P524: Survey of Instrumentation and Laboratory Techniques
Week 6

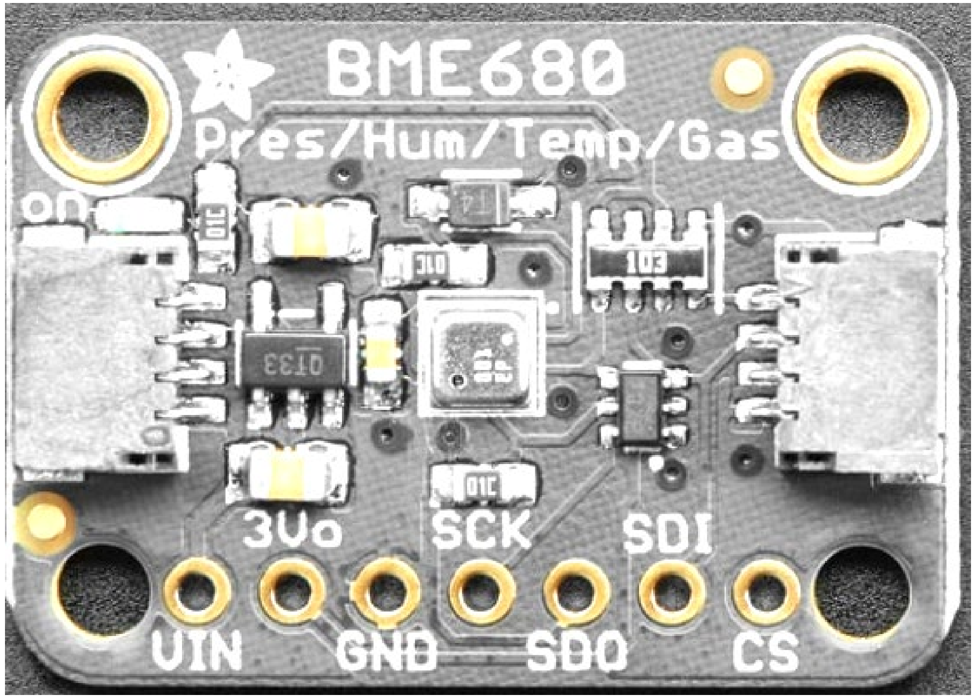
9/24/2024

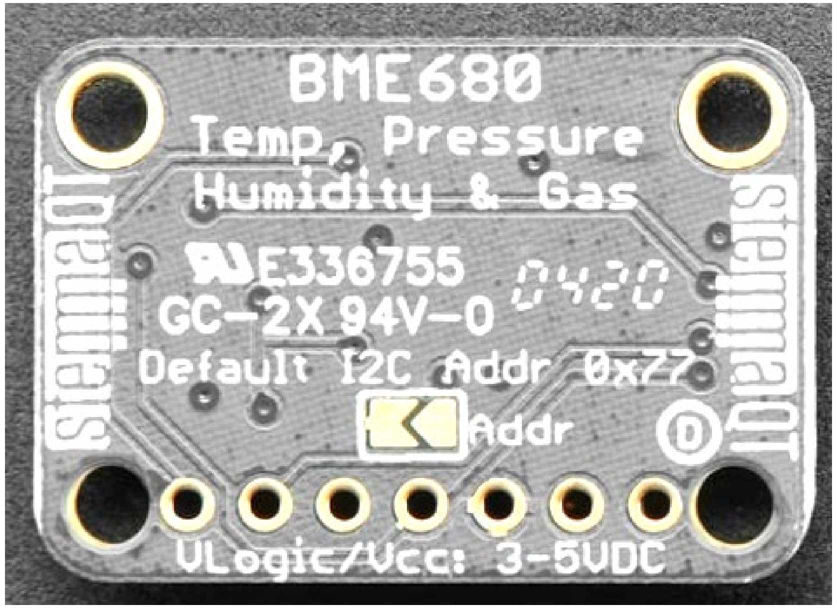
Week 6: sensors-3

Temperature Sensors

BME680: this precision sensor from Bosch can measure

- humidity with ±3% accuracy,
- barometric pressure with ±1 hPa absolute accuracy, and
- temperature with ±1.0°C accuracy.
- Contains a small MOX sensor. The heated metal oxide changes resistance based on the volatile organic compounds (VOC) in the air, so it can be used to detect gasses & alcohols such as Ethanol, Alcohol and Carbon Monoxide and perform air quality measurements.
- Note it will give you one resistance value, with overall VOC content, it cannot differentiate gasses or alcohols.





