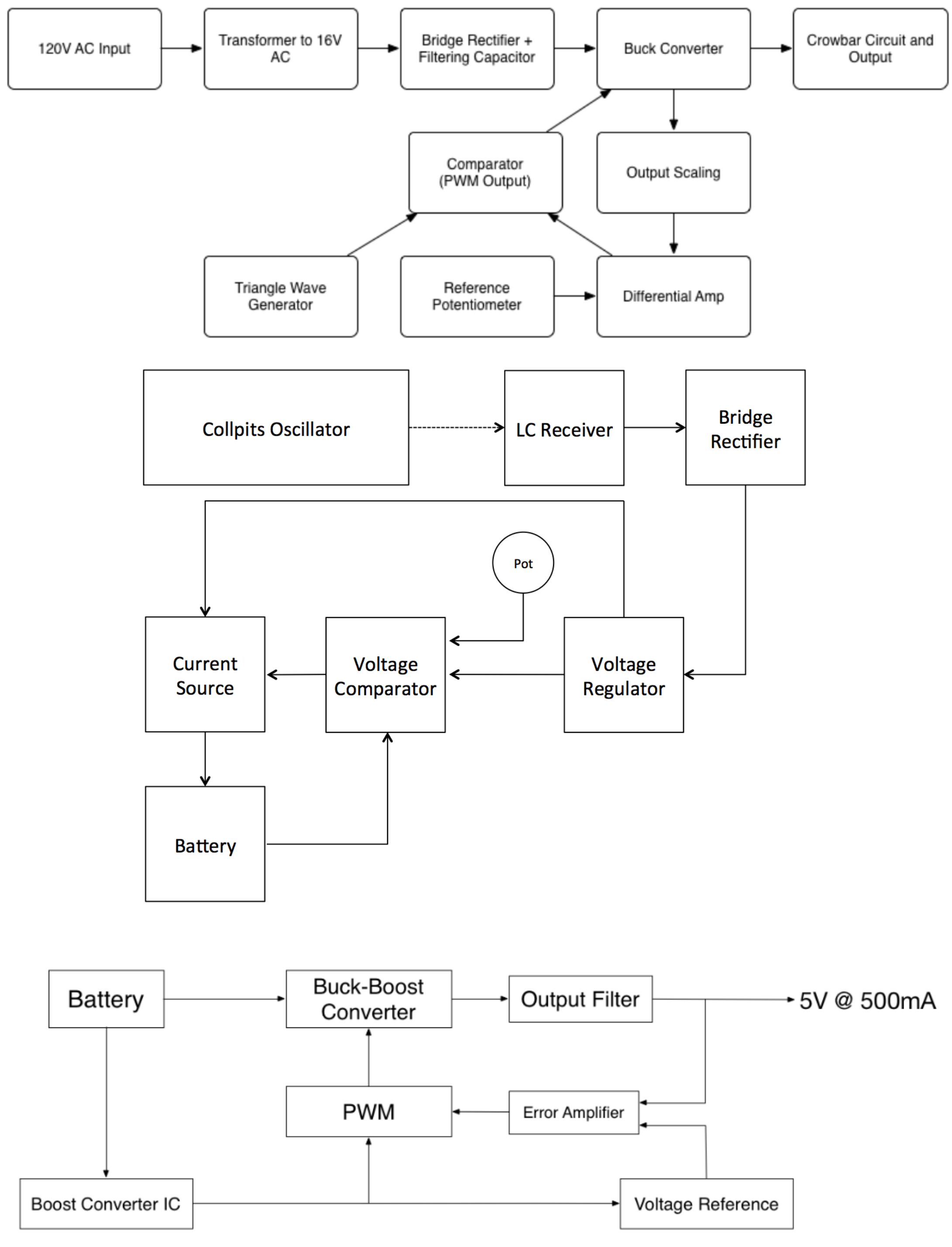
Multi-Stage Power Conversion Proposal

Joe Driscoll, Paul Hemberger, David Yamnitsky

Introduction

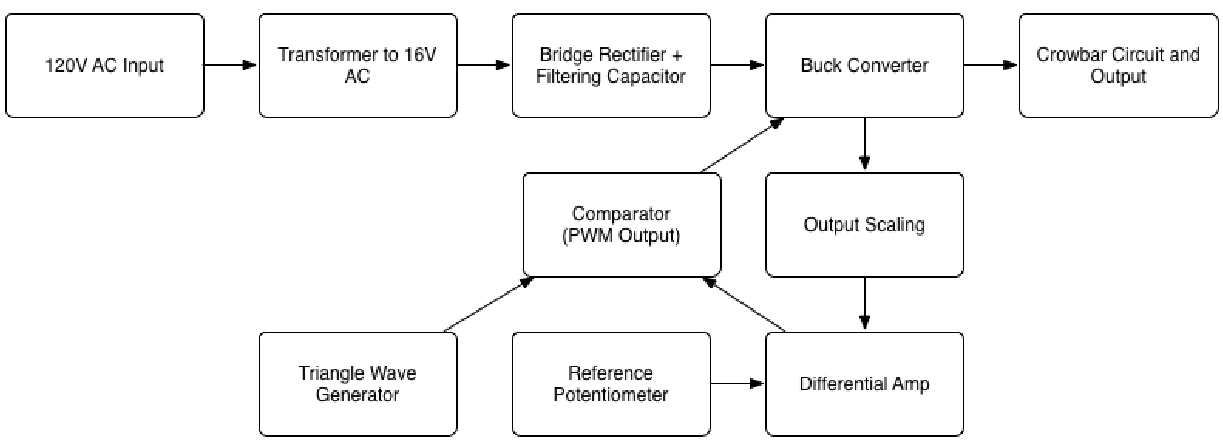
MSPC is a three-stage power converter system where each stage not only supports a useful application, but also powers its subsequent stage. The first stage, a bench power supply, takes AC from the wall and converts it to DC ranging between 1 and 12 volts with up to 2 amps. The second stage, the wireless battery charger, transfers that power wirelessly using a magnetic field, and then charges store-bought rechargeable batteries ranging in voltage from 1.5 to 9 