

BUCK CONVERTER

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Senior Project

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Abstract

The recent sustainable energy growth triggered a huge power electronics demand, specifically related to power conversion. My senior project is a design of a buck converter which steps down the voltage from photovoltaic cells ranging from 5 to 40V to a rechargeable battery with 5V. This converter has a high enough power efficiency to effectively convert the energy harnessed from PV panels.

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Introduction

This buck converter is utilized to harness energy from PV panels and storage it in a battery system. When a PV panel harnesses energy from sun light, the output voltage of the PV panel varies depending on the intensity of the sunlight. Therefore, the buck converter needs to intake various voltages and converter them to a specified value in order to store the electricity regenerated into a battery system. The voltage which is converted to is always determined by the specifications of the battery system. The output voltage and current of the PV panel must match the input voltage and current of the battery system. Because the power generated by the solar panel is usually not constant, the output voltage and current will vary depending on the intensity of the sunlight. A voltage converter takes place to interface the solar panel and a battery unit. Typical solar panels output voltages high than 10V and to practice building a simple converter, a small rechargeable battery with 5V 1A is used, therefore a step down converter is needed. Buck converters step down voltage to a desired value using switches. The duty cycle of the switch determines the output voltage. In order to calculate and predict an output voltage of the converter, a feedback resistor divider is needed. An error amplifier is utilized to constantly sample the output voltage of the circuit and compared to a stable reference voltage. Equation 3 on page 17 is used to calculate the values of the resistor divider and to determine V_{OUT} . The system transfers energy with a very high efficiency and minimal power loss. This system must meet the general safety requirements. It must not shock any users and tolerate any spills on the machine. Any spills must not damage the user or the components. The IEEE code of ethics [1] informs the reasons for protecting users.

Requirements and Specifications

Table 1 below lists marketing requirements and engineering specifications for the project. The input voltage of the buck converter is determined from the output voltage of PV panels. It ranges from 5V – 40V DC throughout a day depending on the intensity of the sunlight. The output voltage and current of the converter must match the input voltage and current of the battery unit. To stand out against other buck converters in the market, the power efficiency is above 90% and increase to its maximum potential. The limitation to how high the efficiency is based on the physical limitations of the components. The price of the buck converter estimated is based on labor and material costs. The size of the PCB and other components determine the dimensions of the buck converter. A well-insulated converter is required for safety issues and to maintain a long life-cycle. Because of time constrain on the senior project, a power efficiency of 80% is acceptable. However, it is recommended to improve the efficiency after the senior project is done after fall of 2014. Safety of all users is concerned when handling the converter. This converter must meet the UL standards [4].

Table 1:
Requirements and Specifications

Marketing Requirements	Engineering Specifications	Justification
1	$5V < V_{in} < 40V$	PV panels output ranges from 5V to 40V.
2	$V_{out} = 5V$	The output voltage is 5V. Output ripple voltage should be $< 20\%$
3	$I_{out} = 1A$	Commercial rechargeable batteries require 1A
4	Power efficiency $> 90\%$. $(\frac{P_{out-dc}}{P_{in-dc}})$	Power efficiency of 90% for testing stage, it is increased in improvement stages after fall of 2014.

5	Dimension per converter = 10 x 10 x 5 inches	Must be small and portable.
6	Price per buck converter = \$300	Estimated based on labor and cost of materials
7	Converter must meet the UL standards.	The UL standards [4] used to assess test components are important for the safety of all users.
Marketing Requirements <ol style="list-style-type: none"> 1. Variable Input Voltage 2. Constant Output Voltage 3. High Power Efficiency 4. Compact Converter 5. Affordable Converter 6. Safe Converter 		

Table 2-2 below shows the dates which certain milestones that need to be met in order to finish the project on time. Notice this project started in winter quarter of 2014. Delivery dates are subjected to change accordingly if the starting date is different.

Table 2:
Buck Converter Deliverables

Delivery Date	Deliverable Description
05/01/2014	Design Review
05/21/2014	EE 461 demo
06/14/2014	EE 461 report
11/10/2014	EE 462 demo
02/10/2014	ABET Sr. Project Analysis
12/01/2014	Sr. Project Expo Poster
12/08/2014	EE 462 Report

Design

The initial design of the buck converter was realized based on prior knowledge obtained from taking EE 410 and EE411.

Level 0 Block Diagram

Figure 3 and Table 3-1 below illustrate a level 0 block diagram and its inputs, outputs, and functionality.

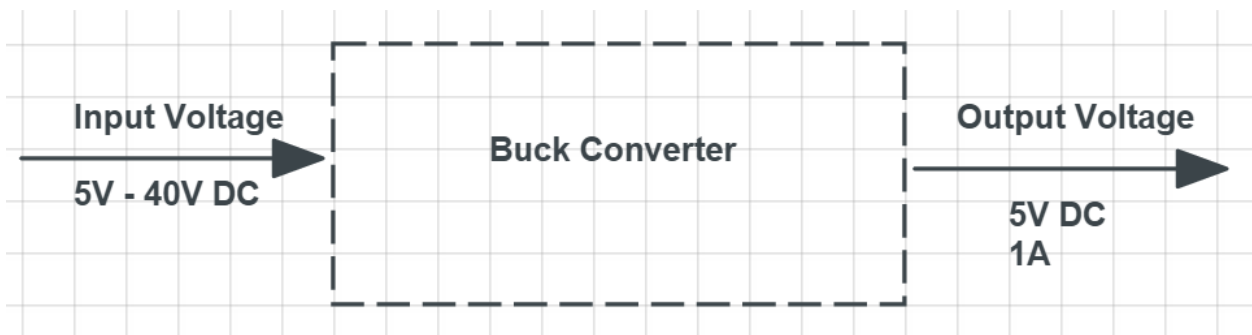


Figure 1: Level 0 Block Diagram

Table 3:
Level 0 Block Diagram Description

Module	Buck Converter
<i>Inputs</i>	Buck Converter input voltage: 5V – 40V DC
<i>Outputs</i>	Buck Converter output voltage: 5V DC and 1A current
<i>Functionality</i>	Buck converter steps down 5V – 40V to 5V DC

In this block diagram, an input voltage ranging from 5V to 45V DC is applied to the buck converter. The reason for the variable input voltage is because PV panels cannot produce a constant voltage at all times since the sunlight intensity is always changing. The buck converter converts the voltage down to 5V DC with 1A current. The output is applied to a battery like system which can store the energy harnessed from the PV panels.

Level 1 Block Diagram

Figure 3-2 below shows the topology of the buck converter with three stages. It includes the main buck converter, error amplifier, and pulse width modulator.