TMP36: an IC sensor

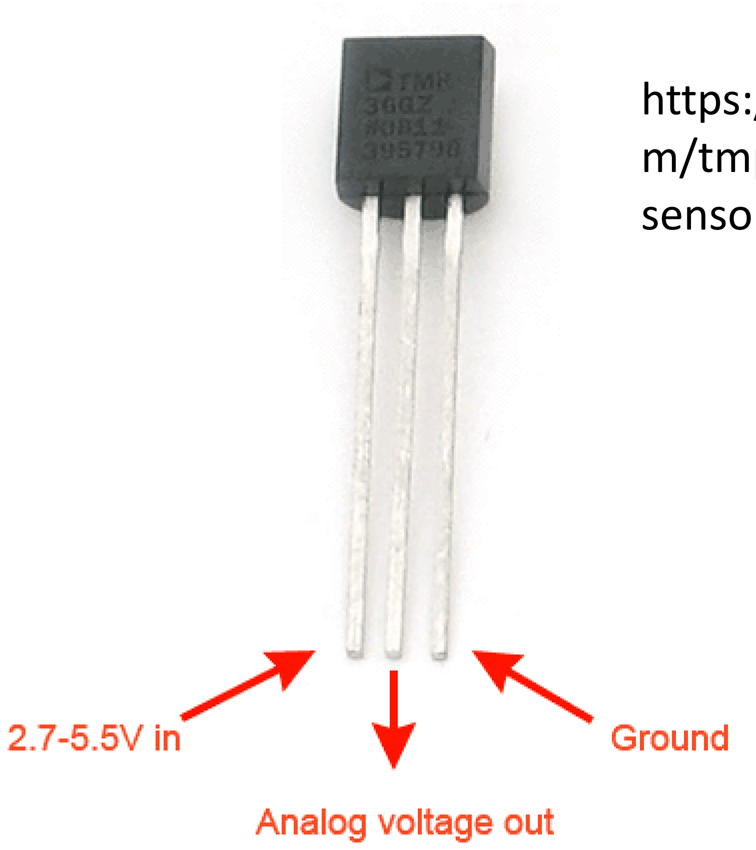
https://learn.adafruit.com/tmp36-temperature-sensor/overview

A solid-state technique to determine the temperature: as temperature increases, the voltage across a diode increases at a known rate.

In practice, the voltage drop between the base and emitter - the Vbe - of a transistor.

By precisely amplifying the voltage change, it is easy to generate an analog signal that is directly proportional to temperature. There have been some improvements on the technique but, essentially that is how temperature is measured.

- The good news is all that complex calculation is done *inside* the chip - it just spits out the temperature, ready for you to use!



- **Temperature range:** -40°C to 150°C / -40°F to 302°F
- **Output range:** 0.1V (-40°C) to 2.0V (150°C) but accuracy decreases after 125°C
- **Power supply:** 2.7V to 5.5V only, 0.05 mA current draw
- The analog voltage is independent of the power supply.

