University of Windsor Space and Aeronautics Team:

Electrical Power Systems (WINSAT)

Design of a 3U Earth Observation Cubic Satellite for Low Earth Orbit

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University of Windsor Space and Aeronautics Team (WinSAT):
Electrical Power Systems (WINSAT)

Electrical Engineering Capstone Team

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Abstract (QB)

The Canadian Satellite design challenge (CSDC) "Selfie-sat mission", is a Canada wide competition to design and build small satellites. WINSAT (University of Windsor Space and Aeronautics team) is a team participating in this competition along with other universities in Canada. WinSAT is a multidisciplinary team consisting eight divisions, ADCS, EPS, Structural, Thermal, RF, Payload & CDH and Business. The EPS team was tasked with collecting power and delivering it to the other units for the secure and effective execution of the space mission. Due to global condition of COVID-19, the deliverables of EPS team were affected and shifted to means of only simulation rather than physical testing also. Team has investigated extensively and come up with the collection of space-rated solar cells that are chosen to maintain the region accessible and the space mission's power requirements. The WinSAT team has unanimously decided to purchase off shelf EPS module for the CubeSat due to time constraints. Analysis and calculation of the STK model were used in the Solar Cells and Battery selection process. In addition, PCBs are designed to connect solar panels to the EPS module. Team was also tasked with providing the power to the various divisions such as ADCS, CDH, RF, and Payload are included. PC104 is equipped to provide power and communication to the other units from the EPS module. Since these PCB boards are built for space application spacing is deemed to be per PCB space requirements. Group was aimed at creating the Simulink model for power generation and battery operation, after carefully choosing the Solar Panels and Batteries. Two Simulink models to show the principle of Battery operation by charging and discharging while designing the Simulink model. We also learned to model the battery process for charging and discharging in these first two models. The third and final effective model is in depth, modelling the production of solar cells, the load with constant voltage and modelling the activity of the battery. The product contains solar cells and battery details from the datasheet, the Simulink device shows the principle of charging the battery when we have strong irradiance, maintaining steady voltage across the load. The final model will sustain the steady voltage over the load while there is less irradiance and show the state of space when there is little or less daylight in space. Simulink model conducts EPS module activity by extracting the power from the solar cells and utilising the MPPT algorithm to control the full power and operate the load with a constant voltage. EPS module protection function is implemented using a breaker in the final Simulink model to hold the battery idle at the moment of full power production.

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1. Introduction

1.1. Background (UC)

Electrical Power System division (EPS) is part of WINSAT team, which is a multi-disciplinary engineering team taking part in Canadian Space Design Challenge (CSDC) 2018-2020, a national competition of Canadian universities tasked to design, test and build a 3U CubeSat for mission operation in Low Earth Orbit (LEO). As an Electrical Power Systems division, we do have an important role by being responsible for the overall power distribution, battery, and solar array operations on our satellite. Team would also be responsible to have conclusive evidence to support in order to decide the battery to be used for the project, and also will design PCB for other division. In order of incorrect selection of solar cells or battery could lead to failure of multiple electrical components resulting in catastrophic events during orbit. Team is comprised of 3 Electrical Engineering Students.

1.2. Objective (QB)

The objective of the team was to create an effective power estimation for the satellite to accomplish the desired task in the satellite mission. This required the selection of battery capacity and space rated solar cells by analysing the techniques to estimate the power consumed by different electronic components. Techniques involved, STK simulation which helps us record the power generated by solar cells in orbit, power budget is calculated using an excel sheet to produce power generation and power consumption analysis and simulation of battery integrator was conducted through Simulink by testing the battery characteristics which were dependent on selected solar cells. PCB design involves special consideration for the correct sizing, layout and tracing while the design in order to integrate our components mechanically and electronically to withstand the vibration testing procedure.

1.3. Scope (MQ)

EPS division was divided into 2 major subdivisions which were Designing of Printed Circuit Boards (PCB) and Power Estimation. PCB boards were designed for multiple divisions of the WINSAT team along with the representation through the Ki-Cad models. Secondly, an effective power budget was assembled to verify the power consumption and the power generation through the solar cells while in eclipse mode. In order to verify our power generation of solar cells various STK simulation were conducted with different parameters in order to select ideal solar cells. Finally, using Simulink model multi-domain dynamical system was analysed and simulated.

2. Benchmarking (QB)

The basic components of the EPS are energy source, energy conversion, power regulation and battery control, energy storage and power distribution [1]. Energy source for the CubeSat mission is solar irradiance therefore space rated Solar cells are selected. These cells are selected by various other CubeSat designers. For power regulation WinSAT team decided to buy the Clyde Space EPS module due to the time restraint. Clyde Space 3rd generation EPS module is state of the art technology and have all the features which are required for Canadian Space Design Challenge. EPS module uses MPPT tracking for charging the battery. Following many research papers, it can be established the features specified by the Clyde Space EPS module satisfy the criteria of a secure and efficient space mission completion. Energy storage is important because there is low irradiance available at the time of operation. Upon doing the analysis, battery is specifically chosen after evaluating how much energy the project generates and consumes, eventually battery chosen is Clyde Space 3rd generation space rated product. Our research for EPS system for CubeSat confirms that our selection for solar cells, EPS module and battery are faultless. The EPS system modules were mostly compared to the others on the market for CubeSats EPS divisions [2].

3. Design Criteria, Constraints and Deliverables

3.1. Design Criteria (UC)

Various principles were taken into consideration for making decisions on design process. The requirements for Canadian Space Design Challenge (CSDC) competition were followed, while making decision on selection of space rated solar cells, space rated battery and dimensions of PCB's. Furthermore, for selection of solar cell's structural layout of the panel sides were taken into consideration to determine the number of cells that can be attached on each side. In addition, for selection of battery was dependent on the requirement of power consumed by the loads from different divisions. Therefore, data regarding power consumed by different components of the load was communicated with ADCS, CDH, RF and Payload. Role of PCB designing was critical due to the correct sizing, layout, tracing and footprints. Tracing is important as PCB's can have multiple layers where tracing can be done on the front and back of the board. Board layout helps in defining the shape, size that is done by drawing in Ki-CAD to further determine the area and shape of the board.

3.2. Constraints (QB)

There are multiple design constraints that were faced during the project:

- Space rated battery is expensive and not available for the test, we have to do multiple tests in order to verify our recordings from the data sheet available to us. Which would give a better understanding while choosing the correct battery size for the project.

- Electronics components mounting on PCB is a constrained in the project due to equipment and skills set available.

- Space rated solar cells are very expensive, it is almost impossible to buy the solar cell in advance and record and confirm the real charging current values for solar cells. Therefore, STK 11 simulation and power budget would allow us to use that data into our battery integrator to charge our battery and discharge our battery.

- Due to reason that our WINSAT project has tight deadlines some of the parts for EPS would be bought off the shelf rather to design and manufacture which include the EPS module.

- Global pandemic slows down the progress for the whole project and affected the deliverable for the project. Physical test for the solar cells, battery and EPS module not been conducted due to the cancellation of Canadian Space Design Challenge (CSDC) 2018-2020.

3.3. Deliverables (QB, MQ and UC)

EPS division were tasked to multiple deliverables. Firstly, selection of solar cells was done by conducting various STK simulations in orbit to obtain the power generation of our satellite. After satisfactory results of our STK simulation Space rated CTJ30 solar cells were selected, total of 16 cells were selected for the cube-sat. Secondly, selection of battery was dependent on effective power budget calculation which was based on an excel sheet of "Small Spacecraft Power Model". After adding our loads details, we can determine the orbit average energy (watt-minutes) which could be compared to the total battery energy in the battery characteristics. After successful comparison Clyde Space 3rd Generation 30Wh Standalone battery was selected for this CubeSat mission. Moreover, Simulink model was designed to analyse the battery characteristics under load while tracking the MPPT (maximum power point tracking) of the PV array. Another essential component that is being used is Clyde Space EPS 3rd Generation EPS module for the mission, this particular module provides robust, high-mission performance capability. One of the main features of the module is the cut-off mode of the power to the battery in order to prevent from overcharging the battery and damage the component. PCBs are built with the aid of KiCad for ADCS board, solar panels, payload computer, system wide schematics. Board configurations have been built to suit appropriately, mount and stack in modular fashion to the necessary mechanical requirements according to CubeSat specifications.

4. Design Methodology
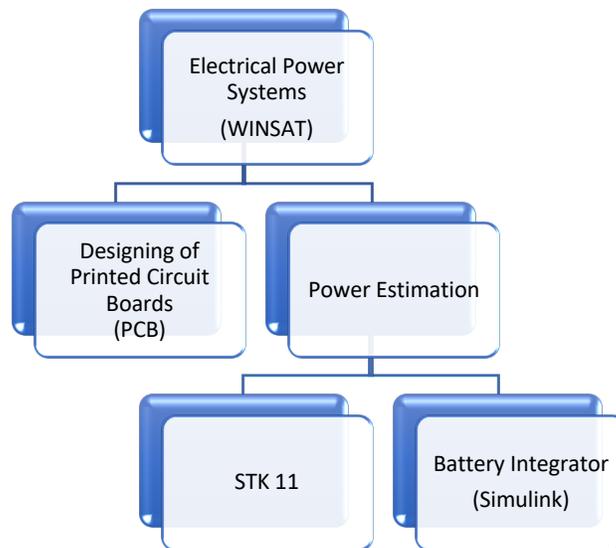
Figure 1: Layout of Design Methodology

As shown in the above Figure 1 that the two major components of the Electrical Power System division were Designing of Printed Circuit Boards (PCB) and Power Estimation. Whereas power estimation was further divided into 2 components of STK simulation and battery integrator that was designed in Simulink.

4.1. Power Estimation

Power estimation was important to create an effective satellite power budget to accomplish the required purpose in the satellite mission. This included the selection of the battery capacity and space rated solar cells by analysing the techniques for estimating the power consumed by various electronic components.

4.1.1. STK Simulation (UC)

Systems Tool Kit (STK) is an Interactive Visualization, physics-based software kit that helps engineers and scientists to conduct complex land, water, air, and space network analyses and exchange findings in one optimised framework. STK simulation objective was to obtain power generation of our satellite by experimenting with different solar cells and in order to select the ideal number of cells to be included on each side. And also obtain data for the worst-case scenario and best-case scenario of our power generation in orbit, which would allow us to have choose the effective solar cell.
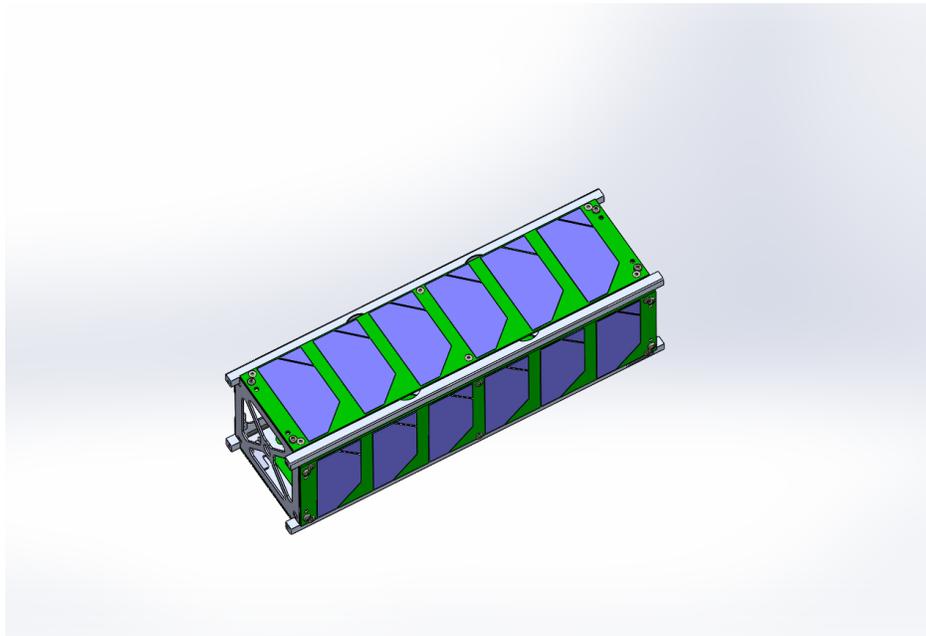
Figure 2: Solidworks Layout of Cube-Sat

To import our satellite model into STK simulation following steps were carried out:

1. Preparing a sample Solidworks model of just the structure and the panels on them as shown in figure 2, and exporting the file as ".STL" format.
2. Importing the ". STL" files into Blender software, Blender is an open source 3D creation suite. Would be used to render down the faces and vertices to reduce the file size. This part is critical as STK does not simulate large files.
3. After completion of rendering, we initialize the Solar panel groups and create separate groups of each side of the panel. This step is known as articulation.
4. Export the articulation file as "Collada"
5. Next step would be editing the existing ancillary file from the STK which is written in C/C++ language. Edit the articulation part by adding the solar panel groups to the code from the Collada file.
6. Save the file as ".dae" extension.
7. Copy and Paste the file in the C-drive of your computer in "Models" folder of STK 11. File is now ready to be imported into the model.
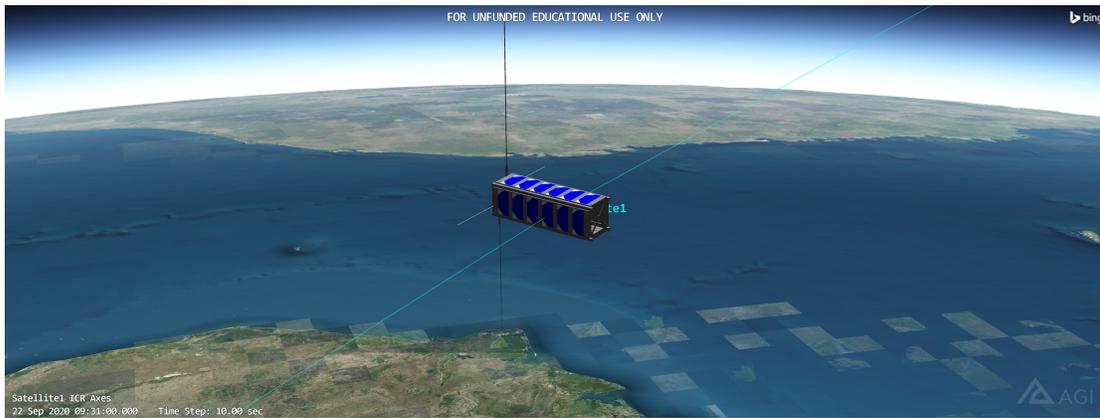
Figure 3: Satellite Model in STK Simulation Environment

For our mission requirements we had to test our satellite in 2 orbits which were Sun-Synchronous orbit and International Space Station (ISS) orbit in Low Earth Orbit (LEO). The table below shows the seasons in which the simulations were conducted for both orbits:

Seasons	Date	Time
Summer Solstice	June 20th, 2020	5:44 pm
Winter Solstice	December 21st, 2020	5:02 am
Spring Equinox	March 19th, 2020	11:50 pm
Autumnal Equinox	September 22nd, 2020	9:31 am

Table 1: STK Simulation Criteria

After successfully running the simulation in both orbits, we recorded our best-case scenario and as well as our worst-case scenario for both orbits. The following are the results for both orbits:

Seasons	ISS Orbit	Sun-Synchronous Orbit
	Power (W)	
Winter Solstice	21.52	24.5
Summer Solstice	19.21	21.72
Autumnal Equinox	22.03	20.58
Spring Equinox	20.17	20.85

Table 2: STK Simulation Orbit results

Therefore, for the sun-synchronous orbit it was recorded the best-case scenario would be in Winter Solstice (Figure 3) and worst-case scenario (Figure 4) would be in Autumnal Equinox. Why these

cases are important to observe is because specially in worst case scenario we should be generating enough power in order to charge the battery and drive the loads.
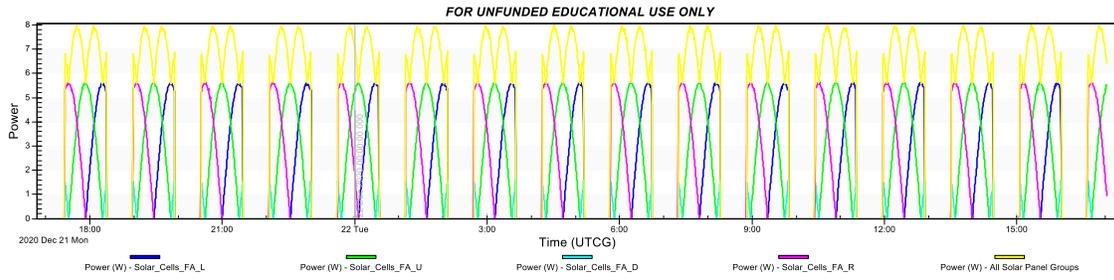
Figure 4: STK Simulation for Winter Solstice in Sun Synchronous Orbit
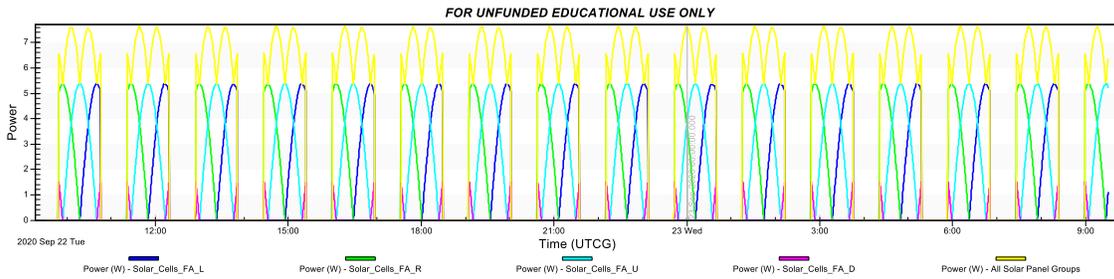
Figure 5: STK Simulation for Autumnal Equinox in Sun Synchronous Orbit

