ECE 445 Project Design Document:

Isolated Guitar Pedal Power Supply

Introduction

Group Members

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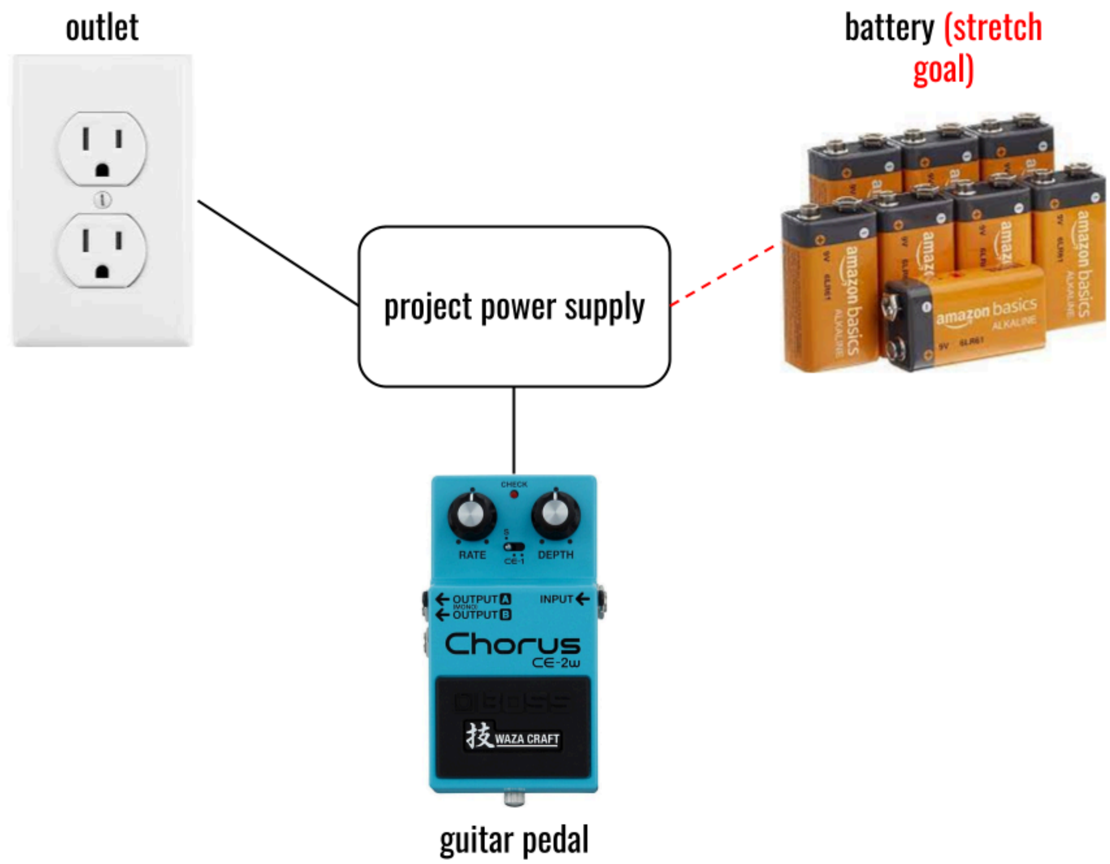
Problem

Guitar players and other instrumentalists often use audio effect boxes, usually referred to just as guitar pedals. These pedals require supply generally at 9V, 12V, or 15V with current ratings usually from 100mA up to 1000mA (in the case of some digital effects units). "Clean power" is the major requirement in these supplies, this means decoupling from AC sources and minimization of noise. Supplies for these pedals also need to have many outputs, as many pedal boards (collections of pedals used in series for one audio signal), have a number of individual units all requiring their own power. Most pedal power supplies on the market are quite expensive, don't always supply the exact combination of required output voltages, and don't have options to vary the output voltages for stylistic purposes. Stylistic variation in supply voltage refers to underpowering, and is used often by effects units to vary normal operation of external effect units. This power “sag” function mimics supply from a dying 9V battery.

Solution

The isolated power supply would plug into the wall, which would mean that we would have to work with AC/DC conversion, as well as output 9, 12 and 15 V on different ports, which would involve DC/DC conversion. The microcontroller would be used to control switches in the DC/DC converter, and while this kind of item exists online, we would want to make it more precise in terms of ripple, and with the option of purposeful undersupplying of voltage for stylistic purposes. Isolation in this case would involve both isolation from noise, which is where ripple precision comes in, and of power, where we would potentially implement a transformer. While we also have the idea to make this have the option of being battery powered as well, this would likely be more of a stretch goal than anything else.

