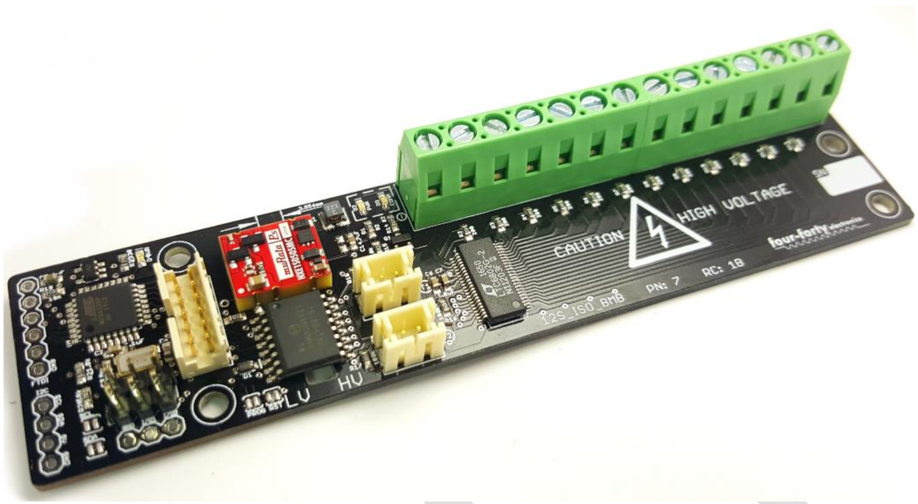
four-forty electronics

Document revision date: 2.3.18
DRAFT: incomplete/subject to change

Battery Monitoring System User Guide



Introduction

This document provides all the information needed to install and configure your battery monitoring system! **All users MUST carefully review the safety section, as well as additional safety warnings placed throughout the text.**

If you are looking for information on how to select a monitoring system for your battery, please check the battery monitor basics guide (coming soon)! It reviews how the monitoring system works, which monitoring products you need, and additional components that will be required. It is highly recommended to review the guide before attempting installation.

If you encounter errors or find information unclear, please don't hesitate to reach out at support@four-forty.com. Happy building!

Table of Contents

Safety

While effort has been made to make your battery monitor safe and reliable, there are numerous unsafe ways that this product can be installed or utilized in a battery system. Please take extreme care when installing this product into your battery pack and follow steps carefully to minimize risk. As always, common sense is your most valuable tool.

This product is, by nature, designed for use with potentially high voltage battery systems. When connected, all parts of the board should be treated as an exposed high voltage component. You should not use or maintenance this product with a high voltage system unless you are comfortable with the safety procedures and hazards associated with it.

The isolation provided by these boards is not independently certified, however, the isolation components used on them are. Reliance on these boards for isolation purposes is done at your own risk. Peak continuous isolation voltage is typically limited by the DC/DC converter included on each board and (to a lesser extent) by the board spacing. Depending on your board version, this may be rated at different values. Check your component datasheet or contact us for assistance. If you believe If you need greater isolation, you must provide your own solution upstream of the BMB that can provide 5V power and logic communications.

This product **must** be used in conjunction with fuses or (less recommended) resistors on the voltage sense lines coming from cells. These fuses must be placed as close as possible to the cell itself to minimize the risk of high current/voltage shorts between sense lines or on the monitoring board itself. We recommend fast acting fuses below 250mA to provide the best protection, down to a minimum of 100mA. Be sure to consider the voltage rating of your fuses during selection. At a minimum, this should be above (single board S-count) * (maximum cell voltage) for the board in question.

Sense lines should be routed, fastened, and shielded in a manner that minimizes exposure to abrasion, sharp edges, and heat. In general, shorter sense lines are preferred to longer.

Monitoring boards should be mounted into an enclosure sealed against fluid/moisture ingress as well as debris such as metal shavings. While the high voltage side of the monitoring board is conformally coated with a silicone layer, this should not be relied upon as primary protection against shorting hazards. As high voltage may be present on the board, it must be installed such that it is touch-safe for humans operating in the vicinity.

Multiple boards may be mounted in a vertically or horizontally stacked configuration. In all circumstances, consider minimum mounting distances between boards to account for high voltage creepage clearance. A minimum baseline of 6.35mm (0.25'') is recommended. Additionally, consideration must be given to the conductivity of material used to fasten boards.

