Research Implementation Report
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1.0 Abstract

This report presents a brief background of the Team 44 underwater ROV project. The focus of this report is the power system which includes the battery, power delivery, and charging. The challenges presented originate from the project requirements and subsystem specific requirements. Research is presented within this report that describes the process that led to the decision for the design of the subsystem. The design is presented along with all design artifacts and references. Implementation details and a discussion of the subsystem limitations are also presented with this report.
2.0 Introduction

2.1 Overview

Team 44 is building an underwater remotely operated vehicle (ROV). An example of an ROV is presented in figure 2.1 (Reference [2]), which provides some insight into the subsystems of the underwater ROV. In figure 2.1, the frame of the ROV houses the pressure enclosure(s), serves as a mounting point for thrusters, lights, ballast weights, and the blue box-like structures on the top right and left house buoyancy foam. The pressure enclosure(s) protects the battery and all of the electronics and control circuitry. The electronics vary but generally include a DC-DC step-down converter, electronic speed controllers (ESC’s), various sensors, and camera(s). The ROV generally interfaces with the surface through a tether, depending on use.

The underwater ROV has many useful purposes including search and rescue, marine biology, oil & gas, power & communication lines, recreation, and much more. The underwater ROV can be used for inspection of power/communication lines or pipes, map a lake bed or seafloor, or record video footage for documentaries/movies. Many applications of the underwater ROV require specialized functionality.

The configuration of the ROV is dependent on its use. An example of this variation is whether the ROV has a gripper/manipulator or more than one. The individual parts themselves may have considerable variation (e.g., varying degrees of freedom on manipulators). The variation is due to a component’s purpose, for example, if a gripper is removing or inserting a connection, one degree of freedom may be adequate. The design of the ROV should consider its intended purpose.

Figure 2.1: BlueROV2

Team 44 has researched these configuration options and has selected subsystems as seen in figure 2.2, most of these subsystems require power. The major subsystems requiring power are the electronic speed controller (ESC), the on-board computer subsystem, the manipulator and the lights. The Arduino embedded subsystem, powered by the on-board computer, sends control signals to the ESC’s which control the power going to
the thrusters. The on-board computer subsystem is comprised of a Raspberry PI which provides power to the sensors, communicates with the control station, and communicates with the Arduino embedded subsystem. This report covers the power subsystems of the underwater ROV including the battery, power delivery, and charging.

Figure 2.2: Underwater ROV Block Diagram

2.2 Purpose

The purpose of this report is to describe the power subsystem of the underwater ROV. The description will include an outline of the requirements, research, and the chosen design solution.

Team 44, the client, teachers, teachers assistants, and anyone interested in underwater ROV’s are the intended audience of this report.

2.3 Scope

The scope of this report is the power system which encompasses the power input to the charging subsystem, the battery subsystem, and the power delivery subsystem and associated interfaces.
2.4 Project Goals

The overall goal of the project is to automate the process of unplugging a connector. A stretch goal for the project is to plug in a connector.

A stretch goal for the power system is to build a charging subsystem for the battery.

2.5 Project Progress

The team has completed the research required to design and build the hardware systems. The remaining activities include integration, testing, and refining the automation to meet our project’s objectives.
3.0 Summary of Expert Topic Areas and Design Challenges

3.1 Engineering Requirements

- Battery Life
  - The system will have a battery life of greater than or equal to one hour under normal use.

- Weight
  - The system will weigh less than fifty pounds.

