Simulation of an Induction Cooktop Circuit, Implementation of Control and Safety Features for an Induction Cooktop Using Microcontroller Unit

Thesis submitted to the

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For award of the degree

of

Bachelor of technology

by

Surakanti Harnav Reddy

Under the guidance of

Dr.Olive Ray

SCHOOL OF ELECTRICAL SCIENCES

INDIAN INSTITUTE OF TECHNOLOGY BHUBANESWAR

April 2024

CERTIFICATE

This is to certify that the B.tech project entitled **Simulation of an Induction Cooktop Circuit, Implementation of Control and Safety Features for an Induction Cooktop Using Microcontroller Unit**, submitted by **Surakanti Harnav Reddy** to Indian Institute of Technology Bhubaneswar, is a record of research review work under my supervision and the report is submitted for End-semester evaluation of the B.tech project.

Date : 2/5/2024.

ORay 2/5/24

Dr.Olive Ray
Assitant professor
School of Electrical Sciences
Indian Institute of Technology Bhubaneswar
Bhubaneswar, India

DECLARATION

I certify that

a. The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor.

b. The work has not been submitted to any other institute for any degree or diploma.

c. I have followed the guidelines provided by the institute in writing the thesis.

d. I have conformed to the norms and guidelines given in the ethical code of conduct of the institute.

e. Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

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Surakanti Harnav Reddy

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I extend my deepest appreciation to Dr.Olive Ray for their exceptional guidance throughout the design journey of Induction Cooktop. Their cool and innovative approach has made this experience not only enriching but also enjoyable.

Dr.Olive Ray has blended professionalism with a relaxed demeanor, fostering an atmosphere where creativity thrives. Their encouragement, trust in our ideas, and openness to unconventional approaches have empowered our team to excel.

Beyond their technical expertise, Dr.Olive Ray has been a mentor and friend, approachable and supportive at every step. Their influence has left an indelible mark on this project and each team member, for which we are immensely grateful.

Thank you, Dr.Olive Ray, for your invaluable guidance and for making this journey memorable. I eagerly look forward to the opportunity to continue our collaboration in my M.Tech thesis.

Surakanti Harnav Reddy

ABSTRACT

The purpose of this paper is to present the innovative design of an induction hob that is specifically designed to enhance cooking efficiency and safety. The market has been traditionally dominated by gas and electric cooktops. However, due to their inefficiencies and safety concerns, there is an increasing demand for alternative solutions. The utilization of electromagnetic induction in induction cooking allows for the direct heating of cookware, resulting in notable benefits such as enhanced energy efficiency, precise control over power, and a decreased likelihood of burns.

The induction hob design being proposed includes various essential features aimed at improving user experience and mitigating common limitations found in current models. The utilization of advanced electromagnetic technology allows for efficient and consistent heating, while simultaneously reducing energy consumption. Furthermore, the implementation of precise temperature control enables users to finely tune heat levels, thereby minimizing the probability of overcooking or burning food. In addition, the appliance is equipped with safety features including automatic pan detection and overheat protection mechanisms. These features are designed to prevent accidents and prioritize the safety and well-being of the user.

The induction hob presented in this paper showcases an innovative design that addresses cost-effectiveness and safety concerns commonly associated with traditional cooking methods. Overall, this solution offers a compelling alternative for users seeking improved efficiency and reduced risks. The proposed induction hob is a notable advancement in kitchen appliance technology due to its combination of energy efficiency, precise control, and enhanced safety features.

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1 Introduction

The induction hob is a cutting-edge feature found in modern kitchens. It offers fast and accurate cooking, as well as improved energy efficiency and safety. The demand for induction hob designs that align with evolving culinary practices and prioritize sustainability has grown significantly. These designs aim to not only meet these demands but also enhance the overall cooking experience. The objective of this project is to develop an induction hob that prioritizes efficiency and safety, while also incorporating user-friendly features and a visually appealing design.

The crux of this project involves the identification and resolution of the constraints associated with current induction cooktops. Although these appliances provide notable benefits compared to traditional cooking methods, they frequently have limitations in terms of heat distribution, user interface design, and compatibility with different types of cookware materials. This project aims to address and overcome the challenges associated with induction cooktops, with the goal of revolutionising and redefining their standard. The ultimate objective is to position induction cooktops as leading-edge kitchen appliances in the modern era.

The objective of this project is to conceptualize and develop a hob that demonstrates exceptional performance, versatility, and user satisfaction by thoroughly examining materials, technologies, and user requirements. The design will meticulously craft every aspect, from optimizing the electromagnetic induction system to enhancing safety features like automatic pan detection and child lock mechanisms. This will result in a seamless and enriching cooking experience.

Moreover, this project acknowledges the significance of sustainability in the design and manufacturing of products. The design process of our cooktop prioritizes energy efficiency, recyclability, and longevity. Our goal is to create a cooktop that not only enhances the lives of users but also minimizes its environmental footprint.

This project explores the intricacies of electromagnetic induction, which is the fundamental principle that underlies the operation of induction hobs in the field of electrical engineering. By employing a rigorous approach to optimizing the electromagnetic induction system, which encompasses the meticulous design of the induction coils and control circuitry, our objective is to achieve the highest possible energy transfer efficiency while also guaranteeing accurate control over cooking temperatures. The induction coils will be regulated using advanced power electronics and control algorithms, enabling rapid heating and precise power control on the cooking surface.

2 Simulation of Induction Cooktop Circuit

2.1 Topology of Single switch based Resonance circuit

2.1.1 Theory

In the context of induction cooktops, switch resonance circuits play a crucial role in controlling the power delivery to the cooking coil. The function of these circuits is to convert the input AC power into high-frequency AC power, which is subsequently delivered to the induction coil. The following is a summary of the current state of the art regarding various types of switch resonance circuits utilized in induction cooktops.

Single-switch resonant converters offer enhanced efficiency and reduced switching losses compared to traditional converters. Operating on the principle of resonant tank circuits, they employ soft-switching techniques to minimize losses and achieve higher efficiency. Key components include an active switch, resonant inductor, capacitor, and sometimes a transformer. Variations like the LLC and LCC topologies provide different advantages in efficiency and complexity. Benefits include reduced EMI, higher efficiency at light loads, and improved controllability. Applications span power supplies, renewable energy systems, and electric vehicle chargers. Single-switch resonant topology is poised to play a vital role in future power electronics due to its versatility and efficiency.

In addition to their efficiency advantages, single-switch resonant converters offer improved reliability and reduced electromagnetic interference (EMI) compared to traditional converters. The converters achieve lower voltage and current stress on components and consequently experience extended lifespan and reduced maintenance requirements by operating at resonance. In addition, the utilisation of soft-switching techniques in resonant converters leads to more seamless transitions during switching events, thereby minimizing voltage spikes and decreasing the production of electromagnetic noise.

2.1.2 Circuit Diagram

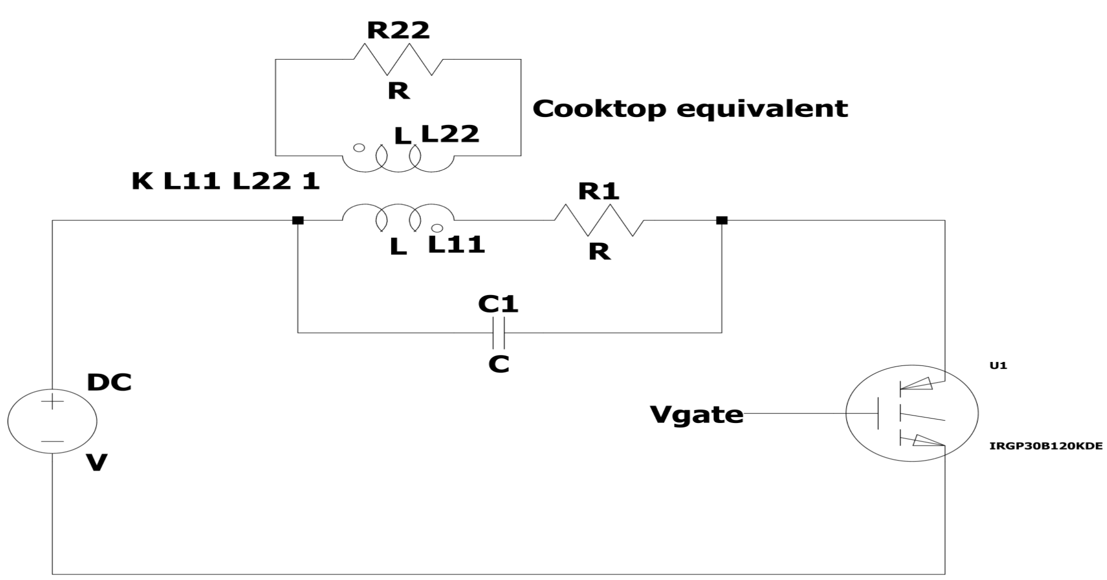


Figure 1: Single switch resonance circuit

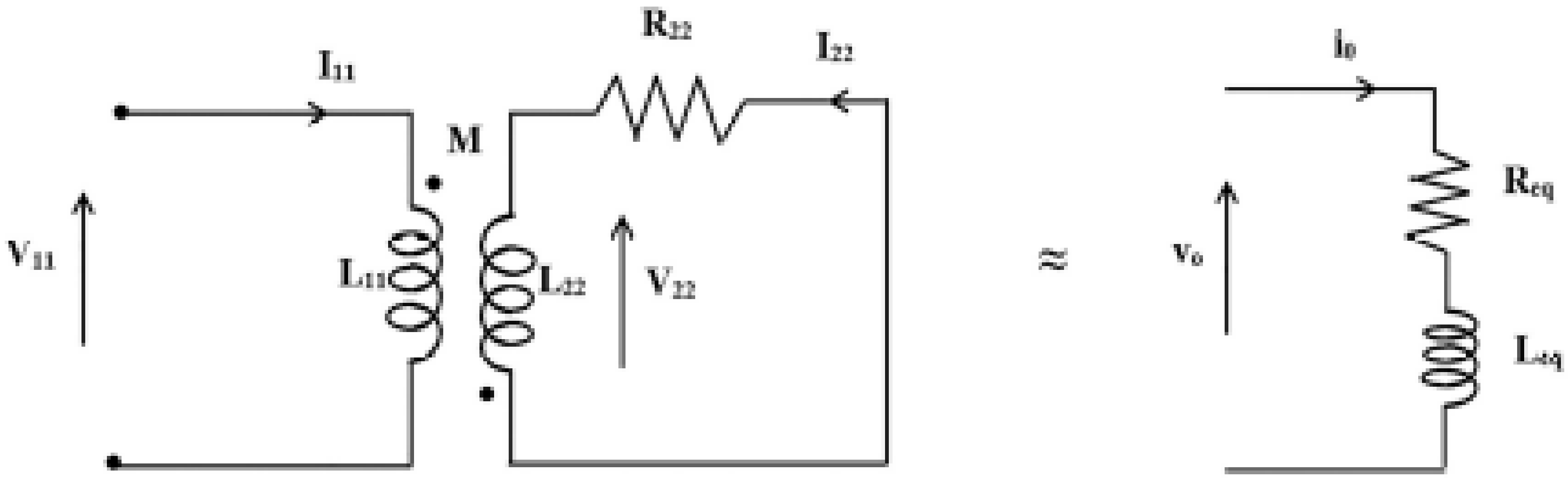


Figure 2: Equivalent circuit of induction coil and cookware

We know that the resistance is due to the eddy currents flowing due to changes in the direction of magnetic fields at high frequency. Therefore, R_{22} can be calculated as follows:

$$R_{22} = \frac{\rho l}{\pi r^2 - \pi(r-\delta)^2} \tag{1}$$

where,

$$\delta = \frac{1}{\sqrt{\mu \pi \sigma f}}$$

δ represents the skin depth,
μ is the permeability,
σ is the electrical conductivity.

From Figure 2 equivalent values of inductor and resistor can be calculated as

$$V_{11} = j\omega_{sw} L_{11} I_{11} - jM\omega_{sw} I_{22}$$
$$0 = -j\omega_{sw} I_{11} M + (R_{22} + j\omega_{sw} L_{22}) I_{22}$$

On solving the above two equations, we get:

$$R_{eq} = \frac{(\omega_{sw}^2 M^2 R_{22})}{R_{22}^2 + (\omega_{sw} L_{22})^2}$$
$$L_{eq} = L_{11} + \frac{(\omega_{sw}^2 M^2 L_{22})}{R_{22}^2 + (\omega_{sw} L_{22})^2}$$

where ω_{sw} is the angular switching frequency.
Using these equivalent values, the equivalent circuit is designed as shown in Figure **??**

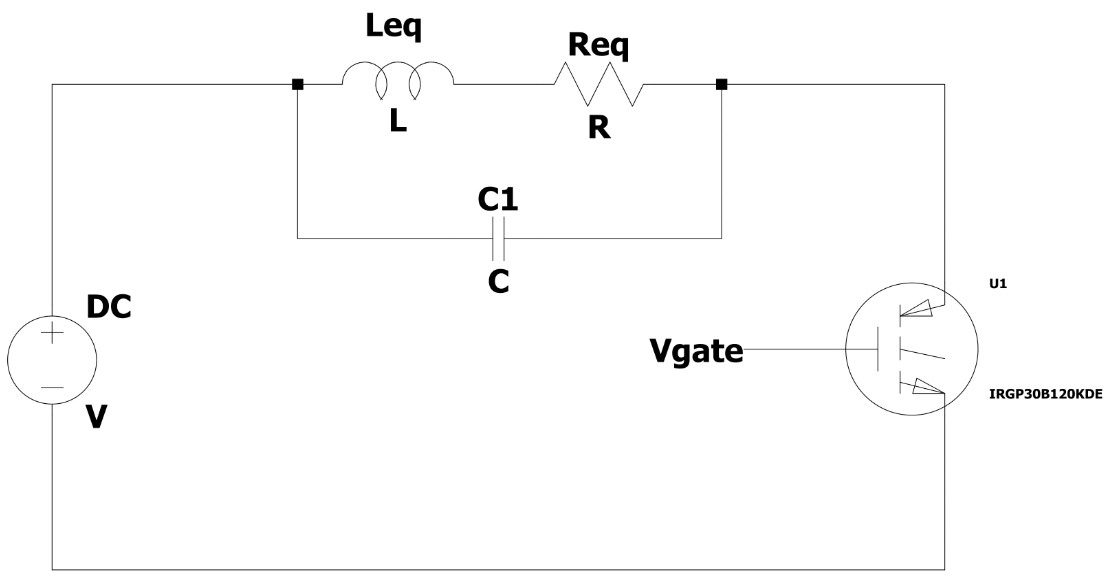
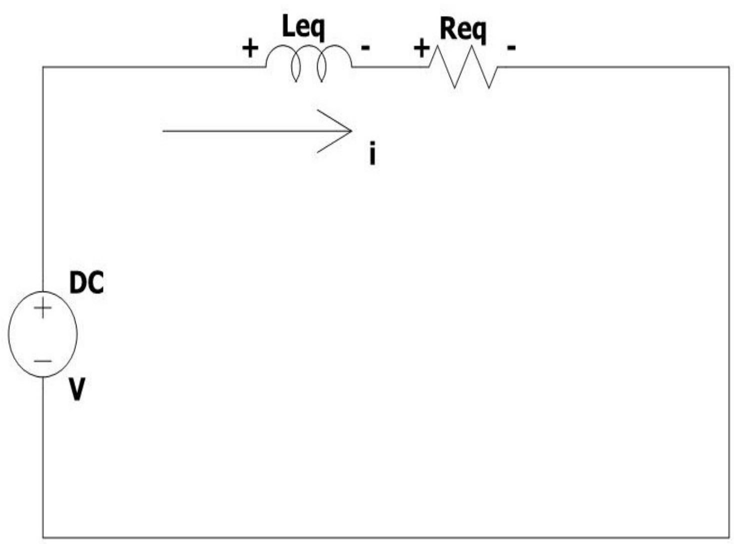
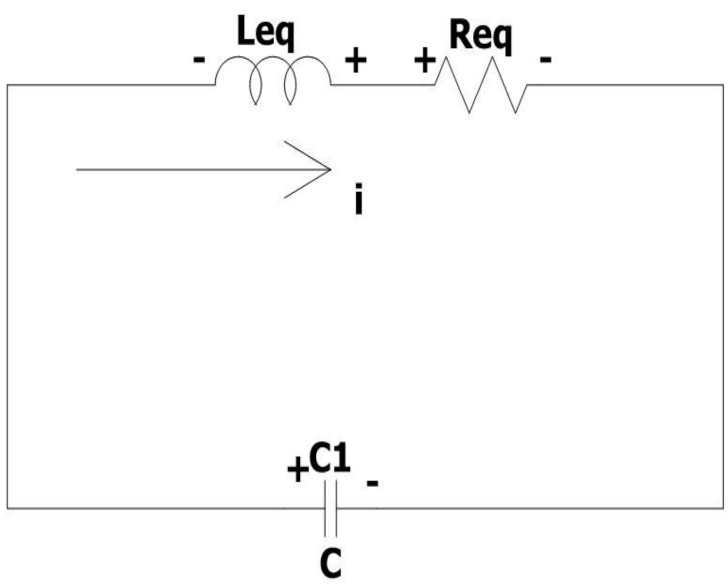


Figure 3: Equivalent circuit of Induction cooktop

Now we will move on to the switching pattern and the i_L waveforms.



a.Equivalent circuit when the switch is in the ON state



b.Equivalent circuit when the switch is in the OFF state

Figure 4: The switching states of the cirucit

When the switch is ON we can see from Figure 4(a) the flow of current is from the positive terminal(+) of the voltage source to the positive terminal(+) of Inductor

$$V = L\left(\frac{di_L}{dt}\right) + i_L \cdot R$$

$$\implies i_L = \frac{V}{R}\left(1 - \exp\left(-\frac{t}{\tau}\right)\right) + i_1 \cdot \exp\left(-\frac{t}{\tau}\right) \tag{2}$$

when the switch is OFF we can see from Figure4(b) the direction of current flow doesn't change because of the inductor.

$$\frac{q}{C} = L\left(\frac{di_L}{dt}\right) + i_L \cdot R \tag{3}$$

On differentiating the both side of (4) we get

$$\implies 0 = L\left(\frac{d^2 i_L}{dt^2}\right) + L\left(\frac{di_L}{dt}\right) - \frac{i_L}{C}$$

By solving the second-order differential equation above, we get

$$\implies i_L = A \cdot e^{\frac{1}{2}\left(-\frac{R}{L}+\sqrt{\frac{R^2}{L^2}+\frac{4}{LC}}\right)t} + B \cdot e^{\frac{-1}{2}\left(\frac{R}{L}+\sqrt{\frac{R^2}{L^2}+\frac{4}{LC}}\right)t} \tag{4}$$

from initial conditions i.e., @t=0 from (2) & (4) we get

$$i_L = \frac{V}{R}\left(1 - e^{-\frac{t_{\text{ON}}}{\tau}}\right) + i_1 \cdot e^{-\frac{t_{\text{ON}}}{\tau}}$$

$$\implies A + B = \frac{V}{R}\left(1 - e^{-\frac{t_{\text{ON}}}{\tau}}\right) + i_1 \cdot e^{-\frac{t_{\text{ON}}}{\tau}}$$

@t= t$_{OFF} i_L = i_1$

$$\implies i_1 = A \cdot e^{\frac{1}{2}\left(-\frac{R}{L}+\sqrt{\frac{R^2}{L^2}+\frac{4}{LC}}\right)t_{\text{OFF}}} + B \cdot e^{\frac{-1}{2}\left(\frac{R}{L}+\sqrt{\frac{R^2}{L^2}+\frac{4}{LC}}\right)t_{\text{OFF}}}$$

As we can see that L_{eq} and R_{eq} depend on the switching frequency of the inverter, we considered the values of already present experimental results in our Ltspice simulation.

