1b. Battery-pack sensing: Temperature

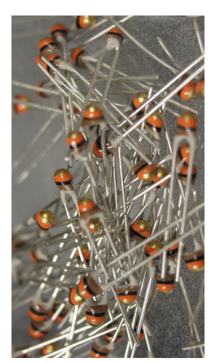
- Battery cell operational characteristics and cell degradation rates are very strong functions of temperature
  - Don't charge at low temperature; control thermal management systems to keep temperature in "safe" region
  - Unexpected temperature changes can indicate cell failure or impending safety concern
- Ideally, we measure each cell's internal temperature; but,
  - With accurate pack thermal model, can place sensors external to one or more cells per module and calibrate internal temperatures

How to measure temperature: Thermocouple

- Electronics cannot measure temperature directly; instead, must convert temperature to voltage, measure via A2D
- One method to produce a voltage proportional to temperature is to use a thermocouple, which comprises two dissimilar metals in contact with each other and acts as a miniature battery
- Thermocouple produces very small voltage when its temperature is different from a reference temperature (proportional to the difference)
- The thermocouple voltage can be amplified and measured and temperature can be computed from this measurement
- Design challenge: the reference temperature must be independently known or measured: thermocouples best suited for laboratory testing and not for production BMS designs

How to measure temperature: Thermistor

- Can instead use a thermistor, which is a component that is designed to have resistance that varies over a wide range with temperature
  - Negative-temperature-coefficient (NTC) thermistors have resistance that varies inversely with temperature, and
  - Positive-temperature-coefficient (PTC) thermistors have resistance that varies proportionally with temperature
- If we can measure thermistor resistance, we can then infer temperature
- But, we cannot measure resistance directly either...

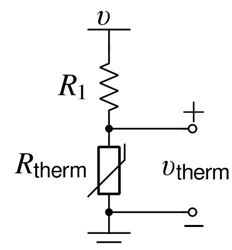


Voltage-divider circuit

- To measure resistance, we can use a voltage-divider circuit
- In the circuit, the top resistor R_1 has resistance that does not vary appreciably with temperature, but the lower resistor R_{therm} has value that is designed to vary significantly with temperature
- We compute overall current as $i = v/(R_1 + R_{\text{therm}})$
- Then, we note that the measured voltage is $v_{\text{therm}} = iR_{\text{therm}}$ or

$$v_{\text{therm}} = \frac{R_{\text{therm}}}{R_1 + R_{\text{therm}}} v$$

- The value of R_1 is designed to limit power loss through the circuit but provide a useful measurement range for v_{therm}



Voltage-divider analysis

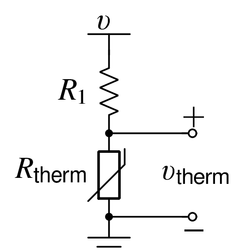
- If we measure v_{therm} and know the circuit-design parameters, we can rearrange the prior expression to get

$$R_{\text{therm}} = \frac{v_{\text{therm}}}{v - v_{\text{therm}}} R_1$$

- Thermistor data sheet will give an equation relating R_{therm} to temperature; for example, we might have

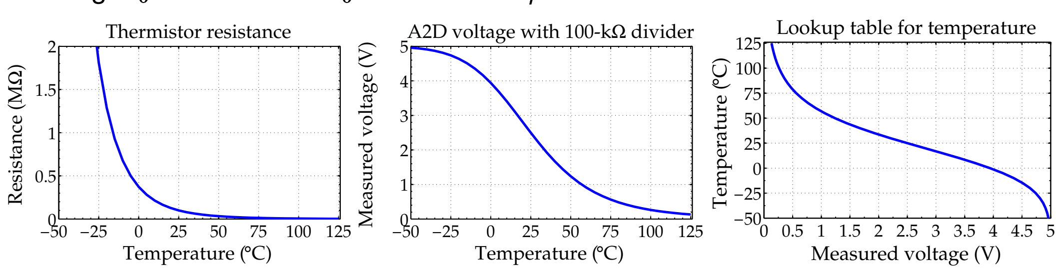
$$R_{\text{therm}} = R_0 \exp\left(\beta\left(\frac{1}{273.15 + T} - \frac{1}{273.15 + T_0}\right)\right),$$

  where T is temperature being measured, R_0 is resistance at reference temperature T_0; temperatures converted from celsius to kelvin by adding 273.15, β is a device parameter



Voltage-divider + thermistor example

- Left plot shows thermistor resistance for an NTC device having $R_0 = 100\,\text{k}\Omega$ at $T_0 = 25\,°\text{C}$ and $\beta = 4282$



- If $v = 5\,\text{V}$, $R_1 = 100\,\text{k}\Omega$, v_{therm} varies with temperature as shown in middle plot
- For efficiency, relationship between v_{therm} and T can be precomputed and stored in a lookup table (LUT, right plot)

Summary

- To preserve battery health, it is important to monitor and control cell temperatures
- Usually too expensive to measure all temperatures; instead measure module temperatures and use thermal model to extrapolate to cells in module
- To measure temperature, must convert into a voltage signal
  - Can use thermocouple with amplifier, or
  - Thermistor plus voltage-divider circuit
- Thermistor-based solutions are most popular in practice

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