

KUMU A‘O CUBESAT: ELECTRICAL POWER SUBSYSTEM DESIGN

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ABSTRACT

The objective of the electrical power subsystem (EPS) of the Kumu A‘o CubeSat will be to receive, store, and distribute the power required by the satellite. Solar energy will be received by solar cells that will be placed around the perimeter of the CubeSat. This energy will be converted and stored using a single lithium-ion battery. The battery will be monitored using a fuel gauge that the command and data handling (C&DH) will communicate with. From the battery, power will be distributed to the respected subsystems of the satellite through the use of DC-DC converters. All components of the EPS will be selected to be able to withstand the space environment. The fall 2007 semester was devoted to the design of the EPS while the spring 2008 semester was spent learning the PCB software and prototyping of the EPS. The fall 2008 Semester was spent prototyping the EPS as well as creating the EPS PCB board.

INTRODUCTION

The translation of “Kumu A‘o” is “source of learning”. The Kumu A‘o CubeSat will provide engineering students at the University of Hawai‘i of Mānoa with the opportunity to get hands on experience with a satellite project from “the cradle to the grave”. The Kumu A‘o CubeSat is a LEO (Lower Earth Orbit) mission, meaning the orbit of the satellite will reach the altitude of about 600 km. The Kumu A‘o Cubesat team is composed of electrical and mechanical engineers from the University of Hawai‘i at Mānoa. I am the EPS team lead with engineer Reid Yamura.

Prior to the fall 2007 semester, a requirements list was created by the previous CubeSat team. From the requirements list, the EPS established voltages and currents that will be required. With these parameters set, a tentative block diagram of the EPS was created. In October 2008, we were able to complete the preliminary design review (PDR) where each subsystem presented their requirements and possible designs for their subsystem. The first PDR that was given was incomplete and needed to be worked on. The EPS had several components that hadn’t been selected. By the second PDR, the EPS had made all component selections. With the second PDR, the EPS and the rest of the team would move on to the next stage of design.

The next step of the design process was the critical design review (CDR). At this design phase, every part of each subsystem should be finalized and ready for fabrication. The CDR was completed on March 2008. In the CDR, the finalized block diagram and the components of the EPS were proposed. In the CDR, the EPS introduced the expected power output factoring in rotation of the CubeSat and intensity from the sun while in space. During the time allocated for questions, key issues were brought up. One problem found was that one of our DC-DC converters didn’t provide enough current at the output. Another problem that was found was in the connections between the different components. Our presentation didn’t have a section that went over the specific connections between all the components.

DESIGN

At the end of the fall 2008 semester, the design of the EPS's block diagram was finalized. Many changes have been made to the components selected during the CDR. The finalized block diagram of the EPS can be found in Figure 1.