Visual aid

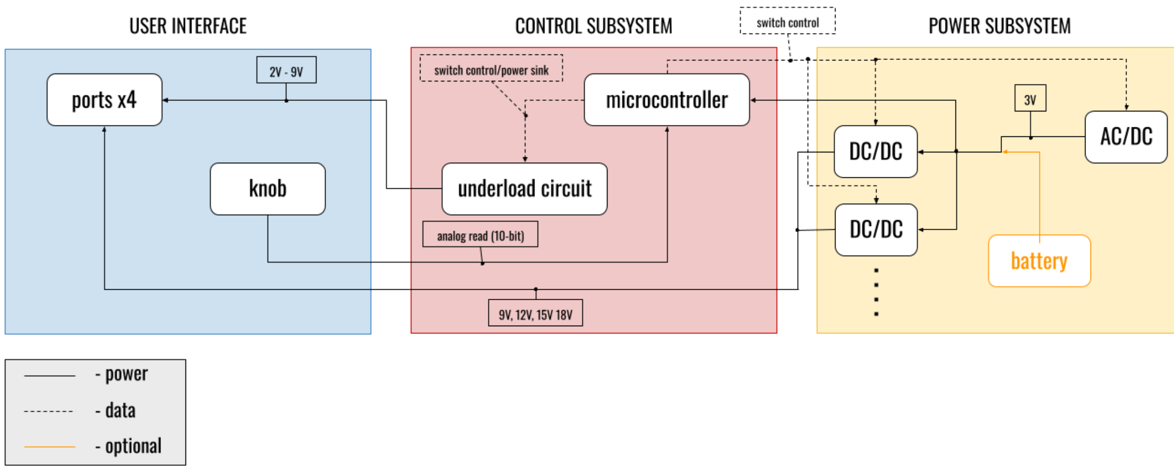


High-level Requirements

- Output ports supply at DC (under +/- 3%) and output ripple of under 100 mV
- Undersupply “sag” output responds to user choice between 2V and 9V
- Response time for underload adjustment under one second

Design

Block Diagram



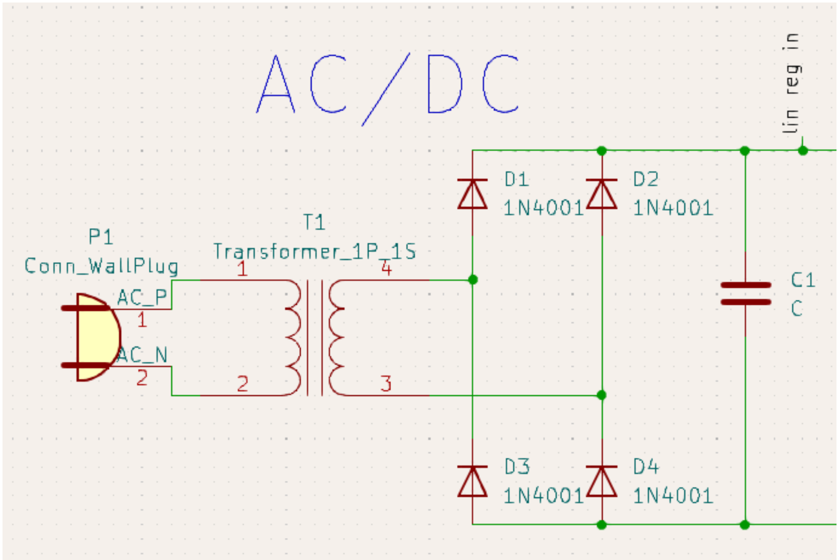
Physical Design

Our device will be housed in a 4x8 metal enclosure with 4 ports with standard barrel jacks, and a C14 jack for power cable input, commonly from a 3 prong to C13 jack cable. This enclosure will house all of our subsystems, as they will all be on a single PCB.

Subsystem 1

AC/DC converter. The AC/DC converter would be based on a bridge rectifier, adjusting the overall schematic as needed. This would include a transformer, diodes, and then some filtering +components. This would bring us from an outlet to the DC power that we work with for the power output. This would go from the AC voltage of 120V from the wall down to a 3V DC output.

