EN2090: Laboratory Practice II
Department of Electronic and Telecommunication Engineering
University of Moratuwa

HOT PLATE TEMPERATURE CONTROLLER

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ABSTRACT

This project is to implement a hot plate temperature controller using the PID controller unit. The project is totally designed using analog electronics-based concepts. PID controller is used to control and maintain the temperature of the hot plate at a desired level. The designed hot plate can be heated up to 200 °C.

PID controller gives the sum of the proportional (P), integral (I) and differential (D) changing error as its output. The error for the PID controller is the difference between the user input temperature and the sensed temperature. Finally, the main circuit controls the average power fed to the hot plate according to the PID output to get the desired temperature level.

The overall project mainly consists of design and testing the circuits, calibration of the sensor and PCB designing. It took nearly one and half months to complete the project.

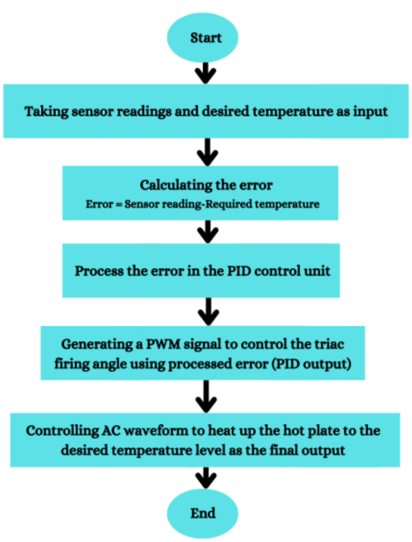
TABLE OF CONTENT

1. INTRODUCTION

Hot plate temperature controller project is an analog electronics-based project. The basic concept here is controlling the temperature of the hot plate by using a PID control unit. Hot plate is powered by a 230V domestic power supply, and its output is to control a 2kW load. The hot plate can be heated up to 200°C.

The project was divided into four main subtasks. They are power supply unit, PID unit, sensor interfacing unit, and firing angle controlling unit. Sensor readings and the user input (required temperature) are the inputs for the hotplate. The difference between these inputs (sensor readings – required temperature) is the error and it is fed to the PID controller unit. The PID unit processes the error and outputs the processed error. A PWM signal is generated according to the processed error to control the triac firing angle. Finally, the circuit outputs an AC voltage to heat the plate to a desired temperature level.

2. METHODOLOGY



3. POWER SUPPLY UNIT

The power supply unit is an important part of the project. The hot plate is used domestic power supply (230V, 50Hz) to power up. But the sensors, op-amps and other sensitive components which have been used in the project use small voltages. Op-amps functioned at 12V and –12V. Sensors which have been used in the project use 5V to function. The task of the power supply unit is to supply required voltages to relevant sections. Capacitors are used to avoid unnecessary noises.
At the beginning of the power supply unit, a center tapped transformer is used to convert the domestic voltage (230 V) to 12V. Then the signal is passed through a bridge rectifier to get a fully rectified signal.

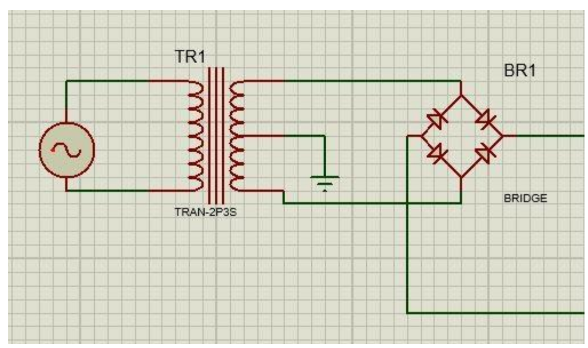


Figure 1:Center tapped transformer and the bridge rectifier

LM7805 IC is used to get 5V DC voltage. Sensor unit uses this 5V voltage.

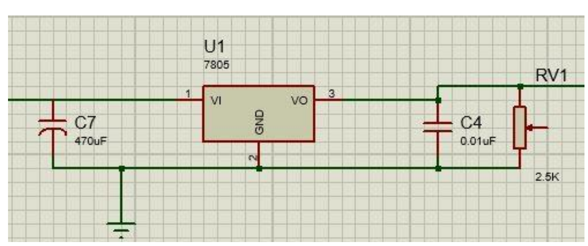


Figure 2:5V regulator circuit

In the PID unit and the firing angle unit, 12V and –12V are used. LM7812 IC is used to get a 12V DC voltage and LM7912 IC is used to get –12V DC voltage.

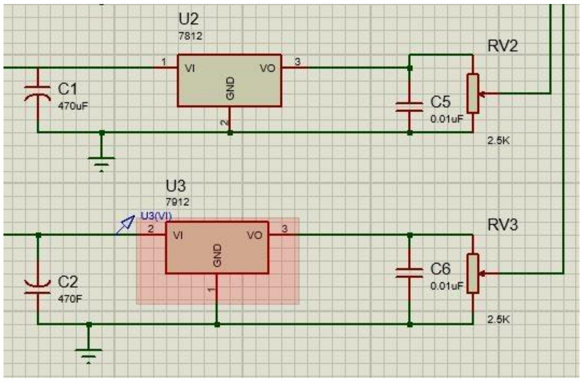


Figure 3:12v and -12V regulator circuit

4. PID CONTROLLER UNIT

The PID Controller is used to control the set temperature at a desired level. A negative feedback mechanism is used with 3 sublevels of the PID controller namely Proportional, Integral and Differential.

The PID Controller is used to control the set temperature at a desired level. A negative feedback mechanism is used with 3 sublevels of the PID controller namely Proportional, Integral and Differential.

