



Wiring & Installation Manual

Revision 2



The Orion Jr. BMS by Ewert Energy Systems is designed to manage and protect Lithium ion battery packs and is suitable for use in stationary energy storage and small mobile applications such as golf carts and material handling equipment.

Table of Contents

SAFETY: READ THIS FIRST	4
Determining which BMS to order.....	7
Overview of Theory of Operation.....	8
Mounting	9
Physical Mounting	9
Thermal Information	9
Wiring the BMS	10
Interfacing the Load and Charger with the BMS.....	11
Current Limiting via the digital CANBUS (CAN-enabled units only)	11
Current limiting via the analog voltage outputs.....	12
Current limiting via an on/off signal from the BMS.....	12
Notes for specific applications.....	12
Digital RS232 Serial Communication	13
Straight Through Pinout	13
Mating Connector Part Numbers	13
Main Input/Output (I/O) Connector	14
Wiring Main Connector.....	16
Fusing	16
Power Supplies	16
LED Status Light	18
Wiring CAN interfaces.....	18
Wiring digital signal outputs.....	19
Checking open drain outputs.....	23
Wiring the multipurpose input.....	23
Wiring the analog 0-5V outputs	23
Thermistors (Pins 10, 12, 16, and 8)	24
Wiring Voltage Taps.....	25
Safety Disconnects and Fuse Position	28
Current Sensor	29
Wiring for high impedance cables and busbars.....	31
Skin effect issues due to AC currents.....	32
Transients.....	33
Wiring Errors	34
Voltage tap harness lengths	34
Internal Isolation.....	35
Fuses on voltage tap wires.....	35
Physical routing and installation of wires.....	35
Verifying Cell Voltage Tap Wiring.....	36

Why Orion Jr. BMS Internal Fuses Blow	37
What causes the fuses to blow?	37
Reason: Altering wiring with the BMS connected (or loose busbar)	38
Reason: Cell tap wires reversed.....	40
Reason: Accidental contact to cell tap.....	41
Reason: Transients (and shorts within the high voltage battery pack).....	41
Reason: Extremely weak cell, internal cell failure (fairly rare)	42
Fuses in the Orion Jr. BMS	42

SAFETY: READ THIS FIRST

Important things to read first that will save you time and possibly a battery pack or BMS.

This product is designed to be integrated into an application. Integration must be performed by a qualified person trained in electrical engineering and familiar with the characteristics and safety requirements of lithium batteries. Proper integration, selection of components, wire selection, installation, routing of cables and interconnects, and the determination of the suitability of this product for the application are fully the responsibility of the integrator. Do not use this product if you are unsure if you have the necessary skills to complete this integration.

- 1.) **The BMS must have a means of controlling and shutting off any connected charger, load, source or any other means of charge and discharge.** At least two shutoff mechanisms should be present to turn off a charger. The charge safety signal is designed to be used as an emergency backup if a digital CAN control or digital charge enable signal fails. If the charger does not support an analog shutoff, an AC relay can be used in series with the charger power supply. This is the last line of defense if a failure occurs and should not be omitted. **In addition** to the above safety, the battery charger should be programmed such that it does not exceed the maximum pack voltage if a failure occurs.
- 2.) The **voltage tap connectors must be DISCONNECTED from the BMS while any battery wiring is being modified** for personal safety and to prevent damage. **Wiring while connected to the BMS may pose a personal safety hazard** and/or fire risk since the remaining wires within the cell group can become electrically ‘hot’ due to internal protection diodes. Additionally, wiring with the BMS connected **significantly increases the risk of damage to the BMS**. Damage to the BMS from mis-wiring, misuse, or altering battery wiring while the BMS is connected is not covered under warranty and may pose a personal safety and/or fire risk. **Immediately disconnect the BMS from the battery if the BMS is damaged.**
- 3.) Always **verify voltage taps and current sensor wires are wired correctly before** plugging them into the Orion Jr. Failure to do so may result in damage to the BMS. **Damage to the BMS from mis-wiring or misuse is not covered under warranty**, and some incorrect wiring may pose a personal safety risk or fire risk from energy from the battery pack. Please see the section “Verifying Cell Voltage Tap Wiring” for methods of testing to ensure the voltage taps are wired properly. Immediately disconnect the BMS from cells if it is incorrectly wired. **Leaving the BMS connected to cells when incorrectly wired may drain incorrectly wired cells, even when the unit is turned off which may permanently damage connected cells.**
- 4.) All battery packs must be protected from over-current with a suitable current limiting device such as a fuse. **If a fuse or safety disconnect is positioned between the first and last cell of a battery pack, they must be wired in certain ways.** If you are using a fuse or safety disconnect between the first and last cell, it is critical to read the entire section on **Safety Disconnects and Fuse Positions** before wiring the BMS. **Failure to comply may result in catastrophic failure of the BMS from full stack potential present across two adjacent cell taps if a fuse blows or if the safety disconnect is removed. Read the full wiring manual before wiring the BMS, especially the cell tap**

harnesses.

5.) Make sure that all cells are connected to the BMS and that all current is measured by the shunt current sensor. **It is the user's responsibility to ensure the BMS is connected to all cells to verify the BMS has a method to limit current in and out of the pack and to determine and supply the correct programming parameters (such as maximum cell voltage, minimum cell voltage, maximum temperature, etc.)**

6.) While every effort is made to ensure that the Orion Jr. operates properly under all conditions, it is the integrator's responsibility to integrate properly into the application such that any failure is a safe failure. For more information, please read "Failure Modes" in the operational manual. The integrator is responsible for the determination of suitability of wire, wiring methods, interconnects, and complying with any regulations, standards, or codes. **The Orion Jr. is not to be used for life support systems, medical applications or other applications where a failure could cause damage to property or cause bodily harm or death.**

7.) Paralleling separate strings of li-ion batteries together requires special considerations and a method to isolate each string from each other. One Orion Jr. BMS per parallel string is required. **The Orion Jr. BMS may not be used with parallel string configurations unless specific external safety systems are provided. Engineering work by a qualified electrical engineer is required for use with parallel strings.** If you are using the Orion Jr. in a parallel string setup, please see the section about parallel strings (Note: this is different from paralleling cells inside of a single string which is very common and can be done with a single BMS.)

8.) Because the Orion Jr. BMS is connected to a high voltage battery pack, hazardous voltages and hazardous energies may be present inside the unit. There are no user serviceable parts inside the unit and ***opening the enclosure or user attempted repairs will void the warranty***. Users should never attempt to repair an Orion Jr. BMS unit. Further, a damaged unit or a unit repaired without authorization may pose additional safety risks. **DAMAGED UNITS SHOULD BE IMMEDIATELY DISCONNECTED FROM ALL POWER INCLUDING THE BATTERY PACK AND REMOVED FROM SERVICE. NEVER CONTINUE TO USE A DAMAGED BMS UNIT.** Please contact the factory or your local distributor for repair options. Ewert Energy is not liable for damage caused by user attempted repairs or continued use of a damaged BMS unit.

9.) The Orion Jr. unit is rated for working voltages not to exceed 60 volts DC (48 VDC nominal). **The Orion Jr. BMS may not be used if the voltage between any two points in the battery pack or the voltage between any 2 pins on the BMS will exceed 60 VDC at any point in time. Orion Jr. units may not be used in series to obtain pack voltages above the 60V maximum.** For applications requiring working voltages above 60 VDC, please consider our standard Orion Jr. BMS.

10.) The shunt current sensor must be installed on the negative side of the battery pack only. Connecting to the positive side will damage the BMS. Damage from incorrect current sensor wiring is not covered by warranty.

ALWAYS READ THE MANUAL BEFORE USE

The most up to date Orion Jr. BMS manuals can be downloaded at: www.orionbms.com/downloads

Determining which BMS to order

The Orion Jr. BMS is available off the shelf in two configurations – with CANBUS and without CANBUS. Both standard configurations support 1 to 16 cells. In larger volumes, customized versions of the Orion Jr. unit are available for cost savings including units supporting fewer cells.

Included with the standard BMS

- Main BMS unit

Optional

- CANBUS support
- Shunt current sensor options
- Pre-assembled wiring harnesses
- Basic displays, data loggers, and PC interfaces are also options

See “Orion Jr. Purchasing Guide” for details on ordering options

Overview of Theory of Operation

The Orion Jr. protects and monitors a battery pack by monitoring several sensors and uses several outputs to control charge and discharge into the battery. The BMS measures inputs from cell voltage taps, the total pack voltage tap, a shunt current sensor, and thermistors. Using user-programmed settings, the BMS then controls the flow of current into and out of the battery pack by broadcasting charge and discharge current limits (via analog voltage references or optionally via a CANBUS) or through simple on/off digital signals depending on which style is appropriate for the application. The BMS relies on the user to provide external controls to enforce the current limits set by the BMS to protect the batteries since the BMS does not have integrated switches. During and immediately after charging, the BMS will balance the cells using internal shunt resistors based on the programmed settings.

The Orion Jr. unit monitors each individual cell tap to insure that cell voltages are not too high or too low (in accordance with the user-programmed values). Using the cell voltages, the amperage going in and out of the pack (provided by the current sensor), and programmed values in the battery pack profile the BMS calculates the pack's internal resistance, the internal resistance of each cell, and open cell voltages. From those calculations, the maximum charge and discharge current limits are calculated and adjustments are made to the pack's calculated state of charge if necessary. These calculations are also used in monitoring the health of the pack. Charge and discharge current limits are provided on the CANBUS or serial bus and can be programmed to trigger on/off digital outputs to allow or deny charging and discharging of the battery pack.

Mounting

Physical Mounting

The Orion Jr. can be mounted in any orientation. Two mounting flanges are provided on the top and bottom for mounting. The BMS is rated to operate in the temperature range of -40C to +80C and is designed for use in moderately protected locations. If the BMS will be in a location exposed to harsh environments such as liquid spray, salt spray, heavy condensation, or other similar conditions, it must be located inside a suitable protective enclosure which provides sufficient heat transfer and protection against water ingress and other elements. It should be noted that lithium batteries themselves must also typically be protected from these harsh environmental elements.

The BMS and all wiring connecting to the BMS should be mounted such that it is separated from flammable materials. **The Orion Jr. BMS may not be used in environments where combustible gasses may be present.**

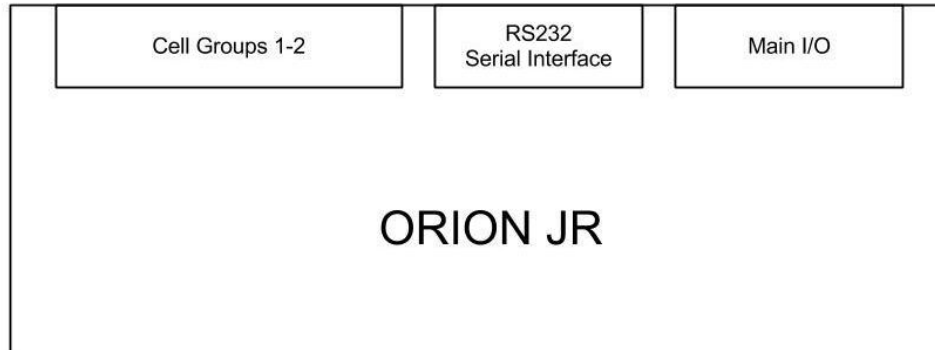
Thermal Information

The Orion Jr. requires unobstructed, adequate ventilation and must not be surrounded or sealed by thermal insulating material. Blocking ventilation or thermally insulating the unit may pose a fire hazard. During certain abnormal fault conditions, the unit has the potential to generate as much as 35 watts of heat. Ventilation must be adequate for this amount of heat even though it will not be generated under normal use.

During normal use, measurable heat is only generated while the BMS is performing balancing, at which time the BMS may dissipate up to 12 watts of heat from normal use. Normal heat dissipation is only around 1 – 2 watts when balancing in inactive.

Wiring the BMS

Overview of system connections



Connector locations on the Orion Jr. BMS as looking at the BMS from the top

Interfacing the Load and Charger with the BMS

The Orion Jr. BMS constantly calculates maximum current limits for both charging and discharging. These current limits are based on many parameters including pre-programmed maximum amperages (usually specified by the cell manufacture), temperature, cell health, state of charge, and several other conditions. The current limits are automatically determined based on a calculated algorithm to prevent the cell voltages from dropping below or going above the minimum and maximum cell voltages respectively. More information on how the current limits are calculated can be found in the operational manual.

While the BMS can accurately calculate current limits to keep the connected cells within safe operating parameters, the BMS unit itself cannot directly enforce these current limits (i.e.: it is up to the load and charger to respect the limits that the BMS sets). For this, the BMS relies on the installer to provide a means to limit charge and discharge current and can only protect cells when this external means of limiting current is properly connected. The BMS must be able to turn off **all** charge and **all** discharge to the battery pack in order to properly protect the cells. ***Failure to provide an external method to limit charge and discharge current will result in the BMS not being able to protect the connected cells.*** Below are the three main methods of controlling a load or charge source.

Current Limiting via the digital CANBUS (CAN-enabled units only)

Many modern chargers, motor controllers, solar/wind inverters, and other equipment come with a digital CANBUS (Controller Area Network) interface. This digital protocol usually has a method of communicating maximum current limit(s) to the device. For example, almost all CANBUS enabled battery chargers will listen to the BMS and charge at an amperage not to exceed what the BMS instructs them to. Likewise, almost all CAN enabled motor controllers can be configured to listen to the BMS and limit the amount of current the motor can draw to the amperage that the BMS specifies. Motor controllers that support regenerative braking usually will also listen for a maximum charge current in order to limit regenerative braking amperage.

