ITP272 SENSOR TECHNOLOGIES AND PROJECT

L04: Sensors and their Principles

AGENDA

- Light detector
- Temperature sensors

LIGHT DETECTORS

Light detector

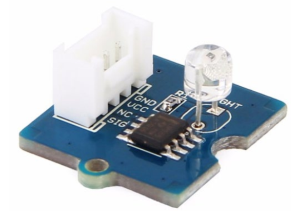
D

- A sensor that provides electrical output corresponding to presence of light
- Light contains particles called photons
- Absorption of photons by a sensing material converts light into electrical energy

Categories / Types

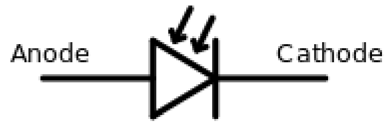
- Photodiode
- Phototransistor
- Photoresistor

LIGHT DETECTORS



Photodiodes

- A sensor that uses light sensitive PIN diode to convert light to electrical signal



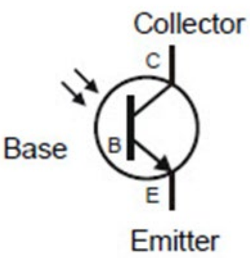
- Photons from the light falls on diode and got absorbed
- Absorption of photons cause electrons to be freed
- This mechanism is also known as the inner photoelectric effect
- Movement of these electrons produces current
- This current is known as photo current

LIGHT DETECTORS

Phototransistor

D

- A sensor that uses light sensitive Bipolar transistor to convert light to electrical signal
- Photons from the light falls on base terminal of the transistor and got absorbed

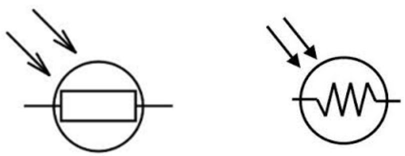


- Absorption of photons cause electrons to be freed
- Movement of these electrons produces photo current at the base terminal of the transistor and turns on the transistor
- The current is then amplified by the transistor resulting in a significant increase in the collector current

LIGHT DETECTORS

Photoresistor

- A sensor that uses Light Dependent Resistor (LDR) to detect light
- Sometimes referred to as a photocell



- Photons from the light falls on resistor and got absorbed
- Absorption of photons cause electrons to be freed
- This force to move electrons reduces the resistance of the resistor
- A power source is required to drive current through the resistor so that changes in resistance causes changes in the voltage across

TEMPERATURE SENSORS

Temperature Sensor

D

- A sensor that provides electrical output corresponding to a thermal energy changes
- Contact sensing requires the sensor to be in direct physical contact with the object
- Non-contact sensing interprets infrared electromagnetic waves emitted from the object

