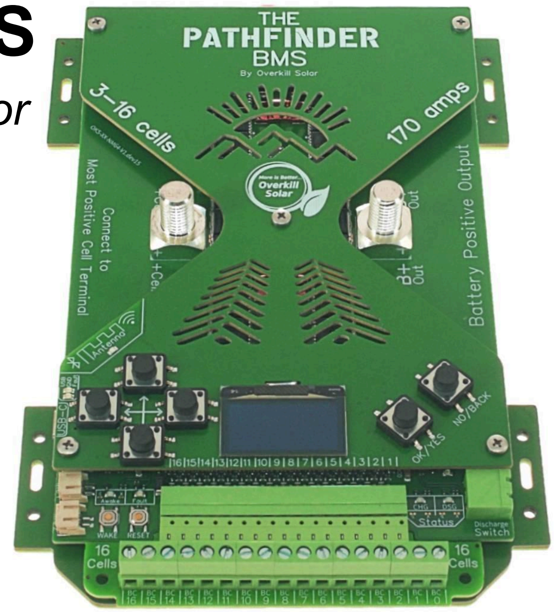
The Pathfinder BMS

Battery Management System for 3 to 16 cell Lithium Batteries

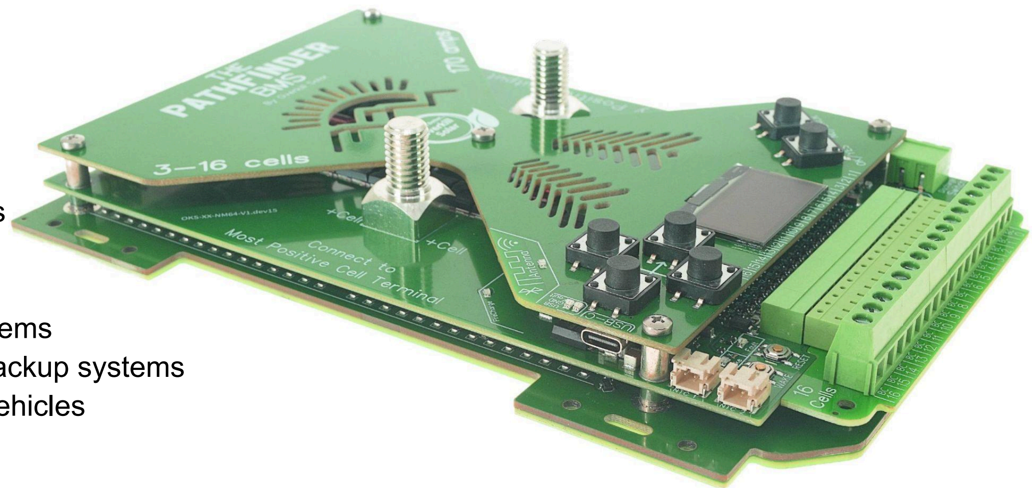
By Overkill Solar LLC



1. Features

- 3 to 16 cells, Min 7V up to Max 64V.
- 170 amps continuous duty current rating.
- Customizable State of Charge tracking.
- Built in OLED user interface.
- DIY focused design with positive side switching.
- Bluetooth, WIFI, & USB interface with free monitoring apps.

2. Applications



- DIY LiFePO4 batteries
- Tesla module conversions
- Recreational Vehicles
- Boats
- Off-Grid Solar power systems
- Grid-connected battery backup systems
- Golf Carts, light electric vehicles

3. Description

The Pathfinder BMS by Overkill Solar is a Battery Management System designed for DIY LiFePO4, NMC, and LTO batteries.

It has been designed and engineered entirely by Overkill Solar, drawing on our years of experience supporting the various JBD BMSs which are now discontinued.
Engineering, Assembly, Testing, and Distribution are done in Naples, FL. Programming is mostly done in Canada, and the components are manufactured in a variety of cheaper countries.

It can operate with battery voltage up to 64V and current up to 170 amps at 100% duty cycle. It features an advanced user interface with a built-in OLED display, user input buttons, Bluetooth and WIFI connectivity, OTA & UF2 firmware updates, MQTT for Home Assistant, and status LEDs.

The cell count is field configurable from 3 to 16 cells for LiFePO4 or LTO, and 3 to 14 cells for NMC.

The Solid state high current switch is on the positive side of the battery for simplified installation and compatibility, and includes a Pre-Discharge circuit.

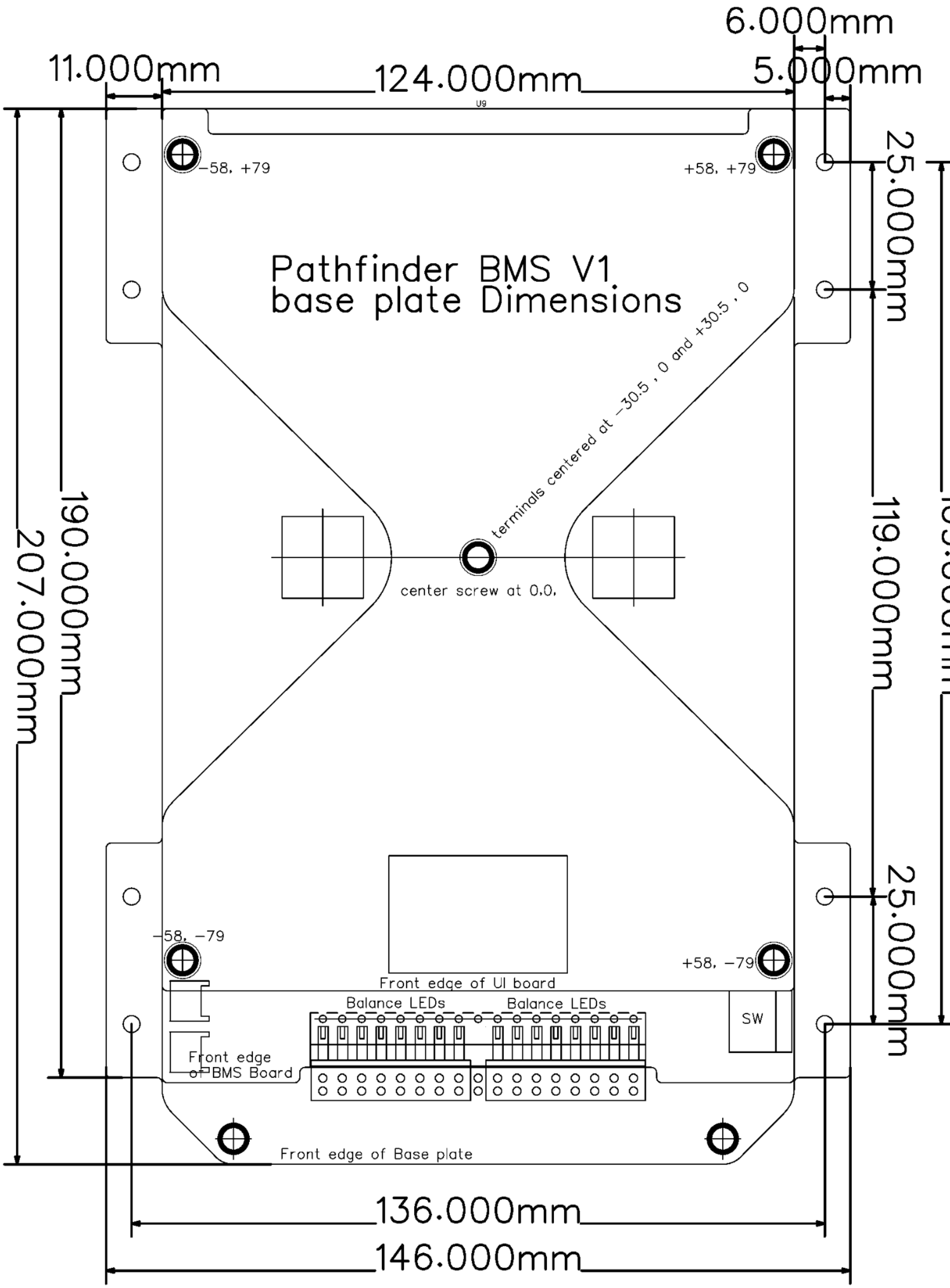
The BMS's basic functions are controlled by the Texas Instruments BQ76952 BMS chip, paired with the BQ34Z100 Fuel Gauge chip and selectable custom SOC algorithms for advanced State of Charge tracking.
The ESP32-S3 host controller configures and monitors the BMS chips, and provides an advanced user interface.

The BMS is constructed with an efficient and serviceable open frame design. The typical configuration includes:

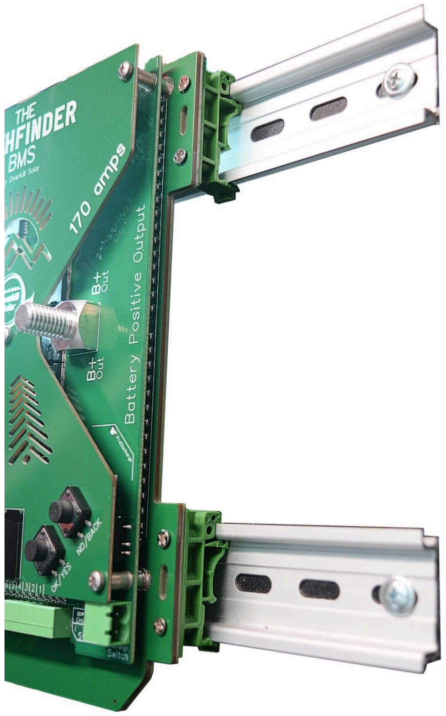
- **Base plate** with a 1 amp passive balancer and several mounting options for surface mounting or DIN rail
- **Main board** with Texas Instruments' BQ76952 BMS chip and BQ34Z100 Fuel Gauge chip, MOSFET solid state switch, Solid brass Main terminals, Pre-Discharge circuit, and integrated copper heat sink.
- **User Interface board** with OLED display, input buttons, and ESP32 microcontroller with USB, Bluetooth and WIFI
- **Balance wire terminal board** with a variety of preconfigured options and a self-test feature.

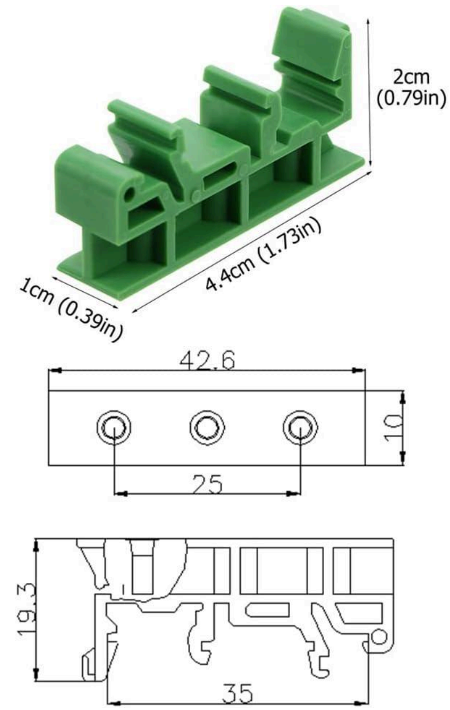
4. Table of Contents

5. Layout and Dimensions

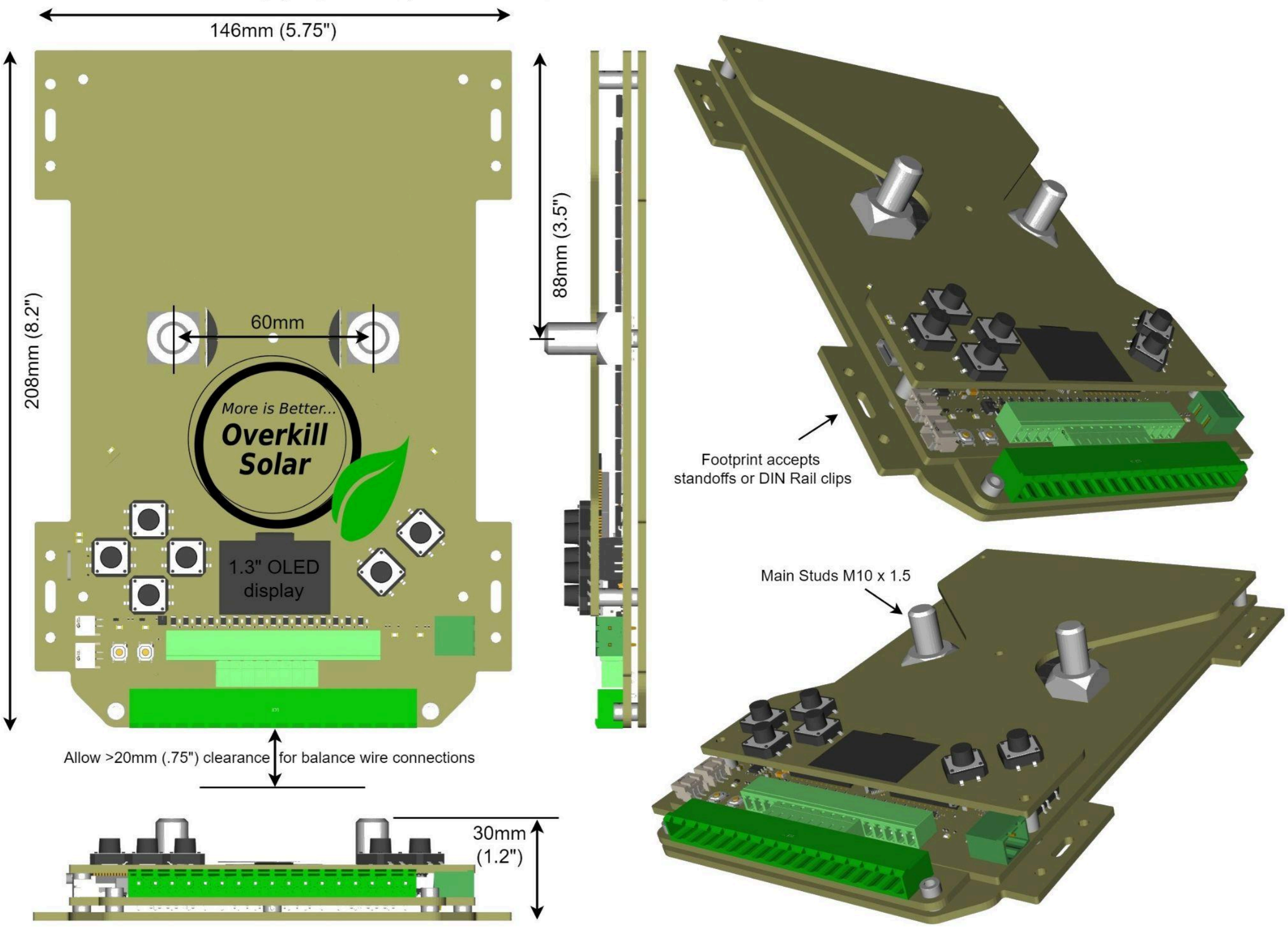


The base plate mounting holes are sized for these commonly available DIN rail clips, to be mounted on 2 parallel 35mm rails, spaced 144mm on center.





Preliminary (pre-production) Dimensions: The Pathfinder BMS by Overkill Solar LLC



6. Ratings

Parameter	Value
Max current at 22c ambient, 100% duty cycle	170 amps
Max current at 30c ambient, 100% duty cycle	TBD
Max current at 35c ambient, 100% duty cycle	TBD
Max current at 40c ambient, 100% duty cycle	TBD
Max current surge, 10 seconds	400 amps
Max short circuit detection setpoint	1000 amps
Max main board operating temperature	80c
Min main board operating temperature	-30c
Shutdown Temperature	85c
Passive balancer temperature limit	100c
Max system voltage	64v
Min system voltage	7v
Max cell count	16 cells
Min cell count	3 cells
Max Battery Capacity	Unlimited* see note 3
Current measurement resolution	Variable* see note 4
Voltage measurement resolution	1mV
Pre-discharge series resistance	10Ω
Current shunt resistance	0.025 mΩ
Total series resistance, all FETs active (+Cell to B+)	0.351 mΩ
Balancer current, main board only	43 mA
Balancer current, passive balancer base (per cell)	1A at 3.6V, 1.17A at 4.2V

7. Compliance info

ROHS:

Not ROHS compliant.
The BMS assembly contains leaded solder, because it’s way better than lead free solder.
To avoid unnecessary exposure to lead, do not eat the BMS.
May cause cancer in California, just like everything else.
Do not dispose of lead in a landfill in Europe.

