ELP 305: Design and Systems Laboratory	**Semester II 2020-2021**

Laboratory Report March 6, Group H: March 6

Note: *LaTeX template courtesy of UC Berkeley EECS dept.[1]*

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1 Requirements for the circuit

1.1 Electrical requirements

The device needs:

- To input 220V- 50Hz AC supply and supply a regulated 5V DC output.
- To be able to function in a wide Voltage range (180-260V AC, 50Hz).

To achieve these requirements, the following components[2] were used to make the charger :

1. One 220V / 12V step-down transformer (turns ratio of 55:3)
2. Four 1N4007 diodes (used in the rectifier)
3. One electrolytic capacitor of capacitance 22mF and one unpolarized capacitance of 1μF respectively.
4. One IC LM7805.

1.2 Mechanical requirements

The device needs to:

- be reliable, intuitive, compact, safe and easy to use.
- Output over a standardized interface such as USB 2.0 / USB-C / USB-3PD.
- be able to function in a wide variety of temperatures and environmental factors.

For these reasons, the following mechanical components are being planned to be included :

1. A Male Pin to attach to the Switchboard plug (IS:1293)
2. One USB cable, single-strand, of 1m length, at-least double wired and of 22 AWG.
3. One USB type C male port
4. One heat sink (according to the IC used)
5. One PCB board (52x84 mm)
6. The device needs to be compact, safe and reliable enough to use.
7. The device needs to operate in a wide temperature range (-20C to 60C) and across wide ranges of other environmental factors.

2 Selection of Components

2.1 Capacitors

The capacitor C1 is used to minimize ripple in output voltage of rectifier. The minimum capacitance required varies inversely as operating frequency and voltage ripple magnitude, and directly as the DC value of the output voltage, along with a constant. By trial and error, 22mF at C2 give reasonably low ripple for all the input voltages. The output capacitor C1 of 1μF helps stability and transient response in output.[3]

2.2 Diodes

1N400X series of diodes[4] are fairly common in rectifier circuits. 1N4007 has the highest DC blocking voltage, i.e, maximum reverse voltage, among these. It can thus handle high voltages quite easily. To allow for large deviations (undesired but as a safety measure) 1N4007 is used.

2.3 Integrated Circuits

The LM78XX family of ICs[5] provide a constant DC output voltage. The XX represents the value of this voltage in Volts. It can be operated for output current of 1.5A DC also (and beyond too with proper considerations, limited by 2.4A) within 150 degrees Celsius. C2 control the ripple to keep the IC's input voltage within tolerance limits. Thus, it is commonly used as a voltage regulator.

2.4 Transformer

A transformer was specified in LTSpice[6] with two inductors coupled together at coupling coefficient 1 and in accordance with the equation,

$$\frac{L_{primary}}{L_{secondary}} = (\frac{N_{primary}}{N_{secondary}})^2 = (\frac{V_{primary}}{V_{secondary}})^2 \tag{1}$$

taking primary and secondary to be 220V AC and 12V AC respectively. While actual designing, we will have to look into the voltage and current ratings of the transformer, generally available in dimensions 42x38mm.

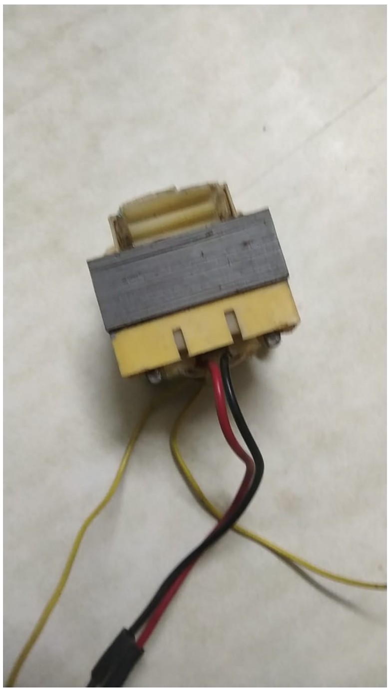

Figure 1: Transformer to be used, left as a square blank space in the PCB

3 Specifications

The mobile phone charger demanded 5V DC output voltage and 1A DC output current. Hence, a load drawing constant 1A current was added to the circuit in parallel with the output capacitor and diode. The AC mains was modelled by a voltage source producing a sinusoidal voltage wave of 220V (RMS), in series with a small source resistance of 1m Ohms.

The circuit acts sequentially:

1. The mains supply voltage is stepped down to 12 V (range - 11.68-12.4V).
2. A full-wave rectifier is used to convert this to a DC voltage.
3. Ripples in output voltage of rectifier are removed by using a large capacitor in parallel with a polar capacitor.
4. The filtered voltage is fed to LM7805[7][8] which outputs constant DC value of 5V.
5. The external load draws a constant 1A current.

