USC University of Southern California

EE 105: Introduction to Electrical Engineering

Lab 3.1

Thermistor temperature sensor

Yasser Khan

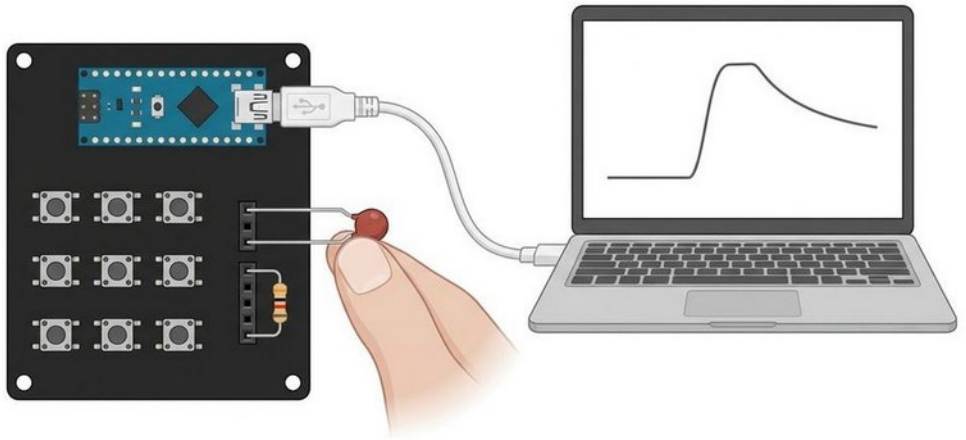
Rehan Kapadia

Today's mission

Turn the board into a thermometer and measure how good it is.

By the end of this lab you can:

- Measure the **RMS noise** and **SNR** of a sensor
- Convert volts to degrees with the **divider** and the **beta model**
- Fit the **time constants** of warm-up and cool-down
- Compare your **sensitivity** with 36.7 mV per °C



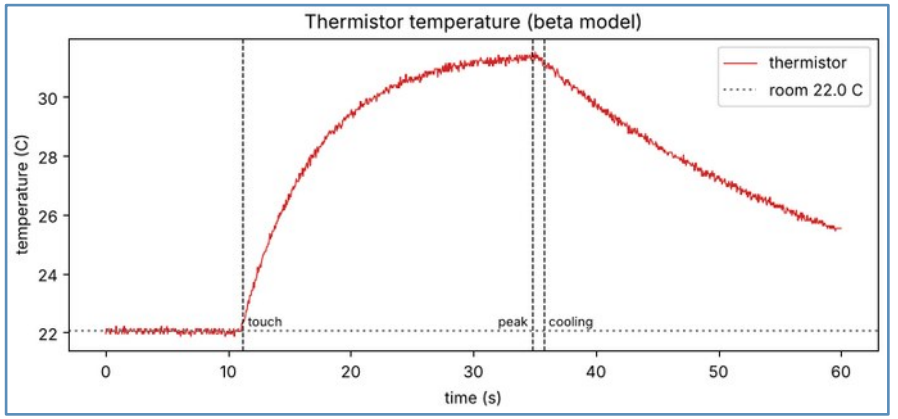
A pinch warms the bead, its resistance falls, and A1 rises.

A	B	C	D	E	F	G
Plug in **10 min**	Noise **20 min**	Finger touch **15 min**	Degrees **25 min**	Response **25 min**	Sensitivity **15 min**	Thermometer **10 min**

Key takeaways

What to remember from this lab, with the numbers that matter.

