Design of Battery Module for Small Satellite -Battery pack design for LEO Satellite using Li-ion cells

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Abstract*— Satellites are being developed all over the world these days due to their countless advantages. Satellites have many sub-systems, one of them is electrical power sub-system (EPS). EPS includes different sub modules like Solar Panel (SPU), Battery Unit, Power conditioning unit (PCU) and Power distribution unit (PDU). Battery module is the secondary source of the satellite and is responsible for the pay loads power requirement. The module supplies the power of 32 to 56W to satellite during the eclipse period of 35 minutes. Battery pack is designed to meet strict parameters of weight, dimensions and protection circuitry in order to maintain the size, weight and to avoid mission failure. The intelligent cell balancing circuitry is implemented to increase the life time of the battery pack which is controlled by microcontroller. Different digital ICs are used to monitor the temperature, current and voltage of batteries. Redundancy is also provided to avoid any single point failure and is designed for the service life of 2 years. Battery pack module will have direct interface with the PCU through telemetries to monitor temperature, voltage and current. This paper describes the design and development of the battery pack module of small satellite.

I. Introduction

Cubesat revolves around the earth in sun synchronous orbit (SSO). [2] The cubesat has 26 on-satellite modules; one of them is the battery module. Battery is the secondary source of electrical power for any satellite as the solar panels are the primary source of providing power. The battery will be designed for a service life of one year and minimum on ground storage life of at least one year. The following philosophies will be observed at all levels without compromising the programmatic objectives, which includes Modularity, scalability, power efficient, as simple as possible and maximum utilization of existing heritage. It will provide the satellite with sufficient power of 56 watts. During the eclipse period, only critical loads will be provided with the power, which will be about 32 watts. The battery will only work during the eclipse period of 35 minutes. The nominal voltage of the battery will be 28 volts and the nominal battery capacity at beginning of life will be 6Ah. Each cell of the battery will be protected against charge/discharge imbalance and battery pack includes the balancing circuits, protections circuits and telemetry circuits. We will have to maintain the charging of the batteries and at the same time look after that it will not get over-charged or get deep discharged.

II. Methodolgy

The design of a battery module requires some important `things, which need to be considered for a good design.

A. Redundancy and Reliability

- Redundancy is provided at all levels to eliminate critical failure modes, single point failures and to improve reliability.
- No single electrical component failure in battery will disable or degrade its required functions in a way that may lead to mission failure.
- Reliability of battery pack is better than 0.97969.
- In case of one cell failure, the corresponding cell or string shall automatically is isolated from rest of the battery in order to keep it operational.

B. Interfacing with PCU and PDU

- Battery has an interface for its power transfer to/from Power Conditioning Unit (PCU) through appropriately sized 2:1 redundant wires.
- Battery receives biasing power for its own electronics (i.e. protection circuits and telemetry) from Power Distribution Unit (PDU) at +5V.
- Battery pack has a direct telemetry interface with PCU to monitor its temperature, voltage, state of charge and status of any critical protection circuits.[3]

This is the block diagram of complete EPS in which battery is shown in red block.[4]

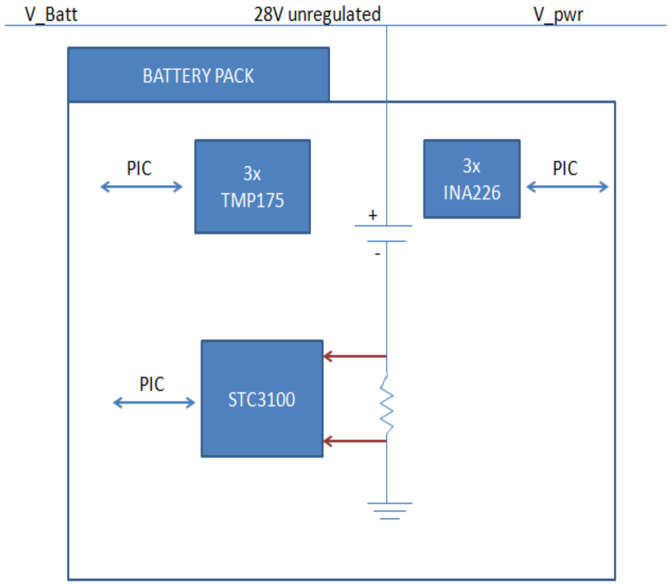


Figure 1: Battery Pack Module Block Diagram

III. Structural Interface

Total mass of battery pack (including Li-Ion cells, electronics, internal harness and housing) is approximately 1.4kg, wherein the mass of housing is limited to 0.45kg. The envelope dimensions of the battery pack are 110 x 110 x 90 mm. The normal operating temperature range of the battery is 10 to 30°C. Thermal analysis of battery is performed while considering its sink temperature variation from 6°C (in worst cold case) to 28°C (in worst hot case).
The batteries will be placed one above the other and the electronic circuitry will be placed on top for ease of access. The dimension of selected lithium battery is **18.2mm** * **68.2mm*93mm.** The unit mounting area will be kept according to the minimum requirement of 0.904 cm^2. The expected shape (excluding harness) of the battery pack with protection circuits is as shown

