Lab 13: Hysteretic heater controller (Version 1.3)
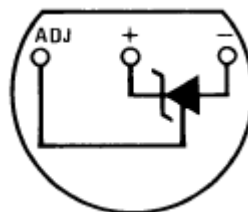
WARNING: Use electrical test equipment with care! Always double-check connections before applying power. Look for short circuits, which can quickly destroy expensive equipment.

Lab preparation

An assigned LabView VI simulates a hysteretic temperature controller (thermostat). Heating is performed by a control current switch and cooling is via constant conductive and/or convective heat flow to a fixed temperature reference. The user specifies two temperature setpoints. Below the lower setpoint the heater is always on. Above the upper setpoint the heater is always off. Otherwise, the heater is on or off depending on the slope of the temperature change. The VI will be modified to incorporate a digital (i.e. ON or OFF) heater switch and an analog temperature sensor. The assignment simulated a cryostat with degrees measured in Kelvin (K). The lab uses units of Celsius (C).
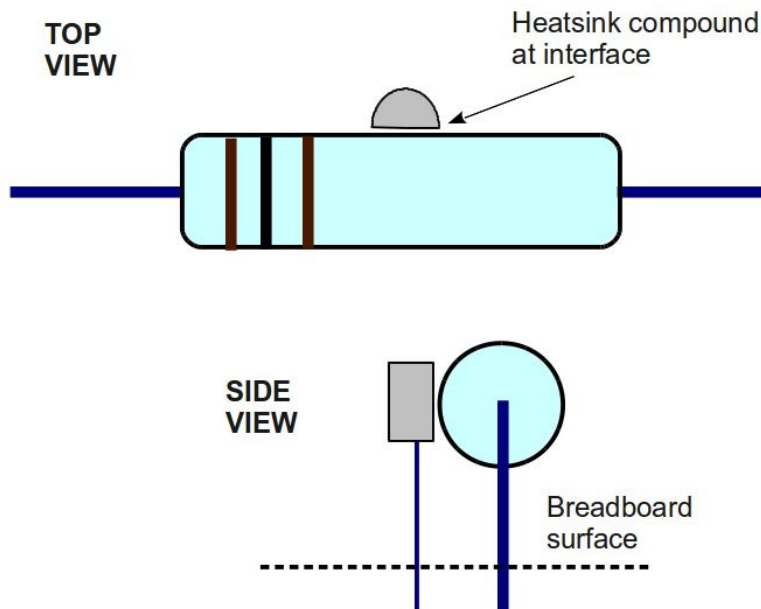
Heater & Temperature Sensor

The heater element is a 100-Ω 2-Watt metal-oxide resistor and the temperature sensor is a LM335A 3-pin integrated circuit in a TO-92 plastic package. The sensor detects the breakdown voltage of an internal reverse-biased Zener diode, which changes in a predictable manner (10 mV/deg) as a function of temperature. The pin diagram for this IC as viewed from the bottom is shown in the figure:
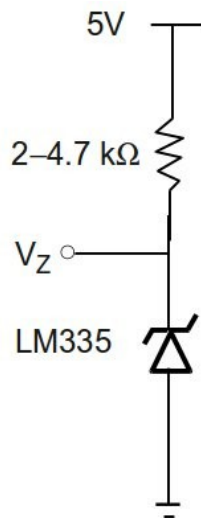

Temperature Sensor: Bottom View

The ADJ pin is not used. The 100 Ω resistor and temperature sensor must be in good thermal contact. The flat face of the sensor should press directly against the body of the resistor as shown in the sketches below. Insert the resistor in appropriately spaced breadboard holes to put it at the height of the sensor. The wires can be bent to create a slight tension that helps keep the two devices in physical contact. Even a small air gap will significantly degrade performance, so this space should be filled with a thin layer of heat-sink compound.
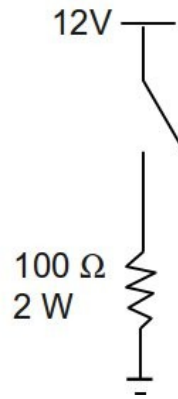
TOP
VIEW

