Department of Electronic and Telecommunication Engineering

University of Moratuwa

EN2091 – Laboratory Practice and projects

Name	Index no.	Contribution
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This is submitted as a partial fulfillment of the module

EN2091: Laboratory Practice and projects

Department of Electronic and Telecommunication University of Moratuwa

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Contents

Abstract

The objective of the project was to design a 10 V Linear power supply with a maximum current rating of 10 A. This report presents the design of a voltage regulator from scratch to drive a high-power load (100 W) from 230 V input voltage. A step-down transformer was provided to reduce the 230V input line voltage to a 15V (rms) AC voltage. The transformer output voltage is rectified using the BR3510 bridge rectifier and smoothed using two 10mF 50V capacitors in parallel configuration. LM7815 voltage regulator, 12V Zener diode, and LM741CN op amp in virtual circuit configuration are used to implement voltage regulation. TIP142 Darlington pair is used in the current regulation stage. Furthermore, our design consists current limiting circuit and a 12A glass fuse is used to overload protection. 12V DC fan and ventilation, heat sinks are used for thermal protection. Our project was finalized with two PCB and a 3D-printed enclosure to house the PCB.

Section 1 - Introduction

Power supplies are used to drive various loads under constant voltage/current conditions. To ensure the reliable operation of a power supply several factors need to be considered including load regulation, line regulation, efficiency, protection mechanism, heat dissipation, etc.

The assigned task is to design a voltage regulator from scratch to drive a high-power load (100 W) from 230 V input voltage.

The power supply to be made should meet the following design requirements.

- 10 V Linear power supply with a maximum current rating of 10 A
- Should include circuit protection mechanisms.
- Power supply efficiency should be considered when developing the circuit.

The design process includes,

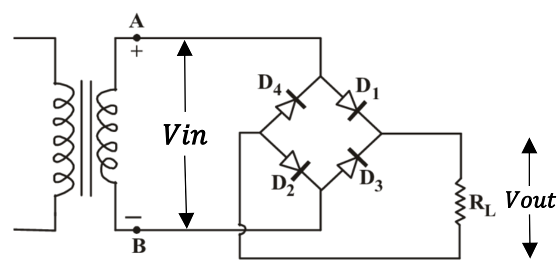
1. **Rectification:** convert AC output from the transformer to DC voltage
2. **Smoothing:** reduce the ripple voltage in the output voltage of the rectifier output.
3. **Regulation:** maintaining the constant output voltage.
4. **Protection**

Section 2 - Methodology

Section 2.1 - Rectification

The first stage of the DC power supply is rectification which involves converting the input sinusoidal AC voltage to an output voltage with a single polarity. There are many different techniques for implementing the rectification stage in a circuit, however, the most used and simplest method is using a Wheatstone bridge rectifier.

Wheatstone bridge rectifier consists of four diodes. Each diode is arranged to conduct only during one half-cycle of the input AC waveform, allowing the output to be a positive voltage.



By analyzing the circuit, we can derive a set of equations that describe the behavior of the rectifier in terms of its output voltage ($Vout$) and the voltage across a reversed-biased diode ($Vrev$), as they relate to the input voltage (Vin) and the nominal voltage drop across a forward-biased diode (Vd). It is important to note that the equations are only applicable when the output current is forward-biased, that is, when $|Vin| \geq 2Vd$.

$$Vout = |Vin| - 2\,Vd \qquad \text{Eq. 1}$$
$$Vrev = |Vin| - Vd \qquad \text{Eq. 2}$$

The transformer provided for this project is a step-down transformer with a voltage ratio of 230:15. Therefore, when connected to the household power supply, the transformer will supply a $15V\ rms$ input voltage to the rectifier. The peak voltage of the input waveform is calculated as $\sqrt{2} \times 15 = 21.21V$. Assuming a nominal voltage drop of $0.7V$ for Vd, the peak voltage of the rectified output waveform can be calculated using Eq. 1 as

$$Vout = 21.21 - 2 \times 0.7 = 19.81V$$

The waveforms of the AC input and the rectified DC output of the rectifier bridge are illustrated in Figure 3.