TMP36

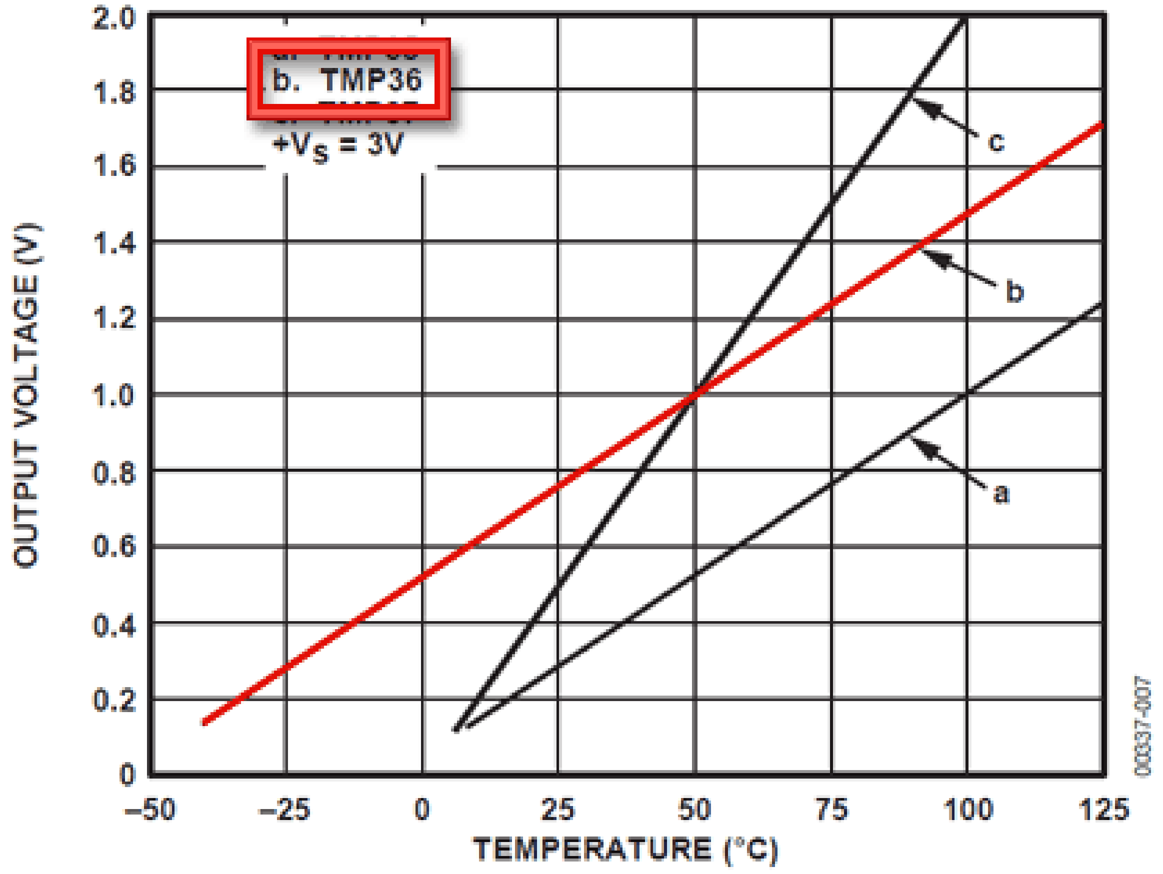


Figure 6. Output Voltage vs. Temperature

Read the voltage from the middle pin.

Temperature conversion:

Temp in °C = [(Vout in mV) - 500] / 10

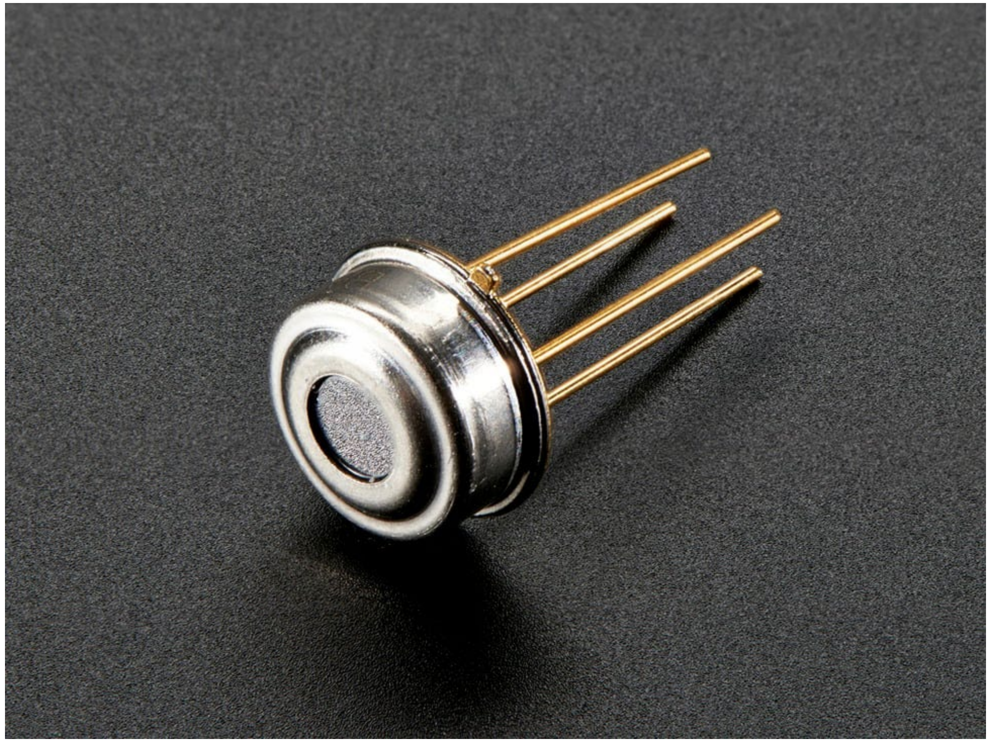
Other common temperature sensors

Barometric sensor: mercury thermometer
Thermocouple: bimetallic stripes, used in HVAC systems, heaters and boilers, kilns, etc.
Thermister: temperature sensitive resistors.