This product contains leaded solder.
Avoid direct contact with food or ingestion of residues from the boards.
Wash hands after handling the circuit boards to reduce exposure to lead.

FCC part 15:

The User Interface board contains an ESP32-S3-WROOM-1U wireless controller.
FCC IDENTIFIER: 2AC7Z-ESPS3WROOM1U
This component has an integrated antenna and is tested and certified for FCC part 15 compliance.

UL listing:

This product has not been evaluated by a Nationally Recognized Testing Laboratory, ie. UL. It is up to you to determine whether they are fit for your particular project, and what regulations apply to that use.

Data Privacy:

Neither the Overkill Solar mobile app nor the BMS itself gathers any personal information. They do not transmit anything via the internet to Overkill Solar or anyone else, except for operational data via MQTT, if configured by the user. (MQTT operates on a local network, but Home Assistant or other apps can relay it via the internet)
OTA updates are read-only, they don’t send data.

8. Cell Protections

The pathfinder BMS monitors the health of the connected battery cells and takes action to protect them by disconnecting from the rest of your electrical system. It’s important to understand that the BMS can not control charge or discharge rates or voltage, except by disconnecting from the system under fault conditions.
All of the protection parameters are initialized during startup when selecting the cell count and chemistry, and all parameters can be customized via the mobile app or the on screen display.

Most of the protection parameters have a setpoint or threshold, trigger delay and reset delay.

Overcurrent protections:

- Overcurrent in discharge level 1 (multi-second delay)
- Overcurrent in discharge level 2 (millisecond delay)
- Overcurrent in discharge level 3 (microsecond delay)
- Overcurrent in charge level 1 (multi-second delay)

Voltage Protections:

- Cell Over Voltage
- Cell Under Voltage
- Shutdown Cell Voltage (fixed at Cell Under Voltage - 10%, 60 second delay)

Note: These parameters can only be set in increments of 50.6mv
(Not our decision, this is what the BQ76852 chip will accept)

Temperature Protections:

- Charge Over Temp
- Charge Under Temp
- Discharge Over Temp
- Discharge Under Temp
- Shutdown Over Temp (fixed at 85c, 5 second delay)

Permanent Fail Protections:

These parameters do not automatically reset. Once triggered, the BMS must be rebooted.

- Charge Overcurrent PF
- Discharge Overcurrent PF
- Cell Over Voltage PF
- Cell Under Voltage PF

9. Cell Balancing

The Pathfinder BMS has a low current balancer built into the main board which controls an optional passive or active balancer built into the base plate.
Balancing parameters can be adjusted via the mobile app or USB app. Adjustment via the OLED will be enabled in a future firmware update.

The Start Voltage parameter can be counterintuitive. It represents the MINIMUM cell voltage to start balancing. The balancer will operate until all cells are within delta to balance, or until all cells are below the start voltage, whichever comes first.

If the battery is severely unbalanced such that one cell is very low and one cell is very high, the balancer will not activate. It would be necessary to manually charge the lowest cells, or disassemble the battery and do a passive parallel balance on the cells. If these cells vary wildly in capacity, it would be best to replace the lowest capacity cells.

The balancer operates while charging or resting, but not while discharging.

To disable the balancer, set the number of cells to zero.

For lower cell counts like 4s, setting the *cells to balance* to 1 may be more effective.

Balancer Parameters:	LiFePO4	NMC	LTO
Start Voltage (MINIMUM Cell Voltage)	3100mv	3500mv	2200mv
Delta to balance	20	20	20
Simultaneous cells to balance. Min 1, Max 8	4	4	4

Standard Passive Balancer

The main board has a low current passive balancer which operates at about 50 milliamps.
When all cell voltages are above the *balancer start voltage*, and the difference between the highest and lowest cells is greater than *delta to balance*, the balancer connects a resistive load to the high cell in order to bleed off excess energy as waste heat. This circuit also activates the high current balancer board, if equipped.

High Current Passive Balancer

The high current passive balancer board operates at about 1 amp. Waste heat is absorbed by the mounting base, and it includes over temperature shutoff circuitry. The BMS has a "*max cells to balance*" parameter, which sets the most cells to balance simultaneously. If the balancer gets too hot, consider reducing the number of cells to balance. The default is 4.

High Current Active Balancer

A high current active balancer option is planned but is not yet available.

10. Cell Count Setup & Balance wire connections

Possible configurations:

LiFePO4: 3 to 16 cells
LTO: 4 to 16 cells
NMC: 3 to 14 cells

The Pathfinder BMS can be configured in the field for any cell count from 3-16, as long as the system voltage is in range. More than 14 cells of Lithium-ion would exceed the 64v maximum.

All of the BMS cell voltage inputs must be connected to the corresponding cell interconnects (bus bars) with balance wires. There will always be cell count + 1 balance wires (example: 4 cells, 5 balance wires)
Acceptable wire sizes are 20ga to 16ga. We recommend using a crimped wire ferrule on the BMS end and a crimped ring terminal on the cell terminal end. The balance wires can be connected to either the positive or negative terminal at each cell interconnect, or fastened in the center of the bus bar. Any of these positions are acceptable. See note “Note 1: Which stud to use? Where is BCx?”

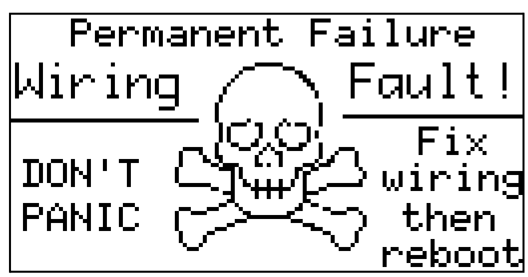
Automatic cell count detection

The BMS auto-detects the cell count and type at startup. If any of the balance wire connections are missing or out of order, the cell count detection will fail. In that case, the BMS can still display the cell voltage measurements on the screen for troubleshooting. Once the faults are corrected, reset the BMS to retry automatic cell count detection.

The balance wire terminal boards simplify the configuration for cell counts less than 16. Boards with screw terminals accept up to 14ga wire. 20ga or 18ga wire is recommended. Tesla kits feature a pre-wired plug-and-play connector.

Warning: connecting balance wires out of order can damage the cell voltage inputs.
Before plugging in the balance wire connector, press the TEST button on the balance wire connector board. Only the green light should light. Any red lights indicate a wiring fault that must be corrected before plugging in to the BMS.

This warning will show if any of the bus bars are open or missing during start up. Cell voltages will be displayed for troubleshooting.



In most cases,
the BMS will avoid damage and the wiring fault can be repaired. Reset the BMS to try again.

Balance Terminal Boards

Each Pathfinder BMS comes with 1 terminal board for the balance wire connections. The 16s board is universal and can be used for any battery from 3-16 cells.

For simplified wiring, a variety of other terminal boards are available. These boards make all of the required jumper connections and only expose the terminals that are needed for the indicated battery setup.

The prewired Tesla boards combine with 1 or 2 of our Tesla module retrofit boards for 24 or 48v Tesla battery assemblies.

Each board has a TEST button. This will show a green light when the button is pressed, and if faults are present, one or more red lights will light. Red lights indicate wiring faults that must be fixed before plugging this board into the BMS.

TODO: update the photos. These are the prototypes without test buttons

A: 16s with screw terminals

B: 12s with screw terminals

C: 8s with screw terminals

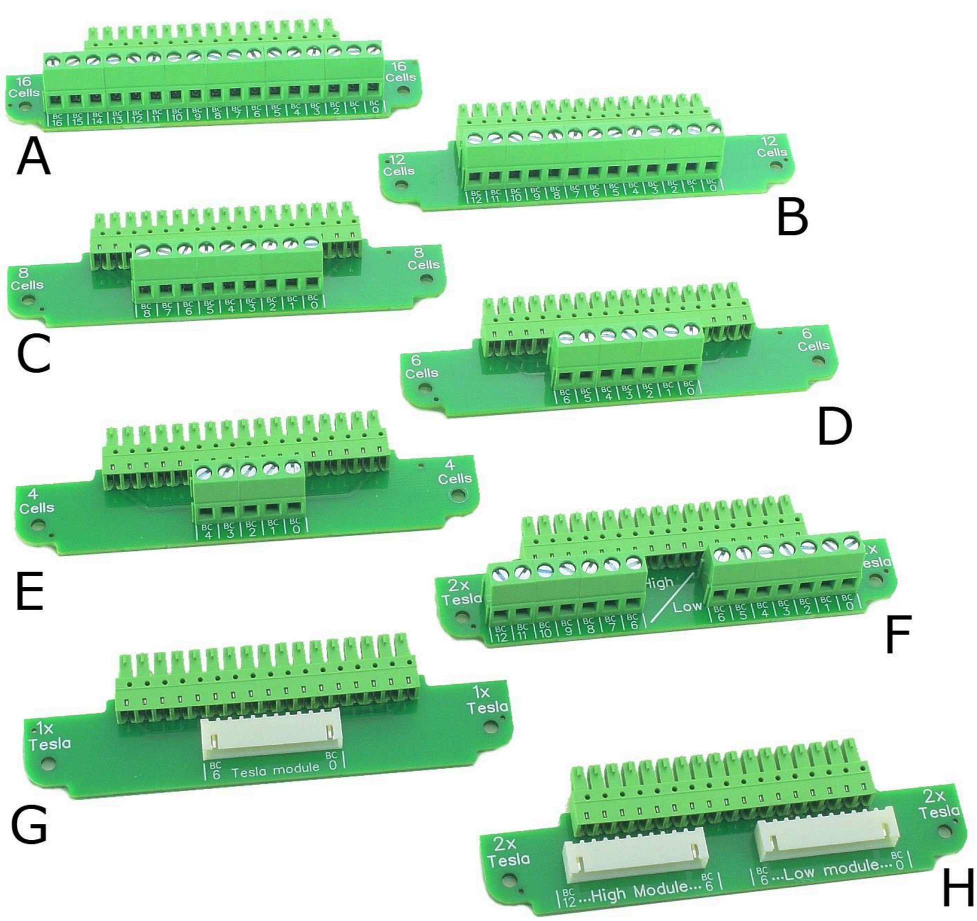
D: 6s with screw terminals

E: 4s with screw terminals

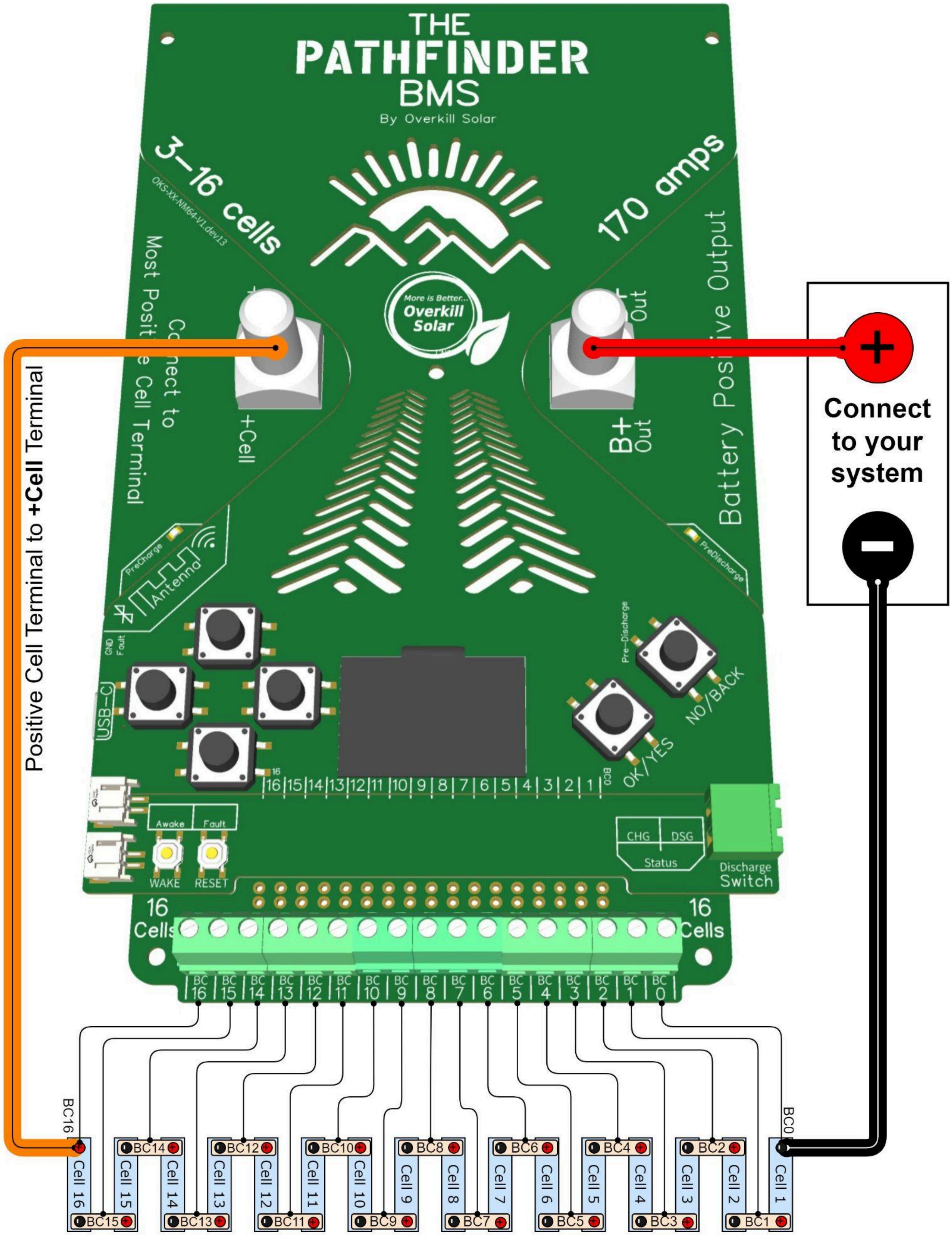
F: 12s Tesla modules with screw terminals (2 series modules)

G: 6s Tesla module, prewired

H: 12s Tesla modules, prewired (2 series modules)



16 Cell Connection drawing



48v Battery Pack: 16 cells in series

This drawing shows the general layout of a 16 cell battery. Note that the most positive terminal (BC16) on the group of cells is connected only to BC16 and the “+Cell” terminal of the BMS.