The Peak Inverse Voltage (PIV rating) is defined as the maximum voltage that can be applied across its reverse-biased diodes. By applying Eq. 2 at the peak of the rectifier input waveform, the PIV value can be computed as

$$PIV = 21.21 - 0.7 = 20.51V$$

The Wheatstone Bridge Rectifier, as illustrated in Figure 2, was used in our design and we implemented it using a commercially available bridge rectifier chip KBPC3510. This chip can support a maximum average output current of $35A$, which is sufficient for a $10A$ DC power supply. Moreover, the maximum peak reverse voltage of the chip is $1000V$, which is much higher than the PIV value suggested by our calculations.

Section 2.2 - Smoothing

Smoothing is the process of reducing variation or ripples of rectifier output voltage. This is typically done by adding a capacitor parallel to the rectifier output. When rectified AC output is applied across the capacitor, the capacitor charges during the positive half and discharges during the negative half. The resulting voltage variation due to the discharge of a capacitor over a resistive load can be expressed by the following equation, which is referred to as Eq.3 in the previous context:

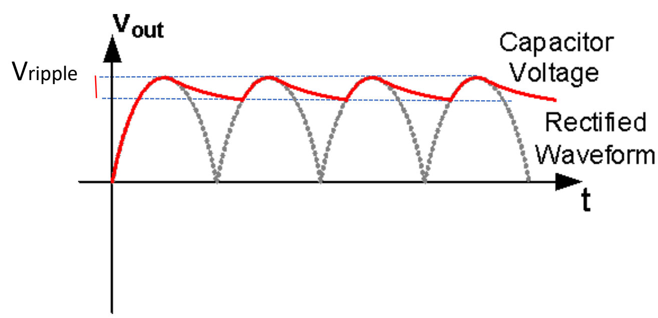
$$V_R(t) = V_p\, e^{\frac{-T}{RC}}$$

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

In this equation, $V_R(t)$ represents the output voltage of the smoothing circuit at a given time t. V_P represents the peak voltage of the rectified AC voltage (maximum voltage that the capacitor can charge up to). RC represents the time constant of the RC circuit.

In order to achieve a better smoothing effect, the capacitor must discharge slowly. $\frac{dV_R(t)}{dt}$ need to be low value. Although this can be achieved by increasing the value of the RC time constant, since R is beyond the control of the power supply, the only controllable factor in the design is the capacitance of the smoothing capacitor C.

However, Increasing the capacitance increases the surge current drawn to charge the capacitor which may cause to damage the rectifier diodes. Thus, capacitors need to be selected considering the surge current limit and desired amount of smoothing.



Since 10V steady voltage is expected,

$$V_{ripple} = 19.81 - 10 = 9.81V$$

Since 50Hz household voltage is used in initial stage, the rectified voltage frequency is 100Hz. Thus, T is 1/100.

$$V_R(t) = V_p\, e^{\frac{-T}{RC}}$$

By approximating,

$$V_R(t) = V_p\left(1 - \frac{T}{RC}\right)$$

$$V_{ripple} = 9.81 = V_p \frac{T}{RC} = 19.81 \times \frac{100}{RC}$$

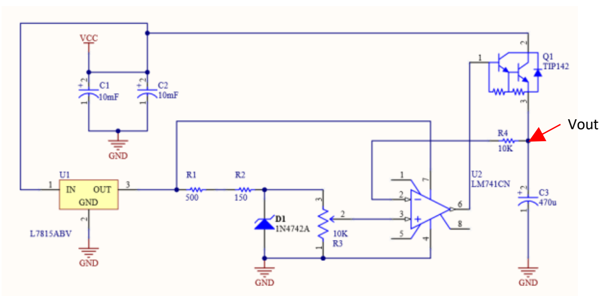
$$C = \frac{19.81}{981 \times R}$$

Since the minimum R is about 1Ω as satisfying the maximum current 10A,

$$C \approx 20.194 \text{ mF}$$

Based on obtained results, 20mF capacitor was selected as smoothing capacitor. This is approached by using two 10mF capacitors in parallel configuration.

Section 2.3 - Regulation



Voltage regulation

The voltage regulation process is a crucial aspect of a linear power supply. To achieve a constant output voltage, a virtual short circuit is utilized in this design. Virtual short circuit refers to a configuration in a differential amplifier such as op-amp where the inverting and non-inverting input have almost same voltage. Initially 15v voltage is regulated and 10V is supplied to one of the op-amp terminals, ensuring a constant output voltage of 10V. The op amp is supplied with 15V and 0V to ensure that positive voltage is fed back to the Darlington. In order to further regulate the voltage to the desired level of 12V, a Zener diode is implemented.