Characteristic	Thermistor	RTD	Thermocouple	IC sensor
Temperature Range	-100 to +500°C	-250 to +750°C	-200 to >+2000°C	-55 to +200°C
Linearity	Worst	Good	Poor	Best
Accuracy	Calibration Dependent	Best	Good	Good
Sensitivity	Best	Less	Worst	Good
Power Consumption	High	High	Low to High	Lowest
External Circuitry	Simple unless high accuracy/low power needed	Complex	Complex	Simplest
Typical Applications	Low precision, moderate temp range – toasters, hair dryers, protection circuits	High precision, extended temperature – gas and fluid flow	Extreme temperature sensing –ovens, kilns, test equipment	Computers, wearables, data logging, automotive

IR thermometer

For non-contact measurements, there's the IR MLX90614, an I2C device that's also good to about half a degree.

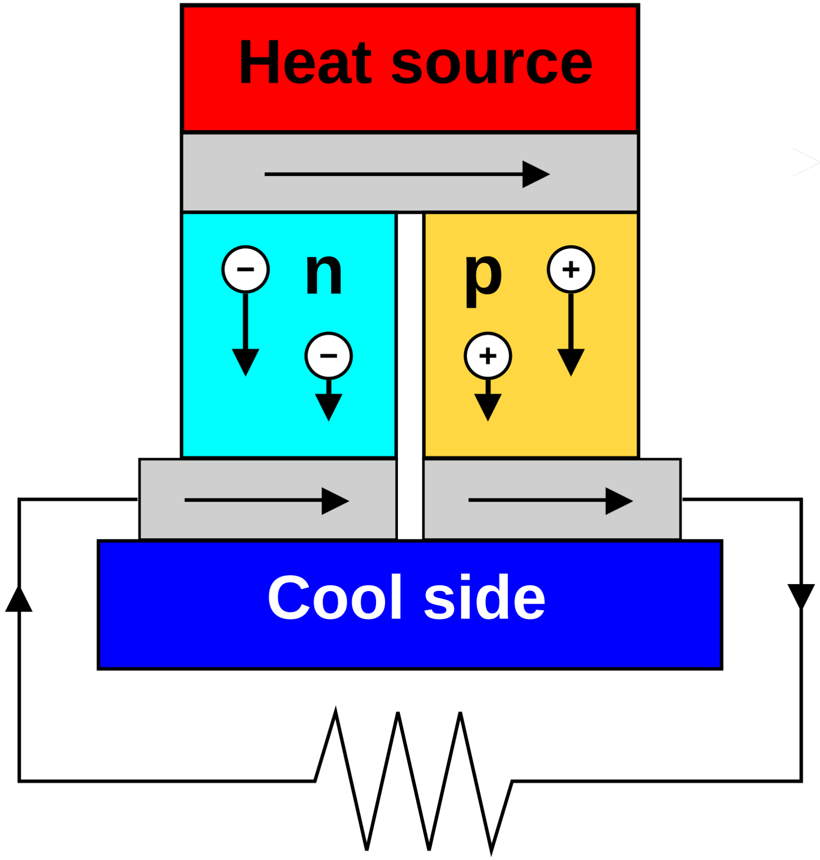


- Factory calibrated
- -40°C to +85°C for sensor temperature
- -70°C to +380°C for object temperature
- ±0.5°C accuracy around room temperatures
- High accuracy of 0.5°C over wide temperature
- 90° Field of view
- 4.5 to 5.5V power
- I2C interface, 0x5A is the fixed 7-bit address

Note that there are two different kinds, meant to be powered by 3V or 5V. I believe you have the 5V version in your parts kit. (If you feed 5V to the 3V version you're probably going to fry it, so be careful.)