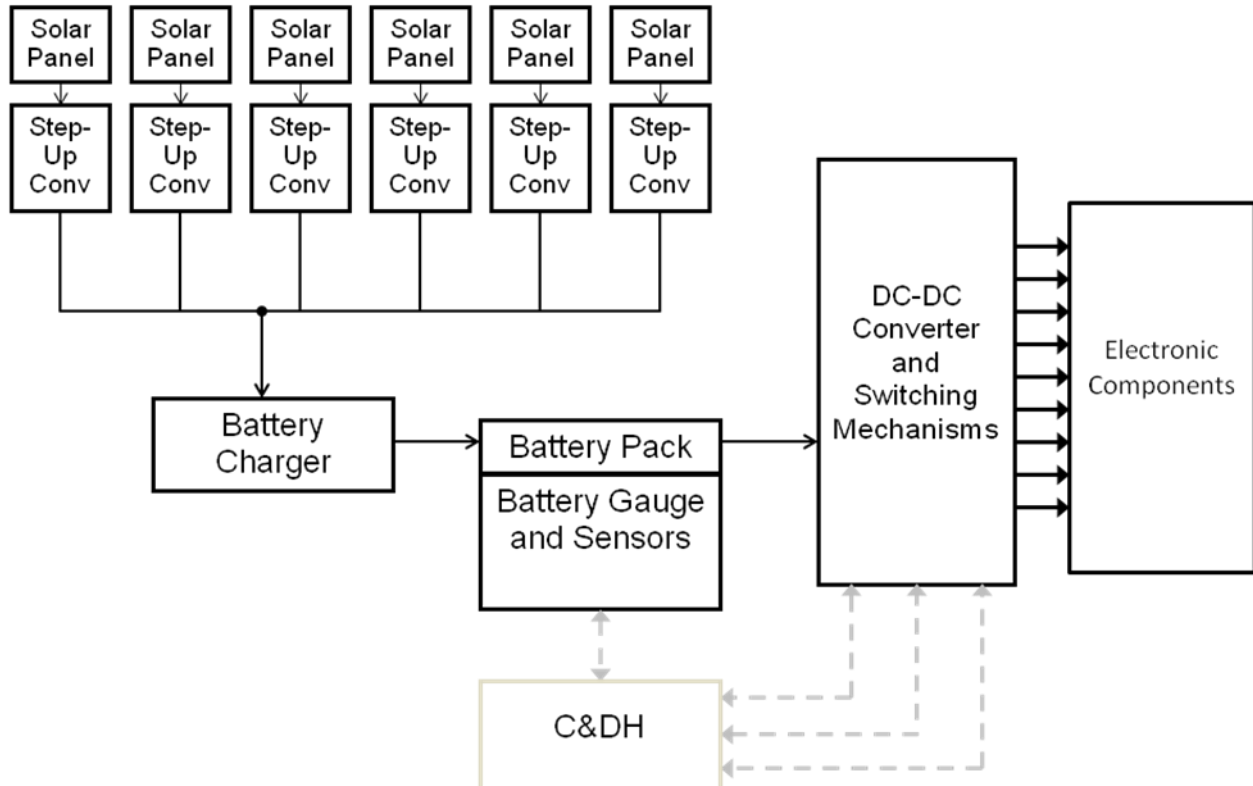


Figure 1: EPS Basic Block Diagram

Solar cells

Spectrolab's Ultra triple junction (UTJ) solar cells will be used for the flight model of the Kumu A'ō CubeSat instead of the Improved Triple Junction (ITJ) solar cells previously selected. Each cell has an efficiency of 28.3%, with an output of 2.7 V and 456.4 mA when maximum power point is achieved. Each panel of the CubeSat will have two solar cells connected in series. Each panel of the CubeSat will then be connected in parallel, as shown in Figure 1. Connecting the panels in parallel will provide redundancy if one panel is not functional. Figure 2 shows a solar panel PCB populated with a set of test solar cells on board the Engineering Model (EM).



Figure 2: Populated Solar Panel on Engineering Model (EM)

The output voltage from each side of the Cubesat will be 4.46 V with a current of 450.8 mA when maximum power point is achieved. The EPS for the Kumu A'ō CubeSat will not have a maximum power point tracking system though. As a result, the solar cells will be operating at a power less than its full potential. Actual power output of the solar panel will be documented using a solar simulator. Each side of the satellite will also have a current sensor which will provide a way to determine the orientation of the satellite.

Battery charger

Since the Critical Design Review (CDR), the MAX1898 linear Li-ion battery charger has been replaced by the switch-mode LTC4001. This change was made for the higher efficiency obtained by the switch-mode charger. The prototyped circuit of the LTC4001 can be found in Figure 3.

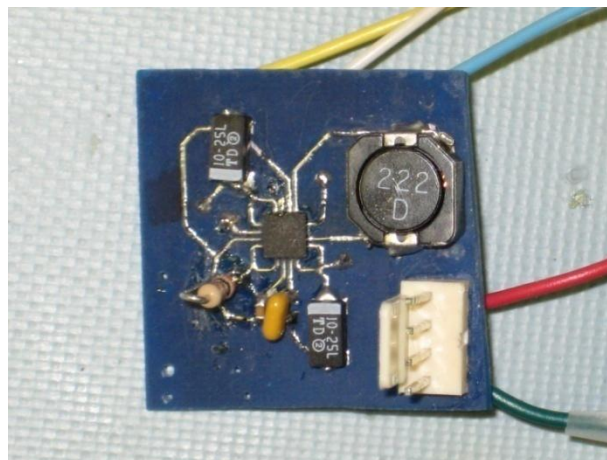


Figure 3: LTC4001 Switch-mode Li-ion Battery Charger

The battery charger was tested by using a variable power supply at the chip's input and attaching a test battery at the output of the charger. The output of the charger was also monitored by a Digital Multi-Meter (DMM). The test battery used for this procedure is a Li-ion battery with a smaller capacity than the selected Saft battery. With the power supply set to 5 V,

the chip was found to be operational. The DMM showed the voltage of the battery increasing steadily. The LTC4001 charged the battery with the “constant current, constant voltage” characteristic that is required to charge the Li-ion chemistry.