Proposed schematic:



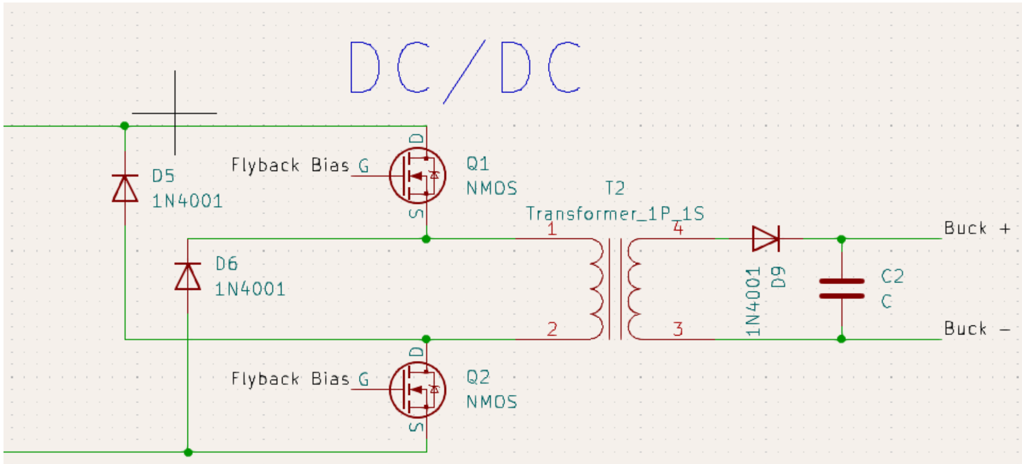
Subsystem 2

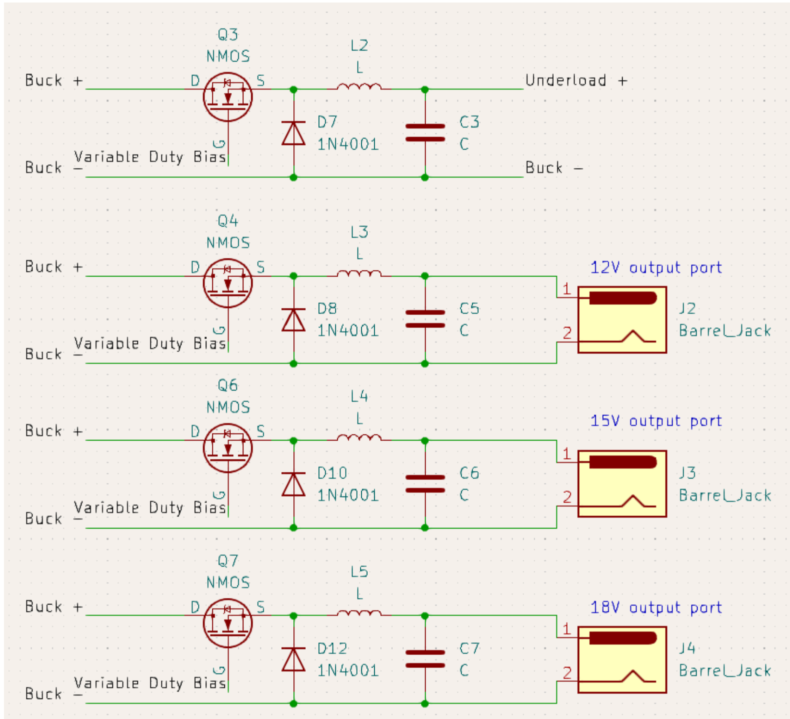
Isolated DC/DC converter. The goal is to essentially create two three-winding transformers, with the outputs equating to as close to 9V & 12V, and 15V & 18V as possible. In this case we will be stepping up from the 3V output from the AC/DC converter. The schematic would be based on a two switch flyback converter, with necessary changes added as they come up. The microcontroller in this subsystem would be used for controlling the switches needed to run the converter.

