Department of Electronic & Telecommunication Engineering

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Hot Plate Controller Using PID

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This report is submitted as partial fulfilment of module EN2091

February 2023

Abstract

This project is for making a hot plate temperature controller within the range of 200°C using the PID feedback algorithm in the analog domain. After tuning the PID Control unit, PID output is fed into a circuit which controls the average power delivered to the hot plate. The project is to carry out four analog circuits, one digital circuit (for display user input) testing, schematics and enclosure design.

Table of Contents

1. Introduction

The purpose of this project is to make a temperature-controlling unit for hot plates, which do not have facilities to control temperature. So this controller can control the temperature of hot plates up to 200°C from room temperature.

In this project, the temperature of a hot plate iscontrolled using the PID algorithm. PID is widely used in controlling systems with a feedback loop mechanism.

By using PT 100 sensor to measure the temperature of the Hot plate, the system will continuously calculate the error i.e. difference between required output and current output and adjusted it by using proportional(P), Integral(I) and Differential(D) parts until the desired, stable output level is reached.

Then use that PID output to generate a PWM signal to control the triac firing angle. That output is used to control AC voltage which goes through the hot plate and it will control the heating of the hotplate.

2. Method and Results

So here four analog circuits are used to achieve the task and one digital circuit for displaying the user input temperature.

2.1 Analog circuits

3 main units are used to take feedback and give output AC waves to Hotplate.

1.)Sensor Interface Unit
2.)PID Control Unit
3.)Firing Angle Control Unit

Another Analog circuit is used to take powerto the above circuit from 230V AC supply.

The interconnection between those 3 main units are as follows.

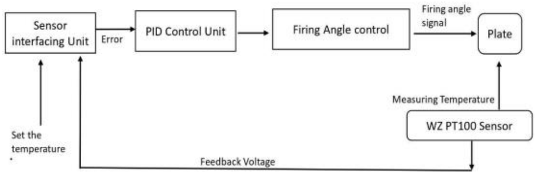


Figure 1 - Interconnection of control units

2.1.1. Sensor Interface Unit

In this unit, WZ PT 100 Sensor is used tomeasure the temperature of the hot plate thermo coil.

Choosing WZ PT 100 temperature sensor forthis experiment has multiple advantages.

- Precise measuring (accuracy up to ±0.5°C)
- Linear temperature- resistance variation
- Short response time
- Low weight.

Since there is a limitation for maximum current which can be flown through the temperature sensor, corresponding voltage for each temperature value could not be directly obtained only with the sensor. Hence, a voltage divider method was used to obtain the corresponding voltage output at each temperature.

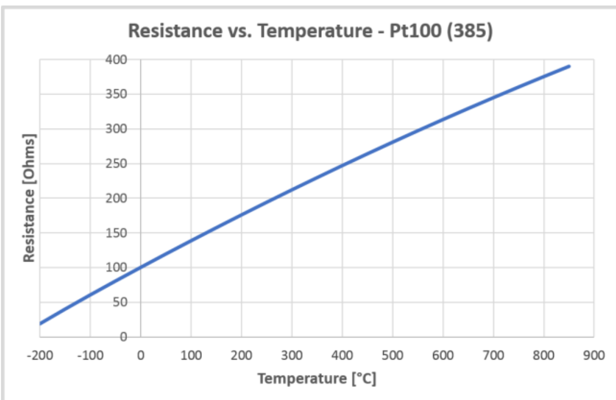


Figure 1 - Resistance vs.Temperature of WZ PT100

The output voltage of the sensor behaves according to the equation

$$v = v_o + \alpha T$$

v ; output voltage of the sensor
α ; amount of voltage difference per unit degree in Celsius.
v_o ; voltage at 0℃
T ; temperature in Celsius

Using an Op-Amp subtractor, $v0$ was removedfrom the equation to make the voltage variation more linear.

Since the variation of voltage per unit temperature was small, an inverting amplifier is used to give an amplification to the output voltage.

Final task of the sensor interface unit is gettingthe user input. User sets the desired temperature and then the difference of the modified linear sensor voltage and voltage set by the user is calculated using an opamp subtractor. This value is the input for the PID unit.

Table 1 - Components for Sensor interface Unit

Name of Component	No.
LM324N Op Amp IC	1
WQ PT 100 Sensor	1
4.7k resistor	1
1k resistor	9
10k preset resistor	4

2.1.2. PID Control Unit

Let E be the error value of difference betweensensor reading and expected temperature value.Then if output of PID is e,

$$e = K_P E + K_D \frac{dE}{dt} + K_I \int E dt$$

K_P = Proportional Coefficient
K_D = Differential Coefficient
K_I = Integral Coefficient

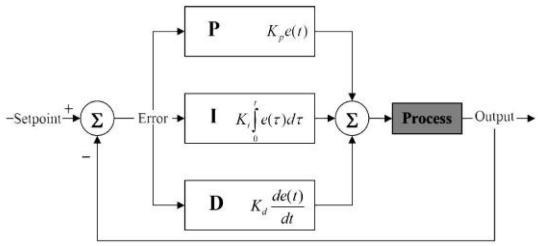


Figure 2 - Control Structure of PID algorithm

By adjusting those three coefficients, smoothand accurate temperature controlling can be achieved.

To implement a PID control unit in the analogdomain, 4 Op-Amps are used.

For proportional,

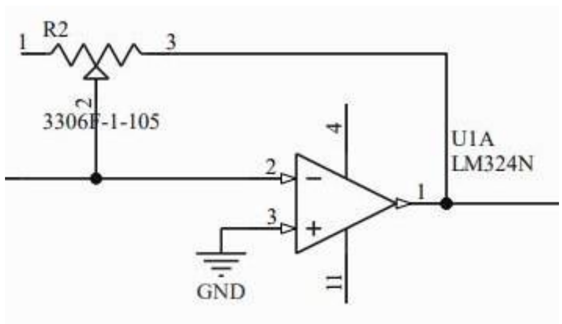


Figure 3 - Op-Amp proportional Diagram

By changing R_5 , K_P can be changed.

For Integral,

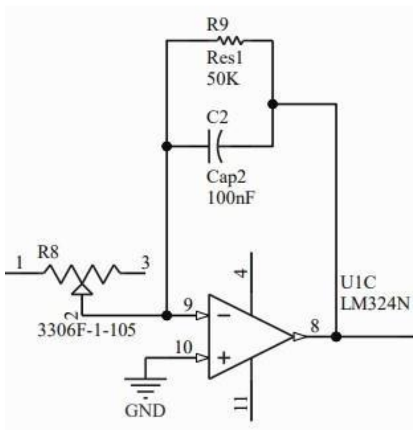


Figure 4 - Op-Amp Integral Diagram

By changing R_9 , K_I can be changed.

