Project Report: Temperature Controlled LED Circuit

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Abstract

This report describes a circuit according to the temperature controlled LED. People can realize the temperature warning by adjusting the threshold temperature. This report also gives a variety of derivative circuits.

1 Introduction

In real life, there are often some environments or equipment that require the upper limit of temperature. For example, for libraries or archives, too high temperature may lead to the destruction of documents, for kitchens, appropriate temperature can improve the quality of cooking, or just for individuals, too high room temperature may lead to heatstroke and other problems. Therefore, I designed an automatic temperature control LED warning light, which allows users to adjust the required temperature from 2 °C to 100 °C. When the temperature exceeds the specified value, the LED will change from green to red to indicate a warning This equipment can help people to be more alert to temperature.

2 Analysis

2.1 Main Component in Circuit

Here first introduce several components and their special feature, which will be important to later analysis.

2.1.1 LM35 Temperature Sensor [1]

`LM35` has three pins,named as `VS`, `VOUT`, `GND`, here in the circuit we are applying **Basic Contigrade Temperature Sensor** [1] ,as below graph [1]:

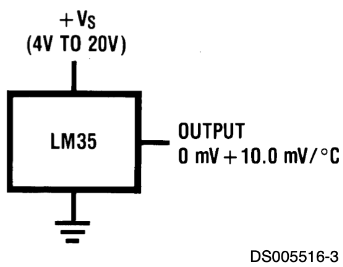

Figure 1: Basic Contigrade Temperature Sensor

`VS` is connected to the `VS` which required to be 4 V to 20 V, `GND` is connected on the ground. The output,`VOUT` outputs a voltage proportional to temperature, and its relationship is as follows [2.1] [1]:

$$V_{out} = T \cdot 10\,\mathrm{mV/^\circ C} \tag{2.1}$$

Where the temperature is in degrees Celsius In this wiring mode, the measured temperature is limited at 2 °C to 100 °C,

2.1.2 LM358AD Operational Amplifier [2]

In the circuit, `LM358AD` is used as a comparator to compare the two input voltages. When the `+` port is large, `VOUT` outputs high level voltage, which is the $V_{CC} - 1.5$ in this circuit, it is about 3.5 V(ignoring the change caused by temperature) [2]. When the `-` port is large, `VOUT` outputs low level voltage, which approximately could be regard as 0 V. This Op-Amp acts as a switch in the circuit to respond to `LM35` temperature change and convert it into instantaneous voltage jump, which will be used in later analysis.Here make a test on the `LM358AD` with the function of camparator(`V2` = 2 V,Apply `DC sweep` on `V1` from 0 V to 5 V,increment as 0.1,output `VOUT`):

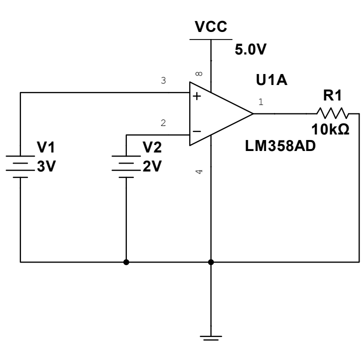

Figure 2: LM358AD test circuit

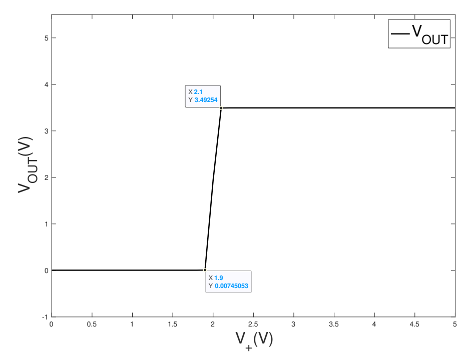

Figure 3: V_{OUT} voltage diagram

2.1.3 BC547A NPN-type Transistor [3]

`BC547A` is a NPN-type transistor, it works as the direct switch for the LED light through controlling V_{BE}. By refering the datasheet [3].The saturation voltage of $V_{BE} \approx 0.7$ V.The `BC` connected when $V_{BE} > 0.7$, otherwise, it is open circuit.

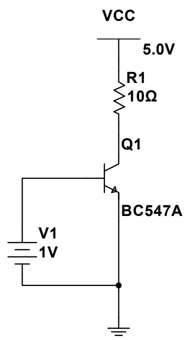

Figure 4: BC547A test circuit

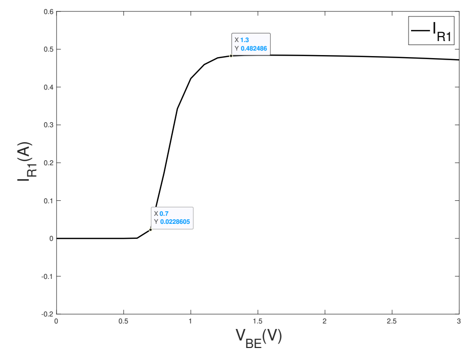

Figure 5: I_{R1} voltage diagram

2.1.4 LED light

Here in this report include three kinds of LED light which are red,green and blue, the turn on voltage is 1.83 V,2.13 V and 3.45 V respectively.All their turn on current at 20 mA.In furthere analysis we use the **Simplified Equivalent Circuit** model to analysis the LED circuit.

2.2 Module Analysis

Next we apply analysis the whole circuit module by module seperately[6].

