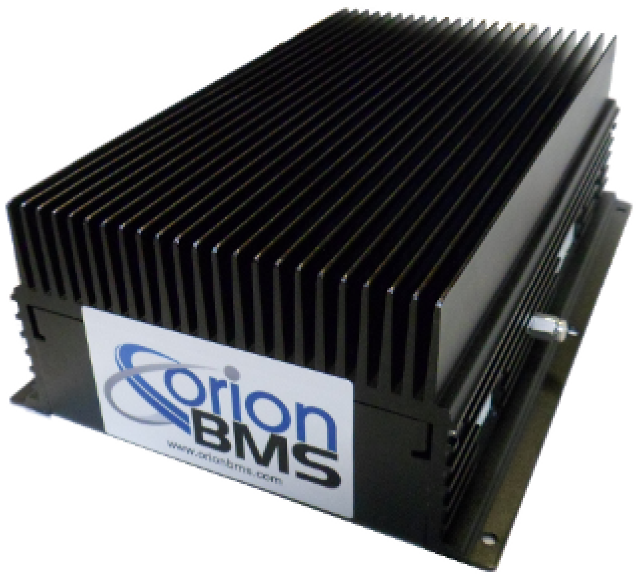
Wiring & Installation Manual

(Document Revision 1.9)



Product Description

The Orion BMS by Ewert Energy Systems is designed to manage and protect Lithium ion battery packs and is suitable for use in electric, plug-in hybrid and hybrid electric vehicles as well as stationary applications.

READ THIS FIRST

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

1.) **The BMS chassis must be grounded** to properly bypass electrical noise to the chassis ground. A grounding lug is provided for this purpose. Additionally, eternal tooth lock washers can be used on mounting screws to ensure good electrical connectivity between the chassis and the Orion BMS. Ground straps should be as short as possible using as large gauge wire as possible.

2.) **The BMS must have a way of shutting off any connected charger, load, source or any other means of charge and discharge.** 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.

3.) The **voltage tap connectors should be DISCONNECTED from the BMS when being wired or when wiring is being modified** for personal safety and to prevent damage. **Wiring while connected to the BMS may pose a personal safety hazard** since the remaining wires within the cell group can become '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 or misuse is not covered under warranty.

4.) Always **verify voltage taps are wired correctly** ***before*** plugging them into the Orion BMS. 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 issue from energy from the battery pack. Please see the section "Verifying the wiring" for methods of testing to ensure the voltage taps are wired properly.

5.) While the Orion BMS does not require the use of safety disconnects or fuses within the battery pack, if they are used, safety disconnects and fuses must be located on a multiple of 12 or ideally 36 cells (or the BMS must be wired such than safety disconnects fall on those breaks.) Read **Safety Disconnects and Fuse Position** for more information. Failure to comply may cause damage to the BMS if a fuse blows or if the safety disconnect is removed and will not provide required safety isolation. Read the entire section on BMS wiring before wiring.

6.) Make sure that all cells are connected to the BMS and that all current is measured by the hall effect 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.)**

7.) While every effort is made to ensure that the Orion BMS operates properly under all conditions, it is the user'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 Orion BMS 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.**

8.) Paralleling separate strings of li-ion batteries together requires extra considerations and a method to isolate each string from each other. If you are using the Orion BMS 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.)

9.) Because the Orion BMS is connected to a high voltage battery pack, hazardous voltages may be present inside the unit. There are no user serviceable parts inside the unit and opening the enclosure will void the warranty. Further, a damaged unit may pose additional risks and a users should never attempt to repair an Orion BMS unit.

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

Determining which BMS to order

In order to reduce costs, the Orion BMS is offered with various numbers of cell group locations populated. Please carefully read “Wiring the BMS” before determining how many cell BMS you require. Ideally, the BMS can be ordered sized to the actual number of cells you have, however, depending on the placement of fuses, safety disconnects or and any high resistance busbars / wires, the BMS may need to be sized for substantially more cells than the pack actually has. For example, a battery that has 48 cells may require a BMS that supports 60 or 72 cells depending on where there any high impedance busbars, fuses or safety disconnects are located. The Orion BMS is available in increments of 12 cells from 12 cells to 180 cells. Multiple units can be connected together in series to support more than 180 cells.

The following table shows the standard available ordering options. Additional custom configurations can be requested

108 Cell Size Enclosure

BMS Size	Cell Groups Populated		BMS Size	Cell Groups Populated
12	1		48-S*	1, 2 and 4, 5
24	1, 2		60	1, 2, 3, 4, 5
24 -S*	1 and 4		72	1, 2, 3, 4, 5, 6
36	1, 2, 3		84	1, 2, 3, 4, 5, 6, 7
36 -S*	1, 2 and 4		96	1, 2, 3, 4, 5, 6, 7, 8
48	1, 2, 3, 4		108	1, 2, 3, 4, 5, 6, 7, 8, 9

* -S ordering options are arranged differently to provide 2.5kV isolation between cell groups

180 Cell Size Enclosure

BMS Size	Cell Groups Populated
120	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
132	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
144	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
156	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13

168	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
180	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15

Included with the standard BMS

- Hardware
- Voltage tap connectors & crimps (number depends on the number of cells ordered)
- Power connector & crimps
- Current sensor connector & crimps (BMS side); current sensor side included if current sensor is ordered with BMS.
- HV Pack voltage sensor connector & crimps

Ordering Options

- The Orion BMS is available with different number of cell groups populated to reduce costs. For example, a BMS with 72 cells is available such that an application requiring less than that does not require a 108 cell version.
- Non standard CAN termination point options
- 2 size enclosures are available - maximum of 108 or 180 cells
- Current sensor options +/- 200A, 500A, 750A and 1000A
- Various thermistor options are available
- Pre-assembled wiring harnesses are available
- See “Purchasing Guide” for details on ordering options

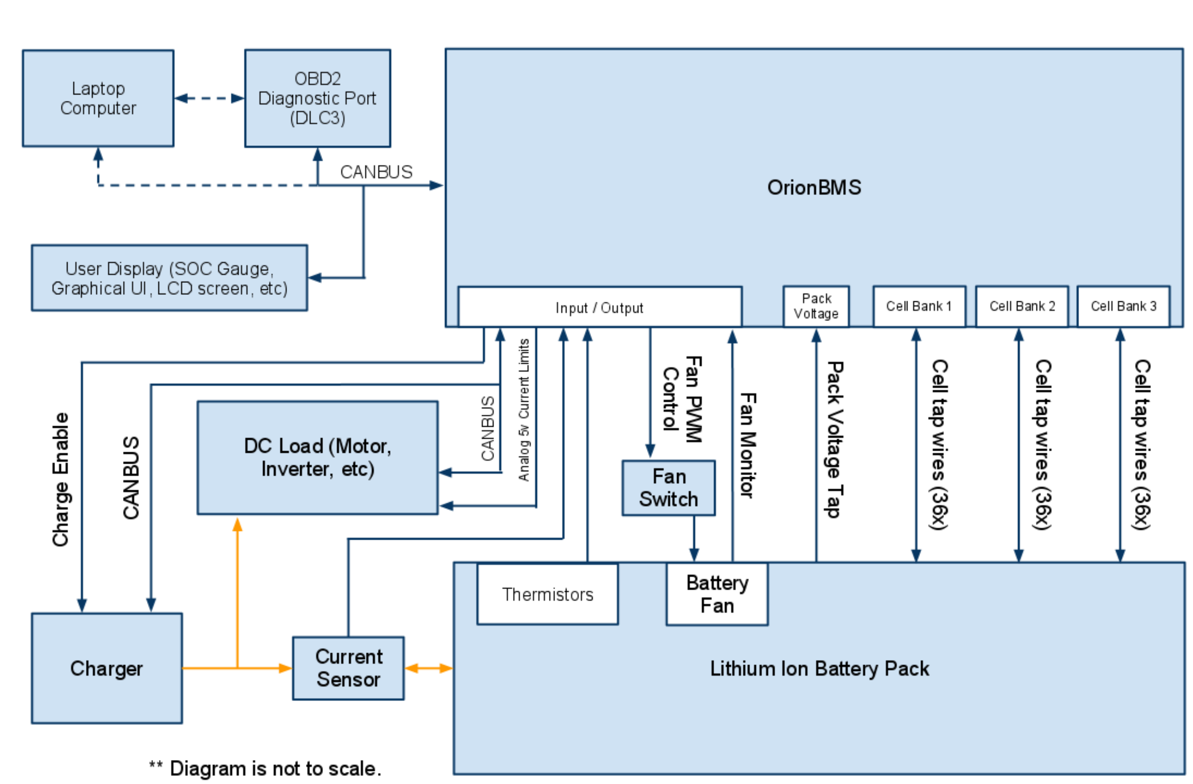
Overview of Theory of Operation

The Orion BMS 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 hall effect current sensor and thermistors. Using the programmed settings, the BMS then controls the flow of current into and out of the battery pack through broadcasting charge and discharge current limits (via the CAN bus or via analog reference voltages) or via simple on/off digital signals depending on which style is appropriate for the application. The BMS relies on the user to provide external controls that respect the current limits set by the BMS to protect the batteries as 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.

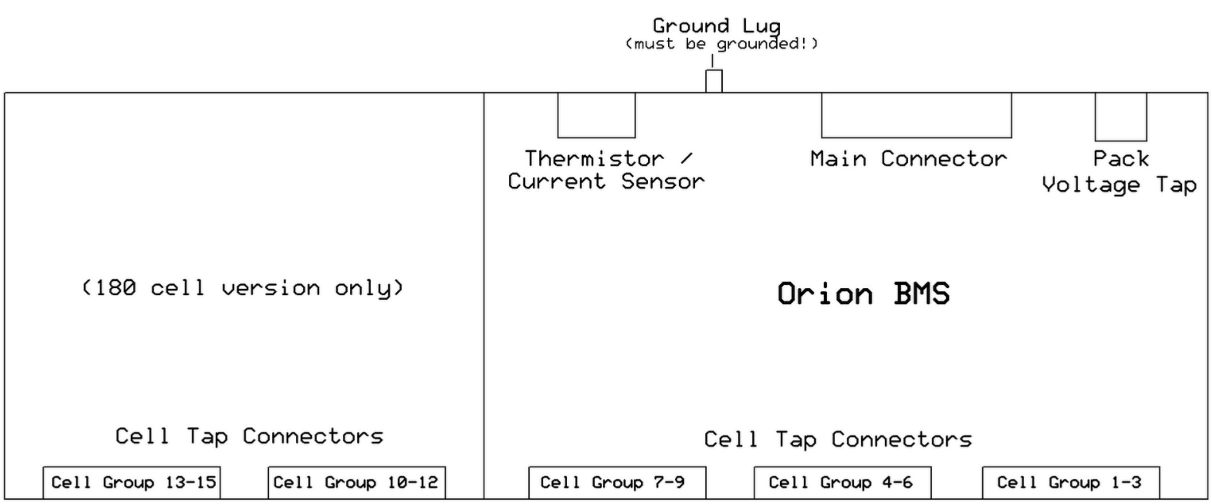
The Orion unit monitors each individual cell tap to insure that cell voltages are not too high or too low (in accordance with the values programmed in.) Using the cell voltages, the amperage going in and out of the pack (provided by the current sensor) and programmed values in the battery pack profile the BMS calculates the pack and individual cell's internal resistance, and open cell voltages. From those calculations, the 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 CAN bus and can be programmed to trigger on/off digital outputs to allow or deny charging and discharging of the battery pack.