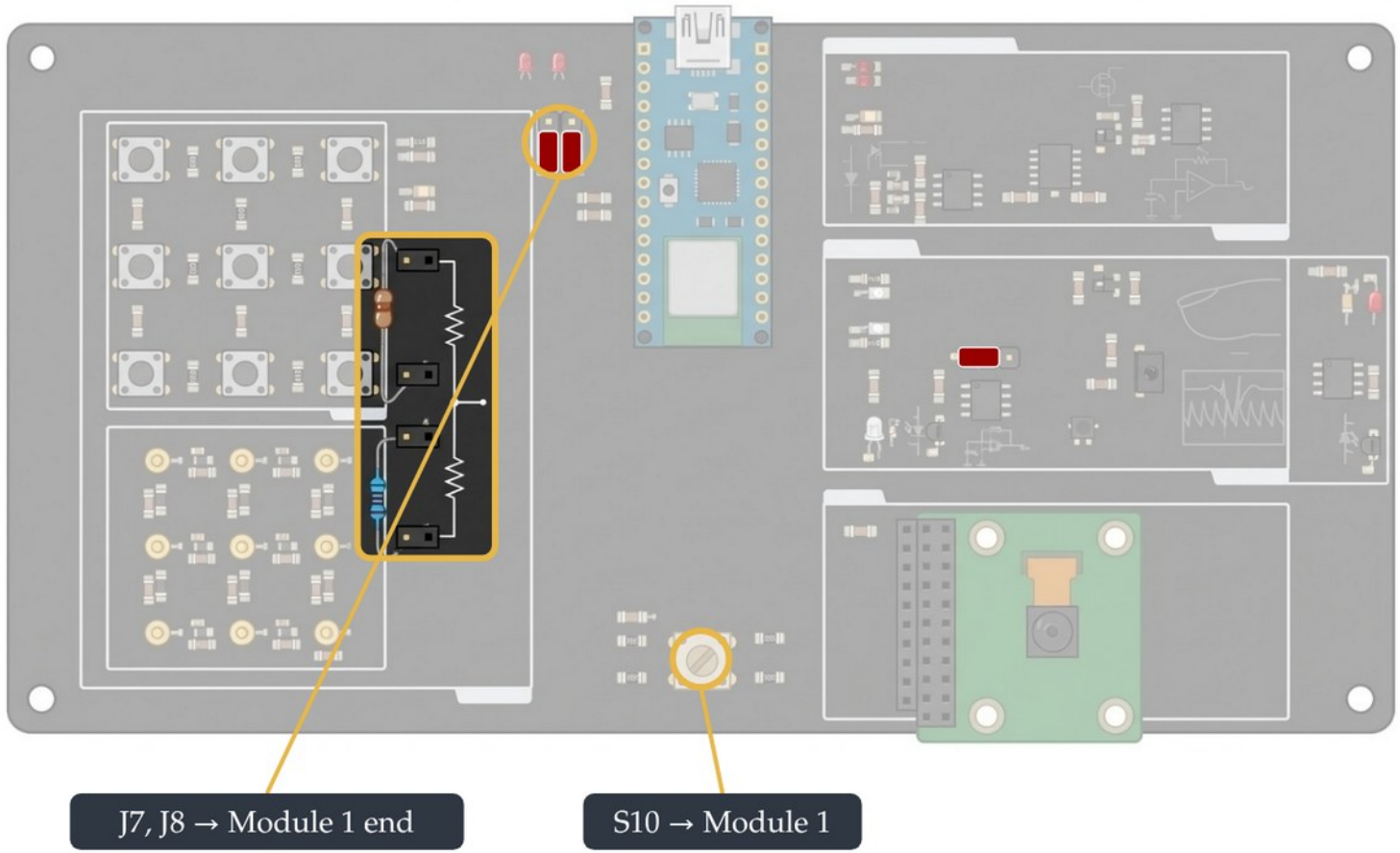
- **Resistance falls about 4.5 % per degree** near room temperature; the beta model turns R_T into a temperature
- **A1 reads 1.65 V at 25 °C,** half the supply, and rises about 37 mV per degree
- **One ADC step is 3.22 mV, about 0.09 °C.** The noise at rest is about as large: 3 mV RMS
- **A finger is 100 times the noise:** a rise of about 0.3 V, an SNR of about 40 dB
- **The bead is an RC circuit:** 63 % of a change after one τ; a few seconds to warm, 20 to 60 s to cool



Expected result of D2 on the simulated board: a pinch warms the bead about 10 °C above the room.