Interfacing with external devices via CANBUS has some significant advantages and is generally the preferred method of controlling external devices whenever a CAN interface is available (with a few exceptions). Because CAN is a digital protocol, the BMS can accurately and quickly specify the current limit to the device. This is particularly useful for applications where a gradual reduction of power either at the end of discharge or end of charge is beneficial or necessary and takes full advantage of the Orion Jr. BMS's capabilities. For example, if the BMS is being used in a light vehicle, it is desirable for the vehicle to gradually slow down when the battery is exhausted rather than suddenly cut out when the battery is depleted. This also allows a greater portion of the battery to be used. Gradual current limiting is necessary to fully charge a battery pack to 100% state of charge (although in most applications it is desirable only to charge to a maximum of 95% for lifespan reasons, which may not require gradual tapering of the charge in lithium batteries).

The Orion Jr. BMS utility has built-in support for many CAN enabled chargers and motor controllers and has an extremely programmable CAN interface which can be programmed for devices that are not already integrated.

Current limiting via the analog voltage outputs.

The Orion Jr. BMS is equipped with two analog voltage outputs which can be used to communicate the amperage limits to external devices. Pin 16 (Discharge Current Limit or DCL) and Pin 5 (Charge Current Limit or CCL) are both outputs which range from 0 to 5 volts and provide an analog representation of the maximum current limits (0V = 0%, 5V = 100% of the maximum limit). If a motor controller does not support CAN, but has a 5V potentiometer for a throttle, it may be possible to use the 0-5V output from the BMS to limit the maximum voltage on the potentiometer and therefore effectively limit current. The BMS can interface with devices requiring a 0-10V signal with the addition of external op-amp circuit to translate the voltage.

Important: Whenever the 0-5V analog outputs are used for controlling current, they must be used in conjunction with the charge or discharge enable outputs from the BMS as a backup to ensure the BMS can fully turn off the device. This is important since the analog 0-5V outputs are not watchdog backed and could potentially lock at a certain voltage in a failure. See “Wiring the Main I/O” below for more information.

Current limiting via an on/off signal from the BMS.

The simplest method to control a load or charger is by using the on / off outputs. These outputs will turn on when charge or discharge are allowed based on the present conditions. Unlike the other above methods of controlling external devices, these outputs are either on or off and cannot gradually taper charge or discharge (though they can be used in conjunction with the other methods). There are 3 primary on / off outputs: Charger safety enable, discharge enable and charge enable. Charger safety enable is used to control a battery charger; discharge enable is used to control a load such a motor controller or AC inverter; and charge enable is used to turn off intermittent charging currents such as charge from regenerative braking.

More information about how the outputs are wired and how they function can be found later in this manual as well as in the operational manual. Information on changing the setting for when these outputs are on can be found in the software manual.

Notes for specific applications

Application notes are available for integrating with many common motor controllers and chargers and include information, tips and recommended wiring specific to those devices. Application notes can be viewed at <http://www.orionbms.com/application-notes/>

Digital RS232 Serial Communication

The Orion Jr. unit must be programmed using a computer and the Orion Jr. BMS utility in order to operate. **The BMS will not function until programmed.** The necessary utility can be downloaded from www.orionbms.com/downloads.

The Orion Jr. can either be programmed by connecting to a computer's RS-232 port or directly to a USB to Serial adapter. A USB to Serial adapter can be plugged directly into the BMS without an extension cable. However, if a serial extension cable is used to physically extend the connection, it must be a **straight through serial cable**. Any other type of RS-232 cable including a null-modem cable will **not** work.

Note that this port is to be used for RS-232 serial communication only. It will not work if connected to the CANBUS or connected using the CANdapter.

Straight Through Pinout

Connector 1		Connector 2
2 (RX)	---	2 (RX)
3 (TX)	---	3 (TX)
5 (GND)	---	5 (GND)
7 (RTS) *	---	7 (RTS) *
8 (CTS)	---	8 (CTS)

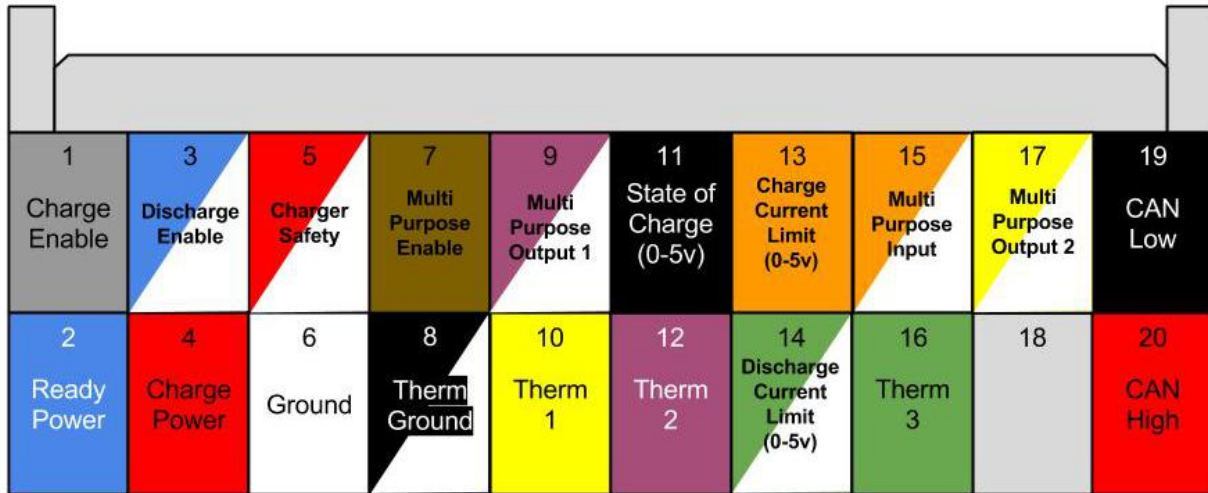
Minimum required connection for straight through serial cable (additional wires 1-1, 4-4, 6-6 and 9-9 may also be present but are not necessary for proper operation.)

*The BMS serial transceiver is powered by the RTS pin and will not function without it.

Mating Connector Part Numbers

<u>Connector</u>	<u>Manufacturer</u>	<u>Part Number</u>	<u>Crimp Part Number</u>
Main I/O (20 pin)	JST	PADP-20V-1-S	SPH-001T-P0.5L
Serial	Various	Standard DB-9	
Voltage Tap (24 pin)	Molex	39-01-2225	39-00-0038

Main Input/Output (I/O) Connector



Looking into back of connector (wires coming toward viewer)

Signal Name	Description
1. Charge Enable Signal (Out)	An open drain digital on/off signal used to signal to a load that the load can charge the battery. This would normally be used to control regenerative breaking in a mobile application or enable a solar or wind charge in a stationary application. This signal can be used as a backup to digital CAN communication with a controller. This is a signal current level (175mA max) and should be amplified for controlling large contactors or relays (see electrical specs.)
2. READY Power Source	This power source should be connected to a 12V - 48V nominal power source whenever the BMS should be active for normal use. This input must be fused at no more than 3A. The voltage on this pin may not exceed 60V at any time.
3. Discharge Enable Signal (Out)	An open drain digital on/off signal used to signal to a load that the load can discharge the battery. This would normally be used to control a discharge contactor or to signal to a controller that discharge must be stopped if this signal is not present. This signal can be used as a backup to digital CAN communication with a controller. This is a signal current level (175mA max) and should be amplified for controlling large contactors or relays (see electrical specs.)
4. CHARGE Power Source	This power source should be connected to a 12V - 48V nominal power source whenever the BMS should be active for a defined charging period. When powered by this source, the BMS enters charging mode. If this power source is connected while the READY power source is also connected, the BMS will activate the "Charge Interlock" state. Must be fused at no more than 3A. The voltage on this pin may not exceed 60V at any time.

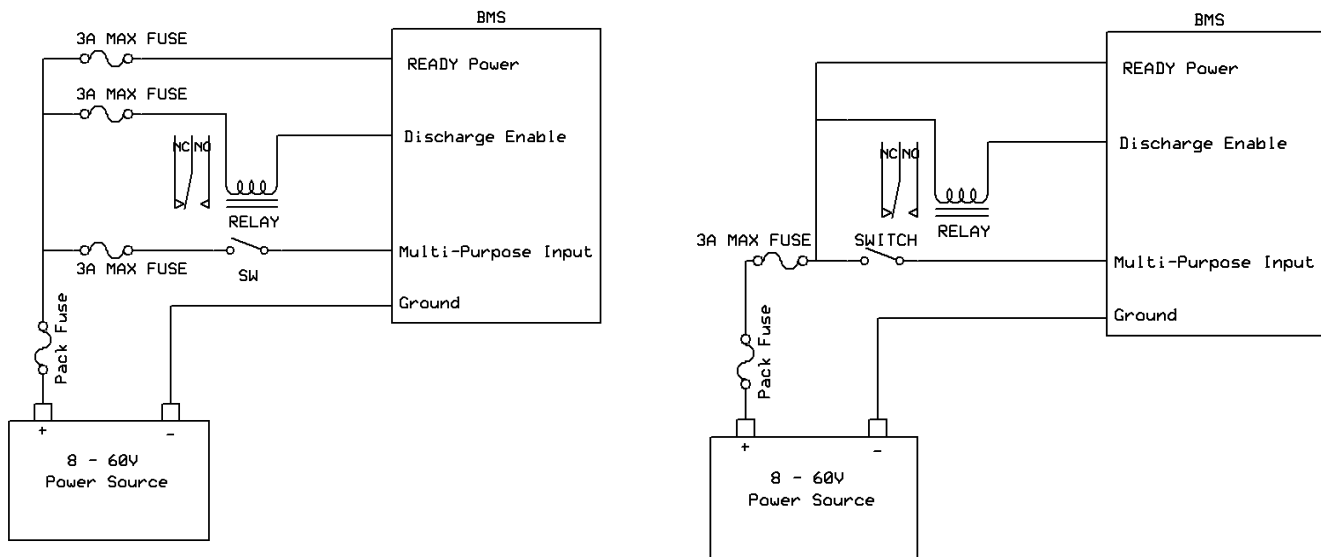
5. Charge Safety Signal (Out)	An open drain digital on/off signal used as a safety switch for a charger. This signal is normally connected to the charger or connected to a relay which enables AC power to the charger such that the lack of this signal will cause the charger to be inactive. This is a signal current level (175mA max) and should be amplified for controlling large contactors or relays (see electrical specs.)
6. Power Ground	This is the ground for the supply power for the BMS. Both power sources (READY and CHARGE) share this ground, and grounds for these power sources must be bonded together externally.
7. Multi Purpose Enable	An open drain digital on/off signal with configurable behavior. This is a signal current level (175mA max) and should be amplified for controlling large contactors or relays (see electrical specs.) Please see the software manual for a complete list of available functions. This output is watchdog backed and will turn off when certain faults occur, regardless of programmed settings.
8. Thermistor Ground	One leg of each of the two thermistors should be grounded to this ground. Both thermistors share this ground return.
9. Multi Purpose Output 1	The behavior of this multi-purpose output is configured in software for additional functionality. This output is often used to drive an LED to indicate the presence of error codes, but can also be used as a CAN controlled output as well as other functions. Please see the software manual for a complete list of available functions. This output is NOT watchdog backed and may remain on when certain faults occur.
10. Thermistor 1 12. Thermistor 2 16. Thermistor 3	One leg of each of the thermistors should be connected to the respective thermistor pin. These pins connect to 10K NTC thermistors.
Analog 5v Outputs: 11. State of Charge 13. Charge Current Limit 14. Discharge Current	0-5V analog outputs that represent charge current limit, discharge current limit, and state of charge.
15. Multi Purpose Input	This is an input signal that can have multiple different input functions such as redundant keep-awake power signals, clearing DTC fault codes and other functions. Please see the software manual for a complete list of available functions. The voltage range for this pin is 9-60V.
17, Multi Purpose Output 2	The behavior of this multi-purpose output is configured in software for additional functionality. Please see the software manual for a complete list of available functions. This output is NOT watchdog backed and may remain on when certain faults occur.
19. CAN_L 20. CAN_H	CAN interface with high and low signal lines. Only available on units ordered with CANBUS. Unless special ordered, the BMS unit has a termination resistor installed inside the unit (120 ohm).

Wiring Main Connector

Fusing

Important: As with all electrical devices, all wires connected to the Orion Jr. BMS unit must be current limited at their source. Any circuit connecting to the BMS **must** be current limited with an appropriately sized fuse (or other current limiting device) to prevent overloading wires in the event of a short. **The external fuse must be sized properly to protect the conductors** and must specifically have a **DC voltage rating** of no less than the maximum possible working voltage and an appropriate DC interrupting current rating for the application.

The maximum fuse size permitted for the CHARGE or READY power, any of the open drain output pins, or multipurpose input pins is 3A, but smaller fuses may be used.



Two diagrams showing fuse placement.