For Differential,

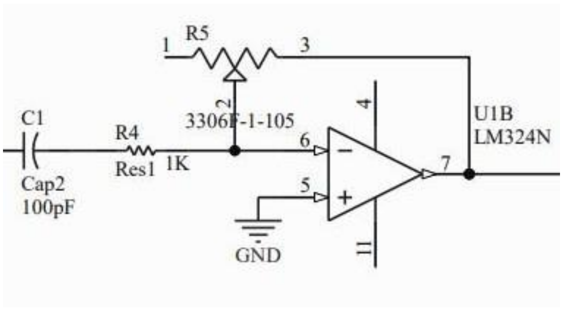


Figure 5 - Op-Amp Differential Diagram

By changing R_5 ,K_D can be changed.

To sum those three individual outputs, anOp-Amp adder circuit is used.Also in this Section, voltage range of PID is mapped into working variable voltage for firing angle unit.

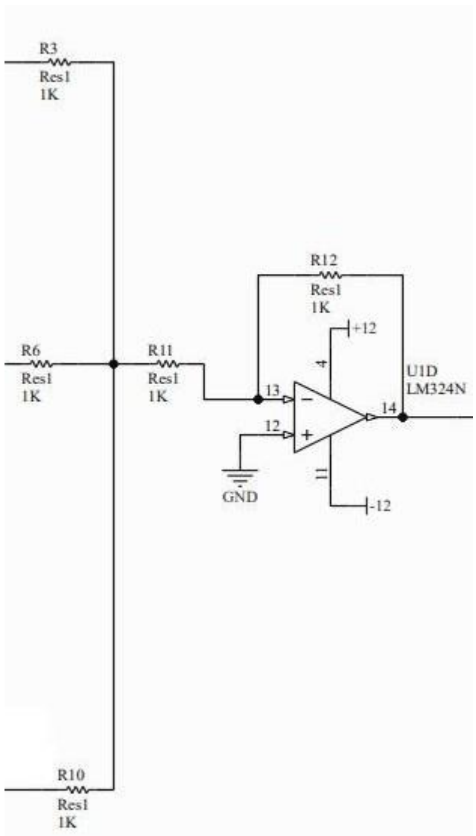


Figure 6 - Op-Amp adder amplifier Diagram

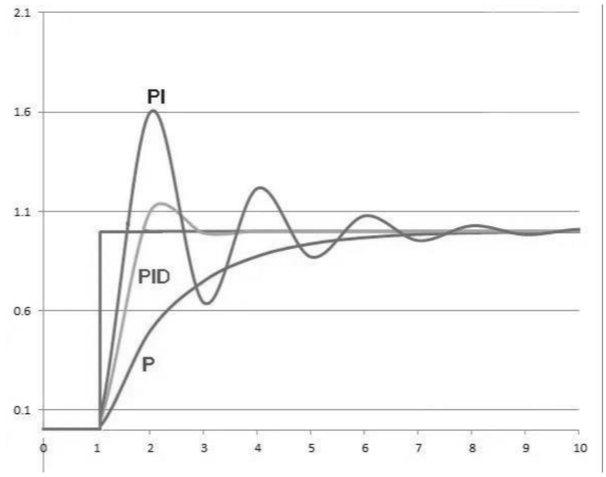


Figure 7 - Tuning the PID output

After Connecting Hot plate Coil for this system, By changing presets the PID unit can be tuned. The Changing of the hot plate is not quick.So in here P part is most affected.So when tuning it should be mostly considerable.

Table 2 - Components for PID Unit

Name of Component	No.
LM324N Op Amp IC	1
1k resistor	7
10k preset resistor	3
50k resistor	1
0.1 uF capacitor	2

2.1.3. Firing Angle Control Unit

This is the most trivial part of the entire system.There are 4 main stages in this Unit.

1.Zero crossing detection.
2.Ramp generation.
3.PWM signal.
4.Triac output control.

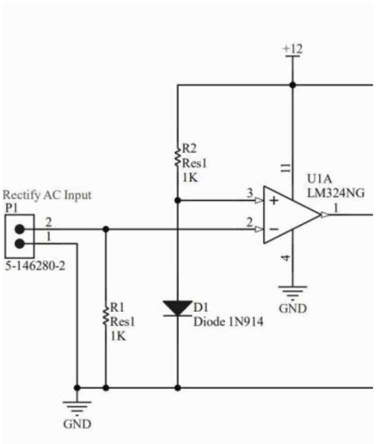


Figure 8 - Zero crossing detection stage

In the Zero crossing detection stage, an op amp comparator is used to detect zero crossinginstances. First, full wave rectified signal of the 12V peak to peak AC signal is given as an input to the inverting terminal of the op amp comparator and 0.7V voltage is given to the non-inverting terminal using a diode. This gives the binary output of 12V when the inverting input is less than the non-inverting input, or 0V when otherwise.

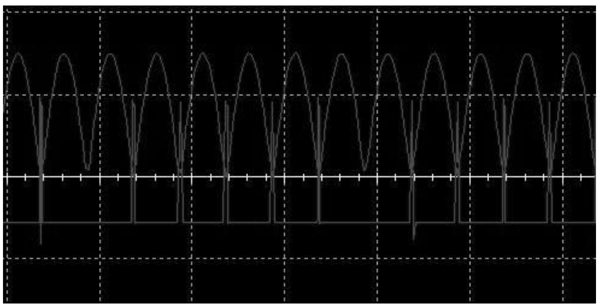


Figure 9 - Zero crossing detection stage output waveform

ramp generation is done simply by using a discharging capacitor and a transistor.The frequency of the charging voltage signal was controlled by the zero detection pulse via a transistor switch.

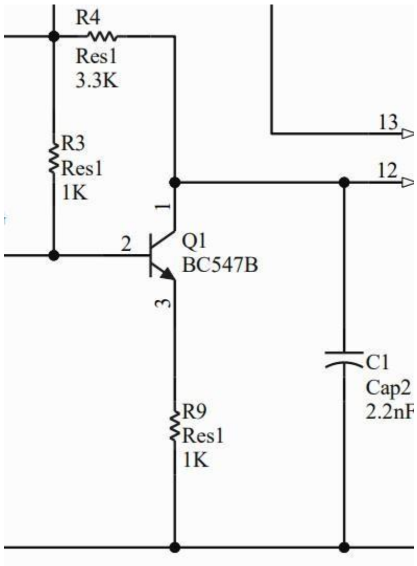


Figure 10 - Ramp generating stage

Ramp signal can be obtained from the collector terminal of the transistor by feeding the base terminal of the transistor from the zero crossing detection pulse.