Boards should be mechanically secured in a manner that does not allow movement and minimizes vibration.

Setting up your board

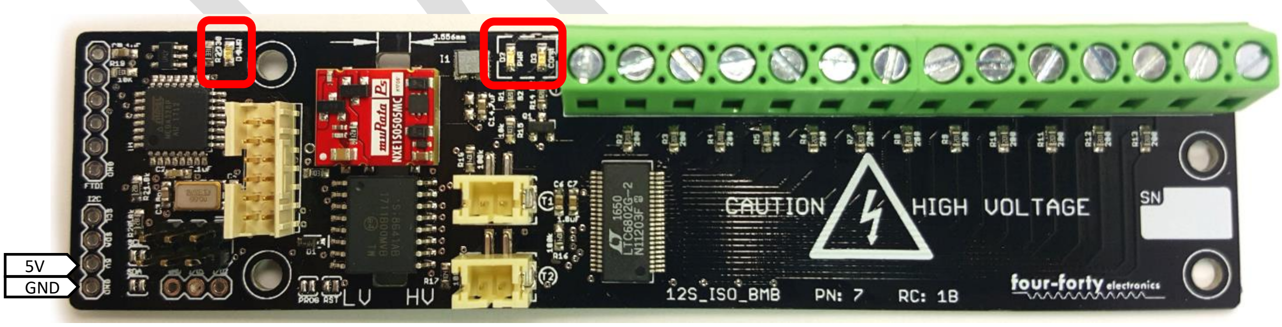
Before beginning, check to make sure you have all the required components to install your battery monitoring system. You will need (at a minimum):

- Your battery
- Monitoring board/s
- Sense line harness (build suggestions below)
- Communication harness (I2C or serial)
- Thermistors (optional)
- FTDI to USB adapter and USB cable (available [here](), [here](), or pretty much anywhere else)
- Computer with terminal program installed (for Windows, we recommend [puTTY]())
- Multimeter
- Screwdriver set
- Wire strippers
- Soldering iron + solder
- Solder wick/sucker (optional)

This guide assumes you are familiar with the basics of how the monitoring system works. If not, check out the battery monitoring basics guide, which covers this and many other topics.

First Steps

First, remove your monitoring board/s from the ESD-safe bag and inspect for damage. If you have a non-expansion board, you can try powering it now with 5V according to the following diagram. Boards ordered with soldered connectors can utilize the screw terminals, those without will need to get their connectors or wire soldered in directly.



The board is **not** protected against reverse polarity hook-ups, so check the wiring twice! If the board is being powered successfully, you should see 3 LEDs turn on in the above locations (lights may blink or go out after startup, this is normal).

Congratulations, your board is being powered successfully. After a short time, you may notice the DC/DC converter (the red component) getting warm. This is normal and expected operation of the DC/DC.

While the board may be powered, it is not yet possible to communicate with the LTC6802-2 chip. It requires power from the battery stack itself to begin operating. Don't worry, it draws extremely low power from the battery and will put itself into an even lower power mode if you stop talking to it for a short while.

This is a good time to select what address you'd like your board to have. If you flip over your board, you'll see 4 sets of solder pads on the PCB. By shorting the center pad to the left or right with solder, you can set that pad to a value of 1 or 0. The four pads together allow you to create a 4 bit binary value, totaling 16 possible unique boards. By default, a non-expansion monitoring board will be assigned an address of 0x00. Each triple pad is labelled 1-4 on the silkscreen. These produce a 4 bit value as follows:

(most significant bit) **[JP4] [JP3] [JP2] [JP1]** (least significant bit)

Address	JP4	JP3	JP2	JP1
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
12	1	1	0	0
13	1	1	0	1
14	1	1	1	0
15	1	1	1	1

By shorting the center to the right pad, you assign that position a zero. By shorting the center pad to the left, you assign that position a 1. Don't short all three pads together at once: this will just pull down the bus voltage.

If you have an expansion board, it is recommended to assign addresses in the order that they will be connected to your battery, from low to high. This will allow the firmware to auto-discover the boards you've connected, and help it return the right values when you query different boards. For instance, if you were monitoring a 36S battery with 1 primary board and 2 expansion boards, you would address them as follows:

Primary board (cell 1-12): 0

Expansion board 1 (cell 13-24): 1

Expansion board 2 (cell 25-36): 2

If you have an expansion board, power will be provided through the IDC socket, the 12 pin shrouded header on the left in the image above. You'll need to assemble or plug in your expansion board wiring harness into the non-expansion board and the expansion boards you want to power before they'll turn on.