Categories / Types

- Semiconductor PN junction
- Thermistor

TEMPERATURE SENSORS

Semiconductor PN junction sensor

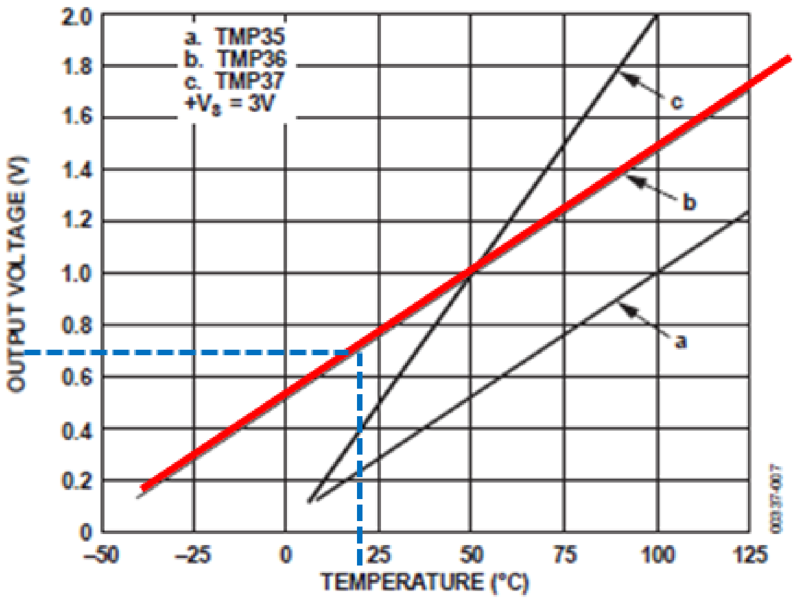
D

- A sensor that relies on the changes of its forward biased voltage of a transistor to measure temperature
- Semiconductor transistor are temperature sensitive
- It is a positive temperature coefficient sensor
  - The higher the temperature, the larger voltage output they produces
- Contact sensing
- Smaller in size
- Cheaper in cost
- Lower resolution
- Slower in response time
- Smaller temperature measurement range
  - Still capable to measure normal ambience temperature

TEMPERATURE SENSORS

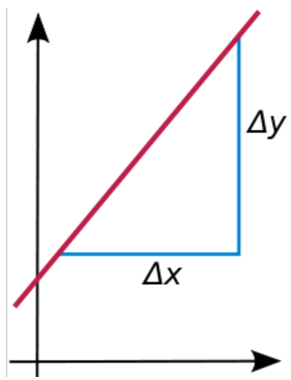
Semiconductor PN junction sensor

- The below shows a output of a TMP36 sensor
- At <u>19 ℃</u>, the sensor will output a <u>0.69 V</u> output



