Battery Design Decision and General Information Sheet

**2012**

Alexander L Carrere

ISAT Group

1/1/2012

|  |  |  |
| --- | --- | --- |
| Revisions Sheet | | |
| **Date** | **Editor** | **New Sheets/ Additions** |
| Jan 2012 | Alex Carrere | Document Created |
| Jan 2013 | Kelly Hering | The Switch to LiFePo4, Conclusion, Protection Circuitry |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

Table of Contents

[Revisions Sheet 2](#_Toc314646600)

[Introduction 4](#_Toc314646601)

[Batteries 4](#_Toc314646602)

[Cube Satellite Standard 4](#_Toc314646603)

[Design Process 4](#_Toc314646604)

[Constraints 5](#_Toc314646605)

[Primary vs. Secondary 5](#_Toc314646606)

[Types of Secondary Batteries 5](#_Toc314646607)

[Li-Ion Battery Selection 6](#_Toc314646608)

[References 8](#_Toc314646609)

# Introduction

The batteries perform a simple and yet key function in the life of the satellite. They must store energy which can then be used to power all the electronics on the satellite including the XFT (Xenon Flashtube), Radio, and Antenna. This document will detail the calculations and design decision process implemented in choosing the battery pack for the satellite.

## Batteries

Battery technology is one of the most heavily researched fields because of its importance to the modern world. Any portable device uses a battery and the battery’s ability to supply power is almost always the limiting factor in the decision of these devices. Many different types of batteries exist, but they all work off of the similar idea of converting stored chemical energy into electrical energy. The actual reaction and process can be looked up on the internet for greater detail. Common battery types used in portable applications are Nickel-Cadmium and Nickel-Hydrogen. These cells are called “dry cells” because they contain only enough moisture to allow current to flow. Other types of cells exist, but they are not useful for the satellite because of the harsh launch conditions. These dry cell batteries can be either primary or secondary. A primary battery is one that can be used directly after manufacture, but can only be used once and not recharged. A secondary battery must be charged first, but after use can be recharged by applying an electrical current which reverses the chemical reaction. A primary battery tends to have a higher battery capacity, but cannot be used multiple times. A battery’s capacity is the amount of electric charge it can store. This capacity depends on discharge conditions such as the magnitude of the current, the allowable terminal voltage of the battery, and temperature. The unit of measurement for battery capacity is reported in ampere hours [A\*h]. As an example, if a battery is rated for 200 A\*h (for a 10-hour rate) then the battery can discharge 20 amperes of current for 10 hours.

## Cube Satellite Standard

As I am sure everyone knows by now, cube satellites are governed by a standard created by Stanford and Cal Poly about 13 years ago in order to help universities obtain cheap launches for nanosatellites. They accomplish this by imposing extreme size, weight, and operational restrictions on the cubesat. The entire standard will not be discussed here (please visit the Cubesat group Dropbox for more information) but the restrictions related to the solar panels will be briefly reviewed. A Cubesat is a 10 cm cube which cannot exceed 1.3 kg. These two constraints will be very important when determining the batteries to be used since the amount of energy necessary for the XFT is large.

# Design Process

This process is a step-by-step walkthrough of the thoughts and actions taken to pick the battery pack to be used in the satellite. Each decision will be discussed to the best of the author’s abilities so that the reasons and facts necessary for each decision are documented and commented on. This process will follow a chronological order to best describe the choices that were made with the given information.

## Constraints

Two important constraints are given from the cube satellite standard. Namely, the battery must be lightweight and small so that the satellite will weigh under 1.3 kg and fit inside a 10 cm cube. Other major payload components such as the solar panels, chassis, and flash capacitor will also take up a lot of space and weight so the battery must be lightweight and take up as little space as possible. Added to this, the battery must be able to store the at least maximum amount of energy which the satellite’s solar panels can produce in two sun periods (which is the current charging cycle length).

## Primary vs. Secondary

As mentioned in the introduction, primary batteries while they cannot be recharged have a much higher battery capacity for the same size battery which would allow for more space for other components in the payload. Secondary batteries can be recharged but have a lower batter capacity. However since the expected life of this mission is over 3 months, the batteries must be rechargeable. No primary battery can hold enough energy for the amount of flashing the satellite must have to be visible since the current version has no G&C (Guidance and Control) and flashes constantly in eclipse. Therefore, a secondary battery was chosen [SMAD 418].