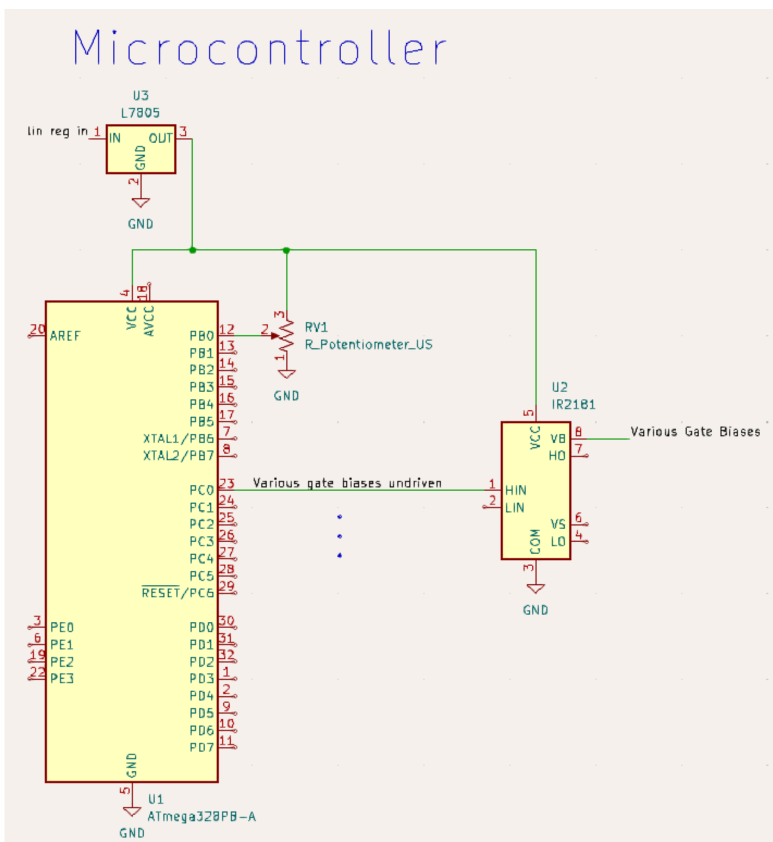
For this subsystem we would likely only need items that can be found in the electronics shop available to the students, such as copper wire, a core, capacitors, resistors, diodes, inductors, as well as switches. Further specifications will be calculated once the shop is visited and available stock is observed.

Proposed switch: IRFP450

Proposed schematic:


DC/DC
Flyback Bias
G
D
S
Q1
NMOS
D5
1N4001
D6
1N4001
T2
Transformer_1P_1S
1
2
3
4
D9
1N4001
C2
C
Buck +
Buck −
Flyback Bias
G
D
S
Q2
NMOS

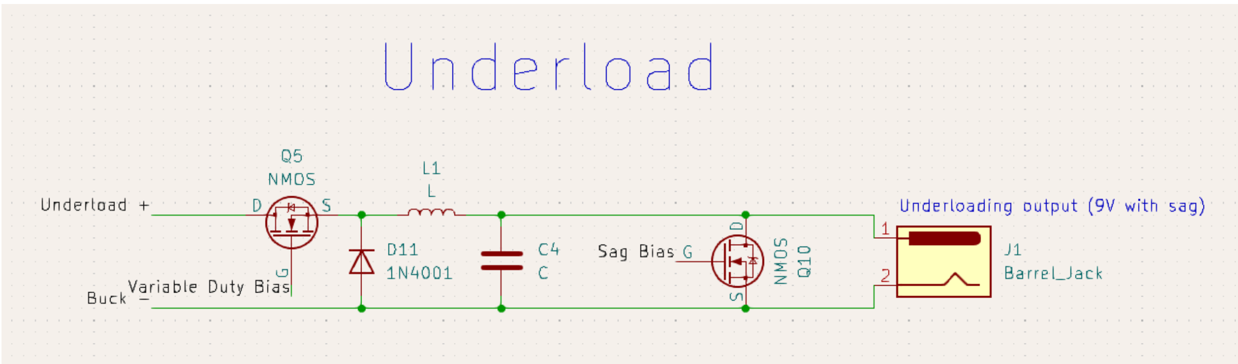

Q3
NMOS
Buck +
D
S
L2
L
Underload +
D7
1N4001
C3
C
G
Variable Duty Bias
Buck −
Buck −
Q4
NMOS
L3
12V output port
D8
C5
J2
Barrel_Jack
Q6
L4
15V output port
D10
C6
J3
Q7
L5
18V output port
D12
C7
J4