Output Voltage vs. Temperature

TEMPERATURE SENSORS



$(y_2 - y_1) = \Delta y. \quad (x_2 - x_1) = \Delta x.$

$$\text{Gradient} = m = \frac{y_2 - y_1}{x_2 - x_1}$$

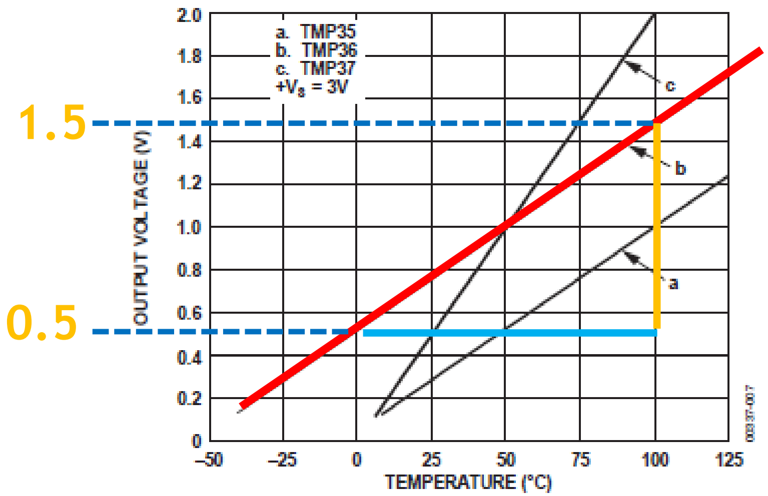


Figure 6. Output Voltage vs. Temperature

Gradient = (1.5 - 0.5) / (100 - 0)
= 1 / 100 = 0.01

If we have get a
voltage = V
Temp = tempC

Gradient = (V - 0.5) / (tempC - 0)
0.01 = (V - 0.5) / tempC

$\boxed{\text{tempC} = 100\ (\text{V} - 0.5)}$

TEMPERATURE SENSORS

Semiconductor PN junction sensor

- Connecting to and ADC with 0 – 3.3V having value of 0 -1023

    0 V => 0
    3.3 V => 1023

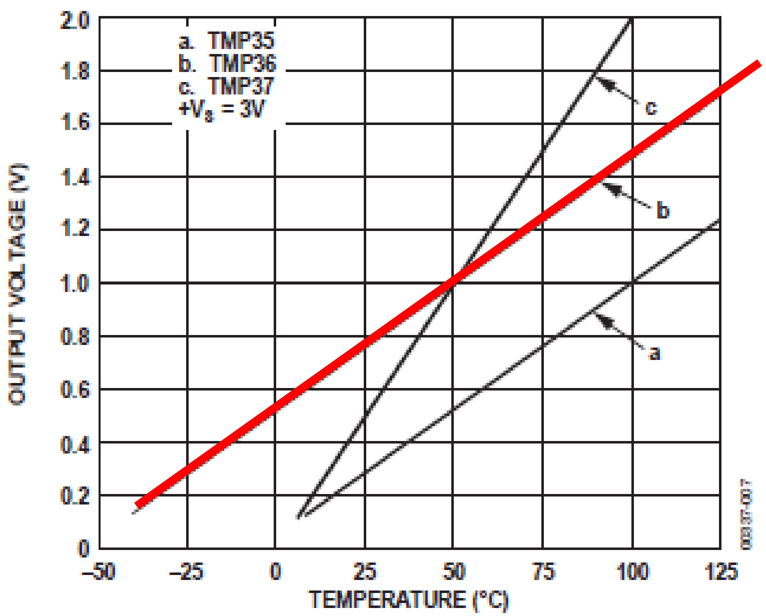


Figure 6. Output Voltage vs. Temperature

Digital to Voltage formula

ADC Value: 214

Voltage = 3.3V*(214/1023)

$\Rightarrow$ 0.69V

$$\boxed{\text{tempC} = 100\,(V-0.5)}$$

tempC = 100 * (0.69 – 0.5)

$\Rightarrow$ 19 °C

TEMPERATURE SENSORS

Thermistors (Resistive)

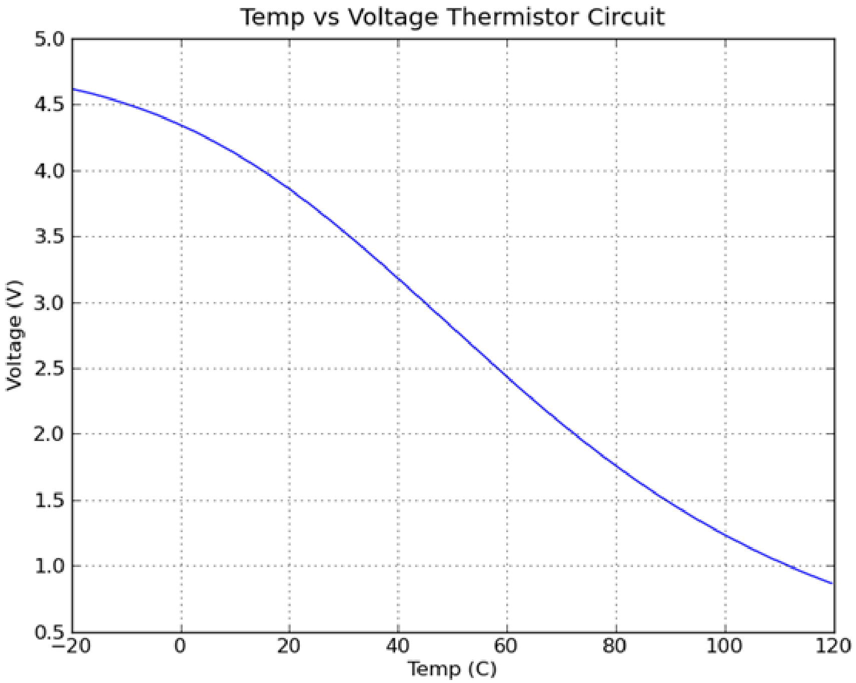
D

- A sensor that relies on the changes of its thermally sensitive resistance to measure temperature
- Contact Sensing
- Available in 2 types
  - <u>Positive</u> Temperature Coefficient (PTC) : <u>Increase</u> in resistance as temperature <u>rises</u>
  - <u>Negative</u> Temperature Coefficient (NTC) : <u>Decrease</u> in resistance when temperature <u>rises</u>
- Coupled with external power (excitation signal) to generate electrical output differences according to temperature changes

