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Overview

The Dilithium Design Battery Management System is a modular BMS designed for Electric Vehicle applications. The BMS is implemented as two assemblies. The BMS Controller (BMSC), consists of the BMS Processor and a measurement board in a single enclosure. The BMS Satellite (BMSS) contains a BMS measurement board. The BMS Controller is a standalone 24 cell BMS, and up to three BMS Satellites may be added, resulting in 48, 72, and 96 cell systems. Multiple systems may be used together to monitor larger packs.

The BMS measurement board uses the Linear Technologies LTC6804 for its measurement technology. The LTC6804 has been optimized for monitoring cells in large lithium packs. Each LTC6804 device can monitor from 4 to 12 cells. All cells can be measured in less than 2.5 ms with a total measurement error of less than 1.2mV. Accuracy is stable over voltage, temperature and time. Multiple devices can be combined to monitor large cell count pack and a high-speed datalink is used so that measurements on multiple devices can be performed simultaneously. The LTC6804 has built-in self test capabilities. It is tolerant of some common wiring errors such as shorted or open connections, and supports diagnostics to identify hardware and wiring problems. The LTC6804 was designed to minimize power consumption, especially during long-term storage where battery drain is unacceptable. In sleep mode, the LTC6804 draws less than 4µA from the batteries. The LTC6804 supports passive cell balancing.¹

A BMS measurement board has two LTC6804 devices and can measure up to 24 cells and 10 thermistor inputs. The BMS Processor contains all firmware and has interfaces for 12V power, CAN bus, cell loop, serial port, and LED. The BMS Processor communicates with each measurement board using a serial datalink.

The BMS performs diagnostics on startup and does an inventory of how many cells are present in the pack. Diagnostics verify proper functioning of measurement circuitry, verify cell wiring, and monitor for communication errors. In operation, all cells in the system are measured approximately 8 times a second with high coherency and accuracy. The BMS performs basic statistic gathering and data reduction so that marginally performing cells can be identified.

When driving, the BMS monitors the pack and collects pack and cell statistics. Statistics include high and low cell watermark data which can be used to track cell performance under load, and Standard Deviation, which measures pack balance.

The BMS supports several error conditions (or “alerts”). When driving, an alert is generated if any cell drops below the configurable Low Voltage Cutoff (LVC) threshold. When charging, the BMS will generate an alert if any cell rises above the High Voltage Cutoff (HVC) threshold which can be used to stop charging. The BMS supports a configurable Balance Voltage Cutoff (BVC) threshold, which can be used to communicate with the charger to reduce charge current.

The BMS supports smart cell balancing. A cell is balanced if its voltage is greater than the average cell voltage for the pack and if its voltage is greater than a configurable minimum threshold (set by BVMIN). Cell balancing occurs when driving and charging, and not just at the very end of a charge cycle.

Architecture
This section describes the BMS architecture. The figure below is a block diagram of the BMS Controller and BMS Satellite.

![Figure 1 – BMSC and BMSS Block Diagram](image)

The BMSC processor has the system interfaces for 12v power, CAN, and a cell loop. The measurement boards have two LTC measurement chips. Each measurement chip can monitor from four to 12 cells, and provides five thermistor inputs. The measurement chips are connected to each other and to the BMSC processor using the IsoSPI datalink.

The BMSC Processor contains all firmware for the BMS. The BMSC is configured using a serial interface, which is used for configuration and to retrieve statistics. The BMSC firmware supports up to eight LTC devices. LTCs are numbered from 1 to 8 depending on the order that the LTCs are connected together. The BMS Controller can support up to three BMS Satellites, resulting in 24, 48, 72 or 96 cell BMS systems.

The LTCs use a two wire datalink (Linear Technologies IsoSPI) to communicate. IsoSPI can operate at 1Mbps over 100 meters of cable and is highly immune to EMI. It supports a Packet Error Code to detect datalink errors. Each LTC has two IsoSPI interfaces: an “upstream” interface and a “downstream” interface.

Figure 1, above, shows the IsoSPI connections on the BMSC and BMSS. Note the internal IsoSPI connection between the BMSC processor and the first LTC, as well as the internal connection between the two LTC devices on a measurement board.

Cell Wiring and Cell Groups
Each LTC can monitor between four and twelve cells wired in series. Each group of 4 to 12 cells monitored by an LTC is a called a Cell Group.

NOTE: All cells in a Cell Group must be wired consecutively. The positive terminal of one cell must connect to the negative terminal of the next cell.

Figure 2, below, shows LTC 1 connected to a Cell Group of 12 cells and LTC 2 connected to a Cell Group of 8 cells.
It requires 13 connections (or wires) to connect to the 12 cells in a Cell Group. In Figure 2, wires are numbered \( w_0 \) to \( w_{12} \) and cells are numbered \( c_1 \) to \( c_{12} \). If fewer than 12 cells are to be monitored, then the unused cell inputs should be at the top, all connected together to \( w_{12} \). The first step in wiring the BMS is to determine the locations of the Cell Groups within the EV Pack.

**NOTE:** A Cell Group MUST NOT “span” a circuit protection device (such as a contactor, a fuse, or a circuit breaker).

This is because if the fuse blows (or contactor opens, or circuit breaker trips), then the LTC may be destroyed (because the voltage difference between adjacent wires on the LTC will become full pack voltage). For similar reasons, an LTC should not span a traction jumper, because the jumper might be disconnected for maintenance. If this cannot be avoided, then the Cell Group be disconnected at the BMS before the traction jumper is disconnected.

The following figure shows an example of what NOT to do.