Power Supplies

Operating power is supplied to the Orion Jr. by two separate power sources. The power supplies will not backfeed each other due to internal diodes. The Orion Jr. consumes approximately 1-2 watts for operating current. Actual current varies depending on supply voltage and may be higher if additional devices are connected to the Orion Jr. *Operating current will be drawn from the higher voltage source if both sources are on at the same time.*

The Orion Jr. units are designed to be powered either from an auxiliary power source or from the pack voltage and operate on 12-48 volts nominal for operating power. Voltages between 9V and 60V are acceptable for continuous operation. Voltages below 9V may cause the BMS to turn off, and voltages over 60V will damage the BMS unit. The supply voltage may not exceed 60V at any time.

If pack voltage is used to supply operating current to the Orion Jr. unit, care must be taken as other I/O pins, including the thermistor inputs on the Main I/O connector, are not electrically isolated from the supply power.

Revision C units have been tested to withstand limited damaging transients on the CHARGE and READY power inputs of up to +/- 300 V, 2mS duration with 5 ohm source impedance as defined in pulse 1 of 1SO 7637-2 (open drain outputs have been tested to withstand transients up to +/-200V, 0.05mS duration with 2 ohm source impedance as defined by ISO 7637-2). If transients beyond these rating are expected on any input to the BMS including the ready or charge power sources, external transient protection must be supplied (Note: very strong transients may also damage other equipment or even the battery cells themselves).

If the BMS is powered directly from the battery pack it is protecting, care must also be taken such that the operating current powering the BMS does not over-discharge the battery in the event the battery is not charged for an extended period of time. Over-discharge of a battery pack may destroy the entire battery pack in one single event, so this is essential. The Orion Jr. unit has an optional low-power shutdown mode which causes the BMS to shutdown and draw about 0.1 watts when the voltage of the lowest cell drops below a certain voltage. This optional low power shutdown feature must be enabled in software (disabled by default). On revision A and B units, it may cause the BMS to lock in the “off” state for up to 5 minutes when triggered, even after power is disconnected. **This feature will slow down discharge, but it will NOT fully protect the battery as the unit will still draw about 0.1 watts or up to about 20mA from the battery pack even when in shutdown and this will eventually drain the battery pack.** Lithium-ion cells can be destroyed in one cycle when over-discharged.

Ready Power Source: This is the primary power source for the Orion Jr. BMS unit. This power source can be thought of as the “ignition” power source when the BMS is used in mobile applications. When power is present at this source, the BMS will allow both normal charge and discharge. When powered only by this power source (i.e. charge power is not present), the BMS will not engage the charger safety output (usually used to control a battery charger) and will not allow cell balancing.

Charge Power Source: This power source should be energized when the battery is in a defined charging phase such as being fully charged by an AC battery charger. When power is present at this pin, the BMS will enter charging mode, which enables cell balancing and enables the charger safety signal output. For most applications, this is used when the BMS is in a defined charging phase from AC power. Because of this, CHARGE power is normally provided by a small AC / DC power adapter powered off the mains.

The BMS will fully operate with both the charge and ready power sources powered at the same time. If both CHARGE and READY power sources are energized at the same time, the BMS will allow normal charge and discharge and will also enable the charger safety output and balancing.

LED Status Light

The LED light on the BMS unit indicates its status: A green light indicates that the unit is powered and that there are no errors present. A red light indicates that the unit is powered, but errors are present. If the light is not lit, the unit is not receiving power or has entered into a low power shutdown. If a unit has firmware revision 2.0.1 or newer (only available for rev C), a rapidly blinking red light indicates that the unit is detecting a voltage greater than 5v on one of the cell taps, which may be damaging the unit. Immediately disconnect the unit if the light begins rapidly blinking red. Note: the absence of the rapid red LED does not indicated wiring is necessarily correct!

Wiring CAN interfaces

This option is only available if the BMS unit is ordered with a CANBUS interface. The CANBUS interfaces can be configured to run at 125, 250, 500 or 1000 Kbps. CAN interfaces are differential mode buses and require twisted pair wire (2 wires) to communicate. For best operation, shielded twisted pair wire should be used for protection against electrical noise immunity, particularly when used in noisy environments. Shields should only be connected in one location to prevent ground loops. While it is necessary for the twisted pair CAN wires to be outside of the shield for a short distance at any connectors, the amount of non shielded, non-twisted wire should be kept as short as possible, ideally less than 2-3 inches, especially in high noise environments.

Controller Area Networks (CAN) require exactly two 120 ohm termination resistors on the two physical ends of the bus to operate properly. Unless specifically ordered without, the Orion Jr. BMS contains one 120 ohm termination resistor inside the unit. A CANBUS can have many nodes attached to a single bus. If only two nodes are attached, they should be at the physical ends of the cable with a termination resistor as close to each end as possible. If additional nodes are used, they should “T” off the main wire. While the entire CANBUS cable can be very long (up to 30 meters for 1mpbs, 100 meters for 500kbps, or 500 meters for 125kbps), the taps off the main wire for additional nodes should be kept less than about 3.5 feet or 1 meter off the main cable. If improperly wired (i.e. only one termination resistor on the bus or long taps off the main cable), the bus sometimes may appear to work, but may then fail or suffer reliability problems at a later time when exposed to more significant noise. ***The bus must be properly terminated even if it appears to work with just one termination resistor!***

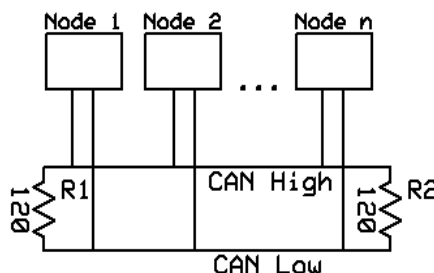


Diagram of a multi-node CANBUS with 120 ohm termination resistors at the ends

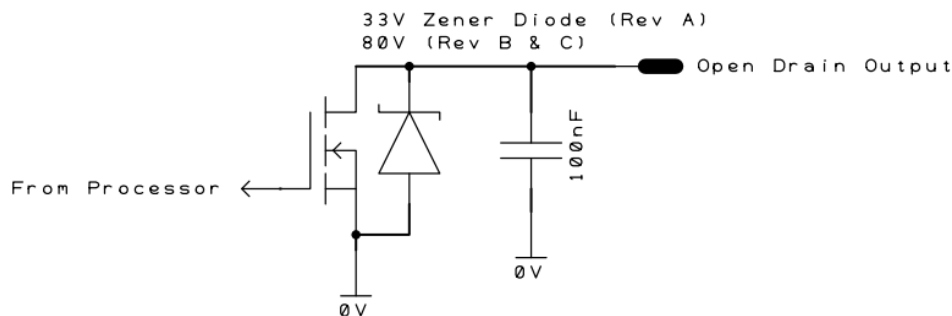
After wiring the CAN interfaces, verify proper termination by using an ohm-meter to check the resistance between CAN_H and CAN_L. In order to verify the resistance, all power must be removed from all devices on the CANBUS. The total resistance should measure 60 ohms (two 120 ohm resistors in parallel = 60 ohms.)

Wiring digital signal outputs

The Orion Jr. has either 5 (revisions A & B) or 6 (revision C) signal level digital I/O outputs - Charge Enable, Discharge Enable, Charger Safety, Multi Purpose Enable, Multi Purpose Output 1, and Multi Purpose Output 2 (revision C only). These outputs are open drain outputs which means that they do not source any current or voltage, but rather pull down to ground and sink current when they are turned on. While this may seem like an odd way to interface with the BMS, this method provides greater flexibility and can interface with a wide range of applications using different **voltages up to 24V nominal / 30V maximum for revision A units and 48V nominal / 60V maximum for revision B & C units**. These outputs pull low when they are “on” and cannot be inverted in software for safety reasons. This is done so that if the BMS connector were to become disconnected, the outputs would fail “off” rather than “on”. For safety reasons, the Charge Enable, Discharge Enable, Charger Safety and Multi Purpose Enable outputs feature an analog watchdog circuit which turns these four outputs off in the event of a processor malfunction, adding an extra layer of safety. The Multi Purpose Outputs 1 and 2 do not have the watchdog feature as it is not designed to control charge or discharge current.

Important: An external fuse rated 3A or less rated for at least the full DC working voltage with a suitable interrupting current rating must be installed at the voltage source to protect the wiring to any open drain output or relay controlled by the BMS. Fuses must have a voltage rating that exceeds the maximum possible working voltage and must be rated with a sufficient interrupting current rating.

Please note that the output of an open drain *cannot* be directly measured with a multimeter as they do not source voltage. Please see below for more information on testing the outputs.



Simplified internal schematic for signal outputs

Charge Enable Output (pin 1) - This pin is enabled in both READY and CHARGE modes and is turned on (pulled low) as soon as the BMS has gone through self checks and determined that the battery is able to be charged. This output will turn off (float high) if the BMS determines that the battery can no longer accept a charge or if the maximum charge amperage is exceeded. This output can be turned back on again automatically when certain criteria set in the software are met. If the BMS turns this output off (and if the charger safety output is also off), but still measures current flowing into the battery pack afterwards, a critical error will be set on the BMS resulting in the disabling of all charge and discharge until the BMS has been reset as a safety feature. Please see the software manual for more details on how the BMS determines when this pin is on or off.

Important: **In addition** to using this output, any charge source should be set such that it will shut off in the event the maximum pack voltage is reached as a secondary precaution against overcharge. While

this is an important backup, never rely solely on the pack voltage to turn off charge sources and always ensure the BMS can turn off all charge sources.

Discharge Enable Output (pin 3) - This pin is enabled in both READY and CHARGE modes and is turned on (pulled low) as soon as the BMS has gone through self checks and determined that the battery is able to be discharged. This output will turn off (float high) if the BMS determines that the battery can no longer provide current or if the maximum discharge amperage is exceeded. This output can be turned back on again automatically when certain criteria set in the software are met. If the BMS turns this output off, but still measures current flowing out of the battery pack afterwards, a critical error will be set on the BMS resulting in the disabling of all charge and discharge until the BMS has been reset. Please see the software manual for more details on how the BMS determines when this pin is on or off.

Important: **In addition** to using this output, any connected loads should be set such that they will shut off in the event the minimum pack voltage is reached as a secondary precaution against over-discharge. While this is an important backup, never rely solely on pack voltage to stop discharge and always ensure the BMS can turn off all discharge loads.

Charger Safety Output (pin 5) - This pin is enabled only in CHARGE mode and is used to control when a charger is turned on. Once the CHARGE power supply is detected by the Orion Jr. BMS, the BMS will go through self checks and ensure that the battery can accept a charge. Once the BMS passes all the tests, this output is turned on (pulled low) to enable the charger. Once the battery has reached its maximum voltage, this output is turned off (float). This output can be turned back on again during balancing or at set intervals when certain criteria set in the software are met. If the BMS turns this output off (and if the charge enable output is also off or disabled), but the BMS still measures current flowing out of the battery pack afterwards, a critical error will be set on the BMS resulting in the disabling of all charge and discharge until the BMS has been reset. The status of this pin can be transmitted via the CANBUS. Please see the software manual for more details on how the BMS determines when this pin is on or off.

Important safety note: At least two shutoff mechanisms should be present to turn off a charger. The charger safety signal is designed to be used as a backup if a digital CAN control or digital charge enable signal fails. If the charger does not support an analog shutoff, an AC relay can be used in series with the charger power supply. This is the last line of defense if a failure occurs and should not be omitted. **In addition** to the above safety, the battery charger should be programmed such that it does not exceed the maximum pack voltage if a failure occurs. While this is an important backup, never rely solely on the pack voltage to turn off the charger! Always ensure that the BMS is able to turn off all connected chargers.

Multi Purpose Enable (pin 7) - The function of this pin is assigned in software. This output is an open drain output. This output will be turned off in the event of a charge or discharge enforcement fault code no matter what function is selected in software.

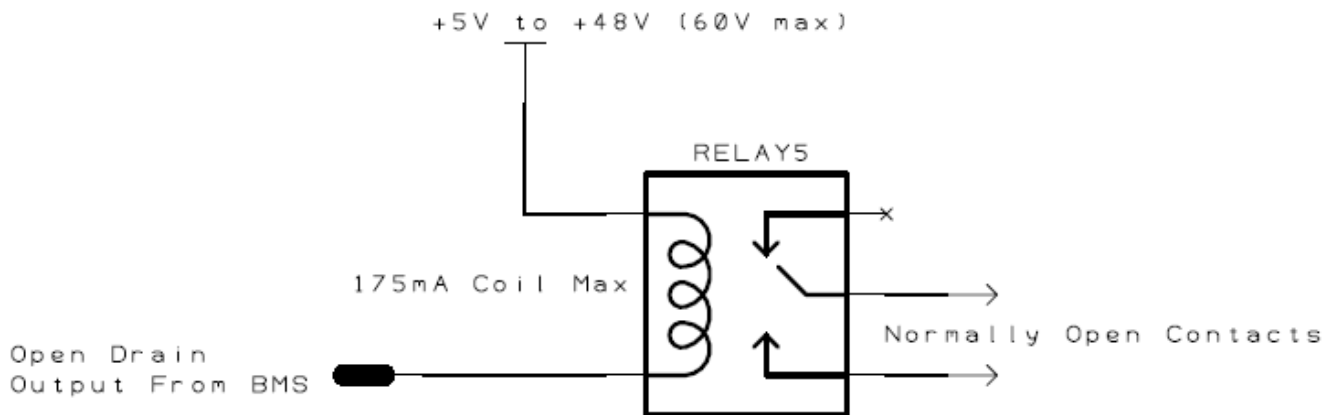
Multi Purpose Outputs (pins 9 & 17) – The function of these outputs can be assigned using the setup utility. One is commonly used as an output to signal whether an error code is present and can be used

to drive an error LED, such as the LED on the Orion Jr. BMS basic display board. These outputs are both open drain outputs which pull down to ground when “ON.” It is important to note that these two outputs are not watchdog backed and will not turn off in the event of certain faults. These two outputs should not be used as the sole mechanism to control charge sources or discharge loads.