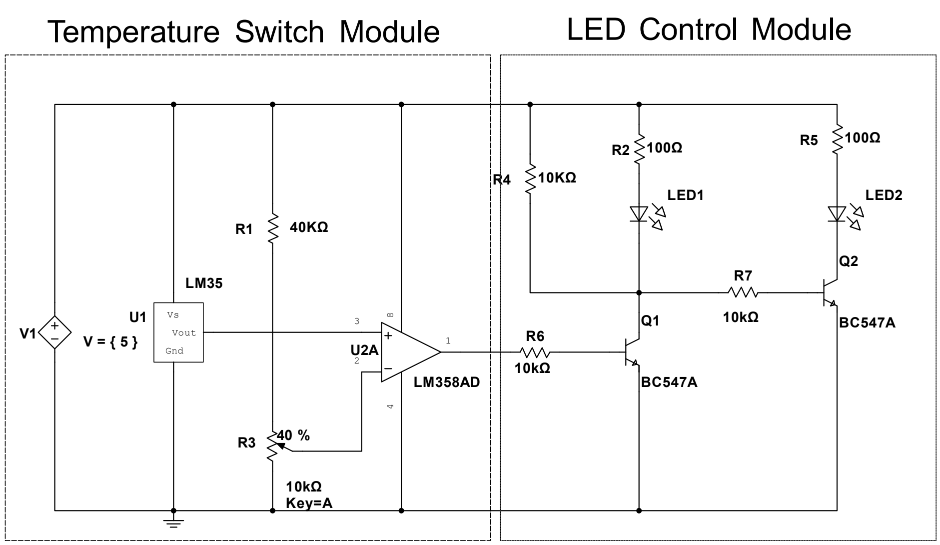

Figure 6: Circuit Devided into Module

2.2.1 Temperature Switch Module

This part is constructed `LM358A` Op-Amp, 10 KΩ potentiometer, and a 40 KΩ resistor, connected as below circuit [7]. The percentage,p, shown in the circuit diagram

[7] refers to the proportion of the upper part of the pointer, which follow the equation below:

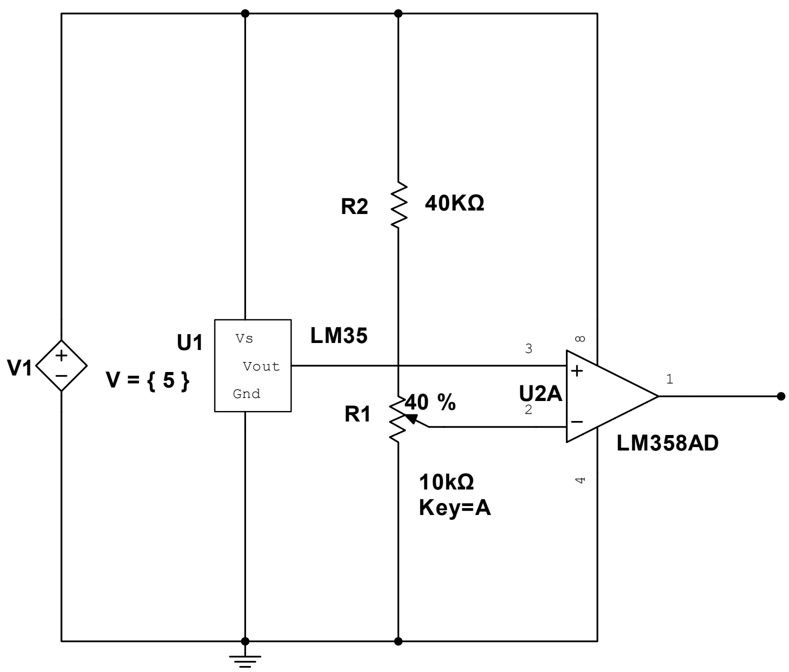

Figure 7: Temperature Switch Module

$$V_{-} = \frac{(1-p)\cdot 10\,\mathrm{K\Omega}}{40\,\mathrm{K\Omega} + 10\,\mathrm{K\Omega}} \cdot 5\,\mathrm{V} = (1-p)\mathrm{V} \tag{2.2}$$

High resistance is used here to reduce the influence between other parts of the circuit and maintain the stability of the circuit.

For `LM358AD`, when $V+ > V_{-}$, V_{out} will output $V_{CC} - 1.5\,\mathrm{V} = 3.5V$, and when $V_{-} > V_{+}$, V_{out} will output 0.By the introduction in [2.1].Therefore we can conclude the result of the threshold temperature for `LM358AD` to switch its output state:

$$T_{\text{Thresold}} = 100 \cdot p\mathrm{K} \tag{2.3}$$

After understanding the functional relationship between the voltage on the two pin ports and related factors, we can simply test this module. First, we adjust the potentiometer to 40%, that is, set the threshold temperature to 60 °C. We perform temperature sweep on the circuit, set the start temperature to 0, set the cut-off temperature to 100 °C, and set 100 sampling points, The sampling interval is about 1.01c, making it output `V+`,`V-`,`VOUT` is the result, and the following chart is obtained [8]:

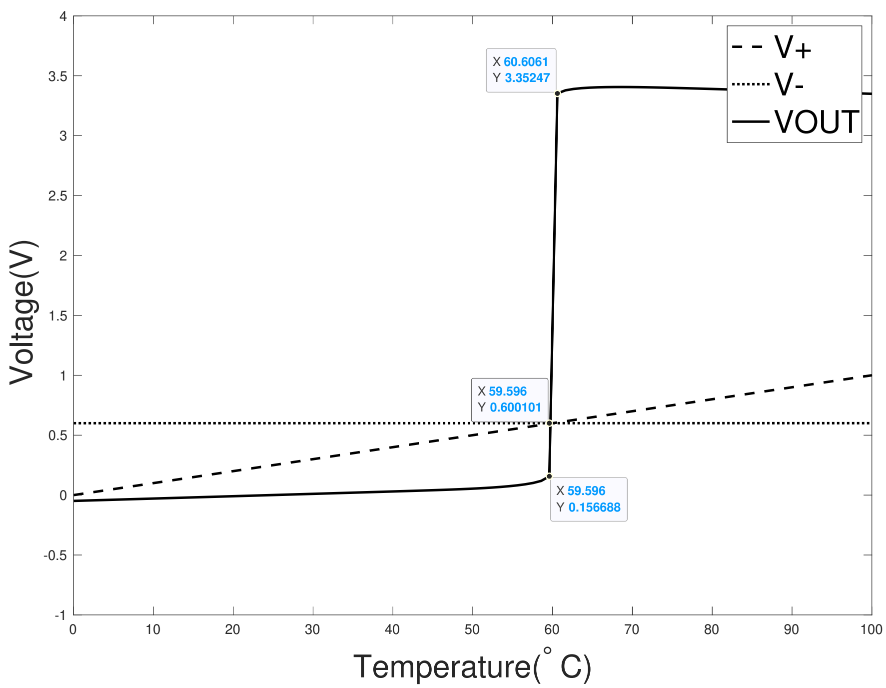

Figure 8: Temperature Switch Diagram Voltage($V+$,$V-$,V_{OUT})

It can be seen that the voltage at the `V+` port increases linearly with the temperature. When the temperature reaches 100 °C, the voltage is qty1V. At the same time, since we adjust the potentiometer at at 40%, the voltage of `V-` is always constant at 0.6 V. Therefore, we can see that `V+` and `V-` cross 60 °C, which is `VOUT` jumps from low level to high level.

