Cell Phone Charger for the DC House Project

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-Andrew Hefner

I want to thank my family and friends for all the help and support through my college education and life. Finally I have reached one of my life goals if it wasn't for them. I want to thank the EE department for teaching great skills and giving me knowledge that will help me in the future. I also want to thank my senior project advisor Taufik for helping us so much through the course of the project and for his great power classes. Additionally, special thanks to Owen Jong for helping me a lot during the troubleshooting of the circuit. Finally, I want to wish the best of luck to the DC House Project and am very glad that I got to participate on it.

-Antonio Magdaleno

Abstract

The goal of this project is to create a multiple output cell phone charger for the DC House project. The cell phone charger is essentially a DC-DC converter. The converter takes an input of 48 volts from the outlet in the DC House and decreases the voltage level to 5 volts; the input voltage level of all cellular devices. By designing an isolated flyback converter with initial specification in LTSpice simulation software, a converter was created. By monitoring the input and output voltage and current using the multi-meters and electronic load, we determined the charger to be 71% efficient when both outputs were running at a full load of 1 ampere. Using the same equipment the load and line regulations were determined. Output one had a load regulation of 1.35% and a line regulation of 0.34%. Output two had a load regulation of 2.02% and a line regulation of 0.3%. By viewing each output on the oscilloscope, we determined the voltage ripple of each output to be 3.45% and 4.42%. With these results, we know we have created a quality and affordable multiple output cell phone charger.

I. Introduction:

Cell phones have become an extremely popular device in the entire world and it is easy to say they are part of our daily lives. In the year 2010 there was an estimate of over 4.6 billion cell phones worldwide and the number has been growing by more than a billion ever since; this translates to more than half the world's population [1]. Both the developed and the developing world countries are buying more cell phones, but it is in developing countries where the cell phone growth stays the strongest [2]. However, cell phones need electric sources to charge their batteries in order to work, but there are people in developing and third world countries that find it hard to access electric sources. For example, one resident of a village in Tanzania describes how he takes all seven of the village's mobiles down to a nearby town with electricity to charge all seven mobiles [3]. Obviously, this is quite different than what we see in the United States or other developed countries. Their inability to access a centralized power grid is due to either or the combinations of two things; the cost of constructing transmission lines to their homes, or the inability to construct transmission lines due to their location. In an attempt to provide electricity to the unfortunate families and residence of these areas in third world and developing countries, the California Polytechnic State University (Cal Poly) and its Electrical Engineering Department created the DC House Project. In this project, students will design and build a house that supplies sustainable energy in the form of DC power for users. There are many components of the project; however, the focus of this project is specifically on the design of a cell phone charger for the DC House.

II. Background:

According to the International Energy Agency, in 2011 1.4 billion people around the world did not have access to electricity [4]. To help with this severe problem and to provide electricity to the underdeveloped world, Cal Poly started the DC House Project. The project, which is led by Professor Taufik and conducted by students of the Electrical Engineering Department, has the purpose of providing help with the energy crisis that third world and developing countries face. The DC house is a house that runs solely on produced sustainable energy in the form of DC power. The house has no dependence on the power grid. The three year project began in the 2010-2011 school year. During the first year, phase one consisted of students developing various forms of DC power generation. These forms of power include: solar, wind generated, hydro-electric, and human generated. We are currently in phase two. This phase includes the design and construction of the house, along with the design of various converters and electrical systems for the house to have the ability to supply power to various appliances for the users. The third and final phase will begin in the 2012-2013 school year [5]. Our goal by the end of phase three is to have a product that provides safe, cheap, clean and reliable energy to under-privileged families, villages and areas of developing and third world countries. For more information on the DC House Project, visit the project's official site at http://www.calpoly.edu/~taufik/dchouse/index.html.

As stated previously, the DC House will provide sustainable DC power for users that are outside the grid. The initial design is very primitive and focuses mainly on providing the simple amenities such as the use of fans and lights to the house. Currently, project members are working on making the house have the ability to provide energy for more complex appliances such as

stoves and refrigerators. The ability to provide use of appliances through safe, reliable, generated energy independent of the grid is a huge step towards helping the energy crisis.

Now that the scope of the project has been outlined, we can discuss our project at hand, the DC Cell Phone Charger. As it is the goal for the entire project team to provide safe and affordable energy to the parts of the world that do not have access to energy; it is our specific goal to provide users the ability to charge their mobile devices without having to go great lengths to charge them, like the case of the Tanzanian man. Our ability to develop this product is significant because the use of mobile devices is constantly growing. According to the Federal Emergency Management Agency (FEMA), it is predicted that in 2020 there will be 6.9 billion mobile phone subscribers worldwide at which “mobile devices will be a primary connection tool to the internet for most people in the world”[6]. Although, by 2020 we hope that power grids are more accessible for third world and developing countries, it cannot be guaranteed, thus showing the importance of creating a product that charges different types of mobile devices through the use of the DC House.

The design of our cell phone charger is based on a previous design of an isolated flyback converter provided by Linear Technology, which will be discussed later [7]. First, it is important to provide some more background on cell phone chargers themselves. Power grids for developed countries use AC power, while cell phones are charged using DC power. This means the most prevalent chargers used today are wall chargers, also known as AC-DC converters [8]. The chargers rectify the AC signal and converter the signal to DC at the specified power rating for the phone chargers. But our goal is to develop and design is a charger that converts from DC-DC at different voltage and current values. The only devices that have been developed using this sort

of configuration are chargers intended for use in cars. Figure 1.1 shows a typical car cell phone charger.

Figure 2.1: Typical Car Cell Phone Charger (DC-DC Converter) [15]

These chargers reduce the voltage from the cars cigarette lighter (12 volts) to a level the cell phone can handle and use to charge (5 volts). In our case, we will have an input from the DC House's outlet at 48 volts, providing our first difference in charger design. According to [9], a very common topology for decreasing the voltage is the Buck topology. But in our design we must use an isolated topology, which rules out the use of a buck converter. Instead we chose an isolated flyback topology provided by Linear Technology. The design provided by LT is intended for a large range of input voltages and a 48 volt output. Cell phones chargers output 5 volts, so our design is loosely based upon the given design by LT. Although this design has never been done before, our cell phone charger design is not a brand new approach, just modified to a different output.

III. Design Requirements

The main goal for our project is to successfully manufacture one dual output DC cell phone charger. Along with our main goal, creating a product that is safe, reliable and useful with low production costs is a major goal as well.

Safety is an imperative issue when designing any product. Any and every designer must take into account the single most important goal for a product; the safety of the consumer. The charger, like all other electrical products, must abide by the standards of the National Electric Code (NEC). These codes are simple, yet extremely necessary to ensure the safety of the user.

Producing a reliable product is essential in this design case. The charger will be available in a package with the DC House and must be reliable for a couple of reasons. First, the product must be dependable because the process for the consumer to get his/her charger replaced is very cumbersome. Without the ability to use the internet or phone services to contact the manufacturers, it may be very difficult to replace a charger. Secondly, a product that does not last, is not a well designed product. If the product does not have a decent life time (1-3 years), consumers will stop purchasing the product.

Designing a charger that is useful for the consumer is also very important. A charger that doesn't supply the necessary charger cable for the user's mobile device renders the product worthless. It is important that the outputs for the charger provide the consumer with a variety of cables that will allow the charger to charge their mobile device.

Below is a list of technical specifications for the DC House cell phone charger. It is important that the charger meet the specifications as they are imperative in creating a DC-DC converter that works efficiently.

- Nominal Input Voltage of 48 volts from the DC House Bus.
- Two Nominal Output Voltages of 5 volts.
- Load Regulation of less than 5% from half to full load while input voltage is at nominal value.
- Line Regulation of less than 5% for ±10% Input Deviation at full load.
- Output Voltage Ripple of less than 5% at 100% load.
- Efficiency of greater than 70% at 100% load.
- 6” x 4” x 3” in size.

The timeline of the project is derived from the goals set, and Table 3.1 gives a Gantt chart of the project. The main milestones set for the first half of the project were the completion of the simulation for our design, and to have a complete list of parts ready to order. The milestones for the second half of the project are the manufacturing of the charger, testing, successfully demonstrating the capabilities of the charger, and the completion of the project report.

Table 3.1: Project Timeline

		Winter Quarter											Spring Quarter										
Week #		1	2	3	4	5	6	7	8	9	10	Finals	1	2	3	4	5	6	7	8	9	10	Finals
Project Proposal																							
Project Timeline																							
Weekly Progress Reports																							
Research																							
Project Report																							
	Table of Contents																						
	Research																						
	Overview																						
	Design																						
	Simulation																						
	Manufacturing/Testing																						
	Results																						
	Analysis																						
EOQ Demo																							
Isolated Flyback Converter																							
	Simulation																						
	Parts List																						
	Order Parts																						
	Manufacturing																						
	Testing																						
Overall Manufacturing																							
Poster Construction																							
Final Demo/Presentation																							
Project Submission																							

IV. Design and Simulation

The solution to creating the DC cell phone charger is to design an isolated converter. Although there are various topologies of isolated converters, we immediately decided upon the flyback topology. We chose the flyback topology because it is small in terms of the numbers of components used, as well as the cost [9]. The size and cost of production was very important in determining the converter topology because of our target consumers. A small and inexpensive charger was necessary for the DC House project.

With the converter topology chosen, we can begin to look at the system diagram shown below in Figure 4.1. The converter should take an input of 48 volts and reduce the voltage to two, 5 volt outputs. To help with design process of the charger, we determined to use the LT3748 Switching Regulator Controller designed and manufactured by Linear Technology due to its intended use for isolated flyback converters.