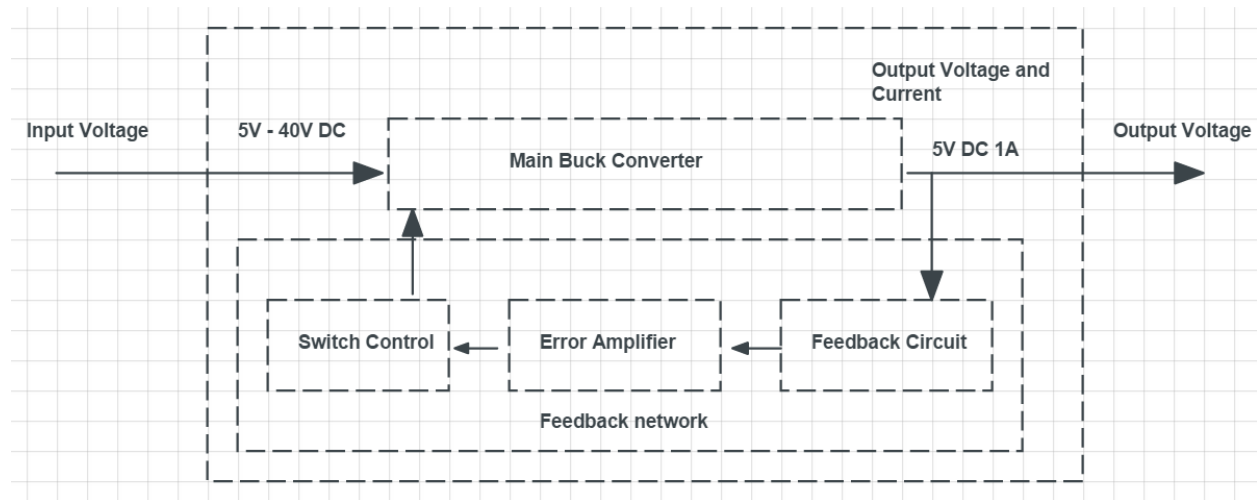


Figure 2: Level 1 Block Diagram

The input voltage is applied to the buck converter then it is converted down to 5V DC. The sensors at the output sense the voltage and current which are lowered to meet the input ratings of the micro controller. The micro controller calculates power by multiplying voltage and current sensed at the output. It then controls a pulse width modulator which is connected to the gate of the switch in the main buck converter. Detailed descriptions under each table below will further explain all the stages.

Table 4:
Main Buck Converter Description

<i>Module</i>	Main Buck Converter
<i>Inputs</i>	Input voltage ranging from 5V to 40V DC
<i>Outputs</i>	Output voltage is 5V DC
<i>Functionality</i>	Steps down input voltage from 5V – 40V DC down to 5V DC

Table 3-2 above describes the Main Buck Converter. The voltage output of a PV panel is the input of the buck converter. The varying sunlight intensity will cause the PV panel to produce an output voltage ranging from 5V to 40V DC. The buck converter steps down the input voltage down to 5V DC only when the input voltage is between 5V to 40V DC. It will not boost the voltage from 0V to 5V DC up to 5V DC since this is a step down converter.

Table 5:
Feedback Circuit Description

<i>Module</i>	Feedback Circuit
<i>Inputs</i>	Output voltage of main buck converter
<i>Outputs</i>	Preset voltage for error amplifier
<i>Functionality</i>	Using a resistor divider to provide a predictable voltage for error amplifier

Table 3-3 above describes the feedback circuit. The feedback circuit utilizes a resistor divider to provide a predictable voltage for error amplifier to compare with its reference voltage.

Table 6:
Error Amplifier Description

<i>Module</i>	Error Amplifier
<i>Inputs</i>	Voltage from the resistor divider network from the feedback circuit
<i>Outputs</i>	Powers Switch Control
<i>Functionality</i>	Keeps output voltage close to a designed voltage

Table 3-4 above describes the Error Amplifier. The Error Amplifier in feedback unidirectional voltage control circuit uses sampled output voltage to compare to a reference voltage. Any difference between the two creates a compensating error voltage which moves the output voltage towards the designed voltage.

Table 7:
Switch Control Description

<i>Module</i>	Switch Control
<i>Inputs</i>	Powered by Error Amplifier
<i>Outputs</i>	Oscillator frequency for the main buck converter
<i>Functionality</i>	Desired frequency is generated by the combination of the resistor divider

Table 3-5 above describes the Switch Control. The Switch Control determines the duty cycle of the device which will determine the output voltage of the system. Below is equation (1), the typical transfer function of a buck converter.

$$V_{out} = D * V_{in} \quad (1)$$

It is apparent that duty cycle, D determines the output voltage and duty cycle is defined by the equation (2) below.

$$D = \frac{T_{on}}{T} \quad (2)$$

Duty cycle D, is determined based on how long the switch is on over the entire period, T.

Research

The LTC3646 is a step-down DC/DC converter with a high side synchronous FET. It draws 140uA supply current at no load according to the datasheet located on their website [5]. It can supply up to 1A load and has a high efficiency due to the low quiescent current by the power switches. The device can handle input voltages between 4 to 40V and the frequency can be set between 200 kHz to 3MHz.

LTC3646, 1A Synchronous Step-Down Converter was found on the Linear Technology website [6]. The price of \$4 and 95% efficiency were appealing, thus was purchased.

Electrical Characteristics

Table 8:
Electrical Characteristics

Symbol	Parameter	Conditions	Min Max	Typ	Units
V_{IN}	Input Voltage Operating Range		4.0 40		V
I_Q	DC Supply Current Forced Continuous Sleep Mode Shutdown Mode	$V_{RUN} = 0V$		620 140 8 875 190	μA μA μA
V_{Out}	Output Voltage Range	LTC3646	2.0 30		V
I_{OUT}	Output Current			1	A
V_{FB}	Feedback Reference Voltage	$-40\text{ }^{\circ}C < T_A < 85\text{ }^{\circ}C$	0.594 0.606	0.6	V

The specifications above in Table 8 are extracted from the datasheet online [5]. The LTC3646 matches with our design specification. The input voltage ranges between 4 to 40V, the output voltage can be implemented to 5V, and the output current is guaranteed to 1A. It is important to keep track of the DC supply current when powering the device, to avoid damaging.

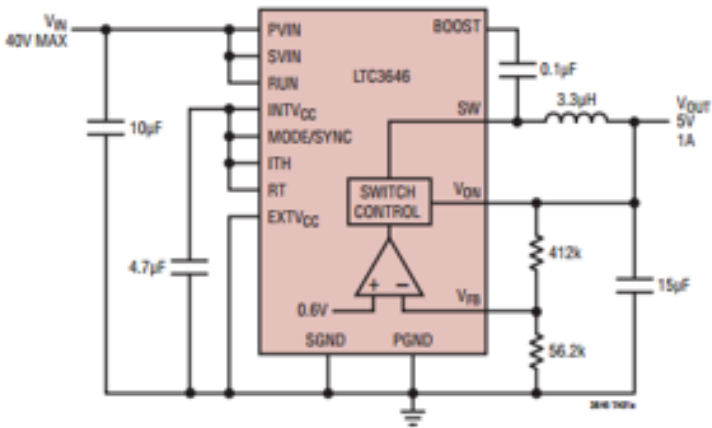


Figure 3: Block Diagram of LTC3646

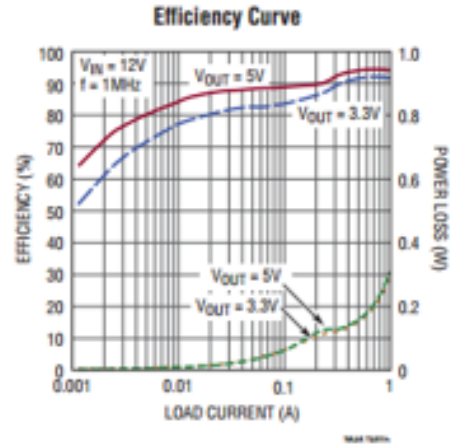


Figure 4: Efficiency vs. Load Current

In Figure 3 above, the block diagram displays three main components that match with our design. Those include the resistor divider on the output side, followed by a voltage feedback into an amplifier, and then switch control takes place. The simplicity of the layout was one of the reasons this device was picked and most of the time, the simple the design is, the less likely it is to make a mistake during the constructing phase.

