RBE 1001: Introduction to Robotics
C-Term 2019-20
HW 3.3: Voltage dividers and the ADC

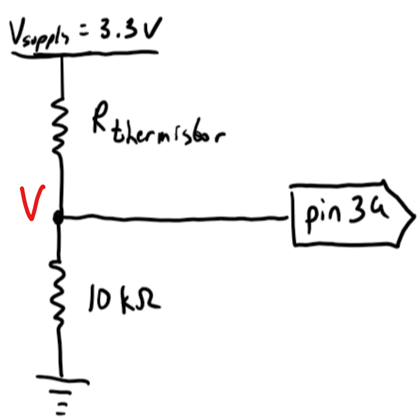
Last modification: February 13, 2020

You are using the thermistor from lecture to measure temperature. You decide to use the circuit shown in Figure 1 and the ADC on the `ESP32` to register the temperature. **Note that we've interchanged the position of the fixed resistor and thermistor from the discussion in class**. This will make the calculations a little easier, but you'll have to re-think the formulas!

$V = \frac{10k}{10k + R_{th}} \cdot 3.3V$

$V(10k + R_{th}) = 10k \cdot 3.3V$

$\boxed{R_{th} = \frac{10k\Omega \cdot 3.3V}{V} - 10k\Omega}$



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

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

Figure 1: Schematic for temperature sensor circuit.

From the datasheet[1], the resistance of the thermistor can be approximated as,

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

where $B = 4300\text{K}$ is a constant specified by the manufacturer, and $R_0 = 10k\Omega$ is the resistance measured at $T_0 = 25C$. Note that the temperatures in Eq. 1 **need to be in Kelvin**, so you'll have to convert to and from Celsius.

The `ESP32` has a 12-bit ADC and uses $V_{ref} = 3.3\text{V}$.

1. Calculate the output voltage of the voltage divider if the temperature is:

   (a) 25 C $R(25C) = 10k\Omega$ (by definition), so $V = \frac{1}{2} V_{supply} = \boxed{1.65V}$

   (b) 30 C $R(30C) = 10k\Omega\, e^{\left[-4300\left(\frac{1}{298} - \frac{1}{303}\right)\right]} = 7881\Omega \Rightarrow V = \frac{10}{10 + 7.881} \cdot 3.3V$

   $= \boxed{1.846\,V}$

[1] Oddly, I can't find the datasheet online anymore, so I'll spare you from having to look it up.

(c) 33 C $R(33) = 10k\Omega e^{\left[-4300\left(\frac{1}{298}-\frac{1}{306}\right)\right]} = 6.857k\Omega \Rightarrow V = \frac{10}{10+6.857} 3.3 = \boxed{1.958V}$

2. Calculate the ADC result for the same temperatures:

   (a) 25 C $ADC = floor\left[\frac{1.65\,V}{3.3\,V} \cdot 4096\right] = \boxed{2048}$

   (b) 30 C $ADC = floor\left[\frac{1.846}{3.3} \cdot 4096\right] = \boxed{2291}$

   (c) 33 C $\boxed{2430}$

3. If the ADC returns a value of 2188, what are the minimum and maximum voltages that could return this value (ignoring noise and other imperfections).

$V_{low} = \frac{2188}{4096} \cdot 3.3 = \underline{1.76279\ V}$ $\quad V_{high} = \frac{2188+1}{4096} \cdot 3.3 = \underline{1.76360\ V}$

4. What temperatures do these voltages correspond to?

O.f. An exercise in significant digits...

$R_{2188} = 8.72032\,k\Omega \longrightarrow T_{2188} = 300.855K$

$R_{2189} = 8.71173\,k\Omega \longrightarrow T_{2189} = 300.876K$

$\boxed{\Delta T = 0.021K}$

We'll call the difference between the highest and lowest temperatures in that range the *resolution* if the system – it's the amount that the temperature needs to change to make the ADC result change by one number, or bit.

5. What would happen to the resolution if you used a 10-bit ADC instead of the 12-bit ADC above?

It would be 4X larger.

6. What would happen to the resolution if you used 5V instead of 3.3V for *both* the voltage divider supply and the ADC reference voltages?

They cancel out, so no effect.

cancel out

$ADC = floor\left[\frac{V}{V_{ref}} \cdot 2^N\right] = floor\left[\frac{\frac{R_1}{R_1+R_2} \cdot V_{supply}}{V_{ref}} \cdot 2^N\right]$