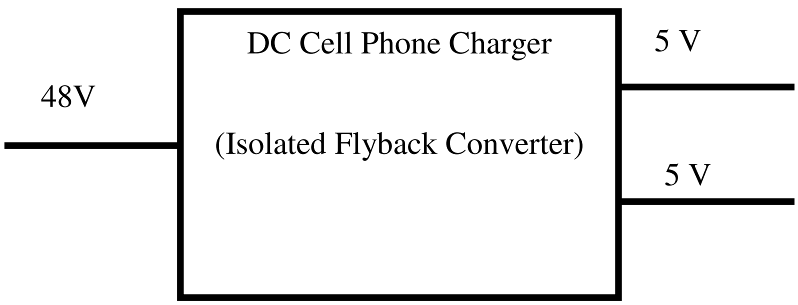

Figure 4.1: DC Cell Phone Charger Block Diagram

A. Design

To begin the design process, we must take a look into the data sheet of the LT3748. The 12 pin structure of the chip must be provided the correct voltage levels in order for the converter to work as intended. Figure 4.2 below shows the internal circuitry of the LT3748. Using the schematic, the pin information provided by [7], and a test jig provided by the LTSpice software, we will provide analysis of the purpose of each component in the design. Also, Figure 4.4 below shows the final design schematic we will use for our cell phone charger.

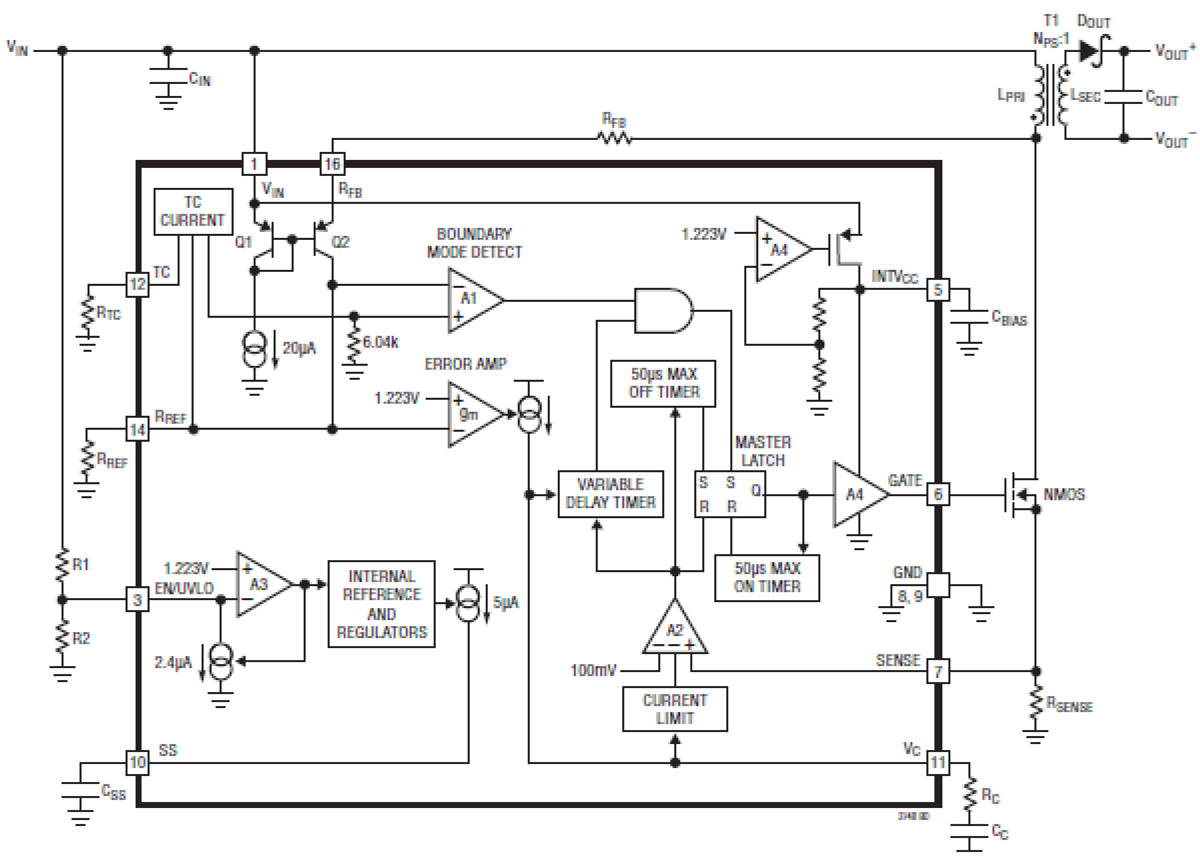

Figure 4.2: LT3748 Internal Circuitry [7]