**Figure 2 – Cell Group Wiring**

**Figure 3 – LTC Wiring Spans A Fuse**
In many cases, an EV pack will consist of a single string of cells, all in series. The following figure shows a 48 cell EV Pack wired as one series string of cells. In this example, there are four Cell Groups, each with twelve cells.

![Figure 4: 48 Cell Pack Wired to the BMS](image)

The BMS also supports EV packs that are configured into multiple parallel strings of cells. In the BMS, each parallel string in the EV Pack is called a Pack. There are no special considerations when wiring an EV with multiple Packs as long as each Cell Group connects to a string of between four and twelve cells wired in series. This is shown in the figure below.

![Figure 5: Two Parallel 24 Cell Packs Wired to the BMS](image)

In the BMS, all LTCs are electrically isolated from each other, even the two LTCs on a single measurement board. As a result, LTCs can be connected to Cell Groups anywhere in the pack and in any order, however it is convenient. However, it is recommended that LTCs on the same measurement board be wired to consecutive cells if possible, as it results in a lower voltage difference between groups on the measurement board. The figure below shows a 44 cell pack where the LTCs are connected to Cell Groups without regard to cell order.
Figure 6 – 44 Cell Pack, LTCs connected where convenient

Pack and Cell Numbering

Once Cell Groups have been wired and the LTCs connected, a cell may be identified by specifying the LTC and Cell number (e.g., physical cell numbering).

As a convenience, an additional form of numbering, logical cell numbering, is supported in the BMS. Logical cell numbering is used to define packs and cell numbering within a pack. Logical cell numbering is supported in the BMS by a “physical to logical mapping” table.

It is not necessary to configure the physical to logical mapping table. By default, the BMS assumes that there is one series string of cells, and that the LTCs are connected to cells in order. The physical to logical mapping may however be changed to when LTCs are not wired in order or if there is more than one Pack.

Example 1: 48 Cell Pack

This is the 48 cell system shown in Figure 4, above. Below is sample output from the command show map and show cells commands which shows the default cell ordering. (See the Command Line Interface, below, for a full description of these commands).

The physical to logical mapping can be displayed by using the command show map.

```
bsmc> show map
ltc|pack|group| cells
----|----|-----|-----------------------------
  1   1   1   | (c1 -c12) . . . . . . . . . .
  2     2   | (c13-c24) . . . . . . . . . .
  3     3   | (c25-c36) . . . . . . . . . .
  4   4   4   | (c37-c48) . . . . . . . . . .
```
In this example, there is one pack with four Cell Groups. Note that LTC 1 is mapped to Group 1, LTC 2 to Group 2, and so on. Each group contains 12 cells.

The following is the output of `show cells`.

```
bmsc> show cells
   c1 - 3.645v ++     c13-  3.637v ++     c25-  3.252v     c37-  3.144v -
c2 - 3.476v +      c14-  3.479v +      c26-  3.319v     c38-  3.082v -
c3 - 3.547v +      c15-  3.554v +      c27-  3.353v     c39-  3.311v
  c4 - 3.478v +      c16-  3.470v        c28-  3.481v +     c40-  3.321v
  c5 - 3.535v +      c17-  3.541v +      c29-  3.053v --     c41-  3.366v
  c6 - 3.469v        c18-  3.468v        c30-  3.278v     c42-  3.394v
  c7 - 3.351v        c19-  3.318v        c31-  3.209v     c43-  3.434v
  c8 - 3.233v        c20-  3.226v        c32-  3.328v     c44-  3.308v
  c9 - 3.208v        c21-  3.223v        c33-  3.069v -     c45-  3.315v
 c10-  3.205v       c22-  3.231v        c34-  3.372v     c46-  3.082v -
c11-  3.217v        c23-  3.230v        c35-  3.068v -     c47-  3.090v -
c12-  3.222v        c24-  3.213v        c36-  3.283v     c48-  3.075v -
```

**Example 2: Two Parallel 24 Cell Packs**

Figure 5, above, gives an example of two parallel packs. LTC 1 and LTC 2 are connected to Pack 1, Cell Groups 1 and 2 and contains cells c1 to c24. LTC 3 and LTC 4 are connected to Pack 2, Cell Groups 1 and 2. In order to define the two Packs, it is necessary to use the `set map` configuration command.

The syntax of this command is:

```
set map <ltc> <pack> <group>
```

Use the following commands to map LTC 3 to Pack 2, Cell Group 1 and LTC 4 to Pack 2, Cell Group 2:

```
bmsc> set map 3 2 1
bmsc> set map 4 2 2
```

Check the configuration with `show map`. Now there are now two packs.

```
bmsc> show map
  ltc|pack|group| cells
  ----|----|-----|-----------------------------
    1 |  1 |  1  |(c1 -c12) . . . . . . . . . . . .
    2 |  2 |  1  |(c13-c24) . . . . . . . . . . . .
    3 |  2 |  1  |(c1 -c12) . . . . . . . . . . . .
    4 |  2 |  1  |(c13-c24) . . . . . . . . . . . .
```

Here is example output of `show cells` with two packs.

```
bmsc> show cells
pack 1 ---------
c1 - 3.646v ++     c13-  3.630v ++
c2 - 3.477v +      c14-  3.476v +
c3 - 3.547v +      c15-  3.553v +
c4 - 3.478v +      c16-  3.468v
  c5 - 3.534v +      c17-  3.540v +
c6 - 3.469v        c18-  3.467v
```

```
Example 3: 44 Cell Pack, LTCs not wired in pack order

See the 44 cell example in Figure 6, above. In this case, LTC 1 is connected to Cell Group 4, LTC 2 is connected to Cell Group 3, LTC 3 is connected to Cell Group 2, and LTC 4 is connected to Cell Group 1. Also note that LTC 1 only has 8 cells.

Configuring the Cell Group mapping is accomplished using the following commands:

```
  bmsc> set map 1 1 4
  bmsc> set map 2 1 3
  bmsc> set map 3 1 2
  bmsc> set map 4 1 1
```

Check the configuration with `show map`.

