback, an LED should turn ON when the heater voltage is turned ON. The switch (a BJT) should be driven by a comparator having a small amount of hysteresis (0.1V) so that switching occurs abruptly.

K-type thermocouple generates a meager 39.2μV/°C (proportional to the temperature difference between the thermocouple junction and cold junctions). The thermocouple output voltage should be amplified significantly to get the required output sensitivity. OPAMPs have an offset voltage between their input pins (ideally, it is zero), and moreover, this offset voltage changes as a function of ambient temperature. For example, LM358 or LM324 (BJT input OPAMPs) have a maximum offset voltage of 7mV, and the offset voltage changes by 7μV/°C. TL062 or TL084 (JFET input OPAMPs) have a maximum offset voltage of 15mV, and it changes by 18μV/°C.

Since a high-gain DC amplifier is needed, an instrumentation amplifier is a good choice to amplify small low-frequency signals accurately. The instrumentation amplifier, built from three OPAMPs (all three on the same chip), cancels the offset voltages, and the offset voltage shifts since two identical temperature OPAMPs are used at its input. Refer to the instrumentation amplifier document found in Moodle. Note that the input voltage range of the OPAMPs should be within the allowed range. Also, note that the v_R input of the instrumentation amplifier needs to be connected to the necessary DC shift voltage to work with a single-supply voltage. If you generate v_R by a voltage divider, ensure that the change in the v_R voltage due to the current going into the difference amplifier resistance, R_2, is not much. In other words, the divider resistances must be much smaller than R_2. Alternatively, you may choose the voltage divider resistors and R_2 such that the equivalent Thevenin voltage is v_R, and the Thevenin resistor is equal to R_2.

Specifications:

1. The output voltage at 2V±0.5V when the thermocouple is at room temperature (thermocouple output voltage is zero).
2. The output voltage is 9V±1V when the temperature is at the required temperature (thermocouple voltage is $39.2 \times T_S$ μV)
3. LED turns ON when the heater resistance is being heated. It should turn OFF when the heater is OFF.

Available components: OPAMPs: LM358 (contains two OPAMPs), TL062 (two OPAMPs, FET input), TL084 (four OPAMPs, FET input), LM324 (four OPAMPs); zener diodes; BJTs: BC238, 2N3904, BC308, BD135, BD136, JFET: BF245 (with njf symbol in LTSpice, n-Channel, VT=−2.3V), MOSFET: 2N7000 (with nmos symbol, n-channel, VT=1.6V), red LED, standard resistors, standard capacitors, K-type thermocouple, 2-pin PCB connector, 10K trimpot.

Datasheets are in Moodle. LTSpice model files of most components are also in Moodle.

Design Phase (Due November 14, 2024)

Simulate your design using LTSpice to show the performance under the abovementioned conditions.

Upload your LTSpice source file *.asy into Moodle. Use Diptrace to generate a nice-looking schematic of your design that shows a component list.

In the lab, measure the input offset voltage and input bias currents of two input OPAMPs to be used for the instrumentation amplifier. Refer to the Instrumentation Amplifier document on how to do it.

To simulate an OPAMP with the known offset voltage and bias currents, place the opamp2Offset.asc and opamp2Offset.asy, and XXXX.txt files (XXXX is the name of the OPAMP to be used. All found in Moodle) in the work directory. In the opamp2Offset.asc schematic, change the parameter lines to the measured input offset voltage and bias currents. Change the ".include XXXX.txt" line, so that XXXX is the name of the OPAMP used. Ctrl-Right-click on the opamp2 symbol to change the Value to XXXX. Save it.

In the new LTSpice schematic (of thermocouple amplifier), use the opamp2Offset symbol for the OPAMPs.

The input offset voltages of the two input OPAMPs may be slightly different and a perfect cancellation of offset voltages does not occur. Generate a second opamp2Offset symbol to simulate the difference. You need to change the value of v_R to compensate for the undesired shift.