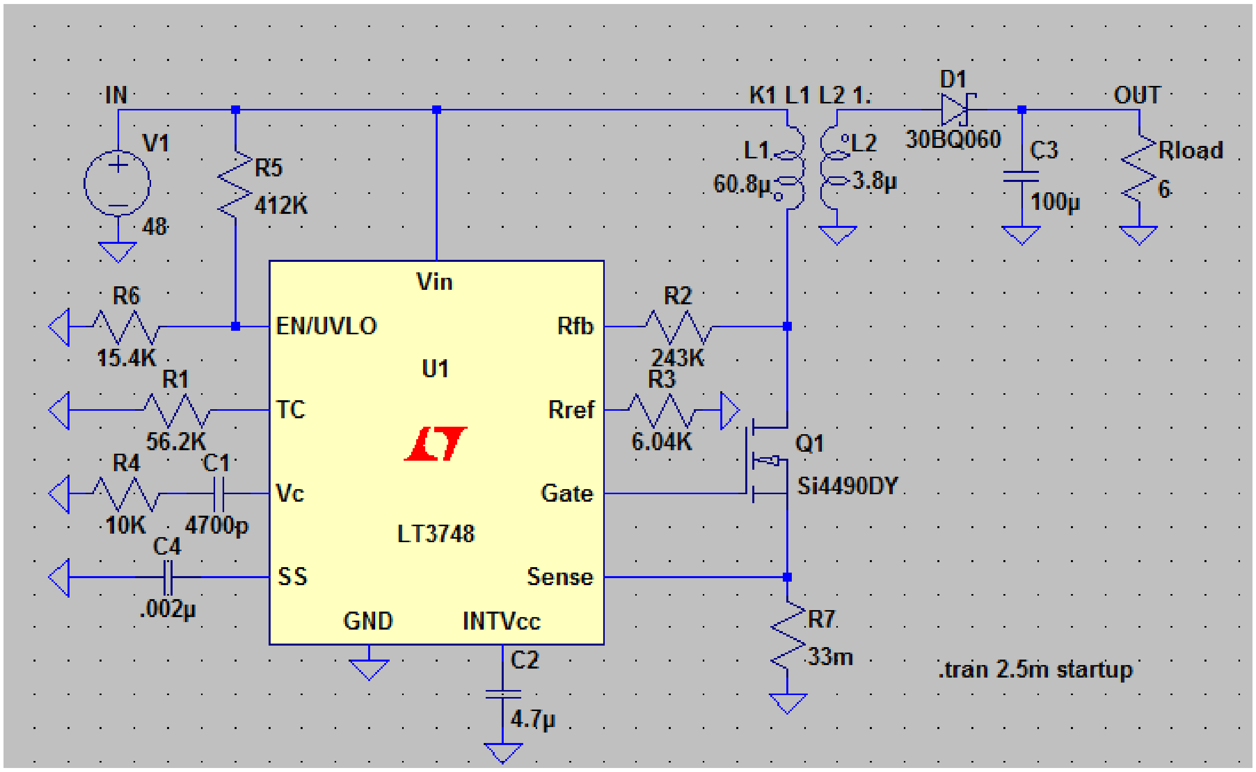

Figure 4.3: LT3748 Test Jig Provided by LTSpice Software

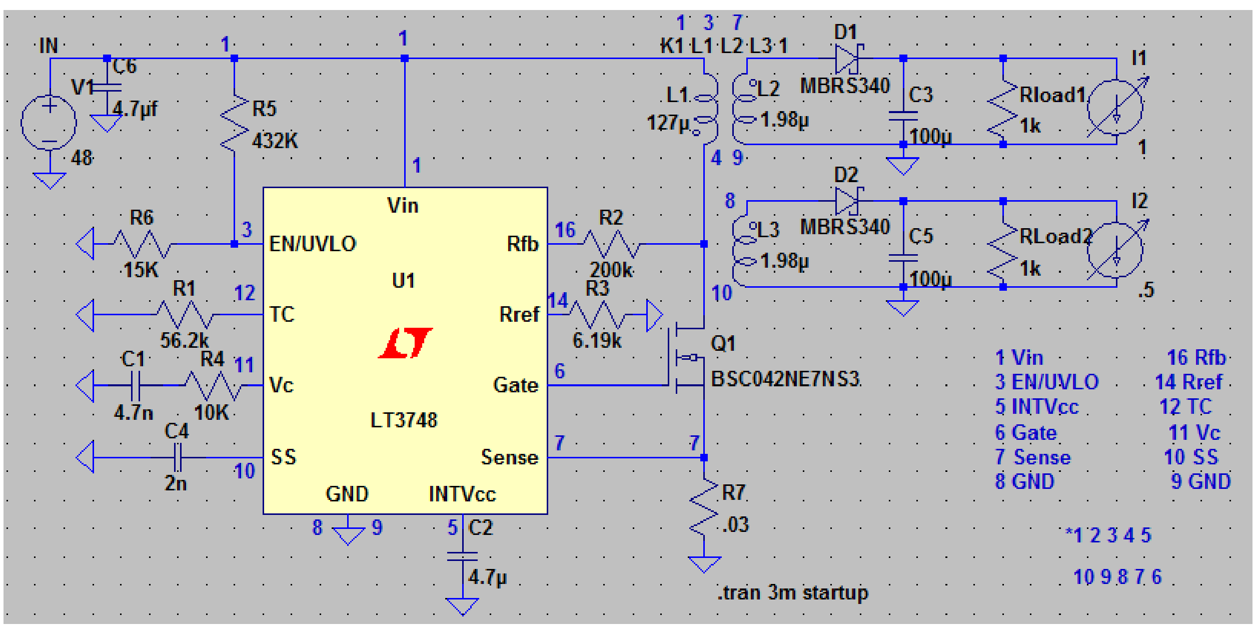

Figure 4.4: LTSpice Schematic for Isolated Flyback Converter Cell Phone Charger

Transformer, MOSFET and Diode Selection

The selection process of the transformer was fairly simple. We had to consider the input voltage the transformer could handle, the turns ratio, the number of secondary windings and the rated output power. Through searching different datasheets of manufacturers, we decided to use a PA1137NL transformer. The data sheet provides us the information necessary to ensure it will work for our application. First, we looked at the input. According to [12], the input voltage range of the transformer is from 33 to 57 volts. Our input voltage will range from 43 – 53 volts. The turns ratio of the transformer is 8:1. The ratio of 48:5 volts is 9.6:1. This specific turns ratio is not available in a transformer but 8:1 is close. This will work for the charger because the controller will change the duty cycle to compensate the output. Our charger is a dual output charger, so the transformer must have two secondary windings. The PA1137NL has two secondary windings with a rated output voltage of 13.5 watts. The maximum load on our two outputs is 5 watts. Therefore this transformer will work for our application.

The MOSFET for the converter must be N-channel. The other consideration we must consider is the maximum drain-source voltage. $V_{DS(max)}$ must be greater than the product of the output voltage and the turns ratio added to the maximum input voltage [7]. This value of V_{DS} is found to be 93 volts. With this information, we chose a MOSFET that provides a V_{DS} of 100 volts. This MOSFET is the BSC060N10NS3.

The diode chosen was the MBRS340 schottky rectifier. This part was chosen due to its large breakdown voltage and its rated average current, 40 volts and 3 amps, respectively. These values will work for our application because the theoretical maximum voltage across the diode is 5.5 volts and the maximum average current is 1 ampere. These values were determined Equation 4-1 and 4-2.

$$V_{BR} > \left(\frac{1}{n} * V_{IN}\right) - V_D \qquad (4-1)$$

$$I_F \geq \frac{P_{o-max}}{V_o} \qquad (4-2)$$

Enable/Undervoltage Lockout Pin (EN/UVLO)

The enable/undervoltage lockout pin controls the start up of the circuitry within the LT3748 chip. For the circuitry to be enabled, the pin must be supplied more than 1.223 volts. When the pin is supplied 1.223 volts, the soft-start pin (SS) sources 5 uA. A resistor voltage divider is used to supply this specific voltage. Using the voltage divider equation below, we can determine the resistor values to provide the pin 1.223 volts.

$$V_{EN/UVLO} = \frac{R_5}{R_5 + R_6} * V_{IN} \qquad (4-3)$$

By setting R_5 to 15k, we can solve for R_6. With $V_{EN/UVLO}$ at 1.223 volts, R_6 is calculated to be approximately 573k.To prevent undervoltage lockout when the input voltage is 10% below the nominal input, we decided to decrease this resistor value to 432k. This increases the pin voltage to 1.61 volts at an input of 48 volts and 1.44 volts at an input of 43 volts.

Resistors R_{FB}, R_{REF}, R_{TC}

The input pin for the external feedback resistor is connected to the primary side of the transformer. This resistor, along with the reference resistor and internal bandgap reference V_{BG}, determine the output voltage. The equation below shows how to determine this resistor value.

$$R_{FB} = \frac{R_{REF} * N_{PS}[(V_{OUT} + V_F) + V_{TC}]}{V_{BG}} \qquad (4-4)$$

To help us determine the exact value for R_{FB} we must also look at; the reference resistor, R_{REF}, the turns ratio of the transformer, N_{PS}, the internal bandgap reference voltage, V_{BG}, the

temperature compensation voltage, V_{TC}, and the diode forward voltage, V_F. According to [10], the diode forward voltage is less than 500 mV. According to [12], the turns ratio of the PA1137NL is 8 to 1. According to [7], the temperature compensation voltage is 550 mV. Therefore, we must look at the reference resistor and the internal bandgap reference voltage.

By looking at Figure 4.3, the circuit provides a comparator connected to the R_{REF} pin. This comparator compares 1.223 volts and the internal reference bandgap voltage. But V_{BG} is determined by the sourced current for the TC pin which is determined by the TC resistor. In our design, we use a resistor value of 56.2k. This value was chosen with the help of the LTSpice software. The software provides test jigs for the different controllers and the default value for R_{TC} was 56.2k. With this value and Equation 4 - 5, we can determine the current sourced from the TC pin to be 9.79 uA.

$$I_{TC} = \frac{0.55\,V}{R_{TC}} \qquad (4-5)$$

Now we can look at the reference resistor. The reference resistor is the resistor connected to the input pin for the external ground-referencing. [7] states this pin should be 6.04k, but can vary between 5.76k and 6.34k. We decided to use a value of 6.04k. Using all of the previous stated values, we found the feedback resistor value to be 240k. Unfortunately, when we simulated this value, the output voltage was too high, approximately 6.3 volts. Therefore we decreased the feedback resistor to 200k, a value available in our resistor box. This value provided an output of about 5.2 volts. To drop this voltage down some more, we know we can change the value of the reference resistor within the specified range on the data sheet. By Equation 4 - 4, increasing the resistor value will decrease the output voltage. We chose 6.19k because the resistor was available

to us and simulated again. The output voltage decreased to 5.1 volts. This voltage is sufficient for our design because we will be using a USB output which will be discussed shortly.

V_C and SS Pins

V_c is the compensation pin for the error amplifier. This pin should be connected to a series RC configuration in order to compensate the switching regulator. The component values we used were provided by the test jig from the LTSpice software in Figure 4.3.

The SS pin is the soft start pin. This pin delays the start up of the controller. The timing of the delay is determined by the size of the capacitor connected to the pin and ground. The value of 2 nF was provided by the test jig in Figure 4.3.

$INTV_{CC}$, Gate and Sense Pins

The gate pin of the LT3748 drives the gate pin of the MOSFET. This pin switches between the $INTV_{cc}$ and ground.

$INTV_{cc}$ is the gate driver bias voltage. The pin provides current to the internal gate circuitry inside the controller. The pin must be connected to a capacitor. The value of 4.7 uF was provided by the test jig in Figure 4.3.

The sense pin is the current sense input for the control loop. The pin should be connected to a resistor, R_{sense}, in the source pin of the MOSFET with the resistor connected to ground. The 0.033 Ω resistor provided by the test jig in Figure 4.3 was changed to 0.03 Ω because it was available in our assorted resistors.

Input and Output Capacitances

The input capacitor, along with the output resistor improves the load regulation of the converter. Load regulation is discussed more in the simulation section. The capacitance value used to improve load regulation was determined by Equation 4 - 6 below, obtained by [11]. Note that the switching frequency is in kHz and the capacitance is in uF.

$$C_{MIN} = \frac{I_{OUT} * D * D' * 1000}{f_{sw} * V_{p-max}} \qquad (4-6)$$

From the initial simulation and our design specifications, we were able to determine the minimum input capacitance. From the simulation, the switching frequency was determined to be approximately 160 kHz and the duty cycle was approximately 0.36. We know from our design specifications that $V_{p\text{-}max}$ is 250 mV, 5% of the output, and I_{out} is one amp. Therefore our minimum input capacitance is 5.76 uF. We use a value of 4.7 uF in the simulation because we help regulate the load with the use of an output resistor which will be discussed shortly.

The output capacitance is used to decrease the output voltage ripple. We used a value of 100 uF. This value was determined by the test jig of Figure 4.3. We were also able to check that this value will work by Equation 4 – 7 from [9]. The minimum value capacitor we must use is 45 nF. The 100 uF is much larger, so it will work for our converter.

$$C_o \geq \frac{D}{R * \Delta V_o * f} * V_o \qquad (4-7)$$

Output Resistor

In order to provide better load regulation, we have implemented a 1k resistor on the output. This provides a resistor to supply power when the intended load is open. Therefore, with no load, the output is still drawing current.

USB Output

For simplicity, we designed the output with a female USB. The USB offers protection to the cell phone which makes it ideal for our design. The voltage range for operation is 4.75 to 5.25 volts which will prevent damage from occurring to the phone [13]. Table 4.1 shows the pin information for the USB.

Table 4.1: USB Pin Descriptions [13]

Pin	Name	Cable color	Description
1	VCC	Red	+5 VDC
2	D-	White	Data -
3	D+	Green	Data +
4	GND	Black	Ground

The USB has four pins that receive different voltage values. Pin 1 and Pin 4 will be attached to positive voltage and the ground on the output of the converter, respectively. According to [14], we must use different voltages for the data pins, pins 3 and 4. Figure 4.5 shows the resistor configuration we will use to connect the data pins of the USB.