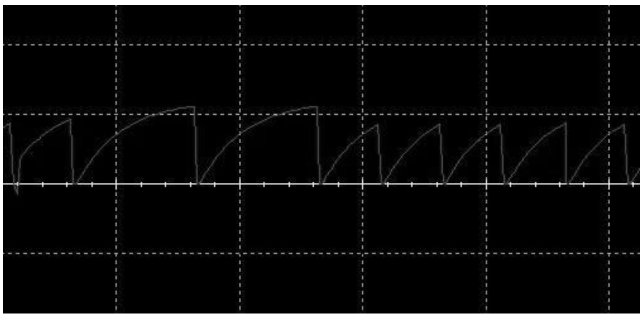


Figure 11 - Ramp generating stage output waveform

It is very important to select most suitable resistor values for the transistor biassing as well as suitable capacitance value in the circuitto get a better ramp function.

The final part of the PWM control circuit is made using comparator logic with the PID output signal being fed into one terminal and the other receiving the ramp input.

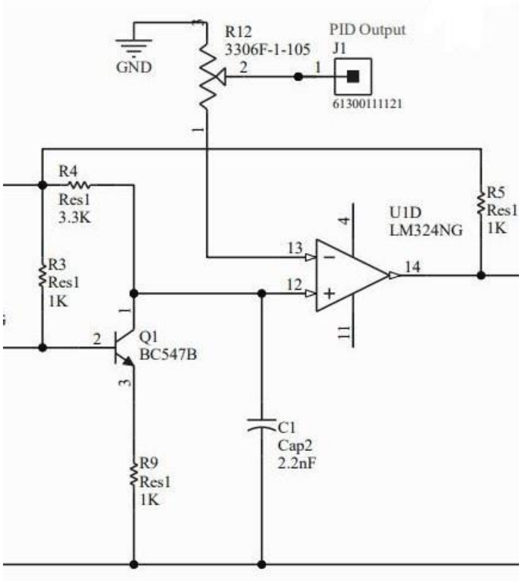


Figure 12 - PWM signal generating unit

When the PID input voltage is higher than thelevel of the ramp voltage, a constant 12V output is obtained. Otherwise, the output is zero. In this manner, a PWM signal which increases with the level of PID input is obtained.

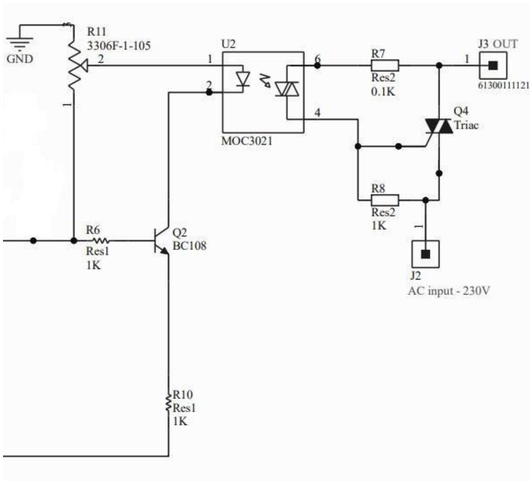


Figure 13 - Firing angle controlling stage

Triac firing angle control is one of the most important stages in this PID temperature controller unit. It is done mainly by using the triac BT 137 and the optocoupler MOC 3021. Since the AC source is directly connected across the triac and the load, the rest of the electronic circuit must be protected from the high current that can flow through them. Whilemaintaining the required isolation, an optocoupler will allow the PWM signal to be passed to the gate of the triac. Input current of the optocoupler will be maintained at a less than 1A level.

The triac BT137 can pass a 230V AC voltageand a current of up to 6A.

Furthermore, MOC 3021 is a zero detection optocoupler, which ensures that the voltage supply does not begin until each cycle has passed a zero point.This prevents the voltagefrom being supplied at unexpected points in the phase.

When the wattage of the hot plate load is about1KW, maximum allowable current which can draw through the circuit is up to 4.5A. Since the hot plate load is inductive, selection of the capacitor across the main terminals of the triac is very important to get the best use from the triac.

Table 3 - Components for Firing Angle Unit

Name of Component	No.
LM324N Op Amp IC	1
1k resistor	5
4.7k resistor	1
1k resistor	9
10k preset resistor	4

To implement circuits which are using Op-Amp, LM324 IC is used.

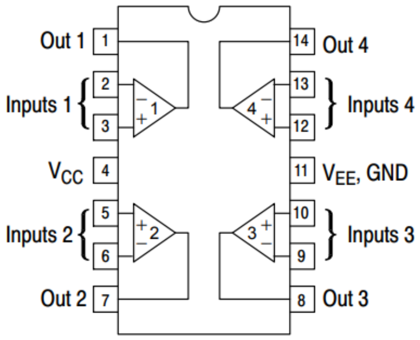


Figure 14 - LM324 Pinout Diagram

This is a general purpose Op-Amp IC, So thatOp-amps inside this can be used for comparator, integral, differential,adder and amplifiers. One IC contains four different Op-Amps. That is an additional advantage.

Table 4 - Voltage Regulators

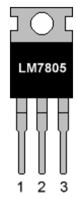
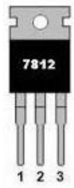
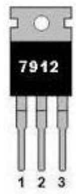
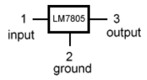
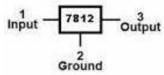
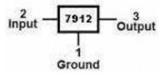
+5V	+12V	-12V
		
		

Table 5 - Components for Power Supply Unit

Name of Component	No.
300mA 15V centre tapped transformer	1
1N4001 Diode	4
LM7805 Voltage Regulator	1
LM7812 Voltage Regulator	1
LM7912 Voltage Regulator	1
0.33 uF Capacitor	3
0.1 uF Capacitor	3

2.1.4. Power Supply Unit

Using a 15V 300mA centre tap transformer, 230V input voltage is converted into 15V. That 15V is given to the Diode Bridge circuit and gets DC voltage.Then using +12V,-12V and +5V voltage regulators are used to outputthose voltages. Parallel capacitors are used forsmoothing.

