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EN2090 - LABORATORY PRACTICE II

LINEAR POWER SUPPLY

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Abstract

Power supplies that are available in the market can be either Linear power supplies or switch-mode power supplies. Both have their advantage and disadvantage. Our task in this project was to design a high power, constant voltage DC power supply for a given rating.

1 Introduction

The given task was to design a high power constant voltage dc power supply without using any digital electronic components or ICs. the power supply should provide constant 10V DC power to the load at a power rating of 100W and the design should withstand a maximum of 10A current.

Our design is a Linear Power Supply that is better than Switch Mode Power Supplies in terms of cost, simpler design, low noise, and performance. Although they do better in these, they are inefficient and produce more heat than Switch mode power supplies. Given the circumstances and the needs, we go with LPS.

Linear Power supplies consist of 4 major phases: Transformer, rectification, filtering, and regulation. Further for the protection against high currents, there is a need for a protection circuit.

In order to decide appropriate methods of implementation, selection of components, modeling, and calculations we went on a literature review.

1.1 Literature Review

1.1.1 AC step down

Most of the power supplies get the input from ac supply. Therefore it is a must to have a step-down transformer. This also served to isolate the power supply from the mains input for safety. The primary and the secondary turns ratio will ultimately define the voltage secondary voltage that will be

used for the rest of the power supply circuitry. Inductance, turns ratio and voltage ratios are related with the following equation,

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = \sqrt{\frac{L_p}{L_s}}$$

1.1.2 Rectification

Full-wave rectification of ac wave from the secondary windings of the transformers is required for higher rms of the voltage. Center tapped or bridge rectifier serves this purpose. The bridge rectifier is preferred over center-tapped rectifier due to the following reasons: no need for ground the output terminal, The transformer is less costly as it is required to provide only half the voltage of an equivalent center-tapped transformer used in a full-wave rectifier, The PIV is one half that of center-tap rectifier.

PIV ratings of the rectifier are a major concern in the implementation of the circuit. Required PIV ratings can be calculated from the following equation,

$$PIV = V_p(sec) - 0.7V$$

The output voltage that appears after rectifier can be calculated from,

$$V_p(out) = V_p(sec) - 1.4V$$

1.1.3 Filtering

Smoothing the rectified DC output is required to reduce the ripple which is another step towards a linear power supply.

Ripple voltage and the capacitance are related with the below equation,

$$V_{ripple} = \frac{I_{max}}{2fC}$$

The capacitor value can be determined according to the ripple we want and vice-versa.

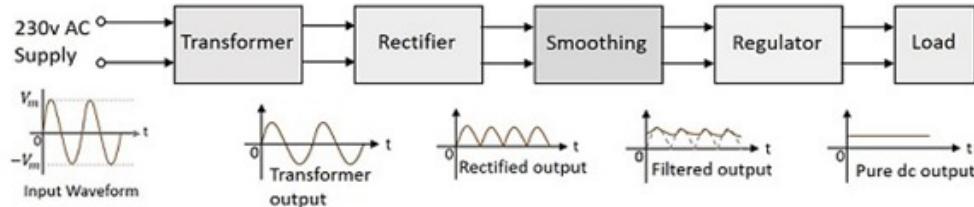


Figure 1: Block Diagram of the Design

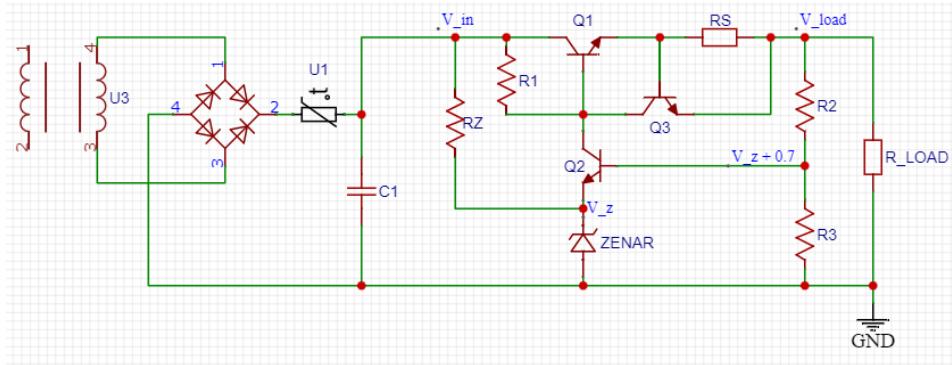


Figure 2: Overall Circuit Diagram

1.1.4 Regulation

The final and maybe the most important task in a linear power supply is Regulation which ensures constant voltage. Regulation can be either shunt or series. A series regulator is connected in series with the load to stabilize the regulator's output voltage. A shunt regulator, on the other hand, is connected in parallel to the load to stabilize the device's output voltage. Since series regulators perform better in high currents than shunt regulators series regulation is used.

