Hot Plate Temperature Controller

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EN 2090 - Laboratory Practice-II

Hot Plate Temperature Controller

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Abstract

Hot plates available in the market are not integrated with a temperature control. Therefore when substances fall directly onto the hot plate hot plate will work continuously causing dangerous flames and drawing large amount of power. The task of this project is to design and implement a temperature control unit for hot plates whick support about 400°C temperature with about 1kW power consumption

0.1 Introduction

The task that was given to our group was to make a temperature controller unit for hot plates without using digital electronics (except for the display). The temperature controller unit should support about 400°C temperature and about 1kW power consumption.

Common temperature controllers used in the industry are digital controls and bimetal strip controls. When using bimetal strips the strip acts as both temperature sensor and the actuator that controls the power supply. Bimetal strips are basically discreet control system that switch on when temperature is below the expecting value and switch on when the temperature is above the expecting value.

Hence we considered to implement a feedback loop analog control system. Such system will consist of a temperature sensor, power supply and a method to compare the sensor reading with the expecting temperature and control the power input according to the feedback (sensor reading).

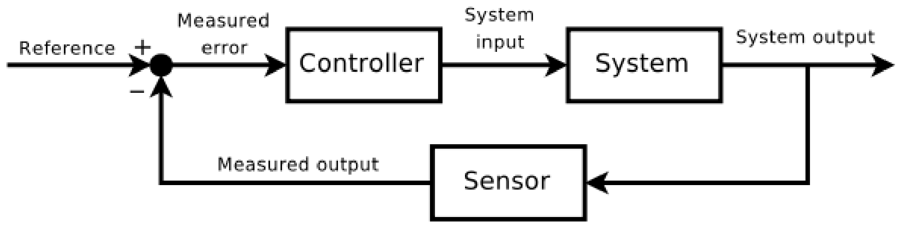

Figure 1: Feedback Control

In order to decide appropriate methods and instruments to design and implement feedback loop temperature controller we went on a literature survey.

Consider power supply voltage is Sri Lankan house supply voltage 230V 50Hz AC.

0.1.1 Literature Review

Feedback Error Control

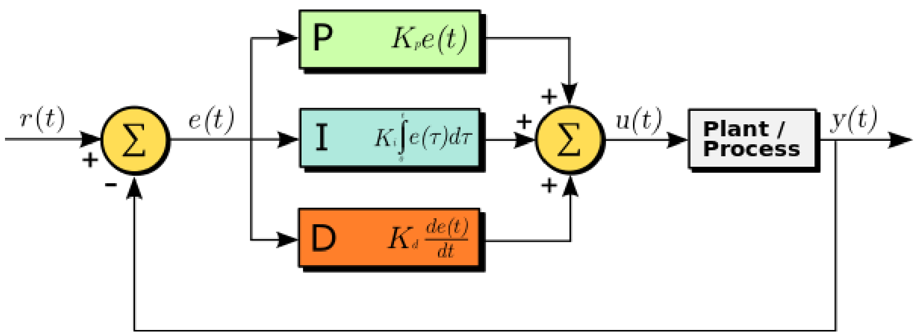

Figure 2: PID Control

When we consider feedback temperature controls. Negative feedback controls are in use because positive feedback controls are unstable. PID and fuzzylogic systems are two approaches. Since PID is more appropriate for an analog approach because continuous values of a parameter (temperature) are considered we decide PID control system

For PID control let E be the error value that the difference between sensor reading and the expecting temperature value. The output is given by the following equation.

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

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

Smooth and accurate temperature controlling can be obtained by adjusting the above three coefficients suitably.

This comparison, multiplication, differentiation, integration and addition should be by analog electronic components. Operational Amplifier is an analog electronic component possess ability to do all above calculations.

Operational amplifier

Provide facility to do comparison between values and arithmatic calculations. Hereby we discript how these different calculations can be obtained by Op- Amps

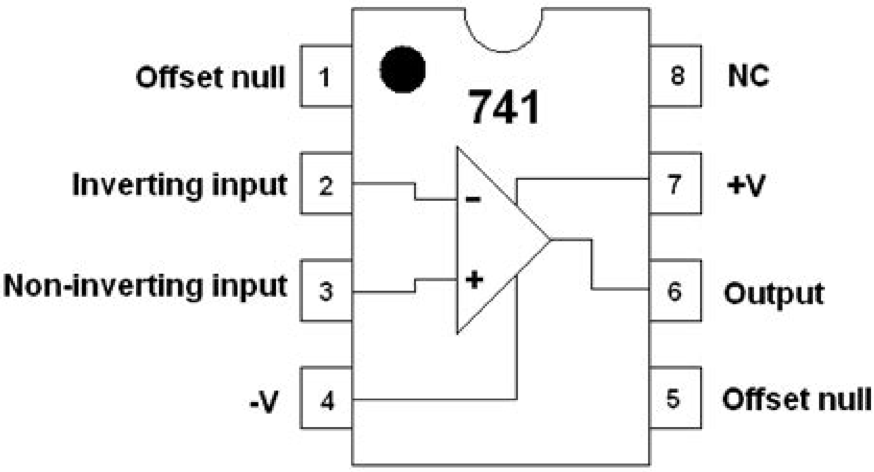

Figure 3: 741 OP-Amp Pin Configuration

Compare Supply two voltages you want to compare to two input terminals of an open loop operational amplifier. If inverting input is higher output will be equal to negative supply voltage and if non inverting input is higher output will be equal to positive supply voltage.

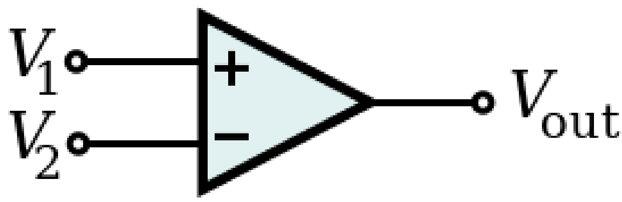

Figure 4: Compare Two Voltages

Differentiate Supply input through a capacitor (of C) to the inverting input and supply negative feedback through a resistor (of R). Ground the non inverting input.