2.2.Digital Circuit

Here the ESP8266 board is used as a microcontroller and Liquid Crystal display for outputting the temperature.

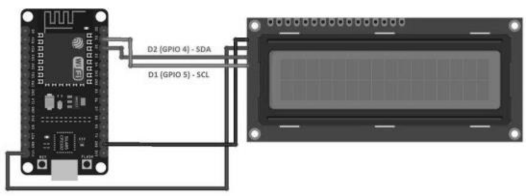


Figure 15 - Connection between esp and LCD display

Pin configuration is,

Table 6 - Connection between LCD and ESP board

12C LCD	ESP8266
GND	GND
VCC	VIN
SDA	GPIO 4 (D2)
SCL	GPIO 5 (D1)

Since temperature varies from room temperature to 200°C , By mapping that range to voltage of the user input potentiometer, user input can be displayed as a temperature value. For that we use Simple Arduino Code.

3.Discussion

Since the practical hot plates are not needed tochange the response quickly in the PID unit, integrator and differentiator sections are not necessary.Mainly Propagation section will be affected.

When the Power Supply Circuit was implemented for the first time, the smoothing was not sufficient because of using low value capacitors. Changing those capacitors to high value would fix this problem.

Since there was 230V AC going into the firing angle control unit circuit, It is dangerousto use that value for testing. So for the first few testing, 24V was given.

To evacuate heat from the system fan was usedand a fused attached plug is used to connect the system to 230V wall socket for safety.

4.Acknowledgements

Since this was our first experience of a fully analog electronic project, it was not an easy task to complete it with a proper ending.

Therefore we received the help of many people to finish this successfully.

First of all we would like to pay our heartiest gratitude to Mr. Niroshan, Mr. Prishan and Mr. Daksith who encouraged us and guided us to overcome the challenges raised on our way to completion.

Then we would like to thank all the staff of thelaboratories in the Department of Electronic and Telecommunication Engineering who always sacrificed their time and effort to ensure the success of ours.

Finally, we take this as an opportunity to be thankful to all the colleagues of our department as well as to all those not mentioned here who helped us in every possible manner.

5.References/Bibliography

Circuits

-PID unit by op-amps
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-Firing Angle Control Unit
http://microcontrollerslab.com/firing-angle-control-circuit-triac/

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Solidworks Tutorials
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Datasheets

-LM324N op amp IC
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-MOC 3021
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-PT-100 sensor
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-LM7805 and LM7812
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-LM7912
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-BC547
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-BC107
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LCD Display
https://randomnerdtutorials.com/esp32-esp8266-i2c-lcd-arduino-id

