Honors Project
EGEE-3210 Electronics I

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December 3, 2021

1 Objective

The objective of this project was to create a thermometer using a diode as a temperature sensor. The circuit should use a voltmeter to display the temperature represented in 10 mV/°F format (e.g., 212° should be displayed as 2.12 V). The circuit should also be able to take in a user-specified temperature (in the form of a voltage in the same 10 mV/°F format) and turn on an LED when the temperature as sensed by the thermometer exceeds that of the temperature set by the user.

2 Theory

Due to its chemistry, the forward voltage drop across a diode changes with the temperature. The voltage drop and the temperature are inversely proportional and have an approximately linear relationship. The coldest temperature will result in the largest voltage drop, and the warmest temperature will result in the smallest voltage drop. So, if two points of (temperature, voltage drop) are measured, the slope of the relationship between the temperature and the voltage drop can be well approximated.

3 Calibration Process

The thermometer was to be calibrated using ice water as the 32°F point and boiling water as the 212°F point. Since as the temperature increases, the voltage decreases, the voltage drop across the diode can be represented mathematically

$$V_D(T) = V_{D0} - s(T - 32),$$

where V_D is the total voltage drop across the diode at a given temperature in Fahrenheit T, V_{D0} is the "initial voltage drop"–the voltage drop when the temperature is 32°F–and s is the "slope" of the relationship between the temperature and the voltage drop. By measuring the voltage drop at 32°F and 212°, V_{D0} and s for a given diode at a constant current can be determined using the following relationships:

$$\begin{aligned} V_{D0} &= V_D(32^\circ) \\ s &= -\frac{V_D(212^\circ) - V_D(32^\circ)}{212 - 32} \end{aligned}$$

I used the circuit in Figure 1 to take the measurements for this calibration using the bench multimeter in lab. I took the voltage measurements across the diode (at the point marked "V_D" with reference to ground).

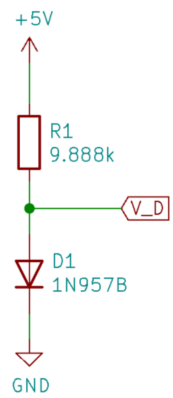

Figure 1: Thermometer Calibration Circuit

The forward voltage drop across the diode measured when the diode was submerged in boiling water was $0.5760V$. The forward voltage drop across the diode measured when the diode was submerged in ice water was $0.7477V$. Thus, using the equations above,

$$V_{D0} = 0.7477V$$
$$s = 0.0009593$$

4 Design Concepts

4.1 Temperature Measurement and Output

For the thermometer design, the general idea is to scale the voltage drop across the diode and then offset it to output the correct voltage. The general initial equation looks like this:

$$V_{OUT} = GV_D + V'_{OFFSET},$$

where V_{OUT} is the voltage outputted by the thermometer circuit (to the multimeter), V_D is the voltage drop across the diode, G is the "gain" to scale the diode's voltage drop, and V'_{OFFSET} is the voltage used to offset the scaled diode voltage drop.

As all signals in this system are DC, this equation can be realized using an operational amplifier weighted summer circuit, as the following equation describes:

$$V_{OUT} = -\frac{R_F}{R_D}V_D - \frac{R_F}{R_{OFFSET}}V_{OFFSET}$$

This equation can be realized with the circuit in Figure 2.

We can choose convenient values for R_F and V_{OFFSET}, and using those values we can calculate what values we need for R_D and R_{OFFSET}. I chose $R_F = 98.86k\Omega$. (I used an $100k\Omega$ resistor, and $98.86k\Omega$ was the measured resistance of that resistor.) I also chose $V_{OFFSET} = -5V$ (looking at the signs in the weighted summer equation, V_{OFFSET} would have to be a negative number in order for V_{OUT} to be positive.). Plugging those values in, we get the equation:

$$V_{OUT} = -\frac{98.86k\Omega}{R_D}V_D - \frac{98.86k\Omega}{R_{OFFSET}}(-5V)$$

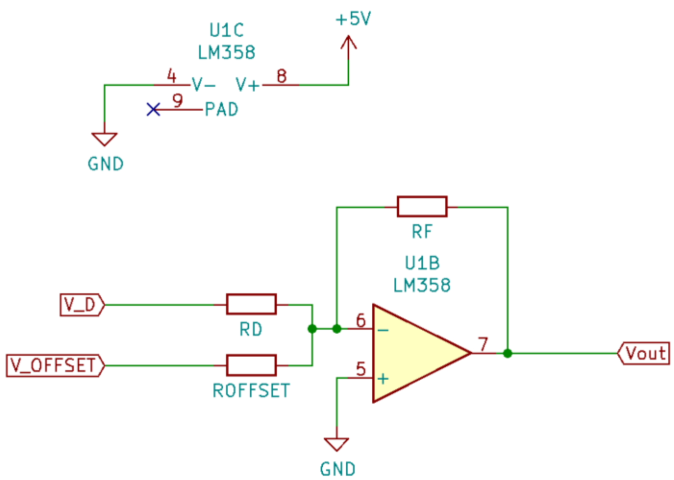

Figure 2: Weighted Summer Circuit

We can find the needed values R_D and R_{OFFSET} from the two points we use to calibrate the thermometer (32°F and 212°F) and the fact that we know what the resulting V_{OUT}s should be for those two points (0.320V and 2.120V, respectively). Using these values and the above equation, we find that

$$R_D \approx 9.426k\Omega$$
$$R_{OFFSET} \approx 60.56k\Omega$$

Using these values and a unity gain buffer to make sure the diode current and the op-amp current are decoupled, the resulting thermometer part of the circuit is depicted in Figure 3.

