University of Moratuwa
Faculty of Engineering
Department of Electronic & Telecommunication Engineering
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EN2091 - Labrotary Practice And Projects

Linear Power Supply

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Group No: 22

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Table of Content

Abstract

We were assigned to design a 10V linear power supply with a maximum current rating of $10A$. A linear power supply powers a load under constant voltage conditions. The design will involve a step-down transformer that is provided to reduce the $230V$input line voltage to $15V(rms)$ AC voltage, which will then be rectified, smoothened and regulated to produce the desired output. The rectification stage was implemented using a BR3510 bridge rectifier chip, and the smoothing stage consists of capacitors. A 2SC5200 Darlington pair, IN4738A Zener diodes ($8.2V$), BC547 transistors, and resistors are used for voltage and current limiting for a $10A$ maximum current. A potentiometer was used to fine-tune the output voltage to the required 10 volts. over current protection has been added. Heat sinks have been used to ensure proper heat dissipation. A $12V$ DC fan was used to cool down the heating components. The final product is a single-layer PCB with high-power paths and a 3D-printed metal enclosure, which will be a versatile and reliable power supply suitable for a wide range of applications.

1 Introduction

The linear power supply provides a constant output voltage that doesn't change according to the connected load. Power supplies are used to provide continuous voltage and current to a load. Several variables are considered while designing the power supply, such as efficiency, load, line regulation, short circuit protection, etc. A voltage regulator from scratch to supply a high-power load ($100W$) utilizing an input voltage of $230V$ is developed. In the process of developing the linear power supply, the most important criterion is to construct it to output a voltage of $10V$ with a maximum current rating of $10A$, as well as circuit protection mechanisms to prevent short circuits and over current, while considering the power supply efficiency.

The mechanism of a linear power supply involves transforming the input voltage, rectifying and filtering the voltage, and then regulating it to provide a stable and precise output voltage to power electronic devices.

A linear power supply is a type of power supply that uses a linear regulator to regulate the output voltage. The main advantage of a linear power supply is that it provides a clean and stable output voltage with low noise and ripple. Linear power supplies are frequently used for devices that require a clean and stable power supply to function properly, such as audio amplifiers, signal generators, and test equipment, in industrial applications where the output voltage needs to be precise and stable, such as industrial automation, robotics, and process control, and in medical equipment such as patient monitors, ultrasound machines, and imaging systems, which require a stable and low-noise power supply to ensure accurate readings. Moreover, linear power supplies are widely used in telecommunications equipment that requires a stable power supply to ensure reliable communication, such as modems, routers, and switches.

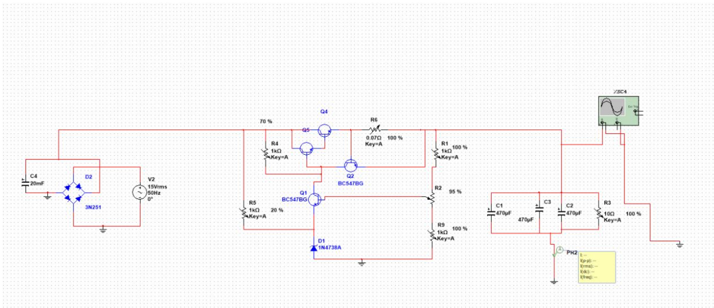


Figure 1: Complete Circuit

2 Methodology

2.1 Rectification

Rectification is the process of converting AC voltage to DC voltage. The AC voltage from the power source is first fed into a transformer, which steps down the voltage to a lower level ($230Vrms$ -$15Vrms$) suitable for the power supply. The stepped-down AC voltage is then fed into a diode bridge, which consists of four diodes arranged in a particular configuration known as the bridge. A bridge of diodes consists of four diodes arranged in a diamond shape with a load connected across two opposite corners and a voltage source connected across the other two opposite corners. Using the principle of balancing electrical currents, a bridge of diodes rectifies an AC voltage and provides a DC voltage to power electronic equipment.

The bridge utilizes diodes to rectify the AC voltage. When an AC voltage is supplied to the bridge, two of the diodes conduct in one direction during the positive half of the AC cycle, while the other two diodes conduct in the opposite direction during the negative half of the AC cycle. This results in a pulsating DC voltage across the load at twice the frequency of the AC input.

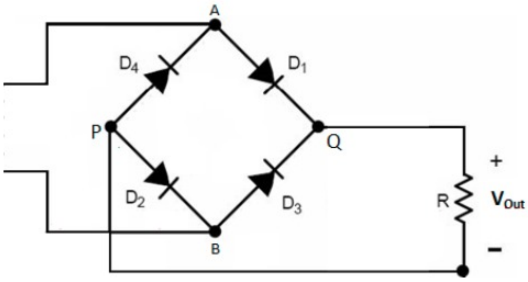


Figure 2: Bridge Rectifier

By analyzing the above circuit, the following equations can be derived when $|V_{in}| \geq 2V_d$

$$V_{out} = |V_{in}| - 2V_d$$

$$V_{rev} = |V_{in}| - V_d$$

Notations are as follows:
V_{in} - Input voltage of the rectifier
V_{out} - Output voltage of the rectifier
V_d - Voltage drop across a forward-biased diode
V_{rev}- Voltage drop across a reversed-biased diode
PIV - Peak Inverse Voltage (Maximum voltage applied across the reverse-biased diodes)

The following calculations are done to sketch the waveforms of the AC input and the rectified DC output of the rectifier bridge.

V_{in}= 15 $Vrms$ (V rms supplied by the transformer)
$V_{in}(peak) = \sqrt{2} \times 15 = 21.21V$
V_d = 0.7 V
$V_{out}(peak) = |V_{in}| - 2V_d = 21.21 - 2 \times 0.7 = 19.81V$
$PIV = |V_{in}| - V_d = 21.21 - 0.7 = 20.51V$

According to the calculation, we have used a BR3510 bridge rectifier chip to implement the rectification stage. This chip supports a maximum output current of 35A, which is sufficiently higher than the required current of 10A. It allows a maximum PIV of 1000V, which is sufficiently higher than the required PIV of 20.51V.

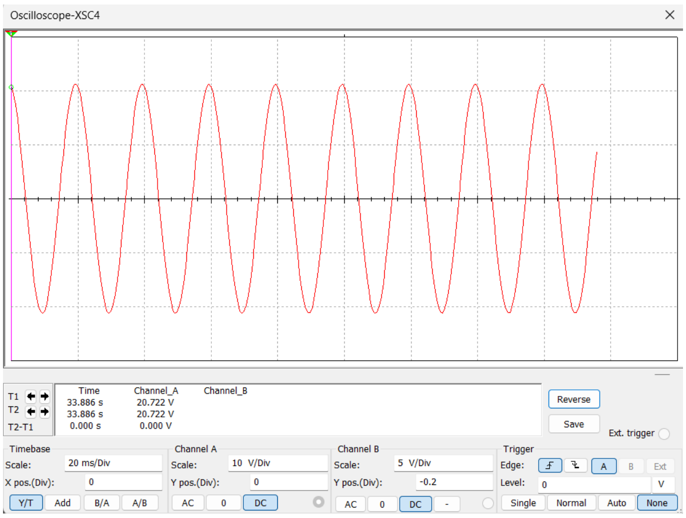


Figure 3: Rectifier Input

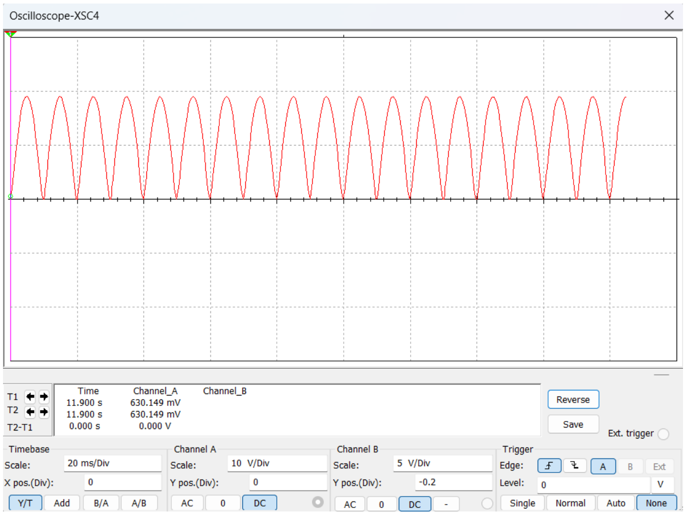


Figure 4: Rectifier Output

2.2 Smoothing

In the linear power supply, the smoothing methodology is used to reduce the ripple voltage or noise in the DC output voltage. This methodology involves using a capacitor filter to smooth out the pulsating DC voltage produced by the rectification circuit, resulting in a more stable DC voltage output.