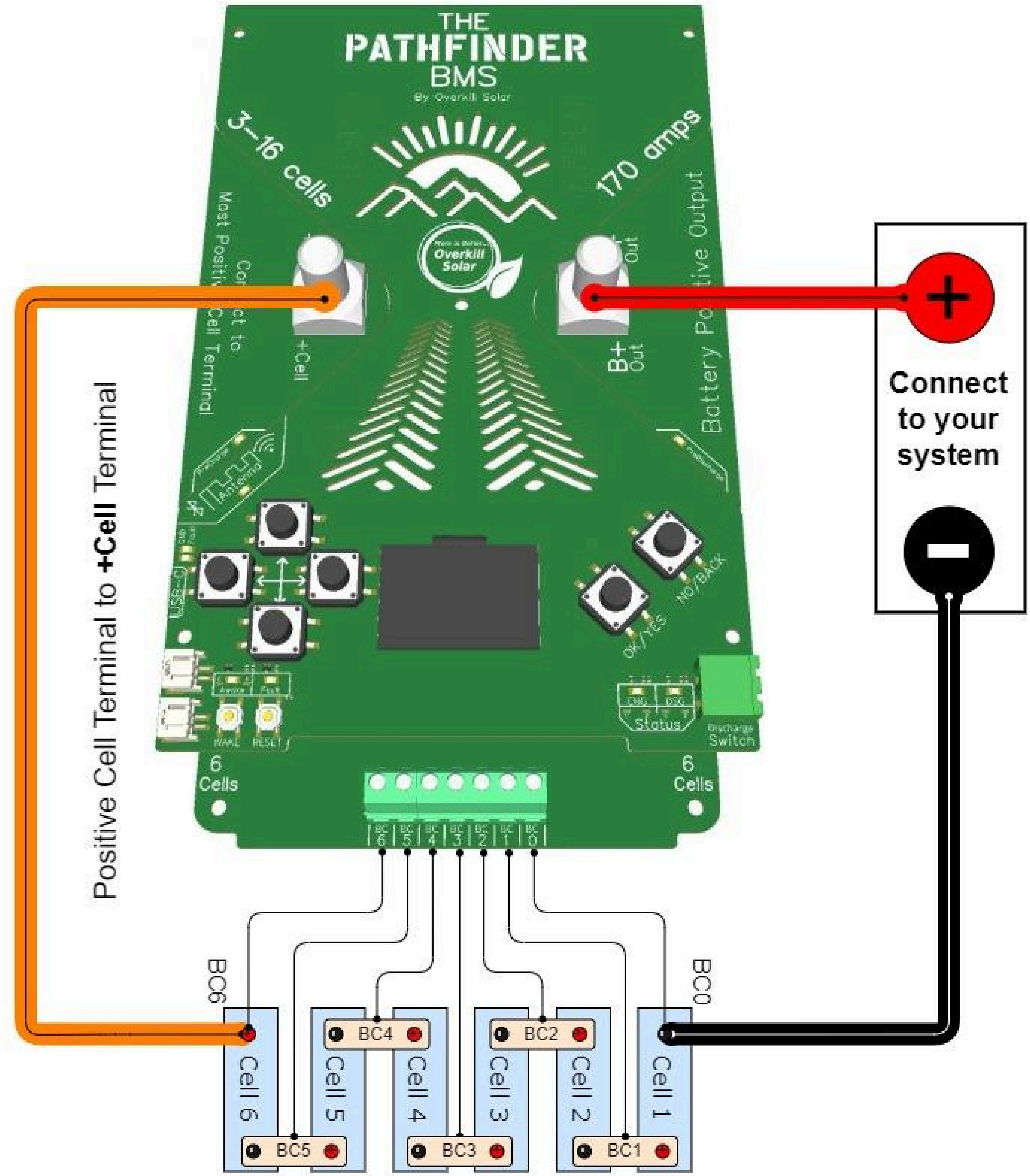
The “B+” terminal connects to the positive side of your electrical system. Do not connect anything else to the cells. Doing so would bypass the BMS protection.

The most negative terminal on the group of cells is connected to the negative (or ground) side of your electrical system. It is OK to connect this wire to a chassis ground, if applicable.

All 17 balance wires (AKA voltage sensing wires) must be connected as shown for a 16 cell battery. See note 1 for tips on connecting balance wires.

The Pathfinder BMS must switch the positive side of the system. If you are retrofitting a battery that has a BMS on the negative side, you must re-wire the battery for positive side switching.

6 cell connection drawing

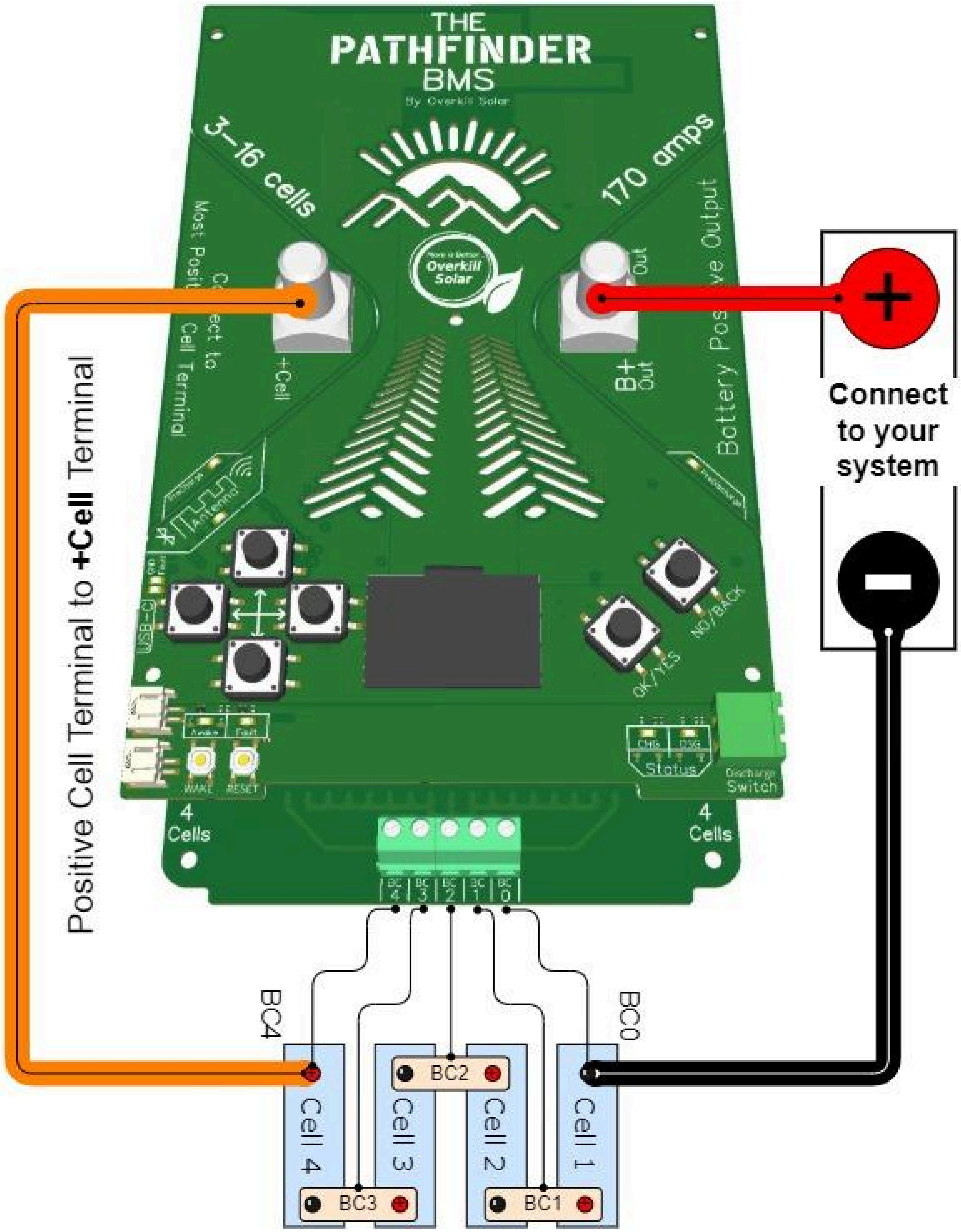


24v NMC Battery Pack: 6 cells in series

This drawing shows a 6 cell terminal board used to connect a 6 cell pack (such as a Tesla model S module).

Note that the terminal board labels the balance connections BC0-BC6. All appropriate jumper connections are made by the terminal board, leaving only the connections needed for the 6 cell battery.

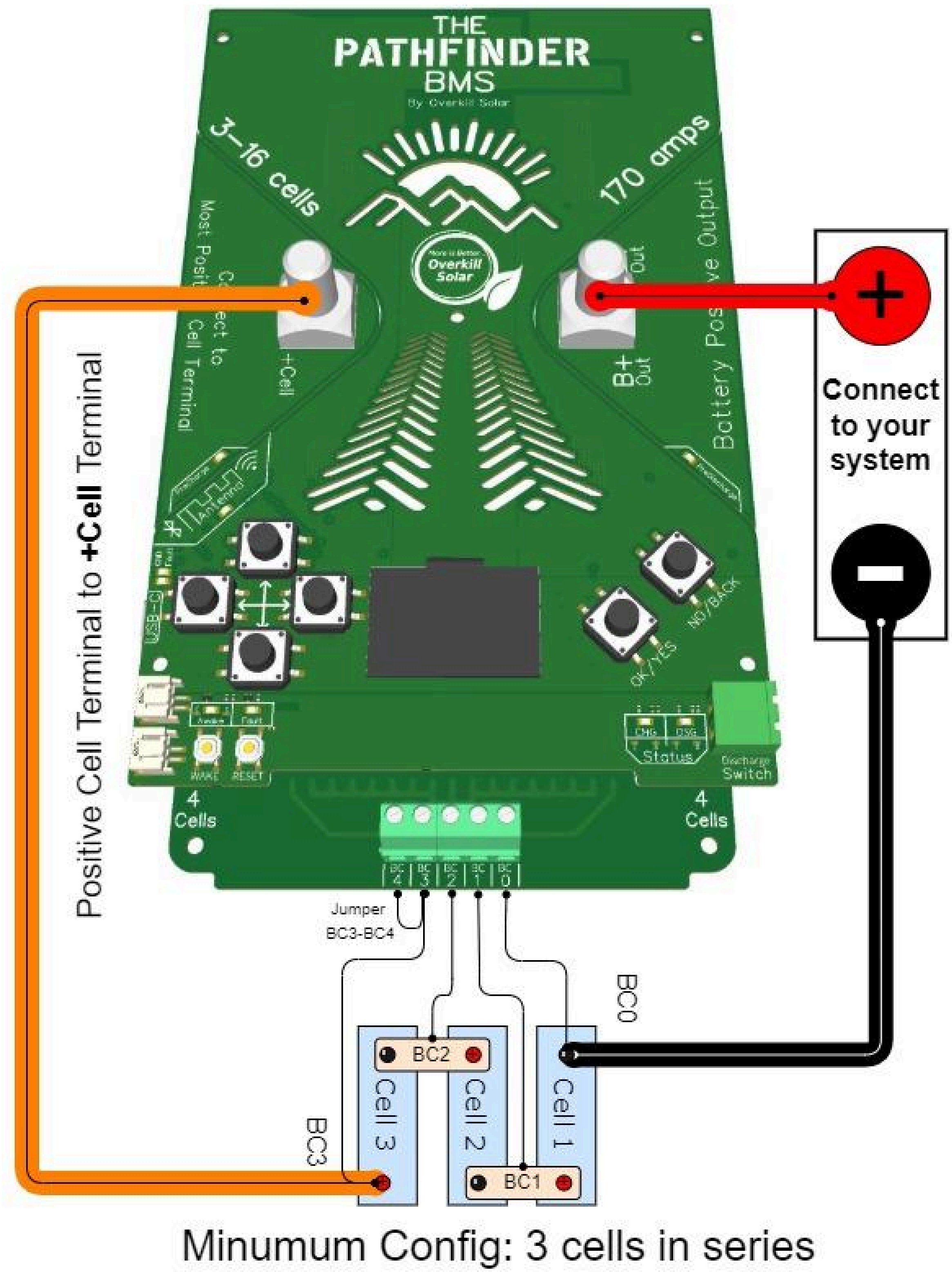
4 cell Connection Diagram



12v LiFePO4 Battery Pack: 4 cells in series

This diagram shows 4 LiFePO4 cells connected for a 12v battery, using a 4 cell terminal board.

3 Cell Connection Diagram



This drawing shows 3 cells connected using a 4 cell terminal board. BC3 is jumpered to BC4.

Arbitrary Configuration

With a 16s terminal board, the Pathfinder BMS can be configured for any cell count from 3 to 16 cells.

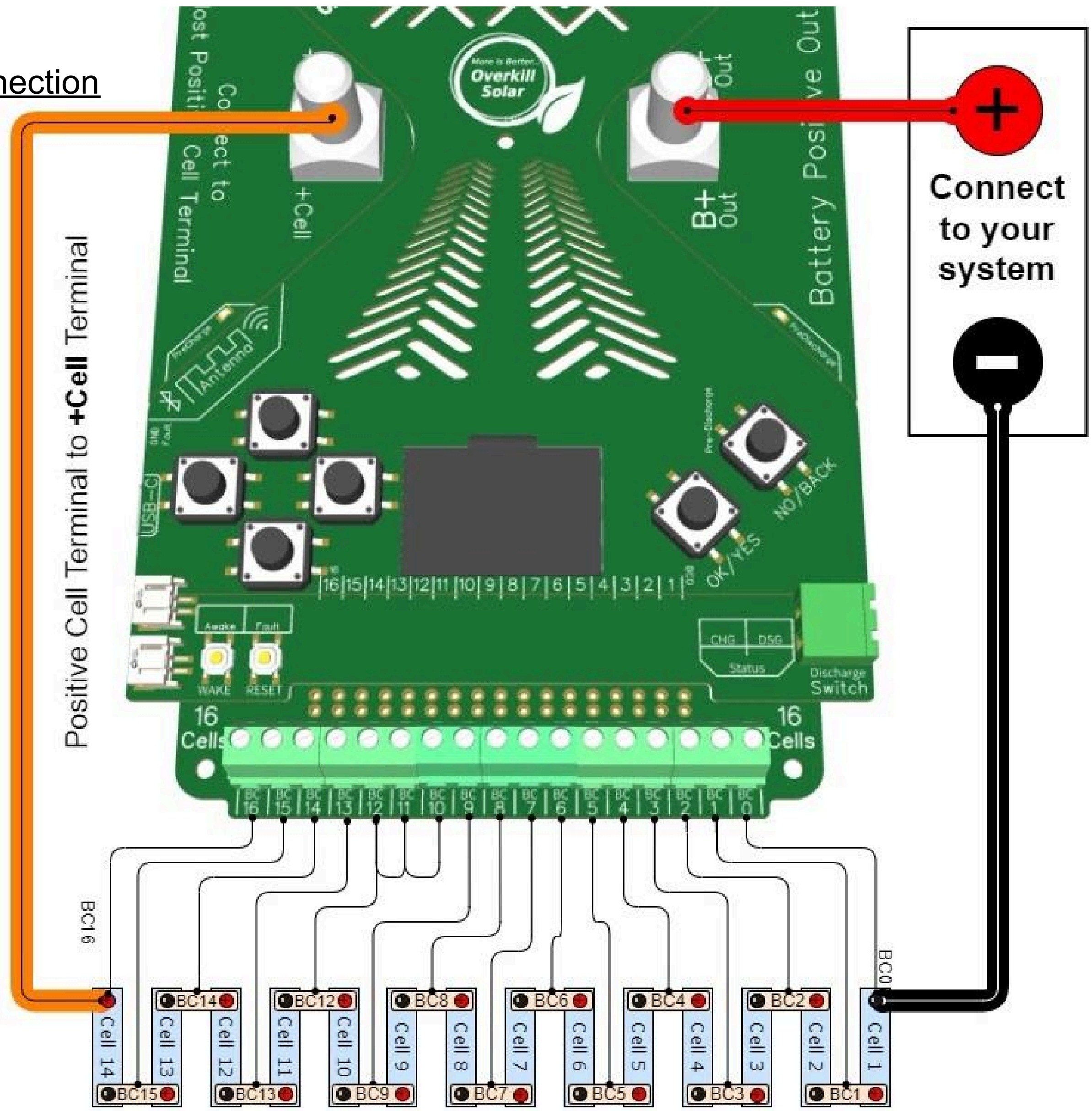
BC0 must be connected to the most negative cell terminal, and BC16 must be connected to the most positive cell terminal. The minimum number of cells is 3. Cell 1 must be connected to BC0-BC1, cell 2 must be connected to BC1-BC2, and the top cell must be connected to BC15-BC16. All other unused cell connections must be shorted together. See the example drawings below.

In other words, **Cells 1,2, and 16 must be connected** at a minimum, and all open balance wire connections will be jumpered to the active cell connections on both sides. Every balance wire connection must be connected to a cell terminal, **there can not be any open or floating cell inputs**.

All other cells can be connected to any of the inputs, as long as they are in ascending order.

For example, for a 14 cell pack, the 2 skipped cells can be in any position excluding 1,2, or 16.