- **Proportional term** – This circuit is designed such that the output will be proportional to the error signal. The proportionality constant can be changed using the potentiometer used as a feedback resistor.

- **Integral term** – This term is introduced to make the actual temperature reaching the exact set temperature. The below image was obtained to check the integrator.

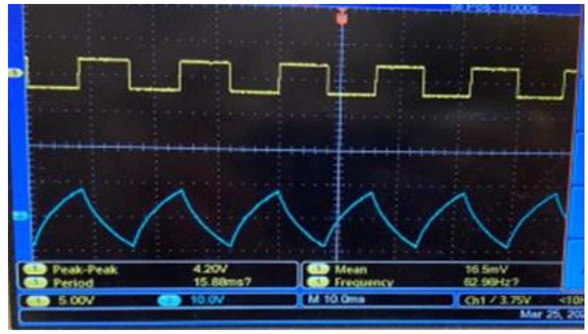


Figure 4:Example for Integral term

- **Differential term** – This term is introduced to minimize the actual temperature fluctuating around the set temperature. The below image will describe the working principle of the differentiator.

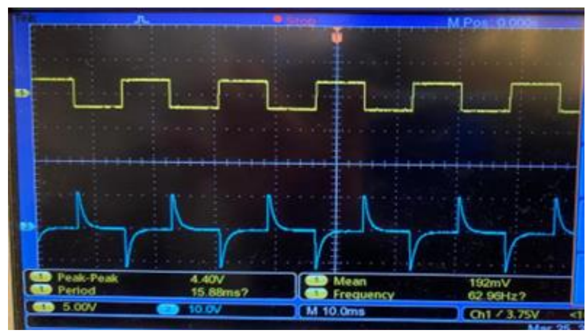


Figure 5:Example for Differential term

The Kp (proportional constant), Kd (differential constant) and Ki (integral constant) values are tuned such that the error signal will not overshoot nor oscillate. The below diagram shows the actual circuit and the simulated circuits of the PID controller part.

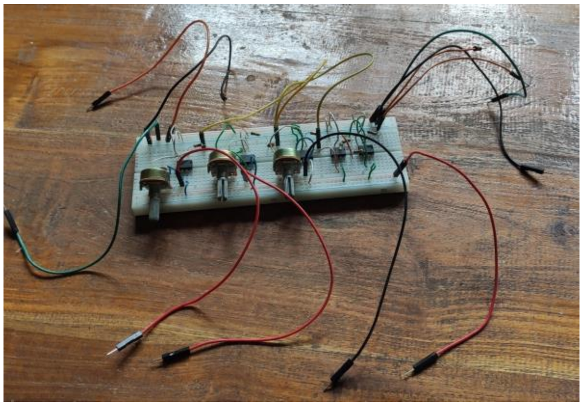
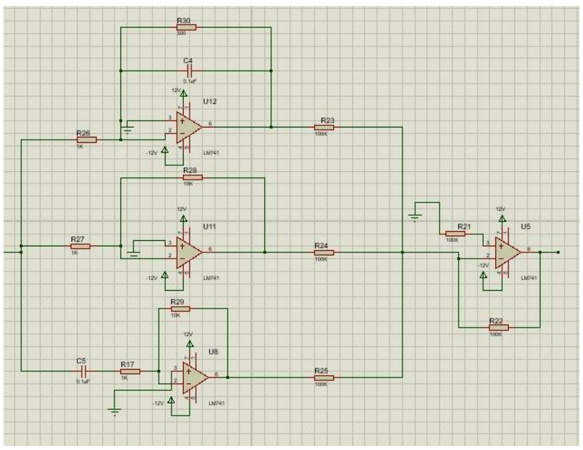


Figure 6:PID controlling circuit



5. SENSOR INTERFACING UNIT

5.1. SENSOR

In order to control the temperature of the coil we need a way to measure the current temperature of the coil. For that we needed a temperature sensor. We've considered four different kinds of sensors for this. Namely Thermocouples, RTDs(Resistance Temperature Detector), Thermistors and Semiconductor based ICs. Even though thermocouples are the most commonly used type of temperature sensor it needs a fixed temperature in one end. And also it gives a very small output voltage which requires precise amplification.

Figure 7:PT100 sensor

So we decided that it's not the best choice for our hotplate project. We also considered using a thermistor but it did not match with our accuracy requirements. So finally we chose PT100 (Figure 7) sensor which is a RTD type temperature sensor. The main reason for the choice was that it can measure a large range of temperatures and in short ranges (like 0-200C) the sensor output is almost linear (Figure 8) so that we can cutoff additional circuitry that would be needed for linearization.

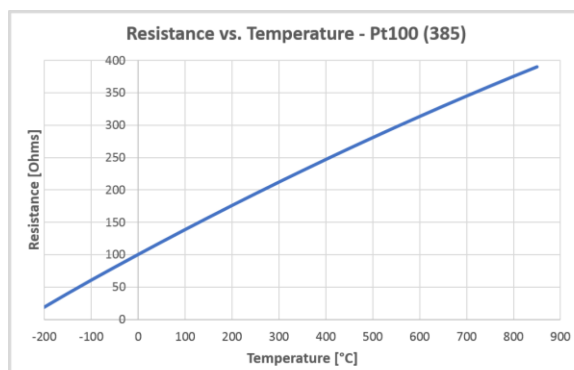


Figure 8:PT100 sensor behaviour

5.2. SENSOR INTERFACING CIRCUIT

PT100 sensors are the most common type of platinum resistance thermometer. PT refers to that the sensor is made from platinum and 100 refers to that it has a resistance of 100 ohms at 0C.