This is the working principle of the temperature switch module.

2.2.2 LED Control Module

For LED control module[9], we use two NPN-type BJT `BC547a` as control switches, labelled as `Q1` and `Q2`. Two LED lights are connected in series with two 100 Ω resistors, `R2` and `R5` to control the current and prevent the LED lights from burning. Due to excessive current `R5` is a large resistance of 10 KΩ, which is used to reduce the current through the the `B` port of `Q2` and keep the voltage between the `VOUT` and the `B` port of `Q2`. `R7` is a large resistance of 10 KΩ, which is used to reduce I_B of `Q2`, while maintaining voltage of `C` port of `Q1` and `B` port of `Q2` consistent, and `R4` is used to protect the circuit and keep the circuit stable.

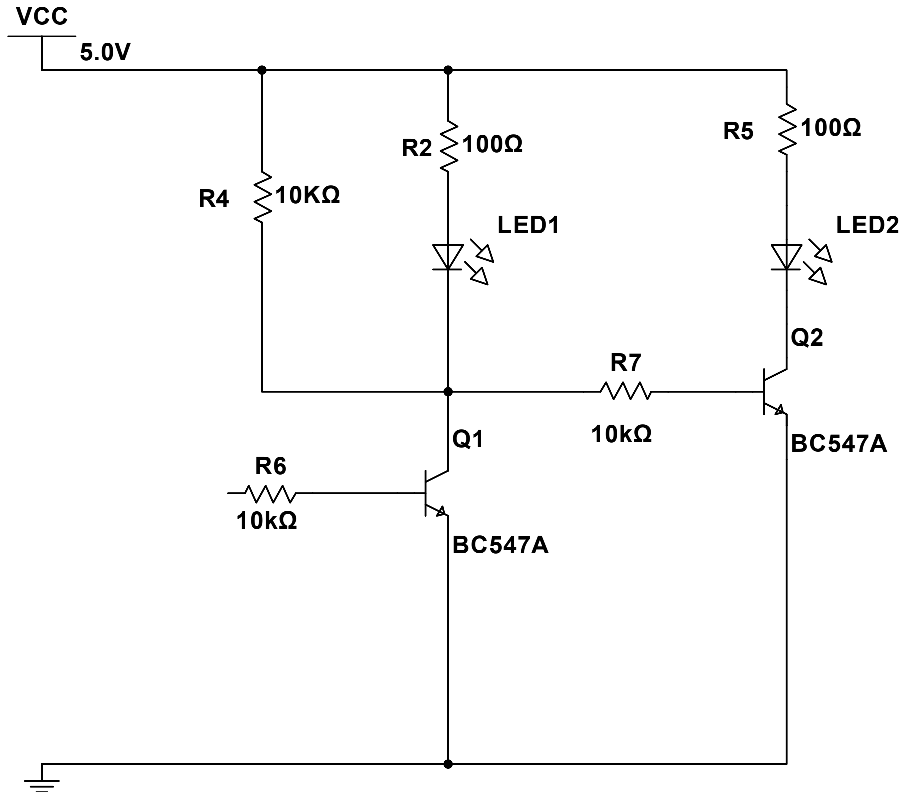

Figure 9: LED Module

Then start to analyze the circuit operation mode. First, the output from Op-Amp can only be high level(3.5 V) or low level(0 V). Therefore, we first assume that the left end through `R6` is high level, and then I_{R6} is almost 0, $V_D \approx V_C = V_{\mathrm{Oh}} \approx 3.5\,\mathrm{V}$, so the `CE` port of `Q1` are connected (here we assume that BJT is ideal), and $V_E = V_{GND} = 0$. Due to $I_{R_6} \approx I_{R_4} \approx 0$, so $V_{BE} \approx 0$, the `CE` of `Q2` is not conductive, so the equivalent circuit can be drawn. It is easy to see that only `LED1` is conductive at this time. At the same time, considering that the LED is a red LED, the circuit can be simplified as:

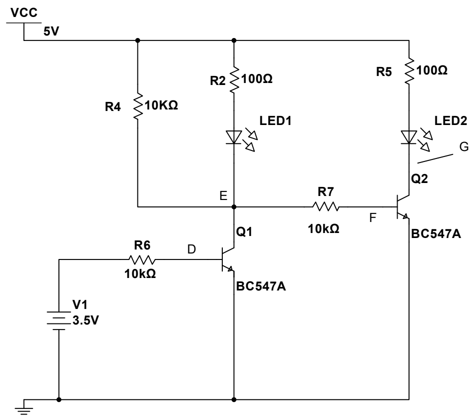

Figure 10: $V_D = 3.5V$

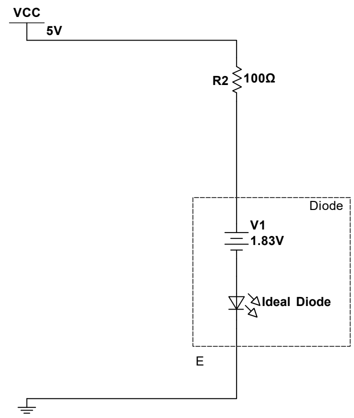

Figure 11: Equivalent Circuit for High-level

It is easy to calculate that the current at this time is approximately equal to [2.4]:

$$I_{eq} = \frac{5\,\mathrm{V} - 1.83\,\mathrm{V}}{100\,\Omega} = 31.7\,\mathrm{mA} > 20\,\mathrm{mA} \tag{2.4}$$

At this time, `LED1` is on and the current is sufficient to illuminate At this time, the corresponding warning light(red LED) is on when the temperature exceeds the set value.