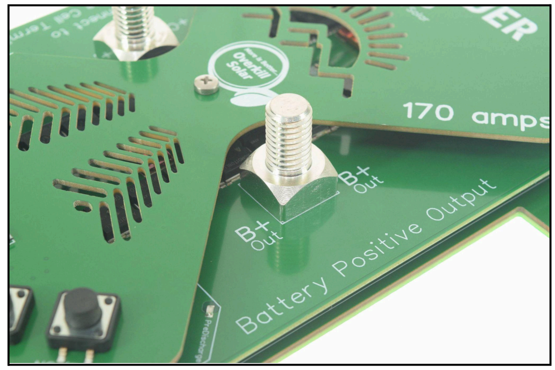
14 cell connection



Arbitrary Configuration: 14 Cell Example

In this 14 cell drawing, BC10, BC11, and BC12 are jumpered together for the 2 missing cells.

11. Main Terminal Studs

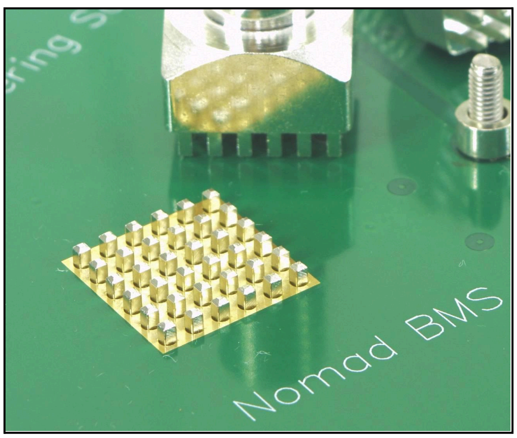


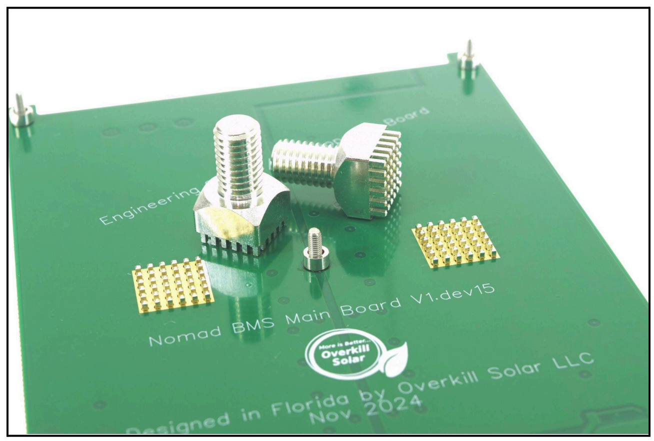
Specifications:

Main lug thread size:	M10 x 1.5
Main lug threaded length:	15mm
Main lug Material:	Tin plated Brass
Tightening torque:	150in-lb (17Nm) with backup wrench

The main terminals use solderless press-fit technology. Pressing the terminals into the main board causes the terminal pins to permanently cold-weld to the copper board plating.
The force to remove these terminals far exceeds the force needed to destroy the board substrate- they will never come out.

In testing, we found that the resistance of this connection is much lower than a soldered terminal.





The studs are milled from solid brass and tin plated. The included nuts and washers are 304 stainless steel.

Use a thin 17mm open end wrench to hold the bottom of the main terminals when tightening the nuts. Ensure that the wrench does not get pinched when the nut is tightened! This can crack the circuit board. **The wrench needs to be less than 8mm thick.**

Do not use an impact wrench or impact driver to tighten the main terminals, as this puts unacceptable vibration stress on the main circuit board.

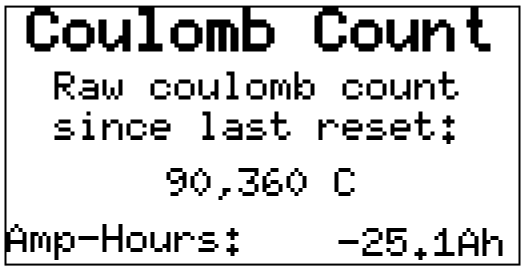
These terminals are available in other shapes and sizes, such as threaded holes instead of studs. Contact Overkill Solar if the standard threaded stud is unacceptable for your application.

12. Coulomb Counter

The Pathfinder BMS tracks the raw coulomb count since the last reset and reports it on the Coulomb count OLED screen. This value is used by the OKS custom SOC tracking algorithms.
Design capacity should be set after a full reset or initial setup. (note that design capacity changes will not be accepted if the BQ34Z100 Learning Cycle is active)

Each algorithm (except the BQ34Z100) applies its own offset value to the raw coulomb count when calculating the state of charge. The current measurement source is the Average Current as reported by the BQ34Z100. This is a 14 second moving average of the raw current measurement (The measurement resolution is variable relative to the design capacity. See note 4.)

This screen also converts the raw coulomb count into raw Amp-hours since the last reset.



13. SOC Measurements

The pathfinder BMS uses multiple semi-independent algorithms to track and calculate the state of charge (SOC). The user can select which algo will report the state of charge, state of health, measured capacity, remaining capacity, and time to empty or full. Other data may be available such as best/worst cell.

The algo selection determines which set of results will be reported on the OLED display and the mobile apps. All of the optional SOC algorithms continue to track SOC regardless of which one is selected, so the selection can be changed at any time without losing learned data.

Only the BQ34Z100 has a learning cycle that must be started by the user. It is very particular about the sequence of events. See section *BQ34Z100 Learning Cycle* below. The other custom algo(s) are designed to be more DIY- friendly.

To change the active algo, navigate to “SOC Algo Select” on the OLED display.

Highlight and click on the desired algo to select it. BasicSOC is the default after a full reset.

SOC Voltage Settings:	LiFePO4	NMC	LTO
Charge Termination Voltage (100% SOC)	3500mv	4000mv	2450mv
Design Voltage (Nominal cell voltage)	3200mv	3600mv	2300mv
Discharge Termination Voltage (0% SOC)	3000mv	3300mv	2100mv

The voltage setpoints are not adjustable as of firmware version V_0.300. In a future firmware update we will add the ability to adjust these values.

BasicSOC

This SOC tracking algorithm uses a simple method of resetting the capacity at high and low voltage points and tracking coulombs in between the reset points.

This method suffers from drift if the battery experiences shallow cycles or long periods of low activity, but maintains good accuracy if the battery routinely sees a full cycle.

When the Pathfinder BMS is first set up or has a total reset, default values will be loaded for the high and low voltage levels, and the SOC will be initialized at 50%.

To learn the battery capacity using this algo, discharge the battery until at least 1 cell is below the low voltage level, then fully charge until at least 1 cell is above the high voltage level. At that point the SOC confidence should reach 100%. It is **not necessary** to maintain a specific charge/discharge rate or complete the full cycle in a certain time frame.

This algorithm keeps track of the total amount of coulombs passed during shallow cycles, and subtracts from the confidence level as more charge is accumulated without a 0% or 100% reset.

Measured capacity, which is used to calculate the State of Health, is updated only when the battery is charged from 0% to 100% without accumulating more than 2 whole cycles in between.

If Design Capacity is changed by the user, Measured Capacity will reset to the new value of Design Capacity, and as a result State of Health will also reset to 100%

Remaining capacity is retained when the BMS is rebooted (or when the firmware is updated), but confidence will drop to 0% until another cycle is completed. Confidence drops after a reboot because the controller has no way to know what happened during the downtime.

Cycle count is calculated from the total passed coulombs divided by measured capacity. Shallow cycles to contribute to the total, not just top-to-bottom full cycles.

BQ34Z100 Learning Cycle

The Pathfinder BMS has a dedicated chip whose only job is to track the battery's state of charge. (BQ34Z100 by Texas Instruments)

During the first boot up or after a full reset, one of the stored configurations will be loaded, based on the detected chemistry type. The user can choose a different chemistry type if it was not correctly detected. (The voltage range of LiFePO4 and NMC overlaps significantly)

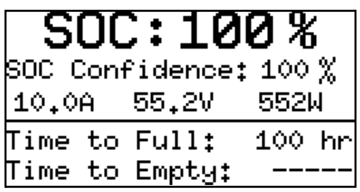
After a config file has been loaded, the BQ34Z100 is set up for the chemistry type but not the specific battery pack. The Design Capacity needs to be set to match the size of the cells.

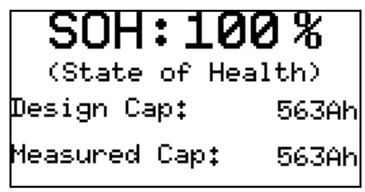
Examples:
For a battery with (8) 320Ah cells in series for 24v, the Design Capacity is 320Ah.
For a battery with (8) 320Ah cells with 4 pairs in series for 12v (2p4s), the Design Capacity is 640Ah.

The maximum Design Capacity is practically unlimited. The measurement resolution will be lower for larger batteries, as the internal values are scaled to keep the data in range. The BMS display rounds to the nearest whole Amp-hour.

Once the capacity parameters are set, the chip will be waiting for a learning cycle to complete. Until the learning cycle is finished, the SOC confidence level will be low, and it will increase as the chip gathers data.

This chip also calculates Time to empty/full based on the average current, and the state of health (SOH), which is defined as the ratio of Design Capacity to Measured Capacity.





The State Of Charge measurement is reset to zero when the discharge termination voltage is reached, and it is reset to 100% when the charge termination voltage is reached. These values are not adjustable as of the first firmware release. We may add adjustable parameters in a future firmware release, if necessary. These are not connected to the Cell Over/Under Voltage protections, so if the protection parameters are set inside the termination voltages, the SOC measurement may never get to a high confidence level.

The BQ34Z100 chip only measures the full stack voltage, so in order to detect the termination voltage, the battery voltage must reach (termination voltage * number of cells).

Examples: A 4 cell LiFePO4 battery has a **Discharge Termination Voltage** of 3000mV*4 = **12.0V.**
The same battery has a **Charge Termination Voltage** of 3500mV*4 = **14.0V.**

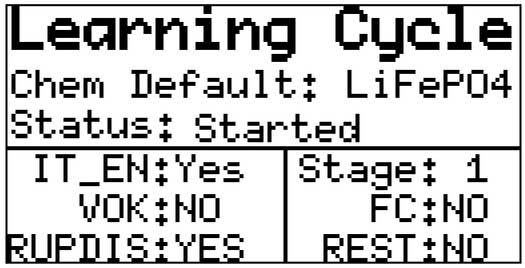
If the cells are unbalanced or mismatched, it's likely that a cell undervoltage or overvoltage alarm will happen before the full stack termination voltage is reached, and the BQ34Z100 may not detect the start/end points of the learning cycle.

Make sure your under/over voltage protection parameters are not set tighter than the termination voltages from the table below- The battery must be able to reach the termination voltages without triggering an under/over voltage cutoff alarm.

The State Of Health measurement is also reset in this way. Measured Capacity will not be accurate until a cycle is complete.

NOTE: Battery capacity (Design Capacity) needs to be set during initial setup, after the cell count and chemistry selection, as well as current and voltage calibrations, if needed. **After the SOC learning**

cycle starts, the BQ34Z100 fuel gauge will not accept configuration changes. The learning cycle can be reset via the reset options screen. After resetting, the design capacity and chemistry selection are reloaded, but the null current calibration should be repeated.



The Learning cycle status screen displays diagnostic information about the learning cycle.

- **Chem Default**: This was picked during initial setup. To change it, do a Total Factory Reset.
- **Status**: Reflects the internal status register for the BQ34Z100 IT algorithm. Possible statuses:
  - Not Started (0x00)
  - Disabled (0x02)
  - Started (0x04)
  - Cap Learned (0x05)
  - Finished (0x06)
- **Stage**: The learn cycle status as interpreted by the Pathfinder BMS firmware.
  - 0: IT algorithm not started. waiting for IT_EN.
  - 1: Waiting for full discharge.
  - 2: Waiting for REST at full discharge.
  - 3: Waiting for Full Charge.
  - 4: Waiting for REST at full charge.
  - 5: Waiting for steady discharge.
  - 6: Waiting for REST at full discharge.
- IT_EN: Impedance Track Algorithm Enabled.
- VOK: The last open circuit voltage measurement can be used to update measured capacity.
- RUP_DIS: Resistance table updates are disabled.
- FC: Full Charge has been detected and SOC has been set to 100%.
- REST: The rate of change in voltage is low enough to record an open circuit voltage measurement.

BQ34Z100 Learning Cycle Procedure

The learning cycle starts with the battery at a middle state of charge. Anywhere close to the nominal voltage is acceptable. The cells should be balanced first.

1. The cycle must be started manually by pressing OK while on the Learn Cycle screen. Note: Learning cycle no longer starts automatically after V_0.221_BETA.
2. Discharge all cells below the *Discharge Termination Voltage* From the table above.
3. Wait for the REST bit to be set. (Monitor via the Learning Cycle screen on the OLED) This indicates that the BQ34Z100 chip has recorded an open circuit voltage measurement and is ready to be charged. This will take up to 5 hours. Make sure there is no current flowing. The Status should say "Started", and “REST: YES”
4. Charge the battery to full. It needs to get above *Charge Termination Voltage * Number of cells* from the table above. During this charge cycle, Measured Capacity and Remaining Capacity will both increase from zero as the charge is integrated. The charger used during this step

must have a cc/cv or end-of-charge taper mode. If the charger shuts off too early, the battery voltage may relax too far and cause the learning cycle to fail. LiFePO4 is especially susceptible to this. The BMS's balancer can also cause this step to fail by drawing down the voltage. Try to get the battery voltage to float at the full charge voltage for several hours.

5. Wait for the FC (Full Charge) and REST bits to be set. This indicates that the BQ34Z100 chip has recorded a full charge and another open circuit voltage measurement. This may take several hours. The Status should change to read "Cap learned".
6. Discharge the battery again. The discharge rate is important during this step. It should be around C/5 and must be greater than C/10. (see note 2) Discharge to below the *Discharge Termination Voltage * number of cells.* **The discharge must not be interrupted during this step!** This is the fine tuning step. The cycle may fail if discharging is paused during this step.
7. Wait for the REST bit to be set again. If successful, the status will change to "Finished", and the learning cycle is complete. At this point the SOC confidence should be high, and the SOC measurement is as accurate as possible.

Measuring State Of Charge is surprisingly difficult and complicated. LiFePO4 is more difficult to measure than NMC. We expect to refine this function in future firmware updates as we gain feedback and experience. The BQ34Z100 was intended to be calibrated at a factory and copied many times to identical batteries, but we are using it in a DIY scenario where this step must be completed in the field for each battery. Your feedback is valuable as we refine the procedure.

For technical and theoretical details on the BQ34Z100 SOC calculation and Learning cycle, refer to these documents from Texas Instruments: (But beware- these documents do contain errors, which is part of the reason we don't have this function refined yet.)

- Theory and Implementation of Impedance Track™ Battery Fuel-Gauging Algorithm - Application Report SLUA364B
- Achieving The Successful Learning Cycle - Application Report SLUA903
- BQ34Z100-R2 Technical Reference Manual - SLUUCO5A

BQ34Z100 Learning Cycle Notes:

- The BQ34Z100 is looking for a very low rate of change of the battery voltage when it sets the REST condition. (about 1 microvolt per second) This is how it signals the next step in the learning cycle process.
- It may help to disable the radio power while waiting for REST at the bottom of the discharge cycle. The radio consumes power that can keep the self discharge rate too high.
- When waiting for REST at the top of the charge cycle, it may save time to disable the balancer if it is working and causing the battery voltage to drop. ONLY IF your battery has already charged above *Charge Termination Voltage * Number of cells*, you can set the *number of cells to balance* to zero to stop the balancer from operating while waiting for REST at full charge.
- Imbalance may cause the learning cycle to fail at the full charge stage. If a cell overvoltage due to imbalance stops the charging prematurely, the BQ34Z100 may not be able to detect FC (full charge) and REST at the same time, which is needed to move on to the next stage. If this happens, charge to full and let the balancer operate until all cells are balanced at full charge, then restart the learning cycle.