Also looking into ISS orbit, it was observed that the best-case scenario would be in Autumnal Equinox (Figure 5) and worst-case scenario (Figure 6) would be in Summer Solstice. Similarly, the worst-case scenario of ISS orbit is producing way less as compare to our worst-case scenario in sun synchronous orbit. Therefore, as per our results it's on border line of our power generation requirement it may take more time than usual to charge the battery even in our worst-case scenario.
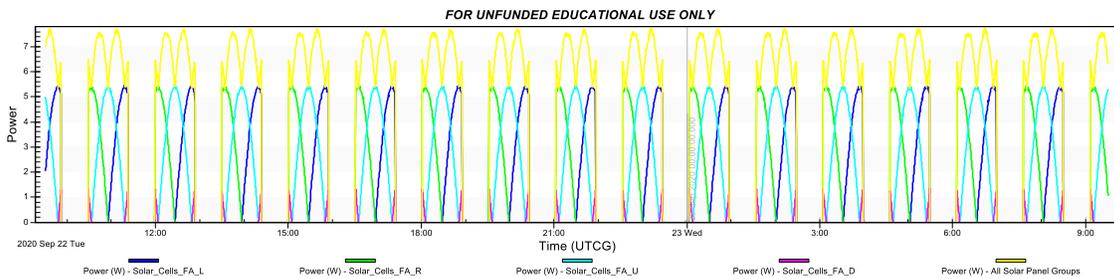
Figure 6: STK Simulation for Autumnal Equinox in Sun Synchronous Orbit
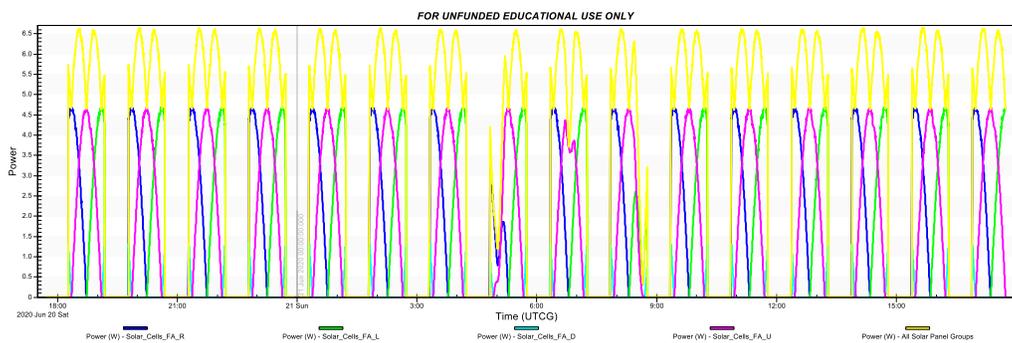
Figure 7: STK Simulation for Summer Solstice in Sun Synchronous Orbit

4.1.2. Battery Integrator (Simulink) (UC and QB)

One of several key components was to choose the space-rated battery for our task and then incorporate it with our Simulink model to identify various characteristics by varying the load. Excel data sheet was used to effectively evaluate the battery "Small Spacecraft Power Model." Initially, the orbit average energy was determined for every part of the load to obtain total output power and total input power per regulator. In addition, the battery properties were input to determine the total available battery energy and to equate it to the total input power. Finally, determining the required time to recharge the EOE (End of Energy) of the battery in positive Sunlit minutes in order to justify our battery selection. Another key of the battery integrator is PV array. Photovoltaic solar panels consist of individual attached photovoltaic cells, so the Solar Photovoltaic Array, also known simply as the Solar Array, is a network composed of a collection of linked solar panels. So, a photovoltaic array is several solar panels electrically wired together to create a much larger PV panel called an array, and typically, the greater the array's total surface area, the more solar power it can generate. Therefore, the photovoltaic cell used for this project is triple Junction CTJ 30, the calculated values from the data sheet are following:

Current at maximum power point:

$$I_{mmp} = \frac{1367 \ W/m^2}{178.491 \ A/m^2} = 7.659 \ A$$

Short circuit Current:

$$I_{sc} = \frac{1367 \ W/m^2}{171.476 \ A/m^2} = 7.972 \ A$$

Open Circuit Voltage:

$$V_{oc} = 2.61 \ V$$

Voltage at maximum power point:

$$V_{mmp} = 2.33 \ V$$

Maximum Power point

$$P_{max} = 1.20 \ W$$

As per the structural dimensions of our satellite we did have at least space of 5 cells on 2 sides on the panel and 1 side containing 6. So, the next major question was that how to connect them?

- All should be in parallel
- All should be in Series
- Or combination of both
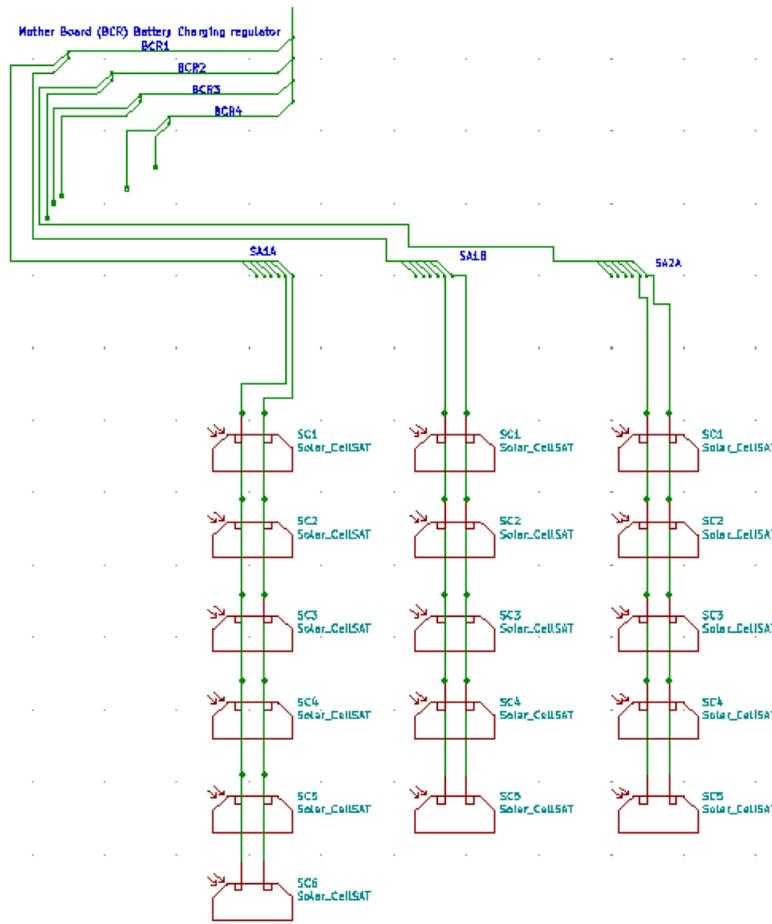
Figure 8: Solar Panel Configuration

Basically, we did select the configuration of series and parallel combination because if it's just connected in parallel it would suffer from low voltage, whereas everything in series would result in risk because if one of them gets shorted it would affect the complete circuit. Therefore, it was decided that on each side of the panels will be connected in series and on each panel all the solar cells will be connected in parallel as shown in the configuration above.

The power generated by the PV cells depends on their point of operation. Therefore, design must include a Maximum-Power-Point-Tracking (MPPT). Solar irradiation that reaches the photovoltaic modules has a variable character depending on the altitude, solar field direction, daytime season and hour. During the course of a day, a shadow can be formed on the cell that can be foreseen, as in the case of a building next to the solar field or unforeseeable like those produced by darkness. The energy each photovoltaic cell emits often depends on the irradiation and the temperature, where irradiance is nothing but Watts/m^2 and temperature is in Celsius. Through such factors, the need to immediately recognise the specific point on the PV generator's V x I characteristic where the highest amount of power transmission to the grid is present arises. The maximum power point refers graphically to the tangent point between the properties of the photovoltaic generator for a given irradiation factor and

the hyperbole of the equation V x l = corresponding constant. As shown in the Figure 9 below, the tangent point changes immediately based on the levels of solar irradiation and the temperature fluctuations.
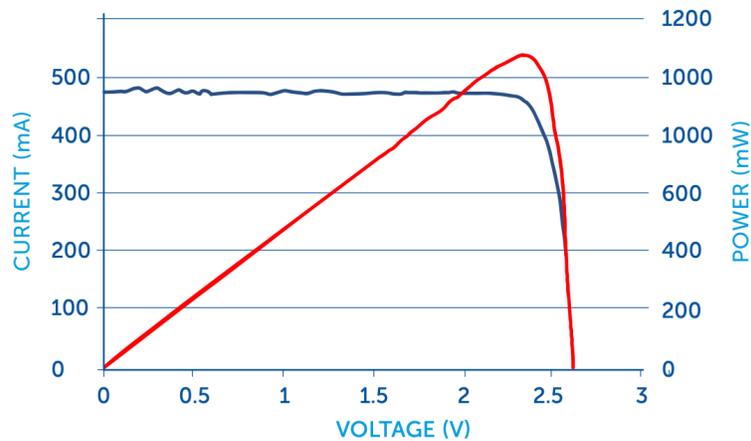
Figure 9: Typical Current – Voltage Characteristic from Data Sheet
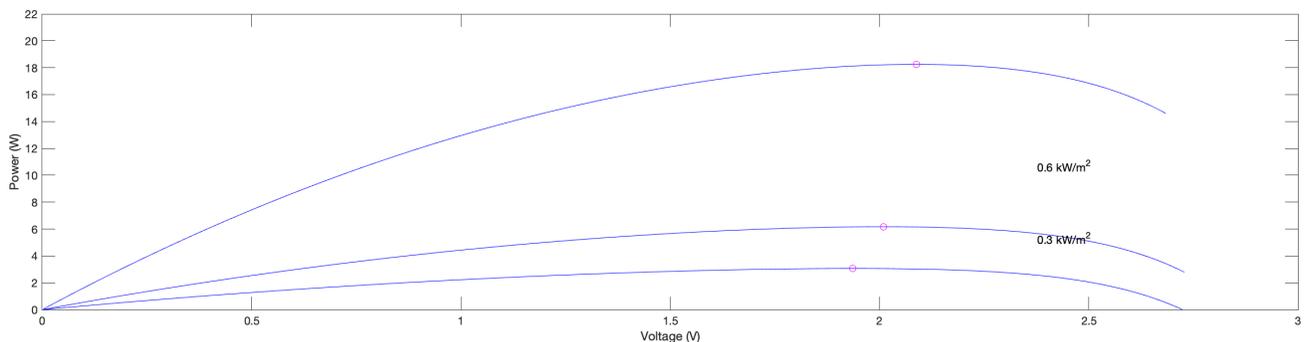
Figure 10: Typical Power – Voltage Characteristic from Simulink

The maximum power point tracking, however, cannot overcome power converter output as it falls in specific power generation contexts. Therefore, the efficiency rate of the power converter must also be improved with an aim of providing full power to varied load. After getting the desired array voltage, boost converter (Figure 11) is used to step up the voltage in order to drive the load. To apply this particular logic, MATLAB script is applied by if the old and new power are not equal and also when the PV voltage is more than 6V activate the diode in the circuit. The diode becomes reverse biased when the switch is turned on, thus isolating the load stage. The source of input stores energy inside the inductor. When the control switch is off, the load stage absorbs energy from both the inductor and the source, thus the load voltage is greater than the source voltage.
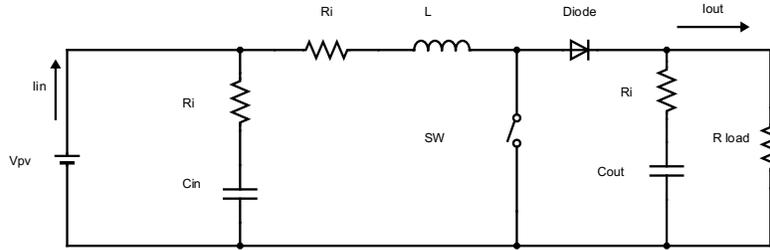
Figure 11: Boost Converter Schematic from Battery Integrator

Calculation for Boost Converter is as follows:

Constant values :

Minimum input voltage $=> v_{in(min)} = 8.446$ v

Desired Output Voltage (also known as Voltage across load in Simulink model) $=> v_{0UT} = 17$ v

Efficiency of the converter $=> \eta = 0.9$

Minimum switching frequency of the converter $=> F_s = 5000$

Inductor Ripple Current $=> I_{ripple} = 0.4$

Power $= 240$ w

To measure the switch current, the first step is to evaluate the duty period, D, for the minimum input voltage. Minimum input voltage is used because this results in maximum switching current.

$$D = 1 - \frac{v_{iN(min)} \times \eta}{v_{0UT}}$$

$$D = 1 - \frac{8.446 \times 0.9}{17}$$

$$D = 55.317 \text{ \%}$$

Inductor Selection:

For parts where no inductor range is given, a good estimate for the right inductor is the following calculation:

$$L = \frac{V_{in} \times (V_{out} - V_{in})}{d\iota \times F_s \times V_{out}}$$

Minimum input voltage $= V_{in}$

Desired Output Voltage $= V_{out}$

Minimum switching frequency of the converter $= F_s$

Estimated inductor ripple current $= d_i$

$$L = \frac{8.446 \times (17 - 8.446)}{11.365 \times 5000 \times 17}$$

$$L = 7.47 \times 10^{-5} \text{ H}$$

Maximum Output Current:

The greater the inductor value due to the decreased ripple current, the greater the maximum output current is, and can be calculated as follows:

$$I_{OUT} = \frac{Power}{V_{OUT}}$$

Desired Output Voltage $= V_{out}$

$$I_{OUT} = \frac{240}{17}$$

$$I_{OUT} = 14.117 \ A$$

Capacitor Selection:

The following calculations are used with external compensation to change the capacitor values for a given capacitor at the input and output stage:

$$C = \frac{I_{OUT} \times D}{F_s \times dv}$$

Maximum Output Current $= I_{OUT}$

Duty Cycle $= D$

Minimum switching frequency of the converter $= F_s$

$dv =$ change in voltage

$$C = \frac{14.117 \ \times 0.55317}{5000 \times \ 0.17}$$

$$C = 9.2 \times 10^{-3} \ F$$

With Equation the inductor ripple current cannot be determined since the inductor is not identified. A fair estimation for the output current of the inductor ripple is 20 per cent to 40 per cent.

$$d_i = I_{ripple} \ \times \bar{I}_{out} \times \frac{V_{OUT}}{V_{in}}$$

Inductor Ripple Current $= I_{ripple}$

Maximum Output Current $= I_{OUT}$

Minimum input voltage $= V_{in}$

Desired Output Voltage $= V_{out}$

$$d_i = 0.4 \ \times \ 14.117 \times \frac{17}{8.446}$$

$$d_i = 11.365$$

Finally, maximum load can be calculated that is supported by this boost converter configuration as following:

$$R = \frac{v_{OUT}}{I_{0UT}}$$

Desired Output Voltage $= V_{out}$

Maximum Output Current $= I_{0UT}$

$$R = \frac{17}{14.117}$$
$$R = 1.20 \ \text{ohms}$$

Bidirectional Converter (BDC) is a buck and boost converter combination that is capable of sending and receiving power on both ends. The bidirectional converter operates in two separate ways. One is the discharge phase during which the bidirectional converter can be used to boost the battery voltage to an effective high-level DC bus voltage, and the second stage is the charging phase in which the BDC is used to buckle the DC bus voltage to an effective low-level battery voltage. Using two PI controllers, battery monitoring is accomplished in the Simulink model. For the second PI controller, the first PI controller (Figure A32) takes reference voltage and bus voltage to equate and the result is used as the battery current reference level. Second PI controller (Figure A33) uses the current value of the battery and the first PI controller were used to measure and placed the bidirectional IGBT switch to charge and discharge the battery. Both PI controllers are calibrated to get the results that are expected.
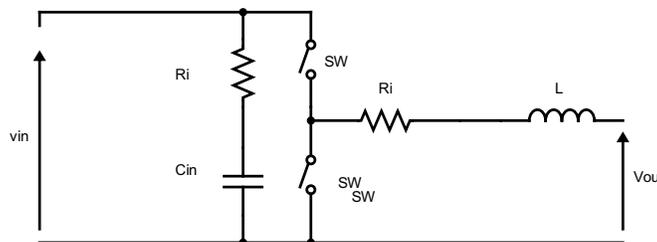
Figure 12: Bidirectional Converter Schematic from battery integrator

For prevention of overcharging of battery an operation of Clyde space EPS module was implemented by creating a breaker with condition of cutting the power to the circuit when the desired SOC levels have approached 80 %. And during this phase our loads will be driven by our PV module, as every battery has a characteristic that its SOC would decay with time. Therefore, when the battery is drained and if still the PV array is generating enough irradiance it would start charging the battery again.
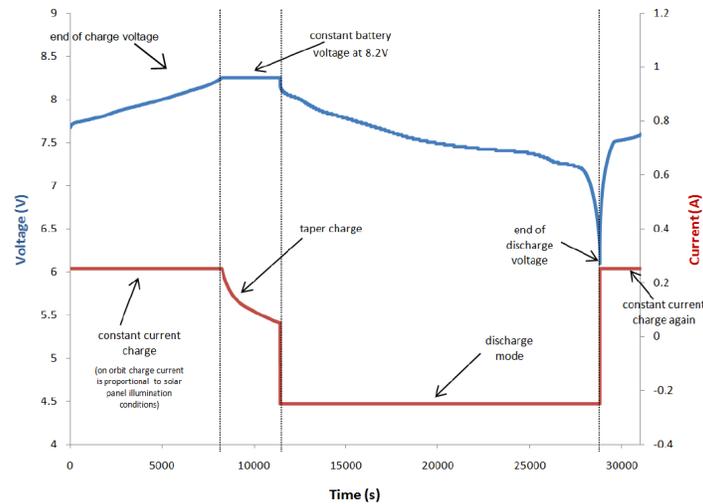
Figure 13: Function of EOC mode

As seen in the figure above the BCR switches to EOC mode until the EOC value is exceeded, which is a continuous voltage charging system. The EOC voltage is kept steady and the panels are provided with a tapering current to top up the battery to maximum power. During EOC mode the MPPT circuit transfers the operating point of the solar array away from the system 's maximum power point, pulling only the required input from the panels. The excess power is left as heat on the arrays and is transmitted to the system by the thermal dissipation methods of the device integrated in the Clyde Space boards.