Another change was made to the EPS in terms of design. The design used to complete the CDR stated that the EPS would not be able to charge and discharge the battery at the same time. This statement implies that the rest of the CubeSat will not be able to operate while the battery is being charged (during the sun times). Also meaning the charger would need to be turned off when the battery is being used to power the other subsystems. After reading the datasheet, it was found that the charger is capable of providing power to the other subsystems instead of only being used to charge the battery. The only drawback to this design consideration is that the load of the charger cannot exceed the output capabilities of the charger.

Battery

The battery selected for this mission is the Saft MP176065. The Saft MP176065 is a single lithium-ion battery and was chosen for its high capacity of 7 Ah and energy density of 26.25 Wh. The Saft battery has a mass of 146 g, which is within the allocated mass requirements set for the battery. The output voltage of the battery ranges between 2.5 V and 4.2 V, having a nominal voltage of 3.7 V. The procured battery which will be used for the Engineering Model of the CubeSat is shown in Figure 4.



Figure 4: Saft MP176065 Li-ion Battery

Fuel gauge

The IC that will be used to record the status of the battery is the BQ27200 fuel gauge. The fuel gauge will be used to read Li-ion batteries’ temperatures, voltages, and currents. The IC is also capable of being programmed to monitor the battery’s capacity. The prototyped circuit of the BQ27200 chip can be found in Figure 5.

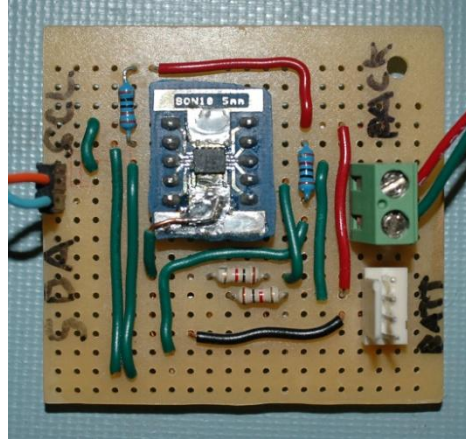


Figure 5: Prototyped BQ27200 Circuit

Once prototyped, the chip was interfaced with the MSP430 Micro-controller. The MSP430 was then interfaced with a computer where the user is able to “talk” to the BQ27200. The user is then able to identify registers already allocated on the chip

DC-DC Converters

The DC-DC converters were also changed during the fall 2008 semester. The TPS6300X converters will replace all DC-DC converters previously selected during the CDR. The TPS63001 and TPS63002 chips are able to output set 3.3 V and 5 V respectively. The converters were changed due to the high amount of space required for the MAX1771 chips, provided there were six circuits required for the design. Another reason for switching to the TPS63001 3.3 V DC-DC converter is for its buck/boost capabilities. The previous chip selected for the 3.3 V output was only a step-down converter, which wouldn't work if the voltage dropped below 3.3 V. The TPS family is also capable of converting the voltage more efficiently than the MAX1771 chips. A prototyped circuit of the TPS63002 PCB can be found in Figure 6.

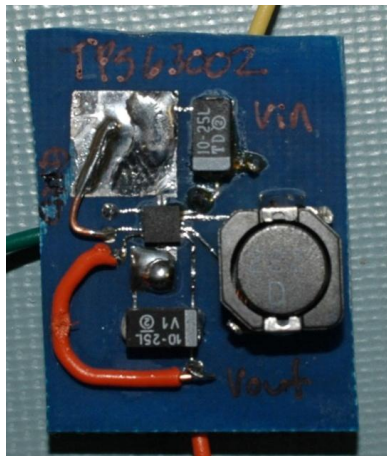


Figure 6: Prototyped TPS63002 Circuit

The TPS63001 and TPS63002 circuit schematics are identical. Having prototyped the board, the chip was characterized by varying the input voltage with a power supply. The output of the chip was monitored by a DMM. The results of the 3.3 V and 5 V chips can be found in Figure 7 and Figure 8 respectively.