BQ34Z100 Learning Cycle in Graphical Form

(From TI application note *Achieving The Successful Learning Cycle*)

This is a graph of voltage and current for a hypothetical 6 cell NMC battery during the learning cycle. Note that the full cycle took 24 hours to complete in this example.

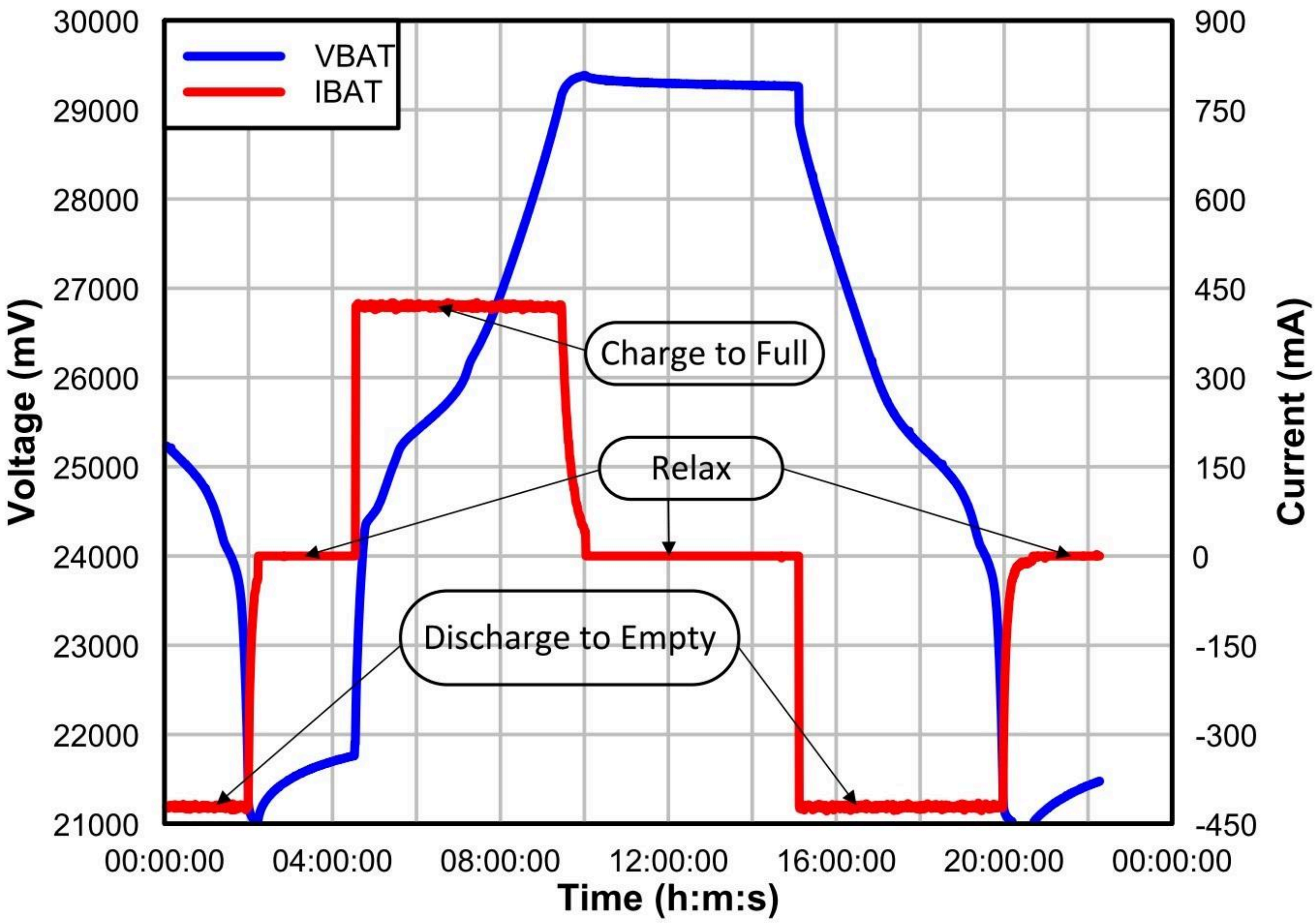
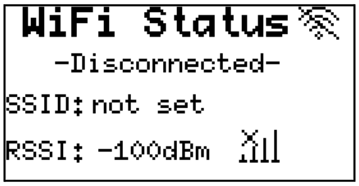


Figure 2. Learning Cycle Overview

14. WiFi

The Pathfinder can connect to a 2.4Ghz WiFi network. Credentials are entered via the built in screen. The wifi connection is used to check Overkill Solar's github for OTA updates (if enabled), and for sending MQTT messages to HomeAssistant (if enabled).



15. Monitoring Applications

The Overkill Solar Bluetooth mobile app Version 2 is available for iOS on the Apple App Store, and Android on the Google Play store. It is also available as a web app using webserial to connect using USB.

Check your mobile app to make sure it has updated to **Version 2.0** or later. Version 1.x DOES NOT support the Pathfinder BMS, only the old JBD BMSs, and it will not show any Pathfinder BMSs on the device tab. If it has not updated, you may need to force-stop and re-open, or uninstall and reload it from the app store. The app version is displayed at the top of the "Home" tab, or at the bottom of "App Info" on android phones.

The USB app relies on "Webserial", which works by default in Chrome, Opera, and Edge. (probably all chromium based browsers). Firefox does not support Webserial, but it can be enabled with an extension called "WebSerial for Firefox" by kuba2k2. This is not an official trusted addon for firefox, and we can not promise that it is secure, but it works.

These apps are used to set parameters and monitor data, but they must be in range of the bluetooth connection. The only way to monitor the BMS remotely is to set up MQTT and Home Assistant. (In a future firmware release we might add remote monitoring to the app(s) using WiFi, but this hasn't been developed yet.)

The Bluetooth connection is encrypted. A PIN is needed one time to pair a new BMS, and the PIN must be entered again to access the parameter settings. The PIN is stored in the BMS and can be changed via the OLED and button interface. Anyone with physical access to the BMS controls can see and change the PIN, but wireless remote access is secure as long as the default PIN has been changed.

The default PIN is 123456. See section "BLE PIN (Bluetooth passkey)"

iOS app: https://apps.apple.com/us/app/overkill-solar/id6444233824
Android app: https://play.google.com/store/apps/details?id=com.marchingband.overkillsolar
Web app: OverkillSolarBMS.expo.app

Note: the USB connection is susceptible to electrical interference from noisy inverters or other things connected to the system. See section "Electrical Interference" for mitigations.

Android Device Compatibility

There is an incredible variation in Android hardware and software, making it near impossible to test compatibility with every device. Version 2.x of the Overkill Solar mobile app is not compatible with some older Android hardware. The older 1.x app version will NOT work with a Pathfinder BMS.

Amazon Fire Tablets will run the Overkill Solar app if it is sideloaded with the .APK file. We tried submitting it to the Amazon app store but it was rejected because the regular Android OS needs location services enabled to make bluetooth discovery work, but Fire tablets do not have GPS location services, and so Amazon says the app is not compatible with their tablets.

The APK archive can be found on OverkillSolar.com or directly at
https://github.com/OverkillSolarLLC/Android_APK_archive

Help request email

The Mobile apps include a “Help” button. Clicking this will send a snapshot all of the BMS data and settings into an email template, which will open in your default email program. You can then add a description of your issue and send it to support@overkillsolar.com.
If you are using the USB version, it will offer to copy the info dump to the clipboard, then you can paste it into your email.

16. Bluetooth (BLE)

The mobile device must be in range of the antenna to use bluetooth.
Bluetooth is always available unless radio power has been turned off via the OLED interface.
The BLE status screen shows the MAC address of the connected device (client) and the signal strength.

BLE Data Encryption

The Pathfinder uses Bluetooth Low Energy (BLE) Secure Manager Protocol (SMP) with LE Secure Connections (LESC) to ensure secure communication.

- Encryption Algorithm: AES-CCM (128-bit)
- Key Exchange: Elliptic Curve Diffie-Hellman (ECDH)
- Encryption Mode: AES in Counter Mode (CTR)
- Integrity Check: Cipher Block Chaining Message Authentication Code (CBC-MAC)
- Pairing Method: Out-of-Bounds (OOB) pairing via manual password entry

This follows the standard BLE security framework and is supported on both iOS and Android.

Android Compatibility (disable BLE encryption)

Some android devices will fail to connect to BLE with encryption.

If your android device can not connect, try disabling BLE encryption via the OLED menu.

Without encryption, it is possible to sniff the BLE passkey or other data wirelessly.
If you are paranoid about that sort of thing, try a different Android device instead.

17. BLE PIN (Bluetooth passkey)

The default BLE PIN is “123456”

Changing the PIN/Passkey

A PIN is required to connect using bluetooth. When a new bluetooth device tries to connect, the BMS will request the passkey from the mobile app. It can be changed via the OLED to any number from 0 to 4,294,967,295. (PIN is stored in a 32 bit unsigned integer) By navigating to the BLE PIN change screen, the user can see the current passkey and change it if needed.

This ensures that only someone with physical access to the BMS hardware can connect to it wirelessly with the mobile app.
This is a reasonable level of wireless access control because anyone with access to the BMS user interface buttons could simply do a factory reset to restore the default passkey.

It is technically possible to brute force guess this simple passkey, but the rate limit in the BMS means that it would take on average 7 years to guess and check a random number in this space. (BLE traffic is encrypted to prevent sniffing the passkey)
The OLED will show a message if the wrong PIN/passkey is tried. This warning may show the first time an unknown device tries to connect. It will also show the number of times a wrong PIN has been tried.

Once the same passkey is set in the BMS and mobile device, it will be remembered on the next connection. If the passkey is changed later on the BMS, the app will ask for the new passkey when trying to connect.

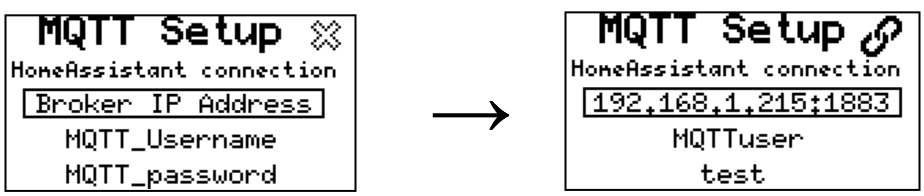
The passkey must be reentered by default when writing any parameters. This prevents accidental changes when unauthorized people have access to the mobile device, for example if children are playing with a tablet used to monitor the BMS.

If the app stalls at “CONNECTING”, try forgetting the device in your bluetooth settings. Your mobile device may remember an old configuration after the BMS firmware has updated.

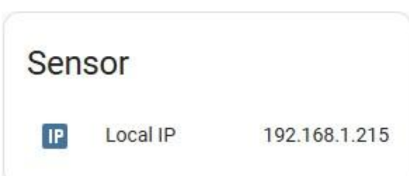
18. MQTT (HomeAssistant)

MQTT is a messaging format used to send data to HomeAssistant or other custom applications. To use MQTT, enter your MQTT broker credentials via the built in screen. We have tested it using Mosquito Broker in HomeAssistant.
When the BMS successfully connects to your MQTT broker, it will publish discovery messages that allows HomeAssistant to automatically discover all of the available BMS data. The HomeAssistant app can then be used for monitoring multiple BMSs remotely over the internet.

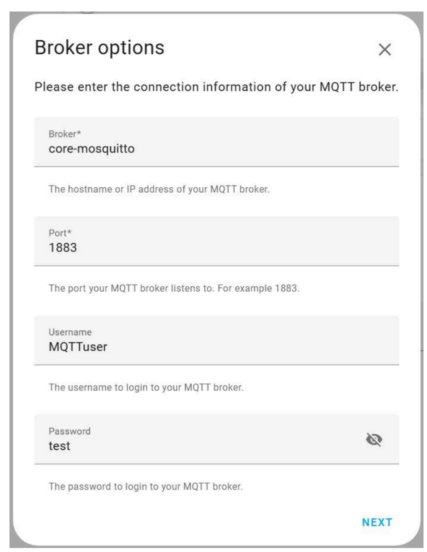
As of the initial firmware release, MQTT is read only. A future firmware update will add writable parameters to MQTT.



You will need to know the IP address and port, and the username and password for your MQTT broker. An easy way to get the broker address is to add a component called “Local IP” to your home assistant dashboard. The port is usually 1883 unless you changed it during broker setup.



The username is one of the “people” in your Home Assistant setup, and it needs to be entered on the broker options screen when you configure the broker.



19. Radio Power

All wireless radio power can be disabled via the built in screen. Once Radio power is turned off, WiFi, Bluetooth, OTA updates, and MQTT will be unavailable, and the BMS will not do any wireless communication. It must be reenabled via the built in screen to use any of the wireless functions.

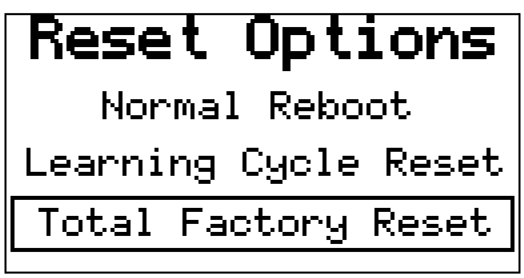
A normal reset will not override this setting, but a Total Factory Reset will reenable radio power.

20. Reset Options

The BMS can be reset 3 ways.

- **Physical reset button:** Press to immediately reboot the BMS and user interface. Settings will be reloaded. This button can also be used to enter “storage mode” (deep sleep)
- **Normal Reboot** via the built in screen: Reboot the BMS and user interface. Settings will be saved and reloaded.
- **Learning Cycle Reset** via the built in screen: This resets everything in the BQ34Z100 fuel gauge chip and reloads your design capacity and chemistry selection. BMS settings will not be changed.
- **Total Factory Reset** via the built in screen: All settings, configs, passwords, and calibrations will be erased and reloaded from factory defaults.

Fallback method: Hold the **UP** button and press reset to trigger a Total Factory Reset.



21. Firmware Updates

OTA: Over-the-air

Over-the-air firmware updates are available if a WIFI connection has been set up.

The BMS checks a folder on Overkill Solar's Github to find new updates. If a new update is found, it will either install the update or prompt you via the OLED screen, depending on the settings. It will load only stable updates by default, but it can be configured to load Beta updates if you want to help test new features. The permission screen will display only the new version number. The change logs will be published on the Overkill Solar website in the UF2 updates archive, and in the OTA github folders:

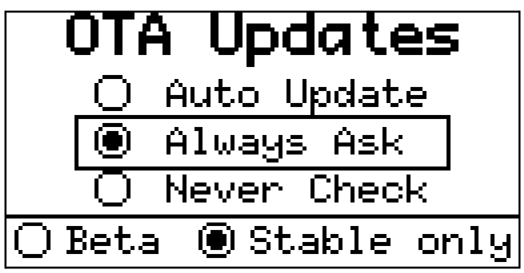
- https://github.com/OverkillSolarLLC/OTA_Beta
- https://github.com/OverkillSolarLLC/OTA_Stable

During the update process the BMS will reboot, and the outputs may turn off (or on) for a short time. Before allowing an update to proceed, make sure your system is in a safe state for this battery to be switched off (or on).

A progress bar will show the progress of the update. It should finish in less than 2 minutes and reboot. Very slow internet connections may result in a slower update. The firmware file is about 2MB.

If you have updates set to automatically install, it is possible for multiple Pathfinder BMSs to update at the same time. They are not intentionally synchronized, but it could happen.

OTA can only load the latest update, so if you want to roll back an update, use the UF2 update method.



The URLs being checked are as follows: (FYI - the user will never need to know this.)