4.2. Designing of Printed Circuit Boards (PCB) (MQ)

PCB's are critical to this mission in order to connect various components electrically and mechanically. Initially, electrical design of WINSAT PC-104 bus, payload module, ADCS module, and Solar arrays were designed. For better understanding of electrical schematic spice model was created for the complete project. The accuracy of the spice model is important before starting any PCB design, spice model is handy in doing hardware pin tracing accurately according to the electrical schematic. For PCB design there are couple of major things to consider. Firstly, defining a shape and size of the PCB board to fit in your application and to integrate all the electronic components. Furthermore, adding electrical footprints which includes through hole pins, and surface mount. According to all the electrical spice schematic, connecting all the through whole pins and surface mount through tracing. To avoid overlapping, shorting and EMI (electromagnetic interference) for RF applications perfection in tracing is important. Tracing also requires any turns to be made on a 45-degree angle. VIA and Jumpers are used to avoid overlapping.

4.2.1. WINSAT PC-104 Bus

PC-104 is an embedded bus standard which is used is various specialized environments and small applications in a modular stackable fashion. The CubeSat uses PC104 as the most commonly used

interface. Many CubeSat developers have implemented PC104 as the bus interface. The benefit of utilising the PC-104 is that it provides a load route on the printed circuit board in the longitudinal direction, such that the actual physical load is not centred on the device, making it easier to attach mechanically. The boards that were interfacing with PC-104 bus are:

- ISIS OBC
- Clyde Space EPS Module
- Clyde Space Battery
- Payload Module (2 Ov2640 Cameras)
- ADCS module
- RF module
- Magnetorquer module
- Reaction Wheel module

Pin outs of all the above boards mentioned above were connected to PC-104 Bus (Figure: A19).

The basic design of the satellite bus includes H2 and H1 pin headers (Table A4) which carry power and ground pins also provides different output voltage for various applications to be used throughout different modules in the satellite. Computer communication is done through I2C protocol. I2C is a serial protocol two wire interface for low speed microcontrollers, A/D, D/A, I/O interfaces. I2C can support multi-master and multi-slave on the same bus without slave select line, which is done in SPI protocol, I2C address base bus protocol you send address to the slaves for communication.
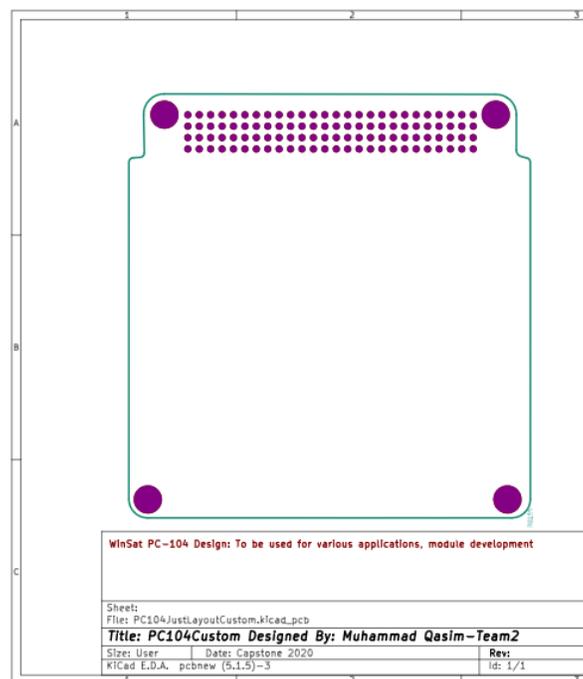
Figure 14: PC-104 Model Design

4.2.2. Payload Module

The payload module required two cameras and raspberry pi compute stick to be interfaced on to a PCB module for satellite photography. I2C communication protocol is done from the WINSAT bus to the raspberry pi compute stick, the two OV2640 camera SPI protocol is used for cam select from the raspberry pi compute stick. Payload board is a two-sided board with forward and reverse tracing. Shortest tracing paths were rendered using angle required in PCB tracing to complete all tracing turns.
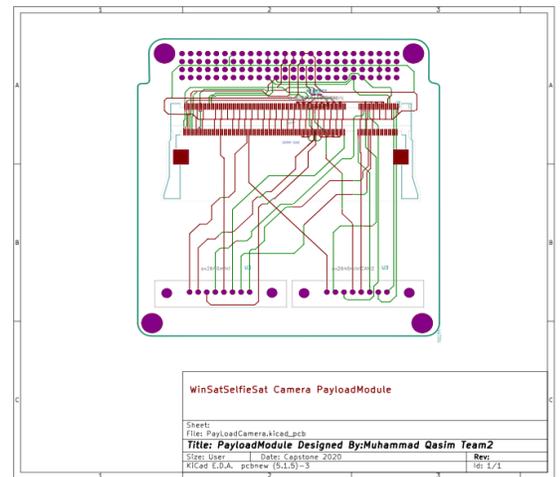
Figure 15: Payload Module Design

4.2.3. Solar Array

CTJ30 cells are used in these solar array designs Samtech connectors are also added for connection with eps module. Different hole spacing have also been placed for various applications. Trace width have been sized to CTJ30 space cell pads for power application. All of the Solar Panels are combined in parallel with EPS module battery charging regulator. Size and layout are done according to the mechanical requirement. The design included in (Figure 16) illustrates solar panel 3 which has 5 cells parallel connected with 2 holes representing the cut out of OV2640 cameras.
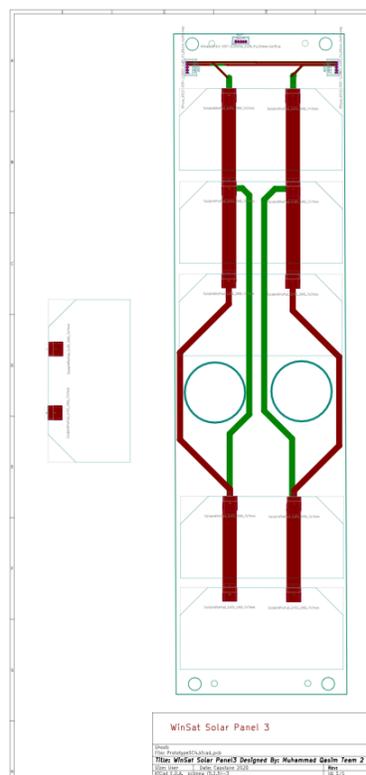
Figure 16: Solar Panel 3 Design

4.2.4. System Wide Electrical Schematic

Headers of combination of 8 modules are available to describe each component which combine into a bus. Bus has common voltage pins and common ground, with different Vout 3V, 5V and 12 V. System Wide Schematic is critical in connection between particular modules to its components. In this project, electrical design of 2 modules were done which include payload module and ADCS module. Payload module included raspberry pi compute stick which is a DDR2 interface and included 2 OV2640 Arduino cameras. The ADCS module included STM Nucleo64 and NXP. Furthermore, the integration of solar panels with the Clyde Space EPS Module can be seen in Figure below.
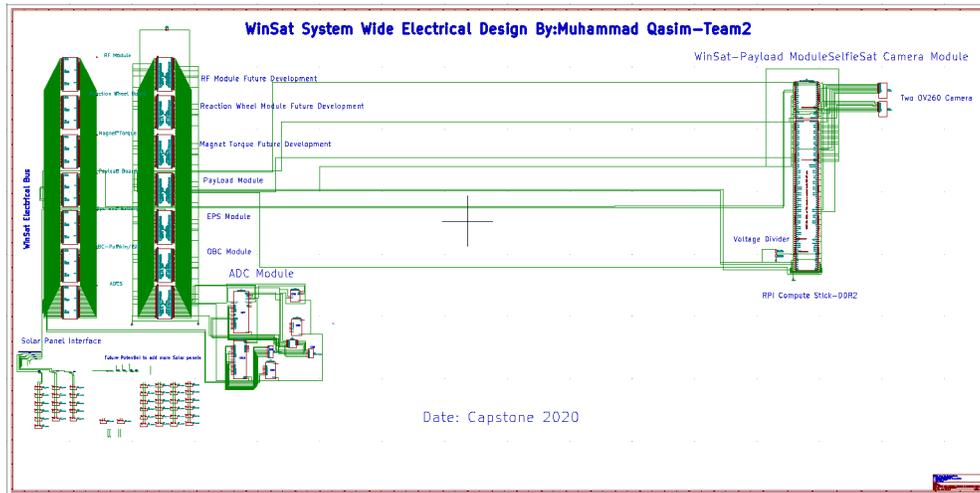
Figure 17: System Wide Schematic

4.2.5. ADCS Module

ADCS module has been essential in detecting satellite movement in space. The ADCS module architecture consists of NXP9DOF, PC-104 bus, STM Nucleo64 board. NXP9DOF is used for detecting motion and orientation, using I2C as communication. Nucleo64 board feature is a micro controller unit that enables users to prototype for embedded applications. Connecting from the PC-104 bus which uses 5V pin for power and I2C as communication to the STM Nucleo64 board is then attached to NXP9DOF to implement the design.
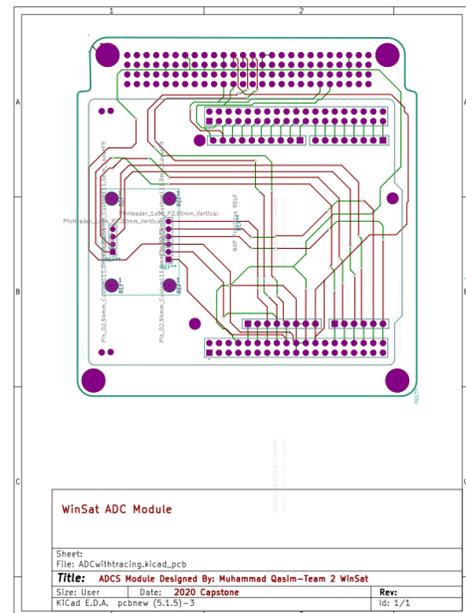
Figure 18: ADCS Module Design

5. Simulation Model Development

5.1. Battery Integrator Model (UC)

After successfully designing of Boost converter, bi-directional converter, selection of solar cells configuration for the PV array and set up for maximum power point tracking final battery integrator can be integrated together. For implementation firstly flow chart was created in order to better understand how the components would be interfacing with each other.

In Figure 19, there are 4 main building blocks which include main power circuit, protection, controller and loads. Main power circuit includes PV module to obtain power generation, the power was then tracked through Maximum power point tracking (MPPT) and boost the voltage to maintain the voltage across the load. Furthermore, bi-directional converter has 2 modes of operation which are charging and discharging mode which are controller driven to step up or step down the voltage from either side of the converter to the other. Last part of the main power circuit is the function of protection of battery which is available within Clyde Space EPS module to avoid over-charging of the battery.

The main controller used for the mission is Clyde Space EPS module which has several tasks when the satellite is released from the launching vehicle which includes:

1. Enable the MPPT, OBC (on-board computer) and communication and RF.
2. Deploy the Antenna.
3. Activate the Push-to talk Pin on the communication and RF, in order to transmit a "Morse code".

The module Clyde Space EPS includes the algorithm MPPT. EPS module notifies the ADCS via the OBC to switch the satellite's three sides to sunlight whenever necessary. In turn, EPS module also tracks the SOC (State of Charge) battery. If it is too low, an alert will be sent to the OBC signalling that power is to be turned off for the loads soon and will be sent to the MPPT if it is a strong warning, in order to slow down power generation. Next major element is block protection and enabling, which plays a vital role in the event of overcurrent scenario. The OBC safety is autonomous in this situation where it will shut off for a couple of minutes and would be turned on again because the OBC regulates the triggering for the loads. Fortunately, the EPS module also does the over-current protection for the satellite. Lastly all the loads are connected as a stack to the I2C bus to the EPS module.

Figure 19: Flowchart for Designing of Battery Integrator

5.2. MPPT and Boost Converter Phenomena (QB)

Power generation from Solar panels is not constant due to the changing values of irradiance and temperature. Overcoming this problem MPPT controller is used. The output voltage of the PV panels is not constant and lower than that of the DC bus voltage. The Boost converter is used to fulfil the load criteria. When the PV system output voltage is small than the DC bus, the converter output has to be increased, i.e. in boost mode and the duty cycle should be varied from 0.05 to 0.95 [2]. In boost converter duty ratio of boost IGBT switch start to reduce from 0.95. With this control scheme, iPV of the PV panel array must charge input capacitor Cpv and VPV voltage can be higher up to a higher level to halt oscillation problems. The MPPT algorithm is used to measure the power gap "DP." Due to this, it created the large changes in the magnitude of pulses with creating uneven changes in duty ratio. This produces more distortions in the outputs of the boost converter.

Figure 20: Flowchart representing MPPT Algorithm

5.3. Simulink Model (QB)

Figure 21 shows the final integrated model designed. Furthermore, the output shown in Figure 22() helps us to successfully meet our objective of battery integrator design. State of Charge (SOC) is dependent on the irradiance provided to the PV modules in order to charge/discharge the battery. The initial charging state is set at 77 percent and it can be noted that as the irradiance initially increased slowly, you see a small shift in SOC as it switches to charging mode when the irradiance is around 900 W/m^2 and goes up to 1800 W/m^2. For the voltage across load begins varying about 8.446 V and has been confirmed by our boost converter model and calculation. As the irradiance is raised there is further power generated resulting in increased voltage supplied to the boost converter where it boosts up voltage by utilising the MPPT. Another significant reading displayed is the circuit breaker mechanism used by the EPS module to turn off the power to prevent the battery from over charging, the cut-off is adjusted to 80 percent in order to be the Clyde Space battery's End-Of-Charge (EOC). Meanwhile, the load is powered by the PV array, and when the irradiance is decreased, it can be

observed that the vbus (voltage across load) decreases because of the low power provided by the PV battery.
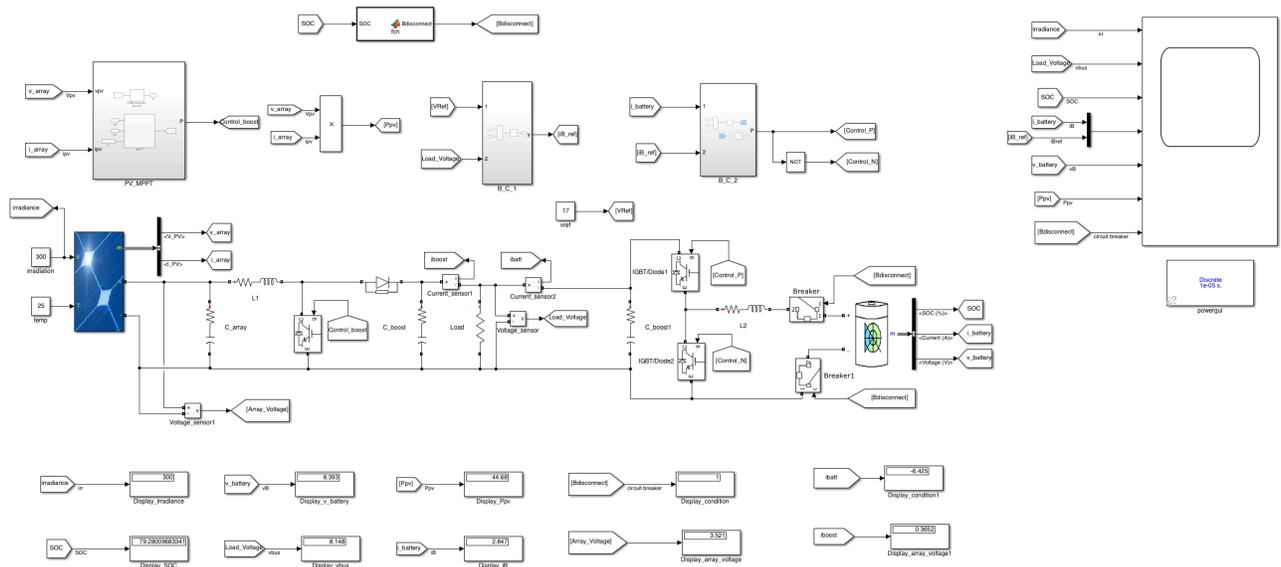
Figure 21: Battery Integrator Simulink Model
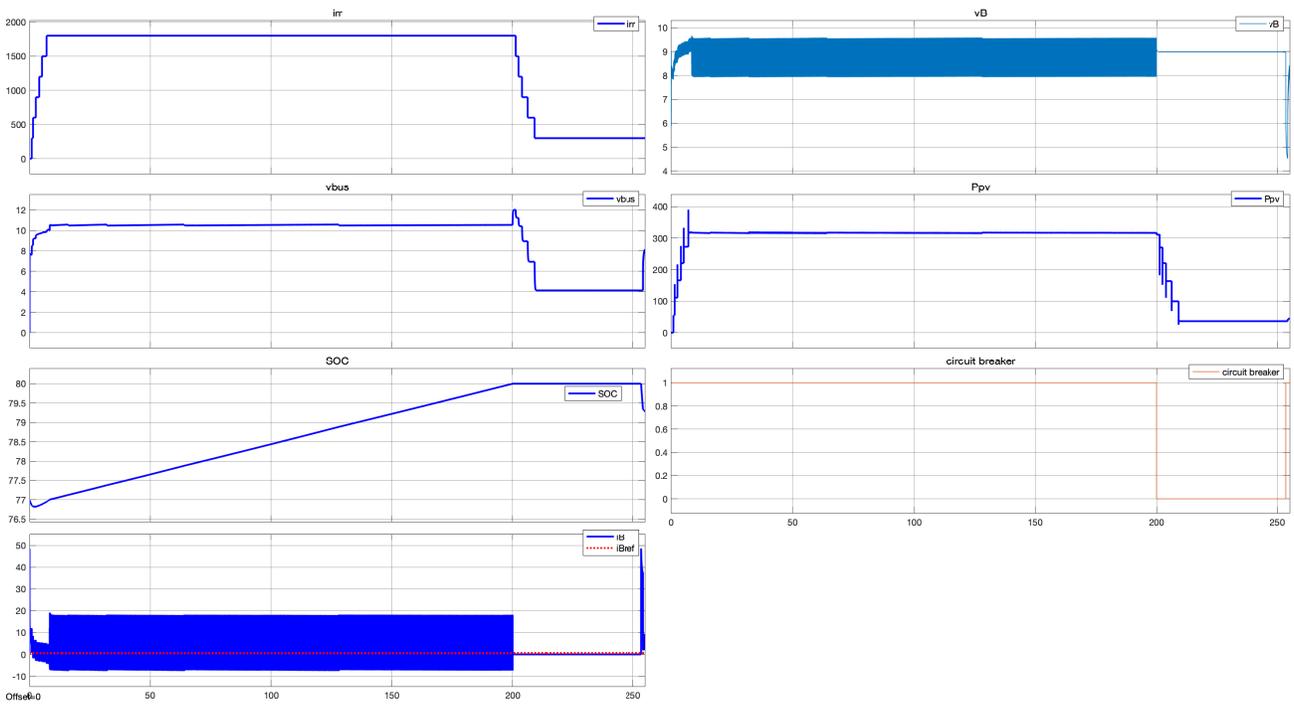
Figure 22: Output of Battery Integrator Simulink Model

5.4. Designing of H1 and H2 header for PC-104 Bus (MQ)

This block is designed to be inter-compatible with Clyde Space EPS module, Clyde Space battery, pumpkin MBM2, ISIS OBC and all our future and current modules. Initially, in schematic editor (ki-CAD) custom spice symbol is created in order to represent PC-104 H1 and H2 headers (104 pins).

