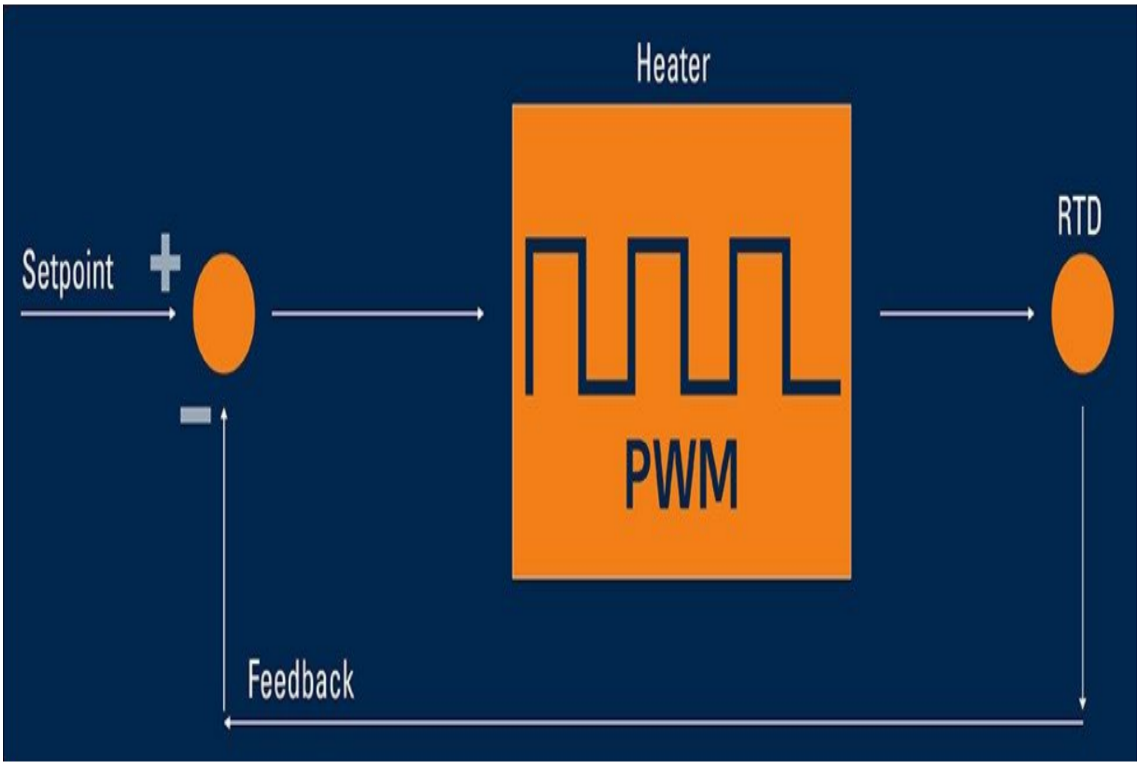
Indian Institute of Technology Bombay
Department of Electrical Engineering

EDL Report-Temperature Control Using PWM



Course: EE 344: Electronic Design Lab

Project Group No: MON-KT-3-2

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Project Title: Temperature Controller using heating element and PWM control

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Abstract:

Temperature control and stability are crucial for almost all manufacturing industries- pharmaceutical, chemical, food, etc. Temperature is the most critical parameter to be controlled in any process that is needed to be performed in a temperature-sensitive environment; all biological processes in our body are pivoted on temperature control. Through this project, we aim to design an optimum temperature controller and use it along with a heating element as a water heater. We aim to achieve a control system design based on negative feedback being fed into a PWM circuit that controls the heating element.

Goal: Temperature control(40oC -50oC) of a DC heater element(50W Water Heater with 2min to heat 50 mL of water) using negative feedback control and Pulse Width Modulator(PWM). Analysis of the temperature sensor characteristics to get an accurate temperature control.Design a means to vary the temperature in the range mentioned above and deliver a prototype in the form of PCB design of the complete set up.

Contents

1 Introduction

The project involves Temperature control of a Heating element using PWM. The Given system is a negative feedback control loop that helps in maintaining the temperature. The output of the DC heater element is fed into the sensor to measure the temperature effectively.The difference in temperature/Desired Voltage level is amplified and fed into the PWM to rectify its duty cycle corresponding to the error .The Mosfet Gate driver in turn drives the DC heater element.