It consists of an element that uses resistance to measure temperature. If we use a voltage source to feed the sensor there might be large currents through the sensor causing the sensor to self-heat. So we had to go with the general practice which is to operate the PT100 sensor at as low current as practical to combat the effects of self-heating of the sensor which can affect the accuracy of the actual measurement. So we've used a constant current source (Figure 9) to feed the sensor.

Since it is a constant current source the voltage difference of two terminals will be proportional to the resistance. But the resistance of the sensor is proportional to the temperature. So the voltage output from the sensor will be proportional to the temperature.

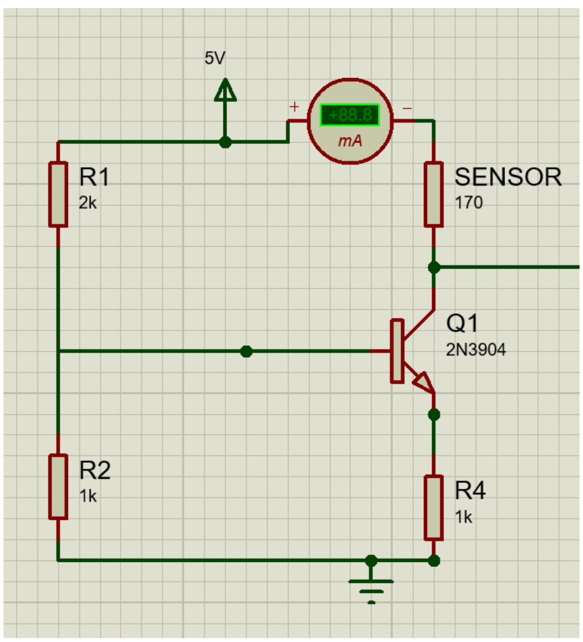


Figure 9:Constant current source

And then we've used a subtractor with a preset for calibration purposes and another subtractor with a potentiometer to generate the error signal using user input value. A simple yet effective circuit to calculate the error signal. Complete circuit schematic is shown below (Figure 4).

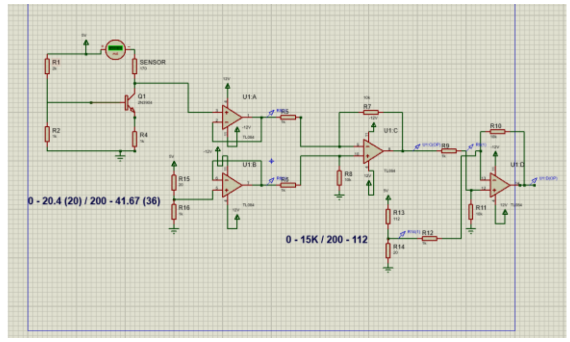


Figure 10

6. FIRING ANGLE CONTROLLING UNIT

In this unit, the output from the PID unit is used to control the amount of power supplied to the hot plate. The Firing Angle controlling of the AC waveform is achieved through three main subunits.

- Zero Crossing Detection
- Ramp Generation
- PWM Signal Generation
- TRIAC Control Circuit

6.1. ZERO CROSSING DETECTION

Zero crossing detection makes it possible to give a pulse to each half cycle of the AC waveform equally. This enables control of every half cycle of the AC waveform in the same way.

When the voltage of the rectified AC waveform connected to the inverting terminal is lower than 0.7V which is the voltage of the non-Inverting terminal the output voltage goes to 12V and stays at 0V otherwise.

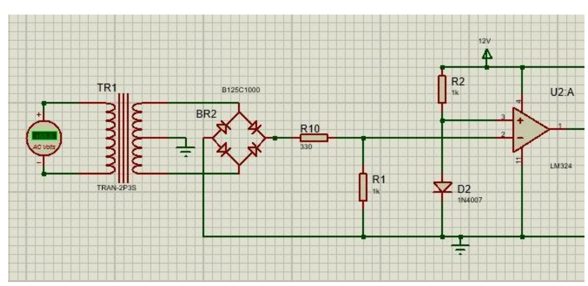


Figure 11

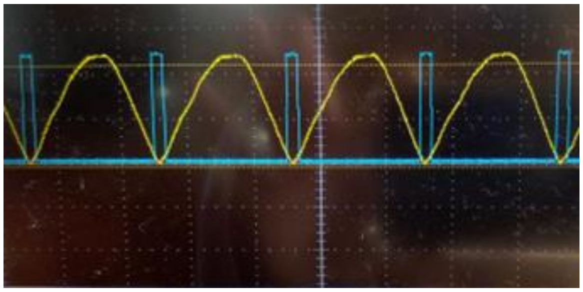


Figure 12

6.2. RAMP GENERATION

The ramp is created by charging and discharging a capacitor. When the output from the zero-crossing detector circuit is less than 0.7V the transistor is in the cut-off region and the capacitor gets charged. Once the output of the zero crossing detector gets high the transistor is driven into saturation (which then acts as a short circuit) and the capacitor discharges through the transistor.
The ramp is created to function as a threshold for the PWM signal generation.