Each header includes 52 pins, which are connected to every module where each module would be using the required specific pins for its application. Which is used in designing the system wide schematic of electrical design of the satellite (Table A4).
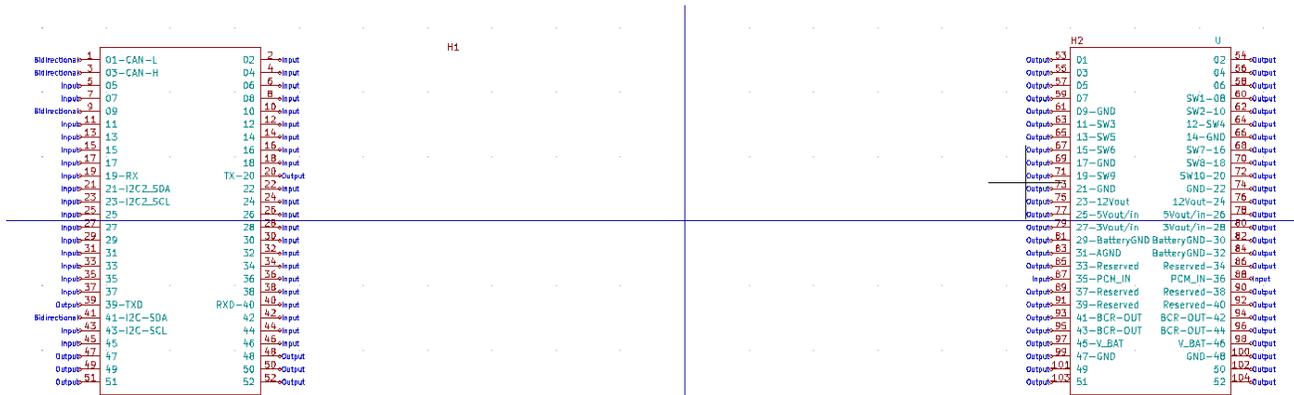
Figure 23: H1 and H2 headers

6. Model Validation and Design Performance

6.1. Initial Models (QB)

In total of three models were designed in order to achieve the desired objective of the battery integrator. For the comparison of both the initial models mentioned in the Appendix in "Figure A25" and "Figure A28," after reading through several research papers and comparing it with a textbook, a battery integrator understanding was developed. Model A was based on Pulse Width Modulation (PWM) which helped monitor the State of Charge (SOC) rates but was not a facilitating as battery charging and discharge conditions were manually managed by changing PWM SOC rates. Hence, this specific model did not achieve our aim of automatically charging and discharging the battery via an ellipse flag, but it was one of the better alternatives that helped us to get an understanding of the characteristics of battery activity. In fact, Model B was a success because we were able to accomplish our target in this specific section by utilising switches and PID (voltage / current) controls. The input switch as constant (1 or 0) enabled us to automate the model via battery charging and discharging conditions. We discovered our EPS module to be smart enough to understand low SOC values and can monitor it close to a switch in charging state (when switch is 1) and discharge state (when switch is 0).

6.2. Boost Converter Validation Model (UC)

The boost converter, needed by a load, is used to "step up" an input voltage to a higher stage. This unique capability is achieved by storing energy in an inductor and at a higher voltage, releasing it to the charge. Therefore, in order to achieve the objective of maintaining the voltage across the load this phenomenon was implemented sample model was designed initially in Simulink. Figure 24, model

can assist in calculating and optimizing the efficiency of the boost converter. As seen in output of boost converter validation model the voltage across the load stays constant around 17 V, with input voltage set to 8.446 V for the simulation.
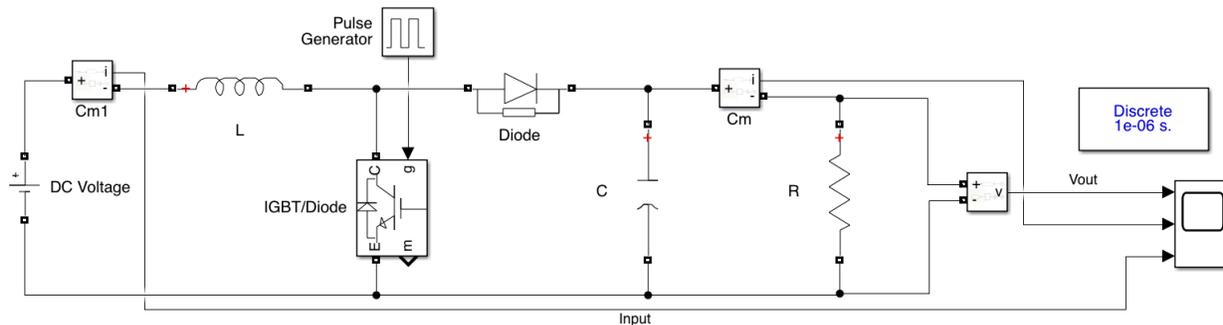
Figure 24: Boost Converter Validation Model
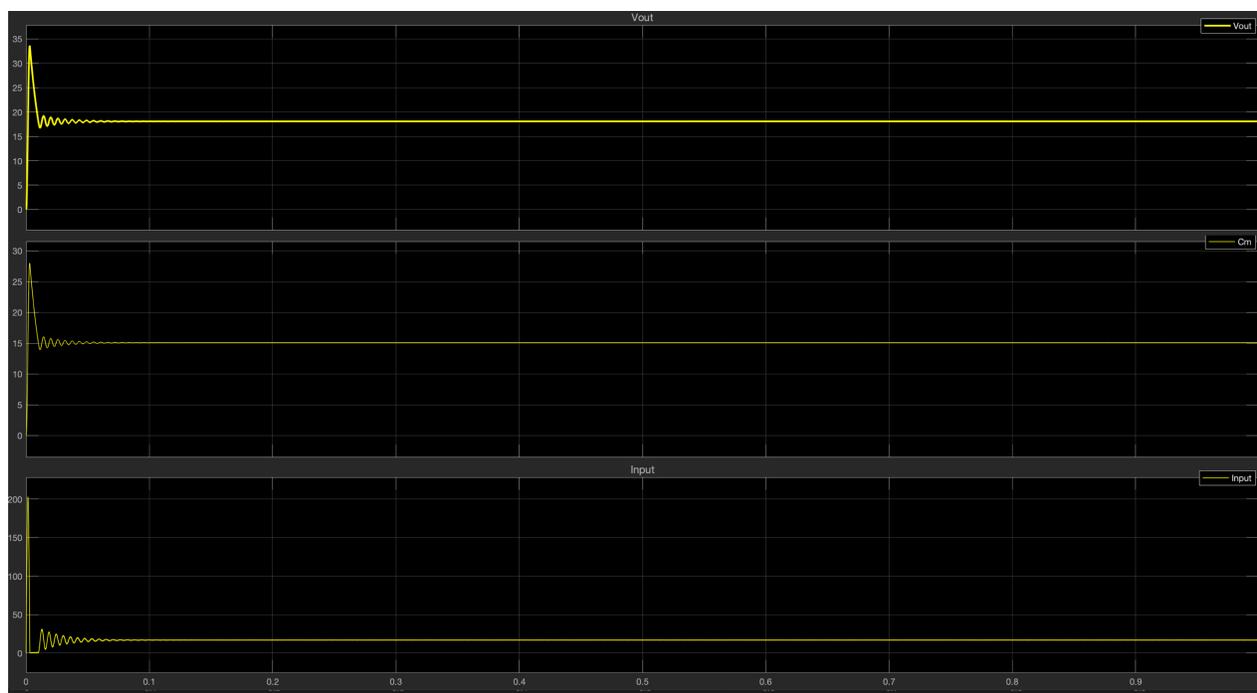
Figure 25: Output of Boost Converter Validation Model

7. Design Specifications

7.1. Clyde Space Battery Specifications (UC)

Battery selected for the project was 30Whr Standalone 3rd Generation Clyde Space battery with nominal voltage of 8.4V and battery cell capacity of 1.3 amp-hrs. Below table illustrates the complete battery characteristics of Clyde Space Battery:

Battery Characteristics	Parameters	Units
Battery Cells in Series String	2.00	Cells
Parallel Strings	3.00	String(s)
Battery Operating Temperature	28.00	deg. C
Battery Temperature Coefficient	-0.0063	V/Cell/deg. C
Cell Voltage (Fully Charged; Under Load)	4.20	V/Cell
Cell Voltage (Typical Operating Condition)	3.85	V/Cell
Cell Voltage (At Lowest S.O.C. Limit)	3.00	V/Cell
Cell Voltage (Fully Charged)	4.20	V/Cell
Battery Cell Capacity	1.3	amp-hrs
Battery Safe Trickle Charge Rate	0.0	amps
Battery Voltage (Fully Charged)	8.4	V
Battery Voltage (At Lowest S.O.C. Limit)	6.00	V
Battery Voltage (Fully Charged)	8.40	V
Battery Voltage (Typical @ 20 degree C)	7.70	V
Battery Capacity	3.93	Amp-Hrs
Battery Reference Temperature	20.00	deg. C
Total Battery Energy	1699.06	watt-min.

Table 3: Properties of Clyde Space Battery

7.2. Solar Cell Specifications (UC)

Solar Cell selected for power generation of satellite in orbit is Triple Junction Solar Cell for space application (CTJ30). Which has open circuit voltage of 2.616 V with solar cell efficiency off 28.60%. Total power generated by the 16 cells combined was recorded to be 21.04 Watts as per the data sheet. Below table illustrates the complete Solar Cell Specifications:

Solar Cell Characteristics	Parameters	Units
Solar Cell Technology:	InGaP/GaAs/Ge	
Solar Cell Dimension A:	54.936	mm
Solar Cell Dimension B:	54.936	mm
Solar Cell Area:	30.180	cm²
Solar Cell Short Circuit Current Density:	0.0168	amps/cm^2
Solar Cell Short Circuit Current (Isc):	0.507	amps
Solar Cell Open Circuit Voltage (Voc):	2.616	volts
Solar Cell Voltage at Max. Power (Vmp):	2.330	volts
Solar Cell Current Density at Max. Power:	0.0167	amps/cm^2
Solar Cell Current at Max. Power (Imp):	0.503	amps
Solar Cell Max. Power Output (Power Knee):	0.000	watts
Solar Cell Efficiency:	28.60%	
Solar Cell Reference Temperature:	28.0	deg. C
Solar Array, Series Cells per String:	3	Cells
Solar Array, Parallel Strings per Panel:	6	String(s)
Solar Array Voltage at Pmax:	6.99	volts
Solar Array Current at Pmax::	3.019	amps
Solar Array Maximum Power:	21.104	watts

Table 4: Properties of CTJ 30 Solar Cells

7.3. Load Characteristics (UC)

Different load's orbit average energy was calculated in order to determine the power consumption of the satellite which would be helpful is selection of the battery capacity. Below table illustrates the Load characteristics:

Load Components	Current +5V regulator	Current +3 regulator	Orbit average Duty Factor	Orbit average energy
ISIS OBC	0.35 V	0 V	100%	162.5 W
RF Helium 100 - RX	0.15 V	0 V	100%	69.7 W
RF Helium 100 - TX	0 V	0 V	50%	0.0 W
GPS Receiver	0 V	0 V	100%	0.0 W
Payload (Selfie-Sat Camera)	0.070 V	0 V	4%	1.3 W
Payload (Global Camera)	0.070 V	0 V	6%	2.0 W
Payload - RPI computer stick	0.700 V	0 V	100%	325.0 W
EPS – Battery	0.02 V	0 V	100%	9.3 W
EPS - Battery Heater	0.12 V	0 V	100%	55.7 W
EPS - Clyde space Module	0.08 V	0 V	100%	37.1 W
ADCS - STM32	0 V	0.003 V	100%	67.3 W
Total Output Power	7.80 Watts	0.01 Watts		729.9 Watts/min
Total Input Power	9.87 Watts	0.01 Watts		839.4 Watts/min

Table 5: Load Characteristics

8. Budget (QB)

Due to the global conditions none of the components were ordered, due to the closure of various companies and delay in the shipments. Therefore, the budget provided in Table 6 is the projected price to date for the selected components. Relative to the budget expected at the beginning of the project, our budget has been expanded to incorporate future-oriented PCB printing costs and also to increase the price of solar cells because more solar cells are included from the original concept proposal.

Items	Price (CAD)
Clyde Space EPS Module and Clyde Space 30Wh Battery	17420
Printing of 6 PCB	4500
Triple Junction Solar Cell for space application (CTJ30) (16 cells)	18080
Total	**40000**

Table 6: Projected Budget

9. Conclusions (UC)

Electrical power systems play a major role in satellite project success. Efficient power needed for operating all satellite divisions. To effectively achieve the mission, power output needs to be higher than the power consumed by the satellite. Solar cell and battery selection were achieved through diligent use of different techniques to ensure the effective power produced by the satellite to complete the mission in the lower orbit. Using solar cell properties, the STK configuration is used to get power generation into the orbit. Additionally, Simulink is used to imitate battery and EPS device working models. Two Simulink models demonstrating the theory of battery activity by charging and discharging while the Simulink model is being assembled. For these first two models, we have also learned to model the battery cycle for charging and discharging. For the final model, which was dependent on the irradiance values input to PV array. For implementing the power generation boost converter was utilized with respect to maximum power point tracking in order to charge our battery. One of the critical functions of the model was the breaker that were installed in order to prevent over charging of the battery which is also built in function of the Clyde Space EPS module. In addition, PCBs are constructed using KiCad for ADCS, solar panels, and the payload, spice layout block diagram was also developed to help render PCB configuration for the payload surface. Board configurations have been configured to suit correctly, mount and stack in modular fashion according to the necessary mechanical requirements according to CubeSat specifications. The PC-104 board

configuration was developed to act as a model for any module which will need to be designed for use in the construction of the CubeSat stacking. Solar panel PCB is planned to be installed on the CubeSat's exterior; camera holes are located on one side.

10. Future Work

Finally, for the future work that needs to be done consists mainly of physical testing of battery, EPS module and integration of solar cells physically with the EPS module. For testing procedure method that has been designed in order for the test.

10.1. Battery Test (QB)

10.1.1. Equipment Required for the SOC test

- Lithium ion Battery
- Load
- Multi-meter
- Oscilloscope

10.1.2. Test procedure for the SOC test

The SoC of a battery can be measured in a number of methods, some of which are; Voltage-based, Current-based, Combination of Voltage and Current-based, Impedance measurement and Model based. The procedure to carry out the SoC test is outlined below. This is just the brief description on how the test would be carried out during our test.

- Charge the battery to 100%.
  - To determine if the battery reached 100%, we can follow one of the two methods
    - Remove the battery from the charger and measure the voltage. If the voltage is at its highest recommended level, proceed to the next testing phase.
    - If the charger has an indicator that shows the completion of charge, safely remove the battery from the charger and proceed to the next testing phase.
- Once the battery is fully charged, the SoC can be measured.

10.2. Solar Panel Test (UC)

Solar Cells will be used in the satellite as a mean of power generation. Since the satellite will not have any access to fuel or any other method to recharge the battery, the solar cell will remain the primary method of power generation for the entire mission. Therefore, the solar cells need to be tested for its output voltage, current and efficiency. The cells have to provide minimum allowable voltage, current and efficiency throughout the entire mission life.

10.2.1. Equipment Required for the Solar Panel test

- Solar Cell

- Multimeter

- Oscilloscope

- Light source to replicate the intensity of the sun in space

- Load

- Dark Room / Black Box

10.2.2. Test procedure for the Solar Panel test

- Place the solar cell inside the black box with the light source being at the centre.

    o Set the multimeter to measure the voltage.

- Connect the positive probe of the oscilloscope to the load terminal of the solar cell and the negative probe of the oscilloscope to the ground.

- Connect the multimeter to the solar panel.

- Make sure to connect the positive and negative correctly.

- Shine the light source directly on the face of the solar cell so that the cell produces maximum output.

- Note down the value of the voltage as the open circuit voltage.

- Set the oscilloscope to record the value of voltage at regular interval.