$I = C\frac{dV_{in}}{dt}$
$I = \frac{-V_{out}}{R}$
$V_{out} = -RC\frac{dV_{in}}{dt}$

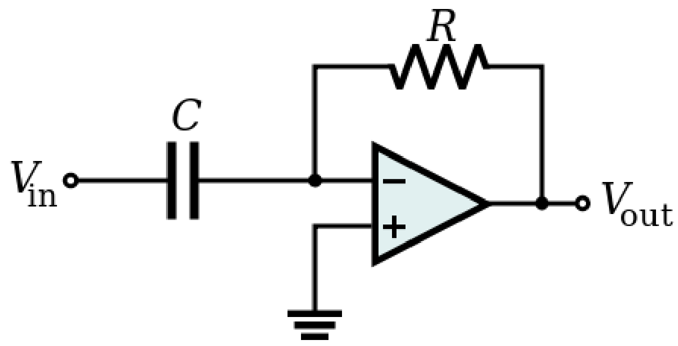

Figure 5: Perform Differentiation with Op-Amps

Integration Supply input through a resistor (of R) to the inverting input and supply negative feedback through a capacitor (of C). Ground the non inverting input.

$I = \frac{-V_{in}}{R}$
$I = C\frac{dV_{out}}{dt}$
$V_{in} = -RC\frac{dV_{out}}{dt}$
$V_{out} = -\frac{1}{RC}\int V_{in}dt$

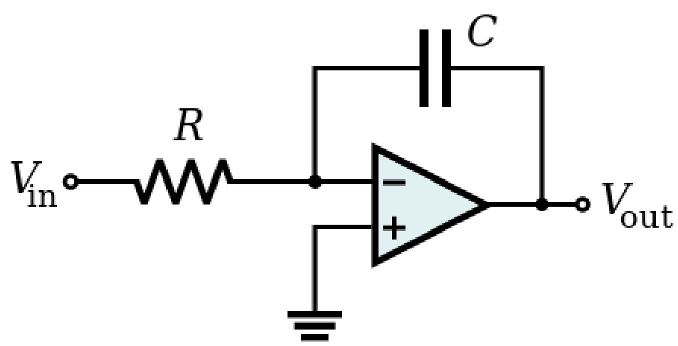

Figure 6: Perform Integration with Op-Amps

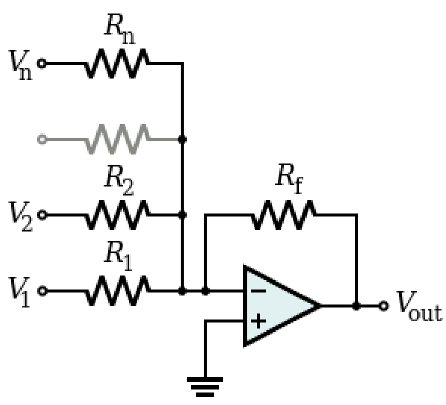

Figure 7: Perform Addition with Op-Amps

Addition Supply inputs through several resistors (of R) to the inverting input and supply negative feedback through a resistor (of R). Ground the non inverting input.

$I = \frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R} + ...$
$I = \frac{-V_{out}}{R}$
$V_{out} = V_1 + V_2 + V_3 ...$

Sensor

Various temperature sensors are available in the market. The major problem is many sensors cannot resist high temperatures such as 400°C. Themocouple will be a solution since it works also in high temperature, however a thermocouple needs a fixed for one end. It is impractical to implement a fixed temperature accurately therefore termocouple is not a suitable solution. A thermistor also can be used but calibration will be difficult and accuracy is low. Therefore we choose PT100 sensor to measure temperature.

> Platinum resistance thermometers (PRTs) offer excellent accuracy over a wide temperature range (from –200 to +850 °C).

("PT100 platinum resistance thermometers", n.d.)

PT100 sensor should be activated by using about 1mA current because higher currents may generate extra heat.

> The current through the sensor will cause some heating: for example, a sense current of 1 mA through a 100 ohm resistor will generate 100 µW of heat. If the sensor element is unable to dissipate this heat, it will report an artificially high temperature. This effect can be reduced by either using a large sensor element, or by making sure that it is in good thermal contact with its environment.

("PT100 platinum resistance thermometers", n.d.)
Therefore special circuit is needed to limit the power to the sensor. It is designed modifying an industrial popular circuit.

> An approximation to the platinum RTD resistance change over temperature can be calculated by using the constant a = 0.00385Ω/Ω/°C (European curve, ITS-90). This constant is easily used to estimate the absolute resistance of the RTD at temperatures between -100°C and +200°C (with a nominal error smaller than 3.1°C).

(Baker, 1998)

> The principle of operation is to measure the resistance of a platinum element. The most common type (PT100) has a resistance of 100 ohms at 0 °C and 138.4 ohms at 100 °C. There are also PT1000 sensors that have a resistance of 1000 ohms at 0 °C.
> The relationship between temperature and resistance is approximately linear over a small temperature range: for example, if you assume that it is linear over the 0

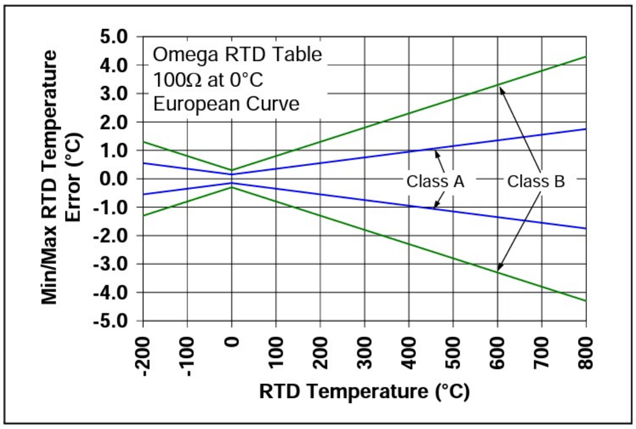

Figure 8: Platinum Sensor Behaviour

to 100 °C range, the error at 50 °C is 0.4 °C. For precision measurement, it is necessary to linearise the resistance to give an accurate temperature. The most recent definition of the relationship between resistance and temperature is International Temperature Standard 90 (ITS-90).