volts. Finally our third stage, the portable smartphone charger, uses those rechargeable batteries to charge a smartphone. This requires that it be able to convert the batteries voltage, ranging from 1.5 to 14 volts, to the 5 volts required to charge smartphones. Figure 1 shows the block diagram for MSPC. David Yamnitsky will be responsible for the bench power supply, Joseph Driscoll will be responsible for the wireless battery charger, and Paul Hemberger will be responsible for the portable smartphone charger.



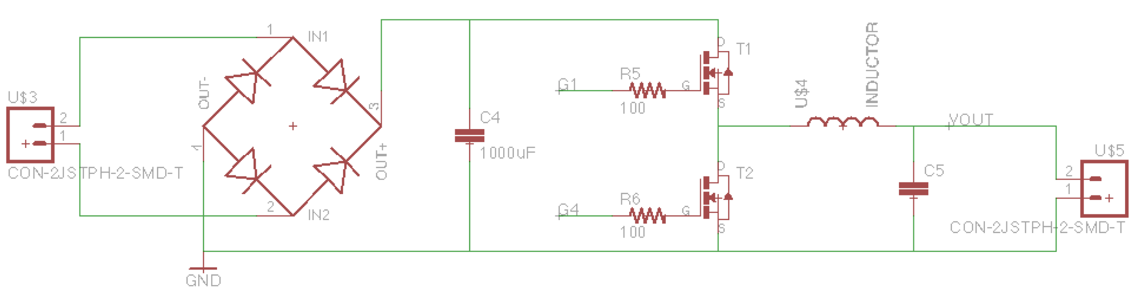
<u>Figure 1</u>: Block diagram of each module: power supply, wireless charger, and USB charger