In Figure 4 above, the efficiency curve displays the efficiency of the device vs. the output voltage under two different applications. Clearly, when a 5V output is implemented, the efficiency results in a higher percentage than the 3.3V design, thus more appealing to our application.

Simulation

A demo circuit provided online [6] gave promising results. With a wide range of input voltage from 7V to 40V, this particular circuit outputs 5V with 1A at a switching frequency of 2.25MHz. To program the output voltage, equation (3) below is used.

$$V_{out} = 0.6V\left(1 + \frac{R_1}{R_2}\right) \quad (3)$$

In order to achieve a 5V output, equation (3) is utilized with a combination of two resistors in the feedback network. If standard resistor values $R_1 = 620k$ and $R_2 = 82k$, then $V_{OUT} = 5.14V$. To achieve a better output voltage, $R_1 = 619k$ and $R_2 = 84.5K$ are chosen, and $V_{OUT} = 4.99V$ which is more accurate than using the standard resistor values to simulate. Choosing large resistor values will improve efficiency but might lead to undesired noise coupling due to the capacitance at the V_{FB} node.

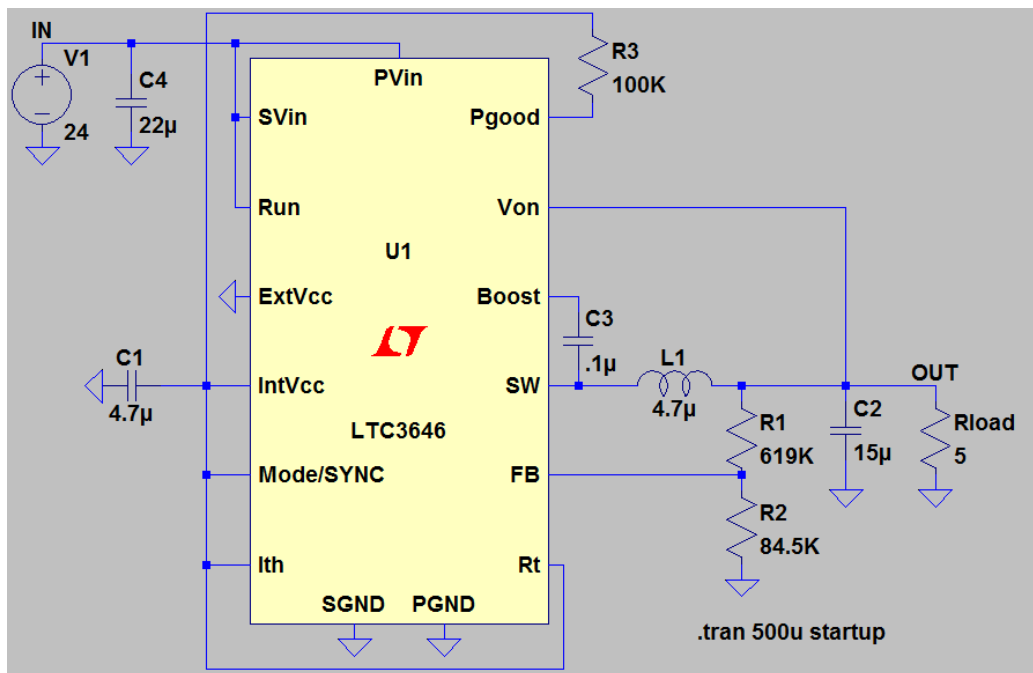


Figure 5: LTspice Circuit Simulation

The pin outs of the LTC3646 in LTspice is different the pin outs of an actual device. It is recommended to redraw the same circuit as it is easier to construct the circuit later.

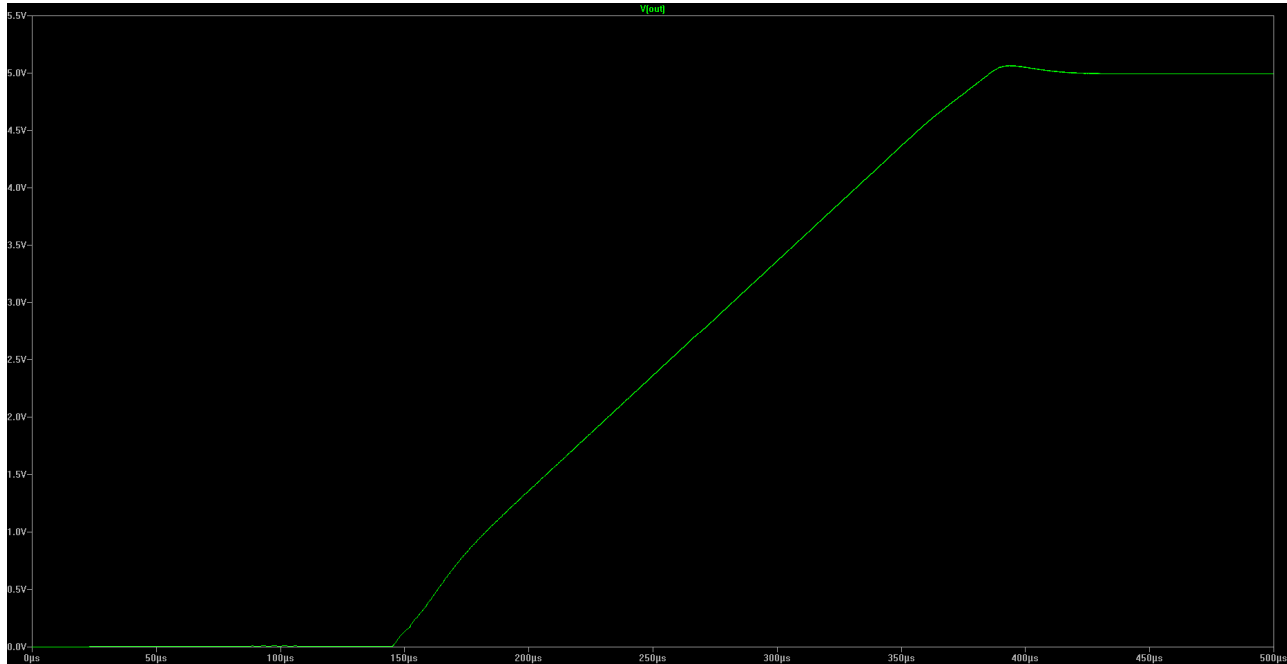


Figure 6: Output Voltage vs. Time

Figure 6 above displays the output voltage over 500µs. The voltage rises linearly from 0V to 5V from 140µs to 380µs. It is safe to say that it takes 500 µs for the device to reach steady state and perform the expected output voltage.

