DC to DC USB-C Charger

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Abstract

The *DC House USB-C Charger* will convert the 48V input from the DC house, found on the Cal Poly campus, to 3 USB-C outputs: 5V, 12V, and 24 volts. The converter will deliver a total of 185 Watts out across all 3 outputs, with an efficiency greater than 82% at full load. The USB-C ports will be used to connect to compatible phones, laptops or any other device for charging/powering purposes. The goal of this project is to develop the most efficient and safe converter to deliver power to multiple outputs using USB-C, for items as small as a cell phone to the size of a mini fridge.

Currently, the DC house does not contain this USB-C feature. USB-C is the connector type that technological companies are using more and more within their new products. With this said, it is necessary to design and implement this charging capability to the DC house. Once implemented, this project will assist in having the house up to date with the most current technological advancements.

Chapter 1. Introduction

Thomas Wilson, Profesor Emeritus of the Department of Electrical and Computer Engineering at Duke University, gave the definition of power electronics as follows, “Power electronics is the technology associated with the efficient conversion, control and conditioning of electric power by static means from its available input form into the desired electrical output form” [1]. Power electronics as we know it today emerged in the 1950s as a vital technology in the power world to convert between forms of electrical power.

The power electronics technology has been around since the early 1900s. Lee DeForest, an American engineer and inventor, developed a “three-element thermionic vacuum tube” in 1907 that used a DC source [1]. This rivaled the magnetic amplifier invented by Alexanderson a few years later since, with a DC source, a battery could be used to power it making it portable [1]. Ultimately, however, the magnetic amplifier was capable of handling significantly more power and made radio connection between the United States and Europe feasible [1]. This was the problem power electronics had, the power demands were higher than the technology at the time was able to handle.

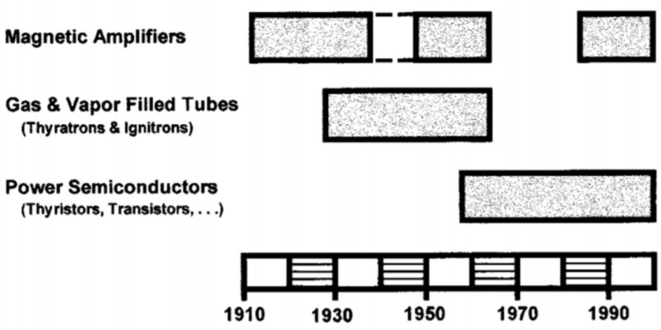


Figure 1.1: Timeline of development of power electronics technologies [1]

The creation of the power semiconductors in the late 1950s and early 1960s is really what catapulted power electronics to where it is today [2]. Semiconductors gave engineers the ability to control the electricity in ways they hadn’t been able to before, such as using diodes, and electrical switches. The efficiency of projects went up and the price went down.

In today’s world, power electronics can be found in many different fields for power engineering, in both small and large scale. Narain Hingorani lays out in his article the four functions of power electronics [3]:

1. Power Conversion (AC-AC, AC-DC, DC-AC, DC-DC)
2. Power conditioning to remove distortion, harmonics, voltage dips, and overvoltage
3. High speed and/or frequent control of electrical parameters (current, voltage impedance, phase angle)

4. High speed and/or frequent circuit interruption, transfer, and current limiting function

Using electronics to convert power comes in many different forms. Examples of these are inverters, which can be used to transform DC to AC, rectifiers to convert AC to DC, and various other converters like transformers and DC-DC converters to convert between AC to AC and DC to DC.

Prior to the Inverters that convert DC to AC power, and more so before the actual creation of semiconductors, the use of a vibrating power supply was very common. Vibrating power supplies converted DC to AC in the way that it used switching contacts that were vibrated using a magnet that would cause the contacts to open and close rapidly. A DC voltage would be its input and with these contacts opening and closing rapidly, an AC waveform would be generated. This waveform would then be injected into the primary side of a transformer, with the secondary side of the transformer having the turns ratio needed for the desired step up voltage [4]. With the use of semiconductors, the inverters that convert DC to AC no longer necessarily need a transformer for such conversion, yet some modern converters do use transformers in their topologies. The most common type of DC to AC inverters, use MOSFET switches. The two main categories of inverters include a Square wave inverter and a pulse width modulated inverter.

With AC to DC, the method prior to semiconductors was utilizing a transformer to step up or step down the voltage then utilizing a mercury arc rectifier to convert the transformed AC to DC [5]. This mercury arc rectifier itself was one of the only methods to convert AC to DC. How it does so is through the use of liquid mercury contained in a low pressure chamber that acts as a cathode and would contain a carbon anode [5]. This in itself with the reaction of moving electrons from the AC current would create DC current. With semiconductors, nowadays, AC to DC converters use rectifiers as well. However, now they utilize diodes and thyristors. These semiconductors, which can be used with or without a transformer, allow for smaller and easier implementation.

As for AC to AC converters, prior to the 1950's, the most common way to convert AC to another form of AC would be to utilize a transformer. One would input the given voltage to the primary side, then using the turns ratio to determine the amount of step up or step down voltage. Variable speed motors were also utilized when wanting to convert in terms of what frequency the desired waveform had. With semiconductors, AC to AC converters do not only include transformers but also AC voltage controllers and cycloconverters. AC voltage controllers allow for one to vary the output voltage of the system when given a fixed input voltage. As for cycloconverters, the duty cycle of the waveform is varied so that in the end, a lower frequency of the waveform is achieved.

Finally, the DC-DC converters prior to the 1950's consisted of a mixture of the converters that have been covered above. Most noticeably, the DC-AC converter of using a vibrating power supply would allow for the DC voltage to be converted into an AC voltage that could be stepped up or stepped down accordingly. Once this was completed, the AC voltage would then be fed into a mercury arc rectifier to then output DC voltage. Easily, one could see a lot of power loss and low efficiency with these practices. Post 1950's and with the semiconductors, DC-DC topologies of today are more efficient than those before. The Different topologies of DC-DC converters can be differentiated between isolated and non isolated converters, where isolated converters will isolate between the input side and load side using a transformer. Isolated converters come in the form of flyback, two switch forward, and full bridge converters. Non-isolated converters are buck, boost and buck-boost converters where there is no isolation between source and load side.

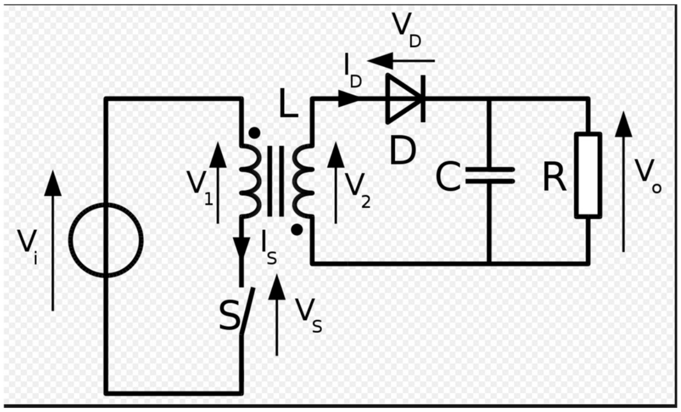


Figure 1.2: Flyback Converter

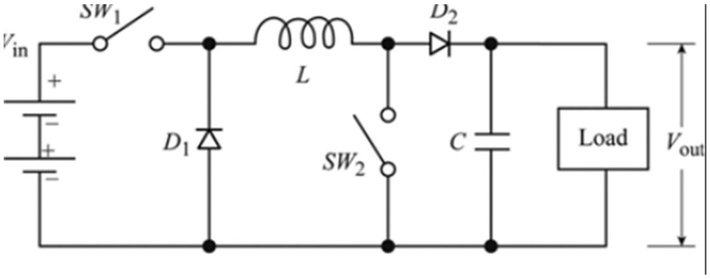


Figure 1.3: Buck Boost Converter

Today with devices becoming smaller and smaller, so is the demand for smaller and more efficient power converters [6]. These DC-DC converters are most commonly being used with consumer electronics, and with how recent trends have shown, these devices have been getting smaller and thinner with each passing year [7]. Therefore, the demand for a smaller and more efficient DC-DC converters grows. Not only that, these electronics use DC-DC converters to charge or power themselves through USB interface. USB comes in various forms, such as USB A, micro usb, and a new upcoming technology known as USB-C.[8]

Chapter 2. Background

The current market has no solution that can eloquently take a DC source and convert it to power consumer electronics. There are ways to do this with multiple steps, but not one that an average person could buy off the shelf and use. This is an issue with the DC-DC house that is currently being developed by Dr. Taufik, as there is no way to power or charge commercial devices. The majority of DC-DC power supplies are used in the IT, telecom and automotive industries [9]. The industry is expected to grow by 1.5x between now and 2025, however, it does not include any commercial electronics growth. This then makes it difficult to use a DC-DC house without the inclusion of an inverter.

Consumer electronics are electronic devices one can purchase off the shelf from a store such as Amazon or Apple. These commonly include laptops, phones, or even TV's which all run off of DC power. As of 2014, when USB-C was first released, consumer electronic devices have begun adapting them for use as they can deliver up to 100W of power [9]. This has led to an explosive growth of devices using USB-C where in 2017 there were 2 million devices using USB-C.

Consumer USB-C chargers convert between AC to DC. However, there are no consumer products that charge USB-C devices from DC to DC. The DC house Dr. Taufik is developing has a 48V DC source. Since the average device charger originally takes in AC as the formal input, one cannot simply attempt to connect a device's charger to this power. Dr. Taufik's DC house is not the only place where this technology may be needed. People who like to travel in a van and have a solar panel on the roof could benefit from not needing an inverter and being able to power their devices directly from the output of the solar panel.

With the push for renewable energy and the studies into microgrids, the way electricity is delivered is rapidly changing. Having the technology to merge consumer products with solar power will be crucial.

Using DC-DC technology to charge a battery has been looked at and done multiple ways. The four most common ways are [10]:

1. Buck converter, when the voltage of the panel is higher than the voltage of the battery, thus requiring a step down from input to output.
2. Boost converter, when the voltage of the panel is lower than than the voltage of the battery
3. Buck Boost, combining the two to let the converter adjust the input voltage so it can accommodate a voltage that is lower and higher than the panel, however reverses the polarity of the output.
4. Cuk (Boost Buck), also able to raise and lower the input voltage but uses a capacitor instead of a inductor for energy storage

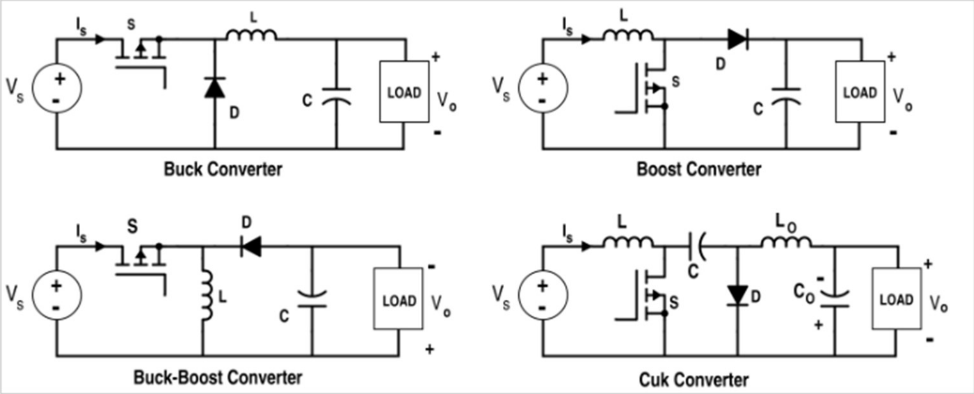
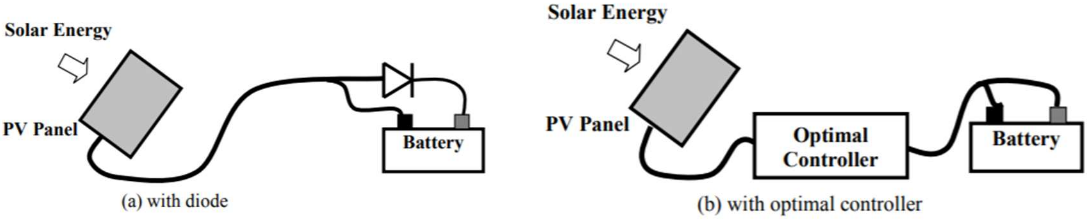


Figure 2.1: Four common converter topologies [11]

DC-DC chargers are starting to be seen more and more with portable solar charging. Usually there would be the solar panel, then a DC-DC converter as the voltage control and then output to a USB [12]. This technology however, has branched to charging electric vehicles in places like airports, golf clubs, and more [12]. The solar charging is the closest to what is being created in this project.

This has been done a few ways over the years starting simply with plugging the solar panel directly into a battery and charging the battery, seen in Figure 2.2a. There would be a diode placed between the panel and battery to prevent the backflow of current to the panel but other than that it was a very simple connection. The advantage was the simplicity of it [12]. However, there were definitely the disadvantages. The panel could only charge the battery if the voltage it was producing was higher than the voltage of the battery and regulating the current when the voltage would change was not possible with this configuration [12].

That's when the DC-DC converters came in. The most common topology used for the solar charging purpose is the buck boost converter. This is because the voltage being output by the solar panel is highly variable and needs the ability to step both up and down the voltage to optimize the charging ability. The buck boost converter is placed in between the panel and the battery, shown in Figure 2.2b.This gave the control needed to make a more efficient and functional charger.



(a) with diode

(b) with optimal controller

Figure 2.2: Solar charger with and without controller [12]

With solar controllers readily available the next step was to implement this into a useful application. That technology is still being used for EV charging and is used for off the grid vans or small structures. Powering structures with DC off the grid is what Dr. Taufik has worked to accomplish. He uses the solar charging method in figure 2.2b discussed and then distributes 48V to his DC house [13]. This project plans to build off what he has started and take Dr. Taufik's 48V output to the house and make it possible for people to charge their everyday devices.

There are a couple more projects and research topics that heavily relate to this project. A project that heavily relates to USB-C technology is from Wen-Hau Yang, who proposed a compact single inductor dual output USB-C converter. It converts a wide 5-20V input down to a 3.3 and 1.2V output. It uses a similar technology to a bridge circuit, inspiring the use of the 20V converter [14].

Another promising technology that could've been used is a buck-boost using a dual output, as shown in figure 2.3. This would incredibly helpful in the design of the buck and boost that is implemented in the project However, with how limited the range and the experimental nature, it was unwise to implement within this project [15].