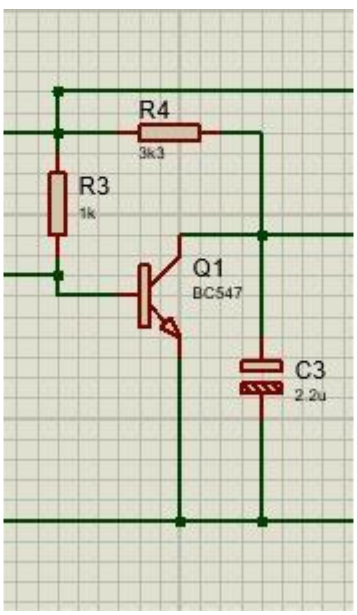


Figure 13

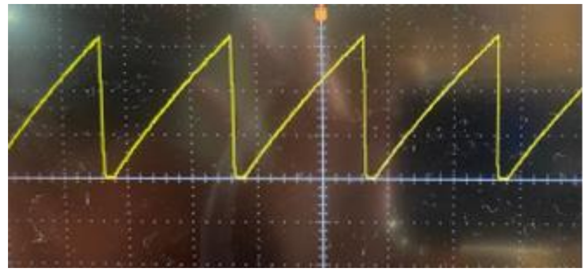


Figure 14

6.3. PWM SIGNAL GENERATION

In this unit the op amp creates a PWM signal which is used to control the AC power. When the ramp voltage is higher than the PID output voltage the output is 12V and otherwise the output is 0V.
When the PID output voltage rises, the width of the pulse created gradually decreases and when the PID output voltage drops the width of the pulse increases.

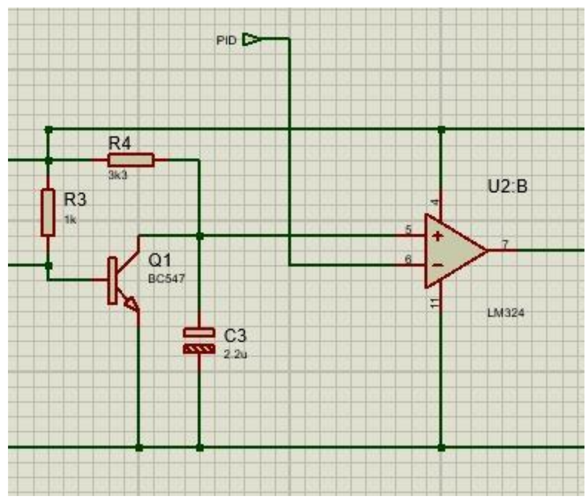


Figure 15

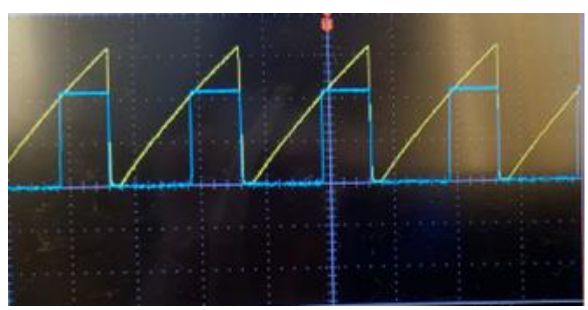


Figure 16

6.4. TRIAC CONTROL CIRCUIT’

The base of the transistor is driven by the pulse created and the PWM signal is passed to the optocoupler through the transistor. The optocoupler is used to create the electrical isolation between the low voltage circuit and the high voltage circuit.
The TRIAC connected to the output of the optocoupler acts as a switch to the AC source connected to terminal 1 and terminal 2 of the triac. The AC waveform is controlled by the optocoupler output signal connected to the gate of the TRIAC.

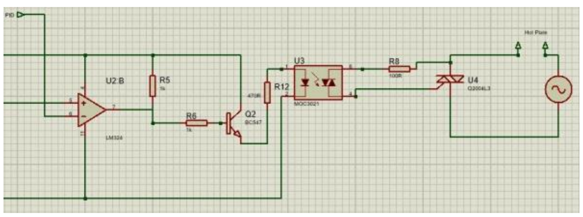


Figure 17

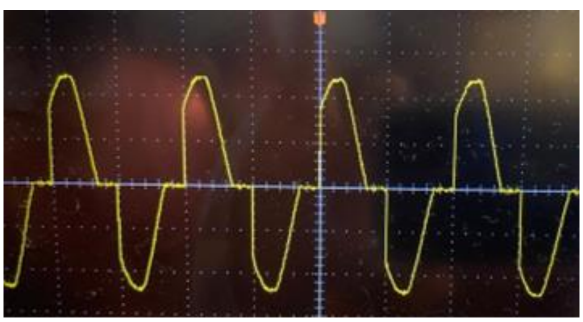


Figure 18

7. RESULTS

The final product, the hot plate, can heat up the load up to 200°C. The hot plate can control a maximum 2kW load. The final product is light weighted, user friendly, and easy to handle.
The project has three PCBs. They are for the power supply unit, firing angle unit, and the sensor controlling part. Schematics and PCB layouts are attached to the appendix.

8. DISCUSSION

We divided the whole project into four subtasks. They are power supply unit, PID controller unit, sensor interface unit, and triac firing angle controlling unit. First, we designed and simulated these circuits using Proteus software and then we built the four circuits on breadboards and did further testing.
In the power supply unit, we used capacitors parallel to the voltage regulators (LM7805, LM7812, LM7912) to avoid unnecessary noises.
In the testing phase, the triac (BT139), which was used in the firing angle control unit was heated up to a very high temperature. For reliability and safety, we used BTA41600B with an integrated heat sink instead of BT139.
In the PID unit, we set a high Kp value by selecting suitable resistors. We use very small (negligible) Ki and Kd values by choosing the most suitable resistance and capacitance values.
We designed three PCBs for our project. They are for power supply, firing angle control unit, and the sensor controlling part.