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Appendices

Tasks Allocation

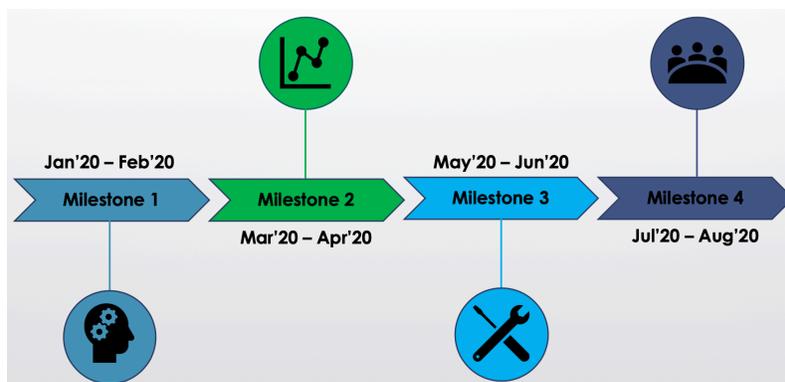| Name of Students	Task Assigned
Muhammad Usman Chughtai	STK 11 Simulation and Battery Integrator Model
Qaiser Mehmood Bhatti	Power Budget Chart and Battery Integrator Model
Muhammad Qasim	PCB Design

Table A1: Tasks Allocation

Milestone

Figure A1: Milestone Flow Chart

Milestone 1	Research and critical thinking
Milestone 2	Analytical Phase
Milestone 3	Designing Phase
Milestone 4	Final Report and Presentation Submission

Table A2: Milestone Description

STK Simulation
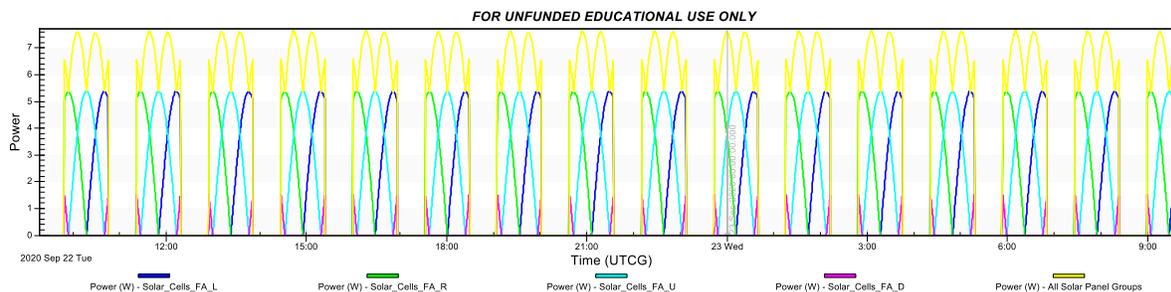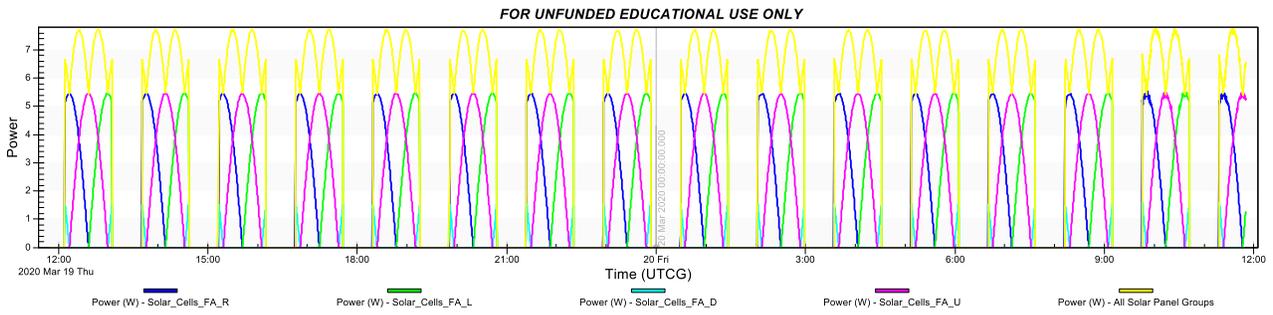
Sun-Synchronous Orbit Results

Figure A2: Autumnal Equinox
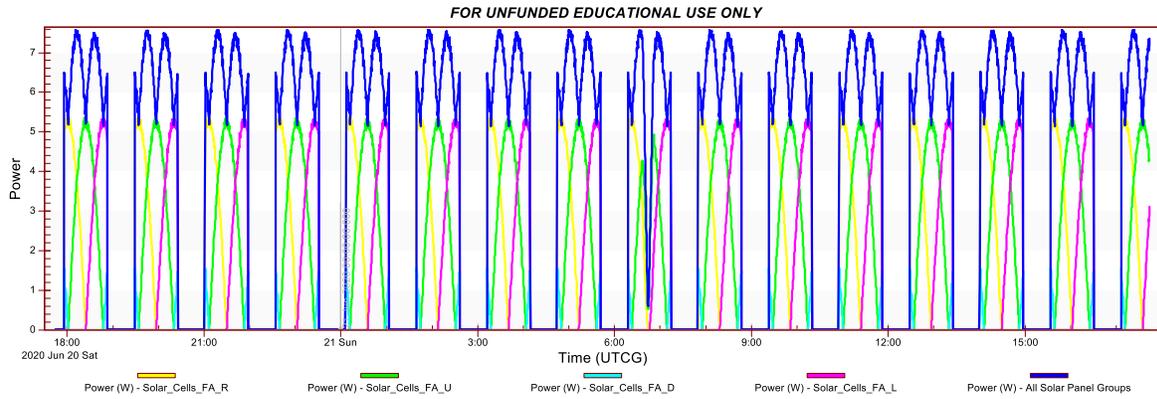
Figure A3: Spring Equinox
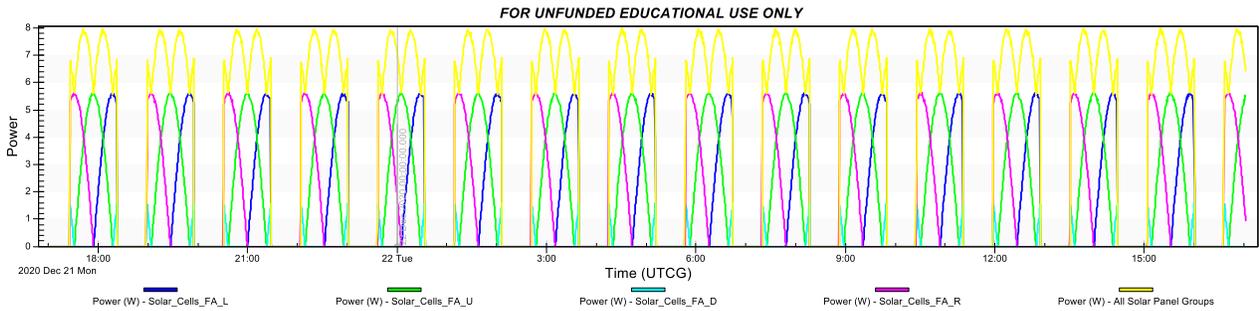
Figure A4: Summer Solstice
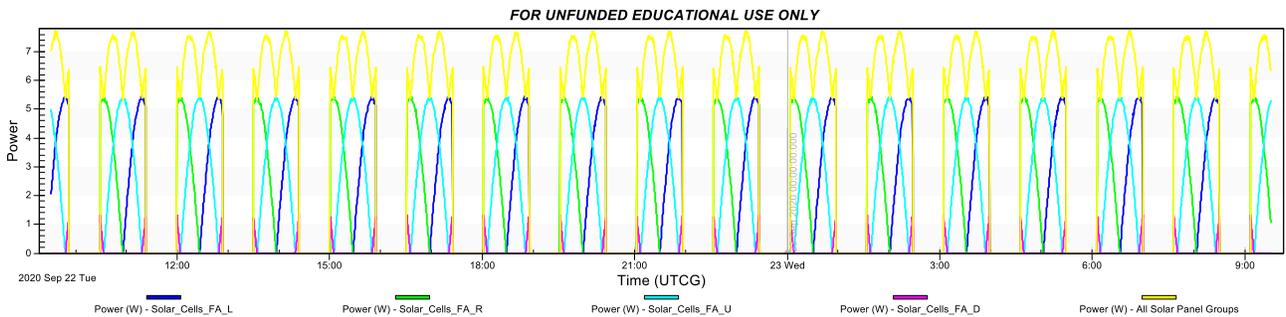
Figure A5: Winter Solstice
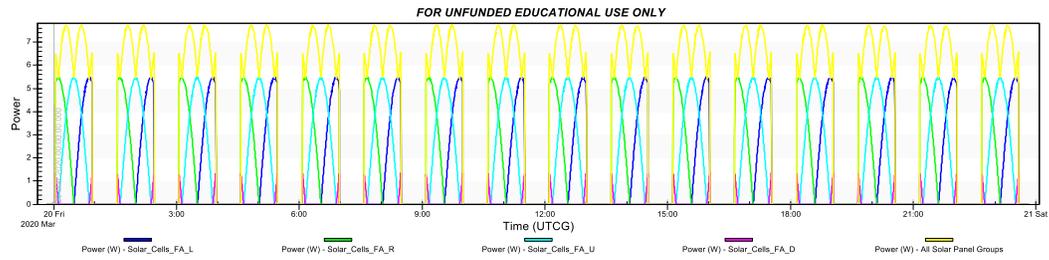
ISS Orbit

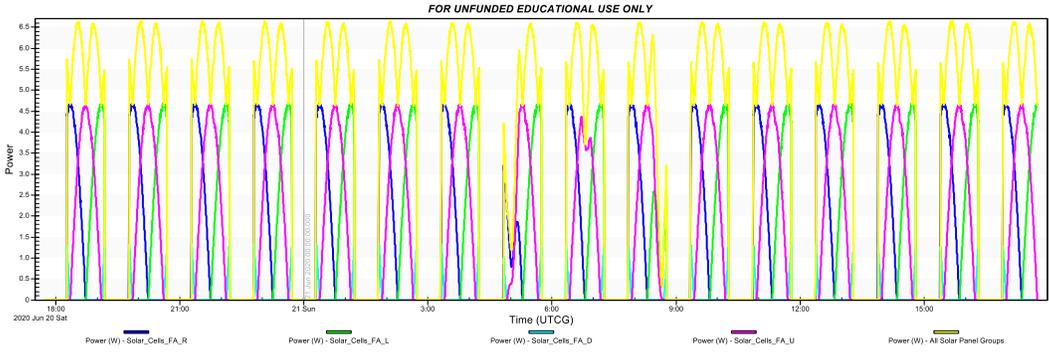*Figure A6: Autumnal Equinox*
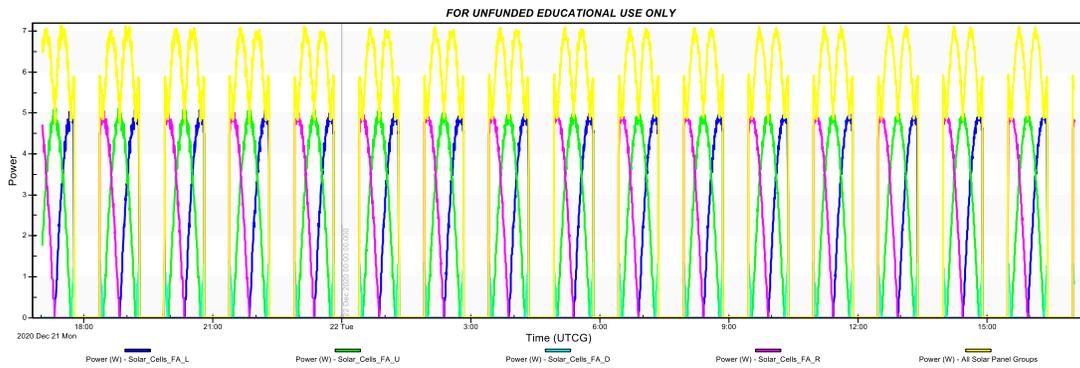
Figure A7: Spring Equinox

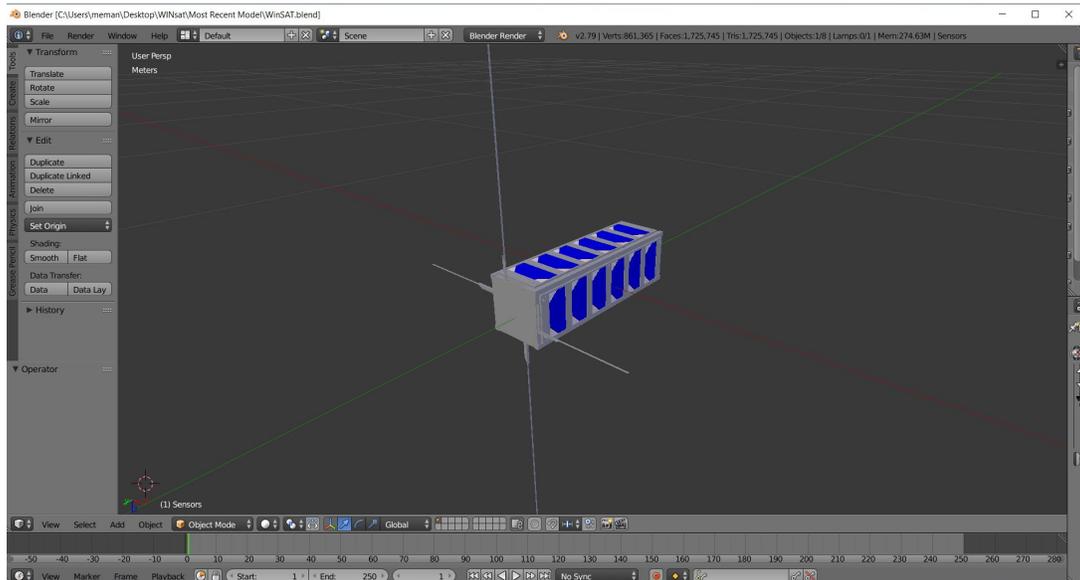Figure A8: Summer Solstice

Figure A9: Winter Solstice

Figure A10: Blender File before exporting into Exporting

Power Budget Data Sheet

Load Characteristics:	Current:	Current:	Current:	Orbit Average	Peak Sub-system		Average Sub-system		Orbit Average	Orbit Average
Component:	Direct from BAT(10.0V):	+5V Regulator:	+3.3V Reg.:	Duty Factor:	Power:	Units:	Power:	Units:	Energy:	Energy (Joules):
ISIS OBC:	0 amps	0.35 amps	0 amps	100%	1.75 watts		1.75 watts		162.5 watt-minutes	9,751 joules
RF Helium 100 - RX:	0 amps	0.15 amps	0 amps	100%	0.75 watts		0.75 watts		69.7 watt-minutes	4,179 joules
RF Helium 100 - TX:	0 amps	0 amps	0 amps	50%	0.00 watts		0.00 watts		0.0 watt-minutes	- joules
GPS Receiver:	0 amps	0.000 amps	0 amps	100%	0.00 watts		0.00 watts		0.0 watt-minutes	- joules
Payload (Selfie-Sat Camera):	0 amps	0.070 amps	0 amps	4%	0.35 watts		0.01 watts		1.3 watt-minutes	78 joules
Payload (Global Camera):	0 amps	0.070 amps	0 amps	6%	0.35 watts		0.02 watts		2.0 watt-minutes	117 joules
Payload - RPI compute stick:	0 amps	0.700 amps	0 amps	100%	3.50 watts		3.50 watts		325.0 watt-minutes	19,502 joules
EPS - Battery:	0 amps	0.02 amps	0 amps	100%	0.10 watts		0.10 watts		9.3 watt-minutes	557 joules
EPS - Battery Heater:	0 amps	0.12 amps	0 amps	100%	0.60 watts		0.60 watts		55.7 watt-minutes	3,343 joules
EPS - Clydespace Module :	0 amps	0.08 amps	0 amps	100%	0.40 watts		0.40 watts		37.1 watt-minutes	2,229 joules
ADCS - STM32:	0 amps	0 amps	0.003 amps	100%	0.01 watts		0.01 watts		67.3 watt-minutes	4,035 joules
Total Output Power/Energy Per Regulator:	0.00 watts	7.80 watts	0.01 watts		7.81 watts		7.14 watts		729.9 watt-minutes	43,791 joules
Total Input Power/Energy Per Regulator:	0.00 watts	9.87 watts	0.01 watts		9.88 watts		9.04 watts		839.4 watt-minutes	50,364 joules

Figure A11: Detailed Load Characteristics

Battery Characteristics:	Unit:	
Technology:	Lithium-Ion Polymer	
Battery Cells in Series String:	2.00 Cells	
Parallel Strings:	3.00 String(s)	
Battery Operating Temperature:	28.00 deg. C	
Battery Temperature Coefficient:	-0.0063 V/Cell/deg. C	Apply Temp. Coeff. to Cell Potentials Below
Cell Voltage (Fully Charged; Under Load):	4.20 V/Cell	
Cell Voltage (Typical Operating Cond.; Under Load):	3.85 V/Cell	
Cell Voltage (At Lowest S.O.C. Limit):	3.00 V/Cell	
Cell Votage (Fully Charged; Under Trickle Ch):	4.20 V/Cell	
Battery Cell Capacity:	1.3 amp-hrs	Capacity = **C**
Battery Safe Trickle Charge Rate	0.0 amps	C/30
Battery Voltage (Fully Charged; Under Load):	8.4 V	
Battery Voltage (At Lowest S.O.C. Limit):	6.00 V	
Battery Voltage (Fully Charged; Under Trickle Ch):	8.40 V	
Battery Voltage (Typical @ 20 deg.C):	7.70 V	
Battery Capacity:	3.93 Amp-Hrs	
Battery Reference Temperature:	20.00 deg. C	
Total Battery Energy	1699.06 watt-min.	28.3176 watt-hrs

Figure A12: Battery Characteristics

Solar Cell Characteristics:	Parameter:	Comments:	
Solar Cell Technology:	InGaP/GaAs/Ge	on Ge substrate	
Solar Cell Dimension A:	54.936 mm	Reference Cell	Calculated from sqrt(Cell Area)
Solar Cell Dimension B:	54.936 mm	Reference Cell	Area (cm^2) 30.18
Solar Cell Area:	30.180 cm²		
Solar Cell Short Circuit Current Density:	0.0168 amps/cm^2	SpectralAB Solar Cell XTJ data sheet	
Solar Cell Short Circuit Current (Isc):	0.507 amps	SpectralAB Solar Cell XTJ data sheet	
Solar Cell Open Circuit Voltage (Voc):	2.616 volts	SpectralAB Solar Cell XTJ data sheet	
Solar Cell Voltage at Max. Power (Vmp):	2.330 volts	SpectralAB Solar Cell XTJ data sheet	
Solar Cell Current Density at Max. Power:	0.0167 amps/cm^2	SpectralAB Solar Cell XTJ data sheet	
Solar Cell Current at Max. Power (Imp):	0.503 amps	SpectralAB Solar Cell XTJ data sheet	
Solar Cell Max. Power Output (Power Knee):	0.000 watts	Solar Cell Radiation Handbook, July 1, 1996, p 6-37	
Solar Cell Efficiency:	28.60%	SpectralAB Solar Cell XTJ data sheet	
Solar Cell Reference Temperature:	28.0 deg. C	SpectralAB Solar Cell XTJ data sheet	
Solar Array, Series Cells per String:	3 Cells	STK model	
Solar Array, Parallel Strings per Panel:	6 String(s)	1 String per Panel	
Solar Array Voltage at Pmax:	6.99 volts	Sun Normal to Array, 28 deg. C	
Solar Array Current at Pmax::	3.019 amps	Sun Normal to Array, 28 deg. C	
Solar Array Maximum Power:	21.104 watts	Sun Normal to Array, 28 deg. C	