The capacitor filter consists of capacitors connected in parallel with the load circuit. During the peaks of the pulsating DC voltage produced by the rectification circuit, the capacitor charges up to the peak voltage. During the drop-down period of the pulsating voltage, the capacitor discharges its stored charge, providing a continuous current flow to the load circuit.

The amount of smoothing or ripple reduction provided by the capacitor filter is dependent on the capacitance value of the capacitor. A larger capacitor will provide more smoothing voltage and reduce the ripple voltage further, but it will also take longer to charge up during the peaks of the pulsating voltage. The load resistance also affects the smoothing, as a larger load resistance results in more smoothing.

The voltage variation of a capacitor while discharging through a load can be calculated using the below equation.

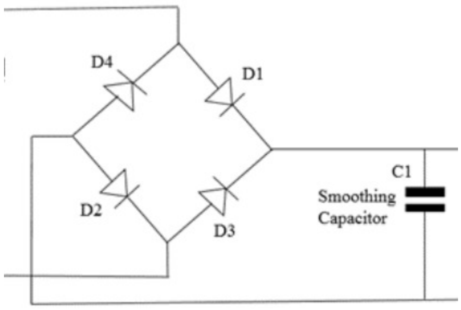


Figure 5: Rectifier with the Smoothing Capacitor

$$V_R(t) = V_p e^{-\frac{t}{RC}} \Rightarrow \frac{dV_R}{dt} = -\frac{V_p}{RC} e^{-\frac{t}{RC}}$$

Notations are as follows:

$V_R(t)$ - Output voltage

V_p - Peak voltage of the rectifier output

R - Load resistance

C - Capacitance

The capacitor must discharge as slowly as feasible to have a greater smoothing effect (I.e. dV_R/dt must be lower). Even though this can be accomplished by raising the value of the RC time constant, R is external to the power supply. So the only design parameter that can be controlled is the capacitance of the smoothing capacitor.

But, as C rises, a bigger transient current is drawn to charge the capacitor during the initial voltage cycle, which might affect the rectifier bridge's diodes. Consequently, it is important to choose the smoothing capacitor carefully to ensure that both the amount of smoothing and the surge current are within acceptable bounds.

$$V_{ripple(pp)} = \frac{V_{p(rect)}}{c.f.R_L}$$

$$= \frac{21.21-1.4}{c \times 100 \times \frac{V}{I}}$$

$$= \frac{19.81 \times I}{c \times 100 \times 10} < 9.81V$$

$I_{max} = 10A$

$c > \frac{19.81 \times 10}{100 \times 10 \times 11.21}$

$c > 20.19mF$

According to the calculation, $21.4mF$ is required. Hence we used one $20mF$ capacitor and three $470\mu F$ capacitors which results the overall capacity of $21.4mF$ in the simulation. We have distributed the capacitors as follows; the $20mF$ capacitor is connected in parallel to the end of the rectifier circuit, and the three $470\mu F$ capacitors are connected in parallel to the load.

Even though $21.4mF$ is required, we only needed $11.4mF$ for practical use. So in our design, one $10mF$ and three $470\mu F$ capacitors are connected parallelly for the smoothing circuit, which results in $11.4mF$ capacitance.

We have distributed the capacitors as follows; the $10mF$ capacitor is connected in parallel to the end of the rectifier circuit, and the three $470\mu F$ capacitors are connected in parallel to the load.

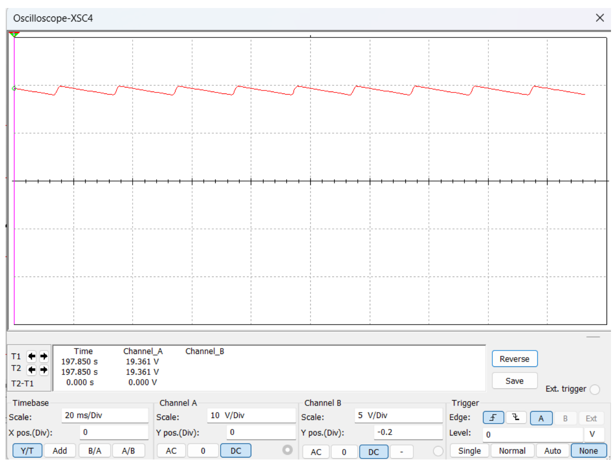


Figure 6: Smoothened Voltage

2.3 Voltage Regulation

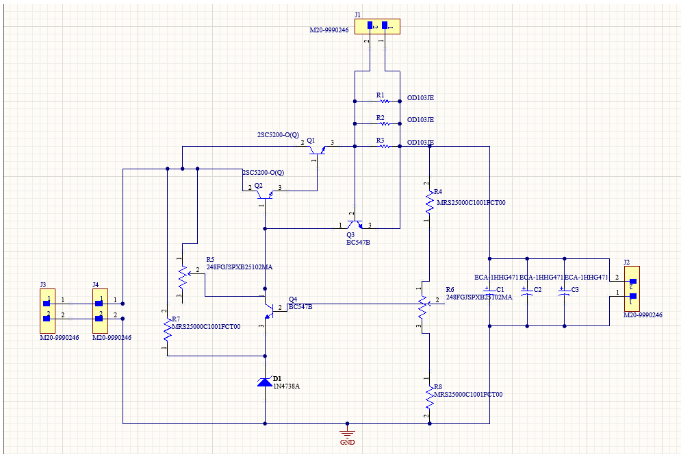


Figure 7: Schematic of the Voltage Regulating Circuit

A linear power supply's voltage regulation mechanism entails preserving a constant DC output voltage despite variations in the input voltage or load resistance. A voltage regulator is used to maintain a constant output voltage level.
V_Z - Zener breakdown voltage $= 8.2V$

V_{be,Q_1} - Base- Emitter voltage of Q_1 transistor $= 0.7V$

$$V_{lower} = V_Z + V_{be,Q_1} = 8.2 + 0.7 = 8.9V$$

This can be considered a voltage divider since the I_b of the Q_1 transistor is negligible. Hence, we can calculate the resistor values of the voltage divider and adjust the R_2 potentiometer to achieve those values and get a steady $10V$ output voltage.

$$\frac{V_{lower}}{V_{upper}} = \frac{R_{lower}}{R_{upper}} = \frac{8.9}{1.1} = 8.09$$

We have used two 2SC5200 transistors to build a Darlington pair that is ideally used for high current amplification applications. The Darlington pair produces a high output current with a small input current. Since the Darlington pair has a small voltage drop across the C-E junction, it operates at lower voltages, reducing the power loss. This supplies a steady high output current.

