Power Distribution System for a CubeSat

Project report to be submitted in partial fulfillment of the requirements for the degree

of

Bachelor of Technology in Electrical and Electronics Engineering

by

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ELECTRICAL AND ELECTRONICS ENGINEERING

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DECLARATION

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We, the undersigned, hereby declare that the mini project report titled *Power Distribution System for a CubeSat* , submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by us under the supervision of Dr. Dinesh Gopinath, Department of Electrical and Electronics Engineering, Government Engineering College, Barton Hill. This submission represents our ideas in our own words and ideas and words of others have been included, we have adequately and accurately cited and referenced the original sources. We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or sources in submission. We understand that any violation of the above will be a case for disciplinary action by the institute and/or the University can also evoke penal action from the sources which have thus not been properly cited or from whom proper permisssion has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other university

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CERTIFICATE

This is to certify that the report titled **Power Distribution System for a CubeSat** submitted by **Mary Angel Gomez, Mayoogha SL, Naveen AB, Navya S** of the **Department of Electrical and Electronics Engineering** to the APJ Abdul Kalam University in partial fulfillment of the requirements for the award of the Degree of *Bachelor of Technology in Electrical and Electronics Engineering* is a bonafide record of the project work carried out by them under my guidance and supervision. This report in any form has been submitted to any other university or institute for any purpose.

Dr. Dinesh Gopinath **Professor**	**Er. Karthika B** **Assistant Professor-Adhoc**	**Er. Thara Mohan** **Assistant Professor-Adhoc**
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Place: TVM
Date: January 3, 2023

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ABSTRACT

CubeSat are miniature version of satellites that offer hands-on experience to engineering students in designing, developing, testing and operating a real spacecraft system. A 1U CubeSat is a cube shaped satellite with dimensions of 10 cm x 10 cm x 10 cm and maximum mass of 1.33 kilograms. CubeSats are traditionally built from COTS-components (Commercial Off-the-Shelf) with low resources. Typically, CubeSat have limited mission time and short development and testing time.

One of the most critical aspects of the CubeSat is the Electrical Power System (EPS) since the electrical power is necessary for a CubeSat to operate. The EPS of the CubeSat consists mainly of solar cells, batteries, voltage converters and protection circuits. The EPS is responsible of providing stable power to the CubeSat subsystems.

The purpose of this project is to design and implement an EPS for a CubeSat. The EPS must be able to power all subsystem components including telemetry, onboard computer, attitude determination and control system , thermal system as well as the payload while also protecting the subsystems from the over-current and over-voltage issues associated with the device failure. The system will be designed to provide power for the satellite throughout the entire orbit, even during periods of eclipse when the satellite is not able to generate power. The EPS should also provide data about voltage and current measurements, battery status, etc. to OBC (On-Board Computer).

ABBREVIATIONS

DC	Direct current
IC	Integrated Circuit
EPS	Electrical Power System
MCU	Micro-controller Unit
OBC	Onboard Computer
PCB	Printed Circuit Board
RBF	Remove Before Flight
TCS	Thermal Control System
ADCS	Attitude Determination And Control System
MPPT	Maximum Power Point Tracking

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Chapter 1

Introduction

A CubeSat is a class of miniaturized satellite based around a form factor consisting of 10 cm cubes. CubeSats have a mass of no more than 2 kg per unit, and often use commercial off-the-shelf (COTS) components for their electronics and structure. CubeSats are put into orbit by deployers on the International Space Station, or launched as secondary payloads on a launch vehicle. As of August 2021, more than 1,600 CubeSats have been launched.

For more than a decade, CubeSats, or small satellites, have paved the way to low-Earth orbit for commercial companies, educational institutions, and non-profit organizations. These small satellites offer opportunities to conduct scientific investigations and technology demonstrations in space in such a way that is cost-effective, timely and relatively easy to accomplish. It give students an experience in developing flight hardware and conducting space missions.

CubeSat missions benefit Earth in varying ways. From Earth imaging satellites that help meteorologists to predict storm strengths and direction, to satellites that focus on technology demonstrations to help define what materials and processes yield the most useful resources and function best in a microgravity environment, the variety of science enabled by CubeSats results in diverse benefits and opportunities for discovery.