6.Appendices

Appendix I - Circuit Diagrams

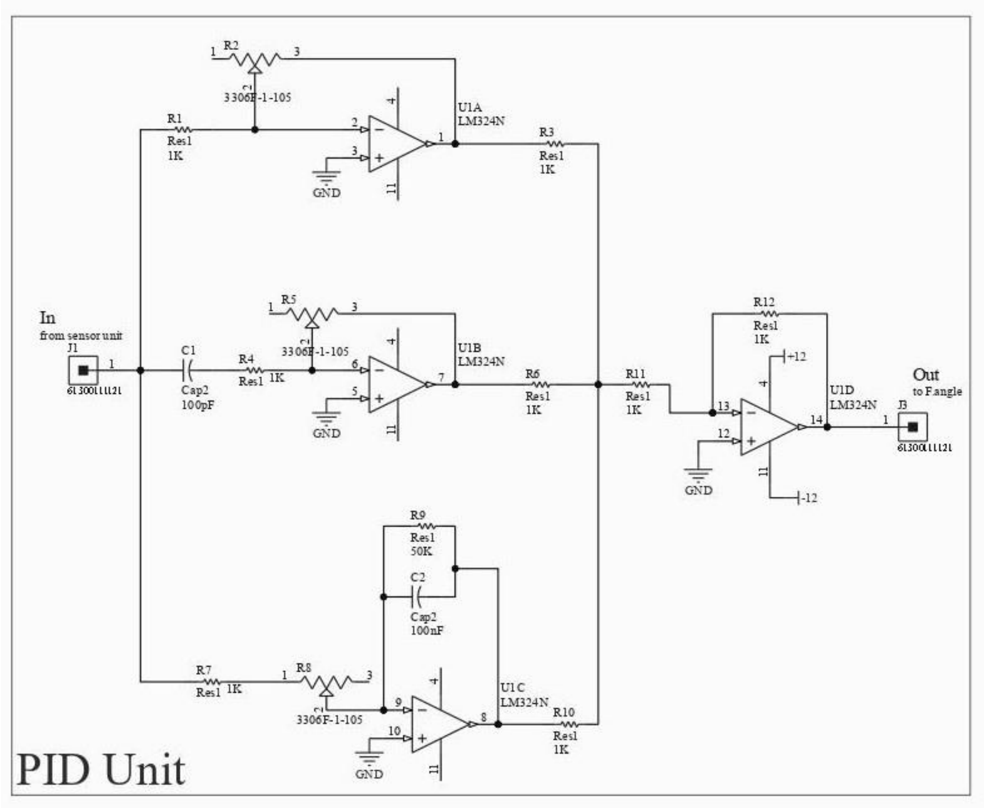

Figure 16 - PID Control unit

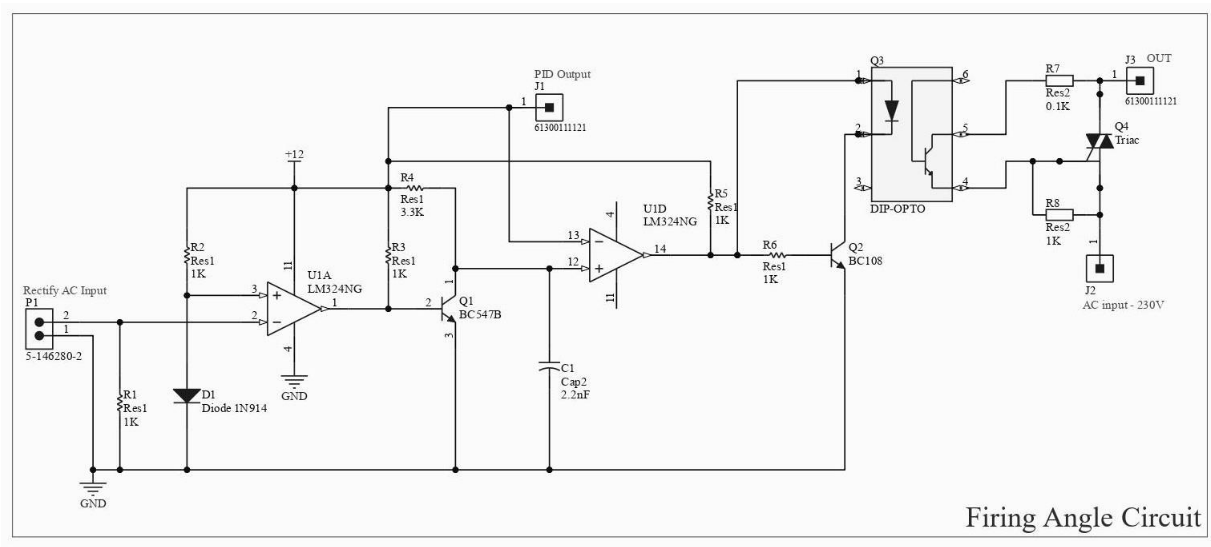

Figure 17 - Firing angle control Unit

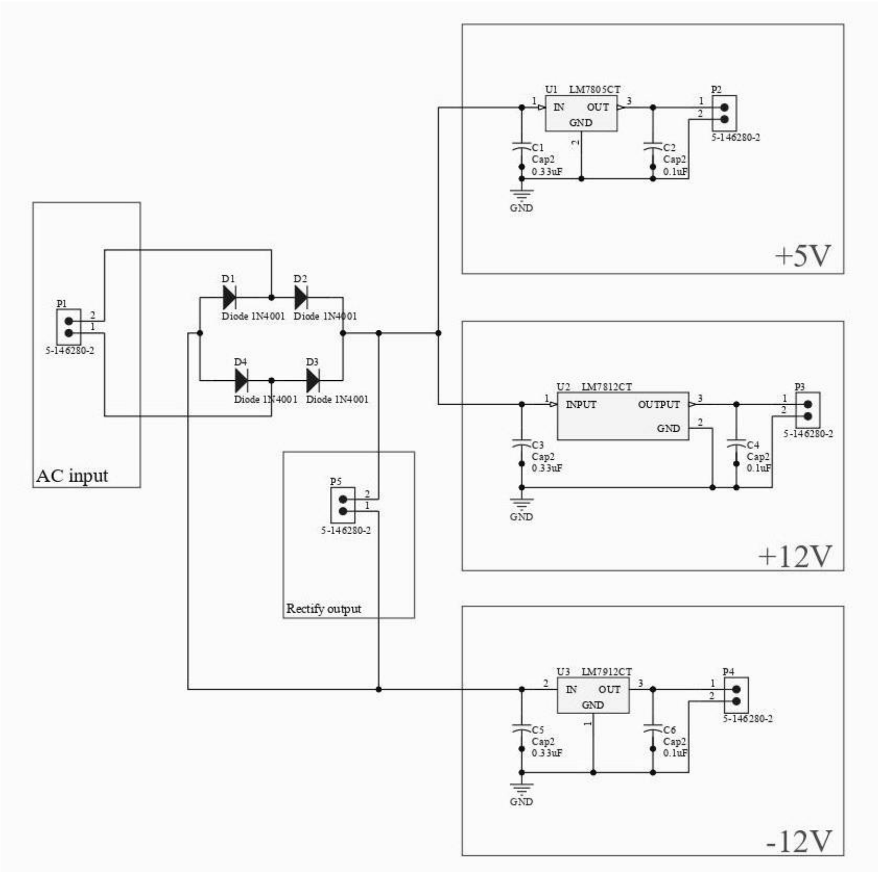

Figure 18 - Power supply unit

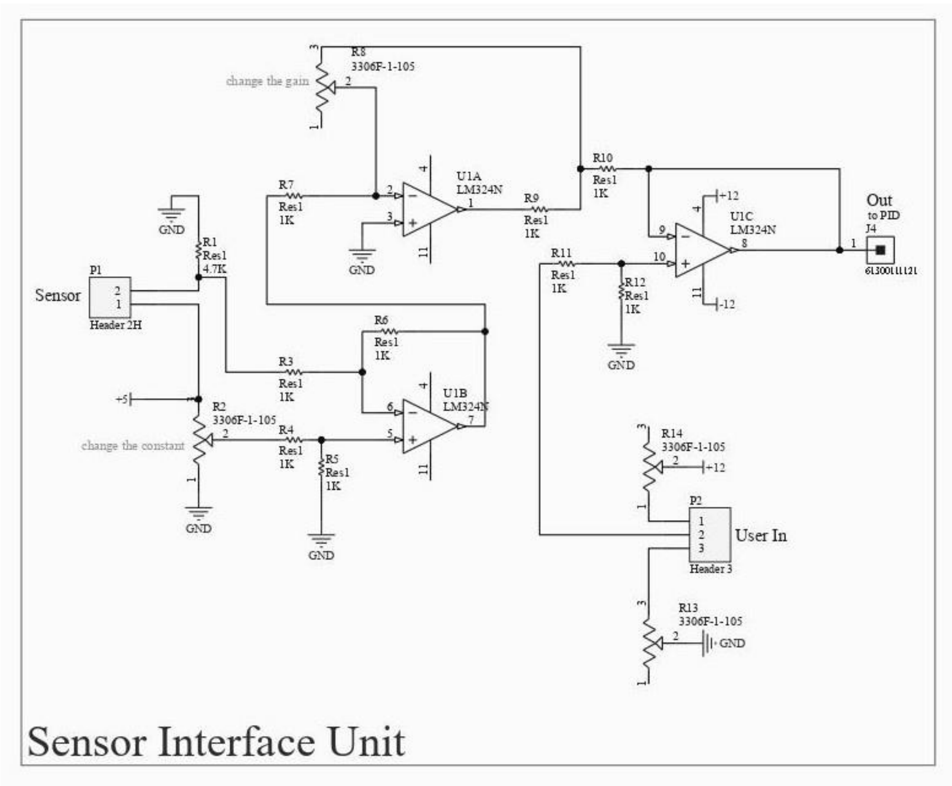

Figure 19 - Sensor interfacing unit

Appendix II - PCB Layouts

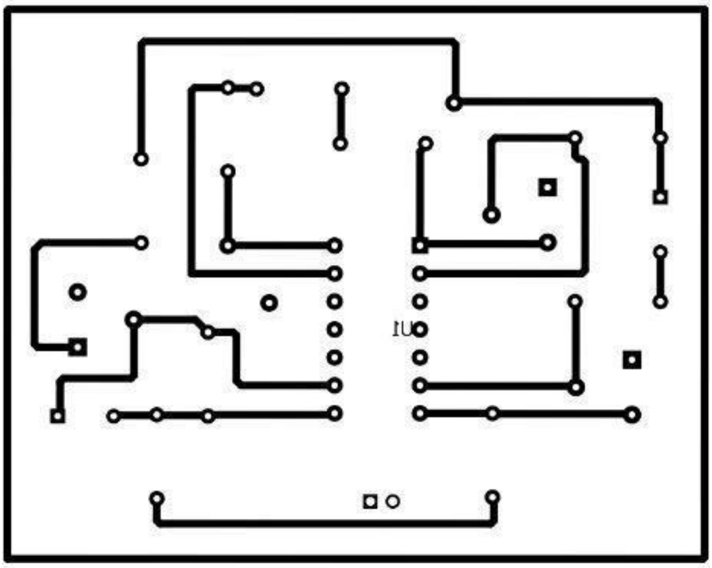

Figure 20 - Top Layer of PID Control Unit