3.2 Background Information

The expected loads on the power subsystem:

Table 3.1: Underwater ROV Loads

<table>
<thead>
<tr>
<th>System</th>
<th>Voltage Range (V)</th>
<th>Nominal Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrusters (x5)</td>
<td>6.0 - 16.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Arduino Embedded</td>
<td>2.7 - 5.5</td>
<td>0.04</td>
</tr>
<tr>
<td>On-Board Computer</td>
<td>4.5 - 5.5</td>
<td>1.52</td>
</tr>
<tr>
<td>Electronic Speed Control</td>
<td>3.3 - 5.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Sensors</td>
<td>4.5 - 5.5</td>
<td>0.50</td>
</tr>
<tr>
<td>Manipulator</td>
<td>4.8 - 6.0</td>
<td>0.28</td>
</tr>
</tbody>
</table>

The thrusters will draw power directly from the battery. To move in one direction the thrusters will need to be operated two at a time. The thrusters can draw a maximum amperage of 12.5A. This means that the thrusters alone will need approximately 25A. Possible battery solutions include Nickel Metal Hydride or Lithium-ion. Due to power density and weight considerations the Lithium-ion seems like the most obvious solution. The Lithium-ion battery will have a maximum discharge and minimum voltage that will need to be considered.

The other components require a DC-DC power converter to reduce the power from the battery voltage to 5V and 12V. The Buck, Buck-Boost, Flyback, or Forward converters are possible solutions.

Depending on the battery solution the charging system will have a maximum charging rate and several other requirements that will need to be considered. The battery needs to be protected from overcharge and over-discharge.
### 3.3 Challenge Research

Table 3.2: Challenges & Research

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>[20]</td>
</tr>
<tr>
<td>Power Delivery</td>
<td>[47]</td>
</tr>
<tr>
<td></td>
<td>[45]</td>
</tr>
<tr>
<td></td>
<td>[22]</td>
</tr>
<tr>
<td>Charging</td>
<td>[1]</td>
</tr>
</tbody>
</table>
4.0 Challenge 1: Power Delivery v2.0

4.1 Requirements

- The power delivery subsystem shall convert the battery voltage to five volts.
- The power delivery subsystem shall provide sufficient current to support all 5V loads.
- The power delivery subsystem shall convert the battery voltage to twelve volts.
- The power delivery subsystem shall provide sufficient current to support all 12V loads.
- The power delivery subsystem shall monitor the voltage of the battery.

4.2 Goals

- The power delivery subsystem should be as efficient as possible.

4.3 Research

Initially, v1.0 of the power delivery system was a flyback converter which is detailed in appendix A. The problem with this solution was insufficient power output. The circuit was designed to deliver 5V, 1A out. As the project evolved the current output needed was increased. To maximize the power output and simplify the design the flyback converter was abandoned for a less complex buck converter design.

For v2.0 two different buck converter will be required to supply power to both the 5V and 12V loads. Additionally, a method for monitoring battery voltage and discharge current will be required.

"Elements of Power Electronics" [56], Chapter 3, "DC-DC Converters", provides an introduction to DC-DC converters. Buck converter relationships can be used to calculate the specifications of the components in the circuit and help with researching the correct integrated circuits (IC’s).
\[ v_{out} = q_1 V_{in} \]  
\[ i_{in} = q_1 I_{out} \]
\[ \langle v_{out} \rangle = D_1 V_{in} \]  
\[ \langle i_{in} \rangle = D_1 I_{out} \]  
\[ P_{out}(t) = P_{in}(t) = q_1 V_{in} I_{out} \]  
\[ \langle P_{out} \rangle = \langle P_{in} \rangle = D_1 V_{in} I_{out} \]  
\[ v_{out}(RMS) = \sqrt{\frac{1}{T} \int_0^T q_1^2(t) V_{in}^2 dt} = V_{in} \sqrt{D_1} \]

### 4.4 Design

The relationship calculations led to the selection of the LT8643 (Reference [45]) for the 16.8V to 5V step-down conversion. The LT8643 is configured in the typical application configuration of “5V 6A Step-Down Converter with Soft-Start and Power Good” as recommended in the datasheet. The power good feature ties the chip enable pin to the voltage source so that on an input voltage greater the 1V the circuit will energize. The soft-start is a feature that prevents current surge on the input power supply by ramping the output. The data sheet recommendations for the PCB layout were adhered to as well which can be seen in figure 4.2. This layout recommendation is to support higher ambient temperatures which may or may not be a concern within our enclosure. The switching frequency was set to 1MHz by R2 being set to 41.2kΩ.