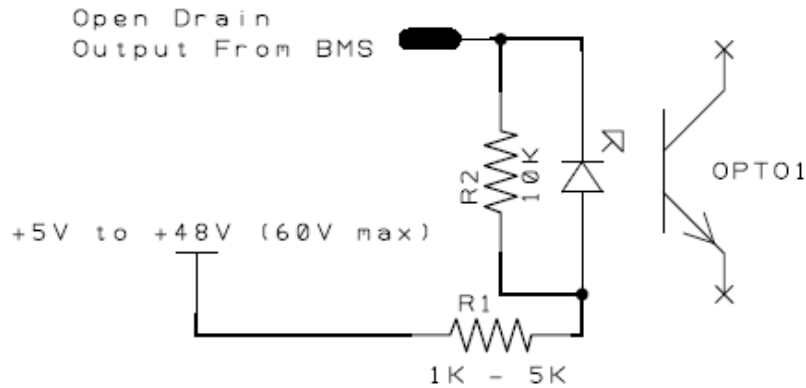
Important notes about digital signal outputs: All of these open drain outputs are capable of directly controlling small relay coils **under 175mA** and a **maximum voltage up to 24V / 30 V maximum for revision A units and 48V nominal / 60V maximum for revision B and C units**. The BMS has internal protection from the back EMF generated by the relay coils, and additional clamping diodes can be added for additional protection if desired. Damage can occur to the BMS if currents larger than 175MA are present, even for short inrush periods. This can lead to undefined behavior of these outputs, including the shorting of the output. These outputs should not be used to directly drive large contactors. Some large contactors have a DC:DC converter attached to reduce average power consumption, but they still require a large inrush current to turn on initially. This large inrush current can damage the BMS units. These outputs must be amplified if used with large contactors (amplification methods listed below). The Orion Jr. units have resettable internal fuses on these outputs, but these over-current protection devices can become damaged from repeated over-current or sustained over-current events. ***Always monitor the first charge and discharge cycle manually and ensure that the BMS has proper control over the loads and the sources of current to and from the battery. If you receive a charge, discharge, or charger safety relay fault error, immediately investigate to ensure over-charging or over-discharging is not occurring.***

Care must be taken to avoid differences in ground potentials between the BMS unit and other parts of the application. A difference in ground potentials can cause the digital signal outputs to sink current due to internal protection diodes (see schematics above). Care must also be taken to ensure that the voltage on these pins never exceeds 60V. While voltages above 60V are never permitted on these pins, a voltage exceed 70V will damage the unit and cause these pins to short on “on.”

If additional power is needed or if galvanic isolation is required, the digital signal outputs can be used to drive opto-isolators or other loads. Below are a sample schematic for connecting a relay with a coil less than 175mA and a sample with an opto-isolator. Please note that the below schematics are for general reference and the suitability of each circuit must be determined by the user.

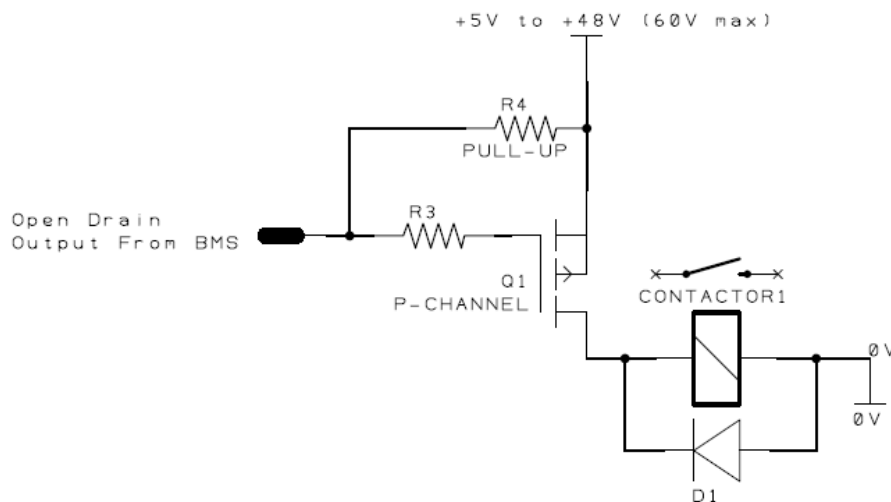


A sample schematic for connecting the open drain outputs with a relay. Note: For Rev A units, the maximum switching voltage is 24V.



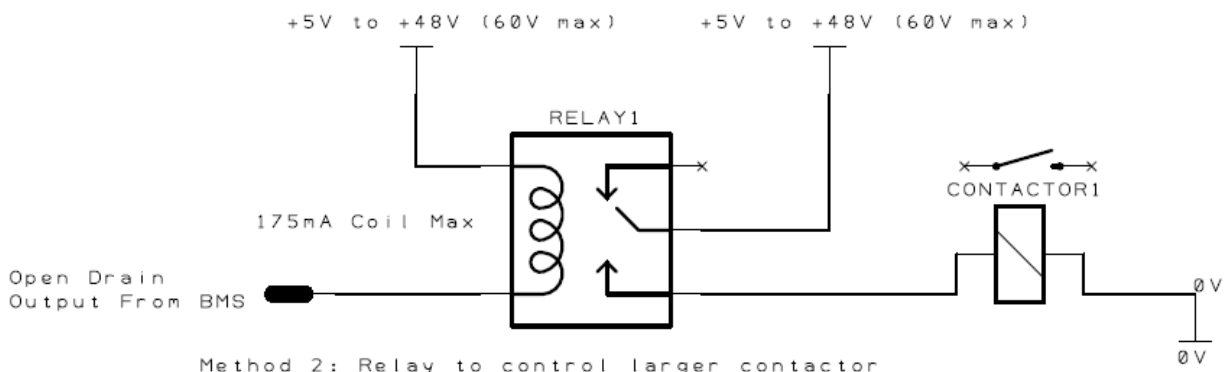
A sample schematic for connecting the open drain outputs with an opto-isolator (resistor values must be calculated based on voltage and opto-isolator requirements). Note: For Rev A units, the maximum switching voltage is 24V.

If the signals will be used to drive relays with coils larger than 175mA, contactors, or other loads, an amplification method must be used so that the BMS does not sink more than the maximum allowable current. A common method for this is to use a MOSFET to amplify the signal to provide power to a larger relay or contactor. A schematic is shown below for this method.



Schematic showing a P-channel MOSFET used to amplify the open drain output. Note: For Rev A units, the maximum switching voltage is 24V.

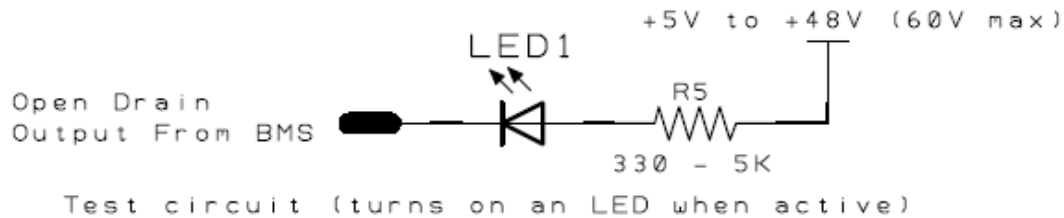
Another method is to use a smaller relay to turn on power for the larger relay/contactor. A schematic for this is shown below.



Method 2: Relay to control larger contactor

Checking open drain outputs

Open drain outputs will read zero volts on a voltmeter whether or not they are on since they sink current rather than source it. A simple method for testing the outputs is to connect an LED or small light bulb (under 100mA) between the output pin and +12v (or any voltage between 5V and 24V for Rev A and 48 V for Rev B.) If an LED is used, a series resistor (often between 330 ohm and 1k ohm) must be used to limit current through the diode. When the output is on, the LED or bulb will illuminate. A schematic for this is pictured below.



Wiring the multipurpose input

The multipurpose input has a user selectable function and can be used for functions such as clearing fault codes or indicating a certain status to the BMS. This input is present only on Rev. B & C units. A voltage of 9 – 60V may be applied to this pin to indicate an “on” status. The voltage of this pin may not exceed 60V at any point and a voltage below 9V may cause the status of this pin to become undefined. The voltage source used to generate the signal for this pin must be fused at the source with a fuse no larger than 3A. Since this input has a current draw of only a few mA, a significantly smaller fuse may be used if the fuse is not shared with other circuits. Fuses must be rated for the full DC working voltage and have a suitable interrupting current rating for the application.

Wiring the analog 0-5V outputs

The Orion Jr. is equipped with three analog 0 to 5V voltage outputs designed to aid in integrating the Orion Jr. with non-digital applications including voltage based displays. The outputs include pack state of charge, charge current limit, and discharge current limit.

Each of the 0-5V analog voltage outputs can provide or sink up to 10mA of current. If more current is necessary or if a different voltage range is necessary, an external analog buffer or op-amp must be used to amplify the signal. The analog voltages are generated inside the Orion Jr. unit by a digital-to-analog converter.

State of charge output (pin 11) - This output provides the calculated state of charge. 0V corresponds to 0% state of charge and 5V corresponds to 100% state of charge. This output often is used to display state of charge in applications where digital communications are not available.

Charge current limit (pin 13) - This output provides an analog representation of the maximum current that the battery can accept at any given time. 0V corresponds to 0 amps and 5V corresponds to the maximum amperage set in the profile for this specific output. Please see the software manual for information on setting this maximum value.

While this output can be reliably used to limit current, it should be used in conjunction with the charge enable signal output (pin 10) which provides an analog watchdog shutoff circuit. Although unlikely, it is possible for the digital-to-analog converter to fail, leaving the voltage in an undefined state.

Discharge current limit (pin 14) - This output provides an analog representation of the maximum current that the battery can discharge at any given time. 0V corresponds to 0 amps and 5V corresponds to the maximum amperage set in the profile for this specific output. Please see the software manual for information on setting this maximum value.

While this output can be reliably used to limit current, it should be used in conjunction with the discharge enable signal output (pin 3) which provides an analog watchdog shutoff circuit. Although unlikely, it is possible for the digital-to-analog converter to fail, leaving the voltage in an undefined state.

Thermistors (Pins 10, 12, 16, and 8)

The Orion Jr. main unit can have up to two (revision A & B) or three (revision C) thermistors directly connected to the unit. These thermistors are designed to provide the BMS with a representative idea of the pack temperature. The thermistors should be spread throughout the battery pack in a manner which provides the most representative temperatures possible. If the battery pack is split into multiple physical locations, at least one thermistor should be placed in each physical location. If the battery pack is in one physical location, sensors should be scattered through different areas of the pack such as the middle and outer portions of the pack.

Some applications may require the measurement of each individual cell temperature while representative temperature readings are suitable for others. It is the integrator's responsibility to determine the necessary number of temperature monitors. If monitoring more temperatures is necessary, an external thermistor expansion module is available which can monitor up to 80 additional thermistors.

The thermistors are 10K NTC thermistors with a B25/50 value of 3380K. Other B values can be used through the use of an external thermistor expansion module. Custom configurations of the main Orion Jr. unit for B values may be available for high volume applications requiring a different B value. One end of the thermistor is connected to the appropriate thermistor pin and the other is grounded to the thermistor ground pin. As thermistors are resistive, polarity does not matter.

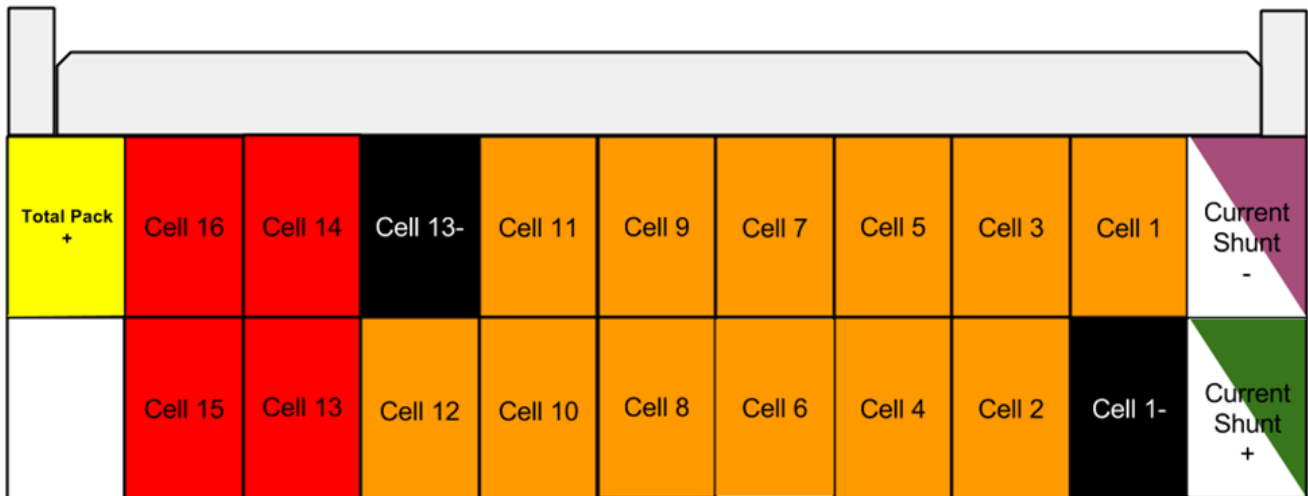
Thermistors can be attached to the battery cells in different ways depending on the type of cell. The thermistors sold with the Orion Jr. have epoxy coated beads at the ends. They can be taped or glued to cells. Some thermistors are attached to ring terminals and can be screwed onto battery terminals. **Care must be taken if the thermistors are attached to ring terminals to ensure that they have sufficient electrical isolation from the battery pack. The thermistor measurement pins are NOT electrically isolated from any other pin on the Main I/O connector, and a breakdown in isolation may cause a short!** Insufficient isolation can cause shorts outside the BMS and/or catastrophic damage to the BMS unit. Fuses to guard against shorts on the thermistors may be necessary in certain applications.

