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6.101 Project Proposal
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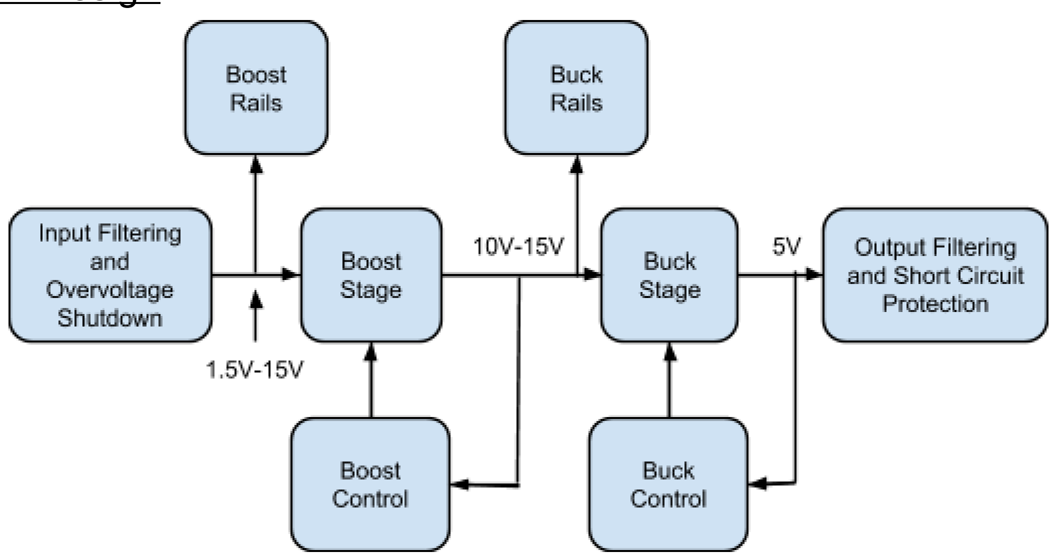
FlexUSB Charger

Introduction

With the rise of cell phones, chargers have become a necessary addition to everyday life. Whether on the road, at work, or at home we depend on having such chargers on hand in order to remain connected via our phones to our friends, family, colleagues and the world at large. Most chargers require either a normal wall outlet or a connection to the USB port of some computer in order to function. This limits recharging opportunities to those situations in which a laptop is handy, or where the user is stationary in residence or other powered area.

In this project, we intend to develop a USB standard charger capable of taking in various DC voltages from AAAs to 12 volt batteries and charging a phone based off of the connected battery alone. This will be accomplished using a boost-buck design, capable of boosting low voltages like those found in batteries to more useful levels and subsequently bucking higher voltages down to the 5 volts used by phones. In doing so, we will make the charging of portable electronics more simple and accessible and take advantage of untapped power sources commonly available.

System Design



Cascaded Boost-Buck System Overview
Fig. 1

In order to accomplish our goal of creating an efficient USB charger from varying inputs, we will utilize a boost-buck cascaded topology. This topology offers the promise of high efficiency which is essential in battery powered applications such as ours. Our system will take inputs varying from as low as 1.5 volts (a typical AA or AAA battery) to 15 volts (common in cars) and convert it to a steady USB standard 5 volts with a minimum possible supply current of 500 milliamps.

The system can be thought of in two major partitions, the initial boost stage that either allows the passing of high voltage inputs (>= 10 volts) or utilizes its boost capabilities to increase lower voltages to a minimum of 10 volts, and the buck stage which will take these heightened voltage levels and convert them to a steady 5 volt output.

The boost stage will have to be powered solely by whatever voltage input is provided and as such all of its components will have to function at 1.5 volts and be capable of withstanding at least 15 volts. In order to control the boost stage, the input voltage and output voltage will be compared to a voltage reference of 1.25 volts. Should the input voltage be higher than the 10 volt minimum output, it will simply be allowed to pass through to the output through the use of control MOSFETs. If it is lower though, it will be boosted using a conventional boost topology and held at a stable output of 10 volts by the control system which will monitor the output.

The control circuitry of the boost converter will consist of a 1.25 voltage shunt, an oscillator, and the control MOSFETs. The shunt will serve as a voltage reference across the range of possible input and output voltages since both will vary. The oscillator will be responsible for driving the power MOSFET in the boost converter with an appropriate signal to increase the output voltage. The control MOSFETs will be used to turn off the oscillator should the input voltage be high enough or should the output voltage reach the desired levels. In addition, there will be filtering capacitors to provide a study input and zener diodes and other safeguards to handle voltages beyond the expected range of inputs.

The buck converter will take the voltage output of the boost stage from 10 - 15 volts and output a steady 5 volts. The buck stage will be able to be powered at a higher voltage (10 volts) than the boost stage as it follows independently from the boost. To control the buck stage, the output voltage of the converter will be compared to a reference voltage and be bucked using a buck topology until a 5 volt steady output is achieved.

The buck control circuitry will consist of a 5 volt reference, a comparator, an oscillator and a power MOSFET. A comparator will output a V error based on the current output voltage and the reference voltage. This reference voltage when compared with a ramp signal from the oscillator will produce a PWM output that will drive the power mosfet, turning it on and off based on the changing duty cycle.