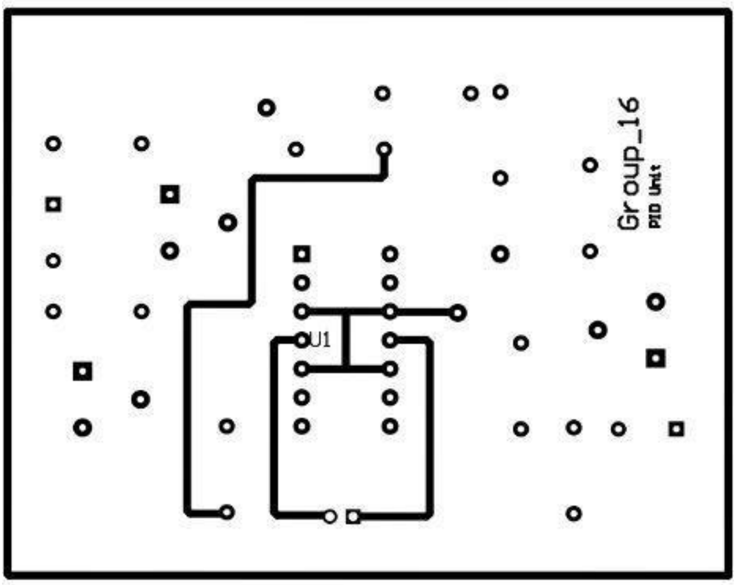

Figure 21 - Bottom Layer of PID Control Unit

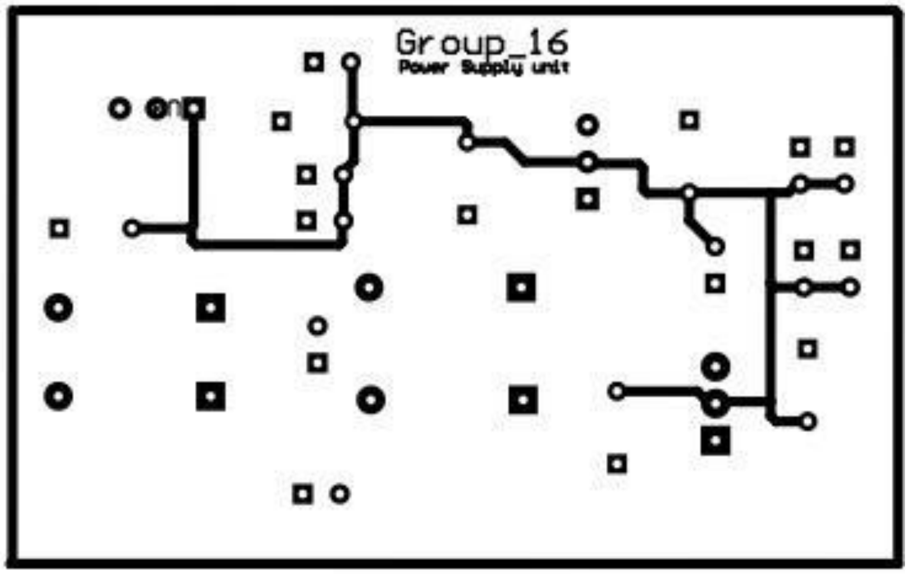

Figure 22 - Top layer of Firing angle control Unit

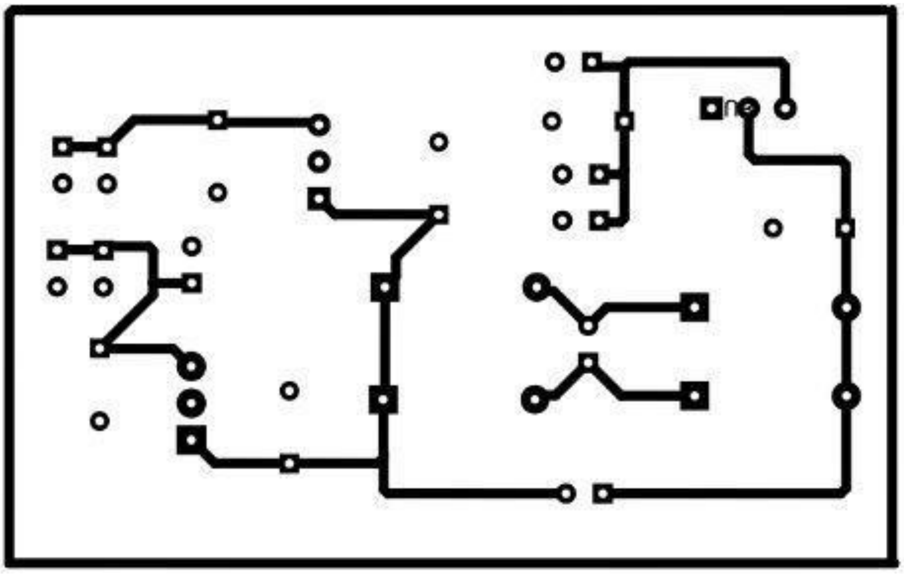

Figure 23 - Bottom layer of Firing angle control Unit

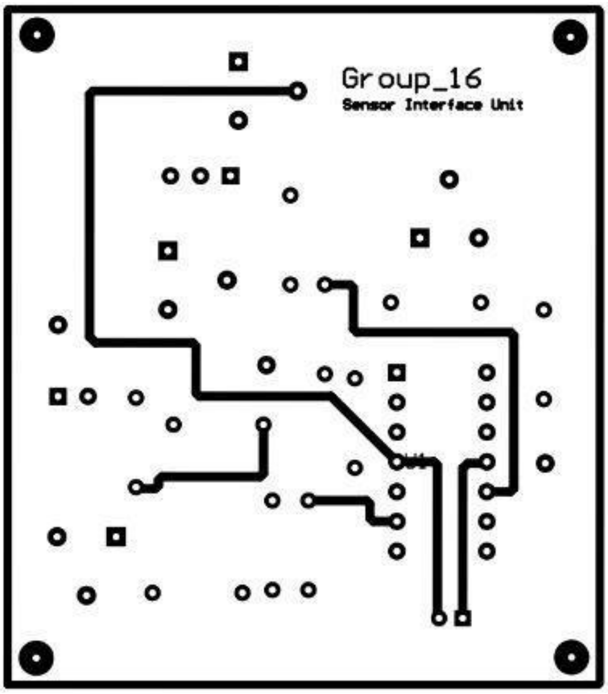

Figure 24 - Top layer of Power supply unit

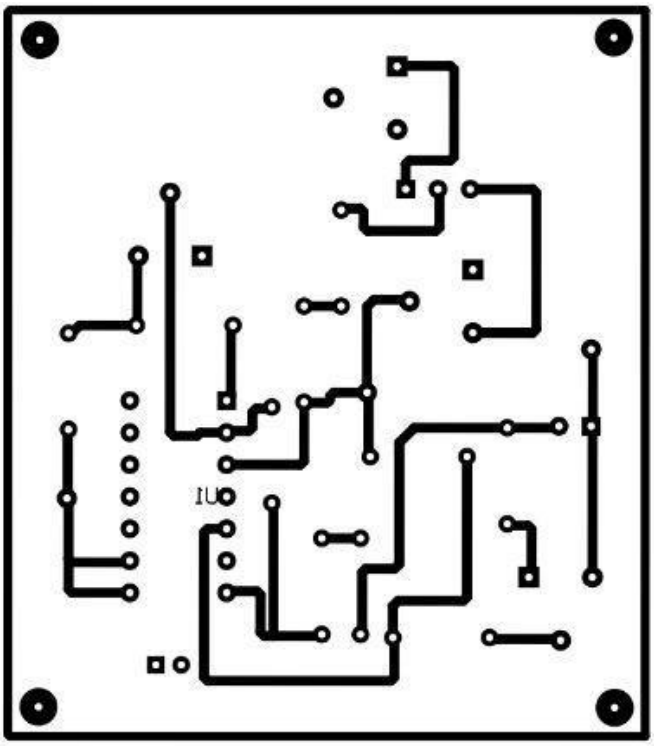

Figure 25 - Bottom layer of Power supply unit