Wiring Voltage Taps

READ THIS ENTIRE SECTION BEFORE WIRING. Several precautions need to be taken for the BMS to function properly, accurately, and safely. While the Orion Jr. does not require the use of an in-pack safety disconnect or fuse, **if a safety disconnect or fuse is used, they must be wired in certain locations.** All battery packs must be suitably protected against over-current. Please see “Safety Disconnect and Fuse Locations” for more information.

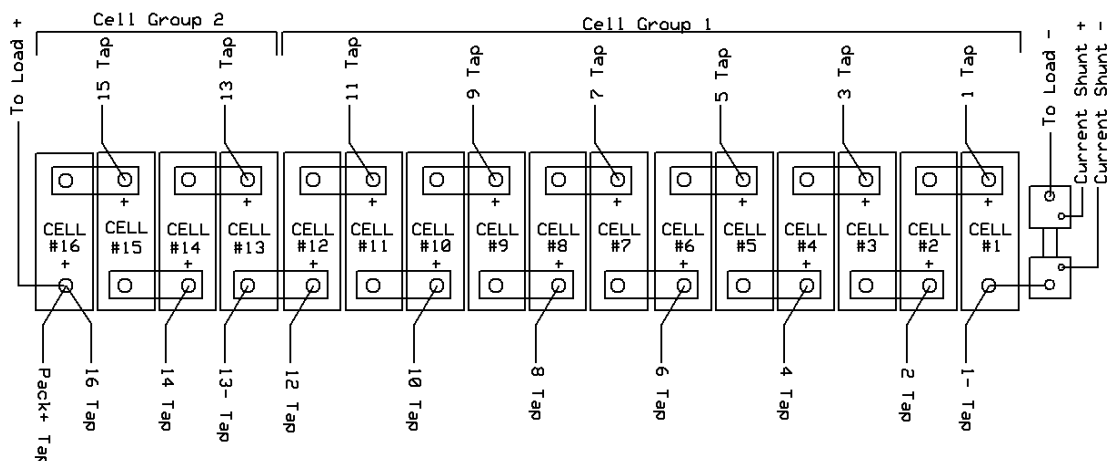
The Orion Jr. BMS is designed to manage as many as 16 cells, up to a maximum possible voltage of 60V DC, whichever is lower. **For the purpose of this document, a “cell” refers to one or more cells directly paralleled together.** Below is the standard wiring diagram for cell taps. One cell tap is provided for each cell with one negative tap for each group of 12 cells (in this case 1- and 13-). Cells are numbered from the lowest stack potential to the highest stack potential (starting at the pack negative and working up in number towards pack positive.)

The Orion Jr. unit can be used to monitor between 1 and 16 cells in series, with the total pack voltage not to exceed 60V at any time.



Looking into back of connector (wires coming towards the viewer)

Wiring - Full 16 Cells



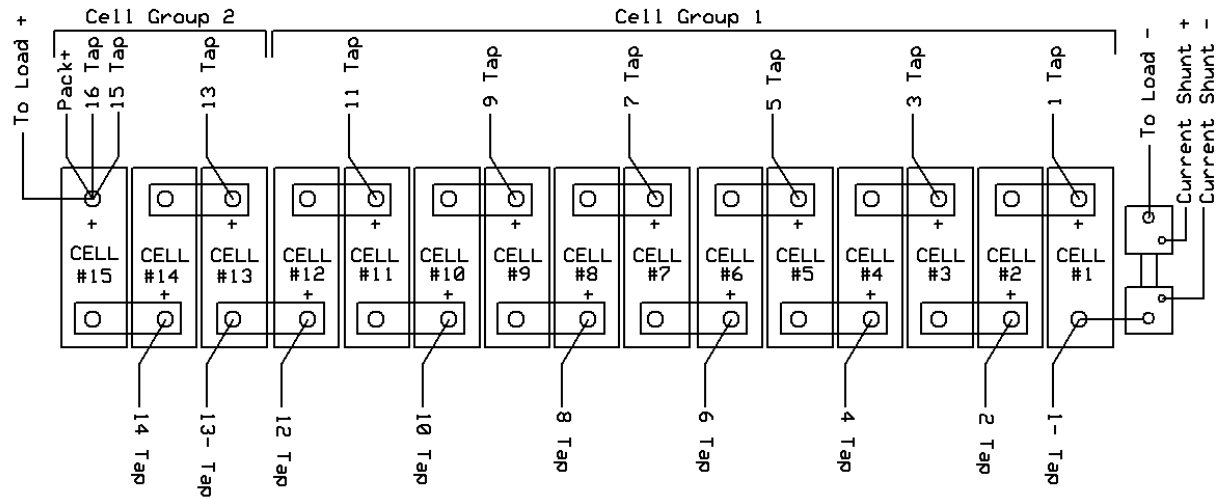
The above image is standard wiring when used with 16 cells.

Rules for fewer than sixteen cells

- If fewer than twelve cells are populated in group 1 or fewer than four cells in group 2, unpopulated cells in that group must all be connected to the positive terminal of the highest potential cell in that group. For example, if only six cells are populated in group 1, taps 6 - 12 are all connected to the positive tap on cell 6.*
- If no cells in the 2nd group (cells 13-16) are used, wires 13-16 (including 13-) should be left disconnected.
- In all cases, the Pack+ wire will be connected to the positive most terminal of the positive most cell.

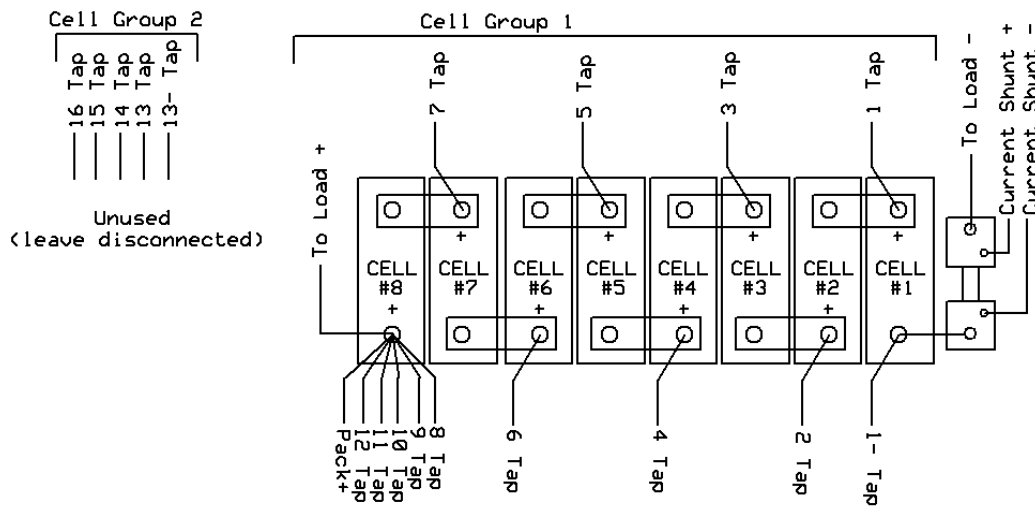
*In this example, cell tap positions 6-11 could be combined into a single wire that runs to the terminal to reduce the number of wires entering the battery area.

Wiring Example - 15 Cells



Wiring example for 15 cells in series. Tap 16 and 15 both attach to positive terminal on cell 15.

Wiring Example - 8 Cells



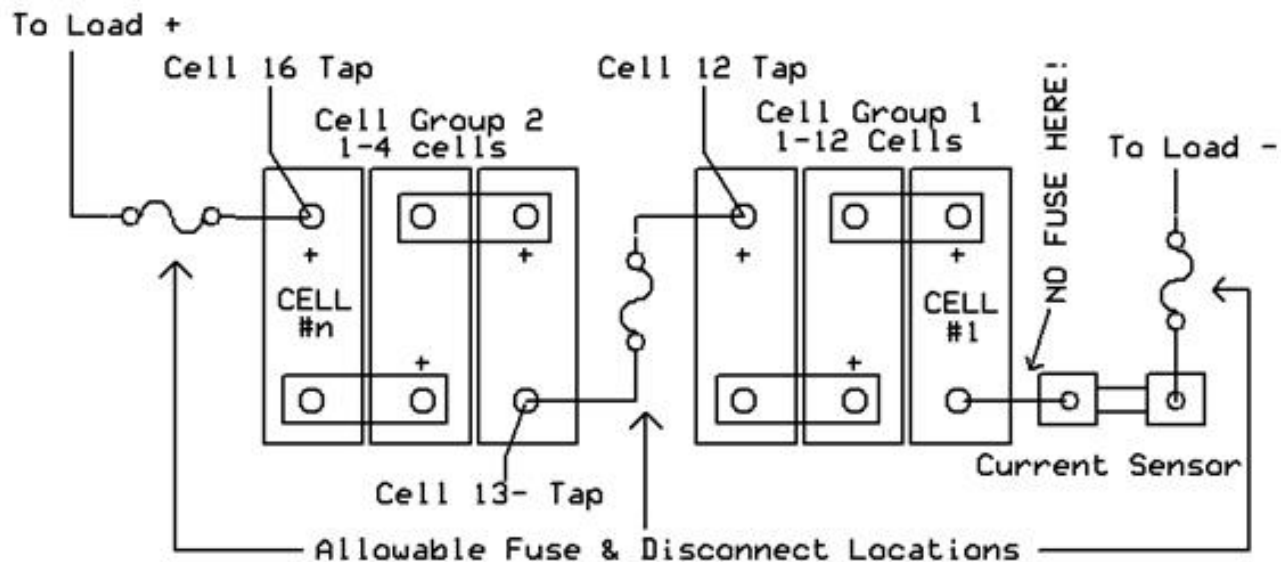
Wiring example for eight cells in series. Taps 8-12 all attach to the positive terminal on cell 8.

Safety Disconnects and Fuse Position

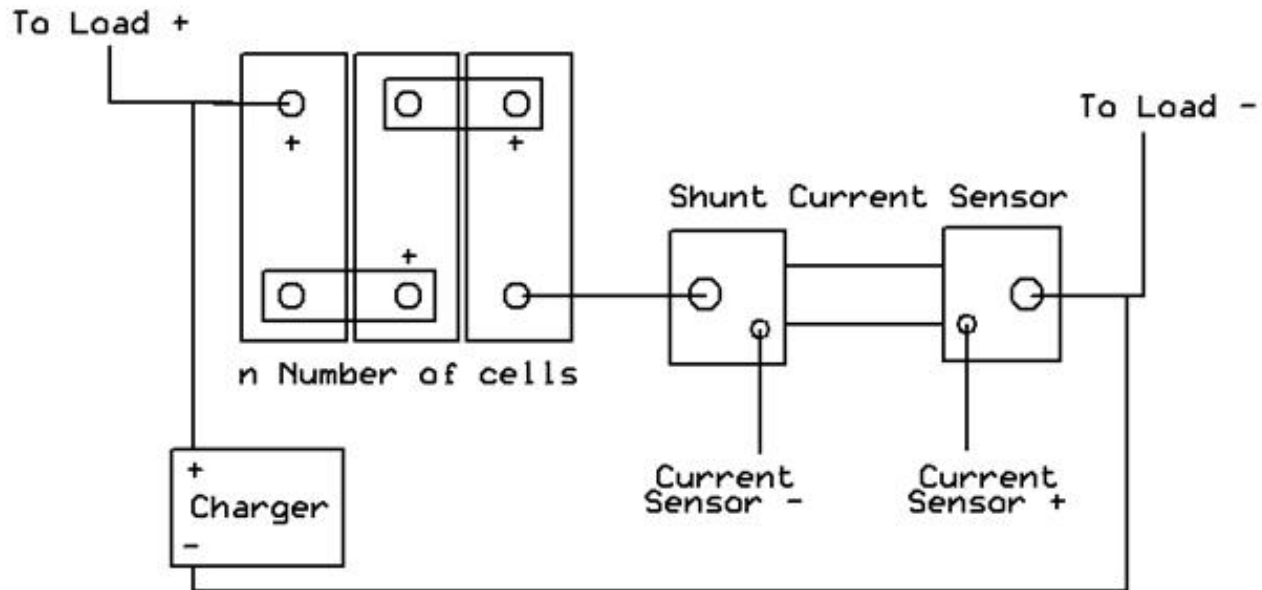
Sometimes a safety disconnect and/or fuse is located in the middle of the battery pack. This is sometimes done for safety reasons because opening the disconnect/fuse effectively splits the battery pack into two smaller packs, making servicing safer by reducing the maximum voltage present and reducing the potential across the positive-most and negative-most terminals to zero (assuming proper isolation.) Often times, fuses are integrated into the safety disconnects since they are often used in conjunction with each other.