2.1.3 Results

The results indicate that the current waveform exhibits an increasing trend when the switch is in the ON state. Conversely, when the switch is in the OFF state, the current value initially experiences a slight increase (attributed to the inductor effect) before gradually decreasing. The calculated results demonstrate a close alignment with the theoretical expectations, thereby confirming the accuracy and reliability of the computational methodology utilised.

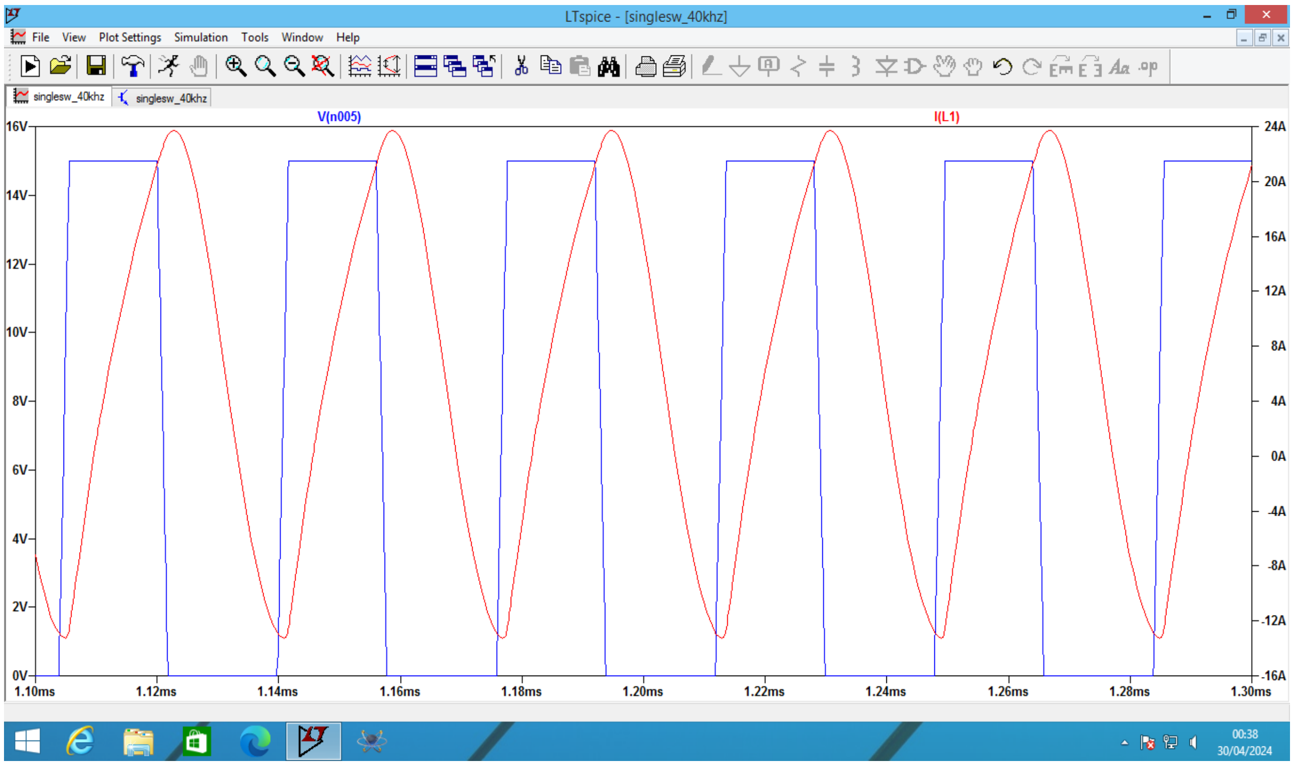


Figure 5: Current waveform and the gate signal

2.2 Detection of Resonant frequency pulse due to different cookware

2.2.1 Theory

Resonant detection circuits make use of the idea of resonance, in which the circuit's reactive elements capacitors, and inductors store and exchange energy at a specific frequency. Signals at a certain frequency can be efficiently detected or amplified by the circuit by matching its resonance frequency to that of the input signal, rejecting signals at other frequencies.

By operating at the resonant frequency of the WPT system, resonant detection circuits enable high-efficiency power transfer over significant distances, with minimal energy loss due to impedance mismatch or radiation. This makes them well-suited for applications such as wireless charging pads for consumer electronics, electric vehicles, and medical implants.

In induction cooktop different cookware consist of different materials which vary in electrical properties, such as conductivity and permeability, which can interact differently with the electromagnetic field generated by the induction cooktop. These interactions can alter the resonant frequency of the circuit, impacting the efficiency and performance of the cooktop. Understanding these effects is essential for optimizing the design and operation of induction cooktops for different cooking applications and environments.

It is detected with the help of a comparator with the terminals connected to the nodes of the resonant circuit.

2.2.2 Circuit Diagram

The AD8039 comparator is utilized for the purpose of comparing sinusoidal high-voltage signals. The circuit produces a square wave output, which is then connected to the voltage-controlled capacitor (V_c). The purpose of V_c is to block the DC offset and generate a square wave with a reduced peak-to-peak voltage. The signal is compared to ground in order to obtain a 5V peak-peak voltage signal that can be conveniently read by the microcontroller unit.

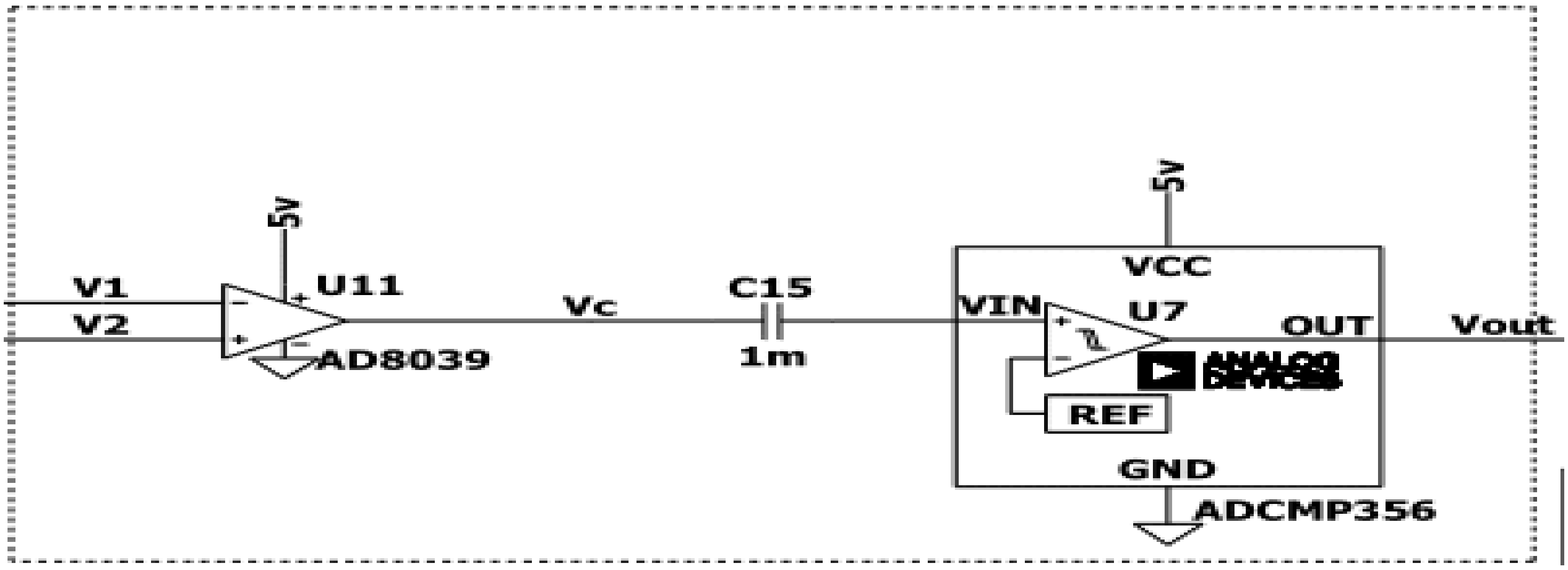


Figure 6: Resonant Detection circuit

2.2.3 Results

The V_c represents the square wave output of the comparator (AD8039) when the inputs V_1 and V_2 are measured across the heating coil, as shown in Figure A. The variable V_c represents the voltage after compensating for DC offset. Lastly, V_{out} serves as the input to the microcontroller unit to measure the resonance frequency of the circuit.

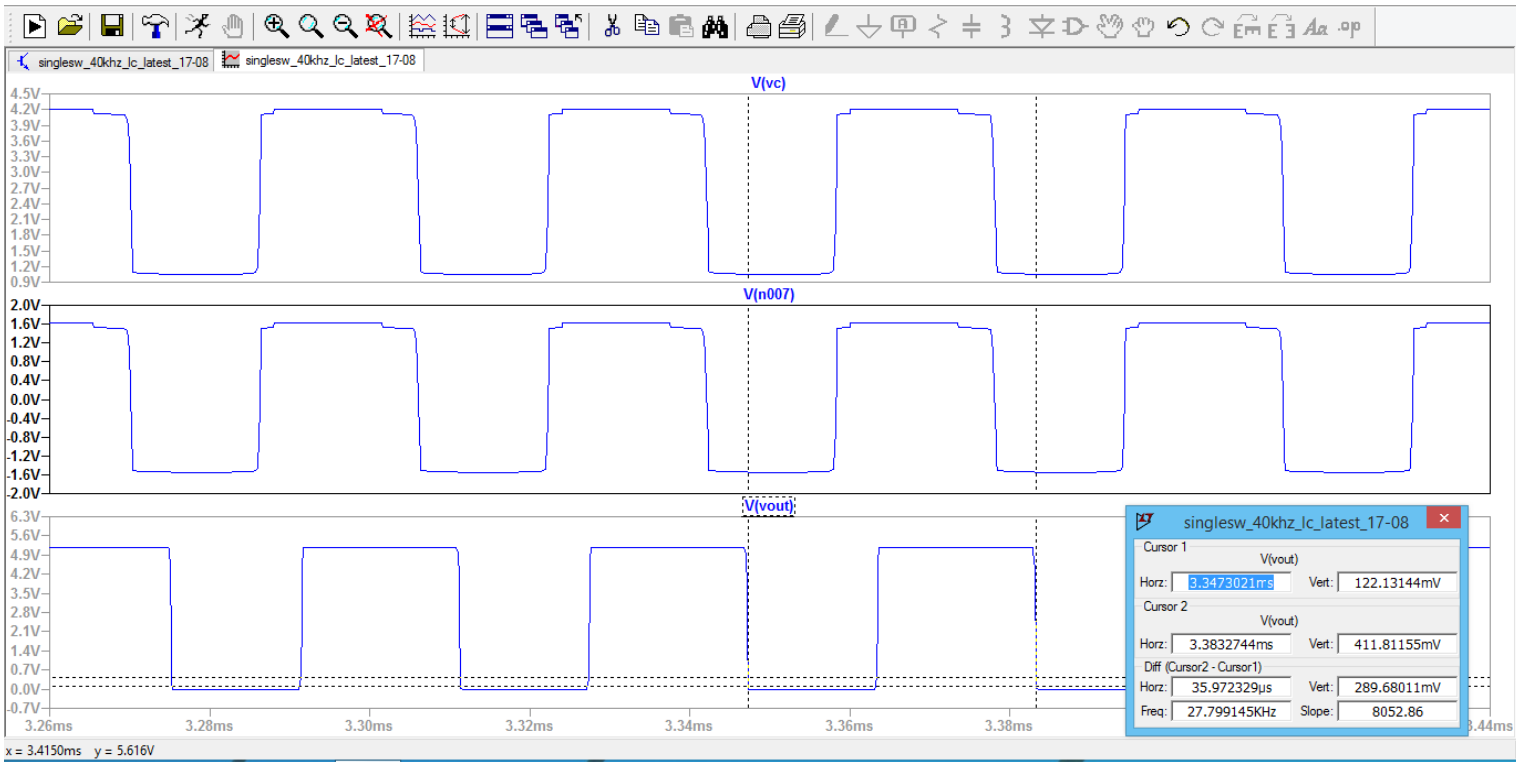


Figure 7: Output of the comparator

2.3 Detecting the presence of cookware over the induction hob

2.3.1 Theory

Cooktop detection systems utilize various sensing techniques such as inductive, capacitive, thermal, or optical sensing to detect the presence and properties of cookware. The theory of hob detection also includes safety features, such as automatic shutdown mechanisms, which are triggered when incompatible or non-metallic objects are detected on the surface of the hob. Induction cooktops guarantee safe and dependable operation in various cooking environments by constantly monitoring for the existence of cookware and potential safety hazards.

We have used the voltage sensing technique to detect the presence of cookware. When cookware is present, the voltage peak sensed at the collector end of the Insulated Gate Bipolar Transistor (IGBT) is reduced due to the voltage loss across the resistor. However, if the cookware is removed, the IGBT voltage increases. The IGBT voltage is compared with a reference voltage, which gives a positive edge when cookware is removed.

2.3.2 Circuit Diagram

The voltage at the collector terminal of the Insulated Gate Bipolar Transistor (IGBT) is reduced by resistors and then passed through a comparator (LTC1441). This comparator is used to generate positive or negative edges (V_{cook}), which are then transmitted to the microcontroller unit for circuit control.

2.3.3 Results

The values of the resistors are calibrated so that the refernce value matches for all the types of cookware used.Based on the output of the circuit used for detection of cookware the microcontroller operates.

