Project of 3031 Electrical and Computer Engineering Design

DC Power Supply

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Abstract

Over the course of about thirteen weeks, our project group worked through the process of engineering design from idea generation to design verification and documentation. We started with vague requirements of a product which we expanded upon using brainstorming and information gathering techniques to find a market for our product and create a more well defined end goal. In the design stage we began to explore options that would allow us to meet the requirements of our power supply, and using methods of selection we settled on one design. Once we had clear idea of our product design we began construction of the various components. After constructing our power supply we tested it under varying conditions to measure performance. At the end of this project we had a working prototype of our power supply delivering approximately 15 V DC at 2 A, which still has room for improvement, as will be outlined in this report.

Introduction

The objective of this project was to design a new product (in our case, a power supply), for a targeted customer or industrial market. We initially identified this market to be the home industry, to provide lower voltage for devices that do not need 120 V to operate. As we worked through the five labs this course entailed, we focused on Idea Generation, Conceptual Design, Detailed Design, Design Verification, and Testing. After determining the needs, constraints, attributes, and technical requirements of the product, we generated design options, and selected the best conceptual design to implement. We built a transformer based on our calculations, and created a Bill of Materials to quantify the components we would need to accomplish the goal of a 15 V DC output with a maximum current draw of 2 A. Once all of the components were received, and built on the circuit board along with the transformer, we conducted various tests to ensure that the product worked as we expected it to. We explored the UL and CSA standards that applied to our product, and made sure that they were followed in our design. Finally, we wrote a user’s manual, so that anyone with an intermediate of electronics could operate our product.

Preliminary Design

Idea Generation:

We started this project in the Idea Generation Stage which was defining the problem statement and also using information gathering techniques to define the attributes and constraints. After choosing the Isolated Power Supply as our product, we as a team, brainstormed on new and unique ideas to use. We initially wrote down general thoughts about our future product and narrowed our options based on the constraints we had. We then discussed possible markets for our product and what applications it could be used for. We decided that the purpose of our power supply is to provide a lower voltage for devices that may not need 120 V to operate (ex. laptop charger). We split the topic into steps as shown below:

1. **Functions**
    - AC - DC conversion
    - 120 V/60 Hz AC Input
    - 15 V DC output
    - Isolation
    - 30 W
    - Thermal Management
    - Voltage Regulation
    - Filtering

2. **Features**
    - Small and lightweight
    - No maintenance requirements
    - Reliable
    - Safe
    - Affordable
    - Easy to use

3. **Constraints**
    - Regulatory → needs to follow standards
    - Economical → affordable for customer
    - Technical → needs to include all of the functions
    - Customer → needs to be user friendly and lightweight.
    - Environmental → using eco-friendly products

After defining these general topics, we put them in a House of Quality shown in *Figure (1)* and ranked them on certain characteristics.

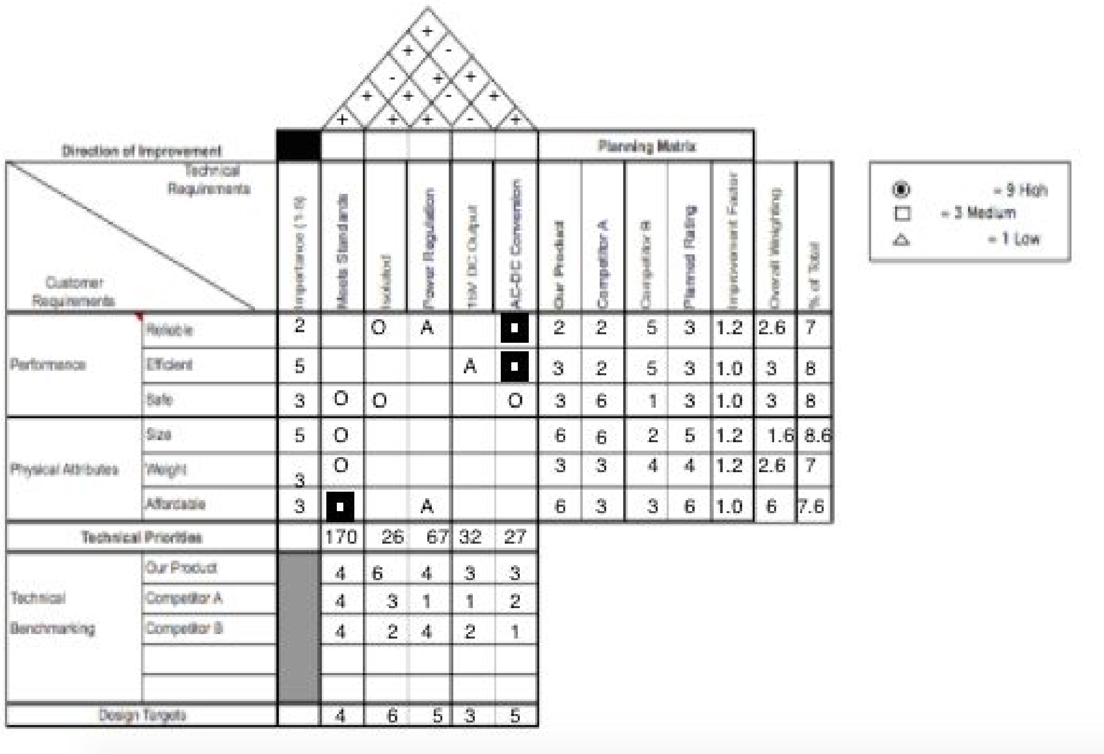

Figure 1: House of Quality

Conceptual Design:

After finishing the Idea Generation Stage, we moved on to Conceptual Design. The first step our group took was to refine the functional structure. We used the brainstorming techniques to develop a Morphological Chart (*Figure (2)*) based on all on the refined criteria. From the Morphological Chart we took the feasible options and condensed our options further and based on the Simple Scores Method we were able to choose the best design solution.

From the Idea Generation stage, we refined the functions of our power supply to include the basic requirements as outlined in the original statement of the project. These included general AC-DC conversion, a 15 V DC output voltage, isolation, and a final power supply of 30 W. We determined that our morphological chart would be designed based on the following functions: Connections; Stepping down voltage; Converting from AC to DC; Voltage regulation; and finally indicating that the supply functioned as expected.