Additionally, the BMS has many redundant safeties, most of which are transparent to the user. For example, the BMS monitors each individual cell voltage as well as the total pack voltage. If the 2 voltages disagree by a set amount (determined in the programmable profile), the BMS will set an error code and go into a fail safe mode. The BMS also can be programmed to monitor for a breakdown in isolation between the battery pack and BMS's ground, to detect a failure of the current sensor and many other internal failures. Please see "failure modes" in the operational manual for more information on failure modes.

Wiring the BMS



Overview of system connections



Connector locations on the Orion BMS as looking at the BMS from the bottom

Physical Mounting and Thermal Information

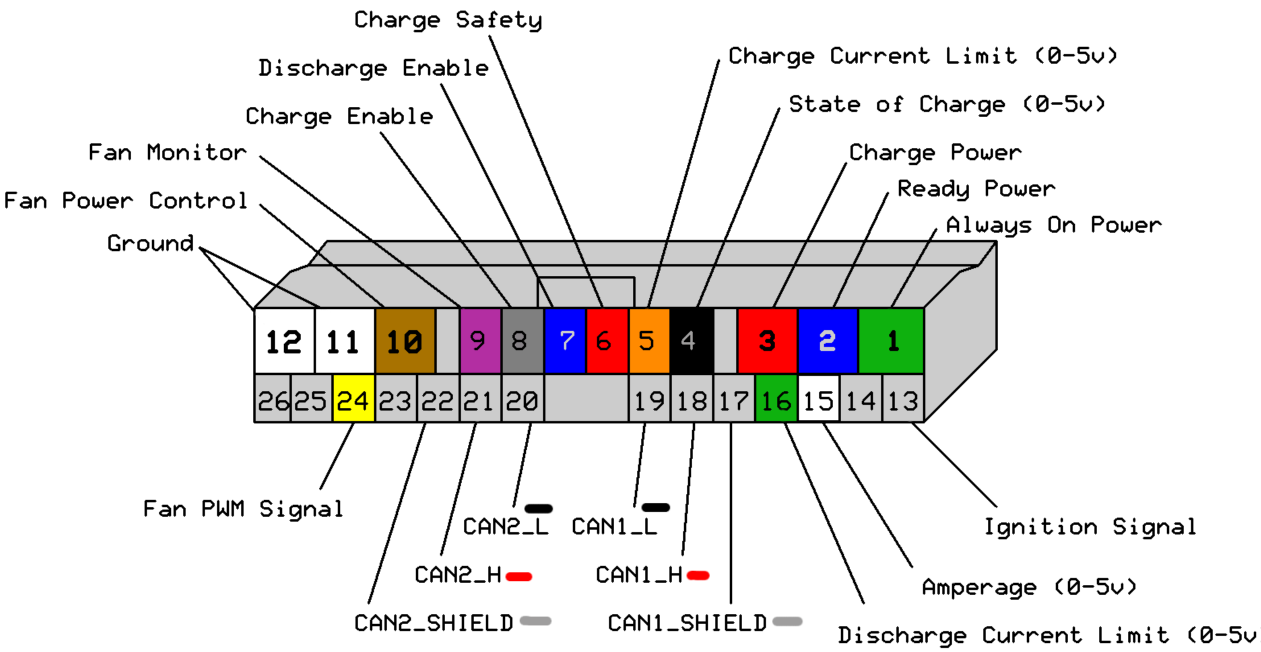
The Orion BMS can be mounted in any orientation. 6 mounting holes are provided on the mounting flanges of the BMS. The BMS is rated for the automotive temperature range of -40C to +80C and is designed for use in moderately protected locations such as inside the passenger compartment of a vehicle. If the BMS will be exposed to harsh environments such as sprayed liquids, salt spay or other similar conditions, it must be located inside a sealed rated enclosure.

While the BMS has a fairly significant looking heatsink, the BMS is designed to dissipate all heat generated via convection in hot environments, and therefore does not generate as much heat as might be expected. A 108 cell BMS unit generates a maximum of 40 watts of heat and a 180 cell unit generates a maximum of 60 watts of heat average. Significant amounts of heat are only generated during the balancing phase during charge while heat dissipation under non-balancing conditions is only about 2 - 3 watts. The Orion BMS is equipped to measure the temperature of the unit and will automatically reduce balancing current if the temperature rises too high. The thermal dissipation should be considered if the BMS will be enclosed in a liquid tight enclosure.

Ground Lug

A ground lug is provided on the outside of the enclosure. **The BMS MUST be grounded to a vehicle chassis or Earth ground (if stationary) for proper electrical noise rejection.**

Main I/O Connector



Signal Name	**Description**
CAN1_H, CAN1_L	First CAN interface with high and low signal lines. With the default ordering option, this interface **includes** a termination resistor.
CAN2_H, CAN2_L	Second CAN interface with high and low signal lines. With the default ordering option, this interface is **without** a termination resistor.
Always On (AM) Power Source	Always on battery source. This should be connected to a +12v nominal power source which is always powered (otherwise accumulated data is reset.) If this line is not powered while READY or CHARGE power source is present an error code is set.
READY Power Source	This +12v power source should be connected to a +12v nominal power source whenever the BMS should be active for normal use. This line will cause the BMS to wake up and resume from sleep.
CHARGE Power Source	This power source should be connected to a +12v nominal power source to signal that the BMS should enter charging mode. If this power source is connected while the READY power source is also connected, the BMS will activate the “Charge Interlock” state.

Power Ground (2x)	This is the ground for the supply power sources for the BMS. All 3 power sources (AM, READY and CHARGE) use this ground. For convenience, 2 ground pins are provided for tying multiple grounds together, though only one is needed.
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 regen in an electric vehicle or enable a charge contactor 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 (100mA max) and should be amplified for controlling large contactors or relays (see electrical specs.)
Charge Safety Signal (Out)	An open drain digital on/off signal used as a safety switch for a charger. This signal must be connected to the charger or be 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 (100mA max) and should be amplified for controlling large contactors or relays (see electrical specs.)
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 (100mA max) and should be amplified for controlling large contactors or relays (see electrical specs.)
Fan power signal	This signal is used to turn on a relay to supply the battery cooling fan with power or ground depending on the configuration. This is an on/off line that is turned on only when the fan is active.
Fan PWM signal	This signal is used to control an external switch (MOSFET) to vary the battery cooling fan speed. This PWM signal is between 10% and 90% duty cycle (full range is not used in order to monitor fan performance.)
Fan monitor signal	The fan monitor signal is used to monitor the external fan voltage. If the BMS is commanding a certain level of fan power, but the voltage does not match, an error code is set.
CCL/DCL/SOC/AMPS analog 5v outputs	0-5V analog outputs that represent charge, discharge current limits, state of charge and instantaneous amperage.

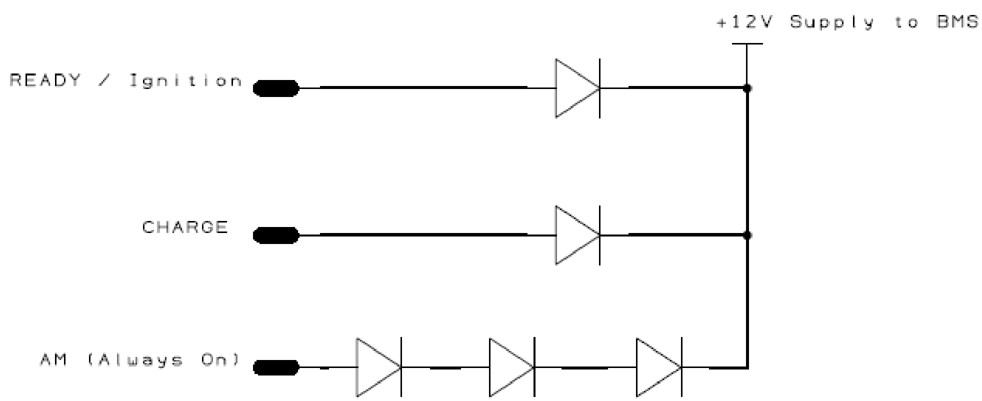
Ignition Signal	This signal is used for firmware revision 2.5 and higher only. This is an input signal is used to wake up the BMS even if the READY power source is lost. This input is intended to be used as a redundant method to keep the BMS alive. If this signal is on and the READY signal is off, the BMS will set an error code to notify the user that the primary power source has been lost. Power is required on the AM power source for this feature.

Wiring Main Connector

Power

Power is provided to the Orion BMS by any of 3 separate power sources - one always on power supply and 2 primary power supplies. The power sources are OR'ed together using diodes to prevent back feeding the other power sources.

As with any other electrical device, the wires bringing power to the Orion BMS unit should be current limited by a fuse or other device to prevent excessive currents in the event of a short circuit. The maximum recommended branch circuit or fuse size is 15A, however slow blow fuses as small as 500mA may be used.



The first source is the always on battery line. This line should be connected to a +12v nominal power source which is always on. This power source is used as a redundant power supply in case the main power source fails and is used to retain system memory when the BMS is in sleep. Additional diode voltage drops are provided on the always on power supply such that the BMS unit prefers to draw power from the other 2 normal power supplies before resorting to the always on (redundant) power supply. While it does not in any way pose a problem to the BMS unit, it is often desirable for power to be supplied by one of the 2 normal power supplies. To prevent power from being drawn from the always on power supply, the voltage on this line should be lower or up to 1.2 volts higher than the 2 normal power sources.

To wake up the BMS and enter normal operation mode, power should be applied to the READY power source. This power source can also be thought of as the “Ignition” power source when the BMS is used in automotive applications. When power is present at this source, the BMS will allow both normal charge and discharge, though it will not allow cell balancing or turn on the charger safety output signal.

