Controllable Voltage Rechargeable Battery Pack with Battery Management Display

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ECE 445 Mock Design Review - Spring 2017

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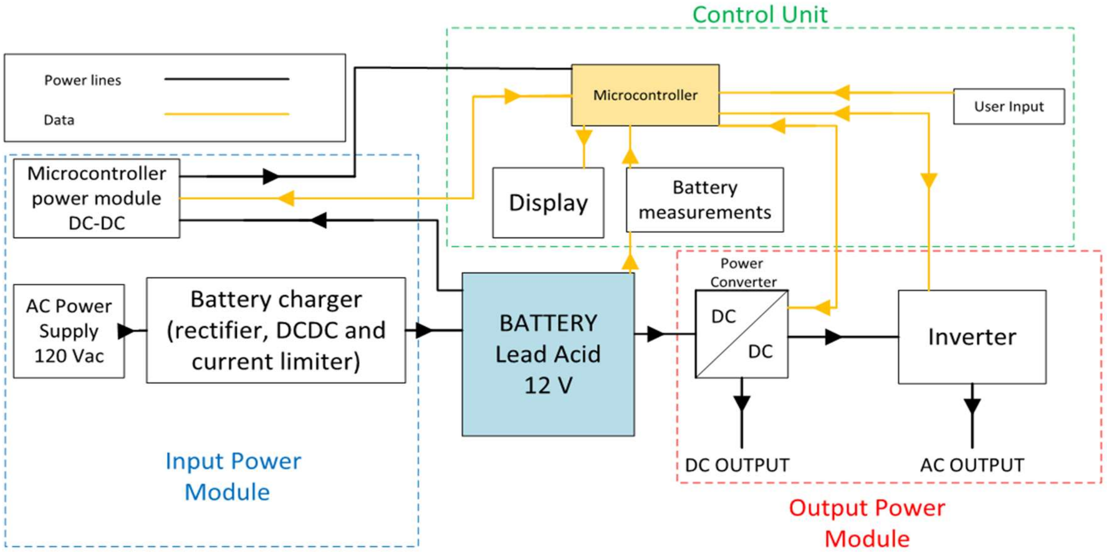
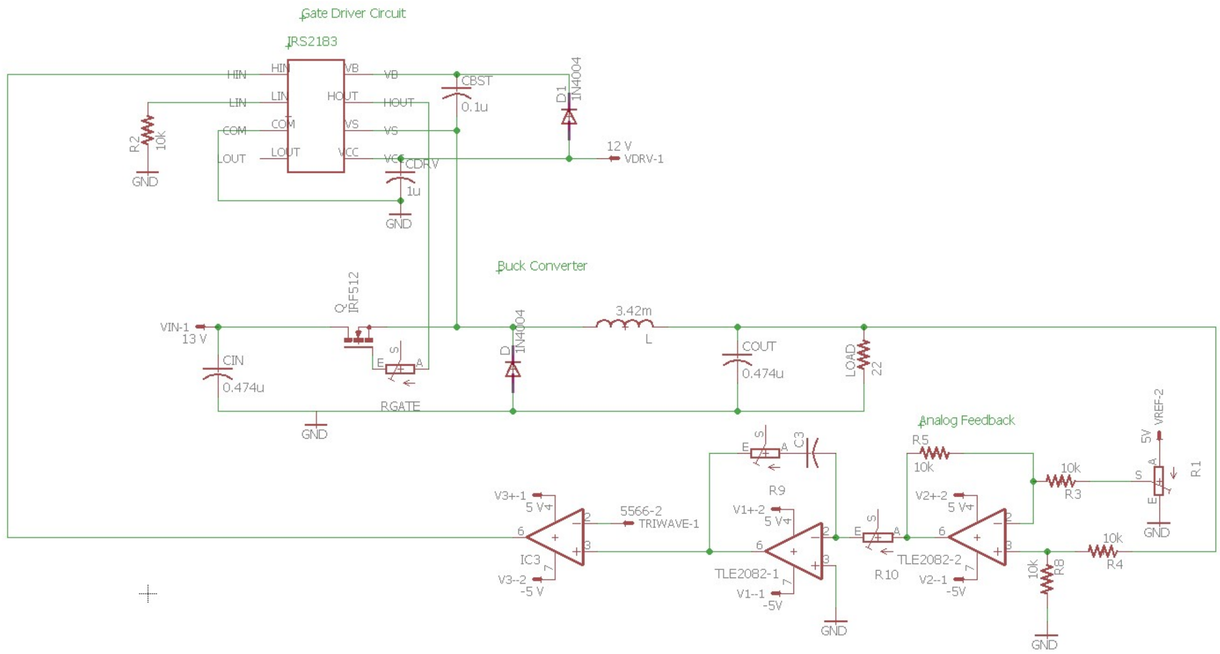
1 TABLE OF CONTENTS

2 BLOCK DIAGRAM



3 CIRCUIT SCHEMATIC

The following circuit schematic is for the buck converter and analog control circuitry within the **Microcontroller power module DC-DC**. The detail functioning of this circuit will be described in part 5, One Block Description.