9. ACKNOWLEDGEMENT

The hot plate temperature controller was our first analog electronics project. Therefore, it was a big challenge for us all to complete this project. We got help from many individuals to make this a success.
First, we would like to thank Mr. Jayathu and Mr. Gershome Senevirathne who guided us and clarified our doubts throughout the project.
Then we would like to thank all the staff of the laboratories in the Department of electronics and Telecommunication Engineering who always try to give their best to ensure our convenience.
This is a nice opportunity to express our gratitude to all the instructors and colleagues of our department who helped us in every possible way to complete the project.

10. REFERENCES

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https://control.com/textbook/closed-loop-control/analog-electronic-pid-controllers/

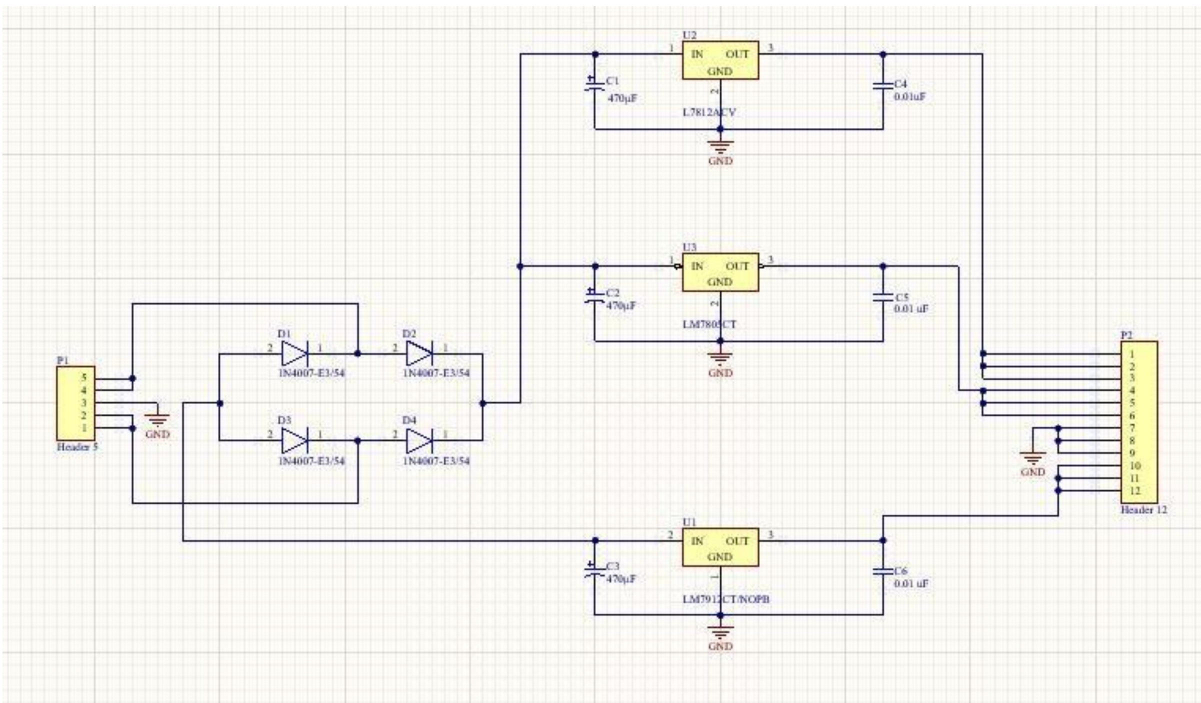
https://www.electroschematics.com/smart-heater-controller-circuit/

11. CONTRIBUTION

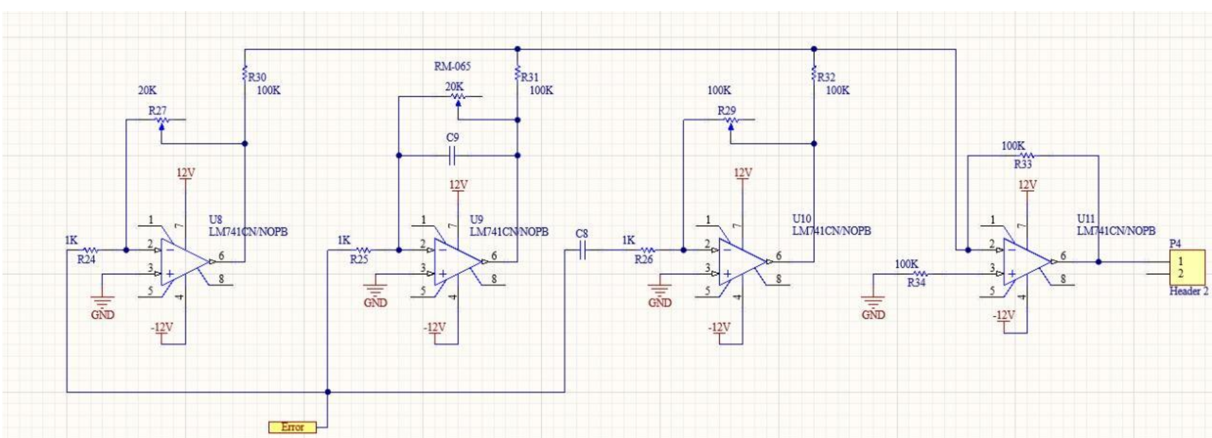
Index No.	**Contribution**
190698D	Power circuit, PID control unit
190712T	Sensor interfacing, Triac control circuit
190713X	Sensor interfacing, Triac control circuit
190719V	Power circuit, PID control unit