Adjustable Bench Power Supply

The adjustable bench power supply will be designed and built by David Yamnitsky. It will take input from an AC-AC wall wart transformer that converts 120VAC to 16VAC, and will be specified to output between 2V and 12V, adjustable with a potentiometer, supply up to 2 amps, and have overcurrent protection circuitry. The circuit will take the 16V AC from the transformer and use a bridge rectifier and large filtering capacitor to produce a DC output of approximately 16V. Then, a feedback controlled buck converter will step down the voltage for the output. For the feedback path, the buck converter output will be passed to a voltage divider to scale it to the 0-5V range, then a differential amplifier will compare it with a reference, produced by a potentiometer, and apply a gain, which I will design to keep the system stable. The gain will then be compared with a triangle wave to produce the PWM signal for the buck converter.



<u>Figure 2:</u> A block diagram of the variable power supply



<u>Figure 3:</u> A schematic of the rectifier and buck converter

Wireless Battery Charger

The wireless battery charger will be designed and constructed by Joseph Driscoll. Figure 4 shows a block diagram of the converter. The wireless battery charger is composed of three sequential modules: the wireless power transmitter, the wireless power receiver, and the variable battery charger. Each will be individually designed and tested before all three are combined into the final circuit.

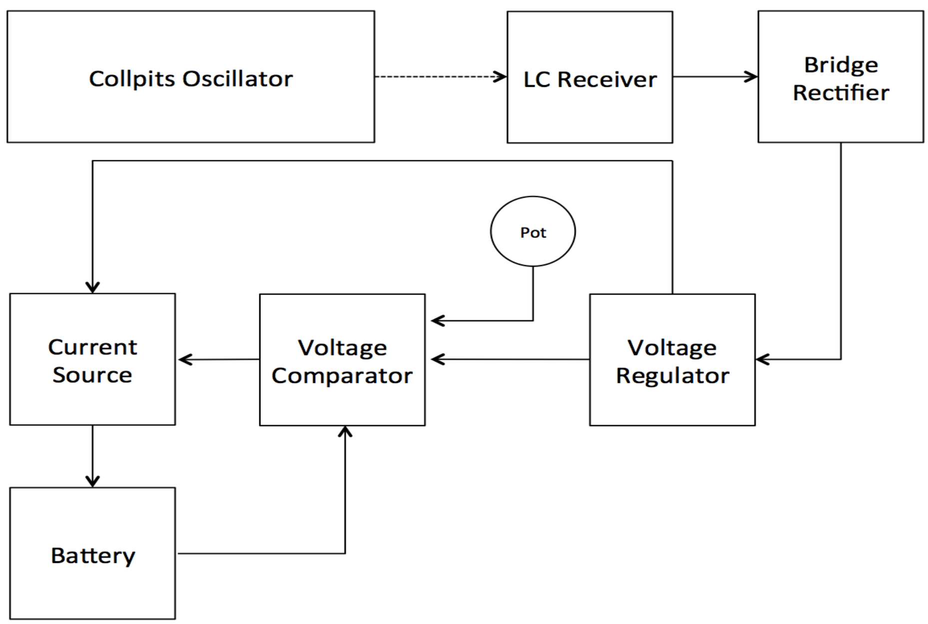


Figure 4: A block diagram of the wireless battery charger

Wireless Power Transmitter

The wireless power transmitter will be designed to convert direct current into a magnetic field, allowing it to relay power to the receiver. The transmitter will receive 30 volts from the bench power supply. One design problem we have currently is that the variable power supply is only rated for 12 volts at 2 amps because of the transformer it will be using. If a better transformer can not be acquired because of cost or safety concerns, the wireless battery charger will be configured to receive input from the power supplies in 6.101 lab. The wireless power transmitter will use an opamp Colpitts Oscillator with a resonant frequency of around 700 kHz. The inductor will be turned by hand out of 12-gauge wire so that its inductance and radius can be easily reconfigured. This module will present two difficult challenges. The first will be transferring power with limited input current, as the bench power supply is limited in power by the transformer it uses from the wall. The second challenge will be in maintaining high efficiency energy transfer.

