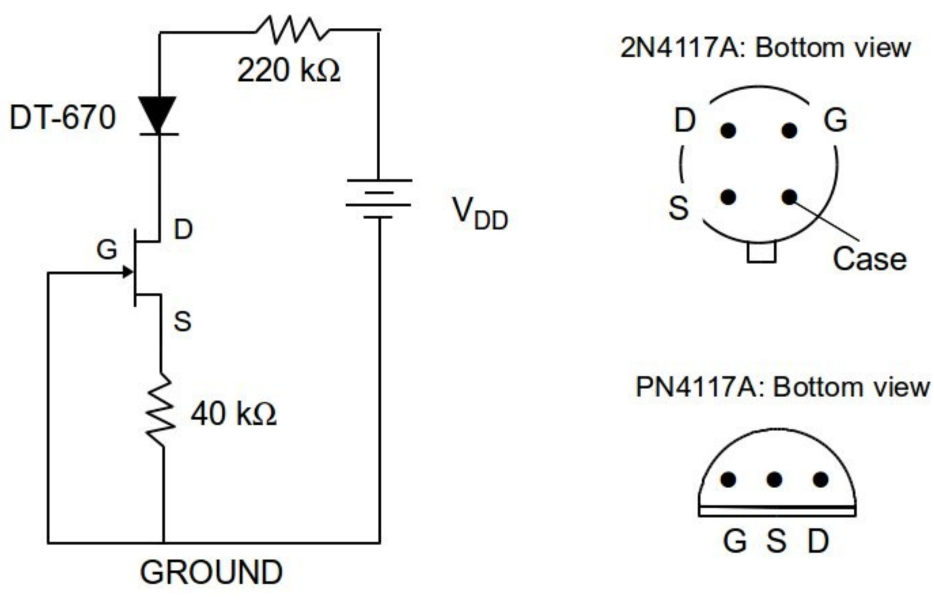
P-I temperature controller for optical cryostat

This project draws on several concepts developed in PHYC 306L to implement a P-I temperature controller for an optical cryostat. Without a controller, the cryostat coldfinger would remain close to the temperature of liquid nitrogen (77K). Although useful experiments can be done at this fixed temperature, a versatile instrument requires flexibility to attain different setpoints above 77K. This is accomplished with an ohmic heater working together with a temperature sensor. The heater and temperature sensor are interfaced to a PC using a DAQ card and DAQmx drivers. Continuous P-I temperature control is performed by a LabView VI that is based on an assigned project in 306L.

Microamp current source

The first step is to read the voltage from a forward biased silicon diode (DT-670) that is attached to the coldfinger. The forward voltage changes with temperature in a known, reproducible way. To attain forward bias, a constant current of ~ 10 μA must be supplied.

The following circuit can provide a reasonably constant (not perfect) source of current for the DT-670 silicon temperature diode. The current should be in the range 10—15 uA and will be relatively insensitive to V_{DD}. Regulation is provided by a 2N4117A or PN4117A JFET (G: gate, S: source, D: drain).

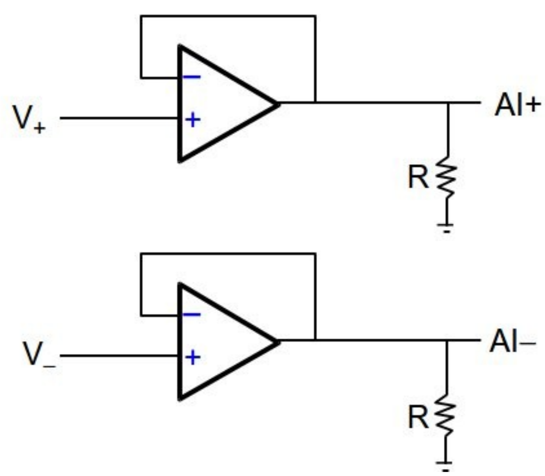


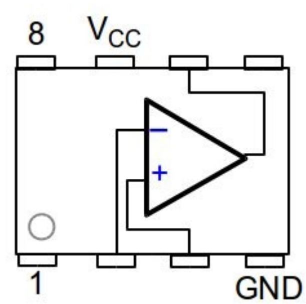
The 40 kΩ source resistor value is not critical; its role is to set the amount of current. Reducing this resistor will increase the current. If the 2N4117A JFET is used, its metal case should be connected to ground using the pin provided. The function of the 220 kΩ resistor is described below.