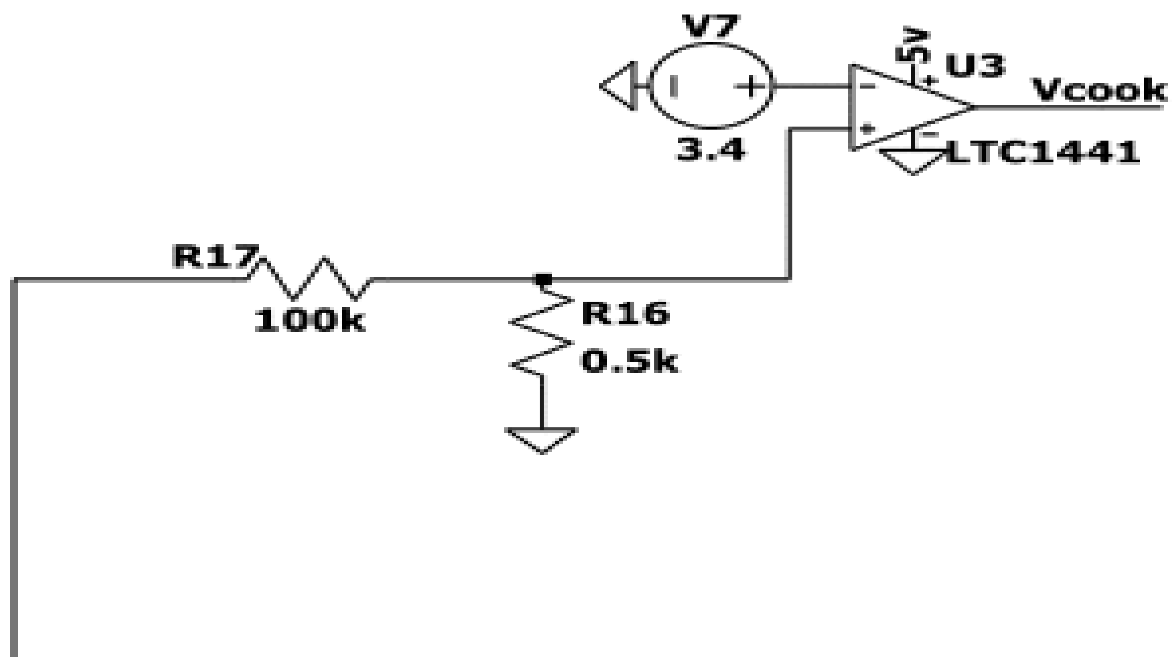
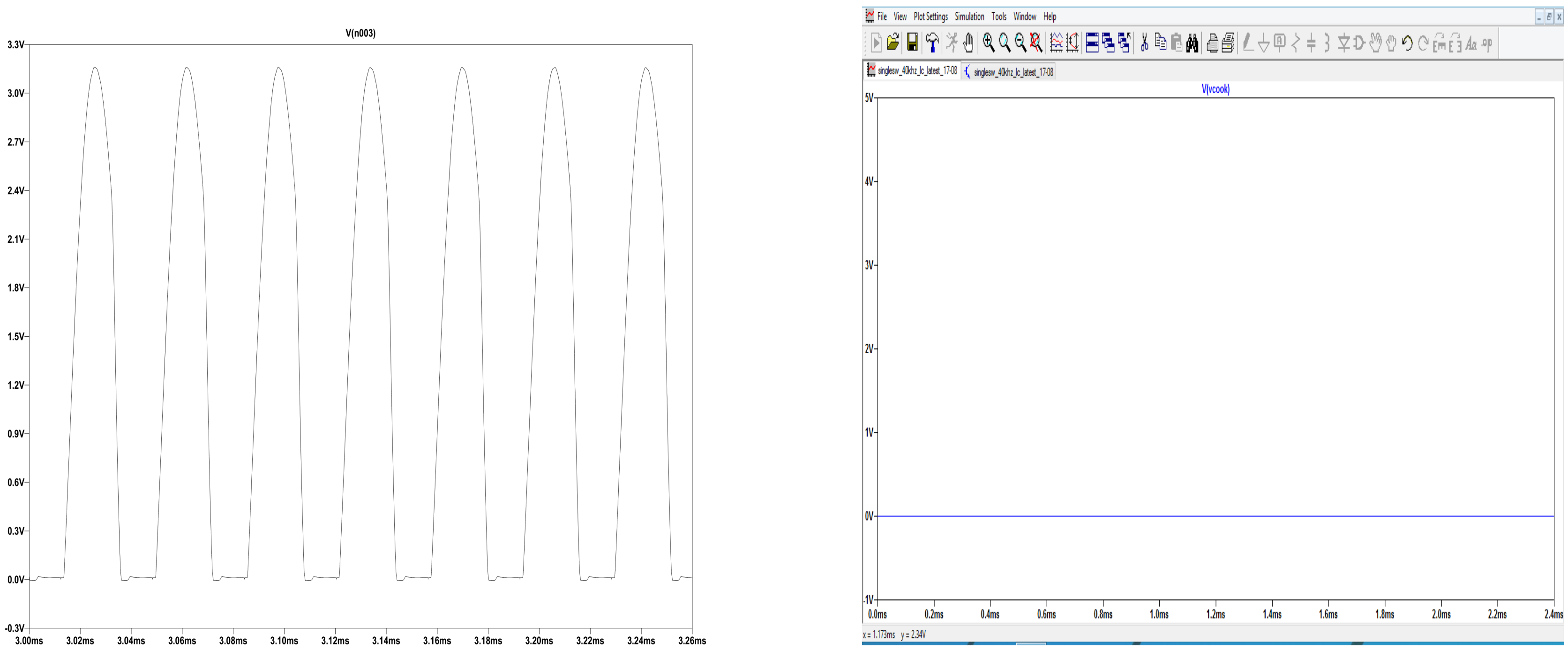


Figure 8: Cookware detection circuit

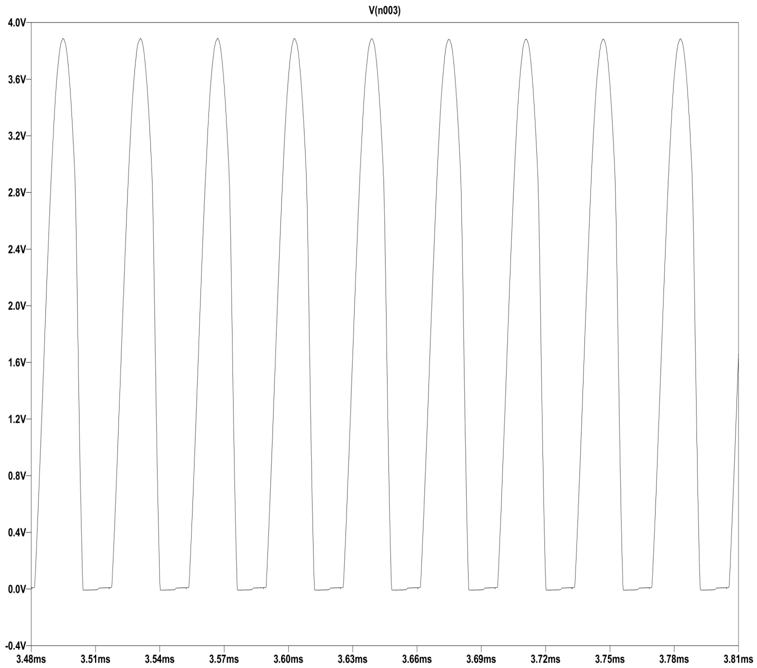
Figure 10 shows the output when there is cookware is present on top of induction hob whereas Figure 10 shows the outputs when the cookware is removed.



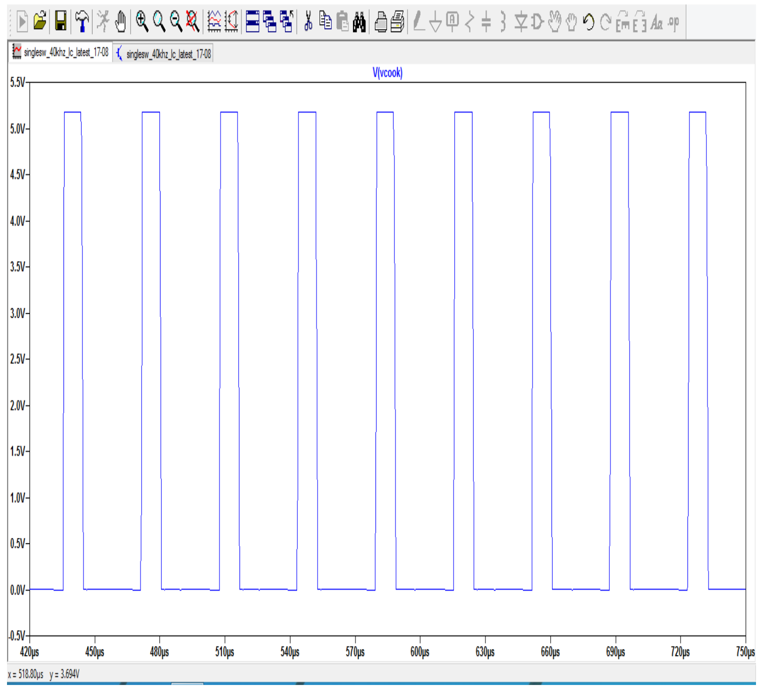
(a).IGBT voltage for the presence of cookware

(b).output of comparator (V_{cook}) with the presence of cookware

Figure 9: The outputs of (a) V_{IGBT} and (b) V_{cook} with the presence of cookware



(a).IGBT voltage with cookware removed



(b).output of comparator (V_{cook}) with cookware removed

Figure 10: The outputs of (a) V_{IGBT} and (b) V_{cook} with cookware removed

2.4 Design and Simulation of gate driver circuit

2.4.1 Theory

The gate driver circuit is an essential component in the regulation of the switching characteristics of power transistors, such as MOSFET or IGBT, in high-power applications such as motor drives, power converters, and inverters.

The current state of gate driver circuits is defined by their high level of integration, fast switching speeds, wide voltage range operation, advanced protection features, improved noise immunity, and the introduction of smart gate driver solutions. The aforementioned advancements play a significant role in the advancement of power electronics systems, enhancing their efficiency, reliability, and intelligence in various applications.

MOSFET in gate driver circuits contributes to faster switching speeds, lower power consumption, improved efficiency, and enhanced reliability in power electronics applications. Therefore MOSFETs are frequently employed as output devices in gate driver circuits to deliver the required high-current drive signals for charging and discharging the gate capacitance of power transistors.

The IRF540 transistor has been selected based on the aforementioned advantages and the specific requirements for high power and fast switching.

2.4.2 Circuit Diagram

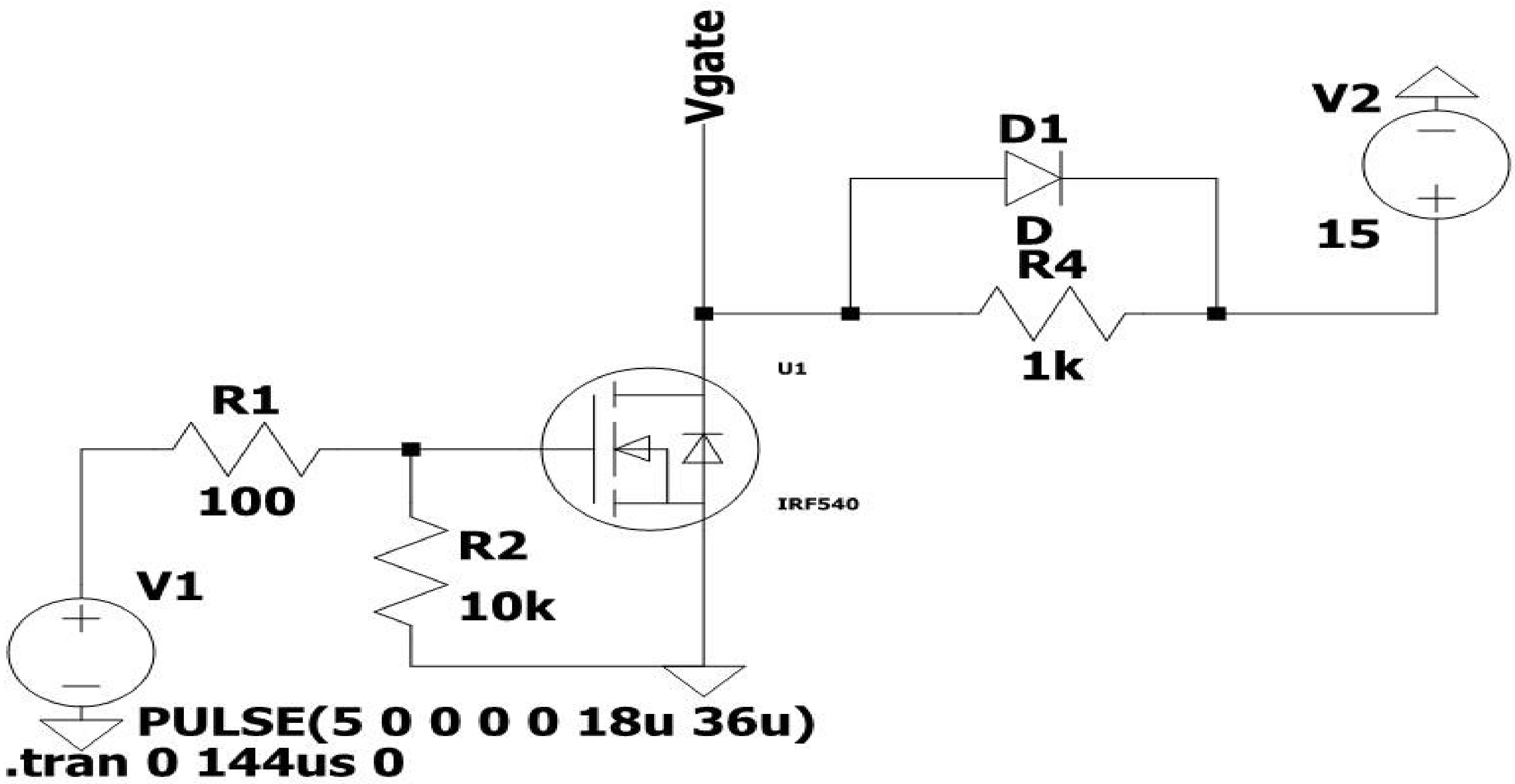


Figure 11: Gate driver circuit

The gate driver circuit has been supplied with a 15V bias supply, an antiparallel diode, and a couple of current limiting resistors that are used to limit current through the gate of the MOSFET.

2.4.3 Results

I have successfully amplified the 5V PWM signal 15V (shown in Figure 12)which is the turn-on gate voltage of the IGBT used in the power circuit.

