2.14/2.140 Lab 2

Assigned: Week of Feb. 24, 2013
Due: Week of Mar. 3, in your lab session.

Lab 2 studies a thermal control loop. The mechanical configuration of the thermal plant is shown below.
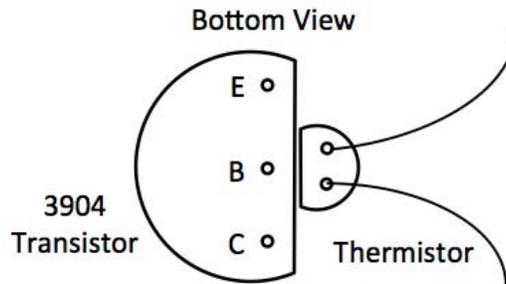
Here a thermistor is attached to a 2N3904 NPN transistor. The thermistor is packaged in a round epoxy bead; we have sanded off one side of the bead in order to create a flat spot to improve heat transfer. The joint thermal conductivity is improved by using thermal grease in the joint. The pair is held together with heat-shrink tubing, and then a styrofoam bead is used as thermal insulation.

The electrical configuration is shown below
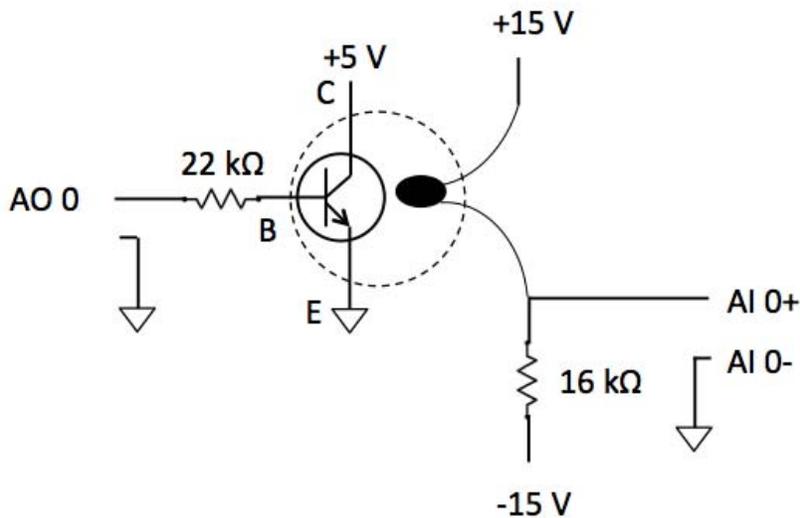
This system will be the focus of the next two labs. The goal of the control system is to regulate the measured temperature to 40 °C. This is done by maintaining the transistor heating at a correct value using the control input at the base resistor. When operating at 40 °C, for small changes the system can be viewed as linear, since temperature can be increased and/or decreased using the control input. (Strictly speaking, the *changes* of the control input are linearly related to the *changes* of the temperature, where these changes are measured relative to the steady-state operating point values.)

For this week, we ask you to do the following:

1. In open loop, manually adjust the control effort so as to set the steady operating temperature at 40 °C. Experimentally save and plot the step response for small control changes about this equilibrium. How well does the measured step response match a fitted first order step response?

2. Experiment with human ON/OFF control. Try this with and without the styrofoam insulation in place. Save and plot an interesting set(s) of data (both control effort and resulting temperature).

3. Experiment with machine ON/OFF control. Try this with and without the styrofoam insulation in place. Save and plot an interesting set(s) of data (both control effort and resulting temperature).

4. Experiment with human *linear* control. That is, you manually move the control effort slider to control the measured temperature to a setpoint of 40 °C. Notice how the control effort must be actuated to make a relatively fast change in the controlled temperature. Try this with and without the styrofoam insulation in place. Also notice the effect of disturbances such as blowing air on or touching the transistor with the insulation removed. Save and plot an interesting set(s) of data (both control effort and resulting temperature).

5. Experimentally tune P and PI linear controller. First tune the loop with only a P term. Then add in an I term. Can you see the effect of the integral control? Save and plot the closed-loop step response to reference temperature changes of the loop operating with these controllers (both control effort and resulting temperature), and record the control gains used. Also, impose some disturbance on the system, for instance, by removing the styrofoam insulation, or putting your fingers on the transistor, or blowing on the device, etc. Save and plot some interesting set(s) of data (both control effort and resulting temperature).