Chapter 2

Literature Review

Information transmission is very vital to human life just as the early men used sticks to produce sound which indicates the location of each other as they wander about also down to the middle era when town crises come into play for the same information propagation to be transmitted from one point to another with the aid of radio communication which necessities the application of radio transmitter and receiver.

Frequency modulation (FM) is a technique for wireless transmission of information where the frequency of a high frequency carrier is changed in proportion to message signal which contains the information. FM was invented and developed by Edwin Armstrong in the 1920's and 30's. Frequency modulation was demonstrated to the Federal Communications Commission (FCC) for the first time in 1940, and the first commercial FM radio station began broadcasting in 1945.

A radio transmitter is device whose major function is to send information (intelligence) from one point to another in most cases the information to be transmitted are voice music and code signals. However the transmission of radio signal is done with the aid of electrical resonance this is when the frequency of the receiver is equal to the incoming one from the transmitter resonance is observed which is the totality of radio communication, frequency modulation (FM) transmitter is less distorted than other wave bands like amplitude modulation and short wave band. The frequency on the tuning dial ranges from 88MHZ to 108MHZ.

Chapter 3

Aim

The aim of this project is to determine requirements for a typical CubeSat Electrical Power System (EPS) and develop a working prototype of the EPS for a CubeSat.

Chapter 4

The Electrical Power System

The Electrical Power System (EPS) is an electronic circuit board that is designed to supply, manage and store energy in an efficient way. The EPS must be able to harvest energy from the solar panels and store it in the battery, as well as delivering power to the satellite, using switch controlled converters to supply a regulated voltage. Redundant circuitry must be present to ensure continuous and reliable operation of the satellite in case of the failure of EPS components.

The output of the solar panels is first run through the power path control. While in sunlight operation, the power path will select the voltage from the panels based on its higher voltage. The output of the Power Path control is sent to DC-DC converters to provide 5V and 3.3V regulated DC supply for the Cubesat modules. During the eclipse, the power path will select the battery to power the circuit components.
The software is implemented in order to manage the overall energy of the satellite, regulate the converters to extract maximum power from solar panels, perform power diagnostics, engage redundant circuitry and to communicate with the On Board Computer. The software also employs four operating modes: Initialization mode, Safe mode, Normal mode and Low Power Mode.

4.1 Components of EPS

The EPS of a cubeSat can be designed with many different architectures, but some components are common to all designs, such as:

- Solar panels to harvest the energy from the Sun
- Battery charger to manage the charging profile of the battery
- Voltage regulators to feed the regulated power bus of the satellite
- Remove Before Flight (RBF) switches and deployment switches, to cut the power while the satellite is not deployed

Other components of the EPS are:

- Battery and associated charging circuit
- Solar panels on 6 faces of the satellite
- MPPT converters which help optimise power collection from the sun
- Buck and boost converters which help provide required voltage busses for components of different voltages
- STM32 used as the MCU which controls the tasks that the EPS performs and monitors the status of the components
- Over Current Protection Circuit which helps protects important components from high current flow
- Current and Voltage sensors to keep track of their consumption.
- Temperature sensors to measure battery temperature, based on which battery heater is used
- Battery heater circuit

4.2 Tasks of EPS

Tasks of the EPS are:

- Collect housekeeping for various components associated with it, like the various current & voltage sensors and the battery's state of charge.

- Handle housekeeping requests and other commands from the OBC (ON/OFF requests of any subsystem by OBC).
- Implement MPPT to optimize power generation.
- Control the Simple Beacon (which contains only the call sign of the satellite) before the TTC gets switched on.
- Implement a watchdog timer to keep a check on the operation of the OBC.
- Take action on the basis of OCPC triggers.
- Deployment of antenna at the time of satellite initialisation.
- Turn on the battery heater when temperature goes below critical level

Chapter 5

Methodology

5.1 Identifying Power Requirements

Before designing the EPS, the power requirements of the various subsystems of the cuesat has to be identified. A power budget has to be prepared accounting all the energy, voltage and current requirements of the subsystems. The orbital parameters at which the cubesat might be operating should also be considered. The orbital altitude, period and eclipse time and the daylight time has to be identified and documented. After this, the peak power budget has to be calculated and total energy and power demands are to be found out.