The regulation circuit consist of two sub circuits: Feedback circuit and over current protection circuit.

1.1.5 Feedback Circuit

Zener diode ensures the voltage across. Zener current should be controlled by the resistor R_z . For a proper operation of Zener the following conditions need to be satisfied,

$$I_K < I_Z < I_{max}$$

Resistors R_2 and R_3 act as potential dividers. Their resistance ratio ensures the output voltage.

1.1.6 Over Current Protection Circuit

Transistor Q_3 act as over current protection and the biasing of it is controlled by the current sensing resistor R_s . Q_3 should forward biased when their is a current exceeding the rate in load.

$$V_{BE} = I_{Load} \cdot R_s$$

Required R_s value can be calculated from this equation.

2 Method

A 230/15V transformer is used to step down the main ac power which is supposed to use according to the project description. There we get a peak voltage of $15\sqrt{2}V$ at the output end. This voltage is fed to the second phase, the rectifier.

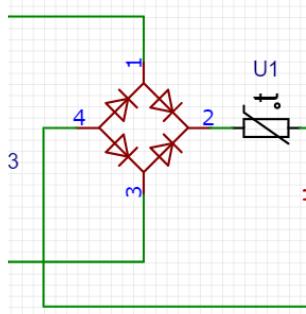


Figure 3: Rectification

The PIV rating of the diodes in the rectifier bridge is as follows,

$$\begin{aligned} PIV &= V_p(sec) - 0.7V \\ &= 15\sqrt{2} - 0.7V \\ &= 20.5132V \end{aligned}$$

From the rectifier we get an output of,

$$\begin{aligned} V_p(out) &= V_p(sec) - 1.4V \\ &= 15\sqrt{2} - 0.7V \\ &= 19.8132V \end{aligned}$$

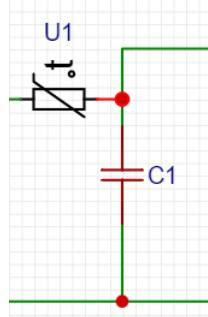


Figure 4: Filtering

Next, this voltage is fed to the filter. At the filter, we should consider both the capacitance of the filter capacitor and the ripple of the output by the filter phase. We have come to a trade-off between ripple and the capacitor value.

The relationship between the ripple and the capacitance is achieved as follows,

$$\begin{aligned} V_{ripple} &= \frac{I_{max}}{2.f.C} \\ I_{max} &= 10A, \\ V_{ripple} &= \frac{10}{2 \times 100 \times C} \\ C &= \frac{1}{20V_{ripple}} \end{aligned}$$

For a capacitance of $4 \times 6800 \mu F$ (that is readily available in local markets) we get a ripple of around 1.8382V which is acceptable for our purpose.

Next, the smoothed DC wave is regulated by the series transistor regulator circuit.

After the smoothing, the DC voltage will drive a darlington transistor in the regulation circuit. The input current to the regulating circuit will divide into this darlington and a Zenar diode that is in the feedback circuit.

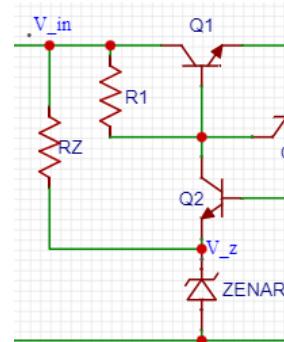


Figure 5: Regulation with Zenar Diode

Current that is going through the Zenar diode is a major consideration. It should be guaranteed that the diode is operating in its reverse biased region.