Before reading from a battery you will need to get a battery wired to the board.

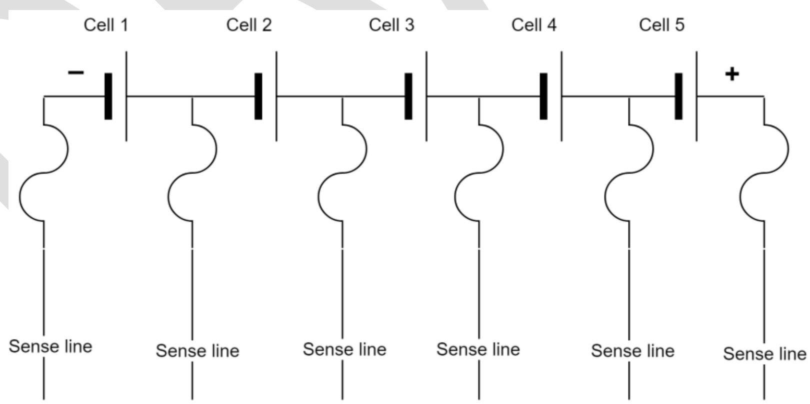
1. Preparing the sense lines

Batteries come in various forms, and as such, it is difficult to create a "one-size fits all" guide to wiring sense lines. Think of the following as guidelines, and always take any additional precautions you deem necessary to do the job safely.

The battery monitor requires a voltage sense line connected to the positive and negative terminal of every cell in series in your stack. There's one exception here – if you have groups of cells connected in parallel (thus, forced to share the same voltage), there's no need to connect more than one line.

When cells (or groups of parallel cells) are connected in series, the negative (anode) of one cell will necessarily be connected to the positive (cathode) of the next. Due to this fact, you only need one wire connected to every *node* where cells are connected in parallel, plus the negative-most and positive-most connection.

Even if a cell isn't high voltage, if shorted it can source considerable current. To provide as much protection as possible, you **must** connect fuses in-line with your voltage sense lines *as close as possible to the cell*. This ensures that if your voltage sense line harness gets shorted anywhere but at the cell itself, you'll have some protection against directly shorting that cell. We recommend fast acting fuses below 250mA to provide the best protection, down to a minimum of 100mA. Be sure to consider the voltage rating of your fuses during selection. At a minimum, this should be above (single board S-count) * (maximum cell voltage) for the board in question. Here's the goal in schematic form:



Another consideration is the size and type of wire you want to use for sense lines. A minimum (maximum gage number) of 28AWG is recommended for both primary and expansion four-forty monitoring boards, as it can maintain the peak balancing current without heating. You also need to ensure that the insulation voltage rating is appropriate for the maximum voltage of your pack. Obviously, individually sheathed or mechanically protected wires are ideal, but often prove impractical in large numbers. A common solution is to use ribbon wire/cable with the appropriate number of conductors. While this is acceptable, it is important to consider both the quality and protection of the cable. Low quality ribbon cables can expose parallel conductors when the strands are split or reduce the insulation to unacceptable thickness. Additionally, it is highly recommended to sheath ribbon cable in abrasion/pinch resistant sheathing.

One last note: keeping voltage sense lines routed in an organized and tidy manner will make the wiring process much easier, especially for high s-count packs. Consider how you want to restrain the wire so it cannot encounter hot surfaces or move in such a way that it can abrade. Especially for higher s-count packs, try to route wires in bundles of similar voltage potential. Making separate wiring runs for different groups of 12S is highly recommended.

2. Connecting the sense lines

Once your voltage sense wiring harness is built, it's time to connect it to your monitoring board. You'll want a multimeter on hand as you perform this, just as a secondary check to ensure that the sense lines are in the correct order.

It is recommended that you use a connector to connect your sense lines to the board. Boards purchased with terminal blocks can serve this function, but some users may wish to solder lines to save space or weight. In this case, try to find a way to avoid soldering "live" sense lines to the board by including a connector at some point along the sense line. Soldering wires at different potentials incurs significant risk of shorting between pads. This is another good reason to fuse your sense lines at the cells!