5.2 Literature Review

In order to select the suitable architecture and topologies, literature study has to be conducted. Various articles regarding the implementation of cubesats and EPS were studied and the findings were recorded.

5.3 Architecture Design and Topology selection

The design of EPS starts with the selection of appropriate EPS architecture based on the comparison of overall efficiency, battery size, and reliability. The EPS design is critical for CubeSat mission success, therefore selection of proper EPS architecture is one of the important steps. Different standard EPS architectures are classified on the basis of various topologies like dc-bus voltage regulation, interface of

PV panels, location of power converters, and number of conversion stages. The necessary topology has to be selected based on the demands and constraints.

5.4 Forming Specifications

After deciding upon a suitable architecture, the specifications of various components of the EPS has to be finalised. This includes deciding the number of required power converters and their input and output parameters, deciding the number, size and type of battery for energy storage and the characteristics of the solar panels and specifications of the MPPT device.

5.5 Design and simulation

Suitable ICs able to perform the various functions of different components in an EPS have to be identified. The ICs must be suitable for operation in outer space. After selecting the ICs, the design of them are to be completed and necessary schematics and PCB design has to be completed. Also, the circuits obtained have to be verified with the help of simulation results.

5.6 Procurement of components

The components which were finalised has to be procured. Surface Mount components are preferred due to the space constraints, also the selected components must be applicable in outer space applications.

5.7 Fabrication and Testing

The components have to be soldered into the PCB and the results are to be observed. Initially, each component maybe developed individually and tested before optimizing the entire circuit into a single, centralized form.

Chapter 6

Power Budget

It is important to determine the power budget at the beginning of the EPS design to determine the characteristics of the system. When the available space for the solar cells and the orbital parameters are known, power production can be estimated. The power requirements of CubeSat as a whole depend upon the power requirements of the individual components and how the components are used together for operations. Together with the efficiency information of the EPS components, this data is used to determine critical elements of the EPS design, like required solar array and battery size.

A CubeSat will have standard set of satellite subsystems: Structural subsystem, Telemetry, Electrical Power Subsystem (EPS), Thermal Control Subsystem (TCS), Attitude Determination and Control Subsystem (ADCS), On Board Computer (OBC) and Payload. For the calculations, a LoRa module was selected as the payload. The orbital parameters are given below:

Parameter	**Value**
Orbital altitude	590 km
Orbital radius	6968.14 km
Flight velocity	7.563 km/s
Orbital period	96.483 min
Eclipse time	31.164 min
Daylight time	65.319 min

The CubeSat has an orbital altitude of 590 km with an orbital radius of 6968.14 km to maintain a flight velocity of 7.563 km/s. The orbital period is 96 min 29 sec with an eclipse time of 31 min 10 sec and daylight time of 65 min 19 sec. Based on the power budget, the energy required by the CubeSat is 1.997 Wh per orbit. Hence, the solar panels must designed be able to produce at least 1.997 Wh per orbit.

Power requirements of various components of each subsystems are given below. Since the power production may vary due to parameters like efficiency of panels, margin and contingency are added to the total power requirements.

Sub-system		**Voltage (V)**	**Max. Current (mA)**	**Power (mW)**	**Contingency 5%**	**Margin 20%**	**Duty Cycle (%)**	**Energy (Wh)**
ADCS	ADCS	3.3	20	66	69.3	83.16	100	0.133725438
	Magnetorquer	3.3	100	330	346.5	415.8	50	0.334313595
OBC	OBC	5	40	200	210	252	100	0.4052286
Rx-Tx	Telemetry	5	300	1500	1575	1890	11	0.334313595
	Beacon	5	20	100	105	126	100	0.2026143
	GPS	3.3	40	132	138.6	166.32	30	0.0802352628
Payload	LoRa	5	20	100	105	126	10	0.02026143
EPS	EPS	-	-	160	168	201.6	100	0.32418288
	Thermal	-	-	250	262.5	315	32	0.16209144
					Tot Power(mW)	**3575.88**	**Tot. Energy**	**1.997**