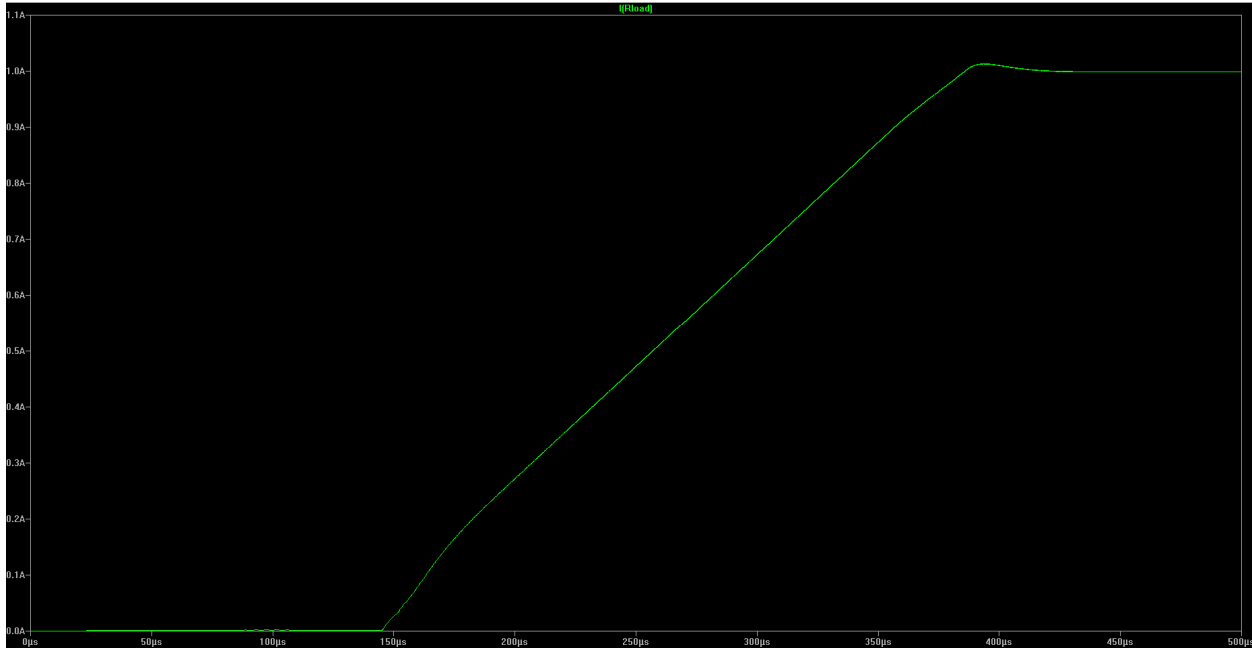


Figure 7: Output Current vs. Time

Figure 7 above displays the output current over 500µs. The current rises linearly from 0A to 1A from 140µs to 400µs. It is safe to say that it takes 500µs for the device to reach steady state and perform the expected output current.

Construct

Prototype #1

Refer to the Cost Estimate Table 9 on page 42 to purchase necessary components for circuit building. Trail 1 was constructed on a double sided Proto-Board because the circuit appears neat and components are securely soldered on. I chose not to build the circuit on a piece of breadboard because components tend to be loose and wires are connected in a messy way as the space on the breadboard is limited.

Equipment needed

- Soldering Iron
- Solder
- De-soldering wick
- Goggles
- Smoke Extraction
- Continuity tester
- Microscope

Because the LTC3646 chip is 3mm by 4mm, it requires a breakout board, thus DFN-14 to DIP-18 adapter was purchased, so it can attach to the Proto-board.

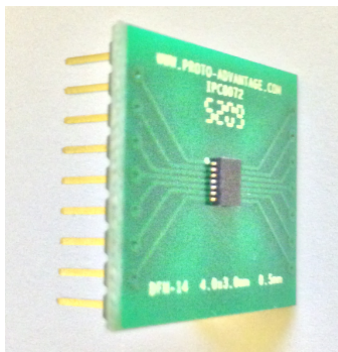


Figure 8: DFN-14 to DIP-18 with LTC3646 Attached

Figure 8 above displays the LTC3646 attached onto an adapter board. Proto Advantage Company was able to solder the component onto the adapter therefore no additional soldering is needed. Notice there are 9 pins on the side while there are only 7 pins on the LTC3646. The top

and bottom pins are not connected to the LTC3646 while they are only for supporting and grounding reasons.

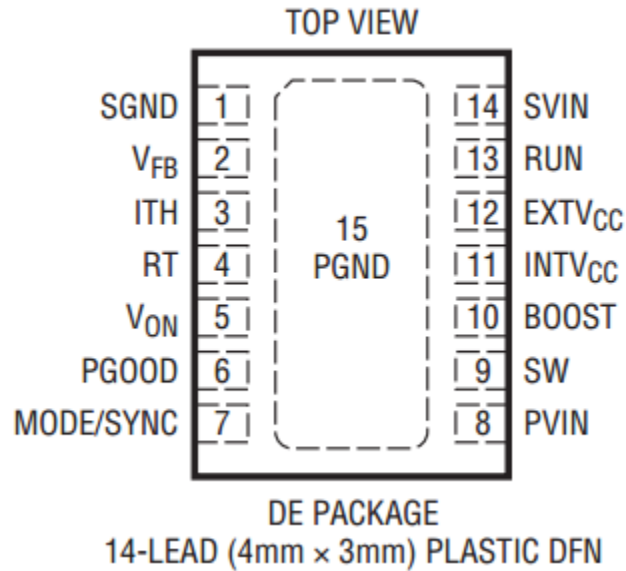


Figure 9: Pinout of LTC3646

Figure 9 above is the pinout of the LTC3646. Notice the pins are not located in the same place as it is shown in Figure 5 of the simulation. It is correct to follow the pinout above to construct the circuit.

Follow Figure 5 to solder all components onto the Proto-board and make sure to continuity check after each connection is made to ensure all connections are made appropriately.

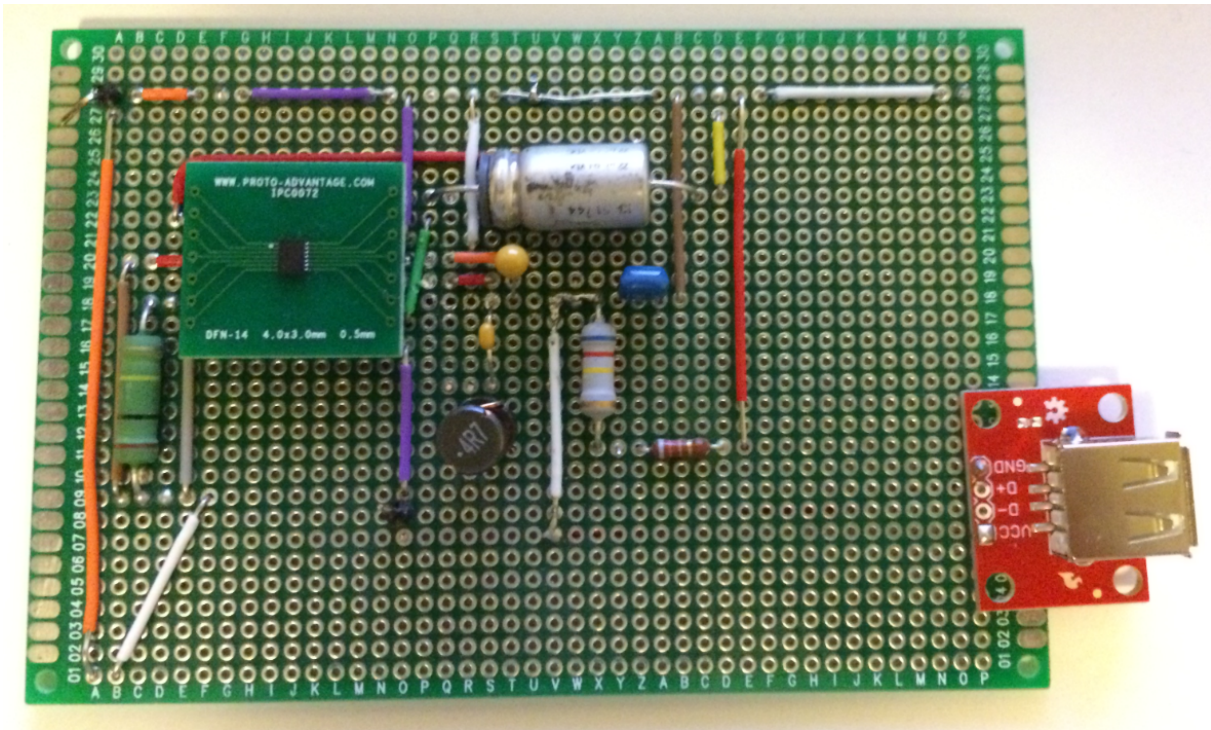


Figure 10: Front Side of Buck Converter on Proto-board

This is my example of the buck converter. Other alternative circuitry may be constructed based on preferences. I had the grounds to run through the entire left and top side of the board as it is easier for close-by components to make connections with ground. The reason I chose the USB output is because I personally own a rechargeable battery that can be attached with a USB to Mini USB cable which I owe prior to the project. It is essential to imagine the layout of the components onto the board before soldering to avoid component clustering and make sure there are spaces for components.