R_z value can control the current through the Zenar diode.

$$\begin{aligned} I_k &< I_z < I_{max} \\ I_k &< \frac{V_{in} - V_z}{R_z} < I_{max} \\ \frac{1}{I_k} &> \frac{R_z}{V_{in} - V_z} > \frac{1}{I_{max}} \end{aligned}$$

$$\frac{V_{in} - V_z}{I_k} > R_z > \frac{V_{in} - V_z}{I_{max}}$$

$$R_z < \frac{(V_{in} - V_z)_{min}}{I_k} \& R_z > \frac{(V_{in} - V_z)_{max}}{I_{max}}$$

$$\frac{19.8132 - V_z}{I_{max}} < R_z < \frac{(19.8132 - 1.8382) - V_z}{I_{Zk}}$$

1N4733A Zener diode is chosen and possible range of values for R_z is calculated accordingly,

For 1N4733A zener diodes,

$I_{Zk} = 1mA$, $I_{ZT} = 49mA$, $I_{Zm} = 179mA$ at $50^{\circ}C$.

$$\frac{(19.8132 - 5.1)V}{178mA} < R_z < \frac{(17.975 - 5.1)V}{1mA}$$

$$82.6584\Omega < R_z < 12875\Omega$$

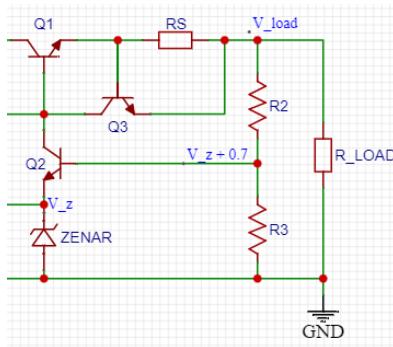


Figure 6: Voltage Divider for Feedback

To ensure the 10V at the load end the R_2 , R_3 resistors which are acting as potential divides in the feedback circuit (base current to the Q_2 transistor is negligible), should maintain the proper ratio. We get a Ratio between R_2 and R_3 as follows,

$$\frac{V_z + 0.7V}{R_3}(R_2 + R_3) = 10V$$

$$\frac{R_2 + R_3}{R_3} = \frac{10}{5.1 + 0.7}$$

$$\frac{R_2}{R_3} = \frac{4.2}{5.8}$$

Practically it is hard to get the resistor ratio only by two resistors. Therefore a variable resistor is placed between two resistors to adjust the resistance ratio.

2.1 Over-current Protection

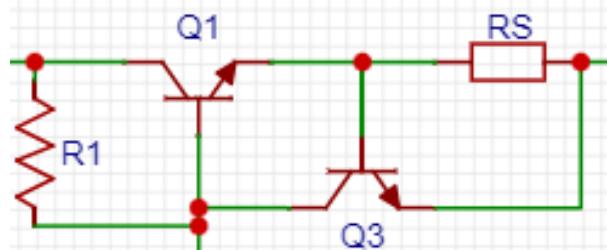


Figure 7: Over Current Protection

The Q_3 transistor will only be forward-biased whenever the current through the load exceeds 10A. So the current sensing resistor value should be,

$$R_4 = \frac{0.7}{10}$$

$$R_4 = 0.07\Omega$$

Whenever there is an over-current Q_3 will be forward biased and draw adequate collector current which ultimately results in a reduction of the base current of the Darlington Transistor Q_1 . reduction in the base current of Q_1 will reduce the emitter current of Q_1 which is the main DC current to the load. Hence the load will be protected from over-currents.

2.2 Heat Dissipation

The MJ11016 NPN Darlington pair is used in the linear power supply design. Using the simulations in LTspice it is observed that, 73.5W amount of power is dissipated from the transistor package at the maximum required power output. This transistor dissipates higher amount of heat. Therefore, proper calculations should be done to determine whether the design need a heat sink and to determine the properties of the heat sink.

The maximum junction temperature rating for the MJ11016 Darlington transistor is mentioned as $200^{\circ}C$ in the datasheet. For more safety, we can choose 80% of that value which is $160^{\circ}C$.

Junction to Case thermal resistance for MJ11016

Darlington transistor, $R_{\theta JC} = 0.87^{\circ}\text{C}/\text{W}$

Case to Sink thermal resistance for TO-3 package with mica, $R_{\theta CS} = 0.36^{\circ}\text{C}/\text{W}$ (*Typical value*)

Sink to Ambient thermal resistance, $R_{\theta SA} = ?$

$$\begin{aligned} \text{Maximum case temperature} \\ = 160^{\circ}\text{C} - 0.87^{\circ}\text{C}/\text{W} \times 73.5\text{W} = 96.055^{\circ}\text{C} \end{aligned}$$

$$\begin{aligned} \text{Maximum heatsink temperature} \\ = 96.055^{\circ}\text{C} - 0.36^{\circ}\text{C}/\text{W} \times 73.5\text{W} = 69.595^{\circ}\text{C} \end{aligned}$$

$$R_{\theta SA} = \frac{(69.595 - 28)^{\circ}\text{C}}{73.5\text{W}} = 0.5659^{\circ}\text{C}/\text{W}$$

Therefore, the heat sink should have a thermal resistance less than $0.5659^{\circ}\text{C}/\text{W}$.