Conventionally, EPS will work on different modes to manage the overall power production and distribution of the CubeSat. The main modes are initializing mode, which is during the initial phase of CubeSat launch and the normal mode, which is the rest of the mission. The initializing mode is divided into three. Pre launch mode, launch mode and initializing. In pre launch mode, all subsystems are off, in launch mode, that is when the CubeSat is deployed into orbit, the EPS and OBC turns on and during initializing, all subsystems are turned on for a small amount of time to check whether all subsystems are working properly. The normal mode consists of safe mode and nominal mode. During safe mode, only the EPS and beacon of telemetry system works, and the CubeSat is in a power saving mode. The nominal mode is the general purpose mode were payload will function.
To calculate battery and solar panel specifications, the peak power budget of the CubeSat is only considered since the power requirements won't exceed that requirements. The other modes are only documented for designing the functioning

of micro-controller which controls the EPS.
From the peak power budget table, the highest energy requirement is 2.307Wh.
Add a 50% contingency => 3.055Wh —-solar panel calculation—- ——battery calculations

Chapter 7

System Architecture

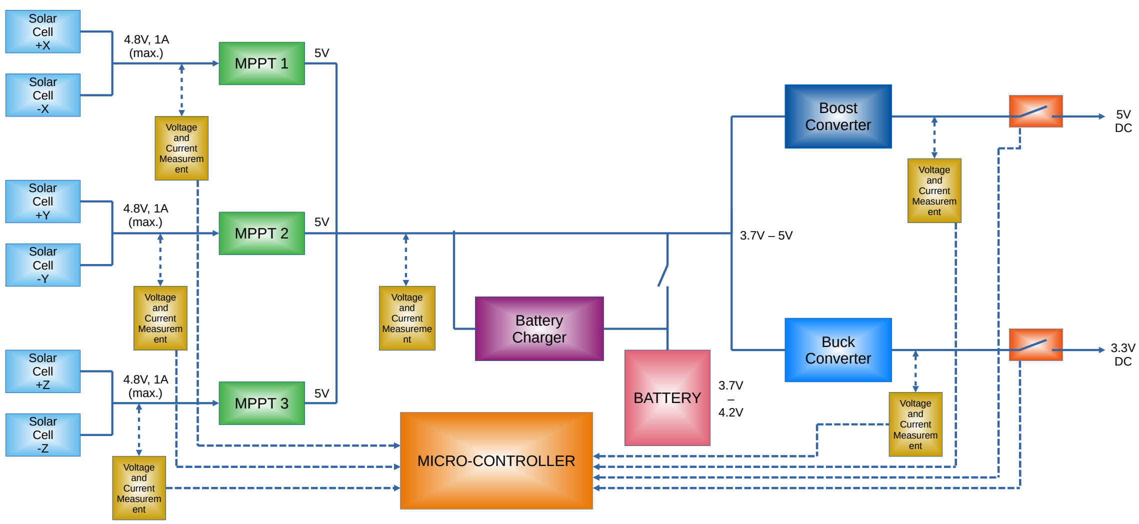

Figure 7.1: System Architecture of the CubeSat EPS

Chapter 8

Component Selection and Design

8.1 Solar Panels

TJ Solar Cell 3G30C - Advanced is selected. This cell is a GaInP/GaAs/Ge on Ge substrate triple junction solar cell. The end-of-life version of the 3G30C solar cell offers best EOL-performance values. Connected to the EPS via an external bypass diode protection.

Specifications:

- Average Open Circuit Voltage: 2.7V
- Maximum Power Point Voltage: 2.41V
- Average Short Circuit Current: 520.2 mA
- Maximum Power Point Current: 504.4mA

It has an average efficiency of 29.8% at 1353 W/m^2. This solar cell is excellent for space applications.
Solar panels are connected in such a way that each side has two cells connected in series.The maximum voltage developed per side is 4.4V and the maximum current that can be generated per side at peak power point is 0.5A. Panels on opposite sides are connected in parallel.