Figure A13: Solar Cell Characteristics

Power Budget:			WinSAT-1	2020 January 30	Version: 0

Parameter:	Value:	Units:	Comments:
Solar Cell Size (Area):	30.18	cm²	1.975 cm X 2.025 cm Cell
Solar Cells Per String Per Spacecraft Side:	3		
Parallel Strings Per Side (Facet):	6		
Solar Cell Efficiency at Reference Temperature:	28.60%		Reference: Solar Cell Radiation Hdbk.
Reference Temperature:	28.00	C°	Add Efficiency vs. Temp. Dependency
Power Per String (0 deg. Beta Angle):	3.50	watts	Sun Normal to Facet; One Panel per Facet
Power Per Spacecraft Side (Facet):	21.02	watts	Sun Normal to Facet; One Panel per Facet
Sunlite Spacecraft Power:			
Minimum:	21.02	watts	Sun Normal to One Facet; One Panel per Facet
Typical:	29.73	watts	Sun in X-Y Plane; Equal Illumination of 2 Facets
Maximum:	46.26	watts	Sun on One Vertex
Average Sunlit Power:	32.34	watts	1/3x(Min+Typ+Max) Improve This Estimate

Orbit Properties:				
Semimajor Axis:	6793.14	km	Earth Radius	6378.2
Eccentricity:	0.001		Orbital Altitude	408
Inclination:	51.66	deg.		
Period:	92.867	minutes		
Sunlit Orbit Fraction:	0.50		Eqn. from "Fundamentals of Space Systems", pg. 331	
Orbit Average Power:	16.23	watts		
Solar Array Orbit Average Energy Output:	1507.25	watt-min.	90.435 kjoules	

Energy Summary:	watt-minutes		watt-hours	joules	
Sunlit Minutes per Orbit:	46.61	min.			
Eclipse Minutes per Orbit:	46.25	min.			
Energy Generated per Orbit:	1507.25	watt-min.	25.12 watt-hrs	90,435 joules	
Energy Consumed by Loads per Orbit:	839.41	watt-min.	13.99 watt-hrs	50,364 joules	
Energy Available to Recharge Battery:	667.84	watt-min.	11.13 watt-hrs	40,070 joules	Per Orbit
Energy Stored in Battery (100% S.O.C.):	1699.06	watt-min.	28.3176 watt-hrs	101,943 joules	
Energy Drawn from Battery During One Eclipse:	418.08	watt-min.	6.97 watt-hrs		
Capacity Drawn from Battery During One Eclipse:	54.30	amp-min.	0.90 amp-hrs	Average Discharge Voltage Estimated - Improve Estimate	
Battery Depth of Drain After One Eclipse:	23.0%				
Energy Required to Recharge Battery (per Orbit):	464.53	watt-min.	7.74 watt-hrs	Considering Battery Charge Efficiency	
Energy Generated Per Minute for Recharging:	14.33	watt-min./min.			
Time Required to Recharge Battery After E.O.E.:	32.42	minutes	Must Be < Sunlit Minutes	This Value Cannot Exceed Sunlit Minutes per Orbit	

        ■ = Positive Power Budget
        ■ = Negative Power Budget

Orbits before Battery Depleation
at Current Discharge Rate: Unlimited Orbits

Figure A14: Power Budget Calculation
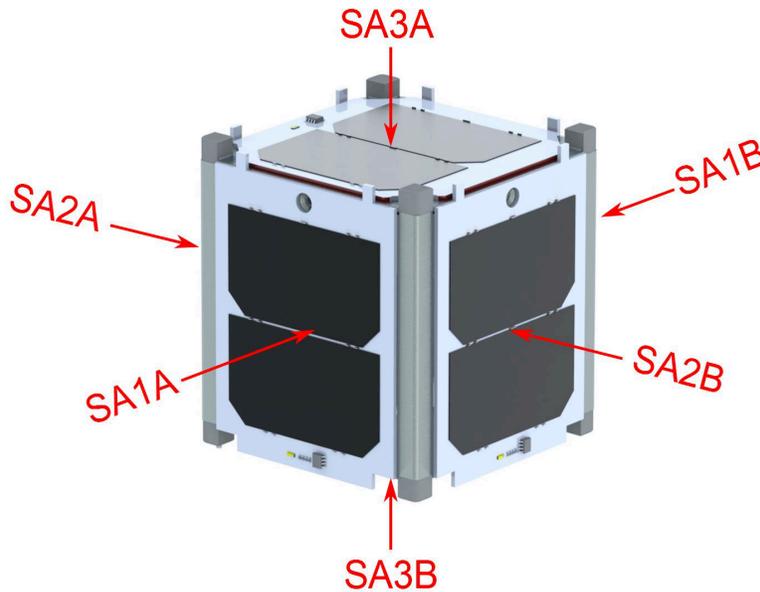
Clyde Space EPS Module

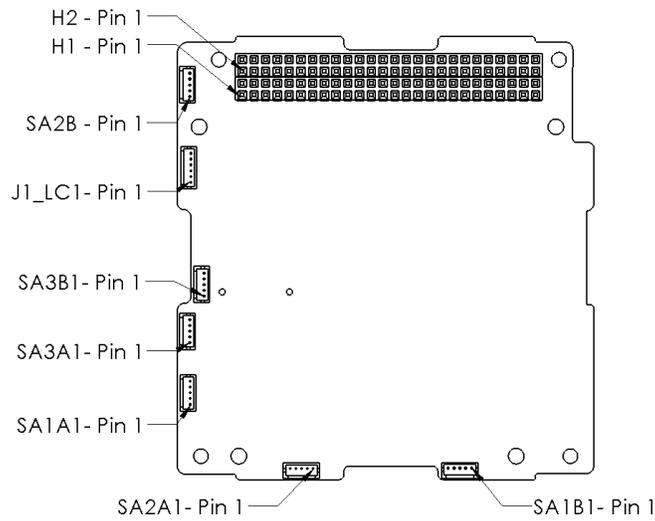*Figure A15: Typical Array Configuration for 25-02451 with Example Allocations.*

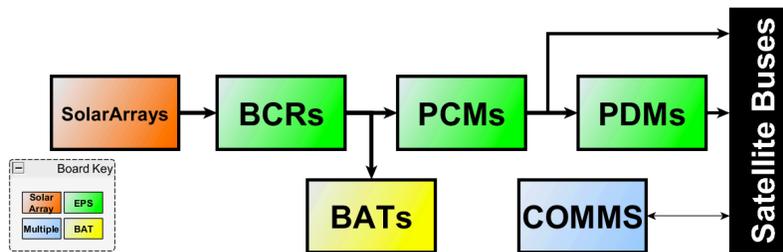*Figure A16: Connector Location Diagram for 25-02452 and 01-02453 Motherboard*
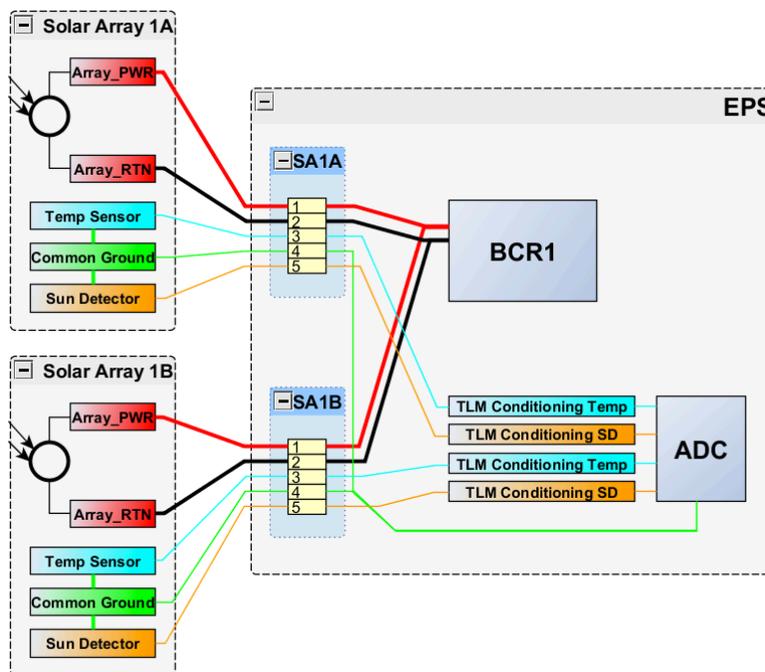

Figure A17: System Diagram

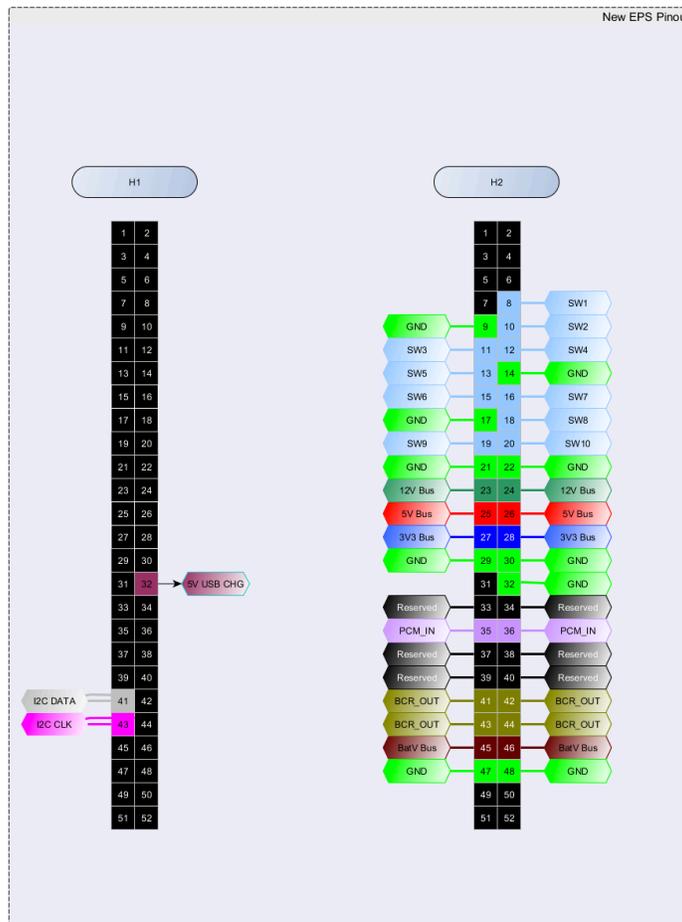*Figure A18: Example Solar Array Configuration SA1-3 and (25-02451 only) SA4*
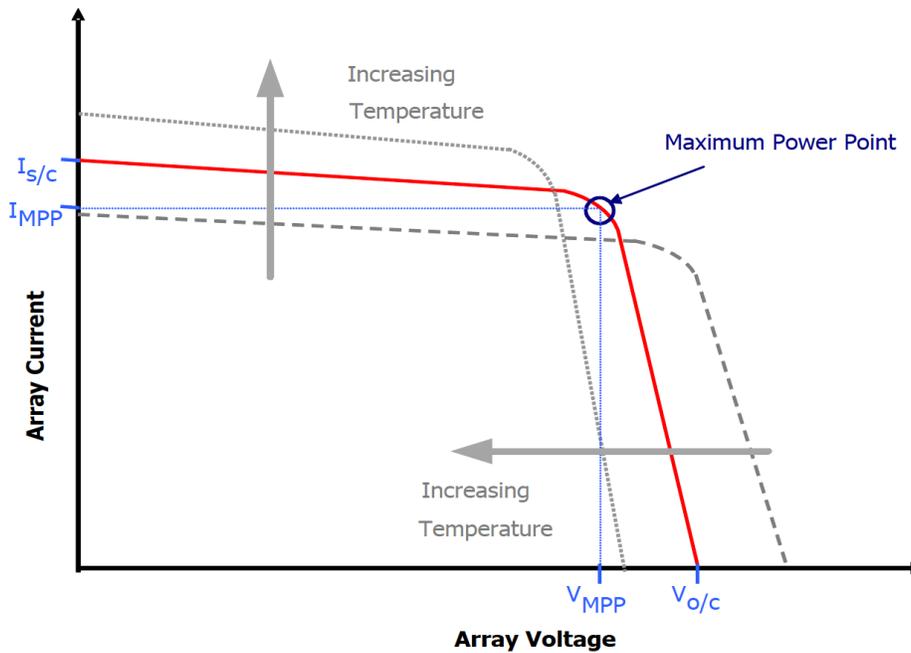
Figure A19: CubeSat Kit Header Schematic

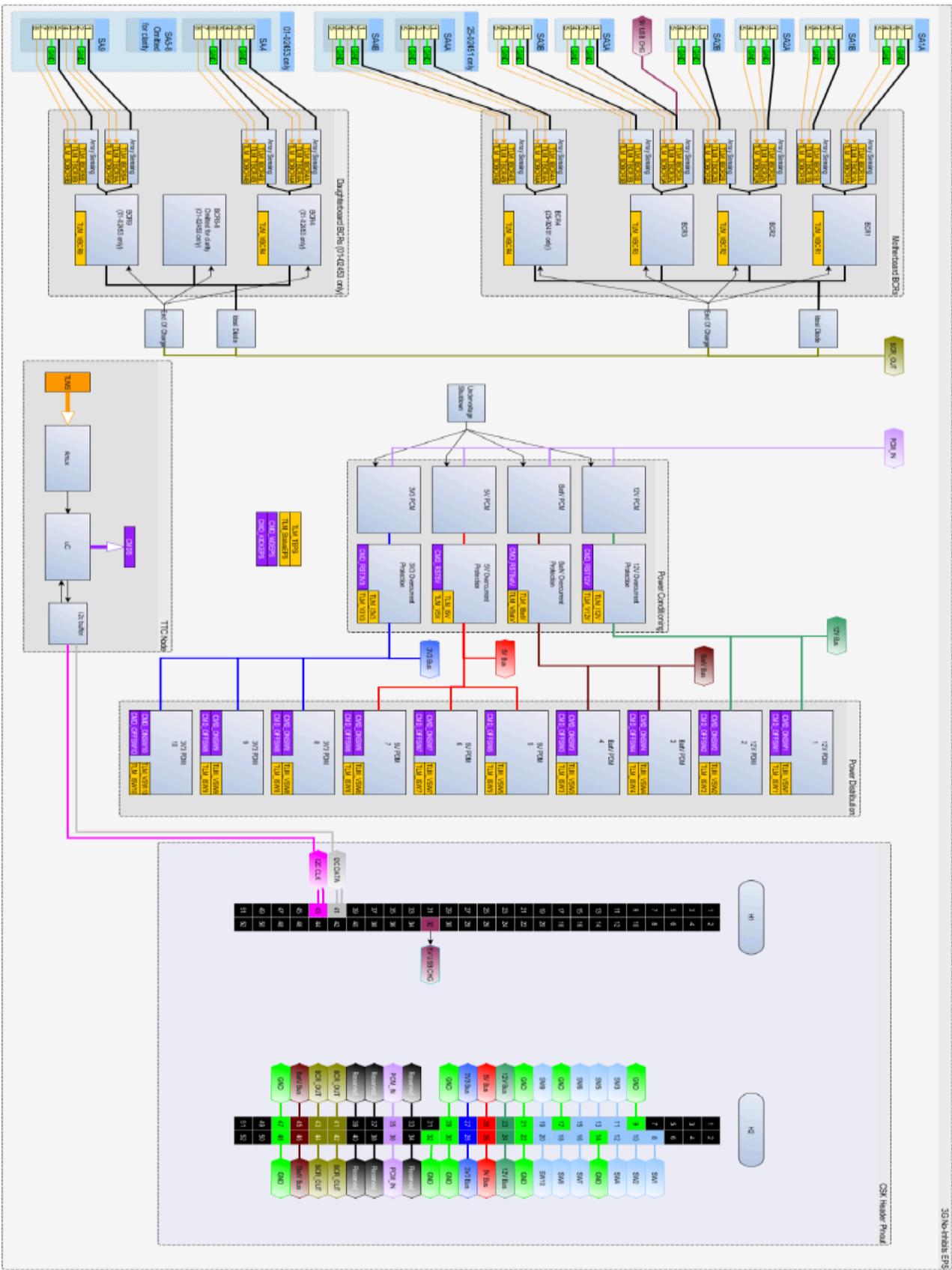*Figure A20: Solar Array Maximum Power Point*

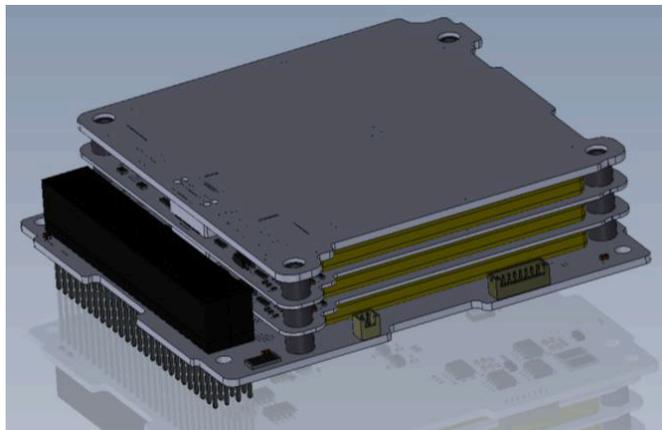*Figure A21: Functional Diagram*

Clyde Space EPS Battery

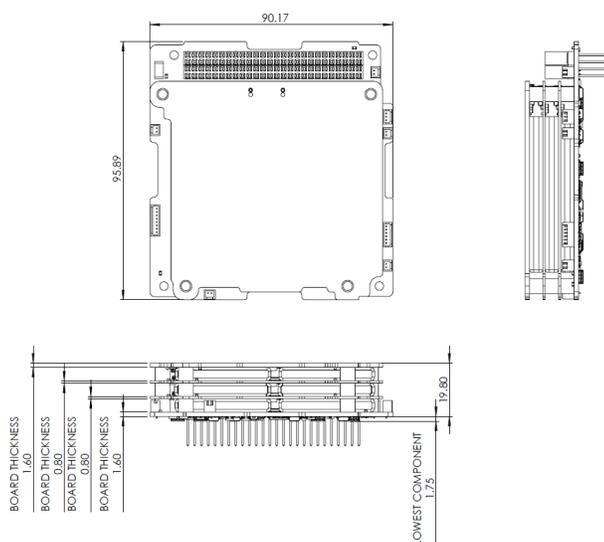*Figure A22: 3G Standalone Battery Configuration*