ALPHA: https://raw.githubusercontent.com/OverkillSolarLLC/OTA_Alpha/main/firmware.bin

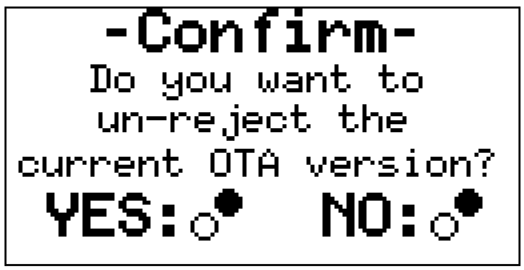
BETA: https://raw.githubusercontent.com/OverkillSolarLLC/OTA_Beta/main/firmware.bin

STABLE: https://raw.githubusercontent.com/OverkillSolarLLC/OTA_Stable/main/firmware.bin

OTA confirmation

If “Always Ask” is selected, this screen will popup when a new update is ready. Pressing “OK” will immediately load the update. Clicking “NO” will reject this version, and it will not ask again.

To un-reject an update, click “Always Ask” on the OTA Updates screen. If an update was previously rejected, a new popup screen will ask if you want to un-reject the update. Pressing “OK” will clear the reject preference and restart the OTA process. If WiFi is connected, a new popup will ask to load the update.



UF2: USB Flashing Format

UF2 (USB Flashing Format) enables the BMS to appear as a mass storage device when connected to a PC via USB-C.

To update the BMS, activate UF2 mode via the button interface, then drag and drop a **.uf2** update file into the drive. If the file is compatible, the BMS will update itself automatically—no WiFi or internet connection required.

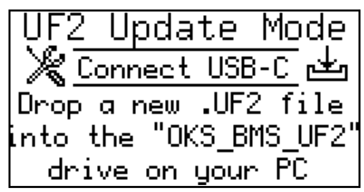
Fallback method: Hold the **BACK** button and press reset to reboot into UF2 mode.

Bonus fallback method: press the reset button or power up the UI board, then ground the BOOT pad on the underside of the board within 500ms. This is the last chance to enter UF2 mode if the main program is corrupted.

Check for new UF2 updates on the Overkill Solar website. All firmware updates will be archived and available to download. Beta and Stable updates will be available in separate folders.

Firmware can be rolled back by flashing the appropriate .uf2 file. (OTA update can't roll back versions)

Do not copy other file types into the BMS while in UF2 mode. It is not a general purpose flash drive or storage device. If the file transfer is interrupted, the BMS will not be able to operate until a complete copy of the .uf2 file is successfully uploaded. Electrical interference can interrupt the file transfer.



UF2 file archive URL: https://github.com/OverkillSolarLLC/UF2

All UF2 update files and their change logs will be left in this public archive until the sun burns out and the universe forgets it ever existed.

22. Ambient Temperature De-rating

The BMS's current rating is primarily based on the temperature of the MOSFET high current switch. For a short time, the MOSFET switch array can handle many times the base current rating without damage, up to the maximum short circuit detection setpoint. This allows the BMS to handle large startup/inrush currents.

The BMS main board has an integrated copper heat sink with a temperature sensor that will protect the BMS from overtemperature damage. The 100% duty cycle current rating is defined by the continuous current that will cause a temperature rise to 50c starting from 22c ambient temperature in still air. (Standard room temperature)
Higher ambient temperatures or restricted airflow will result in higher temperatures on the main board, and lower ambient temperatures or increased airflow will result in lower temperature on the main board.

The following charts indicate the current rating in different ambient conditions:

TODO: add derating charts

23. Pre-Discharge function

The Pathfinder BMS has a pre-discharge circuit in addition to the main solid state switch. The purpose of this circuit is to eliminate hard-start problems caused by capacitor inrush currents.

The pre-discharge circuit will engage when conditions have been met to turn on the main discharge FETs. It connects the battery to the output via a 12.5Ω resistor, and monitors the system voltage until it rises to a sufficient level to prevent a damaging inrush current, at which point the main FET array will switch on.

The pre-discharge behavior can be adjusted by setting parameters via the mobile app:

- Pre-discharge Timeout (min 200ms, max 10,000ms)
- Pre-discharge voltage target (% of battery voltage)(min 10%, max 90%)
- Pre-discharge Retry Delay (min 10s, max 600s)

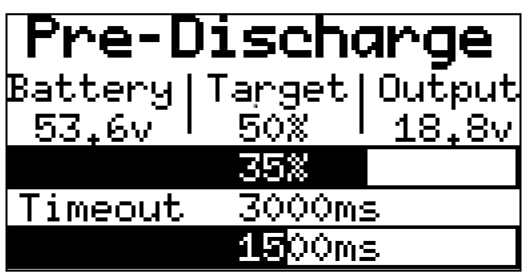
When the pre-discharge mode begins, the BMS monitors the system voltage until the target setpoint is reached, then the main discharge FETs will be switched on for normal operation.

If the timeout expires before the voltage target is reached, the pre-discharge mode will switch off and retry after the specified delay. This failure is usually caused by excessive loads on the system. Switching off loads is the recommended solution. The voltage target can also be reduced. The timeout can be increased, but this should be done carefully to avoid overheating the pre-discharge resistor.

In the event of pre-discharge timeout, the BMS will display a warning suggesting that some loads should be switched off. For example if a water pump is connected to the system and trying to start, it will overload the Pre-discharge circuit.

The BMS main board has a green LED to indicate current flowing in the predischarge circuit, and a red led to indicate that the circuit is overloaded. This led lights when the thermal fuse in the circuit has opened to limit the current.

The OLED will display the status of the Pre-discharge routine while it is active.



24. Functional Modes

Active mode

Full power operation: When the battery is at high SOC or actively charging or discharging.
Screen is on, Bluetooth/WIFI active, FETs active.

Idle Mode

As of the initial release, this function is not ready. It will be enabled in a firmware update.

Power saving operation: When the battery is at low SOC, no charge current, low discharge current.
Screen off, Bluetooth/Wifi status depends on settings.
Reduced update rates are available. FETs are active.
You may have to press a button to wake the user interface from idle mode at low SOC.

Storage Mode

Storage mode is the lowest power mode and can be used for shipping and long term storage. In this mode, the BMS consumes 1 μA on average. (0.000,001 amps)

Alternatively, the balance wire terminal board can be unplugged to reduce power consumption to zero, and prevent the battery from waking automatically.

When the BMS is connected to a battery, with nothing connected to the B+ output, it can be put into storage mode. Press and hold the "Reset" button on the main board for more than 1 second to put the BMS to sleep.

The BMS will periodically check for voltage on the B+ terminal, which will wake it up. Pressing the "Wake" button will also wake the BMS. If the B+ terminal has any voltage from connected equipment, it is not possible to enter storage mode.

Shutdown Cell Voltage is automatically set to 10% lower than Cell Undervoltage Cutoff. If a cell becomes discharged below this voltage, the BMS will completely shut down to prevent further discharge. (The cell may continue to discharge due to its internal cell discharge. Avoid long term storage at low state of charge.)
If the BMS shuts down due to Shutdown Cell Voltage or Shutdown Over Temperature, it will be in shipping mode. It can be woken by voltage on the B+ terminal, then it will allow the low cell to charge.

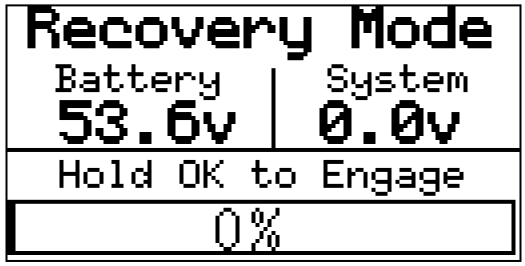
Recovery mode

If the battery has discharged far enough to trigger a low voltage cutoff, it is difficult to recharge the battery using "smart" chargers or solar charge controllers.
This is because they must detect the presence of the battery before they will begin charging, but the BMS has disconnected to protect the cells. The BMS prevents all discharging current but allows charging current. In this state, the system voltage may be zero, which stops smart chargers from beginning to charge.

The pathfinder BMS recovery mode allows you to enable the pre-discharge circuit manually.
This "bumps" the voltage in the rest of the system so that the chargers will start up. If the system still

has loads connected, the voltage may not rise enough for the chargers to start charging. In this situation, intervention will be needed, such as disconnecting all loads, and/or “jump starting” the system with another battery or with a “dumb” charging source like a shore power converter or a raw solar panel.

To use recovery mode, navigate to the Recovery Mode OLED screen on the BMS. **Hold the OK button to engage the predischarge circuit**, which will allow current to flow to the system via the series resistance of the predischarge circuit. Release the button when your charger starts to charge the battery. The screen will issue a warning if the CHG or DSG main FET controls are off.

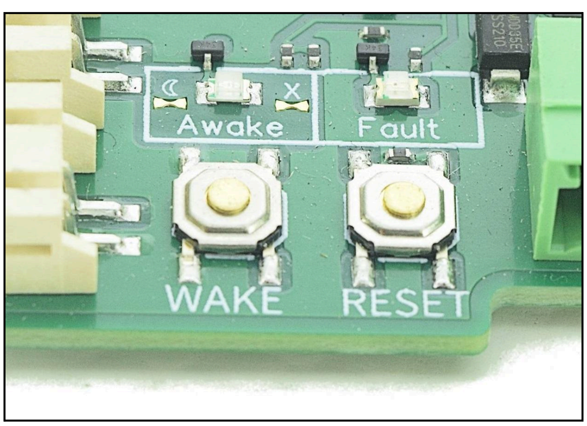


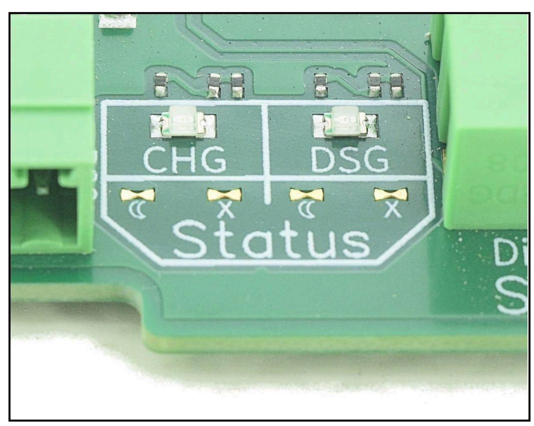
25. LED indicators

The pathfinder has several LED indicators, including antenna activity, Awake, Fault, DSG & CHG FET status, and balancer status.

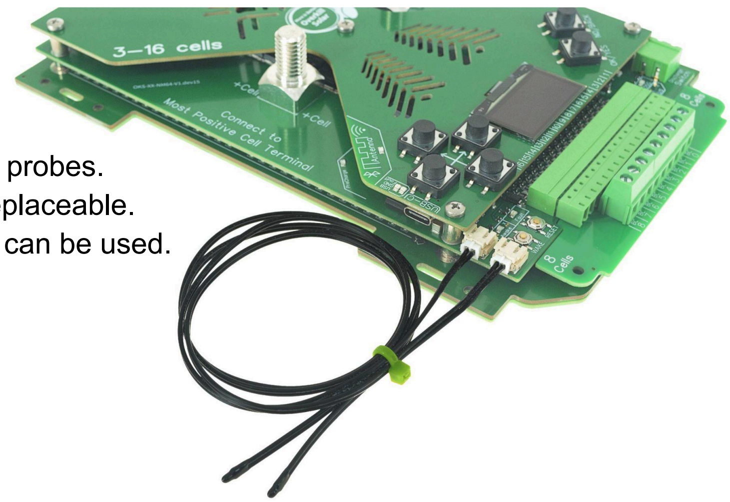
Because they are always on, the Awake and DSG & CHG FET status LEDs are each provided with cuttable traces to reduce the brightness or disable them entirely. In the photos below, the Moon icon indicates the brightness trace- cutting this trace will reduce the LED brightness by about 90%. The X indicates the cut trace to disable the LED. This can be reversed by soldering the cut trace pad, or possibly by covering the cut with conductive ink.

Each green LED with a cut trace consumes 350µA (microamp) at normal brightness, and with the brightness trace cut each consumes only 60µA.





26. <u>Cell Temperature Probes</u>



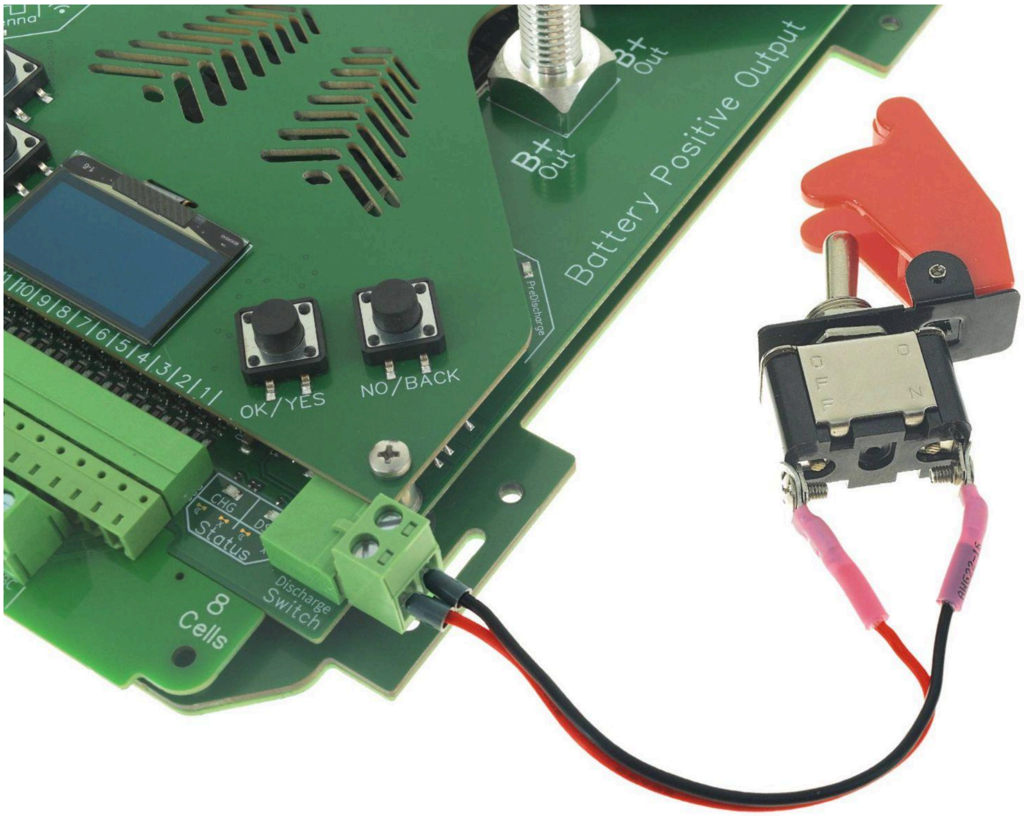
The Pathfinder has 2 external cell temperature probes.
The standard probes are 50cm long and are replaceable.
Any 10kΩ 3950K NTC with a PH2.0 connector can be used.

Replacement probes are available from Overkill Solar in 50cm and 100cm lengths.

27. Discharge Switch

The Pathfinder has a 2 pin connection for an external discharge switch. This functions like a remote battery shutoff. The circuit is normally open ON. When the circuit is closed, the discharge FETs will turn OFF, preventing the battery from discharging. The BMS will still allow the battery to charge.

This input should be connected to a dry contact- either a switch or relay. “dry contact” means that it is not connected to any other power sources or circuitry. It must remain isolated from other parts of the electrical system. The connector can be simply unplugged to disable this function.



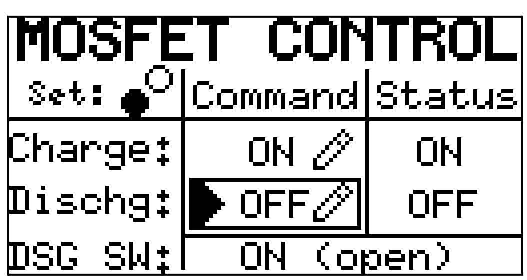
Discharge Switch dry contact example.

28. Manual Output Controls

The main outputs (FETs) can be manually switched off in either direction (charge or discharge) via controls on the mobile app or the built in screen.

This screen Allows the user to command the FETs off, and shows the actual status of the FETS and the discharge switch input.

The DSG and CHG Status LEDs also show The actual state of the output FETs.