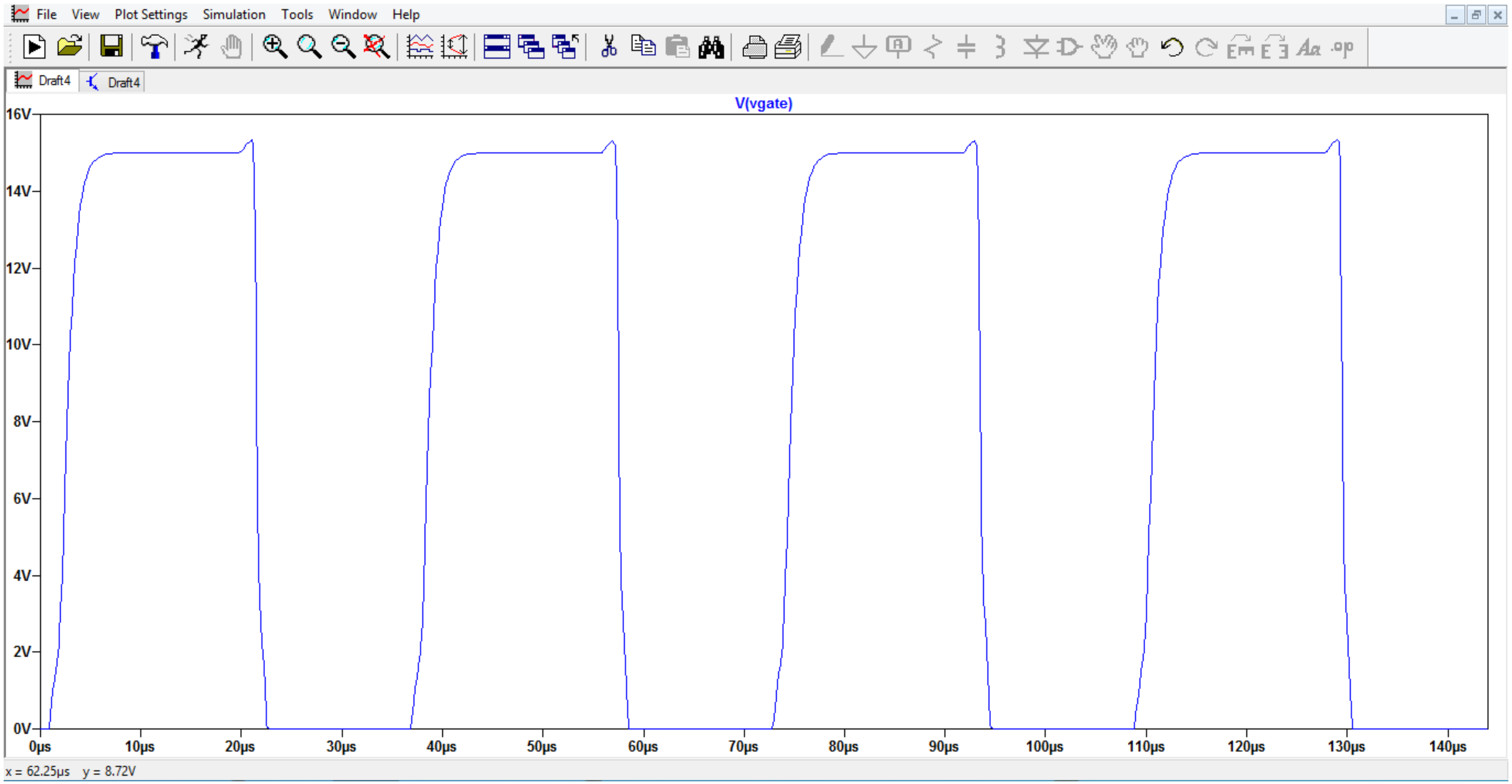


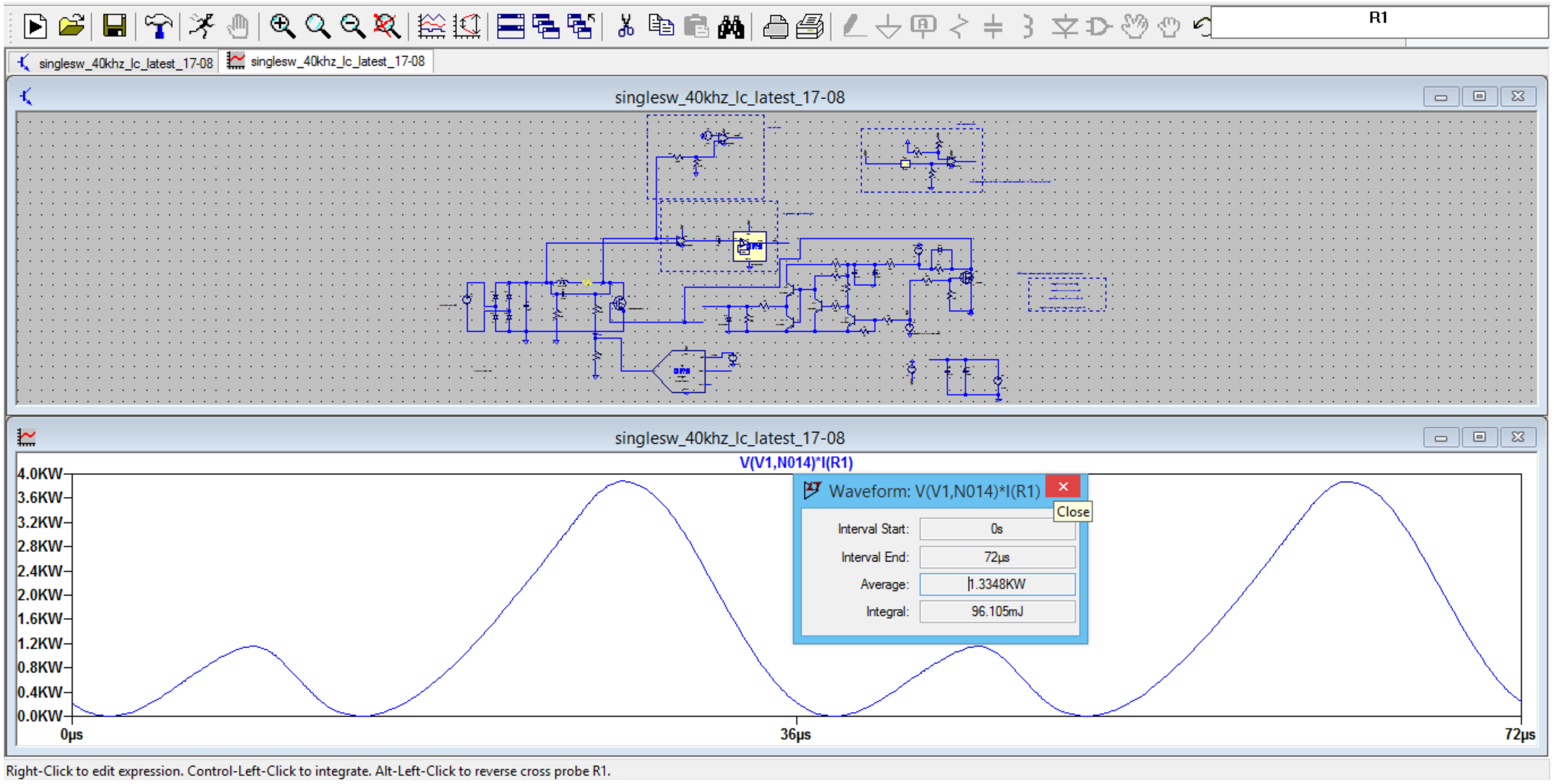
Figure 12: Output of the amplified PWM signal

2.5 Average output power of the converter

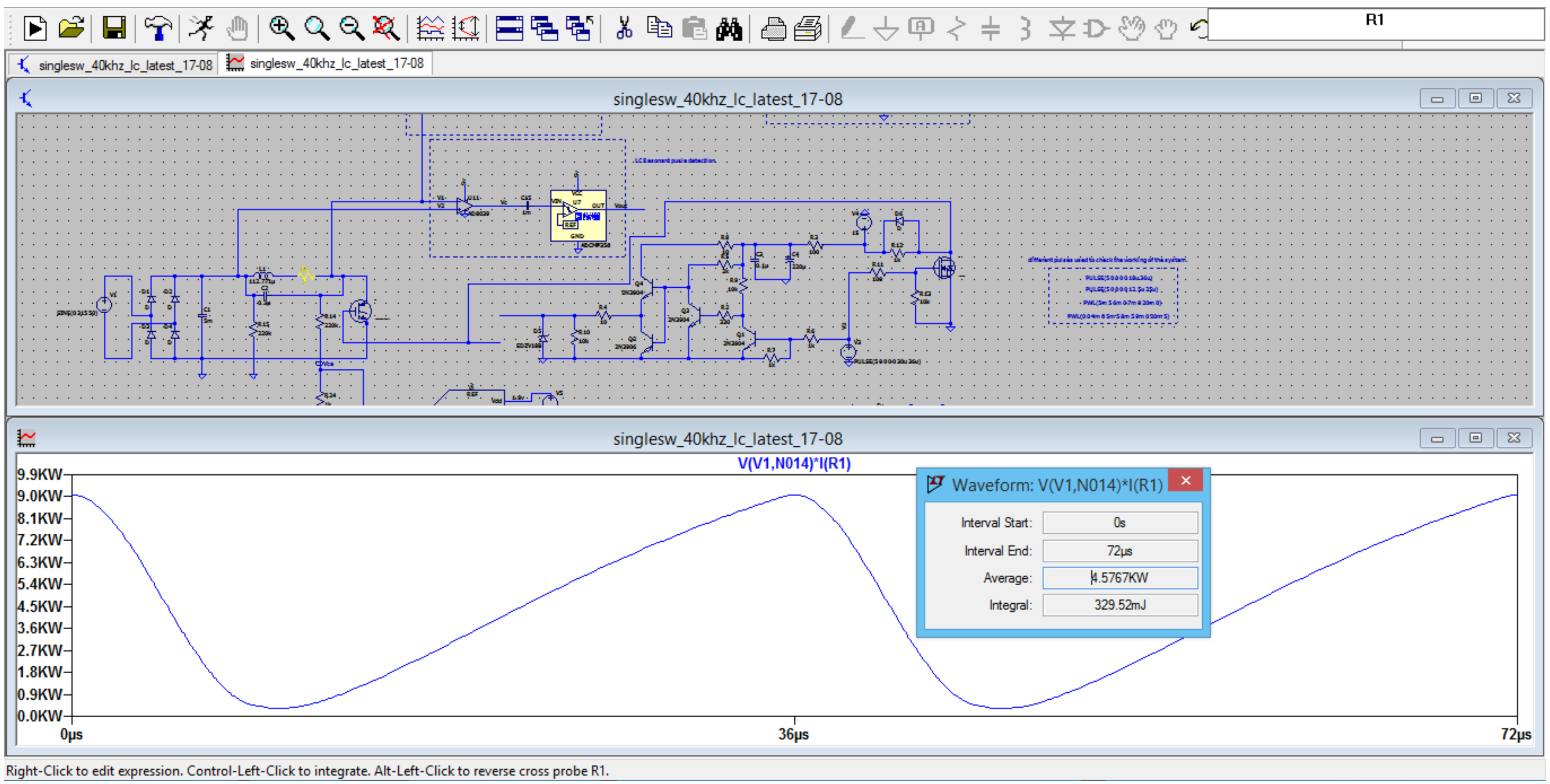
I have obtained results of output power for two different duty cycle values which is

- for d=50% the average power output is 1.3348KW (from Figure 13)
- for d=83.33% the average power output is 4.5767KW (from Figure 13)

It can be concluded that the converter utilized is capable of effectively handling power loads up to 5KW.



Power waveform over two complete cycles of switching at d=50%



Power waveform over two complete cycles of switching at d=83.33%

Figure 13: Output power of the converter

3 Microcontroller Integration and Control Strategies for Induction Cooktop Operation

The functionality, safety, and user experience of an induction hob can be enhanced by integrating a microcontroller into its control system. By interfacing the microcontroller with the cooktop's power supply and control circuits, we can implement advanced features such as:

- **Power control:** The microcontroller can regulate the power delivered to the induction coil based on feedback from temperature sensors, ensuring precise cooking temperatures and preventing overheating.
- **Cooking Timer:** Implementing a cooking timer allows users to set specific cooking durations, after which the cooktop automatically switches off or adjusts to a lower power setting.
- **Safety Features:** The microcontroller can monitor various parameters such as temperature, voltage, and current to detect abnormal conditions like overheating or short circuits. It can then take appropriate actions, such as shutting down the cooktop and displaying an error message.
- **User Interface:** With a microcontroller-driven user interface, users can interact with the cooktop through a digital display, touch controls, or even through a smartphone app, enhancing user experience and convenience.
- **Energy Efficiency:** By intelligently managing power delivery to the induction coil, the microcontroller can optimize energy usage, reducing electricity consumption and operating costs.

Project scope

In this project, we aim to design and implement a microcontroller-based control system for an induction cooktop. The system will feature estimation of resonant frequency using Capture-Compare-PWM module (**CCP**), duty-cycle based power control, a cooking timer, and safety monitoring (cooktop detection,IGBT voltage detection). We will select a suitable microcontroller platform and develop the necessary firmware to interface with the cooktop's hardware components.

- Selection of Microcontroller: Based on the number of input channels, PWM output, Capture-compare-PWM (CCP) modules, output channels, and the memory required alongside with cost-effectiveness of the microcontroller we have chosen the PIC16F1619 microcontroller
- Hardware Interface: The process involves designing the circuitry that facilitates the connection between the microcontroller and various components such as the induction coil, temperature sensors, power supply, and user interface components.
- Firmware Development: The firmware is responsible for controlling the power output of the induction coil, reading data from the temperature sensor, implementing the cooking timer, and managing user inputs. The Microchip MPLAB IDE was utilized to implement all of the aforementioned procedures.

By integrating a microcontroller into the control system of an induction cooktop, we can enhance its functionality, safety, and user experience. This project aims to demonstrate the feasibility and benefits of such a system, paving the way for more intelligent and efficient kitchen appliances in the future

For the control functionalities I have used the circuit given in Figure14 which is made in Proteus.

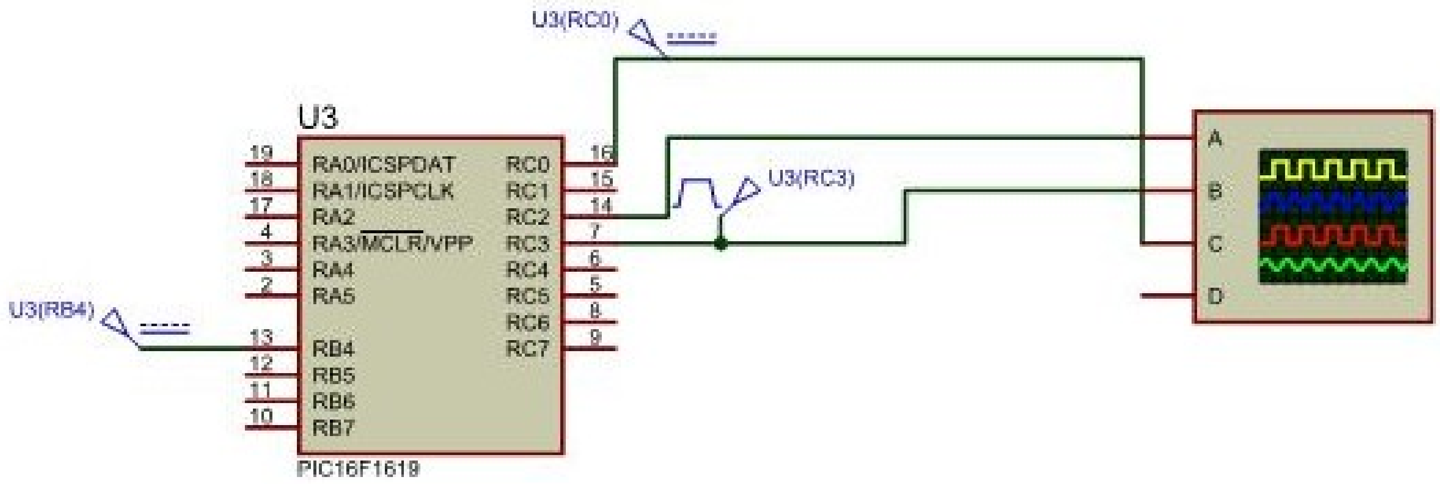


Figure 14: Circuit diagram in Proteus

3.1 Estimation of Resonant frequency using CCP module

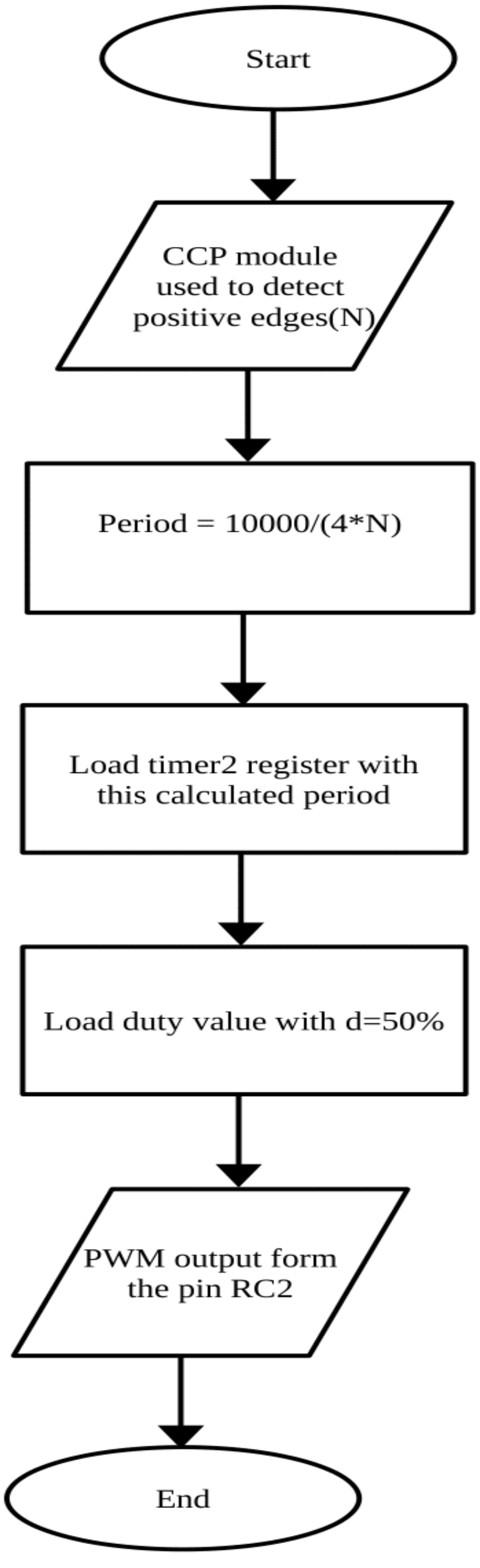
3.1.1 Theory

Microcontrollers and digital signal processors (DSPs) commonly include modules such as Capture, Compare, and PWM (Pulse Width Modulation). They provide flexible functionality for a range of applications, including time measurement, waveform generation, and control signal generation. For this task, we have used only the capture module (mainly the interrupt bit). When a trigger event occurs (e.g., a rising or falling edge), the Capture module captures the current value of a timer or counter and toggles the interrupt bit.
The Capture-Compare-PWM module is utilized for the purpose of approximating the resonance frequency of the circuit. The count of positive edges has been computed by implementing a positive edge detection algorithm over a specific time frame. The period is determined and recorded in the register by dividing the outcome by the register constants.
Formula used

$$PR2 = \frac{10000}{4n - 1}$$

n= number of positive edges
PR2 = timer register

Additionally, the duty cycle needs to be assigned to any specific value because the frequency has been changed. The sequence of commands for estimating the resonance frequency using the CCP module is as follows:



Flowchart Illustrating the Resonant Frequency Estimation Algorithm for Induction Cooktop Control

3.1.2 Results

The resonant frequency is estimated with slight inaccuracies that can be minimized by appropriately calibrating the parameters. Channel-B is the input signal to the DSO and Channel-A is the output of the microcontroller after estimating the frequency.

The estimated value for 5KHz input is 1/210μs (from Figure 15) which is equal to 4.76KHz.