Both of these challenges can be addressed by experimentally finding the best resonant frequency of the LC circuit to transfer power. If this is not sufficient, impedance matching between the transmitter and receiver can be used. This module will be tested by applying a current limited power supply to the input and observing the resonant frequency of the LC circuit.

Wireless Power Receiver

The wireless power receiver will be designed to draw power from the transmitter using magnetic inductance and convert that power into 10 Volts DC. The receiver will collect power using a parallel LC circuit with a resonant frequency of 700 kHz. A bridge rectifier with a ripple capacitor will then convert the alternating current to direct current. A voltage regulator will then be used to create a constant 10 volts output. The biggest challenge presented by this module will be maintaining high efficiency power transfer. As with the transmitter, high efficiency will be achieved with resonant frequency tuning and, if necessary, impedance matching. The voltage conversion and regulation of this circuit will be tested using a function generator and the power receiving capabilities will be tested using the wireless transmitter.

Variable Battery Charger

The variable battery charger will be designed to intelligently charge rechargeable store-bought batteries that vary in voltage. The term intelligent refers to the circuit’s ability to stop charging the battery once the battery has been fully charged, even if the battery is still connected to the charger. It will be able to charge batteries ranging in voltage from 1.5 to 9 volts. The variable battery charger will receive an input voltage of 10 volts. It will then receive the user’s input from a dial specifying what voltage the battery should have when it is fully charged. The dial will be connected to a potentiometer, which will set the reference voltage for a voltage comparator. The output of the voltage comparator will then flow into a current source that will be used to charge the battery. Figure 5 shows a block diagram of this circuit. The biggest challenge of this circuit will be creating the feedback loop that intelligently charges the battery. This circuit will be tested using a 10-volt DC power supply.

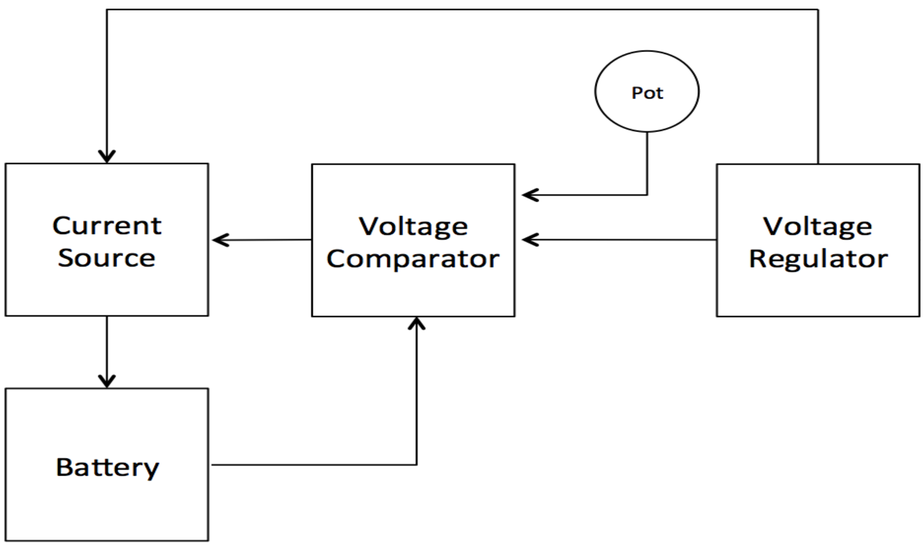


Figure 5: A block diagram of the variable battery charger.