I prefer the double sided Proto-board over a single sided board because if overlapping connections exist on one side of the board, one can simply make a connection on the other side to avoid shorting and unnecessary wirings.

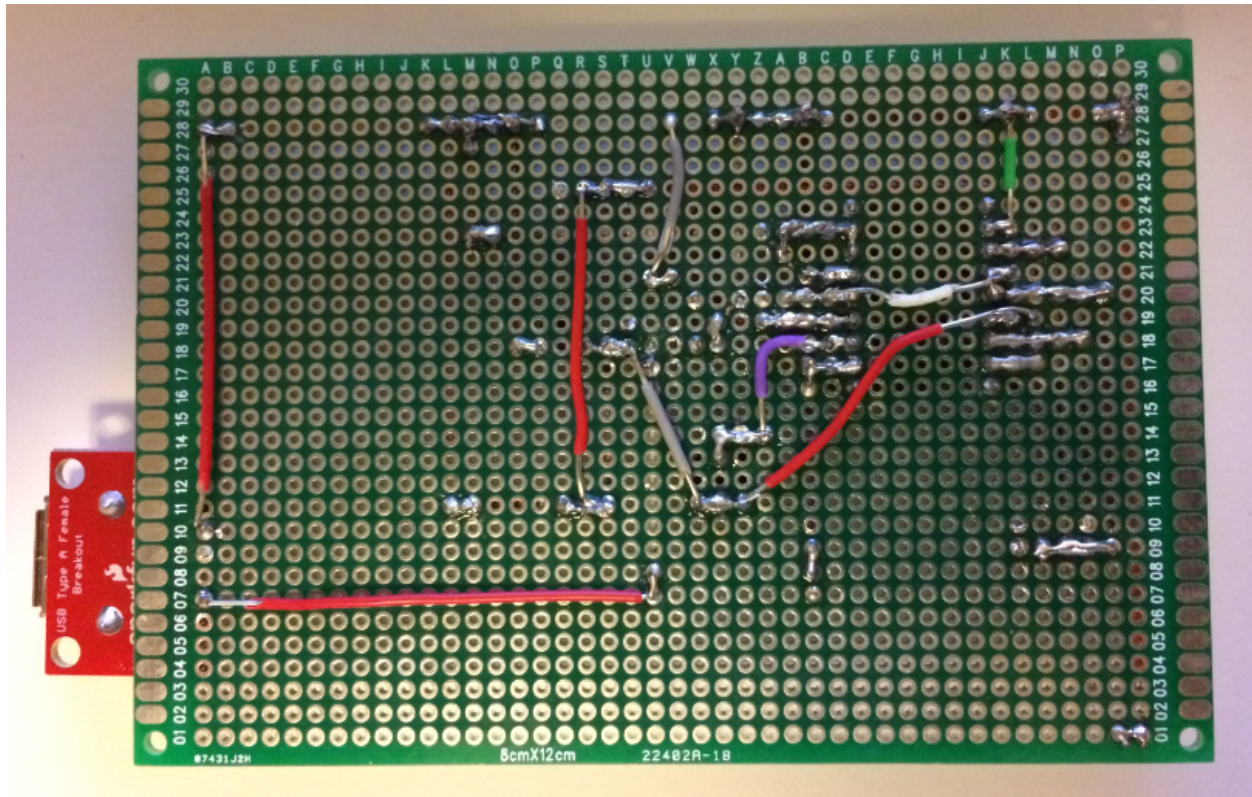


Figure 11: Back side of Buck Converter on Proto-board

Figure # above displays the back side of the buck converter on the Proto-board. While the front side of the converter looks neat, the back side is not. Notice the grounds are the top and right side as the board was flipped 180 degrees horizontally. Located on the right side is where the pins of the LTC3646 are and the all 14 pins of the chip can be seen in the shape of a rectangle. Located on the bottom left side is the USB output which is connected to V_{OUT} of the circuit and ground.

When soldering the 14 pins of the LTC3646, it is extremely important to avoid shaky hands to not make accidental connections as it is very hard to de-solder around the clustered pins. It is also important to check 14 pins are not interconnected using a microscope, unless it is

instructed on the circuit layout from Figure #. After continuity check is performed on all connections, the converter is ready for testing.

Prototype #2

For the second attempt, all procedures and parts remained the same except the circuit is constructed on a breadboard instead of a double sided Proto-board. No soldering equipment is needed as all components and wiring are connected to the breadboard by pushing the pins. It is a lot less time consuming to construct the circuit on a breadboard comparing to soldering on a Proto-board. It took less than an hour to plan out the circuitry and finish all connections. It is very important to plan on the circuitry around the LTC3646 adapter carefully because the body of the adapter takes a lot of space, as shown in picture below. I suggest using a bigger/wider breadboard because it was very hard to construct this circuit onto a skinny breadboard. There was many times where jumper wires were used to redirect components elsewhere on the breadboard, instead of directly connecting the components to the pin outs. With more jumper wires used, the more likely it is to have loose wiring and create bad connections, which can results in shorting and potentially damaging the converter.