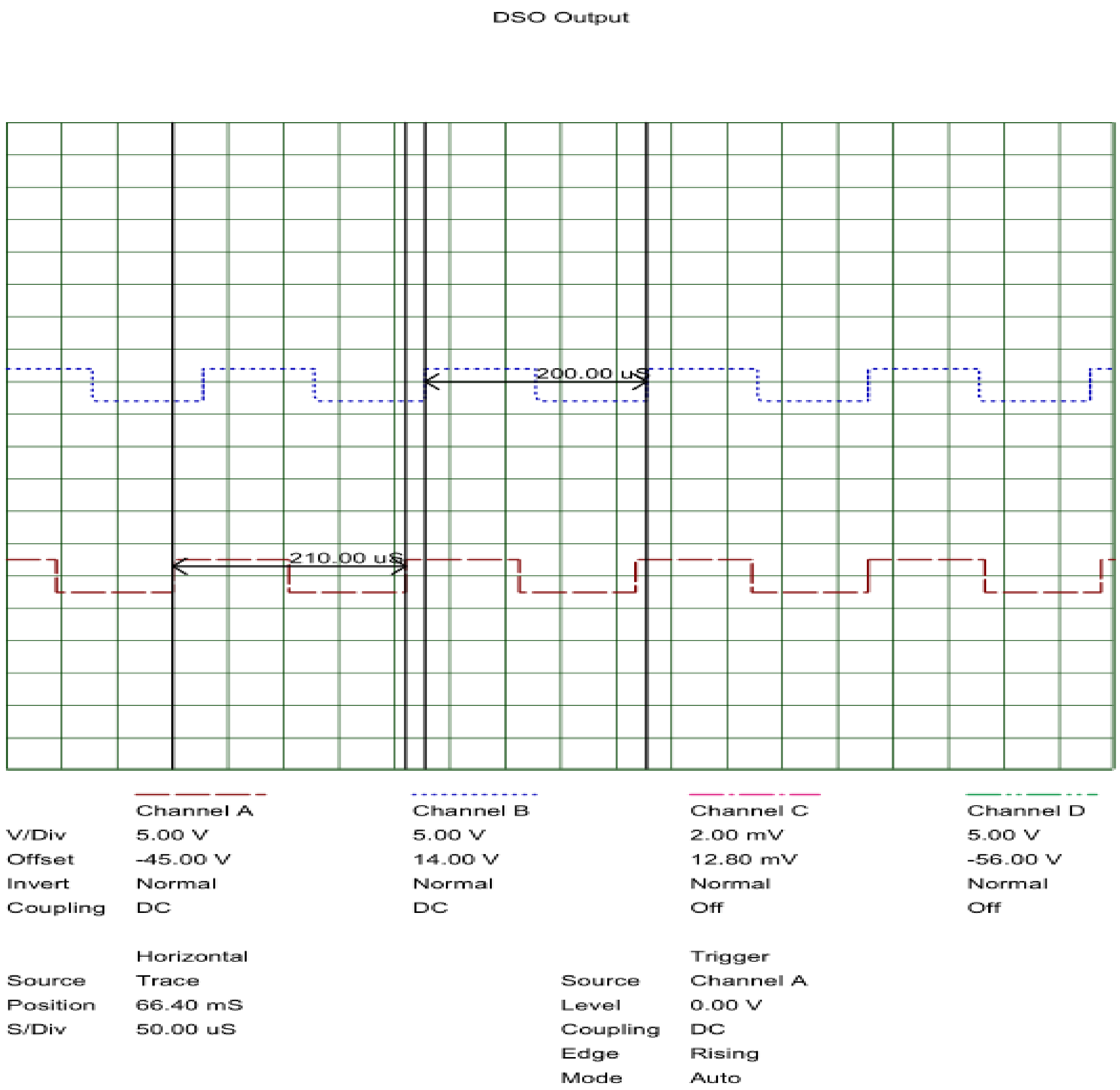


Figure 15: Frequency estimation for 5KHz

The estimated value for 40KHz input is 1/24 μs (from Figure 16) which is equal to 41.67KHz.

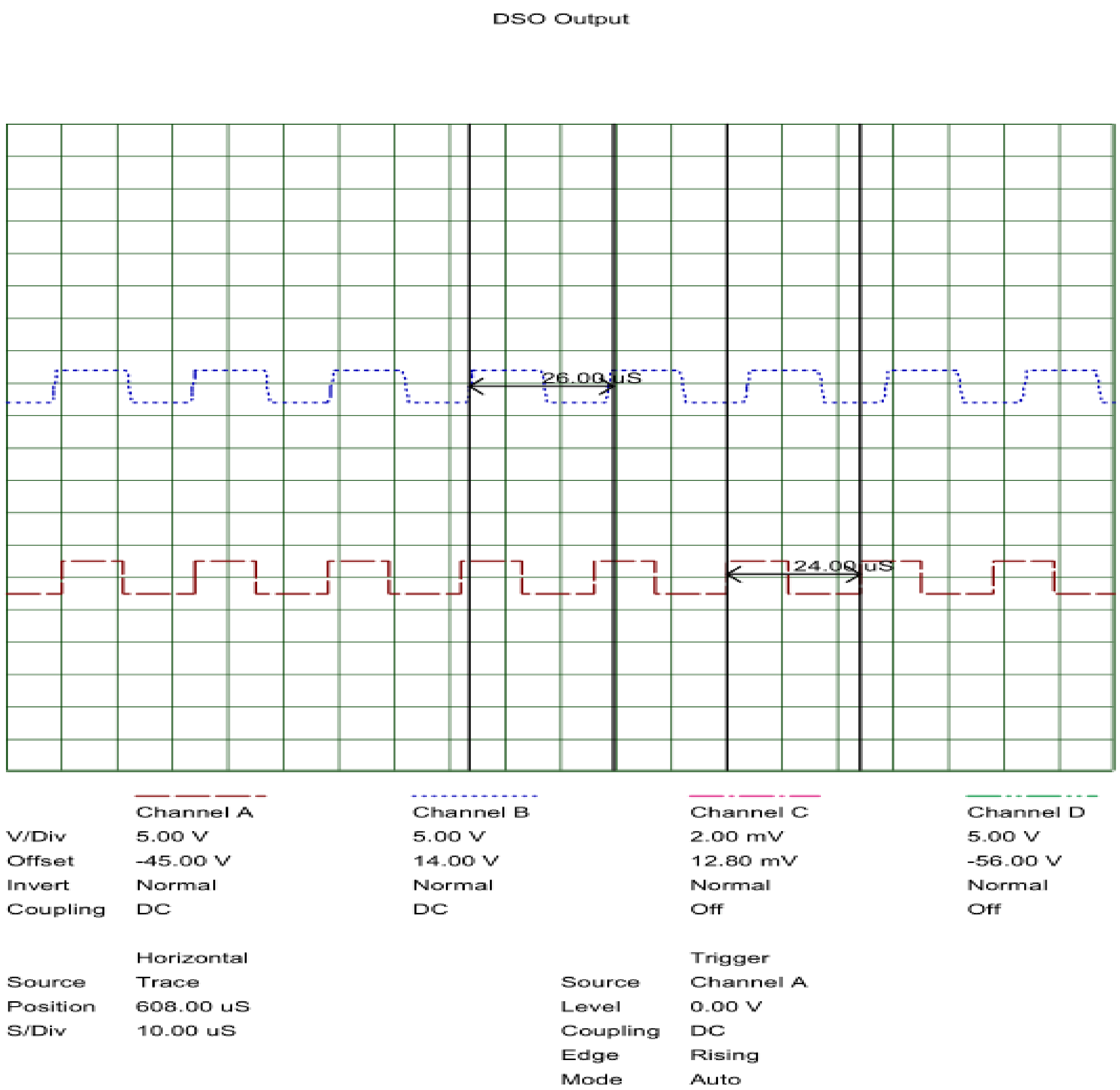


Figure 16: Frequency estimation for 40KHz

3.2 Power Level Control

3.2.1 Theory

Controlling the duty cycle of the power supplied to the induction coil allows accurate power management in an induction cooktop. Typically, induction cooktops employ PWM to adjust the duty cycle. PWM controls average power by rapidly switching power on and off at a given frequency and adjusting the duty cycle width. Adjusting the duty cycle precisely controls induction coil power. The average power output drops and increases with the duty cycle. For precise and steady power control, a closed-loop system is used. Sensors measure current and voltage, and feedback adjusts the duty cycle to maintain power level.

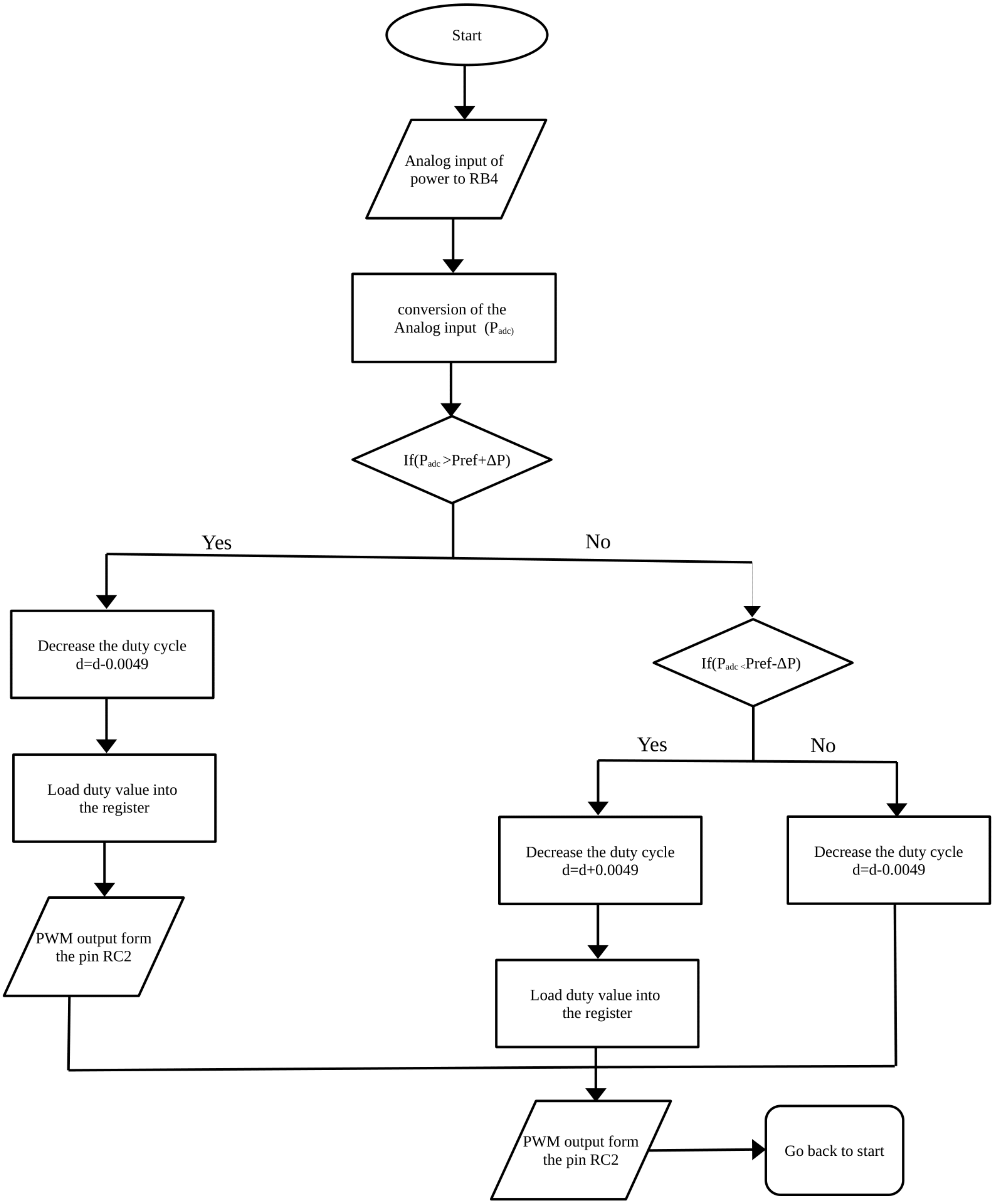


Figure 17: Flowchart Illustrating the Closed loop power control for induction cooktop

3.2.2 Results

It can be observed from Figure18that the duty cycle is decreasing gradually.

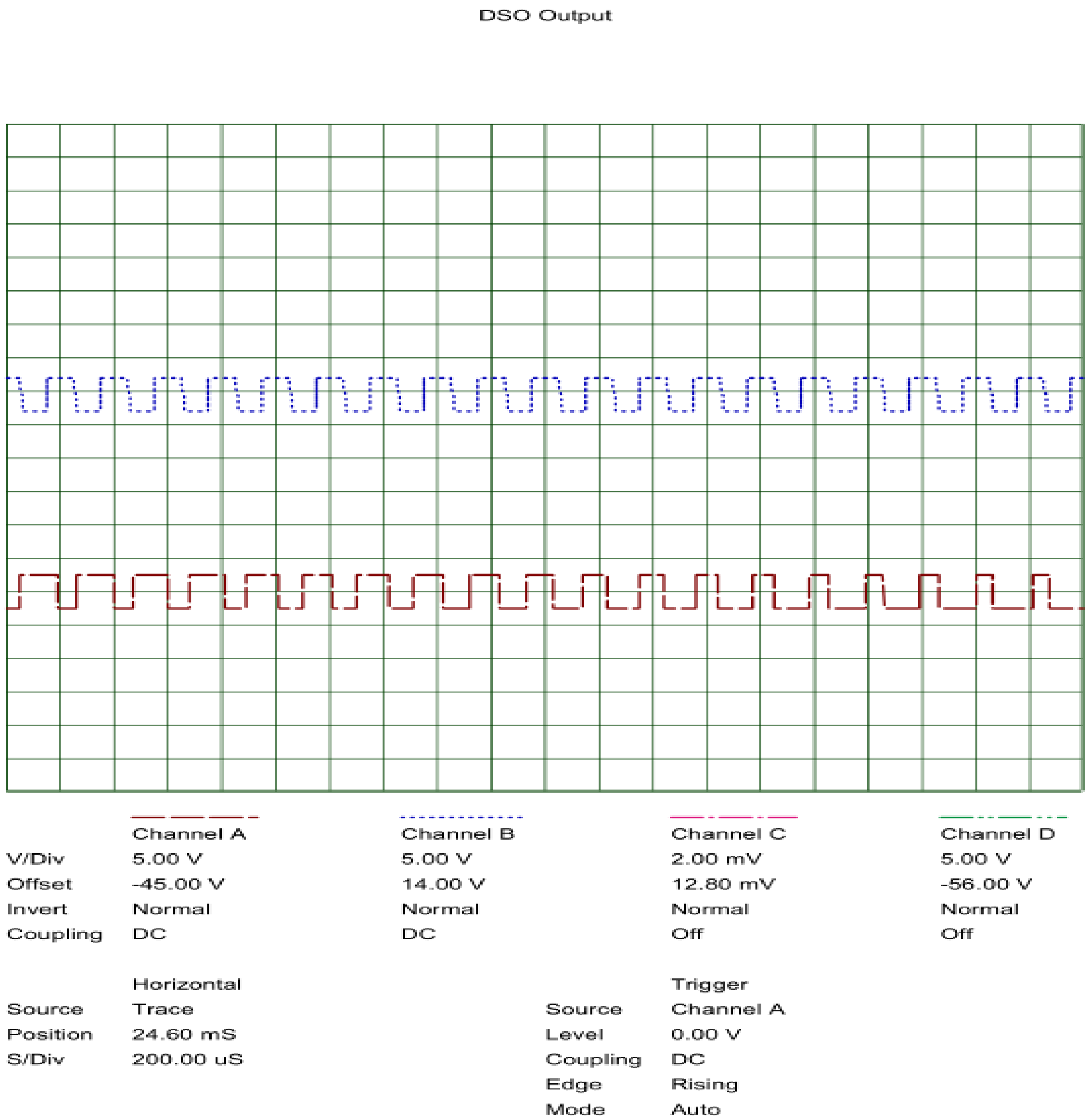


Figure 18: Output of DSO for P_{out} <¡ P_{ref}

It can be observed from Figure 19that the duty cycle is increasing gradually.

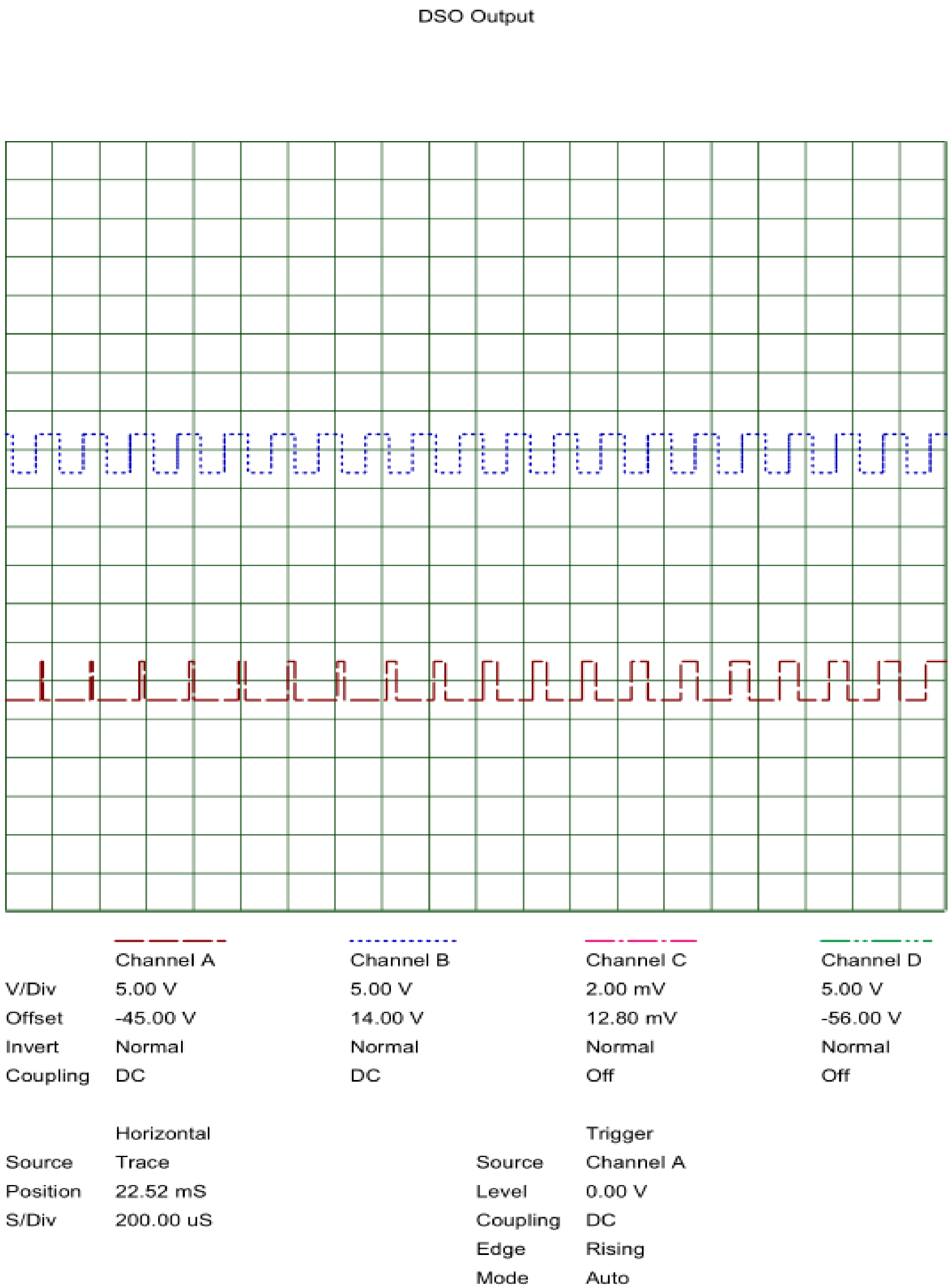


Figure 19: Output of DSO for P_{out} <¿ P_{ref}

3.3 Safety features of the induction cooktop

The inclusion of safety features in induction cooktops is of utmost importance as they serve to prevent accidents and guarantee the protection of users. The following is a list of common safety features that are included in this design:

- **Automatic Shut-off:** The induction cooktops commonly incorporate automatic shut-off capabilities that deactivate the heating elements following a specific duration of inactivity. The implementation of this feature serves the purpose of mitigating the occurrence of overheating and minimising the potential hazard of fire in the event that a pot is inadvertently left unattended.

