



The "Minty Boost®" as an Exciting Laboratory Experience in Learning Power Electronics and Instrumentation

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Introduction

Limor Fried designed and markets a cell phone charger under the trade name, Minty Boost[®]. A Boost Converter, a common power electronic converter circuit, provides the main function: boosting about three Volts from a series pair of AA Alkaline cells to five Volts, the standard voltage of a USB cell phone input. The Minty Boost[®] also contains appropriate logic to protect the circuitry and to enable the higher current mode of the USB. The Minty Boost[®] is packaged as a kit for the user to solder together and then to place inside an Altoids[®] tin or similar container. Hence, its name is Minty for the container and Boost for its function. The Minty Boost[®] provides responsive, mobile power on demand to any USB appliance¹



Figure 1. Minty Boost[®] shown charging a cell phone

With the advent of ubiquitous cell phones and tablets among students of all disciplines, a project like the Minty Boost[®] quickly generates excitement among the students. Power management has become a basic skill of everyone in their generation, not just the electrical engineers. To build such a useful tool while reinforcing their classroom instruction is a “win-win”. The Minty Boost[®] clearly does generate this excitement: Sophomores ask about it a year in advance. It integrates the instruction in dc/dc converters with a practical piece of hardware, requiring study of the behaviors of the boost converter, a knowledge of its characteristic current and voltage waveforms, and an understanding of how the converter’s control system works. The Minty

Boost[®] kit teaches soldering and gives an understanding of the basic operation of a boost converter while having fun with an open-source project.¹ The board's layout does not lend itself to easy measurement of things electrical by a junior undergraduate electrical engineering student. Yet, making measurements presents an interesting and realizable instrumentation challenge for an undergraduate energy course's laboratory requirement. These challenges include the following:

- measuring floating voltage waveforms,
- measuring and displaying current waveforms from a circuit board,
- synchronizing those voltage and current measurements,
- engaging and then making such voltage and current measurements in the presence of a time-varying load, and
- measuring dc power and energy efficiency in this environment.

The Minty Boost[®] provides an exciting laboratory vehicle to learn power electronics. This paper describes a way to do this, beginning by first describing the circuitry. Assembly and soldering the kit finishes a functioning charger for a cell phone. Second, the Minty Boost[®] fits readily into a standardly equipped undergraduate electrical engineering circuits laboratory environment. Such a laboratory's equipment can provide voltage measurements, but a simple circuit modification is necessary to measure the converter's inductor current. A small number of elementary measurements provides appropriate insight into converter operation. Third, procedures for making these measurements are described, followed by a few salient results. Finally, an assessment of student learning completes this paper.

Context

The Minty Boost[®] laboratory exercise is the seventh of eight laboratory exercises in a junior-level introductory course in electrical power. This is a mandatory course for all who seek a baccalaureate degree in Electrical Engineering at this university, the first of four courses in sequence in electric power engineering. With the exception of DC machines, most of the topics typical of a junior-level electric machines course are taught in the second course in this sequence.

This course significant topics in electric power that all electrical engineers are likely to encounter, not merely subjects unique to those students who propose to make a career of electric power engineering. For example, the following subjects are taught: dc and single phase ac power fundamentals, inductive and capacitive energy storage, real and reactive power methods, single phase transformers, per unit normalization, electromechanical analogs, heat sinking, magnetic circuits, motor and generator laws, dc motors, dc/dc converters, switch mode power supplies, electrical wiring, and power quality basics. It is indeed a full course of 45 hour-long lessons. It has a companion laboratory course with a sequence of eight, three-hour laboratory exercises in most of the topics listed above. The Minty Boost[®], the seventh of these laboratory exercises immediately follows the classroom work on switch mode power supplies.