The linearization equation is:

$R_t = R_0(1 + At + Bt^2 + C(t - 100)t^3)$

Where:

R_t is the resistance at temperature t, R0 is the resistance at 0 °C, and $A = 3.9083 \times 10^{-3}$ $B = 5.775 \times 10^7$ $C = 4.183 \times 10^{12}$ (below 0 °C), or $C = 0$ (above 0 °C)

("PT100 platinum resistance thermometers", n.d.)

Figure 9: PT100 Sensor

Power Controlling

The power supply to the hot plate should be controlled according to the sensor reading. Likewise this is done by pwm in digital electronics we have to cut down the AC wave. This can be done by a triac.

Table 1: Advantages and Disadvantages.

Advantages	**Disadvantages**
Very accurate and stable	Expensive solution
Reasonably linear	Required current excitation
Goodrepeatability	Danger of self heating Low resistive element

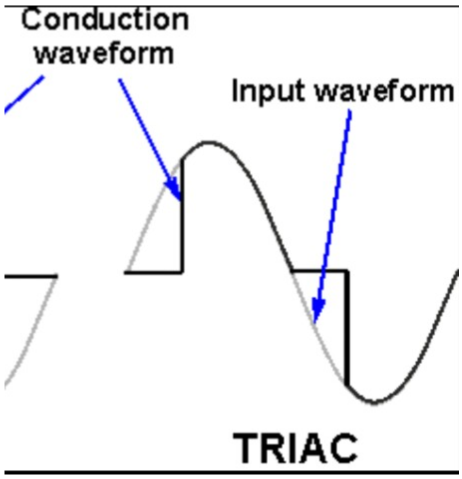

Figure 10: AC Signal Controlled by a TRIAC

Triac

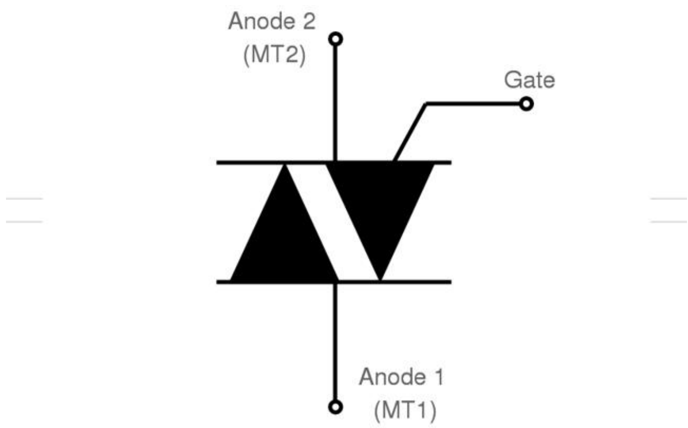

Figure 11: TRIAC

AC currents can flow through a Triac. When an AC voltage is supplied to a Triac current does not flow until gate votage is supplied - Triac is fired. When gate voltage is supplied the current will flow until the start of next half cycle. Therefore we can cut AC waves vertically using a Triac by providing gate voltage at the phase we like.

To provide gate voltage repeatedly at the required phase we have to control Triac firing angle. To this purpose triac firing angle circuit should be implemented.

0.2 Method

PT 100 sensor is used to measure temperature. Power is supplied to the sensor through a current control circuit. PT100 reading value is compared with a known voltage - corresponding to required temperature.

The difference between above two votages is called error hereafter. Error is added to its derivative and integral and time domain with weighting coefficients for each component in order to get PID output

This multiplication differentiation integration addition and comparison is implemented by 741 Op amps. Variable resistors were connected serially with fixed resistors in order to tune PID coefficients by changing the value of variable resistors.

MOC3022 Optocoupler is used to seperate main power supply from the temperature controller circuit to ensure safety.

AC power supply goes through a TRIAC. Power supply controlled by adjusting Triac firing angle - the gate voltage supply phase.

0.2.1 Triac Firing Angle Control Circuit

Triac firing angle control circuit has several parts: Step down and rectifying, Zero crossing detection, Ramp Generation, Compare with a voltage value

Step down and Rectifying

Power supply is step down to ±12V by a transformer and the it is subjected to full wave rectify by a diode bridge.

Zero crossing detections

Above rectified signal is connected to the inverting input of an open loop OpAmp and a voltage through a diode (0.7V) is connected to the non inverting input. Negative supply of the Op Amp is grounded while positive power supply is 12V.

In the short time when the voltage is smaller than 0.7V a 12V pulse is generated. This pulse indicates when zero crossing voltages occur. These needle pulses are used to generate a periodic ramp signal.

Ramp Generation

A capacitor is connected to 12V voltage (through a resistor) and ground. A transistor is connected to high voltage pin of the capacitor and the ground by collector and emitter pins. When the transistor is cut off the capacitor will charge. When the transistor is activated the capacitor will discharge through the transistor. When the needle pulse array of the above section is supplied to the base terminal of the transistor, transistor will discharge the capacitor when a pulse occurs. Therefore when a pulse occurs voltage between the capacitor will become zero and then it will gradually charge and increase to 12V until next pulse will discharge it again to 0V.