Microcontroller
U3
L7805
lin reg in
IN
OUT
GND
RV1
R_Potentiometer_US
U2
IR2181
Various Gate Biases
Various gate biases undriven
HIN
LIN
VB
HO
VS
LO
COM
AREF
PB0
PB1
PB2
PB3
PB4
PB5
XTAL1/PB6
XTAL2/PB7
PC0
PC1
PC2
PC3
PC4
PC5
RESET/PC6
PE0
PE1
PE2
PE3
PD0
PD1
PD2
PD3
PD4
PD5
PD6
PD7
U1
ATmega328PB-A

Subsystem 3

Undersupply of voltage. Mimics a dying 9V battery for stylistic purposes. This would be an option for the 9V output, where we can use the microcontroller to control the level of undersupply happening. We can implement some sort of nob or slider to control the corresponding voltage level. This would likely involve a transformer in combination with a controlled variable resistor.

Proposed schematic:



(Stretch Goal) Subsystem 4

This is something that we would look into further, if we think we have time for it down the line, but essentially the idea would be that you could disconnect the AC/DC converter from the rest of the system and attach the battery.

Subsystem Requirements

Starting with the power subsystem, this goes from the wall, taking from the average outlet and into our system with our power converts, going through AC/DC to step down from the 120V from the wall and then stepping up using DC/DC converters to get to the desired output voltages, going out to the ports in the user interface subsystem. While only two DC/DC converters are pictured in the block diagram, the trailing dots underneath indicate the existence of more, to match the number of ports outlined in the high level requirements. Precision in this subsystem will be the key to reaching our high level requirement of having less than +/- 5% ripple. The power subsystem also includes the option of replacing the AC/DC converter with a battery instead of having outlet support, for flexibility sake, but this particular segment is a stretch goal for now.

- Current outputs for the output ports should not exceed 1A (but should stay in the ballpark of 500mA +/- 3%)

Power also leads into the microcontroller, which leads us to the control subsystem. The microcontroller, as the brain of the whole project, will be connected data-wise to the switches to aid in the voltage conversions, as well as to the underload circuit. This is most crucial to the underload circuit, as its modulation is one of the key requirements outlined for the project.

- Underloading DC/DC component should be adjustable anywhere 2 to 9V with minimum ripple across all possible voltages (+/- 3%)

The user interface subsystem is relatively simple, with the previously mentioned ports, which would be connected by power to both the DC/DC converters for normal voltage output, and the underload circuit. We are also implementing a modular knob on the user interface side to indicate to the microcontroller the level of underloading desired, as outlined in our high level requirements.

- For the non underloading DC/DC component we need it to output 4 voltage levels (9, 12, 15, 18) +/- 3% with a ripple under 100mV

Requirement	Verification
Current outputs for the output ports should not exceed 1A (but should stay in the ballpark of 500mA +/- 3%)	Place the current probe of the oscilloscope in the current path of the output port and measure average and peak-to-peak amperage to make sure they are within the required values.
Underloading DC/DC component should be adjustable anywhere 2 to 9V with minimum ripple across all possible voltages (+/- 3%)	Place the voltage probes of the oscilloscope between the output port and ground and measure average and peak-to-peak voltage to make sure they are within the required values.
For the non underloading DC/DC component we need it to output 4 voltage levels (9, 12, 15, 18) +/- 3% with a ripple under 100mV	Place the voltage probes of the oscilloscope between the output port and ground and measure average and peak-to-peak voltage to make sure they are within the required values.

Tolerance Analysis

There are not many big concerns we have regarding the logistics of this project. We are looking to use basic AC/DC and DC/DC conversion to step a wall voltage down to four different voltage outputs: 9, 12, 15, and 18. For the AC/DC side we will be using an isolated linear rectifier to go from 120 V rms AC to a 3 V DC output. By isolating the AC side, the input can be stepped down enough to yield a smaller output. On the DC/DC side, we are planning on using two flyback converters side to side each with two output windings on each transformer. Looking at the ideal conversion ratio for a flyback, we get:

$$V_{out} = \frac{D}{1-D}\frac{N_2}{N_1}V_{in}$$

By stepping to 9, 12, 15, and 18 V from a 3 V input, we can build transformers with a reasonable number of windings on each end. The transformers may need some sort of clamp circuit to mitigate the concerns of leakage inductance. The biggest concern we have with these models are losses that come with parasitic elements and heat. To mitigate the losses, we are planning on adjusting the needed duty ratios to account for these losses. As for heat, we will pick out parts rated for much higher power and use heat sinks below the switches to prevent as many conduction losses as we can.