In addition to the heat sink, a cooling fan is used to control the temperature inside the enclosure.

2.3 Component Selection

To select the components, LTspice was used as the simulation software to determine the power dissipated by each component and exact component values. According to those power requirements, transistors and resistors were selected.

Refer the [component list](#) generated using Altium Designer.

3 Results

The required output of 10V was perfectly achieved for no load condition accurate up to two decimal places. There is a small voltage drop of about 0.6V, when the load requires more current.

The maximum current that can be achieved from the power supply was 7.56A because the transformer is rated for 8A output.

Refer the [data sheet](#) to see the device specifications obtained from laboratory testings.

3.1 PCB Design

PCB design was done using Altium Designer. We calculated the trace width with the help of the

Digi-Key PCB Trace Width Calculator. 5mm trace width is enough to manage the maximum current of 12A.

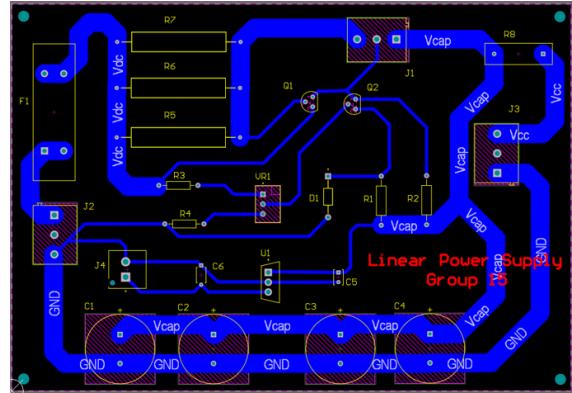


Figure 8: PCB Design

3.2 Enclosure Design

Enclosure Design was done using Solidworks software. The linear power supply contains heating elements. Therefore, metal is chosen as the material to produce the enclosure for the linear power supply. The enclosure is designed as a block made from a metal sheet and during the assembly the sheet is folded to get the required appearance of the enclosure. Find additional images of the enclosure [here](#).

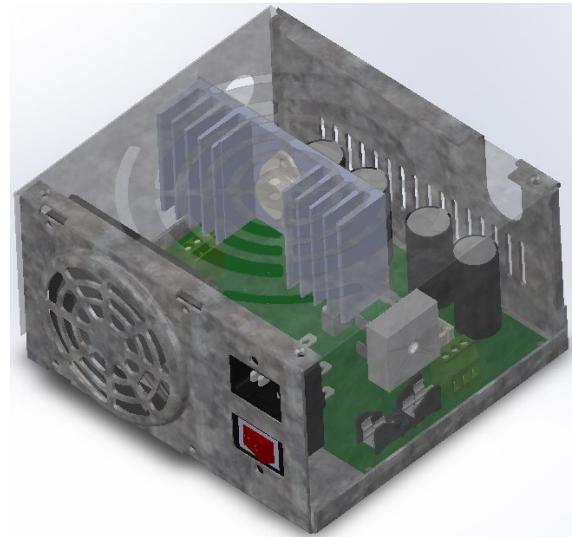


Figure 9: Overall Enclosure Design

4 Conclusion

After studying the required specifications, every block of the circuit was analyzed, and the design met the required specifications (10V constant output) under low power conditions. But there is a slight voltage drop whenever the load requires high current, due to the inability of the transformer to produce 10A to the circuit. In this design, regulation is comparatively slow due to the use of a BJT as the feedback element instead of Op-amps. Further, High power applications like this need proper safety methods to ensure the safety of the device and the user end. Proper grounding is essential for the device due to the metallic enclosure. Aluminum is preferred over copper as the material for the PCB tracks due to the advantages in heat

dissipation and thermal transfer than standard FR-4 constructions.

5 Acknowledgement

We would like to extend our deepest gratitude to our supervisor Mr.Pramitha Muthukudarachchi, for his valuable guidance, collaboration, patience, and other essential instructions and comments provided during progress meetings. We must also thank all the academic lecturers, instructors, and other academic staff whose contribution indirectly helped us a lot in the completion of this project successfully. Finally, we would like to thank our fellow batch mates for sharing their knowledge and experience during the hard times.