When connecting cells to the board, **start with the negative most potential** (your stack negative), and connect it to the negative most sense line terminal on the board, indicated with a circled minus sign as seen below:

Now proceed to the next potential voltage sense line, which should be connected to the next series cell in the stack.

Continue this process until you have connected all sense lines, or have reached the 13 line limit of a single board.

If you have fewer than 13 total sense lines (including top and bottom of your stack), you'll need to **jumper the topmost sense line to each of the remaining sense line connection points on the board, up to the second to last**. The one remaining position is a duplicate of number 13. This is illustrated with a hypothetical 6S battery below:

If you plan to monitor more than 12S, you'll need to split your sense lines between multiple boards. This also means that sense line number 13 will be top of stack on your first board, *and* bottom of stack on the second. To accommodate this, use the 14^{th} position to run a wire jumper to the negative-most position on the next board.

This system of jumpering to the next board can be used for up to 8 total boards.

There's one exception to this, and that is if you will have less than 10V worth of cells on the second/final board. 10V is the minimum operating voltage required by the monitoring chip on any single board to function, and thus a different arrangement will be needed. First, calculate the minimum number of cells needed to always provide at least 10V:

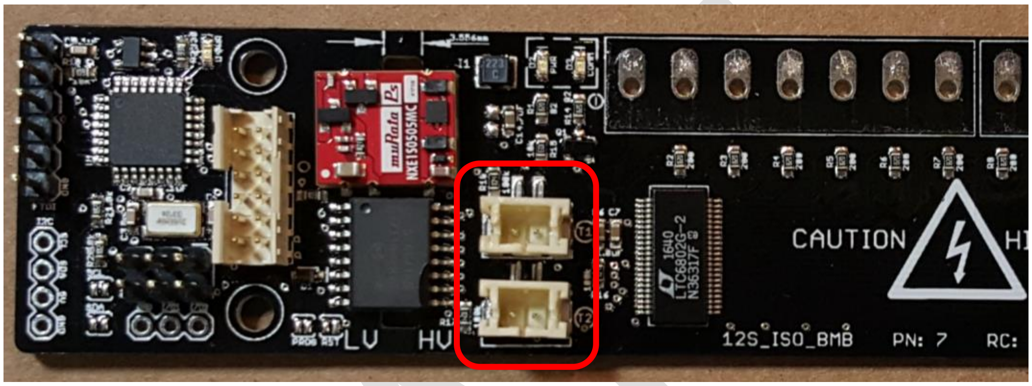
$$ceiling\left(\frac{10}{cell\ voltage_{minimum}}\right) = number\ of\ cells\ needed\ on\ the\ next\ board$$

For most conventional li-ion cells, you never want to discharge below 2.5V. That means that 4 cells (minimum) are needed on the second board. In this case, when you reach the negative terminal of the 4^{th} to last cell, you would jumper that value to each remaining position on board 1, as well as jumper it to the negative-most position on board 2. Then, you would continue to connect the sense lines of the last 4 cells on board two, jumpering the top of stack to each remaining position until you reach the positive-most on board 2.

Always ensure that you are connecting the sense lines from negative-most to positive-most, checking order as you go. This is the place to double and triple check your connections! As you complete each connection, check the voltages with a multimeter. You should see a steady jump of one cell voltage per position as you probe across each neighboring position. Congratulations, you've finished the hardest part!

3. Connect thermistors (optional)

Thermistor connections are made with the 2 JST-Molex connectors found on the right side of the board below:



Many pre-terminated thermistors are available online. The only requirement for your chosen thermistors is that they have a nominal 100kOhm resistance, and that they will operate in a useful temperature range for your battery. Basic thermistor lookup tables are provided for the following commercial thermistors in the four-forty BMB codebase:

Product links coming soon

If you want to use a different thermistor, or need to terminate one by hand, you can purchase the mating male connectors and pins at the following pages:

Male connector housing

Male connector pins (unterminated)

Male connector pins (terminated)

Note: the connectors are very small and difficult to properly crimp without purchasing the crimping tool. If another solution is desired, the female connectors can be de-soldered and wires can be soldered directly into the plated holes. Contact us if you'd like to purchase a board without these connectors and we'll be happy to accommodate.

It is important that thermistor wires are electrically insulated from battery potentials. Even with glass bead tips, there is a danger of unintentional connection with high voltage. Keep in mind that insulation materials should be rated to temperatures well above the maximum operating temperature of the battery.