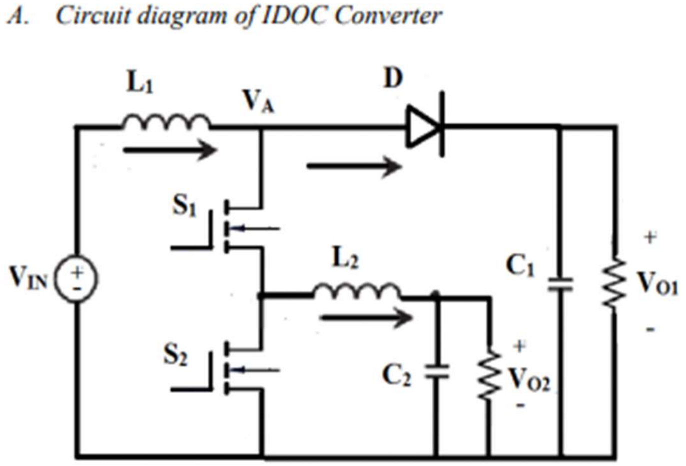
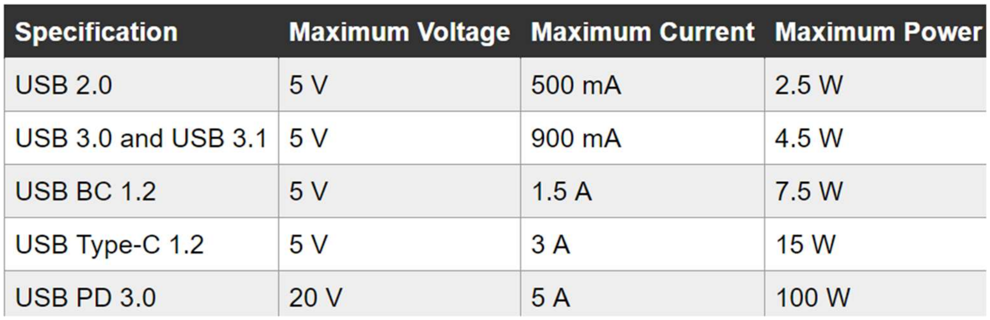


Figure 2.3: Dual Output Charger

Amongst consumer electronics, DC-DC converters are commonly used to charge or power the respective devices. Common topologies used in this domain are the buck converter, and buck boost converter, where rectified DC voltage is stepped down and batteries are either stepped up or stepped down to meet a target voltage. What interfaces the devices and how they are charged is typically done with USB. There are various forms of USB, all with different maximum power delivery, with the newest technology, USB-C, at the forefront due to its ability to deliver the most power, up to 100W, as shown by the figure below.

Table 2.1: USB ratings



Specification	Maximum Voltage	Maximum Current	Maximum Power
USB 2.0	5 V	500 mA	2.5 W
USB 3.0 and USB 3.1	5 V	900 mA	4.5 W
USB BC 1.2	5 V	1.5 A	7.5 W
USB Type-C 1.2	5 V	3 A	15 W
USB PD 3.0	20 V	5 A	100 W

USB-C is a powerful technology, such that many new devices are beginning to incorporate it, with an expected growth of close to 1.5 times between this year and 2021. However, since it is still so new, there are still difficulties in implementing it [9]. These difficulties include compliant chargers where proper power is not drawn and devices are damaged, with the Nintendo Switch, and Google Nexus 5 and 6 as prime examples [16]. These issues stem from software issues with USB PD and how current is drawn; there are also issues that stem from wide range inputs and the instability that it causes. Therefore, there aren't any commercial DC-DC converters specifically for USB-C with a wide range input.

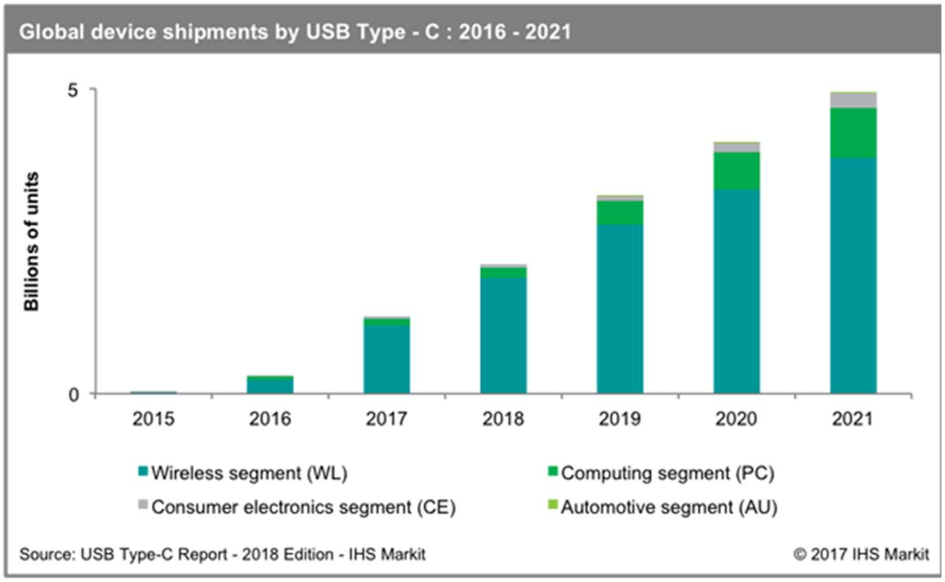


Figure 2.4: Growth of USB products

However, on the other hand, there are countless chips being developed just for USB-C. Since the amount of products using USB Type-C is growing rapidly, so is the technology for supporting it. There are many integrated chip, combining both Power Delivery and DC-DC switching technology, as well as stand alone chips that simply control USB Power Delivery [9].

This project hopes to make this possible, and create a charger that can have an input range of 12V to 55V max. Along with that wide input range, this project also keeps up with the current USB-C technology discussed. The DC-DC converter technology is developed but the intent of the project is to improve the input range and make it compatible with current technology, such that it can be used with more than just Dr. Taufik's DC house. With a minimum 12 volt input, this allows it to be used with automotives, and various other systems that run off primarily DC. The 55 volt input maximum also helps in the event that the input voltage drops or rises above the nominal voltage.

For two of the three circuits being designed, a buck converter will be used to step the voltage down from 48V to 5V and 12V. It’s straightforward topology and easy design make it an ideal choice for an initial design.

For the final converter, a 4 switch buck boost topology will be used. This will be because at the 20 volt output, depending on the input, there needs to be a boost or a buck. Using a 4 switch buck boost allows for both buck and boost to be achieved without the problem of a negative polarity. However, this chip requires more components to use and is of much higher complexity then the previous two buck converters.

This project is to create a DC-DC charger to be used in Taufik’s DC house. It will be a single input, multiple output converter at 5, 12 and 20V. Each respective output will provide 5, 5 and 3A total with built in output protection. It will be enclosed by a 5’x7’x2’ 3D printed enclosure with slats in the side for ventilation. This charger will be used to power and charge consumer devices through USB-C. By the end of the project, the goal is to have a charger that has successfully implemented a wide input range and compatibility with the USB-C technology. The charger will be tested and implemented in Dr. Taufik’s DC house at the end of the year.

Chapter 3. Design Requirements

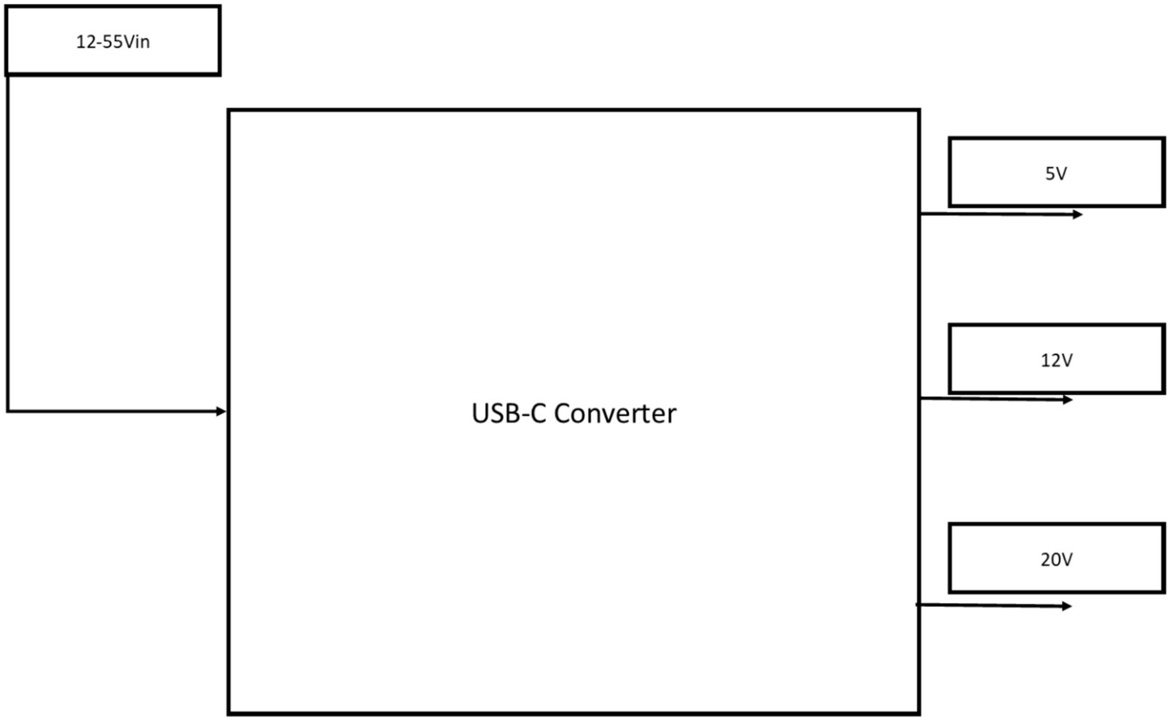


Figure 3.1: Level 0 Block Diagram

The level 0 block diagram of the project shows what the input and output of the converter is and what exactly the project consists of. There is a 48 nominal voltage input with a wide range of 12V-55V. There are 3 outputs of 5V, 12V, and 20V.

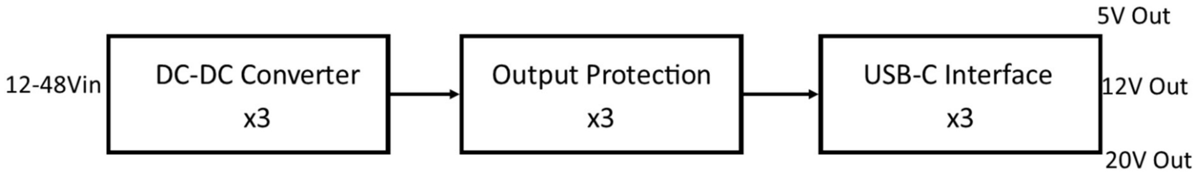


Figure 3.2: Level 1 Block Diagram

The level 1 block diagram has more detail and shows each block the input must go through before it becomes the output. The input voltage will go into a DC-DC converter. There will be input protection as well to stop inrush currents. After moving through the DC-DC converter there will be fuses in place for output protection, followed by the last block which is the USB-C interface. The detail to notice in the level 1 block diagram is the “x3” in all the boxes. Each output will have its own circuit to go through. There are 3 DC-DC converters as well as 3 output protection circuits for each converter. This charger will act as 3 separate chargers in one box.

The design specifications and requirements are laid out in Tables 3.1 and 3.2. For the technical requirements there will be a wide input range of 14-55V so the converter allows for incredible flexibility not just with Dr. Taufik's DC house, but also allows for operation with different DC systems such as automobiles. There will be 3 output voltages at the common voltages of 5V, 12V, and 20V. The 5V output will be for devices like cell phones, the 12V for small appliances such as TV's and monitors, and the 20V is not as common but gives room for larger appliances to be powered off this charger. The current set for each output is 5A for the 5 and 12V and then 3A for the 20V. This is to stay within the 100W rating of the USB-C cable as well as it is maintaining a reasonable output.

The regulations put on these circuits are for the safety and efficiency of the charger. There is a 2% load regulation and this allows for constant output voltage on all converters such that no loads are damaged. Also a 2% line regulation which allows for constant output voltage regardless of whatever input voltage is applied to it. 2% ripple voltage will also be required to prevent damage to loads. This insures as perfect a DC as possible with as little AC in order to prevent damage as well as having the most quality power delivered to the load. For the efficiency of the overall system an 82% efficiency will be required at full load.

Lastly for the technical specifications there is the input and output protection. This is in place to protect the power supply and load from potential damage on the output. The input protection will be an ideal diode in OR-ing controllers to stop an inrush of current. The output will have a fuse to protect the load.

The mechanical specifications to this project are the size of the box which will hold all three converters and be 5"x7"x2". It will have ventilation in the side to help keep the electronics cool. A heat sink on the circuit is not needed as the maximum power being reached doesn't warrant that. The input connection will be banana leads so it can be easily tested and used in a lab setting. The output will be USB-C receptacle.

Table 3.1: Technical Design Requirements

Input Voltage	12-55 Volts
Output Voltage and Current 1	5 Volt, 5A Output
Output Voltage and Current 2	12 Volt, 5A Output
Output Voltage and Current 3	20 Volt, 3A Output
Load Regulation	2%
Line Regulation	2%
Ripple Voltage	2%
Efficiency at Full Load	85%
Input Protection	Ideal Diode in OR-ing Controllers
Output Protection	Fuse

Table 3.2: Mechanical Design Requirements

Size of Enclosure	5”x7”x2”
Ventilation	Holes/slats on sides to let air flow through
Input Connection	Banana Plugs
Output Connection	USB-C receptacle

Chapter 4. Design and Simulation

The design utilizes two buck converters as well as a four switch buck boost converter. The five volt buck converter uses a synchronous buck converter for maximum efficiency, while the twelve volt converter uses an asynchronous converter to achieve 100% duty cycle low voltage conversion. For both of the buck converters, there needed to be careful design choice of the power stage. The power stage consists of the input capacitor, inductor, and output capacitor. These values are all based off of the output current, input voltage, output voltage as well as the switching frequency. Secondly, there needed to be design choices for the control stage of the converter. This was based off of the datasheet of the converter in order to design for the output voltage as well as the compensation network.

For all three converters, please note their respective parameters shown in table 4.1.