To wake up the BMS and enter charge mode, power should be applied to the CHARGE power source. When power is present at this pin, the BMS will enter charging mode which allows for cell balancing and for the charger safety signal output to be enabled. 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 an AC / DC power adapter powered off the mains. For automotive use, this would be powered when the vehicle ignition is turned off, but the vehicle is plugged in and charging. The voltage on this pin should be higher or up to 1 volt lower than the voltage on the Always On power source at all times in order to prevent the BMS from drawing current from the Always On source if draining an auxiliary battery is a concern.

Voltages are sensed by the BMS at each of the power sources, including the always on source. If power is present only on the always on power source, the BMS will enter a low power sleep mode within a few seconds. If power is present at either the CHARGE or READY power sources but not at the always on power source, the BMS will operate normally, however a diagnostic trouble code (error) will be set on the BMS to alert the operator of the abnormal condition.

In some applications such as non-automotive applications where the BMS is powered by a single power supply or an automotive application with a secondary charger or DC-DC converter topping off the 12v auxiliary battery, it may be more convenient to wake the BMS up using a low current signal rather than supply the full operating current. In this situation, a 1K resistor can be put in series with the CHARGE or READY power supplies. The BMS will detect the voltage at the power source pins, but will be unable to draw operating current from the power source pins due to the 1K series resistor. While this method will not provide redundant power supplies to the BMS, it will wake up the BMS and cause it to draw operating current from the always on power source and may be more convenient for some applications.

The BMS will operate with both power sources powered at the same time, however as a charge interlock feature for automotive applications, the MIL signal (error indicator) will be turned on which can be used to inhibit a vehicle from driving away while plugged in if both the CHARGE and READY power sources are energized at the same time. This will not set an actual DTC error code, however. All other functionality of the BMS will remain the same.

Wiring CAN interfaces

The Orion BMS comes by default with two separate CAN (controller area network) interfaces - CAN1 and CAN2. The 2 interfaces are not connected internally and can operate at different baud rates and can transmit and receive different messages. This is particularly useful if the application has multiple CAN buses with different baud-rates. 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 vehicles or around other noisy devices. For convenience, 2 locations are provided on the Orion BMS connector to terminate the shields on the cables. Shields should only be connected in one location to prevent ground loops, so if the shield grounding locations are used on the Orion BMS connector, the shields should not be connected anywhere else. Some applications may require grounding of the shields in locations other than the Orion BMS connector to properly divert noise. While it is necessary for the 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 a couple inches or less in very high noise environments.

Controller Area Networks (CAN) require exactly 2 120 ohm terminator resistors on the 2 physical ends of the bus to operate properly. A CAN bus can have many nodes attached to a single bus. If only 2 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 CAN bus cable can be very long (up to about 30 meters for 1mpbs or 100 meters for 500kbps or 500 meters for 125kbps), the taps for additional nodes should be kept less than about 3.5 feet or 1 meter off the main cable. One important note is that 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.

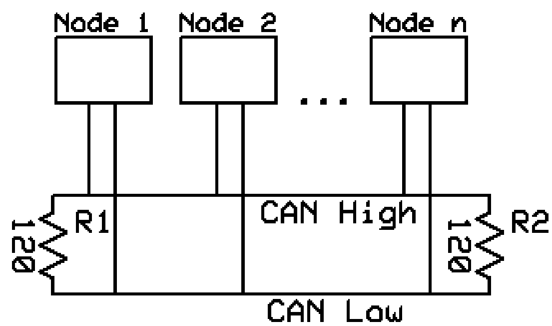


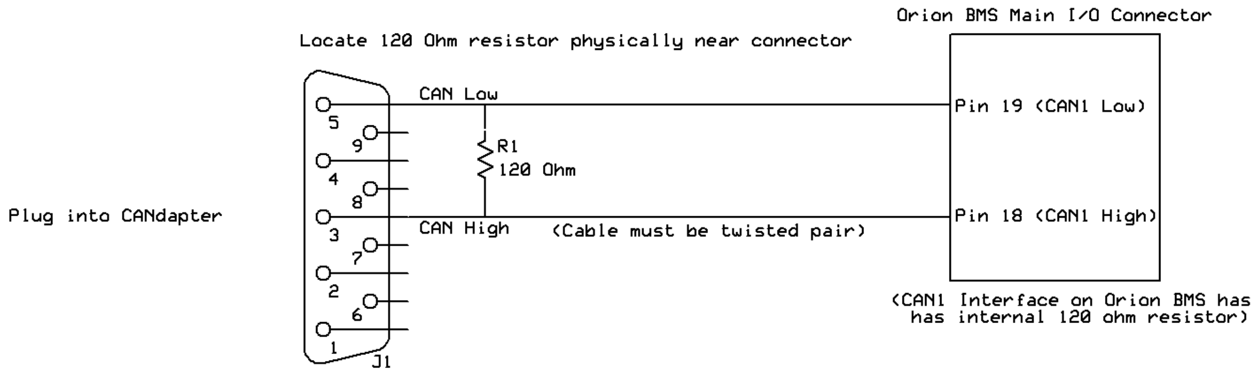
Diagram of a multi-node CAN bus with 120 ohm termination resistors at the ends

For convenience, the CAN1 interface on the Orion BMS (unless specially ordered) has a terminator resistor built in, whereas the CAN2 interface does not, allowing the default Orion BMS unit to be easily integrated either at the physical end of a bus or in the middle of an existing bus. A termination resistor can be added externally on the CAN2 interface if needed. The Orion BMS can be special ordered with specific termination resistors loaded or unloaded.

The 2 CAN interfaces are functionally the same with the one exception that only the CAN1 interface may be used to perform field updates on the BMS firmware (the BMS profile & settings may be updated from either CAN interface, but the actual firmware software on the BMS can only be updated via CAN1). For this reason, it is recommended that CAN1 be used to interface with any diagnostic connectors or DB9 connectors (to connect to the CANdapter).

Wiring the CANdapter (For Programming)

The following diagram is provided for connecting the Orion BMS’s CAN1 interface directly to a DB9 that can connect to the CANdapter. Other nodes may be added to the CAN1 bus, however this drawing does not show that configuration.

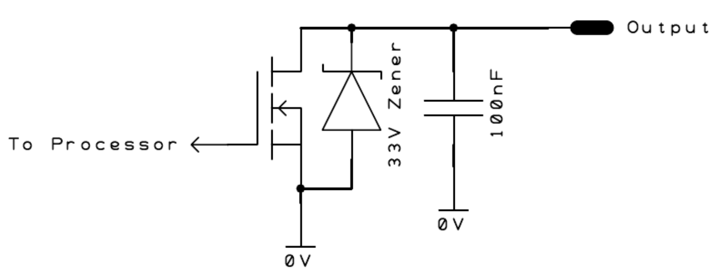


In some applications, it may be desirable to connect the Orion BMS to a diagnostic connector for easy programming or diagnostics. Any style of connector suitable for differential mode digital communications can be used as a diagnostic port including a DB9 connector (as pictured above) and OBD-2 connectors.

Wiring digital signal outputs

The Orion BMS has 3 signal level digital I/O outputs - Charge Enable, Discharge Enable and Charger Safety. These 3 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. These 3 outputs pull low when they are enabled and cannot be inverted in software for safety reasons. This is done such that if the BMS connecter were to become disconnected, the outputs would fail off rather than on. For safety reasons, each of these 3 outputs feature an analog watchdog circuit which turns the outputs off in the event of a processor malfunction adding an extra layer of safety.

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



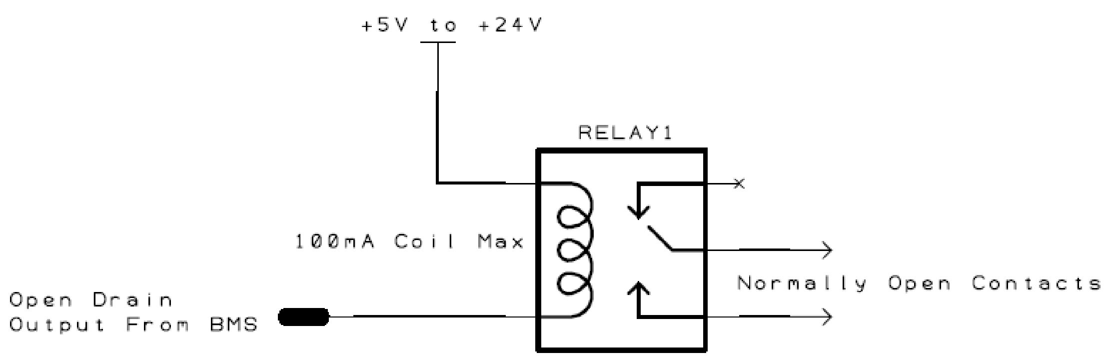
Internal schematic for signal outputs

Charge Enable Output (pin 8) - This pin is used in both READY or CHARGE mode 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 (please see the software manual for more details on how the BMS determines when this pin is on or off.)

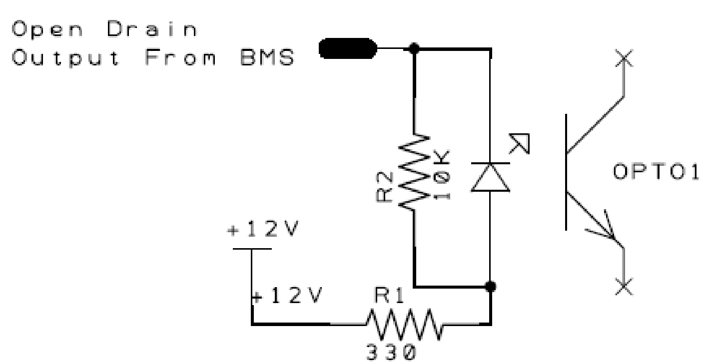
Discharge Enable Output (pin 7) - This pin is used in both READY or CHARGE mode and is turned on (pulled low) as soon as the BMS has gone through self checks and determined that the battery is able to be discharged. This output will turn off (float high) if the BMS determines that the battery can no longer provide current or if the maximum discharge amperage is exceeded (please see the software manual for more details on how the BMS determines when this pin is on or off.)

Charger Safety Output (pin 6) - This pin is used 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 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 it's maximum voltage, this output is turned off (float.)

All three of these open drain outputs are capable of directly controlling small relay coils under 100mA. The BMS has internal protection from the back EMF generated by the relay coils, however additional clamping diodes can be added if desired for additional protection. The outputs can also drive opto-isolators or other loads. Below is a sample schematic for connecting a relay with a coil less than 100mA 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.