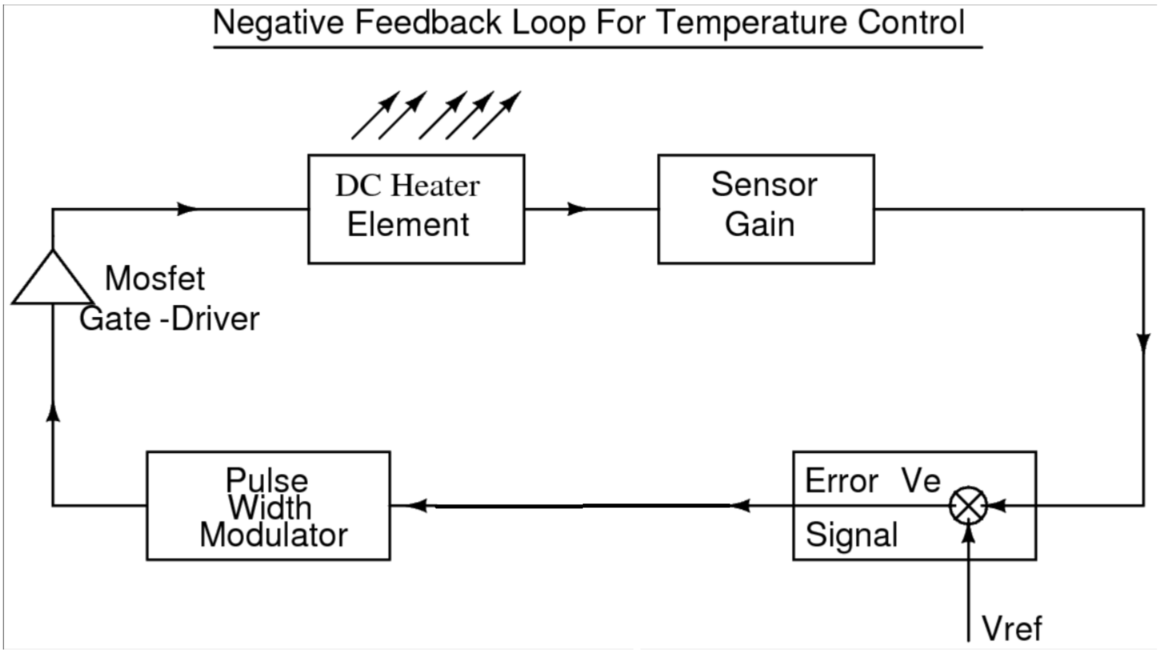


Figure 1: Block Diagram

2 System Overview

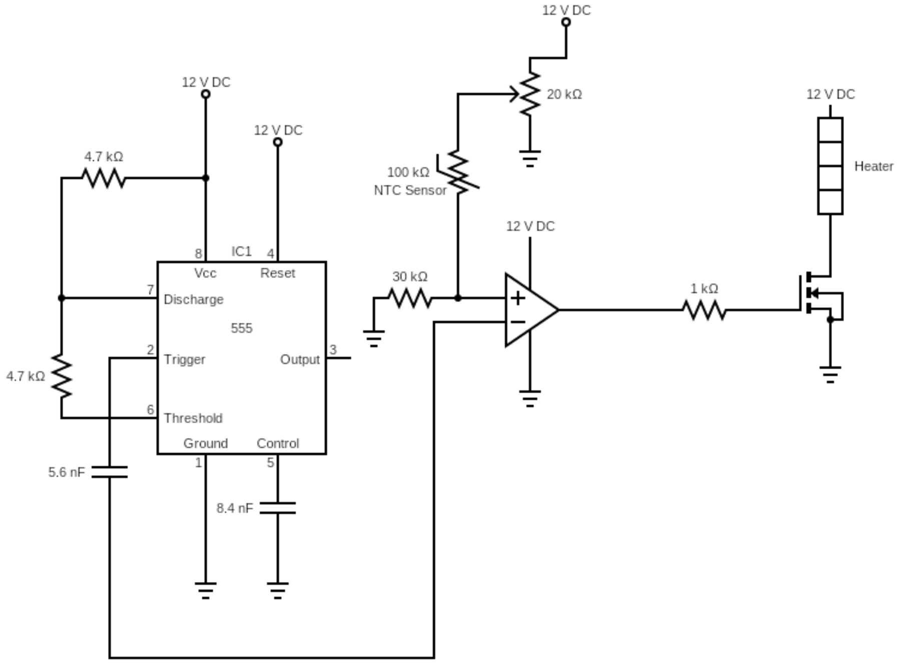


Figure 2: Circuit Diagram-LM555 Timer(PWM) , UA741(Error Amplifier) , Heater(5 Ω) , NTC Sensor

3 Project Implementation

3.1 NTC Thermistor

$$B\left(\frac{40°C}{25°C}\right) = \frac{(40+273.15)(25+273.15)}{40-25}\ln\left(\frac{100k}{55k}\right) = 6224.37\ln(1.818) = 3720$$
$$R_T = 100ke^{-B\left(\frac{1}{T_0}-\frac{1}{T}\right)} \tag{1}$$