Table 4.1: Converter Specifications

Output Voltage (V)	**Input Voltage (V)**	**Output Current (A)**	**Output Ripple (%)**	**SW Frequency (kHz)**
5V	12-48V	5	2	2000(2M)
12V	12-48V	5	2	350
20V	12-48V	5	2	350

The calculations used to find the power stage values are shown. Beginning with the two buck converters. Every single equation in the that of the power stages for the buck converter require the duty cycle. From there input, output voltages and percentages of which they are specified for determining the value of capacitance and inductance necessary.

$$D = Vout/Vin$$

$$L = \frac{[(1-D)Vo]}{(.35*Io)*2*fsw}$$

$$C_O = \frac{(1-D)}{8*L*f^2*\%Vo}$$

$$C_{In} = \frac{D(1-D)Vo}{\Delta Vin*fsw*R_{min}}$$

An example calculation to find inductance can be used for the 12V buck converter. For this calculation, the worst case scenario must be used, where the max input voltage must be stepped down by the inductor.

$$L = \frac{(1 - \frac{12}{55}) * 12}{(.35 * 5)\ *\ 2 * 350k}$$

$$L\ =\ 7.65uH$$

Since the four switch buck boost converter is a different topology then the buck converter, it requires a different set of equations to solve for the power stage. The inductor requires two calculations in order to solve for the minimum amount of inductance necessary

$$L_{BOOST} > \frac{V_{IN(MIN)}{}^2 \bullet \left(V_{OUT} - V_{IN(MIN)}\right) \bullet 100}{f \bullet I_{OUT(MAX)} \bullet \%Ripple \bullet V_{OUT}{}^2} H,$$

$$L_{BUCK} > \frac{V_{OUT} \bullet \left(V_{IN(MAX)} - V_{OUT}\right) \bullet 100}{f \bullet I_{OUT(MAX)} \bullet \%Ripple \bullet V_{IN(MAX)}} H$$

The inductance for the boost comes out to 22uH and the inductance for the buck converter comes out to 6uH. Therefore, the 22uH inductor is chosen to be used in the converter. Once the inductance was found, the next stage was to calculate for the input and output capacitance values. This is found from specifying the voltage ripple desired on both the input and output. Secondly, the voltage ripple on either end is determined by the mode the converter is operating in. For example, when the converter is operating in boost mode, there will be a significant output ripple, however, when it is operating in buck mode, there will be a considerable input ripple. Since the specification on the converter requires a 2% ripple on the output, the output capacitance calculation is as follows.

$$\Delta V_{RIPPLE(BOOST,CAP)} = \frac{I_{OUT(MAX)} \bullet \left(V_{OUT} - V_{IN(MIN)}\right)}{C_{OUT} \bullet V_{OUT} \bullet f} V$$

This calculation comes out to 150uF.

The input capacitance calculation is the same as the buck converters equation, as the only time there will be major input ripple is when the converter is operating in buck mode. This gives an input capacitance of 30uF.

Table 4.2: Calculation Results

Converters	Inductor(uH)	Input Capacitance(uF)	Output Capacitance(uF)
5V	1.3	15	50
12V	7.3	12	130
20V	22	30	150

After all major values for the power stage has been found, as seen in table 4.2, the next step in choosing components would be to derate them properly. The equations below show the calculations necessary to size the inductor for all three converters as well as sizing the switch and the diode for the buck converter. Sizing capacitors are based off of the voltage that is across the capacitor primarily. Resistors are sized off of the power that will be through it. To find the power across resistors a combinations of Ohm's law and the power formula is used, which is seen below.

$$I_L max = Io + \frac{(1 - D) * Vo}{2 * L * f}$$

$$I_{sw} = I * D$$

$$I_D = I * (1 - D)$$

$$V = I * R$$

$$P = I^2 R = \frac{V^2}{R} = IV$$

The control stage need to be set in order to drive the correct output voltage, output current and proper output stability. To program the correct output voltage, all three converters use a voltage divider from the output with the equation shown below.

$$V_{OUT} = 0.8V \bullet \left(1 + \frac{R_{FB2}}{R_{FB1}}\right).$$

The equation is used when Vout is known and when one of the resistors used in the feedback is known as well. In the 5V converter, R_{FB1} is known as 100k, thus R_{RB2} is 525k.

After designing power stage and the control stage off all three converters, they were simulated in LTSpice to check the viability. Below one will see the 5, 12 and 20 volt converter respectively. Important simulation results to notice are the output ripple voltage and stability of the output, to see if the converter is working properly at max and minimum input voltage.

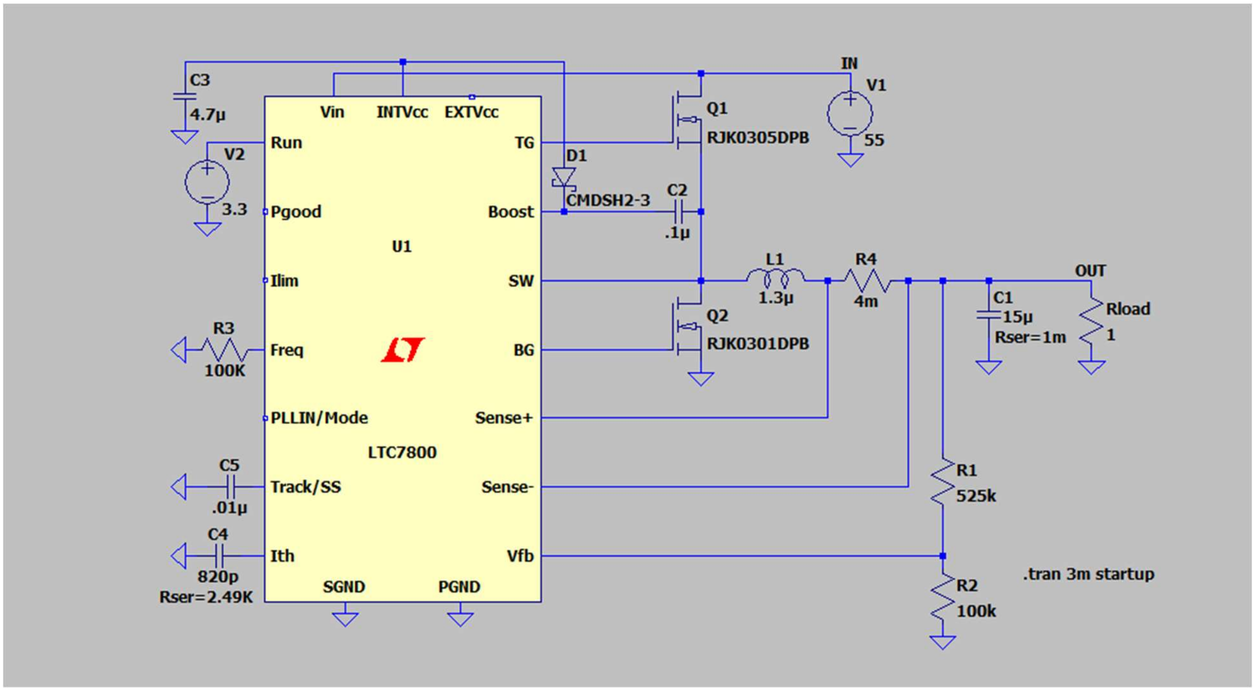


Figure 4.1: Schematic used to simulate the 5V converter

Figure 4.2 shows the 5V converter output ripple. It can be seen that there is minimal ripple. It hovers just around a peak to peak of 10mV. While figure 4.2 shows the stability of the output with very little transients as it reaches 5V.

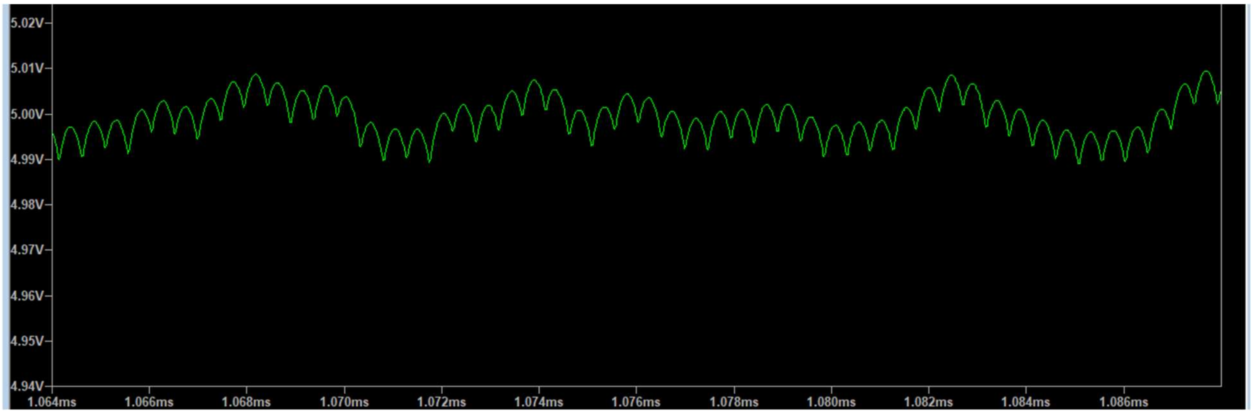


Figure 4.2: 5V converter (Steady State Output Voltage Ripple)

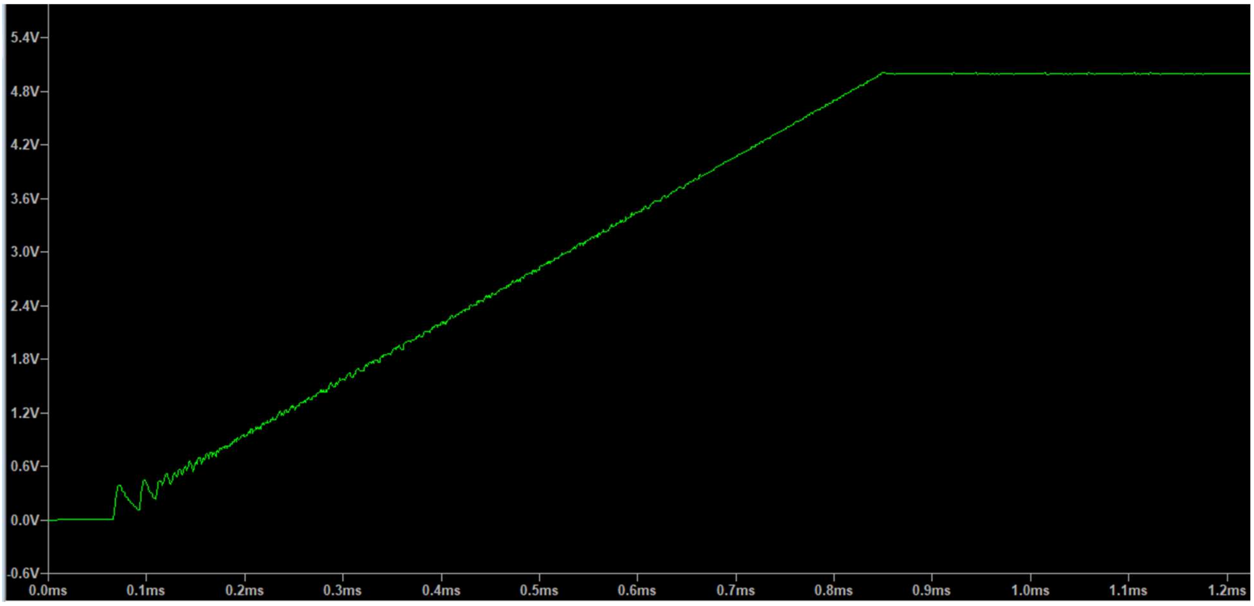


Figure 4.3: 5V Output Simulation

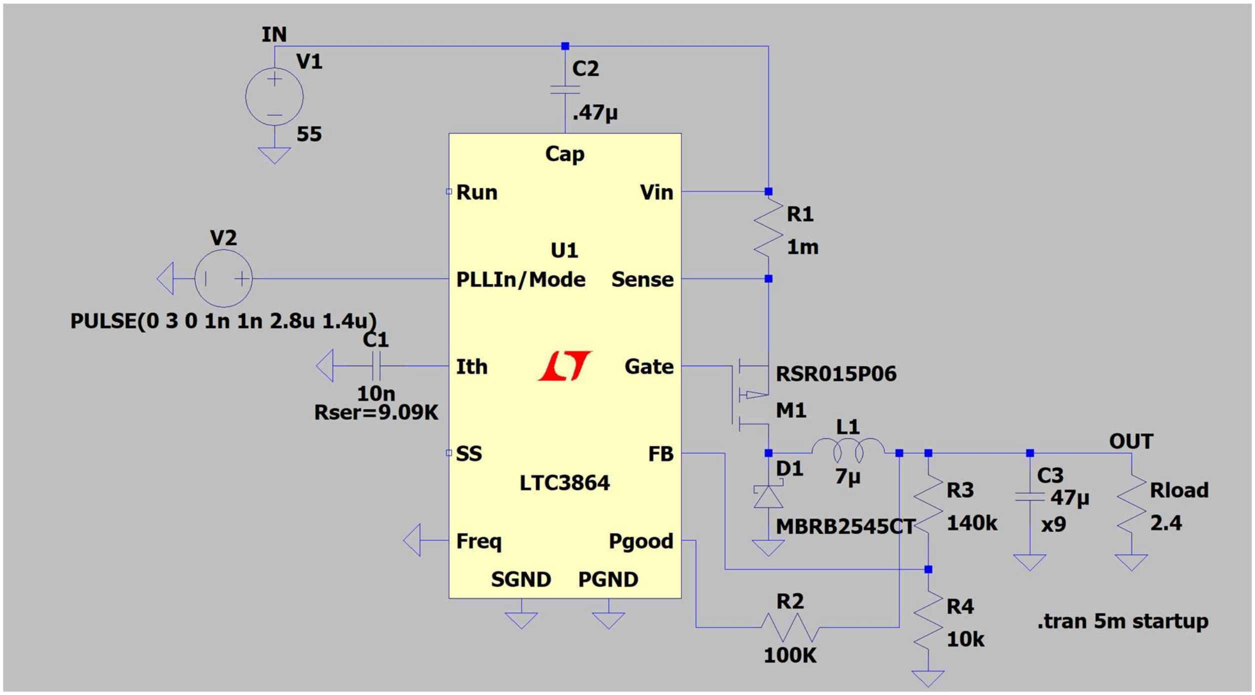


Figure 4.4: Schematic used to simulate 12V converter

Figures 4.5 and 4.6 show the output voltage ripple and steady state of the 12V converter. The output voltage ripple is slightly larger than the 5V with a peak to peak of about 0.2V but this is still a relatively small ripple that still falls within specification. As the voltage reaches 12V it is smooth with very little transients and a stable output.

