Modular SmallSat Battery (MSB)

Technical Reference Manual

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1 APPROVALS AND TRACKING

1.1 Signatures

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1.2 Revision History

Revision	Description	Date
-	Initial Release	05/9/2019
A	Updates: - Changed header and Cubic Aerospace to "Ibeos" - Section 4.3: Storage: Enumerated storage condition requirements. Added clarification and extra bold text describing the importance of the inhibit jumper. Updated recommended storage SoC. Added recommendation to check the battery voltage monthly to ensure cells don't over discharge. - Added within Handling Instructions a stipulation that batteries must be <100 mV apart in voltage when being connected in parallel to avoid higher than expected charge/discharge currents - Added TBCs to Section 5, pack-level cycling conditions. - Change language from "guarantee" to recommendation.	12/12/2019
B	Updated: - Change "Cubic Aerospace" to "Ibeos - Fixed typos and Figure numbering	02/04/2021

2 ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
BCR	Battery Charge Regulator
BOL	Beginning-of-Life
EOL	End-of-Life
CCA	Circuit Card Assembly
DC	Direct Current
EoC	End of Charge
EPS	Electrical Power System
ESD	Electrostatic Discharge
FOD	Foreign Object Debris
GND	Ground
ICD	Interface Control Document
LET	Linear Energy Transfer
MSB	Modular Smallsat Battery
SEE	Single Event Effect
SET	Single Event Transient
SEU	Single Event Upset
SI	Silicon
SOC	State of Charge
TBC	To Be Confirmed
TID	Total Ionizing Dose
RBF	Remove Before Flight
SoC	State of Charge
DoD	Depth of Discharge

3 INTRODUCTION

3.1 Document Purpose

This document intends to provide all information necessary to implement Ibeos's Modular SmallSat Battery (MSB) in a spacecraft-level assembly. It describes the high-level specifications of the system, system handling and storage guidelines, the electrical power interfaces, the mechanical/thermal interface, and testing guidelines.

3.2 System Overview

The Ibeos Modular SmallSat Battery (MSB) is a radiation-tolerant and reliable battery with integrated fault protection. The high-level features of the MSB include:

- 45-Watt-hour beginning-of-life (BOL) capacity
- Integrated 8-Watt heater
- Integrated thermistor
- Remove-Before-Flight (RBF) inhibit for minimizing self-discharge current during storage
- Overvoltage, undervoltage, and overcurrent fault protection
- Full system radiation tolerance up to 30 kRad(Si) total ionizing dose (TID), operating through single event effects (SEE) with a LET of up to 37 MeV-cm^2/mg and surviving SEE's with a LET of up to 55 MeV-cm^2/mg.

3.3 Block Diagram

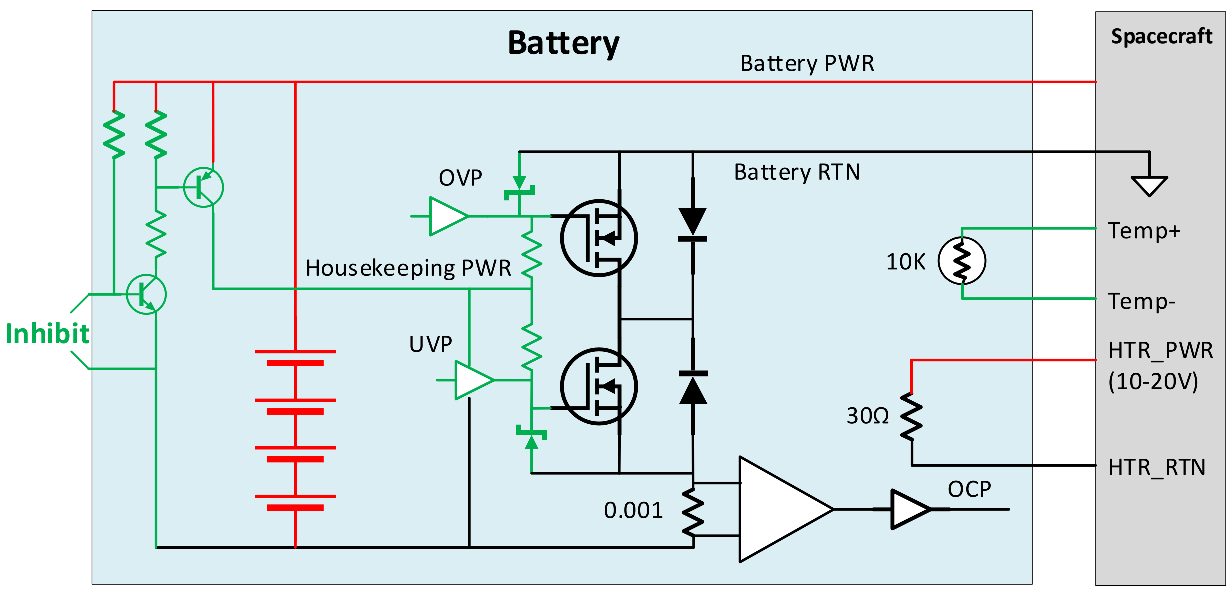

Figure 1. MSB Functional Block Diagram

4 HANDLING AND STORAGE GUIDELINES

The specific handling and storage guidelines for the MSB are included below. Failure to follow these guidelines may result in damage to the MSB hardware or degradation in system performance.