2.4 Circuit Protection

Circuit protection is an important feature of a linear power supply to ensure safe and reliable operation, and to prevent damage to electronic components.

2.4.1 Over current Protection / Short Circuit Protection

To prevent short circuits, we utilize an $12A$ Fuse (AC fuse). This fuse can withstand a maximum current of $12A$. Hence, the fuse will burn and stop further conduction, preventing any harm to the circuit, if the input current exceeds $12A$. Nonetheless, it's possible that the circuit will experience a larger current for a short period of time before the fuse melts. The transistor, capacitors, and bridge rectifier have a chance to be impacted by this current. So that in the component selection, those are selected to withstand such strong currents.

In order to achieve the overcurrent protection, we have used a resultant resistance of $0.07\ \Omega$. We have utilized three parallel $0.22\ \Omega$ resistors in series with the Q_1 transistor. The voltage across 0.07Ω resistance will be high if the output current exceeds $10A$. The Q_3 transistor will switch from the active region to the saturated region if the voltage exceeds $0.7V$, which is the V_{be} of the transistor. As a result, the I_c current will be high. That required current will be supplied through the R_5 resistor. Because of the significant voltage drop across the R_5 resistor, V_b of Q_2 will be reduced, which results in a low base-emitter voltage for Q_1.

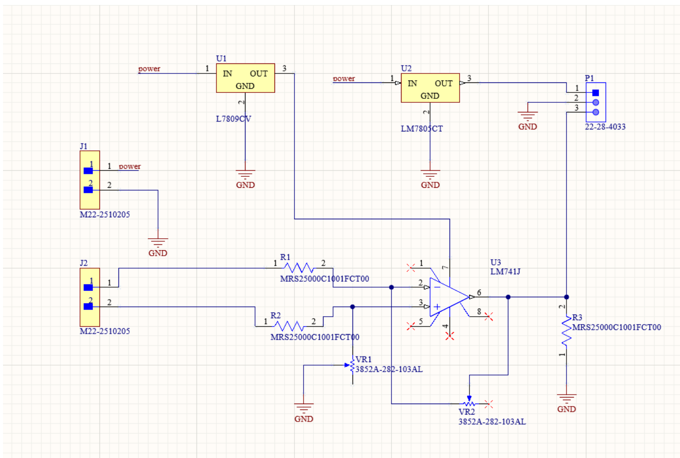


Figure 8: Schematic of the Short Circuit

2.4.2 Thermal Protection

Thermal protection is an important feature of a linear power supply to prevent damage from excessive heat. We have used a heat sink, which is designed to absorb and dissipate heat, for the transistor and bridge rectifier in our design to dissipate the heat generated by the power supply components and prevent the temperature from rising too high.

Also polygons have been used in our PCB design, in order to provide an additional copper area for a net on the PCB which helps to reduce resistance and increase the current carrying capacity of the net. The polygon is connected to a ground plane to provide a low-resistance thermal path for heat to dissipate. Therefore, it is used as a thermal pad or thermal relief to help manage heat on a PCB.

Ventilation is an important consideration in the design of the linear power supply to minimize the heat generated by the power supply. Natural convection is the most suitable and appropriate method for ventilation in our design. Natural convection occurs when the heat rises and cool air is drawn in to replace it. So in our design, this is accomplished by placing vents and holes in the enclosure.

Also, we have used a 12V DC fan to cool the power supply components by forcing air over them. This helps to dissipate the heat generated by the components and prevent the temperature from rising too high.

3 Results

3.1 Verifying the Functionality

Following the planning and simulation phases, as the basic step we constructed our circuit on a breadboard and tested the performance of the power supply unit. The PCB was assembled for the linear power supply after successfully implementing the circuit on the breadboard for a maximum of 1A current. Defects in the circuit, covering component soldering, wire connections, component pin configurations, and electrical continuity of the paths, were checked. The circuit was then tested for functionality, and the results we required were obtained. There we connected the transformer, and using the potentiometer, we set the output voltage under no load condition, as 10.3V.

3.2 PCB Design

The copper thickness is important for the current carrying capacity of the PCB traces. A thicker copper layer will provide a lower resistance path for current flow, reducing power loss and voltage drop. An appropriate copper thickness is used for our PCB design, which supports up to $10A$ of current.

The trace width should be determined based on the current requirements of the power supply. A wider trace will be able to carry more current without overheating. According to the calculations, our design required a trace width of 7.19 mm. Instead of that, polygons have been used in our PCB design, in order to provide an additional copper area for a net on the PCB, which helps to reduce resistance and increase the current carrying capacity of the net.

Adequate clearance and spacing between components and traces are also considered in designing our PCB, which is necessary to prevent electrical shorts and improve reliability. The minimum clearance and spacing were increased to account for the higher current requirements.

3.3 Enclosure

The enclosure design of the linear power supply is required to protect users from any potential electrical hazards. Hence, we ensure that all exposed metal parts are grounded and that there are no exposed electrical components.

The linear power supply generates heat during operation, so the enclosure design is supposed to dissipate that heat effectively. Therefore, ventilation (including vents on the side of the enclosure and holes) is used to ensure that the components remain cool. This helps to dissipate the heat generated by the components and prevent the temperature from rising too high.

The enclosure is required to be large enough to accommodate all of the components of the power supply, including the rectifier, and other components.

Also, the enclosure is designed to allow easy access to the components for maintenance or repair purposes by using removable doors.

Considering the above requirements, the enclosure design was designed using SOLIDWORKS software. Physically, the enclosure was made using metal.