```
  bmsc> show map
  ltc|pack|group| cells
  ----|----|------|----------------------------------
    4 | 1 | 1 | (c1 - c12) . . . . . . . . . .
    3 | 2 | 1 | (c13 - c24) . . . . . . . . .
    2 | 3 | 1 | (c25 - c36) . . . . . . . . .
    1 | 4 | 1 | (c37 - c48) . . . . . . . . .
```

Note that LTC 4 is mapped to, group 1, LTC 3 to group 2, LTC 2 to group 3 and LTC 1 to group 4.

Example output of `show cells` in this case would be:

```
  bmsc> show cells
  c1 - 2.866v  c13-  2.971v  c25-  3.770v +  c37-  3.792v +
  c2 - 2.789v  c14-  3.010v  c26-  3.581v  c38-  3.585v
  c3 - 2.995v  c15-  3.035v  c27-  3.656v  c39-  3.663v
  c4 - 3.004v  c16-  3.148v  c28-  3.562v  c40-  3.599v
  c5 - 3.044v  c17-  2.760v  c29-  3.635v  c41-  3.662v
  c6 - 3.070v  c18-  2.964v  c30-  3.557v  c42-  3.596v
  c7 - 3.133v  c19-  2.930v  c31-  3.438v  c43-  3.484v
  c8 - 2.996v  c20-  3.018v  c32-  3.321v  c44-  3.335v
```
Cell Discovery and Configuration

The BMS firmware automatically detects when an LTC is connected or disconnected. When an LTC is discovered, the BMS performs an LTC diagnostic and then prints a message to the serial port:

ltc1 detected
ltc2 detected
ltc3 detected
ltc4 detected

The BMS also discovers how many cells are connected. This can be shown using the command `show map`.

```
bmsc> show map
ltc|pack|group| cells
---|---|---|---------------------------
1 | 1 | 1 | (c1 - c12) . . . . . . . . .
2 | 2 | (c13-c24) . . . . . . . . .
3 | 3 | (c25-c36) . . . . . . . . .
4 | 4 | (c37-c48) . . . . . . . .
```

The output of `show map` shows a “dot” for every cell detected. In this example, LTCs 1 and 3 have 12 cells connected, LTC 2 has 10 cells connected and LTC 4 has 6 cells connected.

The BMS automatically uses all discovered cells in its HVC and LVC calculations. Other than setting HVC and LVC values, it is not necessary to do any additional configuration in order to use the BMS.

The BMS detects when an LTC has been disconnected or is no longer communicating, it will then print a message:

```
ltc3 was present, and is now gone
ltc4 was present, and is now gone
```

The `lock` command is used to configure LTCs and Cells. Once the `lock` command has been entered, the BMS will generate an alert if any locked LTCs or cells are not present.

The `show map` command shows the status of the cell.

```
bmsc> show map
ltc|pack|group| cells
---|---|---|---------------------------
1 | 1 | 1 | (c1 - c12) . . . . . . . . .
2 | 2 | (c13-c24) . . . . . . . . .
3 | 3 | (c25-c36) . . . . . . . . .
4 | 4 | (c37-c48) . . . . . . . .

bmsc>

bmsc> lock
bmsc> show map
ltc|pack|group| cells
---|---|---|---------------------------
1 | 1 | 1 | (c1 -c12) X X X X X X X X X X X
```

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“Locked” cells are shown as “X”s.

If the cells in LTC 4 are now disconnected (for example, by disconnecting the cell harness), the BMS will output the following messages:

```
bmsc> ltc4 was present, and is now gone
ltc4: not all configured cells detected!
```

And the output from `show map` will look like:

```
bmsc> show map
ltc|pack|group| cells
-----|-----|-----|----------------------------------
 1 |  1 |  1  |(c1-c12) X X X X X X X X X X X X
 2 |    |  2  |(c13-c24) X X X X X X X X X X X
 3 |    |  3  |(c25-c36) X X X X X X X X X X X X

```

where “?” indicate a locked but not present cell.

When the configuration is locked, the BMS will still detect new LTCs and cells. Suppose, for example that when the harness for LTC was disconnected, two additional cells got connected. In that case, when the harness gets reconnected, the output would look like:

```
bmsc> show map
ltc|pack|group| cells
-----|-----|-----|----------------------------------
 1 |  1 |  1  |(c1-c12) X X X X X X X X X X X X
 2 |    |  2  |(c13-c24) X X X X X X X X X X X
 3 |    |  3  |(c25-c36) X X X X X X X X X X X X
 4 |    |  4  |(c37-c48) X X X X X X . .

```

Once the configuration has been locked, it can be locked again.

In all, the map shows four possible entries for each cell:

- `<blank>`: cell not locked, cell not detected
- `.`: cell not locked, cell detected
- `?`: cell locked, cell not detected
- `X`: cell locked, cell detected
Measurement and Statistics

In operation, the BMS performs cell measurements approximately eight times a second. A request is broadcast to all LTC devices, measurements are made simultaneously, and then the BMS retrieves the measurements approximately 5ms later. In a fully populated system, all 96 cells can be measured in less than 10ms and the measurements are taken within 2ms of each other.

When the data is collected, the BMS determines if any cells are beyond the provisioned High Voltage Cutoff, Low Voltage Cutoff, and Balance Voltage Cutoff thresholds.

The BMS records “low watermark” and “high watermark” cell values, which are the lowest and highest values for the cell since reboot. (Or since reset stats). The BMS calculates the average cell voltage and the Standard Deviation². Standard Deviation is a measure of how well balanced the cells are … the lower the better. Standard Deviation is used to derive further statistics. For each cell, the Standard Deviation Multiple (SDM) is calculated. The SDM is a ratio of Variance (the difference between the cell voltage and the mean cell voltage) to Standard Deviation. SDM is stored as a number from -9.9 to +9.9.

Example:

if

\[
\begin{align*}
SD &= 0.020v & // value of standard deviation \\
ave &= 3.800v & // the average cell voltage \\
c8 &= 3.820v & // current voltage of cell c8 \\
c9 &= 3.790v & // current voltage of cell c9
\end{align*}
\]

then

\[
\begin{align*}
SDM(c8) &= 1.0 & // cell c8 is ave + 1.0*SD \\
SDM(c9) &= -0.5 & // cell c9 is ave - 0.5*SD
\end{align*}
\]

Positive values of SDM mean the cell voltage is higher than average, and negative values of SDM means the cell voltage is lower than average.

The minimum and maximum values of SDM are kept over time. The difference between the maximum and minimum SDM (the “delta”) can give an idea of cell performance under load: the larger the “delta” the more nonlinear the cell. The following is example output of show stats.

```
bmsc> show stats
bms| show stats
total| mean cell voltage------| standard deviation------------
| 3.414v | 0.261v
pack1| voltage------min----max--| deviation------min--max--delta--
c1 | 3.447v 3.392v 3.520v | 0.033v +0.1s +0.1s +0.1s 0.0s
c2 | 3.400v 3.345v 3.471v | -0.014v +0.0s +0.0s +0.0s 0.0s
c3 | 3.473v 3.417v 3.546v | 0.059v +0.2s +0.2s +0.2s 0.0s
c4 | 3.414v 3.359v 3.486v | 0.000v +0.0s +0.0s +0.0s 0.0s
c5 | 3.463v 3.407v 3.536v | 0.049v +0.1s +0.1s +0.1s 0.0s
```

High Voltage Cutoff

If a cell voltage exceeds the configured hvc value, then an HVC alert will be raised. If this occurs while charging, the charger will be notified of this condition either by the cell loop or by CAN message, and stop charging. When the charge current stops, cells drift back down below the HVC threshold.

² Standard Deviation is a concept from statistics that measures “variance”. See Wikipedia for more details.
There are some charging scenarios where it is desirable to leave the charger ON, and use the HVC condition to control charger output current. This might be the case, for example, if the charger remains connected for float charging or balance charging at the end of charge cycle. In this case, the result is that the charger may quickly cycle ON and OFF as a cell exceeds HVC only to drop back quickly once the charging current stops.

To support this application, an additional parameter \texttt{hvcc} (HVC “clear”) is provided. The purpose of \texttt{hvcc} is to provide hysteresis for the HVC alert condition. Once a cell exceeds \texttt{hvc}, the HVC alert is set. The HVC alert is not cleared until the cell drops lower than the configured \texttt{hvcc} parameter.

**Cell Balancing**

Automatic cell balancing is enabled using the command \texttt{enable balance}. When enabled, the BMS determines one balance candidate out of each group of six cells.

The best candidate for balancing will have a cell voltage that is:

- the highest voltage of any other cell in its six cell group.
- higher than the configured \texttt{bvmin} value, and
- higher than the pack mean voltage + 2.5mv.

Once a balance candidate has been chosen, then its shunting resistor is turned on. The hardware supports a 24 ohm, 1W resistor, which will shunt about 170ma at 4V.

Approximately once a minute, the balance candidates are reevaluated: charge shunting is disabled, cell measurements are retaken, new balance candidates are determined, and then charge shunting is resumed.

If enabled, cell balancing runs whenever the BMS is turned on, whether the car is being driven or being charged.

**Thermistor Operation**

Each LTC device supports five thermistors. By default, thermistor operation is disabled. The \texttt{enable thermistor} and \texttt{disable thermistor} commands are used to enable and disable thermistor inputs. The \texttt{show thermistor} command shows which thermistors are enabled.

```
$ bmsc> show th
ltc| T1 | T2 | T3 | T4 | T5
---|-----|-----|-----|-----|-----
 1 | 16C | 18C |
 2 | 18C | 17C |
 3 | 19C | 18C |
 4 | 17C | 17C |
```

The thermistor threshold temperature is determined by the configuration parameter \texttt{thmax}. If a thermistor is enabled and if the measured thermistor value is greater than \texttt{thmax} an alert is raised and a message is printed.

```
$ ltc2: T3 OVERTEMP!
```

Once the thermistor reading drops below \texttt{thmax} the following message is printed:

```
$ ltc2: T3 temperature OK
```
Alerts and Alert Operation

The BMS generates the following alerts:

- pack in HVC
- pack in LVC
- pack in BVC
- configuration not locked
- not all configured cells detected
- thermistor overtemp
- LTC<n> fault

In general, an alert affects: serial port messages, show command output, LED operation, cell loop and the CAN interface.

The full list of messages is given below, see Output Messages.

Active alerts may be retrieved by show.