4.1 General Handling

During all handling of the MSB system, care must be taken to keep the system clear of any contaminants, both conductive and non-conductive. Foreign object debris (FOD) can create circuit shorts which can permanently alter system performance even after the FOD is removed.

Caution: When handling the battery, caution should be taken to not short terminations connected to battery power. Failing to do so may result in hazards.

It is recommended that gloves we worn when handling MSB flight units to minimize the transfer of oils and outgassing materials.

It is recommended that flight units be removed from the delivery packaging and handled only in a cleanliness-control environment.

4.2 Electro-Static Discharge (ESD)

The MSB implements several electronic devices that are sensitive to ESD and therefore the circuit card must only be handled in a static-dissipative environment with proper ESD protective equipment.

4.3 Storage

1. **Temperature and Humidity:** The MSB is delivered in anti-static packaging with a hygroscopic drying agent to keep the relative humidity of the packaged system very low. Upon receipt of MSB units, it is recommended that they be stored in an anti-static, humidity-controlled environment with a temperature between 0 and 20°C If the storage is for a long duration, maintaining a storage temperature between 0°C and 10°C will significantly reduce cell degradation. Storage at higher temperature is possible but may result in higher capacity degradation. It is strongly recommended that the maximum storage temperature be limited to 30°C.

2. **Inhibit Jumper (RBF):** The batteries are delivered with the low resistance (<10 Ω) jumper across the inhibit interface (the inhibit jumper). This jumper comes connected to the battery via a Remove Before Flight (RBF) circuit connected to Battery J1. With the inhibit jumper installed, the self-leakage current of the MSB will be < 200 uA nominal. Without the Inhibit Jumper installed, the batteries will self-discharge significantly faster (may be on the order of days, depending on the beginning battery state-of-charge. **KEEP THE INHIBIT JUMPER INSTALLED AT ALL TIMES WHILE THE BATTERY IS IN STORAGE. UPON REMOVAL OF THE INHIBIT JUMPER, SPECIAL CARE MUST BE TAKEN TO ENSURE THE BATTERIES DO NOT OVER DISCHARGE.**

3. **Storage State-of-Charge (SoC):** To minimize degradation, while also ensuring the battery voltage does not drop critically low, it is recommended that the MSB state of charge (SOC) is kept between 5% and 75% while in long-term storage. It is recommended to check the state of charge of the MSB on a monthly basis and charge it up to 15.2V open circuit voltage if the measured voltage falls below 13.2 V open-circuit.

4. **Minimum Battery Voltage:** Cell voltages may become imbalanced at extremely low SoC (<3 V). If the open-circuit state-of-charge ever measures below 12 V, there is a possibility of overdischarge. Ibeos does not recommend using a battery that has ever experienced an over-discharge event and should be consulted prior to using a battery that has been overdischarged.

Caution: Discharging any battery cell below 2.5 V may cause permanent damage to the cells. Operating damaged cells may result in increased battery dissipation and should be considered a hazardous operation.

4.4 Connecting Batteries in Parallel

For customers using the MSB in a double-pack configuration, care must be taken to ensure that the packs are close in voltage prior to connecting them in parallel. If pack voltages are too far apart, higher than desired current can be observed. When connecting two battery packs in a parallel configuration, **ensure that no more than 100 mV exists between the batteries prior to hooking up the batteries in parallel**.

5 SYSTEM SPECIFICATIONS

5.1 Absolute Maximum Operating Conditions

Table 1. Absolute Maximum Operating Conditions

Parameter	Min	Max	Units
Battery Voltage	12.0	16.8	V
Charge Current	-	3.0	A
Discharge Current	-	6.0	A
Battery Temperature (Non-Operating)	-25	45	°C
Battery Temperature (Operating)	0	45	°C

5.2 Recommended Operating Conditions

Table 2. Recommended Operating Conditions

Parameter	Min	Max	Units
Battery Voltage	13.2	16.8	V
Charge Current (V_{Batt} > 12.0 V)	-	1.5	A
Charge Current (Undervoltage)	-	1.0	A
Discharge Current	-	3	A
Battery Interface Temperature	10	25	°C

5.3 System Specifications

Unless otherwise noted, the conditions in the following table apply to the specifications throughout the remainder of this section.

Table 3. Default Conditions for MSB Specifications

Parameter	Value	Units
Battery Voltage, V_{Batt}	16.0	V
Battery Temperature, T_A	0 - 45	°C

5.3.1 General Specifications

Parameter	Conditions	Min	Nom	Max	Units
BOL Capacity	25 °C, 3.25A CC discharge	3000	3200	-	mA-hr
Self-Discharge Current	Inhibited	-	320	350	uA
Self-Discharge Current	Operating	-	7.3	8	mA
Self-Discharge Current	Undervoltage	-	7.3	8	mA
Mass	-	-	355	365	G
Heater Resistance	-	28.9	32.1	35.3	Ω
Thermistor Resistance	25 °C	-	10	-	kΩ
Thermistor Current	-	-	-	1	mA

5.3.2 Fault Protection Specifications

Parameter	Conditions	Min	Nom	Max	Units
Undervoltage	Rising	13.1	13.6	14.1	V
Undervoltage	Falling	12.2	12.4	12.6	V
Overvoltage	Rising	17.0	17.3	17.7	V
Overvoltage	Falling	16.5	16.9	17.3	V
Overcurrent Discharge	-	9.9	11.0	12.1	A
Overcurrent Discharge Hysteresis	-	-	1000	-	ms
Overcurrent Charge	-	4.9	5.5	6.1	A
Overcurrent Charge Hysteresis	-	-	500	-	ms

5.3.3 Radiation Performance

Parameter	Conditions	Min	Nom	Max	Units
Total Ionizing Dose (TID) Immunity Threshold	-	30	-	-	kRad(Si)
Single Event Transient/Upset Immunity Threshold	-	37	-	-	MeV-cm^2/mg
Single Event Latchup Immunity Threshold	-	55	-	-	MeV-cm^2/mg

6 BATTERY CAPACITY

The MSB consists of four 18650 lithium-ion cells in a 4S1P configuration. The usable battery capacity depends on several factors including:

1. Temperature
2. Discharge Current
3. Cycle Degradation
4. Calendar Degradation

Figure 2 below shows the typical beginning-of-life cell discharge voltage versus discharge rate. The usable Amp-hour capacity with a 2.5 V end-of-discharge voltage is relatively consistent between 0.2C and 2C discharge rates, but the usable Watt-hour capacity is significantly lower at the high-rate discharge due to the series resistance of the battery. With an end-of-discharge voltage of 3 V, the difference in capacity is significantly lower in both Amp-hour and Watt-hour.

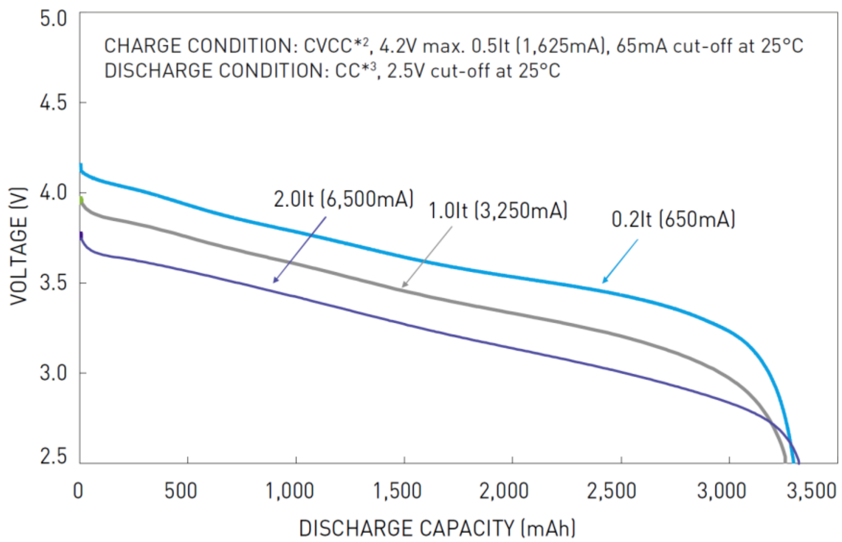

Figure 2. Cell SoC vs. Open-circuit Voltage (Voc) vs. Discharge Current from Cell Manufacturer Datasheet

Figure 3 shows the typical beginning of life discharge voltage versus discharge temperature at a discharge rate of 1C (3.25 A). There is significantly less usable capacity at cold temperature. While the usable capacity is highest at 40°C, it should be noted that the long-term cell degradation is increased at high-temperature.

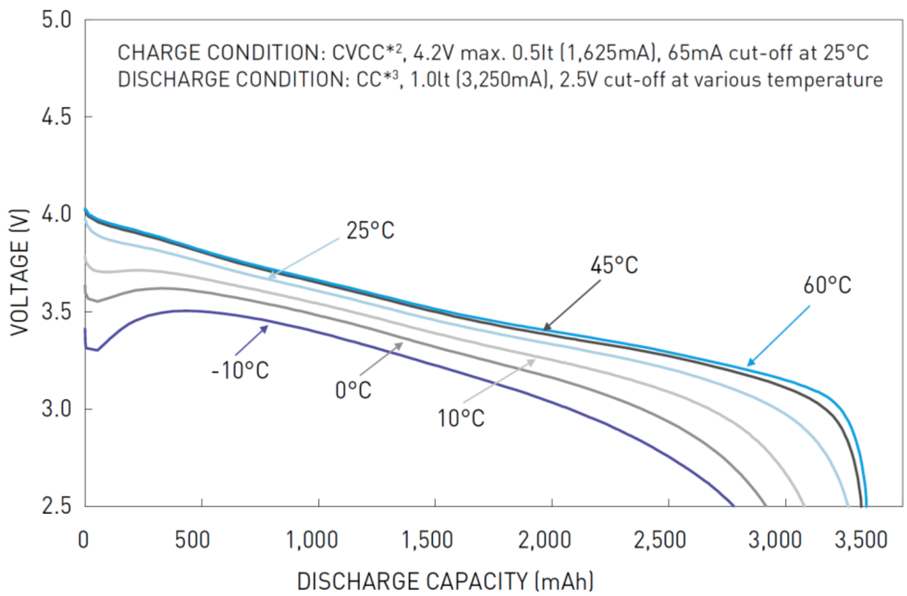

Figure 3. Cell SoC vs. Open-circuit Voltage (Voc) vs. Discharge Temperature from Cell Manufacturer Datasheet]

Figure 4 shows the cell charge characteristics for a charge at C/2 = 1.625 A to an end-of-charge (EOC) voltage of 4.2 V and a taper charge until the charge current drops below 65 mA.

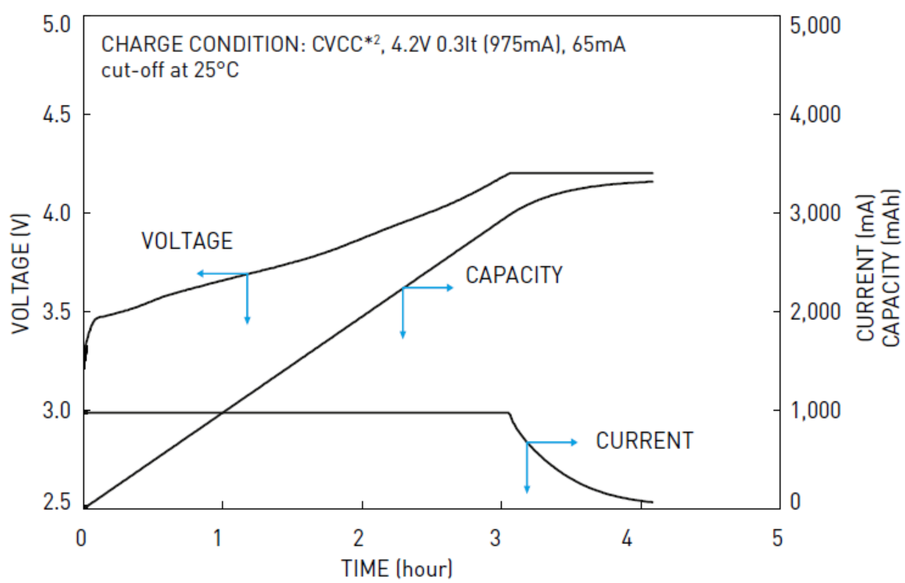

Figure 4. Cell Charge Characteristics vs. Temperature

6.1 Cell-Level Degradation Data

Cell-Level capacity degradation data provided by the cell manufacturer is shown in Figure 5. This data shows that 14% of capacity is lost after 500 100% discharge cycles at 25°C, C/2 charge rate, and 1C discharge rate.

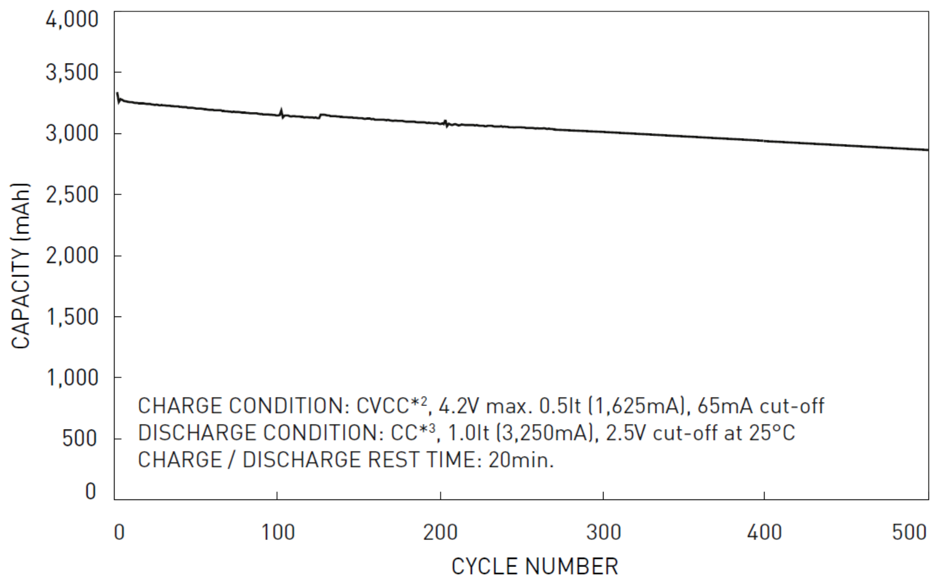

Figure 5. Cell Capacity Degradation vs 100% DoD Cycles at 1C Discharge

6.2 Pack-Level LEO Cycling Degradation Data

Ibeos is carrying out pack-level, real-time degradation testing for the MSB. This allows us to provide conservative capacity and internal resistance estimates based on anticipated cycling conditions.

Lithium-ion cell degradation is a combination of calendar and cycling fade. Degradation mechanisms include loss of active material and increases in internal resistance. These mechanisms are driven by chemical and mechanical phenomena, which are in turn driven by a combination of temperature, cycle count/DoD, and charge/discharge rates. Finally, the susceptibility of cells to these phenomena is driven by the chemistry, thermal/mechanical design, and manufacturing characteristics specific to each cell design.

Due to the complexity of lithium-ion cell degradation, accurate prediction of MSB pack-level degradation requires testing under conditions that exposes the cells to the anticipated environment and cycling conditions as closely as possible. The most common, high cycle-count application for the MSB is low Earth orbit (LEO) with a maximum eclipse duration of about 30 min and orbital period of about 90 min.

Ibeos is carrying out degradation testing on 12 battery packs with cells from the same manufacturing lot as those used in flight assemblies. Each battery chassis is mounted to a 30°C plate and insulated to minimize convective cooling. The elevated temperature (at the top of the recommended 15°C to 30°C range) results in conservative degradation results. Using the MSB chassis and thermal interface materials ensures that temperature changes during charge and discharge reflect those on-orbit. Each pack is constant power discharged during the LEO "eclipse" period of 30 min, then charged to 100% SoC at constant current over the remaining 60 min of the simulated LEO orbit.

Groups of three packs each are exposed to distinct cycling conditions to provide statistics on measured degradation effects under each set of conditions. One group each will be discharged to 10%, 20%, and 30% DoD and recharged to the standard EoC voltage of 4.2 V. The fourth group will be discharged to 30% DoD and recharged to a reduced EoC voltage of 4.1 V to quantify improvements in cycle-life with reduced EoC voltage.

Battery degradation is measured by an increase in pack resistance (measured by pulse loading the pack and measuring voltage drop) and total capacity (measured by discharging to the end-of-discharge voltage and integrating power over time). Trending of these parameters drives our empirical model of battery degradation. Inquire for degradation estimates based on our current model.

7 BATTERY PROTECTION FEATURES

7.1 Overview

The MSB implements overvoltage, undervoltage, overcurrent charge, and overcurrent discharge fault protection. The following sections details the behavior of each form of fault protection.

7.2 Overvoltage Protection

When the battery voltage exceeds the nominal overvoltage rising threshold, the MSBs overvoltage protection circuit opens a low-side series switch that prevents further charging of the battery. In this state, the battery can still be discharged through a diode in parallel with the low-side series switch. Once tripped, the overvoltage circuit will remain tripped until the battery voltage falls below the nominal overvoltage falling threshold.

7.2.1 Transient Filtering

The overvoltage protection circuit has a low-pass filter to prevent nuisance trips due to transient currents generated by changes in battery loading during charge operations. This filter has a corner frequency of approximately 3 Hz.

7.2.2 Overcurrent Charge Protection Hysteresis

The MSBs overvoltage protection also causes the hysteresis on the overcurrent charge protection to be activated, which may cause a delay of up 1 second if the charge current was above 0.4 A prior to the overvoltage protection tripping.

7.3 Undervoltage Protection

When the battery voltage falls below the nominal undervoltage falling threshold, the MSBs undervoltage protection circuit opens a low-side series switch that prevents further discharging of the battery. In this state, the battery can still be charged through a diode in parallel with the low-side series switch. Once tripped, the undervoltage circuit will remain tripped until the battery voltage rises above the nominal undervoltage rising threshold.

7.3.1 Transient Filtering

The undervoltage protection circuit has a low-pass filter to prevent nuisance trips due to transient currents generated by changes in battery loading during charge operations. This filter has a corner frequency of approximately 3 Hz.

7.3.2 Overcurrent Discharge Protection Hysteresis

The undervoltage protection also causes the hysteresis on the overcharge discharge protection to be activated, which may cause a delay of up 1 second if the discharge current was above 0.8 A prior to the undervoltage protection tripping.

7.4 Battery Overcurrent Charge Protection

When the battery charge current exceeds the nominal rising limit, the MSB's overcurrent charge protection circuit opens the same low-side series switch as the overvoltage circuit. This circuit has significant hysteresis to prevent the switch from cycling at a high-rate and potentially experiencing thermal stress.

When this protection is active, the battery can be discharged through a diode in parallel with the charge-disabling switch.

7.4.1 Overvoltage Protection Hysteresis

The overcurrent charge protection also causes the hysteresis on the overvoltage protection circuit to be activated. This results in the charge-disabling switch remaining open until the battery voltage falls below the overvoltage falling threshold.

7.5 Battery Overcurrent Discharge Protection

When the battery discharge current exceeds the nominal rising limit, the MSBs overcurrent discharge protection circuit opens the same low-side series switch as the undervoltage circuit. This circuit has significant hysteresis to prevent the switch from cycling at a high-rate and potentially experiencing thermal stress.

When this protection is active, the battery can be charged through a diode in parallel with the discharge-disabling switch.

7.5.1 Undervoltage Protection Hysteresis

The overcurrent discharge protection also causes the hysteresis on the undervoltage protection circuit to be activated. This results in the discharge-disabling switch remaining open until the battery voltage rises above the undervoltage rising threshold.

7.6 Battery Over-Temperature Protection

The MSB does not provide internal battery over-temperature protection. It is strongly recommended that an external controller monitor battery temperature(s) and minimize charge and discharge currents if the battery temperature exceeds 45°C.

Internal battery over-temperature protection is not provided for several reasons including:

1. To maximize the compatibility with different types of excitation sources for resistance measurements
2. To enable the user to have the flexibility to adjust the conservatism in setting a maximum temperature

Note: It is expected that the maximum battery temperature will increase during the life of the battery due to the internal series resistance increasing as the battery capacity degrades. The user should pay close attention to the trend of the MSBs peak discharge temperature and reduce the peak current if it starts to consistently exceed 45°C.

8 BATTERY HEATER

8.1 Overview

The MSB has a 30Ω heater for maintaining the battery's temperature. If multiple batteries are being used in parallel, two of the heaters may be wired in parallel with a common power source as long as the batteries are co-located and share a common thermal path.

Note: The MSB does not perform any temperature control internally. It is the responsible of an external controller to operate the MSBs heater. See Section 7.6.

8.2 Pinout

The two terminals of the heater are passed through to J1. See Section 15.1 for the connector pinout.

8.3 Power

A single battery heater is intended to be powered by either a 16-Volt regulated output or an unregulated battery power output. More generally, the heater may be operated from any supply with a voltage between 10-20 V.

8.4 Thermal Design Considerations

A spacecraft level thermal design should ensure that the heater power is sufficient for maintaining the battery temperature above 10°C given the radiator design and all relevant thermal paths. If a thermal analysis is performed, it is recommended that the battery be able to maintain a 15°C temperature with a 50% heater duty cycle.

To minimize battery degradation, 15-30°C is the recommended cell temperature range for thermal control using the heater. A tighter temperature range of 15-20°C will further maximize battery life but may excessively constrain spacecraft-level thermal design.

9 BATTERY THERMISTOR

9.1 Overview

The battery provides a single 10 kΩ negative temperature coefficient (NTC) thermistor.

The thermistor used is TDK Electronics P/N: B57541G1103F005. The respective datasheet shall be referenced for all details regarding resistance to temperature conversions.

Note: Thermistor current should be limited to 1 mA to minimize self-heating.

9.2 Pinout

The two terminals of the thermistor are passed through to J1. See Section 15.1 for the connector pinout.

10 MULTIPLE BATTERY PACK CONFIGURATIONS

Multiple MSB units may be operated in a system if higher energy capacity is required. When implementing multiple MSBs, pairs of units can be mechanically/thermally integrated to achieve a single, larger battery. In this configuration, the following recommendations are provided:

1. Procure the units as a mechanically/thermally integrated pair from Ibeos
2. Configure the heaters in parallel. The J1 connector of a single MSB has two pins for heater power supply and two pins for heater power return. This is done so that two units can be daisy-chained. It is not recommended that more than two units be daisy-chained together.
3. Wire the battery power supply and return lines in parallel. In larger configurations with more than two batteries, these lines may be spliced together if the number of battery I/O pins is greater than the number of I/O pins on the spacecraft's power system. Performing the splice with an enable plug may minimize the harness complexity. Care should be taken to ensure that the battery DC current does not exceed 2 A per pin. With multiple batteries, the overall harness length between each pack and the spacecraft's power system should be kept similar (to the extent practical).
4. If two packs are mechanically integrated, it is possible to monitor the pair via a single thermistor if there is an insufficient quantity of telemetry channels. The thermistor of the pack further from the thermal interface should be used in this configuration (ie. the pack that has the higher peak temperature).

If two or more units are being electrically connected for the first time or if two previously mated units have been de-mated from each other, care should be taken to limit the voltage differential between them. It is recommended that the open-circuit voltages of each unit be within 100 mV of each other prior to being electrically connected. To get them within 100 mV, they may either be charged or discharged with an external power supply or load. It is also possible to install a series resistance between them to limit the current while they equalize. If this is done, the resistance should be chosen to limit the current to 3 A (ie. the resistance should be no less than 1/3rd of the voltage difference).

11 INHIBIT INTERFACE

11.1 Overview

The battery provides an inhibit interface that allows the internal electronics to be put into a low-current quiescent state. While in this state, the battery is disabled from being discharged. The purpose of this interface is to allow the battery to be stored without maintenance for longer periods of time.

11.2 Pinout and Operation

The inhibit interface is accessible at the J1 connector via two pins. One pin is connected to battery return and the other is connected to the positive battery terminal through a 100 kΩ pull-up resistor. When the resistance between these two pins is <100 Ω, the bias supply for the protection circuits and discharge enable switch is disabled.

See Section 15.1 for the pinout of J1.

11.3 Quiescent Current Calculation

The quiescent current in the inhibited state can be calculated as:

$(V_{batt}$ / 100 kΩ) + the aggregate leakage current of the string of cells

11.4 Inhibited Charging

It is possible to charge the battery in the inhibited state, but not recommended. If inhibited charging is to be conducted, the protection circuits will cause a significant voltage drop due to the lack of an internal bias supply. This voltage drop is approximately 3 V and will cause a significantly high power dissipation on the battery electronics. If charging in this configuration is ever performed, the maximum recommended rate is 1.0 A.

Additional care should be taken to monitor the battery temperature if charging is conducted while in the inhibited state.

12 BATTERY INSTALLATION RECOMMENDATIONS

12.1 Mechanical and Thermal Considerations

There are several mechanical and thermal recommendations with respect to battery installation. Mechanically, the battery is designed to accommodate installation in several different orientations. See the ICD for appropriate mounting configurations and interfaces.

The battery should be thermally attached to a good thermal sink. It may be advisable to thermally isolate the battery mounting interface from high dissipation components if the spacecraft thermal control system is not able to limit the MSBs mounting interface to a temperature at or below 20°C.

Low-fidelity thermal modeling of the MSB can be accomplished by modeling it as aluminum 6061 solid. Dissipation can be modeled using the expected load current and representing the MSB as a resistance between 0.8 Ω and 1.3 Ω. Note that the an MSB resistance of 1.3 Ω is a conservative, EOL value.

Note: Higher temperatures are tolerable but may further constrain the maximum allowable sustained discharge current. Higher temperatures may also result in higher performance degradation.

12.2 Battery Grounding

All of the MSBs battery protection circuitry operates by disconnecting the return path of the battery. Therefore, it is essential to keep the battery negative terminal isolated from low impedance paths to both electric ground as well as structure ground. The MSB is designed to provide a single level of insulation between cell terminals and the battery chassis. It is recommended that a second insulation level be provided between the spacecraft structure and the battery chassis. Insulated, thermally conductive washers or other interface material should be used when mounting the battery to a conductive interface. This insulation will protect against any failure within the battery that cause a connection of either a negative or positive cell terminal to the spacecraft chassis.

Note: A short from a positive cell terminal to the chassis will activate the internal, passive cell protection mechanism and momentarily disconnect the short.

The MSBs connector jackposts may be connected to spacecraft structure ground; there is a 100kΩ isolation resistor between the battery structure and the jackposts.

The MSBs connector (J1) also has a high impedance (100 kΩ) connection from pin 21 to the battery chassis. This may be used to minimize electrostatic charging between the battery chassis and spacecraft structure.

See Section 15.1 for further details regarding the J1 connector.

13 BATTERY OPERATION RECOMMENDATIONS

13.1 Maximum Battery Discharge Currents

It is recommended to size the battery for a maximum sustained discharge current of 3.2 A. Higher transient discharge rates can be supported with a maximum recommended discharge current of 6.4 A.

Note: At high discharge currents, the output voltage may have significant drops due to series resistance, especially at end-of-life.

13.2 Maximum Battery Charge Currents

The recommended typical charge rate is 1.6 A (C/2) with a constant voltage taper charge at a pack voltage of 16.8 V. Higher charge rates may be used if necessary, up to 3.2 A for sustained charging.

If charging the battery with the cell temperatures <10°C, charge current should be limited to below 0.25C.

Note: High charge rates may result in increased cycle degradation.

13.3 Adjusting Battery End of Charge Voltages

Operating the battery with a lower end-of-charge voltage can help reduce cycle degradation. For missions with especially long durations, operating with a 16.0 V end-of-charge voltage during the beginning of the mission and increasing the end-of-charge voltage gradually to 16.8 V as the battery capacity degrades may result in higher end-of-life capacity.

14 BATTERY OVERDISCHARGE WARNING

Ibeos does not recommend using an MSB unit that has had one or more cells discharged to an open-circuit voltage below 2.5 V. It should also be understood that cell voltages may begin to diverge at an extremely low state of charge so a single cell may fall below 2.5 V while the total pack voltage is above 10 V.

The MSBs circuitry will allow a pack that has been discharged below 10 V to be charged. If the pack voltage is at a very low voltage (<5 V), it may cause the charge-disabling switch to have a higher voltage drop (~3.2 V). This will result in a high power dissipation and the charge current should be limited to under 1.0 A if the battery is charged in this configuration.

Note: This guidance should not be construed as a recommendation to use a battery that has been overdischarged. Overdischarge can cause internal dendrites to form within the battery cells which can create low resistance shorts across a cell (which prevent charging the cell) or moderate impedance shorts (which cause increased self-discharge and thermal dissipation). In the case of moderate impedance shorts, this may cause one or more cells to reach significantly higher temperatures which can cause cell venting as well as other undesirable behavior. Extreme care should be taken when performing any operations with a cell that has been overdischarged. It is recommended that Ibeos be contacted before performing any operations with a cell that has experienced overdischarge.

15 ELECTRICAL INTERFACE

15.1 J1 – Power, Telemetry, and Housekeeping Connector

The MSB's J1 connector provides an interface to systems protected battery power, heater and thermistor terminations, and inhibit inputs.

The connector shell is electrically connected to chassis ground through a 100 kΩ resistor.

Ref. Designator: J1
Connector Type: 21-Pin, Right-Angle Through-Hole, 2-Row, Micro-D, Male
Part Number: MWDM2L-21PCBRPT
Manufacturer: Glenair, Inc.
Pin Definition:

Pin	Signal	Description	Pin	Signal	Description
1	BATT_POS	Positive Battery Terminal	12	INH_NEG	Negative Inhibit Terminal (connected directly to battery return)
2	BATT_POS	Positive Battery Terminal	13	BATT_NEG_SENSE	100 kΩ to Protected Battery Return
3	BATT_POS	Positive Battery Terminal	14	BATT_POS	Positive Battery Terminal

Pin	Signal	Description	Pin	Signal	Description
4	BATT_POS	Positive Battery Terminal	15	INH_POS	Positive Inhibit Terminal
5	BATT_POS_SENSE	100 kΩ to Positive Battery Terminal	16	HEATER_P2	Battery Heater Terminal 2
6	THERMISTOR_P1	Thermistor Terminal (Note 1)	17	THERMISTOR_P2	Thermistor Terminal (Note 1)
7	BATT_NEG_EPS	Protected Battery Return	18	HEATER_P2	Battery Heater Terminal 2
8	BATT_NEG_EPS	Protected Battery Return	19	HEATER_P1	Battery Heater Terminal 1
9	BATT_NEG_EPS	Protected Battery Return	20	HEATER_P1	Battery Heater Terminal 1
10	BATT_NEG_EPS	Protected Battery Return	21	CHASSIS_SENSE	100 kΩ to Battery Chassis
11	BATT_NEG_EPS	Protected Battery Return	-	-	-

1. Thermistor average current should be limited to under 1 mA to limit self-heating.

16 SYSTEM TESTING

Testing of the MSB shall be in accordance with the *MSB Test Procedure* document. Flight unit testing includes a full functional test at ambient, hot, and cold conditions including both hot and cold-start. Hot testing is performed at an ambient temperature of 45°C; cold testing is performed at an ambient temperature of 0°C.

Flight acceptance testing includes 9 hot and 8 cold plateaus with capacity tests performed at the first hot and cold plateaus. Abbreviated functional tests of the battery electronics are performed at the first hot and cold plateaus. The first plateau is hot 1; the last is hot 9. During cycles hot 2 through hot 8 (encompassing cold 2 through 7), the MSB is operated in monitor mode.

Monitor mode is a static configuration with the battery voltage and temperature telemetry monitored, the heaters off, and no charge or discharge.

In addition to thermal cycles, ambient temperature capacity testing is performed on each MSB after assembly and prior to shipment.

The number of capacity tests and their depth of discharge are limited to the extent practical in order to limit the test-induced battery cycle degradation.

In addition to the full system tests, the battery electronics undergo stand-alone testing. Flight circuit card assemblies are operated in monitor mode over 9 hot and 8 cold thermal cycles from -25°C to +60°C and functionally tested at the first and last hot and cold plateaus prior to their integration with the battery cells.

17 CELL MATCHING AND SCREENING

Prior to installation in the battery assembly each cell is subjected to screening and match testing. Cell capacity and internal resistance are measured so that packs contain closely matched cells. Limited thermal cycling and deep cycling at hot and cold temperatures is performed to verify that cell-level degradation and performance parameters trend with qualification data collected from cells in the same lot. This practice of cell acceptance testing by trending against cell qualification data removes some amount of life from the cells, but significantly reduces risk inherent in using commercial lithium-ion cells in a high-reliability application.