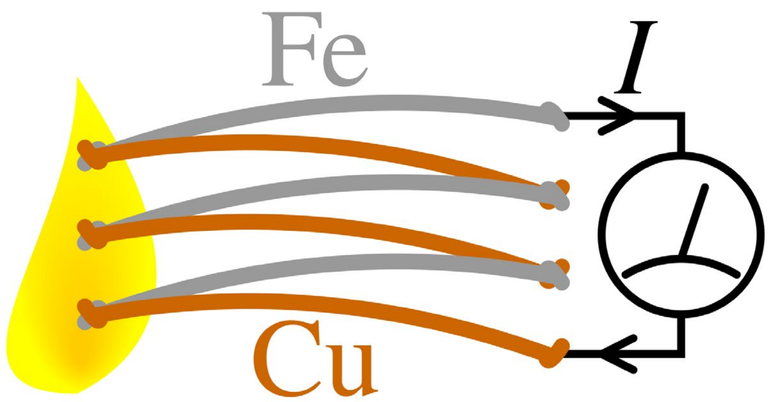
Thermoelectric effect

- At the atomic scale, a temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side. This is due to charge carrier particles having higher mean velocities (and thus kinetic energy) at higher temperatures, leading them to migrate on average towards the colder side, in the process carrying heat across the material.
- Depending on the material properties and nature of the charge carriers (whether they are positive holes in a bulk material or electrons of negative charge), heat can be carried in either direction with respect to voltage. Semiconductors of n-type and p-type are often combined in series as they have opposite directions for heat transport, as specified by the sign of their Seebeck coefficients.
- The **Seebeck effect** is the electromotive force (emf) that develops across two points of an electrically conducting material when there is a temperature difference between them. The emf is called the *Seebeck emf* (or thermo/thermal/thermoelectric emf).

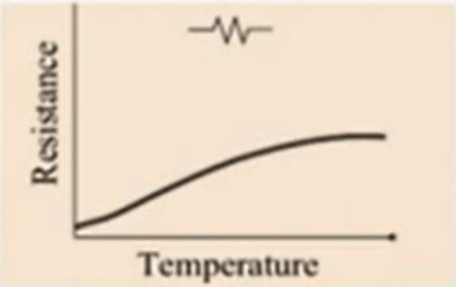
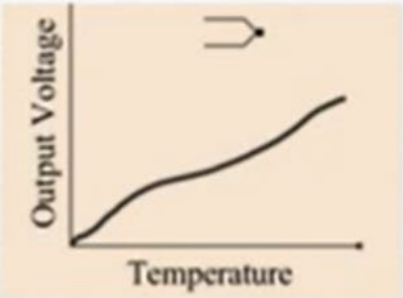
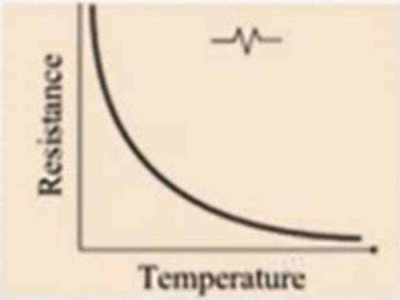


Thermocouple

- One difficulty in using thermocouple sensors is that the voltage to be measured is very small, with changes of about 50 μV per °C (a μV is 1/1000000 Volts). While it is possible to read these voltages using a clean power supply and nice op-amps.
- There are other complications such as a non-linear response (it’s not always 50μV/°C) and cold temperature compensation (the effect measured is only a differential and there must be a reference, just as ground is a reference for voltage).



RTD, thermocouple, thermister

RTD	Thermocouple	Thermistor
		
Most Accurate **Best Stability** **Higher Linearity**	**Self Powered** **Rugged** **Large Temperature Rage**	**Small Size** **Fast Response** **Highest Sensitivity**
Current Source Required	**Lowest stability** **Cold junction ref required**	**Limited Temp Range** **Nonlinear**
-260 °C to 850 °C	**-200 ^{0}C to 1750 ^{0}C**	**-80 ^{0}C to 300 ^{0}C**

Single metal (Pt)

Two dissimilar metal (Seebeck effect)

Metal oxide

RTD, thermocouple, thermistor

Selection criteria:

- Range
- Accuracy
- Cost
- Speed of response
- Sensitivity
- Sensing material

Sensor type	Thermistor	RTD	Thermocouple
Temperature Range (typical)	-100 to 325°C	-200 to 650°C	200 to 1750°C
Accuracy (typical)	0.05 to 1.5°C	0.1 to 1°C	0.5 to 5°C
Long-term stability @ 100°C	0.2°C/year	0.05°C/year	Variable
Linearity	Exponential	Fairly linear	Non-linear
Power required	Constant voltage or current	Constant voltage or current	Self-powered
Response time	Fast 0.12 to 10s	Generally slow 1 to 50s	Fast 0.10 to 10s
Susceptibility to electrical noise	Rarely susceptible High resistance only	Rarely susceptible	Susceptible / Cold junction compensation
Cost	Low to moderate	High	Low