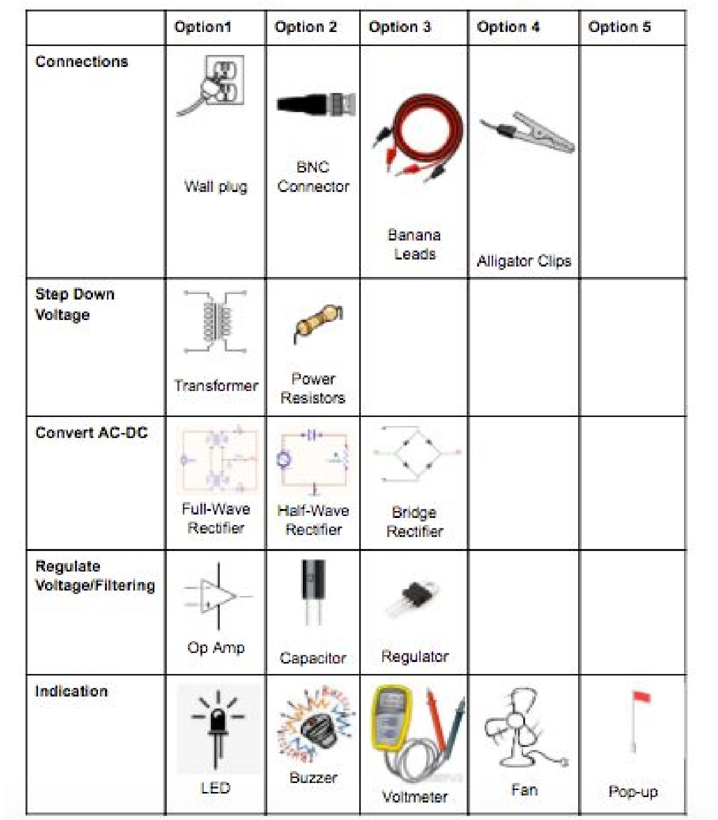

Figure 2: Morphological Chart

With the Morphological Chart we were able to find 4 feasible concepts:

1. Alligator Clips → power resistors → full-wave rectifier → op amp → fan
2. Wall outlet → transformer → bridge rectifier → caps → voltmeter
3. **Wall outlet → transformer → bridge rectifier → regulator → Voltmeter**
4. Banana Leads → transformer → half-wave rectifier → regulator → LED

The Simple Scores Method (*Figure (3)*) gave us our best design concept which was Concept #3 with the highest score of 163.

Criteria	Importance	Concept 1	Concept 2	Concept 3	Concept 4
Reliable	5	3	5	4	3
Efficient	4	4	4	4	4
Safe	5	4	3	4	2
Size	3	1	3	4	1
Weight	2	2	4	5	1
Affordable	3	2	3	4	2
Meets standards	5	4	4	4	3
AC - DC conversion	5	4	5	5	3
15V/2A DC output	5	5	5	4	4
Environmental	2	4	3	4	3
Total		137	158	163	108

Figure 3: Simple Scores Method

With our final design concept chosen, we were able to move on to the Detailed Design section where the bulk of the calculations and components were decided.

Detailed Design:

In February, we made the initial sketch of the project in a block diagram as well as in schematic (*Figure (4)*). Our initial design did not change much when we compared it to our latest power supply schematic (*Figure (7)*) and block diagram.