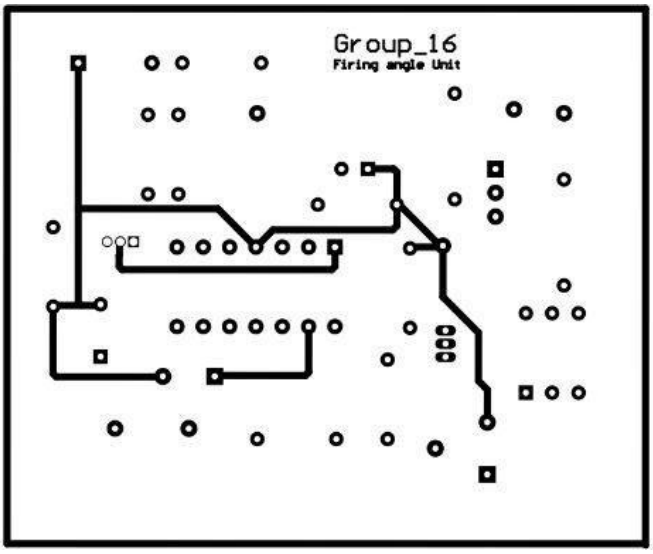

Figure 26 - Top layer of Firing Angle Unit

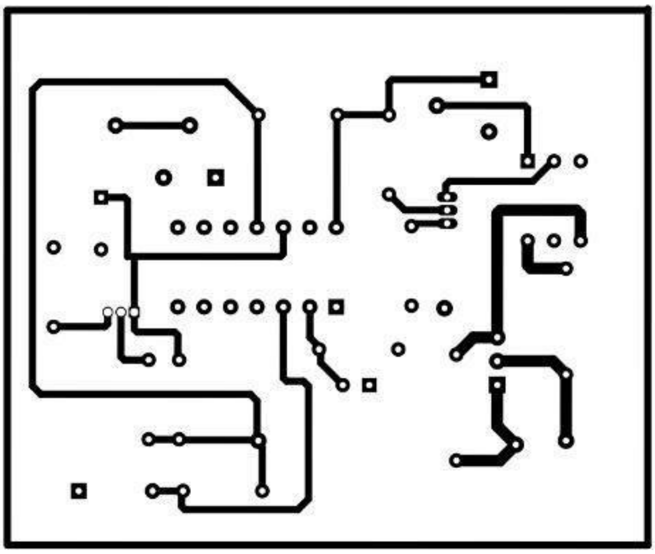

Figure 27 - Bottom layer of Firing Angle Unit

Appendix III - Enclosure Designs

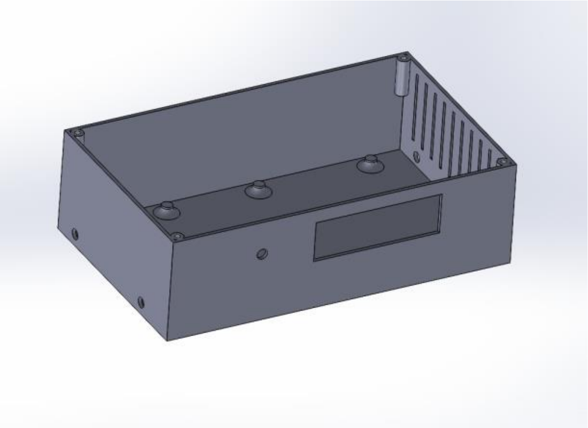

Figure 28 - 3D view I

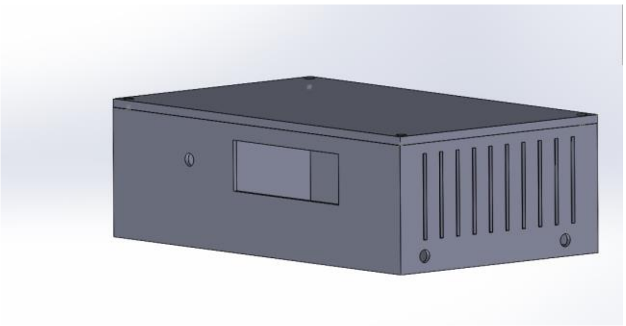

Figure 29 - 3D view II

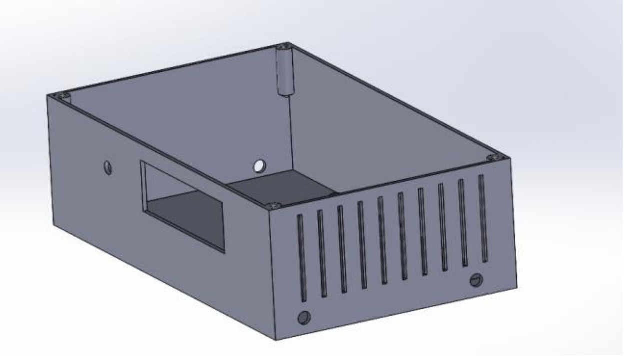

Figure 30 - 3D view III

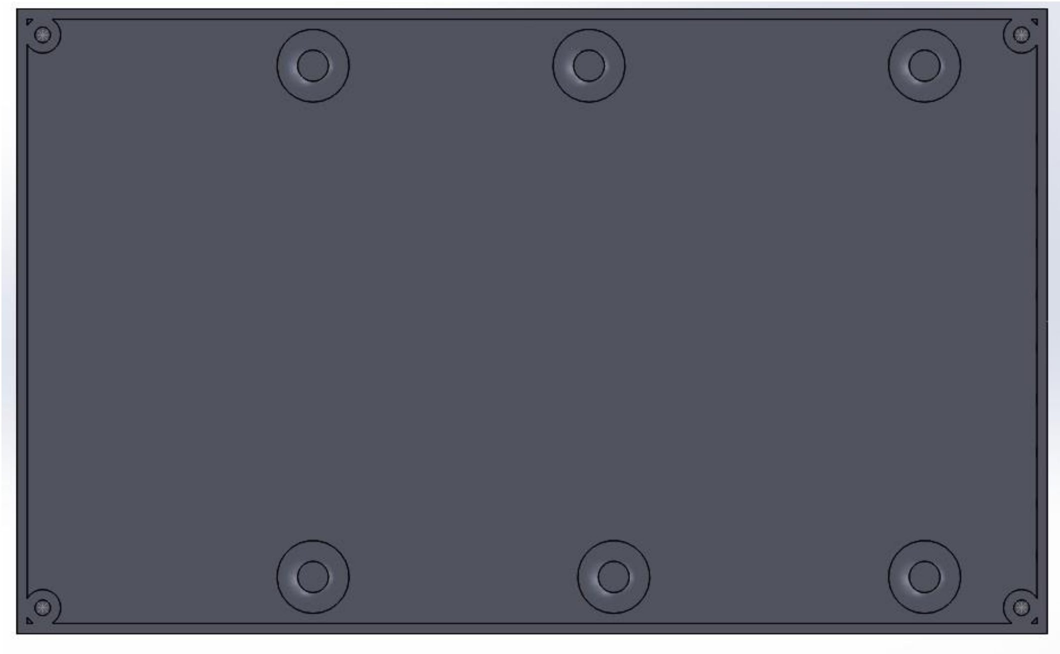