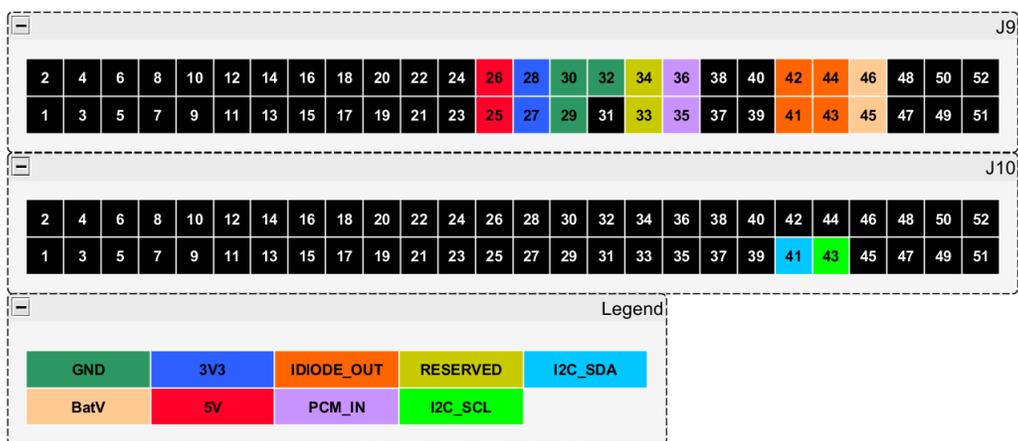

Figure A23: 30Whr Standalone Battery External Layout

Figure A24: CubeSat Kit Header Schematic
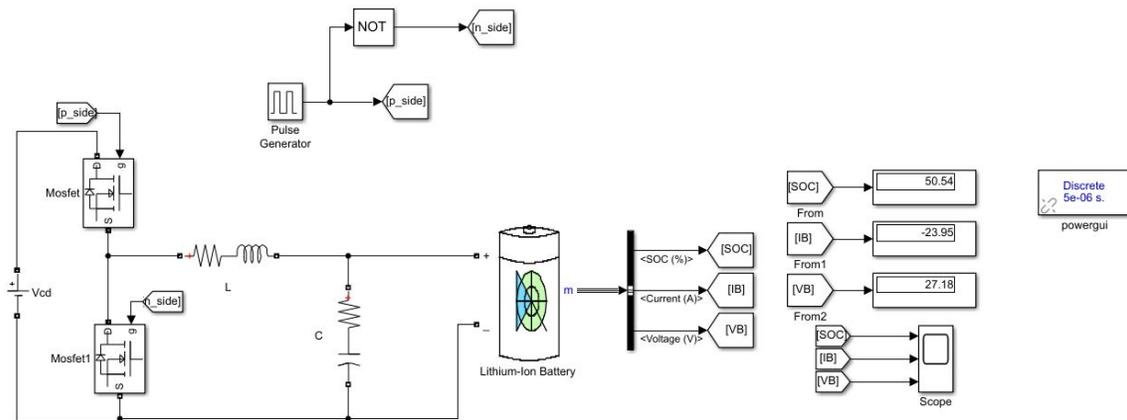
Simulink

Initial Model A

Figure A25: Model (A) Schematic for battery Integrator with PWM generator
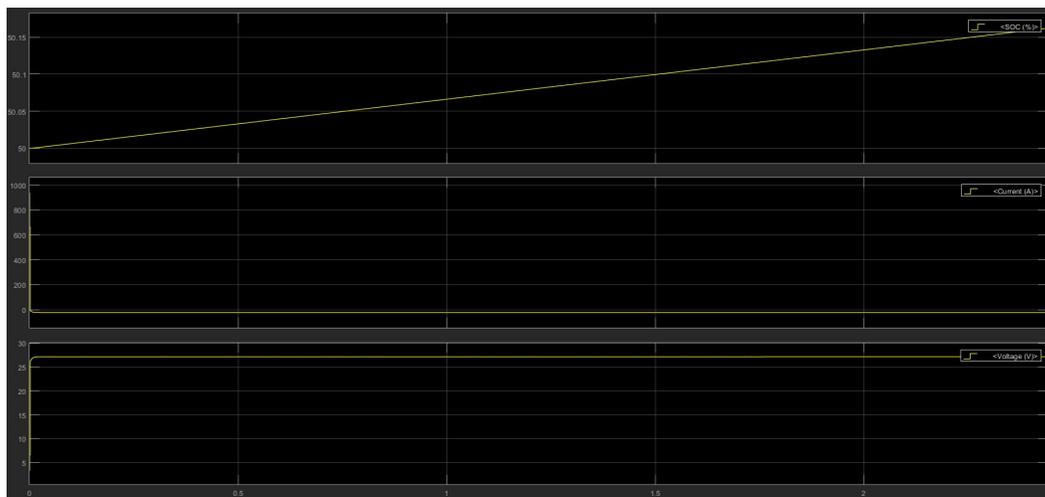

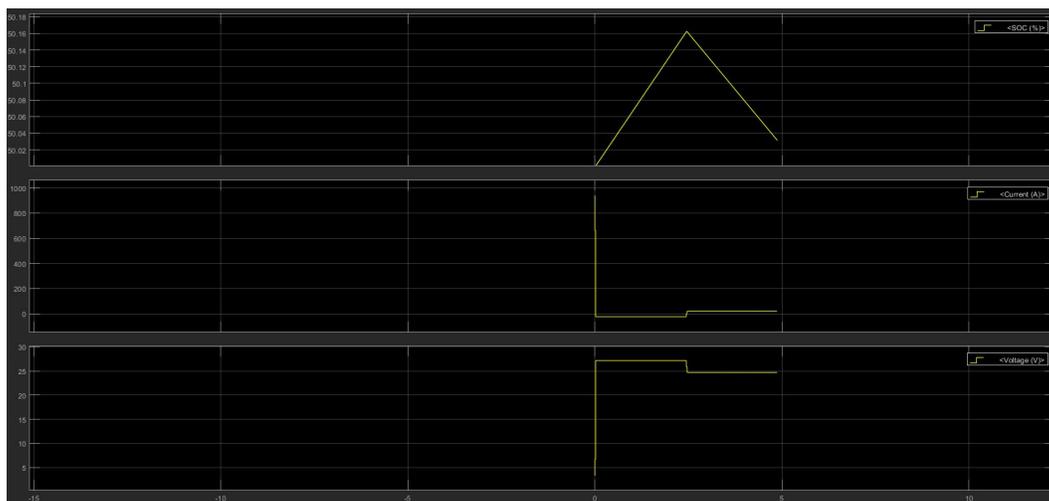*Figure A26: Model (A) Charging condition Output*

Figure A27: Model (A) Discharging condition Output
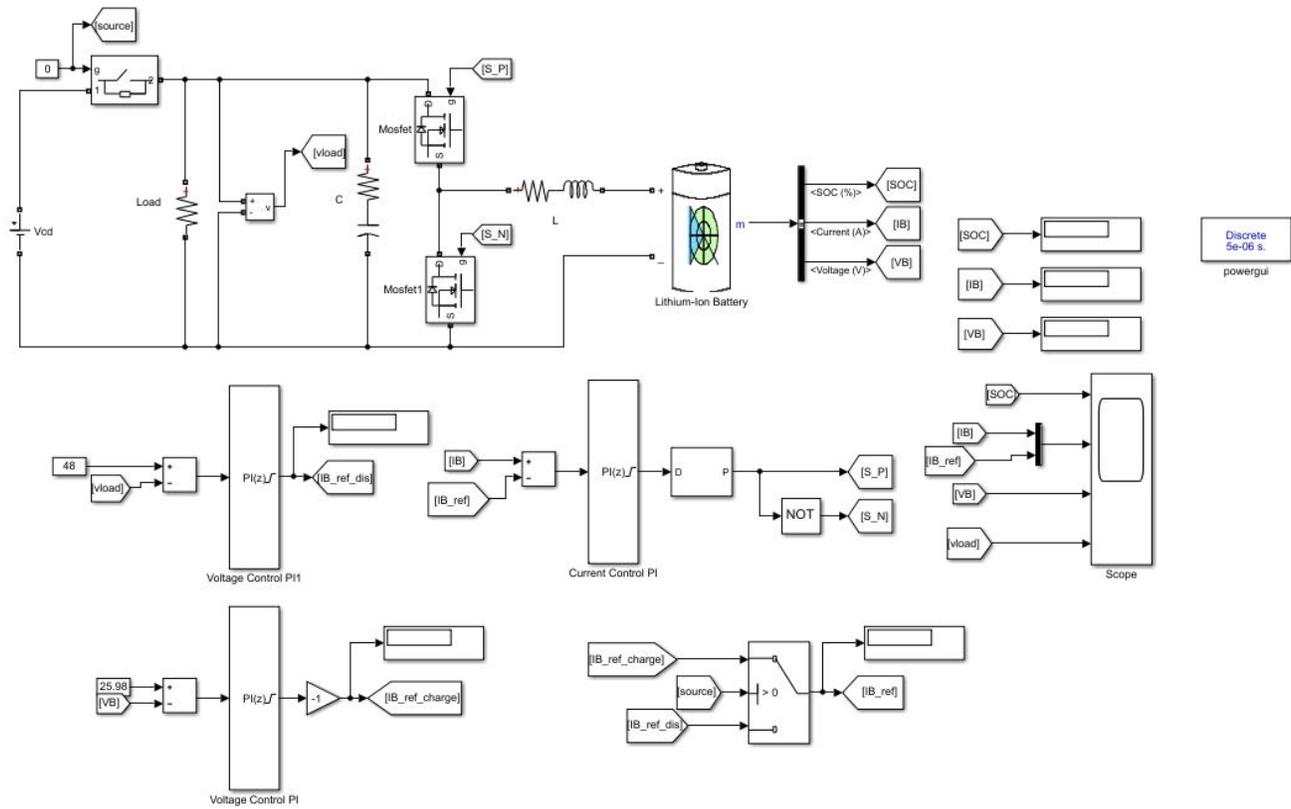
Initial Model B

Figure A28: Model (B) Schematic for battery Integrator with PID controller
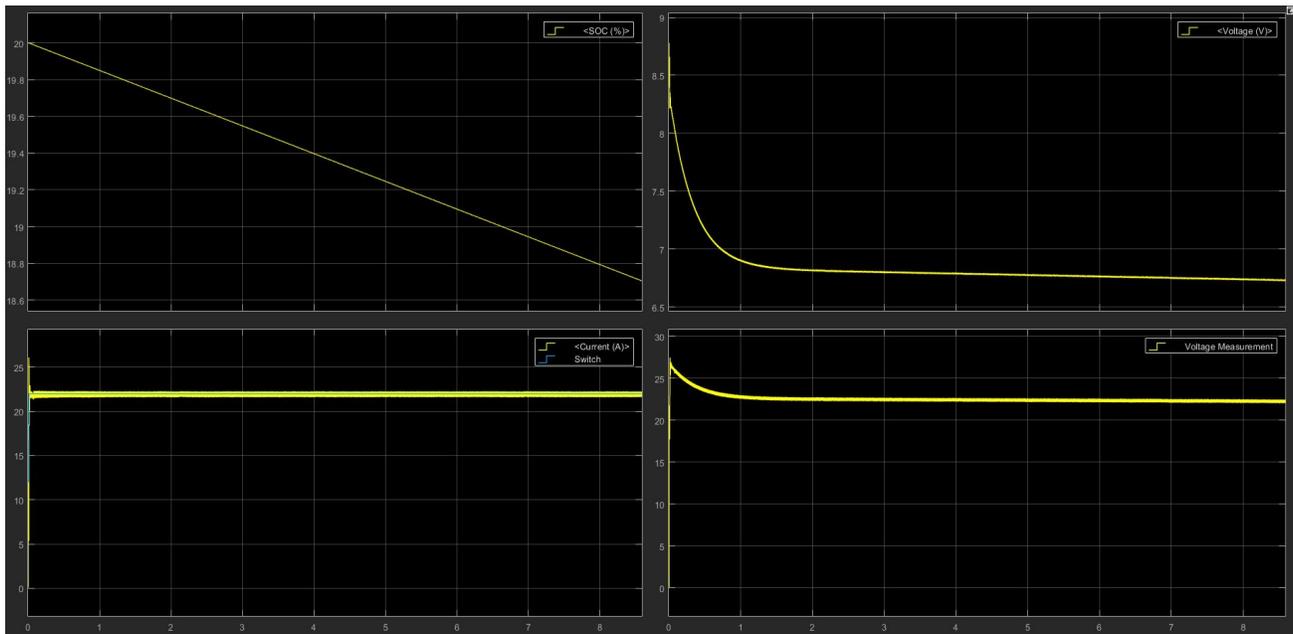

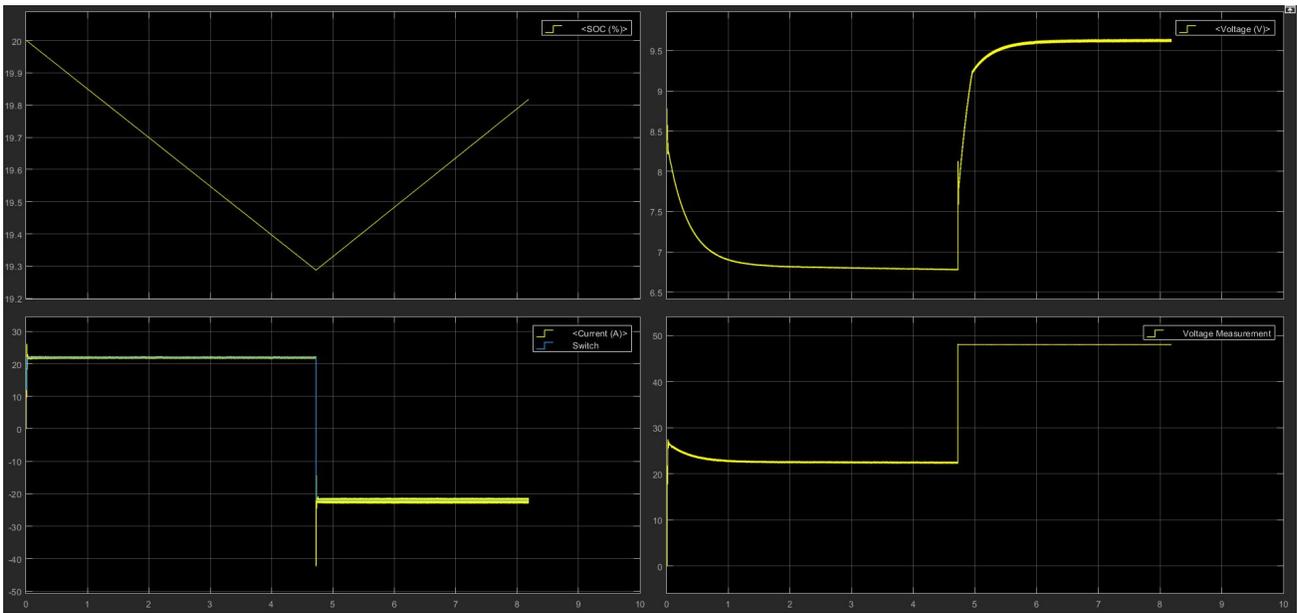*Figure A29: Model (B) Discharging condition Output*

Figure A30: Model (B) Charging condition Output
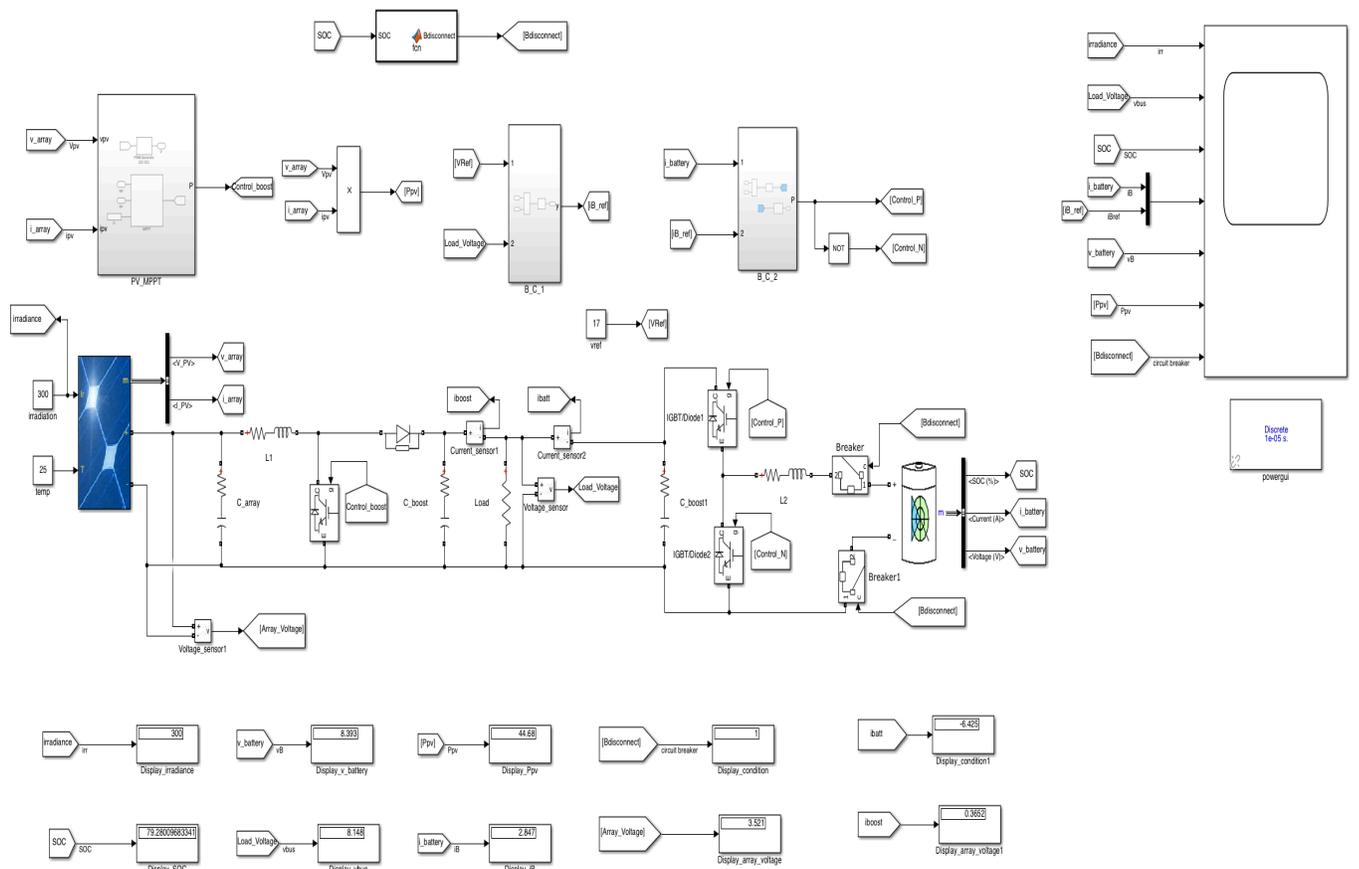
Selected Model