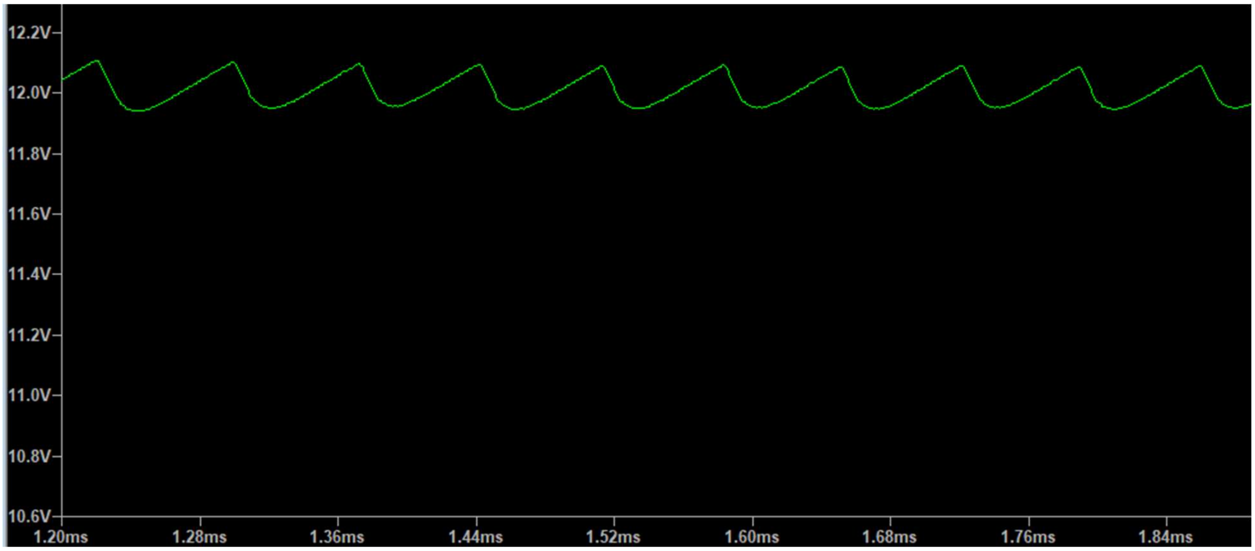


Figure 4.5: 12V converter (Steady State Output Voltage Ripple)

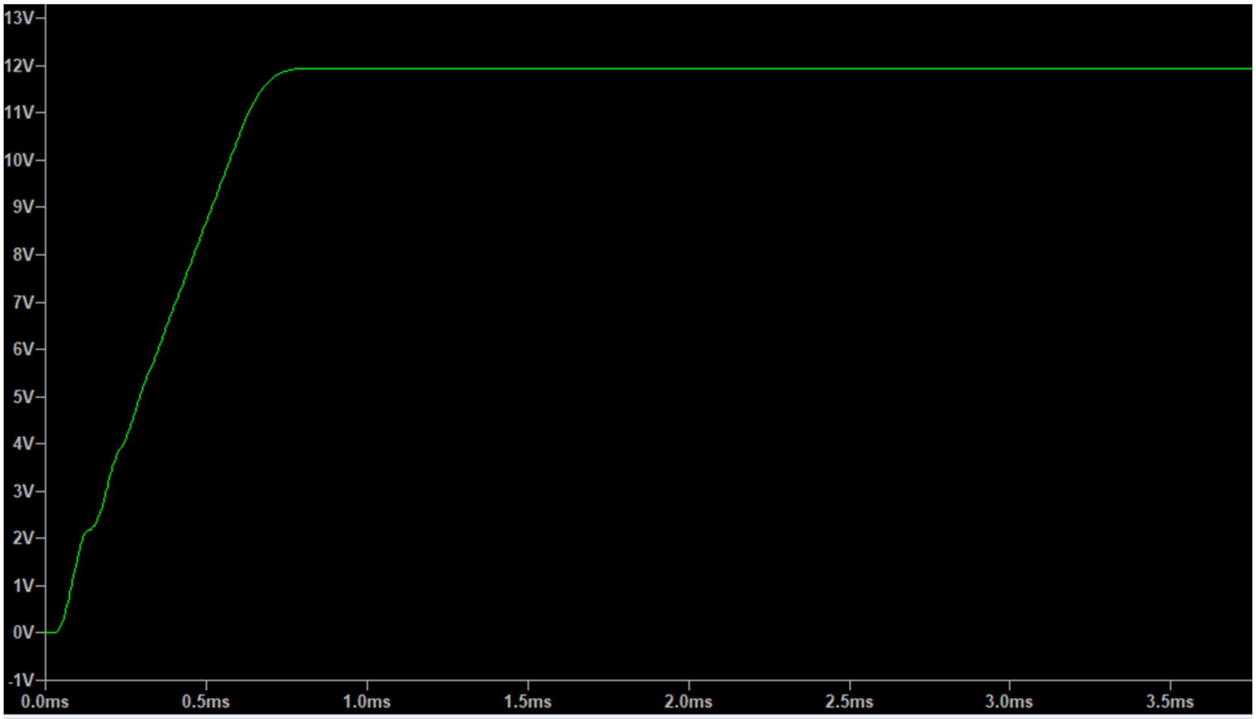


Figure 4.6: 12V Output Simulation

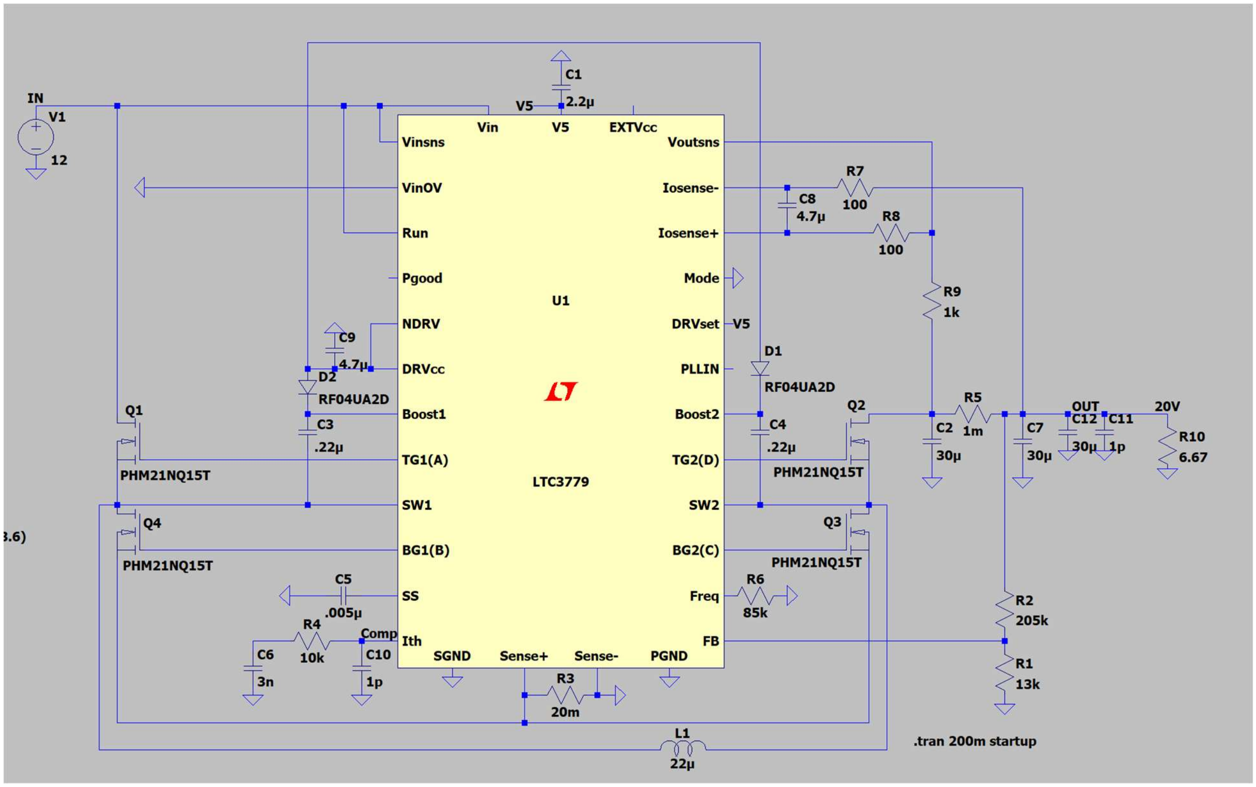


Figure 4.7: Schematic used to simulate 20V converter

Figure 4.8 and 4.9 are the simulation results of the output voltage and ripple as for the 2 previous converters. The output ripple is well within specification at a peak to peak of 50mV and the output has a steady rise with no strange transients.

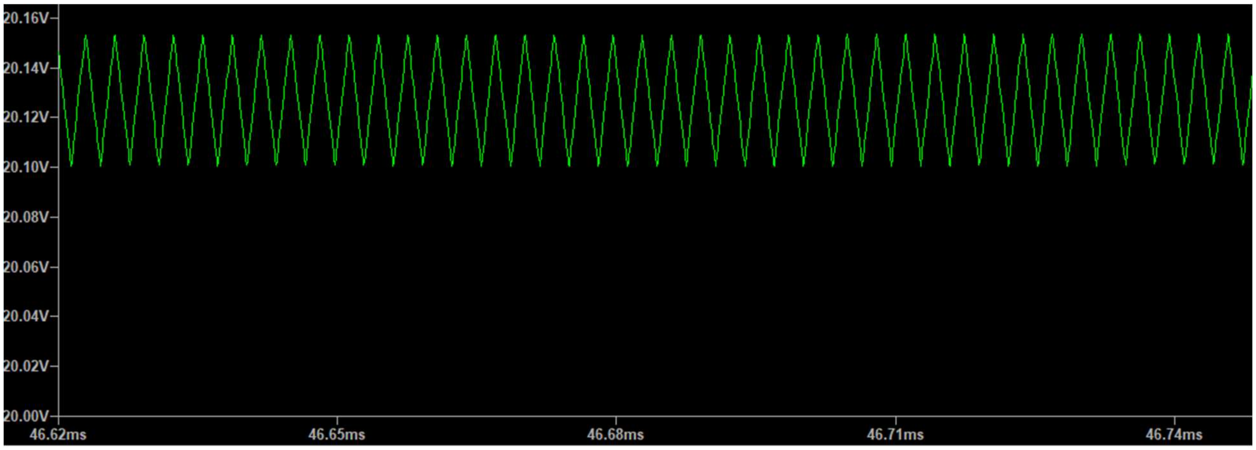


Figure 4.8: 20V Converter (Steady State Output Voltage Ripple)

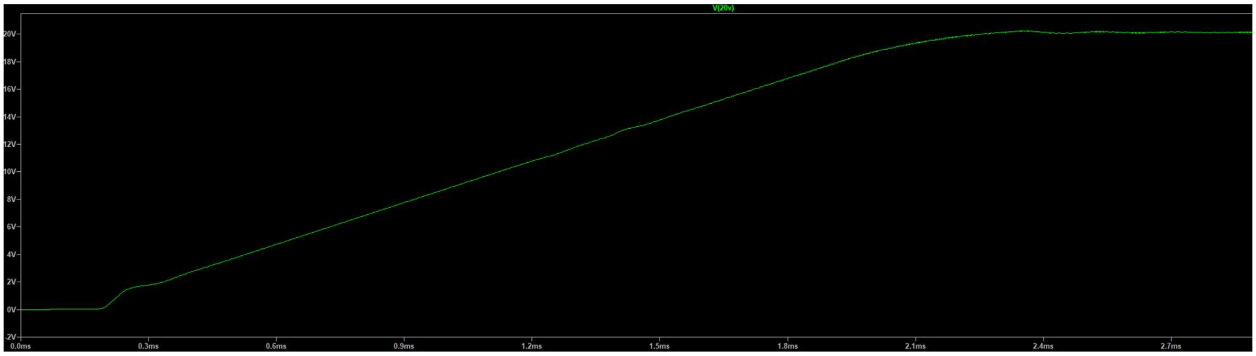


Figure 4.9: 20V Output Simulation

Chapter 5. Hardware Test and Results

Upon receiving and inspecting the PCB, it was discovered that the footprint for the 20V IC did not match the component. This was discovered with the footprints for the 5V and 12V inductors as well. Although the 5V and 12V board foot prints were incorrect in sizing, the inductors as well as using thick wires were utilized in making the circuit work. The 20V board was also missing a via connection along with the input pads so a corrected second iteration was needed.

Each board was hand soldered and tested using the setup in Figure 5.1. The input was connected to a DC power supply and the output connected to an electronic load as well as a multimeter for appropriate measurements. An oscilloscope was used to troubleshoot by analyzing the waveforms at different locations. The testing process for each was started to see if the board would regulate to the correct output voltage with no load connected. If it could do that, then we would start to add load on 0.5 A increments up to the specified full load.

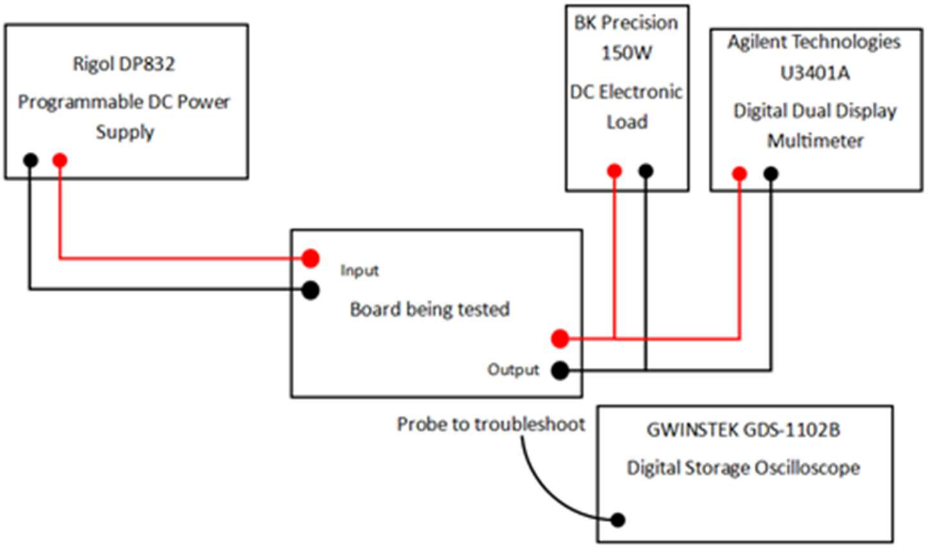


Figure 5.1: Block Diagram of Test Setup

Figure 5.2: 5V Converter Printed Circuit Board

Figure 5.2 shows the 5V converter, with the input being the banana plugs on the left and the output on the right. Small input ceramic capacitors are meant to decrease high frequency switching noise, which have a smaller equivalent series resistance (ESR) compared to the larger capacitors thus significantly reducing the large ESR introduced by the electrolytic capacitors. The MOSFETs regulate the voltage across the inductor, which in turn controls the amount of charging the discharging the inductor will do to step down the input voltage. The component missing from this layout is the sense resistor, which would help regulate the current going into the MOSFET. Output capacitors are present to filter out high frequency noise as well as switching noise in the same fashion as the input capacitors. After the capacitors the current output protection, in the form of a fuse, is present to protect the load. Finally, the converter outputs in the form of USB-C.

Testing and inspection of the 5V revealed that the schematic was faulty. The sense resistor was missed between the inductor and the input. The IC used for the 5V board was very small and when attempting to dead-bug the sense resistor a short occurred on the input. Many attempts were made to fix the issues with the 5V but it came down to a layout issue that would require a new PCB to be manufactured.

The 12V board as shown in Figure 5.3 is similar to the 5V board in terms of layout and ordering. However, instead of a synchronous buck converter with two MOSFETs, this board is asynchronous with a MOSFET and a Schottky diode to facilitate the switching necessary for the buck converter. The input and output capacitors are still present to reduce ringing and noise. The current sense resistor can be seen on this board before the MOSFET and its function is to limit the current flow into the inductor based on light or heavy loads. In all three layouts the power stage and control stages have separate grounds (power ground and signal ground) and are physically apart. This is to help with noise on the signal ground from the power ground as the signal ground path requires.