8.2 Maximum Power Point Tracking Circuit

The MPPT converter connected to the solar panels increases the efficiency as the maximum power is transferred from the radiated energy that is on the solar panels. As each solar panel has different temperatures and incident radiance angles, the Maximum Power Point (MPP) is also different. So each solar panel has a MPPT converter to assure that the maximum power available at the solar panels is transferred independently from their working power points.Since the peak power point cannot be accurately predicted, many different algorithms exist for finding the best approximation. The MPPT can be implemented in the EPS using one of three algorithms: **Perturb and Observe, Incremental Conductance, Constant Voltage**

The SPV1040 was chosen as the MPPT IC. It is a boost converter with duty ratio controlled by Perturb and Observe MPPT algorithm. The perturb and observe algorithm is based on monitoring either the voltage or the current supplied by the DC power source unit so that the PWM signal duty cycle is increased or decreased step-by-step according to the input power trend. This chip has inbuilt over-current protection and a cutoff mechanism if the solar panel connection is reverse-inserted to prevent damage to the IC and the external circuit.

Specifications of SPV1040:

- Input Voltage: 0.3 - 5.5V
- Output Voltage: 5V
- Switching Frequency: 100kHz
- Efficiency: 95%

The MPPT circuit schematic is shown below:

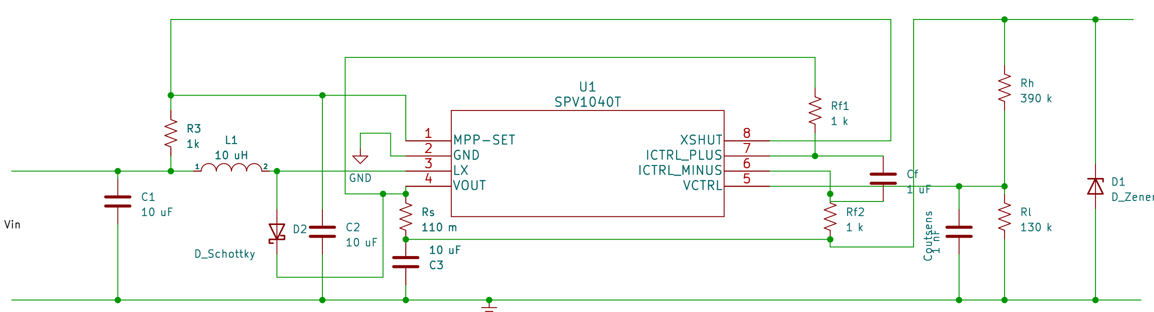

Figure 8.1: MPPT circuit with SPV1040

8.3 Battery

The most popular types of batteries use the following materials: Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Nickel Hydrogen (NiH2), Lithium Ion (Li-Ion) and Lithium Polymer (Li-Po). The Li-Po and Li-Ion became the standard use in space technology due to their high energy density (Upto 200 Wh / kg on Li-Po and upto 250 Wh / kg on Li-Ion) and also due to the number of charging cycles being as high as the NiMH, whilst presenting higher operating temperatures. The Panasonic NCR 18650 GA Li-Ion cell was selected based on the calculation of EOL power, EOL efficiency and due to it's high energy density. Specifications of Panasonic NCR 18650 GA:

- Voltage: 3.7V - 4.2V
- Capacity: 3500mAh
- 1800 cycles till capacity reduces to 60%

8.4 Battery Charger

The battery also needs a charger to regulate its current and voltage while charging. BQ25302, a synchronous Buck Battery Charger IC was selected and connected in external power path mode.