Minty Boost[®] Description

Adafruit Industries[®], Limor Fried's company based in New York City, sells the Minty Boost[®] battery charger as a kit for less than twenty US dollars.¹ When assembled and placed into an Altoids[®] tin, the Minty Boost[®] charges most cell phones and other portable consumer electronics at the rate of 500mA into a USB port. This kit comes with all of the specified parts and a through-hole circuit board on which to mount them. Consistent with Limor Fried's design philosophy, the entire kit, schematic, and instructions are "open source". Figure 1 shows a completed and functioning Minty Boost[®]. Figure 2 is the open source schematic. There are readily common, recognizable circuits within this schematic, such as a boost converter, voltage dividers for analog address security and decoding, analog filtering and decoupling, and appropriate and effective grounding connections.

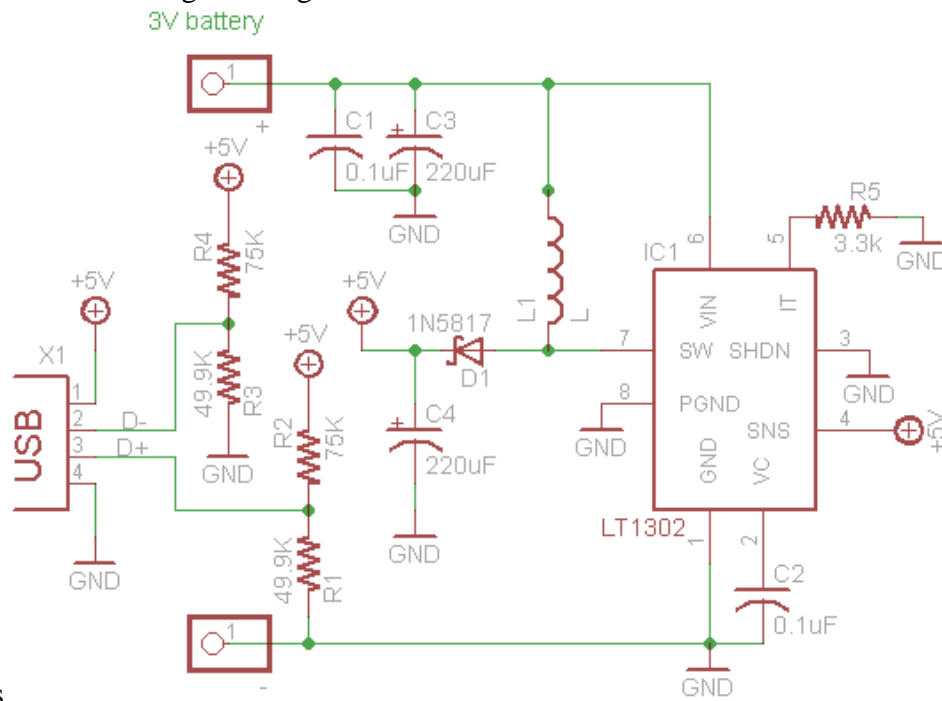


Figure 2. Schematic of the Minty Boost[®] power electronic converter circuit²

Complete parts list are available on the Adafruit Industries[®] website.² Adafruit offers customer service and volume discounts.^{1,2} Assembling and soldering the kit finishes a functioning charger for a cell phone or any other electronic device with a USB port that can charge the device's batteries. For our lab, we finance the Minty Boost[®] through laboratory fees.

Laboratory Equipment and Procedures

A standardly equipped undergraduate electrical engineering circuits laboratory has most of the equipment necessary for an insightful instructional laboratory exercise. This equipment includes the following:

- DC Power Supply, 2-5V, 500mA, as an input voltage for testing
- DC Power Supply, $\pm 12V$, for an active current sensor, if necessary

- Voltmeter, DC, to measure up to 5.0 Volts
- Ammeter, DC, to measure up to 500mA
- Oscilloscope, to measure $\pm 12\text{V}$, 500kHz voltage waveforms
- Isolating voltage probe
- Current probe

Of these instruments, the two probes may not be available in an undergraduate circuits laboratory. They are both typical of a standardly equipped power electronics laboratory.

An isolating voltage probe is a two-terminal probe that can measure voltages without regard to having the reference terminal common grounded to the oscilloscope's ground. Typically, these isolating voltage probes have the two input leads or terminals to connect to the circuit, an interface that provides the isolation, and an output terminal or cable to connect to the oscilloscope. Common units have 2500 Volt optical isolation. Most units have onboard attenuation of the input signal: Typical attenuations are 10:1, 100:1, or 1000:1. These can be purchased for less than the cost of a low-end oscilloscope from any oscilloscope retailer.