4 CALCULATION

Below, we demonstrate the calculations to select minimum values for the inductors and output capacitors. These components determine the output voltage ripple. This values are calculated assuming ideal components. In our actual circuit, we expect to use capacitance and inductance values of higher magnitudes to compensate for nonideal circuit characteristics. We also include calculations for the duty ratio, assuming a 90% efficiency. This is a demonstration to show that the duty ratio is realistic. It is not necessary for us to know the exact duty ratio required, since the closed loop feedback system will compensate for deviations in output voltage.

$$V_{in} = 13 \leftrightarrow 11.5\ V \qquad I_{out} = 150\ mA \qquad f_{sw} = 80\ kHz$$

$$V_{out} = 3.3 \pm 1\%\ ripple\ V \qquad \eta = 90\%$$

$$D = \frac{V_{out}}{V_{in} * \eta} = \frac{3.3}{13 * 0.9} = 0.2821\ ; D = \frac{3.3}{11.5 * 0.9} = 0.3188 \rightarrow\ \mathrm{D} = 28.21\%$$

$$\Delta I_L = \frac{(V_{in} - V_{out}) * D}{f_{sw} * L}$$

$$with\ \Delta I_L = 10\ mA \rightarrow L = 3.42\ mH$$

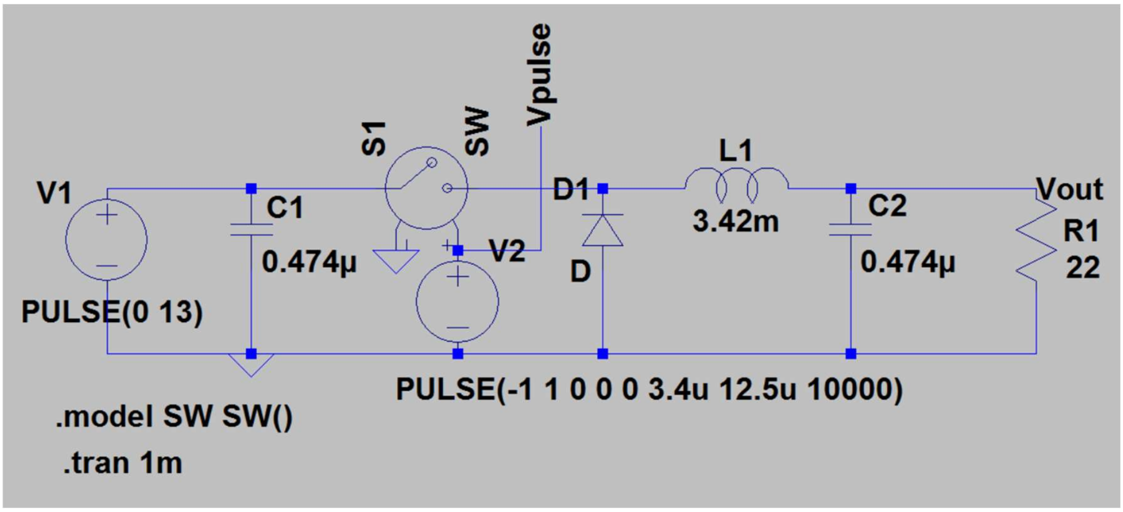
$$C_{out} = \frac{\Delta I_L}{8 * f_{sw} * \Delta V_{out}}$$