The LTC1624 was selected for the 16.8V to 12V step down conversion. One of the limitations identified during the configuration of this IC is that the minimum input voltage to produce 12 volts is 12.3 volts. As the 12V output is only intended for lighting this isn’t too much of a concern. This IC has a set 200kHz switching frequency and utilizes an external N-Channel MOSFET.

The selection of the LTC2945 was largely based on it’s capability to output I2C and its wide input voltage range. This circuit utilizes a current sense resistor and will provide current usage of all loads connected to this board. It will also provide the battery output voltage. This circuit is being powered by the 5V output of the LT8643 circuit to maximize efficiency.

### 4.5 Schematic and Board Layout

The schematic is shown in figure 4.1 and the board is shown in figure 4.2.
Figure 4.1: Schematic
4.6 Data Sheets

Table 4.1: Data Sheets

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Part Number</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>5V Converter Controller</td>
<td>LT8643</td>
<td>[45]</td>
</tr>
<tr>
<td>U5</td>
<td>12V Converter Controller</td>
<td>LTC1624</td>
<td>[22]</td>
</tr>
<tr>
<td>U6</td>
<td>I2C Power Monitor</td>
<td>LTC2945</td>
<td>[47]</td>
</tr>
<tr>
<td>J1</td>
<td>Molex Connection Header</td>
<td>0431601102</td>
<td>[28]</td>
</tr>
<tr>
<td>J2, J3, J4, J5, J6, J7</td>
<td>XH Connector</td>
<td>B2B-XH-A(LF)(SN)</td>
<td>[46]</td>
</tr>
<tr>
<td>USBC1</td>
<td>USB Type C Receptacle</td>
<td>1054500101</td>
<td>[27]</td>
</tr>
<tr>
<td>R1</td>
<td>0.02Ω</td>
<td>CSR1206FK20L0</td>
<td>[32]</td>
</tr>
<tr>
<td>R2</td>
<td>41.2kΩ</td>
<td>ERA-3AEB4122V</td>
<td>[13]</td>
</tr>
<tr>
<td>R3</td>
<td>100kΩ</td>
<td>RR0816P-104-D</td>
<td>[51]</td>
</tr>
<tr>
<td>R4</td>
<td>1MΩ</td>
<td>RC0603FR-071ML</td>
<td>[43]</td>
</tr>
<tr>
<td>R5</td>
<td>243kΩ</td>
<td>ERA-3AEB2433V</td>
<td>[11]</td>
</tr>
<tr>
<td>R6</td>
<td>6.49kΩ</td>
<td>ERA-3AEB6491V</td>
<td>[14]</td>
</tr>
<tr>
<td>R7</td>
<td>68mΩ</td>
<td>RL0816T-R068-F</td>
<td>[52]</td>
</tr>
<tr>
<td>R8</td>
<td>6.8kΩ</td>
<td>CRGCQ0603F6K8</td>
<td>[33]</td>
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<tr>
<td>R9</td>
<td>35.7kΩ</td>
<td>ERJ-1GNF3572C</td>
<td>[6]</td>
</tr>
<tr>
<td>Component</td>
<td>Value</td>
<td>Part Number</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>R10</td>
<td>3.92kΩ</td>
<td>ERA-3AEB3921V</td>
<td></td>
</tr>
<tr>
<td>C1, C8, C10</td>
<td>0.1µF</td>
<td>C0603C104Z3VACTU</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>4.7µF</td>
<td>CL21A475KAQNNNG</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>100µF</td>
<td>CL32A107MPVNNNE</td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>4.7pF</td>
<td>CC0603CRNPO9BN4R7</td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td>330pF</td>
<td>CC0603KRX7R9BB331</td>
<td></td>
</tr>
<tr>
<td>C6</td>
<td>10nF</td>
<td>CC0603KPX7R9BB103</td>
<td></td>
</tr>
<tr>
<td>C7</td>
<td>1000pF</td>
<td>CC0603KRX7R9BB102</td>
<td></td>
</tr>
<tr>
<td>C9</td>
<td>470pF</td>
<td>CC0603KRX7R9BB471</td>
<td></td>
</tr>
<tr>
<td>C11</td>
<td>100pF</td>
<td>CC0603JRNPO9BN101</td>
<td></td>
</tr>
<tr>
<td>C12, C13</td>
<td>22µF</td>
<td>EEE-HA1V220WR</td>
<td></td>
</tr>
<tr>
<td>C14, C15</td>
<td>100µF</td>
<td>EEE-HC1C101XP</td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>3.3µH</td>
<td>HCMA0703-3R3-R</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>47µH</td>
<td>CDRH125NP-470MC</td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>Schottky Diode</td>
<td>MBR140SFT1G</td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>MOSFET N-Channel</td>
<td>SIS412DN-T1-GE3</td>
<td></td>
</tr>
</tbody>
</table>
5.0 Challenge 2: Battery