At this time, we analyze the output low level at `C`, and the same $V_C = V_D$, at this time, for `Q1`, $V_{BE} \approx 0$, BC not conducting.

At this time, `R4` and `R2`, `LED1` are connected in parallel, and the excessive resistance of `R4` can be ignored The circuit diagram is as follows. At this time, since `R7` is a large resistance, the current through `R2` and `LED1` is very small. Therefore, it can obtained that $V_F = 0$, so at this time,for `Q1`, $V_{VE} \approx 5\,\mathrm{V} > 0.7\,\mathrm{V}$, `CE` is on, and considering that `LED2` is a green LED with turn on voltage of $2.13\,\mathrm{V}$, the circuit diagram can be equivalent to the following:

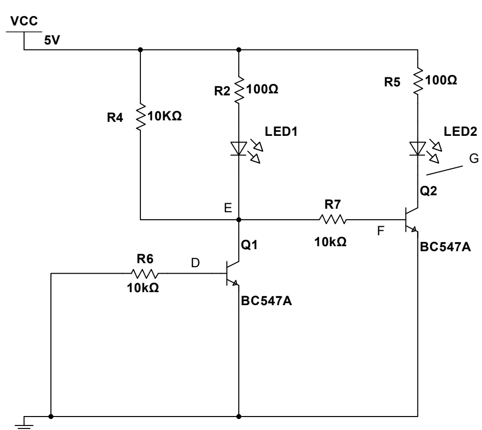

Figure 12: $V_D = 0V$

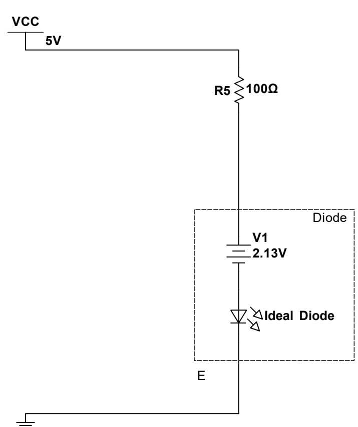

Figure 13: Equivalent Circuit for Low-level

Here we can obtain the current flow through LED2 as [2.5]:

$$I_{eq} = \frac{5\,\mathrm{V} - 2.13\,\mathrm{V}}{100\,\Omega} = 28.70\,\mathrm{mA} > 20\,\mathrm{mA} \tag{2.5}$$

At this time, LED2 is on and the current is sufficient to illuminate At this time, the corresponding green light(LED2) turns on when the temperature does not exceed the set value We can add a regulated voltage to the module , perform DC sweep on it, adjust the voltage from 0 V to 3.5 V, set the increment to 0.1, and perform simulation to output the current through R2 and R5, that is, the current through LED1 and LED2, so as to reflect the circuit conduction state. The image is as follows:

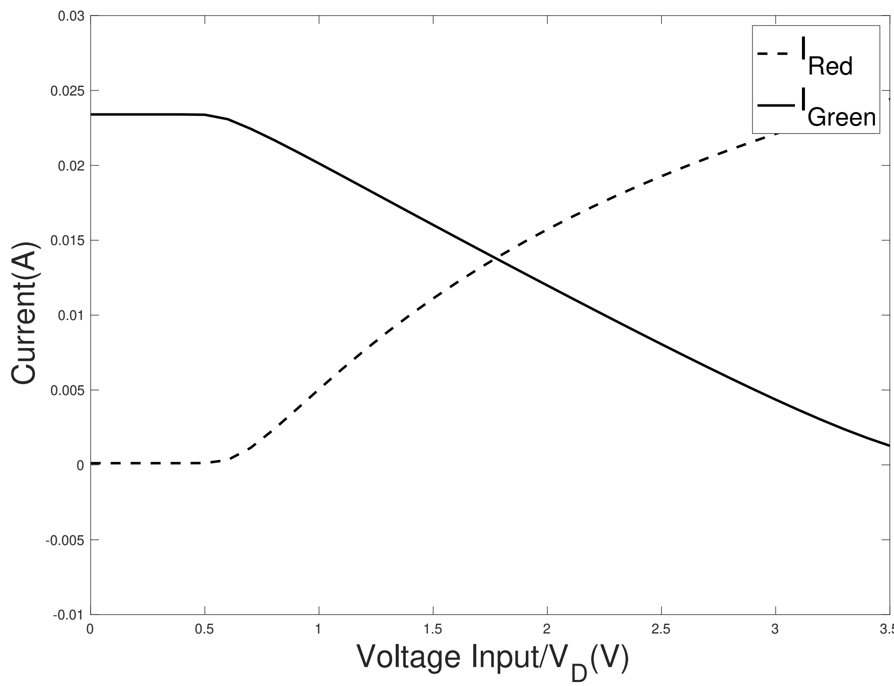

Figure 14: I_{RED} and I_{GREEN}

Result is as the same as we expected in analysis.