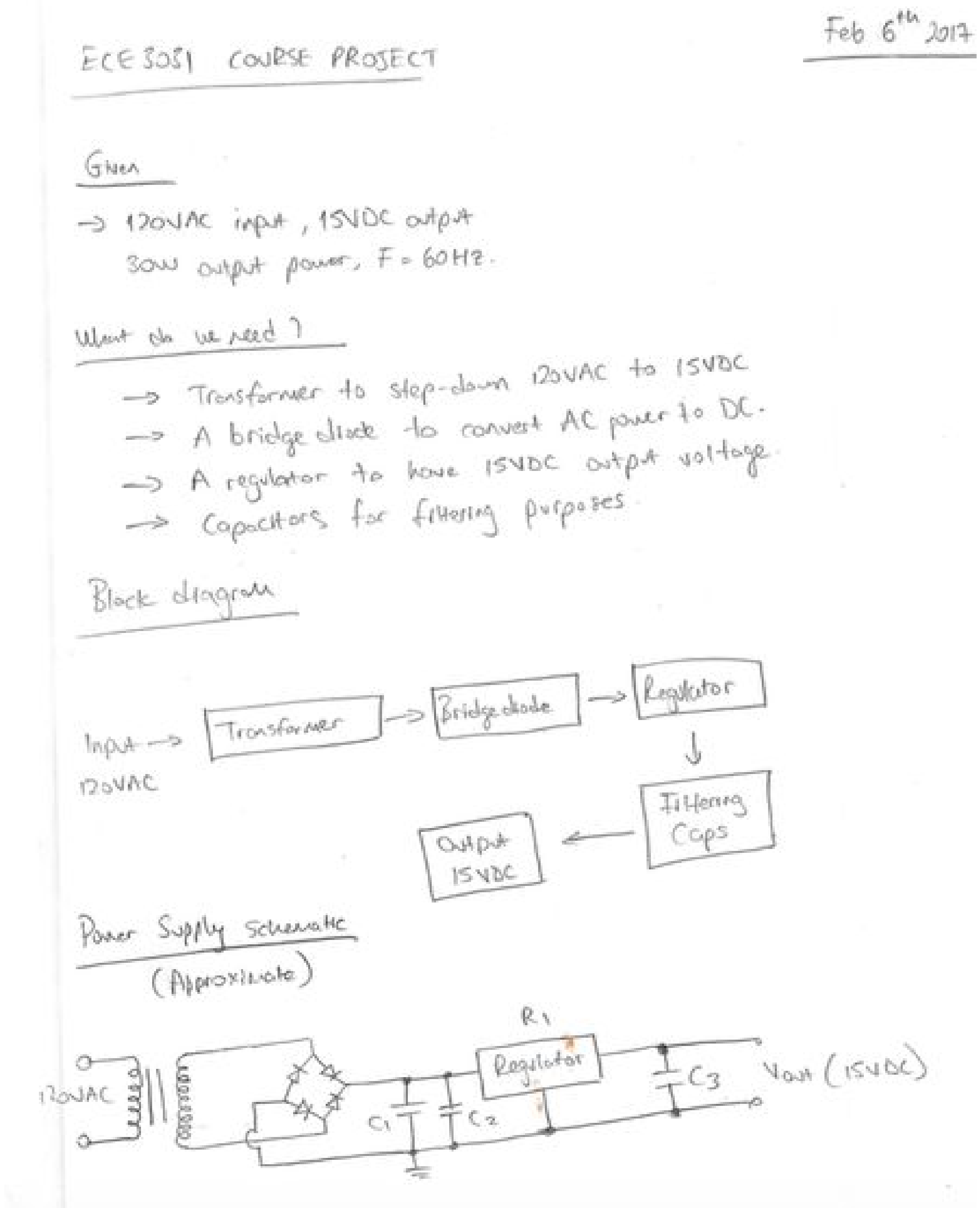

Figure 4: Initial Project Design

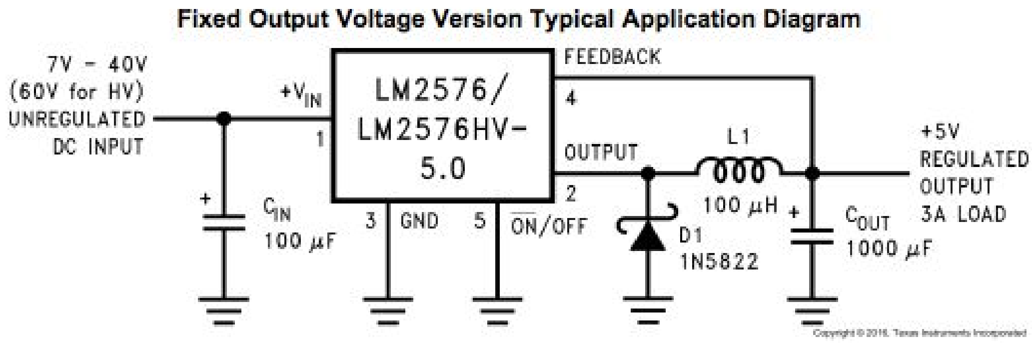

Figure 5: Schematic given in LM2576 Datasheet [16]

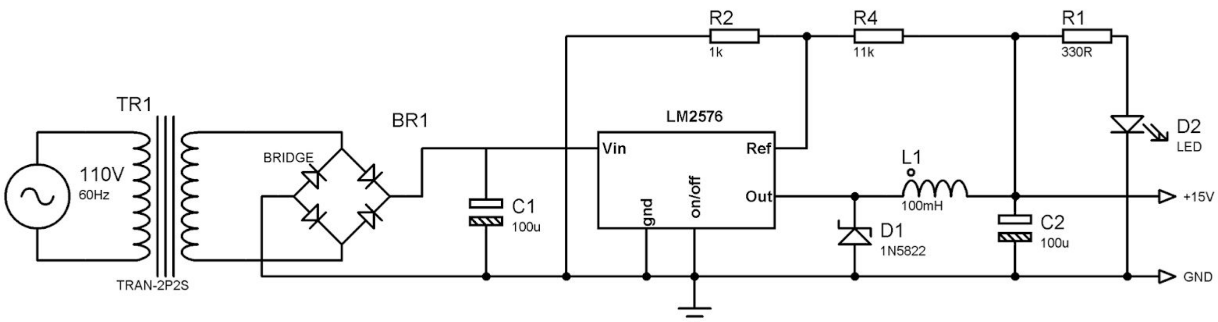

Figure 6: Project Prototype

In *Figure (6)*, our very first project prototype is shown. Initially the input capacitor C1 for filtering was only 100μF/25V. This caused significant voltage drops in the output when the load resistance was decreased. To solve this issue, we added two 2200 μF/25V electrolytic capacitors to the input of the prototype circuit. Because we have decided not to use an LED to indicate the on/off state of the power supply, the LED is removed from our current schematic shown in *Figure (7)*.

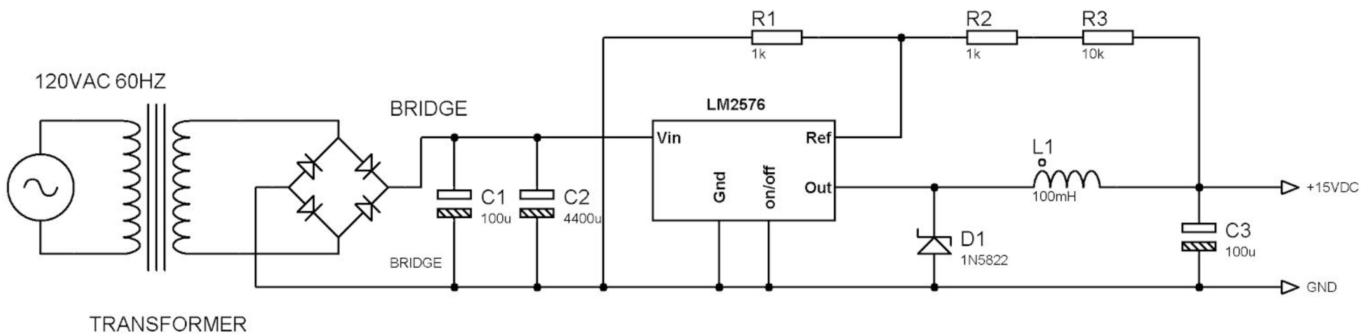

Figure 7: Final Schematic of Power supply

Reference voltage calculation for the regulator:

$$V_{ref} = \frac{R_1}{R_2 + R_1} * V_{out} \qquad (1)$$

$$V_{ref} = \frac{1k\Omega}{1k\Omega + 11k\Omega} * 15V = 1.25V$$

The current going through R_2 and R_3:

$$I_R = \frac{V_{out}}{R_1 + R_2} = \frac{15V}{(1k\Omega + 11k\Omega)} = 1.25mA \qquad (2)$$

Because the resistors are ¼ W resistors, the maximum current that can go through R_2 (1 kΩ) is about 15.8 mA, and through the R_3 (10 kΩ) resistor is 5 mA. There is 1.25 mA or less going through R_1 since the current divides from the V_{ref} node. As we found above, the current I_R is 1.25 mA; therefore the quarter Watt resistors worked fine for this design.