29. UART connector

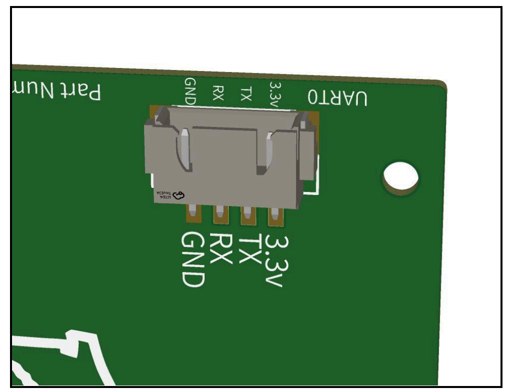
The Pathfinder UI board has a UART port connector at the top edge. This is **non-isolated and 3.3v tolerant only**. Serial port settings: 115200 Baud, 8-N-1. (not adjustable)

This port works with the Serial API, CSV logs, and system debugging logs. (same as the USB port)

The USB module that Overkill Solar offers is isolated and works well for isolating the UART and connecting to a PC USB port if needed. Various adapters can be used with this port such as an RS485 transceiver pair for long range wired connections.

If you want to connect this to another microcontroller, make sure it operates at 3.3v, or use a level shifter or isolation module. **Do not connect 5v signals directly to the UART connector**, this may damage the user interface controller.

GND, RX, TX, 3.3v



The connector is a JST XH-4, The pitch is 2.54mm.
It is located at the top edge of the user interface board.
Pinout is labeled on the bottom side of the board.

30. USB-C Connector

The Pathfinder UI board has a USB-C connector on the lower left side. It is not isolated from the battery ground. Before connecting to a PC, make sure it has the same ground potential as the BMS.

This port has multiple functions depending on the state of the user interface controller.

In normal operating mode, it presents a virtual com port and a MSC drive (mass storage device). This drive will be used for importing and exporting BMS settings. This feature will be added in a future firmware update.
The virtual com port works with the Serial API, CSV logs, and system debugging logs. (same as the UART port)

In UF2 update mode, the USB port presents a different MSC drive named “OKS_BMS_UF2”. This drive is only used to upload new firmware in UF2 format.

31. Data Logging

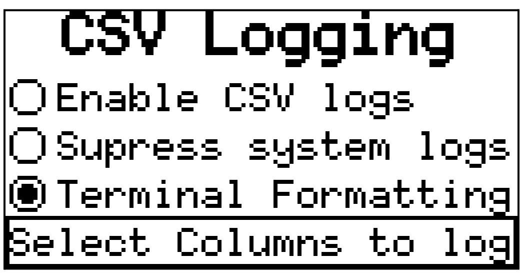
The Pathfinder has an optional CSV formatted logging feature. When enabled, the USB port and/or the UART port will stream the selected fields in CSV format. A Terminal program can be used to save these logs to a .CSV file. This feature can also be used for simple read-only custom monitoring applications.

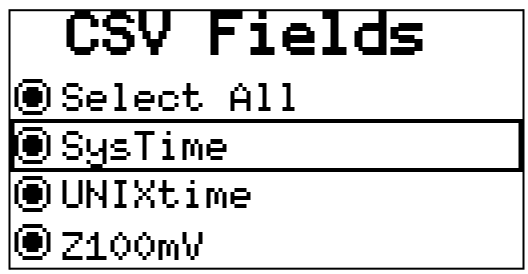
To enable CSV logging, navigate to the CSV Logging screen on the OLED display. Highlight *Enable CSV Logs* and click OK. The CSV data will begin streaming.

Occasional system debugging logs will interrupt the CSV stream. To suppress most of them, select *Suppress System Logs.* Only error-level logs will be printed with this option enabled.

By default, the CSV header row will be printed once when CSV logging is started. The *Terminal Formatting* option will reprint the header every 50 rows, and pad all the fields to a fixed width for human readability in a terminal window. This option roughly doubles the file size due to the padding bytes (spaces).

By default, *System time*, *Z100mV*, *Z100mA*, and *NTC1* are selected. To select additional fields, highlight *Select Columns to Log* and click OK. See table *Selectable CSV logging fields* for a list and description of available fields. Future firmware updates may append additional fields to the list.





Selectable CSV logging fields

Field	**Description**
SysTime	Seconds since the last reboot of the user interface controller.
UNIXtime	UNIX timestamp in seconds (Available after connecting WiFi to sync real time).
Z100mV	Stack voltage reported by the BQ34Z100
Stack_mV	Stack voltage reported by the BQ76952
B+_mV	Pack voltage measured at PACK+
CHG_FET	CHG FET status (1 = ON, 0 = OFF)
DSG_FET	DSG FET status (1 = ON, 0 = OFF)
ALARMS	Bitfield showing Active alarms and faults. See table *Alarms bit field definitions* below
PFALARMS	Bitfield showing Permanent fault alarms. See table *PF Alarms bit field definitions* below
BALANCE	Bitfield showing which cells are balancing. Bit 0 = Cell 1 … Bit 15 = Cell 16
Cell_1mV	Voltage of cell 1
Cell_2mV	Voltage of cell 2
Cell_3mV	Voltage of cell 3
Cell_4mV	Voltage of cell 4
Cell_5mV	Voltage of cell 5
Cell_6mV	Voltage of cell 6
Cell_7mV	Voltage of cell 7
Cell_8mV	Voltage of cell 8
Cell_9mV	Voltage of cell 9
Cell10mV	Voltage of cell 10
Cell11mV	Voltage of cell 11
Cell12mV	Voltage of cell 12
Cell13mV	Voltage of cell 13
Cell14mV	Voltage of cell 14
Cell15mV	Voltage of cell 15
Cell16mV	Voltage of cell 16

Field	Description
Z100_mA	Current reported by the BQ34Z100
Z100_avg	Averaged current reported by BQ34Z100
BQ_mA	Instantaneous current reported by BQ76952
BQmA_AVG	Averaged current reported by BQ76952
NTC_1	Temperature probe 1
NTC_2	Temperature probe 2
NTC_3	FET temperature sensor, located on the main board
NTC_4	Internal chip temperature of BQ76952
NTC_Z100	Internal chip temperature of BQ34Z100
Z100_SOC	(BQ34Z100) State of Charge (%)
Z100_CONF	(BQ34Z100) SOC confidence level (%)
Z100STAT	(BQ34Z100) Internal status of the BQ34Z100 IT algorithm Learning Cycle
LC_Stage	BQ34Z100 Learn cycle status as interpreted by the Pathfinder BMS firmware
ZmeasCAP	(BQ34Z100) Measured capacity of the battery (Qmax), in mAh
ZremCAP	(BQ34Z100) Remaining capacity of the battery, in mAh
Z_VOK	(BQ34Z100) Last open circuit voltage measurement OK for Qmax updates
Z_RUPDIS	(BQ34Z100) Resistance table updates are disabled
Z_QEN	(BQ34Z100) Qmax updates are enabled
ZFullCHG	(BQ34Z100) Full Charge detected, SOC set to 100%
Z_REST	(BQ34Z100) Battery is at rest- Voltage is stable enough to record OCV
Z_CF	(BQ34Z100) Condition Flag indicates learning cycle is needed
Z_IT_EN	(BQ34Z100) Impedance Track algorithm enabled
Z_LIFE	(BQ34Z100) LiFePO4 relax feature is enabled
ZFRSTDOD	(BQ34Z100) Set when relaxing, cleared upon valid QMAX update
Z_DODEOC	(BQ34Z100) Capacity at End-of-Charge was updated
B_SOC	(BasicSOC) State of Charge (%)
B_SOH	(BasicSOC) State of Heath (%) measured capacity / design capacity

Field	Description
B_CONF	(BasicSOC) SOC confidence level (%)
BMEASCAP	(BasicSOC) battery capacity as measured in mAh
BREMCAP	(BasicSOC) remaining capacity in mAh
B_LOCELL	(BasicSOC) The index of the cell that triggered the last 0% SOC update
B_HICELL	(BasicSOC) The index of the cell that triggered the last 100% SOC update
B_OFFSET	(BasicSOC) Offset relative to the raw coulomb counter, in coulombs
BCONFCYC	(BasicSOC) Tenths of a full cycle, used for tracking shallow cycles and confidence
B_CYCLES	(BasicSOC) Full cycles. Includes accumulated shallow cycles
HEAP	Bytes of free RAM in the user interface controller

Alarms bit field definitions

Bit Position	Alarm Label	Description
0	UTC	CHG Undertemp
1	UTD	DSG Undertemp
2	UTINT	Internal Die Undertemp
3	OTC	CHG Overtemp
4	OTD	DSG Overtemp
5	OTINT	Internal Overtemp
6	OTF	FET Overtemp
7	CUV	Cell Undervoltage
8	COV	Cell Overvoltage
9	OCC	CHG Overcurrent
10	OCD1	L2 DSG Overcurrent
11	OCD2	(unused)
12	SCD	DSG Short Circuit
13	OCD3	L1 DSG Overcurrent
14	SCDL	(unused)

Bit Position	Alarm Label	Description
15	OCDL	(unused)
16	COVL	(unused)
17	PTO	(unused)

PF Alarms bit field definitions

Bit Position	Alarm Label	Description
0	OTPF	(unused)
1	DRMF	(unused)
2	IRMF	(unused)
3	LFOF	(unused)
4	VREF	(unused)
5	VSSF	(unused)
6	HWMX	(unused)
7	CMDF	(unused)
8	CFETF	(unused)
9	DFETF	(unused)
10	LVL2	(unused)
11	VIMR	(unused)
12	VIMA	(unused)
13	SCDLPF	(unused)
14	SUV	PF Cell UnderVoltage
15	SOV	PF Cell OverVoltage
16	SOCC	PF OverCurrent CHG
17	SOCD	PF OverCurrent DSG
18	SOT	(unused)
19	SOTF	(unused)
20	CUDEP	(unused)

Bit Position	Alarm Label	Description
21	HWDF	(unused)

32. Serial API

The serial API is documented fully here: TODO link to Serial API document.

This open API is used by the Overkill Solar mobile app and is available for custom applications.
It allows writing parameters as well as monitoring the BMS.
All functions are initiated by the client application and the BMS will respond if the request is properly formatted.

The existing functions will remain stable from now on. New functions will be appended with new opcodes in the future.

This API is available on the USB port, UART port, and via BLE (Bluetooth).

When connected via BLE the serial API adds a passkey to prevent unauthorized wireless connections. The passkey is not used for wired connections. The default passkey is 123456 and can be changed via the OLED display.

33. Electrical Interference

Cheap inverters can create a lot of electrical noise that may affect the performance of the UART and USB port connections.

We found when testing with a low quality inverter that the USB connection was being interrupted, but adding a ferrite choke (or 2 or 3) to the USB cable restored the connection. Switching off the inverter also eliminated the interference as a temporary fix.

If electrical interference interrupts the USB port, the BMS may need to be rebooted to restore communication.

Examples of clamp-on ferrite chokes:

34. Parameters

Description of all parameters that can be adjusted by the user. Most of these can only be set using the Overkill Solar mobile app or USB web app. Some parameters must be set via the OLED display and buttons, for example WiFi and MQTT credentials, and Bluetooth passkey.
A future firmware release will enable all parameter settings via the OLED interface.

Name	Description	Default value	Set via
Design Capacity	The capacity of your battery in Amp-hours. Max 3,277Ah Used in SOC calculations.	100Ah	BLE USB UART
Predischarge Timeout	How long to try predischarge, in milliseconds. Min 200ms, Max 10,000ms (10s)	3000ms	BLE USB UART
Predischarge Target	The percentage of battery voltage to target. Predischarge will end when this voltage is reached on the B+ output terminal. Min 10% Max 90%	50%	BLE USB UART
Predischarge Retry Time	How long to wait before trying again after a predischarge failure. Min 10s, Max 600s (10m)	10s	BLE USB UART
Balancer Start Voltage	The balancer will activate when ALL cells are above this threshold, in millivolts. (The lowest cell must be higher than the threshold)	LiFePO4 3100mv NMC 3500mv LTO 2200mv	BLE USB UART
Balancer Delta to Balance	The balancer will activate if the difference between the highest and lowest cells is greater.	20mv	BLE USB UART
Balancer Max Cells	The max number of simultaneous cells to balance. The balancer can balance ½ of the cells at a time.	4 simultaneous cells	BLE USB UART
Charge Over Temp	Charge current will be cut off if the temperature is above this value on the NTC1 or NTC2 temperature probes.	LiFePO4 55c NMC 45c LTO 65c	BLE USB UART
Charge Over Temp Reset	Charge current will be re-enabled if the probe temperature falls below this value.	LiFePO4 50c NMC 40c LTO 60c	BLE USB UART
Charge Over Temp Delay	The time delay before a Charge Over Temp alarm is set.	2s	BLE USB UART
Charge Under Temp	AKA Low Temperature Cutoff. Charge current will be cut off if the temperature is below this value on the NTC1 or NTC2 temperature probes.	LiFePO4 0c NMC 0c LTO -40c	BLE USB UART
Charge Under Temp Reset	Charge current will be re-enabled if the probe temperature rises above this value.	LiFePO4 5c NMC 5c LTO -35c	BLE USB UART

Charge Under Temp Delay	The time delay before a Charge Under Temp alarm is set.	2s	BLE USB UART

Name	**Description**	**Default value**	**Set via**
Discharge Over Temp	Discharge current will be cut off if the temperature is above this value on the NTC1 or NTC2 temperature probes.	LiFePO4 60c NMC 60c LTO 65c	BLE USB UART
Discharge Over Temp Reset	Discharge current will be re-enabled if the probe temperature falls below this value.	LiFePO4 55c NMC 55c LTO 60c	BLE USB UART
Discharge Over Temp Delay	The time delay before a Discharge Over Temp alarm is set.	2s	BLE USB UART
Discharge Under Temp	Discharge current will be cut off if the temperature is below this value on the NTC1 or NTC2 temperature probes.	LiFePO4 -20c NMC -20c LTO -40	BLE USB UART
Discharge Under Temp Reset	Discharge current will be re-enabled if the probe temperature rises above this value.	LiFePO4 -15c NMC -15c LTO -35c	BLE USB UART
Discharge Under Temp Delay	The time delay before a Discharge Under Temp alarm is set.	2s	BLE USB UART
Cell Over Voltage	Discharge current will be cut off if any cell voltage rises above the threshold.	LiFePO4 3648mv NMC 4256mv LTO 2681mv	BLE USB UART
Cell Over Voltage Reset Hysteresis	When the offending cell voltage drops below the Cell Over Voltage threshold by this amount, the alarm will be cleared.	101mv	BLE USB UART
Cell Over Voltage Delay	The time delay before a Cell Over Voltage alarm is set.	1s	BLE USB UART
Cell Under Voltage	Charge current will be cut off if any cell voltage rises above the threshold.	LiFePO4 2483mv NMC 2787mv LTO 1773mv	BLE USB UART
Cell Under Voltage Reset Hysteresis	When the offending cell voltage rises above the Cell Under Voltage threshold by this amount, the alarm will be cleared.	101mv	BLE USB UART
Cell Under Voltage Delay	The time delay before a Cell Under Voltage alarm is set.	1s	BLE USB UART