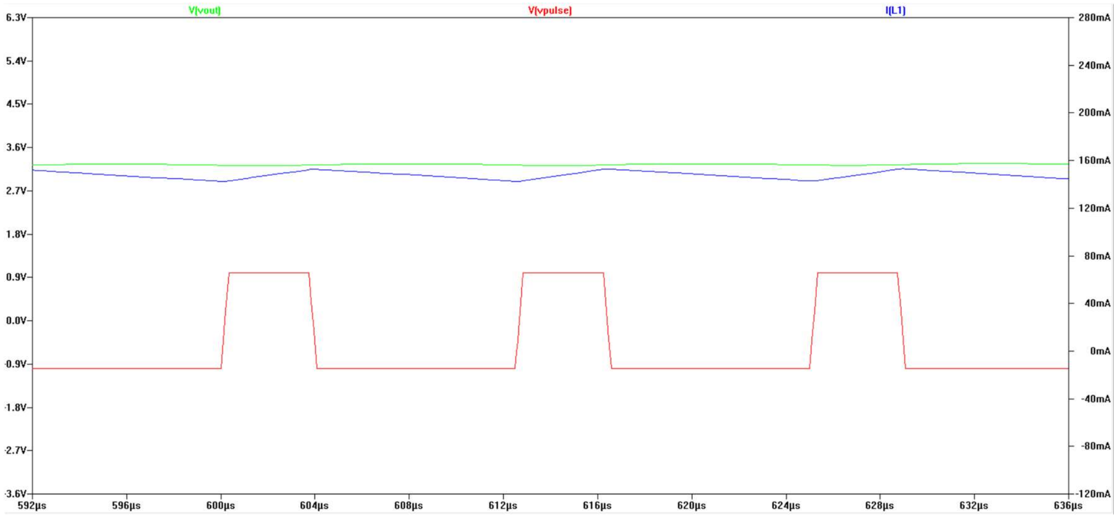
$$As\ \Delta V_{out} = 33\ mV \rightarrow C_{out} = \frac{0.01}{8 * 80000 * 0.033} = 0.474\ \mu F$$

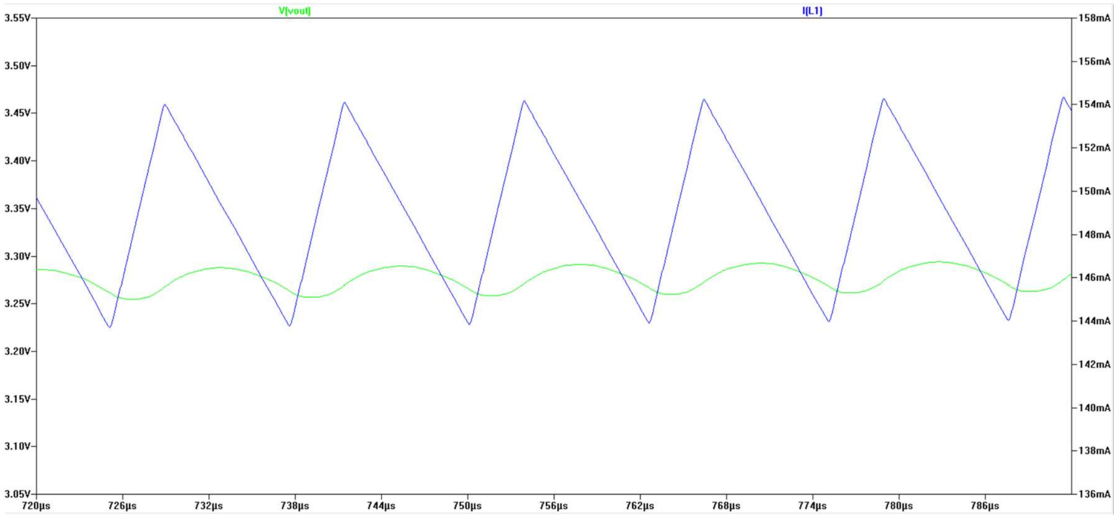
$$C_{in} \leq C_{out} \rightarrow C_{in} = 0.474\ \mu F$$

5 PLOT

This plot originates from the LTSpice simulation of the circuit schematic in part 2. This shows the output voltage over time, from time T = 0. The purpose of this plot is to demonstrate that our design and passive component parameters will meet the requirements of a 3.3V output voltage with a maximum 1% voltage ripple.


V1
PULSE(0 13)
C1
0.474µ
S1
SW
Vpulse
V2
D1
D
L1
3.42m
C2
0.474µ
Vout
R1
22
PULSE(-1 1 0 0 0 3.4u 12.5u 10000)
.model SW SW()
.tran 1m


V(vout)
V(vpulse)
I(L1)
6.3V
5.4V
4.5V
3.6V
2.7V
1.8V
0.9V
0.0V
-0.9V
-1.8V
-2.7V
-3.6V
280mA
240mA
200mA
160mA
120mA
80mA
40mA
0mA
-40mA
-80mA
-120mA
592µs
596µs
600µs
604µs
608µs
612µs
616µs
620µs
624µs
628µs
632µs
636µs


V(vout)
I(L1)
3.55V
3.50V
3.45V
3.40V
3.35V
3.30V
3.25V
3.20V
3.15V
3.10V
3.05V
158mA
156mA
154mA
152mA
150mA
148mA
146mA
144mA
142mA
140mA
138mA
136mA
720µs
726µs
732µs
738µs
744µs
750µs
756µs
762µs
768µs
774µs
780µs
786µs

6 Block Description

We will describe the **Microcontroller Power Module, DC-DC.** This is a buck converter that will step down the battery voltage of ~12V to the 3.3V required by the microcontroller.