Battery-powered Smartphone / USB Charger

Paul will design the smartphone / USB device converter. The converter will be a high-efficiency design that can charge a USB device from any battery in the range of 1.5V to 14V. Its output will be a fixed 5V and will provide at least 500mA of current, the standard power draw for USB devices.

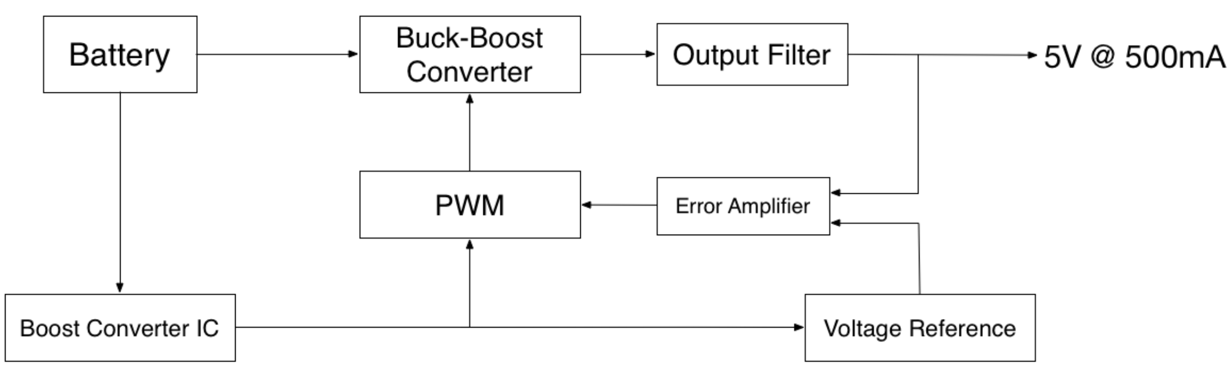


Figure 6: A block diagram of the USB converter

The central piece of the converter is a feedback-controlled buck-boost circuit. The input voltage range will be wide, from 1.5V to 14V, so a DC-DC converter that can produce voltages both above and below the target voltage is required. A switching supply is also desirable, as they are significantly more efficient than linear supplies, and it would be a shame to waste the battery's energy as heat. A buck-boost can meet both of these design goals, making it a logical choice.

Pulse Width Modulation will be used as feedback to control the buck-boost's output. A 555 timer will generate a triangle wave which will be compared with the error of buck-boost's output, and appropriately adjust the buck-boost's output voltage.

One challenge of low-power devices like this is generating the necessary voltages to operate the active components within the circuit. In this module, the error amplifier and PWM blocks will likely contain op-amps and MOSFETs that will require separate voltages from those at the input and output. In order to power them, a boost converter integrated circuit will be used that can boost the minimum input voltage (1.5V) to a level more acceptable for active components. The exact specs of this IC are to be determined.

A known difficulty with switching power supply designs is the high level of high-frequency noise in the output signal generated by the PWM block. To counter this, a low-pass filter will be used to minimize the amount of noise in the output signal. Fortunately, the USB specification is fairly generous when it comes to power specs, offering an accepted operating range of 5.0V +/- 0.25V. Our converter should be well within this range, so ripple and noise should not be a great concern.

This design will consist of standard components, with the exception of the boost converter IC, which should make it easy to prototype on a breadboard or perfboard. Its output is straightforward to verify with a multimeter, and as a final test it will be used to charge a modern smartphone from both a single AA battery and a 14V source.

Lastly, in recent years, electronics manufacturers like Apple have made an effort to prevent their devices from charging without specific resistors across the data pins of the USB connector. This is in an effort to sell their own chargers, by artificially preventing competitors chargers from working with their devices. A switch will be added to our device to toggle between sets of resistors, so that *all* devices can be charged.

Timeline

The project will be completed over a period of 5 weeks starting April 7th. Figure 7 consists of a Gantt chart displaying the stages of our project on a scale of weeks. We designated 1 week to designing our project, 2.5 weeks to build the circuits, 1.5 weeks to test them, 1 week to integrate our modules, and finally 1.5 weeks to write our report. The goal is to complete our circuits by April 27th.