Figure 31 - Top View

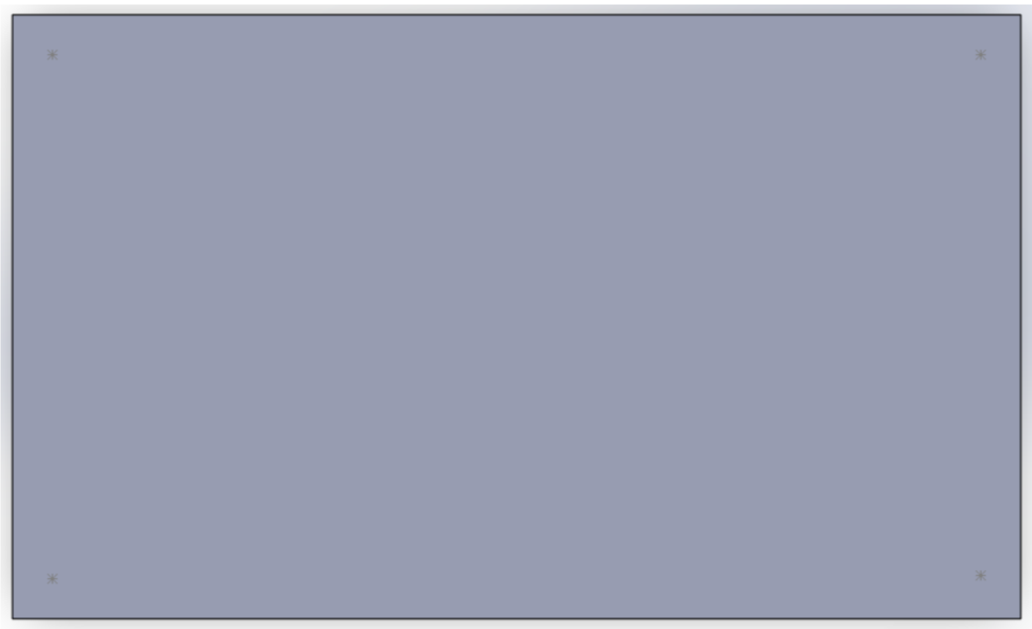

Figure 32 - Bottom View

individual contributions of each group member

Group - 16

DESHAN K.A.G.D. - 200117T

-Power Supply Circuit Design
-Encloser

KAVINDA W.M.C. - 200301D

-Firing Angle Circuit Design
-assembly
-Digital Circuit

PERERA G.L.S.M. - 200455C

-Sensor Interface Circuit Design
-Prepare Report
-soldering circuit

WEERASINGHA R.D.H.C. - 200699C

-PID control Circuit Design
-PCB design