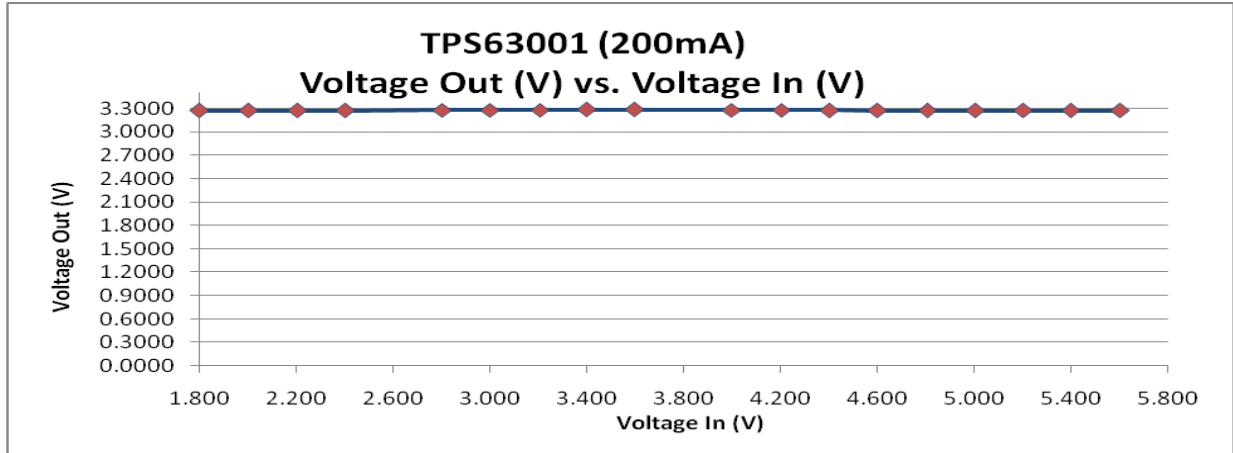


Figure 7: TPS63001 3.3 V Output Voltage vs. Input Voltage

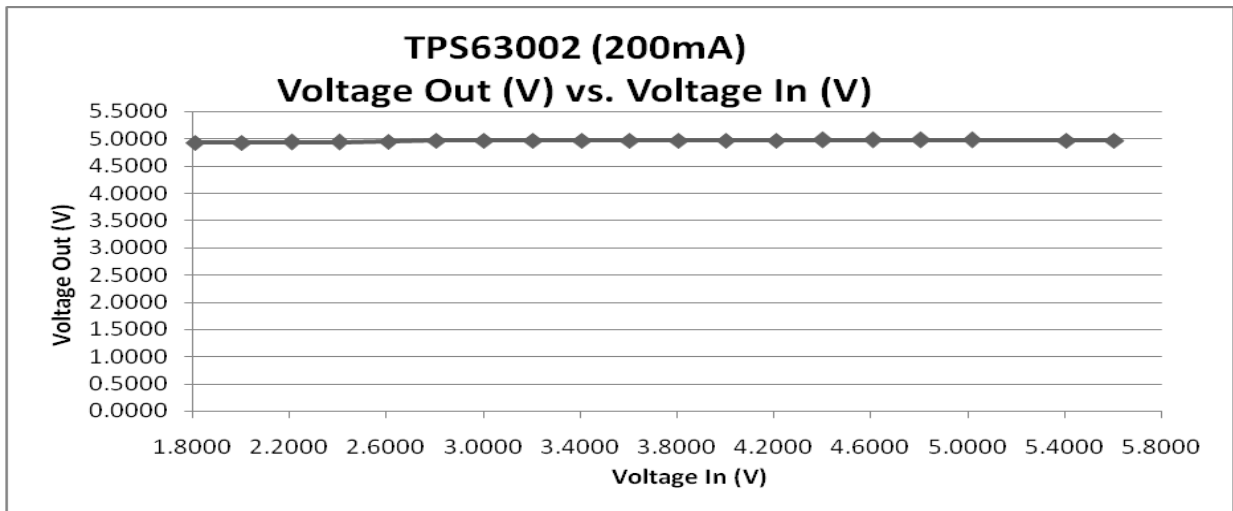


Figure 8: TPS63002 5 V Output Voltage vs. Input Voltage

From the characterizations, it is verified that the chips work properly throughout the varying voltages. It is also verified that the TPS63001 chip will be operational when the input voltage is dropped below 3.3 V.