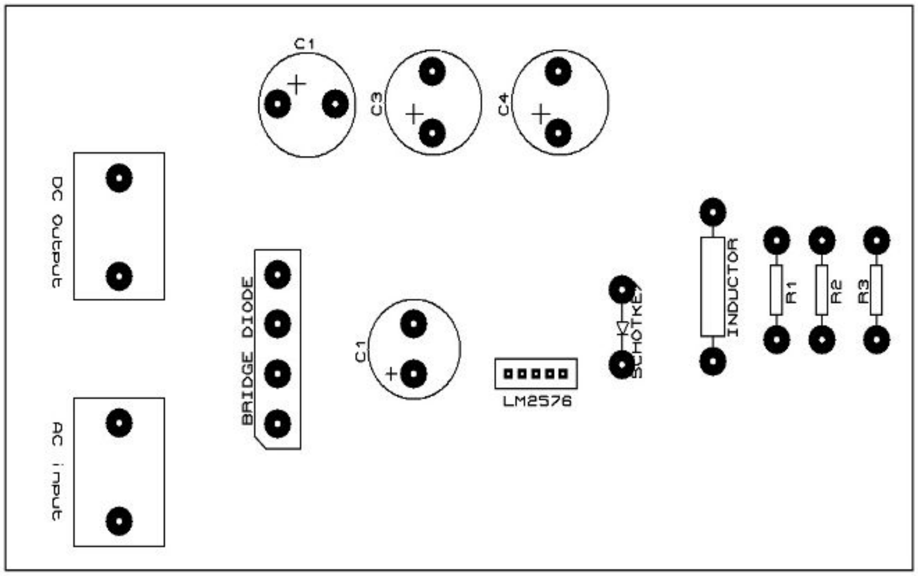

Figure 8: Top View of PCB

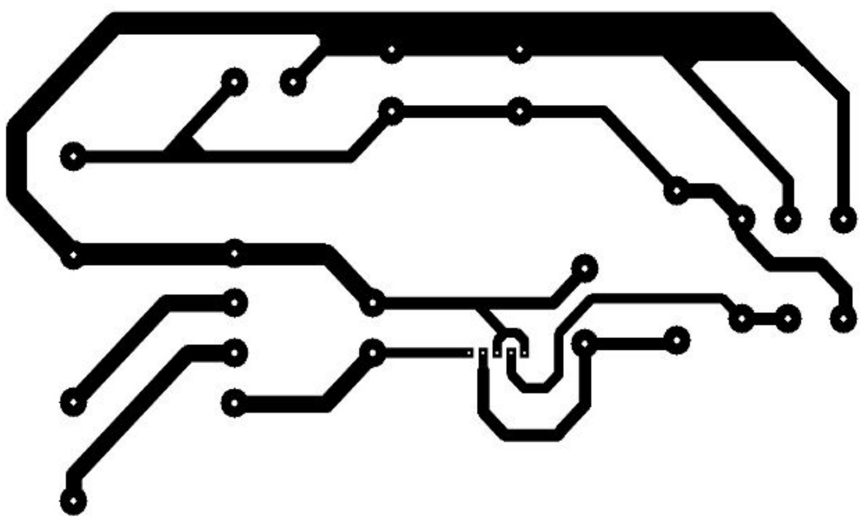

Figure 9: Bottom view of PCB

Parameter	Value
Number of Laminations	56
Number of Primary Turns	616
Number of Secondary Turns	114
AWG for Primary	27
AWG for Secondary	20

Table 1: Transformer Parameters

The transformer we have wound has met our expectations and its specifications are given in *Table (1)*. The ratio between the primary and the secondary sides is 5.4:1, meaning for every 5.4 turns on the primary side, there is 1 turn of winding on the secondary side. This makes the transformer step-down.

Part Number	Quantity	Name	Package	Total Cost
HS112-ND	1	Heat Sink	TO-220	$0.26
P5170-ND	2	2200μF/ 25V Electrolytic capacitor	Radial	$2.78
4498PHBK-ND	1	100 μF/ 25V Electrolytic capacitor	Radial	$1.59
LM2576T	1	Regulator	TO-220	$3.38
KPB2005GD	1	Bridge Diode	4-SIP KBP	$0.68
1295-1171-ND	1	100 mH Inductor	Tray, Radial	$3.94
SR2010-TPCT-ND	1	1N5822 Schottky Diode	Cut-tape DO-204AL	$0.74
36-3557-2ND	1	Fuse Block	-	$1.60
F989-ND	1	3A Fuse	Tube	$0.35
BKTCT2230-2ND	1	Banana Jack Connector	-	$1.06

Table 2: Bill of Materials

Heat Sink:

After doing the necessary calculations, shown in Appendix A, to pick a heat sink for the voltage regulator LM2576, we decided to use a TO-220 heat sink (part number HS112-ND on digikey.ca).

Fig. 27

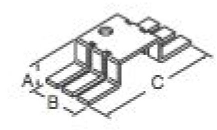

Figure 9: Heat sink used [19]

The heat sink has the following specifications [19]:

- Dimensions:
  - A: 9.52 mm, B: 17.78 mm, C: 44.45 mm
- Thermal resistance at Natural: 15.6°C/W
- Power dissipation at temperature rise: 2W @ 40°C

Design Verification and Tests:

We have conducted the following tests on our project:

Output power verification:

In order to conduct more tests on the power supply, we first had to verify the output power. We begun testing the power supply with no load. Without a load, on the secondary side of the transformer, we measured about 20 VAC, and at the output of the DC power supply, 15.21 VDC was measured, as is shown in *Table (5)*. From these values, we can say that there is approximately 6W of power consumption without a load. When the load resistance is decreased, expectedly, the current amount going through the power supply circuit increases. At full-load, the power supply was able to provide 2A with 14VDC in the output (28W power consumption). There was about a 1V voltage drop as the load amount changed from no-load to full-load.

Soldering Tests:

Before the power supply passed the quality control test, we needed to check if the soldering on the board was good. The soldering test included checks for cold joint, overheated joint and disturbed joint [17]. Fortunately, there were no problems with soldering the components to the board.

The Wiring Tests:

The wiring test we conducted included short-circuit prevention, damaged wiring, and possible wiring thickness problems, such as melting or breaking from excessive current, as more current was drawn from the power supply. There was no wiring that was damaged, however since the transformer windings on the primary and the secondary sides were wound with wires thinner (AWG #20 for secondary and AWG #27 for primary) than they were supposed to be, the transformer became hot, about 128°C as shown in *Table (1)*, every time we drew current more than 1 A. We examined the transformer separately and found out this existing problem.