Initially, an LM7812 was used, but it produced unacceptable ripple. Therefore, an LM7815 and a 12V Zener diode (IN4742) have been substituted. Finally, to ensure safety, a resistor R1 is incorporated into the circuit.

Current regulation

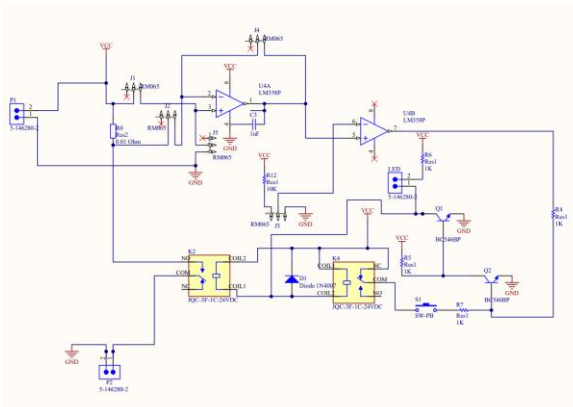
TIP142 Darlington pair is utilized to control the current. The op-amp provides feedback to the Darlington pair and by using that control the current. Here, the Darlington pair work as a current controlling gate.

Initially, a MOSFET was utilized for current control, but it resulted in a high-frequency oscillation at higher current levels. Therefore, the MOSFET has been substituted with a Darlington pair for improved performance.

Section 2.4 - Current limiting

This power supply is required to limit the maximum current up to 10A. When the current through a circuit exceeds its rated current, it may cause overheating, and component failure. Thus, implementing an over-current protection circuit, prevent damage to the device and ensures proper functionality.

There are many techniques to implement current limiting circuit. The use of a relay is a common practice. In such circuits, changeover contacts are utilized to connect the supply voltage when the current is lower than the rated current and to open the contact when the current exceeded the rated current. Two spdt relays are utilized in this design. Since normally open contact points are used, current must be allowed to flow through the coil so that the contacts remain closed. To address this, an NPN transistor (Q1) is added in series with the coil, along with a 1k resistor (R6) between the supply voltage and the base of the transistor. When voltage is applied to the circuit, current flows through the base-emitter path of the transistor and causes it to operate in the saturated region. As a result, the coil of both relays are energized, and the contact is closed. A flyback diode is added to prevent the occurrence of huge voltage spikes when the relay coil is de-energized. A green LED is used to indicate the absence of over current problem.



To deactivate the coil when an over-current issue occurs, an NPN transistor (Q2) is added to the base of the first transistor. If an error signal is applied to the base of the second transistor (Q2), the base current of the first transistor (Q1) will flow through the second transistor. This causes the coil to deactivate, the LED to turn off, and the contacts to open.

To detect current exceeding 10A a low-value power resistor (Res2) is added between the supply voltage and the first relay contact. 0.1-ohm 10W resistor is intent to use for this design. Since it’s not available in market thick copper wire is used. This creates a voltage drop proportional to the flowing current, which is amplified using an operational amplifier (op-amp U4A) in differential amplification configuration. The amplified signal is connected to the non-inverting input of the second op-amp (U4B), whose inverting input is directly connected to the potentiometer, which acts as a variable reference voltage. Since the op-amp functions as a comparator, its output is pulled high when the current sense voltage is higher than the reference voltage. This triggers outputs that are connected to the base of the second transistor (Q2) through a resistor (R5), thus turning off the relay when the current exceeds 10A.

However, once the relay is no longer activated, the flowing current decreases and turns off the output of the comparator, allowing the relay to be activated once again. Since over-current will flow once again when the relay is activated, the comparator triggers once again, and the cycle repeats repeatedly.

To address this, a reset switch (S1) (normally closed push button) with a resistor (R7) is connected between the normally closed contact of the relay K4 and the base of the Q2. When current exceeds 10A, the relay turns off, but since the normally closed contact is closed, the base of the Q2 is still pulled to the supply voltage, even though the comparator output is low. As a result, the relay remains off until the reset button is pushed, which interrupts the base current of the Q2, allowing the relay to be activated once again.

Section 2.5 - Protection

Section 2.5.1 - Short circuit protection

The current limiting circuit discussed in section 2.4 is used as short circuit protection. When a short circuit occurred, the current limiting circuit will be activated.