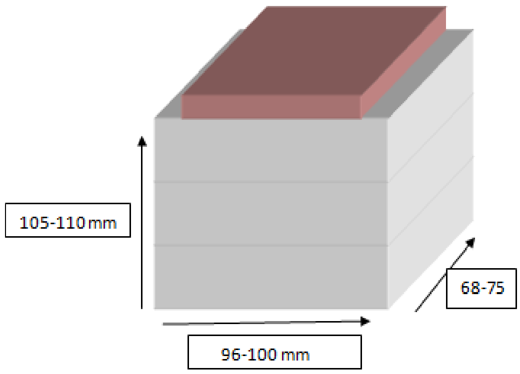


Figure 2 : Dimensions

IV. Functional Architecture Of Battery Module

The cells are arranged in series and parallel combination to design a battery according to the required specification. An additional string of cells is added in the module to provide redundancy. There are 3 strings containing 8 cells each which are connected in series and then these strings are connected in parallel to gain the required capacity of 6Ah. As the cell selected is of 3.6V and 3Ah so connecting 8 cells in string will give us required voltage of 28V and connecting 2 strings in parallel gives us 6Ah, while third string is for redundancy.

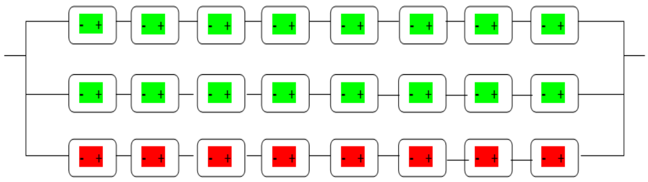


Figure 3: Functional Architecture

V. Cell Balancing

Whenever we design a multi-cell battery packs, the most important task is to balance the cells. Cell balancing increases the lifetime of the battery pack and determine the runtime it will provide. [6] It is actually the state of charge, which is to be managed; the cells with same state of charge placed together because the imbalance causes the decrease in over-all capacity of the battery pack and reduces its life. So the cells with different state of charged are balanced by equalizing them which increases the battery life and make it more reliable for longer.
The main reason of cell-imbalance is the difference in cell

voltages but this problem can be solved by using by-pass technique for the cells with higher voltages. This can be done by giving commands to a micro-controller like we will give a defined value of the maximum and minimum voltages and if the voltage of any cell increases or decreases from the threshold value then the bypass gets activated. This cell balancing can only be done when the battery pack will on charging mode. The algorithm will check the voltage of the cell needs to be balanced with the cell of highest voltage value.

VI. Cell Balancing Techniques

There are many techniques which can be used for cell balancing, the two basic techniques for cell balancing are

1. Active Cell Balancing
2. Passive Cell Balancing

Passive cell balancing includes the procedure of removing the energy from the cells with high charging and giving this energy to cells with low charging, and the wasted energy converts to undesired heat. While in active cell balancing, we simply transfer the energy from the cell with high state of charge to the cell having low state of charge and this method saves the energy losses.
We have explained one of the techniques of cell balancing which we have used in our design that is cell balancing using single capacitor.

A. Cell Balancing using single capacitor

This is the active cell balancing technique in which we use a single capacitor to balance the cells connected in series. We connect a capacitor in parallel with the string so that the cell with highest voltage in the string will charge the capacitor and then the capacitor will charge the next cell which has low voltage and this sequence continues until all the cells get balanced

Example:

We used two strings of eight cells each to make the battery pack and one extra string for redundancy. Suppose we have two strings, string-A and string-B. There are several techniques which can be used for balancing of cells and the technique we have proposed is capacitor based in which we used a single capacitor is connected in parallel with each string to balance the voltages of all cells of the respective strings.
SiP32448 are selected to use as switches, which are used in the cell balancing circuit for example suppose Bat-4(cell) is at highest voltage and Bat-5(cell) is at lowest voltage from the string which contains 4 cells and we want to balance the voltage of both cells then we turn on switch-**A** and **A´** to charge the capacitor C-5 by taking voltage from Bat-4 and once the capacitor gets charged then we will turn off switch-A and **A´** and turn on switch-**B** and **B´** which will charge the Bat-5 by discharging the capacitor.