The biggest concern in our project is the underloading circuit. The underload circuit attempts to mimic a dying battery, so it needs to drop from 9 volts to 2 at the lowest, while maintaining the same current. In order to step down the voltage, we were thinking of using a regular buck converter, since the level can be easily adjusted by adjusting the duty ratio. The issue that comes with this solution, however, is by decreasing the voltage causes the current to step up, due to the transfer of power. In order to mitigate this issue there needs to be a method to draw current out of the circuit while maintaining the output voltage. In order to mitigate this we plan on adding a mosfet in parallel with the output. This way we can control the current being absorbed by controlling the gate voltage we input through the microcontroller. By operating in the linear regime, we are able to induce a variable current through the mosfet:

$$I_{DS} = u_n C_{ox} \frac{W}{L}((V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2})(1 + \lambda V_{DS})$$

Since we are going to underload at finite values, we will have gate signals calculated for each option, so the microcontroller is easily able to switch between the signals being outputted.

Cost and Schedule

Cost Analysis

component	part no.	quantity	cost / unit	total cost
diode	1N4001	10	$0.29	$2.90
220uF cap	ECA-1HM221B	3	$0.16	$0.48
220uF cap ceramic	490-GRM31CC80E227ME11KTR-ND - Tape & Reel (TR)	3	$0.92	$2.76
MOSFET	IRF100B202-ND / IRFI1310NPBF-ND	9	$1.82	$16.38
ATMega chip	ATMEGA328PB-AU-ND	1	$1.63	$1.63
inductor core	T80-3	5	$1.23	$6.15
prewound flyback transformer	POE300F-24L	1	$3.98	$3.98
transformer	2457-WBC4-1TLC-ND	1	$3.24	$3.24
gate driver	IR2181PBF-ND	6	$5.76	$34.56
c14 jack	https://a.co/d/fv0PUJq	1	$8.34	$8.34
ports	https://a.co/d/7UGdp0i	1	$8.99	$8.99
enclosure	DC-58P Heavy-Duty Electronics Enclosure	1	$14.37	$14.37
linear regulator	1662-1360-1-ND	1	$1.87	$1.87
human labor hours x3		24	$30	$720
				TOTAL
				$825.65

Schedule

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
2/19		Design document & proposal v2			Design document Breadboard	Proposal regrade Breadboard	Finish breadboard testing
2/26	Order parts	Design review	PCB design in KiCad			PCB review	Revise PCB
3/4	Revise PCB	Revise PCB	First PCB orders	Teamwork Eval Microcontroller code	Microcontroller code	Machine shop revisions	
3/11	SPRING BREAK						
3/18			Second PCB orders Soldering	Soldering	Assemble/ Microcontroller code	Assemble/ Microcontroller code	Assemble/ Microcontroller code
3/25	Revise PCB (if necessary)	Revise PCB (if necessary)	Third PCB orders	Progress report	Assemble/ Microcontroller code	Assemble/ Microcontroller code	Assemble/ Microcontroller code
4/1	Testing	Testing	Fourth PCB orders Testing	Testing	Testing	Testing	Testing
4/8	Testing	Testing	Fifth PCB orders Testing	Testing	Testing	Testing	Testing
4/15	Mock demos						
4/22	Final demos						
4/29	Final pres			Final paper	Lab checkout Award ceremony Lab notebook		

Dearborn - green
Abigail - blue
Connie - yellow
Whole group - pink

Ethics and Safety

Our project does not provide any greater ethical concerns than any common household low voltage power supply. While there may be ethical concerns in sourcing our materials, these are more high level ethical concerns that are not specific to this project. The project itself is only meant to be a tool to help power, and is not meant to breach privacy or harm anyone, physically or otherwise. In terms of safety, while the project does deal with power, this is relatively low power, and thus creates only a low risk of danger of electric shock or heat issues. If we look at the manual for the MXR iso-Brick Power Supply[1], which is a product very similar to ours, we can see that the voltage and amperage are low enough not to cause major concerns, and everything should be concealed within an enclosure, to provide extra safety for users, along with a sleeker look. As the user interface simply includes four low barrel jack power ports and a very familiar plug (C13/C14 power plug) to power the device itself, therefore users have very low risk while interacting with the device.

Citations

1 . MXR® iso-BrickTM Power Supply. Dunlop. (n.d.).
https://www.jimdunlop.com/mxr-iso-brick-power-supply/