Section 2.5.2 - Overcurrent protection

12A 250V Fast Blow Glass Fuse (AC fuse) is utilized to implement overcurrent protection. The maximum current allows through the fuse is 12A. Fuse is connected to the 15V transformer output, which burns out when input current exceeds 12A. However, the circuit may experience a higher current for a short amount of time until the fuse wire melts. This current will go through the KBPC3510 bridge rectifier, capacitors, and TIP142 Darlington pair. Thus these components need to tolerate such high currents.

Section 2.5.3 - Thermal Protection

Thermal protection is an important consideration in linear power supplies to protect against overheating and potential damage to the circuit. In this design, Heatsinks, Fans and ventilation, and proper PCB design are utilized to implement thermal protection.

12V DC fan is used to ventilate the power supply unit. LM7812V is used to provide 12V DC power supply to the fan. Enclosure design includes air vents for the heated air to flow outside.

To provide effective thermal conductance, heat sink is utilized. In this design, heatsinks are utilized for the TIP142 Darlington pair the KBPC3510 bridge rectifier since a higher current of $10A$ will pass through these components during extreme conditions. Heatsinks are used for LM7812 and LM7815 as well due to the fact that these components generate a significant amount of heat. Also, we used thermal paste and thermal conducting current insulated mica sheet to make the contact between the heatsinks and the components.

Furthermore, heatsinks are mounted using spacer screws to avoid any contact with the PCB. In the PCB, copper traces designed to carry the load current were made wider and shorter to reduce path resistance, which ensures that PCB does not overheat during extreme conditions. Furthermore, proper wire connectors with necessary current ratings were used for the devices connected to the external heat sinks to avoid overheating and other failures.

Section 3 - Results

After the designing stage, the circuit was tested using multisim simulation software. In the next stage, the prototype was built using breadboards and tested. Since breadboard implementation met the requirements, Finally prototype was built using PCB.

Checking the Circuit

Checking the Circuit is important to identify any problems or faults such as loose connections, damaged components, short circuits, etc. Here, we checked for any error in the circuit, including the component soldering, electrical continuity of the paths, wire connections, and component pin configurations.

Verifying the functionality

First, we checked functionality in no load configuration and the 10K potentiometer is calibrated to obtain 10V steady voltage. Short circuit protection circuit is verified by creating short circuit configuration purposely. At the next step measurements are obtained for the datasheet by varying the load resistor value.

PCB design

Since 10A current draw through the circuit in extreme condition, PCB can get heated up easily. To avoid heating of PCB, several techniques are used. High-power components such as rectifier two mF capacitors and the Darlington pair are placed outside the PCB and fixed to the enclosure. copper traces designed to carry the load current were made wider and shorter to reduce path resistance, which ensures that PCB does not overheat during extreme conditions. Furthermore, power wires are used for high power paths.

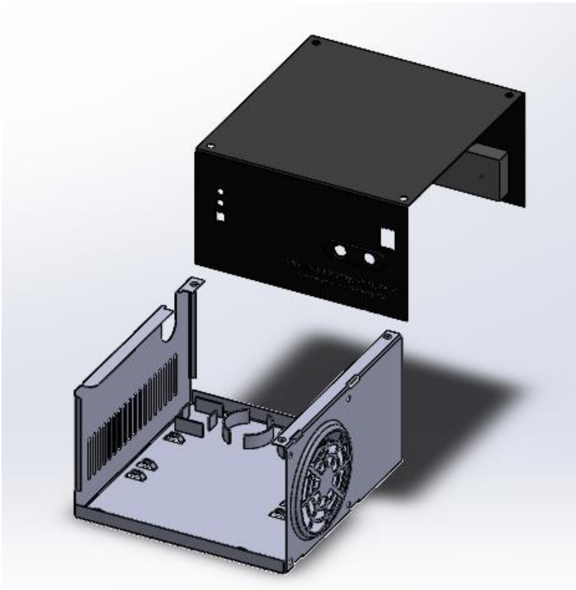
Enclosure

Since metal providing electromagnetic shielding, high heat dissipation and the degree of wire resistance, metal enclosure is used.

<u>Enclosure Design</u>

The enclosure design for the Linear Power Supply was designed using SOLIDWORKS 2020 software.

Enclosure design contain of two parts. Those parts are assembled using four screws.



Ventilation holes are used to allow for airflow and heat dissipation.