## Types of Secondary Batteries

Many types of secondary batteries exist such as nickel-cadmium which are the most field tested, or nickel-hydrogen which is newer but has a higher energy density. The current rechargeable battery with the highest energy density though is the Lithium-Ion battery [SMAD 420]. Lithium-ion batteries are relatively new to the space field and were only invented in their current form about 20 years ago. As becomes readily obvious in the space field, putting untested objects into space is only done with extreme reticence because of the small chance of failure. This small chance of failure of one part could disrupt or compromise the entire mission. After speaking with an amateur space expert recommended by Professor Fleeter, Ray Zenik, the author was convinced that this type of battery would be safe for space flight. And as it turns out, it is readily used currently in newer satellites. Besides this problem, Lithium technology has almost no downside. The current Lithium batteries have a higher power density, are much lighter, have no memory effect, and have a lower self-discharge rate than other batteries. Specifically, they offer a 65% volume advantage and a 50% mass advantage over other varieties [SMAD 421].

Two types of Lithium technology batteries are commonly and cheaply manufactured. The first is a lithium-ion battery and the other is a lithium polymer battery. An advantage of the polymer battery is that it can be molded into many different shapes and therefore may take up less room in the satellite. However after speaking with Ray Zenik, a disadvantage of the polymer battery became apparent. The problem is that the battery is housed in a pressure vessel; therefore, if it is punctured then it will begin to react. This possibility may cause problems in obtaining the satellite’s clearance through regulations for launch. The difference between Li-ion and Li-polymer is slight enough (concerning power density and weight) that the choice was easily made to buy a Li-ion battery.

## Li-Ion Batteries

After selecting which type of battery to purchase, the size/amount of batteries to buy had to be calculated. Following a talk with Ray Zenik, the Li-Ion 18650 battery was chosen. According to Ray and verified later in articles, the 18650 had been flown on spacecrafts before, was safe, and was small enough to fit in the satellite. Here are the basic specifications for a generic 18650 cell [AA Portable Power Corp].

|  |  |
| --- | --- |
| Typical Capacity | 2200mAh |
| Nominal Voltage | 3.7 V |
| Max/Min Charging Voltage | 4.2/2.75 V |
| Weight | 45g |
| Diameter | 18 mm |
| Length | 64.8 mm |

Table : Li-Ion 18650 Cell Specifications

But, the amount of 18650 cells still needed to be determined. In order to settle on this amount, the battery capacity necessary to store enough energy for the satellite’s normal cycle discharge conditions needed to be calculated. The following equation was used to determine this necessary capacity [SMAD 422]

Where Cr= Battery Capacity, Pe = average Eclipse Load, Te= Time in eclipse, DoD = average depth of discharge over an orbit, n= transmission efficiency. The average eclipse load is the power used during eclipse. The load necessary will be about 4.3W every other eclipse. The time of eclipse is determined by the satellite’s orbit which is designed to be 300 km. This gives an eclipse time of .605 hr [SMAD]. The efficiency of transmission cannot be determined exactly except through experimentation but is approximated here at 97% since Li-Ion batteries are quite efficient [Bachman]. The depth of discharge (DoD) is a percentage of the battery’s energy which has been spent before it is recharged. A higher DoD will lead to a higher rate of battery capacity degradation over time. A high DoD will also lower the voltage of the battery over a discharge cycle which may adversely affect the circuitry which are supplied power. The battery capacity degradation at a certain DoD can best be observed through experimentation. In order to do this though, the amount of cycles in this mission must first be determined. Since the maximum lifetime of this satellite is around 6 months (due to the orbit and solar activity) that means that the battery will go through a max of around 1500 cycles. According to Figure 1, even at a 40% DoD the battery capacity will not degrade significantly after 1500 cycles [Fellner 867]. Additionally, at a 100% DoD, the cell retains 80% capacity even at >500 cyles [Fellner 867].

With this information, a high DoD could be chosen without dramatic loss of battery capacity. But a high DoD will create a decrease in voltage since batteries decrease voltage as they lose energy. According to Professor Patterson, this decrease is unacceptable due to the sensitivity of the electronics which are attached to the battery’s circuit. Knowing this, a low DoD of 15% was chosen. To review,

* Pe= 4.3W, Te=.605 hr, DoD=15%, n=97%

Due to the unpredictability of space, if possible, the amount of battery storage should be doubled [SMAD 422]. This gives a redundancy which is essentially if a battery fails. Therefore to be safe, the battery pack should have around a 35.8 Wh capacity. Since each 18650 cell has 8.14 Wh (, 4 of these cells has 32.6 Wh. This capacity, though lower than initially wanted, will operate within the allowable limits since the DoD can be higher if necessary. A battery pack of four 18650 cells was chosen with a voltage of 7.4V. This voltage was chosen because the voltages of the satellite’s components were close to this number. Having a bus (circuit) voltage close to the necessary component voltage minimizes voltage bucking or boosting which leads to higher circuit efficiency. Finally, the Tenergy 31007 Li-Ion 18650 7.4V 4400 mAh Rechargeable Battery PCB Module with 20 AWG bar leads was picked for the satellite and shown below in Figure 1 (<http://www.batteryjunction.com/tenergy-74-4400-pcb.html>).