Heatsink compound
at interface

SIDE
VIEW

Breadboard
surface

Verify electrical operation

Build the following circuit to test the sensor. Connect it through a bias resistor with resistance in the range 2--4.7 kΩ to a 5V supply on the Elvis board. Use a DMM (external or Elvis board) to read the DC voltage (V_Z) across the LM335. It should be very close to 3V at room temperature (22C). If it is not, the temperature sensor has probably been inserted with the wrong polarity. Record the room temperature voltage (V_{REF}).
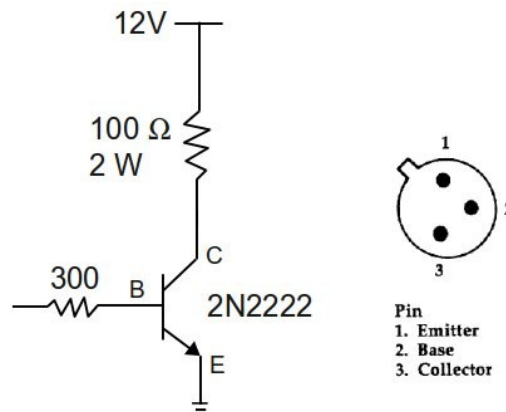
5V

2–4.7 kΩ

V_Z

LM335

Now apply 12V to the 100-Ω resistor using the external power supply. (It may be convenient to use red and black cables connected to a pair of banana jacks on the left side of the Elvis board. Connect jumper wires to the corresponding terminals.) The switch shown in the diagram below is implemented with the power supply on/off button.

Observe the LM335 voltage (V_Z) on the DMM. The voltage will increase linearly with temperature by 10 mV/deg C. The rate of temperature rise will help you determine the wait time in your LabView While Loop. Assuming a 22C starting temperature, estimate the maximum steady-state temperature of the resistor. WARNING: It will be hot!

Turn off both power supplies. Switching action in the control loop is performed by a 2N2222 transistor. Modify the heater circuit by adding the 2N2222 transistor with a 300 Ω base resistor as shown. Leave the input of the base resistor unconnected. Place the DMM across the transistor output to read DC voltage from the collector to ground. Turn on the 12V power supply; the transistor should be off corresponding to approximately 12V on the DMM. Now turn the transistor on by placing 5V DC on the unconnected side of the base resistor. The transistor should turn on with the collector voltage collapsing to < 300 mV. If this on/off switching operation cannot be obtained, check the transistor connections.

Modifying your LabView VI for DAQmx Read

The next task is to interface your LabView VI to the electrical components on the breadboard. It will have to read the temperature sensor and turn the transistor on and off. Make a backup copy in case you need to start over. Put a copy on the desktop, start LabView, and open your VI.
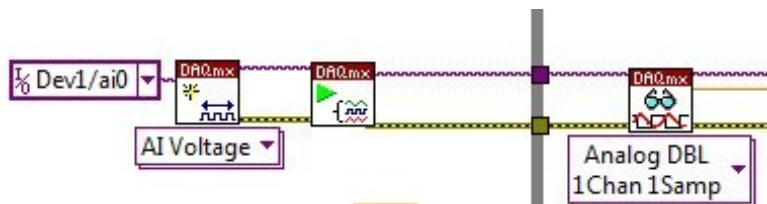
Inside the While Loop, remove the heater2.vi and the Shift register that was connected to Input and Output temperatures. Also remove the Case Structure that provides the Low, Medium, and High current options (only one fixed current is relevant here) and the ambient temperature input. You may wish to do a Ctrl-B to clean up all the broken wires. Two DAQmx channels have to be configured: one is an analog read and the second is a digital write.

Turn on the main power switch of the Elvis board. Right-click on an open space in the block diagram, locate the Measurement I/O palette: NI-DAQmx--Data Acquisition. Use the thumbtack in the upper left corner of the window to hold it open. It is also recommended that the Context Help (Ctrl-H) of LabView be enabled to assist in wiring.

Select the Create Virtual Channel VI and place it on the left-outside of the While Loop that forms your State Machine. On the menu immediately below the icon, select Analog Input. Find the **physical channels** input connection on the left side of the icon; right-click and create a constant. Clicking on the blank constant should display a list of the available analog input lines on the upper left of Elvis board, for example Dev1/ai0. Referring to the Elvis board analog inputs, the (+) terminal is connected to V_Z (i.e. readout of LM335) and the (−) terminal connects to circuit ground.
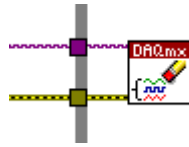
LabView must be instructed to start the DAQmx interface you have just configured. To do this, go to the Data Acquisition palette and select the Start Task VI. Place it immediately to the right of the Create Virtual Channel VI, but outside the While Loop. You may notice that LabView will try to automatically connect the Task-Out and Task-In lines as well as the Error-Out and Error-In lines of the adjacent VIs. If this doesn't happen, wire them together manually. When communicating with external hardware as done here, it is good programming practice to use the Error Handling line to assist in diagnosing problems.