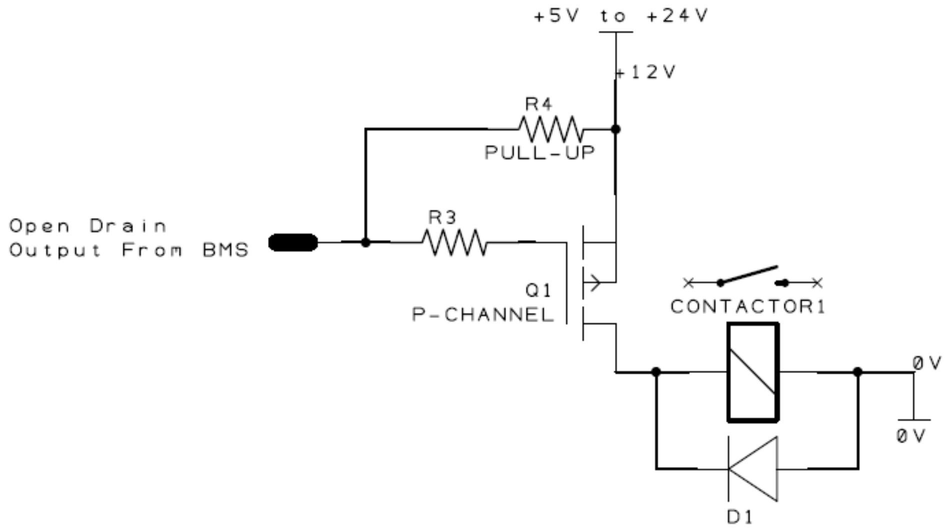


A sample schematic for connecting the open drain outputs with a relay



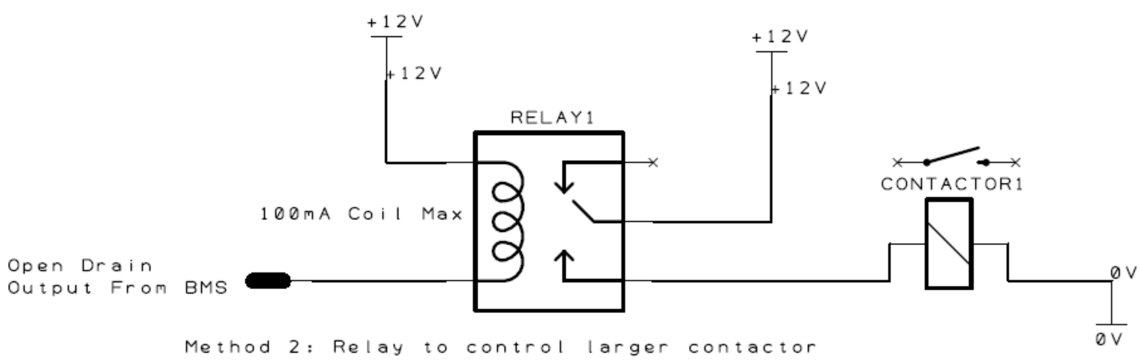
A sample schematic for connecting the open drain outputs with an opto-isolator

If the signals will be used to drive relays with coils larger than 100mA, contactors or other loads, an amplification method must be used so that the BMS does not sink more than 100mA. 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

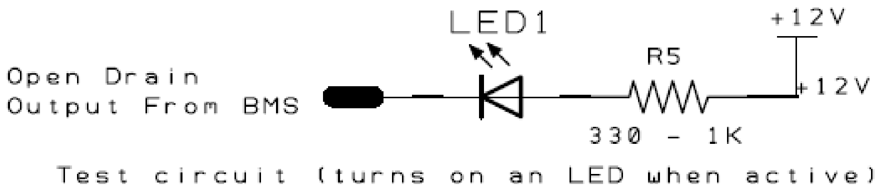
Another method is to use a smaller relay to turn on power for the larger relay/contactor. A schematic for this is shown below.



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.) If an LED is used, a 330 ohm to 1k ohm series resistor 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 analog 0-5V outputs

The Orion BMS is equipped with 4 analog 0 to 5V voltage outputs designed to aid in integrating the Orion BMS with non-digital applications including voltage based displays. The outputs include pack state of charge, amperage going in and out of the pack, 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, an external analog buffer (i.e. op-amp) must be used to amplify the signal. The analog voltages are generated inside the Orion BMS unit by a digital-to-analog converter.

State of charge output (Main I/O pin 4) - 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 for applications when digital communications are not available. It can also be used to provide data to the

Amperage output (Main I/O pin 15) - This outputs provides an approximate amperage in and out of the battery pack. Since this output can display either positive or negative amperage, 2.5V corresponds to 0 amps. A voltage above 2.5V indicates discharge where-as a voltage below 2.5V indicates charge.

The formula for converting the analog voltage to amperage is as follows:

totalAmpRange = ((sensor_size * 0.25) + sensor_size) * 2)
Amps = ((analog_voltage / 5.0) * totalAmpRange) - (totalAmpRange / 2)

sensor_size = the nominal current rating of the current sensor. This would be 200 for a 200A current sensor or 750 for a 750A current sensor.

While this output is useful for a user display showing the rough rough amperage in and out of the pack, voltage offset errors and 10 bit resolution make it difficult to use this output for precision amperage measurements. If more precise measurements are necessary, the digital CAN information should be used.

Charge current limit (Main I/O pin 5) - 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 (Main I/O pin 8) 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 (Main I/O pin 16) - 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.)

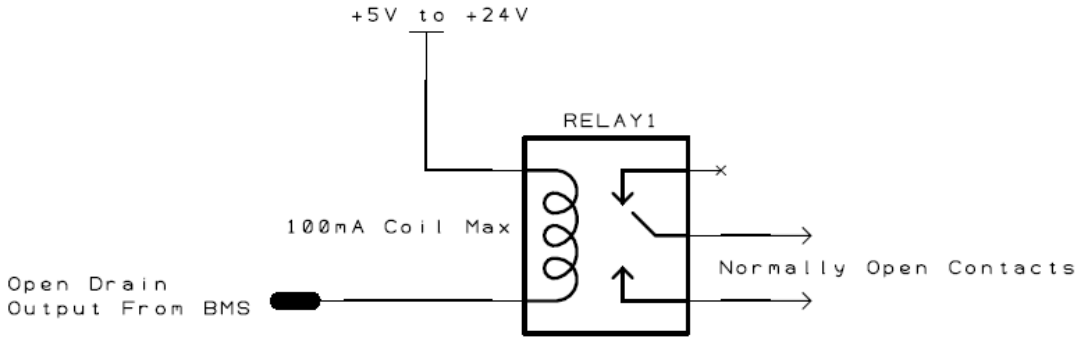
While this output can be reliably used to limit current, it should be used in conjunction with the discharge enable signal output (Main I/O pin 8) which provides an analog watchdog shutoff circuit. Although unlikely, it is possible for the digital-to-analog converter to fail leaving the voltage in an undefined state.

Wiring the fan controller

The Orion BMS features a thermal management system consisting of thermistors for measuring battery temperature (and optionally for measuring intake air temperature), an on/off output and PWM output designed to control a fan and a voltage monitoring circuit designed to ensure that a fan is operating properly.

The Orion BMS base unit supports up to 4 thermistors directly connected to the BMS. More than 800 additional thermistors can be connected to the Orion BMS using thermistor expansion modules. For more information on the thermistors, please see the “Current sensor / thermistor connector” section.

Fans and liquid cooling systems can be controlled in an on/off or variable speed manner by the Orion BMS. The simplest method of connecting a fan is the on/off approach. The Fan Power Control (Main I/O pin 10) pin on the Orion BMS is an open drain output designed to drive loads up to 100mA. In most instances, this output is connected to a relay coil or MOSFET which then supplies higher power to the battery fan. Below is a schematic showing a possible connections for powering a fan in an on/off manner.

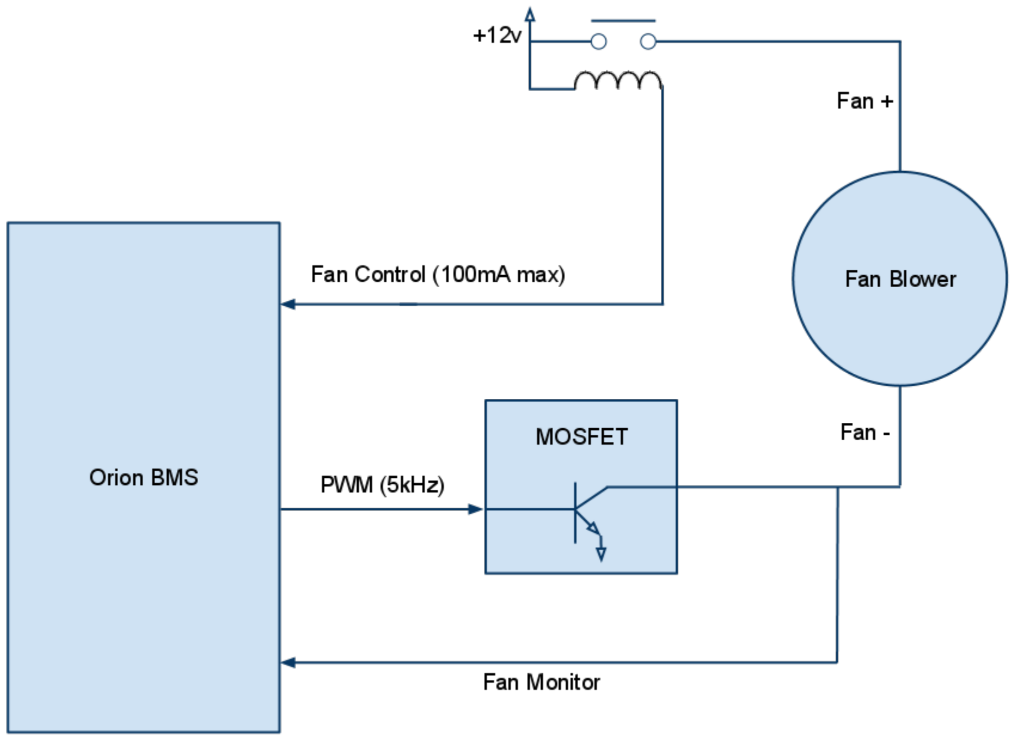


A PWM output is also provided to provide variable speed fan controls. The PWM output can be used to drive a compatible fan or liquid cooling system. Care must be taken in selecting a fan or motor that is compatible with PWM. It may be necessary to convert the PWM signal to a DC voltage for some fans.