In addition we will have an output stage that will have filtering for any ripple and limiters for the output current and voltage as a safety feature.

Testing of Modules

The goal of testing our modules is to ensure proper performance under normal conditions. By doing this in a modular fashion we can make the debugging process faster and easier than if we were trying to fix the entire system at once.

The boost module can be tested by applying a voltage between the specified 1.5 and 15 volt input limits. If the boost and control are working, the output should stabilize with a low ripple voltage between 10V and 15V depending on the input.

To test the boost itself alone, a duty cycle can be applied to its MOSFET in place of the control circuitry and the output monitored to make sure it obtains the level expected in relation to the chosen duty cycle and input voltage. The equations governing the input-output-duty cycle relations of boost converters are well known so confirming successful implementation should not be difficult even without a feedback control stage.

The boost control can be tested specifically by applying power supply voltages within the specified input limits and providing a fake output voltage. The boost control should respond to the chosen output voltage by changing its output drive appropriately, thereby demonstrating successful feedback response. What exactly the output drive should be as a function of output voltage is still to be determined upon completion of the oscillator design.

Beyond the boost and control circuitry, the input stage also will feature zener diodes that will be activated should the input voltage exceed 16.5 volts. At that point, additional protection security will work to ensure that the system is not damaged and that the boost stage does not output voltage beyond its intended specification to the buck stage. This can be tested by removing it from the rest of the circuitry if it is not built in and by applying a voltage of 17 volts for example to ensure activation of the appropriate devices and the drop of voltages at appropriate locations.

The buck converter can be tested in much the same way as the boost module. To test the buck individually, a duty cycle can be applied to the MOSFET to achieve a calculated output for a given input. The relationship between input, output voltages and duty cycle is very straightforward and easily calculated.

The buck control can be tested by applying a test output voltage and reference voltage and measuring the circuit’s response. The circuit’s output drive will be able to demonstrate whether successful feedback response is occurring.

Beyond the buck and control circuitry, the output stages will also involve filtering to mitigate any ripple current or voltage on the output. As well, we will put in place voltage and current limiting features as a safety precaution. These can be tested by putting the circuitry under the conditions where normal operation may break down and observing the system's response. Output ripple can also be easily measured using an oscilloscope.

Materials

Our boost and buck converters will require certain tailored parts in order to handle the power requirements associated with such a wide range of input voltages. In particular, to handle very low input voltages down to 1.5 volts, certain specialty op amps and comparators will be required on the boost's input stage. Linear Technology offers a wide range of parts that will be useful in this endeavor.

- LT1634 voltage reference shunts
- LT1017 low supply voltage comparator(s)
- At least two inductors
- At least two schottky diodes
- Zener diodes
- Power MOSFETs
- Logic level MOSFETs
- Various capacitors
- Various resistors
- Copper wiring
- Oscillator
- Expected inputs (AA, AAA, 9 volt batteries)

Timeline

Our timeline is as follows:

By April 12th: Design schematic completed and order all needed parts
By April 16th: buck and boost modules tested and working
April 14th or 16th: Project Presentation
By April 22nd: control circuitry tested and working
By April 24th: Input and output stages tested and working
April 27th: project implementation status due
May 5/6: Final presentation and checkoff

This timeline gives us two weeks of time incase something in our project isn't working or two weeks to expand and improve our original design.

Division of Labor

The topology we have settled on lends itself easily to the division of labor amongst the two of us. Alex will work on the input and boost stages given the specifications stated above and provide the 10-15 volts input to the buck and output stages which Fiona will work on. This division allows for both of us to easily test ideas and experiment without having to worry about interfering with one another's design decisions. So long as both of us meet the specifications that we have outlined, our respective modules should meld together to achieve our overall system design goals. In addition, should one of us not be able to successfully carry out part of the project the other should still have a completed project capable of at least part of the overall specification by the end of the course.

Beyond easing the design process, splitting work between the two separate main stages allows us to progress at our own pace without relying on the completion of each others modules. For instance, should the buck stage be completed early and breadboarded before the boost stage, it can be tested with its own specified control circuitry. This should result in more rapid and efficient completion of the project as a whole as we will not spend time waiting on each other at nearly any point.

Beyond the system itself and in regards to the presentations and written portions of the project, both Alex and Fiona will work together to write proposals, specifications, timelines, checklists, and reports and will jointly prepare for any and all presentations and meetings. Both of us will focus upon our respective modules but will work to have a full understanding of each others designs such that our written and presented work will demonstrate well thought out and steady progress towards the completion of our project.

Conclusion

To conclude, by the end of this project we hope to have a working variable input USB charger that will output 5 volts at the USB standard for any given DC input from 1.5 up to 15 volts. This is a highly relevant project given the recent rise in the number of devices that can be charged based on USB. Should we have time, we could expand our project in many directions including allowing our project to be wall adaptable. Our project will be challenging but feasible in the restricted time we have. One of the challenges we face is the low input voltage, which complicates the design and limits the parts that can be used. Another challenge is the control circuitry and it’s ability to maintain a stable output given the complex system we are building. Regardless, we are confident in the scope of the project and our ability to complete it on time.