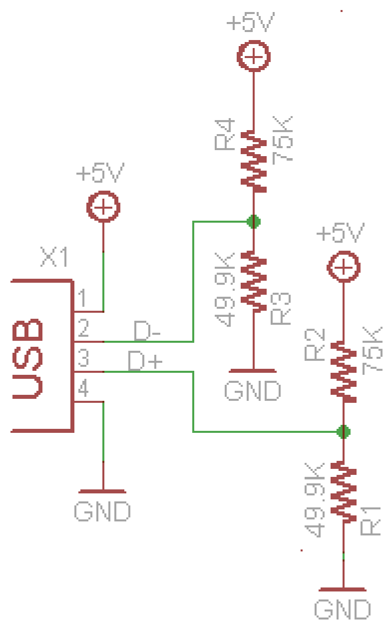

Figure 4.5: Resistor Configuration for USB Pins [14]

Connecting the data pins to different voltages than the output causes the phones to charge at different rates. By using the configuration of Figure 4.5, the data pins will be connected to 2 volts and the phones should charge at a rate similar to a common wall charger.

B. Simulation

Using the LTSpice software, we used our schematic from Figure 4.6 to simulate the converter. The importance of the simulation is to provide theoretical values and evidence that the cell phone charger will stay within the technical specifications listed in chapter three.

The first item on the list of chapter three is the nominal input voltage. This specific value will be 48 volts. This value is determined by another student's portion of the DC House project. Therefore, we will move on to the second bullet of the list. This will be the two, nominal output

voltages at approximately 5 volts. Figure 4.6 below shows the converter's two outputs of the LTSpice simulation, both running at full loads with the input at 48 volts.

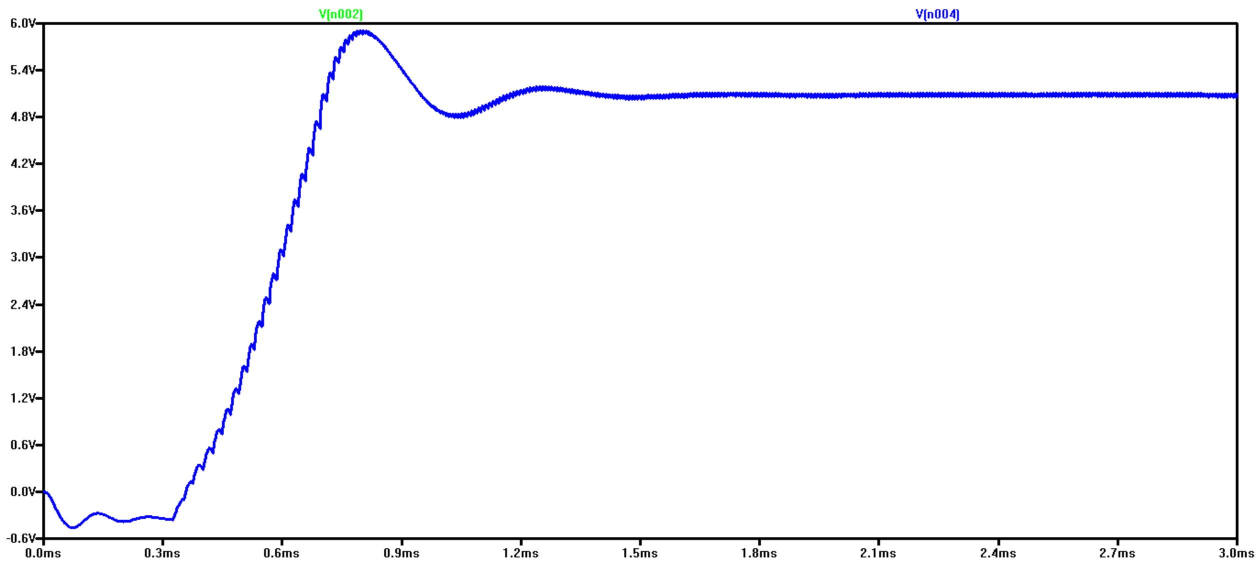

Figure 4.6 Converter Output Voltages at Full Load

As you can see in the Figure above, when both loads are running at 100%, the outputs are identical. The loads are running at just above 5 volts. Also, you may notice the increasing slope and steadying of the output as the system starts. This is due to the converter needing some time to become steady-state. As the Figure shows, this takes about 1.5 milliseconds. This will not be an issue in the manufacturing process as the 1.5 milliseconds is an extremely short amount of time.

Load Regulation

Load regulation is a very important aspect of any electrical system because loads are constantly varying. According to [9], load regulation refers to the ability of a converter to maintain the output voltage even when the output power fluctuates; therefore, how well the converter's maintains the output voltage when the load pulls less current. Equation 4 – 8 shows the mathematical definition for load regulation. As discussed in the research chapter, we will

consider from half load to full load because the minimum and maximum output currents of cell phone chargers are 1 amp and 500 mA, respectively. To show this we provided Figure 4.7, a simulation of the two outputs, one at half load and one at full load.

$$\% \, Load \; Regulation = \frac{V_{out\,(\,low\,load)} - V_{out\,(high\,load)}}{V_{out\,(high\,load)}} * 100\% \qquad (4-8)$$

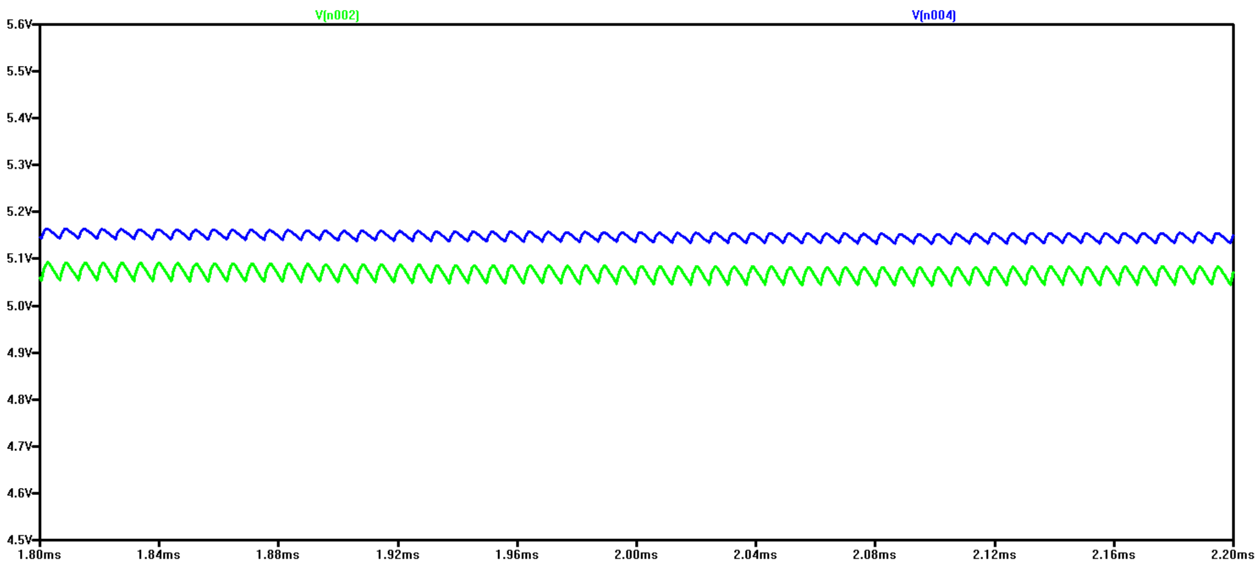

Figure 4.7: Output Voltages of Converter at Half and Full Load, Blue Half Load (top), Green Full Load (bottom)

The Figure above shows the two output voltages. The higher voltage indicates the output at half load. As stated before, the load regulation refers to how well the converter maintains the output voltage while the load varies. Our simulation shows the converter does this very well. At half load the output voltage is approximately 5.15 volts. At full load the output voltage is approximately 5.07 volts. By using Equation 4 - 8 for load regulation, we find the load regulation

of the converter to be 1.57%. In chapter three the technical specifications call for load regulation within 5% from half load to full load. Our converter is well within this range.

Line Regulation

For the DC House project, the output voltage of the outlets may fluctuate due to an abundance of supplied renewable energy or an insufficient amount of energy. To account for this we must provide good line regulation in the converter. Line regulation, as described in [9], is the ability of the converter to maintain output voltage even when the input voltage fluctuates. The equation for line regulation is provided below. Also, to verify the converter stays within the line regulation specifications detailed in chapter three, we have included the following two figures, Figure 4.8 and Figure 4.9, below.

$$\%line\ Regulation = \frac{V_{out(high\ input)} - V_{out(low\ input)}}{V_{nominal}} * 100\% \qquad (4-9)$$