```
bmsc> show
pack
  voltage: 157.14v
  cells : 48
  mean : 3.274v
  std dev: 0.142v
alerts : pack in HVC
  : thermistor overtemp
uptime : 0 hour(s), 5 minute(s), 18 second(s)
```

Additional information may also be available with other commands (show map, show cells, show thermistors).

Alerts may affect the LED behavior and the cell loop. And finally, the alert status may be present in the CAN BMS_Status_Msg, which is periodically sent.

The following table summarizes behavior.

<table>
<thead>
<tr>
<th>Alert</th>
<th>Serial Port Message</th>
<th>Loop</th>
<th>Additional Status</th>
<th>CAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powered Down</td>
<td>not OK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Configuration not Locked</td>
<td>(1) show map</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell Census Error</td>
<td>yes</td>
<td>not OK</td>
<td>show map</td>
<td>yes</td>
</tr>
<tr>
<td>LTC Fault</td>
<td>yes</td>
<td>not OK</td>
<td></td>
<td>yes</td>
</tr>
<tr>
<td>Thermistor Overtemp</td>
<td>yes</td>
<td>not OK</td>
<td>show thermistor</td>
<td>yes</td>
</tr>
<tr>
<td>HVC</td>
<td>yes</td>
<td>not OK</td>
<td>show cells</td>
<td>yes</td>
</tr>
<tr>
<td>LVC</td>
<td>yes</td>
<td>not OK</td>
<td>show cells</td>
<td>yes</td>
</tr>
<tr>
<td>Discharge In Progress</td>
<td>(1) show cells</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All OK</td>
<td>OK</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) these alerts do not affect loop status
The BMSC supports a bicolor (red/green) LED. ("yellow" is created by turning on both red and green). In all, the following blink patterns are defined. In the diagram, each “square” represents 125ms.

<table>
<thead>
<tr>
<th>Alert</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powered Down</td>
<td>off</td>
</tr>
<tr>
<td>Configuration not Locked</td>
<td>R/G blink</td>
</tr>
<tr>
<td>Census Error</td>
<td>R/G blink</td>
</tr>
<tr>
<td>LTC Fault</td>
<td>R long blink</td>
</tr>
<tr>
<td>Thermistor Overtemp</td>
<td>R long blink</td>
</tr>
<tr>
<td>HVC</td>
<td>R fast blink</td>
</tr>
<tr>
<td>LVC</td>
<td>R fast blink</td>
</tr>
<tr>
<td>Discharge In Progress</td>
<td>Y slow blink</td>
</tr>
<tr>
<td>All OK</td>
<td>G slow blink</td>
</tr>
</tbody>
</table>

**Using Multiple BMSCs**

There may be up to four BMS Systems in an EV. Each BMS is identified by its Id. By default, the Id is set to 1, but it can be set from 1 to 4 and may be changed using the `set id` command. Setting the Id affects the command prompt (to `bmsc1>`, `bmsc2>`, `bmsc3>`, `bmsc4>`) and it changes the CAN Id used to identify the BMSC processor.

*NOTE: Be careful not to define two BMSCs with the same Id!*  

**Powering**

The BMSC is powered from +12V and the LTC6804 devices are powered from their pack connections. When “on”, the BMSC consumes approximately 15mA of 12V. It is recommended that the BMSC NOT be continuously powered from the 12V accessory battery.

When the EV is not being driven or being charged, the BMS will be powered off and the LTC6804 will enter a SLEEP mode. In SLEEP mode the current draw from the Cell Group is typically 4 µA. Because of the low power draw, it is safe to leave the BMS connected but unpowered for long term storage. However, it is prudent to measure the cells every few months in any case!

The LTC6804 automatically wakes and enters a READY mode when IsoSPI datalink messages from the BMSC arrive. When in READY mode, the LTC6804 requires current for the IsoSPI datalink and for cell measurement. Current is needed in very short bursts: when actually sending a message or making a measurement. On average, between 2-3 ma of current is required from the group when the BMSC is powered. Power is drawn from the Cell Group as a whole, not from individual cells, and the same amount of current is drawn from the Cell Group regardless of the number of cells in the group.
Installation

BMS Controller
The BMSC is housed in a 3.3” x 5.4” x 1.1” enclosure (the Serpac WM031). For detailed enclosure specifications, see http://www.serpac.com/userprints/WM031_UP.pdf.

System connections are made at the 8pin pluggable connector.

```
IPO  IMO  CANH  CANL  LP1  LP2  12v  gnd
```

Power is provided at **12v** and **GND**. The BMS requires approximately 15ma of 10-15V power. The BMS should be powered both when the EV is being driven and when being charged.

The **cell loop** output is provided at **LP1** and **LP2**. The BMS controls a solid state relay that closes the loop between LP1 and LP2 if all cells are within configured limits. The relay is rated to 200ma. The loop is closed if all cells are “good”; the loop is open if the BMS if any cell is “bad”, the BMS has a fault, or if the BMS is not powered. If cell loop is not used, these pins may be left unconnected.

**CAN** is provided on **CANH, CANL**. If CAN is not used, these pins may be left unconnected. See below for guidelines on wiring and configuring CAN operation.

The **IsoSPI datalink** is given on **IPO** and **IMO** (IsoSPI Plus Out and IsoSPI Minus Out). These signals are connected to the IPI and IMI signals on the first BMS Satellite. If this is a 24 cell BMS, then there is no BMS Satellite and these pins are left unconnected.

BMS Satellite
The BMSS is also housed in the same enclosure as the BMSC, see above.

```
IPO  IMO  IPI  IMI
```

The IsoSPI datalink is given on **IPO** and **IMO** (IsoSPI Plus Out and IsoSPI Minus Out) and **IPI** and **IMI** (IsoSPI Plus In and IsoSPI Minus In).

Cell Wiring
The Cell Harness connections are shown below.