The Orion Jr. BMS has internal protection diodes within each cell group that can pass current from one cell to another if the voltage of the adjacent cell is more than 5V or less than 0V. **If a safety disconnect or fuse is incorrectly wired to the Orion Jr. such that it is in the middle of a cell group, current can flow through the Orion Jr. BMS when the fuse blows or when the safety disconnect is removed, bypassing the safety disconnect or fuse and leading to dangerous conditions.** This can cause pack voltage to be present at the terminals of the battery pack even though there should be no voltage present, and large currents can be forced to flow through the Orion Jr. BMS, damaging the BMS unit. Catastrophic damage to the BMS is possible, and damage from incorrect wiring is not covered by the warranty.

If a pack safety disconnect or fuses are used, they must be wired in any of three specific locations - either on the positive-most side of the battery pack, the negative-most side of the battery pack, or between cell taps 12 and 13- as shown below. In all cases, the BMS cell taps must be on the battery side of any pack fuse or pack safety disconnect. If a fuse is installed on the negative side, it must be located on the load side of the current sensor. Please see below for more information.



Current Sensor



The above image shows current sensor wiring.

The Orion Jr. BMS uses an inline shunt resistor to measure current. When current runs through the shunt resistor, a small voltage drop is produced. The BMS measures this small voltage drop to calculate the current flow.

Because the shunt is in-line and is electrically connected to the battery pack, **the shunt resistor may ONLY be electrically wired between the negative terminal of the negative-most cell and the load negative.** While it is permissible for cable to be between the negative terminal and the shunt resistor, no fuses, safety disconnects, contactors, or other disconnecting means may be between the negative terminal and the shunt current sensor as this may cause full stack potential to be applied to the current sensor monitoring circuit, damaging the BMS. Always unplug the BMS before making any wiring changes to any battery wiring. All current, including the charger, must flow through the shunt current sensor to be measured (as pictured above).

While the direction of the current sensor shunt itself does not matter, the connection of the current sensor + and current sensor - wires does matter. The current sensor - wire should be on the side of the current sensor connected to the negative terminal of the battery and the current sensor + side should be connected to the load side of the sensor. The above diagram shows the standard orientation of the current sensors, but if the wiring is backwards, the current sensor direction can be inverted in the Orion Jr. profile using the utility software. In the initial setup of the unit, the direction of current should be verified by using the BMS utility to ensure proper configuration. Test the wiring of the voltage taps and current sensor wires before connecting to the BMS.

The Orion Jr. units are designed to be used with 50mV shunts. 75mV shunts can also be used, but the current measurement is limited by the equivalent 50mV rating ($\frac{2}{3}$ of the 75mV rating.) For example, a 200A 75mV shunt is the equivalent of a 150A 50mV shunt. Either shunt may be used, but

the maximum amperage in either case is 150A. The table below lists currently supported shunt sizes. Support for additional sizes may be available on request.

<u>Max Current</u>	<u>50mV Shunt</u>	<u>75mV Shunt Equivalent</u>
20A	20A / 50mV	30A / 75mV
50A	50A / 50mV	75A / 75mV
100A	100A / 50mV	150A / 75mV
150A	150A / 50mV	200A / 75mV
200A	200A / 50mV	300A / 75mV
333A	N/A	500A / 75mV
400A	400A / 50mV	600A / 75mV
500A	500A / 50mV	750A / 75mV
600A*	600A / 50mV	900A / 75mV
1000A*	1000A / 50mV	1500A / 75mV

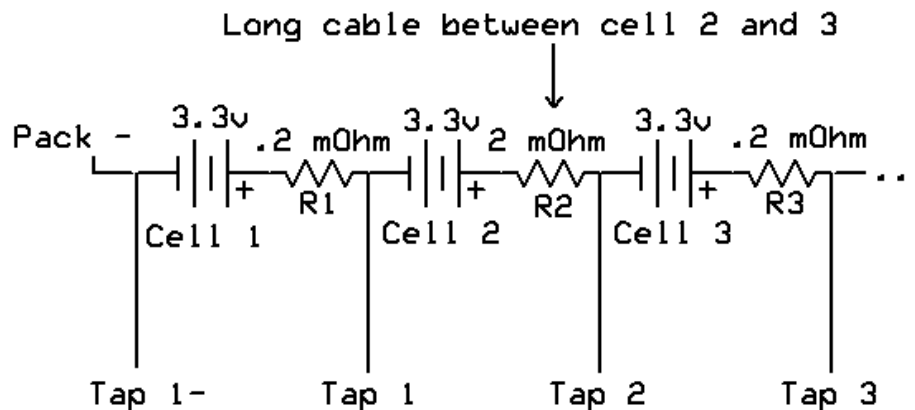
* Current sensors sized above 500 A are supported, but will have a reduced accuracy and resolution.

Wiring for high impedance cables and busbars

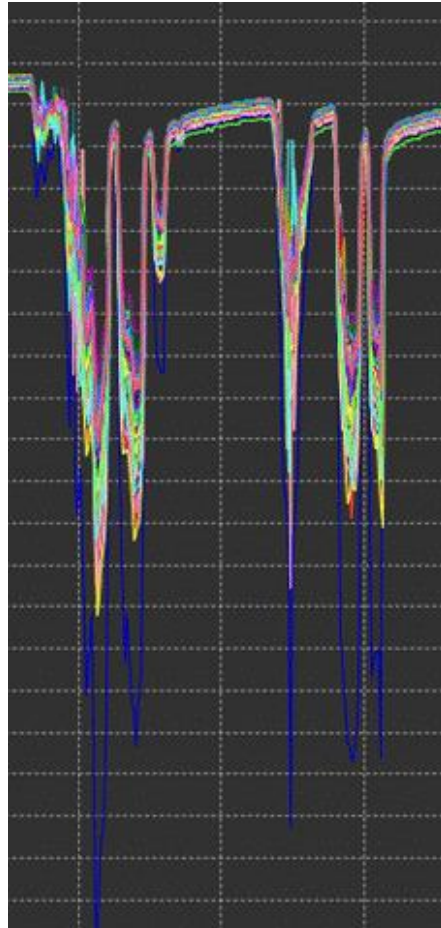
Voltage measurements are taken by the Orion Jr. with respect to the next lowest cell or the negative wire in each cell group. For example, when the Orion Jr. measures cell 1's voltage, it measures the voltage between tap 1- and 1. Likewise, for cell 2, the voltage is measured between tap 1 and tap 2 to determine cell 2's voltage.

While battery cables and busbars may be very large and have a minimal resistance, all cables have some electrical resistance. The cell taps by necessity will “see” the additional resistance from busbars, battery interconnects, and cables unless they fall between cell groups (12 cells). The diagram below shows the first 3 cells wired in a group.

Because of the way the cells are connected, the differences in resistance from one interconnect to another will be reflected in the instantaneous voltage measurements and would show up to the Orion Jr. as extra resistance for that particular cell. In the example below, all of the cells have a resistance of 3 milli-ohm, but due to the busbar resistances, the BMS sees the extra 2 mOhm resistance for a total of 5 mOhm on cell 2. Even though cell #2 is still healthy, it appears to be a weak cell without any compensation. This is where busbar compensation comes in.



For relatively low resistance, this extra resistance can be compensated out by the BMS using “busbar compensation” (see the software manual for information on setting up busbar compensation). For high resistance busbars / cables (or higher amperage applications), it is possible for the voltage drop (or voltage increase if the battery is being charged) to be large enough that it can cause the voltage at the tap to exceed 5V or drop below 0V, which are the maximum and minimum voltages for the Orion Jr. BMS. If the voltage can swing outside those maximum voltages, the Orion Jr. must be wired such that the cable falls between a cell group break (between cells 12 and 13) and be wired such that voltage drop induced by the busbar cannot be seen by the Orion Jr.



Voltage drop under load from an uncompensated high impedance busbar (blue)

Maximum voltage swing can be calculated if the maximum cell voltage, resistance of the busbar / cable, and maximum amperage are known using the following formulas. Please keep in mind that the resistance of the busbar or cable must include the resistance of the terminal and any crimps. Headroom must be left for possible small increases in resistance due to eventual corrosion, etc.

$$\text{Peak_voltage} = V_{\text{max_cell}} + (R_{\text{busbar}} * I_{\text{max_charge}}) \text{ (Peak_voltage must be } < 5\text{v)}$$

$$\text{Lowest_voltage} = V_{\text{min_cell}} - (R_{\text{busbar}} * I_{\text{max_discharge}}) \text{ (Lowest voltage must be } > 0\text{v)}$$

In the above example, if the cells have a maximum voltage of 3.65v ($V_{\text{max_cell}}$) and a minimum of 2v ($V_{\text{min_cell}}$) and a maximum amperage of +/-200A ($I_{\text{max_charge}}$ and $I_{\text{max_discharge}}$), the peak voltage with the given 2 mOhm cable would be 4.05v and the lowest voltage 1.6v. These voltages are within the limits and busbar compensation could be used.

Skin effect issues due to AC currents

The vast majority of motor controllers available on the market provide some amount of filtering on the DC bus in order to limit radiated and conducted emissions. While most motor controllers generate high levels of noise, the noise generally does not lead to a significant AC component on the DC bus. A small minority of motor controllers lack adequate internal bulk capacitance and filtering and actually produce a high frequency AC component on the DC bus.

The Orion Jr. is extremely resistant to electrical noise (EMI) and has been tested in real world situations to operate successfully with this excessive noise. However, a strong high frequency AC component can create a “Skin Effect” on the cables connecting the batteries. Skin effect occurs when eddy currents form within the cables, causing only the outside portion of the wire to carry current and effectively increasing the resistance of the wire.

Although the Orion Jr. has been tested extensively to operate and measure voltages properly in these extremely harsh noise environments, the BMS may correctly measure unpredictably changing resistance values since the effective resistance of the cable is changing considerably with respect to amplitude and frequency. The Orion Jr. BMS bases many calculations on the measured resistance of the cells, including open cell voltage calculations which are used for determining maximum current limits and determining when cells are weak. If a significant skin effect is present, it can introduce inaccuracies with some calculations even though the Orion Jr. BMS continues to operate.

The overwhelming majority of motor controllers have adequate filtering to reduce conducted emissions to levels that prevent a skin effect from forming. For the small number that do not, the skin effect can be mitigated somewhat by using suitable rectangular busbars or straps rather than round cables. In an environment where a skin effect forms, any round cables should be wired such that they fall between cell groups since the BMS cannot effectively compensate them out. Preferably, it may be possible to add external filtering to the motor controller to suppress the conducted emissions generated by the motor controller to a tolerable level. Extremely high amounts of AC noise can also cause back EMF from stray inductance in the cabling. If this occurs, the emissions will need to be limited to a safe level.

Transients

Transients on the battery pack must be limited to reasonable levels. This is important both for the protection of the BMS and the protection of the attached lithium cells. Lithium cells exposed to extreme transients may short and enter thermal runaway. Extreme transients are often generated by the combination of rapid changes in current and stray inductance. These usually occur when bulk capacitors in motor controllers or chargers are switched into circuit or by other rapid changes in current such as from a blowing fuse or sudden connection of current. Transients due to normal switching from contactors can be limited by using proper pre-charge circuits and limiting slew rates for motor controllers. The use of multiple chargers with series diodes is not recommended for use with the Orion Jr. BMS as these configurations can cause damaging transients.

Excessive transients may cause damage to the Orion Jr. BMS unit or to connected lithium ion cells. In the event that excessive transients have occurred, the Orion Jr. unit and lithium cells should be immediately inspected or tested for damage as damage can lead to safety risks.

If a unit has been damaged by transients, it must be disconnected immediately from service and repaired or replaced. Never continue to use a damaged unit.

Wiring Errors

Wiring errors can cause serious damage to the Orion Jr. BMS that is not covered under warranty. The Orion Jr. has internal fuses on each cell tap wire to protect the BMS and connected wiring from excessive currents. The Orion Jr. is designed to withstand certain minor wiring errors such as accidentally swapping the order of 2 cells or even wiring cells in the reverse order. The internal fuses are designed to blow with voltages more than +/- 24V for Rev A units, +/-48V for Rev B units, and +/- 60V for revision C units (though there are some rare situations where fuses can still blow at lower voltages and some situations where they won't blow until voltages are higher). The Orion Jr. can withstand wiring errors only for a short period of time and repeated or extended exposure to wiring errors may cause permanent damage which may alter the accuracy of the voltage measurements. ***If an Orion Jr. unit is wired improperly, small currents may flow through the BMS, and the BMS unit may heat. An incorrectly wired unit should not be left connected to the battery pack for more than 5 minutes as it will eventually drain and can destroy cells connected to it.*** If there is question as to whether the harnesses are wired properly, do not leave them connected to a unit for any length of time. The Orion Jr. units may report an "open wire fault," "wiring fault," or "low cell fault" if incorrectly wired. Revision C units with firmware 2.0.2 or newer may also rapidly flash the red LED to indicate incorrect wiring that is damaging the unit. The absence of a rapidly flashing red LED does not necessarily indicate correct wiring. If the red LED begins to flash rapidly, immediately disconnect the cell tap harness and inspect the wiring. **If a unit has been damaged, do not continue to use the unit.**

Voltage tap harness lengths

Standard voltage wiring harnesses are available for the Orion Jr. in 6 foot lengths. The length of the tap harness slightly affects the accuracy of the voltage readings by the Orion Jr. The length of cable does not significantly alter the accuracy of the voltage measurement.