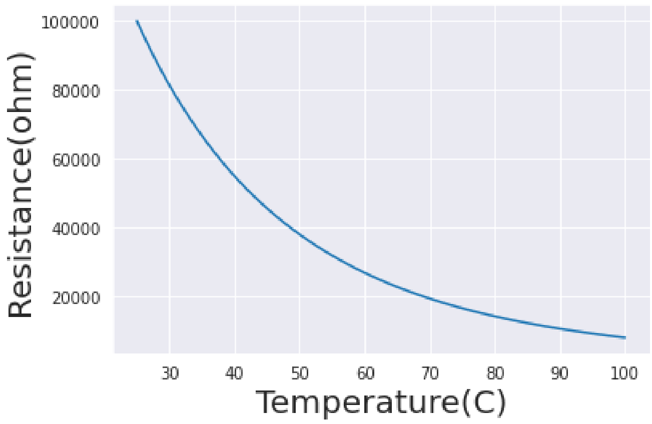


Figure 3: NTC Resistance vs Temperature Realation Graph

3.2 PWM Frequency

In the circuit, oscillator frequency follows the formula
$Rise\ time : t1 = 0.693(R_1 + R_2)C$
$Fall\ time : t2 = 0.693R_2.C$
$T = t1 + t2 = 0.693(R_1 + 2R_2)C$
$f = \frac{1.44}{(R_1+2R_2)C} = 12.644\ kHz$

3.3 PWM Duty Cycle

1. On initial power-up, the flip-flop is RESET (and hence the output of the timer is low). As a result, the discharge transistor (which is connected to Q') is driven to saturation. The timing circuit's capacitor C is connected to Pin 7 of the IC 555 and will discharge through the transistor. At this point, the timer's output is low. The trigger voltage is represented by the voltage across the capacitor.

2. So, while discharging, if the capacitor voltage falls below 1/3 VCC, the reference voltage used to trigger the comparator (comparator 2), the output of comparator 2 becomes high. This will SET the flip-flop, causing the timer's output at pin 3 to become HIGH.

3. The transistor will be turned off if its output is too high. As a result, the capacitor C begins to charge via the resistors R1 and R2. The capacitor voltage is now the same as the threshold voltage (as pin 6 is connected to the capacitor resistor junction). During charging, the capacitor voltage increases exponentially towards VCC, and when it reaches 2/3 VCC, the reference voltage to the threshold comparator (comparator 1), its output becomes high.

4. As a result, the flip-flop has been RESET. The timer's output is set to LOW. This low output will turn on the transistor, providing a discharge path to the capacitor once more. As a result, the capacitor C will discharge via the resistor R2. As a result, the cycle continues.

5. As a result, when the capacitor charges, the voltage across it rises exponentially, and the output voltage at pin 3 is high. Similarly, when the capacitor discharges, the voltage across the capacitor falls exponentially, resulting in a low output voltage at pin 3. The output waveform is a series of

rectangular pulses. In the astable mode, the waveforms of capacitor voltage and output are shown below.

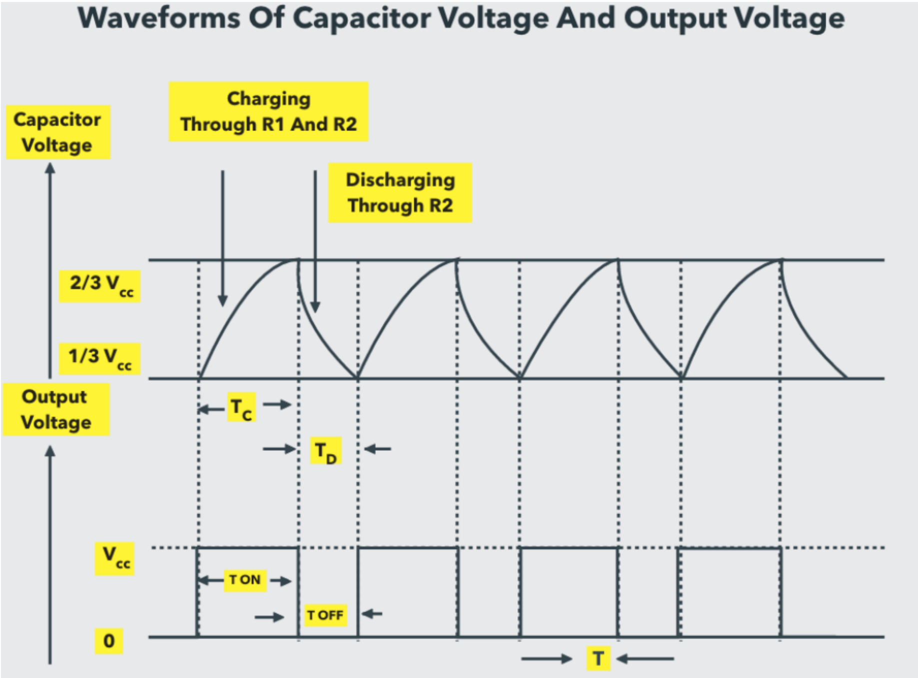


Figure 4: Astable Multivibrator Source

3.4 Water Heater Specifications

$$\mathrm{Q} = \mathrm{m} \cdot \mathrm{C} \cdot (\boldsymbol{\theta}_2 - \boldsymbol{\theta}_{\mathbf{1}})$$