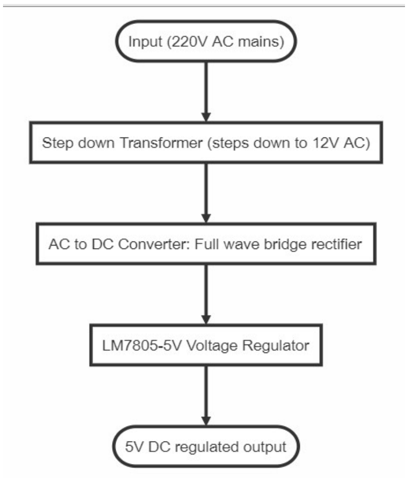

Figure 2: Circuit schematic

3.1 Circuit schematic diagram

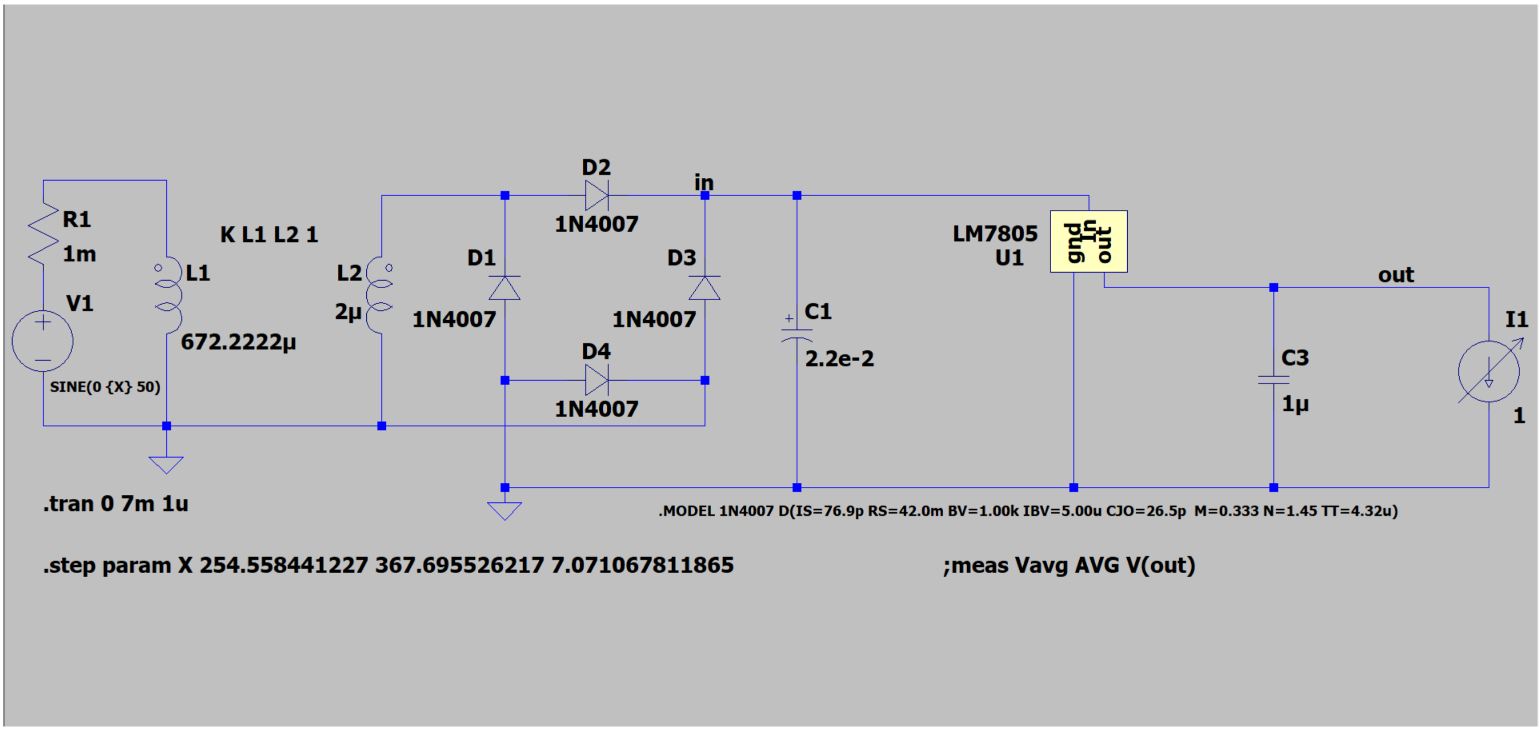

Figure 3: Circuit schematic

3.2 Simulation of regulated DC output

The output voltage at input voltage of 230V AC (RMS) was plotted.

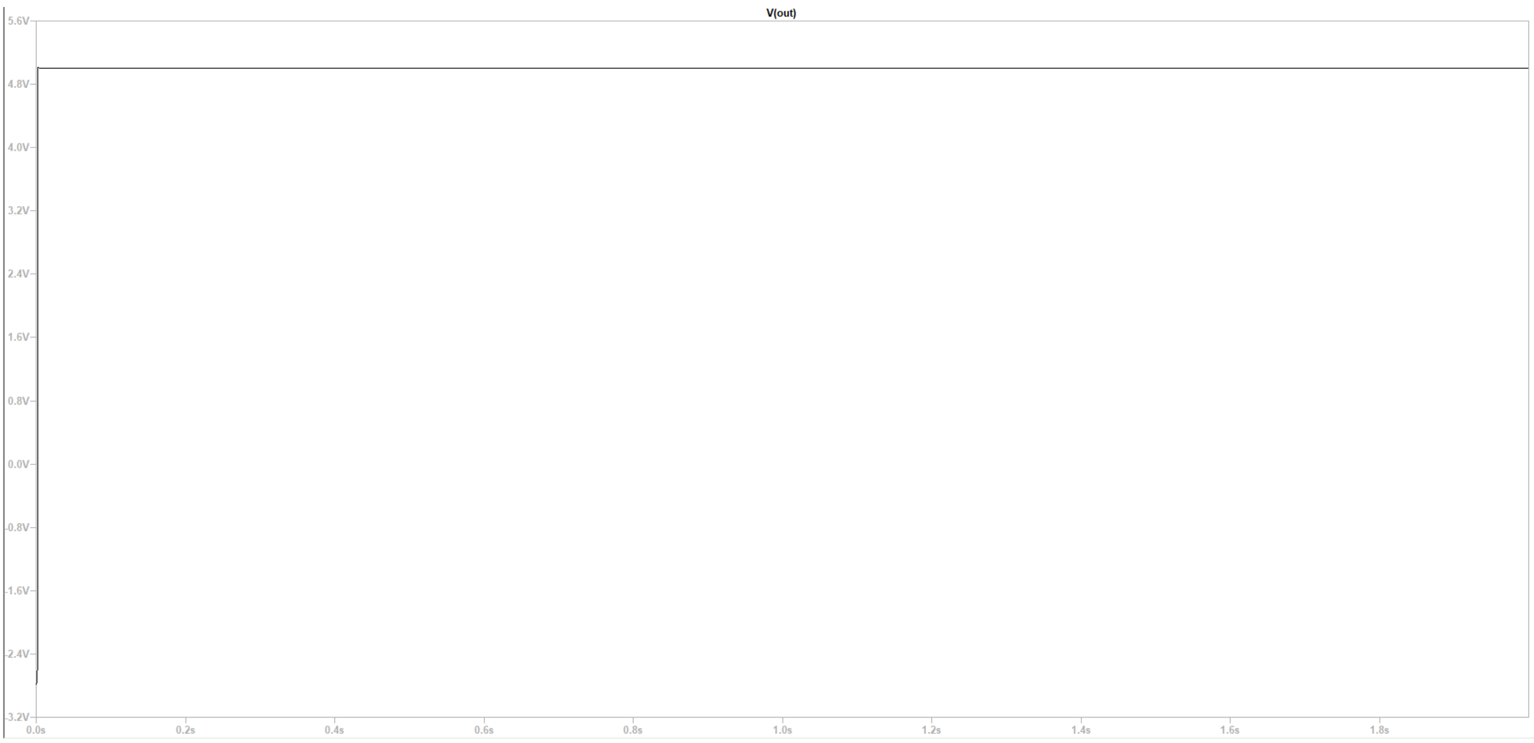

Figure 4: V(Out) settling times

It was found to settle at 5V DC.
The input voltage to the LM7805 was plotted.