SETUP

Selector, jumper caps, and two parts in the divider header.



1 **S10 → Module 1**
Turn the selector to Module 1, the circuits block.

2 **J7, J8 → Module 1 end**
Both caps on pins 2-3: A1 then reads the divider header.

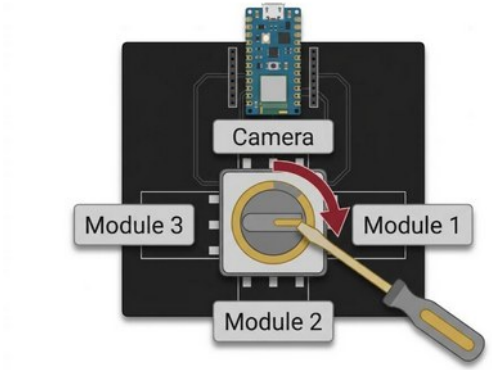
3 **Thermistor in J1-J2 (top)**
The glass bead from 3.3 V to A1. The 10 kΩ (brown, black, orange) goes in J3-J4 (bottom).

4 **USB data cable**
Plug in last, then run the first cell.

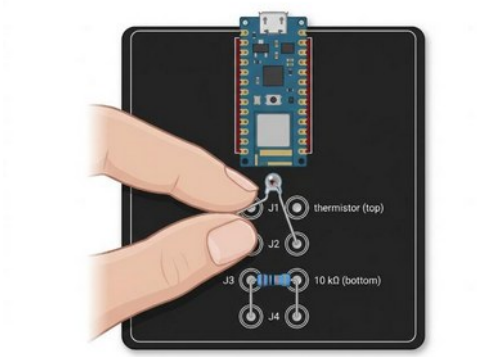
Part A: Plug in and connect

Set the selector, plug the thermistor into the top of the divider header, run the first cell.

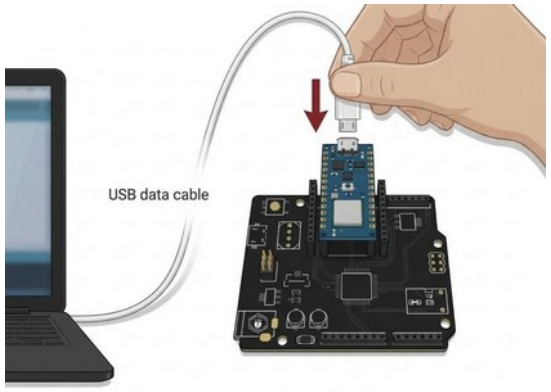
PART A **Goal: A1 · DO** plug in the thermistor, connect, check the selector.



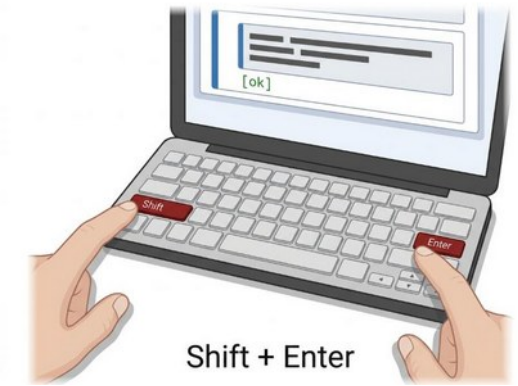
1 Turn S10 to Module 1



2 Thermistor in J1-J2 (top), 10 kΩ in J3-J4 (bottom)



3 Plug the USB data cable into the Nano



4 Run the first cell with Shift+Enter

You should see: two **[ok]** lines and **A1 = 1.46 to 1.65 V** at room temperature. Far outside that? Check the caps of J7 and J8 and the two parts.