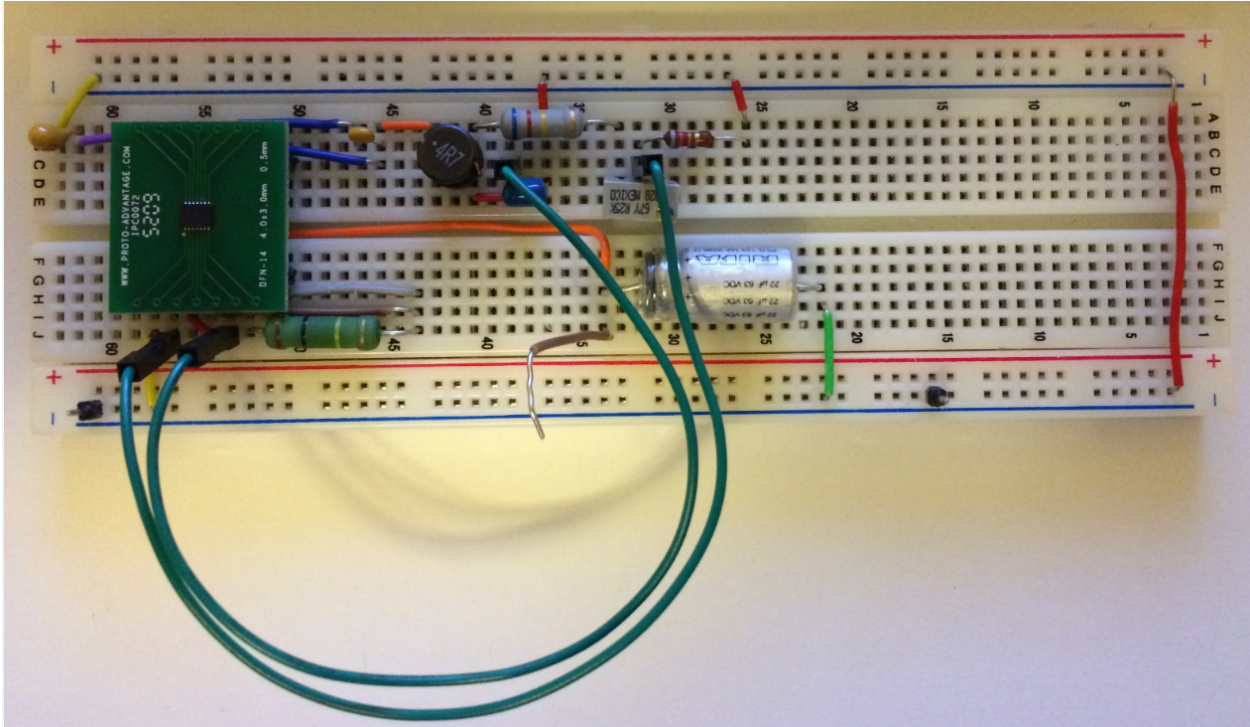


Figure 12: Buck Converter on Breadboard

Figure 12 above displays the completed buck converter on a breadboard. The components on the board are not as secure and flimsy comparing to soldering the components on a Proto-board.

Test Results and Conclusions

Test Results #1

Equipment needed:

- Power supply
- Oscilloscope
- Multi-meter

To test the converter an input voltage between 7V to 40V is applied and an output voltage of 5V and current of 1A should appear on the output. Apply 7V to pin 8 shown in Figure # by using the power supply, and attach the multi-meter to the output at pin 5.



Figure 13: Output voltage of the Buck Converter on Proto-board

Approximately 0V is displayed in Figure # above. Usually when there is no output produced, the switch is not being powered correctly, so the next step is to check the switching node at pin 9 using the oscilloscope.

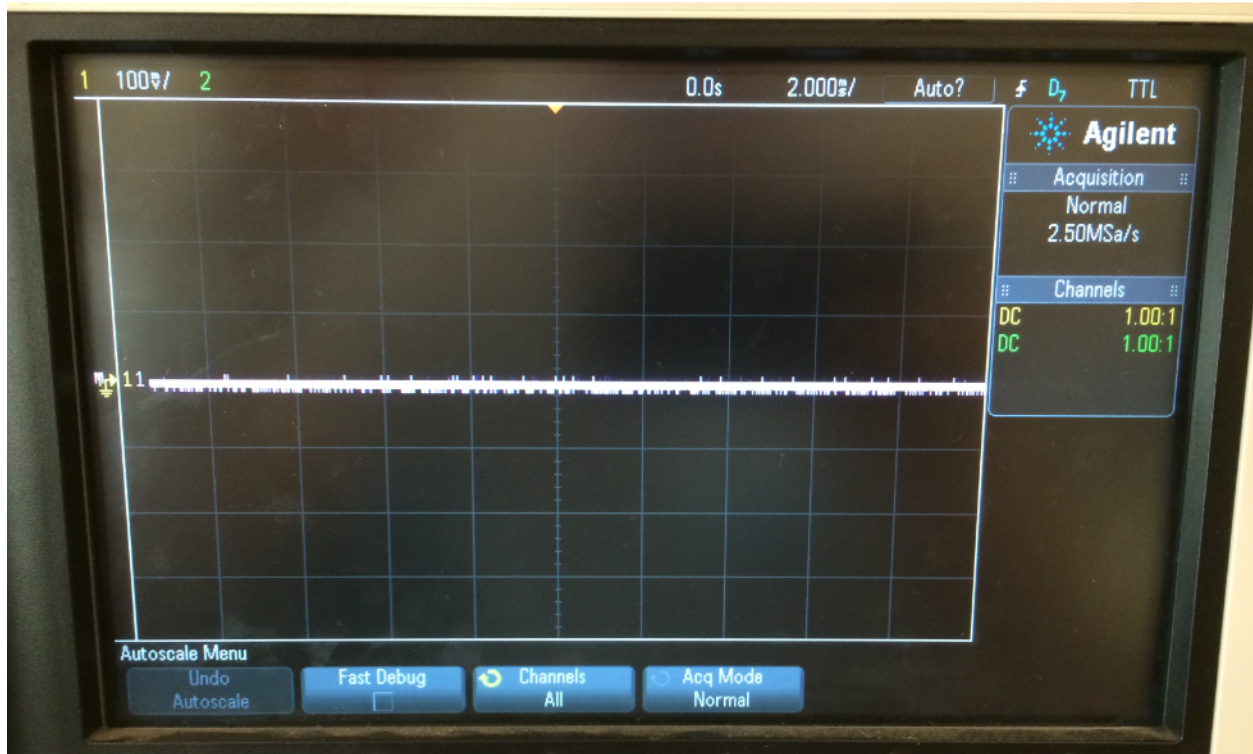


Figure 14: Voltage at Switching Node Pin 9

Approximately 0V is displayed in Figure 14 above. The switch is not working according to the oscilloscope as no switching is occurring.

Soon after, I realized the LTC3646 was extremely hot and there is a dark circular spot around the chip. Hoping my chip was not damaged; I carefully went through the continuity check

again and found an error. From my recollection, when I attached one end of the continuity checker to ground and the other end of the wire to pin 5, a beeping noise occurred periodically.

To fix the connection for pin 5, I performed the continuity check on all connections made with pin 5 and de-soldered them. After re-soldering pin 5 and the wires attached to it, the error was fixed and preceded with testing. The results remained the same as 0V and I concluded the LTC3646 was damaged due to shorting and overheating.

Prototype #1 Conclusion

Due to a poor circuit construction and continuity checking prior to applying power to the circuit, the LTC3646 chip was overheated and damaged. The construction of the circuit on a Proto-board was very time consuming, it took several hours to carefully solder each component and check each connection between each step. If one decided to test the circuit on a Proto-board, I recommend to thoroughly checking all possible connections prior to applying power. I was overly excited to see the results and did not pay very close attention to continuity checking which resulted in damaging the main chip of the converter. This resulted in over a week of delay to the project as I had to order and wait for a new chip to arrive. Another reason for the long delay is because the Proto-Advantage company also has to solder the small chip onto the adapter which takes time. Even though Prototype #1 failed to work, I still learned many things from it. I learned to be patient with building and checking the circuit before applying power to it. If the previous steps were not done so accurately and safely, then more mistakes are likely to occur later on in the project which can potentially result in redoing many things such as re-ordering parts, re-soldering, and testing.

Test Results #2

The same equipment as Prototype #1 is used in testing the buck converter. Apply 7V to pin 8 in Figure # by using the power supply and display the output voltage of pin 5 using a digital multi-meter.