$$\rho = \frac{\text{mass}}{\text{Volume}}$$

$Q =$ efficiency. Power. Time $= \rho$.Volume. C. $\Delta\theta$ Volume $= 50$ mL $= 5.10^{-5}$ m^3, $\rho = 1000$ kg m^{-3}, C $=$ 4184JkgK^{-1}, Power $= 40W$

$$\text{Time } = \frac{1000.5 \cdot 10^{-5}.4184}{40.ef\text{ ficiency}} = \frac{209.\Delta\theta}{40.ef\text{ ficiency}} = \frac{5.2.\Delta\theta}{\text{efficiency}}$$

Let efficiency $= 75\% = 0.75$

$$\text{Time } = 7\Delta\theta = 7.20 = 140s \approx 2\,\text{min}$$

4 specifications

4.1 Temperature Sensor

NTC Thermistor accuracy temperature sensor 10K 1% 3950 Waterproof probe

1. Stainless steel sheath and waterproof measurement range: -20 to 105 C
2. Length of wire : 1 m
3. Size of probe: 5 x 25 mm Output 2 wires
4. Type: NTC 10k 1
5. LINK Resistance to temperature conversion table LINK B-constant : 3380K -/+ 1
6. Typical Dissipation Constant: 5mW/ C
7. Probe insulation: greater 100MOhm
8. Peak Voltage sustain time: 2 seconds, AC1800V 1mA 2 seconds
9. Stress sustain: 9.8N (1kgF) for 1 minute no deformation

4.2 MOSFET Gate driver-IRFZ44N

Power MOSFET used a switch to control the heater element

Number of Channels	1 Channel
Transistor Polarity	P-Channel
Drain-Source Breakdown Voltage (Vds)	-100 V
Continuous Drain Current (Id)	-23 A
Drain-Source Resistance (Rds On)	0.1170Hms
Gate-Source Voltage (Vgs)	20 V
Gate Charge (Qg)	97nC
Operating Temperature Range	$-55 - 175°C$
Power Dissipation (Pd)	140 W
Number of Channels	1Channel

4.3 Heating Element-Cartridge Water Heater

Voltage(V)	12
Power (W)	40
Lead Length (mm)	20
Lead Diameter(mm)	6
Wire Length (cm)	100
Lead Material	Stainless Steel

(a) NTC thermistor

(b) NMOS

(c) Cartridge heater

5 Experimental setup

The above figure has a glass that contains 50mL of water for heating purpose which has a cartridge heater (in red) and an NTC sensor(in white) dipped inside the glass.Varying the 20K potentiometer results in changing the desired temperature .We calibrate the pot by taking observations at different resistance across the pot and noting the stabilized resistance value of the NTC sensor.

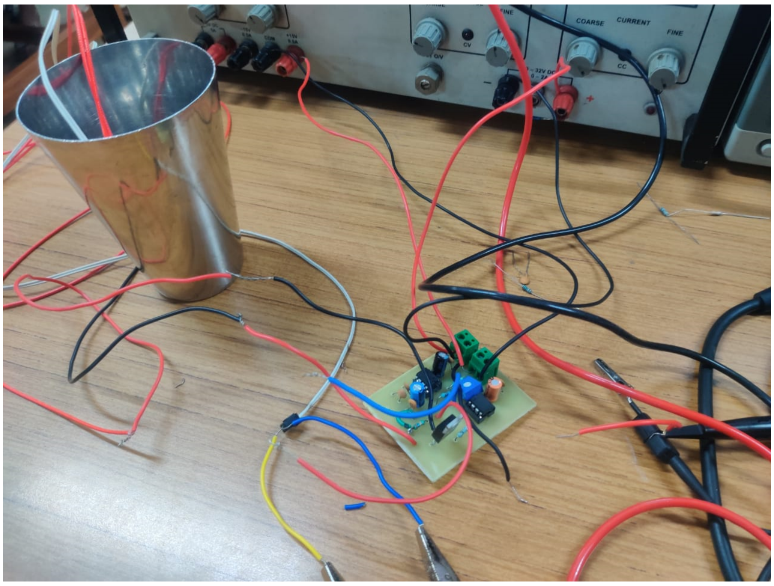


Figure 6: Setup

6 Experiments and Results

As the time progresses mean of the voltage across heater decreases as there is negative feedback which reduces the error between reference and output ,hence the duty cycle keeps on reducing as the water keeps on heating.Finally the output stabilized at mean voltage of 4.7V which implies Resistance of NTC=55kohm which further implies Temperature of 40C.