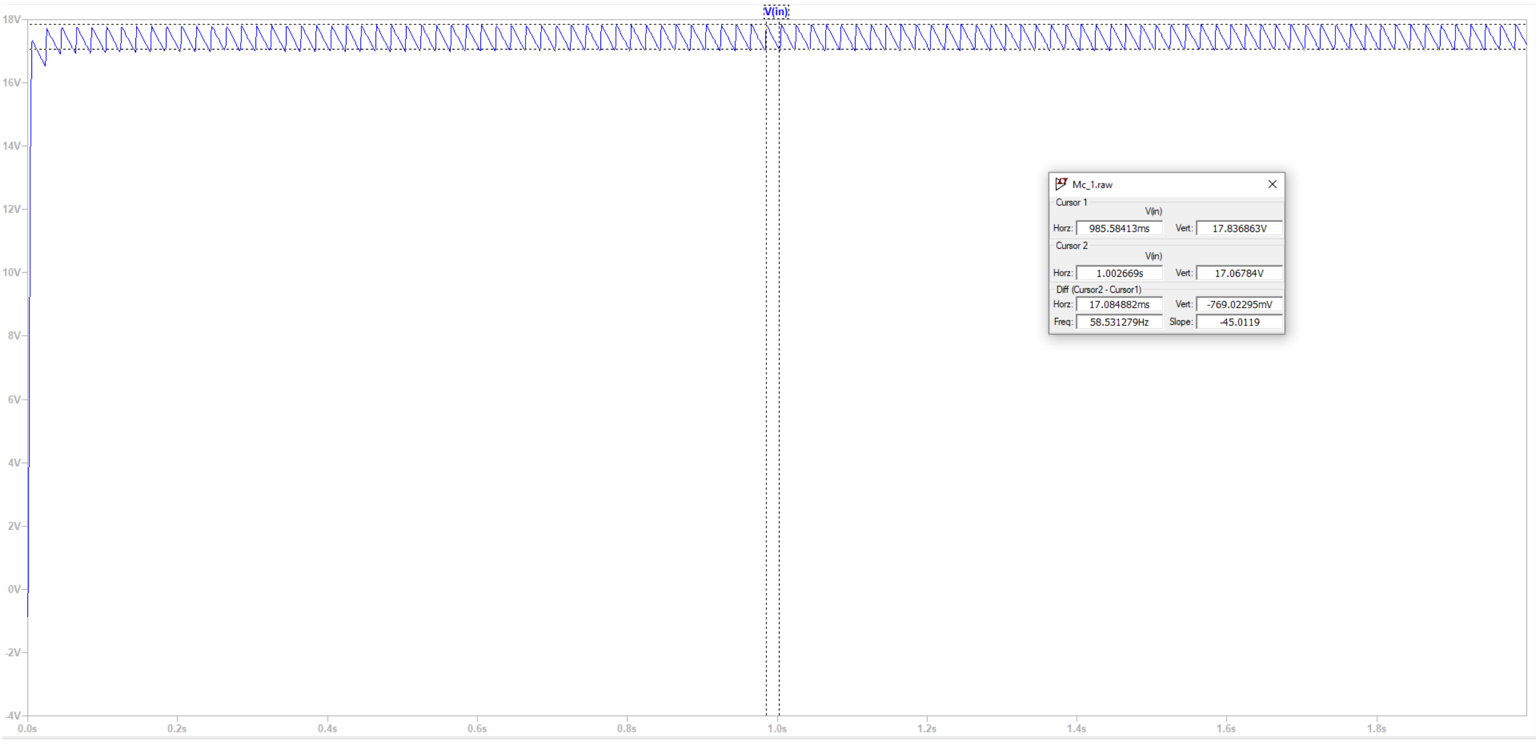

Figure 5: V(Out) settling times

A ripple of 769mV around the DC value of 17.44V, i.e., 4.4% , was observed.

3.3 Sensitivity to input mains variation

The input voltage of LM7805 (output of rectifier) was plotted for different input voltages.

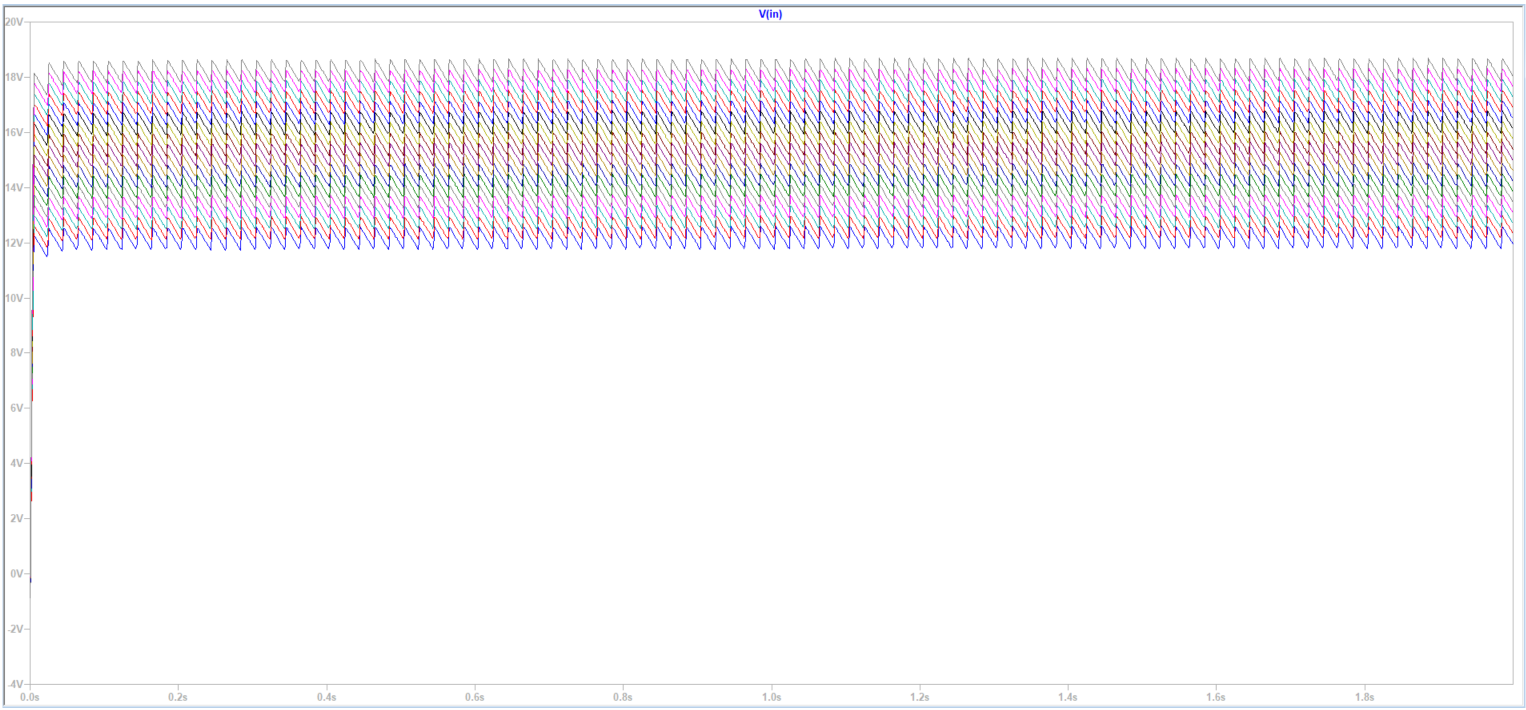

Figure 6: V(Out) settling times

The input of the LM7805 has ripples of 5.34% (at 180V (RMS)) or lower.

The output voltage was plotted for the range of input voltages.

Figure 7: V(Out) settling times

The output voltage, however, settles at a constant 5V DC.

3.4 Settling time

The simulation was run for 2.29ms with 230V AC supply voltage.