2.2.3 Total Simulation

We combine the two modules, connect the VOUT port of Op-Amp with the switch port of LED control module, and connect them to the voltage of 5 V. At this time, we need to use the state when the sliding rheostat is set at 40% as an example. At this time, through the previous description, at this time, $V_{OUT} = 0\,\mathrm{V}$ below 60 °C. At this time, in the LED control module, LED2 is on. When the temperature exceeds 60 °C, VOUT outputs a high level of 3.5 V, and LED2 in the LED control module is turned on, we use Multisim for Temperature Sweep analysis to linearly increase the temperature from 2 °C to 100 °C, and the sampling points are still 100, so that it outputs I_{R2} and I_{R_5} is used to reflect the on state of the circuit.Result below

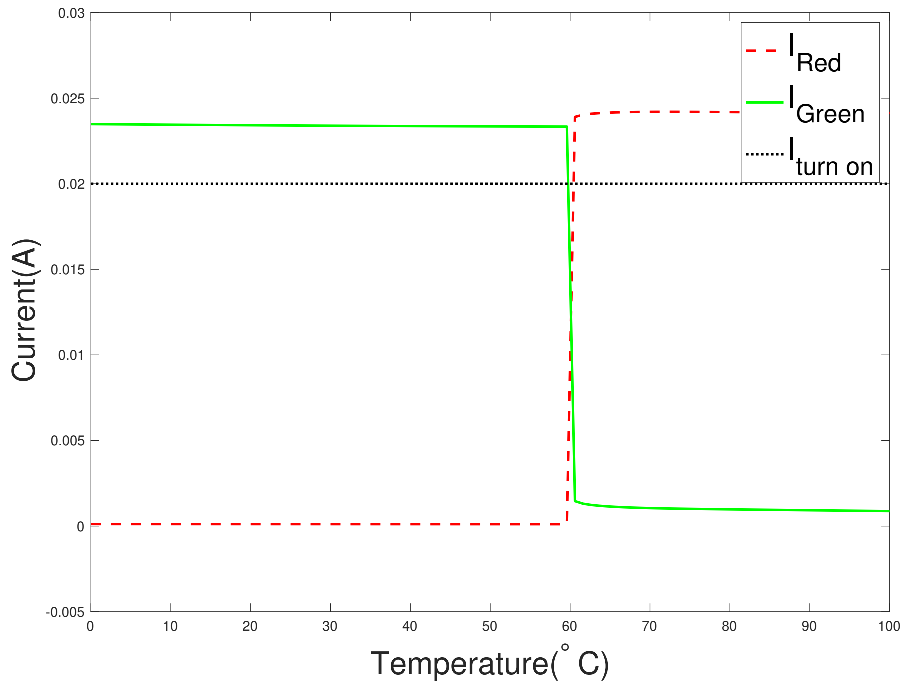

Figure 15: I_{RED} and I_{GREEN} when temperature sweep

It can be seen from our analysis that the green light is always on when the temperature is less than 60 °C. When the temperature is close to 60 °C, the two temperatures quickly jump off to the other state. When the temperature exceeds 60 °C, the red light is on.

3 Furthermore

Through this circuit, people can easily set the temperature and monitor the circuit, which greatly facilitates and improves the quality of life and safety.

At the same time, we can make basic adjustments to the circuit to make it more in line with the needs of life:

3.1 Battery as power scheme

The operating voltage of the circuit is 5 V, but in life, the voltage of the dry battery is often 1.5 V. Therefore, we can convert the 6 V voltage of the four dry batteries into a stable 5 V voltage by adding a voltage stabilizing diode or a voltage stabilizing LDO in the circuit, and then input the circuit to facilitate people's use The following figure shows the voltage stabilizing circuit made by zener-diode [16] and its output stable voltage, which is stable at about 5.00 V.

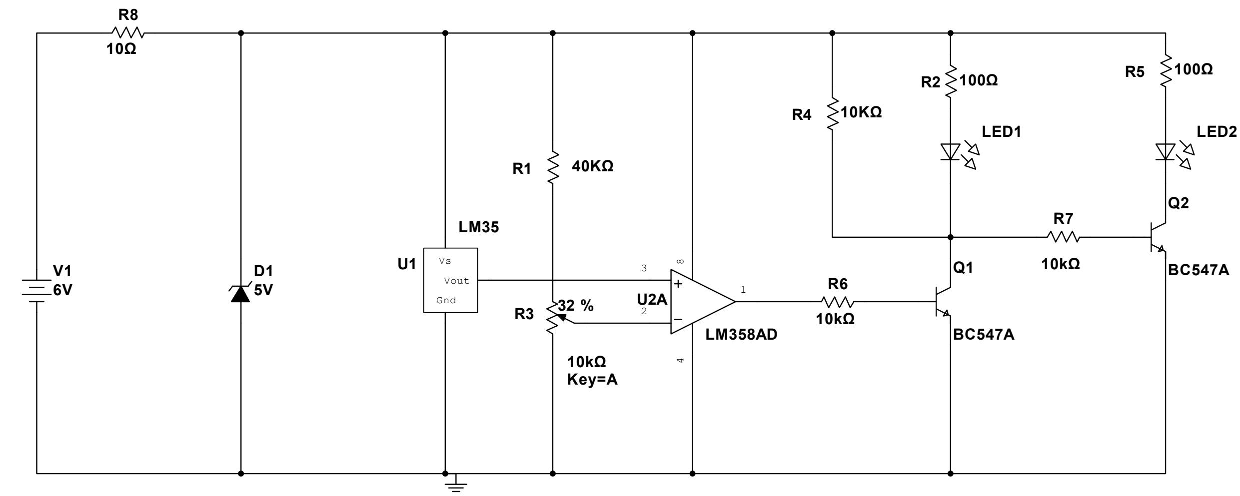

Figure 16: Voltage Reduction with 5V-Zener-diode

The zener diode is not very suitable. It can be seen from the figure that the resistance connecting the zener diode will produce additional power consumption.