Figure 7: mean=5.91V

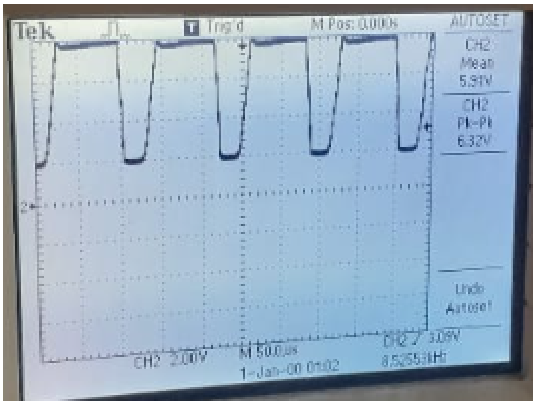


Figure 8: mean=5.95V

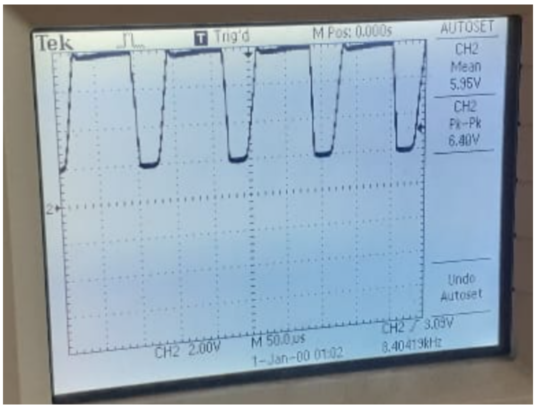
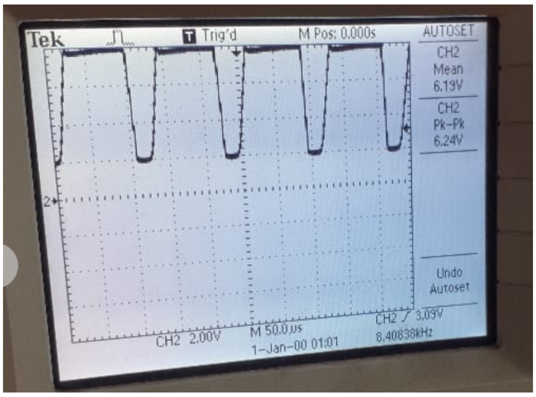