- **Pan Detection:** Induction cooktops often come with pan detection sensors that have the capability to deactivate heating elements automatically in the absence of cookware on the surface. The implementation of this feature ensures that the hob remains inactive when not in use, thereby minimizing unnecessary heat generation and optimising energy efficiency.

- **Voltage Fluctuation Protection:** Induction cooktops are equipped with voltage fluctuation protection mechanisms that serve to protect against power surges or fluctuations in the electrical supply. The purpose of this feature is to safeguard the electronic components of the hob and maintain a consistent level of performance. Induction cooktops often come with pan detection sensors that have the capability to deactivate heating elements automatically in the absence of cookware on the surface. The implementation of this feature prevents the hob from heating up unnecessarily, resulting in a reduction in energy consumption.

- **Timer Function:** The timer functions enable users to establish a precise cooking duration for each individual cooking zone. Upon reaching the designated time, the heating element will deactivate itself, thereby minimising the potential for overcooking or scorching of food.

- **Cooling Fans:** Certain induction hob models are furnished with integrated cooling fans to avert the occurrence of excessive heat in the internal components. These fans aid in the dispersion of excessive heat produced during extended usage, guaranteeing that the hob stays within the boundaries of acceptable operating temperatures.

These safety features help make induction cooktops safer to use and minimize the risk of accidents, burns, and other hazards in the kitchen.

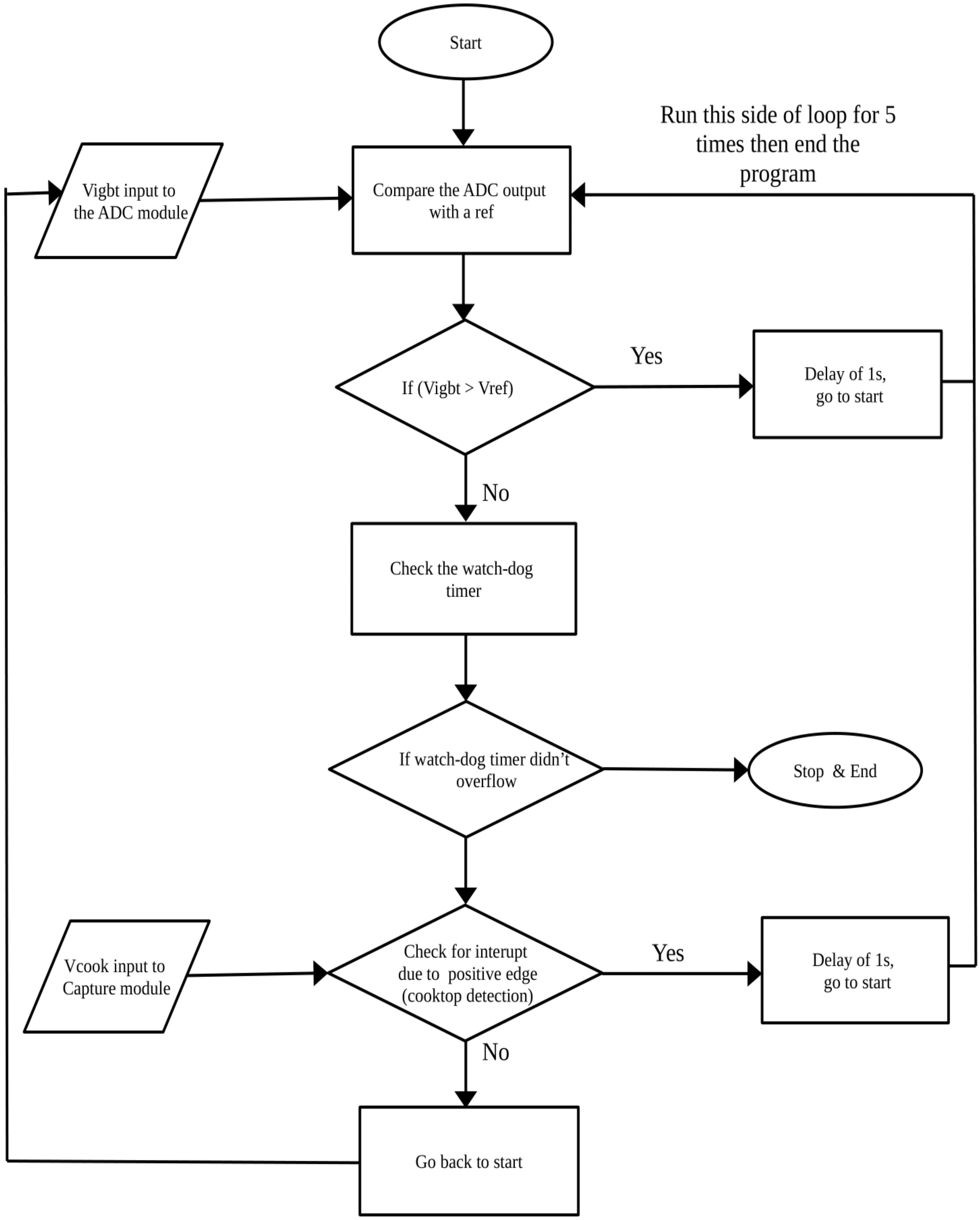


Figure 20: Flowchart Illustrating the Closed loop power control for induction cooktop

3.3.1 Results

At t=0(with some delay due to delay in processing), it is evident that the voltage becomes a constant value of 5V. The reason for this behaviour is that the interrupt handler has been executed, resulting in the timer value being reset to 0. As a result, a 5V contact output is generated.

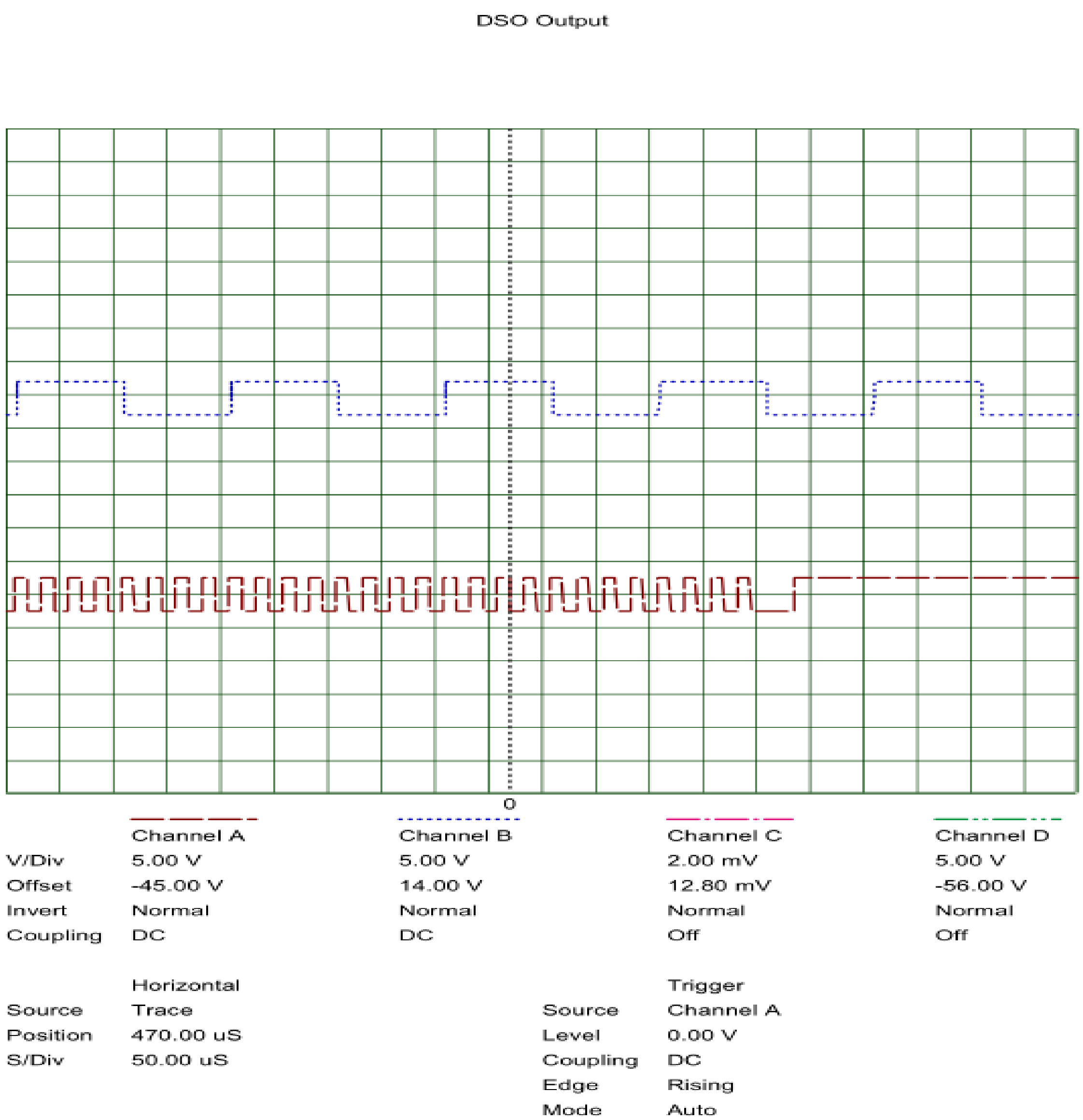


Figure 21: Detection in overvoltage or cookware removal

4 Experimental Validations

4.1 connections made on the breadboard to test the control using Microcontroller

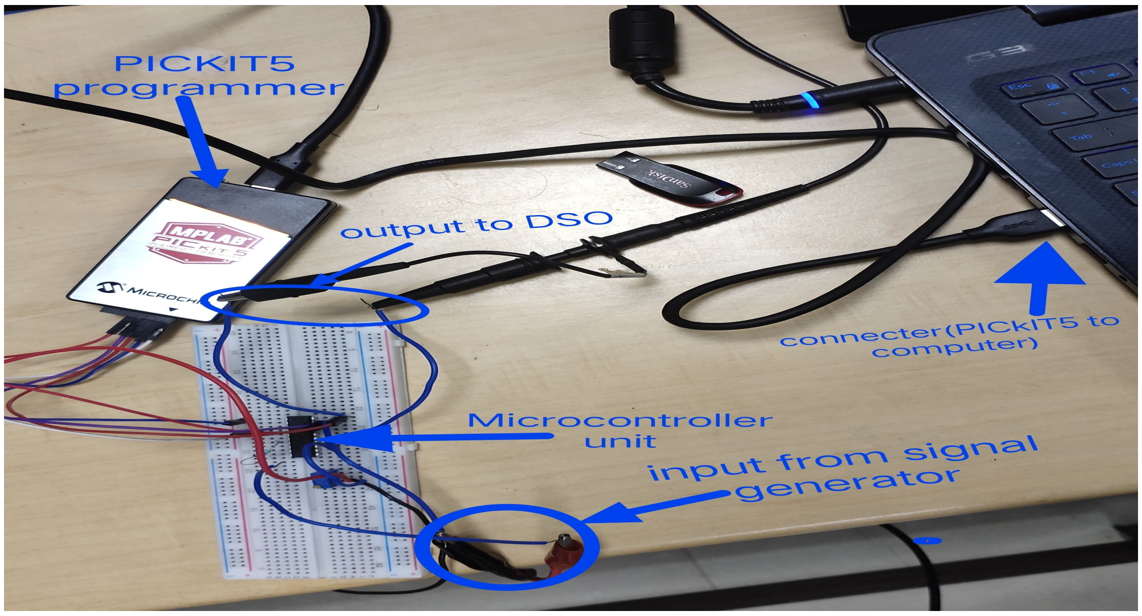


Figure 22: Circuit made on the breadboard

4.2 Estimation of Resonant frequency

Channel-1 (CH1 yellow trace) represents the input from the signal generator, while Channel-2 (CH2 blue trace) represents the PWM output generated using the discussed estimation method to estimate the resonance frequency.