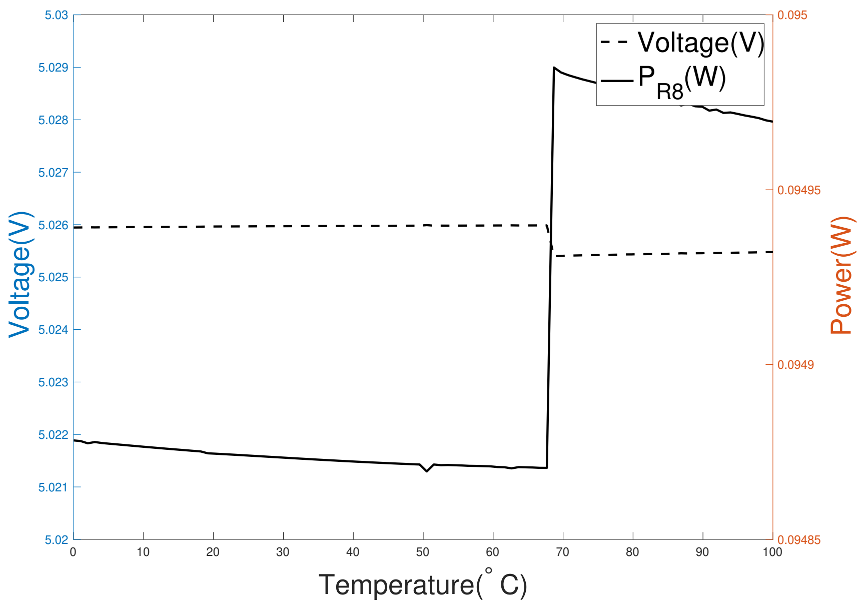

Figure 17: Voltage after reduction and Power Loss on R8

3.2 Add other device for better use

Some results of temperature switch can be used as switches to control other equipment, such as connecting electrical appliances with temperature regulation function, such as water heater and fan, so as to realize negative feedback regulation of temperature and maintain constant temperature or connect it to the buzzer [18] to indicate a stronger warning.

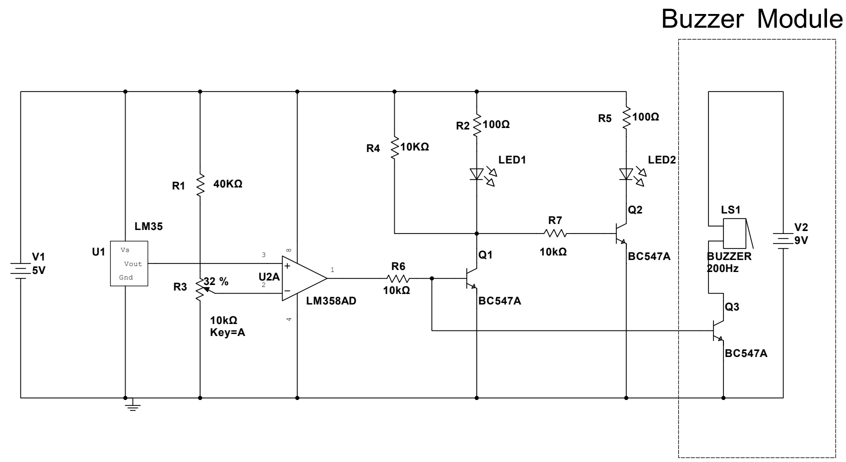

Figure 18: Add Buzzer module

3.3 For low-emperature use

In some application scenarios, the operating temperature may be lower, but because the connection mode of `LM35` sensor in the circuit is Basic Contigrade Temperature Sensor [1], we can realize the full range measurement of `LM35` by adjusting the wiring mode to monitor the environment below 0 °C [19].

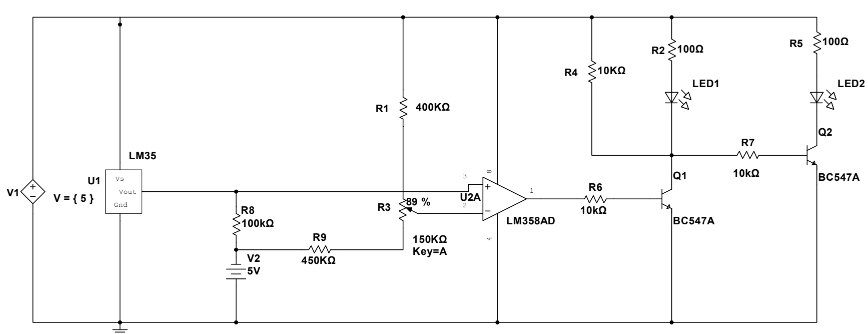

Figure 19: Full-Range Version Temperature Controlled LED Circuit

.The potentiometer can be adjusted to adjust the threshold temperature from 50 °C to 100 °C, and the relationship [20] between the corresponding value and percentage is

$$T_{\text{thresold}} = (-50 + 150(1 - p))^{\circ}\text{C} \tag{3.1}$$

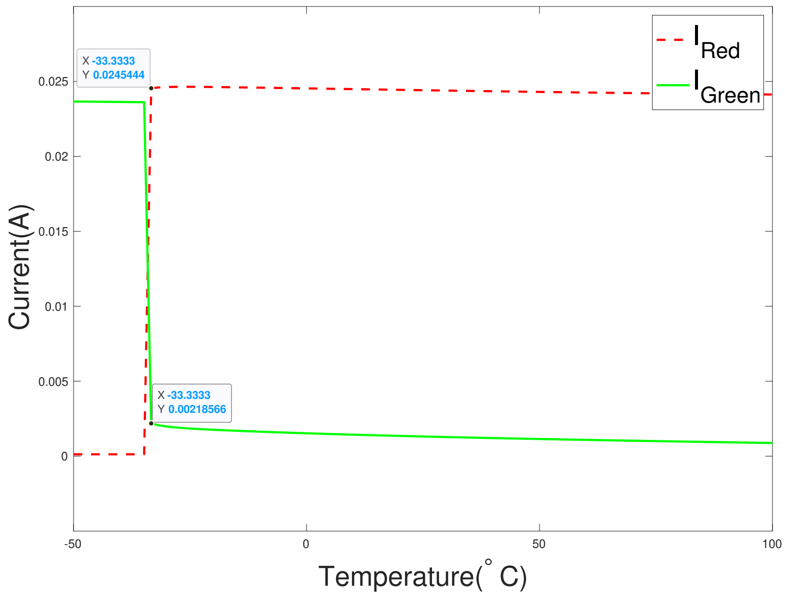

Figure 20: Thresold Temperature below 0°C in Full range measurement

3.4 Range-monitoring System

In daily life, we often need a fixed temperature range rather than a single temperature threshold. Therefore, we can design the following two circuits: 2-light temperature control range LED and 3-light temperature control range LED.People can set the upper and lower temperature limits by adjusting two potentiometers.