```
W0  W2  W4  W6  W8  W10  W12
W1  W3  W5  W7  W9  W11
```

As a reminder, all cells within a cell group must be series connected cells within the EV Pack. Each cell group has 13 connections to connect to the 12 cells in the group. If fewer than 12 cells are to be monitored, then the unused cell
inputs should be at the top, all connected together to w12. And finally, a cell group must not span a circuit protection device.

A Cell Harness tester is provided with BMS. Once the cell group is wired, use a voltmeter to verify that cells are connected with the proper polarity, that they are in series.

**NOTE:** The Harness Tester is connected directly to pack voltage and so there can be up to 60V connected on the harness. Be Careful! While it is connected to the pack, do not place the harness tester on anything metallic!

Once the cell harness is verified, it is safe to plug into the BMSC or BMSS. Cell Harness connectors may be plugged in or unplugged in any order. It is not necessary to remove 12V power from the BMS in order to plug or unplug Cell Harness connectors.

The following picture shows the meter measuring the voltage of Cell 1.

---

**Datalink**

IsoSPI is a datalink (Linear Technologies IsoSPI) to communicate. IsoSPI can operate at 1Mbps over 100 meters of cable and is highly immune to EMI. It supports a Packet Error Code to detect datalink errors. Each LTC has two IsoSPI interfaces: an “upstream” interface and a “downstream” interface.

The wiring guidelines for IsoSPI are similar to those of CAN. Twisted pair is recommended: for short runs, hand twisted wire is fine. However, for longer runs, shielded cable is recommended. Note that IsoSPI is a point to point link, not a bus. Two wires are used between nodes and external termination resistors are not required.
CAN

CAN is a robust communications protocol designed for automotive applications. CAN uses a two wire interface; the signals are designated CANH (“CAN High”) and CANL (“CAN Low”). A CAN network is a daisy-chain, multistation network that should be terminated on both ends of the string by 120ohm termination resistors. See below for a simple network diagram.

![CAN Network Diagram](image)

**Figure 2 – CAN Network Diagram**

CAN wiring should be kept short and the conductors should be twisted. Wiring should be placed away from EMI (ElectroMagnetic Interference) such as the motor and controller, and parallel runs next to the traction cabling should be avoided.

In a simple installation, there will be only a few nodes on the network: the BMSC, the EVCC, and the charger, with short and direct connections between the three. In this case, hand-twisted wiring should be fine. For longer runs, more nodes, or cases where EMI may be an issue, shielded cable is recommended. If a shielded cable is used, the shield should be connected to chassis ground at a single place.

The BMSC supports a CAN data rate of 250Kbs and 29-bit CAN addressing. These parameters are not software configurable.

The BMSC also supports a programmable can termination resistor (see `enable canterm`).

**Cell Loop**

The Cell Loop outputs connect internally to a solid state relay. The contacts are normally open, and are only closed if the cell loop is “OK”. (See the discussion on alerts, above). The cell loop contacts are rated at 200ma.

The Cell Loop may be wired in the EV to control a buzzer or to enable and disable charging.

**Thermistors**

The BMS has been designed to work with the Vishay NTCLE413E2103F520L thermistor. There is a 10p connector provided on the measurement board which allows connection to the thermistors. It is necessary to open the enclosure to get access to this connector.
Integration with the Thunderstruck EVCC
If the Thunderstruck EVCC is being used, then the BMSC installation is simple:

- Connect BMSC +12V to the EVCC 12V_SW output, and BMSC GND to EV chassis ground.
- Connect BMSC CANH and CANL to the EVCC and charger CAN network.
  - Make sure the CAN termination resistors are enabled at the ends of the CAN network.
  - Configure the EVCC to use the CAN BMS (“evcc> set bms can”).

When using the BMS with the EVCC, the CAN interface is recommended, and the Loop Interface is not necessary.

Using Multiple BMS Systems
Up to four BMSC systems may be used in an EV. When using multiple BMSC systems, install the systems individually, and wire all to the EV CAN network.

Each BMSC requires a unique id, from 1 to 4. By default the BMS has an id of 1.

If the EVCC is being used, enable all BMSCs.

Example, if three BMSCs are being used, with ids 1, 2, and 3, then these may be enabled in the EVCC by the command

evcc> set bms can can2 can3
Bringup Checklist and Troubleshooting Hints

Planning
1) Read documentation
2) Determine the number of packs and cell groups required
3) Plan system connections, powering strategy, CAN bus and IsoSPI routing

Physical Installation
4) Physically install BMSCs and BMSS
5) Route power, CAN, IsoSPI datalinks, Cell loop wiring

Wiring Harnesses
6) Make harness to cell connections
7) Verify harness with harness verification tool

System Bringup
8) Install terminal drivers and terminal emulation program (if necessary)
9) Power up BMSC and verify serial port operation
10) Set BMSC id (if necessary)
11) Enable CAN termination (if necessary)
12) Connect cell harnesses
13) Verify that Cells are “discovered” (show cells)
14) Configure HVC and LVC
15) Enable Cell Balancing, if desired (enable balance)

Basic operations are now working. Further system testing depends on the installation. If the EVCC is being used with CAN, then CAN messages can be verified at the EVCC (using “trace can”).
Output Messages

Startup Banner
When the BMSC is powered up, it prints a banner message with the version number.

************************************************************************************
*                                             BMS Controller v2.2.2              *
*                  Dilithium Design                *
************************************************************************************

Hardware Discovery and LTC Diagnostics
On startup (and periodically afterwards), the BMSC probes to see how many LTC devices are present. A diagnostic test is performed on all LTC devices. In addition, the BMSC determines how many cells are present in each LTC.

If the configuration has been “locked”, the BMSC will perform a “census check”. An error is printed if not all “locked” cells are detected. Example output is given below:

Initial discovery:
ltc1 detected
ltc2 detected
ltc3 detected
ltc4 detected

Initial discovery, with a failed diagnostic:
ltc1 detected
ltc2 detected
ltc3 detected, diagnostic failure=0x1000
ltc4 detected

Note that there are several internal diagnostics performed on the LTC devices to verify proper operation.

Initial discovery, census error:
ltc1: not all configured cells detected !
ltc1: not all configured cells detected!

Note that this message repeatedly prints on the serial port.

LTC goes absent:
ltc1 was present, and is now gone
ltc2 was present, and is now gone
ltc3 was present, and is now gone
ltc4 was present, and is now gone

IsoSPI Errors
IsoSPI messages have a Packet Error Code which is checked for every message and errored packets are printed. If a measurement board loses power or gets disconnected from its pack connection, then there may be a short burst of datalink errors until the BMSC determines that the LTC is no longer connected. Repetitive errors that the datalink is experiencing errors. (Possible mitigations are: check connections, shorten the data link if possible, add shielding, or
Example output looks like:

bmsc> 00:01:28.7  0004 03 ffff ffff ffff ffff 4c66
00:01:28.9  0004 03 ffff ffff ffff ffff 4c66
00:01:29.0  0004 03 ffff ffff ffff ffff 4c66
00:01:29.2  0004 03 ffff ffff ffff ffff 4c66

**HVC LVC Messages**

When a cell voltage exceeds the High Voltage Cutoff (HVC) threshold, or goes below the Low Voltage Cutoff threshold, then a message is printed, which includes the Pack and Cell Number. If the cell recovers then a message is printed. Example output:

1/c25: in HVC !
1/c26: in HVC !
1/c25: OK
1/c26: OK
1/c12: in LVC !
1/c11: in LVC !

Note that if a cell is declared as HVC and if the hvcc parameters is being used, then the HVC condition will not clear until it drops below hvcc.

**Thermistor Messages**

When a thermistor exceeds the thmax threshold a message is printed. The message includes the LTC number and thermistor number.

ltc2: T3 OVERTEMP!

And when it recovers a message is printed.

ltc2: T3 temperature OK

The thermistor threshold temperature is determined by the configuration parameter thmax. When a thermistor is overtemp an “alert” is present in the show command. The measured value can be determined by the show thermistor command.
Command Line Interface
This section describes the command line interface commands.

help
The help command prints out command help.