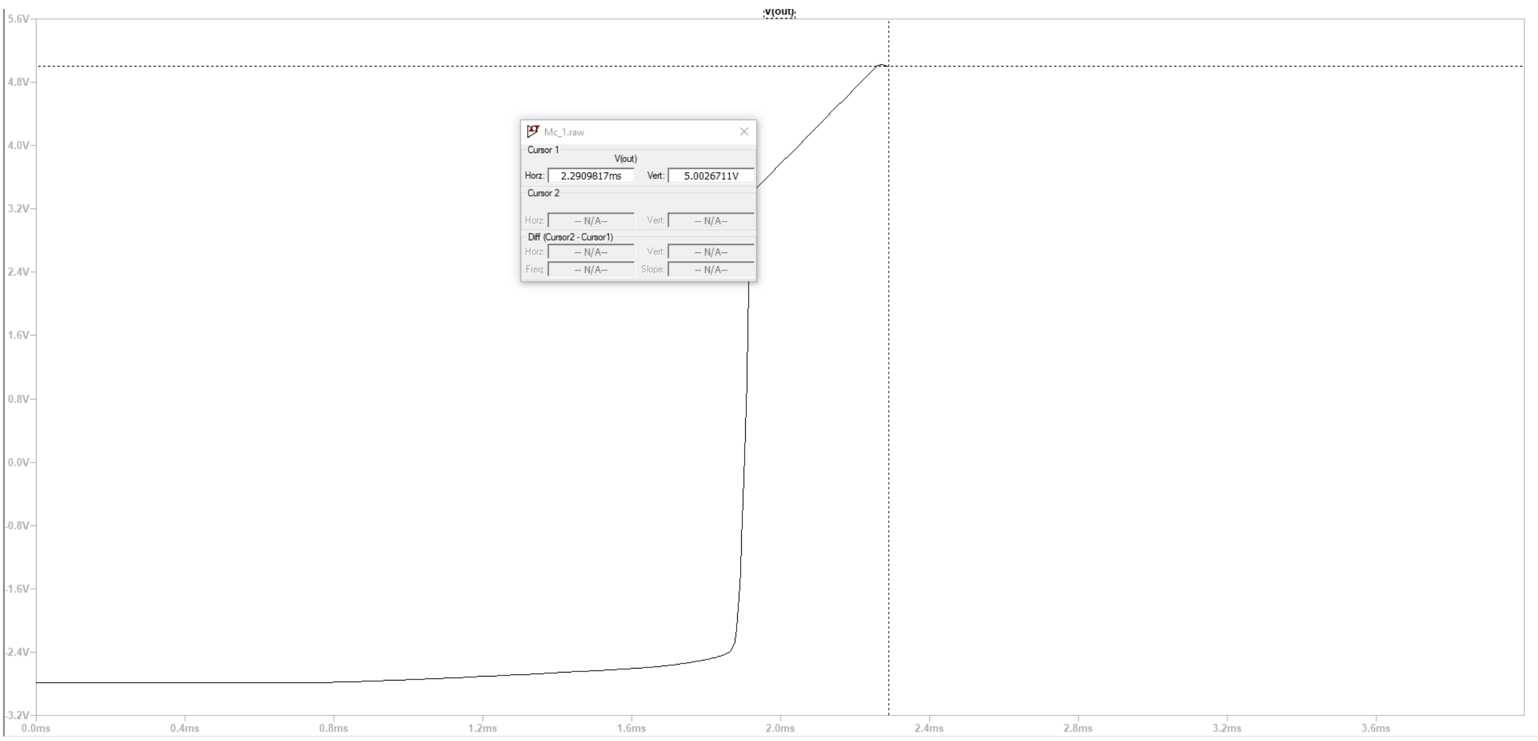

Figure 8: V(Out) settling times

The settling time for input voltage of 230V (RMS) AC was found to be around 2.29ms. All of them settle to the same output voltage of 5 V DC.

The input voltage (RMS) was swept from 180 V to 260 V. The corresponding set of curves of output voltage was plotted across time.

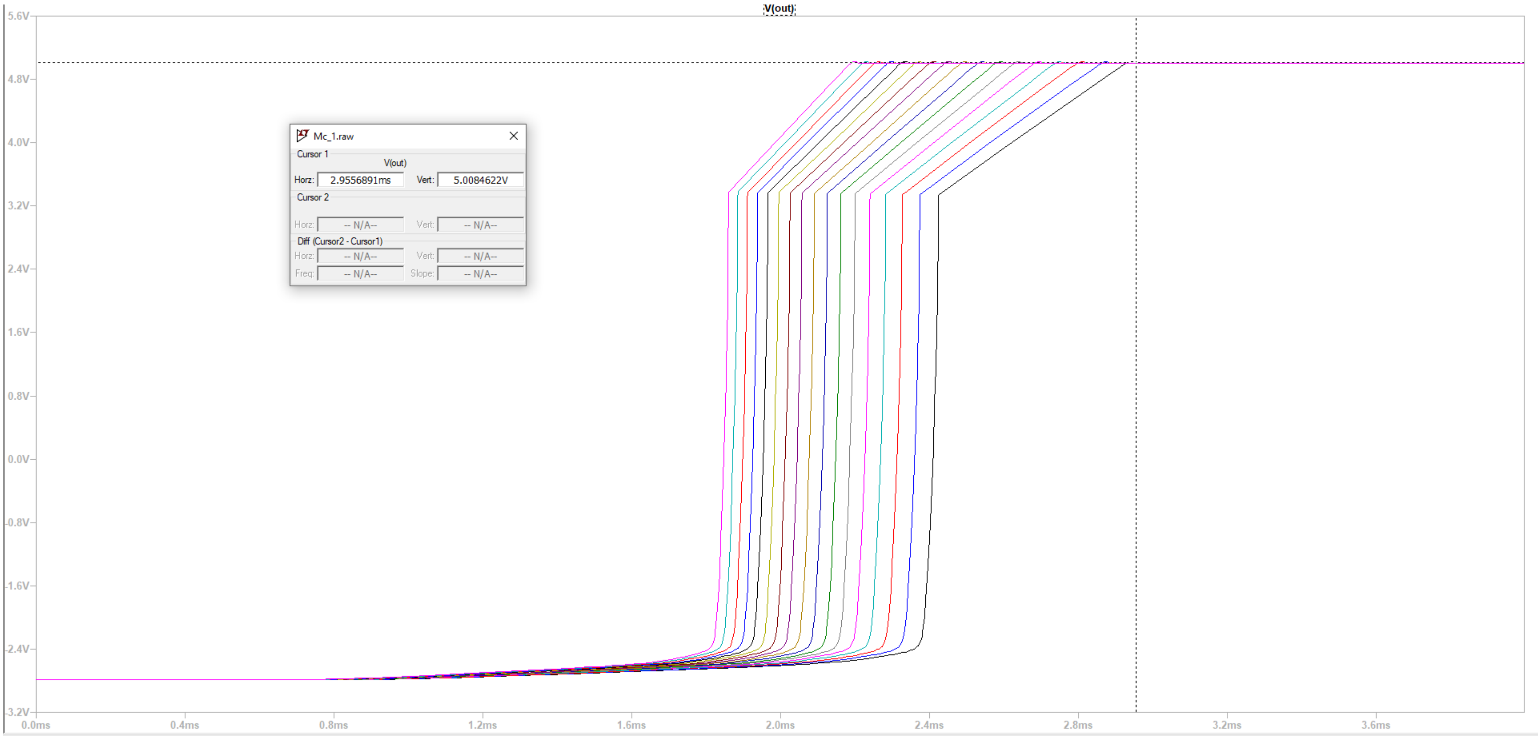

Figure 9: V(Out) settling times at different Voltages

The settling time varied from 2.2ms to 3ms.

4 PCB Design

4.1 Layered View Of PCB Layers

Following are the views of various layers of PCB design. The screw size used is a standard 3.2 mm diameter.