The Board Testing:

As the last step of quality control and testing, we did a final board check for any kind of damage to the board as well as any circuits that might cause permanent damages to the components we used. Any non-conductive trace on the board could cause the power supply to not supply enough output power or cause an excessive amount of power loss, so with a multimeter we finalized the board testing by checking each trace that goes through the components. As shown in *Table (4)*, the TO-220 heat sink used for the regulator would get as hot as 46°C when full-load was applied to the power supply. The heat sink prevented the LM2576 regulator from breaking due to excessive heat dissipation by cooling it.

Test Plan:

Is there 120AC voltage on the primary side of the transformer?	✔
Is there (stepped-down) 20VAC voltage on the secondary side of the transformer?	✔
Does the rectifier (bridge diode) rectify the 20VAC input?	✔
Do C1 and C2 filter the AC input?	✔
Is there more than (unregulated) 15VDC at the input of the regulator?	✔
Does the regulator work to supply 15VDC at the output?	✔
As the current drawn from the supply increases, is there constant 15VDC at the output of the regulator?	**X**
Is the power supply capable of supplying 2A?	✔
Is there excessive heat dissipation from the power supply?	✔

Table 3: Test Plan for Power Supply

Parameter	Test Value
DC Voltage Output (no load)	15.21 V
DC Voltage Output (full load)	14.00 V
Voltage Regulation	8.64%
Efficiency	84%
Max. Temperature of Heat Sink	46℃
Max. Temperature of Transformer	128 ℃

Table 4: Maximum Test Values

Secondary Side Transformer Voltage (VAC)	DC Output Voltage (V)	DC Output Current (A)	Output Power (W)
20.01	15.21	0.0 (no load)	--
19.17	14.81	0.4	5.92
18.97	14.78	0.5	7.39
18.88	14.75	0.6	8.85
18.73	14.73	0.7	10.31
18.50	14.71	0.8	11.77
18.37	14.68	0.9	13.21
18.18	14.63	1.0	14.63
17.97	14.59	1.1	16.05
17.76	14.56	1.2	17.47
17.52	14.51	1.3	18.86
17.43	14.48	1.4	20.72
17.21	14.45	1.5	21.68
17.18	14.39	1.6	23.02
17.14	14.31	1.7	24.33
17.09	14.25	1.8	25.65
17.05	14.12	1.9	26.83
17.03	14.00	2.0	28.00

Table 5: Test Results - Output Voltages at Varying Loads and Associated Output Power

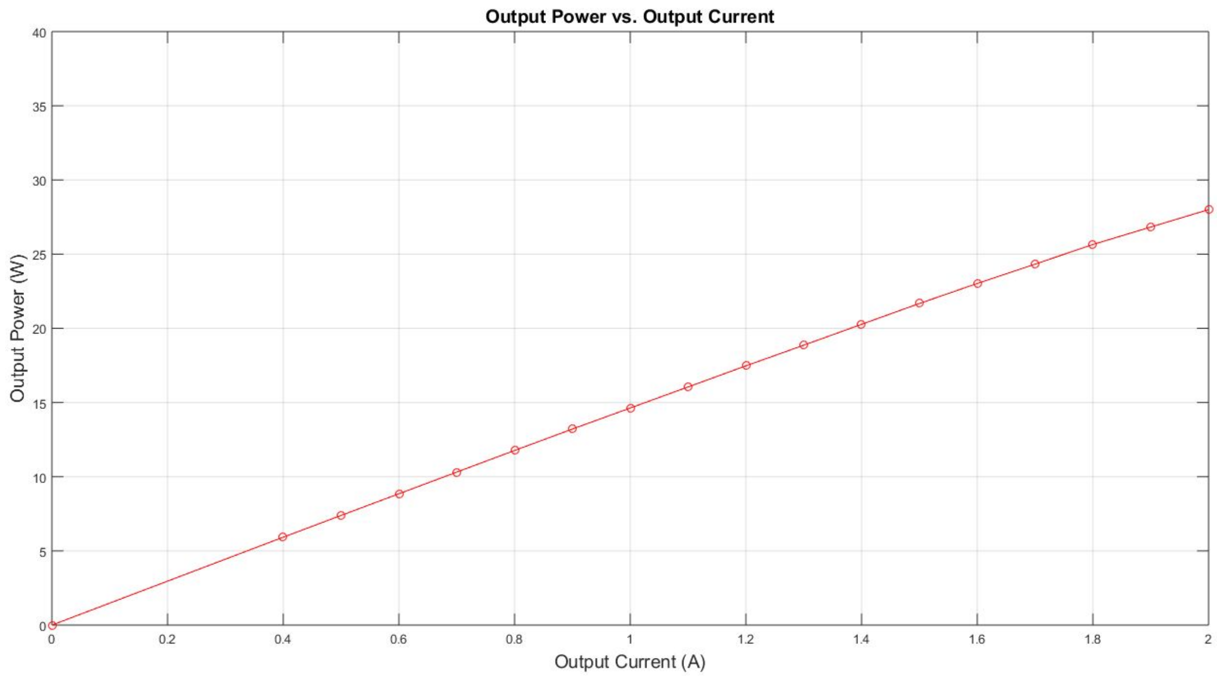

Figure 10: Output Power vs. Output Current

$$P = I * V \tag{3}$$

In *Equation 3*, we multiply current with voltage to find the power at the output or at a point in a circuit. In *Figure (10)*, we can see that the output power increases as the current drawn from the power supply increases due to the relationship between current and voltage shown in *Equation 3*. The amount of current, therefore, significantly affects the power and has direct relationship with the voltage value in the equation. In *Table (5)*, it is shown that the maximum output power that can be obtained is 28W when 2A is drawn which can be seen in *Figure (10),* as well.