Part B: Noise at rest

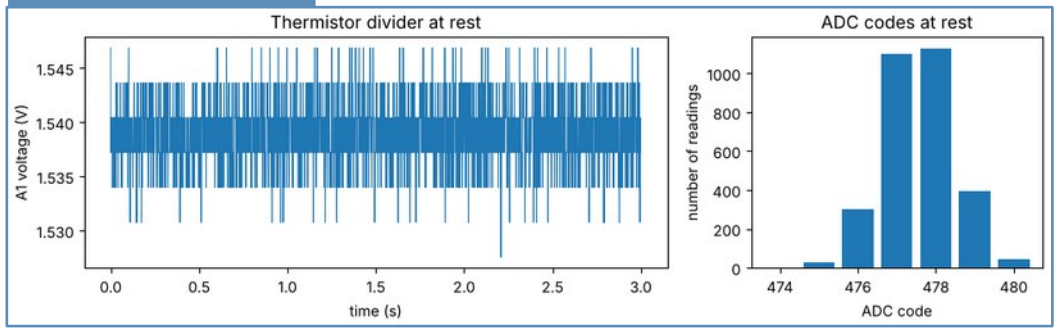
Hands off: 3 s of A1, one reading per millisecond. The readings jump between a few codes.

PART B

Goal: measure the mean voltage and the RMS noise at rest.

- **B1 · RUN** Hands and breath away from the bead; record 3 s
- **B2 · EDIT** The mean, and the RMS noise from the definition; compare with **np.std**
- **B3 · RUN** The old file **temp_data_with_finger.csv** next to yours (Question 6)

Expected result · B1



You should see: RMS noise about **3 mV**, about **1 LSB** (3.22 mV), the readings spread over **3 to 6** neighboring codes. Mean 1.5 to 1.7 V.

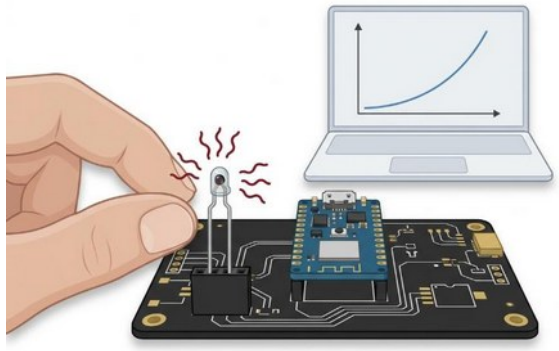
Part C: Record a finger touch

60 s of A1, live: 10 s hands off, 25 s pinching the bead, then hands away.

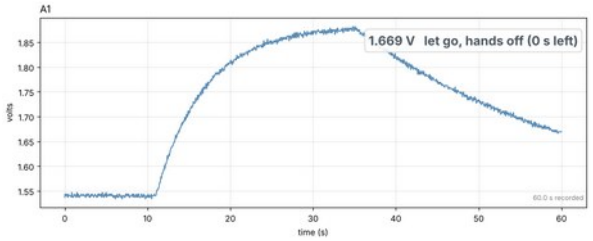
PART C

Goal: record a finger touch and compute the signal-to-noise ratio.

- **C1 · DO** Run the recording and **follow the plot title**: pinch only the **bead** for 25 s
- **C2 · RUN** Check the rise (USE_BACKUP only if the sensor is broken)
- **C3 · EDIT** SNR = rise / RMS noise, and 20 log10(rise / noise) in dB



Touch only the bead



Expected result of C1 (simulated board): a rise, then a slower fall

You should see: a rise of **0.25 to 0.4 V**, an SNR about **36 to 42 dB**. Saved as thermistor_finger.csv.

Check (Checkpoint 1): noise a few mV, a clear rise in the finger plot, SNR above about 30 dB.