Driving & sensing a thermistor

- Unlike voltage sourcing temperature sensors such as thermocouples, the thermistor needs modest voltage or current excitation in order to measure its resistance

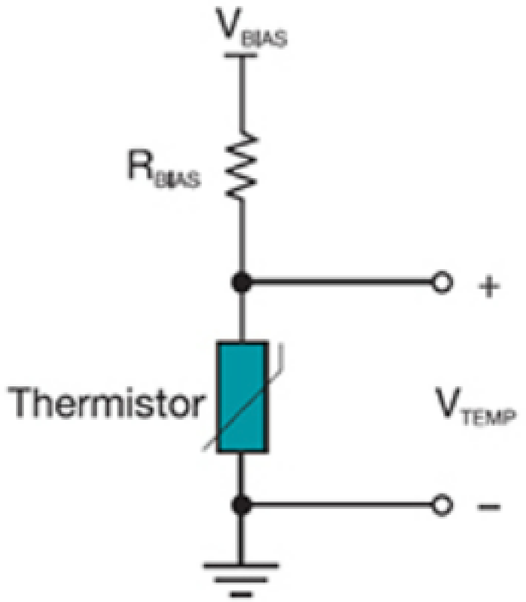


Figure 3: A simple voltage source and resistor voltage divider arrangement is all that is needed in principle to measure the thermistor resistance corresponding to V_{TEMP}. (Image source: Texas Instruments)

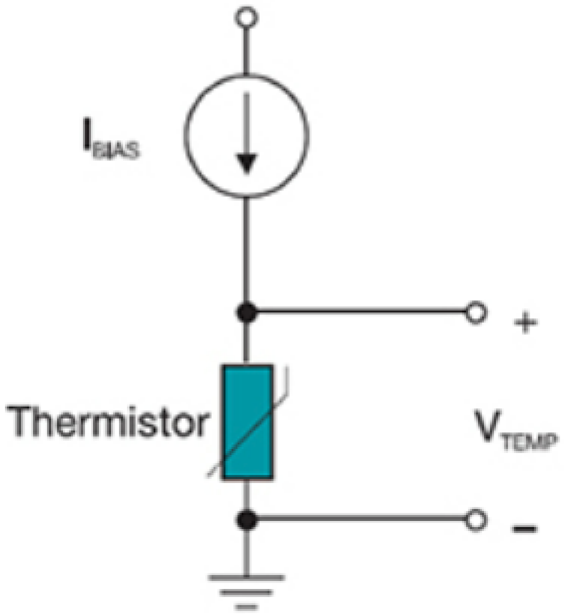


Figure 4: A current source is often used rather than a voltage source and divider due to its improved performance and control of the voltage reading. (Image source: Texas Instruments)