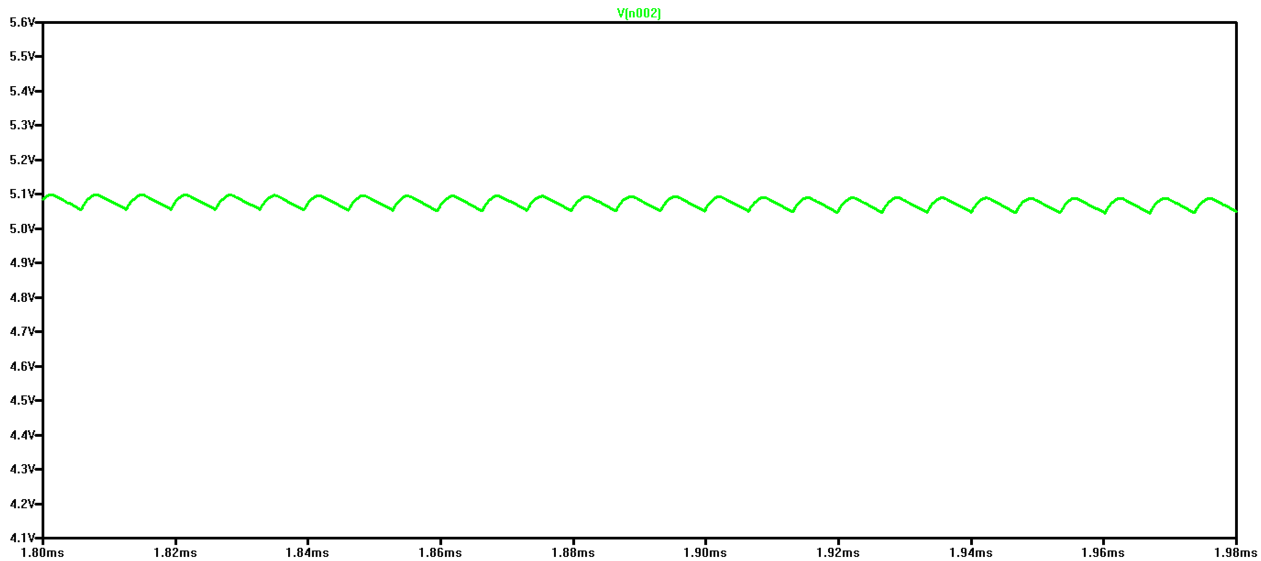

Figure 4.8: Full Load Output Voltage with 43 Volt Input

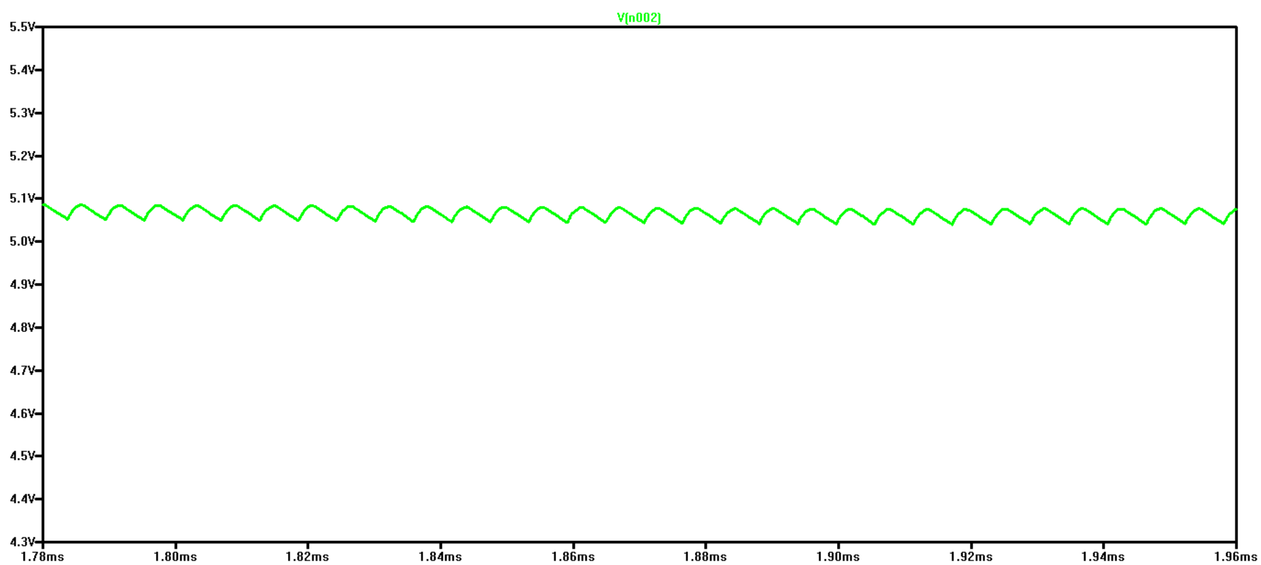

Figure 4.9: Full Load Output Voltage at 53 Volt Input

In Figure 4.8, the input voltage is 43 volts, approximately 10% less than the desired input of 48 volts. The output voltage is essentially the same. In Figure 4.9 the input voltage is 53 volts, approximately 10% greater than the desired input of 48 volts. Once again, the output voltage is

essentially the same. Using the equation we determine the line regulation to be less than 1% which is within the 5% specified in chapter three.

Output Voltage Ripple

For all dc converters, it is important to minimize the peak to peak output voltage ripple. By decreasing the ripple, the output looks more like a dc voltage. This is important because too much ripple can harm the load of the electronic and can infer problems in the device. In order to minimize the voltage ripple, a capacitor is used on the output. Figure 4.10 below shows the peak to peak output voltage ripple. Because output voltage ripple is given in percentage of average output voltage [9], we see that the output voltage ripple is approximately 1%. The peak to peak ripple is about 40 mV and the output is 5 volts which results in a ripple about 1%. This value was determined by Equation 4 – 10 below.

$$Percent\ Voltage\ Ripple = \frac{\Delta V_o}{V_o} * 100 \qquad (4-10)$$

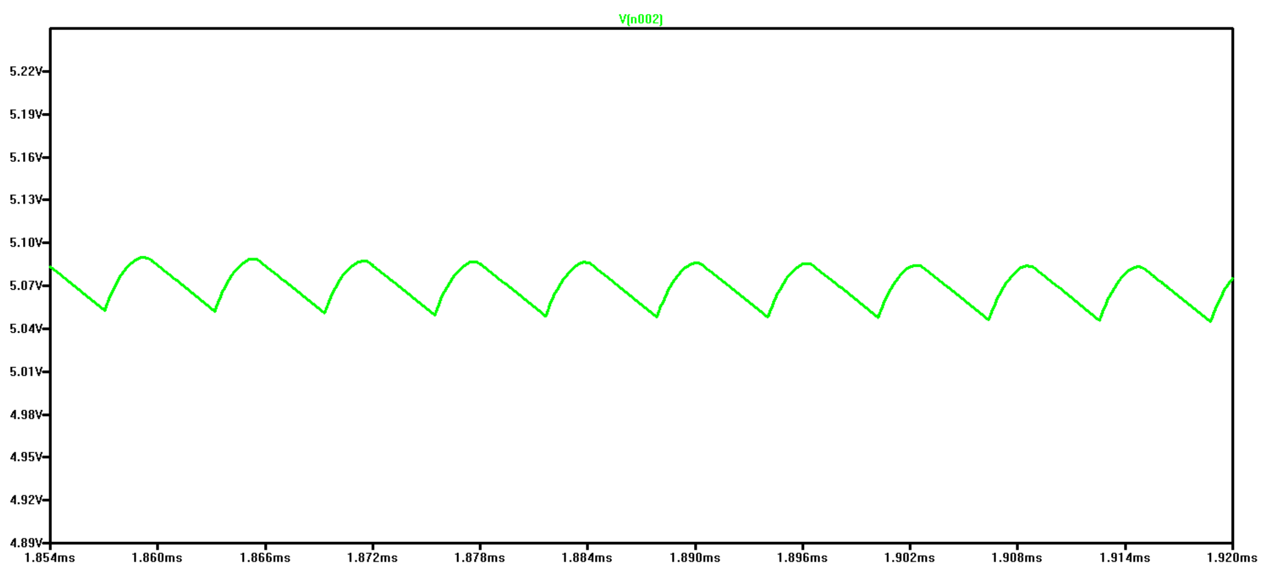

Figure 4.10: Full Load Output Voltage Ripple

Efficiency

The most important aspect of any power electronics is the efficiency: that is, the percentage of the input power used on the output. In all electrical systems there are losses and it is very important to minimize these losses to improve the efficiency. The losses can be due to various reasons; leakage current within a transformer, losses in capacitors due to equivalent shunt resistance (ESR), losses within resistors, etc. In power electronics it is important to keep the efficiency above 70%. Figure 4.11 below shows the output power of the system and Figure 4.12 shows the efficiency simulation results. The input power is not shown because the LTSpice software provides a very noisy input current that makes it difficult to read, but with simulation software's ability to find averages, the input power is 11.83 watts at full load. That information, along with the output power shown in Figure 4.11, we can determine the efficiency. With an input power of 11.83 watts and two outputs with output powers of 5.08 watts, we determine the efficiency to be 85.9%, which is above our technical specifications.