DSO output for 5KHz input

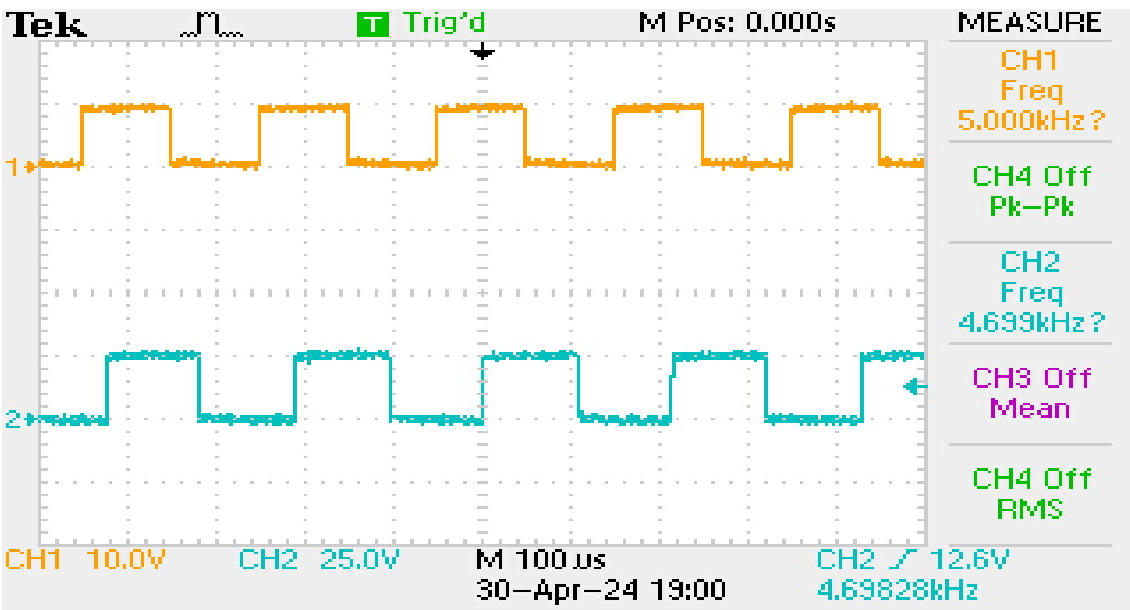


Figure 23: DSO output for 5KHz

DSO output for 40KHz input

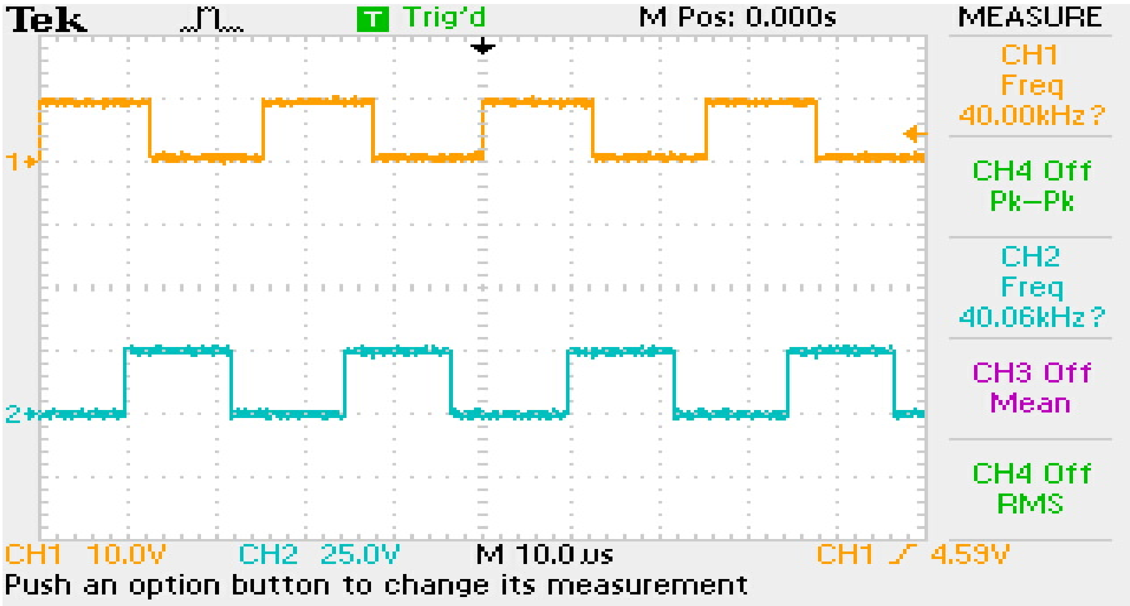
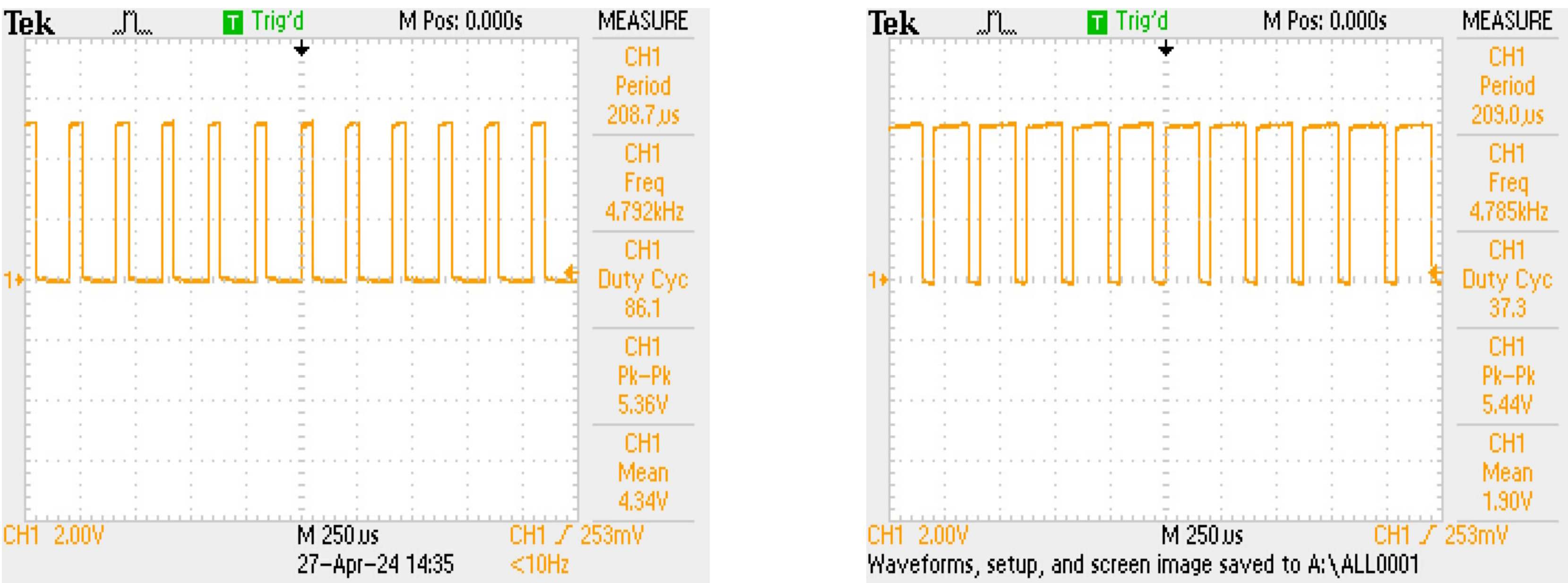


Figure 24: DSO output for 40KHz

The value of mean voltage shoes that the duty cycle is equal to 50%.

4.3 Modulation of duty cycle

This is experimental validation for the closed-loop power control technique used to maintain constant power while heating.

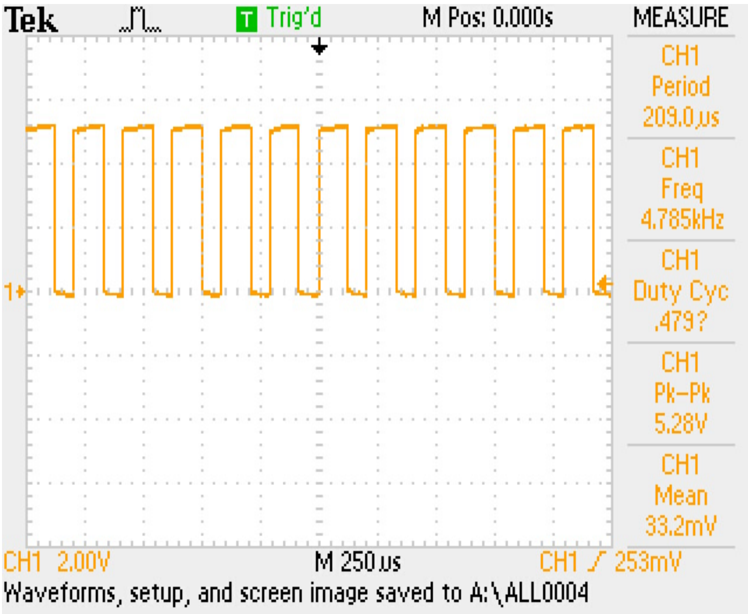


a.DSO output

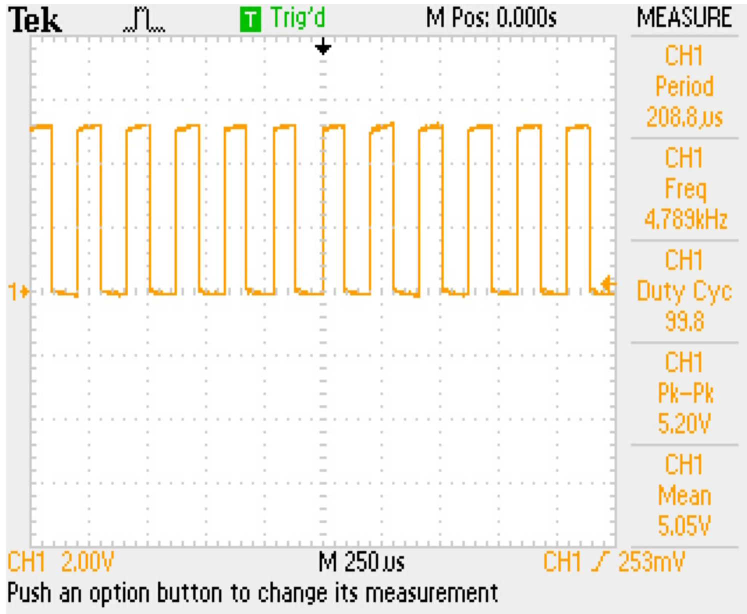
b.DSO output

Figure 25: DSO output snaps taken at two different instants for decreasing duty cycle value

The duty cycle of PWM is modulated based on the value of ADC output. Hence, for P_{out} <¡P_{ref} the duty cycle is decreased which can be observed from Figure 25



a.DSO output



b.DSO output

Figure 26: DSO output snaps taken at two different instants for increasing duty cycle value

The duty cycle of PWM is modulated based on the value of ADC output. Hence, for P_{out} <¿P_{ref} the duty cycle is increased which can be observed from Figure 26

5 PCB design and Schematics

Designing a printed circuit board (PCB) is a fundamental aspect of electronic product development. PCBs serve as the backbone of electronic devices, providing a platform for connecting and integrating various electronic components into a functional system.