Figure 10: Top Solder Mask View

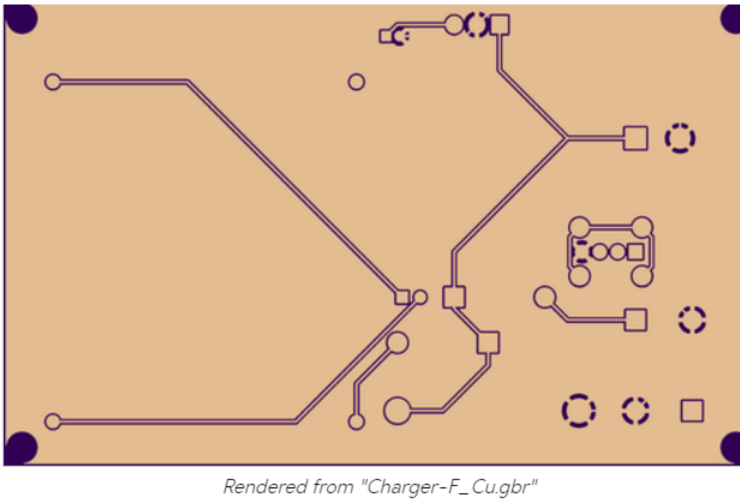

Figure 11: Top Layer View

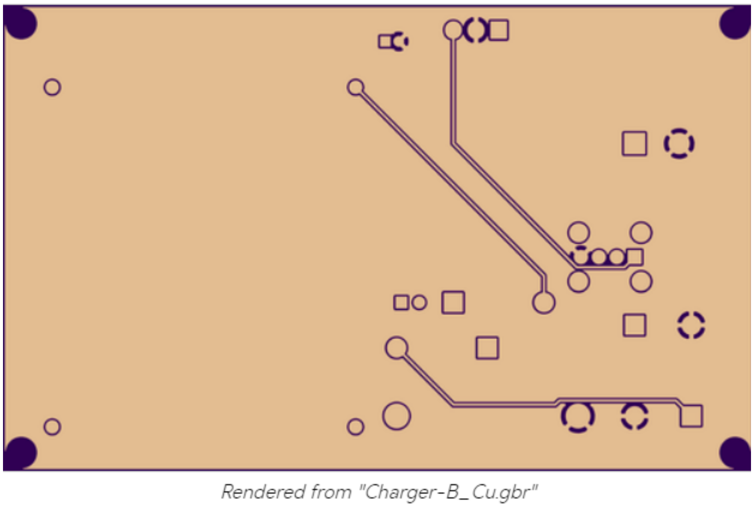

Figure 12: Bottom Layer View

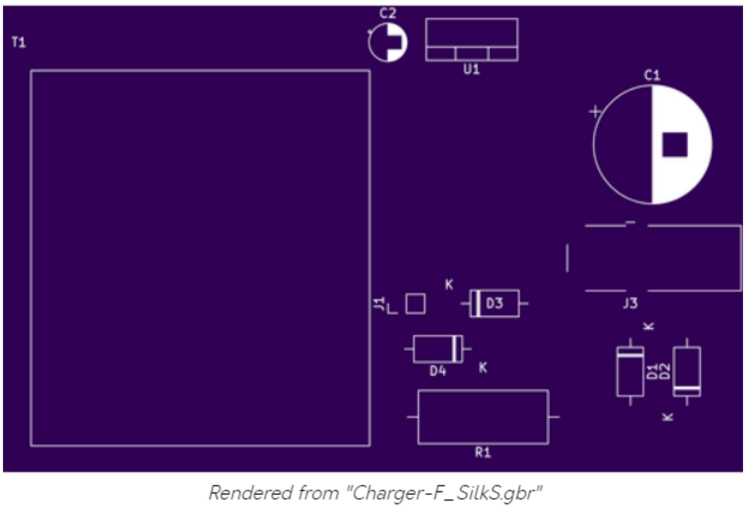

Figure 13: Top Silk Screen View

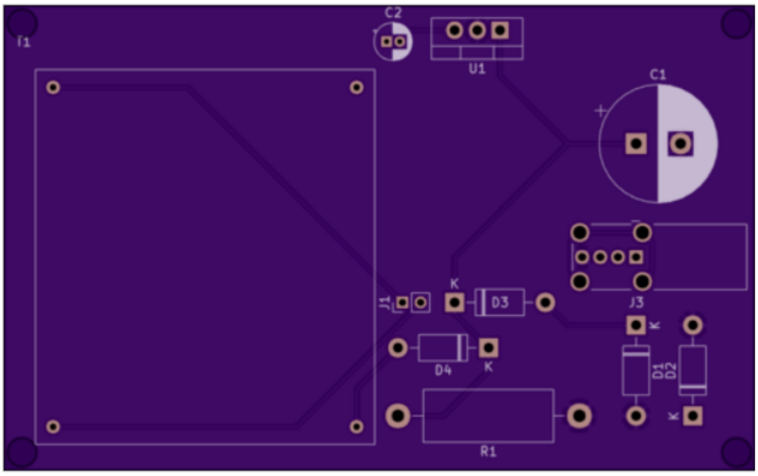

Figure 14: Board Top

PCB Footprints		
S.no.	Device Name	Footprint
1	C1	Capacitor_THT:CP_Radial_D13.0mm_P5.00mm
2	C2	Capacitor_THT:CP_Radial_D4.0mm_P1.50mm
3	D1	Diode_THT:DO-41_SOD81_P10.16mm_Horizontal
4	D2	Diode_THT:DO-41_SOD81_P10.16mm_Horizontal
5	D3	Diode_THT:DO-41_SOD81_P10.16mm_Horizontal
6	D4	Diode_THT:DO-41_SOD81_P10.16mm_Horizontal
7	J1	Connector_PinHeader_2.00mm:PinHeader_1×02_P2.00mm_Vertical
8	J3	Connector_USB:USB_A_Wuerth_614004134726_Horizontal
9	R1	Resistor_THT:R_Axial_DIN0614_L14.3mm_D5.7mm_P20.32mm_Horizontal
10	T1	Transformer_:Rectangle_board_size38×42mm_4_holes_each_2mm_away_from_corner
11	U1	Package_TO_SOT_THT:TO-220-3_Vertical