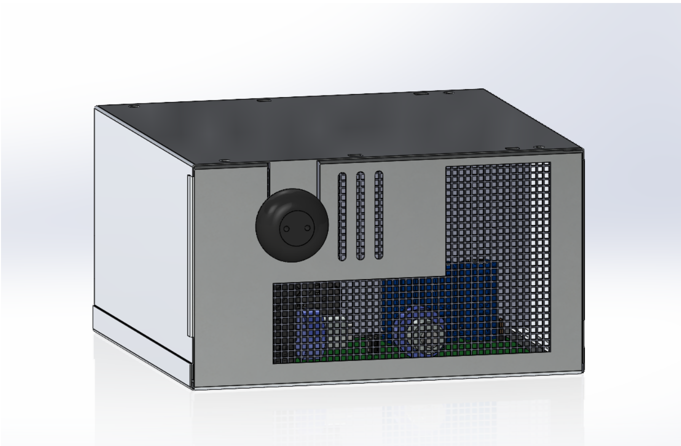


Figure 9: Front view

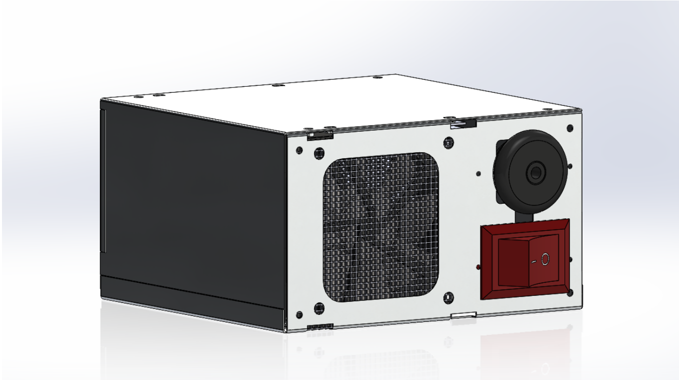


Figure 10: Back view

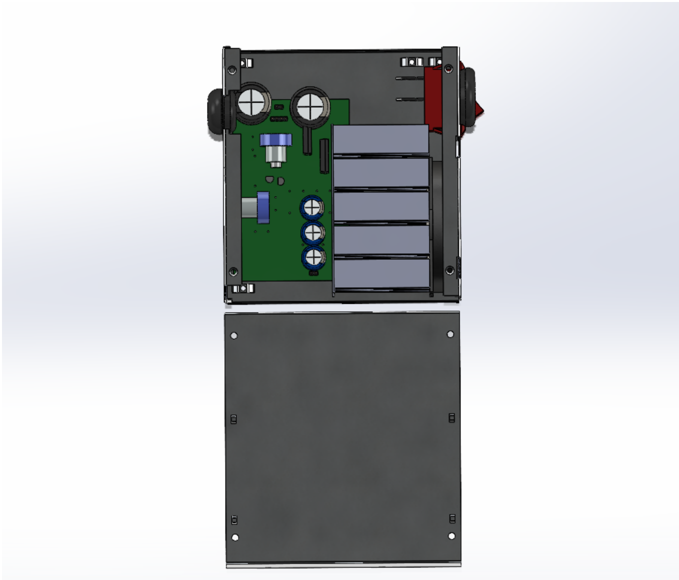


Figure 11: From up

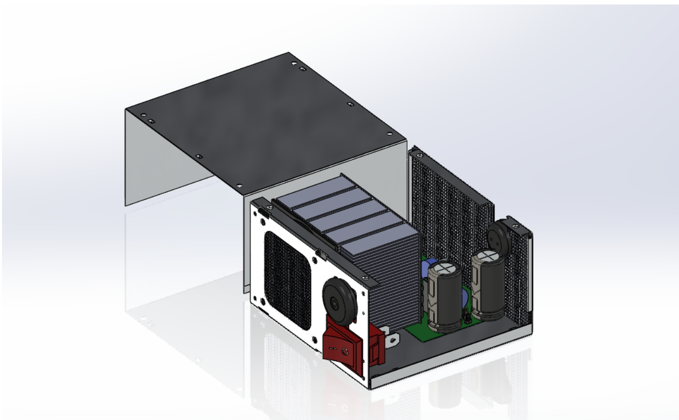
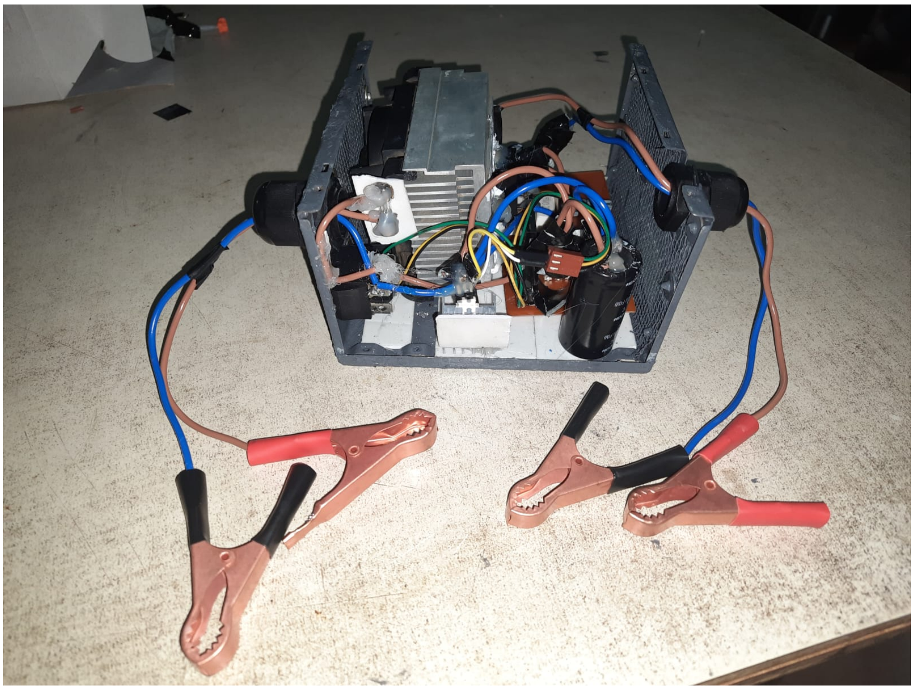
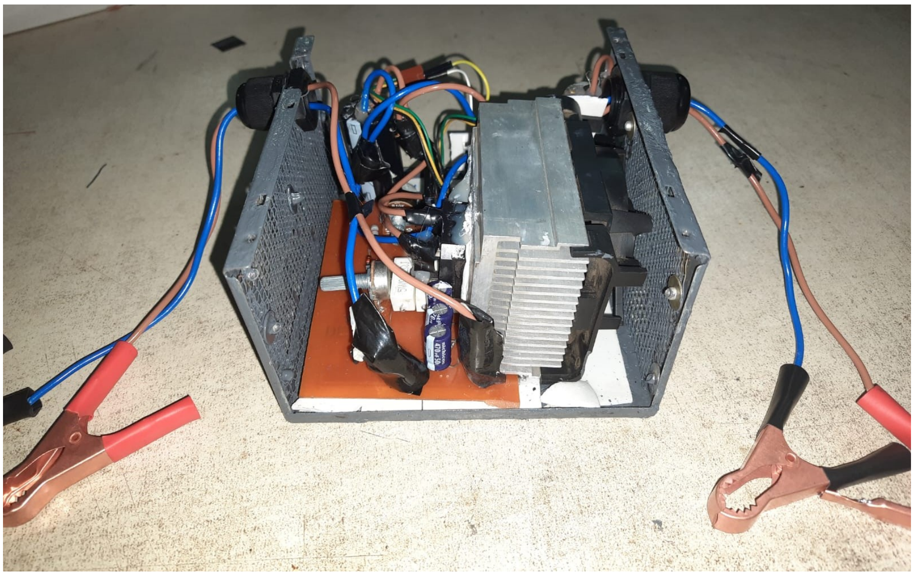