1. In the 2 light version [21], as long as the temperature exceeds the temperature range corresponding to the potentiometers, the red light(`LED1`) will be turned on and the green light(`LED2`) will be turned off.
2. In the 3 light version [23], when the temperature is higher than the set maximum temperature, the high temperature warning light (red `LED2`) will light up, and when the temperature is lower than the set minimum temperature, the low temperature warning light (blue `LED1`) will light up.
3. When the temperature is within the set range, the green light(`LED3`) are on.

Here set the `Tmin`(`R8`) and `Tmax`(`R3`),then we can obtaint the diagram of the current flow through the LED lights with 2 light version and 3 light version,respectively.

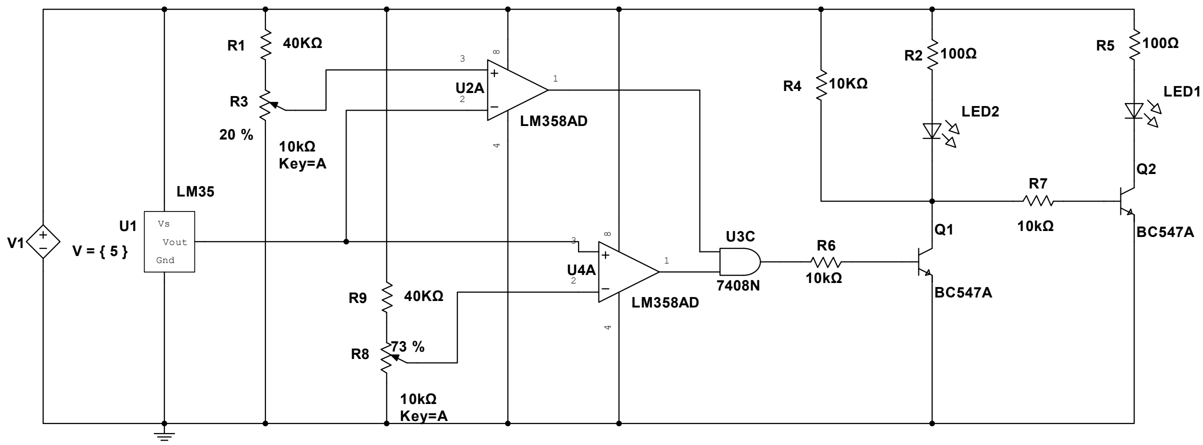

Figure 21: 2-light temperature control range LED

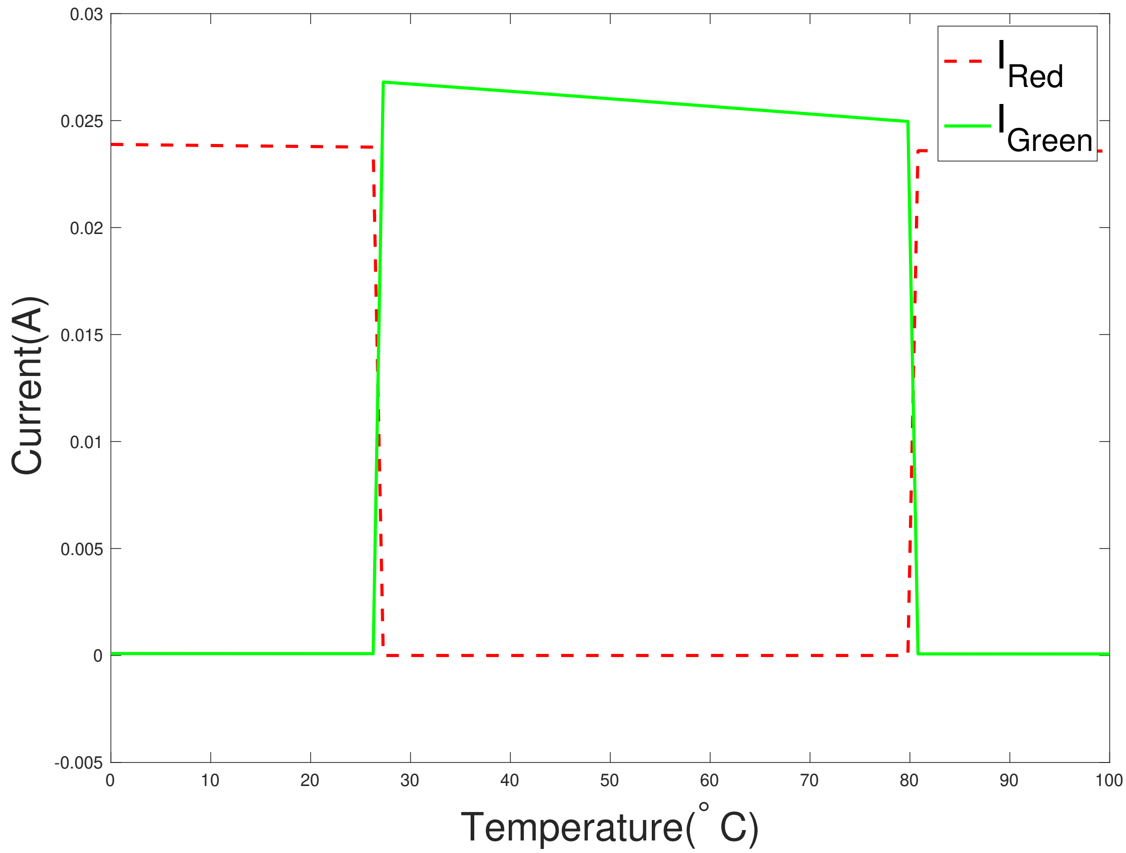