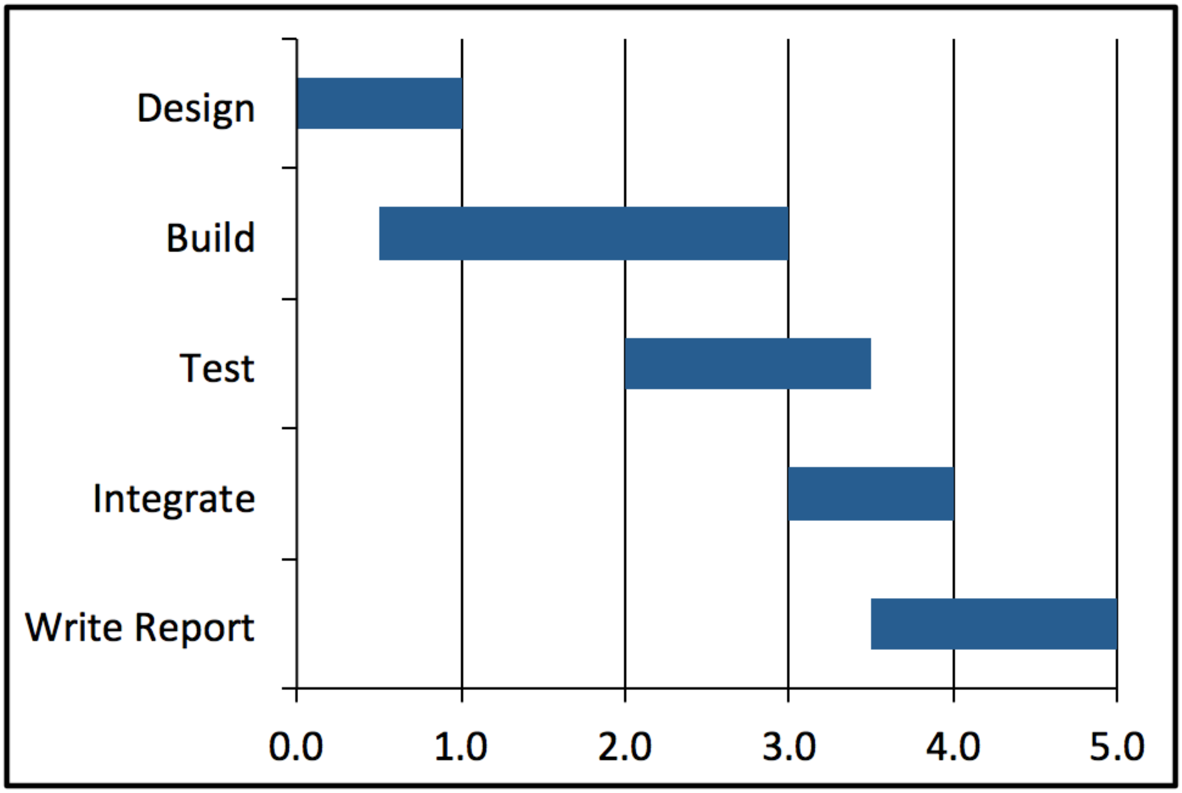


Figure 7: A Gantt chart of project stages in weeks.

Conclusion

Our proposal, MSPC will provide three modules for useful power conversion. It will provide a bench-top power supply, a wireless battery charger, and a smartphone / USB charger. Each component will be able to function independently, and collectively they should be able to cover a broad range of power conversion needs.

We do not anticipate any problems that aren't part of the regular design cycle. Because each component is modular, we can work on each piece without depending on the success of the rest of the components. Of course, this doesn't mean we won't run into our fair share of problems in the design, but that should be expected in any project. We hope that are circuits are effective enough so that we can continue to use them well past the end of the class!