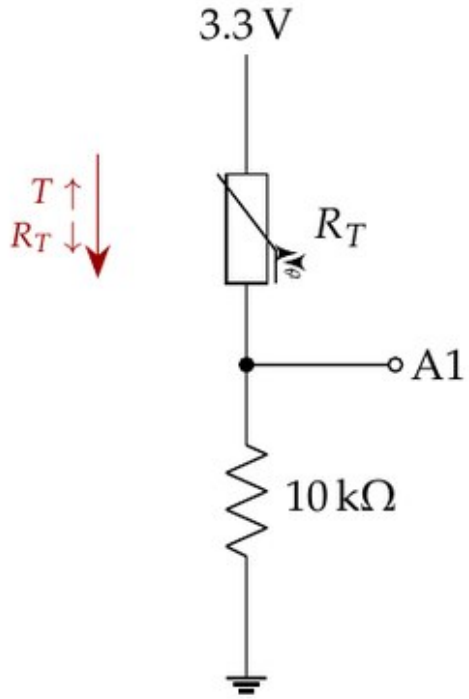
Part D: From volts to degrees

The divider equation gives R_T; the beta model turns R_T into a temperature.

PART D

Goal: write volts_to_ohms and ohms_to_celsius and convert your recording.

- **D1 · EDIT** R_T = R (3.3 V / V_out - 1), with R = 10 kΩ
- 1/T = 1/T0 + ln(R_T / R0) / β, with T in kelvin: R0 = 10 kΩ, T0 = 298.15 K, β = 3950 K
- **D2 · RUN** Room, touch, peak and cool-down are marked



Thermistor on top, 10 kΩ below.

You should see: the check: code 560 = **1.805 V = 8.29 kΩ = 29.3 °C**. Room **20 to 25 °C**, peak **30 to 34 °C**.

Part E: Response time

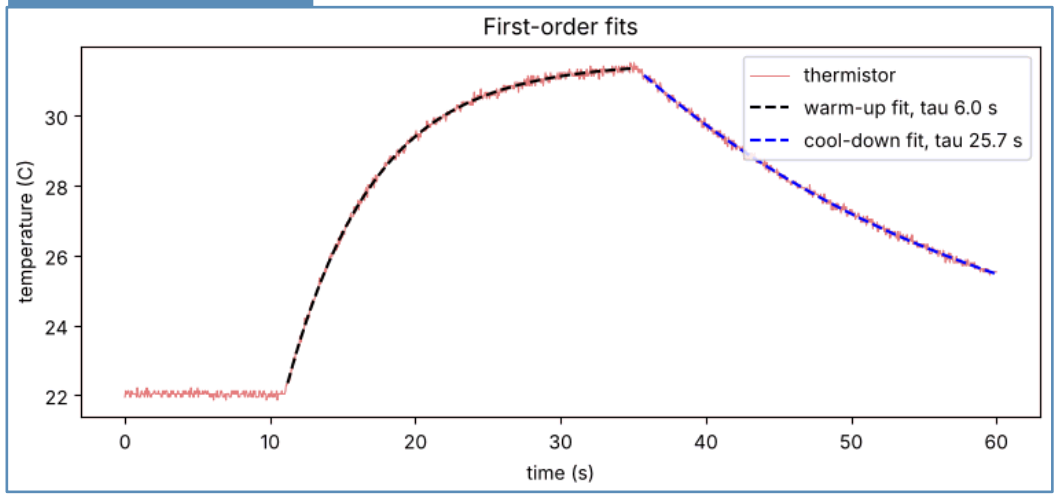
Like an RC circuit, the bead approaches its final temperature exponentially.

PART E

Goal: fit time constants to the warm-up and to the cool-down.

- **E1 · EDIT first_order(t, T_final, T_start, tau)** and the two p0
- Fit the warm-up (touch to peak) with **curve_fit**
- Fit the cool-down (from i_cool to the end); read p0 off the plot
- **E2 · RUN** Both fits over the recording

Expected result · E2



You should see: warm-up τ **a few s to about 15 s**, cool-down τ **20 to 60 s**, always slower than the warm-up.

Check (Checkpoint 2): both fits follow the data, and the cool-down time constant is longer than the warm-up one.