11. APPENDIX

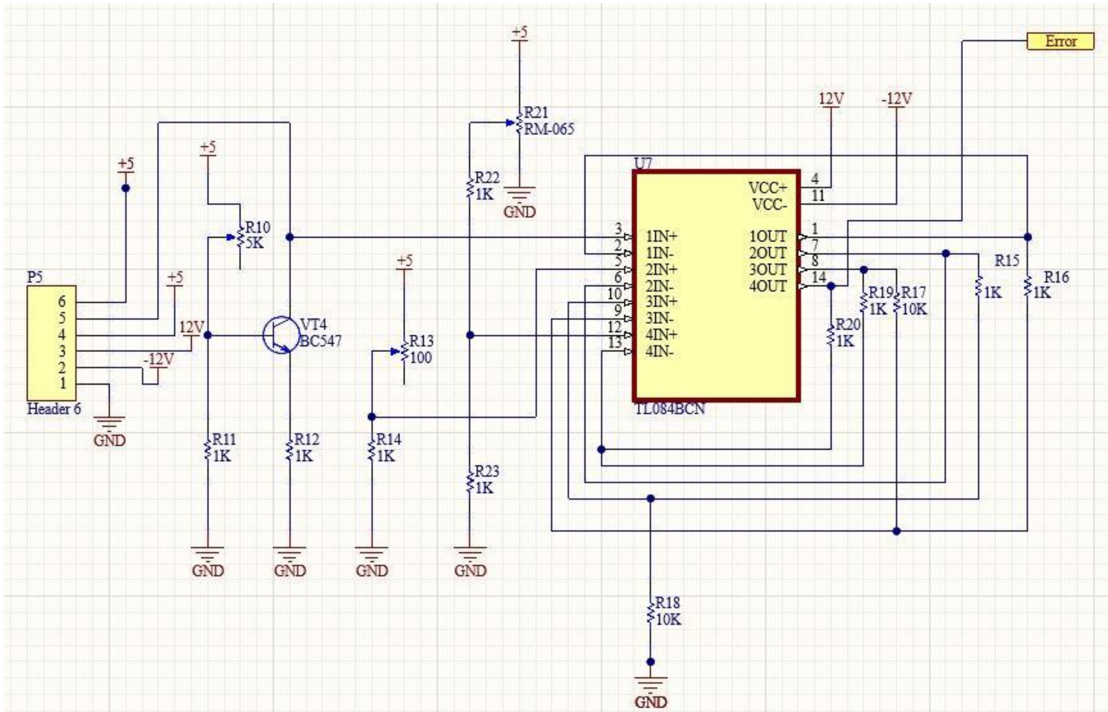
11.1. SCHEMATICS



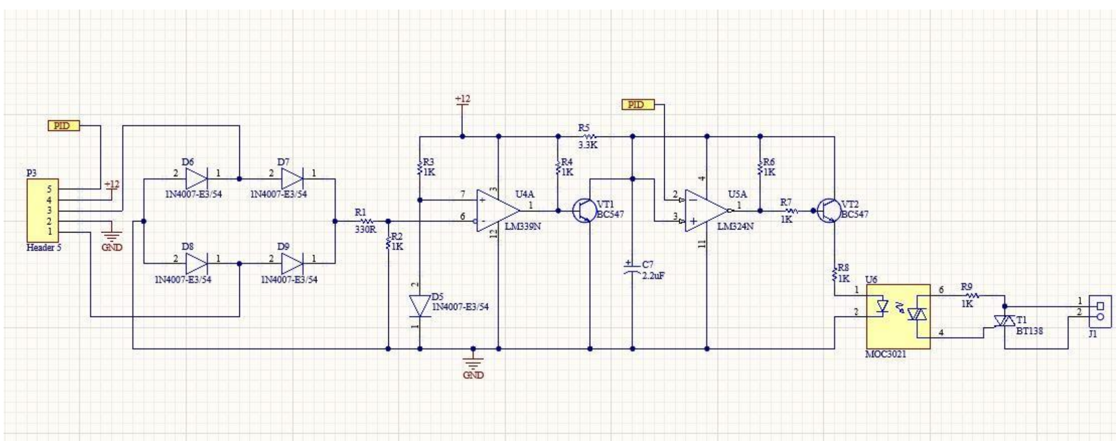
Power Supply Unit



PID Controlling Unit



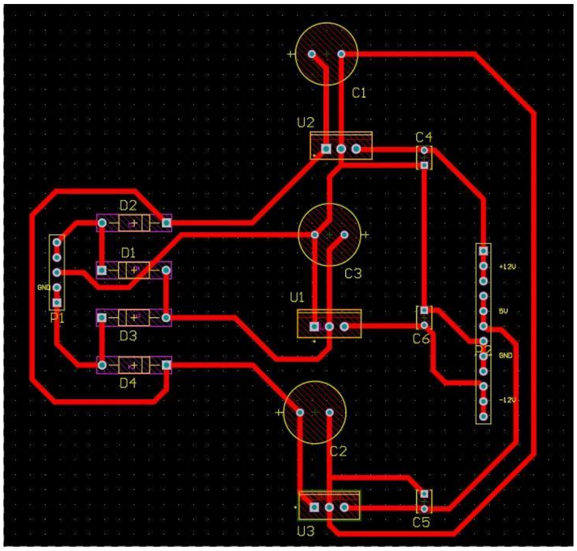
Sensor Interfacing Unit



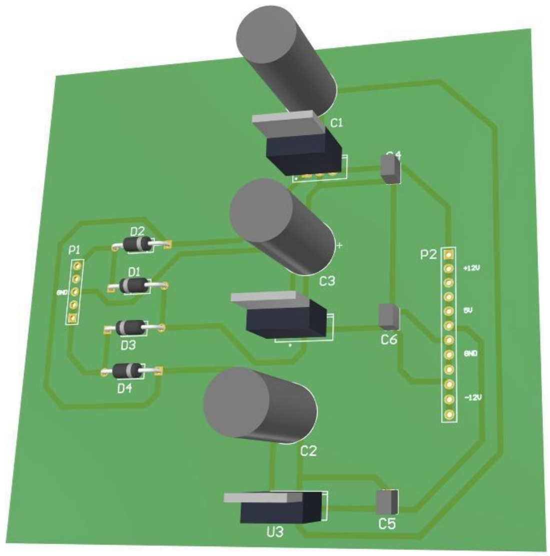
Firing Angle Controlling Unit

11.2. PCB LAYOUTS