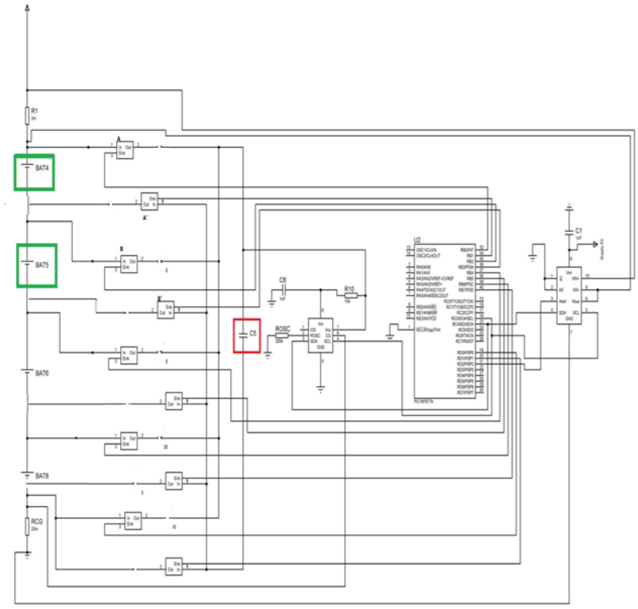


Figure 4: Cell Balancing Example using Single Capacitor

VII. Choice of Cell

The choice of cell is a very important factor while designing a battery pack for any satellite because it is very important to keep in mind the voltage and current requirements as well as the weight, volume, energy density and many other features while selecting a cell. The QL2900-18650 [7] is selected to design a battery pack for our cubesat with nominal voltage 3.6 volt per cell.

Figure 5 : QLI2900-18650 Li-ion Cell

QLI2900-18650 is a lithium-ion rechargeable cell, optimized for high energy density and high power capability. Its key features include high-energy density, high reliability and

highly safe. We will connect these cells in series and parallel combination, 16 such cells are required to design one battery pack and further more will be required to provide redundancy.

A. *Specifications*

Electrical Characteristics	
Nominal Capacity	2.9 Ah
Nominal Voltage	3.6 V
Max Continuous Discharge	6.15 A
Discharge Temperature	-20 to 60°C

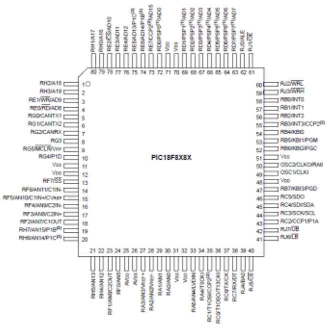
Table 1:Electrical Characteristics Of Cell

Physical Characteristics	
Diameter	18.6 mm
Height	65.2 mm
Weight	44.5 g
Volume	17.7 cc

Table 2: Physical Characteristics of Cell

VIII. CHOICE OF MICROCONTROLLER

Selection of microcontroller was very important step for the module design and the microcontroller we have selected is PIC18F8585. PIC18F8585 is the 80 pin, high performance microcontroller with ECAN module shown below



Micro-controller controls all the digital ICs used in the module which includes STC3100 for voltage monitoring, INA226 for current monitoring and Tmp175 for temperature monitoring purpose. Furthermore all the load switches which are used in the cell balancing circuit are controlled by microcontroller and we have programmed it according to our requirement like when we switch on or off the switches to charge the capacitor and then to charge cells from the capacitor. It is used in I2C interface to read or write data from the ICs by master slave concept using SCL and SDA pins.

IX. POWER BUDGET

1. <u>INA226</u>
   Supply voltage = 5V
   Supply Current = 420µA
   Power = 2.10 mW

   3*2.10mW = 6.3mW

2. <u>Tmp175</u>
   Supply voltage = 5V
   Supply Current = 85 µA
   Power = 0.4 mW

   3*0.4mW = 1.2mW

3. <u>STC3100</u>
   Supply voltage = 5V
   Supply Current = 100 µA
   Power= 50mW

   3*50mW = 150mW

4. SiP32448
   Supply voltage = 5V
   Supply Current = 130 µA
   Power = 65 mW

   48*65mW = 3.12W

5. PIC18F858
   Max power dissipation = 1 w

   Total Power dissipation = 4.5W

The power consumption analysis is very important while designing a battery pack module of any satellite as it identifies the life of the module and its safe range. As the total power dissipation is 4.5 Watts so the design finalization depends upon this value.