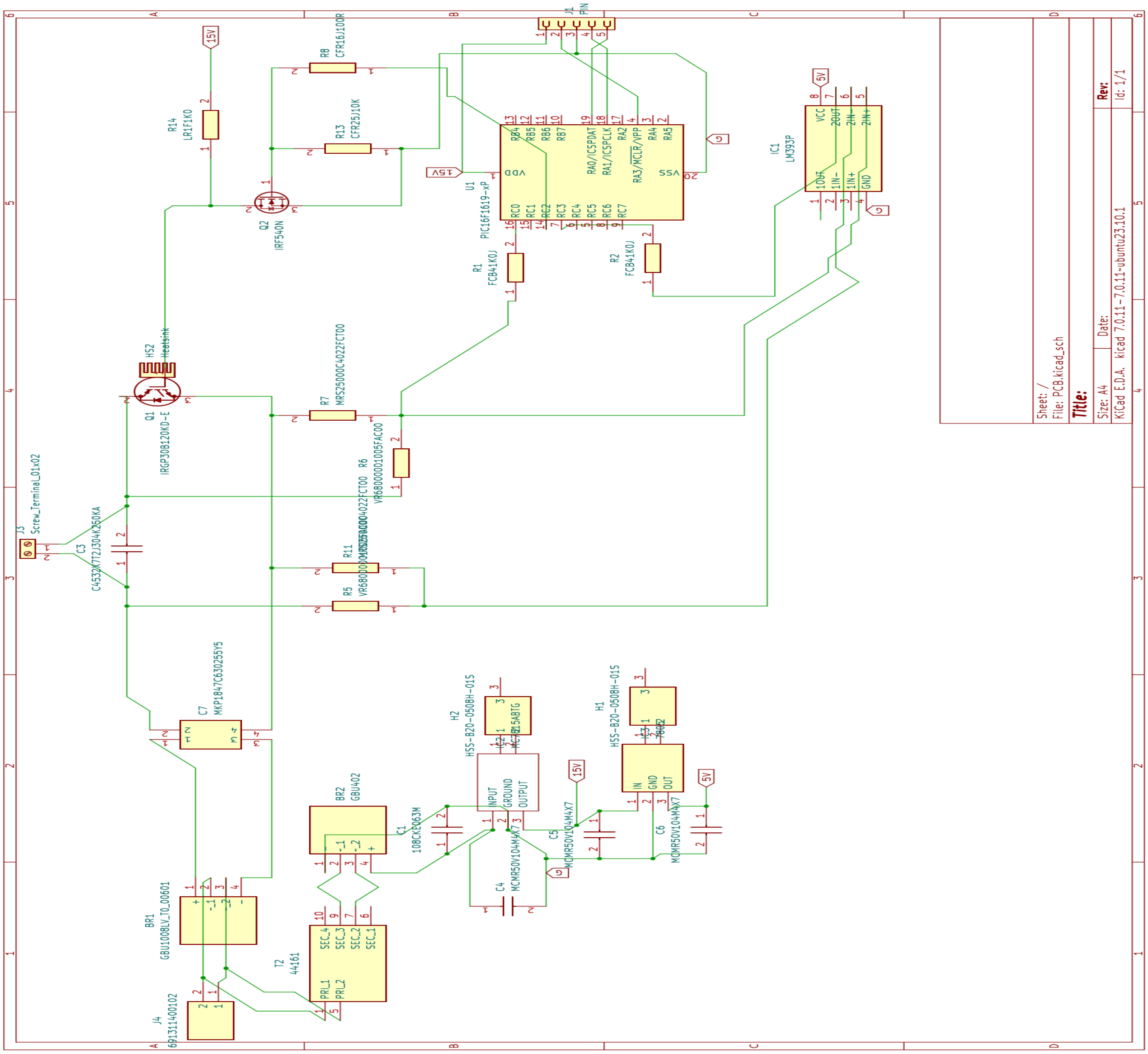


Figure 27: Circuit schematic in KiCad

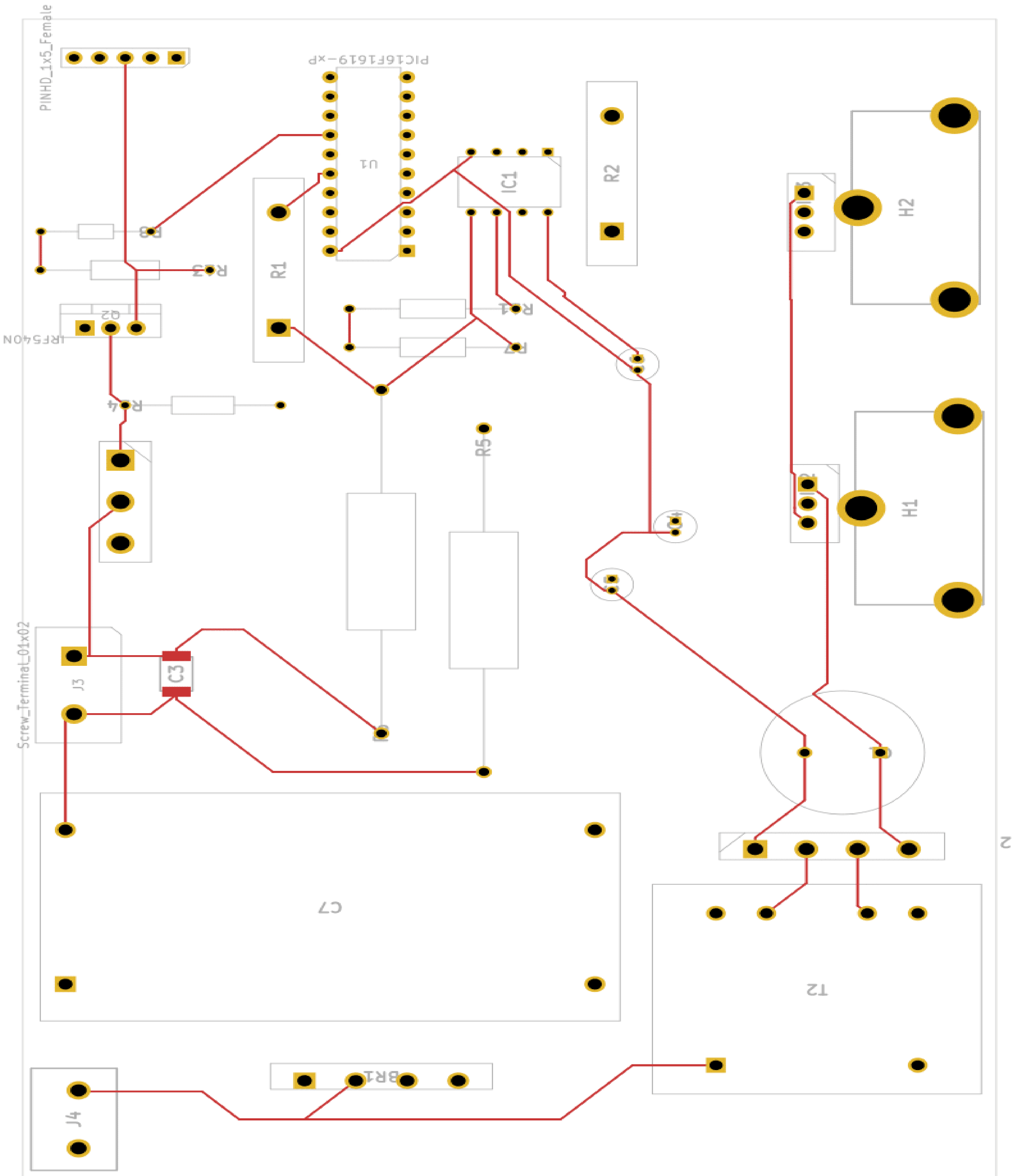


Figure 28: PCB design of top layer in KiCad

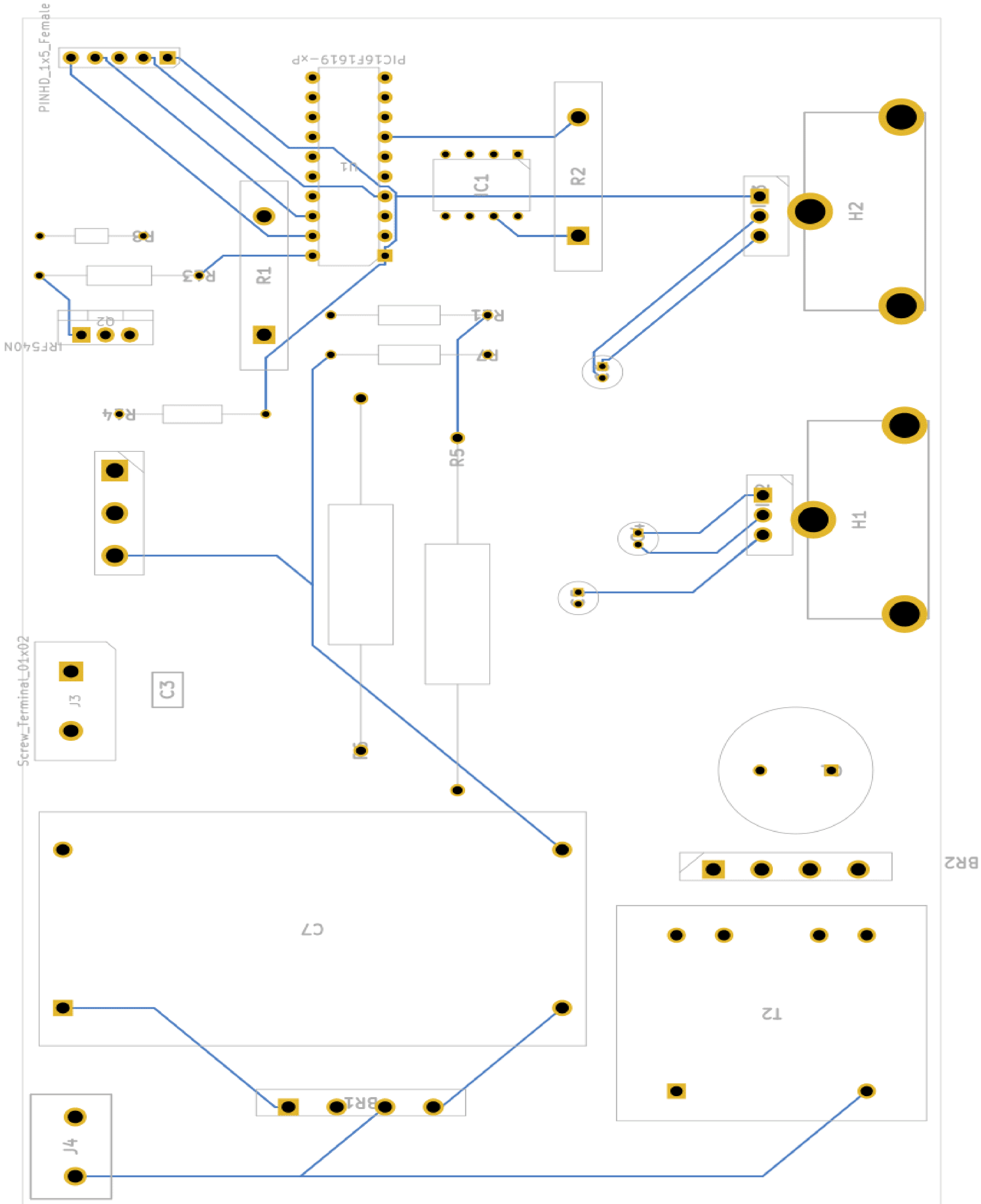
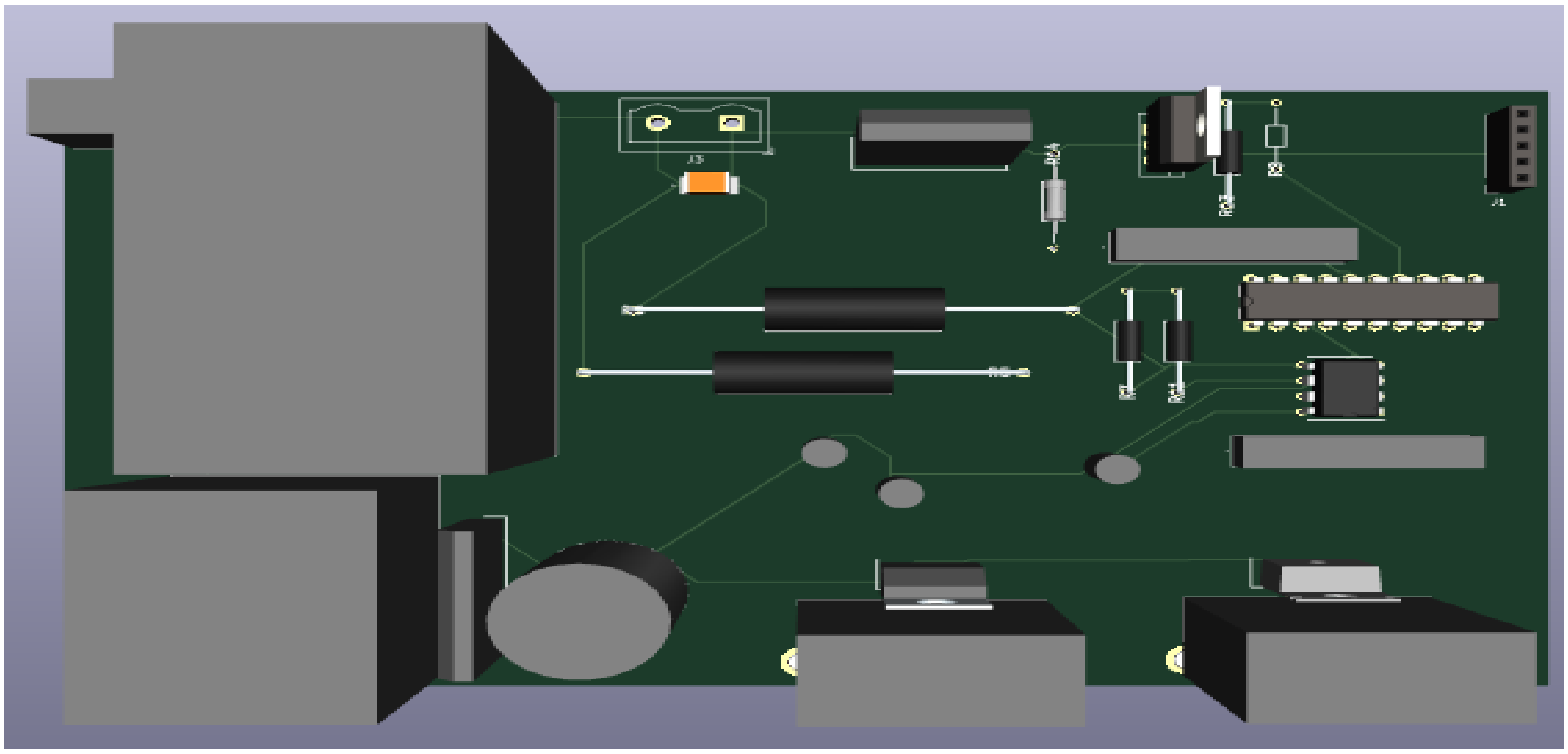
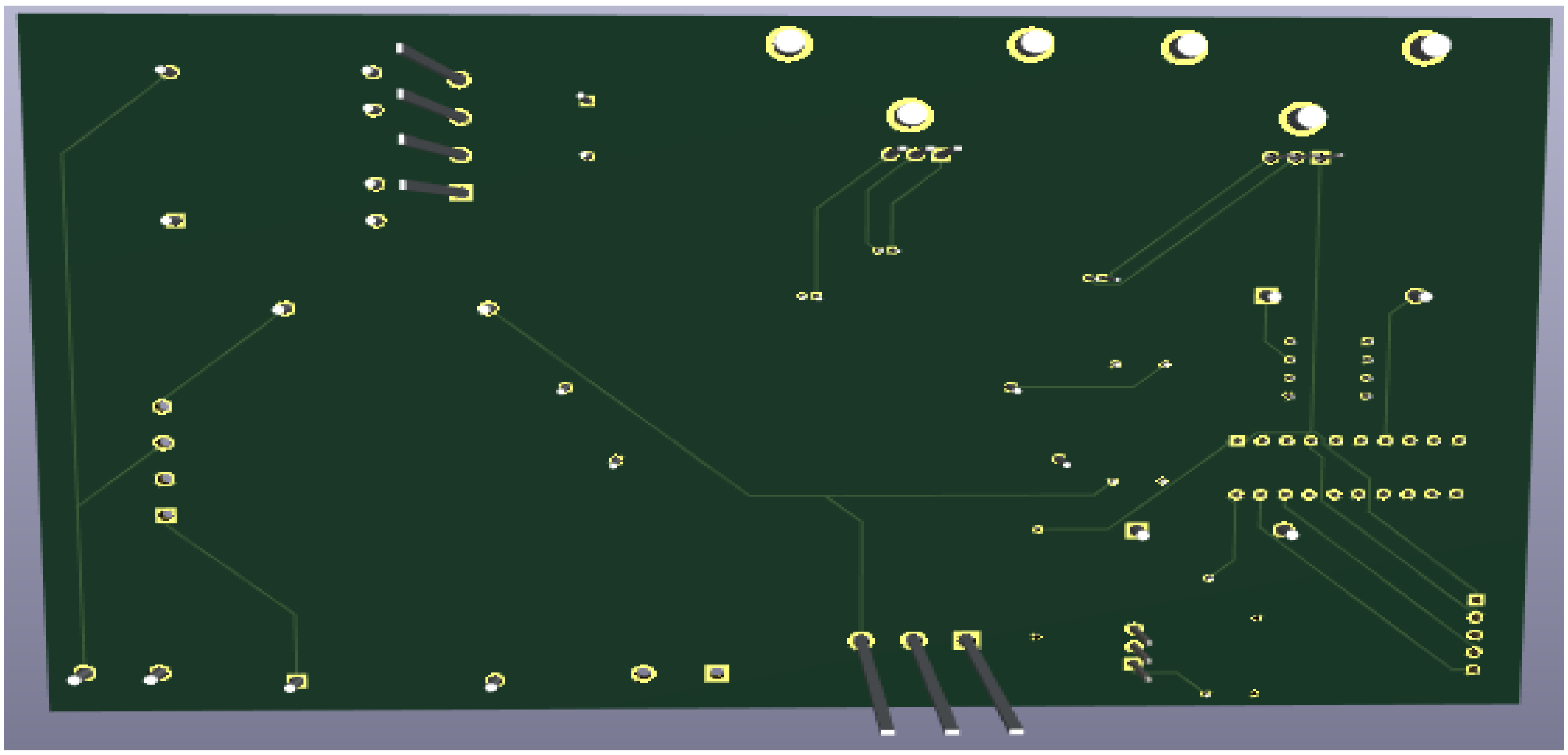


Figure 29: PCB design of bottom layer in KiCad



toplayer of 3-d PCB design



bottom layer of 3-d PCB design

Figure 30: 3-d Veiw of PCB design

6 Conclusion

Through a thorough examination of different elements of induction hob design and functionality, this project delves into the intricate details of circuit simulation, microcontroller integration, control strategies, and experimental validations. Starting with the simulation of the induction hob circuit, the project delves into the study of single-switch-based resonance circuits, explores ways to detect resonant frequency pulses caused by various cookware, and examines techniques for detecting the presence of cookware on the induction hob. In addition, a thorough analysis is conducted on the design and simulation of gate driver circuits, as well as an evaluation of the average output power of the converter.

Going forward, the project will now concentrate on integrating microcontrollers and developing control strategies for operating induction cooktops. By utilizing the CCP module, this project investigates the estimati-on of the resonant frequency. It delves into theories and presents results to showcase the effectiveness of the approach. In addition, this article covers power-level control strategies, offering theoretical insights and presenting corresponding results for comprehensive evaluation. In addition, the project explores the incorporat-ion of safety measures for induction cooktops, which are essential for safeguarding users and avoiding mishaps.

The experimental validations section offers a hands-on evaluation of the theoretical concepts discussed earlier in the project. Through the process of establishing connections on the breadboard, testing the control using a microcontroller, validating the estimation of resonant frequency, and assessing the modulation of duty cycle, the experiments provide evidence of the effectiveness and feasibility of the proposed methodologies.

Ultimately, this project provides a thorough examination of the design, simulation, integration, and validati-on of induction hob systems, providing valuable insights into circuit design, control strategies, and safety consid-erations. With a deep understanding of electrical engineering principles, the project makes significant strides in improving induction hob technology. This work has the potential to greatly enhance the efficiency, reliability, and safety of modern kitchen appliances.

7 Future Work

- I have utilized a single switch resonant circuit for its simplicity and cost-effectiveness. However, there are alternative topologies such as the Half-Bridge Resonant Inverter, Full-Bridge Resonant Inverter, ZVS/ZCS Topologies, and Multi-level inverters that can be employed to reduce losses.
- It is important to design a heating coil that meets the specific power and temperature requirements.
- Hardware testing is required. For optimal performance of the control loop in the future, it is crucial to calibrate the resistor values, V_{ref} and P_{ref} with utmost precision.
- We need to incorporate a closed temperature control loop that functions similarly to closed loop power control.
- The current PCB board is lacking in terms of meeting the necessary guidelines for creating a robust and compact PCB design for optimal performance.
- The communication interface must be developed so that users can program the main power circuit controller according to their desired cooking conditions.
- The resonance frequency can be estimated using the counting method, or by utilizing the registers of the capture block to determine the frequency.

A Appendix A

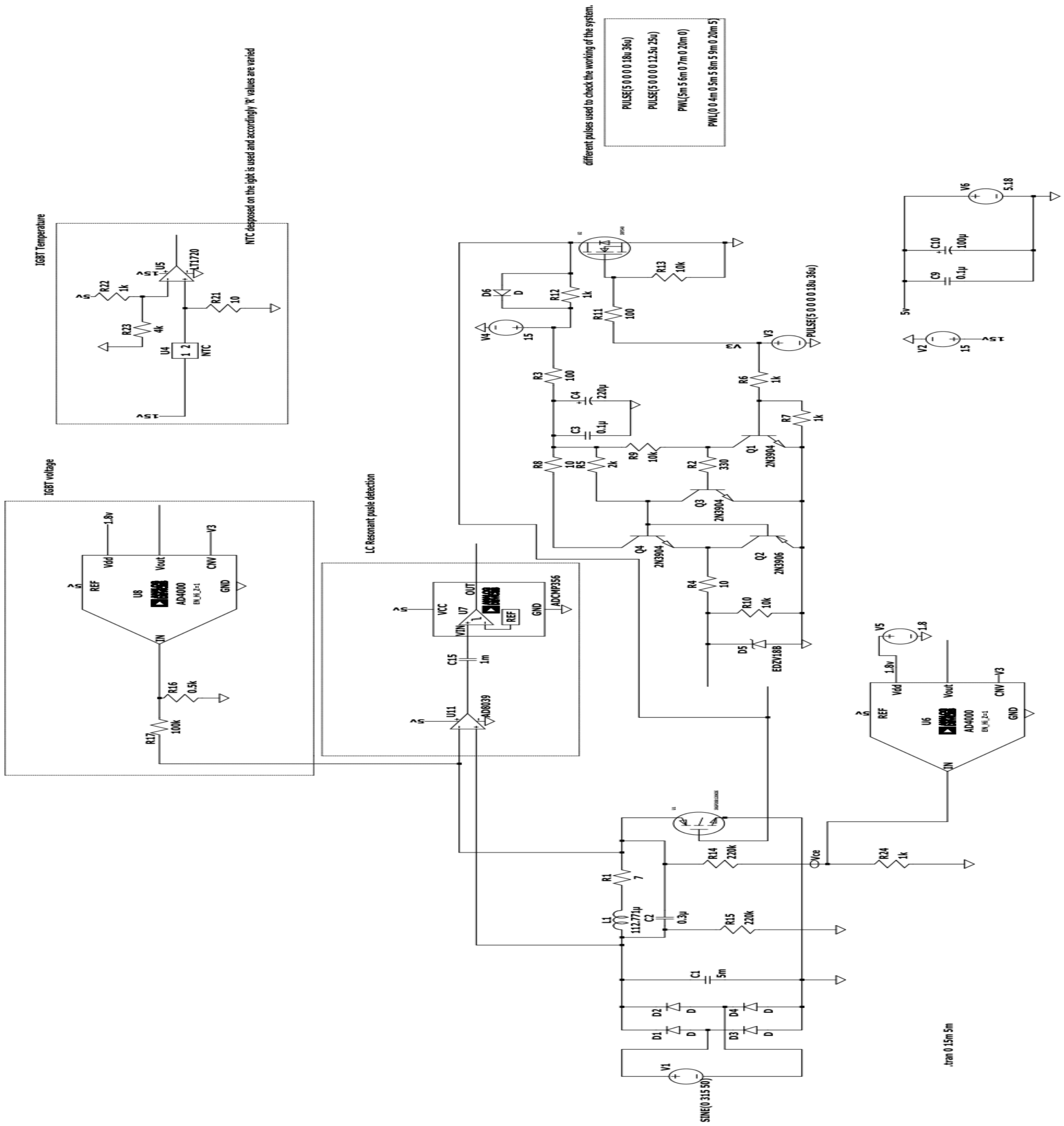


Figure 31: Circuit diagram in LTspice

B Appendix B

MPLAB code :

```
int main(void)
{
    SYSTEM_Initialize();                  //intializing the entire system
    uint16_t delay=2;                      //defining required variables
    uint16_t duty=0;
    uint16_t power=0;
    uint16_t period =0 ;
    uint16_t Difference=0;
         for (int i = 0;i<=1000;i++)
         {
        bool status = PIR2bits.CCP2IF;     //loading the interrupt bit to
                                                    // status
if (status)
       {
Difference=Difference+1;                   // counting the positive edges
        CCP2_CaptureISR();                       //calling capture module
                                          // interrupt service routine(ISR)
       }
        PORTCbits.RC4 =!PORTCbits.RC4;
        }
    period = 10200/(4*Difference);                  // calculating period
    Timer2_PeriodCountSet(period);              // loading the calculated
                                         // period to TMR2 period register
    duty= 2*period;                                    // duty cycle =50%
    PWM3_LoadDutyValue(duty);           // loading the duty cycle value to
                                                  // PWM3 module


    while(1)
    {
        bool status = CMP2_GetOutputStatus();   // loading the output of
                                                    //comparator
      if (status)
      {
         CMP2_ISR();                      // clearing the  interrupt flag
                                                  // by ISR
```

```
        Timer2_PeriodCountSet(0);        // on interrupt overflow this
                                            // sets the timer off
      }
      else
      {
          Timer2_PeriodCountSet(period);
      }


    power= ADC_GetConversion(0x0A);           // starting the conversion
    power = ADRESH + (ADRESL&0xC0)/64;      // loading the register value
      if (power < 10)                         // adjusting the duty cycle
         duty= duty+5;
      if (power > 0x2FF)
         duty= duty-5;
      if (power>10 && power<0x0FF)
          duty= duty;
    PWM3_LoadDutyValue(duty);          // loading the changed duty cycle
                                              // to PWM module
    ADC_ISR();                         // clearing the interrupt overflow
    for (int i = 0;i<=1000;i++)
    {
         delay=2;                                    // creating a delay
         delay=delay+1;
    }
    }
}
```

C References

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