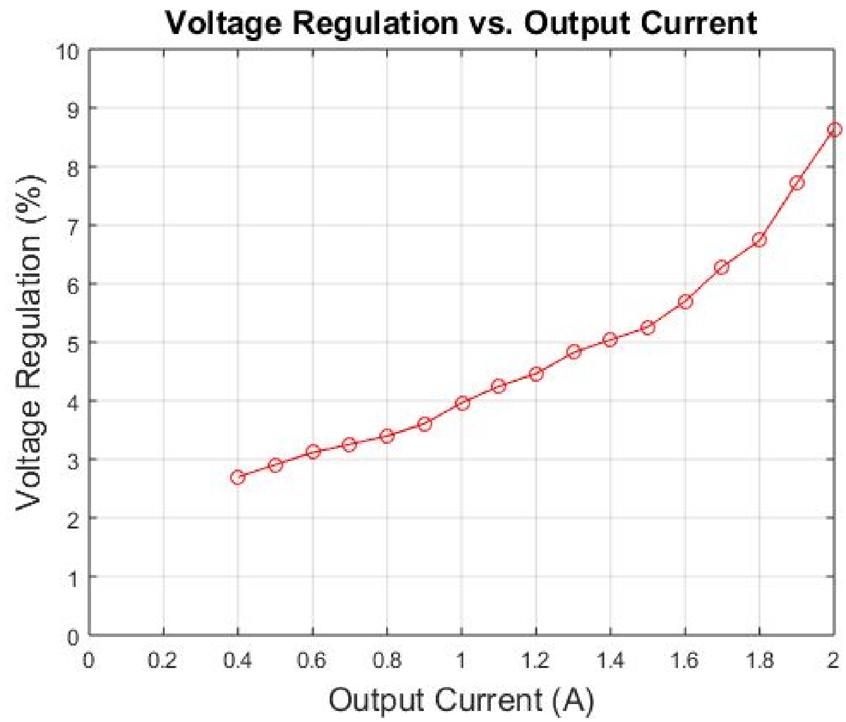

Figure 11: Voltage Regulation vs. Output Current

$$VR_{percent} = \frac{V_{noload} - V_{fullload}}{V_{fullload}} * 100 \tag{4}$$

The voltage regulation (%) was calculated using *Equation 4* given above. We can see that the VR increases (due to increased current) as the output load resistance decreases. When there is no load, the voltage regulation is nearly 3%, however the VR increases 3 times when full-load is applied. We can say that the voltage amount in the output changes 9% from the initial output voltage when there is no load.

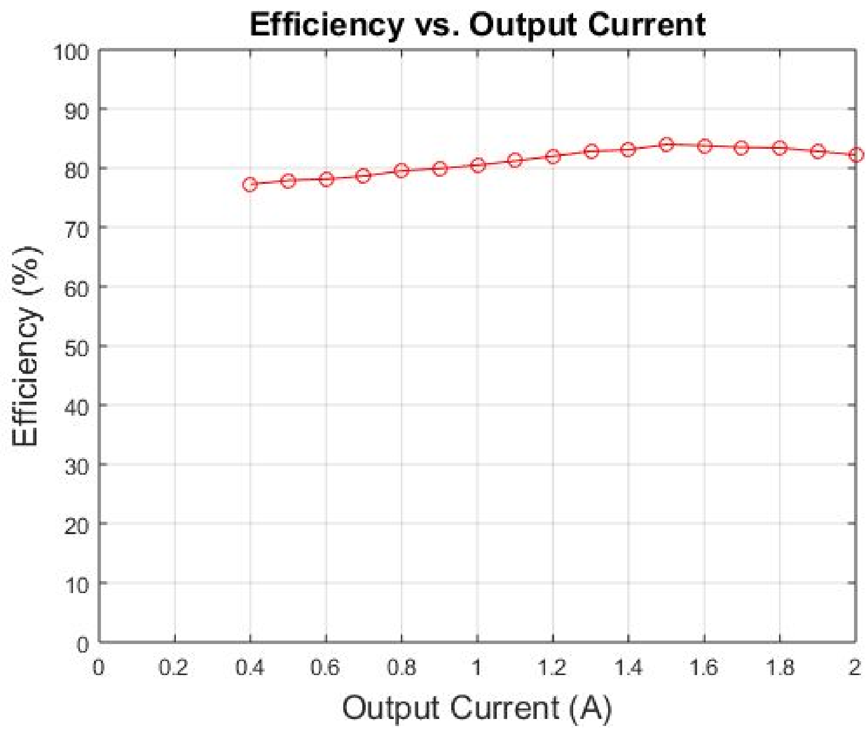

Figure 12: Efficiency vs. Output Current

The efficiency in power supply designs matters because we do not want too much power loss to occur. We want to get the most from the output. As shown in *Table (4)*, the maximum efficiency of our design is 84%. Having 100% efficiency is nearly impossible, as there will always be losses such as heat dissipation in the transformer and the circuit. As seen in *Figure (12)*, the efficiency is at its maximum when approximately 1.5 A is drawn from the power supply. The efficiency decreases a little when full-load is applied and 2 A is drawn.

Standards Applicable to the Project:

Title of Standard	Product Application
UL 50: Enclosures for Electrical Equipment, Non-Environmental Considerations	Performance, testing, and construction of enclosure of product to provide personal protection against contact with electrical components
UL 50E: Enclosures for Electrical Equipment, Environmental Consideration	Environmental testing for product protection (to be used in conjunction with UL 50)
UL 101: Leakage Current for Appliances	Limits of and testing for leakage currents in the product
UL 5085-1: Low Voltage Transformers - Part 1: General Requirements	Testing, assembly of transformer
UL 5085-2: Low Voltage Transformers - Part 2: General Purpose Transformers	Testing, assembly of transformer (to be used in conjunction with UL 5085-1)
CSA C22.1-15: Canadian Electrical Code, Part 1, Safety Standard for Electrical Installations	Operation and performance requirements and testing of product for use in Canada

Table 6: UL and CSA Standards Applicable to the Design

The standards applicable to the project are given in *Table (6)*. The UL50 standard is about enclosures for the electrical equipment and non-environmental considerations. This standard has been taken into consideration when the box for the power supply was chosen. The UL50E standard specifies environmental testing for product protection. The components in the power supply are lead-free and mercury-free. The solder we used has Sn60/Pb40 specification and meets the JIS-Z-3282 A CLASS standard [18]. During our tests on the power supply circuit, we checked if there was any current leakage through any short-circuit to meet UL101 standard with our product. In order to meet UL5085-1 and UL5085-2 standards for the transformer, we checked the wiring gauges and laminations used for any kind of current leakage and safety hazard. Finally, we again checked the operation voltage on the voltage supply (wall outlet) as well as on the primary side of the transformer to verify that there was 120VAC. In addition to our tests to meet CSA C22.1-15, we used a power cable that meets the standards given in the *Table (6)*.

Conclusion and Future Work:

In summary, the final project we have built is a power supply that, given 120 VAC/60 Hz at the input, will provide 15 VDC at the output. The device shall be supplied power from any standard wall outlet in North America, and its regulated DC output may be accessed via banana jacks. The power supply includes many components, both hand-made, and purchased from digikey.ca. Calculations were done in order to build the transformer, and to determine which heat sink was necessary for the design. The transformer was built to step-down the 120 VAC from the wall outlet to 20 VAC. The voltage is then rectified, regulated, and filtered before arriving at the user output at 15 VDC. These processes were accomplished using a bridge diode, capacitors, resistors, and a regulator.