To measure currents on the Minty Boost[®], an active clamp-on current probe is desirable. Most clamp-on current probes are passive, sensing time-varying currents only. An active current probe employs the Hall Effect to measure both DC current components and time-varying currents. Oscilloscope vendors usually have a selection of active current probes available. If the cost of an active current probe is too great, there are Hall Effect current sensors available from several companies, for example,³. These Hall Effect current sensors require a biasing source, typically a double-sided $\pm 12\text{V}$ source, and a small resistor, typically 100 Ohms, $\frac{1}{4}$ Watt, for the sensor's open-collector output. An example sensor system using a LEM[®] model LV 25-P current sensor is shown in Figure 3.⁴ The current to be measured flows into terminal +HT and out of terminal -HT. Terminals labelled + and - are the double-sided biasing voltage source. 0V is the biasing source reference ground. R_1 is the source impedance or a current-limiting impedance of the circuit under test. A reading appears across calibration resistor R_M as a voltage proportional to the current of the device under test and the calibration resistor.

Connection

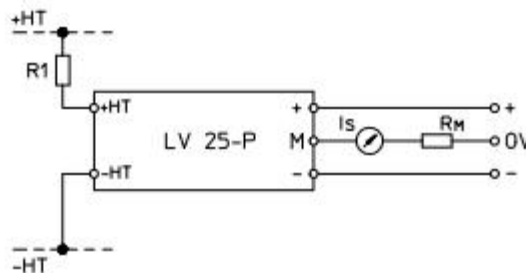


Figure 3. Less expensive current sensor circuit.⁴

Though any low-end oscilloscope that is common to an undergraduate electrical engineering circuits laboratory works find for the measurements described in this paper, we have found that automated data collection can be conveniently taught in this laboratory exercise. Our students

are familiar with the Digilent[®] Electronics Explorer laboratory measurement system.⁵ Their circuits course instructors require them to install the software on their laptop computers and to use the Digilent[®] Electronics Explorer measurement system breadboards in sophomore circuits laboratories. Therefore, the students come into the Minty Boost[®] laboratory exercise already exposed to an automated data collection system. A repeated warning that they will be required to take data with that Digilent[®] measurement system is usually sufficient to encourage review.

The Digilent[®] Electronics Explorer is convenient, but it is by no means the only system of its kind, either commercially available or instructor-designed, that is capable of displaying results directly to the student's laptop computer. Any system that is capable of collecting voltage measurements and oscilloscope traces at the voltage and isolation specifications given above should be sufficient.

Experimental procedure

This laboratory exercise has a preparation and a measurement phase. Preparation consists of assembling the circuit board and verifying its operation.

Instruction in soldering has been offered in a combination of four ways: for many years, a laboratory technician provided a hands-on class in our project laboratory for those who students want to attend. The past two years, the professor chose to ask the class, "Who knows how to solder?" About half of the class raised hands. The professor then responded, "Ladies and Gentlemen, look around and see who can provide you with mentoring on how to solder your project." There are a host of good soldering videos on YouTube.⁶ Adafruit Industries has a superb soldering tutorial on its website.⁷ Regardless of the method chosen, all circuits were soldered and without an objectionable difference in the quality of their soldering. Of course, failure to solder a board together earned an immediate grade of zero. To date, few have failed to show up for class without a soldered and working Minty Boost[®].

Students are instructed to make the following adjustments to the Minty Boost[®] assembly instructions:

- a) Only solder in one end of the inductor to the board. We will be making current measurements in the inductor.
- b) Do not solder in the 2xAA battery holder so that tests can be performed on the Minty Boost[®] assembly. Instead, solder on leads to the holes marked + and -. These will be used later to connect a DC Power supply to perform various tests on the Minty Boost[®] USB charger.

Instruction a) enables measurement of the boost converter's inductor current, an important state variable leading to understanding of how the converter works. Instruction b) is merely a convenience. The battery holder tends to flop around and get in the way during testing.