References

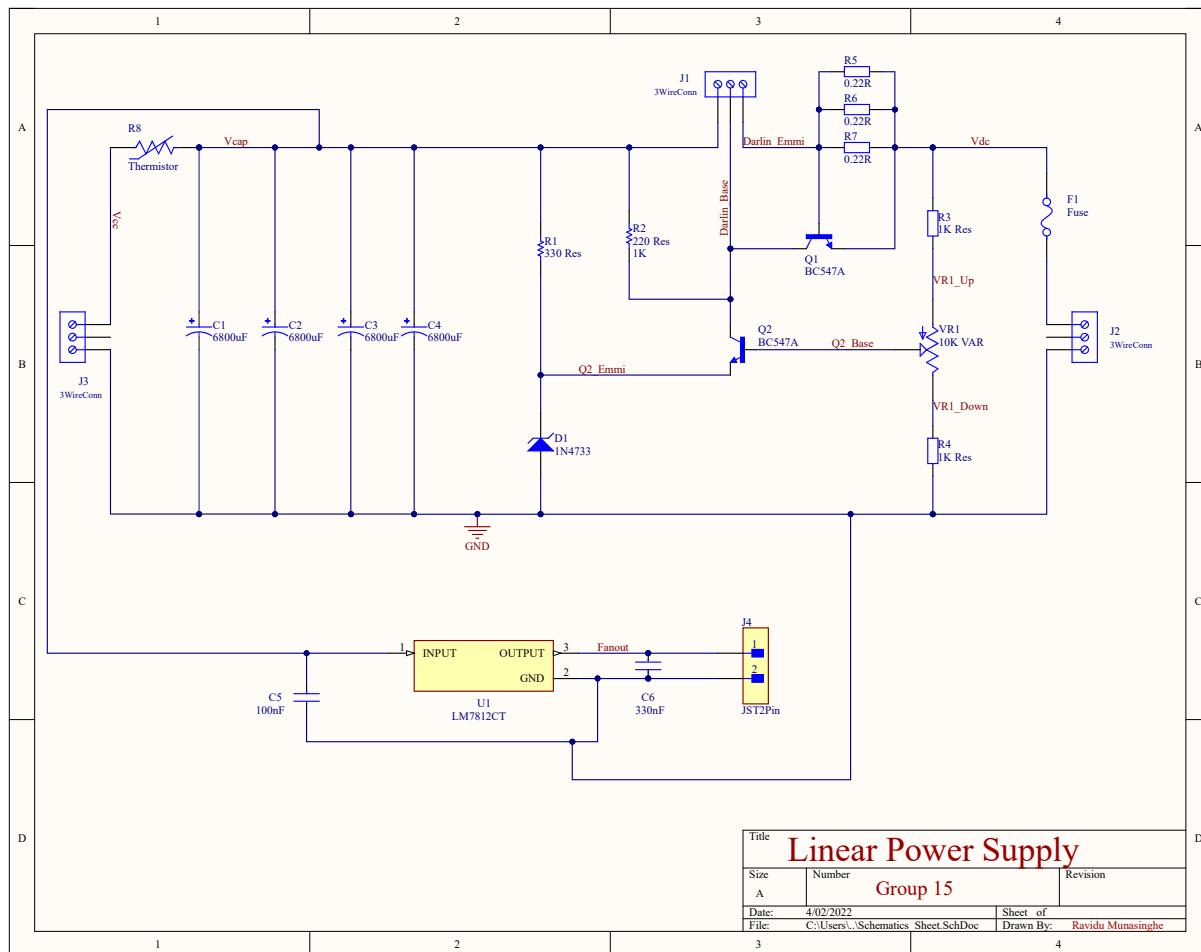
- [1] "Basic linear power supply circuits design." <https://circuitlib.com/index.php/lessons/91-basic-linear-power-supply-circuits-design>, Sept. 2013.
- [2] "Power supply current limiter circuits » electronics notes." https://www.electronics-notes.com/articles/analogue_circuits/power-supply-electronics/current-limiter-circuit.php.
- [3] Sasmita, "Series feedback voltage regulator." <https://electronicspost.com/series-feedback-voltage-regulator/>, Sept. 2015. Section: Electronics Post.
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6 Contribution