5.1 Requirements

- The system will have a battery life of greater than or equal to one hour under normal use.

5.2 Goals

- Minimize the battery weight and size to fit in the enclosure.

5.3 Research

Based on similar designs of Underwater ROV manufacturers we are considering the Samsung INR18650-30Q [20]. This will be configured 4 cells in series and enough of these in parallel to support our time requirements with expected loading. Some of the challenges include limiting the discharge so that the overall battery voltage does not drop below 12V or 3V per cell. The charging of these batteries will need to be distributed evenly which will require that this be built into the battery pack with a separate connector. Additionally, the temperature should be monitored with thermistors, since discharging Lithium-ion batteries or charging them can cause them to heat up and become damaged or worse lead to a fire or explosion.

The standard rectangular design, as seen in many battery wall applications, for the battery holder was not going to work for this project since the pressure enclosure is cylindrical and the required number of batteries would have caused the battery holder to exceed the diameter of the enclosure. Many methods exist for building non-standard dimension batteries, some of the methods identified during research included simply hot gluing the batteries together in the desired shape. Other methods included custom 3D printed enclosures. The advantage of hot gluing is the battery would be more compact. The advantage to a 3D printed enclosure is the spacing between the batteries allows for some cooling and if a single battery needed to be replaced, it is feasible.

Some of the approaches for providing the electrical connection included using springs, bullet connectors, soldering directly to the battery, and nickel strips. The advantage of springs and bullet connectors is that single batteries can very easily be removed for travel or replacement purposes. The challenge is finding a spring or bullet connector that supports the amperage requirements of our project. The soldering method provides the best electrical connection at the risk of damaging the battery due to heat. Pulse spot welding nickel strips to the battery is the least risky in terms of heat damage, but has some drawbacks too. Nickel is not as good of a conductor as copper, additionally the more current pushed through nickel strips the more they heat up. To allow more
current, the nickel strips can be stacked. The advantage to nickel over copper is corrosion resistance.

5.4 Design

The enclosure has been 3D printed as seen in Figure 5.1 and 5.2. The enclosure has been designed to firmly hold the batteries in place, allow clearance for the nickel strips, and provide locations for mounting the battery management system and active cell balancing systems discussed in section 6.

The nickel strips will be pulse spot welded to the batteries and tabs will be created for the main current-carrying wires and equalization wires. The nickel strips will need to be stacked in order to support the amperage required for our project.

5.5 Enclosure Design

Figure 5.1: Battery Enclosure Top
5.6 Data Sheets

Table 5.1: Data Sheets

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Part Number</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>14.8v</td>
<td>INR18650-Q30</td>
<td>[20]</td>
</tr>
</tbody>
</table>
6.0 Challenge 3: Charger

6.1 Requirements

- The charging subsystem shall not exceed the charging limits of the battery.