Internal Isolation

The Orion Jr. has nominal isolation between cell voltage tap sensors and the control electronics and between cell groups 1 and 2 for functional purposes only.

Fuses on voltage tap wires

The Orion Jr. BMS has internal fuses on each of the positive cell tap wires. While these fuses protect the BMS, guard against excessive current flowing through the internal protection diodes, and are designed to blow if the maximum voltages are exceeded, ***the internal BMS fuses do not protect against two tap wires that short together outside the BMS***, against shorts at the connector on the BMS, or against excessively high cell tap voltages. While many major OEM vehicle manufacturers have carefully calculated and rely upon the fusing characteristics of the cell tap wires, fuses are strongly recommended as this technique requires much testing and engineering. **Some applications will require the use of fuses on the cell taps. It is the sole responsibility of the integrator to determine if these external fuses are needed.**

If external fuses are used, they should be kept as low resistance as possible with reason and rated no larger than 3A. Fuses must always be rated for the maximum possible DC working voltage with a suitable DC interrupting current rating. Certain electrical codes or regulations may dictate the maximum fuse size, and it may be smaller than 3A depending on wire gauge and other considerations. Fuses sometimes have relatively high resistance, and the additional resistance can reduce the accuracy of monitoring the cells. Additionally, fuses may be necessary on thermistors to protect against a possible short between a thermistor and a terminal of a battery. It is the sole responsibility of the integrator to determine if fuses are necessary on the cell tap wires.

Physical routing and installation of wires

The integrator is solely responsible for designing proper external wire routing, including the selection of suitable wire types and selection of other external components including wire types and wire conduits.

For safety reasons, all external wires must be adequately protected from damage including abrasion from rubbing, vibration, or sharp objects. The integrator must consider all possible environmental aspects including, but not limited to, corrosion or loosening of joints or screws, galvanic reactions, expansion and contraction of wires, busbars, and interconnects due to temperature, condensation, etc. The integrator must also ensure the separation of components and wires from flammable materials. The integrator is solely responsible for ensuring that the application complies with any applicable codes, regulations, and standards.

Verifying Cell Voltage Tap Wiring

The wiring must be verified prior to connecting any of the wiring harnesses to the Orion Jr. BMS. Improper wiring can cause damage to the BMS unit, catastrophic failure, or even personal safety risks depending on the extent of the wiring mistake.

The most important connector to verify is the cell voltage tap harness, which includes the current sensor wires. There are two methods for doing this:

The first is the tap validation tool which is available for rental or purchase. The tool can be connected to the wiring harness already connected to the battery pack and will verify that cells are wired in the correct order and can detect most wiring mistakes. The validation tool is designed to withstand incorrectly wired harnesses without damage. **It is strongly recommended to use the validation tool before plugging the harness into the Orion Jr. BMS as it is very easy to make an error wiring the harness, and errors may not be obvious.** Please refer to the cell tap validation tool manual for more information on proper testing. While the tester can catch most wiring faults, it cannot detect all intermittent and high impedance faults.

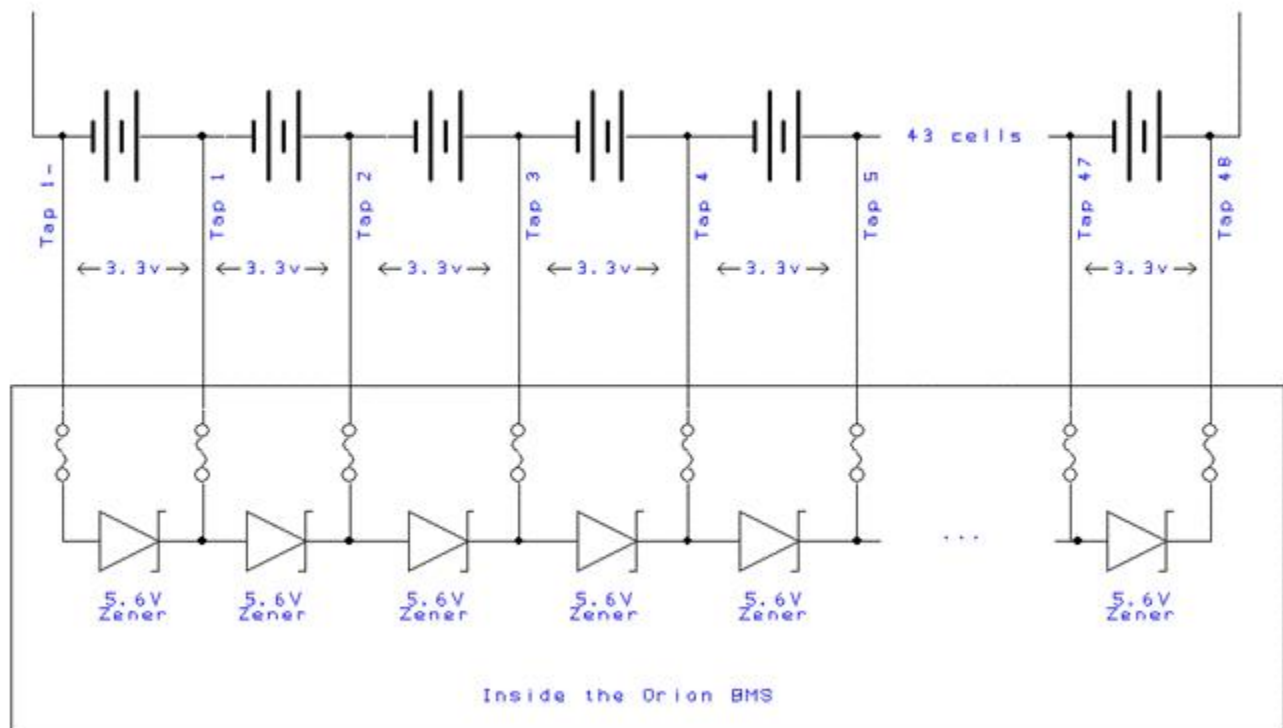
Wiring can also be verified by carefully using a multimeter, but the use of the tap validation tool is the recommended method. **Care must be taken not to short any pins with the multimeter. Personal safety equipment including protective eye-wear and gloves and arc-flash resistant clothing should be worn for protection in the event of an arc flash.** In order to avoid two probes on the connector, the negative probe should be attached to the negative most terminal of the negative most cell in the pack rather than on the connector. Then, being careful not to short pins or touch the probe, carefully measure each of the pins on the connector starting with the current sensor - and + wires and the pin for 1-. The current sensor -, +, and the 1- pin should all read 0V since the negative probe of the multimeter is connected to the same potential. Pin 1+ should read the voltage of the first cell (3.3V for example), pin 2 should read the sum of the first two cells (6.6V for example), and so forth. The connection for cell 12 and 13- should read the same voltage since they are connected to the same potential.

When connecting the harness to the BMS for the first time, (after verifying correct wiring), first adjust the cell population settings in the BMS software so the BMS is aware which cells it should be expecting to see. Once you have uploaded the profile to the BMS (see the software manual for more information on this), use the live cell voltages screen to verify that all cell voltages are reading correctly. Then verify on the diagnostic trouble code screen that no “open wire faults,” “wiring faults,” or “low cell” faults are present on the BMS. Open wire or wiring faults indicate that the BMS has detected a problem with the cell tap wiring. ***If errors are found or if cell voltages are not matching properly, do not leave the BMS connected to the pack for long periods of time as it may drain cells and cause damage to them. If the BMS begins to rapidly flash the red LED (Rev C units only), immediately disconnect the cell tap harness as this indicates that the BMS may be getting damaged by incorrect wiring.*** Note that the absence of a rapidly flashing red LED does not necessarily indicate correct wiring

Why Orion Jr. BMS Internal Fuses Blow

The Orion Jr. BMS has an internal fuse for each of the cell voltage tap wires. These fuses are designed to blow in over-voltage and reverse-voltage conditions. Sufficient current to blow the fuses will only flow through the tap wires during an over-voltage or reverse-voltage condition.

Below is a diagram showing a sample 48 cell battery pack connected to an Orion Jr. BMS unit. While this example is a higher voltage than the Orion Jr. BMS can handle, the same principal applies. The internal fuses and protection diodes inside the unit are depicted below. In the diagram, all cell tap voltages are within 0 – 5 volts with respect to the next lower cell. As a result, none of the zener diodes conduct and no significant current is flowing through the BMS. Since no current is flowing, all fuses remain in a closed state.



What causes the fuses to blow?

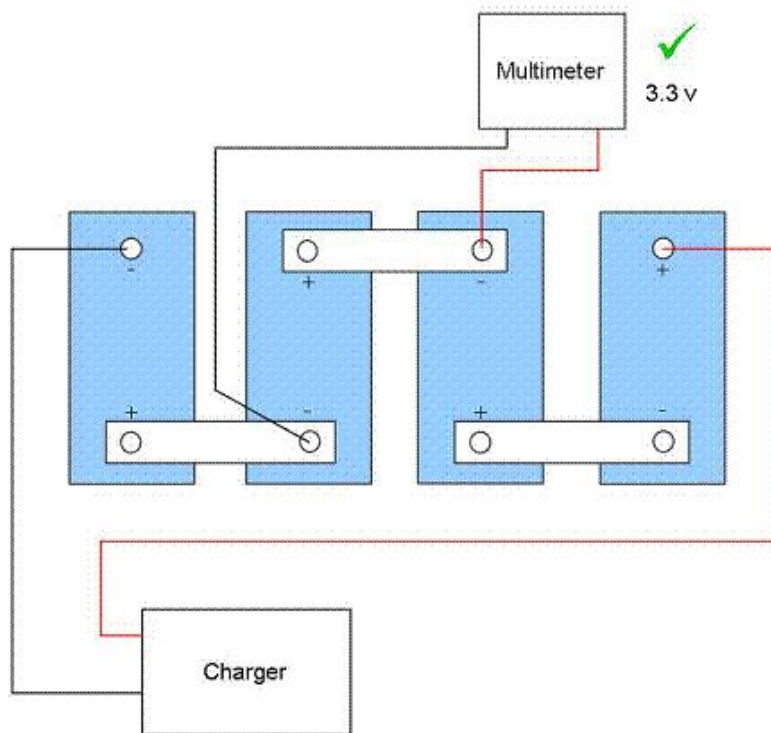
The only time the internal fuses on the tap wires will open is from an over-voltage or reverse-voltage condition. When an over-voltage or reverse-voltage condition occurs, the zener diodes will begin to conduct, causing current to flow through the tap wires and causing the fuses on the taps to blow. This is necessary in order to protect the voltage measurement electronics from damage. Over-voltage and reverse-voltage conditions are both with respect to the adjacent lower cell tap and the adjacent higher cell tap. There are many situations that can lead to over-voltage and reverse-voltage occurring, some of which may be unexpected. While the following few pages are not an exhaustive list, they cover the most common causes.

Reason: Altering wiring with the BMS connected (or loose busbar)

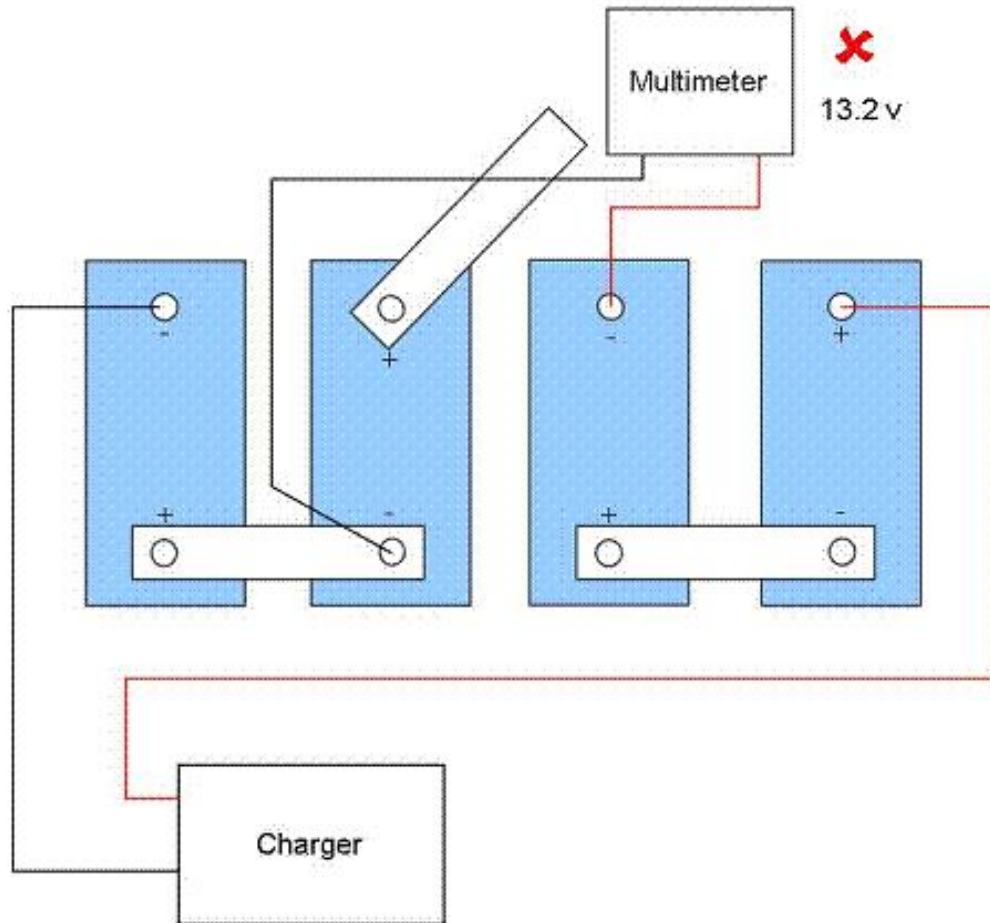
By far, the most common cause of blown fuses and/or more serious damage to the Orion Jr. BMS is when battery pack wiring is altered with the Orion Jr. BMS still connected. While it may seem counter-intuitive, removing a busbar with the BMS cell tap wires connected can result in the voltage of the entire battery pack across two adjacent cell tap wires due to capacitors in a battery charger, resistance from a connected load (motor controller, DC:DC converter, lighting, etc.), stray capacitance, a breakdown in isolation within the battery pack, or other such causes. Since these voltages are well beyond the maximum rated voltage between two cell taps, damage to the unit is likely to occur.