Figure 12: Side view

4 Appendices

Appendix A - Our Design





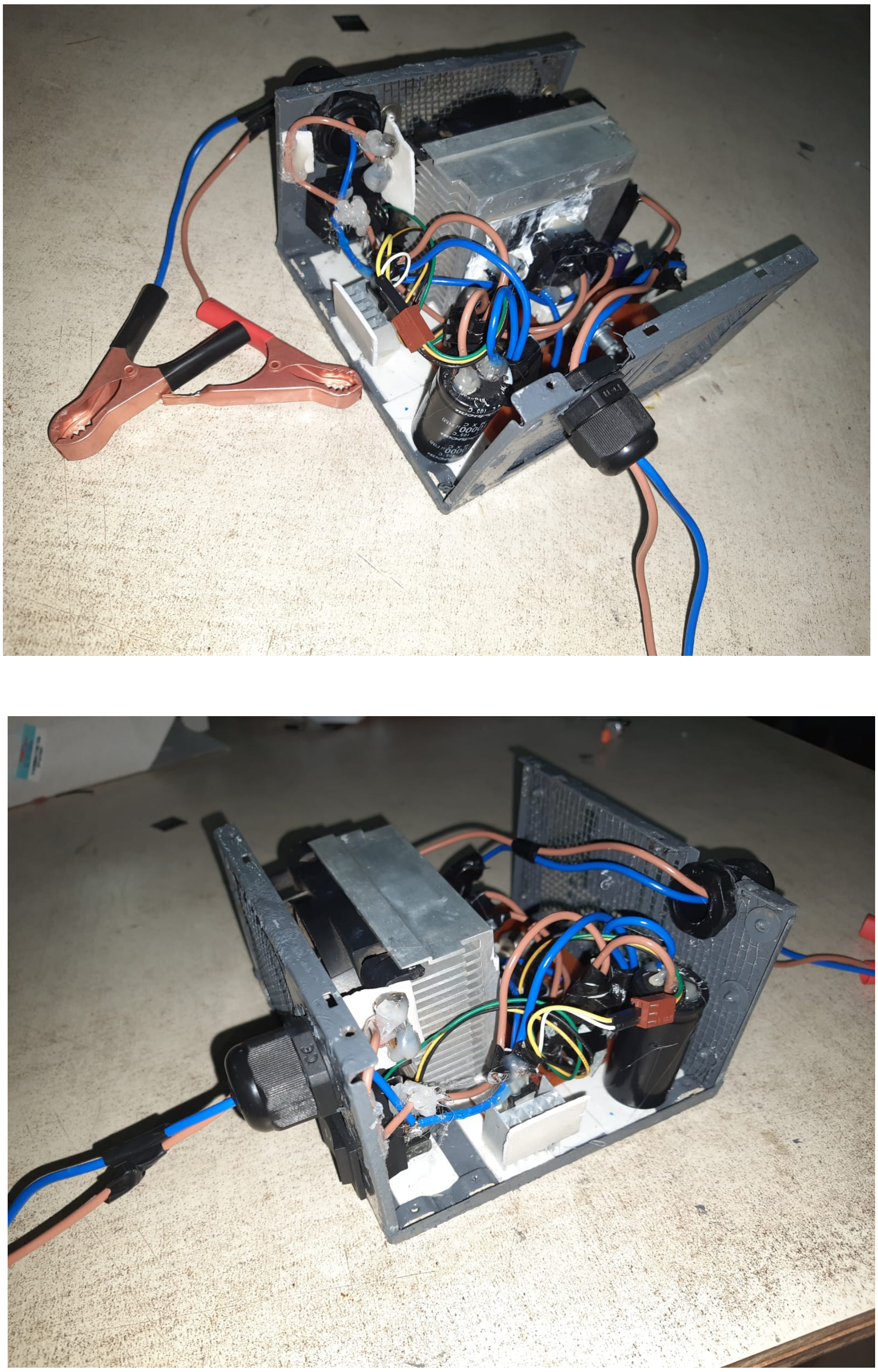


Figure 13: Our Design

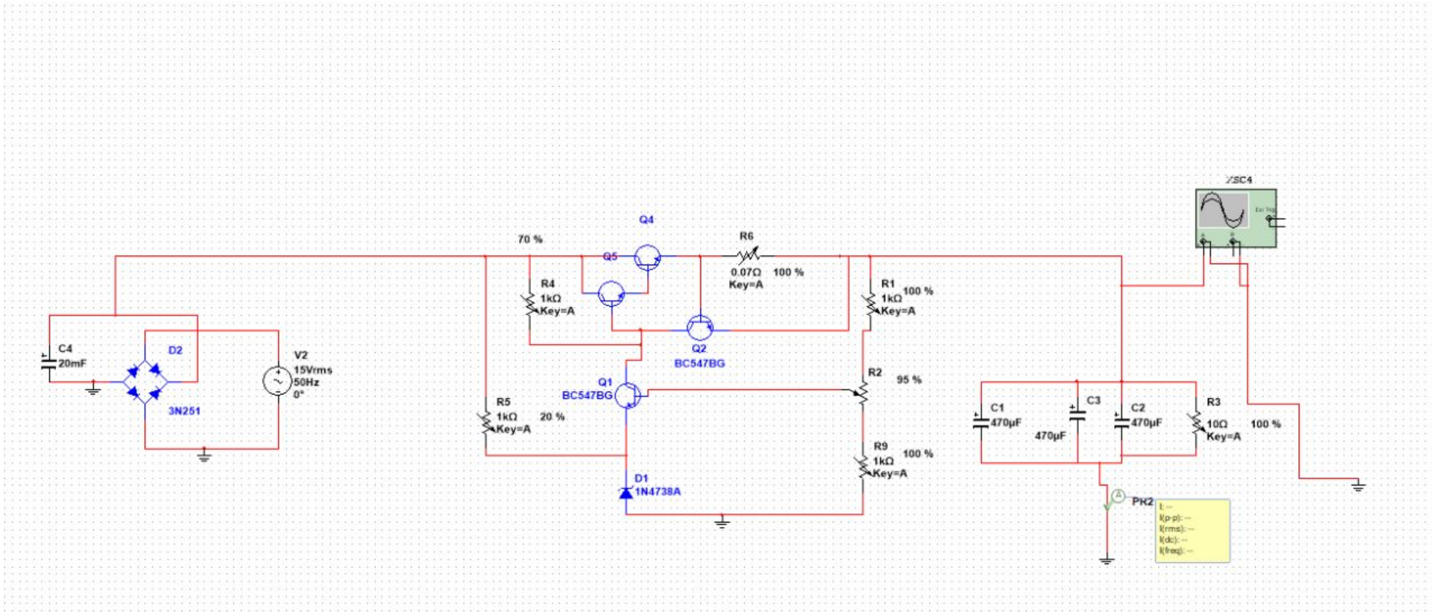


Figure 14: Complete Circuit

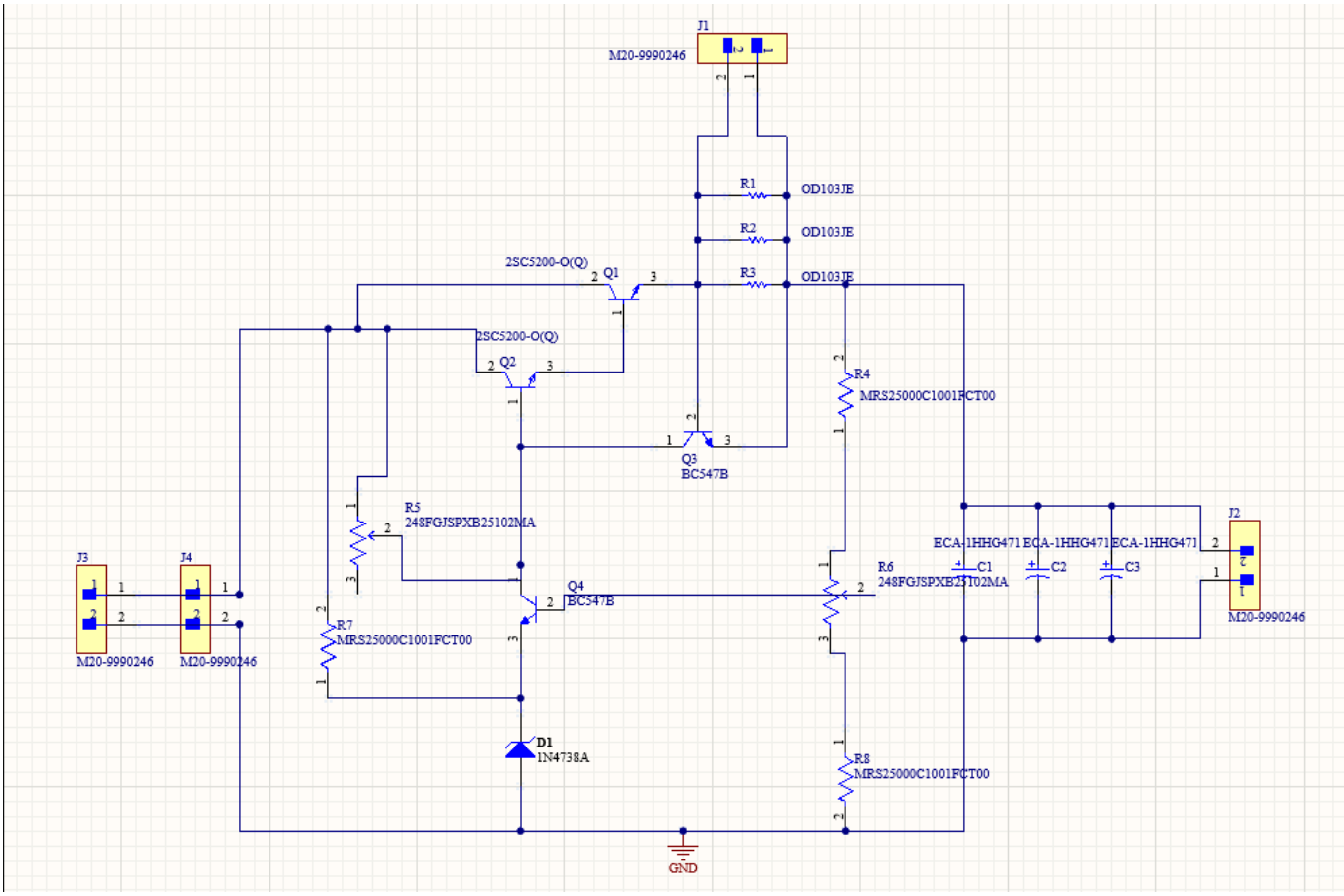


Figure 15: Schematic of the Voltage Regulating Circuit

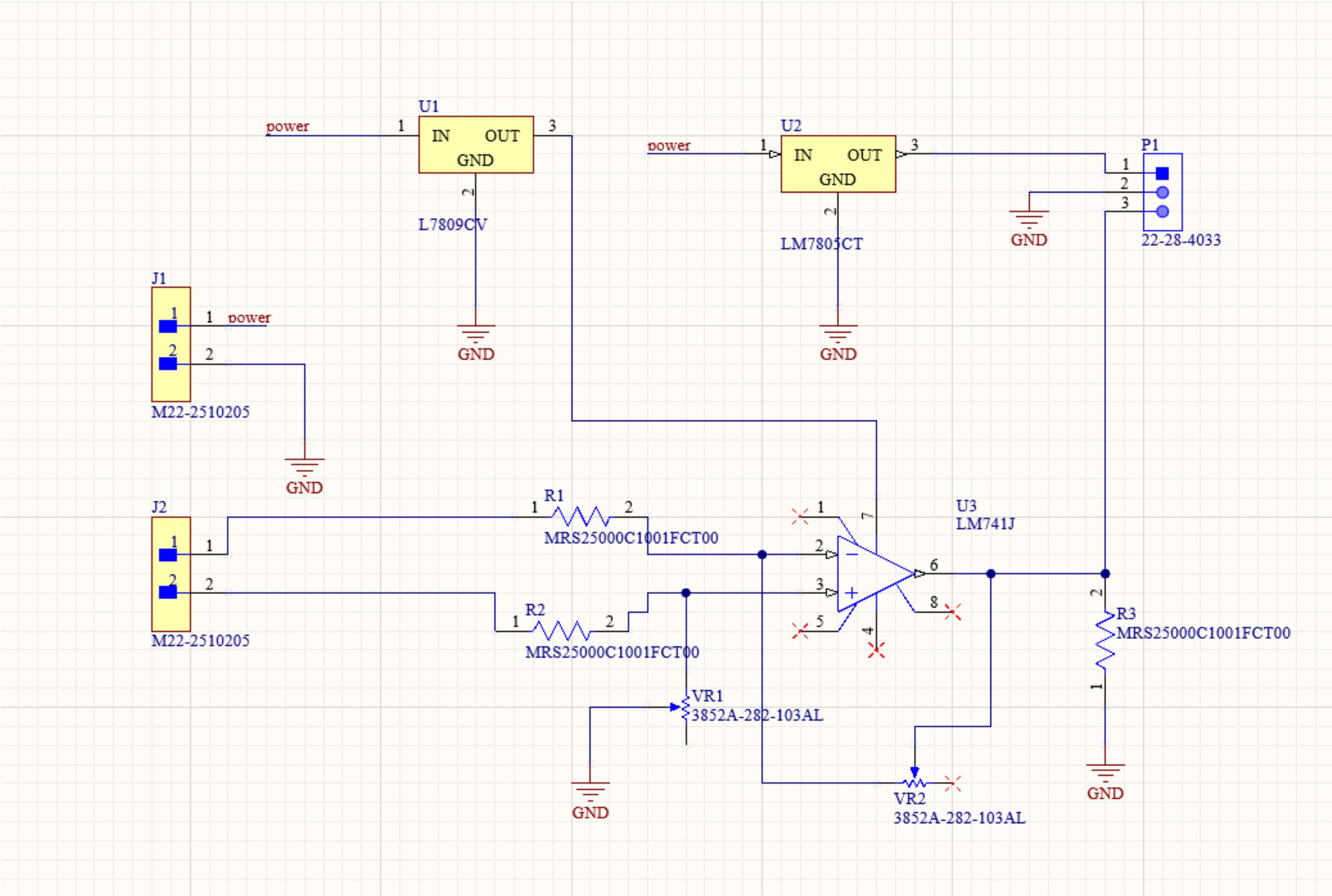


Figure 16: Schematic of the Short Circuit