Another addition to the changes made with the DC-DC converters is the absence of the 6 V DC-DC converter mentioned earlier in the CDR. The requirement for 6 V at 2 A was dismissed when an on-board DC-DC converter was discovered. This discovery was made when the Yaesu Transceiver was stripped for the FlatSat Model. A FlatSat model of the EPS is shown in Figure 8.

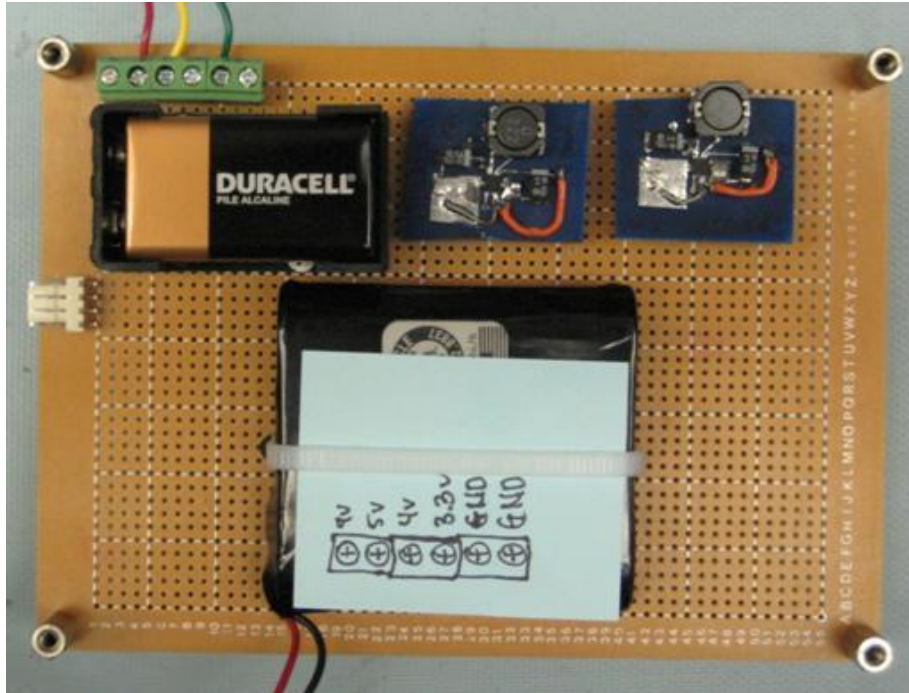


Figure 8: FlatSat EPS Board

The FlatSat EPS board consists of a 9 V primary battery, which will be used for the antenna deployment system, along with 3.3 V and 5 V TPS6300X chips and the secondary Saft battery. The FlatSat EPS model shown is missing the battery charger, fuel gauge, solar panels, and solar panel DC-DC converters. This model was able to power telecom and C&DH subsystems when transmitting and receiving data.

PCB Software

The first half of the spring 2008 semester was devoted to the learning of the PCB software. The software chosen for the PCB layout is Advanced Circuit's PCB Artist. Through the PCB software, the components of the EPS were placed on a PCB. The first step in using the software is to create the chip. Creation of specific chips was required because the library of PCB Artist was found to be limited to what chips were available. Once the chip was created, the creation of the circuit's schematic was done. The final step in the schematic design was placing the schematic on the PC104 template which was created by teammate Jeremy Chan. Once this was completed, the schematic was converted to PCB by software. The software provides an option to auto-place chips as well as auto-routing tracings between components. This stage of the design process gave problems because the software was not able to create all the connections required. Even with a four layer board, the software wasn't able to make all the connections. Placement of components, as well as routing tracings was done by hand. Indication of connections was made by software, through creating the schematic, to simplify routing of tracings. The finalized PCB layout for the EPS board is shown in Figure 9.