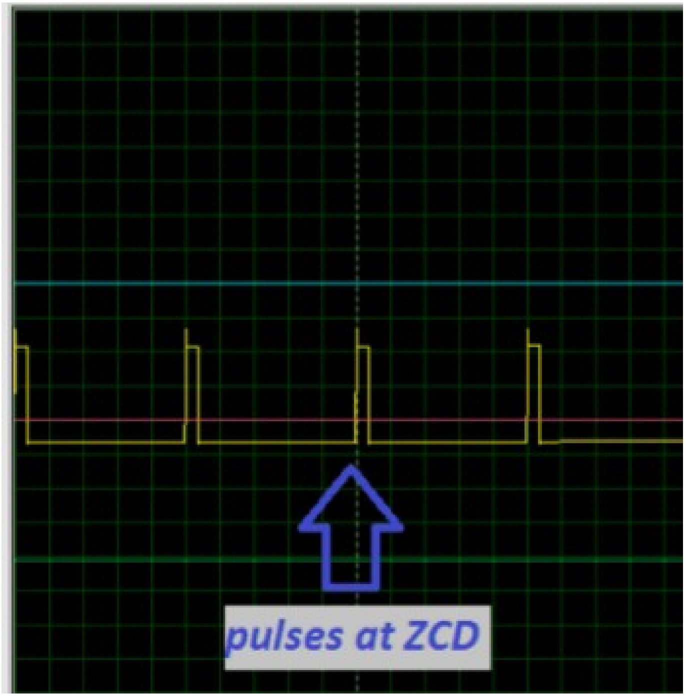

Figure 12: Zero Crossing Detection

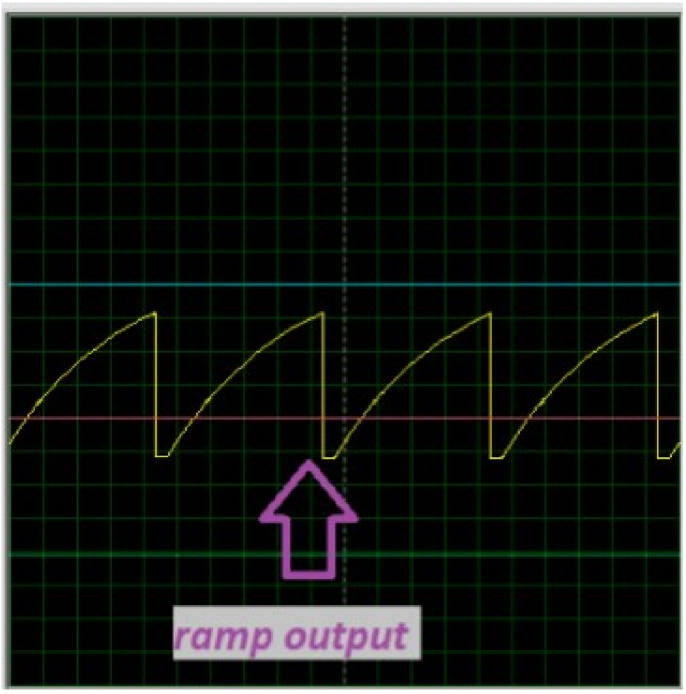

Figure 13: Ramp Generation

Compare with PID Voltage

Then the ramp is compared with the PID output voltage by an open loop Op amp. This will genarate a pulse width modulated signal. This is supplied to the gate of the Triac in order to pulse with modulate the AC power supply.

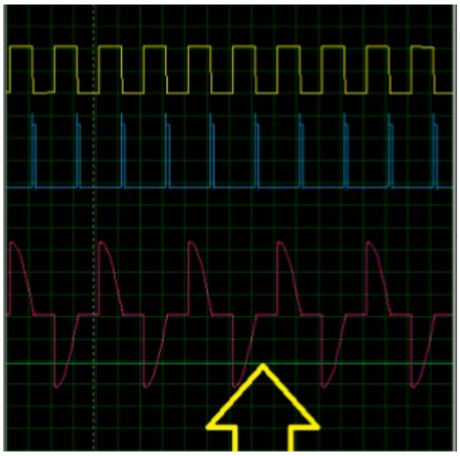

Figure 14: Controlled Power Signal

0.2.2 Operation

When the AC power is supplied hot plate will work and temperature will go on sensor will measure the temperature and PID uniy will compare it with the required temperature and calculate the PID output.

Triac firing angle unit will create a pulse width modulated signal of twice of frequency of power supply. Pulse with will indicate power that should be supplied to the hot plate. Triac will control the power supply according to the pwm signal. The temperature of the hot plate will be controlled in this manner.

0.3 Results

Your Result

Table 2: Result Table.

Resistance R (kΩ)	**Temperature** θ (°C)	**Current** I (A)	**Power** P (W)
1	4	a	
2	5	b	
3	23	c	

According to Table 2 we can say ...

0.4 Conclusion

Your conclusion

0.5 Acknowledgements

We offer our gratitude to Mr. Janith Kalpa Gunarathana for providing us consultation and relevant details.

References

Baker, B. (1998). Precision temperature sensing with rtd circuits. *AN687, Microchip Technology Inc.*

Pt100 platinum resistance thermometers [Computer software manual]. (n.d.). Retrieved from `https://www.picotech.com/library/application-note/pt100-platinum-resistance-thermomet`