6.2 Goals

- The charging subsystem should be capable of charging all cells at once.
- The charging subsystem should equalize the charge on each cell to the battery specifications.

6.3 Research

The charging system is a stretch goal for our team. It will most likely be connected to the whole pack and must meet the constant voltage and current requirements as specified by the battery vendor. This is a challenge because substantial research is required in this area but should not consume our whole project.

6.4 Design

The battery management system selected is the Anmbest 4S 16.8V 40A 18650 Charger PCB (Reference [1]). This circuit is directly connected to the battery at all times and provides a wide variety of protections including over-discharge protection, over-current protection, and overcharge protection. This will prevent the cells from dropping below 3.0V and exceeding 4.2V. This circuit has a limited discharge current of 40A and charge current of 20A. This circuit will allow us to directly connect a DC power supply to charge the battery.

In addition, we will be using an active balancer BMS which will maintain the cells within a 30mV difference if the cells differ by more than 0.1V. This will improve the life of the battery.

6.5 Data Sheets

Table 6.1: Data Sheets

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Part Number</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BMS</td>
<td>Anmbest_MD145</td>
<td>[1]</td>
</tr>
<tr>
<td>2</td>
<td>Active Balancer</td>
<td>JW-4C1.2A</td>
<td>[55]</td>
</tr>
</tbody>
</table>
7.0 Implementation and Discussion

Implementation is in progress. The power delivery board is on order and all of the parts have arrived. Once the board gets here it will need to be assembled and tested.

The battery enclosure parts have all been 3D printed. The nickel plating, pulse spot welder, BMS, cables, and connectors are all here and this is ready to be assembled. This addresses both the battery and the battery charging systems.

7.1 Limitations

At this time the battery will limit the voltage and current of the thrusters. This will require our team to implement some interlocks to prevent more than two thrusters from being used at a time. The ESC’s providing power to the thrusters are capable of handling 26V at the top end, which our battery system (16.8V fully charged) will not be capable of supporting. The battery has limits on the charge and discharge rates, which are now being driven by the BMS at 20A charge and 40A discharge.

V2.0 of the power delivery system is capable of supplying 5V and 6A (30W) to the 5V loads and 12V and 1A to the 12V loads. The only limitation is that if the battery drops below 12.3V the buck converter will no longer be capable of providing power to the 12V loads.
8.0 References


[3] CDRH125NP-470MC. Power inductors, smd type: Cdrh series, Sumida America Components Inc. 47μH.

[4] C0603C104Z3VACTU. Surface mount multilayer ceramic chip capacitors, KEMET. 0.1μF.


[6] ERJ-1GNF3572C. Precision thick film chip resistors, Panasonic Electronic Components. 35.7kΩ.

[7] EEE-HA1V220WR. Aluminum electrolytic capacitors, Panasonic Electronic Components. 22µF.

[8] EEE-HA1V220WR. Aluminum electrolytic capacitors, Panasonic Industry. 22 µF.

[9] EEE-HC1C101XP. Aluminum electrolytic capacitors, Panasonic Electronic Components. 100µF.

[10] ERA-3AEB182V. Metal film (thin film) chip resistors, high reliability type, Panasonic. 1.8 kΩ.


[12] ERA-3AEB3921V. Metal film (thin film) chip resistors, high reliability type, Panasonic Electronic Components. 3.92kΩ.

[13] ERA-3AEB4122V. Metal film (thin film) chip resistors, high reliability type, Panasonic. 41.2kΩ.

[14] ERA-3AEB6491V. Metal film (thin film) chip resistors, high reliability type, Panasonic. 6.49kΩ.

[15] ERA-3AEB9311V. Metal film (thin film) chip resistors, high reliability type, Panasonic. 9.31 kΩ.