6. **For graduate students only:** Create a thermal model competent to explain the observed dynamics. Estimate the thermal mass on the basis of the system dimensions and some reasonable assumptions of specific heat. Use experiments to determine the thermal loss modeled as a resistance to ambient, both with and without the styrofoam peanut insulation. Fit parameters to this model and compare with your experimental step measurements.

Checkoff in lab session: In this week's lab session demonstrate to one of the teaching staff your working controller and some experimental results. Progress shown in this checkoff will count towards half of your lab grade.

Answer sheets: At the start of next week's lab session you must submit your lab writeup. These write-ups are due at the start of the lab session, and will not be accepted late. Please attach to this lab assignment clearly labeled answers and plots for all the questions above. This lab report will count towards half of your lab grade.

It is key that you submit your lab report on time at the start of the lab session next week, as we will begin work on Lab 3 during that session.

Mechanical Configuration

2N3904

E B C

Sanded flat

Thermistor

polarity not important

Bottom View

E ○
B ○
C ○

Thermistor
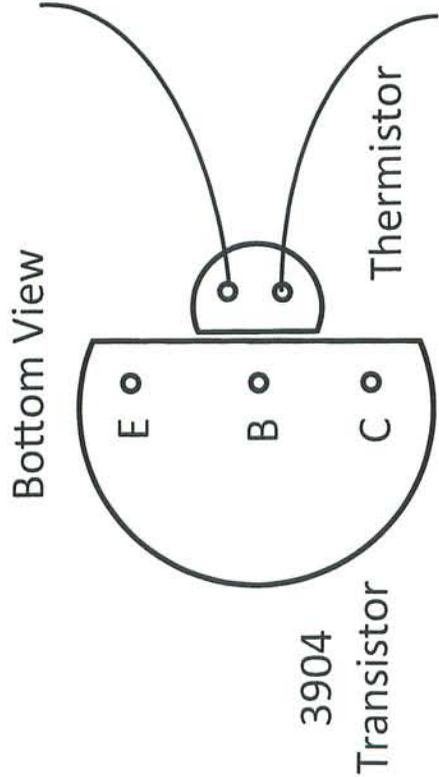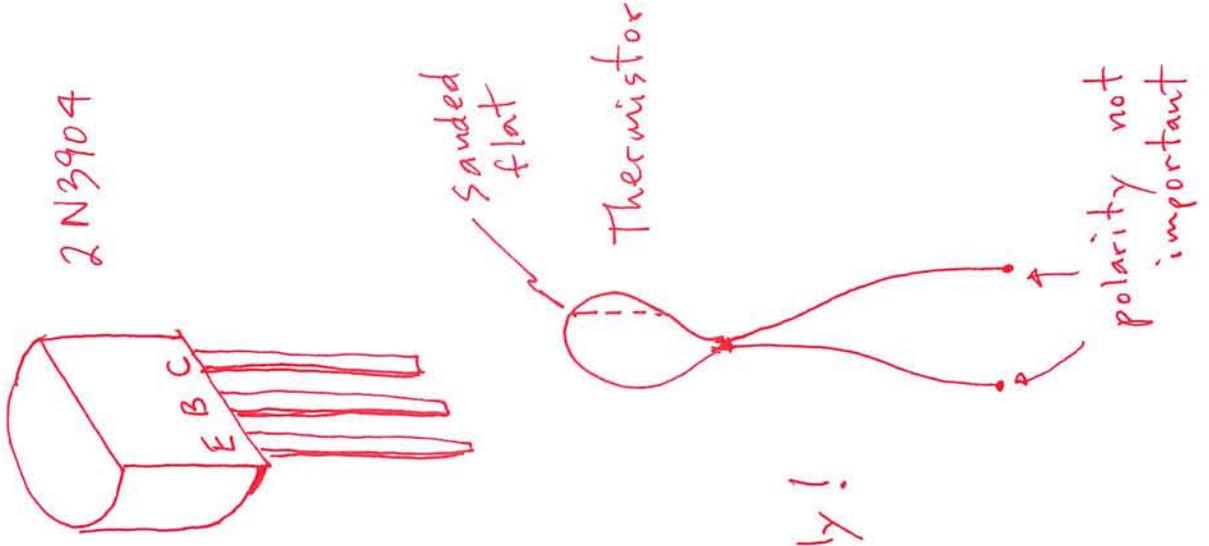
3904 Transistor

Note **EBC**. Be sure to wire correctly!