It is very important, both for safety and for the health of the BMS, that all cell tap wires are always disconnected before any modifications are made to the wiring of the battery pack. We recommend designing the battery box enclosure to require the cell taps to be disconnected before the battery wiring can be modified or applying warning stickers throughout the battery pack indicating that the BMS must be disconnected before the battery pack is serviced.

The below example shows a 13.2 volt battery pack. A volt meter is measuring 3.3v from cell tap #1 to #2 in the example.

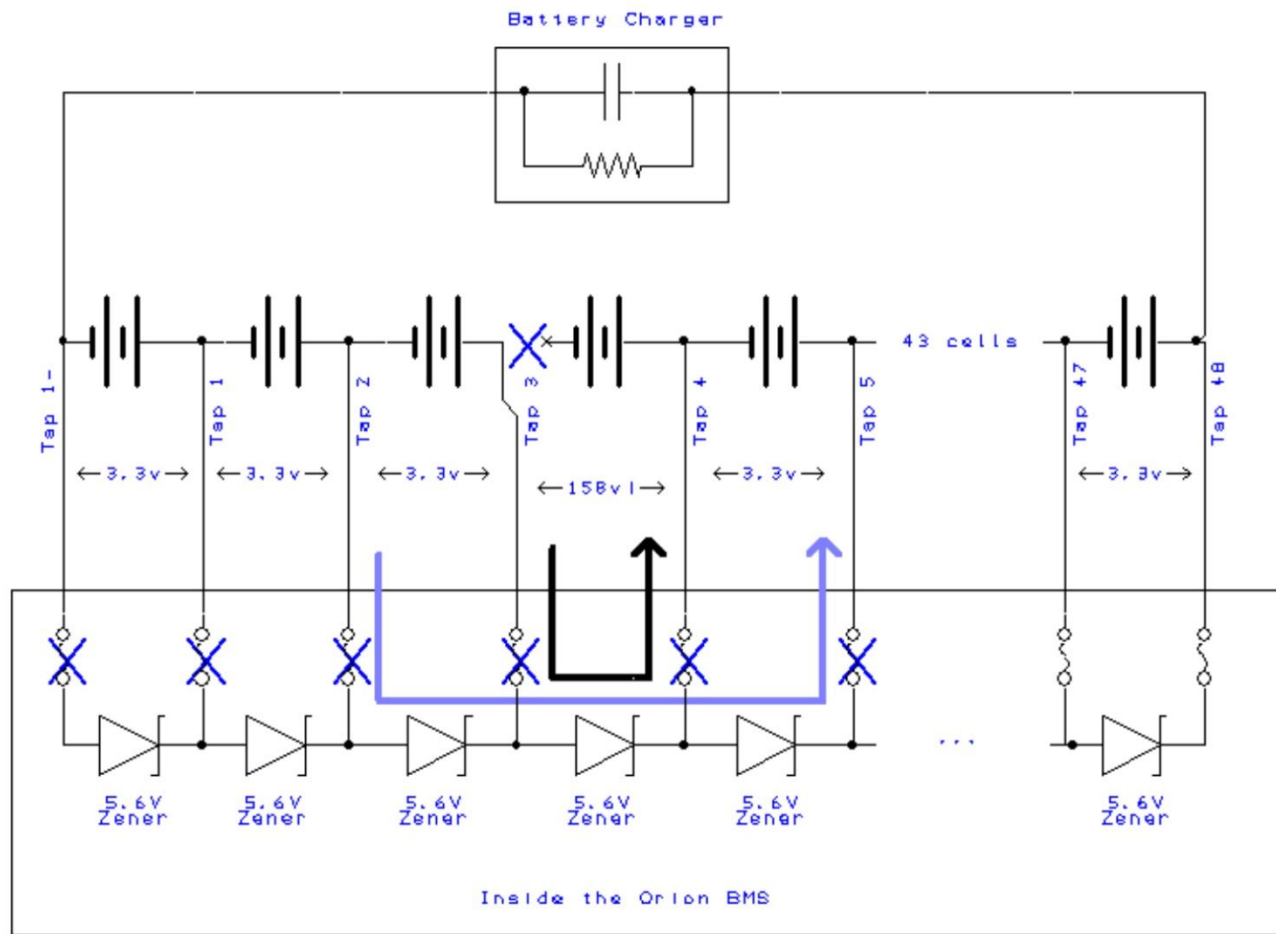


The next diagram shows what happens when the busbar is disconnected. As the busbar is now open, battery voltage is no longer present at the battery charger, but the internal capacitors in the charger are still charged at the pack voltage (13.2 volts) and have no place to discharge. Because of this, the full battery voltage is present across cell tap #1 and #2 (the multimeter leads in the diagram). Because the voltage is now the full battery voltage, the zeners inside the BMS break down and conduct, causing the fuses inside the BMS to blow.



In the above example, the total pack voltage is only 13.2 volts, which may not cause damage on an Orion Jr. BMS. However, if this same scenario were to occur on a higher voltage battery pack, internal fuses may blow. The below electrical diagram shows the same situation, but with a larger 158v battery pack (Note: the maximum voltage for the Orion Jr. BMS is 60v). When the voltage between the cell taps rises rapidly, the zener diodes inside the BMS begin to conduct, discharging the battery charger's capacitors, resulting in blown fuses. In this case, it is possible to blow all fuses within a particular cell group. Typically current will first flow through the two closest cell taps as it is the path of least resistance (black line in the following diagram) and then seek alternative paths as fuses blow (light purple line.)

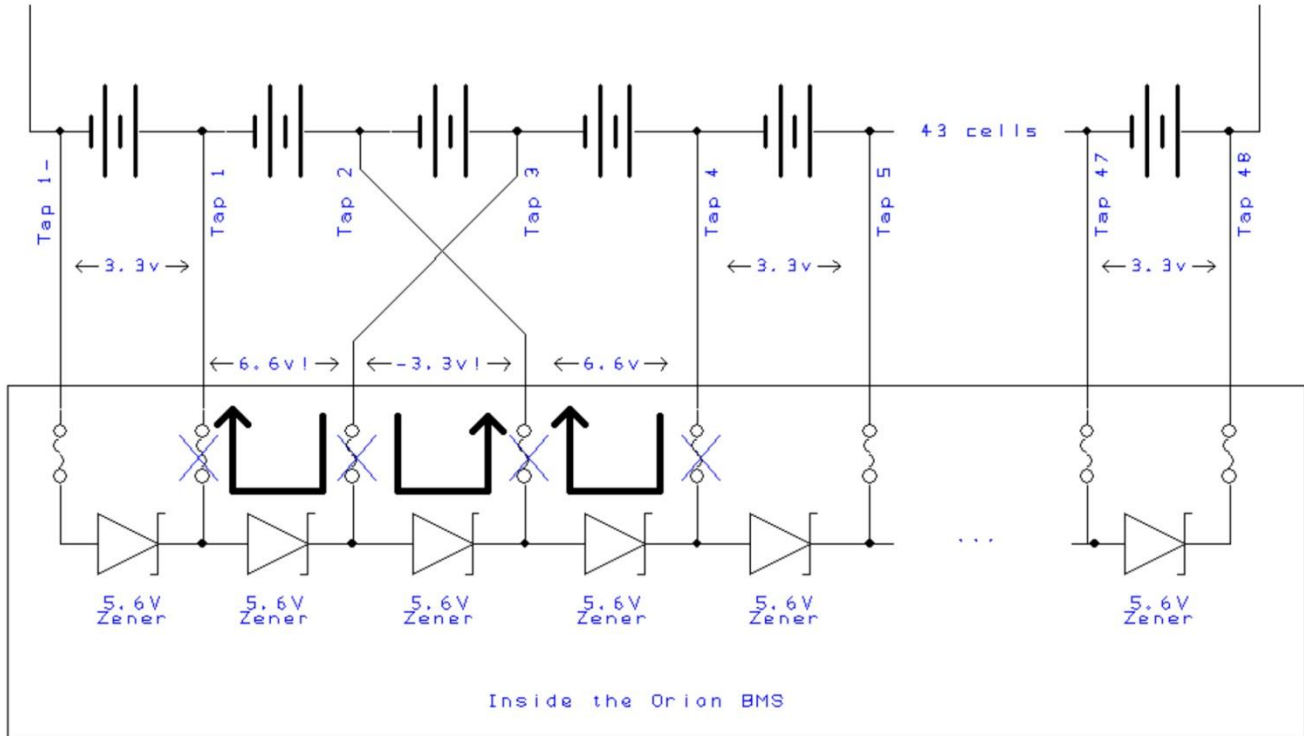
It is important to note that a battery charger or load does not need to be connected to the battery pack to cause high voltages between cell taps when a busbar is removed. Isolation faults, built up charge against the chassis (stray capacitance), or capacitors on snubber circuits can all be enough to cause damage. Damage from this can be prevented by ensuring that the cell tap harnesses are fully disconnected from the BMS before any wiring is altered on the battery pack. Additionally, this can be caused by intentional re-wiring of the battery pack or by loose busbars (which also pose a fire risk from arcing.)



While this diagram shows a 158v battery pack, please note that the maximum voltage for the Orion Jr. BMS is 60v. However, the same principles apply.

Reason: Cell tap wires reversed

The Orion Jr. BMS is designed to survive a single tap wire reversed for short periods of time, but the unit may not survive for longer times or if multiple wires are crossed. Never leave a BMS unit connected with reversed tap wires. Even though the BMS may survive, this condition will drain attached cells.



In the above schematic, cell taps 2 and 3 are reversed. This leads to 6.6v between cell taps 1 and 2 and 3 and 4 with a reverse voltage between taps 2 and 3. In this case, 4 of the zener diodes will conduct and current will flow through the tap wires. This condition leads to up to 4 fuses blown (but may be as few as 2 fuses depending on the order that they blow.) In this situation, fuses will generally reset to their normal state once the above fault is fixed.

Reason: Accidental contact to cell tap

If a cell tap wire accidentally comes into contact with a different voltage cell while the harness is plugged into the BMS unit, significant voltage may be present. This can also happen if a tap wire is cut or abrades and shorts to another wire or another terminal. Cell tap wiring must not be altered with the BMS connected both for safety reasons and to prevent damage to the BMS. Care must also be taken to route the cabling in such a way that it cannot abrade or be cut by objects.

Reason: Transients (and shorts within the high voltage battery pack)

Transients may also cause fuses to blow inside the BMS. Transients are very rapid voltage spikes that can occur as a result of switching loads, rapid changes in current or other causes. Small transients occur regularly due to loads switching on and off, and the BMS is designed to withstand these common transients. Very large transients, typically caused by shorts within a battery pack or by hard switching very large loads, can be very high voltage and can cause damage, not only to the BMS, but also to lithium-ion cells.

Reason: Extremely weak cell, internal cell failure (fairly rare)

When current is flowing through the battery pack, high resistance connections within the battery pack can cause “voltage drop” that will cause higher or lower voltages at certain cell taps. This most commonly occurs with extremely weak cells or faulty cells which have become internally open. This failure is fairly rare. If cells have become over-discharged or over-charged, the cell impedance will become very high. The BMS will not allow charge or discharge if it detects a seriously under-charged or over-charged cell. However, if the user ignores the BMS and continues to charge or discharge, the cell can cause significant voltage drop (or in some cases reverse voltages) that can cause fuses to blow.

Fuses in the Orion Jr. BMS

The Orion Jr. BMS contains standard fuses, but also contains additional resettable fuses which protect against certain kinds of temporary lower voltage wiring faults. In **most** cases where the over voltage or reverse voltage conditions are less than 24 volts for less than 10 minutes, the resettable fuses will reset to normal after the fault is cleared. In situations where faults result in higher voltages across two cell taps, the standard fuses are designed to blow. If this occurs, the BMS must be returned for service.