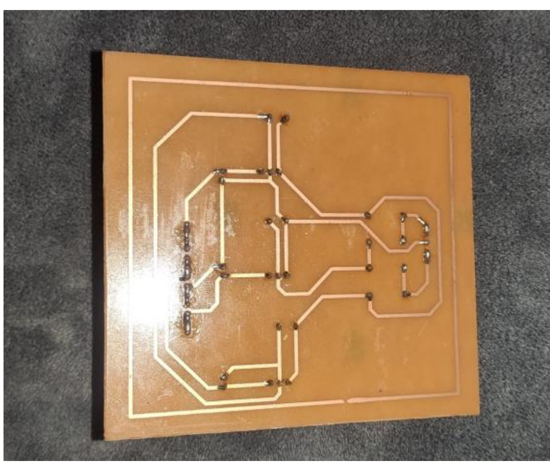
11.2.1. POWER SUPPLY UNIT

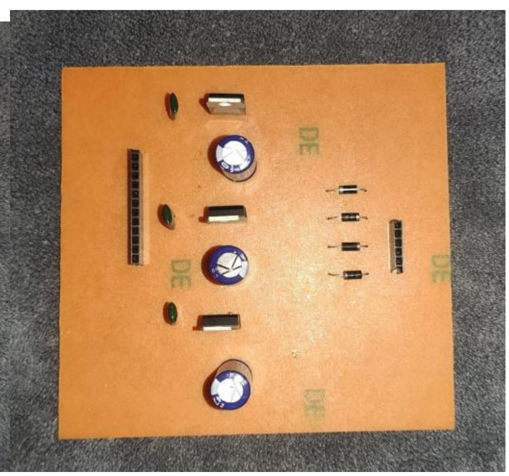


PCB Layout

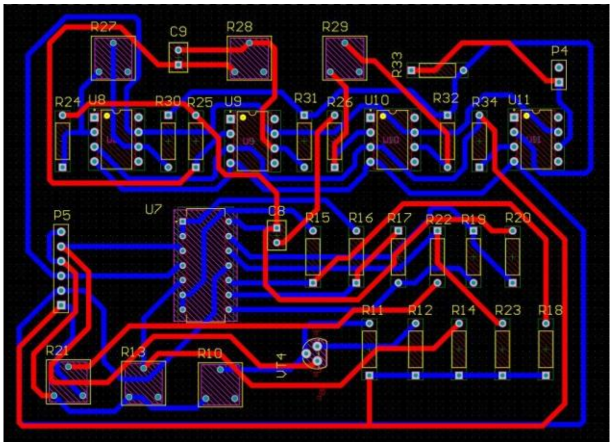


3D View

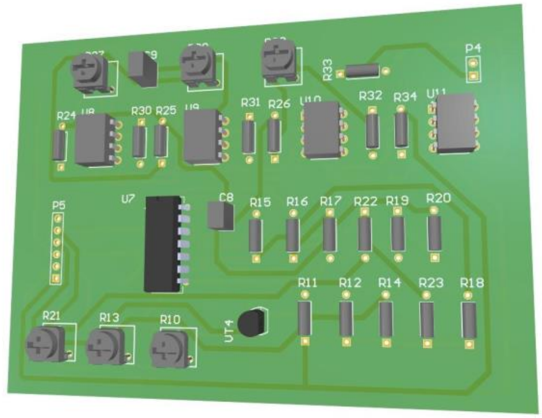




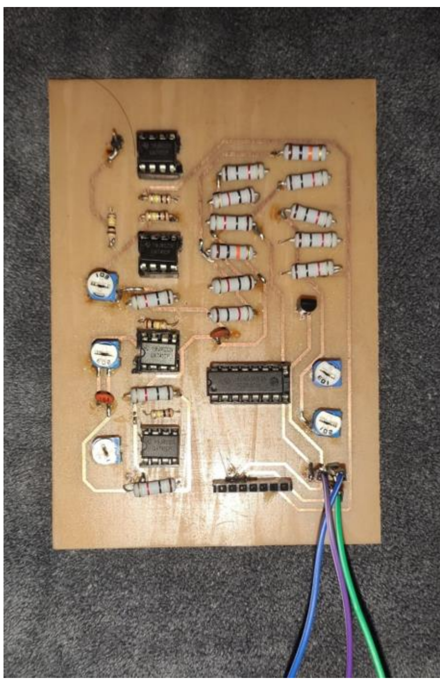
11.2.2. SENSOR INTERFACING UNIT AND PID CONTROLLING UNIT