Specifications and Operating Conditions of BQ25302:

- Input Voltage: Upto 5V
- Output Voltage: Upto 4.2V
- Switching Frequency: 1.2MHz
- Output Current: Limited to 1.2A by connecting a 33.5k resistor at ICHG pin
- Efficiency: 94.3% at 1A from 5V input
- Thermistor: Semitec 103AT-2 (10kΩ)
- Charging Temperature: Limited between 0 - 45 ^oC

The Battery Charger circuit schematic is shown below:

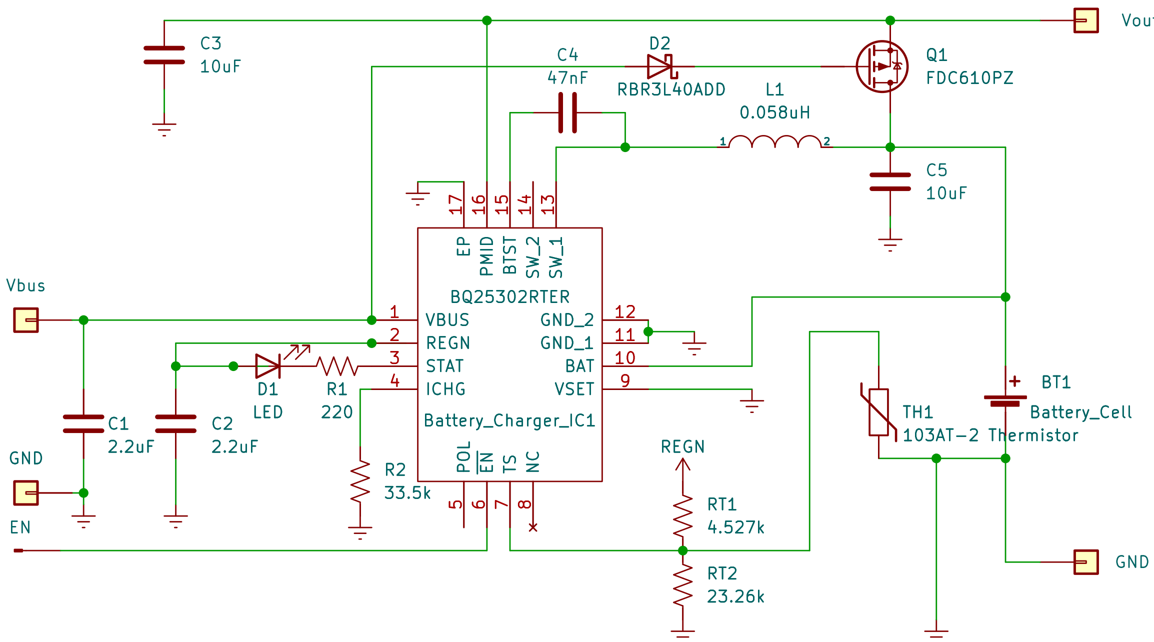

Figure 8.2: Battery Charger circuit with BQ25302

8.5 Buck and Boost Converters

The power conditioning is associated with regulating the voltage to accommodate for the charging voltage and the voltages of the satellite's subsystems. In most subsystems, the need for a specific voltage requires a regulation of either a step-up or a step-down of the supplied voltage. It can be done by buck convertor(step-down) and boost converter(step-up). TPS62203 was selected as the buck converter to provide step down voltage of the DC bus to supply the 3.3V loads.

Specifications and Operating Conditions of TPS62203:

- Input Voltage: 3.6 - 5V
- Output Voltage: 3.3V
- Switching Frequency: 1MHz
- Output Current: 300mA (max.)

LTC3426 was selected as the boost converter to provide step up voltage of the DC bus to supply the 5V loads.

Specifications and Operating Conditions of LTC3426:

- Input Voltage: 3.6 - 5V
- Output Voltage: 5V
- Switching Frequency: 1.2MHz
- Output Current: 500mA (max.)

All convertors operate in continuous conduction mode.