[16] ERA-1ARW3011C. Metal film (thin film) chip resistors, high reliability type, Panasonic. 3.01 kΩ.

[17] UWX1A221MCL1GB. Aluminum electrolytic capacitors, Nichicon. 220 µF.
[18] GRM033R61E331KA01D. Chip monolithic ceramic capacitor for general, muRata. 330 pF.

[19] GRM033R6YA104KE14D. Chip monolithic ceramic capacitor for general, muRata. 0.1 µF.

[20] INR18650-30Q. Lithium-ion rechargeable cell for power tools, Samsung.


[22] LTC1624. High efficiency so-8 n-channel switching regulator controller, Linear Technology/Analog Devices.

[23] HCMA0703-3R3-R. Automotive grade high current power inductors, Eaton - Electronics Division. 3.3 µH.

[24] VP1-190-R. Versa-pac inductors and transformers (surface mount), EATON. 12.2 µH.

[25] BSC252N10NSFG. Optimos 2 power-transistor, Infineon. MOSFET.


[27] 1054500101. Usb type c receptacle, Molex.


[29] BZX84B7V5LT1G. Zener voltage regulators, ON Semiconductor. 7.5 V.


[32] CSR1206FK20L0. Thick film current sensing resistor, Stackpole Electronics, Inc. 0.02Ω.

[33] CRGCQ0603F6K8. Smd aec-q200 compliant thick film chip resistor, TE Connectivity Passive Product. 6.8kΩ.

[34] CC0201KRX5R8BB102. Surface mount multilayer ceramic capacitors, Yageo. 1 nF.

[35] CC0603KPX7R9BB103. Surface-mount ceramic multilayer capacitor, Yageo. 10nF.

[36] CC0603KRX7R9BB102. Surface-mount ceramic multilayer capacitors, Yageo. 1000pF.

[37] CC0603KRX7R9BB331. Surface-mount ceramic multilayer capacitor, Yageo. 330pF.

[38] CC0603KRX7R9BB471. Surface-mount ceramic multilayer capacitors, Yageo. 470pF.
[39] CC0603CRNPO9BN4R7. Surface-mount ceramic multilayer capacitor, Yageo. 4.7pF.

[40] CC0603JRNP09BN101. Surface-mount ceramic multilayer capacitors, Yageo. 100pF.

[41] RC0603FR-07100RL. General purpose resistors, Yageo. 100 Ω.

[42] RC0603FR-0710RL. General purpose chip resistors, Yageo. 10 Ω.

[43] RC0603FR-071ML. General purpose chip resistor, Yageo. 1MΩ.

[44] RC0603FR-0726K7L. General purpose chip resistor, Yageo. 26.7 kΩ.

[45] LT8643. 42v, 6a synchronous step-down silent switcher 2 with 2.5μa quiescent current, Linear Technology/Analog Devices.


[47] LTC2945. Ic power monitor i2c, Linear Technology/Analog Devices.

[48] MBR140SFT1G. Surface mount schottky power rectifier, ON Semiconductor. Schottky Diode.

[49] CL21A475KAQNNNG. Multi-layer ceramic capacitor, Samsung Electro-Mechanics. 4.7μF.

[50] CL32A107MPVNNNE. Multi-layer ceramic capacitor, Samsung Electro-Mechanics. 100μF.

[51] RR0816P-104-D. Metal thin film chip resistor, Susumu. 100kΩ.

[52] RL0816T-R068-F. Low resistance chip resistors, Susumu. 68mΩ.

[53] MCT06030C2401FP500. Professional thin film chip resistors, Vishay. 2.4 kΩ.

[54] SIS412DN-T1-GE3. N-channel 30 v (d-s) mosfet, Vishay Siliconix. MOSFET N-Channel.