The “Fan PWM Signal” (Main I/O pin #24) provides the PWM signal. The PWM signal is signal level and is current limited by an internal 300 ohm resistor. In BMS hardware revisions B and C, the output is a totem pole output between 0V and 5V. This output has been changed in the upcoming revision D (due for release mid summer 2012) to a open drain output in order to accommodate a wide range of voltages up to 24V. The frequency of the PWM signal and polarity of the signal can be altered in the profile.

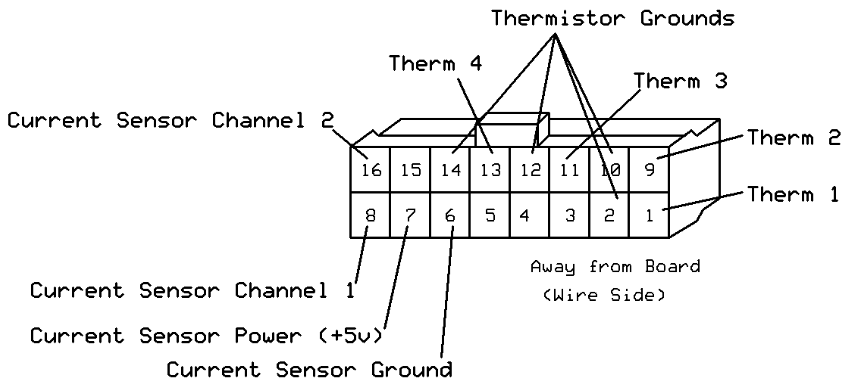
If the PWM method is used, the “Fan Monitor” (Main I/O pin 9) pin can be used to monitor a voltage from 0 to 12V to detect fan failures. The fan monitor feature can be setup in software to verify that the voltage present at the fan monitor pin matches the expected voltage for the desired fan speed. The fan monitor polarity is invertible in software. Please see the software manual for more information about setting up voltages and error thresholds the fan monitor feature.

Below is a simplified overview of the fan circuit using PWM and the fan monitor feature. This is an example, however there are many other ways of using the thermal interface.



General fan circuit diagram.

Current Sensor / Thermistor Connector



Signal Name	**Description**
Thermistor GND (4x)	One leg of each of the 4 thermistors should be grounded to one of these grounds. Any thermistor can be grounded to any of the available thermistor ground pins, order does not matter and all can optionally be grounded to one pin.
Thermistor 1, 2, 3, 4	Thermistors returns (non-grounded lead of the thermistor). These thermistors are embedded into the battery pack to provide the BMS with the general temperature of the pack. One of these thermistors can be used as an air intake temperature sensor to measure ambient air temperature for more intelligent control of the fan (selected in software).
Current Sensor Vdd	+5v supply provided to the external hall effect current sensor.
Current Sensor Chan. 1	First current sensor channel. This is the more sensitive of the 2 channels and measures the smaller current range.
Current Sensor Chan. 2	Second current sensor channel. This is the less sensitive of the 2 channels, but the one that measures the full current range.

Current Sensor & Thermistor Taps

The current sensor wiring harness consists of 4 wires for the standard current sensor options. The standard current sensor options are actually a combination of 2 current sensors in one for redundancy and accuracy. Current sensor wires should be kept as short as possible, ideally less than 18” in length. While it is possible to extend the wires if needed, longer wires will reduce the accuracy and make the sensor more susceptible to electronic noise.

The current sensor polarity can be inverted in the Orion BMS profile (using the BMS utility software), so it is not particularly important that it is physically installed in one direction or another. It is important that the Orion BMS unit is setup showing current in the proper direction or otherwise many of the calculations will show up incorrect.

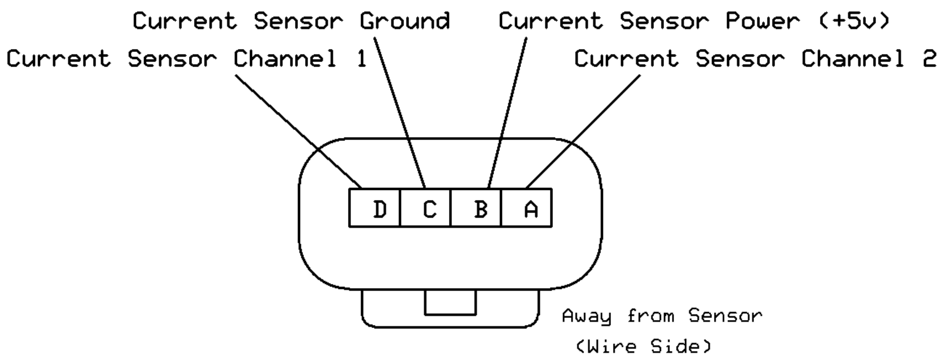


Diagram of connector which attaches to the current sensor

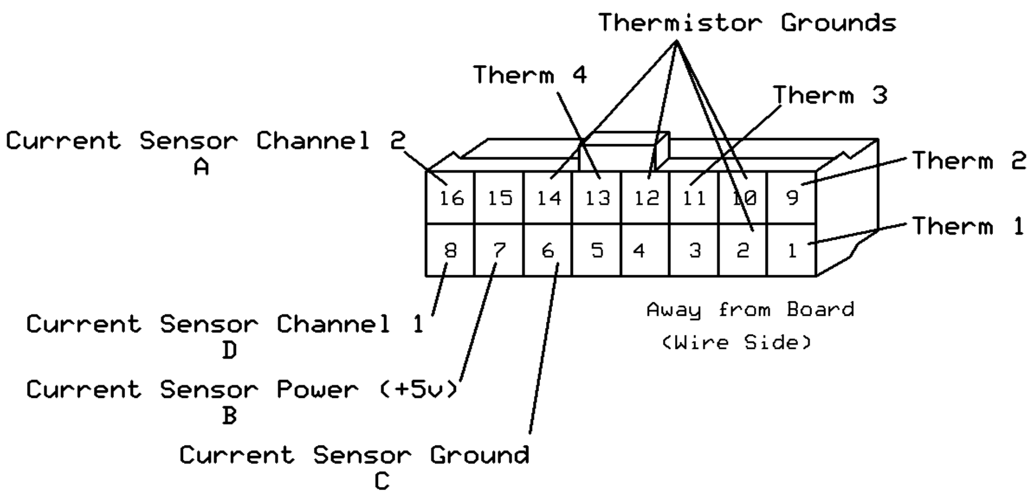


Diagram of the connector which attaches to the Orion BMS unit

Above are 2 diagrams showing the wiring between the connector attaching to the current sensor and the thermistor / current sensor connector on the Orion BMS unit.

The Orion BMS main unit can have up to 4 thermistors directly connected to the unit. These 4 thermistors are designed to provide the BMS with a representative idea of the pack temperature. The 4 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.

One of the 4 thermistors on the base unit can be selected as an intake air thermistor (any of the 4 thermistors can be configured for this in the software profile.) This allows the BMS unit to monitor the incoming air temperature to determine if cooling would be effective or not by comparing the intake temperature with the battery temperature. If cooling is needed and the

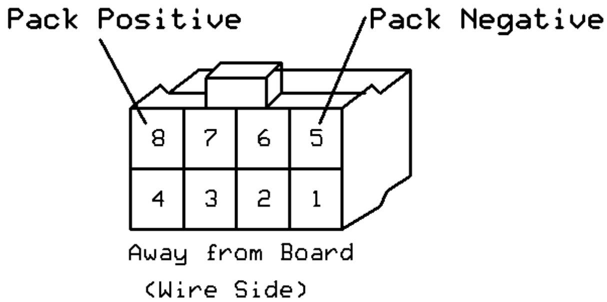
BMS determines that the intake temperature is higher than the battery temperature, it can prevent the fans from turning on since the fans would not be effective in cooling the battery in that case. It also allows the BMS to turn on the fans when heating is desired if the intake temperature is higher than the battery temperature in colder climates.

If monitoring more than 4 temperatures is necessary, an external thermistor expansion module is available which can monitor up to 80 additional thermistors per module with up to 10 modules connected measuring up to 804 thermistors total which should be sufficient for most applications.

The thermistors are 10K NTC thermistors with a B25/50 value of 3380K. Other B values can be used, though the accuracy will be reduced. Custom configurations 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 one of the thermistor ground pins. As thermistors are resistive, polarity does not matter and the order of thermistor ground pins does not matter. All thermistor common wires can be connected to a single thermistor ground pin if helpful for cable routing.

Thermistors can be attached to the battery cells in different ways depending on the type of cell. The thermistors sold with the Orion BMS 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. Insufficient isolation can cause catastrophic damage to the BMS unit.

Pack Voltage Sensor Connector



NOTE: Follow the above diagram instead of the pin numbers listed on the connector.

Signal Name	**Description**
Pack Negative	Negative pack voltage sensor. This should be connected to the negative output from the battery pack. This is used to redundantly monitor the total pack voltage as well as monitor for isolation faults.
Pack Positive	Positive pack voltage sensor. This should be connected to the positive output from the battery pack. This is used to redundantly monitor the total pack voltage as well as monitor for isolation faults.

HV Pack Voltage Sense Connector

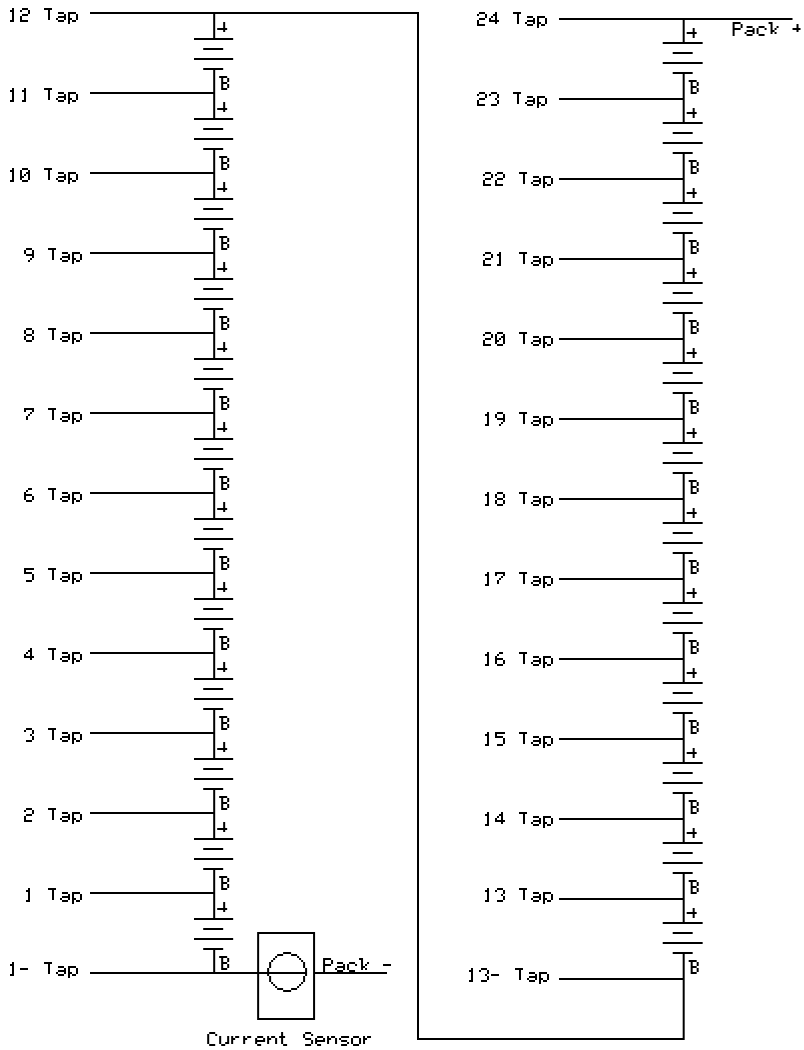
The pack voltage sensor consists simply of 1 wire going to the total pack negative and the other to the total pack positive. This connector is used for redundant voltage monitoring for error detection as well as for isolation fault detection.