Figure 9: 6.19V



7 Experimental display of results using arduino

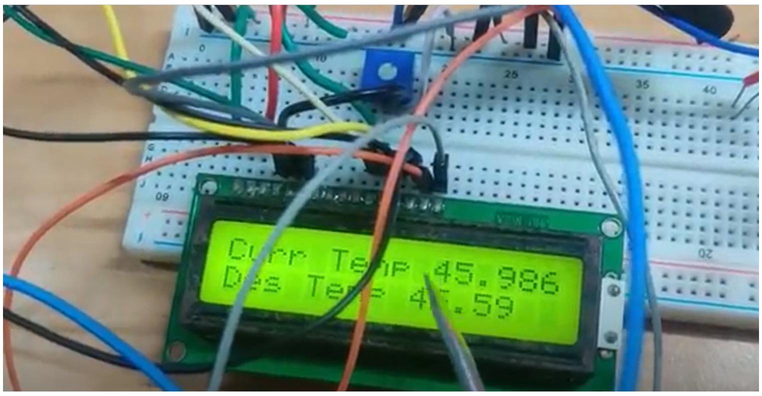


Figure 10: Regulating the temperature at 45^oC

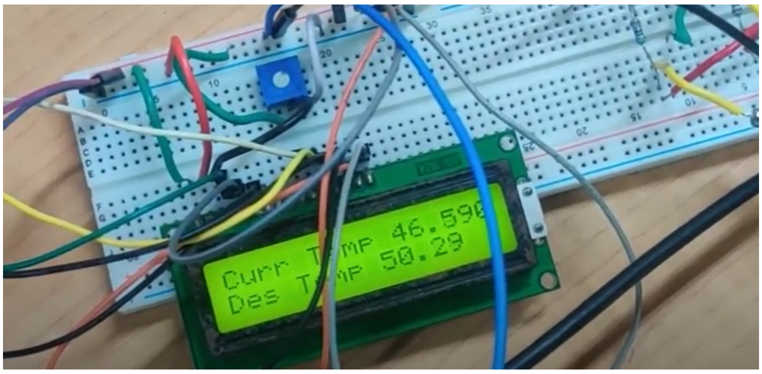


Figure 11: Setting the temperature at 50^oC

Figure 12: Temperature set at 50^oC

8 PCB

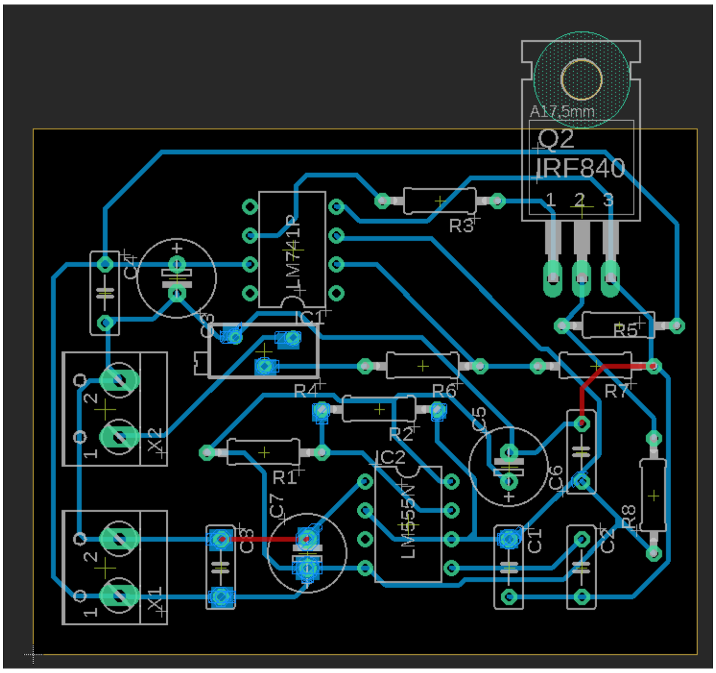


Figure 13: PCB layout Eagle

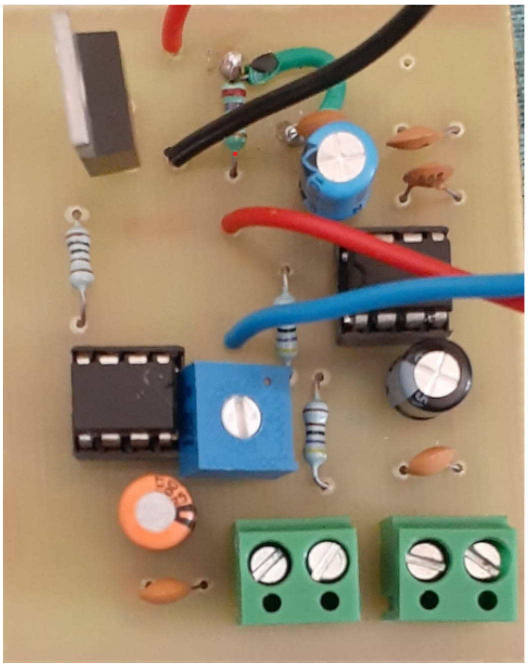


Figure 14: Soldered PCB

9 Simulation Results

From the below two simulation graphs it is clear that as time progresses, water gets heated as a result the resistance of the sensor keeps on decreasing and the duty cycle keeps on decreasing. For Resistance =25ohm simulation the duty cycle is greater than 50% whereas for Resistance=10ohm(decreasing resistance with time) simulation the duty cycle is less than 50%.