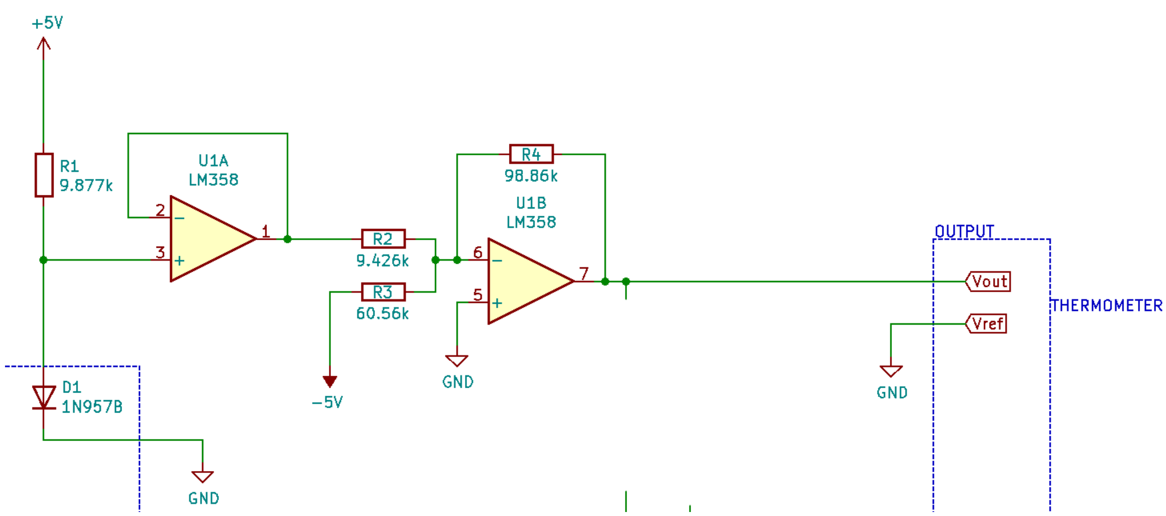

Figure 3: Temperature Measurement and Output Circuit

4.2 User Input and Comparison

In order to fulfill the second major objective of the project (to accept user input and light up an LED if the ambient temperature is higher than that user input), I needed a way to compare two values A and B and turn on the output if and only if A is greater than B (and not if B is greater than A). This functionality can be realized by a single op-amp. If V^+ is tied to $+5V$, V^- is tied to ground, the aforementioned A signal is connected to the non-inverting terminal of the op-amp, and the aforementioned B signal is connected to the inverting terminal of the op-amp, the output will be $+5V$ if signal A is greater than signal B and will be $0V$ if signal A is not greater than signal B. This part of the user input and comparison circuit is found in Figure 4.

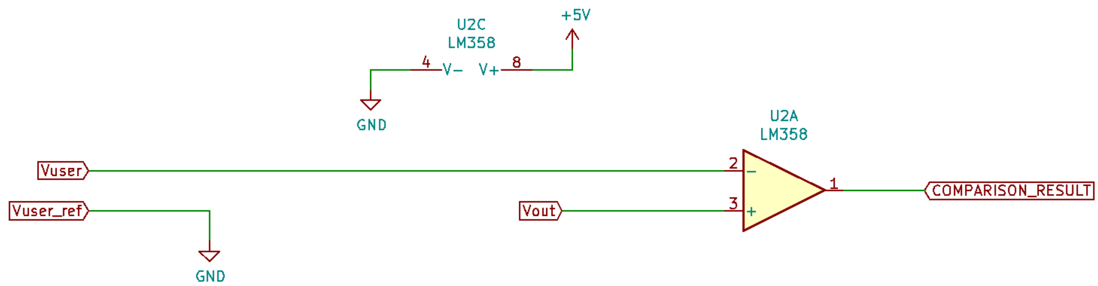

Figure 4: User Input and Comparison Circuit, Part 1

Thus, the comparison result can be connected to an LED in series with a resistor connected to ground, and the LED will light up if the measured temperature signal (V_{OUT}) is greater than the user input voltage (V_{USER}).

However, there's still one problem with this circuit. If there is no user input, meaning if V_{USER} is left floating, the output of the LED is unpredictable and unstable and flashes on and off. Ideally, if there's no user input, the LED should just be turned off. In order to achieve this functionality, I added a pull-up resistor on the V_{USER} line. Then, if there is some signal on the V_{USER} line, that signal is let through. However, if there is no user-inputted signal on the V_{USER} line, the V_{USER} line is held at $+5V$. There is no possible way that the output of the temperature circuit could exceed $+5V$, so it is given that the LED will stay off. The resulting circuit with both the LED and the pull-up resistor is in Figure 5. It will turn on the LED if and only if V_{OUT} is greater than V_{USER}.