Figure 5.3: 12V Converter Printed Circuit Board

The initial testing of the 12V board showed it was able to regulate properly up to a 2A load with a 24V input. When a higher input voltage or load current was applied, the load regulation started to fail. We noticed that the input and output are very noisy, due to the lack of high frequency capacitors. Additional ceramic capacitors were added onto both the input and output, yet noise problems still persisted. This was most likely due to a ground loop, as where the signal ground connects to the power ground is right underneath the switching node. This was verified when probing the sense resistor. The 12V board was ultimately able to reach approximately a 4A load with a 48V input with some modifications made to the layout of the PCB to attempt to eliminate noise.

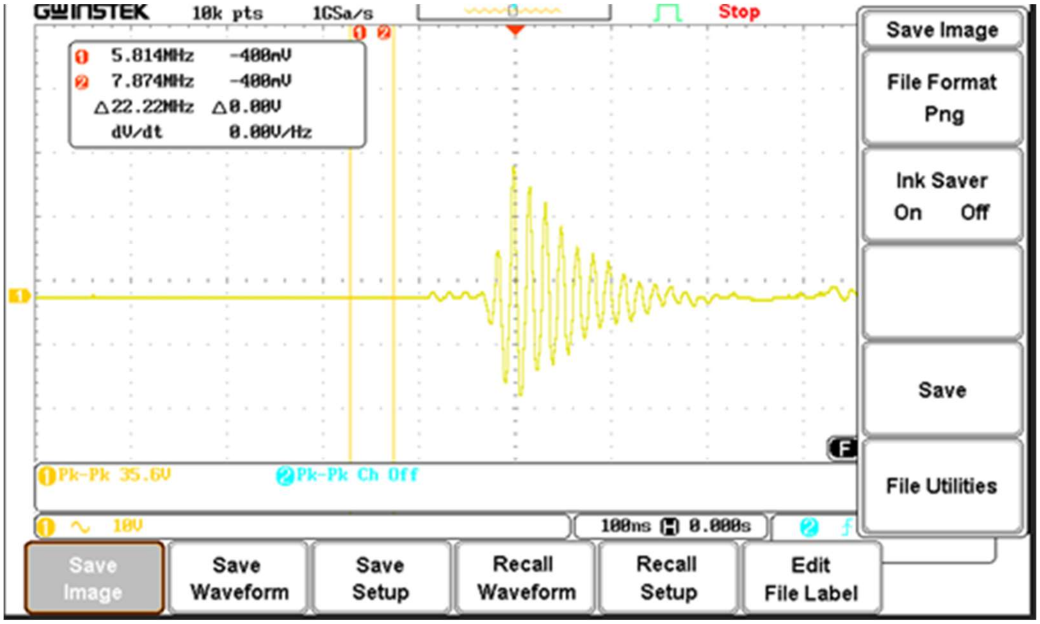


Figure 5.4: Noise on the sense resistor

The noise was a major problem as it began to cause the MOSFET to conduct even when it was not meant to, as depicted in Figure 5.4. This led to thermal issues and prevented the board from running at full load. The MOSFET turning on during times when it was meant to be off means that the switching losses of the MOSFET were essentially doubled. This was verified with an oscilloscope as shown in Figure 5.5 when probing the switch node in conjunction with the MOSFET gate pin.

The switching losses contribute the most to the thermal rise of the MOSFET. When viewing the board at 3A under a thermal camera as seen in Figure 5.6, the MOSFET rises to about 70°C-80°C. As the MOSFET is the hottest component on the board, it is safe to assume that the majority of power loss we have is through it. At a 3A load with an input voltage of 24V, the MOSFET dissipates approximately 4-5 watts of power with 1-2 watts being DC loss through the circuit. This explains the thermal problems as the MOSFET junction to ambient thermal rise is 19°C/W, leading to an expected 80-90°C rise.

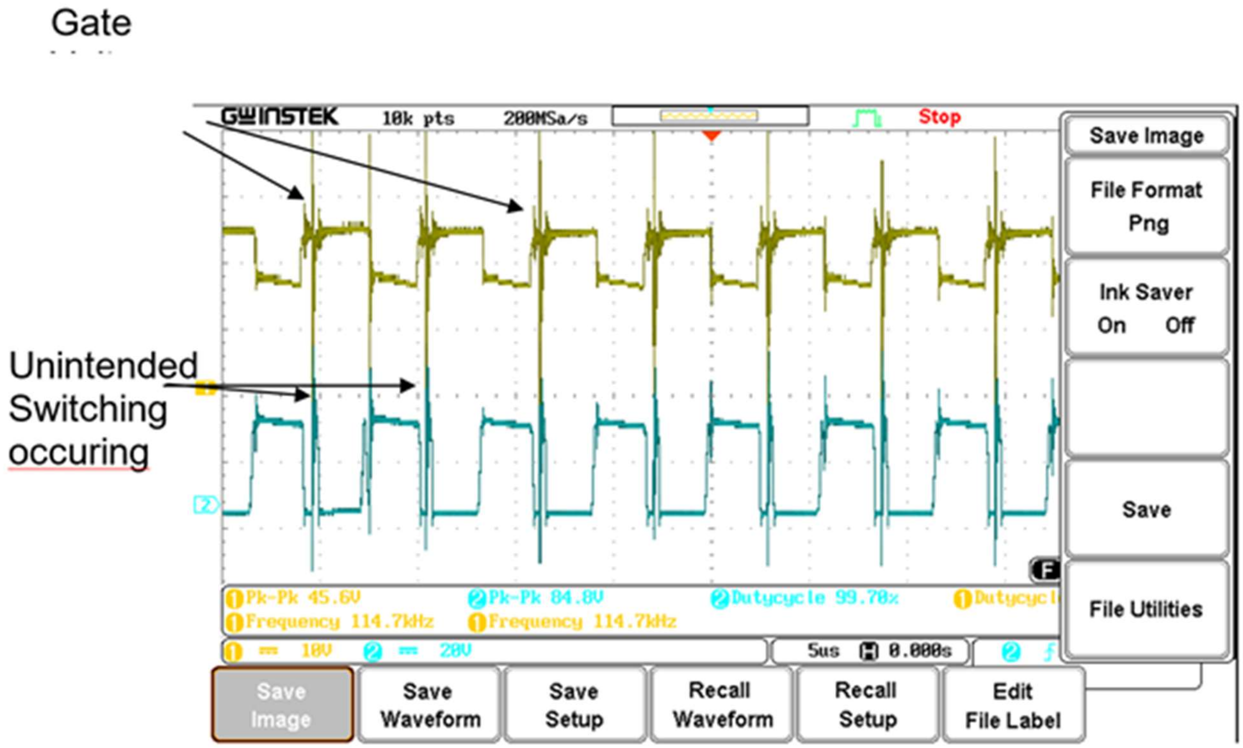


Figure 5.5: The MOSFET Gate (Yellow) and Switching Node (Blue) voltages

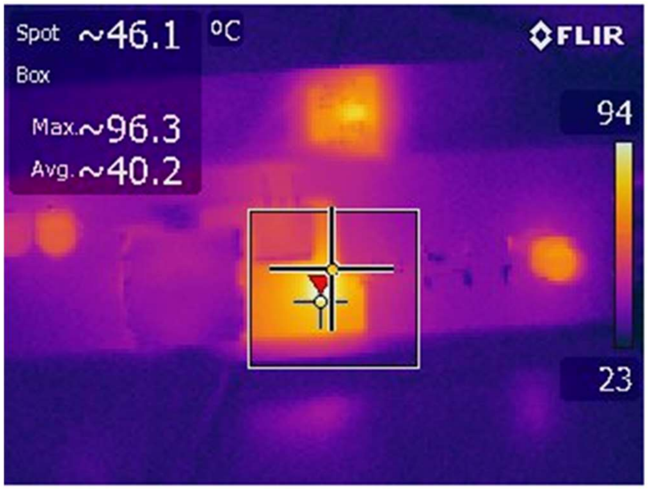


Figure 5.6: 12V converter thermal image of MOSFET

In Figure 5.7 it can be seen that the output of the 12V converter doesn’t quite reach the output voltage peak to peak ripple specification of 2%. The waveform reads 448mV which is about 4% ripple.

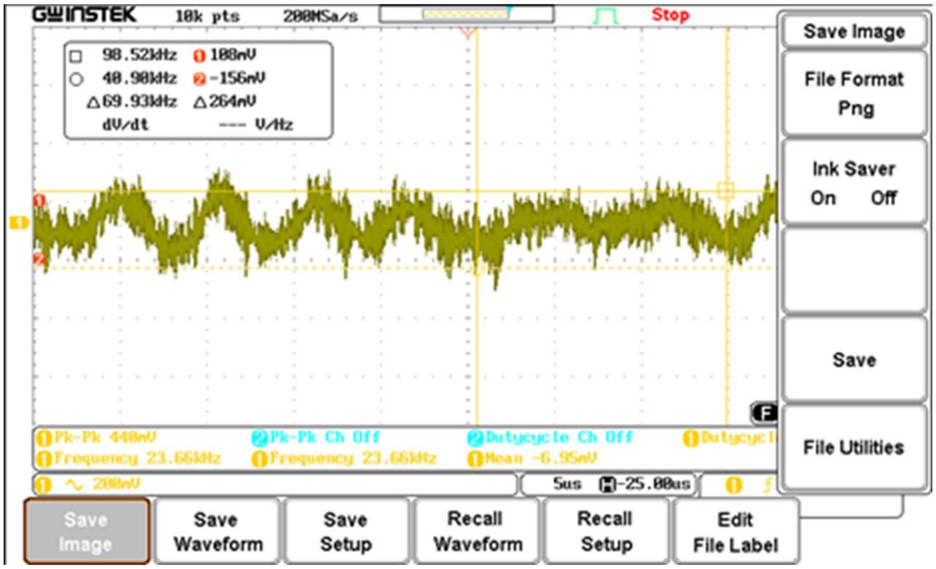


Figure 5.7: Output ripple of the 12V converter

The results listed in Table 5.1 are for the 12V output converter. It can be seen that with a low input voltage we meet the efficiency specification, but as the input gets closer to the nominal input voltage the efficiency drops. When the converter was given a 12V input it was able to reach 3A before discontinuing to regulate a 12V output.

Table 5.1: 12V Output Test Results									
Input Voltage (Volts)	**12**								
Output Current (Amps)	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
Pin (Watts)	0.12	6.23	12.34	18.33	24.44	30.54	38.06		
Pout (Watts)	0	6.03	12.05	18.01	23.86	29.65	36.06		
Overall Efficiency	0.00%	96.68%	97.62%	98.24%	97.63%	97.07%	94.75%		
Input Voltage (Volts)	**24**								
Output Current (Amps)	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**

Pin (Watts)	0.12	7.2	13.92	20.42	27.86	34.83	41.79	49.24	53.56
Pout (Watts)	0	6.02	12.03	18.05	24.03	30.01	35.98	41.65	45.92
Overall Efficiency	0.00%	83.66%	86.44%	88.40%	86.27%	86.16%	86.08%	84.58%	85.74%
Input Voltage (Volts)	**48**								
Output Current (Amps)	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**
Pin (Watts)	0.12	8.16	15.85	23.05	30.25	37.94	45.14	52.32	59.4
Pout (Watts)	0	6.06	12.01	18	23.96	29.94	35.9	41.88	47.84
Overall Efficiency	0.00%	74.23%	75.79%	78.10%	79.20%	78.91%	79.54%	80.05%	80.54%
Line Regulation	-0.50%								
Load Regulation	-1.34%								

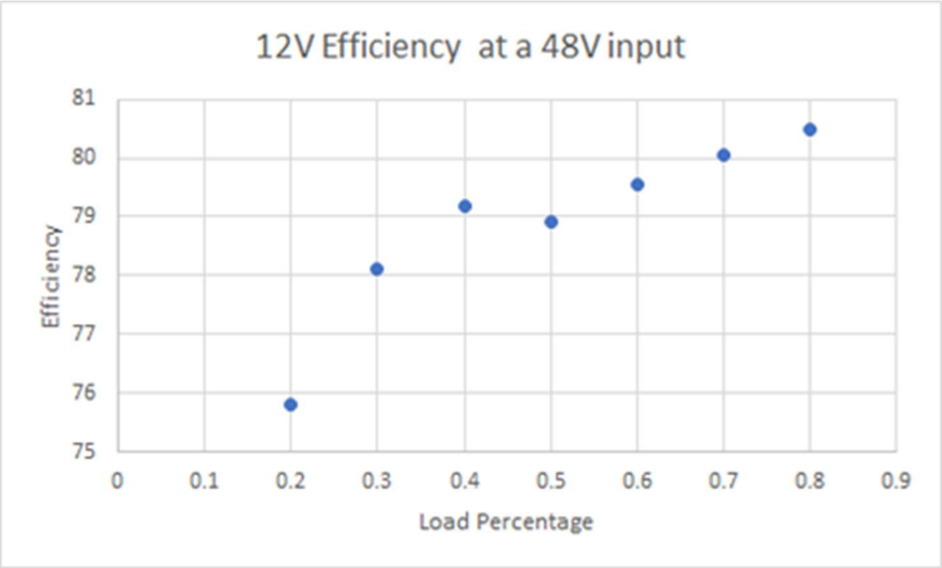


Figure 5.8: Efficiency plot of the 12V board

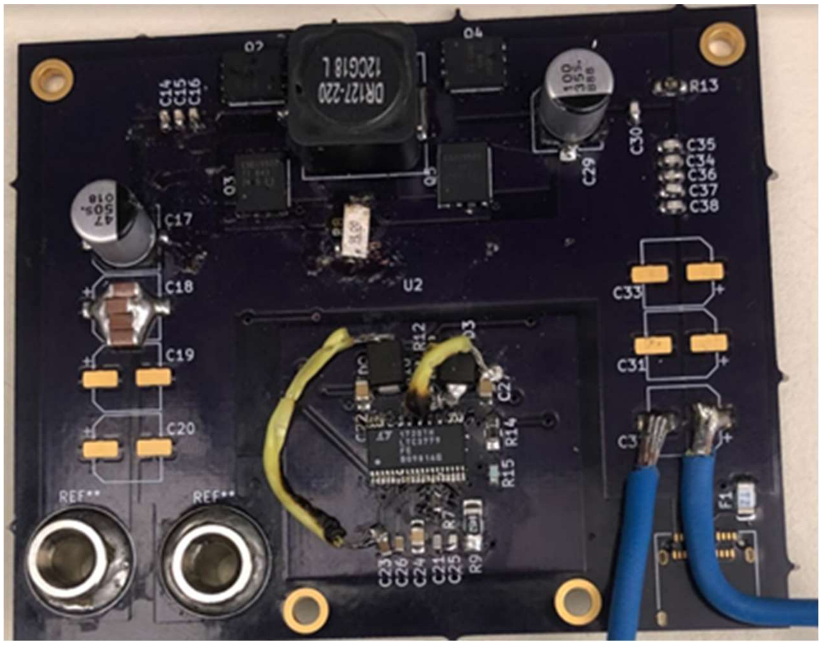


Figure 5.9: 20V Converter Printed Circuit Board

The 20V board is unique compared to the previous two board as the topology is the 4-switch buck boost. This topology allows for any input to be converted to the correct output such that it can be stepped down or up. This is done with a full bridge topology, with four switches are on either side of the inductor. The four switches is what allows for the flexibility of the input. Capacitors are on the input and the output for the same reason as the 5V and 12V board, that is to filter out noise.