Index Number	Name	Contribution
190397E	Munasinghe B.S.V.W.	<ul style="list-style-type: none"> • Circuit Design and Calculations • Testing LTspice Simulations • Component Selection • Prototype testing and calibration • Soldering and Final Assembly
190399L	Munasinghe M.M.R.H.	<ul style="list-style-type: none"> • Circuit Design and Calculations • PCB Design • Component Selection • Prototype testing and calibration
190413D	Nifla M.N.F.	<ul style="list-style-type: none"> • Circuit Design and Calculations • Simulation Schematic Design • Documentation • Prototype testing and calibration
190423H	Nushath M.N.M.	<ul style="list-style-type: none"> • Simulation Schematic Design • Enclosure Design • Component Selection • Prototype testing and calibration

7 Appendices

7.1 Appendix I - PCB Schematic



7.2 Appendix II - Component List

Comment	Description	Designator	Footprint	LibRef	Quantity
6800uF	6800 μ F 35 V Aluminum Electrolytic Capacitors Radial, Can - 2000 Hrs @ 85°C	C1, C2, C3, C4	Capacitor	493-11046-ND	4
100nF	Cap Ceramic 100nF 100V X7R \pm 10% Radial 2.5mm +125°C Automotive Ammo Pack	C5	capacitor 0.1uf	CMP-06035-052488-1	1
330nF	Cap Ceramic Monolithic 330nF 100V 10% Thru-Hole Bulk	C6	Cpacitor 0.33uf	CMP-06035-045092-1	1
1N4733	Zener Diode 5.1V	D1	1N4733	D Zener	1
Fuse	FUSE BLOK CARTRIDGE 600V 12A PCB	F1	Fuse	CMP-26292-000005-1	1
3WireConn	Serie 2365 - 5.08 mm Horizontal Cable Entry Modular with Rising Cage Clamp WR-TBL, 3 pin	J1, J2, J3	Connector	CMP-1502-02614-1	3
JST2Pin	CONN HEADER VERT 2POS 3.96MM	J4	JST 2 Pin	CMP-17439-000031-1	1
BC547A	Bipolar (BJT) Transistor NPN 45 V 100 mA 300MHz 625 mW Through Hole TO- 92	Q1, Q2	BC547	2368-BC547A-ND	2
330 Res	330 Ohms \pm 5% 1W Through Hole Resistor Axial Fusible, Safety	R1	330/470ohm	2368-F1W133-ND	1
220 Res	220 Ohms \pm 5% 1W Through Hole Resistor Axial Flame Proof, Safety Metal Oxide Film	R2	330/470ohm	470W-1-ND	1
1K Res	1 kOhms \pm 5% 0.25W, 1/4W Through Hole Resistor Axial Flame Retardant Coating, Safety Carbon Film	R3, R4	AXIAL-0.4	CF14JT1K00TR-ND	2
0.22R	Wirewound Resistors - Through Hole 0.22ohms 5% Tol 7W	R5, R6, R7	0.22 Ohm Ceramic Res	280-CR10-0.22-RC	3
Thermistor	Thermistor PTC 470 Ω 2-Pin Screw Mount Radial Bulk	R8	Thermistor	CMP-06022-000249-1	1
LM7812CT	IC REG LINEAR 12V 1A TO220-3	U1	Fan_Regulator	CMP-07128-000015-1	1
10K VAR	10 kOhms 0.1W, 1/10W PC Pins Through Hole Trimmer Potentiometer Carbon 1.0 Turn Top Adjustment	VR1	Var_Res_Final	478-601030-ND	1