Add a comparator using another OPAMP to turn on an LED and the switch when the heater temperature is below the aimed temperature.

You can simulate the thermocouple with a voltage source. At room temperature, this voltage source should be set to zero. At 1°C above the room temperature, the voltage source is set to 39.2μV. At T_S, the voltage source is $39.2 \times T_S$ μV.

Always use standard value resistors or capacitors. If a resistor value needs tuning, place a parallel resistor of higher value to reduce the resistor value slightly. For fine adjustment you can use a trimpot.

Upload the LTSpice simulaton file (asc) and PDF report showing the three specifications are satisfied with corresponding simulation outputs.

PCB Design Phase (Due November 25, 2024)

Before designing the PCB, test your design on a breadboard. Then, using the Diptrace, generate a PCB layout. Use the 2-pin PCB connector to connect to the thermocouple, and/or power supply. Use a one-layer board of size 55 mm × 55 mm. Spend time on placement. Place the components either vertically or horizontally. Refer to the Diptrace PCB layout document in Moodle.

The project circuit so simple that a PCB with no jumpers is possible. A good placement is very important for a good layout. Upload the gerber file and report showing your PCB design to Moodle before the deadline. If you submit earlier than the deadline, you will receive your fabricated PCB earlier, giving you more time for experimentation and testing.

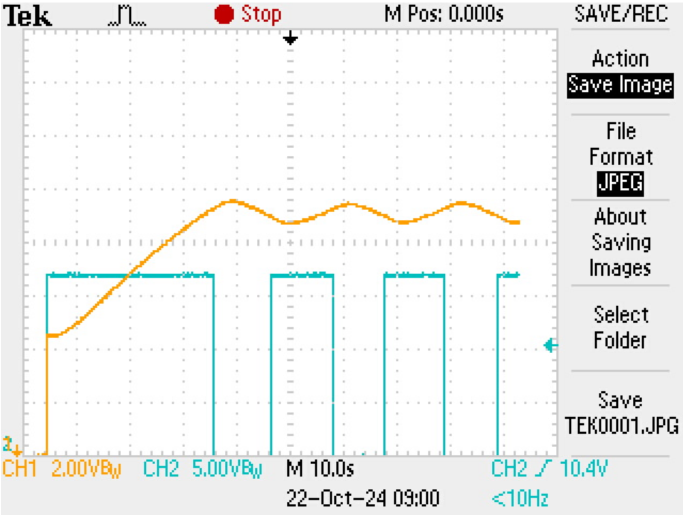
Upload three files to Moodle: Diptrace schematic (dch), layout (dip), and Gerber (zip four files: bottom, board, top silk, drill) files.

Experiment and demonstration (Due Dec 16, 2024)

Build your design on the PCB. Be very careful while soldering the components. Since the fabricated PCB has no (green-colored) solder mask, you may easily short-circuit the nodes to each other. Using a magnifying glass, inspect the solder joints to ensure you do not have any cold solder joints or short circuits.

Test the specifications given above. Demonstrate your work.

An example of output voltages is shown below: The yellow trace shows the instrumentation amplifier output voltage while the blue trace shows the comparator output. Note that the horizontal scale is 10s/div.



Youtube video (Due Dec 16, 2024)

Prepare a 3-minute video, demonstrating your circuit. Upload the video to Youtube. Provide the youtube link in Moodle. You can use this link as an entry in your CV.

Grading criteria:

Design Phase (5 pts)

Nice looking schematic with component list: 0.5pts

Satisfaction of all criteria in LTSpice: 4.5pts

PCB Design Phase (4 pts)

A nice looking PCB without errors and a minimum number of jumpers. All components are neatly placed on one side of the PCB.

You lose 0.5pt for each error. You lose 0.2pt for each jumper.

You lose 2 pts each time you order a new PCB.

Experimental and Demonstration: (5 pts)

Nice looking PCB with good solder joints: 0.5pts

Experimental satisfaction of the criteria: 4.5 pts

Youtube video (1pt)