The Buck and Boost Converter circuit schematic is shown below:

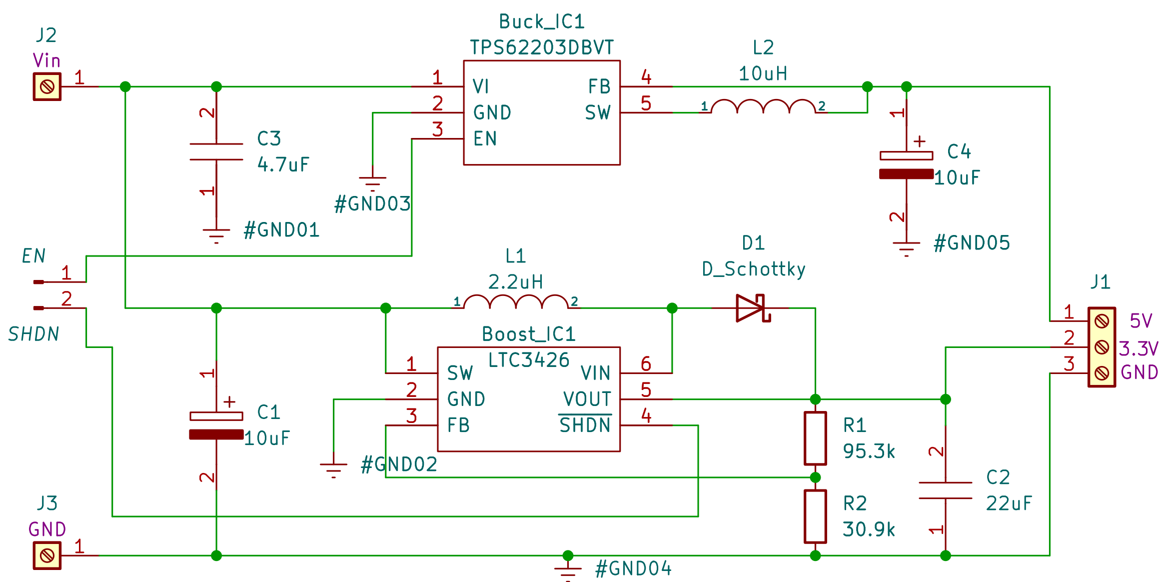

Figure 8.3: LTC3426 as boost IC and TPS62203 as buck IC

8.6 Protection Circuits

The circuit used for the protection purpose is the current limiting circuit. Unlike a fuse that breaks a circuit connection, a current limiter only limits the current at a predetermined level. The current limiting circuit can be as simple as a single resistor (a passive current limiter), with the voltage drop across the resistor being dependant on the consumed current by the load. Higher the current drawn by the

load, higher the voltage drop on that resistor. In many cases, this is not preferable. An active current limiting circuits does not drop the voltage if the current drawn by the load is below the allowable range. With this mechanism, all power is delivered to the load in the normal condition. If the load tries to draw a current that is more than allowed then the current limiting circuit will act as a resistor, controlling its resistant value to limit the current to a predetermined level.
LTC4361-2 is selected as the over voltage and over current protection IC. It control an external N-channel MOSFET as a switch to cut the path of current if there is an event of over current or voltage. Manual control of the MOSFET is also possible which may be useful to turn off power to buses by the micro-controller as per different modes of operation of the CubeSat.

8.7 Voltage and Current Measurement

Voltage and current passing through each bus and subsystems are continuously monitored by sensors and this information is fed to the micro-controller. These measurements help in estimation of load requirement of subsystems and also help in triggering of protection circuits if a subsystem needs to be turned off in case of an occurrence of a fault.
LTC2990 was chosen as the voltage and current monitor. It can measure the voltage of four external channels and it's supply voltage (V_{cc}) simultaneously. It has a 14 bit ADC for measurement. The LTC2990 has the ability to perform 14-bit current measurements with the addition of a current sense resistor. The measurements are passed on to the micro-controller through I2C interface.

Chapter 9

Component List

Sl No.	Component
1	TPS62203
2	LTC3426
3	BQ25302
4	Panasonic NCR 18650 GA Li ion cell
5	SPV1040T
6	TJ Solar Cell 3G30C
7	PCB
8	Resistors
9	Capacitors
10	Inductors

Chapter 10

Workplan

Activites	**Timeline**
Identifying Power Requirements	Completed
Literature Review	Completed
Architecture Design and Topology selection	Completed
Forming Specifications	Completed
Design and simulation	Partly Completed
Procurement of components	February
Fabrication	March
Testing	April
Final Project Report	As per KTU Schedule

Chapter 11

Conclusion

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