Circuit Diagram

For simple analysis, ignore 0.6 V base-emitter drop:

$$i_b \approx \frac{V_i}{R_b} \quad \text{and} \quad i_c = \beta i_b \quad \{\approx 100 \text{ for } 3904\}$$

Power dissipated in 2N3904:

$$P_{diss} \cong 5V \cdot i_c \quad (i_b << i_c)$$

$$= 5V \cdot \frac{\beta}{R_b} \cdot V_i$$

Output:

$$V_o = 30V \frac{R_a}{R_a + R_x} - 15V$$

$$= -30V \frac{R_x}{R_a + R_x} + 15V$$

$$= -15V \frac{R_a}{R_a + R_x} - 15V \frac{R_x}{R_a + R_x}$$

Three equivalent expressions.

Thermal insulation

+15 V

+5 V

C i_c

B i_b

E i_e

$R_b =$ 22 kΩ

V_i

AO 0

R_x

V_o

AI 0+

16 kΩ R_a

AI 0−

−15 V
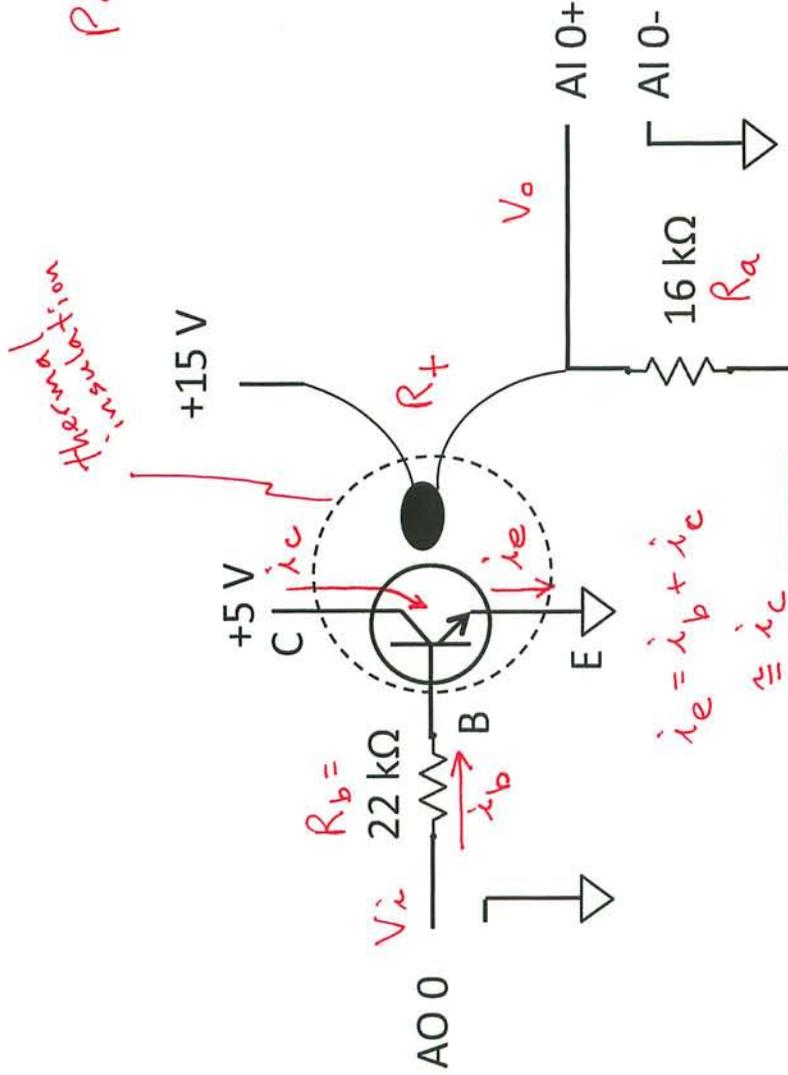
$i_e = i_b + i_c$

$\cong i_c$

since $i_c = \beta i_b$

Bipolar transistor model

2.14 / 2.140 Analysis and Design of Feedback Control Systems
Spring 2014