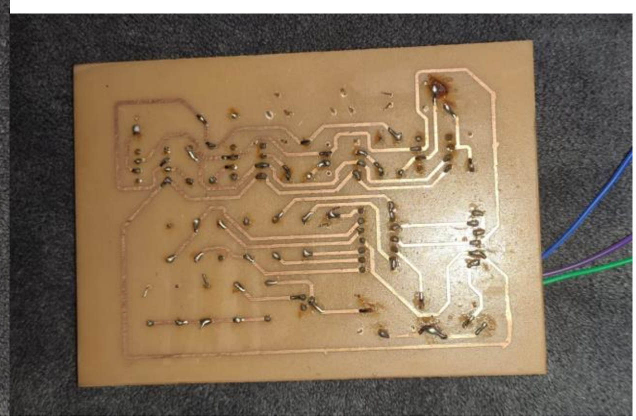


PCB Layout

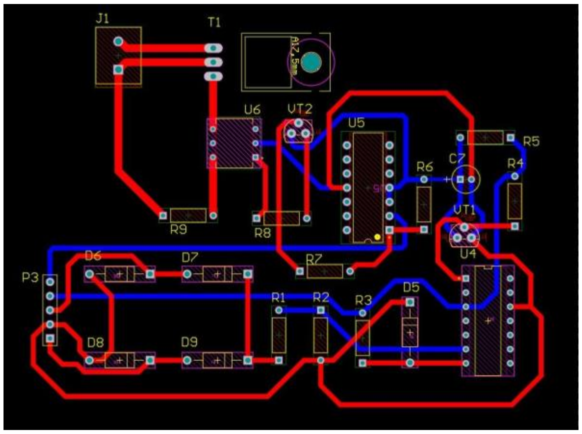


3D View

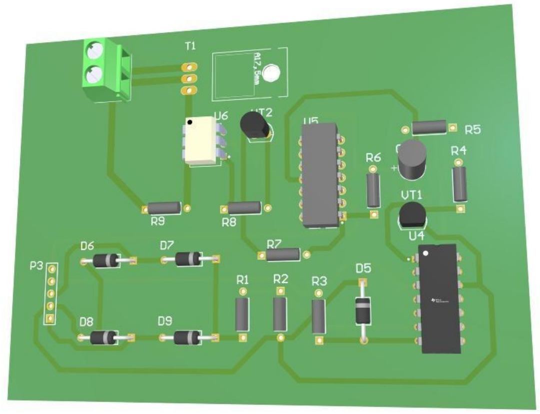




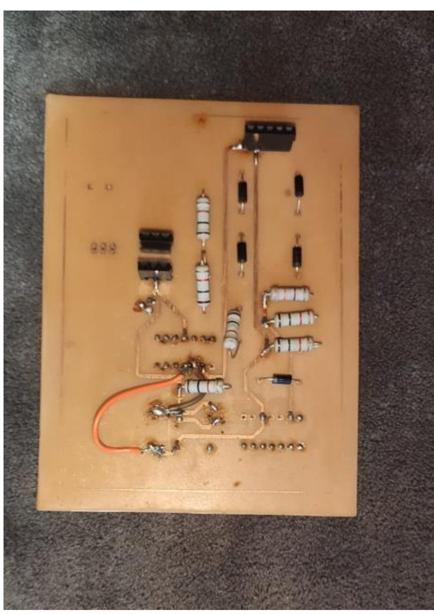
11.2.3. FIRING ANGLE CONTROLLING UNIT

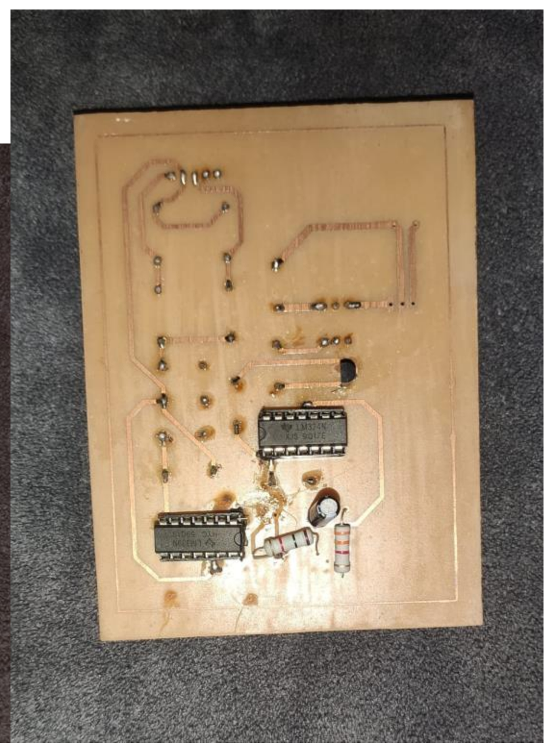


PCB Layout



3D View





12. DATA SHEET

PID Hot plate controller
Data Sheet

1 Overview

- 230V AC Power input
- PID Control
- Temperature is adjustable to a desired level
- Coils up to 1.5KW can be handled
- Can be calibrated manually

2 Description

- Fast heating. Uninterrupted power until it reaches desired temperature.
- Perfectly tuned PID controller is used to keep the coil at the desired temperature.
- Any unexpected temperature drifts can be handled manually by calibrating knob.
- High power industrial triac BTA41 is used.
- Control circuit is isolated using an optocoupler
- Separate circuit to handle AC for better isolation
- Extremely accurate and very stable PT100 sensor is used

3 General Specification

	UNIT	VALUE
POWER INPUT	V(rms)	230
MAXIMUM CURRENT	A	12
DIMENSIONS	mm*mm*mm	50*150*180
COIL TEMPERATURE	C	20-200
WEIGHT	g	300

4 Pinout

PORT	PINOUT
1	AC power
2	To coil