Appendix B - PCB Design

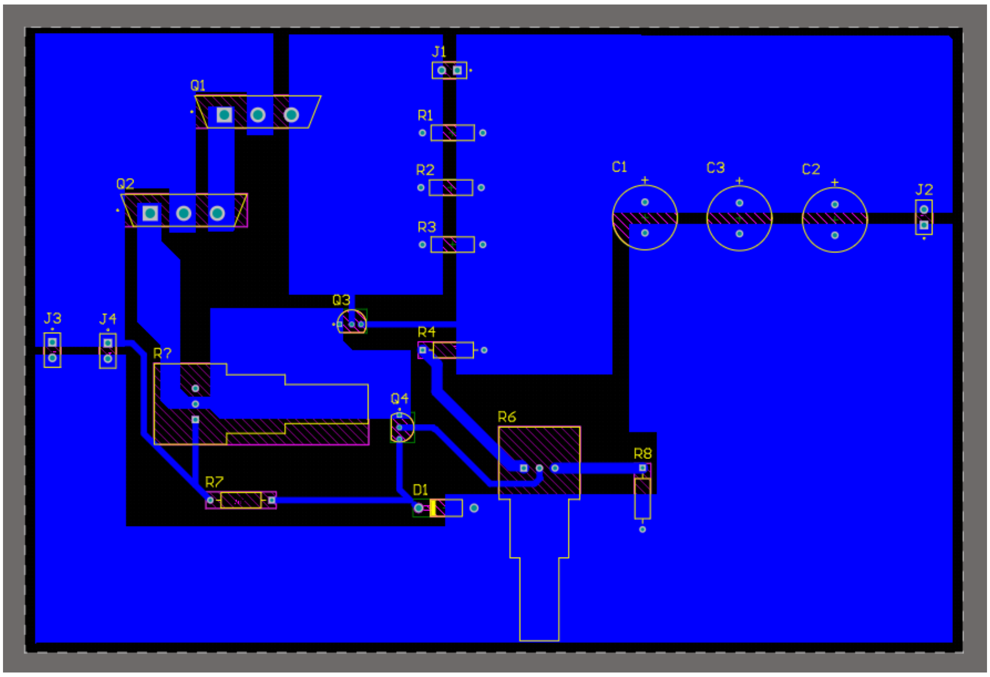


Figure 17: PCB Layout of Voltage Regulating Circuit

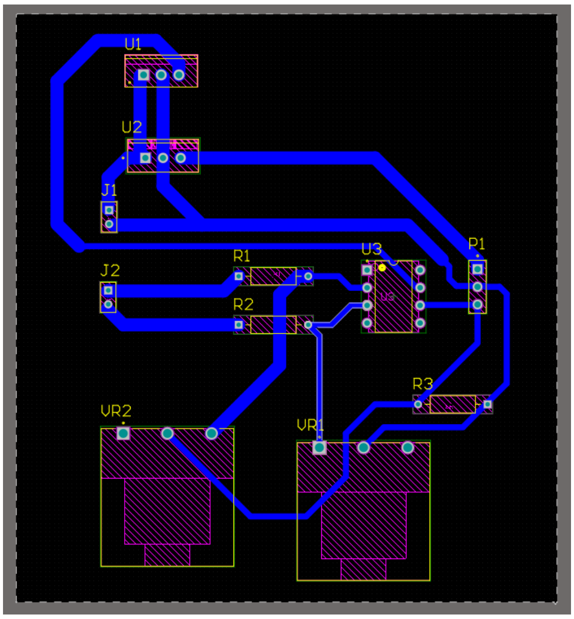
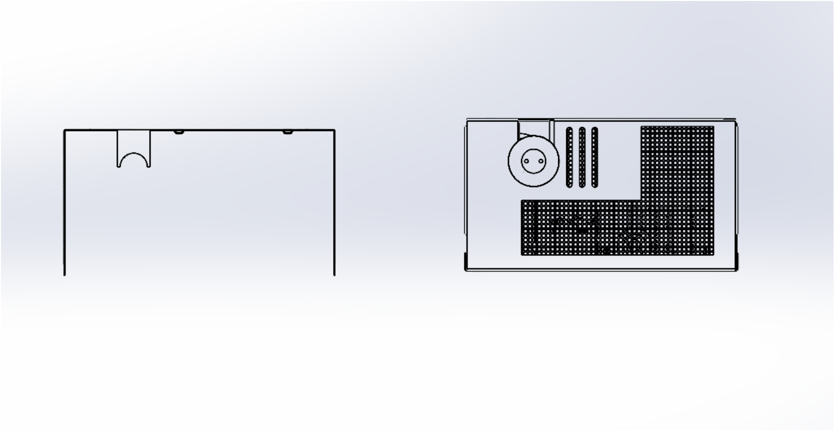
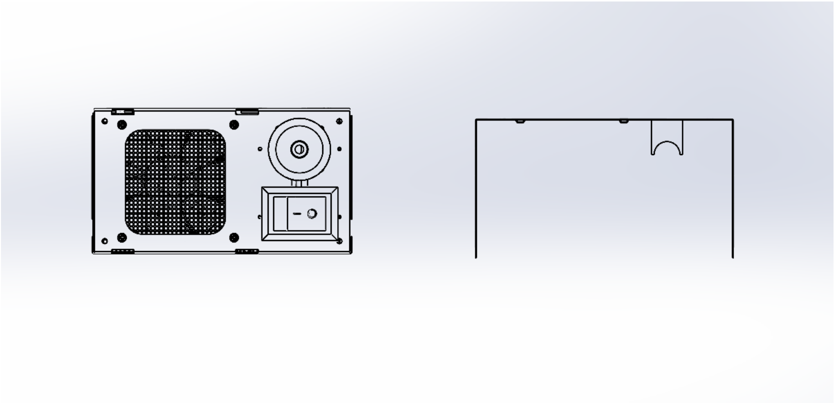
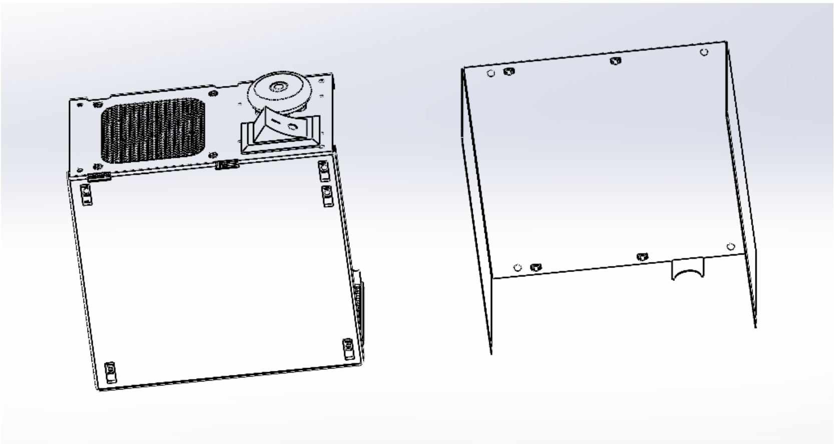


Figure 18: PCB Layout of Short Circuit

Appendix C - Enclosure Design







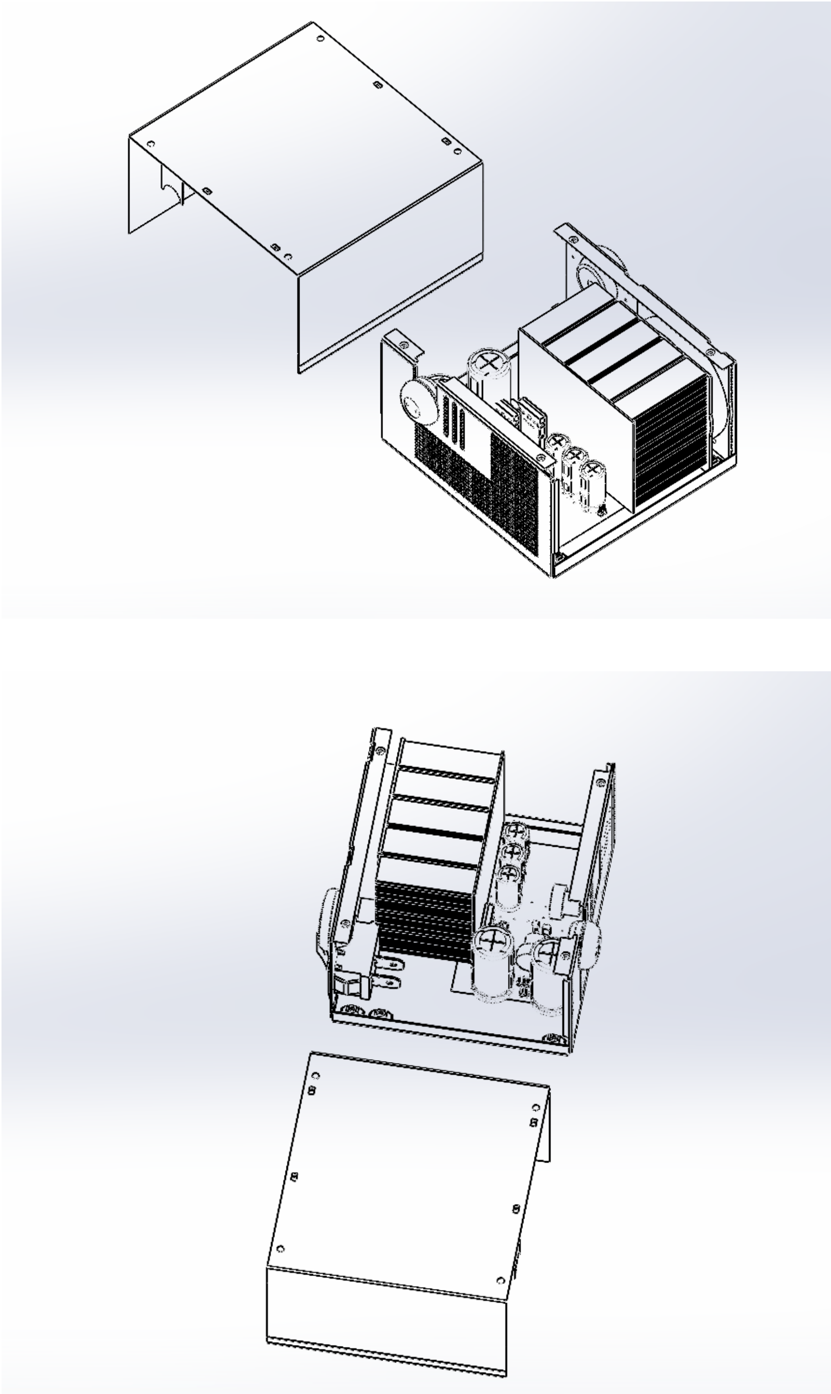


Figure 19: Enclosure Design

5 Data Sheet of the Linear Power Supply

VAC Input	230 V / 50Hz
VDC Output	10.2 - 9.8 VDC Current Rating - 10A
Output Ripple	Negligible up to 10Ω
Over Voltage Protection	Automatic Voltage limit
Overload Protection	Automatic Current limit
Short Circuit Protection	Fusing
Fusing Requirements	Rating of the Fuse – 12A (AC) Fast Blow Glass Fuse 2A 250V