```plaintext
bmsc> help
    SHOW [<>|Version|Config|MAP|CELLS|STATS|Thermistors|LTC]
       <>   - status
       version   - firmware version
       config   - configuration
       map   - cell group map
       cells   - cell summary
       stats   - cell statistics
       thermistors   - thermistor readings
    SET [<>|ID|HVC|HVCC|LVC|BVC|BVMIN|MAP]
       <>  - show config
       hvc  - High Voltage Cutoff
       hvcc  - High Voltage Cutoff Clear
       lvc  - Low Voltage Cutoff
       bvc  - Charge balancing Voltage Cutoff
       bvmin  - Auto Balancing Voltage Minimum
       id  - set bmsc ID (1..4)
       map <ltc> <pack> <grp> - Map an LTC to a Pack/Cell Group
    RESET [CONFIG|STATS]
       config  - reset configuration to defaults
       stats  - reset cell statistics
    ENABLE | DISABLE [BALANCE|CANTERM|CANTX|Thermistor]
       balance  - enable/disable cell balancing
       cterm  - enable/disable CAN termination resistor
       thermistor <ltc> <num> - enable/disable thermistor
       LOCK  - lock configuration
    UPGRADE  - performs a firmware upgrade
```

In many cases, either a full version or an abbreviated version of a command (or command parameter) can be used. This is shown in the “help” with the use of uppercase and lowercase letters. For example, the abbreviation for show is sh, and the abbreviation for show thermistors is sh th.

show
The show command displays configured parameters or status. If show is entered without parameters, current status is displayed. This includes per-pack and total statistics, alerts, and BMS uptime.

In the following example, there is a single pack. In this case voltage is pack voltage, cells is the number of cells, mean is the average cell voltage, and std dev is the cell standard deviation.

```plaintext
bmsc> show
    pack
        voltage: 150.92v
        cells : 48
        mean  : 3.144v
        std dev: 0.137v
        alerts : configuration not locked
```
For the pack statistics, the voltage is determined by summing the values of the individual cells. Cells give the number of non-zero voltage cells.

bmsc> show
pack1
  voltage: 78.65v
  cells  : 24
pack2
  voltage: 78.50v
  cells  : 24
total
  cells  : 48
  mean   : 3.274v
  std dev: 0.143v
alerts : pack in HVC
uptime : 0 hour(s), 25 minute(s), 47 second(s)
bmsc>

The mean is the average cell voltage and the std dev is the standard deviation.

The list of alerts is the following:
- configuration not locked
- pack in HVC
- pack in LVC
- pack in BVC
- not all configured cells detected
- thermistor overtemp
- LTC<n> fault

The parameter uptime gives the time since power on.

show version
The show version command displays firmware version number and build date.

bmsc> show version
version     : v2.2.2 ; Feb 03 2017 11:58:21
bmsc>

show config
The show config command displays configuration parameters.

bmsc> show config
id     : 1
lvc    : 2.400v
hvc    : 3.400v
hvcc   : n/a
bvc    : n/a
bvmin  : n/a
thmax  : 50C
options : cantx (CAN reports are enabled)
The **id** is the BMSC Id, one of 1, 2, 3, or 4.

The **lvc** is the Low Voltage Cutoff, in volts. The **hvc** is the High Voltage Cutoff, in volts.

The **hvcc**, **bvc**, and **bvmin** parameters are optional. If they are configured to be 0, they are not used. The **hvcc** is the High Voltage Cutoff Clear parameter, in volts, this value affects when the HVC alert is cleared. The **bvc** is the Charge Balancing Voltage Cutoff, in volts, and **bvmin** is the automatic Balancing Minimum Voltage, in volts. For these parameters see the text for more details on operation.

The following options may be configured
- **canterm** - Enables the programmable CAN termination resistor
- **balance** - Enables automatic cell balancing