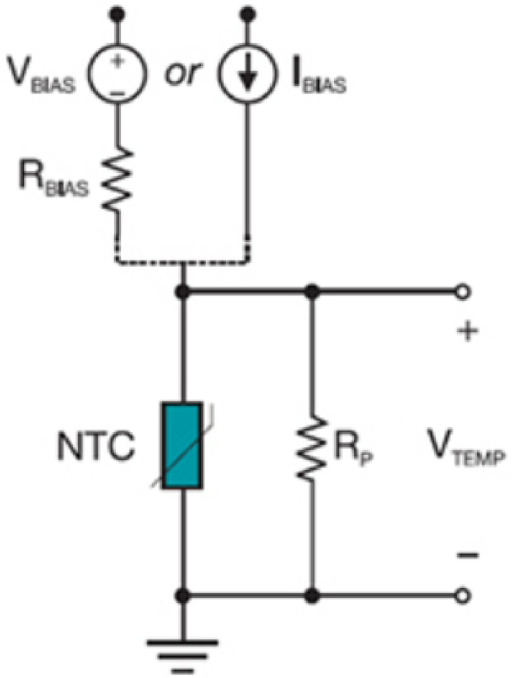
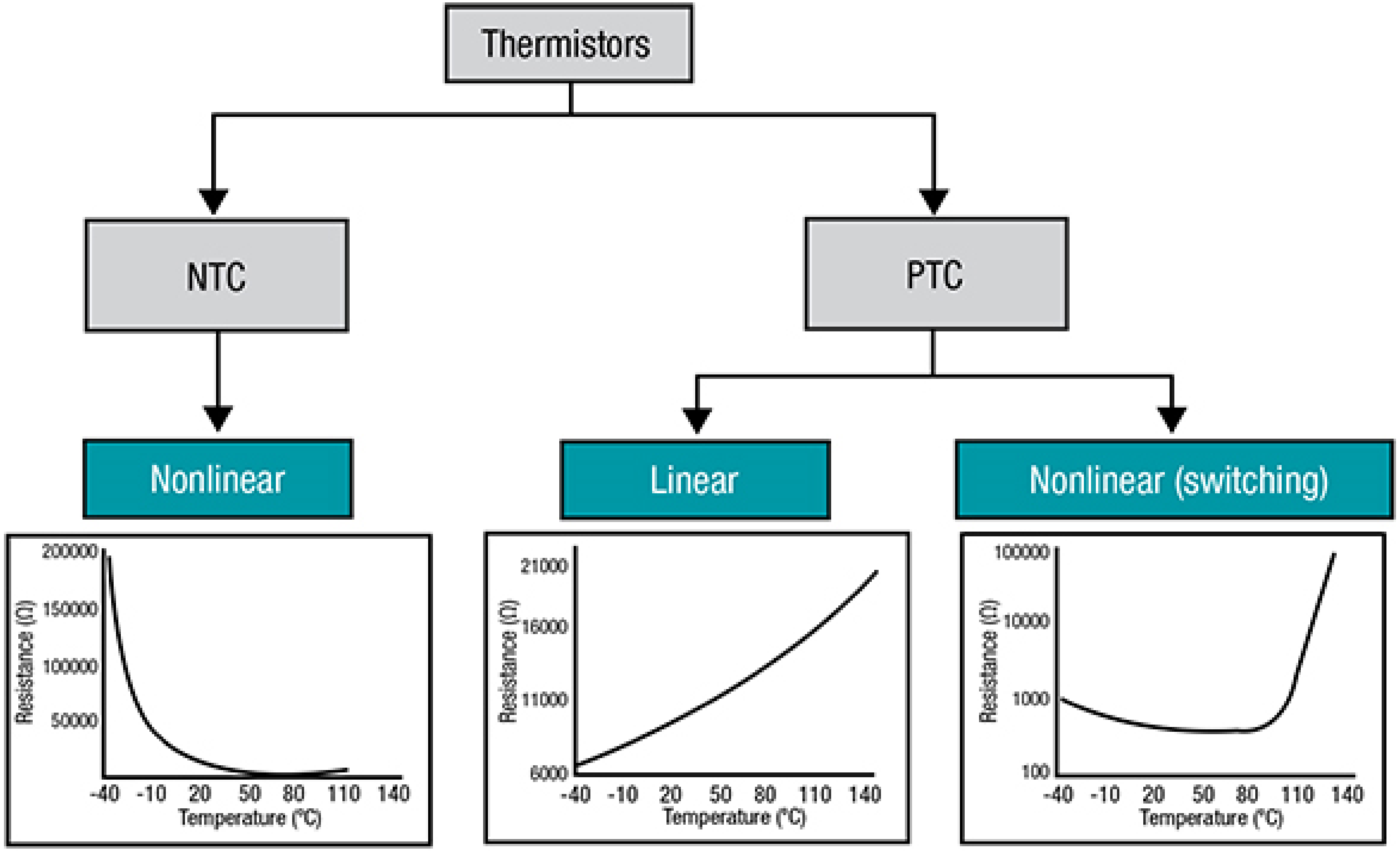


Figure 5: Whether using a voltage or current source to drive the thermistor, adding a parallel resistor will improve its linearity, but at a penalty in component BOM and power use. (Image source: Texas Instruments)

Thermistors



Exercise

1. Wire up two BME680s to an Adalogger: have one use SPI and the other I2C. Be sure to place bypass capacitors between power and ground for each BME680.
2. Code up a loop that will, each pass through the loop, read the temperature from both devices (using the usual default parameters for the temperature sensors) and store the values obtained in an array. Add whatever delay() is necessary to make the loop take about 10 seconds to record 1,000 values from each sensor.
3. Write these values to a microSD memory card, either as plain text or as comma-separated value files, making sure to include something that will let you distinguish among various data sets that you'll store on your laptops, either when opening an SD file or else when transferring the data to a laptop.
4. Have your Adalogger calculate the following for each run of 1,000 recordings: average temperature (through I2C and SPI readings) and the RMS deviations from the means of TI2C, TSPI, and TI2C - TSPI. Write these to the end of each file of data.