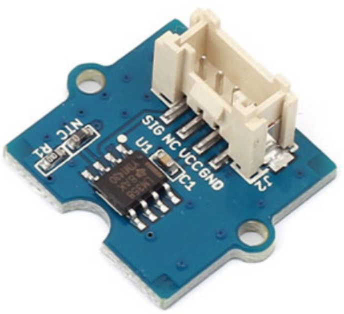
TEMPERATURE SENSORS

Thermistors (Resistive)

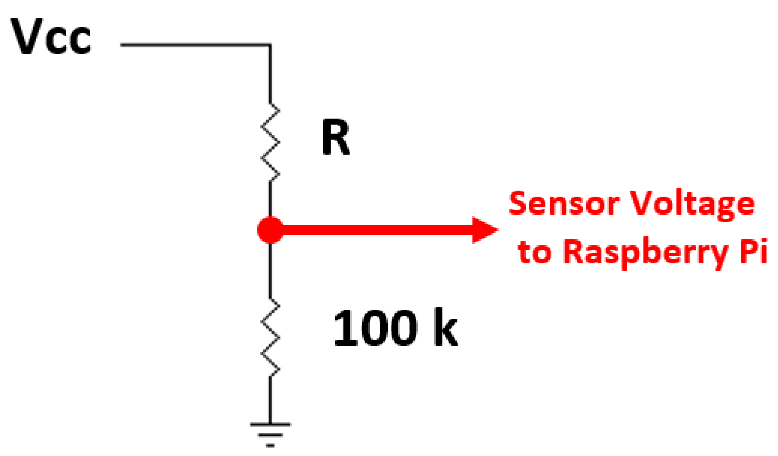
- Output voltage is mapped to retrieve absolute temperature
- The following shows an example of NTC thermistor



TEMPERATURE SENSORS



Thermistor (in our Lab)

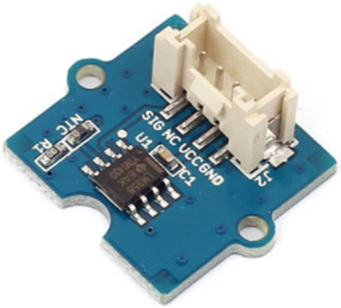


- Our Lab Temperature sensor circuit is as above (from specs)

Thus using Voltage divider rule

- Sensor Voltage = (100k / R + 100k) * Vcc 1

TEMPERATURE SENSORS

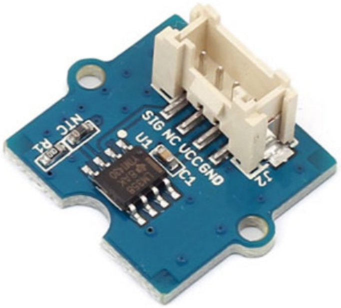


Thermistor (in our Lab)

- We learnt in Signal Conditioning – ADC lecture
- We need to find out the ADC Resolution, M
  - For Raspberry Pi3, it uses 10 bit resolution, thus M = 10
- Maximum Quantization, $\boxed{N = 2^M - 1}$
  - $N = 2^{10} - 1 = 1023$
- ADC Voltage Resolution, $\boxed{Q = E_{FSR} / N}$
  - E_{FSR} = Vcc, thus Q = Vcc / 1023
- Sensor Voltage, $\boxed{\text{Sensor voltage} = \text{ADC Value} * Q}$
  - Sensor Voltage = (ADC Value /1023) * Vcc

- Sensor Voltage = (ADC Value / 1023) * Vcc 2

TEMPERATURE SENSORS



Thermistor (in our Lab)

- From 1 and 2
- (100k / R + 100k) * Vcc = (ADC Value / 1023) * Vcc

$$\frac{100k}{R+100k} = \frac{Adc}{1023}$$

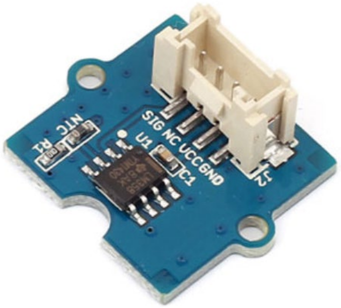
$$1023 * 100k = R * Adc + 100k * Adc$$

$$R * Adc = 1023 * 100k - 100k * Adc$$

$$R * Adc = 100k\,(1023 - Adc)$$

$$R = 100k\,(1023 - Adc) / Adc \qquad 3$$

TEMPERATURE SENSORS



Thermistor (in our Lab)