If multiple Orion BMS units are being used in series, the total pack voltage sensor connection should be connected only to the portion of the pack that the BMS is controlling.

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 BMS does not require the use of in-pack safety disconnects or fuses, **if safety disconnects or fuses are used, they must be placed in certain locations.** Please see "Safety Disconnect and Fuse Locations."

Each BMS is designed to handle up to 9 (108 cell version) or 15 (180 cell version) groups of 4 - 12 cells. **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 following example is for a 24 cell pack.



Voltage Tap Connector Pinouts

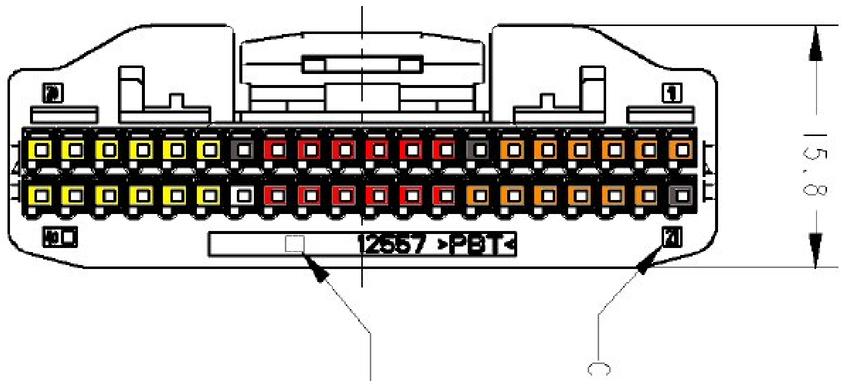
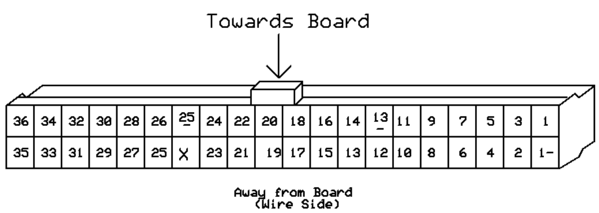
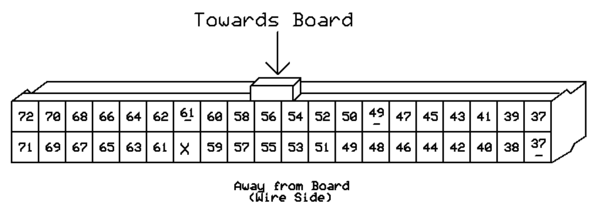


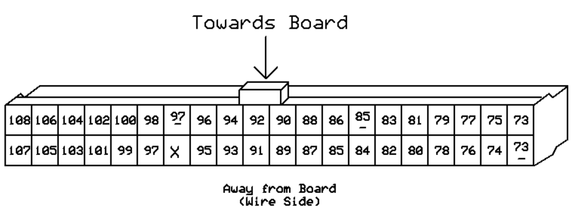
Diagram of the pre-wired harness connector. Cell Groups 1 in orange, 2 in red and 3 in yellow. Cell group ground wires are in black. Looking at the wire side of the connector looking into the ECU.



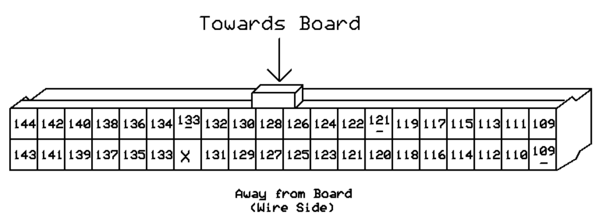
Cell group 1-3 connector



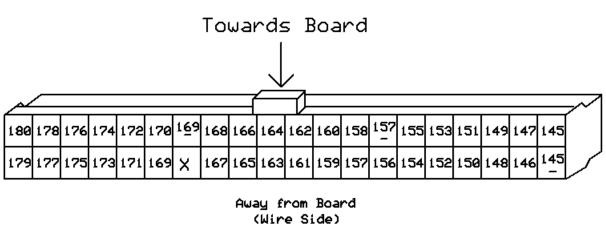
Cell group 4-6 connector



Cell group 7-9 connector



Cell group 10-12 connector (180 cell version)



Cell group 13-15 connector (180 cell version)

Safety Disconnects and Fuse Position

While the Orion BMS does not require the use of safety disconnects or fuses in line with the battery pack, the Orion BMS has locations specifically designed to facilitate disconnects and fuses if they are used. Please see below for more information.

Many times with high voltage or high amperage battery packs, it is highly desirable for safety reasons to have a disconnect and/or fuse(s) located in the middle of the battery pack. In this case, removing the safety disconnect or fuse effectively splits the battery pack into 2 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.

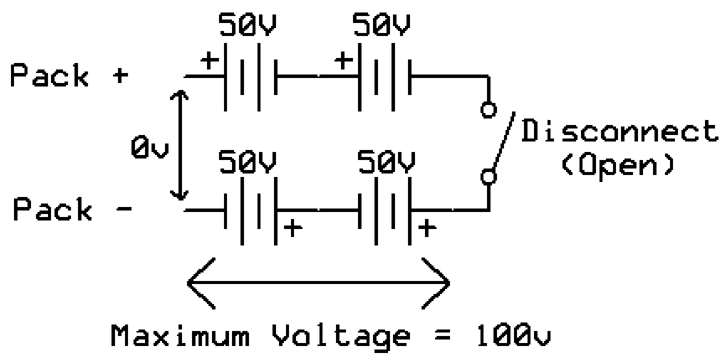


Illustration of a properly functioning safety disconnect or fuse

The above schematic shows the advantage of a mid-pack safety disconnect. The disconnect essentially splits the 200 volt nominal battery pack into 2 smaller 100v sections, thereby theoretically reducing the voltage at the pack terminals to zero volts and limiting the maximum voltage in the pack to roughly half the nominal voltage.

Isolation is critical if a safety disconnect is used. If there is not sufficient isolation or if there is an additional path around the safety disconnect or fuse, current can still flow and high voltage can be present at the battery pack's terminals as pictured below. The resistor in the following schematic represents leakage current from a breakdown in insulation, arcing across an insufficient insulation barrier or another current path such as through protection diodes inside the Orion BMS. Even if the effective resistance is in the 100's of kilo-ohms, the voltage at the terminals of the pack can present a shock hazard as the full voltage of the battery pack may be present.

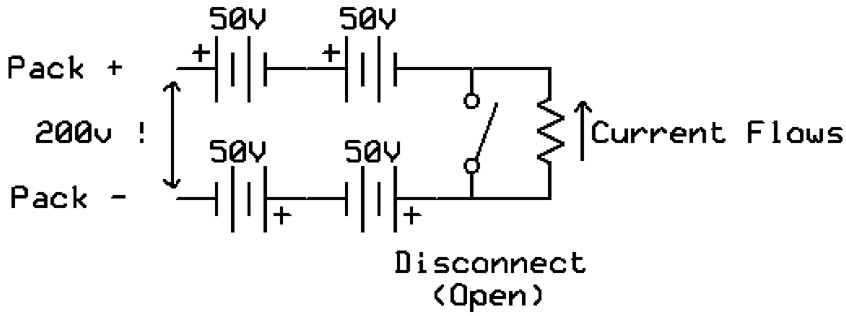


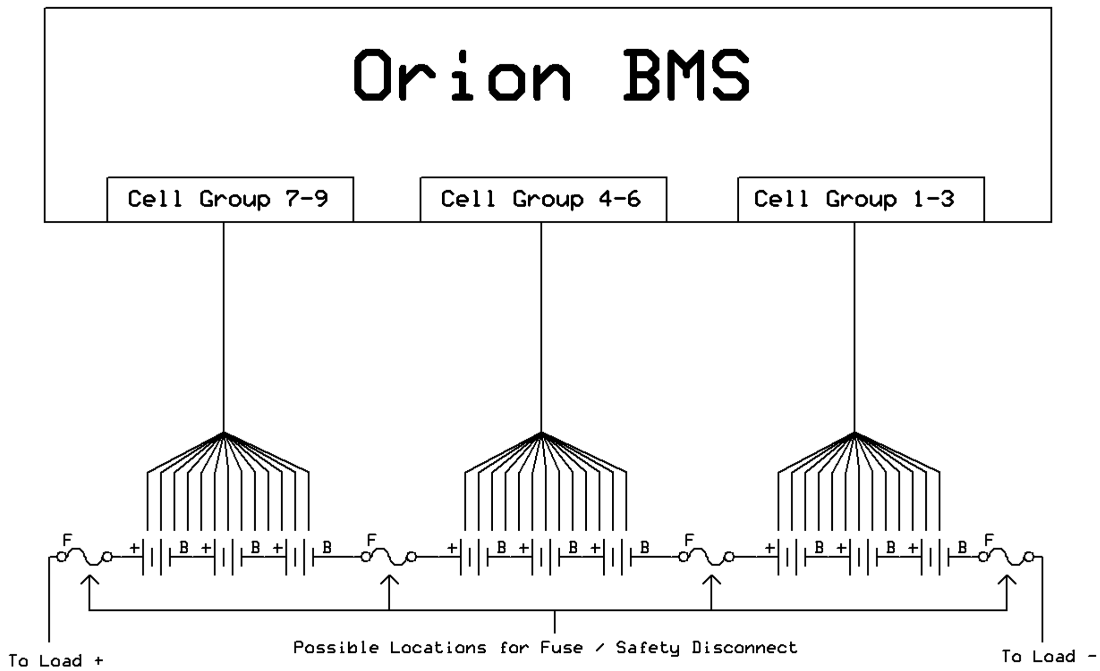
Illustration of a safety disconnect with a dangerous alternative current path

The Orion BMS was designed with support for safety disconnects and fuses inside the pack at certain intervals. 2.5kV safety isolation is provided between each battery voltage connector on the Orion BMS (each connector can handle 36 cells, so isolation barriers are on multiples of 36 cells.) This is done such that safety disconnects can be connected in a way where no current can flow around the safety disconnect or fuse. While the Orion BMS also has nominal isolation between each individual cell group, it is not recommended for safety disconnects or fuses since the total stack voltage of the battery could be present across those terminals in the event of a short, which could potentially arc over the isolation barrier. Additionally, if a fuse blows due to over-current, stray inductance from the battery cables can cause significant voltage transients which can also arc over smaller isolation barriers.