4.2 3-D View Of PCB

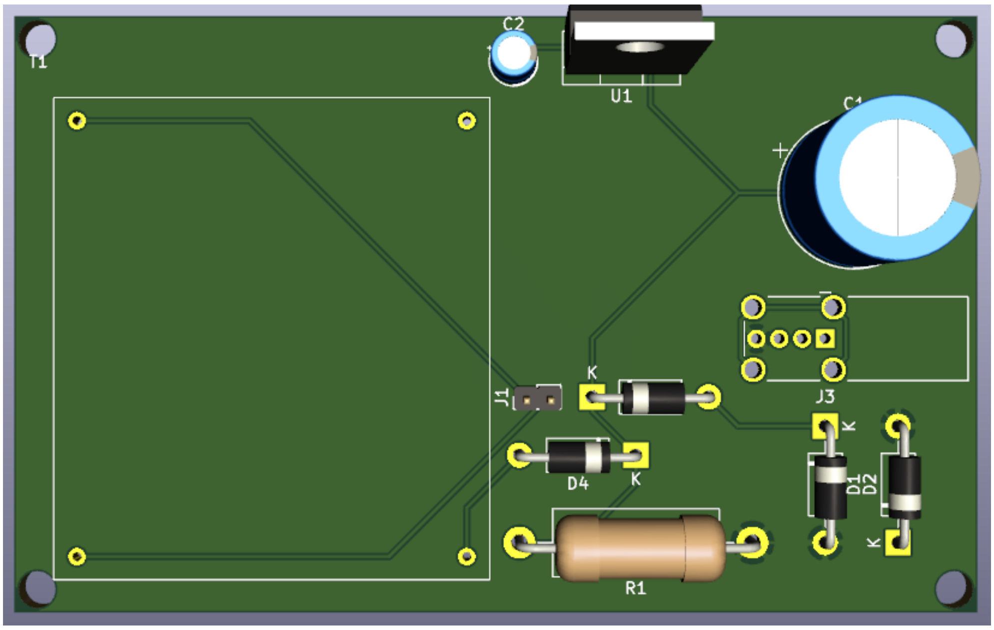

Figure 15: Top 3-D View

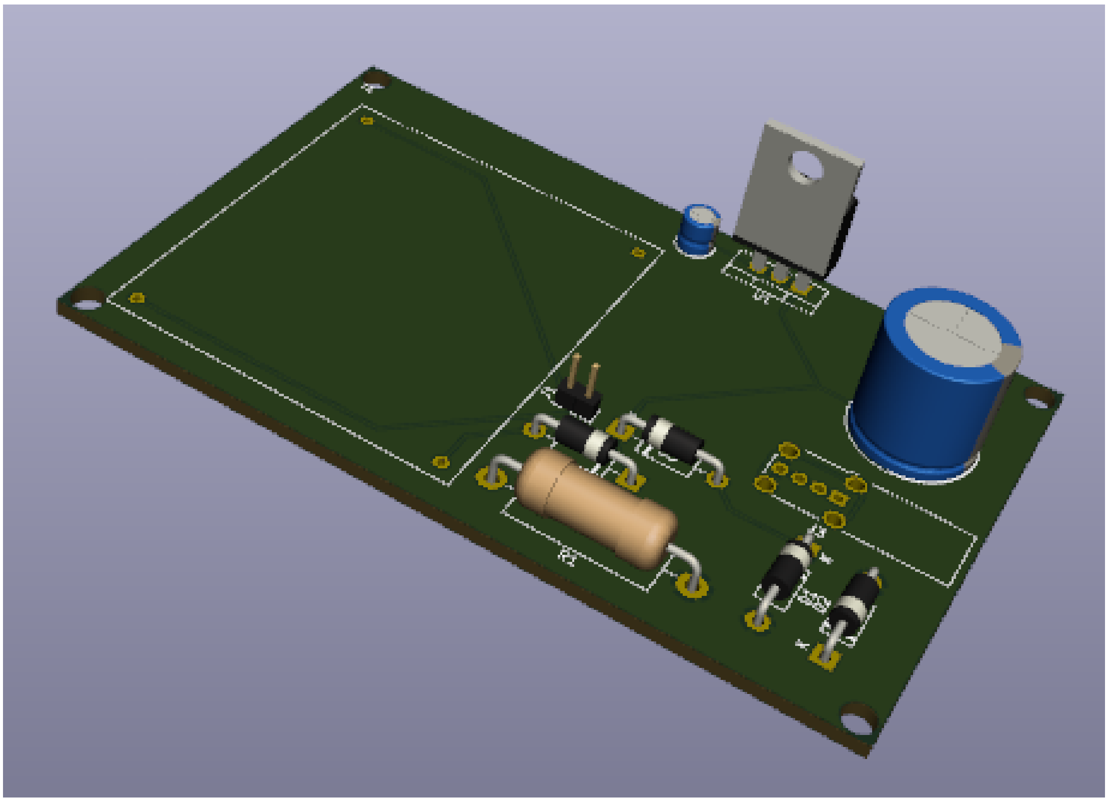

Figure 16: Final 3-D View

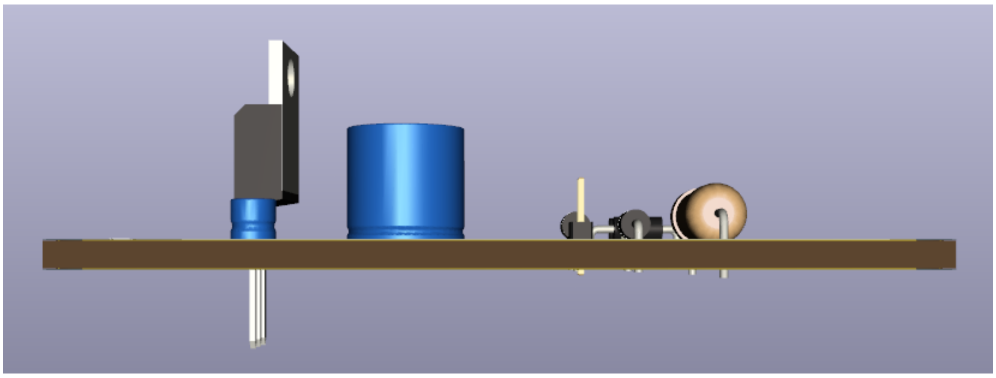

Figure 17: Side 3-D View

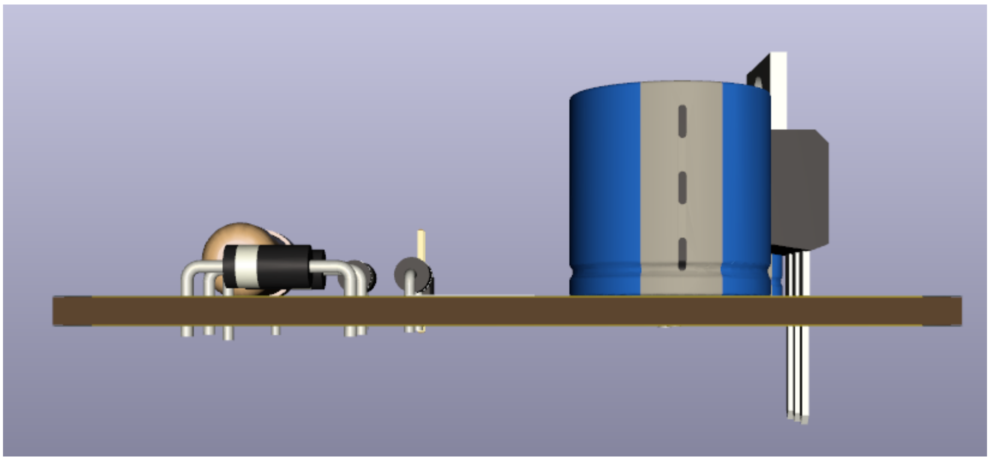

Figure 18: Side 3-D View

Enclosure Dimensions		
S.no.	Part	Dimensions
1	Base	50 mm x 90 mm x 16 mm
2	Cover	56 mm x 90 mm x 51 mm
3	Head	62 mm x 33 mm

5 Dimensions of Enclosure

The above table denotes the dimensions for parts of our proposed enclosure.

6 Heating Problem - A Heat Sink

The PCB has been made keeping in mind that the LM7805 Element can get heated up to high temperatures. To counteract that, we use the following heat dissipating heat sink

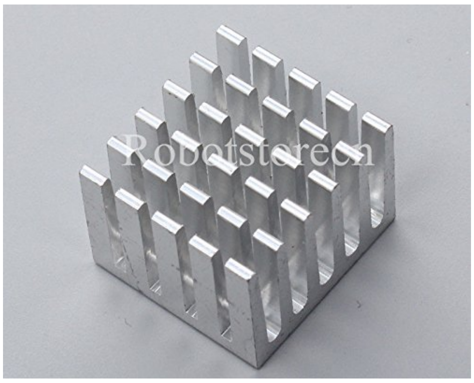

Figure 19: The Proposed Heat Sink

The dimension of this heat sink is 20x20x15 mm[9], which is an exact fit for our circuit. Another option will be to use a smaller heat sink

Figure 20: Another Heat Sink

This is a smaller, but less effective heat sink[9]

7 Enclosure Design

We used the general-purpose parametric 3D computer-aided design modeler FreeCAD[10] to design our enclosure for charger.