In order to improve our design, the first step would definitely be to create our own PCB, as this would give us more flexibility in our design. Secondly, we would have liked to explore some redesign for our transformer in terms of cooling options, as the transformer itself reached about 128°C at its maximum temperature. In order to maximize safety and efficiency, the transformer should be cooled, and, given more time, we are confident that we could accomplish this. Our final recommendation for future work would be to modify the box that our power supply was housed in. Although our box served its intended purpose of providing a casing to hold all the components of the power supply, we would have liked to be able to include several more features including an LCD display, a switch, an LED, and a 3D printed box. The LCD display would serve to show the output voltage, and perhaps the load current or input voltage as well. The LED would be used to show that the device was turned ‘on’, with the switch of course being the mechanism that would turn it on. Finally, we would have liked to 3D print a box for our product, as this would have given us more freedom in terms of shape, size, and material, but unfortunately the wait at UNB’s Makerspace was too long to be a feasible option for this project.

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Appendices

Appendix A: Heat Sink Calculations

Since we are using the TO-220 heat sink, the following data was collected from the datasheet:

T_{amb} = 35 °C
T_{jxn} = 110 °C
$R_{\theta jc}$ = 2 °C/W
$R_{\theta grease}$ = 0.1 °C/W
$R_{\theta insulation}$ = 0.2 °C/W

Then from this information we were able to make the following calculations:

(1) $Pin = \frac{Pout}{\eta}$
$= 30 / 0.88 = 34.09$ W

(2) $P_L = P_{in} - P_{out}$
$= 34.09 - 30$
$P_L = 4.1$ W

(3) $R_{\theta T} = \frac{\Delta T}{PL} = \frac{Tjxn - Tamb}{PL}$
$= \frac{110 - 35}{4.1}$
$R_{\theta T}$ = 18.28 °C/W

(4) $R_{\theta T} = R_{\theta jc} + R_{\theta grease} + R_{\theta insulation} + R_{\theta HS}$
$18.23 = 2 + 0.1 + 0.2 + R_{\theta HS}$
$R_{\theta HS}$ = 15.98 °C/W

From this value for the thermal resistance we were able to pick a heat sink from Digikey. The heatsink we chose was HS112 - ND.

Appendix B: Transformer Design Calculations

A code was created in MATLAB to determine our transformer parameters:

```
% ECE 3031 - Course Project Design Matlab Script
% Description:  15 V 2Amp 30 W DC power supply design
%-----------------------------------------------------------------

clear;
clc;

%--------Parameters----------%
%%% tech specs
    V1 = 120;
    V2 = 20;              % set to allow drop across diodes
    I2 = 2;
    Sout = V2 * I2;
    f = 60;
    NofPhase = 1;
%%% measured values
    %%%% bobbin measurements
    BobThick = 1.2;       % thickness, mm
    hm1 = 26;             % primary winding area width, mm
    hm2 = hm1;            % secondary winding area width, mm
    LD = 123;             % perimeter, mm
    %%%% core lamination
    d = 0.05;             % core lamination thickness, mm
    Sw = 3.63;             % window area, cm^2
    Lc = 12.26;           % avg length of magnetic path, cm
    V = (6.6*4.4-2*Sw)*d;   % volume of lamination, cm^3
%%% selected values
    J = 3.4;              % (2.5 - 4 A/mm^2) current density
    VoltReg = 0.10;        % (5% - 20%) voltage regulation percent
    Km = 0.35;            % (0.22 - 0.54) copper fill factor
    Ta = 25;              % ambient temp, degrees C
%%% fixed values
    Bo = 1.4;       % Bo -> No-Load magnetic flux density, T
    Sm = Km * Sw;   % net area of winding conductors in core window, cm^2
    Ps0 = 2.9;      % no load core loss per kg, W/kg
    Ho = 6;       % no load magnetic field intensity, A/cm

% Conduct basic steps of calculations:
%%% step 1: core size estimation
Bl = Bo * (1- (VoltReg/2))    % The full-load flux density, T
Sc = Sout/(2.22*f*Bl*J*Sm*10^-2) % cross sectional area of magnetic core, cm^2
LamNo = 33/0.5                % number of laminations
```

```
%%% step 2: calculate numer of turns of windings
TV1 = (1e4)/(4.44*f*Bo*Sc)          % Turn per volt on the primary side
TV2 = TV1 / ( 1-(VoltReg/2))^2      % Turn per volt on the secondary side
N1 = TV1*V1                         % Primary side turn #
N1 = input('Round up N1 ');
N2 = TV2*V2                         % secondary side turn #
N2 = input('Round up N2 ');

%%% Step 3: Calculation of no-load current:
Gc = V*LamNo*7.75*1e-3;             % total core weight, kg
Ic0 = (Ps0*Gc)/V1;                  % No-load core loss current, A
Iphi0 = (Ho*Lc)/N1;                 % No-load magnetizing current, A
I0 = sqrt(Ic0^2+Iphi0^2);           % No-load current, A

%%% Step 4: Primary Current Calculation
I2p = (N2/N1)*I2;                   % Referred secondary current
Ps = input('B1 based Ps? ');         % full load core losses, W/kg
Ic = (Ps*Gc)/V1;                    % Core-loss current at rated load
H1 = input('B1 based H1? ');         % magnetic field intensity, A/cm
Iphi = (H1*Lc)/N1;                  % magnetizing current, A
I1p = I2p + Ic;                     % Active component of the primary circuit
I1 = sqrt(I1p^2+Iphi^2);            % total primary current, A

%%% Step 5: Wire Size calculation
A1 = I1/J*1e-2               % winding conductor cross-sectional areas
A2 = I2/J*1e-2               % select guages from this, cm^2

%%% Step 6: Winding Structure Calculation:
dm1 = 2*sqrt(A1*100/pi)         % diameter of primary wire w/insulation, mm
dm2 = 2*sqrt(A2*100/pi)         % diameter of secondary wire w/insulation, mm
if A1 < 0.112
    kd1 = 1.15;                 % determine winding displacement factor
    kl1 = 1.2;                  % determine winding layer factor
elseif (0.112 <= A1) && (A1 <= 0.15)
    kd1 = 1.1;
    kl1 = 1.15;
elseif 0.15 < A1
    kd1 = 1.05;
    kl1 = 1.15;
end
if A2 < 0.112
```

```
        kd2 = 1.15;               % determine winding displacement factor
        kl2 = 1.2;                % determine winding layer factor
    elseif (0.112 <= A2) && (A2 <= 0.15)
        kd2 = 1.1;
        kl2 = 1.15;
    elseif 0.15 < A2
        kd2 = 1.05;
        kl2 = 1.15;
    end
    m1 = hm1 / (dm1*kd1);         % turn per layer on the primary side
    m2 = hm2 / (dm2*kd2);         % turn per layer on the secondary side
    s1 = N1/m1;                   % Number of layers of the primary winding
    s2 = N2/m2;                   % Number of layers of the secondary winding
    ThickPrimary = dm1*s1*kl1+(3*1e-3*25.4*s1)+(3*1e-3*25.4); % thickness, mm
    ThickSecond = dm2*s2*kl2+(3*1e-3*25.4*s2)+(3*1e-3*25.4);  % thickness, mm
    if (LD < (ThickPrimary+ThickSecond));
        disp(['yikes step 2'])    % check thickness
    end
    Im1 = (LD+pi*ThickPrimary)*1e-1;                  % Avg wire length per turn of primary
    Im2 = (LD+pi*(ThickPrimary+ThickSecond))*1e-1;  % Avg wire length per turn of the secondary
    l1 =Im1*N1;                    % Total wire length of the primary(cm)
    l2 =Im2*N2;                    % Total wire length of the secondary(cm)

    R1 = input('R1 based on wire size table? '); % ohms/cm
    R2 = input('R2 based on wire size table? '); % ohms/cm
    PWireResist = l1*R1;                     % Primary Resistance @ 20 deg
    SWireResist = l2*R2;                     % Secondary Resistance @ 20 deg
    kt = 3.93*1e-3*(234.5 + Ta + 30);        % temperature coeff.
    RpFullLoad = kt*PWireResist;             % primary resistance @ full load
    RsFullLoad = kt*SWireResist;             % secondary resistance @ full load

    % Step 7: Voltage Ratio Check
    U20 = (N2/N1)*V1;                        % Secondary No-load voltage
    E1 = V1-I1*R1;                           % Primary EMF
    E2 = (N2/N1)*E1;                         % Secondary EMF
    U2 = E2-I2*R2;                           % Secondary full-load voltage

    % Step 8 : No-Load losses
    P0 = Ps0 * Gc + (I0^2*PWireResist)       % No-load losses

    % Step 9 : Voltage Regulation Check
    VR = ((U20-V2)/V2)*100;                   % voltage regulation check
    VRpercentDiff = abs(VoltReg*100 - VR)/(VoltReg*100) % check if close, if not redo

    % Step 10 : Efficiency Calculation
    Eff = (V2*I2/(V2*I2+(I1^2*RpFullLoad+I2^2*RsFullLoad)+(Ps*Gc)))*100 % efficiency