Figure 22: Current pass LED in 2-light temperature control range LED

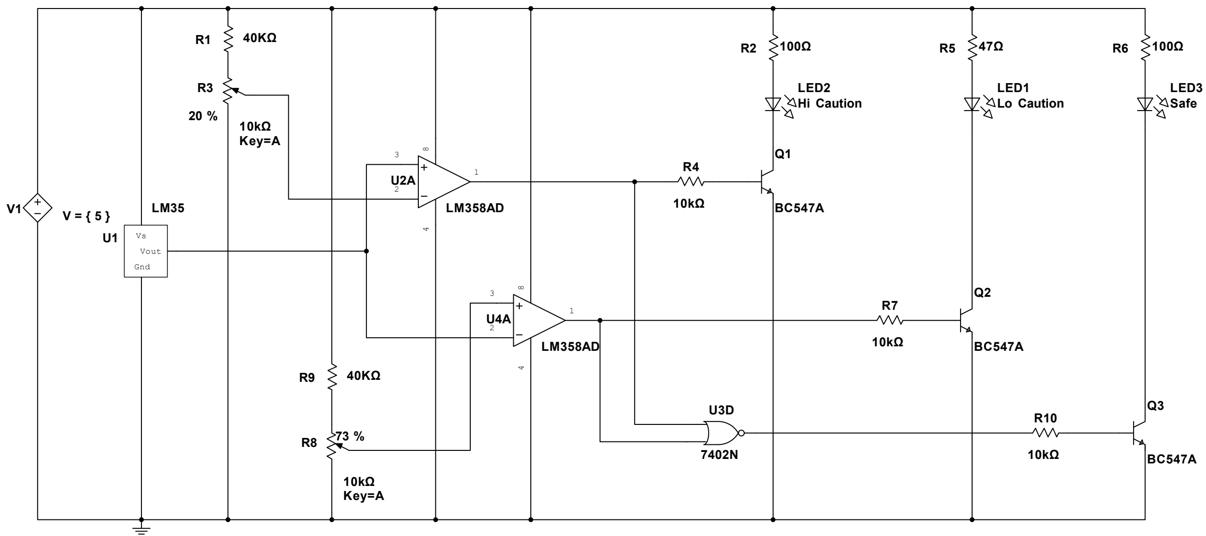

Figure 23: 3-light temperature control range LED

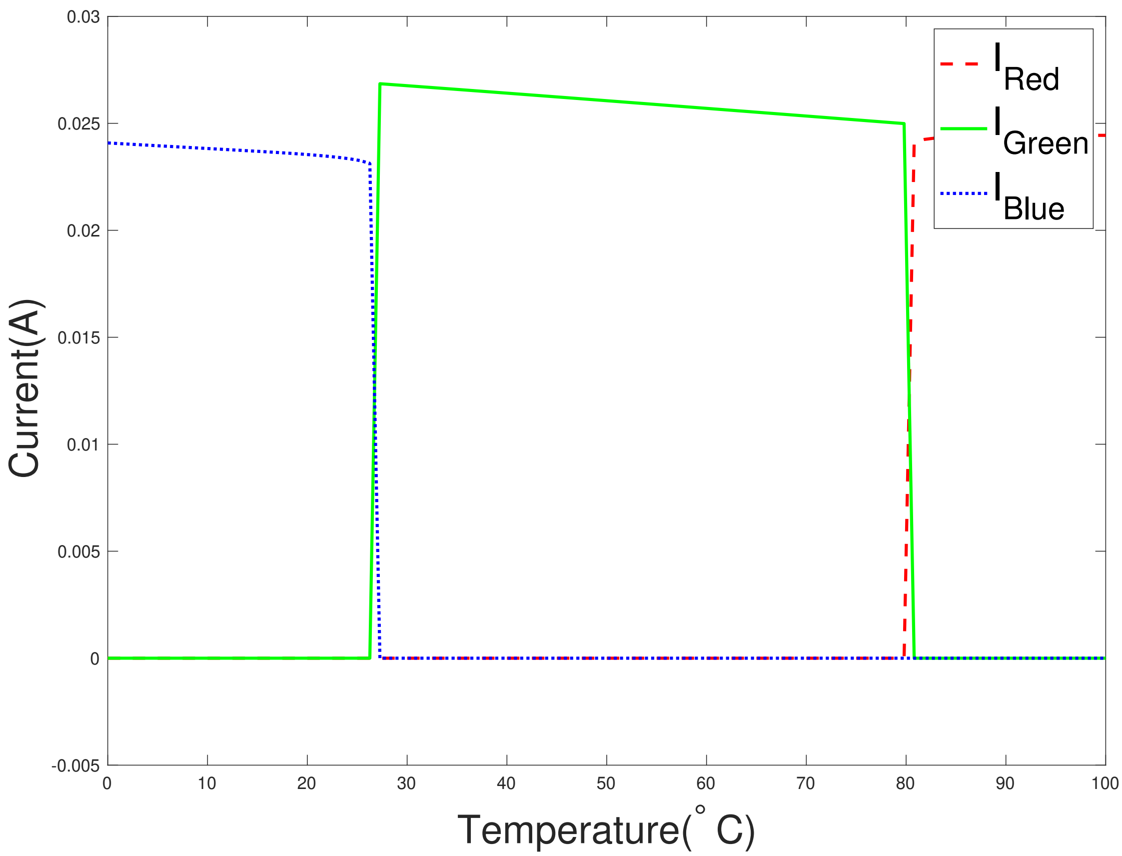

Figure 24: Current pass LED in 3-light temperature control range LED

References

[1] *LM35 Precision Centigrade Temperature Sensors*, Texas Intrument, 2011, rev. H. [Online]. Available: https://www.ti.com/product/LM35?qgpn=lm35

[2] *Industry-Standard Dual Operational Amplifiers(LM358AD)*, Texas Intrument, 2021, rev. H. [Online]. Available: https://www.ti.com/product/LM358A

[3] *BC547/BC547A/BC547B/BC547C*, onsemi, 2021, rev. 8. [Online]. Available: https://www.onsemi.com/products/discrete-power-modules/general-purpose-and-low-vcesat-transistors/bc547a

A Attached File

The output data, diagram, Multisim file, plot program attached in Github(https://git.io/JyctL).

B Full Diagram