Appendices

.1 Schematics

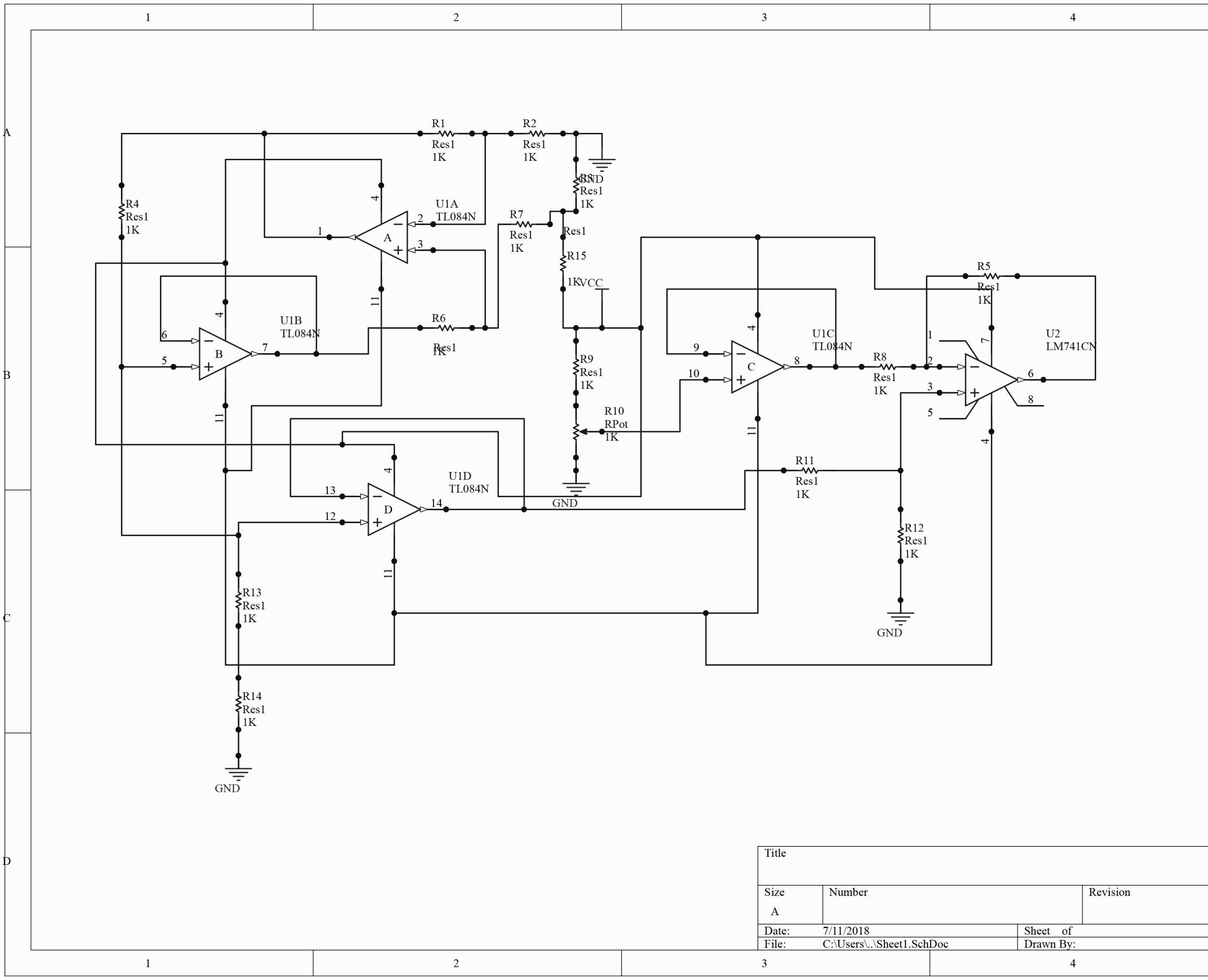

Figure 16: Sensor Input Circuit

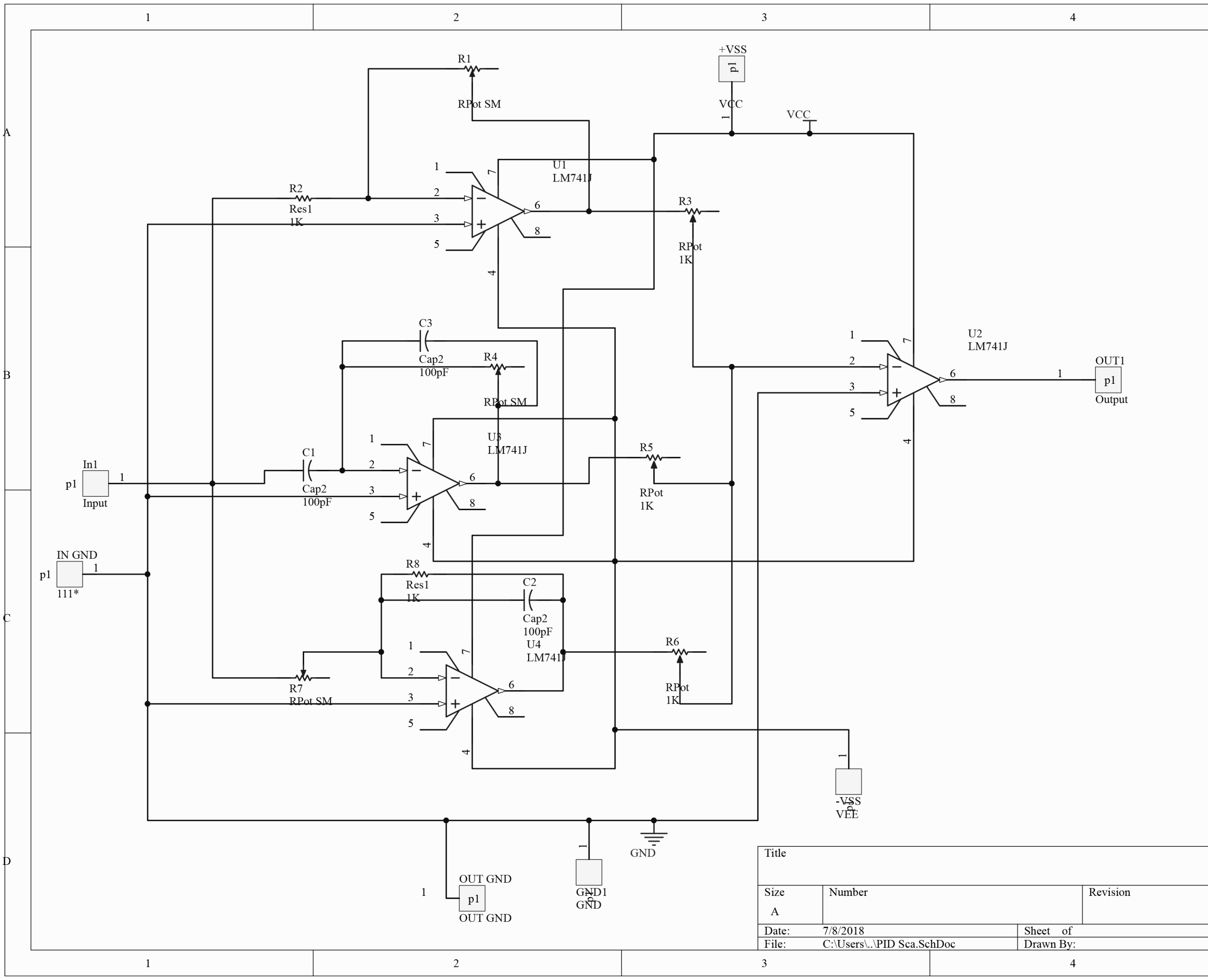