Students take the following measurements:

- Input DC voltage and output DC voltage over a range of input voltage values. This illustrates the active switching voltage regulator function of the Minty Boost[®].

- Inductor current waveform. Per instruction a) given above, a wire or lead connected between the open inductor terminal and the through hole on the circuit board provides a convenient place to attach the current sensor. The current waveform is then displayed on the oscilloscope or Digilent® data display on the student's laptop computer.

To perform correctly, the Minty Boost® requires a load. Students volunteered their cell phones to provide this load.

Students performed the voltage regulation exercise individually. Groups of two or three students engaged the current waveform measurement because there were only two current sensors for sections of approximately twenty students.

Results

The laboratory experiment had two parts: a voltage regulation experiment and a current waveform experiment. Appendix A shows the experiments' instructions.

The voltage regulation portion of the experiment showed less than 1% variation in output voltage for a variation input voltage from 2.5 Volts to 4.5 Volts, but with a substantial loss of regulation for a 2.0 Volt input.

The inductor current waveform is the typical triangle wave with a DC offset. The DC offset is the charging current for the battery. The triangle wave ripple is a large fraction of the DC offset. The Minty Boost® maintains both voltage regulation and current regulation by regulating the duty cycles of each pair of two consecutive switching cycles. The result is a triangle wave with a controlled duty cycle that is periodic every second cycle. Waveforms varied with the charging state of the load. . It is possible to get discontinuous conduction for light loads. Waveforms for discontinuous conduction are intermittent, difficult to capture and interpret. Discontinuous conduction can be easily avoided by using a load that needs charging.

Certainly, more could be done in investigating the Minty Boost®. Some examples include: the boost converter's control system, the circuitry that determines the switching frequency and modulates the boost converter, and the clever hardware key that unlocks a high current mode in iPhones. What was done seemed sufficient for a single hour of time in a junior undergraduate energy systems laboratory.

Assessment

Assessment was performed in three ways: a summary of student comments on course evaluations, an examination on power electronics immediately following the laboratory exercise, and an observation about how the students maintained an opinion of the Minty Boost® laboratory exercise long after the course ended.

Each year, course evaluations indicate a strong approval of the Minty Boost® laboratory. Typically, over 10% of the students respond with unsolicited written comments indicating favorable opinions of this laboratory exercise. In six years of offering this laboratory, no student

has ever made an unfavorable comment on the university's course evaluations or on the instructor's more detailed written course evaluation. This is nearly the last laboratory exercise in the course, so it is not likely to be forgotten if it was unpleasant or unproductive.

The last formative examination in the course immediately follows the Minty Boost[®] laboratory exercise. It is a one-hour in-class examination. Student performance exhibits no significant deviation on questions related to the boost converter compared to questions on other topics.

Students may keep their Minty Boost[®] if they wish. In six years, only four students have decided not to keep their Minty Boost[®]. Several students have carried and used their Minty Boost[®] for years. Some reveal it on their person from time to time during their senior classes. Even alumni returning to visit the campus have shown their Minty Boost[®] to their professor. The Minty Boost[®] provides an opportunity to introduce power electronics in a project that generates student interest and excitement as well as a reminder that many of the students carry with them for years.

Summary

The Minty Boost[®] is a battery charger kit designed by Limor Fried of Adafruit Industries[®] to provide emergency charging to a cell phone having a USB charging option. Assembling the kit and investigating the resulting device's performance provides hands-on experience in power electronics for junior undergraduate electrical engineering students. This investigation consists of measuring the charger's voltage regulation and its inductor current waveform. Instruments are those common to an undergraduate electrical engineering circuits laboratory plus a voltage isolating probe and a current probe. The project assessment generates an excitement in learning unmatched by other laboratory work within the course. This is one laboratory exercise that nearly all actually look forward to and speak fondly of, even to the point of being known for continuing to use it several years after graduating.

References

¹ Adafruit Industries, Kits and Projects > Minty Boost v3.0, <http://www.adafruit.com/products/14> , accessed February 1, 2015.