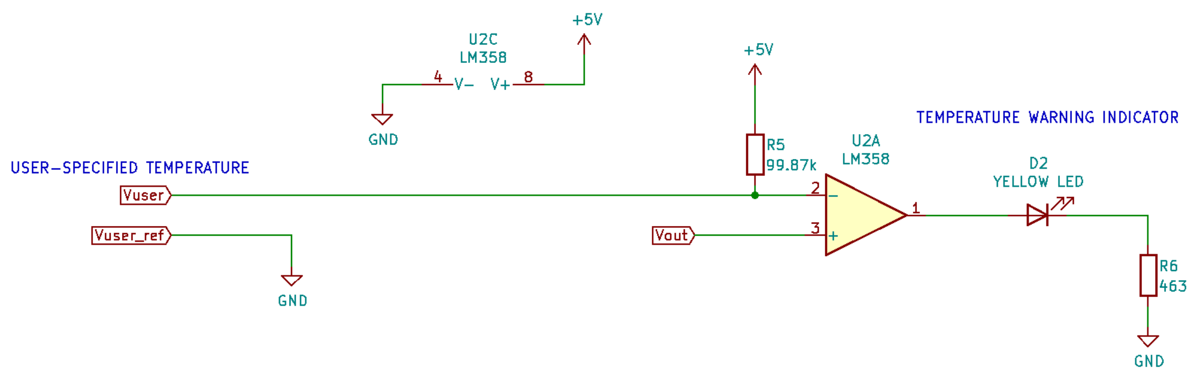

Figure 5: User Input and Comparison Circuit, Part 2

5 Results and Final Circuit

The final circuit is depicted in Figure 6. In testing, the thermometer was able to accurately measure and display water-freezing, water-boiling, and room temperature. It was also able to accurately turn on the LED warning indicator if the temperature measured was greater than the user input temperature (and kept the LED off if there was no user input).

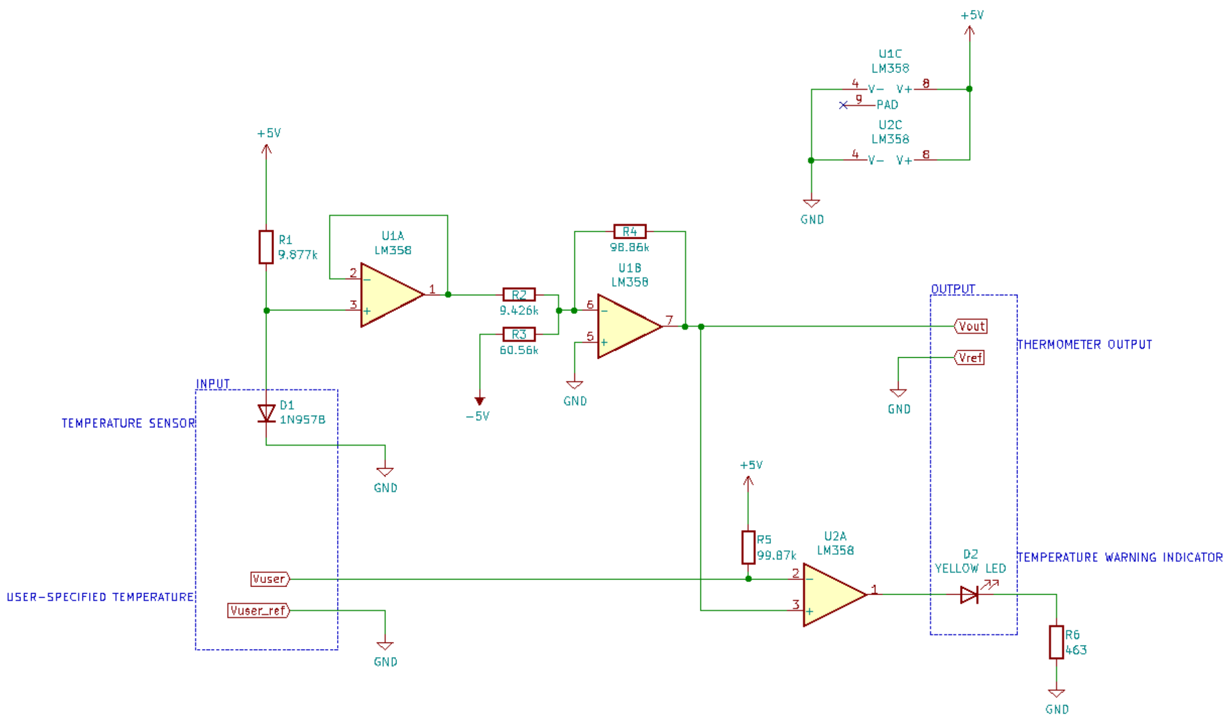

Figure 6: Final Circuit