Figure 17: PID

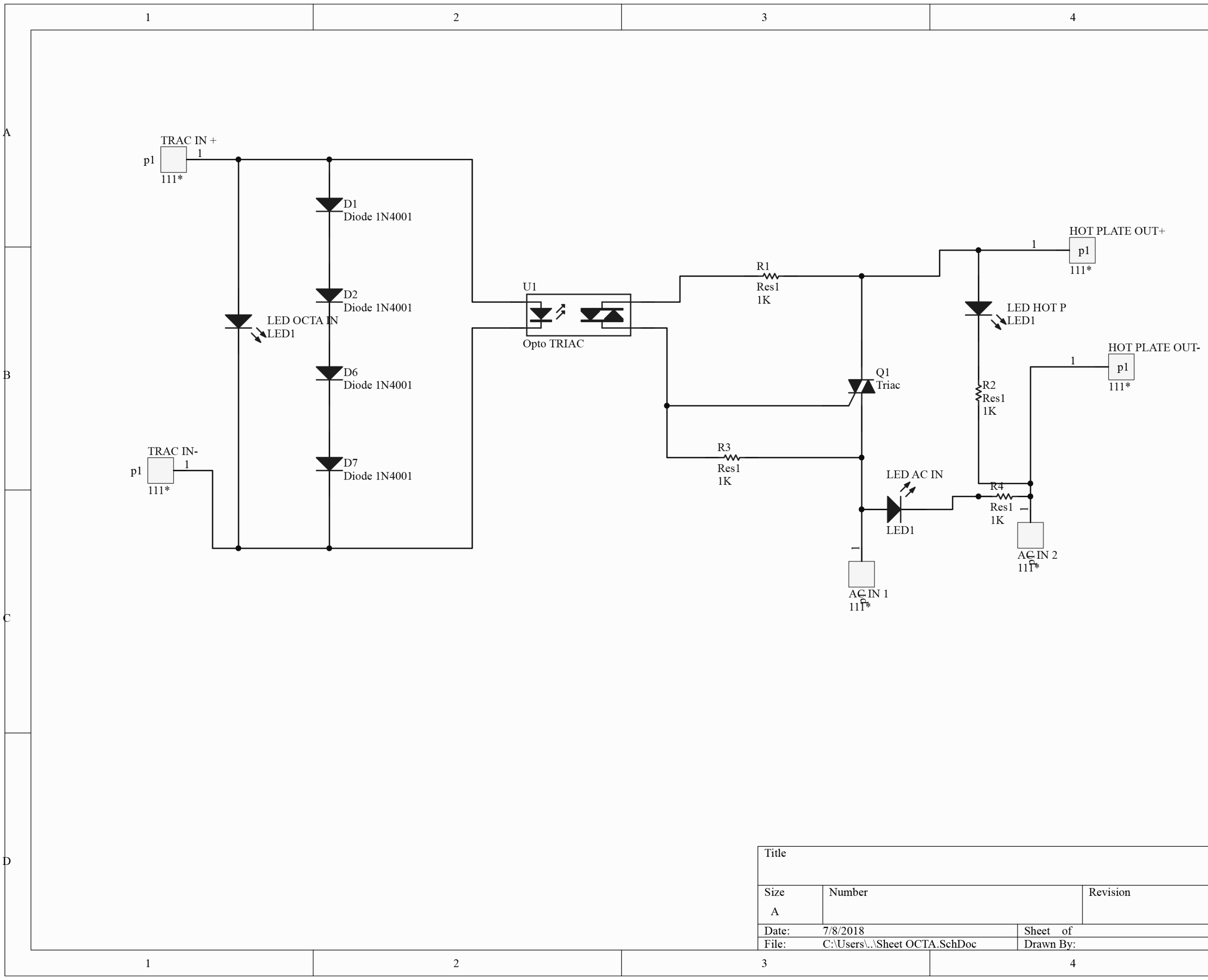

Figure 18: Track Driver

.2 Layouts

CAMtasticDXP (TM):