² Adafruit Industries, discussion board: Forum > Supported Products & Projects > Minty Boost > Minty Boost v3.0 PCB schematics available for download?, <http://www.ladyada.net/images/mintyboost/mintyboostv3sch.png> , October 6, 2010, accessed February 1, 2015.

³ "LEM Hall Current Transducers," GMW Associates, http://www.gmw.com/electric_current/LEM/hall-transducers.html, accessed February 1, 2015.

⁴ RS Components Ltd, "Closed Loop Hall Effect Current Transducer," <http://www.seekic.com/uploadfile/ic-mfg/2011427225635428.jpg> , 2014, accessed February 1, 2015.

⁵ Digilent[®], Inc., "Digilent[®] Electronics Explorer USB Reference Manual", <http://www.digilentinc.com/Products/Detail.cfm?NavPath=2,842,883&Prod=EEBOARD> , October 19, 2014.

⁶ YouTube.com; Do a search on How to Solder Electronics.

⁷ Adafruit Industries, "Adafruit Guide to Excellent Soldering," <https://learn.adafruit.com/adafruit-guide-excellent-soldering/preparation> , 2010, accessed February 1, 2015.

Appendix A

Laboratory Instructional Handout

Experiment No: 7

MINTY BOOST PROJECT

Objective:

The objective of this project is to construct and test a Minty Boost small battery-powered USB charger.

Procedure:

1. If you have not soldered before, visit the following website for available tutorials:

<http://www.ladyada.net/make/mintyboost/prep.html>

Soldering tools are located in the senior design lab in BEL216 for students to use.

2. Verify that you have received all of the needed materials to make the kit.

3. Visit the following link for a schematic of the Minty Boost:

<http://www.ladyada.net/make/mintyboost/parts.html>

Use this schematic when making the kit.

4. Follow the instructions listed on the Ladyada website to assemble the Minty Boost kit. To perform needed tests later, we will make two adjustments to her procedure (see below).

<http://www.ladyada.net/make/mintyboost/solder.html>

Adjustments to Minty Boost Instructions:

a) Only solder in one end of the inductor to the board. We will be making current measurements in the inductor.

b) Do not solder in the 2xAA battery holder so that tests can be performed on the Minty Boost assembly. Instead, solder on leads to the holes marked + and -. These will be used later to connect a DC Power supply to perform various tests on the Minty Boost USB charger.

5. To test the Minty Boost kit, connect a DC Power Supply (these are available up in the senior design lab) to the +/- leads that were connected in place of the battery holder. Turn on the DC Power Supply and set it to 3 V.

6. Before attempting to charge a device, make sure that you measure the output and input voltage. *Note that this step is included in the procedure on the Ladyada website.*

a) Use a multimeter to measure the output voltage across pin 1 and 4 (two outer pins of the USB connector). The voltage should be between 5 and 5.2V.

b) Use a multimeter to measure the voltage across pins 1 and 2 and pins 1 and 3. These voltages should be about 2V.

7. Once your Minty Boost converter is working, determine the following:

a) Measure the inductor current using the oscilloscopes in the senior design lab. Then save the waveform and include it in your final report.

b) Vary the input voltage using the DC Power Supply and measure the output voltage. Record this information in Table 1 and include it in your report.

Table 1 - V_{in} versus V_{out}

DC Power Supply – Ideal V_{in}	V_{in} (V)	V_{out} (V)
2.0 V		
2.5 V		
3.0 V		
3.5 V		
4.0 V		
4.5 V		

Comment and explain the various output voltage values.

Attend the appropriate lab section to show your TA that your Minty Boost charger is working properly.

Report: Due at the beginning of class during dead week (lab final). Include the following sections:

- **Title Page**
- **Executive Summary** - an executive summary should include what was done, how it was done, principle results, and their significance.
- **Objective**
- **Results** - include the following:
 - Inductor waveform plot, comment and explain this waveform.
 - Input versus Output voltage table, comment and explain the various output voltage values.
 - Any tests performed to verify the operation of the Minty Boost charger.
 - Schematic (link given in step three)
 - Describe how the Minty Boost charger works.
- **Conclusion**