In the Data Acquisition palette, select the Read VI. Place it inside the While Loop near the above Start Task icon. Configure it as Analog: Single Channel: Single Sample: DBL. Now make the connections from the DAQmx Start Task VI output terminals (task out, error out) to the corresponding input connections on the Read VI as shown.

The DAQmx interface should be cleared after it executes. This is performed with the

Clear Task VI on the Data Acquisition palette. Place it outside the While Loop and connect the task and error lines from the Read VI.

Create an indicator for the analog voltage (V_Z) on the LM335 by right-clicking on the **data** output terminal of the Read VI. This voltage (V_Z) must be converted to temperature (T) in LabView by programming this linear equation:

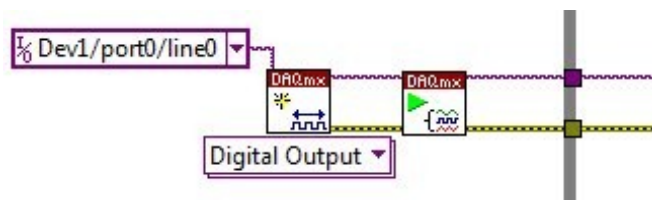$$T = \left(\frac{\text{deg}}{10 \text{ mV}} \right) (V_Z - V_{REF}) + T_{REF}$$

V_{REF} is the voltage read from the unheated circuit that was measured above. It is a constant in the equation. T_{REF} is room temperature that can also be set as a constant T_{REF} = 22C. Connect the calculated temperature (T) to the input logic used to turn on and off the heater as well as the temperature display and waveform chart.

The read operation can be tested at this point. Power on the Elvis board but disable the 12V supply. If the resistor has cooled off from previous testing, the VI should display a voltage and temperature close to 3V and 22C, respectively.

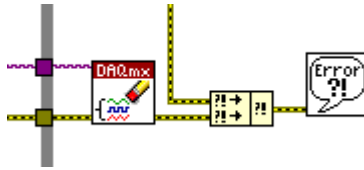**Modifying your LabView VI for DAQmx Write**

Select a second Create Virtual Channel VI and place it on the left-outside of the While Loop. On the menu immediately below the icon, select Digital Output. Find the **lines** input connection on the left side of the icon; right-click and create a constant. Clicking on the blank constant should display a list of the available digital output lines on the upper right of the Elvis board (example: Dev1/port0/line0). Select one of these lines and make a physical connection to the 300 Ω base resistor of the 2N2222 transistor.

Place a Start Task VI adjacent to the Create Virtual Channel VI, but outside the While Loop and wire them together:
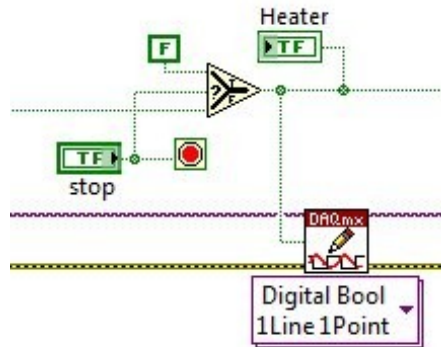

In the Data Acquisition palette, select the Write VI and place it inside the While Loop. Configure it as Digital: Single Channel: Single Sample: Boolean (1 line). Now make the connections from the DAQmx Start Task VI output terminals (task out, error out) to the

corresponding input connections on the Write VI. Be sure to clear the DAQmx write task in the same way as done for the analog read:

Use the Merge Errors function to collect the error cluster outputs from both DAQmx clear operations and wire it to the Simple Error Handler. This will supply diagnostic information on the user interface if an error occurs.

Your temperature control logic should have a Boolean T/F output for turning the heater on and off. Connect this to the **data** input terminal of the Write VI. Also create a Boolean indicator on the front panel so you can tell if the heater is on or off. Wire this indicator to the on/off logic. As a final precaution, turn the heater off when the VI stops. This can be easily done by inserting the Stop Button into the heater Boolean line as shown:

Running the temperature controller

Choose temperature setpoints below the maximum achievable temperature. Values of 30C for Low and 33C for High and a While Loop wait time of 500 ms should produce switching dynamics that can be observed on the temperature chart. Demonstrate the working circuit for the instructor. Save your working VI as it will be used in the next lab.

Writeup

None. There are separate grades for the assigned VI using the simulated heater and a working thermostat.