### 9.0 Revision History

Table 9.1: Revision History

<table>
<thead>
<tr>
<th>Revision</th>
<th>Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Draft</td>
<td>12/05/2019</td>
</tr>
<tr>
<td>2</td>
<td>Draft sent for peer review</td>
<td>1/15/2020</td>
</tr>
<tr>
<td>3</td>
<td>Final</td>
<td>2/6/2020</td>
</tr>
</tbody>
</table>
A.0 Challenge 1: Power Delivery v1.0

A.1 Requirements

- The power delivery subsystem shall convert battery voltage to five volts.
- The power delivery subsystem shall provide sufficient current to support all 5V loads.

A.2 Goals

- The power delivery subsystem should be as efficient as possible.

A.3 Research

“Elements of Power Electronics” [56], Chapter 3, “DC-DC Converters”, provides an introduction to DC-DC converters. Although a Buck converter would work and may be v2.0 of this design, the Flyback converter was selected due to it’s:

- non-inverting output,
- wider conversion ratio N1/N2,
- isolated output, and
- separate input/output reference ground.

Some useful Equations:

\[
\frac{V_2}{V_1} = \frac{N_2}{N_1} \quad (A.1)
\]

\[
\frac{I_2}{I_1} = \frac{N_1}{N_2} \quad (A.2)
\]

\[
\frac{R_2}{R_1} = \frac{N_2^2}{N_1^2} \quad (A.3)
\]

\[
\frac{L_2}{L_1} = \frac{N_2^2}{N_1^2} \quad (A.4)
\]

\[
\frac{V_{OUT}}{V_{IN}} = \frac{D}{1 - D} \times \frac{N_2}{N_1} \quad (A.5)
\]

A.4 Design

Utilizing the data sheet for the converter controller [21] the values for individual components connected to the circuit can be calculated or are just given. So while many of the
above equations can be used to get a rough estimate, the controller can be used to find a realistic transformer. After determining all of the correct values, simulations were run to ensure the circuit performed as desired.

### A.5 Simulation

```plaintext
1 V1 N001 0 14.8
2 LP2 N013 N006 12.2u Ipk=0.85 Rser=0.145
3 LS1 N002 0 12.2u Rser=0.2
4 M1 N013 N014 N005 N005 BSC252N10NSF
5 D3 N002 Vout MBRS340
6 R7 Vout 0 200
7 XU1 MP_01 MP_02 N008 N007 N011 MP_03 0 MP_04 MP_05 0 N005 N001 N012 N010
   N004 LT1425
8 C2 N001 0 0.1u
9 C1 N001 0 22u V=35
10 LP1 N006 N001 12.2u Ipk=0.85 Rser=0.145
11 R6 N014 N001 10
12 D2 N005 N001 MURS120
13 R5 N008 N013 26.7k tol=1
14 R4 N011 0 3.01k tol=1
15 R2 N015 0 1.8k
16 Q1 0 N015 N004 0 2N3906
17 C5 N004 0 1000p
18 R1 N001 N009 2.4k
19 D1 N015 N009 BZX84B7V5L
20 C4 N007 0 1000p
21 R3 N010 0 9.31k
22 C3 N012 0 0.1u
23 LS2 N002 0 12.2u Rser=0.2
24 LS3 N002 0 12.2u Rser=0.2
25 LS4 N002 0 12.2u Rser=0.2
26 R8 N003 N002 100
27 C6 Vout N003 330p
28 C8 Vout 0 220u V=10
29 C7 Vout 0 220u V=10
30 I1 Vout 0 1
31 .model D D
32 .lib C:\Users\steve\OneDrive\Documents\LTspiceXVII\lib\cmp\standard.dio
33 .model NPN NPN
34 .model PNP PNP
35 .lib C:\Users\steve\OneDrive\Documents\LTspiceXVII\lib\cmp\standard.bjt
36 .model NMOS NMOS
37 .model PMOS PMOS
38 .lib C:\Users\steve\OneDrive\Documents\LTspiceXVII\lib\cmp\standard.mos
39 K LP1 LP2 LS1 LS2 LS3 LS4 1
40 .tran 0 0.1 0 0.2
41 .print tran output_variables
42 * 5V, 1A
43 .lib LT1425.sub
```
The LTSpice graphical version of this model is shown in figure A.1.