(Homework): Write a python program that will read a data file and generate graphs of the values of T_I2C, T_SPI, and T_I2C – T_SPI as functions of sample number. Also have your program generate histograms of the values of these three quantities for the data file. Do this for several different files you've stored

Adafruit Feather M0 Adalogger

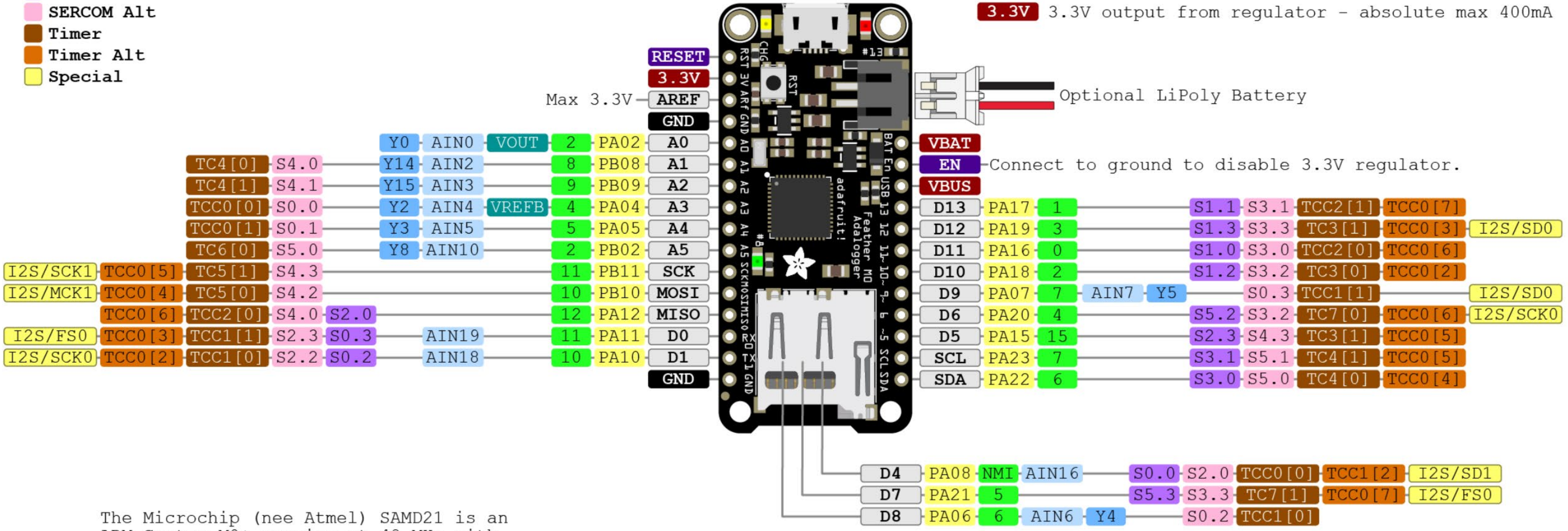
https://www.adafruit.com/products/2796

- Power
- GND
- Control
- CircuitPython Name
- GPIO
- INT
- DAC/AREF
- ADC
- Touch
- SERCOM
- SERCOM Alt
- Timer
- Timer Alt
- Special

VBUS Connected to 5V USB port - absolute max 500mA

VBAT The positive voltage from the JST battery jack

3.3V 3.3V output from regulator - absolute max 400mA



The Microchip (nee Atmel) SAMD21 is an ARM Cortex-M0+ running at 48 MHz with 32kB on-chip SRAM, 256KB Flash memory and built in USB. All GPIO is 3.3V in/out max unless otherwise stated. SERCOMs can be used as UART (TX on SERCOM pad 0 or 2, RX on any pad), I2C (SDA on pad 0, SCL on pad 1), or SPI (SCK on pad 1 or 3, MOSI on pad 0 or 3 (SCK on pad 1) or pad 0 or 2 (SCK on pad 3), MISO on any pad remaining)

Absolute max per pin 10mA, 7mA recommended.

Absolute max 130mA for entire package.