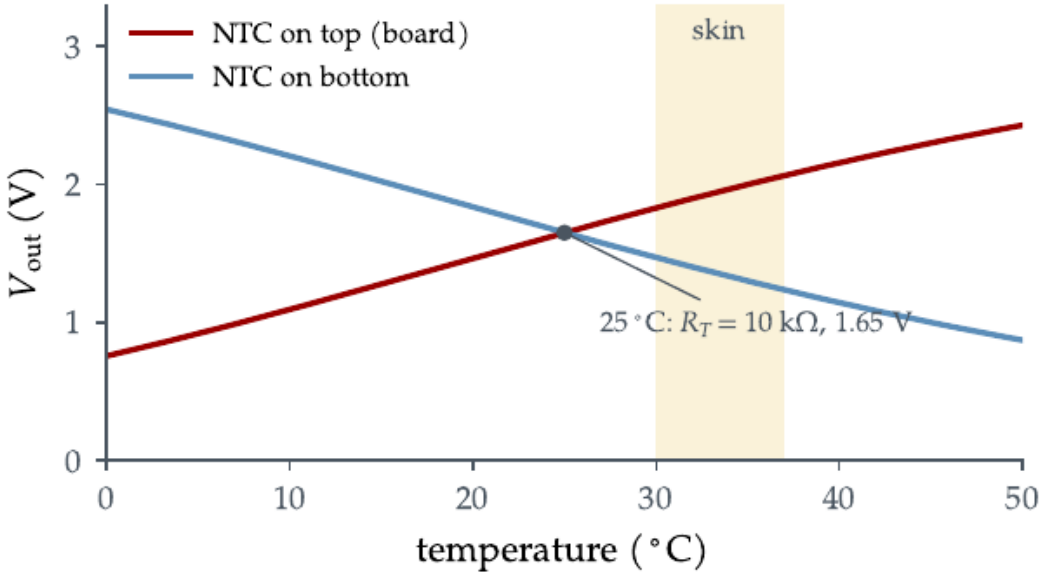
Parts F and G: Sensitivity, live thermometer

Sensitivity is the slope dV/dT. Then your two functions make the board a thermometer.

PARTS F, G

Goal: compare your sensitivity with the formula, then read temperature live.

- **F1 · EDIT sensitivity(T_c)** from the chain-rule formula
- Chord slope **S_data** = ΔV / ΔT, from room temperature to the peak
- **F2 · RUN** The sensitivity plot
- **G1 · DO** Run the live thermometer and pinch the bead



Divider output against temperature: the slope is the sensitivity.

You should see: 36.7 mV/°C at 25 °C (37.2 at 22 °C), a chord near **36 mV/°C**; one LSB is about **0.09 °C**.

Check (Checkpoint 3): a plausible live temperature, and a chord slope close to the formula.

Stuck?

Check these first. If the fix does not help, raise your hand.

A1 falls when you pinch

Thermistor and resistor are swapped: the thermistor goes on top, J1-J2.

A1 near 0 V, or a 60 Hz wave

A1 floats: caps of J7 and J8 on the Module 1 end, S10 on Module 1, parts seated.

The finger check fails

Fix the wiring and record again. USE_BACKUP only if the sensor is broken.

The cool-down fit fails

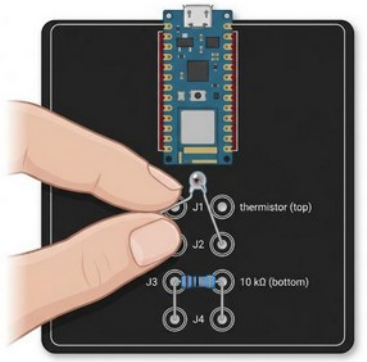
Let go on time, keep your hand away, record C1 again; take p0 from the plot.

No rise at all

Pinch the bead, not the resistor. A broken lead? Ask for a spare.

Noise far above 3 mV

A hand, your breath or a fan near the bead: keep still and record again.