X. RELIABILITY ANALYSIS

Reliability analysis of different ICs we have proposed for our design of battery pack is done referring Mil-Hbbk-217F.
Reliability is calculated by finding all the parameters C_1, π_T, C_2, π_E, π_Q, π_L for all the digital ICs and for the microcontroller

$$\text{Part Failure rate } \lambda_p = (C_1\pi_T + C_2\pi_E)\pi_Q\pi_L$$

After finding all the parameters reliability is calculated by putting value of λ_p in formula given below

$$R = e^{-\lambda_p}$$

Total reliability of the battery pack module is approximately 99.9%

XI. Battery Monitoring process

Satellite works in a proper manner without interference if all the modules of an electrical power sub-system of a satellite are well designed. To avoid any errors it is very important to monitor the battery and designer has to cater all the conditions which can the cause the failure of the processor. Few conditions to monitor the battery are given below.[10]

A. Low Battery Voltage Method.

Under normal condition of temperature if the battery voltage lowers to value of 2.8 volts and is battery is about to get discharged then the electrical power sub-system warns the system to power off the processes going on inside on board computer to take off all the payload from batteries. On board computer and EPS will continue working because these modules need very less power as compared to the other modules and EPS monitors the battery voltage and when it reaches the voltage level of 3.3 volts then there will not be any error. The BQ76PL536 measures the current and voltage values.

B. Low Temperature Method.

The voltages and current capacity of the batteries depends upon the temperature values for example as we discussed above the battery will not operate in a normal manner if it temperature get very low because it will drain the voltage to 2.8 volts and it will also decreases the current capacity. So the temperature can be controlled by controlling the thermal system which increases the temperature upto the required value and we can control the voltage and current capacity in this way.

XII. State Of Charge Monitoring

While designing a battery module for any satellite it is very important to maintain the state of charge of the battery in order to make the electrical power system of satellite in proper working state. SoC[11] of battery can get lower that the defined value which can cause a serious damage to the batteries. So we use different methods to keep the batteries operating at pre-defined value in order to make them perform the required operations.[10]

A. Voltage Level Measuerement

We can use a capacitor which defines the voltage and battery's state of charge. The batteries in satellites should have a constant voltage but it is an ideal case because the voltages vary constantly with time due to capacitor. But still the voltage measurement gives information about the battery's SoC, which may be a rough estimate but is useful.

B. Coulomb Count Measurement

The charge capacity of batteries is measured in Ampere hour. A coulomb counter method is used to measure the input and output current of the batteries by using shunt resistor. State of charge is measured at start of the process and then by adding the charge which is accumulated gives the final SoC[11]. The process though has errors like the counter does not consider the change in temperature of the battery due to heat produced but it only measures the external currents. There is a certain amount of charge cycles a battery has so it makes the time interval of coulomb counter very important. So to achieve the perfection we need to make the time intervals short otherwise the precision will keep on decreasing after every charge discharge cycle of the battery

C. Current Sense Measurement

It is very important to sense the current values of batteries for maintaining the module. In order to measure the current we need to connect ammeters which have resistors to sense the current, so it will results in loss of power. We can also use Hall sensors which can indirectly measures the current as we know that when a current passes through a wire it produces a magnetic field. So Hall sensor measures this magnetic field and tells the current by comparison of the current with the strength of magnetic field. Another method is to use a shunt resistor by connecting it between load and source. We know the drop of voltage across the shunt resistor so the current can simply be measured using V=IR.

D. Combined Measurement

State of charge can also be determined by combine measurement. In order to measure the precise state of charge we have to compute the voltage and temperature values. There are many algorithms which can be used to measure all these by using specific ICs. The most preferable method is to calibrate the battery by précising the charge discharge cycles of the batteries completely. We can achieve 100% state of charge by using this method but in space we find it difficult because batteries does not get fully charged or discharged according to the specific rating.

XIII. Thermal Design

Battery thermal control is accomplished by judicious selection and primarily with the use of passive thermal control elements. These elements may consist of any or all of the following. However, heater may be used in battery pack if indispensable

- Selected absorption and emissivity finishes
- Selected material conductivity
- Insulators

- Temperature sensors
- Materials required for protection of thermal surfaces

The thermal design guarantees that the battery can achieve its specified performance for the operating thermal environment. The temperature reference point is clearly identified on the external surface of the battery and it is accessible for temperature sensor installation. The internal thermal design of the battery is such that it can dissipate the components power dissipation, for all modes of operation, on the whole external housing of the battery pack when subjected to the thermal environment. Thermal analyses of such units which are mounted internal to the spacecraft is taken into account radiation and conduction to the nominal spacecraft internal environment. Heat dissipation of the battery is transferred to the spacecraft via conductive coupling at its mounting surface interface and radiation from the battery pack to its surrounding. Battery thermal control is primarily be accomplished by absorptive and emissivity controlled coatings, super insulation and heaters.

XIV. Conclusion

The detailed study and survey gives you the best options to design a battery module with all the factors need to be present in a satellite to survive in a space. All the components selected have history of being used in space missions already and it is also very important to test your module several times before you set it in a satellite for mission.

XV. Acknowledgment

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