Future works

We plan to replace the copper wire currently used in the current limiting circuit with a reliable resistor. Additionally, we wish to improve the efficiency and to employ high-quality PCBs to develop a high-quality product.

Conclusion

This report has presented the designing process of 10V linear power supply with 10A maximum current. Both the simulation and the physical implementation confirmed its required performance with good voltage regulation and lo

implementation confirmed its required performance with good voltage regulation and low ripple.

References

KBPC3510datasheet

https://pdf1.alldatasheet.com/datasheet-pdf/view/814963/DGNJDZ/KBPC3510.html

LM7815 datasheet

https://pdf1.alldatasheet.com/datasheet-pdf/view/83945/ETC/LM7815.html

LM741N datasheet

https://pdf1.alldatasheet.com/datasheet-pdf/view/198081/SEOUL/LM741.html

LM358P datasheet

https://pdf1.alldatasheet.com/datasheet-pdf/view/3067/MOTOROLA/LM358.html

BC546 datasheet

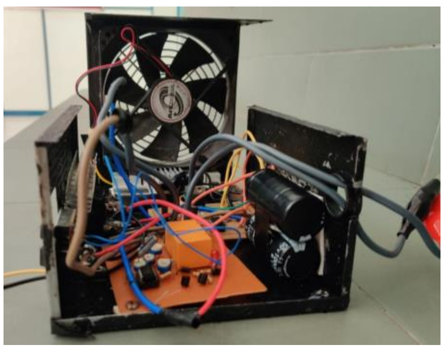
https://pdf1.alldatasheet.com/datasheet-pdf/view/596620/FAIRCHILD/BC546.html