- From Website specs/datasheet, Transfer function formula is

1. Zero-power Resistance of Thermistor: R

   $R = R_0 \exp B (1/T - 1/T_0)$ ······································(1)

   R: Resistance in ambient temperature T (K)

   (K: absolute temperature)

   R_0: Resistance in ambient temperature T_0 (K)

   B: B-Constant of Thermistor

2. B-Constant

   as (1) formula

   $\boxed{B = \ell n (R/R_0) / (1/T - 1/T_0)}$ ··································(2)

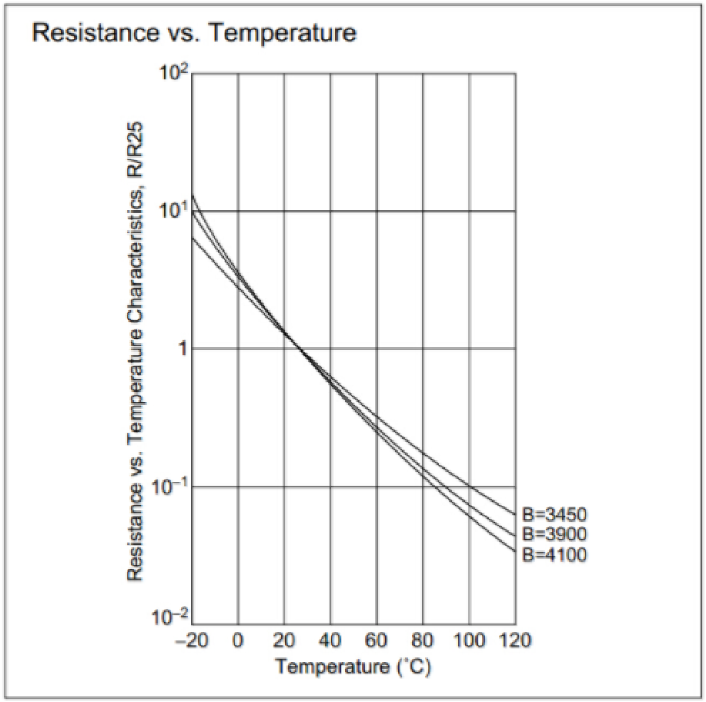
3. Thermal Dissipation Constant

   When electric power P (mW) is spent in ambient temperature T_1 and thermistor temperature rises T_2, there is a formula as follows

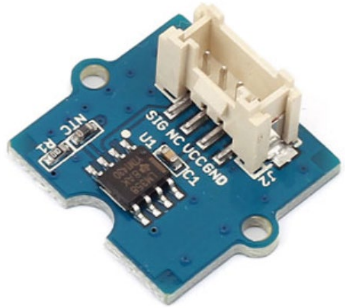
   $P = C (T_2 - T_1)$ ··(3)

   C: Thermal dissipation constant (mW/°C)

   Thermal dissipation constant is varied with dimensions, measurement conditions, etc.



TEMPERATURE SENSORS



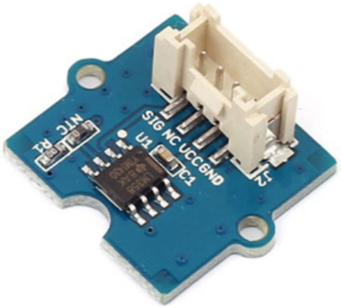
Thermistor (in our Lab)

$$B = \frac{\ln\left(\frac{R}{R_0}\right)}{\frac{1}{T} - \frac{1}{T_0}}$$

- T is the temperature measured by the sensor (in Kelvin), T_0 is a known reference temperature
- For calculation, we use room temperature as T_0 = 25°C
- To convert Kelvin to °C, we need to + 273.15
  - So T_0 of 25°C = 25 + 273.15 = 298.15 (in Kelvin)
  - So T in °C= T + 273.15

$$B = \frac{\ln\left(\frac{R}{R_0}\right)}{\frac{1}{T+273.15} - \frac{1}{298.15}}$$