Upon receiving and soldering the newly designed 20V board, the output voltage only came up to 3.6V. When checking the voltage of the bootstrap node, it was discovered that the internal regulator was not connected to the diode of the bootstrap node, and a wire was dead-bugged from the internal regulator to the anode of the bootstrap diode, bringing up the output voltage to the expected 20V.

The board regulated with an input of 48V until the output was loaded up to 0.8A. Once it reached .82A, the output voltage would drop out. The switch node was probed while the board ran at .5A with a 48V input to reveal that the ringing was much higher than we would want. This is shown in Figure 5.9. It is seen that the switch node rings from 0V to 80V when the switch turns on, much greater than expected, and as the output load was increased, the ringing voltage grew bigger.

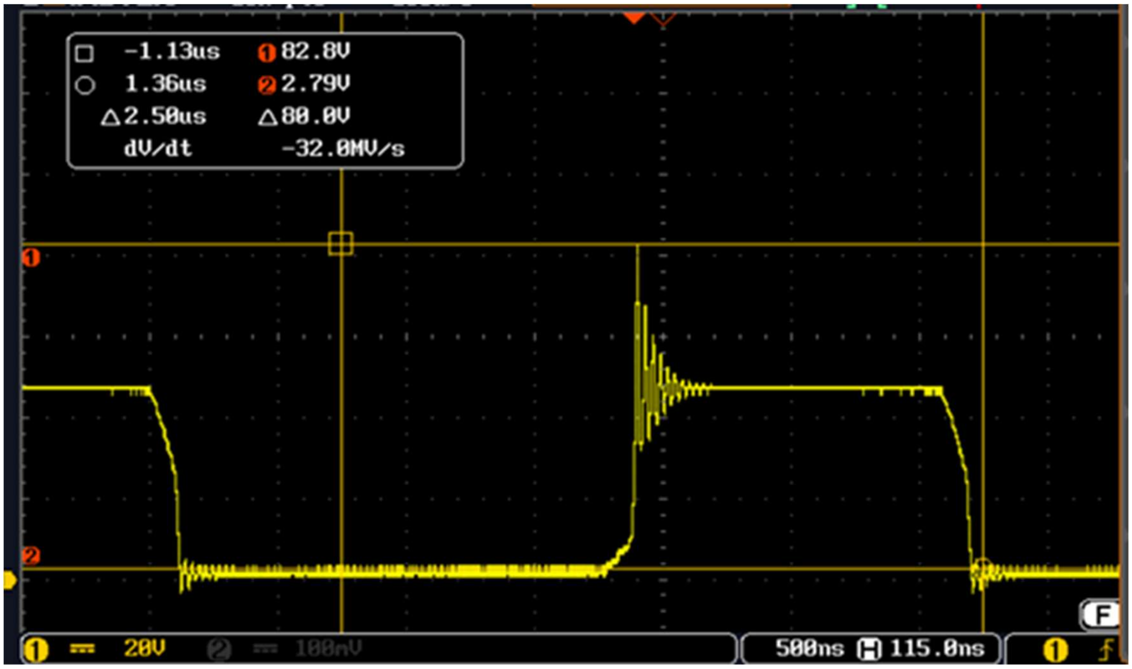


Figure 5.10: Switching node voltage of the 20V Converter

This high ringing is the explanation of why the 20V converter cannot operate higher than .82A load at 48V input. Upon moving to a lower input range, 24V, the converter was able to operate at full load which can be seen with the test results in Table 5.2. The maximum operating input voltage the converter was able to operate with full load was at 36V.

With a lower input voltage of 12V, it was difficult to test. The converter drew more current then the power supply was capable of handling. It is difficult to estimate how well the converter can run at 12V input; however, since the ringing was our major issue preventing the converter from running, we conclude it would successfully regulate.

The high ringing prevents the operation of the board for many reasons. First, it stresses the MOSFETs as the ringing is pushing close to the operating range of the MOSFETs. Second, the ringing radiates noise onto more sensitive components such as the two sense resistors controlling the current operation of the board. The initial solution to this was to lower the value of the sense resistors to decrease the sensitivity to the noise on the board, as well as placing a snubber circuit on the switching node. The lowered value of the sense resistor could not be lowered enough to prevent the full input voltage from causing the board to shut down past a certain current threshold. An RC snubber was implemented; however, due to time and resource constraints, the circuit could not be made well enough to make a significant difference.

The ripple voltage was measured at 36V input and full load; as close to nominal input as possible while still being able to operate the board at full capacity. This was done with a scope probe, with as short as possible of a ground loop on the output of the board. This is shown in Figure 5.10. The ripple voltage meets the specification of 2% at full load.

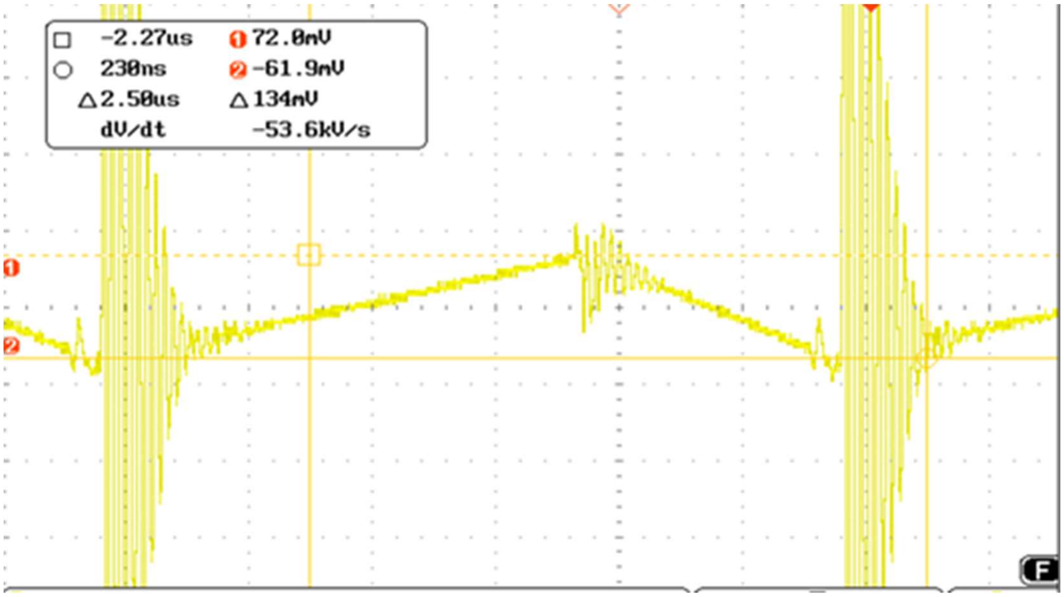


Figure 5.11: Output Ripple Voltage of the 20V board, 36Vin, 3A out

Table 5.2: 20V Output Test Results

Input Voltage (Volts)	**12**						
Output Current (Amps)	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**
Pin (Watts)	1.32	11.64	22.32	33.6			
Pout (Watts)	0	10.05	20.09	30.12			
Overall Efficiency	0.00%	86.34%	90.01%	89.65%			
Input Voltage (Volts)	**24**						
Output Current (Amps)	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**
Pin (Watts)	2.88	12.72	23.76	34.08	44.64	55.2	66
Pout (Watts)	0	10.07	20.14	30.2	40.26	50.31	60.37
Overall Efficiency	0.00%	79.15%	84.77%	88.62%	90.19%	91.14%	91.47%
Input Voltage (Volts)	**48**						
Output Current (Amps)	**0**	**0.5**	**0.6**	**0.7**	**0.8**		
Pin (Watts)	3.36	14.41	16.32	18.72	20.6		
Pout (Watts)	0	10.04	12.02	13.96	15.9		

Overall Efficiency	0.00%	69.69%	73.64%	74.57%	77.17%		
Line Regulation	-1.06%						
Load Regulation	-1.06%						

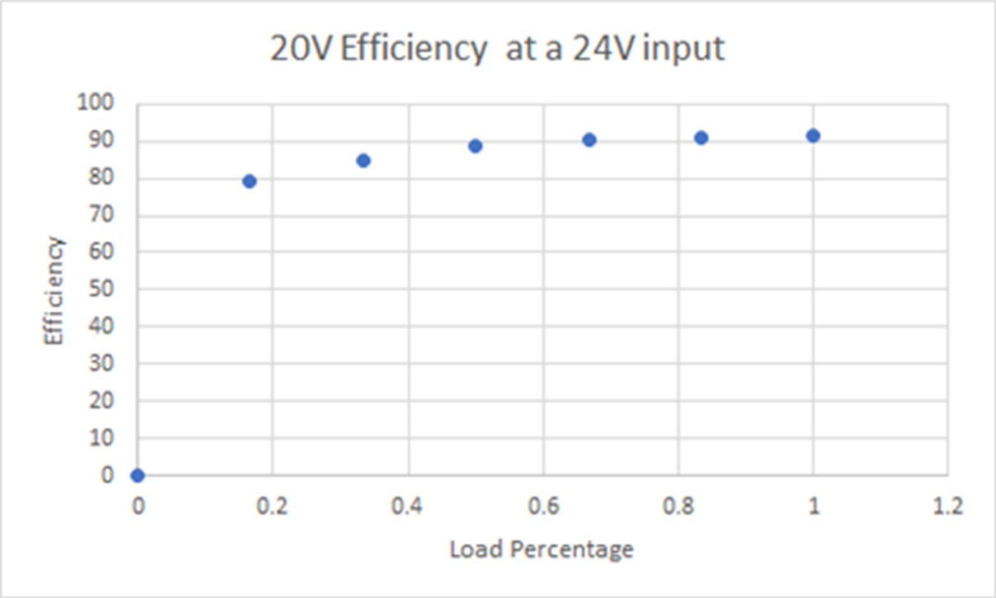


Figure 5.12: Efficiency plot of 20V board

Chapter 6. Conclusion

This goal of this project was to create a charger with three output voltages with varying input voltages. The project met several specifications but required improvements to achieve others. Three designs were made utilizing different topologies that eventually were made into Printed Circuit Boards. The major issues encountered with the project were mostly related to the board layout. We attempted to make some necessary changes that would improve the three converters. However, it became clear that with more time and iterations of the design, meeting all the specifications for this project is completely feasible.

Along with meeting the electrical specifications, the size of the converter was very large. Ultimately, designing all three converters on one board and having components closer together would make it smaller and more portable. Having it be smaller and more portable would make it a more realistic charger for a house beyond the prototype on Cal Poly's campus.

The recommendation in improving the 5V board comes from primarily a better layout as well as a better schematic. Due to a forgotten component, a sense resistor, the 5V board was unable to work properly as that component was vital to the control loop of the controller chip. Secondly, the chip that was chosen was difficult to hand solder without using an automated placer as it was a QFN component. These two problems in conjunction with one another prevented the 5V board from working to its full potential.

Recommendations for the 12V and 20V board are similar, where layout and poor MOSFET choice contributed to problems that were not inherent when simulating both boards. Improving layout means moving to 4 layers and having a dedicated signal layer with less parasitics and closer routing of signal traces in order for less parasitics on the signals. Secondly, the MOSFETs chosen had a relatively high gate capacitance, which meant that more power than usual was dissipated. This led to the MOSFETs getting very hot at 80-90°C for both boards, which could be solved with a lower gate capacitance or using a MOSFET compatible with a heat sink.

Overall, this project was a valuable experience on understanding the importance of layout and prototyping. The knowledge gained through testing and troubleshooting led to realizations that can be put to use the next time we encounter a project like this. This experience can only lend itself to improve ourselves and the process was valuable and a learning opportunity.

Looking forward, this project can be taken beyond where it is with making the charger have a varying output that is controlled with a microcontroller instead of needing three different designs, increase the input range, and decrease the size of the overall charger to make it more portable.

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Appendix D:

Analysis of Senior Project

Project Title: DC-DC USB-C Charger
Students: Nikki Gmerek, Kenneth Nguyen, Uriel Serna
Advisor: Dr. Taufik

Summary of Functional Requirements

The DC-DC charger needs to be able to take a 48V DC input and convert to 5V, 12V, and 24V DC outputs. On top of those initial requirements there will also be a input range of 12V-48V DC. There are multiple specifications mentioned earlier in the report including synchronous and asynchronous buck topologies and a 4 switch buck-boost topology. All DC-DC topologies and has a USB-C output.

Primary Constraints

The constraint that will be hardest to meet will be the size of the charger. The aim for this charger is it will be small and portable. Since there are three switching converters all within close vicinity, the ambient temperature of the board could be quite high. Heat sinks and ventilation will need to be included in the design making it hard to keep the product small and compact. Overall, with the improvements suggested for the layout to be able to reach electronic specifications it will pose challenging to get the controller more compact and a portable size.

Economic

Human Capital:

Development and manufacturing of this project will create jobs in engineering, manufacturing, marketing, and sales industries. This product will also create power options for those in rural areas and give them more first world luxuries and hopefully the opportunity to go work and make money with less daily needs at home. This product also can help move the solar panel industry as this product gives customers a way to charge their devices easily.

Financial Capital:

The financial capital gained from this product is the revenue made from selling this product. Disrupting the current market both globally and locally in the United States will create a market for our product. This will generate more investors and capital.