TIP142 datasheet

https://pdf1.alldatasheet.com/datasheet-pdf/view/2772/MOSPEC/TIP142.html

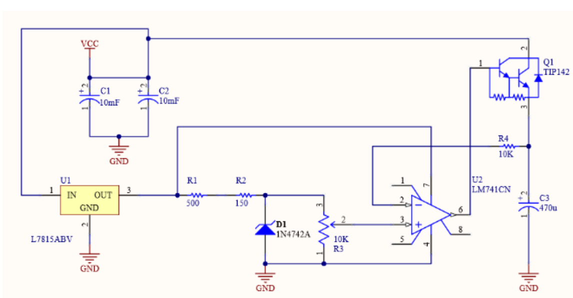
Appendices

Appendix A - Our product

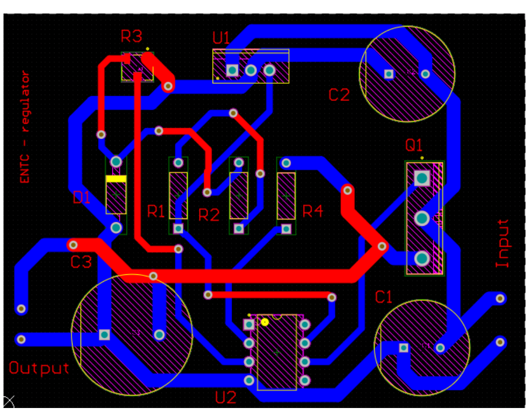


Appendix B - PCB Design

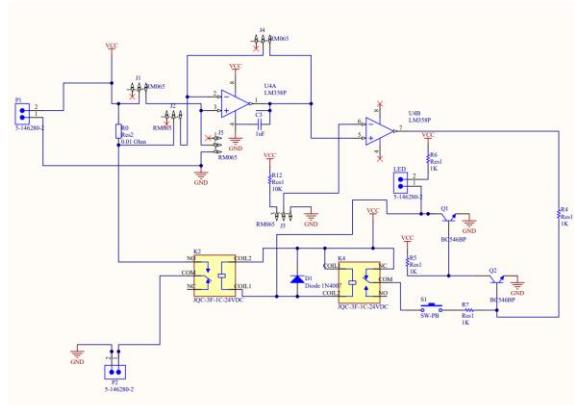
Voltage regulation circuit - schematic



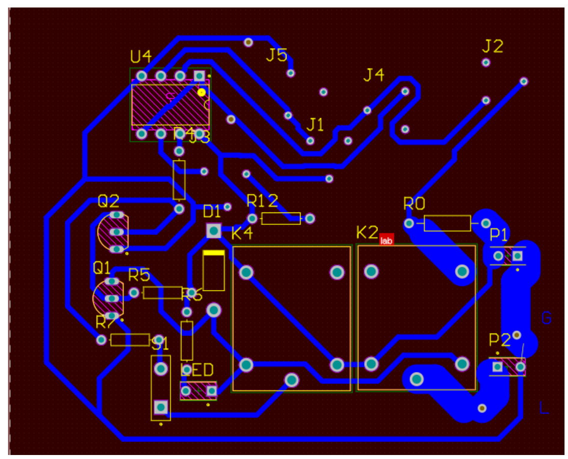
Voltage regulation circuit - PCB Layout



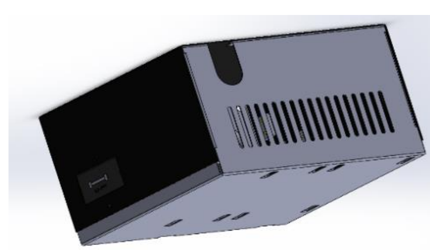
Short circuit protection - schematic



Short circuit protection - PCB Design



Appendix C - Enclosure Design



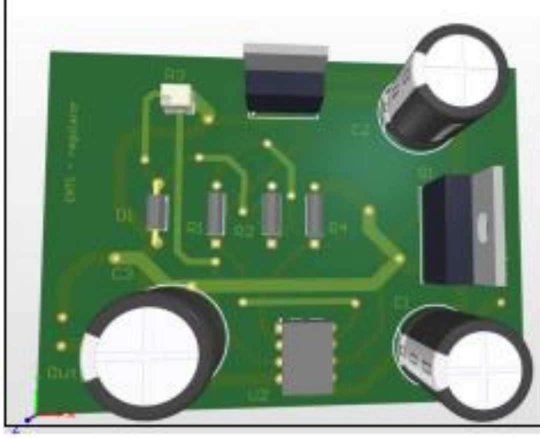
Appendix D - Data sheet of Linear Power Supply

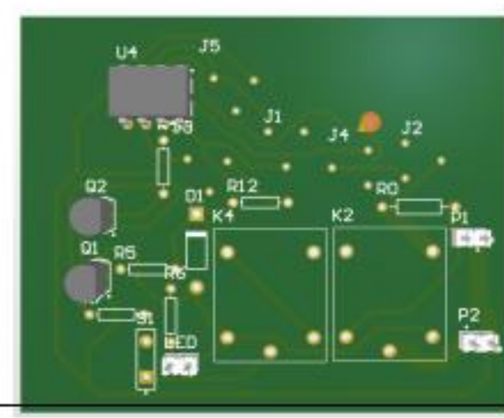
1

Data sheet – Linear Power Supply

Description

- Linear power supply with 10V and 10A rated current.
- High Durability and reliability.
- Applications – 1) DC voltage required appliance.
  2) Industrial applications.
  3) Other applications.