The buck converter is a switching power converter that is ideal for stepping down a source voltage to a lower voltage. The circuit schematic can be reviewed in part 2, One Circuit Schematic, but it will be described in detail here. The input voltage from the battery is connected in parallel with an input capacitance, whose role is to smooth out irregularities in the power supply. The switch is a MOSFET, with a high side gate driver fed by an analog comparator feedback loop. This is the only power converter in our project that requires an analog feedback loop. The other converters we are designing will be digitally controlled. This is because the digital feedback depends on the microcontroller that this buck converter is powering. The buck converter must be independent of the microcontroller. We select a switching frequency is 80kHz, as used in the calculations. The switch creates a PWM voltage waveform from the input. The duty ratio of this waveform determines the output voltage magnitude. This PWM this is fed through a low pass filter made up of an inductor and output capacitor in order to produce a DC voltage. The size of the inductances and capacitances determines the ripple.

7 Requirement and Verifications for One Module of the Block Diagram

In this part, we present the requirements and verifications for the buck converter.

7.1 Requirements

1. The output voltage must be 3.3 V with a 1 percent ripple to the microcontroller
2. Regulate for input voltage fluctuations with analog closed loop feedback
3. Built onto a PCB

7.2 Verifications

1. Test the converter at a range of resistive loads (20 Ohms - 100 Ohms) and verify that the output voltage is regulated
2. Test the converter at a range of possible input voltages (11-13V), verify that the output voltage is regulated
3. Verify that the output voltage ripple is within acceptable limits (.33Vpp)

8 Safety Statement

8.1 Mechanical safety

Our principal mechanical safety concern is an explosive failure of the lead acid battery. Lead acid batteries may produce trace amounts of hydrogen gas that in concentrations above 4% could be explosive. In addition, when lead acid batteries are overcharged they undergo hydrolysis, producing oxygen and hydrogen [1] and this presents an explosion risk. An explosion could cause total destruction of the system, leak lead into the environment and cause potential harm to end users. The hydrogen risk is minimal, so long as the gas is not allowed to concentrate. We may mitigate this risk by providing a small ventilation port that could also be used for thermal management. The risk of a hydrolysis-induced explosion is too high to tolerate, so we have decided to acquire a battery charger off-the-shelf instead of building our own. This charger comes with functionality to prevent overcharging, and thus mitigate the electrolysis risk.

8.2 Electrical Safety

Our circuitry will handle high voltages (up to 170V peak) and currents (up to 5Amps). These are high enough to pose a potential health risk to people. However, our circuitry will be isolated from the end user within an enclosure. Unless this enclosure is compromised, we do not anticipate that our device poses an electrocution hazard.

In the event of a failure, the most serious risk is that a short circuit will cause a current of large magnitude to flow. This may initiate thermal events and propagating damage to other components. We have determined to place fuses in at the terminals of the batteries to prevent such an occurrence, so that if the system fails, the damage is mitigated and potentially repairable.

8.3 Lab Safety

We believe we can mitigate lab hazards by testing components in isolation. We can test our power converters independently of the battery within a controlled power laboratory environment where we have access to emergency kill switches. If our converters work with a laboratory power source, they will work with the battery, so we do not need to risk too much time with the battery. We will however, need to use the battery in lab to test the functionality of our measurements and displays, but we can conduct those tests independent of the power converters. By having modular components that can be tested independently of each other, we minimize the testing risk, as the failure of one module in testing will be isolated and not cause damage to other modules.

8.4 Safety Plan

We will follow a few simple rules to ensure personal safety during testing and verification.

1. The battery will only charged through a proper battery charger
2. All hardware testing will be conducted with at least two group members
3. Safety glasses will be worn when the battery is in active use, or if the tested circuitry includes electrolytic capacitors
4. Circuitry will be verified using laboratory power supplies before being applied to the battery
5. If the battery starts to bulge we will move to a safe distance, and request assistance.

9 Citations

[1] Battery University, “Charging Lead Acid”. 2016[Online]. Available: