TECHNICAL MANUAL
FOR

PRESSURE TOLERANT UNDERWATER BATTERY

BATTERY OPERATION

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FIGURES AND TABLES

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1 Operations

1-1 OVERVIEW

The Bluefin Pressure Tolerant Battery is designed for use in underwater vehicles. The battery is comprised of two parts; the first is a solid encapsulated section that contains Lithium Polymer Cells and four Temperature Sensors. The second is a small oil-filled section that houses the Intelligent Battery Controller.

The battery lid is made of anodized aluminum and acts as a seal, mounting plate, and heat sink for the electronics. Exiting the lid are two waterproof cables, an oil filler tube, relief screw, and cathodic protection.

The battery consists of eight cell bricks in a series, with each brick containing several cells in parallel. Bluefin batteries come in three models differentiated by their nominal charge capacities of 1, 2, and 3.5 kWh. However, it should be noted that these are nominal capacities and actual model capacities may vary. Other than nominal charge capacities, battery electronics for each model are identical in construction and function.

The Battery Electronics Board controls the power switching during charge and discharge and implements several protection mechanisms in Hardware and Firmware to ensure the safety of the user, vehicle, and battery. The Battery Board monitors battery parameters such as voltage, current, and temperature for switching, protection, and logging purposes. The Battery Board also switches the power port to facilitate charging and discharging. Additionally, the battery board controls conditioning and monitors several vital statistics for the battery.

1-2 ELECTRICAL AND CHEMICAL CHARACTERISTICS

Model	1020	2040	3500
Chemistry	Lithium-ion polymer / Manganese Oxide cathode		
Nominal Voltage	30V		
Nominal Capacity (C)	35Ah	70Ah	118Ah
Max. Discharge rate	17A	30A	30A
Max. Charge Rate	10A	20A	25A
Shelf life	Shelf life is maximized with proper charging maintenance.		

Table 1: Electrical and Chemical Characteristics

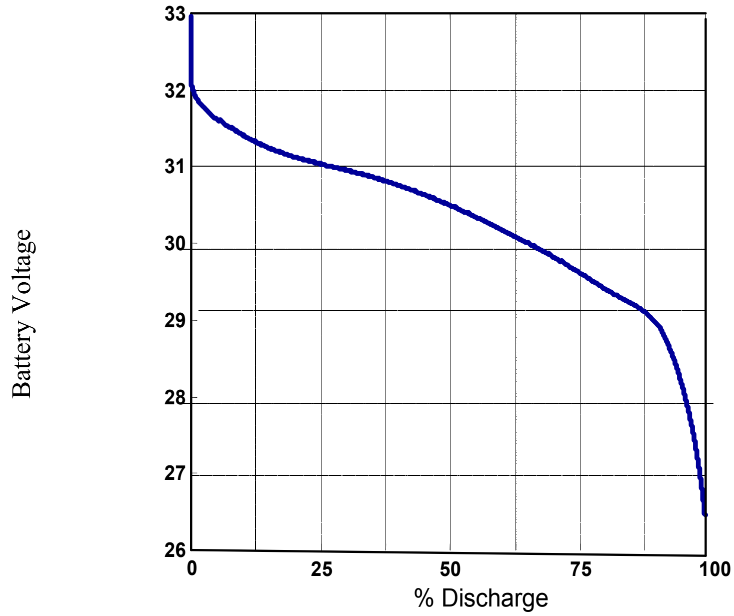


Figure 1: Typical Battery Discharge Curve (C/7 discharge rate)

1-3 SAFETY INFORMATION

Under normal operating conditions, there are no known hazards associated with the use of Lithium Polymer Batteries. However, the following two conditions are known to cause the batteries to give off gas, which can create a potentially hazardous situation:

1. Direct exposure of the Lithium Polymer Cell material to water.
2. Over charging/discharging of the cells.
3. Overheating >45°C.

The conditions listed above can cause the cells to give off irritating and/or toxic fumes. If either of these situations occurs, avoid breathing in the fumes and immediately air-out the space. Additionally, the cells that have emitted gas may be contaminated with a residue irritating to eyes, skin, and mucous membranes. Therefore, cells that have leaked must be handled using protective gloves. In the event of a fire, Lithium Polymer Cells emit irritating and/or toxic fumes. In a fire situation, a Self Contained Breathing Apparatus (SCBA) and protective clothing should be worn. As with other electrical fires, dry chemical or CO_2 may be used as an extinguishing agent. Like cells that have been damaged by water exposure or improper charging/discharging, cells damaged by fire may be contaminated with a residue that is irritating to eyes, skin, and mucous membranes and should be handled with protective gloves.

NOTE
Water or foam should only be used if no other form of extinguishing agent is available.

Damaged batteries are of no further use and must be disposed of properly in accordance with the applicable federal and state regulations.

Warnings

Over voltage is the most dangerous condition for the batteries and can cause a fire hazard. Because of this, the protection systems on the Battery Board should never allow this to happen. This is not likely to happen underway, during discharge. However, it is possible that one battery is inadvertently placed into charge mode while on deck, with shore power connected. If this occurs, the Battery Board should protect the battery. However, it is another level of safety to flag this problem to the user and to turn off all batteries.

For detail safety information regarding Lithium Polymer Batteries please see the attached **Material Safety and Data Sheet**, **provided by Valence Technology, Inc.** – the manufacturer of the Lithium Polymer Cells.

1-4 MASTER/SLAVE BATTERIES

Reference is made to Master/Slave batteries throughout this document. Any battery/board can be configured as a Master or Slave. This is done using the charger software. There is no external indication that a battery is a Master. However, when communicating with a Master Battery, each battery summary query response will have the word "master" or "primary" appended to it.

The difference between a Master Battery and a Slave Battery is that a Master delivers power the instant the enable line is grounded. The Master and Slave battery setup is used for vehicle safety and functionality, as described below:

1. **Safety:** Each Battery Board is capable of delivering 30A continuously. If all battery packs switched on instantaneously when power was applied, then a fault condition could theoretically provide 90A from three batteries, without fault. This would result in failure of wiring and connectors without causing a fuse to blow. Setting one battery as a Master gives a measure of protection against this situation.

2. **Function:** Using a Master Battery enables the user to turn the battery on without requiring power to operate the vehicle. Once powered, the vehicle can then turn on the remaining batteries at will.

NOTE
Only one battery in a vehicle should be designated a Master.

NOTE
There is no obvious external indication that a battery is a Master, so great care should be exercised when connecting a battery to equipment that might be damaged by the battery suddenly discharging into it.

1-5 Physical Characteristics

Battery Dimensions And Weights

# Of Cells	Capacity	LxHxW	Weight
64	1kWh	11”x10.5”x5”	15kg
128	2kWh	1[illegible]x10.5”x5”	27kg
216	3.5kWh	28.6”X10.5”x5”	42kg

Table 4: Battery Dimensions and Weights

1-6 First Time Use / Powering Up a Battery

The following procedure is used to select the address and Master/Slave setting for one battery at a time:

1. Switch on the Battery Charge computer.
2. Connect the Battery Negative (7 pin) connector to the computer using the Battery Charge Cable.
3. Using the Battery Charger Software, communicate with the pack. Alternatively, you can use a Generic Terminal Program and type the commands found in the firmware guide (see the **3-1 Getting Started**, under the **Communications Quick Start Section**).
4. Set the Pack Address and set one pack, and one pack only, as a Master/Primary.
5. Repeat for all system batteries, designating them as Slave/Secondary.

NOTE

If you have problems communicating with the batteries, connect a computer using a terminal program at 9600,n, 8,1, then disconnect and reconnect the battery. The battery will transmit an ASCII string showing its revision number and designation (Master/Slave).

1-7 Connecting Battery Packs to the Vehicle

1. Take great care in a multiple battery pack installation because **if any battery pack is enabled ALL +V connections are live**.
2. Make certain that the Battery Enable Line is OFF.
3. Connect up all Negative Battery Terminals first.
4. Connect up all Battery Positive Lines.
5. Enable the batteries by toggling the Reed Relay (you may have elected to use a different on/off switch system).
6. All batteries will now communicate and the Master Battery Pack will power up the vehicle.

7. The following steps outline intended behavior for an application specific scenario:

    a. Battery Driver on application host computer starts.
    b. Driver interrogates battery packs and determines the battery pack addresses.
    c. Driver interrogates battery packs and determines the capacity, temperature, and voltage of each battery.
    d. Driver posts data for logging, as required by logging system.

Parallel Connection

Each battery pack has a Diode and a Semiconductor Switch on its output. This allows multiple batteries to be joined in parallel. However, this does not mean that battery currents will necessarily be equal. In fact, only the highest battery pack will provide any current at all. To achieve balance, turn all battery packs on simultaneously and allow the battery with the highest voltage to discharge.

Battery Pack efficiency is inversely proportional to battery current squared, as stated in the equation below. Therefore, it is beneficial to operate batteries in parallel. Each battery has a diode and a FET with an effective resistance of 10mΩ. Therefore, paralleling battery pack outputs can reduce part of the energy loss. With three battery packs at 30A, 6W can be gained by running all of the batteries simultaneously.

$$Loss \approx I_{Total}^{2}\left[\frac{R}{N}\right]$$

Software

The details of the Software Driver for the batteries are beyond the scope of this document. In general the guidelines in the following section apply. Smart Battery Driver (SBD) refers to the Software residing on the Host Computer.

General Use

The SBD switches batteries on and keeps them on unless an event occurs that affects the safety of a user, the vehicle, or the battery itself. The vehicle battery packs are connected in parallel and utilize a single RS485 communications port running a simple Master/Slave communication topology. Each Battery Board is individually addressable and can accept new addresses as needed. For manufacturing, tracing, and logging purposes, each Battery Board has a unique identifying serial number, which cannot be changed.

Turning Batteries On

In order to reduce the SBD workload, protection mechanisms and functions have been installed on the Battery Boards themselves. However, the one very important exception to this rule is current monitoring. The individual boards monitor current, but do not communicate with one another and therefore, are not aware of each other's current loads.

Very high currents can be generated without error when many battery packs are discharging in parallel. This is a vehicle level Meta problem that requires batteries to be switched on individually, with a delay before the next battery is switched on. The SBD checks for faults and switches the battery off if required, as each battery is switched on. After one battery is turned on, the SBD should only turn on the next battery if the total battery current is at an acceptable level.

Turning Batteries Off

The SBD's ability to turn batteries on and off is autonomous. In addition, when the battery off command is received, all the batteries are switched off immediately. However, a global vehicle abort does not necessarily turn off the batteries. In addition to the above, the Battery Driver determines the following:

1. The SBD interrogates the battery packs to determine which batteries are connected to the vehicle, their capacity, and to monitor temperatures and voltages.
2. The SBD extracts serial numbers for logging purposes.
3. The SBD attempts to switch on battery packs in a stepped manner until all batteries are in use. This is an attempt to balance the current flow in each battery.
4. The SBD produces an estimation of remaining mission time at the current discharge rate, as follows:

    a. Initially, the SBD reads all the cell capacities, sums the energy remaining, and performs a simple calculation.
    b. Later, a mapping method based on battery pack history is used.

5. The SBD can post data for logging, as required by logging system.
6. The SBD monitors the batteries for problems and flags warnings as appropriate.

1-8 Communication and Networking

Connection Basics

Communication with the Smart Battery takes place over an RS485 serial bus (9600, N, 8,1). This communications link allows the user to control the battery and to query its state. Since multiple batteries may be connected to the same RS485 bus, each battery has a programmable two digit hexadecimal (8 bit) address that allows it to be distinguished from another. Addresses can be changed through the serial port if necessary. For convenience, all batteries always respond to the address 00.

Batteries can be networked using the standard RS485 topologies. Networked batteries must share the same ground point. Star Earthing is good practice and recommended.

The Firmware includes a unique time-driven method to discover battery addresses that enables all batteries to respond to a specific command after a time interval proportional to their address. This solves the network problem of automatic address detection in a simple manner.

For detailed communication and networking information, including software commands, see the **3 Communications Quick Start Section**.

1-9 Fault Conditions

If a battery problem is detected by the Driver the Driver will consult the Fault Table and perform the action requested based on the value of the fault.

If the fault is a temporary fault and is removed (i.e. Over temperature is a possible temporary fault), the Driver should reset the pack and resume normal operation.

Some suggested fault tables follow, they are indicative only and these actions may or may not be present on the client vehicle.

Battery Water Alarm

Level	Value	Local Action	Suggested Global Action
Warning	Binary	Turn off Battery immediately.	Power to surface on remaining batteries.

Table 5: Battery Water Alarm Actions

NOTE
Water in the battery represents a critical failure. Therefore, it is not necessary to differentiate between a warning, danger, or abort.

Over Current

Level	Value	Local Action	Suggested Global Action
Warning	>28A	Issue alarm.	Turn off the last hardware turned on until problem desists.
Danger	>30A	Issue alarm.	Leave “best “ battery on.
Abort	>35A	Turn off all batteries.	Set tailcone elevator to “up.”

Table 6: Over Current Actions

NOTE
Individual batteries have current protection, but batteries do not talk to one another, so an over current condition can occur without any protection mechanism being activated.

NOTE
Over current conditions can rapidly destroy wiring or Penetrators. To avoid damage, leave only one battery on to invoke that battery's protection circuitry. This protection operates on the time scale of milliseconds and protects the vehicle.

Oil Over Temperature

Level	Value	Local Action	Suggested Global Action
Warning	>45°C	If I_{total} ok, turn on all packs. Issue Alarm.	Undefined
Danger	>48 °C A	Issue Alarm.	Reduce Thruster Power.
Abort	>49 °C A	Turn off pack.	Power to surface??

Table 7: Oil Over Temperature Actions

1-10 CHARGING

Charging must take place using the Bluefin Charge Station. The Bluefin Charge Station interfaces with the battery electronics to provide a safe and even charge.

In–Situ Charging

The inclusion of Power Switching components and Protection Diodes in the battery packs has several advantages, not least of which is the ability to charge batteries while in place in the vehicle. This works because the charge FETs allow control over the individual batteries.

The specifics of charging the batteries In-Situ vary depending on vehicle architecture. One way this scheme may work is that the Shore Power Cable is attached to the vehicle in the normal way and a Charge Computer is allowed to talk to the battery packs directly through an Ethernet/Serial interface inherent on the Main Vehicle Computer (MVC). The Battery Charge Computer then enables the charge FET on a single battery pack and charging takes place.

The small disturbance in charge current caused by the vehicle itself, during the Constant Current Mode, should not affect the process unduly. After one battery pack is charged, the charger switches to another battery pack.

Charge Process

It is impossible to control individual cell voltages in a series configuration, but it is possible to charge one of those cells in the correct manner by using a procedure similar to that applied to a single cell.

The Bluefin charge process and circuitry does not replicate the standard charge process, but instead aims to closely follow it.

Conditioning

The battery pack is automatically conditioned during charging. However, during normal operation, series connected cell bricks will drift out of balance and therefore, need to be "conditioned" to equalize individual voltages. This can be performed using a specific Firmware command. For more information on commands, see the **3 Communications Quick Start Section**.

2 Battery Hardware and Software

2-1 Smart Battery Electronics Overview

The electronics consists of a Mother Board and eight Daughter Cards. In general, they will be referred to as one, as they are interdependent and permanently connected in operation. The Mother Board integrates the power switching elements, electronic protection, controller, and connectors. The Daughter Boards are individual measurement boards that are used use to monitor and balance each cell.

Battery electronics include power switching components and power diodes. This allows battery packs to be paralleled without exterior components.

2-2 Enabling a Battery For Communication And Power

Each battery pack has an Enable Line that has to be connected to the Battery Negative (for that battery) in order to function. Internally, this powers up the electronics board. To enable a battery for use, connect the Switch Loop to the Battery Negative (i.e. jump pin 5 to 1-4 on the LPIL-7-FS connector). After the Switch Loop is connected the Battery Board "wakes up" and can be communicated with through its serial port. The Board can then poll its sensors and to set the battery to charge or discharge. In the case of a Master Battery Pack, enabling the battery also causes it to begin discharging. The Board must be enabled to allow any communication with the battery.

NOTE

The battery pack should never be left unattended with the enable line grounded. If this should happen in shipping or storage (for instance), the pack may be drained and the battery pack permanently damaged.

NOTE

Master batteries produce an output when enabled. Slave battery packs do not (see section **1-4 Master/Slave Batteries** for details).

Enableline	Primary/Power	Secondary/Power	Communication	Current
Floating	No Output	No Output	No Comms	<1mA
Grounded	Output on Connection	No Output on Connection	Comms	30mA

Table 2: Status of pack with Enable Line in various states

NOTE
A Master battery pack that has shut down due to a protection will not output power until the enable line has been toggled.

2-3 MONITORING

The following parameters are monitored and are available to the host:

1. Cell Brick voltage.
2. Cell temperatures (four locations in housing).
3. Oil volume temperature.
4. Pack voltage (independent of cell voltages).
5. Pack current.
6. Remaining capacity (calculated from pack current).
7. Water leak: There is one water alarm that detects water in the oil pocket.

2-4 LOCATION, MOUNTING, AND ELECTRICAL ISSUES

The Mother Board is designed to mount with its underside attached to the lid of the battery pack. There are two holes in the Mother Board through which the external Penetrator Wires will pass. These wires are designated the negative and positive cable, but in fact, the negative cable also carries RS485 communication and an Enable Line. The wires terminate in a Positive Pack Output Stud located on the Mother Board and on a Ground Stud. The Ground Stud is shared with the Battery Ground. Three wires over from the "Negative" wire terminate, in the only Minifit Connector on the Board, are the RS485 and Enable Lines. Other connectors include the Temperature Monitoring (10 pin Microfit), Water Alarm (2 pin Microfit), and a Positive Input Power Stud.

2-5 CAUTION

There are no user serviceable parts or components on the Battery Board. There is a mixture of voltages on the Mother Board and **ALL PARTS ARE LIVE**, even with the Board Enable disconnected. The only suitable location for connecting a Ground Referenced Meter is the Ground Stud.

NOTE
The customer should **NEVER** open battery pack lid. Only a qualified Bluefin technician should service the Battery Board.

NOTE
Measurements on the current sensing circuitry must be performed with care, as the “-Ve” for this portion of the circuitry is referenced to the Battery Positive and the highest voltage sits at +6V above the battery pack voltage.

Test points are located on the edge of the Daughter Boards and are included for ease of testing.

NOTE
Shorts between the Test Pins or the connection of the ground of a Ground-Referenced Meter will certainly cause damage to the boards. This damage can include but is not limited to the fusing of the Daughter Card fuses.

High temperatures may exist near the power components. Running the Board at high currents in air without adequate heat sinking may damage these components (the power diodes are unprotected components).

NOTE
The Battery Pack to Board Power Lines are un-fused (fusing is on the circuit board) and as such, represent a hazard, so care should be taken to avoid shorts in the cable.

2-6 PROTECTION

The most important function of the Battery Board is to protect the battery and its operator from damage or injury. To do this, the Battery Board has Hardware and Firmware mechanisms that monitor the vitals of the battery and shut off charging or discharging if a fault occurs. The conditions that the Board prohibits are:

- Over-current.
- Under-voltage (Cells and pack).
- Over-voltage (Cells and pack).
- Over-temperature (Electronics and batteries).
- Communication failure.
- Water ingress.

There are several protection levels, including: Software (application level), Firmware (board level), and Hardware.

Software Protection

It should be noted that the Software does not affect individual battery safety. However, the Software protection is designed in concert with the vehicle to maximize battery performance and to protect against external battery faults such as seawater connection and high currents from a number of battery packs.

Firmware Protection

The Firmware is designed to prevent a battery from charging or discharging if a fault should develop. The user is informed of the fault and the nature of the fault, via the serial port. The Firmware also adds the protection of a communication watchdog (see section **2-7 Watchdog**) to shut off the batteries if either the computer monitoring charge or discharge fails to communicate.

Hardware Protection

The Hardware is designed to act quickly in the event of a fault. The user is informed of the fault via the serial port, but not of the nature of the fault. The Hardware is designed in such a way that once a safety mechanism is tripped (either Firmware or Hardware), the battery must be issued the off command to reset the fault system before the battery can be used again. In the event of such a failure, the hardware circuit protection is designed to instantaneously (<10mS) shut down the Battery Boards. Under such conditions, shut down is automatic and cannot be overridden by any external software communication. Additionally, in such instances, the Battery Boards do not alert the MVC or communicate the fact that they are about to shut down. Therefore, users must test the batteries after the fact, to determine that the hardware circuit protection mechanism caused the battery packs to stop discharging.

Protection	Error state	Limit
Battery over-voltage	V	34.0V (4.25V/cell)
Battery under-voltage	V	26.0V (3.25V/cell)
Battery over-current	I	30.0A
Cell over-voltage	C	4.25V
Cell under-voltage	C	3.15V
Over-temperature	T	Approx 50C
Water Leak	W	Any
Hardware protection	H or h	Any
MVC watchdog	M	60 seconds

Table 3: Protection and Error States

Circuit Fusing

The Electronics Board, Monitoring Cards, and Power Circuit all have individual fuses. These fuses are non-resetable and are not intended to be replaced. Failure of a fuse implies that a fault has developed that the Board circuitry has not prevented.

NOTE
Replacement of the Board by a qualified technician is recommended if a fuse blows.

2-7 Watchdog

The watchdog mechanism is designed to protect the battery and operator in the event of a communications failure. It is activated when a "charge" (bc), "discharge" (bd), or "balance" (bb) command is received and deactivated when an "off" (bf) command is received.

The watchdog can be reset or “touched” by sending any valid command to the affected battery. If the watchdog is not touched at least once each 60 seconds, the battery will return to the "off" state and the Error State of the battery will be set to “m”. As with all other error conditions, the “off” (bf) command must be sent to clear the Error State before the battery can be used again.

For a secondary pack this means that the watchdog is active whenever the battery is being charged, discharged, or balanced. Additionally, communications must be maintained to keep the battery from turning itself off.

For a Master, there is a subtle, but important difference. When a Master is first enabled, it discharges automatically. At this point, the watchdog is **NOT** activated. Therefore, the Master will continue to discharge indefinitely without timing out. This allows the vehicle to be powered up without the risk of the batteries powering down before communications can be established. However, once the battery receives a charge, discharge, or balance command the watchdog will be activated and the battery will time out if further communications are not received.

2-8 TROUBLESHOOTING DURING OPERATION

Cells Over Temperature

Level	Value	Local Action	Suggested Global Action
Warning	>45°C	If I_{total} ok, turn on all packs.	Not defined.
Danger	>48°C	If I_{total} ok, turn off “hot” pack.	Not defined.
Abort	>50°C		Power to surface.

Table 8: Cells Over Temperature Actions

Current passing through the battery causes I^2R heating. The battery temperature is a summation of the battery power output plus the ambient operating conditions and battery insulation. If battery temperatures exceed 60°C, the batteries may begin an exothermic reaction.

NOTE:
Battery damage occurs at temperatures in excess of 50°C.

The thermal inertia of the battery pack should prevent the pack from sudden (Rise Time <30 second) temperature changes, so rapid response is not warranted. If the temperature rises after switching on all the battery packs, there is clearly a problem and the “hot” battery pack has a fault. If the temperature is still rising with the battery pack off, there is a severe fault and the vehicle should rise to the surface.

Cell/Pack Under Voltage

Level	Value	Local Action	Suggested Global Action
Warning	<3.3/3.3*8	Issue Warning and turn on next battery pack.	Not defined.
Danger	<3.2/3.2*8	Issue Warning and turn on all battery packs.	Not defined.
Abort	<3.1/3.1*8	Turn off low battery pack.	Not defined.

Table 9: Cell/Pack Under Voltage Actions

Cell/Pack Over Voltage

Level	Value	Local Action	Suggested Global Action
Warning	>4.1	Issue Warning.	Not defined.
Danger	>4.2	Issue Warning.	Inform operator.
Abort	>4.3	Turn off all battery packs.	Not defined.

Table 10: Cell/Pack Under Voltage Actions

2-9 BATTERY AND ERROR STATES

The Battery Board monitors the state of several vital battery characteristics and performs an emergency shutdown if specific preset thresholds are violated. Therefore, the actual state of battery operation can change without notice.

The Firmware determines the state of the battery using a mechanism that is independent of the tools that change the actual state of the battery. Additionally, the Firmware records any event leading to a battery shutdown. These are expressed as follows:

- Battery State: Represents the current condition of the battery.
- Error state: Illustrates the reason for a shutdown (if one has occurred).

These are reported in the Battery Summary Query (q0).

NOTE

Whenever an error occurs, the Firmware locks out the ability to discharge, charge, or balance until the error state is cleared by issuing the “off” (bf) command.

Battery State:

f	off
d	discharging
c	charging
b	balancing

Error State:

-	all clear
V	battery over-voltage (charging only)
v	battery under-voltage (discharging/balancing only)
I	battery over-current
C	max cell over-voltage (charging only)
c	min cell under-voltage (discharging/balancing only)
T	over-temperature
W	water leak
H	hardware protect – usually voltage/temperature
h	transient hardware protect – usually current
m	MVC watchdog timeout

Fault Handling

If any fault is detected, charge and discharge switches are switched off and latched off permanently. The boards can be reset only after the fault has been removed and a specific sequence is transmitted to the Battery Board. This sequence is detailed in the **3 Communications Quick Start Section**. In the fault condition, the Battery Board locks the value and the parameter that caused the fault for diagnosis.

Protection and Abort Actions

The vehicle operator should use the following precautions when operating a vehicle that includes multiple high-current power sources:

1. Check all connections for reverse polarity, short circuits, and connections to sea (ground faults). If these basic connections are without fault, then the first battery is turned on.
2. At this point, the protection offered by that one battery will limit current to 30A giving a margin of safety should a fault develop.
3. Subsystems are switched on one-by-one and the battery current is monitored incrementally.
4. Once all systems operate as expected, the operator can switch on the secondary and tertiary battery packs.

Every system has many levels of normality (i.e. start up transients, switching, etc.). Therefore, the only way the vehicle operator can reliably perform the tasks listed above is if he has knowledge of the expected operating parameters for each subsystem. There are quantifiable limits for each system. If, during monitoring of the vehicle, the operator becomes suspicious that a subsystem may be operating beyond its designed specifications (i.e. getting too hot or pulling too much current for the task at hand), then it is recommended that the operator turn off the batteries or limit the current to a safe level. If the fault persists or exceeds to dangerous levels, it is recommended that the operator turn off all the batteries and return the vehicle to the surface for diagnostics. The operator's decisions depend upon the fault, system knowledge, and the environment.

NOTE
The precise abort actions that follow a failure are the responsibility of the vehicle designer.

2-10 MAINTENANCE

The following maintenance procedures should be followed:

- Do not leave batteries in a completely discharged state for more than 12 hours.
- If the batteries are taken out of service for extended periods charge and check them every six months.
- Give batteries a service charge if any brick voltage is below 3.6V.
- Never leave batteries with the enable line grounded.

Oil Fill Procedure

The battery oil used is DRAKEOL 9 Mineral Oil NF By Penreco. Fill oil cavity to 10psi over ambient pressure making sure all air is evacuated through Bleed Screw.

For detail safety information regarding DRAKEOL 9 Mineral Oil NF, please see the attached **Material Safety and Data Sheet**, **provided by Penreco** – the manufacturer of the oil.

NOTE
Do not shorten the Tygon Tube as is serves to compensate for oil volume changes.

All fittings have O-rings and should be serviced using standard procedures, which are beyond the scope of this document.

Fitting	O-ring	Body Torque	Sealing Nut Torque
Hummel/Heyco PG 13.5	2-018	70 in-lbs	80 in-lbs
Hummel/Heyco PG 16	2-020	120 in-lbs	124 in-lbs
SwageLok O-seal	2-118	Light wrench pressure	Use gage MS-IG-468
10-32 Bleed screw		Firm screwdriver	N/A
10-24 Lid fasteners	N/A	100 in-oz + ¼ turn	N/A

Table 11: Fitting Tolerances

Conditioning

The batteries are deigned to automatically condition themselves during the charge process. However, once every six months batteries should be left in Conditioning/Balancing Mode for an extended period to align all the cells and allow a full charge to take place.

Calibration

In order to achieve high precision measurements the Battery Voltage, Battery Current, and Cell Voltage Sensors must be calibrated. **Calibration should only be preformed by a Bluefin technician**. Since the Firmware (though not the Hardware) protections are based on the calibration values, it is important for safety purposes, to contact Bluefin and have a qualified technician make sure the battery is properly calibrated.

Since the calibration procedure requires opening the Battery Electronics Compartment, the operator should not change calibration values. Calibration values are stored in EEPROM, so they are not lost when the Battery Board is powered down.

NOTE
Calibration is performed at Bluefin before the battery is released. Alteration of these calibration values voids all Warrantees, for more information see the **Warranty Certificate**. If a calibration value appears to be in error, only an authorized Bluefin technician should service the battery.

Firmware

Firmware updates can be made via a serial port connection.

NOTE
Only a qualified Bluefin technician should perform Firmware updates.

2-11 HANDLING, SHIPPING, AND STORAGE

To minimize uneven stresses on the battery cells and the risk of permanent deformation, batteries are best stored and used lying firmly supported on a flat surface.

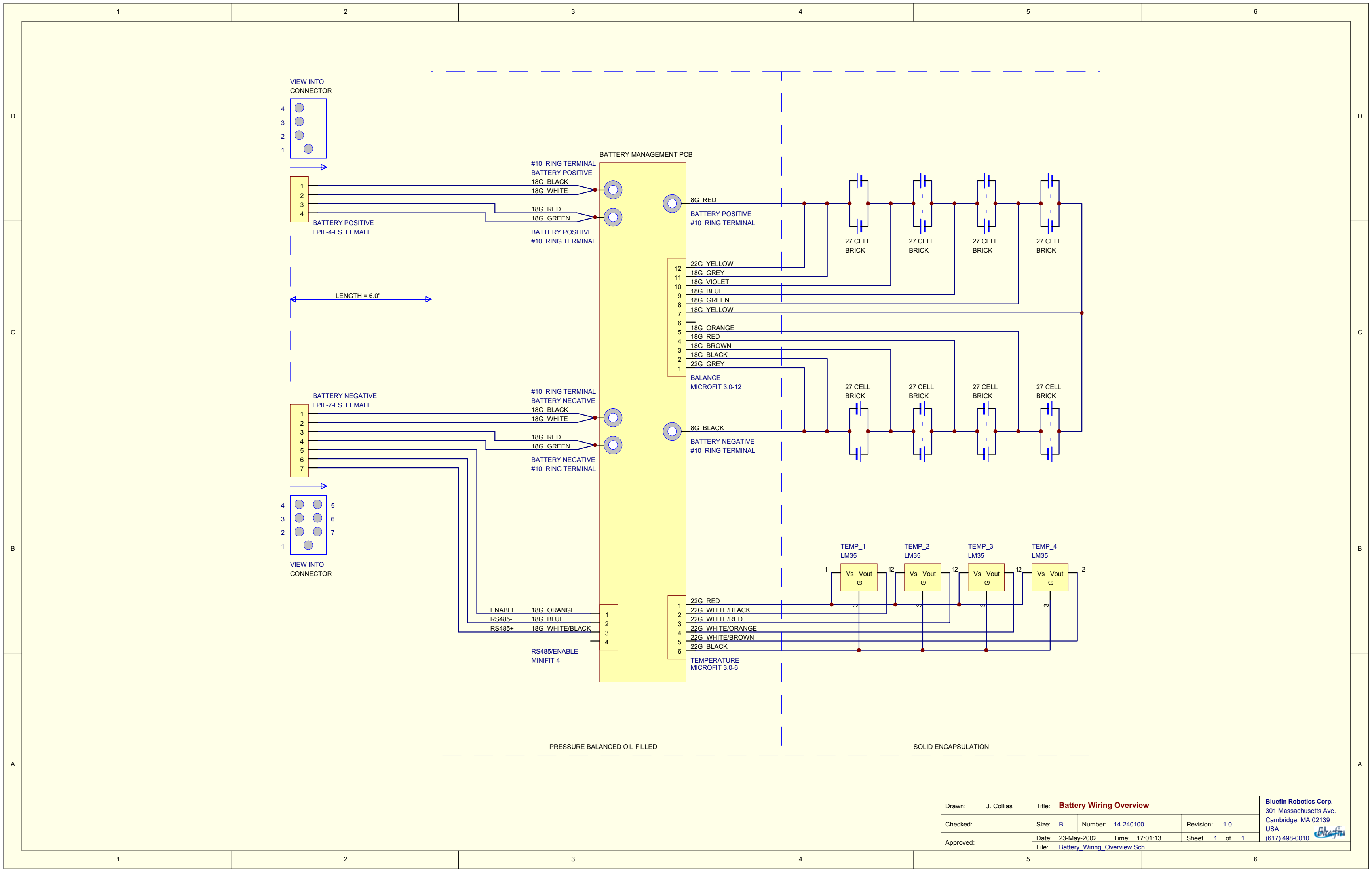
NOTE
Battery Temperature must not exceed 40°C during storage. Do not store in direct sunlight.

NOTE
Before storing or shipping, each of the eight battery bricks must be charged to an open circuit voltage of 3.8V or higher, resulting in a total brick voltage of 31V or higher for all eight bricks. A battery that is left in a completely discharged state will suffer irreparable damage within days or weeks depending on the actual charge remaining. Batteries in long-term storage should be checked every 6 months, and charged as necessary (for more information on charging see section **1-10 Charging**).

Batteries must be shipped in compliance with regulations for Lithium Batteries. Additionally, Bluefin recommends reducing the oil pressure to ambient for air shipping.

Lithium cells and batteries are not subject to hazardous waste disposal under the Universal Waste Regulations. However, local regulations vary and spent or damaged batteries must be disposed of in accordance with such laws.

Electrical Schematic



Mechanical Schematic

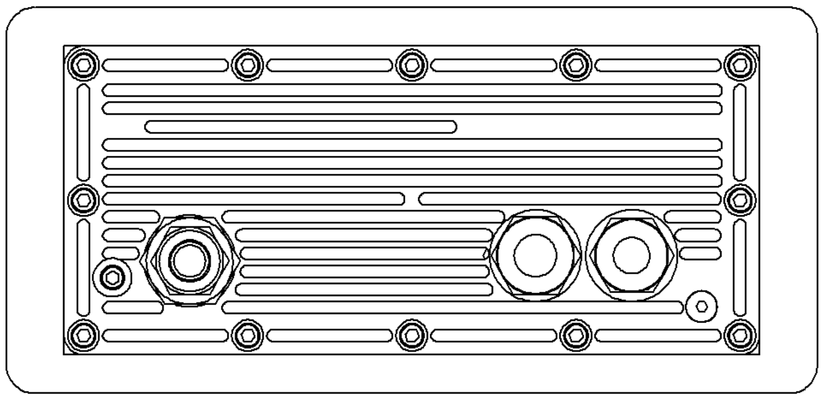


Figure 2: Frontal Battery View

3 Communications Quick Start Section

3-1 Getting Started

1. Connect the batteries following instructions in section **1-6 First Time Use/Powering Up A Battery**.
2. Set up a laptop as defined in section **1-8 Communication & Networking.**
3. Enable/Disable/Enable the battery pack. The battery pack should respond with the startup string. Type in !? and the Battery Board will respond with its address.
4. Type in #00qo/r, and you will get the Battery Summary for battery 02. The summary will be in the following form:

$00q0c- 30.76 14.99 38.14 3.77 3.82 0   806.91 06:31:43 m\r\n

This information is broken down further in section **3-4 Command Summary**, but to get you started, the summary above means the following:

- The battery address 00 received command q0 (Summary).
- The battery is charging (c), with no faults (-).
- The battery has a battery pack voltage of 30.76 volts.
- The battery has a current of 14.99 Amps.
- The battery has a temperature of 38.14 degrees.
- The lowest cell voltage is 3.77 volts and the highest cell voltage is 3.82 volts.
- The capacity is 806.91 AH.
- The discharge time is 06:31:43.
- The battery is a master.

3-2 Input Specification

#[aa][b][c] <arg>[\r or \n]

aa - address (hex)
b – command
c - circuit (hex)

[] - required
<> - optional

The start of a new message is signaled by the '#' character. This character is reserved and may not appear elsewhere.

This character is immediately followed by four bytes. The first two bytes make up a hex number that specifies which Battery Board is being addressed. The third byte is interpreted as the command and the fourth as a circuit number (in hex).

Some commands require additional data. In these cases, the argument should be separated from the command by a single space (' ').

All commands must be terminated with a '\r' or '\n'.

For Example:

#01bf\r	turn battery 01 off
$01bf 1\r\n	
#02q0\r	get battery summary for battery 02
$00q0 c- 30.76 14.99 38.14 3.77 3.82 0 806.91 06:31:43 m\r\n	
#03?8 04\r	change address of battery 03 to 04
#03?8 1\r\n	

3-3 Output Specification

$[aa][b][c] [value][\r\n]

In response to a message, the Battery Board sends a '$' character followed by an echo of the address, command, and circuit, which in turn is followed by a space and the return value. Return values vary with commands and can be a 1 or 0 (TRUE or FALSE), or a more complicated string. Finally, the response is terminated with a "\r\n".

3-3 ADDRESSES

Each board has a two-digit hex address stored in EEPROM, which allows the MVC to talk to multiple battery boards sharing the same RS485 bus. Boards only respond to messages addressed to them or to address 0x00.

NOTE
Since all boards respond to address 0x00 at the same time, messages should only be sent to this address when one battery is connected.

NOTE
Since Battery Boards are "born" with the address 0xFF, it is recommended (but not required) that this address not be used. Also, the Firmware permits Battery Boards to be set to address 0x00. However, using the address 0x00 in a networked topology is discouraged, because all batteries respond to this address.

Address Detection

When several batteries are connected on the same RS485 line it is necessary to know the address of each, in order to talk to each battery. However, the Battery Board Firmware automates the address discovery process. When the synchronization command (“!?[\r or \n]”) is received, each battery responds with its address (in hex), followed by a space after a time of 4ms times its address. With 256 addresses, this process takes approximately 1024ms.

For Example:

Main vehicle computer:		!?\n
Batteries:	**01 02 04**	

3-4 COMMAND SUMMARY

Command	Return	Description
? - address query		
?0	hex	print address
?8 <hex>	0/1	set address
B - battery commands		
bf	0/1	battery off (also clears errors)
bd	0/1	discharge battery
bc	0/1	charge battery
bb	0/1	balance battery
Q - queries		
q0	string	battery summary (see below)
q1	string	cell voltages from last update (see below)
q2	string	temperatures (see below)
V – battery voltage		
v0	float	print battery voltage
v8 <float>	0/1	calibrate battery voltage
I – battery current		
i0	float	print battery current
i8 <float>	0/1	calibrate battery current
K – temperatures		
k0-k3	float	print cell temperature n

k4	float	print oil temperature

NOTE
Temperature Sensors are not calibrated.

C – cell voltages

c0-c7	float	print cell voltage n from last update
c8-cf <float>	0/1	calibrate cell voltage

NOTE
Cell voltages are updated once per minute.

E – battery energy

e0	float	print battery energy
e8 <float>	0/1	set battery energy

S - streaming mode

s0	1	stream off
s1 <int>	1	stream on (at given period, if specified)

M – master mode

m0	1	set as secondary pack
m1	1	set as master (discharges on startup)
m2	0/1	is this pack a master?
mf	1	disable MVC watchdog (dangerous!)

T - time

t0	string	print time
t8 ##:##:##	0/1	set time

Z - version info

z0	string	print battery info string (see below)
z1	hex	print serial number
z1	hex	print battery number
z2	int	print nominal voltage (V)
z3	int	print nominal capacity (Ah)
z9 <hex>	0/1	set serial number (Can only be set once!)
za <hex>	0/1	set battery number
zb <int>	0/1	set nominal voltage
zc <int>	0/1	set nominal capacity

P - processor commands

p0 bootload	0/-	start bootloader (if present, else reset)
p1 reset	0/-	reset PIC

p2 sleep	0/-	sleep PIC
p3 halt	0/-	crash board

Queries

q0 - battery summary

Sample:

#00q0
$00q0 c- 30.76 14.99 38.14 3.77 3.82 0   806.91 06:31:43 m

bytes	meaning
4+1	$ and command echo
2+1	battery and error state (see below)
5+1	battery voltage (##.## V)
5+1	battery current (##.## A)
5+1	max temperature (##.## C)
4+1	min cell voltage (#.## V)
4+1	max cell voltage (#.## V)
1+1	water leak (0/1)
8+1	estimated capacity (-####.## WH)
8+1	current time
1	m for master, s for secondary
2	\r\n

total: 60 bytes

q1 - cell voltages

NOTE
Due to power and timing considerations, cell voltages are updated only once per minute. Queries for cell voltages return the results of the latest update.

Sample:

#00q1
$00q1 3.77 3.80 3.81 3.80 3.78 3.79 3.82 3.80

bytes	meaning
5+1	$ and command echo
8x(4+1)	cell voltages (#.## V)
2	\r\n

total: 48 bytes

q2 - temperatures

Sample:

#00q2
$00q2 37.02 35.14 38.14 33.32 27.54

bytes	meaning
5+1	$ and command echo
4x(5+1)	temperatures 0 to 3 (##.## C)
5	oil temperature (##.## C)
2	\r\n

total: 37 bytes

z0 – battery information

Sample:

#00z0
$00z0 02 m 0002 0002 030 035 v1.42

bytes	meaning
5+1	$ and command echo
2+1	address
1+1	(m)aster or (s)econdary
4+1	battery board serial number
4+1	battery number
3+1	nominal voltage (V)
3+1	nominal capacity (Ah)
~5	firmware version
2	\r\n