4. Mounting the boards

Both primary and expansion BMBs use the same 4-hole mounting pattern, available from the product page. These holes are sufficiently large for either M3 or 4-40 fasteners. It is recommended that boards are mounted to an insulative surface (due to exposed pads/voltages on the bottom of the board), or in a stack with insulated spacers.

It is important to leave a suggested minimum of 6.35mm (0.25") spacing between boards in a stack configuration to ensure sufficient airflow and isolation. Boards mounted directly to a surface should also be offset slightly using washers or spacers.

Board mounting location will be highly dependent on the application, but should meet the following minimum requirements:

- Boards are fastened to minimize vibration or movement
- Boards are mounted in an enclosure or location where fluids or foreign conductive debris cannot come in contact with the board
- Boards are finger touch safe. Where high voltage is present (or could become present), shielding should be in place to prevent contact.

5. Connect monitoring board stack (only for 12S+ batteries)

For batteries with greater than 12S, a primary and one or more expansion boards are needed. These are connected with a ribbon cable IDC harness, parts for which are available from four-forty or at the following source:

IDC socket

Ribbon cable

Product link coming soon!

Installing the harness is extremely simple. For boards laid out single file in a line, the harness can simply travel in the direction of the boards, with male connectors plugging into the boards with the same orientation.

For boards stacked atop each other (with insulated spacers!), the cable can plug into each board then flex out and around to the next, climbing the stack.

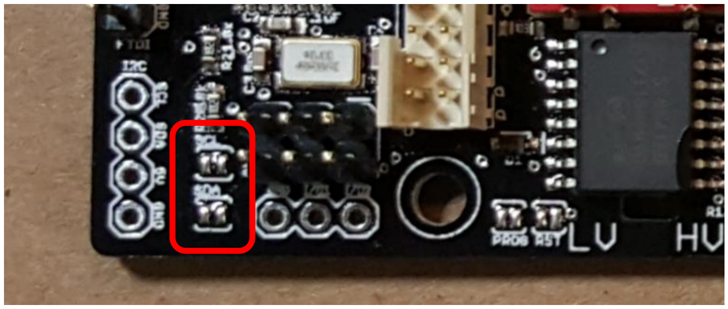
Images coming soon!

6. Communicating with the BMB

For BMB interface information, please reference the BMB interface guide).

Ensure that you plug into the header with the proper orientation (check the position of 5V and GND). The board can either be powered externally or over USB, provided that it is given a clean 5V rail. The board does not provide voltage regulation or filtering, so it is recommended that steps are taken to provide clean 5V at the board input for best operation.

For I2C connections, the board already features 1.8kOhm pull up resistors on the SDA and SCL lines:



If your bus already has pull up resistors, these can be disabled by cutting the thin trace between them on the top side of the board with a sharp hobby knife. They can also be re-enabled by jumping the pads again with solder.

7. Tips for hacking your BMB

It goes without saying, modifications to your BMB are done at your risk. Make sure you know what you are doing before bricking your board or putting yourself in a dangerous situation.

Primary boards use an ATmega 328p microcontroller pre-bootloaded with Arduino. Want to make tweaks to the firmware? Start by cloning the repo below:

Repo link coming soon

Interactions with the LTC6802-2 are primarily handled by the (not comprehensive) LTC6802 library (check out LTC6802.h and LTC6802.cpp). Major operating parameters are defined inside configuration.h. If you do intend to add processing overhead, consider the two watchdog timers on the board – both should generally get updated in less than 1000ms, through a call to pingWatchdog().

If you want to program through the Arduino IDE and an FTDI serial adaptor, select a board type of "Nano" with a 328p processor. If you need to reset the microcontroller for debugging purposes, just temporarily short across the "RST" jumper (just to the left of the logic isolator). Don't solder this unless you want a non-operational microcontroller.

If you want to bypass the Arduino bootloader all together and use an ICSP programmer, the 6 pin header has been broken out just to the left of the IDC connector on the board (see the pinout guide on the product page for details). Space is tight, you many need to slightly modify your connector to fit properly.

In both cases, **you will need to desolder the "PROG" jumper** just to the left of the logic isolator. This isolates the hardware watchdog so that it doesn't interfere with the programming process. Don't forget: **re-solder this jumper again when you are done**.

You may have noticed the additional lines broken out to the IDC header. These can theoretically function as additional chip select lines, opening up the possibility of adding additional SPI slaves to the bus.