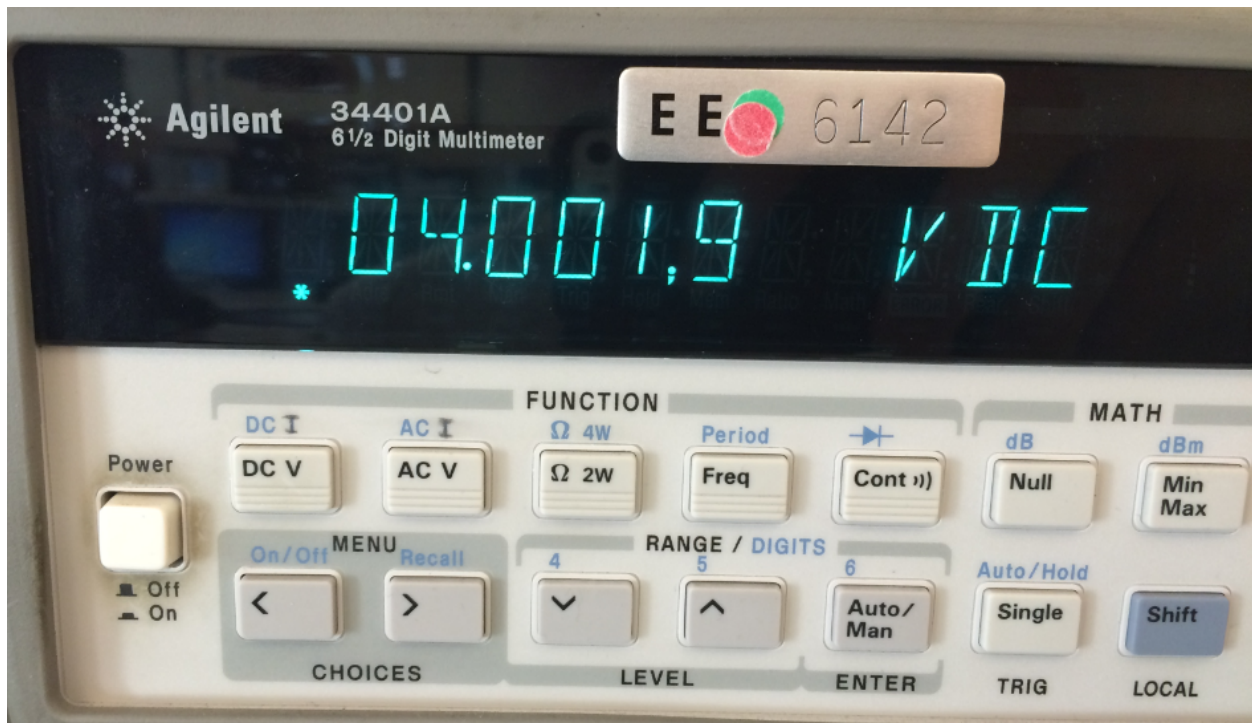


Figure 15: Output Voltage of Buck Converter on Breadboard

Figure # above display the output voltage of the Buck Converter. The value of the output voltage is 4.0019V which is an improvement than the results obtained in Prototype #1. However the desired output is 5V, therefore I began troubleshooting by removing resistors R1 and R2 from the feedback resistor divider network and measured their values individually. Equation 3 is used again to see if the actual values of the resistors result in the desired value $V_{OUT} = 5V$.

$$V_{out} = 0.6V\left(1 + \frac{R1}{R2}\right) \quad (3)$$

The actual values of R1 is 582kΩ and R2 is 92kΩ which results V_{OUT} to be 4.4V using the equation above. This result was successful because it matched up with our calculation by an error of 9.07% which is decently good. Even though the result is not exactly what was expected, it is easy to alter the resistor divider R1 and R2 to change the output value. In order to achieve the desired output of 5V, I decided to add a potentiometer in series with R1 to increase the net resistance which results in 5V at the output.

$$V_{out} = 0.6V\left(1 + \frac{582k+x}{92k}\right) = 5V \quad (4)$$

Using equation 4 above, x represents the value of the potentiometer. By solving the equation, x is approximately 92.667k. I adjusted the potentiometer to 92.67kΩ and attached it in series with R1. Now the buck converter is ready to undergo testing.

After applying 7V to the input, an output of approximately 0V appeared on the output. I proceeded to double check the physical connection of the resistors including the potentiometer. No accidental connection error was made, so I removed the potentiometer in hope to achieve the 4V output again. Unfortunately that was not the case, and 0V remained as the output. The LTC3646 chip's exterior appeared to be very hot, and I concluded the device was damaged.

Prototype #2 Conclusion

The circuit was constructed on a breadboard which took less than an hour. It was a much quicker method than soldering all components onto a Proto-board. An output voltage of 4.0019V was achieved shown in Figure #. To change the output voltage to 5V, a potentiometer of 92.67k Ω was added in series with R1. The LTC3646 chip was damaged after and I could not determine the reason why adding a potentiometer can potentially damage the converter. Because only 2 chips were ordered which were both broken, there was not enough time to order another chip and undergo testing. It is good news that I was able to produce an output voltage of 4.0019V which was 0.9981V less than the desired value of 5V.

Improvements

Tips and Recommendations:

- Using surface mount on PCB vs. through hole on breadboard/proto-board
- Thorough continuity checking
- Component checking

At the beginning of the construction phase, I contemplated whether to build the circuit on a PCB or breadboard/proto-board. I decided to solder components on a proto-board since I had prior experience with soldering and had no experience with surface mount components. I have realized how much longer soldering through-hole components onto a proto-board is and the trouble of de-soldering. I recommend others to look into surface mount components and assembling onto PCB. It is less time consuming and easier to de-solder with the use of a heat gun.

De-soldering using a soldering iron, wick, and solder sucker is time consuming and one can potentially damage the components if the soldering iron makes physical contact with the components for a long time. Therefore, I suggest the use of PCB with surface mount components.

It is extremely important to thoroughly conduct continuity checking for all connections prior to testing. For prototype #1, I made a mistake on rushing this step and a shorting had caused to damage the device. Too much excitement can cause one to rush steps which need careful attentions. For prototype #2, I believe the added potentiometer had cause to damage the chip since the converter was working. I could not come up with a reason why the potentiometer had caused trouble as it is just a simple variable resistor. Continuity checking is a very important step because one can potentially damage the device on accident.

It is also important to check the component values prior to constructing. Especially with resistors, their actual value are usually different than the nominal value. In my case, both of the resistors of R1 and R2 were off by approximately 7% which made a difference of 1V off for the output voltage. I recommend buying components with the least percent tolerance within budget.

Conclusion

The goal of the Buck Converter project was not met. The requirement of a 5V output was not achieved, however 4.0019V was obtained before the LTC3646 chips were damaged due to shorting of wires and overheating. Two essential techniques which must be thoroughly conducted during circuit building are continuity checking and the measuring of component values. It is important carefully conduct these two steps above and avoid rushing to test. This ensures the safety of the device and to produce a successful outcome. It is also recommended to purchase components with the least percentage of tolerances and calculate the output voltages based on the worst case scenarios which the feedback resistors can be using equation 3. In addition, constructing the circuit using surface mount components on a PCB is suggested because there are no wires used. This can minimize the possibilities of shorting which can potentially damage the device. Even though the desired output was not achieved, I was able to gain experience through researching for an appropriate device, simulating the circuit using LTspice, constructing, testing, and troubleshooting the circuit. This project is aimed to charge a common rechargeable battery with low voltage and current, while future implementations will aim towards charging larger battery storage units such as electrolysis fuel cells.

References

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Appendix

ABET Senior Project Plan Analysis

Buck Converter

Bowen Liu

Dr. Ahlgren

Summary of Functional Requirements

The buck converter is capable of converting high voltages from PV panels to low voltage to lower voltage to charge a battery system. This converter has high power conversion efficiency to store the energy harnessed from PV panels. All specifications and functional requirements are found on chapter 2 starting on page 6.