Figure A31: Final Implemented Model
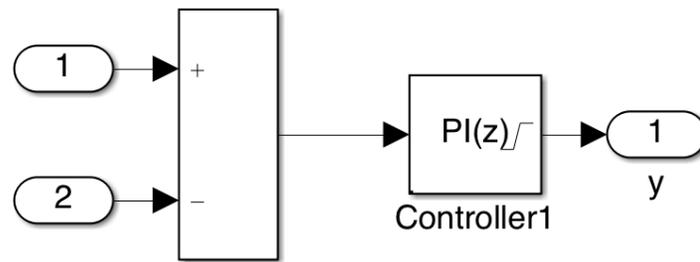
Battery Controller

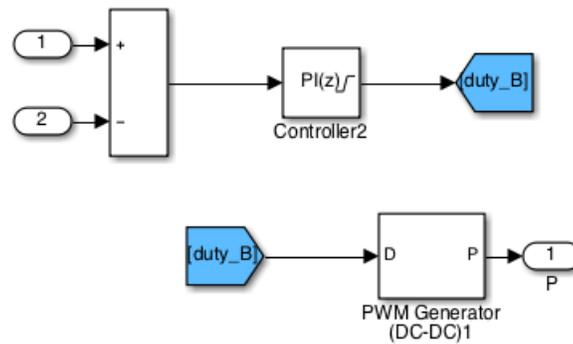*Figure A32: Battery Controller 1 mask file*

Figure A33: Battery Controller 2 mask file

Maximum Power Point Tracking (MPPT)
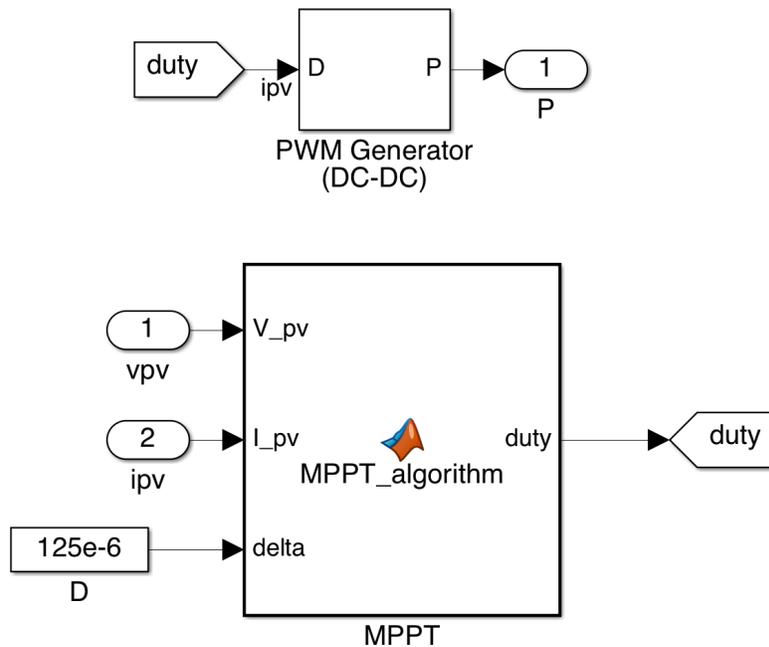
Figure A34: MPPT mask file in Simulink

Below code interprets the MPPT_algorithm block:

```matlab
function duty = MPPT_algorithm(V_pv,I_pv,delta)
initial_duty = 0.05;

% min and max value to limit duty

min_duty = 0;
max_duty = 0.75 ;

persistent old_V old_P old_duty;
if isempty(old_V)
    old_V=0;
    old_P=0;
    old_duty=initial_duty;
end
P= V_pv*I_pv;
dV= V_pv - old_V;
dP= P - old_P;

% if the derivative equal to zero
% duty will not change
% if old and new power not equal & pv voltage bigger than 6V

if dP ~= 0 && V_pv>6
    if dP < 0
        if dV < 0
            duty = old_duty - delta;
        else
            duty = old_duty + delta;
        end
    else
        if dV < 0
            duty = old_duty + delta;
        else
            duty = old_duty- delta;
        end
    end
else
    duty = old_duty;
end

%the below if limits the duty between min and max

if duty >= max_duty
    duty=max_duty;
elseif duty<min_duty
    duty=min_duty;
end

% stored data

old_duty=duty;
old_V=V_pv;
old_P=P;
```

Figure A35: PV Array Properties for Simulink Model

Designing of Printed Circuit Boards

ADCS Module

Figure A36: ADCS Electrical Schematic

H1, H2 Headers	Function	STM
H1Pin-21,41	SDA	CN5-D14
H1Pin-41-43	SCL	CN5-D15
GND	GND	GND
H2Pin-24-12v	Vin 12V	CN6-8

Table A3: ADCS Module from WINSAT Bus to STM

STM-CN7	NXP	NXP	STM-CN8
CN7-18	Vin	A1	A0
CN7-16	3Vo	A2	A1
	GND	A3	A2
CN7-38	SCL	A4	A3
CN7-36	SDA		
CN7-14	Reset		

Table A3: ADCS Module from STM to NXP9DOF, NXP to STM
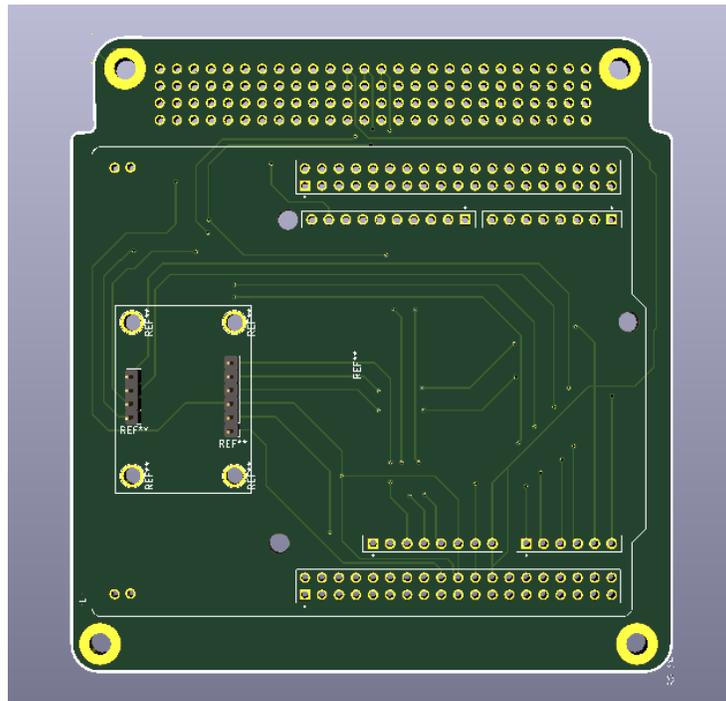
Figure A37: 3D mode of ADCS Front
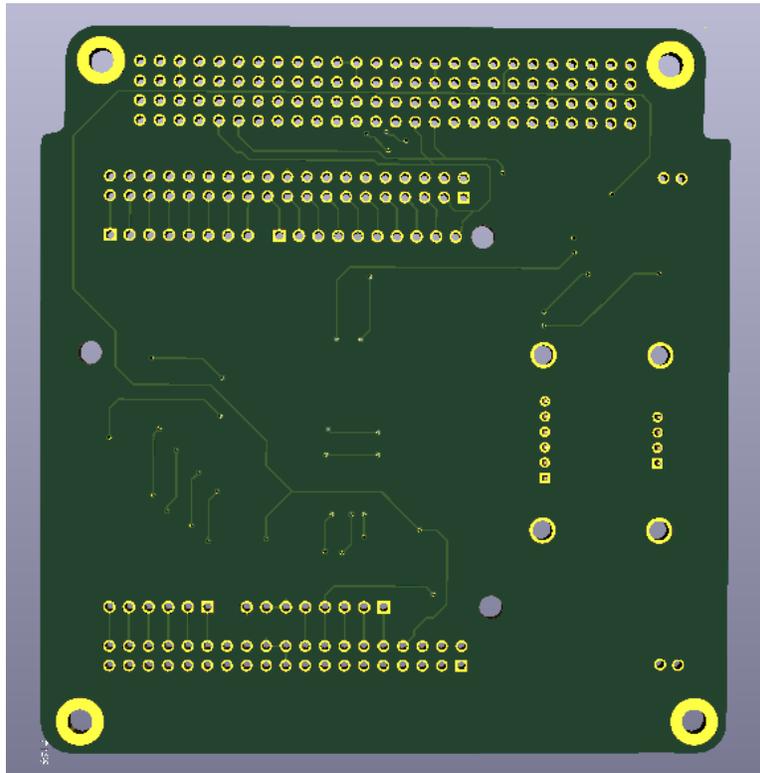
Figure A38: 3D mode of ADCS Back

Payload Module

Figure A39: Payload Electrical Schematic

Figure A40: Payload Selfie-Sat Cam Module

Solar Panels

Figure A41: Solar Panel Type 1
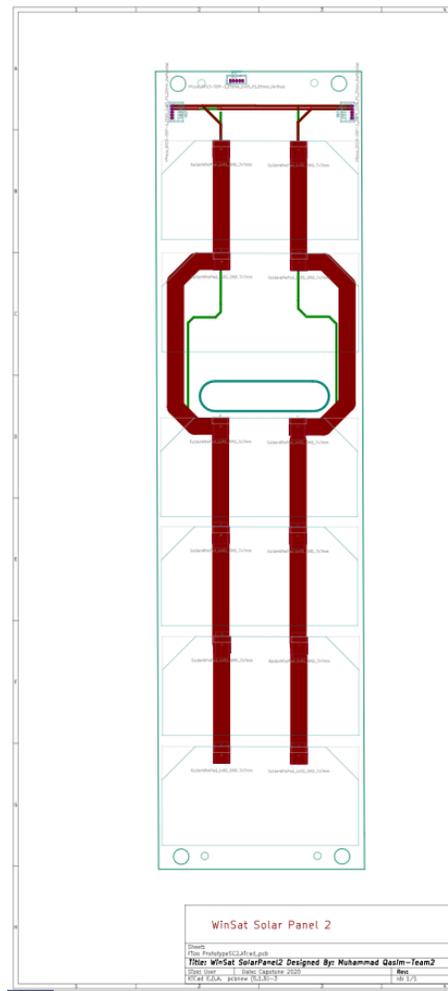
Figure A42: Solar Panel Type 2

STM32 Nucleo F401RE Development Board

1 November 2018 - 0 Comments
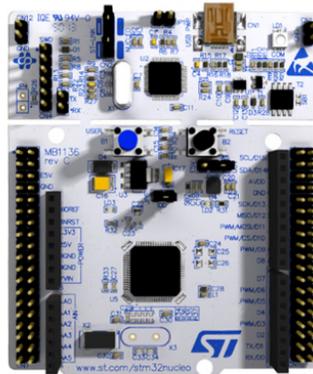
STM32 Nucleo F401RE Development Board
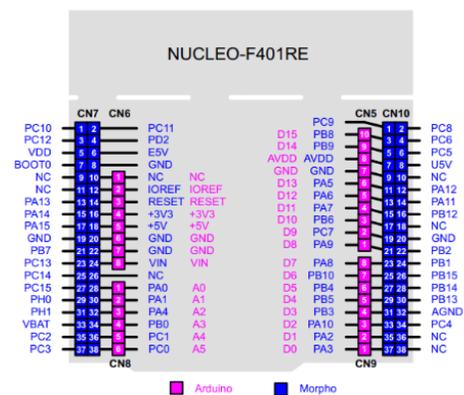
STM32 Nucleo F401RE Pinout

Figure A43: STM32 Nucleo F401R3 Development Board

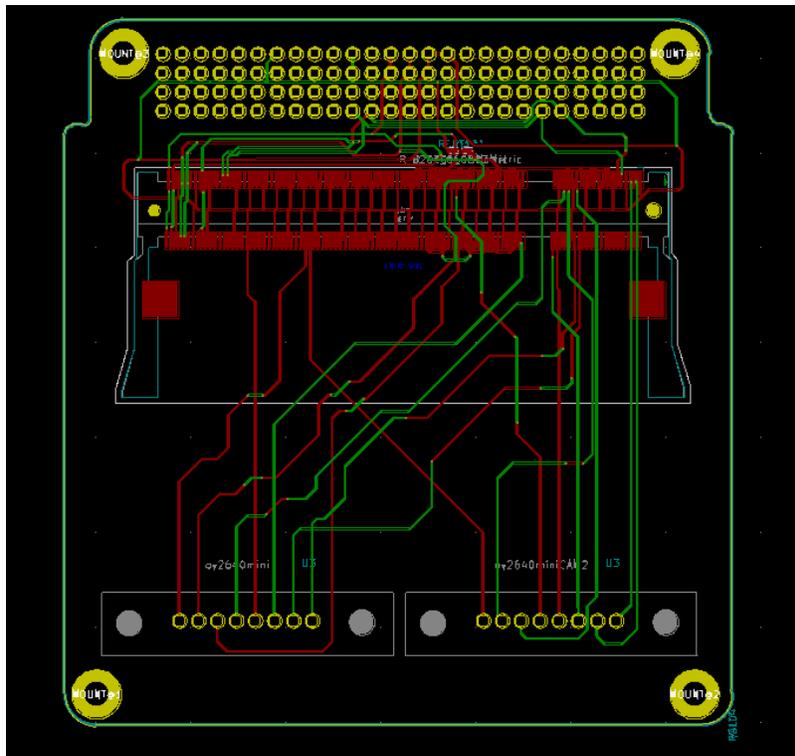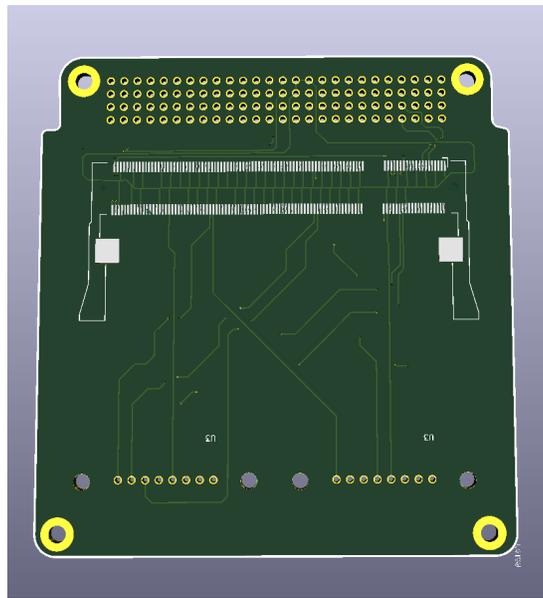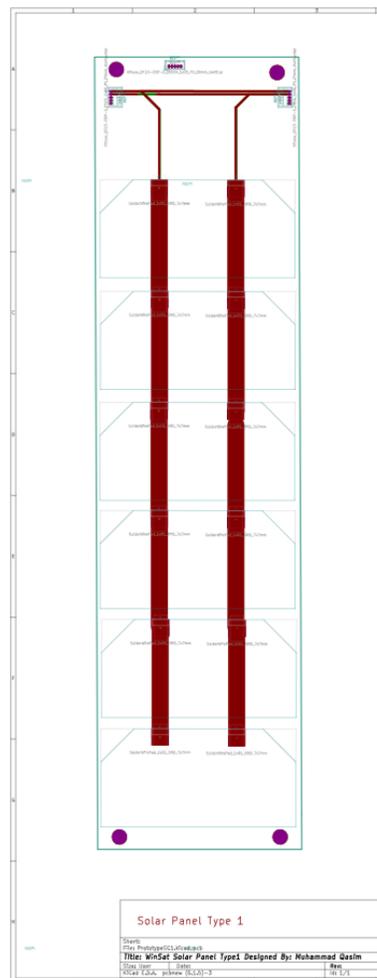| H2	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
				SW1	SW2	SW4	GND	SW7	SW8	SW9	GND	+12V	+5v	+3v	GND	GND	R	PCM	R	R	BCR	BCR	VBAT	GND		
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51
					GND	SW3	SW5	SW6	GND	SW10	GND	+12V	+5V	+3V	GND		R	PCM	R	R	BCR	BCR	VBAT	GND		
H1	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51
											SCL	SDA									IC2SDA	IC2SCL				

Table A4: H1 and H2 Headers

Figure A44: OV2640 Cameras

Gantt Chart

WINSAT

Electrical Power Systems
Constructed by: Usman Chughta

Project Start Date: 2020-01-17

Scrolling Increment: 1

Legend:
| On Track | Low Risk | Med Risk | High Risk | Unassigned |

Milestone Description	Category	Assigned To	Progress	Start	No. Days
PCB					
Ki-Cad	On Track	Muhammad Qasim	100%	2020-01-17	3
PC-104	On Track	Muhammad Qasim	100%	2020-01-20	30
Payload	Milestone	Muhammad Qasim	100%	2020-02-19	10
Solar Panel	Low Risk	Muhammad Qasim	100%	2020-01-27	60
ADCS/CDH	Low Risk	Muhammad Qasim	100%	2020-02-16	25
System Wide Schematic	On Track	Muhammad Qasim	100%	2020-02-16	60
Battery Integrator					
Matlab for Variable Load	Milestone	Qasier/Usman	100%	2020-02-06	45
Battery Model A	On Track	Qasier	100%	2020-02-16	15
Battery Model B	Milestone	Usman	100%	2020-03-02	11
Power Generation (MATLAB)	Milestone	Usman	100%	2020-02-08	7
Power Budget					
STK 11 Simulation	On Track	Usman	100%	2020-01-17	30
Sun Synchronous Orbit	High Risk	Usman	100%	2020-01-17	22
ISS Orbit	High Risk	Usman	100%	2020-02-03	25
Power Consumption Chart	On Track	Qasier	100%	2020-02-06	95
Planned					
Battery Testing	Goal		0%	2020-04-26	0
			0%	2020-04-26	0

Figure A45: Gantt Chart