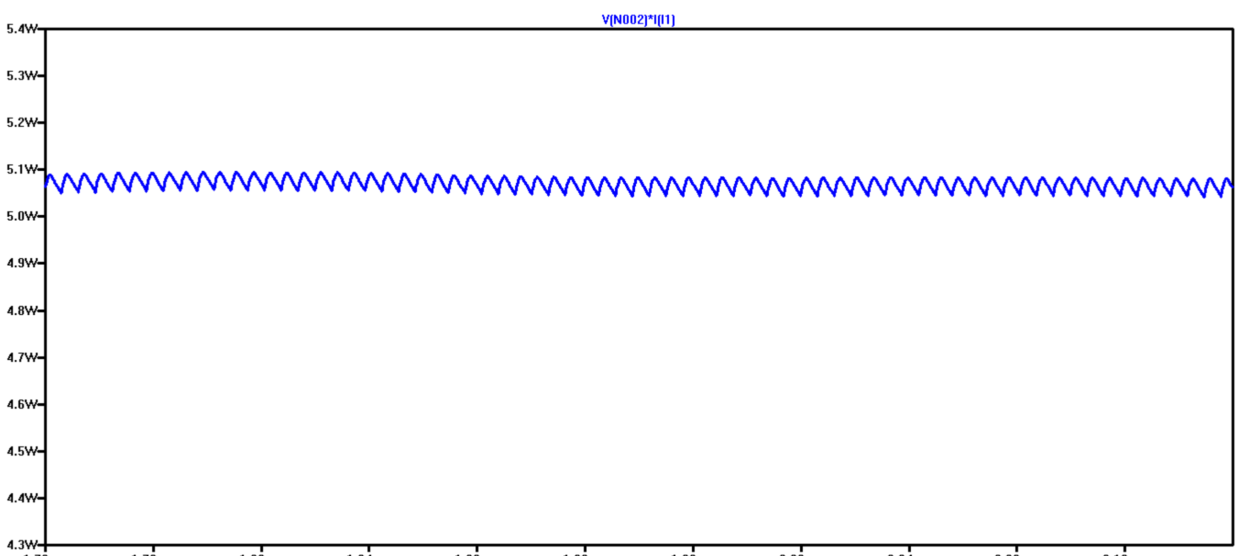

Figure 4.11: Full Load Output Power

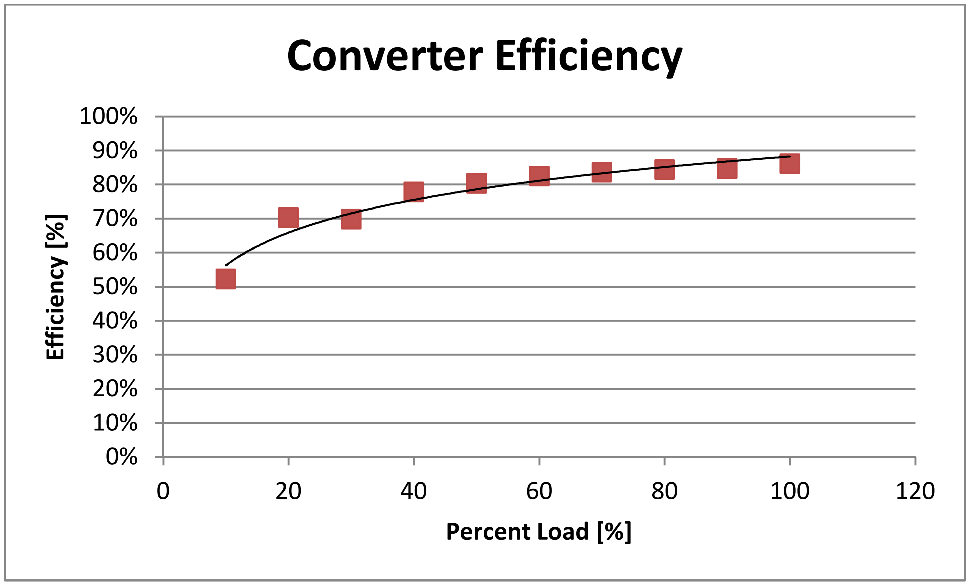

Figure 4.12: Simulation Converter Efficiency

The LTSpice simulation provides theoretical evidence that our design for the converter will work. With the graphs provided by the simulation, we see that our converter meets the technical specifications outlined in chapter three. Thus we are ready to manufacture the converter.

V. Manufacturing and Testing

A. Manufacturing

The manufacturing process for the converter is very simple. With the components used in the design and a conductor board, we can create the converter. The first step was determining how to integrate all of the components onto the conductor board specifically made for the LT3748 controller chip, shown below in Figure 5.1.

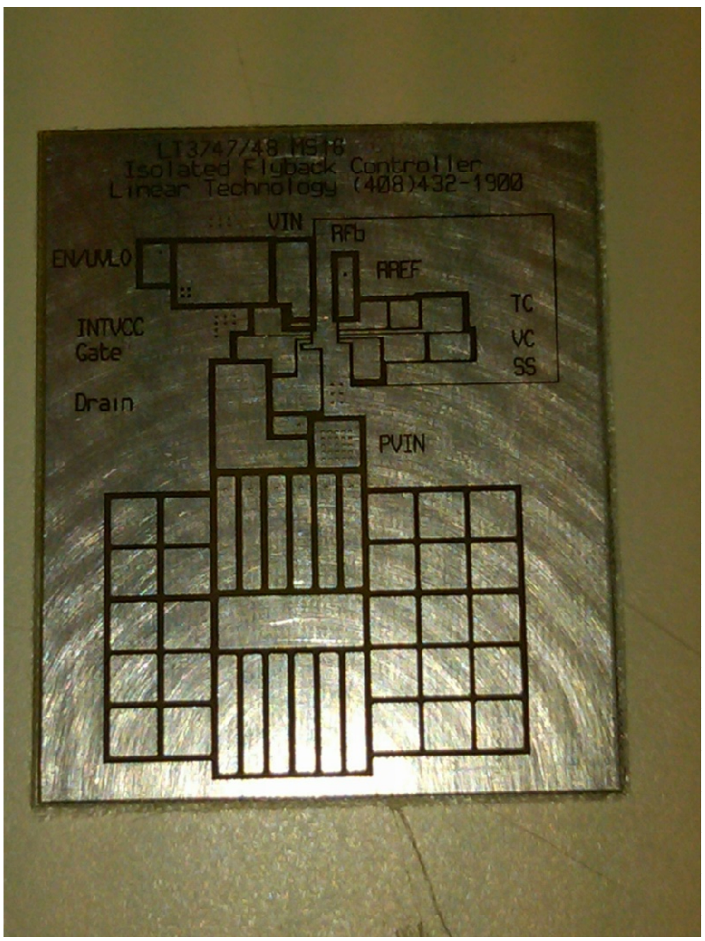

Figure 5.1: LT3748 Conductor Board

The top of the conductor board is designed specifically to fit the LT3748 chip with the pins separated. The bottom of the board provides an area for a transformer to be placed. Therefore, the two components' locations were pre-determined. The location of the components connected to the pins of the chip were also pre-determined as the chip has a set location. The only component location needed to be determined was the components upon the output. With the provided square areas to the left and right of the transformer location, we decided to put the two outputs of the converter. With the manufacturing design in place, it became time to manufacture the converter. With the use of a soldering iron and solder wire, we connected the components as per the design detailed in chapter four.

On top of manufacturing the converter, we also created a voltage divider for the USB output discussed in the design. The voltage divider offered us the ability to connect our data pins to a different voltage level. For the final manufacturing, we connected the female USB devices by soldering their wire to the high output voltage, ground and a 2 volt pin specifically for the two data pins.

The final portion of the manufacturing procedure was the packaging of the device. We bought an electronics package from Radio Shack in order to provide a box for the charger. By using a drill gun, we made holes in the packaging for the USB female outputs, the input, and holes for the board to sit securely in the package. For the input, we used two banana lead females. We put holes in the package to allow the leads to be connected without showing the inner circuitry of the device. We did the same for the output USB females.

B. Testing

The testing for the cell phone charger of the DC House required meeting the following specifications: load regulation of less than 5% from half to full load while voltage is at 48 volts nominal value, line regulation less than 5% going from 43 volts to 53 volts, efficiency greater than 70% at 100% load, voltage ripple lower than 10% at full load, and the ability to properly charge the cell phones. All these specifications need to be met with one and two outputs working.

For the testing part of the project we are using the DC Regulated Power Supply to provide the 48 volts DC and the two 150W DC Electronic Load for the loads and the circuit looks as the black box in Figure 6.1.

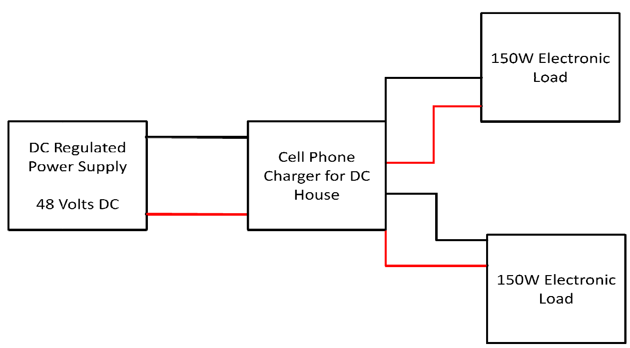

Figure 5.2 DC Cell Phone Charger Testing Diagram

The electronic loads will eventually be replaced for the following cell phones: I-phone, Blackberry, LG lotus, and HTC evo 4g.

The first phase of testing consisted in using only one electronic load while the second one would remain open, the second phase of testing consisted of having two electronic loads running at the same time, and the last phase was to replace the electronic loads for actual cell phone

devices. The cell phone charger was tested in three phases to make sure every requirement was properly met.