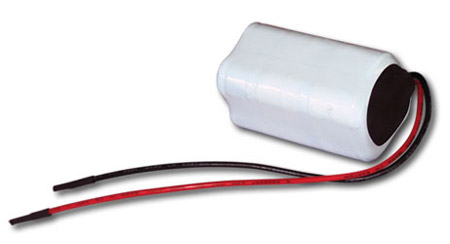


Figure : Li-Ion Battery Pack

|  |  |
| --- | --- |
| Battery Type | Li-Ion 18650 |
| Battery Number | 4 |
| Pack Capacity | 4400mAh (32.6Wh) |
| Nominal Voltage (Peak) | 7.4 V (8.4V) |
| Dimensions | 36mm x 36mm x 70mm |
| Weight | 181 g |
| Cut off Voltage | 6 V |

Table : Li-Ion Battery Pack Specifications

The other major advantage of using this battery pack is the protection integrated circuit included in the battery pack. This circuit will prevent the battery from over-draining below its minimum voltage (3V) and over-charging above its limit (4.2V). Over-draining will result in a nonfunctional battery while over-charging will make the battery unstable [Buchmann].

# The Switch to LiFePO4 Batteries

When the optical beacon changed from the Zenon flash tube to a panel of LEDs, the battery choice needed to be modified to accommodate the new power needs of the flash system. The battery constraints needed to include some higher power density, due to the large increase in power over a short duration to flash the LED panel. The voltage of the pack is very close to that of the Lithium Ions as well. The batteries are purchased from A123 Systems off Battery Space at about $8 a cell.



Figure 2: LiFePO4 cell

|  |  |
| --- | --- |
| Battery Type | LiFePO4 18650 |
| Battery Number | 2 |
| Pack Capacity | 1100mAh |
| Nominal Voltage (Peak) | 6.4 V (7.2 V) |
| Dimensions | 65 mm x 36 mm x 36 mm |
| Weight | 78 g |
| Cut off Voltage | 6 V |

Table : LiFePo4 Battery Pack Specifications

The LiFePO4 batteries have not been used in space before to our knowledge, however, they have an overall safer chemistry than Li-Ions and could therefore be the up and coming battery for space use. The thermal runaway concerns of Lithium Ions are no longer an issue, leaving more leeway in terms of charge regulation for the protection circuit.

While considering the new batteries, we wanted to keep our mass budget in mind. The LiFePO4 batteries were not only lighter on a cell-by-cell basis from the Li-Ion, but they also allowed us to remove two batteries in parallel due to their high discharge currents. They will be in a 2S-1P configuration.

# Protection Circuitry

The Lithium Iron Phosphate batteries do not come in a pack with added circuitry as the Lithium Ions did, which means an external protection circuit and charge regulator must be considered. Currently, we have found one that monitors over and under current and voltage for both charge and discharge for a 2S-1P configuration. However, this circuit limits the discharge current to 5A. While this is still larger than that of the Lithium Ion pack, it eliminates the benefits of the high discharge ability of the batteries. We are looking into designing our own circuitry to avoid this issue.



Figure 3: PCM for LiFePO4 battery pack

# Battery Testing

Currently, charge-discharge tests are being planned to get the appropriate profiles for the LiFePO4 batteries. We will also be testing the PCM and its capabilities. Further tests include integrated tests with the solar panels. More to come!

# Conclusion

While initial decisions were made to use Li-Ions, new choices have been made to switch to LiFePO4 in interest of accommodating the power needs of the flash panel.

# References

(Can all be found in the Dropbox under Power->Battery or online)

* Buchmann, Isidor. "Charging Lithium-Ion Batteries." *Battery University*. Cadex Electronics. Web. 18 Jan. 2012. <http://batteryuniversity.com/learn/article/charging\_lithium\_ion\_batteries>.
* Fellner, J. P., G. J. Loeber, and S. S. Sandhu. "Testing of Lithium-ion 18650 Cells and Characterizingrpredicting Cell Performance." *Journal of Power Sources* 81.82 (1999): 867-71. Print.
* AA Portable Power Corp, comp. *Li-ion Battery Specifications (Steel)*. Tech. no. HYB/QP-09-E167-NH. Print.
* Wertz, James Richard., and Wiley J. Larson. *Space Mission Analysis and Design [SMAD]*. Torrance, CA: Microcosm, 1999. Print.