Primary Constraints

Two limiting factors are cost and time. There is not enough funding and time to design, implement, and test a buck converter that takes a couple hundred volts as input and steps it down to less than fifty volts. It is determined to follow the buck converter experiment done at the University of Colorado [1] to get a feel of interfacing PV panels with battery storages. The buck converter experiment at the department of Electrical and Computer Engineering utilizes a 35V DC input and 12V DC output for the buck converter, which is cheaper to manage. It is reasonable to spend three quarters and a couple hundred dollars on this project.

Economic

People would use this buck converter for their facilities where PV panels and batteries exist with matching specifications such as the output voltage and power of PV panels and input voltage and power of battery storages. This converter can be sold along with PV panels and battery storages for extra profit. Manufacturing personnel are benefited from producing this product. Sand and copper are two major Earth's resources and they are used for production.

The project's cost and benefits accrue after it is bought by consumers and used on PV panels and battery storages.

Inputs of the project are based off of the buck converter experiment done at the University of Colorado, Boulder [1]. The original estimated cost of component parts is \$176.43. The actual final cost of component parts is to be determined. The additional equipment costs are determined as project develops further.

The project earns about \$50 dollars per unit sold. The people who earn the profits are I, Dr.Ahlgren, and anyone who contribute to the project enough to develop effective results.

The original estimated development time as stated in the Gantt chart is 12 months and the actual development time will be determined. After the project ends, further improvements will be made to the project in terms of power conversion efficiency, exterior appearance, and marketing strategies. After these three criteria's have been developed, then production can start and the product should exist on the market for 5 years before the next improved version finishes developing. The maintenance cost exists when products are malfunctioning and the operation costs exist when converter is powered by any energy source.

If manufactured on a commercial basis

- Estimated number of devices sold per year is 200.
- Estimated manufacturing cost for each device is \$200.
- Estimated purchase price per device is \$350.
- Estimated profit per year is \$30,000
- Estimated cost for user to operate device per unit time is \$10 per month.

Environmental

Natural resources such as sand and copper are used when manufacturing the converter. The total natural resources associated with sand and copper will decrease as more converters are produced. The manufacturing process requires copper and plastic. The air is polluted by producing this product but the energy and electricity consumption are reduced by using this converter. There will be slightly less sand on the beach which might impact species living in such environment. The air is affected which matters to all species that breathe the air.

Manufacturability

The buck converter uses pre-manufactured items such as resistors, inductors, capacitors, and pulse width modulators. Assembling and soldering components are the most challenging process since precision of component placing and neatness of it are very important to successfully build a buck converter.

Sustainability

This converter is not hard to maintain. Regular circuitry checkup and dust cleaning might be needed annually. This converter will help the PV panels convert power more effectively and store it into a battery cell. This process improves the regeneration of energy and electricity resources. Improving the power conversion efficiency is the primary upgrade for the project. Improving the power conversion efficiency requires heavy research, cost and time. With better efficiency, the component cost increases dramatically and heavy research comes with times which are required in order to improve the efficiency of the converter.

Ethical

Taking the Utilitarian ethical approach, the factor of saving more power from a very efficient power conversion can overcome the negative side of producing such product, polluting the air and using natural resources. The product is misused if it is manufactured but not interfaced between PV panels and battery storages, therefore not utilizing the product for its purpose. The following will address the IEEE code of ethics [2].

1. The authors of this project have the responsibilities. The economic, environmental, and sustainability analysis addresses the health and safety issues of the project.
2. No conflicts exist at the moment.
3. The introduction in chapter 1 on page 5 explains the reasons of following a similar buck converter experiment done at another university. Table 5-1 shows various estimates for the project.

4. Potential briberies may exist. Semiconductor companies and manufacturers could bribe the authors to buy the entire project and make it their own products.
5. Similar products already exist. However, this project will help users to interface technologies related to energy harnessing. One feature of the project is the maximum power tracking done by using a micro controller and sensors.
6. The author of the project purse a degree in Electrical Engineering at California Polytechnic State University of San Luis Obispo at the time this was written. Advisor Dr.Ahlgren and UL standards [4] provide safety guidance.
7. The project receives many technical reviews, comments, and honest criticism from many Electrical Engineering students graduating in fall of 2014, and professors David Braun, Taufik, and William Ahlgren.
8. This product does not discriminate based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression; however, users should have electrical engineering and safety knowledge to ensure no one is harmed when operating the product.
9. This product does not injure any users, property, reputation, or employability. It does not negatively affect other systems when interfacing.
10. This report informs users and manufacturers on guidelines to follow and pitfalls to avoid.

Health and Safety

One health and safety concern associated with designing the project is the lack of sleep from working overnight and overloading one's self. One health and safety concern associated with manufacturing the project is from the toxic chemicals producing when soldering

components and the making of PCB. The major safety concern associated with the use of the project is getting shocked by the electricity when handling the converter.

Social and Political

When designing the project, it is important to have an ultimate goal of minimizing power consumption and maximizing power conversion efficiency because the PV panels and electrolysis are used for renewable energy usages. This converter's purpose is to assist PV panels and battery storages to better harness and storage energy from the sun.

The direct stakeholders of this project are the companies that a designer buys components from, companies that the designers sell the products to, my advisor Dr. Ahlgren, people who utilize my product and help me design, and me. The indirect stakeholders are drivers who deliver components bought for the project, late night food providers where designers purchase food from working on the project at night, and other students in the electrical engineering major who help me design the project.

The project can harm some of the designers' health because the designers might overload themselves and work overnight which might cause lack of sleep and other health issues associated with overworking. The project will benefit the drivers, companies with money from the purchasers. It will also benefit the designers with improvement of knowledge on converters, how to manage time better, and foresee the future of renewable energy technology.

The stakeholder will benefit equally depends on how much effort they put into the project. Most of the indirect stakeholders will benefit from the project without knowing it. The project

creates many inequities because not everyone can partake on designing a specific section of converter. The many contributors for the project is the advisor and myself.

Most of the stakeholders' locations, communities, and access to resources, economic power, knowledge, skills, and political power will take place near Cal Poly San Luis Obispo because the project is being designed at school. The companies and driver who benefit from the project might take place in other areas of the country depending on which companies the designers choose to buy components from.

Development

From developing the project, I learned the importance of producing an excellent project plan, including engineering specifications and functional block diagrams. It is extremely important to be clear and concise when planning for the project since the cost of changing any part of the project exponentially increases with time. It is a good practice to simulate the converter using LTspice before buying components for testing. It is also important to have regular checkups with the advisor for feedbacks.

Cost Estimate

Table 9:
Cost Estimate

Item	Value	Quantity	Price Per Unit	Total Cost	Provider	
Resistor	82k Ω	3	\$0.37	\$1.11	Digi-Key	
	100k Ω	3	\$0.63	\$1.89		
	620k Ω	3	\$0.25	\$0.75		
Capacitor	0.1uF	3	\$0.37	\$1.11		
	4.7uF	3	\$0.67	\$2.01		
	15uF	3	\$1.71	\$5.13		
	22uF	3	\$11.9	\$23.8		
Inductor	4.7uH	3	\$1.09	\$3.27		
Female USB Breakout		1	\$3.95	\$3.95		Sparkfun
Various Jumper Wires		1	\$8.99	\$8.99		Radioshack
Breadboard		1	\$8.00	\$8.00	Amazon	
Double Sided Proto-Board	8.00 x 12.00cm	1	\$7.62	\$7.62		
LTC3646		2	\$6.08	\$12.16	Digi-Key	
DFN-14 to DIP-18 SMT Adapter	4.0 x 3.0mm body	2	\$14.89	\$29.78	Proto Advantage	
Total:				\$110.57		