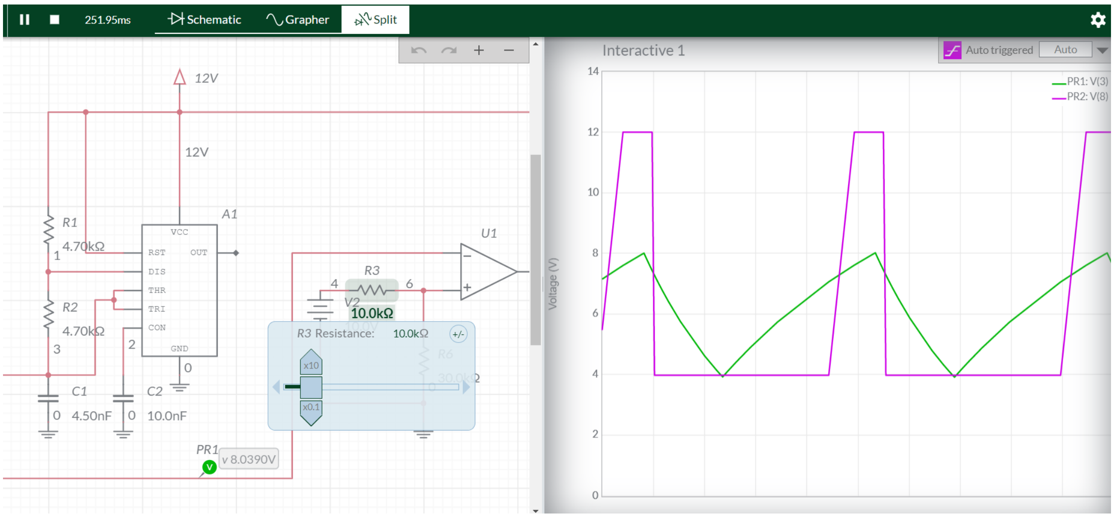


Figure 15: Resistor of sensor=$10k\Omega$

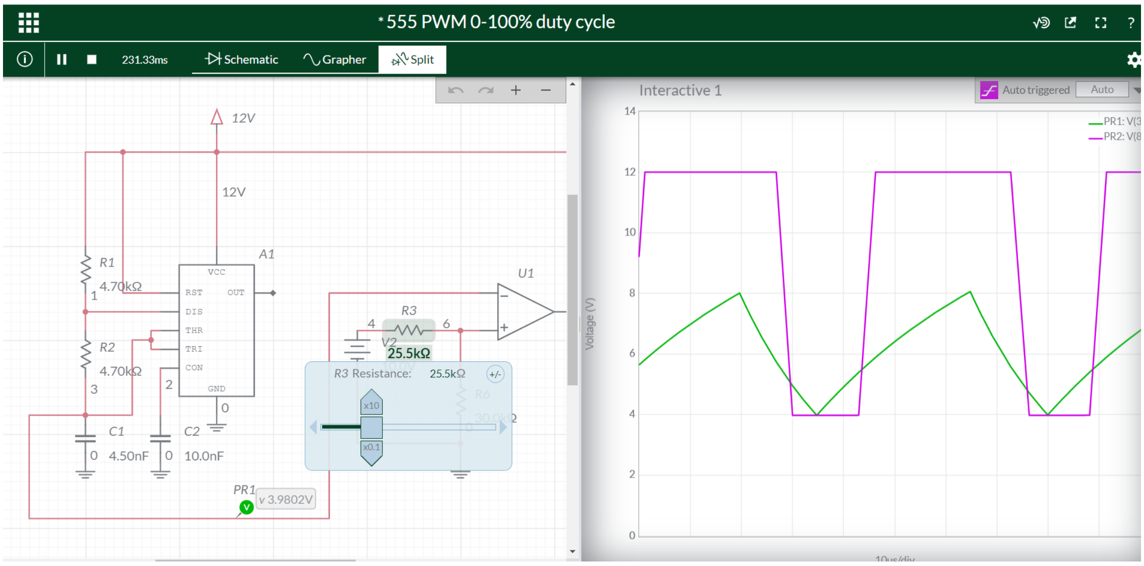


Figure 16: Resistor of sensor=$25.5k\Omega$

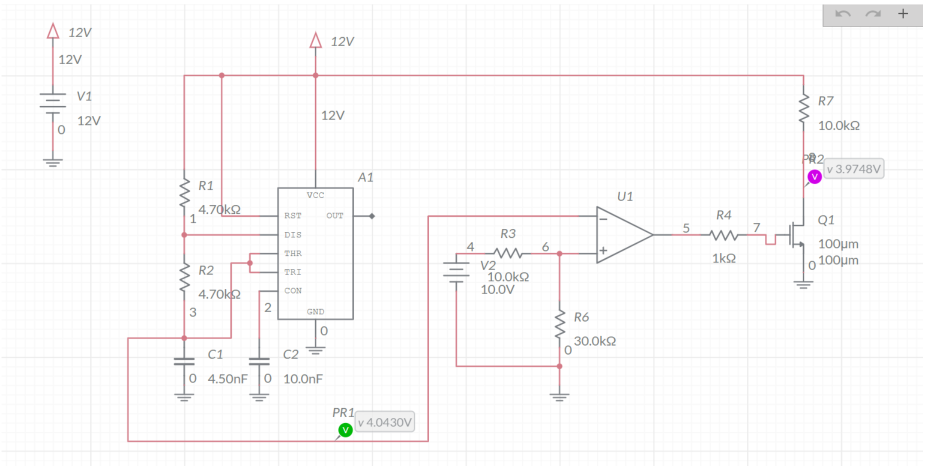


Figure 17: Simulation Circuit Diagram

10 Calibration

Varied the reference voltage from 9V to 15V in steps of approximately 0.5 and measured the corresponding settling temperatures.As seen from the graph the trend is linear.The line plotted is the best fit line through the points.