Figure A.1: LTSpice Model

A.6 Schematic and Board Layout

The schematic is shown in figure A.2 and the board is shown in figure A.3.
A.7 Data Sheets

Table A.1: Data Sheets
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Part Number</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>22 μF (Polar)</td>
<td>EEE-HA1V220WR</td>
<td>[8]</td>
</tr>
<tr>
<td>C2</td>
<td>0.1 μF</td>
<td>GRM033R6YA104KE14D</td>
<td>[19]</td>
</tr>
<tr>
<td>R1</td>
<td>2.4 kΩ</td>
<td>MCT06030C2401FP500</td>
<td>[53]</td>
</tr>
<tr>
<td>D1</td>
<td>7.5 V Zener Diode</td>
<td>BZX84B7V5LT1G</td>
<td>[29]</td>
</tr>
<tr>
<td>T1</td>
<td>Coupled Inductor</td>
<td>VP1-190-R</td>
<td>[24]</td>
</tr>
<tr>
<td>R5</td>
<td>26.7 kΩ</td>
<td>RC0603FR-0726K7L</td>
<td>[44]</td>
</tr>
<tr>
<td>C4</td>
<td>1 nF</td>
<td>CC0201KRX5R8BB102</td>
<td>[34]</td>
</tr>
<tr>
<td>R4</td>
<td>3.01 kΩ</td>
<td>ERA-1ARW3011C</td>
<td>[16]</td>
</tr>
<tr>
<td>R2</td>
<td>1.8 kΩ</td>
<td>ERA-3AEB182V</td>
<td>[10]</td>
</tr>
<tr>
<td>Q1</td>
<td>Transistor</td>
<td>2N3906</td>
<td>[26]</td>
</tr>
<tr>
<td>C5</td>
<td>1 nF</td>
<td>CC0201KRX5R8BB102</td>
<td>[34]</td>
</tr>
<tr>
<td>U1</td>
<td>Converter Controller</td>
<td>LT1425</td>
<td>[21]</td>
</tr>
<tr>
<td>R6</td>
<td>10 Ω</td>
<td>RC0603FR-0710RL</td>
<td>[42]</td>
</tr>
<tr>
<td>C3</td>
<td>0.1 μF</td>
<td>GRM033R6YA104KE14D</td>
<td>[19]</td>
</tr>
<tr>
<td>R3</td>
<td>9.31 kΩ</td>
<td>ERA-3AEB9311V</td>
<td>[15]</td>
</tr>
<tr>
<td>Q2</td>
<td>MOSFET</td>
<td>BSC252N10NSFG</td>
<td>[25]</td>
</tr>
<tr>
<td>CR1</td>
<td>Diode</td>
<td>MURS120-13-F</td>
<td>[31]</td>
</tr>
<tr>
<td>R8</td>
<td>100 Ω</td>
<td>RC0603FR-07100RL</td>
<td>[41]</td>
</tr>
<tr>
<td>C6</td>
<td>330 pF</td>
<td>GRM033R61E331KA01D</td>
<td>[18]</td>
</tr>
<tr>
<td>U2</td>
<td>Schottky Diode</td>
<td>MBRS340T3G</td>
<td>[30]</td>
</tr>
<tr>
<td>C7</td>
<td>220 μF (Polar)</td>
<td>UWX1A221MCL1GB</td>
<td>[17]</td>
</tr>
<tr>
<td>C8</td>
<td>220 μF (Polar)</td>
<td>UWX1A221MCL1GB</td>
<td>[17]</td>
</tr>
<tr>
<td>R7</td>
<td>200 Ω</td>
<td>ESR03EZPF2000</td>
<td>[5]</td>
</tr>
</tbody>
</table>