```

After running the code the output in the command window was as below in *Table (7)*:

Bl =	1.3300
Sc =	5.2270
LamNo =	66
TV1 =	5.1296
TV2 =	5.6838
N1 =	615.5572
Round up N1 =	616
N2 =	113.6763
Round up N2 =	114
Bl based Ps =	2.9
Bl based Hl =	4.5
A1 =	0.0012
A2 =	0.0059
dm1 =	0.3841
dm2 =	0.8654
R1 based on wire size table =	$1687.6*10^{-6}$
R2 based on wire size table =	$332.3*10^{-6}$
P0 =	1.8269
VRpercentDiff =	0.1039

Table 7: Command Window

Based on A1 and A2 and using Appendix 2 from [10], the AWG values for the primary and secondary side windings were determined to be 28 and 20, respectively.

It should be noted that the number of laminations (66) was determined by dividing the length of the bobbin window by the thickness of core laminations.

Appendix C: User Manual

ECE 3031 Course Project

A User's Guide to a DC Power Supply

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April 2017

Table of Contents:

General Information

System Overview:

The product is a DC power supply with 120VAC input from any wall socket and 15VDC regulated output that can supply up to 2A.

General Safety Summary:

Injury Precautions:

To avoid any kind of fire hazard or overloading in the power cord, use only the specified and supplied power cord that is approved according to international standards.

Avoid Electric Overload:

In order to prevent any kind of damage to the product or electrocution to the user, do not connect a load that might need more than 2A for a long period of time. Do not attempt to supply voltage any higher or lower than 120VAC.

Ground the Product:

Grounding is to protect users. Make sure that the wall socket this product is connected to has grounding. The case of the product is also grounded to prevent any current leak reaching the user.

Do not Disassemble Product:

Taking the product apart may cause damage to the components in the device. Electric shock is a life-threatening risk when this product is being repaired by untrained users.

Do not Operate Product Outdoors:

This product supplies power to external devices. Wetness and/or dampness may cause the internal parts of the product to corrode and short-circuit. Wetness also creates a risk for electric shock.

Use Proper Fuse:

A fuse is used to prevent any overloading damage to the product when there is more than 2A drawn. Use a fuse that is approved by International (specifically North American) standards.

Certification of Product:

CSA certification includes the product and power cords supplied to work with this device. All power cords supplied are approved for use in North America.

Getting Started

Steps of Use:

- The user must put in the 3A fuse given with the power supply if it is not placed in the circuit.
- In order to use the DC power supply, the necessary input supply voltage is approximately 120VAC with a frequency of 60 Hz.
- The user must make sure that there is grounding in the wall outlet in use.
- After plugging in the power cord to the wall outlet, the power supply should be on and there should be approximately 15VDC in the DC output ports.
- If there is 15VDC in the output, the power supply is ready to use to supply 15VDC with maximum of 2A to any load.

Caring for the Product:

- The device should be maintained only by trained persons. The user should not open and repair the device.
- The power supply should be used indoors and in dry conditions. Damp or wet environments may cause corrosion or a short circuit which may cause life-threatening risks to the user.
- The power supply case can be cleaned using a damp towel when necessary.
- If the fuse in the power supply is broken, replace it with a new 3A 110/220V fuse.

Replaceable Parts:

- Power cord
- 110/120V 3A fuse

Troubleshooting:

- If there is no voltage at the output, check if there are any problems with the wall socket or the power supply cable.
- If there is still no output voltage, check if the fuse is functional.
- If the fuse is still functional, there must be a damaged component in the supply circuit. Have the product serviced by a trained professional.