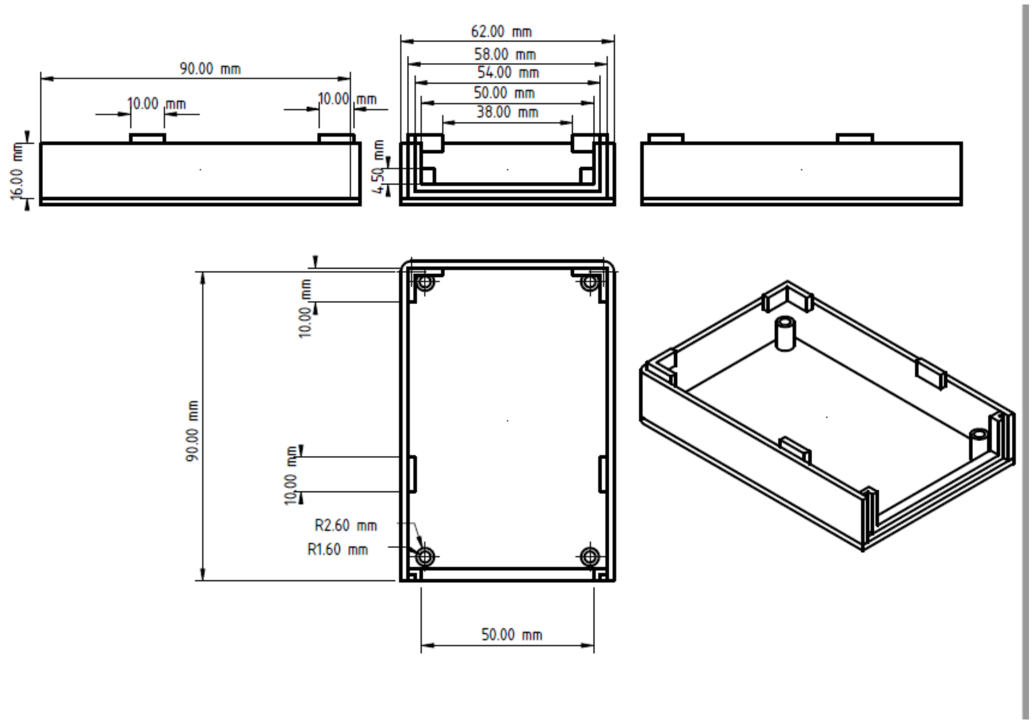

Figure 21: Proposed Design for Base

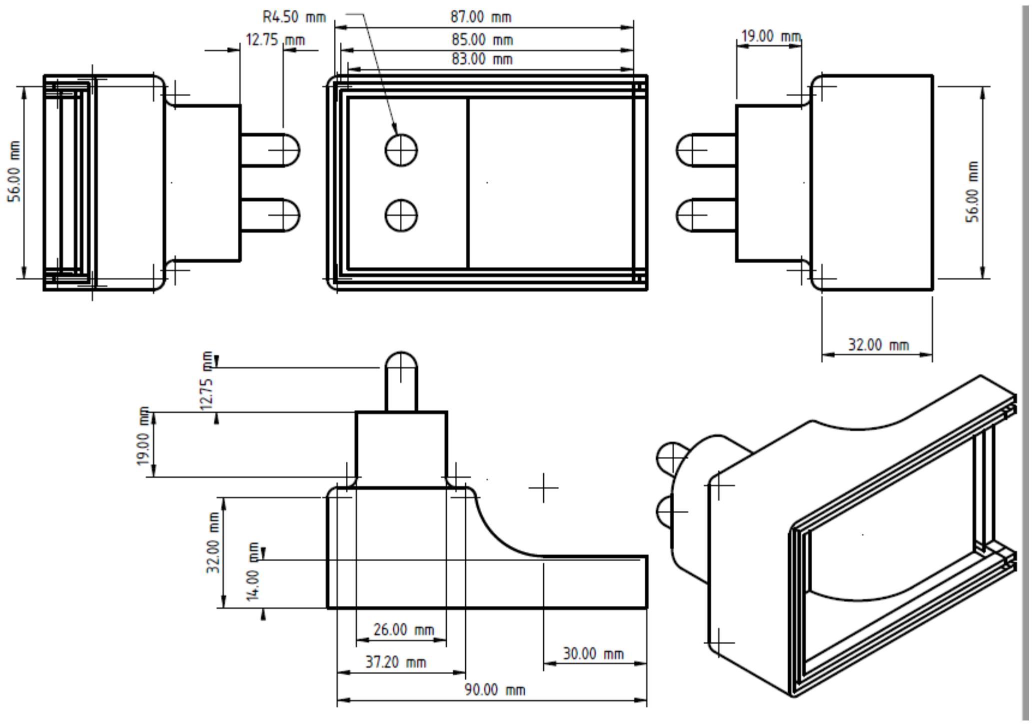

Figure 22: Proposed Design for Cover

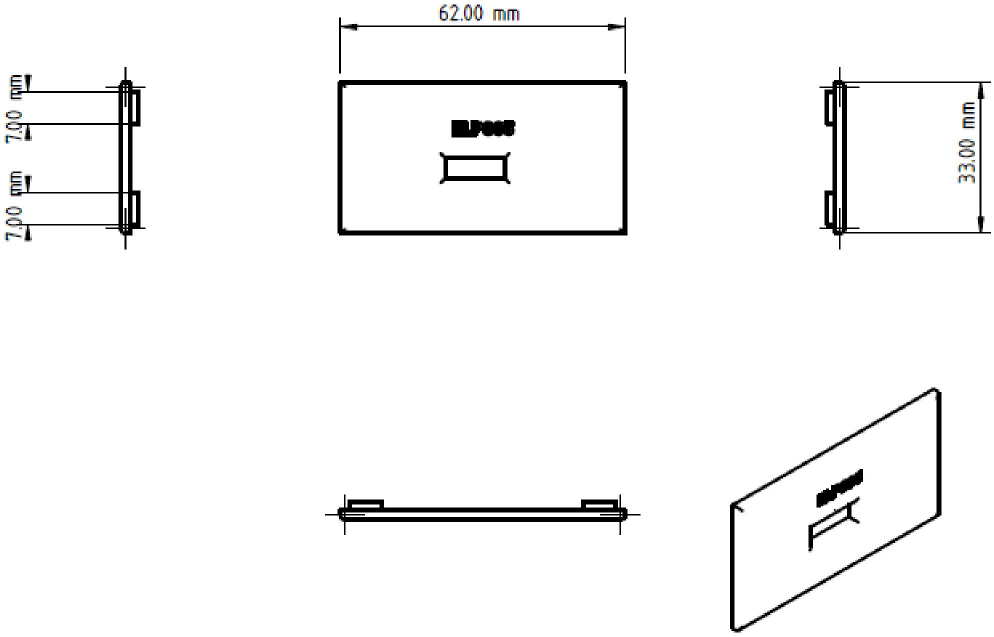

Figure 23: Proposed Design for Head

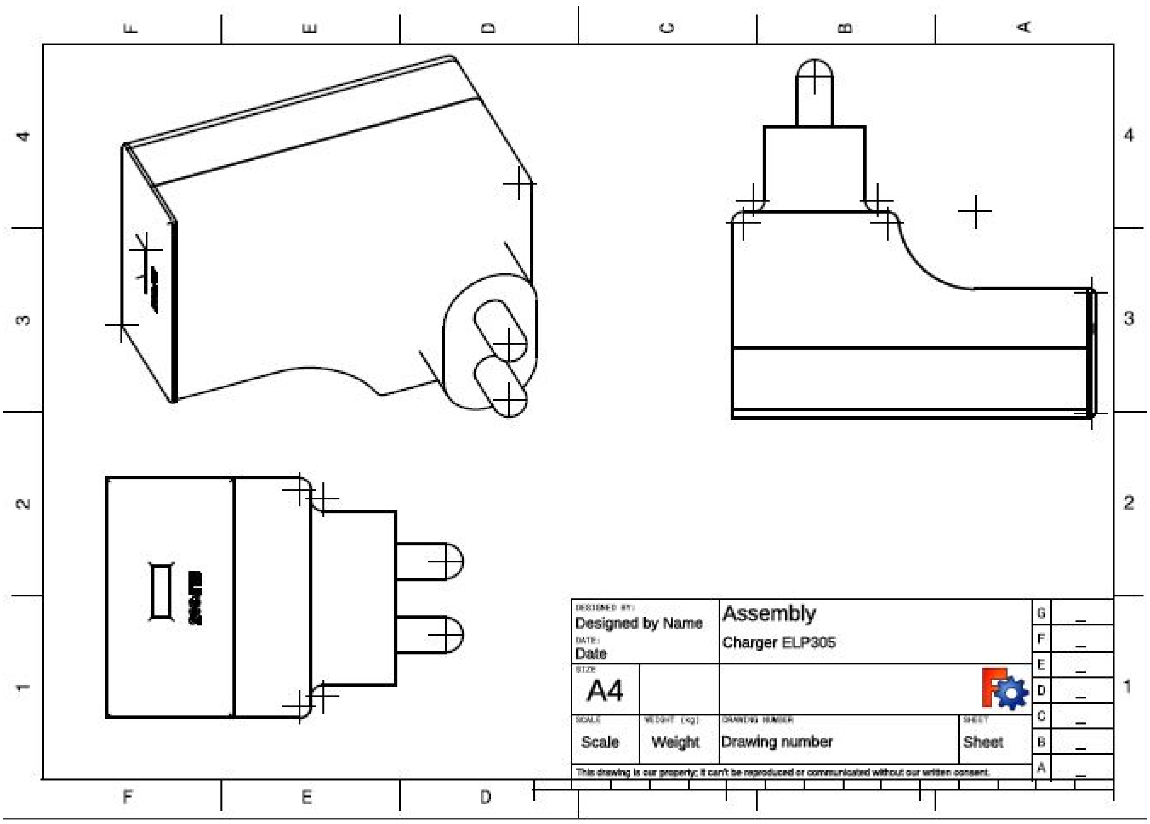

Figure 24: Proposed Assembly Design

8 USB SPECIFICATIONS

L6LUC009-CS-R

Figure 25: 2.0 USB A Male to USB C Male(0.9mt)

Technical Specifications

Type	USB-A Male to USB-C,reversible
Technology	USB 2.0
Data Transfer rate	0.48Gbps
Power Output	up to 3 A

Figure 26:

Physical Specifications

Cable Dimensions(L*W*H)	6.5*0.8*9 cm
Cable colour	Black
Cable weight	21.6 g
Connector Plating	Nickel

9 3D Assembly

We used FreeCAD[11] to assemble various parts of our proposed charger, as depicted.

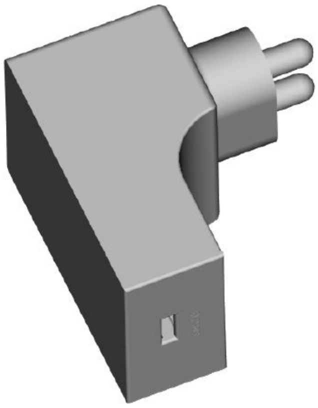

Figure 27: Proposed Assembly Design

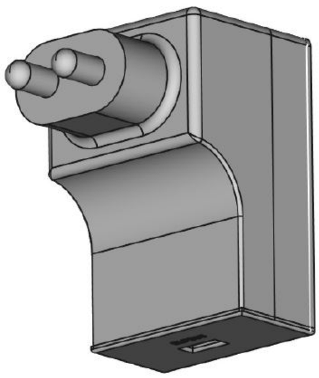

Figure 28: Proposed Assembly Design

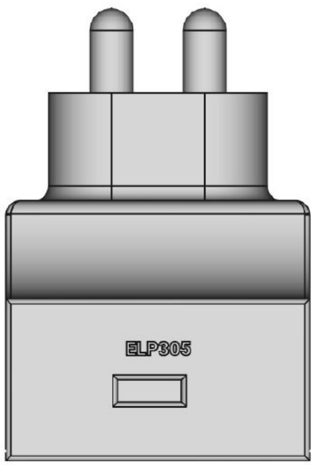

Figure 29: Proposed Assembly Design

10 Bill of Materials

The estimated cost of the proposed PCB is around 200 Rupees. The breakup of cost by parts is done as shown in the following table.

Bill of Materials		
Device	Link to buying Site	Price wrt Quantity
PCB	[12]	15.5 (Rs. 100/ sq. inch)
1u	[13]	10.53 (per 5 cap)
22m	[14]	14
1N4007	[15]	40 (per 50 pcs)
Conn_01x02_Male	[16]	9 per 40 pins
USB_A female	[17]	15
20Meg	[18]	0.7
Transformer_1P_1S	[19]	99
USB A To USB C	[20]	370
LM7805_TO220	[21]	9

Taking into account a bit more expenses for soldering and fabrication etc, the total cost comes around **200 Rupees** for the PCB, which is an upper limit. The most expensive component is the Transformer.