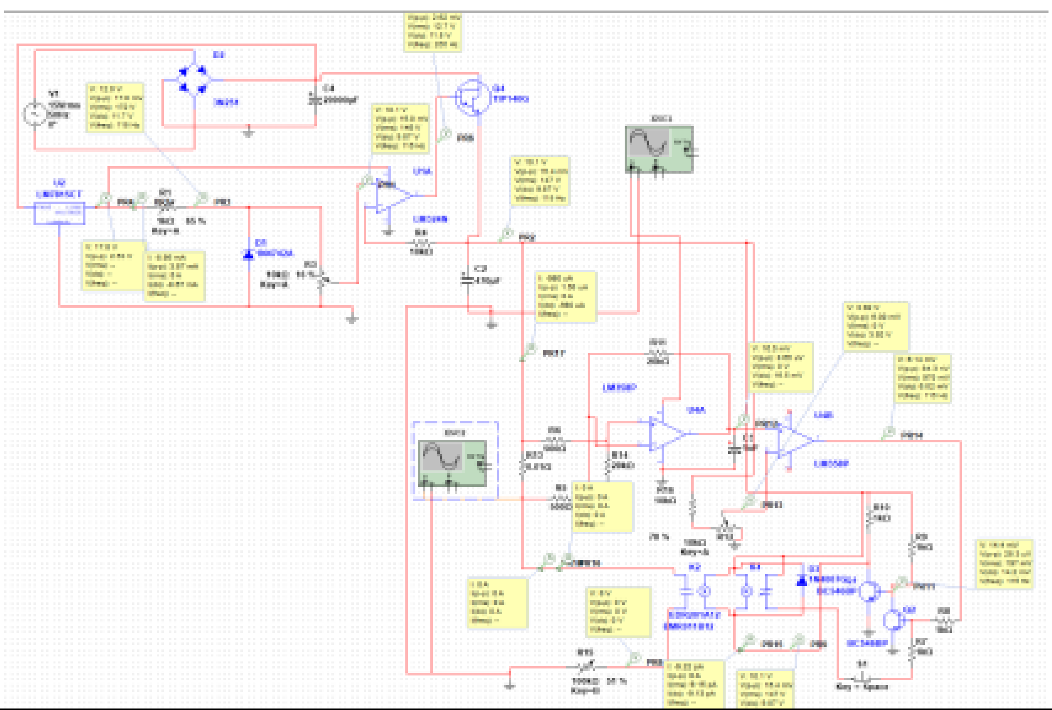


2

Specifications – Linear Power Supply

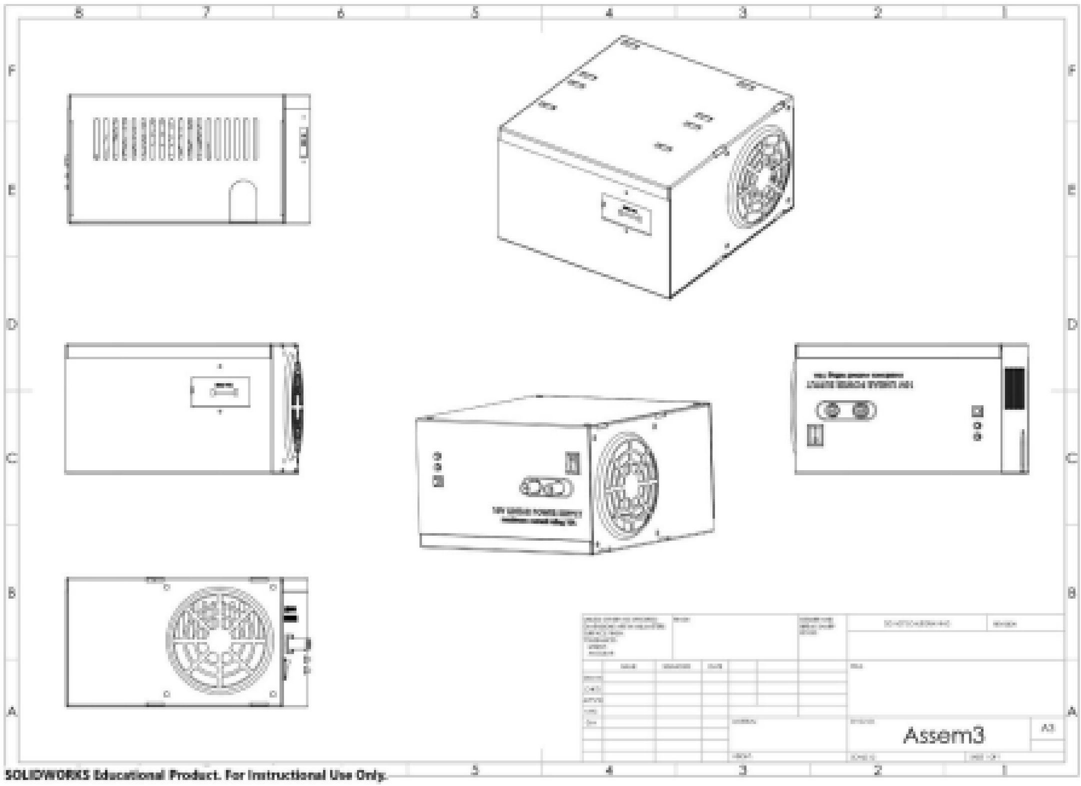
Input Voltage (V_{AC})	• Voltage range - 230V ± 10% • Frequency range - 50Hz ± 5%
Output Voltage (V_{DC})	• Voltage range – 10V ± 10%
Output current (I_{DC})	• Maximum current – 10A
Overload protection	• Automatic switching circuit is used to limit the current above 10A. • Fuse is used for further protection (12A rated)
Short circuit protection	• Automatic switching circuit is used for this

Circuit Design



3

Case Design



Load Vs Output Voltage