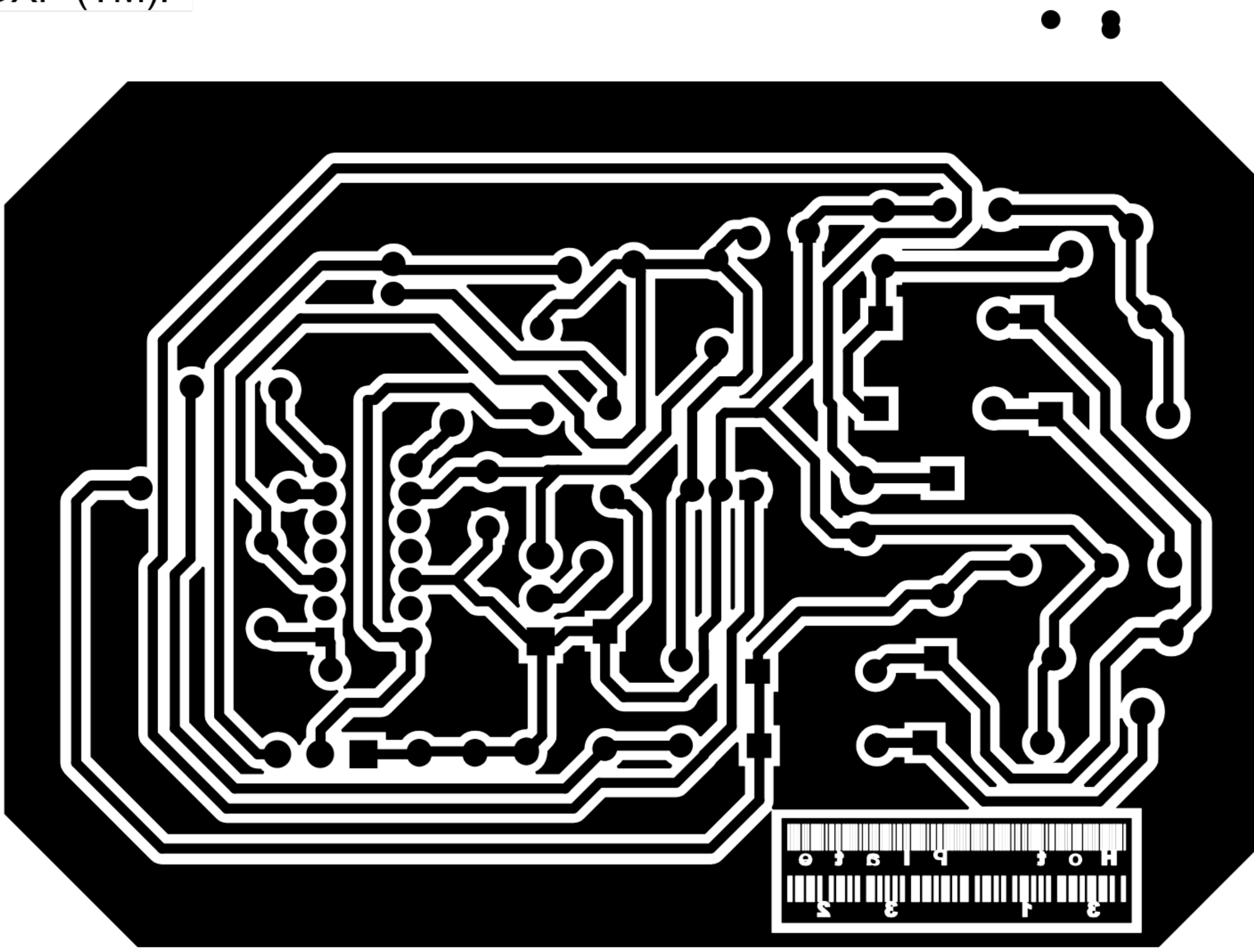

Figure 19: Track Driver

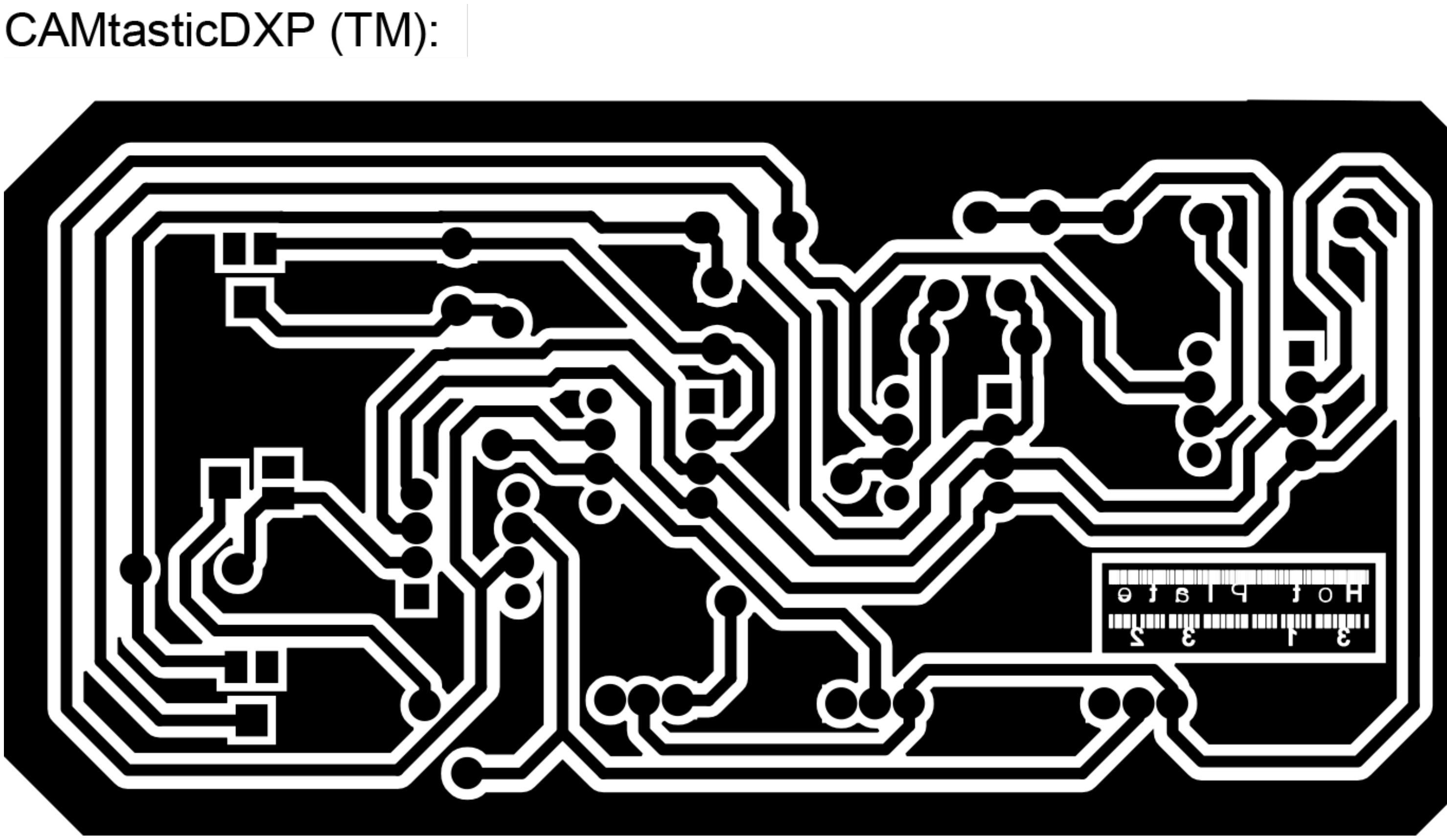

Figure 20: PID

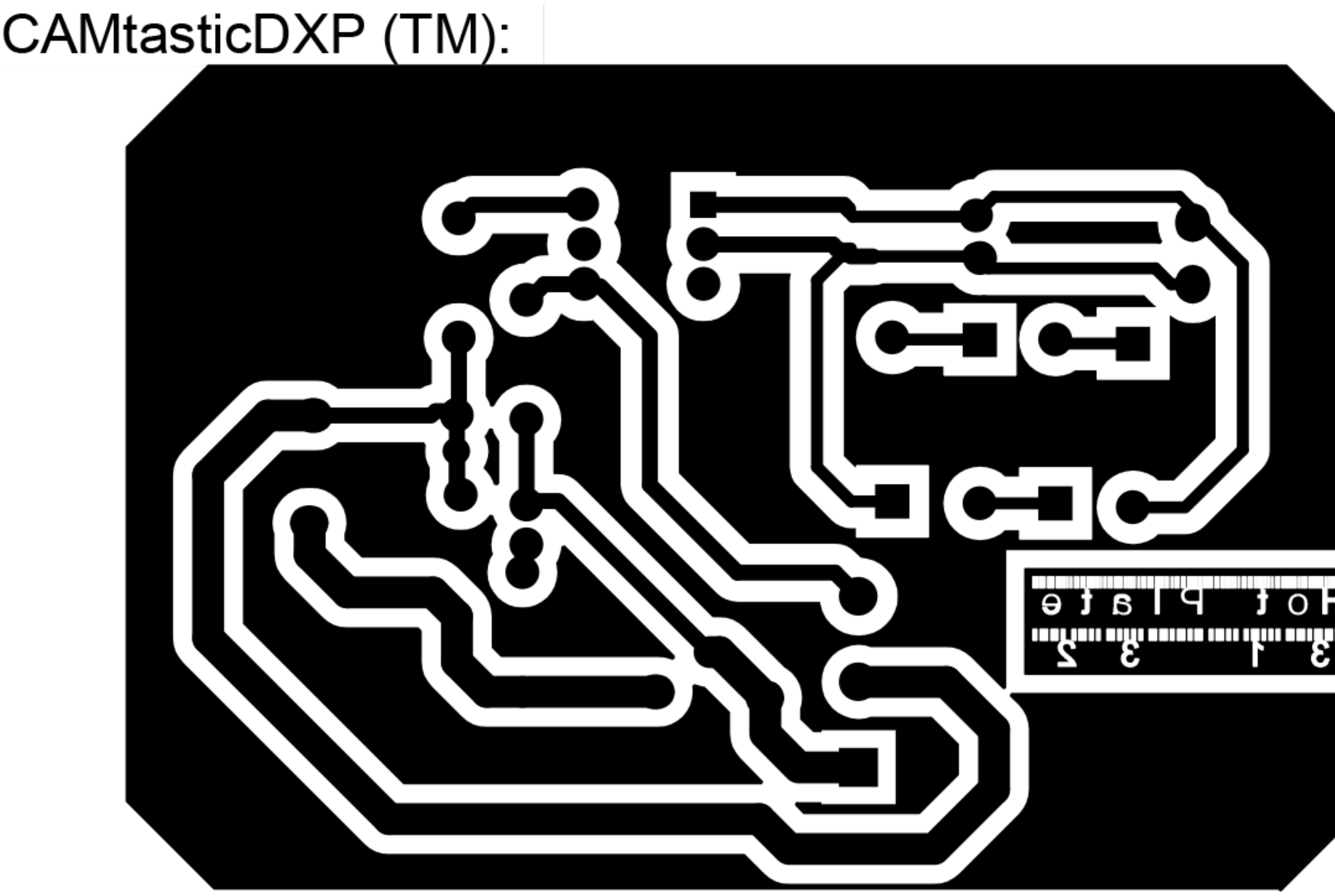

Figure 21: Power Supply

.3 Datasheet

MORA INDUSTRIES

Hot Plate Temperature Control

Hot plate temperature controller is made by a group of students in University of Moratuwa as their analog electronic project. This Hot plate temperature control is an external device connected to a normal hot plate in order to control the temperature at required level.

Inventors

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R.M.I.P. Rajapakshe
K.U.K.U.M. Rajapaksha
T.M. Piyadigama

Supervising **:** Janith Kalpa Gunarathne

Specifications

Supply Voltage	230V 50Hz
Operating Voltage Range	90% - 110% of supply voltage
Power Consumption	1kW
Input	PT 100 sensor
Control Method	PID control
Setting Method	Analog
Indication Method	No indication
Control Output	3-5A
Working Temperature	350-500°C

Characteristics

Setting accuracy	---
Hysteresis	---
Proportional Band	8--10
Control Period	Approx.30s
Reset Range	No reset function incorporated
Weight	300g
Applicable Socket	Three pin plug point

Operation

230V 50Hz power should be supplied. PT 100 sensor should place at the hot plate and hot plate should be plugged at output socket.

About 350-500°C temperatures can be maintained.

Figure 22:

List of Figures

List of Tables