Buffer amplifiers

Temperature is determined by reading the voltage drop across the forward-biased DT-670 diode and converting it to degrees using the manufacturer's calibration table. One must use care when making this voltage measurement. If the measuring device has an input impedance that is too low, it will draw non-negligible additional current and distort the measurement. A hand-held digital voltmeter has input resistance > 10 MΩ and will work in this application. The typical DAQ card differential input resistance, however, is too low.

To address this problem, high impedance buffer amplifiers can be used to isolate the diode from the analog input of the DAQ card. The purpose of a buffer amp is to duplicate the input voltage at its output while presenting a very high impedance to the input voltage source. The LF411 op-amp is a good choice because it uses field-effect transistors on the input terminals that draw < 1 nA. This is many orders of magnitude smaller than the nominal current flowing through the diode. The LF411 was also used as a buffer amp in 306L.





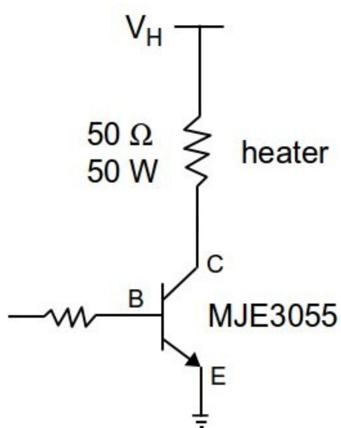
LF411 pinout

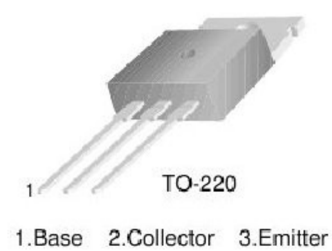
The buffer amplifiers can drive sufficient current into the DAQ card as well as the resistors that define the reference (ground) voltage for the card. The choice of R is not critical (10kΩ should be adequate) but both resistors should be as close to the same value as possible.

It is convenient to power the two op-amp chips with the same power supply used to bias the diode, i.e. V_{DD} is made the same as V_{CC}. This presents a problem, however, if V_{DD} is connected directly to the diode's cathode terminal. Most op-amps are unable to push their output voltage to the same level as their power supply, i.e. the output voltage of the LF411 can never reach V_{CC}. To solve this, a voltage difference is introduced between the power supply and diode using a large resistor. A 220 kΩ resistor causes a ~ 2.2 V drop when 10 μA is flowing in the diode. The amount is not critical provided it is ~ 1 V or more. The AI+ buffer amp can then be connected to the cathode of the diode. It is important to verify that both buffer amps are closely mirroring their respective input voltages. Make note of any voltage offset at the output of the differential amplifier and include it in your error analysis.

Heater

The cryostat is heated by passing current continuously through a 50 Ω resistive load attached to the coldfinger. Maximum power dissipation in the heater is 50 W. Current is supplied to the heater using a circuit that is almost identical to that used in the P-I temperature control project of 306L. A much higher power transistor is substituted for the 2N2222A used in the previous lab.





An MJE3055 n-p-n bipolar junction transistor is capable of switching the needed heater current. It will handle a maximum of 10 A at a collector voltage as high as 60V and dissipate as much as 75 W with a good heatsink. To be safe, setup the circuit to drive the heater with no more than 30 W. This will specify the heater voltage V_H. The voltage and current demands of the heater will require the use of a second power supply.

Your LabView P-I program will supply a control signal to the base of the MJE3055 transistor using an analog output channel of the DAQ card.