Charge Over Current	Charge current will be cut off if the current rises above this value.	172A Reset time: shared	BLE USB UART
Charge Over Current Delay	Time that Charge Current must remain above the threshold to trigger the alarm, in milliseconds	300ms	BLE USB UART
Discharge Over Current	Discharge current will be cut off if the current is greater than this value. Discharge current is expressed as a negative value.	-170A Reset time: shared	BLE USB UART
Name	**Description**	**Default value**	**Set via**
Discharge Over Current Delay	Time that Discharge Current must remain above the threshold to trigger the alarm, in seconds.	2s	BLE USB UART
Fault Reset Time (Levels 1 and 2)	Shared reset time for Charge Over Current, Discharge Over Current, and Level 2 Discharge Over Current. After the reset time expires these faults will be cleared.	15s	BLE USB UART
L2 Discharge Over Current	Discharge current will be cut off if the current is greater than this value. (faster than Discharge Over Current) Discharge current is expressed as a negative value.	-400A Reset time: shared	BLE USB UART
L2 Discharge Over Current	Time that Discharge Current must remain above the L2 overcurrent threshold to trigger the alarm, in milliseconds.	300ms	BLE USB UART
FET Over Temp	Over Temperature threshold for NTC3 (near the FET array) and NTC4 (internal to the BQ76952 chip). Charge and Discharge will be cut off if the temperature rises above this value, and the BMS may shut down completely.	80c	BLE USB UART
FET Over Temp Reset	The FET Over Temp alarm will be cleared when the FET temperature and/or internal temperature falls below this value	65c	BLE USB UART
FET Over Temp Delay	Time delay before the FET Over Temp alarm is set.	2s	BLE USB UART
Short Circuit	The discharge current threshold to trigger a short circuit alarm. (Fastest over current cutoff)	900A	BLE USB UART
Short Circuit Reset Time	Time to wait before clearing the Short Circuit alarm. When the alarm resets, the predischarge routine will start. This can usually detect a short circuit or overload and prevent the main FETs from reengaging until the fault is repaired.	30s	BLE USB UART
Short Circuit Trigger Delay	Time that discharge current must remain above the Short Circuit threshold for the alarm to trigger, in microseconds. A setting of zero triggers the alarm on the first measurement over the threshold.	0µs	BLE USB UART
PF Charge Over Current	The charge current threshold to trigger a Permanent Fail Charge Over Current alarm. The BMS must be manually reset to clear this alarm.	1000A	BLE USB UART

PF Charge Over Current Delay	Time delay for the PF Charge Over Current alarm to set.	1s	BLE USB UART
PF Discharge Over Current	The discharge current threshold to trigger a Permanent Fail Charge Over Current alarm. The BMS must be manually reset to clear this alarm.	-1500A	BLE USB UART
PF Discharge Over Current Delay	Time delay for the PF Discharge Over Current alarm to be set.	1s	BLE USB UART

Name	**Description**	**Default value**	**Set via**
PF Cell Over Voltage	If any cell voltage is measured above this value, the Permanent Fail Over Voltage alarm will be set. The BMS must be manually reset to clear this alarm.	4500mv	BLE USB UART
PF Cell Over Voltage Delay	Time delay before the PF Cell Over Voltage alarm is set.	1s	BLE USB UART
PF Cell Under Voltage	If any cell voltage is measured below this value, the Permanent Fail Under Voltage alarm will be set. The BMS must be manually reset to clear this alarm.	1000mv	BLE USB UART
PF Cell Under Voltage Delay	Time delay before the PF Cell Under Voltage alarm is set.	1s	BLE USB UART
NTC Enable 1,2,3,4	Enable or disable each temperature sensor. A disabled sensor will still be measured, but it will be ignored by the BMS. Missing sensors read as very cold, around -60c. Shorted sensors read as very hot, around 122c	All Enabled.	BLE USB UART OLED

35. Calibration

The Pathfinder BMS measures current in and out of the battery positive cable, and the voltage of each cell, plus the full battery stack, and the B+ output terminal. Each of these can be calibrated by the user.

Null current can be calibrated via the BLE/USB apps or the OLED display.
The actual current must be zero when this procedure is started.

This procedure should be repeated after doing a learning cycle reset or a Total Factory Reset.

Null current is also affected by a trimpot on the main board. This is adjusted during manufacturing to null out variations in the current amplifier circuit. If this becomes out of adjustment, the null current calibration routine will fail and a message on the OLED will instruct the user to make the adjustment.

Current gain can also be calibrated via the BLE/USB apps or the OLED display. The adjustment is entered in increments of 0.1% plus or minus. A reliable external current meter should be used for the reference current.

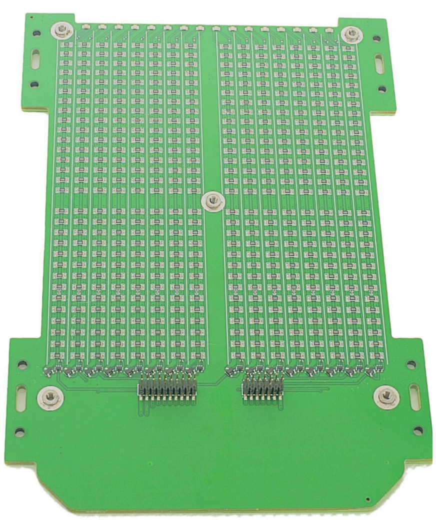
Each cell voltage can be adjusted via the BLE/USB apps only. This will be added to the OLED interface in a future firmware update.

TOS Voltage gain (Top Of Stack - the full battery voltage - BC16 to BC0) and B+ terminal voltage can be calibrated via the mobile apps and the OLED. The adjustment is entered in increments of 0.1% or 1% plus or minus. Adjust the scaling one click at a time until the displayed voltage matches your external voltage reference.

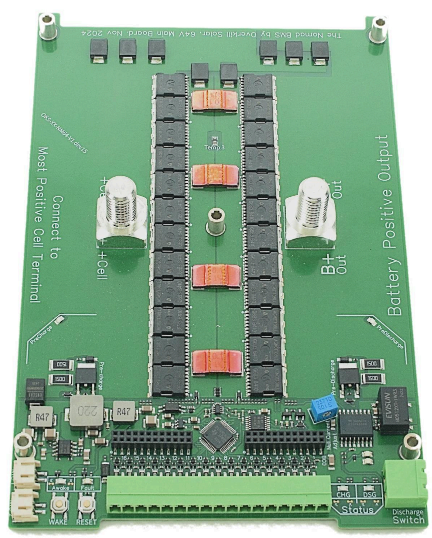
36. Interchangeable Parts

A Pathfinder BMS is an assembly of 4 printed circuit boards that are normally packaged and sold together as an assembly. Each component board has a descriptive part number and version number. All component boards with the same major version number (V1.x) are compatible and interchangeable.

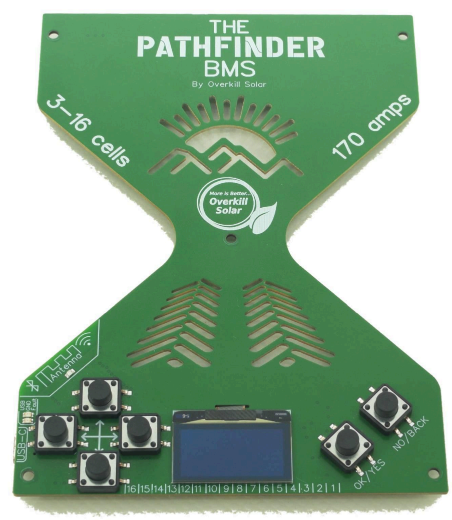
These boards will be available as spare parts, and the assembly is user serviceable to the extent of swapping boards. Always unplug the balance wire assembly before separating the other boards.



Base with Balancer

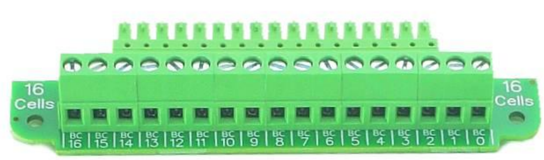


Main Board



User Interface Board

Balance connection board (multiple options)

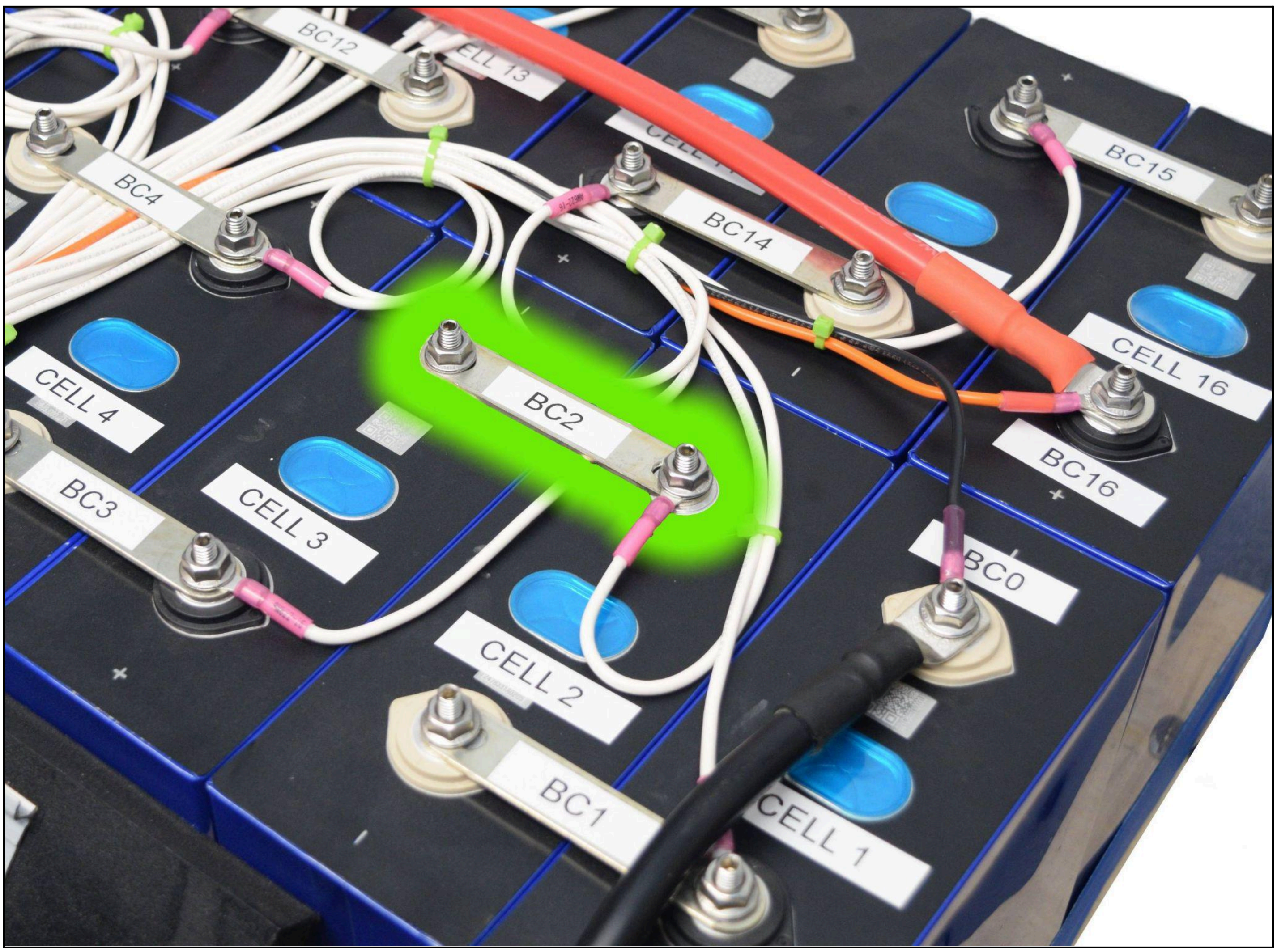


Notes & FAQ

Note 1: Which stud to use? Where is BCx?

We usually specify that each balance wire should be attached to the positive terminal of the corresponding cell.
For example, “connect wire BC2 to the positive terminal of Cell 2.”
This is only for consistency in the instructions, because anywhere on the node between 2 cells is the same as far as electricity is concerned.
For example, wire BC2 can be connected to the positive terminal of cell 2, or to the negative terminal of cell 3, or it can be bolted or soldered to the center of the bus bar connecting these cell terminals. In fact, attaching the wire to the center of the bus bar may be technically superior, but we don't think it’s worth the extra effort in practice.

In this photo, all of the highlighted parts are "BC2"



Note 2: What is C-rate (C/5, C/10, etc)

C-rate is the current expressed as a fraction of the battery capacity. For example, If the battery capacity is 100 amp-hours, and the desired C-rate is C/5, then the current should be 20 amps. (100 / 5)

Note 3: Max battery capacity

Design Capacity is stored as a 32 bit integer, which makes the actual upper limit 2,147,483,647mAh (2.1 million amp-hours). When design capacity is changed the current scaling factor is recalculated. This scale factor allows the Pathfinder to handle large capacity values while keeping the values in range for the BQ34Z100 fuel gauge chip.
The same scale factor applies to the current measurement resolution, so a larger battery has less current measurement resolution. This has no effect on basic BMS functions, only SOC measurement.

Note 4: Current Measurement Resolution

The BMS has 2 chips that measure current.
The BQ76952 handles all basic BMS functions, and its current resolution is fixed at 200ma.
The BQ34Z100 handles State Of Charge tracking, and its resolution varies depending on the design capacity setting.
Examples: At 100Ah, the resolution is 6mA. At 640Ah, the resolution is 20mA.

Note 5: Key combinations & secret functions

Some special functions are available by pressing special key combinations.

- Load Alpha OTA firmware: On the OTA Updates screen press *up, down, left, right*.
  - Please don't use this unless asked- this version may be unstable.
- Log all alarm registers (via USB or UART Serial): on the alarms list screen press *right*.
- Un-reject an OTA firmware version: click "Always Ask" on the OTA Updates screen.

37. Definitions

LiFePO4: Lithium-Iron-Phosphate, our favorite lithium cell chemistry.

NMC: Nickel Manganese Cobalt, classic lithium ion cell chemistry.

LTO: Lithium Titanate, lower cell voltage cell chemistry, very long cycle life, less common.

BMS: Battery Management System, the circuit board that protects lithium cells.

OTA: Over-the-Air Update, uses an internet connection to fetch updates.

UF2: USB Flashing Format, a file format designed by Microsoft for offline updates.

DIY: Do-it-yourself, it's what we do.

OLED: Organic Light Emitting Diode, a dot matrix display in which each pixel emits its own light.

MOSFET: metal-oxide-semiconductor field-effect transistor, the component used for switching high current.

FETs: shorthand for MOSFETs- The solid state high current switching component.

Balance Wire: The connection between each cell interconnect (bus bar) and the corresponding input on the BMS. Balance wires are used for voltage sensing of each cell and they carry the balancer current when the balancer is active. There will always be cell count + 1 balance wires (example: 16 cells, 17 balance wires)

Hysteresis: Reset Hysteresis defines how much the cell voltage must return from the protection threshold before a fault is cleared. It prevents rapid toggling of the protection status due to minor voltage fluctuations near the threshold.

Coulomb: Unit of electrical charge. (1 C = 1 Amp-second) (1Ah = 3600 C)

Algo: Algorithm: a formula or function that tracks various inputs and returns the results. (like SOC)

38. Units and Conversions

"s" The lowercase s is used as an abbreviation for X number of cells. As in 4s, 8s, 16s.
Also used for seconds in this document, depending on context.

"C" Temperatures are in units of celsius.
To convert to Fahrenheit, use the formula (C * 9/5) +32
To convert to Kelvin, use the formula C + 273.15

39. Revision History

March 2025: First edition
3-14-2025: added PF warning screen and BLE encryption details. Change 12s NMC limit to 14s.
4-14-2025: update photos, add terminal board test feature, remove pre-charge feature, add pre-discharge details, add balancer specs.
5-16-2025: increased max battery capacity rating to 3,276 Amp-Hours, added UART connector description.
5-30-2025: add all parameter descriptions.
6-4-2025: Remove unfinished screens from flowchart, add learning cycle procedure.
6-9-2025: fix C-F formula
6-17-2025: add to learning cycle description. Update Learn cycle voltage parameters.
6-25-2025: update capacity and current resolution spec, add notes 3,4. Add learning cycle reset to reset options. Add recovery mode description.
7-1-2025: Added description of data logging. Added details to learning cycle section.
7-3-2025: Learning cycle no longer starts automatically.
7-22-2025: Add OTA un-reject details. Update CSV logging details. Add USB port and UART port details. Update PF faults delay time. Add coulomb counter details. Add BasicSOC SOC tracking algorithm.
7-31-2025: Add UF2 bonus fallback method. Add BLE Encryption disable function (improved Android compatibility)

40. Screen Flowchart

A PDF flowchart of the built in screen navigation is appended to this PDF:

Pathfinder BMS
By Overkill Solar LLC
Control screen flowchart