TEMPERATURE SENSORS



Thermistor (in our Lab)

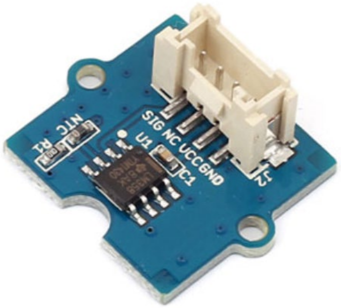
$$B = \frac{\ln\left(\frac{R}{R_0}\right)}{\frac{1}{T+273.15} - \frac{1}{298.15}}$$

$$\frac{1}{T+273.15} - \frac{1}{298.15} = \frac{\ln\left(\frac{R}{R_0}\right)}{B}$$

$$\frac{1}{T+273.15} = \frac{\ln\left(\frac{R}{R_0}\right)}{B} + \frac{1}{298.15}$$

$$T + 273.15 = 1 \;/\; \left(\frac{\ln\left(\frac{R}{R_0}\right)}{B} + \frac{1}{298.15} \right)$$

TEMPERATURE SENSORS



Thermistor (in our Lab)

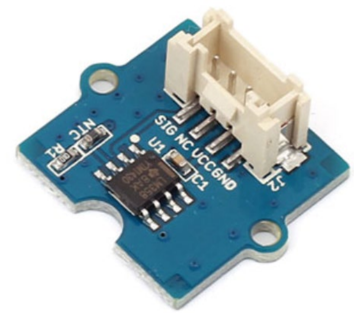
$$T + 273.15 = 1 \;/\; \left(\frac{\ln\left(\frac{R}{R_0}\right)}{B} + \frac{1}{298.15} \right)$$

$$T = 1 \;/\; \left(\frac{\ln\left(\frac{R}{R_0}\right)}{B} + \frac{1}{298.15} \right) - 273.15$$

$$T = 1 \;/\; (\ \ln(R \;/\; R_0) \;/\; B + (1 \;/\; 298.15)\ ) - 273.15$$

4

TEMPERATURE SENSORS



Thermistor (in our Lab)

$$R = 100k\,(1023 - Adc)\,/\,Adc$$ 3

$$T = 1\,/\,(\ \ln(R\,/\,R_0)\,/\,B + (1\,/\,298.15)\ ) - 273.15$$ 4

- From Website specs

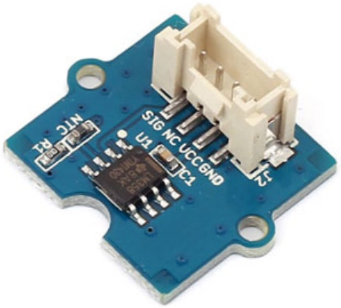
Specifications

- Voltage: 3.3 ~ 5V
- Zero power resistance: 100 KΩ
- Resistance Tolerance: ±1%
- Operating temperature range: -40 ~ +125 ℃
- Nominal B-Constant：4250 ~ 4299K

Room Temp Resistance, R_0 = 100k

B = 4250

TEMPERATURE SENSORS



Thermistor (in our Lab)

- Finally, with
  - $B = 4250$, $R_0 = 100k$

$$R = 100k\,(1023 - Adc) / Adc \quad (3)$$

$$T = 1 / (\ \ln(R / R_0) / B + (1 / 298.15)\ ) - 273.15 \quad (4)$$

- In Lab

```
//Calculation explained in Lecture notes
int B = 4250, R0 = 100000;
R = 100000 * (1023.0 - adcValue) / adcValue;
tempCalcuated = 1 / ( Math.Log(R/R0) / B + 1/298.15 ) - 273.15;
```