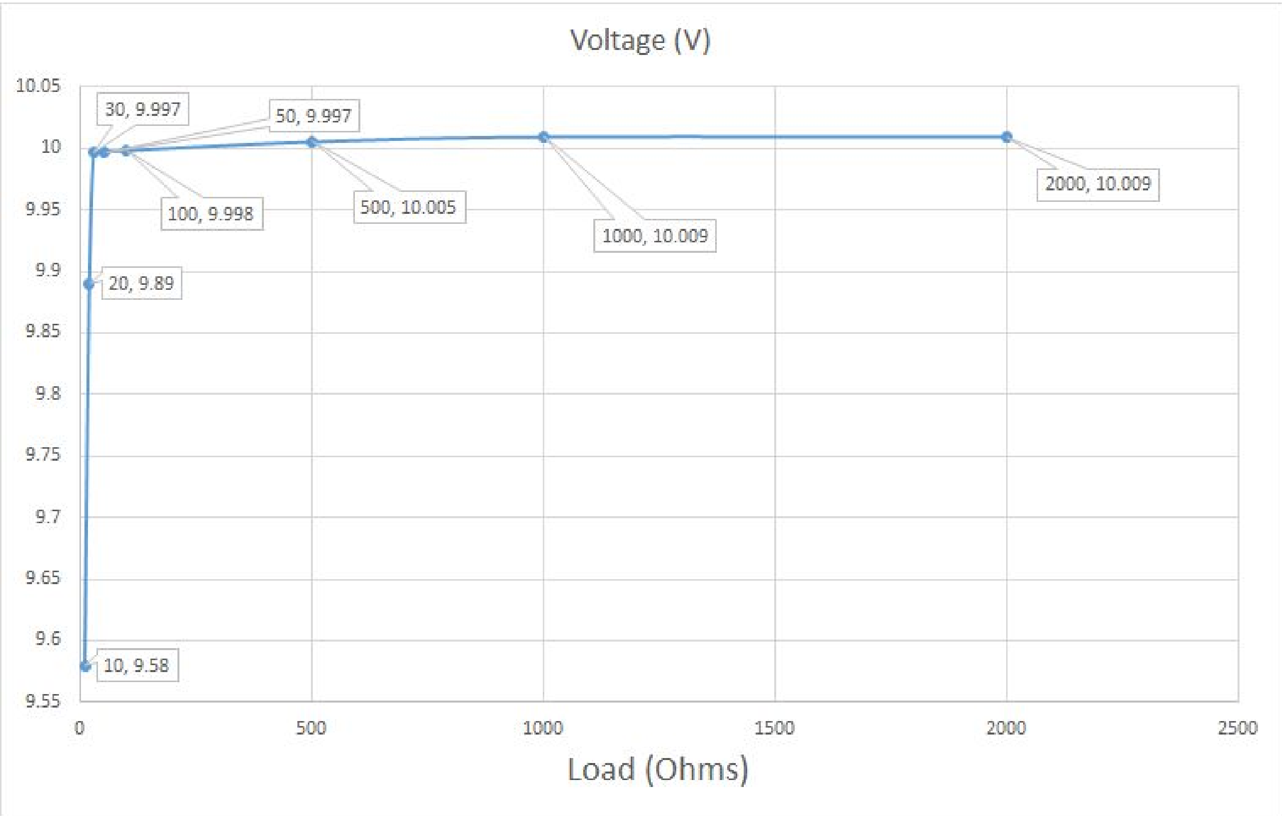


Figure 20: Output Voltage vs. Resistance of the Load

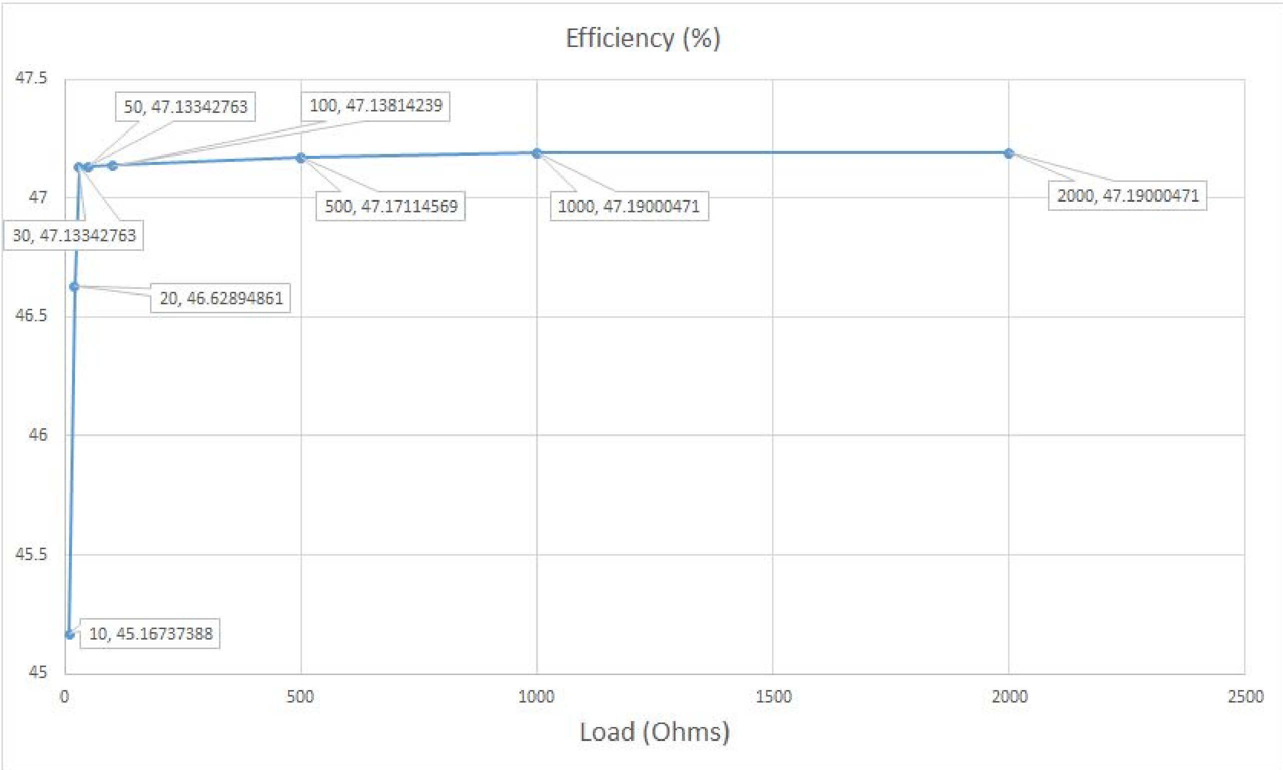


Figure 21: Efficiency vs. Resistance of the Load