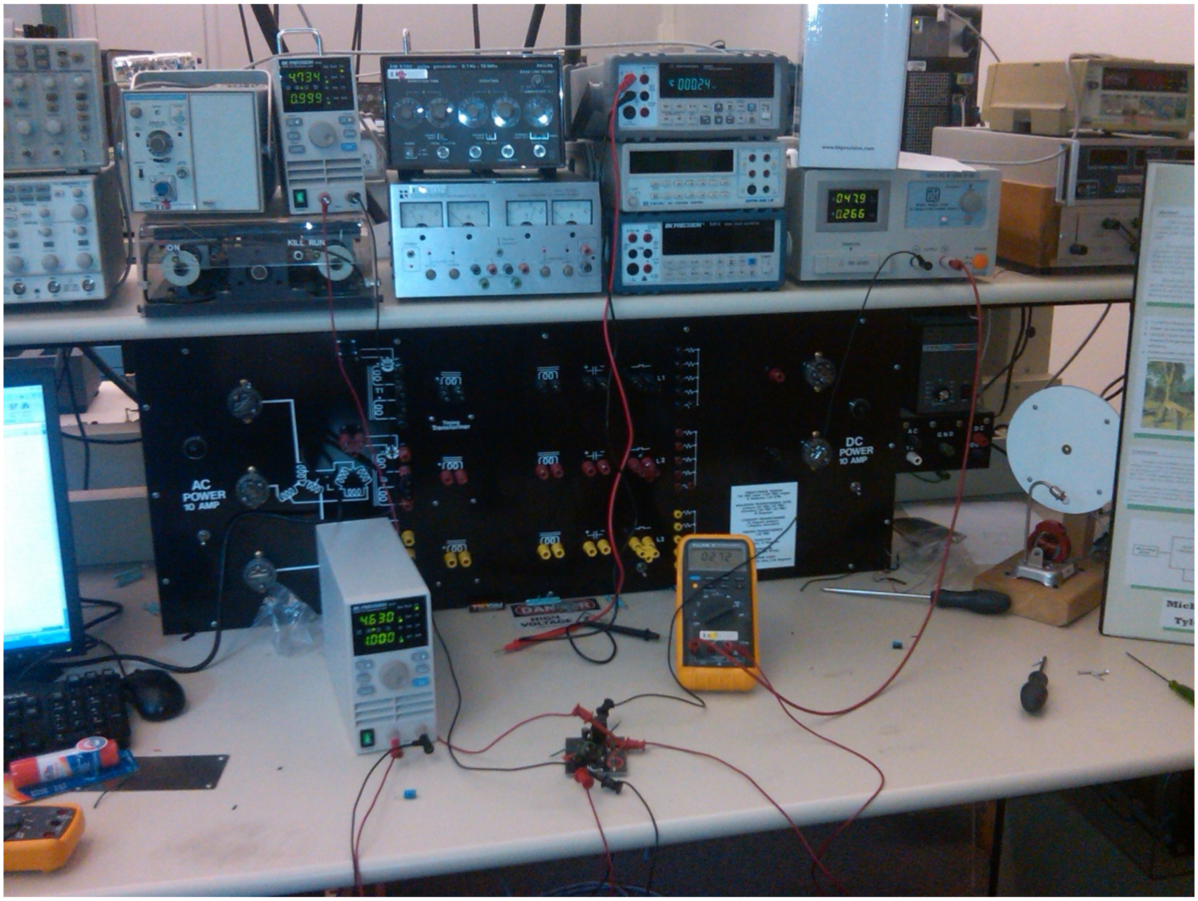

Figure 5.3: Bench Testing Configuration

VI. Results and Analysis

The testing section in chapter 5 explains the various methods we troubleshot problems we saw in the converter. The results of the final project are shown below with oscilloscope screen shots and tables with data. The data were determined by using the electronic load and digital multi-meters to measure current and voltages.

Full Load Output Voltages

By supplying the input with 48 volts from a DC power supply and connecting the outputs to electronic loads, we were able to view the output voltage level. To stay within the technical specifications of chapter 3 the two output voltages should be approximately 5 volts while running at a full 1 amp load. At full load the two outputs voltages to be 4.88 and 4.86 volts. These values are similar to the design but not exactly the same. The difference in voltages may be due to losses in the system or the controller not operating in the same way as the simulation.

Load Regulation

The simulation section described load regulation, so we will head right into the results. Our specifications for the converter state the load regulation should be less than 5% from half load to full load at the nominal input of 48 volts. In the design we used a 1k resistor on the output, but in practice our load regulation was too large. To decrease the load regulation, we needed to decrease the resistor. Using Ohm’s law we determined there was too much power dissipated into the 1k resistor and we decided to decrease the resistor value. We chose a resistor value of 68.1. With this value the converter outputs can decrease to 10% load and still say within a 5% voltage output deviation. Table 6.1 shows the output voltages at full load and half load. By using Equation 4 - 8 of Chapter 4, we find the load regulation of each output to be 1.35% and

2.02%, respectively. These values are well within our technical specifications and very similar to the simulation results of Chapter 4.

Table 6.1: Converter Load Regulation Characteristics

Input [V]	Load [%]	Vout 1 [V]	Vout2 [V]
48	50	4.943	4.956
48	100	4.877	4.858

Line Regulation

As discussed in the simulation portion of this report, the line regulation is important for our charger's application. Our specifications for the converter state the line regulation should be less than 5% for ±10% input deviation at full load. Table 6.2 shows the output voltages with inputs of 43 and 53 volts. By using Equation 4 - 9 of Chapter 4, we calculate the line regulation of each output to be 0.34% and 0.3%. Just like the simulation results the line regulation of each output is less than 1%. These values are also within the technical specifications of Chapter 4.

Table 6.2: Converter Line Regulation Characteristics

Input [V]	Vout 1 [V]	Vout2 [V]
43	4.871	4.893
53	4.888	4.878

Output Voltage Ripple

As discussed in the simulation portion of this report, we must investigate the output voltage ripple. The specifications for the charger state that the output voltage ripple should be less than 5% at full load. By connecting the two outputs to the oscilloscope, we were able to capture images of the output voltage ripple and determine its value. Figures 6.1 and 6.2 show the output voltage ripples. Table 6.3 shows the results for the percent output voltage ripple and the values necessary to calculate the ripple using Equation 4 - 10 of Chapter 4. The figures have two outputs shown. The top output is the switching gate pin of the LT3748 controller. We used this

pin to trigger the output in order to view the voltage ripple of the output on bottom. Note in Figure 6.2, the switching output is not shown. Our file was corrupted when the data were taken. Fortunately, the output voltage ripple is still shown. We find the output voltage ripples to be 4.50% and 3.45%. These results are larger than the simulation due to the capacitors used on the output of the converter. In the design, we use 100uF capacitors on the output. The ESR for those capacitors was too large, even if we put multiple in parallel to reduce it. Therefore, we used 4, 4.7uF ceramic capacitors in parallel. If our conductor board didn't become clustered, we could have increased the number of output capacitors to decrease the voltage ripple.

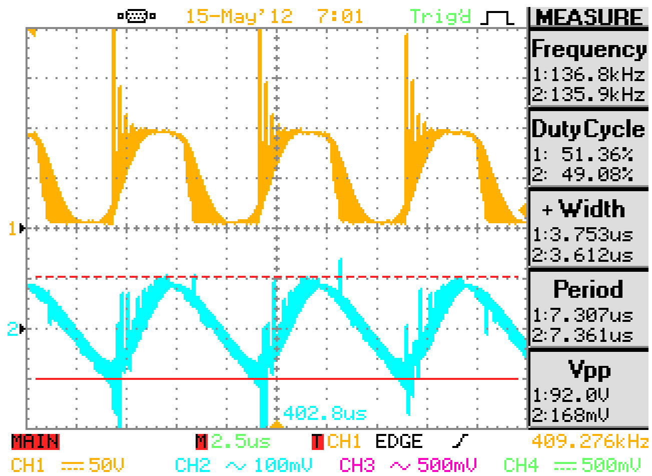

Figure 6.1: Output Voltage Ripple for Output 1

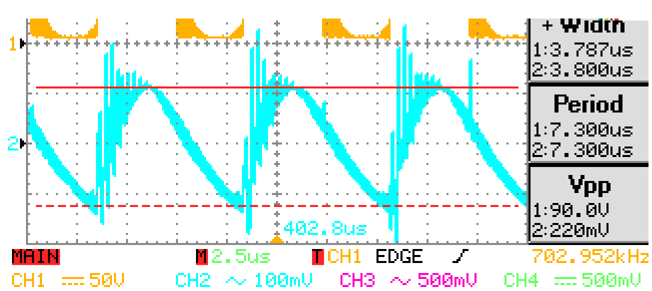

Figure 6.2: Output Voltage Ripple for Output 2

Table 6.3: Output Voltage Ripple Characteristics

Output #	Ripple [%]	Ripple Vpp [mV]	Output Voltage [V]
1	3.45	168	4.875
2	4.50	220	4.887

Efficiency

The efficiency of our converter is very important because we do not want to waste the power used. Efficiency is the percentage of power used on the output that is supplied by the input. Table 6.4 and Figure 6.3 show the results of the efficiency in terms of percentage load. At full load the converter is 74% efficient. That stays within our technical specifications in Chapter 3. Figure 6.3 shows the converters hardware and simulation efficiency. The simulation is a little more efficient because the simulation doesn't take into account losses within resistors, within capacitors ESR and leakage inductance in the transformer. Also, we see that the efficiency decreases as the load decreases. This is not detailed in the specifications, but we would like to note that even at half load the converter is almost 70% efficient.