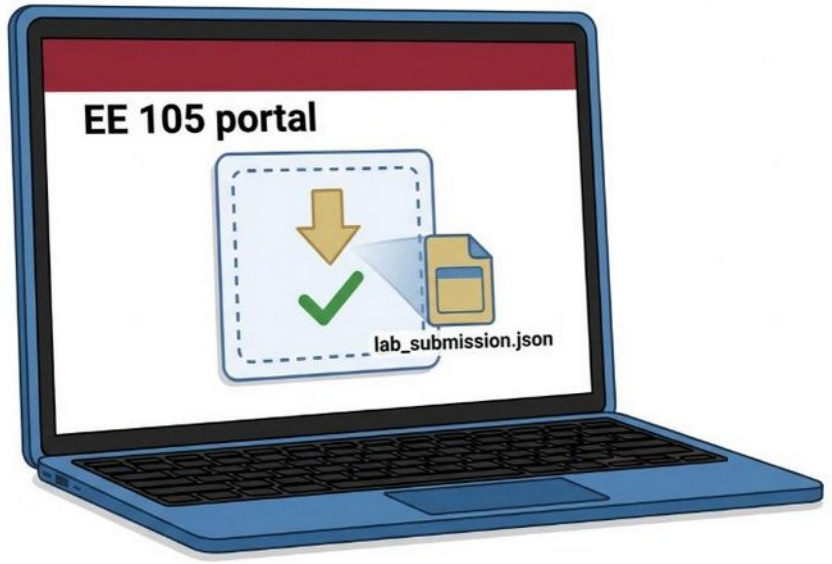
Thermistor on top (J1-J2), 10 kΩ below.

Submit your results

The last cell saves your results in one file. Upload it on the course portal.

```
lab3.1_submission.json
```

1. **Save · RUN** writes **lab3.1_submission.json** next to the notebook
2. It holds your numbers and the recordings behind them
3. Log in at **ee105.org/portal** with your student ID and portal PIN; open Lab 3.1
4. Upload: the portal recomputes room and peak temperatures from your recording



ee105.org/portal

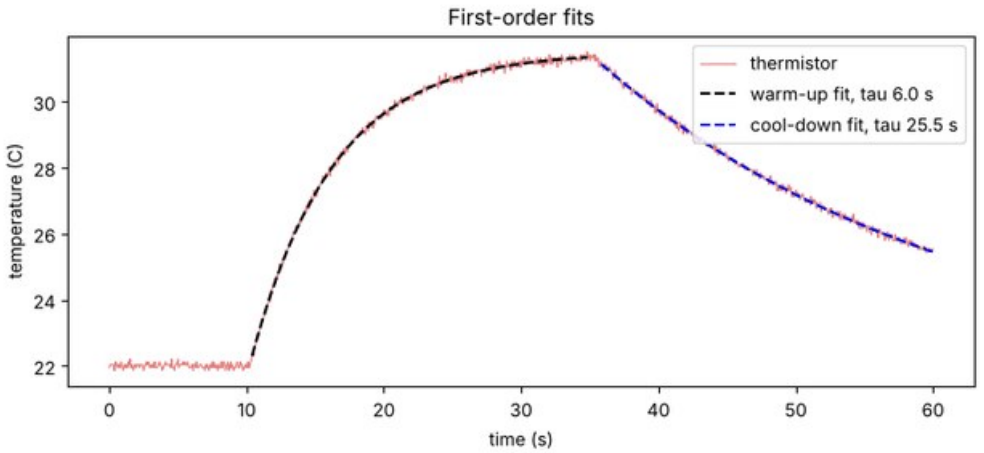
Check: the portal shows your grade. thermistor_finger.csv stays in the lab folder for your report. A simulated or backup run earns no credit.

Lab complete

You built a thermometer and measured how good it is.

You built:

- A noise and SNR measurement of a real sensor
- A volts-to-degrees conversion with the beta model
- Warm-up and cool-down time constants from curve fits
- A live thermometer that resolves about 0.1 °C



Warm-up and cool-down, each a first-order response.

Did you know?

A thermistor changes by a few percent per degree, about ten times more than a platinum RTD (0.39 % per degree), but it is strongly nonlinear (Chapter 3).

Next

Lab 3.2, pulse oximeter and PPG: heart rate and blood oxygen from light through your fingertip (S10 on Module 3).