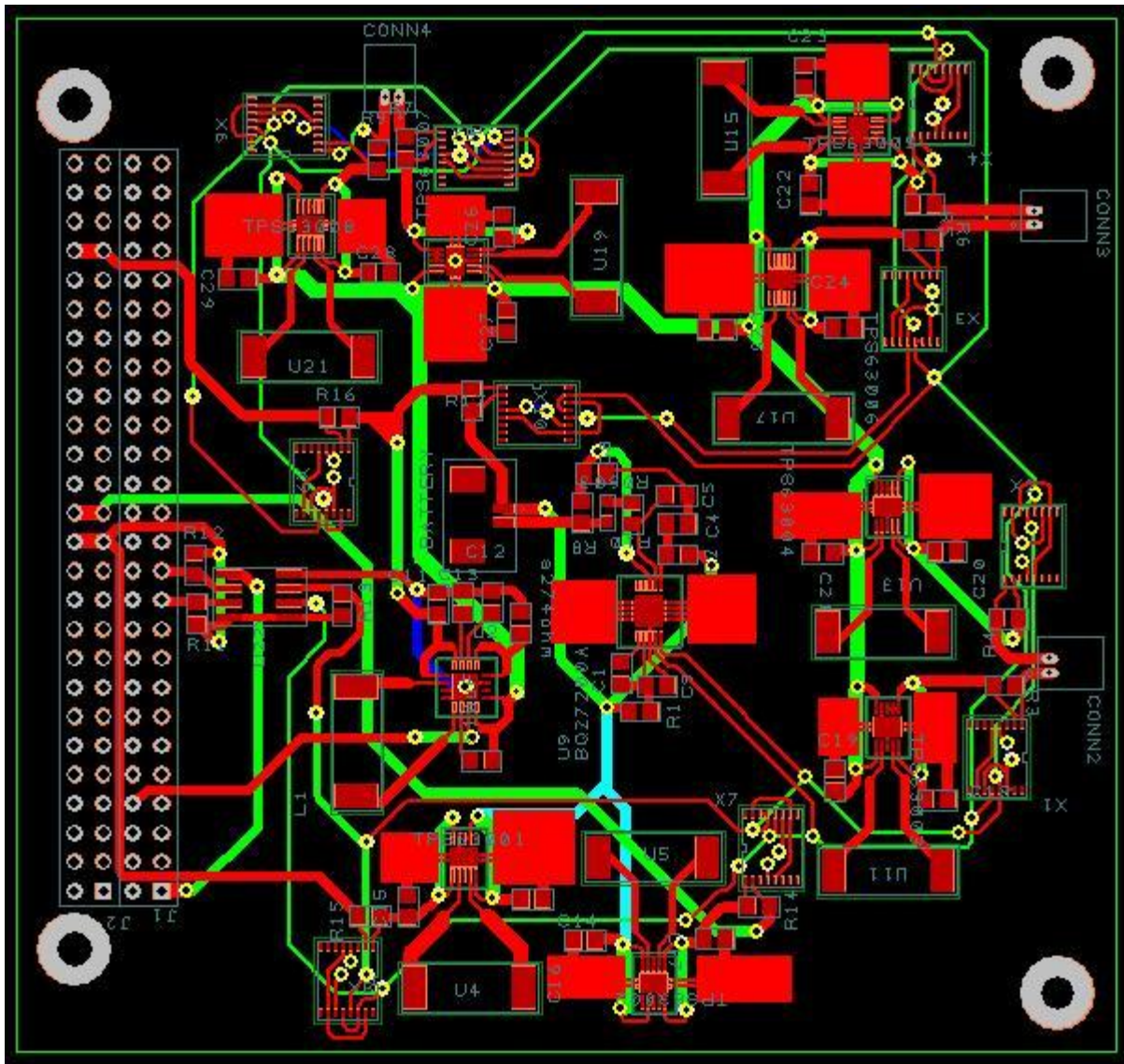


Figure 9: EPS PCB Layout

CONCLUSION

The fall 2008 semester, much progress was made in the design and fabrication of the EPS. A valuable lesson learned from this experience was that a chip's datasheet needs to be read through thoroughly to avoid problems later on in the design process. Prototyping and testing of individual circuits also proved to be more difficult to accomplish than expected. The circuit schematics were viewed to be simple in terms of design. When prototyping the chips however, roadblocks were ran into when trying to solder the QFN packages. By trial and error, the prototyping method of fabricating PCB's for the circuit was found to be the most effective. Through our experiences with PCB Artist, it was apparent that not everything can be done with the software.

ACKNOWLEDGEMENTS

I would like to thank the Hawai'i Space Grant Consortium for granting me the irreplaceable experience to participate in a prestigious program. I would also like to thank all of the Kumu A'o Cubesat team for being a cohesive unit. Also, thank you to mentors Lloyd French and Byron Wolfe who gave valued advice throughout the semesters.

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