The Orion 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 BMS such that it is in the middle of a cell group (12 cells), if the fuse blows or the safety disconnect is removed, current can flow through the Orion BMS, bypassing the safety disconnect or fuse leading to dangerous conditions.** This can cause high voltage to be present at the terminals of the battery pack when there should be no voltage present and force large currents to flow through the Orion BMS damaging the BMS unit. Damage from incorrect wiring is not covered by the warranty.

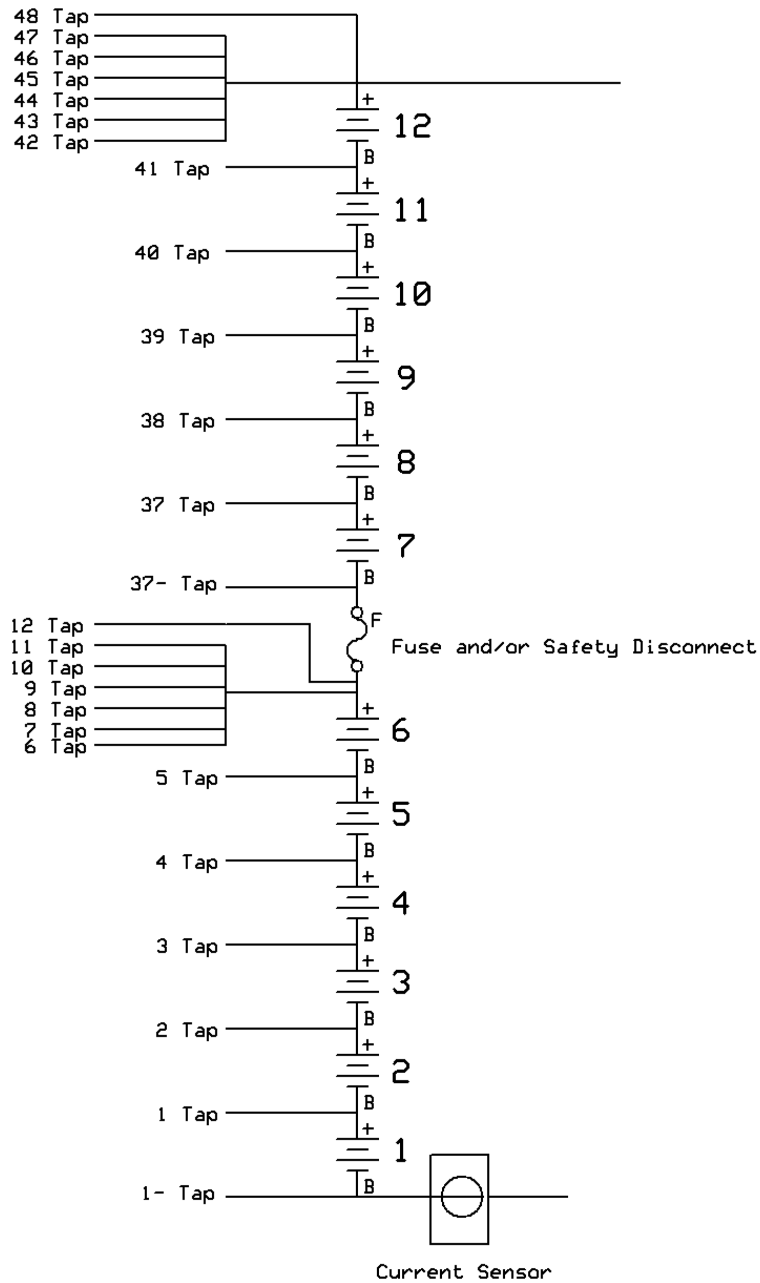
If safety disconnects or fuses are used within a battery pack the Orion BMS must be wired such that the fuses or safety disconnects fall between the connectors (between taps 36 and 37 or 72 and 73 or 108 and 109 or 144 and 145.) ***Failure to do this may result in damage to the BMS and will not provide the required isolation across the safety disconnect.*** The Orion BMS does not require the use of safety disconnects or pack fuses in the pack and if your application does not use a safety disconnect or a fuse inside the battery pack then this does not apply. Please see the “Isolation” section below for more details and a diagram of the isolation provided by the Orion BMS.

The diagram below visually shows locations where safety disconnects and fuses can be located with respect to the connectors on the Orion BMS. While the disconnect and fuses need to be wired such that they are located between the cell voltage tap connectors (on a multiple of 36 cells) to maintain safety isolation, safety disconnects do not need to be located between cell numbers 36 and 37 since cells and cell groups can be skipped with the Orion BMS wiring.



If safety disconnects and fuses are used and cannot be located on multiples of 36 cells, cell positions on the BMS must be left unpopulated such that the safety disconnects fall between a multiple of 36 cells on the BMS. Safety disconnects or fuses can be used on the positive most or negative most terminals of the battery pack, provided that the Orion BMS voltage taps are on the battery side of the fuse or disconnect and cannot provide a path for current to flow around the disconnect or fuse.

The following wiring diagram shows the proper wiring technique if a pack with 12 cells is wired with a safety disconnect between cells 6 and 7. Note that for this example, a 24-S or 48 cell or higher model BMS would be necessary even though only 12 actual cells are present. In this case, a 24-S model is the lowest cost option. Placing safety disconnects or fuses in the ideal locations provided by the Orion BMS is usually the most cost effective method.


48 Tap
47 Tap
46 Tap
45 Tap
44 Tap
43 Tap
42 Tap
+
12
41 Tap
B
+
11
40 Tap
B
+
10
39 Tap
B
+
9
38 Tap
B
+
8
37 Tap
B
+
7
37- Tap
B
F
Fuse and/or Safety Disconnect
12 Tap
11 Tap
10 Tap
9 Tap
8 Tap
7 Tap
6 Tap
+
6
5 Tap
B
+
5
4 Tap
B
+
4
3 Tap
B
+
3
2 Tap
B
+
2
1 Tap
B
+
1
1- Tap
B
Current Sensor

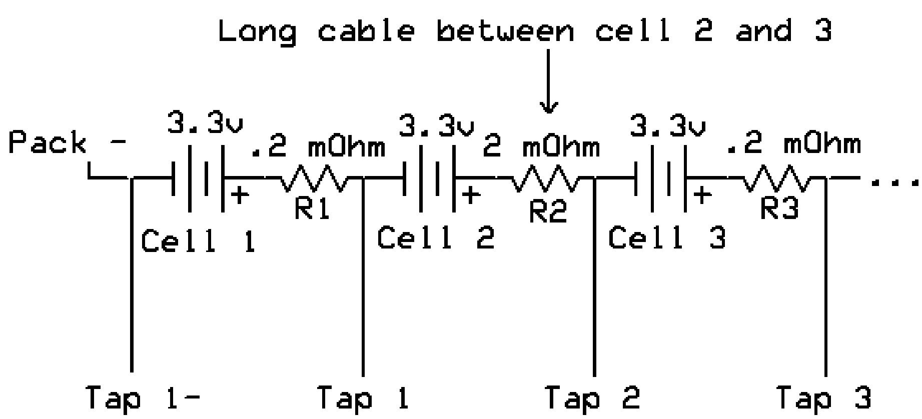
Wiring for high impedance cables and busbars

Voltage measurements are taken by the Orion BMS with respect to the next lowest cell or the negative wire in each cell group. For example, when the Orion BMS 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.

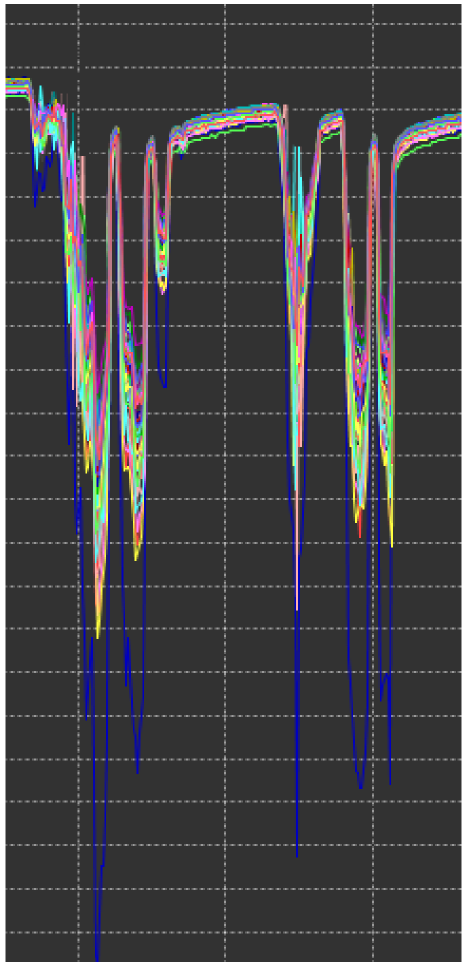
While battery cables and busbars may be very large and have a minimal resistance, all cables have some electrical resistance. The cell taps by necessity will see the additional resistance from busbars, battery interconnects and cables unless they fall between cell groups (12 cells). The diagram below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

If cell voltages are measured by the Orion BMS with no current flowing through the circuit, the voltages measured are exactly the voltage of the cells. When a current is running through the pack, the measured voltage of each cell will drop (or increase) due to the internal resistance of the cells and the measured voltage (instantaneous voltage) and the open cell voltage of the cells will be different. There is a more detailed description in Appendix A of the operational manual of how this works.