Natural Capital:

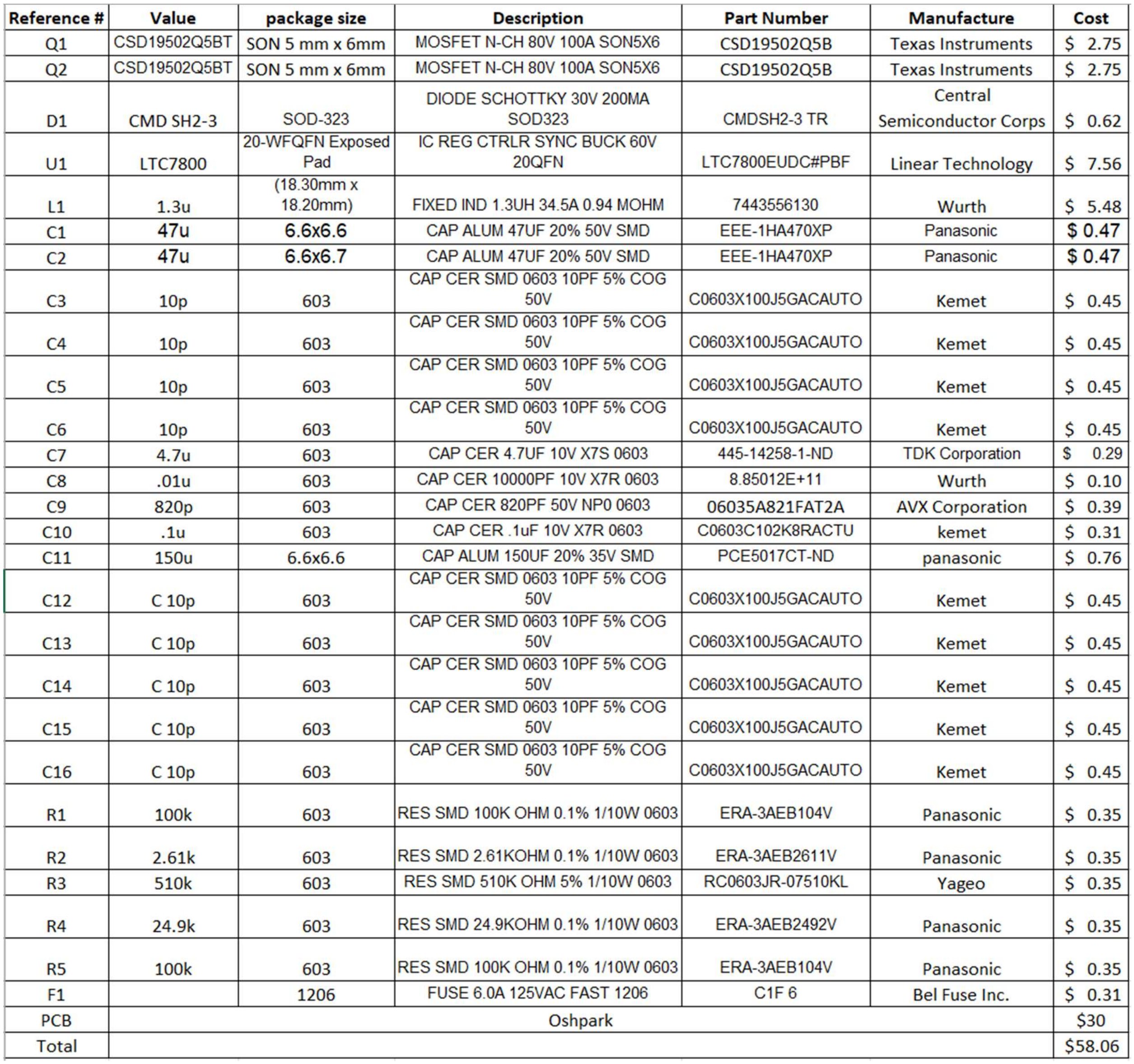
The product does use electronics and mechanical components that may be harmful to manufacture and dispose of. The other side to take into consideration is that this will be offset by it allowing the direct use of renewable energy sources to charge a given device.

Costs and Timing:

The products initial design is set to be done by June 2019 for senior project expo and then after the initial reaction changes can be made before release the following year. The charger will cost around $40 when made in large quantities.

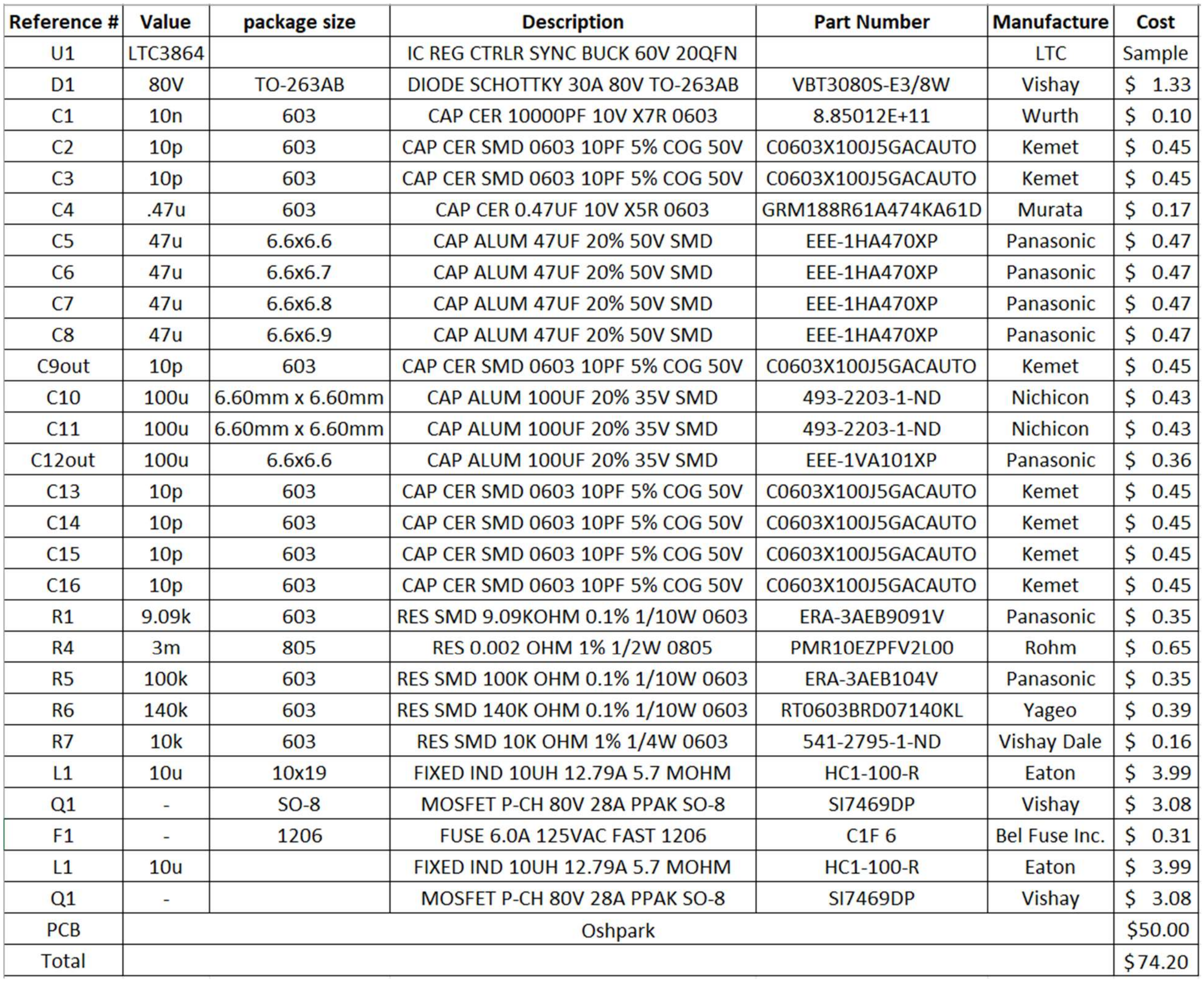
Cost Breakdown

Table #7.1: Cost Breakdown of 5V Converter



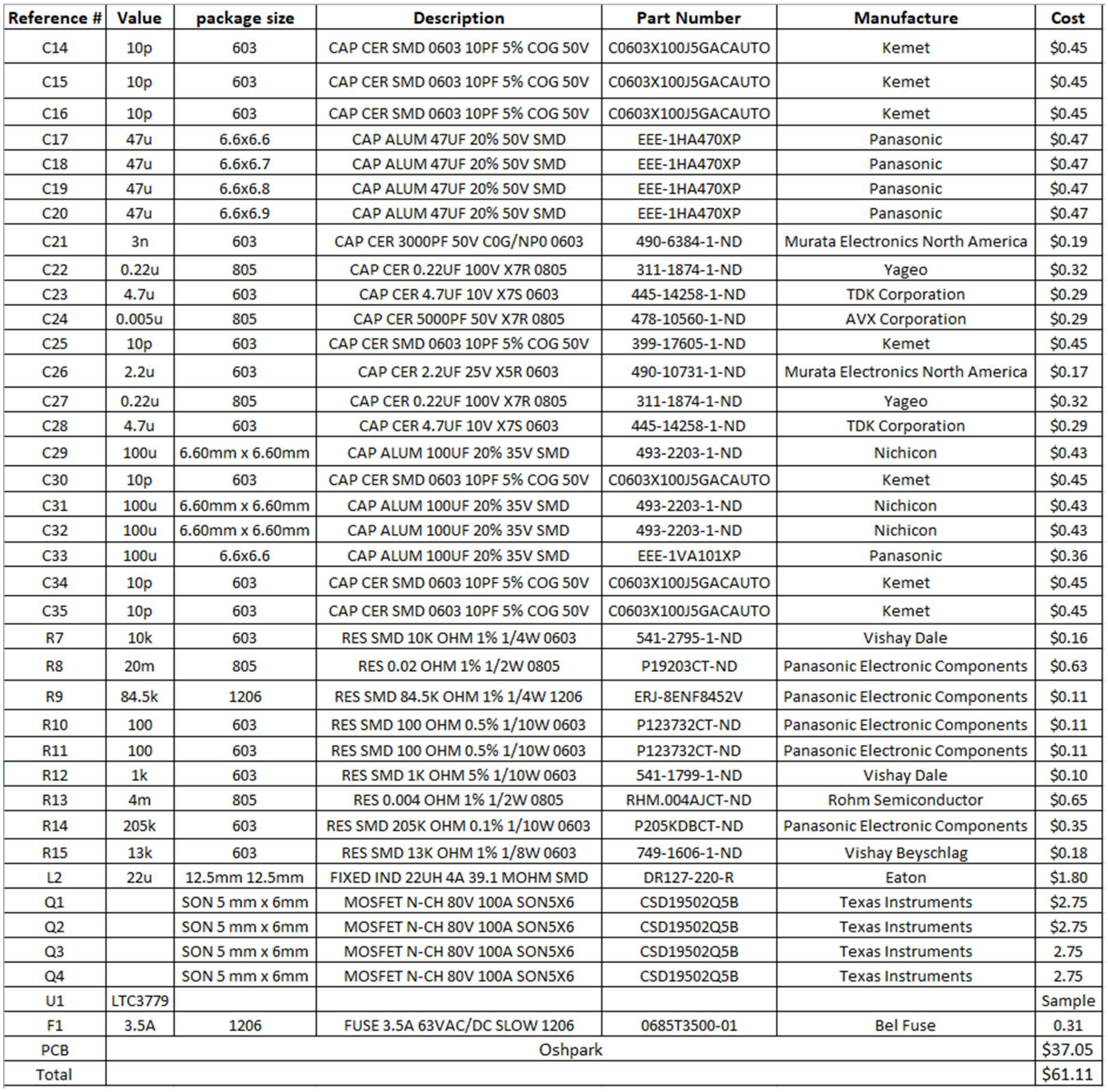
Reference #	Value	package size	Description	Part Number	Manufacture	Cost
Q1	CSD19502Q5BT	SON 5 mm x 6mm	MOSFET N-CH 80V 100A SON5X6	CSD19502Q5B	Texas Instruments	$ 2.75
Q2	CSD19502Q5BT	SON 5 mm x 6mm	MOSFET N-CH 80V 100A SON5X6	CSD19502Q5B	Texas Instruments	$ 2.75
D1	CMD SH2-3	SOD-323	DIODE SCHOTTKY 30V 200MA SOD323	CMDSH2-3 TR	Central Semiconductor Corps	$ 0.62
U1	LTC7800	20-WFQFN Exposed Pad	IC REG CTRLR SYNC BUCK 60V 20QFN	LTC7800EUDC#PBF	Linear Technology	$ 7.56
L1	1.3u	(18.30mm x 18.20mm)	FIXED IND 1.3UH 34.5A 0.94 MOHM	7443556130	Wurth	$ 5.48
C1	47u	6.6x6.6	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$ 0.47
C2	47u	6.6x6.7	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$ 0.47
C3	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C4	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C5	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C6	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C7	4.7u	603	CAP CER 4.7UF 10V X7S 0603	445-14258-1-ND	TDK Corporation	$ 0.29
C8	.01u	603	CAP CER 10000PF 10V X7R 0603	8.85012E+11	Wurth	$ 0.10
C9	820p	603	CAP CER 820PF 50V NP0 0603	06035A821FAT2A	AVX Corporation	$ 0.39
C10	.1u	603	CAP CER .1uF 10V X7R 0603	C0603C102K8RACTU	kemet	$ 0.31
C11	150u	6.6x6.6	CAP ALUM 150UF 20% 35V SMD	PCE5017CT-ND	panasonic	$ 0.76
C12	C 10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C13	C 10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C14	C 10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C15	C 10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C16	C 10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
R1	100k	603	RES SMD 100K OHM 0.1% 1/10W 0603	ERA-3AEB104V	Panasonic	$ 0.35
R2	2.61k	603	RES SMD 2.61KOHM 0.1% 1/10W 0603	ERA-3AEB2611V	Panasonic	$ 0.35
R3	510k	603	RES SMD 510K OHM 5% 1/10W 0603	RC0603JR-07510KL	Yageo	$ 0.35
R4	24.9k	603	RES SMD 24.9KOHM 0.1% 1/10W 0603	ERA-3AEB2492V	Panasonic	$ 0.35
R5	100k	603	RES SMD 100K OHM 0.1% 1/10W 0603	ERA-3AEB104V	Panasonic	$ 0.35
F1		1206	FUSE 6.0A 125VAC FAST 1206	C1F 6	Bel Fuse Inc.	$ 0.31
PCB	Oshpark					$30
Total						$58.06