The USB cable depends on the specifications required by the customer. The USB - a to USB - C is just a default, we can also connect USB A to USB B if needed. This is a very adaptive design.

The body is made of plastic. It costs about Rs 30 for fabrication. The screws will cost additional costs. The plug pins will cost Rs 10 [22]. So, considering all technicalities, the total price of the finished product will come out around **Rs 300**. at max. If the customer wants to buy the cable also, it will cost extra

11 Precautionary measures that have been taken

1. The most compact design of the charger done with a bit of air space to allow heat flow within, preventing overheating.
2. Dust and moisture protection by a solid tight plastic casing.
3. Strain reliever (at cable connection point) is taken care by the cable purchased.
4. It is compact enough to withstand drops from shoulder heights.
5. Plastic body prevents user from getting electric shocks.

12 Conclusions

A mobile charger delivering 1A current at constant 5V DC was designed and simulated on LTSpice using relatively cheap and commercially available circuit elements and it's model was implemented on PCB using KiCad. The specifications have been met as far as possible.

References

[1] *Latex Template Berkeley.* URL: http://wifo.eecs.berkeley.edu/latex/.

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[20] *USB Buying Link*. URL: https://www.amazon.in/AmazonBasics-Type-C-USB-Male-Cable/dp/B01GGKYKQM/ref=sr_1_2_sspa?dchild=1&keywords=USB+Type-C+to+USB-A+cable&qid=1614963890&s=electronics&sr=1-2-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUE2VVhBU =.

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