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 BMS as extra resistance for that particular cell. In the example below, all of the cells have a resistance of 3 mili-ohm, however 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 lower 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 BMS.) If the voltage can swing outside those maximum voltages, the Orion BMS must be wired such that the cable falls between a cell group break (every 12 cells) and be wired such that voltage drop induced by the busbar cannot be seen by the Orion BMS.



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.

Peak_voltage = Vmax_cell + (Rbusbar * Imax_charge) (Peak_voltage must be < 5v)
Lowest_voltage = Vmin_cell - (Rbusbar * Imax_discharge) (Lowest voltage must be >0v)

In the above example, if the example cells have a maximum voltage of 3.65v (Vmax_cell) and a minimum of 2v (Vmin_cell) and a maximum amperage of +/-200A (Imax_charge and Imax_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

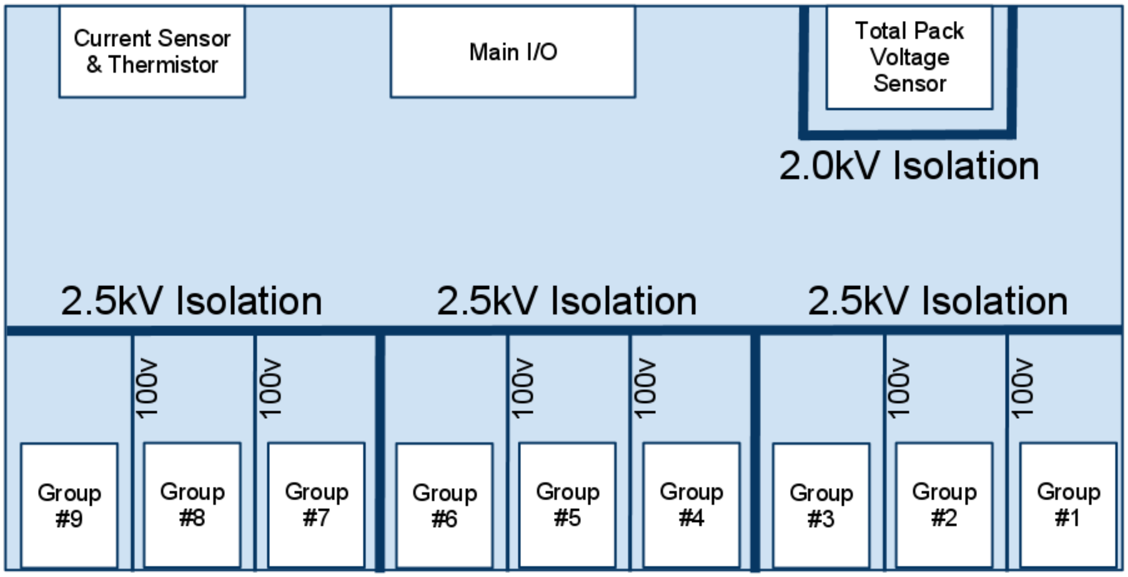
The vast majority of motor controllers available on the market provide some amount of filtering on the DC bus in order to limit radiated and conducted emissions. While most motor controllers generate high levels of noise, the noise generally does not lead to a significant AC component on the DC bus.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

The Orion BMS 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 what is called a “Skin Effect.” Skin effect is where eddy currents form within the cables and effectively only the outside portion of the wire carries current, effectively artificially increasing the resistance of the wire.

Although the Orion BMS has been tested extensively to operate and measure voltages properly in these extremely harsh 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 BMS bases many calculations on the measured resistance of the cells, including open cell voltage calculations which are used for determining maximum current limits. If a significant skin effect is present, it can introduce inaccuracies with some calculations even though the Orion 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, however a small number of controllers on the market do not. In those cases, skin effect can be mitigate 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 a cell group since the BMS cannot effectively compensate them out. Alternatively, 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.

Internal Isolation



Isolation Diagram for 108 cell system (180 cell version can be extrapolated.)

The Orion BMS provides 2.5kV isolation between cell voltage taps and control electronics as well as between groups of 36 cells. The total pack voltage sensor is isolated from all other electronics by 2.0kV DC isolation. Isolation between cell groups 1, 2 and 3 is a nominal 100v isolation which is an ideal placement of high resistance busbars or cables between cells, but cannot be used for a safety disconnect or fuse since it is not rated to withstand the full stack voltage.

Note that units configured with less than 108 cells do not have all 9 groups populated. For 120 - 180 cell units, the same pattern of isolation continues with groups #10, 11, 12, 13, 14 and 15 with 2.5kV isolation between groups 9 and 10 and 12 and 13.

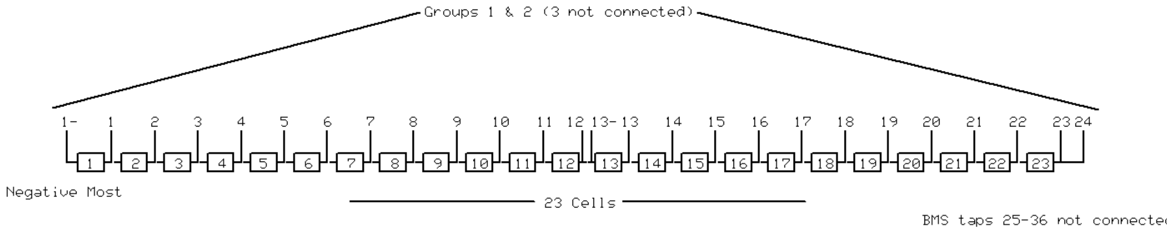
Cell Groups with less than 12 cells

Each cell group must have a minimum of 4 cells and up to 12 cells, with a minimum voltage of 13V per group. If less than 12 cells are used, each wire must still be connected to maintain proper operation and accuracy.

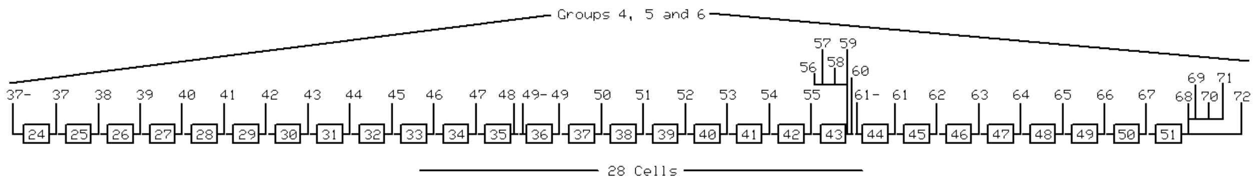
Rules for less than 12 cells

- If less than 12 cells are populated in a group, unpopulated cells must all be connected to the highest potential cell. For example, if 6 cells are populated in a group, taps 6 - 12 are all connected to the positive tap on cell 6.
- If less than 12 cells are populated in a group, unpopulated cells except for cell 12 may share the same wire. Cell 12 must have a separate wire from the BMS to cell to maintain accuracy due to voltage drop.
- No cell group may have less than 4 cells connected (higher minimums may apply if nominal voltage is lower than standard li-ion cells.) If the last group of cells has less than 4 cells, some cells must be skipped in the previous group and wired into the last group to ensure that a minimum of 4 cells are present in the last group.

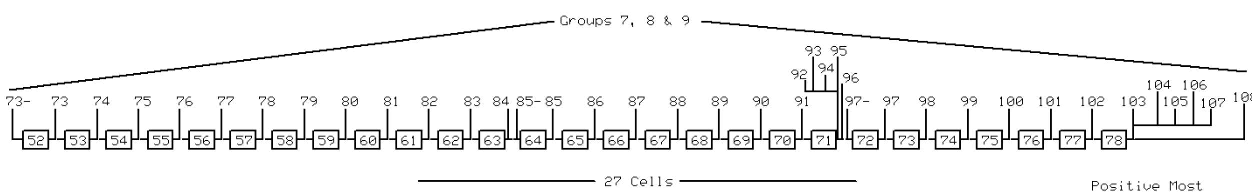
Example: A battery pack of 78 cells is divided into 3 sections with a fuse and a long, high impedance cable located between cells 23 / 24 and 51 / 52. 23 cells are in the first section, 28 in the 2nd section and 27 in the third section.



In the first section of this example battery, cell group one is wired normally with 12 cells. Group 2 is wired with 11 cells and because of that, BMS tap #23 and #24 are tied to the same cell (cell #23). Because 2.5kV isolation is required between cell #23 and cell #24, group 3 is left disconnected and the next section starts with group 4.



In the second section of this battery, group 4 (starting with BMS tap #37-) is wired normally starting with cell #24 and has all 12 cells connected. Since the 2nd section has 28 cells and 12 cells have already been connected, that leaves 16 cells left to connect to groups 5 and 6. If 12 cells were connected to group 5, that would leave 4 cells for group which is the minimum number of cells per group allowed. While that would be suitable and meet the minimum criteria, the best solution is to split the remaining cells between the 2 groups with 8 cells per each group to ensure that the 13 volts per group minimum is always met. The unused BMS taps are tied to the same potential as shown.



The third section is similar to the 2nd section, however with 37 cells. Group 7 is wired normally with all 12 cells, however that leaves 15 cells left in the section. If group 8 were wired with 12 cells, it would leave only 3 cells for group 9 which is below the minimum required. In this instance cell group 8 must have no more than 11 cells such that enough cells are left for group 9.

Fuses on voltage tap wires

The Orion BMS has internal fuses on each of the positive cell tap wires. While these fuses protect the BMS and guard against excessive current flowing through the internal protection diodes and are designed to blow if the maximum voltages are exceeded, the fuses do not protect against 2 tap wires that short together outside the BMS. While many major OEM vehicle manufactures do not fuse the cell voltage taps, fuses can be added for additional protection if desired. If additional fuses are used, they should be kept as low resistance as possible within reason. Fuses sometimes have relatively high resistance and the additional resistance can reduce the accuracy of monitoring the cells.

Verifying the Wiring

The wiring must be verified prior to connecting any of the wiring harnesses to the Orion BMS. Improper wiring can cause catastrophic failure or even personal safety risks.

The most important connectors to verify are wired correctly are the cell voltage tap harnesses. There are 2 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 disconnected wires. The verification tool is designed to withstand incorrectly wired harnesses without damage. **It is strongly recommended to use the verification tool before plugging the harness into the Orion BMS since it is very easy to make an error wiring the harness and it may not be obvious. Mis-wired voltage tap harnesses can cause significant damage to the Orion BMS that is not covered under warranty.**

Wiring can also be verified by carefully using a multimeter (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 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 pin for 1-. On the first connector, the 1- pin should read 0V since the negative probe of the multimeter should be connected to the same cell. 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 fourth. The connection for cell 12 and 13- should read the same voltage since they are connected to the same potential and the same is true for every multiple of 12.