Table 7.2: Cost Breakdown of 12V Converter



Reference #	Value	package size	Description	Part Number	Manufacture	Cost
U1	LTC3864		IC REG CTRLR SYNC BUCK 60V 20QFN		LTC	Sample
D1	80V	TO-263AB	DIODE SCHOTTKY 30A 80V TO-263AB	VBT3080S-E3/8W	Vishay	$ 1.33
C1	10n	603	CAP CER 10000PF 10V X7R 0603	8.85012E+11	Wurth	$ 0.10
C2	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C3	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C4	.47u	603	CAP CER 0.47UF 10V X5R 0603	GRM188R61A474KA61D	Murata	$ 0.17
C5	47u	6.6x6.6	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$ 0.47
C6	47u	6.6x6.7	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$ 0.47
C7	47u	6.6x6.8	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$ 0.47
C8	47u	6.6x6.9	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$ 0.47
C9out	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C10	100u	6.60mm x 6.60mm	CAP ALUM 100UF 20% 35V SMD	493-2203-1-ND	Nichicon	$ 0.43
C11	100u	6.60mm x 6.60mm	CAP ALUM 100UF 20% 35V SMD	493-2203-1-ND	Nichicon	$ 0.43
C12out	100u	6.6x6.6	CAP ALUM 100UF 20% 35V SMD	EEE-1VA101XP	Panasonic	$ 0.36
C13	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C14	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C15	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
C16	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$ 0.45
R1	9.09k	603	RES SMD 9.09KOHM 0.1% 1/10W 0603	ERA-3AEB9091V	Panasonic	$ 0.35
R4	3m	805	RES 0.002 OHM 1% 1/2W 0805	PMR10EZPFV2L00	Rohm	$ 0.65
R5	100k	603	RES SMD 100K OHM 0.1% 1/10W 0603	ERA-3AEB104V	Panasonic	$ 0.35
R6	140k	603	RES SMD 140K OHM 0.1% 1/10W 0603	RT0603BRD07140KL	Yageo	$ 0.39
R7	10k	603	RES SMD 10K OHM 1% 1/4W 0603	541-2795-1-ND	Vishay Dale	$ 0.16
L1	10u	10x19	FIXED IND 10UH 12.79A 5.7 MOHM	HC1-100-R	Eaton	$ 3.99
Q1	-	SO-8	MOSFET P-CH 80V 28A PPAK SO-8	SI7469DP	Vishay	$ 3.08
F1	-	1206	FUSE 6.0A 125VAC FAST 1206	C1F 6	Bel Fuse Inc.	$ 0.31
L1	10u		FIXED IND 10UH 12.79A 5.7 MOHM	HC1-100-R	Eaton	$ 3.99
Q1	-		MOSFET P-CH 80V 28A PPAK SO-8	SI7469DP	Vishay	$ 3.08
PCB	Oshpark					$50.00
Total						$74.20

Table 7.3: Cost Breakdown of 20V Converter



Reference #	Value	package size	Description	Part Number	Manufacture	Cost
C14	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$0.45
C15	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$0.45
C16	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$0.45
C17	47u	6.6x6.6	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$0.47
C18	47u	6.6x6.7	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$0.47
C19	47u	6.6x6.8	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$0.47
C20	47u	6.6x6.9	CAP ALUM 47UF 20% 50V SMD	EEE-1HA470XP	Panasonic	$0.47
C21	3n	603	CAP CER 3000PF 50V C0G/NP0 0603	490-6384-1-ND	Murata Electronics North America	$0.19
C22	0.22u	805	CAP CER 0.22UF 100V X7R 0805	311-1874-1-ND	Yageo	$0.32
C23	4.7u	603	CAP CER 4.7UF 10V X7S 0603	445-14258-1-ND	TDK Corporation	$0.29
C24	0.005u	805	CAP CER 5000PF 50V X7R 0805	478-10560-1-ND	AVX Corporation	$0.29
C25	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	399-17605-1-ND	Kemet	$0.45
C26	2.2u	603	CAP CER 2.2UF 25V X5R 0603	490-10731-1-ND	Murata Electronics North America	$0.17
C27	0.22u	805	CAP CER 0.22UF 100V X7R 0805	311-1874-1-ND	Yageo	$0.32
C28	4.7u	603	CAP CER 4.7UF 10V X7S 0603	445-14258-1-ND	TDK Corporation	$0.29
C29	100u	6.60mm x 6.60mm	CAP ALUM 100UF 20% 35V SMD	493-2203-1-ND	Nichicon	$0.43
C30	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$0.45
C31	100u	6.60mm x 6.60mm	CAP ALUM 100UF 20% 35V SMD	493-2203-1-ND	Nichicon	$0.43
C32	100u	6.60mm x 6.60mm	CAP ALUM 100UF 20% 35V SMD	493-2203-1-ND	Nichicon	$0.43
C33	100u	6.6x6.6	CAP ALUM 100UF 20% 35V SMD	EEE-1VA101XP	Panasonic	$0.36
C34	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$0.45
C35	10p	603	CAP CER SMD 0603 10PF 5% COG 50V	C0603X100J5GACAUTO	Kemet	$0.45
R7	10k	603	RES SMD 10K OHM 1% 1/4W 0603	541-2795-1-ND	Vishay Dale	$0.16
R8	20m	805	RES 0.02 OHM 1% 1/2W 0805	P19203CT-ND	Panasonic Electronic Components	$0.63
R9	84.5k	1206	RES SMD 84.5K OHM 1% 1/4W 1206	ERJ-8ENF8452V	Panasonic Electronic Components	$0.11
R10	100	603	RES SMD 100 OHM 0.5% 1/10W 0603	P123732CT-ND	Panasonic Electronic Components	$0.11
R11	100	603	RES SMD 100 OHM 0.5% 1/10W 0603	P123732CT-ND	Panasonic Electronic Components	$0.11
R12	1k	603	RES SMD 1K OHM 5% 1/10W 0603	541-1799-1-ND	Vishay Dale	$0.10
R13	4m	805	RES 0.004 OHM 1% 1/2W 0805	RHM.004AJCT-ND	Rohm Semiconductor	$0.65
R14	205k	603	RES SMD 205K OHM 0.1% 1/10W 0603	P205KDBCT-ND	Panasonic Electronic Components	$0.35
R15	13k	603	RES SMD 13K OHM 1% 1/8W 0603	749-1606-1-ND	Vishay Beyschlag	$0.18
L2	22u	12.5mm 12.5mm	FIXED IND 22UH 4A 39.1 MOHM SMD	DR127-220-R	Eaton	$1.80
Q1		SON 5 mm x 6mm	MOSFET N-CH 80V 100A SON5X6	CSD19502Q5B	Texas Instruments	$2.75
Q2		SON 5 mm x 6mm	MOSFET N-CH 80V 100A SON5X6	CSD19502Q5B	Texas Instruments	$2.75
Q3		SON 5 mm x 6mm	MOSFET N-CH 80V 100A SON5X6	CSD19502Q5B	Texas Instruments	2.75
Q4		SON 5 mm x 6mm	MOSFET N-CH 80V 100A SON5X6	CSD19502Q5B	Texas Instruments	2.75
U1	LTC3779					Sample
F1	3.5A	1206	FUSE 3.5A 63VAC/DC SLOW 1206	0685T3500-01	Bel Fuse	0.31
PCB	Oshpark					$37.05
Total						$61.11

Items listed in tables 7.1-7.3 are the bill of materials for this project. The PCB fabrication was the single more expensive thing however the components added up quickly. The total spent was about $60 per board.

If the product were to be manufactured in large quantities, the costs are expected to lower as components would be able to be bought in bulk. By this time, design would be finalized and the board design would be smaller minimizing the cost. Testing would be done to assure product quality. This would cut cost labor cost significantly.

If manufactured on a commercial basis:

If this product was manufactured on a commercial basis, tens of thousands of this device could be expected to be sold. The estimated cost of manufacturing would be expected to be a fraction of the purchase price, which would be expected to be in the 30 to 40 dollar range. Our profit would be assumed to be a bit low in the beginning years, yet overall the expected profit per year would be expected to be in the hundreds of thousands of dollars per year.

Timeline

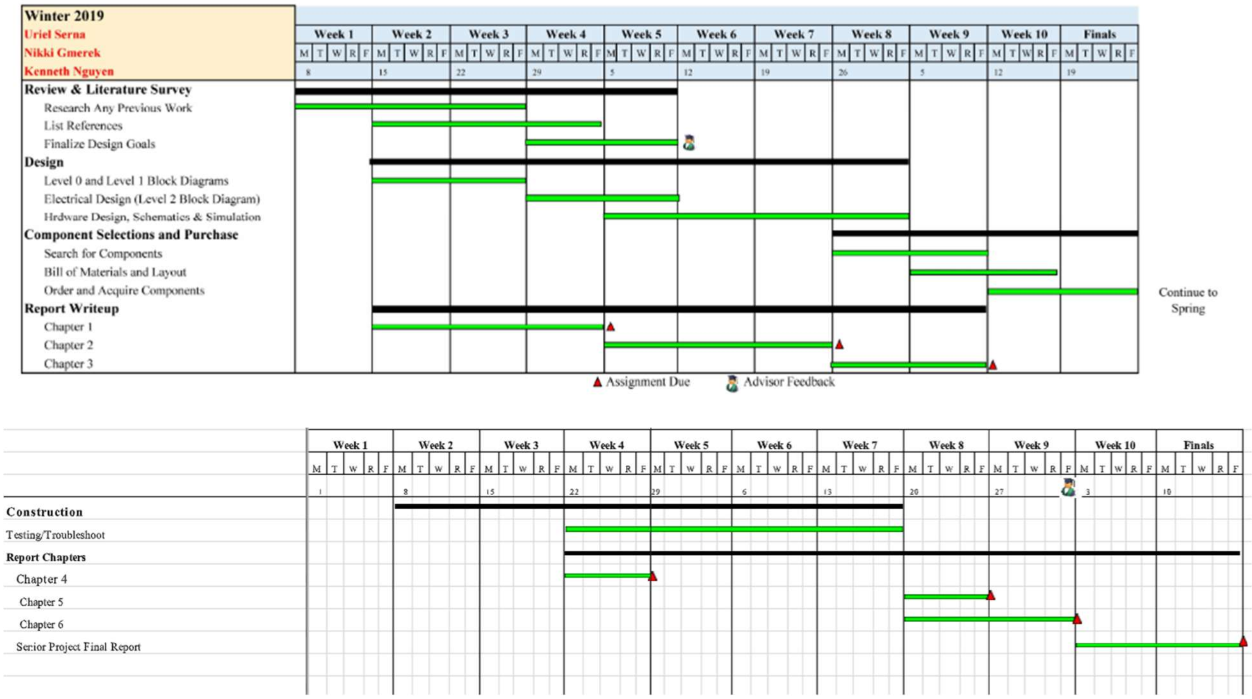


Figure 7.1: Gantt Charts for Winter and Spring Quarter

For how our group will keep track of the certain tasks that we need to complete for our senior project, a Gantt chart with appropriate deadlines and milestones was created and can be seen in figure 7.1. The milestones themselves serve as major tasks that need to be completed before moving into any other task that follows on the schedule.

Environmental

The environmental issues to keep in mind when designing and working with this product is in the manufacturing and disposing of the charger. Making sure to use manufacturers focused on sustainability and good work practices will help with the manufacturing impact and then making it easy to recycle properly the charger when it is broken will help when the customer goes to dispose of it. Both can be provided by this company. Research into the manufactures and not necessarily always taking the cheaper option. Then for recycling, the company can provide drop boxes or locations that the customer can dispose of the charger and then the company can send it to the correct electronic recycling plants.

Manufacturing

The manufacturing of the charger will be challenging given the size and specifications. There will be small surface mount components as well as making sure that there is enough airflow the product won't overheat in a small enclosure.

Sustainability

Describe any issues or challenges associated with maintaining the completed device or system.

The issues foreseen in maintaining this charger is on the durability side. The enclosure needs to be sturdy enough to keep the components inside safe and secure. The charger needs to be watertight. The there needs to be protections on the both the input and output ports so they can handle multiple uses of being plugged in and unplugged. The other part of maintaining this project that is easier to control is the actual electronics itself. There needs to be enough ventilation, so the electronics don't overheat. All the ratings of the components need to be followed with extra room for inrush of currents or other unforeseen variables like that.

Describe how the project impacts the sustainable use of resources.

The components themselves are often harmful to the environment. The mining of the metals and minerals used in electronics hurts the environment by polluting water and destroying landscapes and habitats [18]. The manufacturing of the sources of DC inputs for the charger have the same concerns however the actual use of this product will not have any direct environmental impacts. The disposal however is another area of concern and an impact on the natural resources. Many of the components in the charger cannot be thrown into a landfill safely. Electronics need to be disposed of properly preferably in electronic recycling facility where they will separate and send the particular pieces where they need to go.

Describe any upgrades that would improve the design of the project.

Minimizing the size would have the largest impact in the design today. Unfortunately, the components needed for this technology are not to a more sustainable place yet but whenever fewer components can be used or a smaller overall enclosure can help improve the project and make it more sustainable.

Describe any issues or challenges associated with upgrading the design.

The largest issue is the project is already set with this idea of keeping it small. Finding those opportunities while still meeting the specifications will pose challenging. There is certain trace distances on the PCB and certain components need to be far enough apart from one another. Also, the need for heatsinks will also make it hard to minimize the size. Furthermore, incorporating upgrades will increase the cost of this device, this would be counter intuitive as the product is designed to be a cheap alternative to existing solutions.

Ethical

Many potential ethical issues are taken into consideration throughout the design process for the USB-C Charger. Ensuring the safety of the user(s) is our first priority, as well as maintaining a working product should a mishap occur . Another ethical dilemma would be delivering the products within specs to the best of our knowledge.

Potential issues regarding the safety of the users would be fire hazards or overheating hazards. With this type of hazards, as designers, buffers need to be in place to ensure that when the product is in operation or in standby, it is designed so that no damage occurs to the product, any devices connected to the charger, or any harm is done to the user. This will include having fuses in designated locations, as well as having a fail safe pathway to prevent any form of short circuiting to occur within the circuit. We will also take the necessary precautions to warn the user within the documentation of the product, of any possible hazards .

To understand certain aspects of the chargers characteristics, this means there needs to be extensive testing done before selling the final product.This goes hand in hand with the reliability of the chargers and whether or not it meets specification. This will include completing multiple tests on the product for both charging speed as well as performing extreme tests. This will stress our product and ensure the reliability as well as whether the product meets spec or even exceeds it.

The testing will also assist us in how to market the product. With knowing certain information on how the product acts, we will be able to be honest in how well the product works under certain conditions. If it says the charger will charge phone in 2 hours, it needs to charge their phone very close to that amount of time, within reason. If they use the charger wrong then it may not charge to spec but if the customer uses the charger as instructed it should work to spec.

Once completed, someone with experience in this industry and/or a third party group will help determine the how well the product meets its specifications. In this case, Professor Taufik, who holds a Phd in Electrical Engineering with a focus in Power Electronics, will decide who tests the product . If the product does not meet specifications and safety standards he believes are necessary to encapsulate all ethical issues, then as designers, we will take his suggestions and criticism and improve it to meet the requirements.

Health and Safety

When it comes to the health and safety of the customer and user of our product, their wellness is first priority. The product will be created with materials that do not harm individuals when exposed to said material. This will also be taken into account when determining the types of components that will be used in the design of the charger. No components will be included that, after a certain time, create harmful chemical or toxins when the product is in use. Also, as stated in the ethical section, when designing the charger we the design itself will be created with the intent to mitigate any forms of hazards that may come with improperly designing a product.

Social and Political

Socially this product subjects itself to those who have a DC input. The people who only have AC sources will not be able to benefit from the charger. However, it can make social change. If people see the ease of using the charger, they may move to have solar or some sort of DC input and change the way society delivers their power.

Politically, the hope is to disrupt the AC charger market and could change the stock market or the amount that shareholders get in the other companies. Also, if there were to be that shift from AC to DC power sources the government could be forced to help in converting the power system to something more like the microgrid, that can handle more DC sources.

Development

For the development of the product it was necessary to learn to learn how to use Electronic Design Automation software, such as Kicad. Secondly, learning how to test equipment is important, because the design and the boards need to be verified according the specifications that have been laid out.