Table 6.4: Converter Characteristics to Determine Efficiency

% Load [%]	Vin [V]	Iin [A]	Vout 1 [V]	Iout 1 [A]	Vout 2 [V]	Iout 2 [A]	Efficiency [%]
10	47.95	0.048	4.983	0.1	4.993	0.1	43%
20	47.95	0.078	4.975	0.2	4.982	0.2	53%
30	47.95	0.1	4.963	0.3	4.974	0.3	62%
40	47.95	0.126	4.956	0.4	4.968	0.4	66%
50	47.95	0.15	4.943	0.5	4.956	0.5	69%
60	47.95	0.174	4.925	0.6	4.934	0.6	71%
70	47.95	0.199	4.911	0.7	4.923	0.7	72%
80	47.95	0.224	4.882	0.8	4.893	0.8	73%
90	47.95	0.25	4.88	0.9	4.875	0.9	73%
100	47.95	0.276	4.877	1	4.858	1	74%

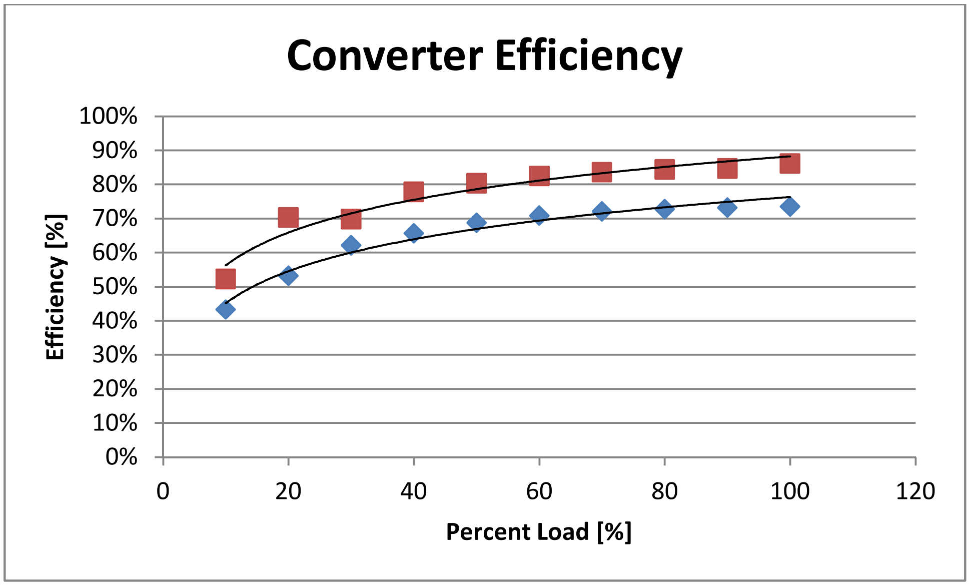

Figure 6.3: Converter Simulation and Hardware Results, Simulation (red), Hardware (blue)

Charging Rates

To determine how well our converter charged our cellular devices, we connected an ipod, a HTC and a Blackberry to the charger. We charged the devices for 10 minutes. The Blackberry charged 20%. The HTC charged 2% and the ipod charged 33%. We compared these values to the charging rate of devices connected to a wall charger and a computer USB hub. These charging values were similar to their regular phone charger. While connected to the wall charger for 10 minutes, the Blackberry, HTC and ipod charged 15%, 6% and 39%, respectively. While connected to the computer USB hub for 10 minutes, the Blackberry, HTC and ipod charged 5%, 2% and 18%, respectively. These values are outlined below in Table 6.5.

Table 6.5: 10 Minute Charging Rates for Devices and Charging Source

Device	Wall Charger	Computer USB Hub	DC Charger
HTC	6%	2%	2%
Blackberry	15%	5%	20%
Ipod	39%	18%	33%

Parts List

Table 6.6 outlines the parts and their costs to give us an estimate for production costs. The total listed below is the cost of one converter. We purchased a higher quantity of the parts in the case of errors, as well as other necessities, which are not included in the parts list.

Table 6.6: Parts List

	Type	Price	Quantity	Total
Controller Chip	LT3748	$ 4.49	1	$ 4.49
Diodes				
Diode #	Schottky			
D1,D2	MBRS340	$ 0.47	2	$ 0.94
MOSFET	IRF640	$ 1.09	1	$ 1.09
Transformer	PA1137NL	$ 4.83	1	$ 4.83
Capacitors	Value			
C1	4.7 nF	$ 0.47	1	$ 0.47
C2	4.7 uF	$ 0.88	5	$ 4.40
C3	4.7uF	$ 0.88	4	$ 3.52
C4	2 nF	$ 0.88	2	$ 1.76
C5	4.7 uF	$ 0.88	4	$ 3.52
C6	68 uF	$ 0.40	1	$ 0.40
Resistors	Value			
R1	100k	$ 0.80	1	$ 0.80
R2	200K	$ 0.80	1	$ 0.80
R3	6.19K	$ 0.80	1	$ 0.80
R4	10k	$ 0.80	1	$ 0.80
R5	432K	$ 0.80	1	$ 0.80
R6	15K	$ 0.14	1	$ 0.14
R7	30m	$ 0.14	1	$ 0.14
R8	68.1	$ 0.14	1	$ 0.14
R9	68.1	$ 0.14	1	$ 0.14
Mini USB		$ 1.99	1	$ 1.99
Micro USB		$ 1.75	1	$ 1.75
Apple		$ 1.95	1	$ 1.95
USB Females		$ 1.00	2	$ 2.00
Project Box		$ 5.49	1	$ 5.49
Circuit board		FREE	1	FREE
			Total	**$ 43.16**

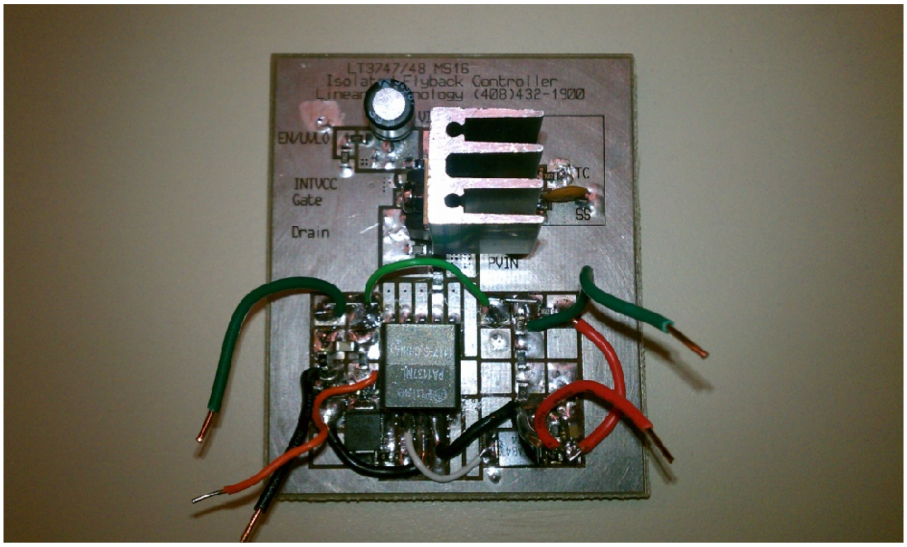

Figure 6.4: Pre-Packaged Cell Phone Charger

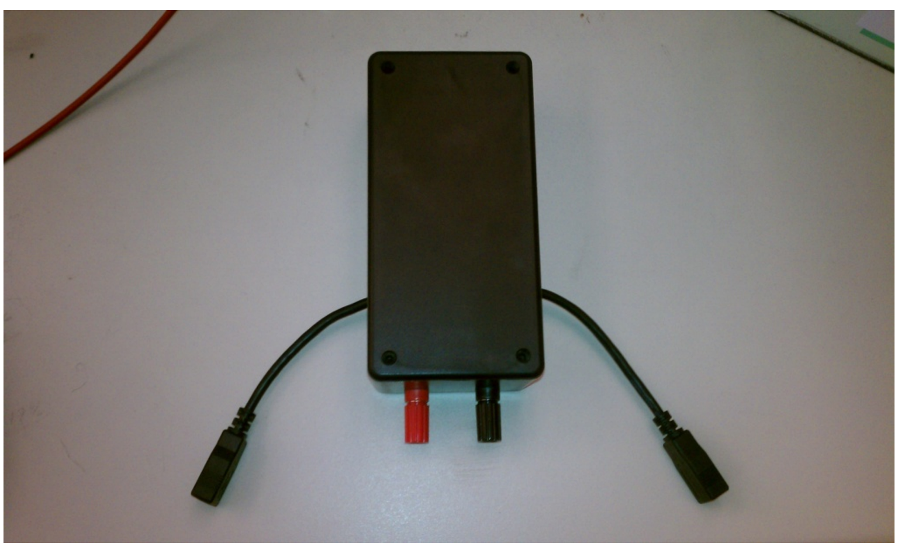

Figure 6.5: Packaged Cell Phone Charger

VII. Conclusion

Through research, design and testing, the project's purpose was to build a cell phone charging device for the DC House Project. The goal of the project was to take an input of 48 volts and convert the voltage to, two, 5 volt outputs for charging cellular devices.

By using the resources at hand we designed the cell phone charger. The design was a 48 volt input, 5 volt output isolated flyback DC-DC converter. Using the LTSpice software and the LT3748 chip, we designed the converter to stay within technical specifications necessary to ensure the safety of the electronics. We also took into consideration in design the cost and the size, trying to minimize both to make an inexpensive, yet quality product.

Once designed, the charger was manufactured using surface mount components, the LT3748 controller and a conductor board. By soldering the components on the board, in the configuration of the design schematic, we created the charger and tested it to make sure it was within the technical specifications. The testing ensured our product worked and then it was packaged. The converter worked to specifications, is safe and was inexpensive to manufacture. All of those three aspects of the charger were very important parts to making a quality product for the DC House Project.

If there is anything we would like to improve upon our charger, we would increase the efficiency when the load is less than 70% and decrease the output voltage ripple. The efficiency issue might be difficult to do and we do not know any ways to improve this value. The output voltage could be decreased by adding more capacitors in parallel on the output. We were unable to due to the lack of space on the conductor board.

Overall, we are very happy with the converter, its costs and the results it provided. It was a great experience partaking in the DC House Project and we are glad we created a quality product.

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