7.3 Appendix III - Data sheet

DATASHEET

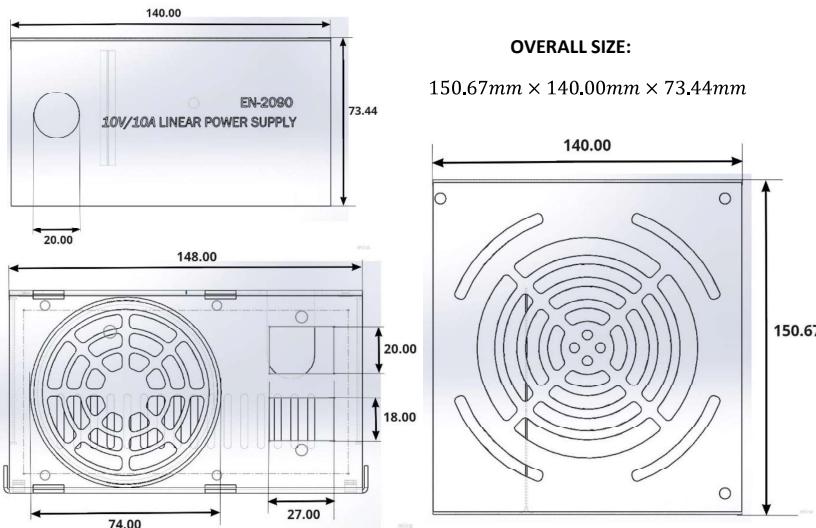
LINEAR POWER SUPPLY



VAC INPUT:
• 15VAC 10A
VDC OUTPUT:
• 9.4V-10V
• MAXIMUM CURRENT: 10A
INPUT RIPPLE FACTOR:
• 5.4%
TEMPERATURE RATINGS:
• RATED AMBIENT TEMPERATURE: 28°C
FUSING REQUIREMENTS:
• OUTPUT CURRENT OF GREATER THAN 12A WILL BURN THE FUSE UNDER SHORT CIRCUIT CONDITION
• REPLACE THE BURNED FUSE WITH A 12A GLASS TUBE FUSE



FUSE HOLDER

SHORT CIRCUIT PROTECTION:														
• FUSED AT OUTPUT CURRENT OF 12A														
OVERLOAD PROTECTION:														
• AUTOMATIC CURRENT LIMIT USING CURRENT SENSING RESISTOR														
EFFICIENCY: (TESTED LOADS)														
<table border="1"> <thead> <tr> <th>LOAD Ω</th> <th>EFFICIENCY</th> </tr> </thead> <tbody> <tr> <td>1.05</td> <td>51.397%</td> </tr> <tr> <td>2</td> <td>47.323%</td> </tr> <tr> <td>3.34</td> <td>46.829%</td> </tr> <tr> <td>4.4</td> <td>45.655%</td> </tr> <tr> <td>5.57</td> <td>44.584%</td> </tr> <tr> <td>6.6</td> <td>43.887%</td> </tr> </tbody> </table>	LOAD Ω	EFFICIENCY	1.05	51.397%	2	47.323%	3.34	46.829%	4.4	45.655%	5.57	44.584%	6.6	43.887%
LOAD Ω	EFFICIENCY													
1.05	51.397%													
2	47.323%													
3.34	46.829%													
4.4	45.655%													
5.57	44.584%													
6.6	43.887%													
LINEAR POWER SUPPLY CASE:														
 <p>The diagram shows three views of the linear power supply case: front view, top view, and side view. The front view indicates a depth of 20.00mm. The top view shows a circular fan with dimensions 148.00mm width, 74.00mm height, and 27.00mm thickness. The side view shows a height of 150.67mm. The case is labeled with 'EN-2080' and '10V/10A LINEAR POWER SUPPLY'.</p>														
OVERALL SIZE: 150.67mm × 140.00mm × 73.44mm														
ALL THE MEASUREMENTS IN THE DIAGRAM ARE IN MILLIMETER SCALE														