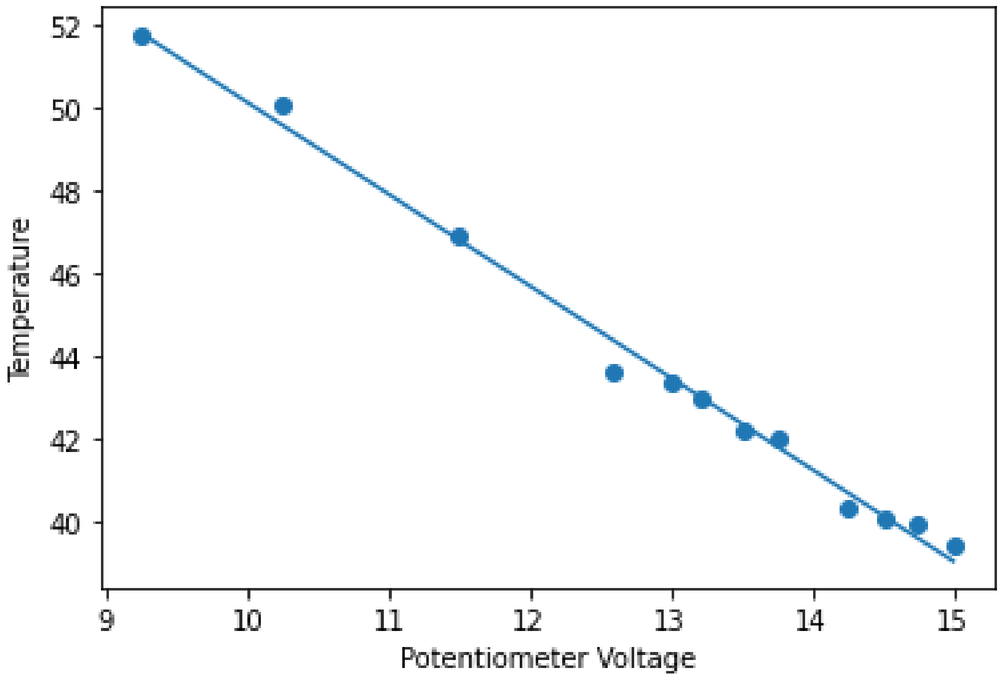


Figure 18: Temperature vs Reference Voltage Calibration

11 Bill Of Materials

1. Tesseract ATC Semitec 104GT-2 300 Degree (1m Cable) Thermistor High Temperature Sensor for 3D Printer (Pre-Wired with Teflon Insulated Wiring) - Rs199
2. 3D Innovations 12V 40W Cartridge Heater wire for Extruder: 1 meter long wire (Quantity:2 pcs) - Rs310

Appendices

11.1 Arduino PseudoCode

```
pot=(pot)*0.0049*4.45;
ntc=(ntc)*0.0049*4.15;
V_ntc=pot-ntc;
I_ntc=ntc/26.5;
R_ntc=V_ntc/I_ntc;
Tdes=-2.218*pot+72.7337;
T=1/(1/298.15+(log(R_ntc/100)/3720))-273.15;
```

11.2 Calibration PseudoCode

```
a, b = numpy.polyfit(y, temp, 1)
plt.scatter(y, temp)
z=numpy.add(numpy.multiply(a,y),b)
plt.plot(y,z)
plt.xlabel("Potentiometer Voltage")
plt.ylabel("Temperature")
```

References

[1] Available : url ,Accessed on April 10,2022

[2] Available :url , Accessed on April 10,2022

12 Questions Asked During EDL Project Demo

Q1)As seen in the Figures 7,8,9 we have the minimum value of the output as 2V ($\geq 0V$).Give Reason

Ans-Since the Vgs-Vth>Vds the NMOS is operating in linear region.Hence there is a linear resistance in series with the external drain resistance.Hence a resistor divider is formed with Rds On resistance$\approx 1\Omega$. Heater is of 5Ω specification hence potential across NMOS=$\frac{V_{dd}.1}{(1+5)} = 12/6 \approx 2V$

Q2)Reason for triangular peaks for lower duty cycle

Ans-The duty cycle is the ratio of a pulse width to the total cycle time $\frac{\tau}{T}$. Every MOS transistor needs an on time and an off time where the device is transferred from the off state to the on state and vice verse. In the on state there is the on power losses which is Ion.Von and the OFF power loss which is $I_{off}.V_{off}$.

The on and the off power , the switching power is $\frac{I_{on}.V_{off}}{2}$.The off power is normally neglected.

Then the total power energy loss in one cycle=$V_{on}.I_{on}.T_{on} + \frac{I_{on}.V_{off}T_{sw}}{2}$,

where T_{sw} is switching on time assumed equal switching off time. For efficient operation the first term must be greater than the second term That is $V_{on}.Ion.Ton > \frac{I_{on}.V_{off}.T_{sw}}{2}$, The power consumption during the on period which is the useful period must be greater that losses at the switching transitions which is not useful in the sense of operation of a switch.

It follows that $V_{on}.T_{on} > V_{off}.T_{sw}/2,\ or\ 2V_{on}/V_{off} > T_{sw}/T_{on}$,the duty cycle is $\frac{(Ton+2Tsw)}{T}$.

As seen from the above duty cycle expression $D = \frac{(Ton+2Tsw)}{T}$,for NMOS to operate we have $D > \frac{2T_{sw}}{T} \geq 0$ hence it tapers off like a triangle at lower duty cycle due to switching speed limit of mosfet.