7.4 Appendix IV - Enclosure

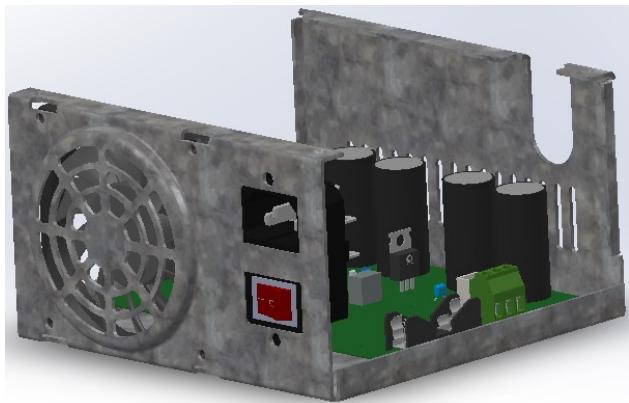


Figure 10: Enclosure Part I Front

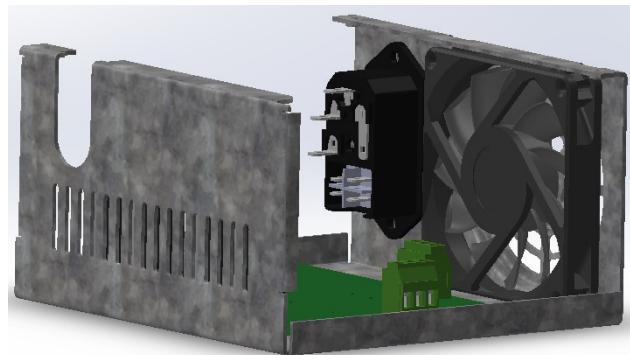


Figure 11: Enclosure Part I Back

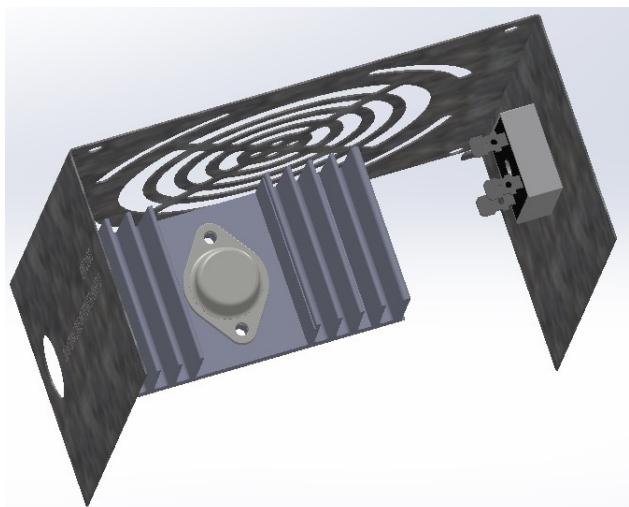


Figure 12: Enclosure Part II Front

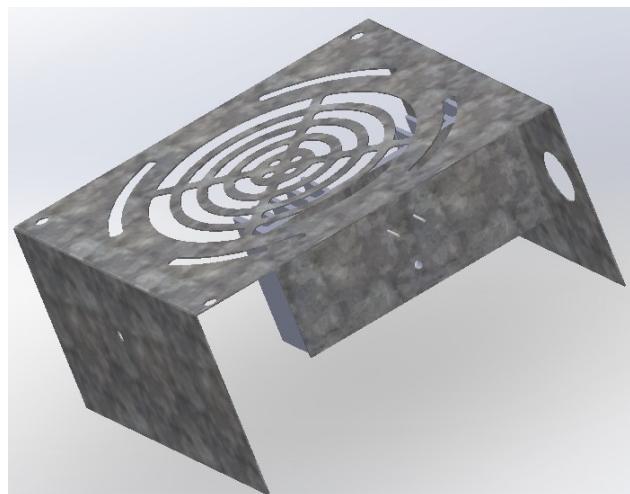


Figure 13: Enclosure Part II Back

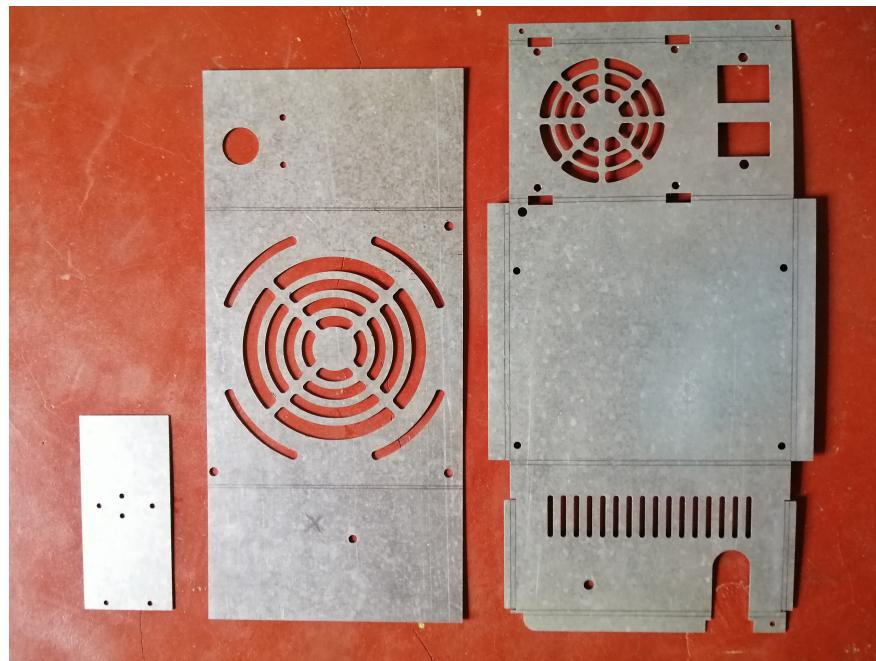


Figure 14: Enclosure Block



Figure 15: Assembled Product