```
bmsc> show config
id       : 1
lvc      : 2.400v
hvc      : 3.400v
hvcc     : n/a
bvc      : n/a
bvmin    : n/a
thmax    : 50C
options  : balance (cell balancing is enabled)
           : canterm (CAN termination resistor enabled)
```

**show map**
Each LTC is mapped to a Pack and a Cell Group, and the **show map** command shows the mapping.

```
bmsc> show map
ltc|pack|group| cells
-----|----|-----|----------------------------------
 1 |  1 |  1  |(c1 -c12) X X X X X X X X X X X X
 2 |    |  2  |(c13-c24) X X X X X X X X X X X X
 3 |    |  3  |(c25-c36) X X X X X X X X X X X
-----|----|-----|----------------------------------
 8 |  2 |  1  |(c1 -c12) .........................
 6 |    |  2  |(c13-c24) .........................
 5 |    |  3  |(c25-c36) .........................
 7 |    |  4  |(c37-c48) .........................
```

In this display, the following letters indicate the state of the cell:

- `<blank>`  cell not locked, cell not detected
- `.`           cell not locked, cell detected
- `?`  cell locked, cell not detected
- `X`  cell locked, cell detected

See the text for examples of this command. Also see the commands **set map** and **lock**.

**show cells**
The **show cells** command lists current cell voltage measurements and status.
If the cell value shown is:

------ then the cell voltage is less than 20mv
?????? the cell is configured, but not present
otherwise the latest cell voltage is shown.

After the cell voltage, there may be an Indicator Flag. There is room for only one Indicator Flag, with the following priority:

>>DIS the cell is being discharged
>HVC the cell voltage is greater than the High Voltage Cutoff threshold
>HVCC the cell voltage was in HVC and is now greater than the High Voltage Cutoff Clear threshold
>BVC the cell voltage is greater than the Charge Balance Voltage threshold
<LVC the cell voltage is less than the Low Voltage Cutoff threshold

If there is no Indicator Flag, then there may be a Deviation Flag. The Deviation Flag is determined by the Standard Deviation Multiple (SDM). See the text above for an explanation of this field.

++ SDM is > 1.5
+ SDM is > 1.0
- SDM is < 1.0
-- SDM is < 1.5

If there is no Indicator Flag and no Deviation Flag, then the cell is within 1 Standard Deviation of the mean.

The design intent of the Deviation Flag is to highlight low or high cells.

Example output:

bmsc> show cells
   c1 - 3.042v +   c13 - 3.027v +   c25 - 2.718v -   c37 - 2.713v -
   c2 - 3.472v >HVC c14 - 2.995v   c26 - 2.918v   c38 - 2.706v -
   c3 - 3.421v >HVCC c15 - 3.054v +   c27 - 2.959v   c39 - 2.908v
   c4 - 3.012v +   c16 - 2.993v   c28 - 3.080v ++   c40 - 2.913v
   c5 - 3.052v +   c17 - 3.045v +   c29 - 2.706v -   c41 - ??????
   c6 - 3.001v +   c18 - 2.991v   c30 - 2.910v   c42 - ??????
   c7 - 2.799v   c19 - 2.766v   c31 - 2.708v -   c43 - ??????
   c8 - 2.788v   c20 - 2.773v   c32 - 2.920v   c44 - ??????
   c9 - 2.774v   c21 - 2.777v   c33 - 2.714v -   c45 - ------
   c10 - 2.771v   c22 - 2.783v   c34 - 2.980v   c46 - ------
   c11 - 2.783v   c23 - 2.783v   c35 - 2.722v -   c47 - ------
   c12 - 2.788v   c24 - 2.770v   c36 - 2.917v   c48 - ------

bmsc>

show stats
The show stats command lists current cell statistics.
Average cell voltage and std deviation (standard deviation) are calculated over all cells. For pack data, the voltage is the current reading of the cell. The min and max values are the lowest and highest value of the cell since power on.

The variance is the difference, in volts, of the current cell voltage with the average cell voltage. For an explanation of sd, min, max, and delta, see the text above.

```bash
bmse> show stats
```
```
  total | mean cell voltage | standard deviation
  ------|-------------------|---------------------
       | 3.414v            | 0.261v              
pack1 | voltage | min | max | deviation | min | max | delta
  c1   | 3.447v  | 3.392v | 3.520v | 0.033v | +0.1s | +0.1s | +0.1s | 0.0s
  c2   | 3.400v  | 3.345v | 3.471v | -0.014v| +0.0s | +0.0s | +0.0s | 0.0s
  c3   | 3.473v  | 3.417v | 3.546v | 0.059v | +0.2s | +0.2s | +0.2s | 0.0s
  c4   | 3.414v  | 3.359v | 3.486v | 0.000v | +0.0s | +0.0s | +0.0s | 0.0s
  c5   | 3.463v  | 3.407v | 3.536v | 0.049v | +0.1s | +0.1s | +0.1s | 0.0s
  c6   | 3.403v  | 3.348v | 3.475v | -0.011v| +0.0s | +0.0s | +0.0s | 0.0s
  c7   | 3.175v  | 3.123v | 3.242v | -0.239v| -0.9s | -0.9s | -0.9s | 0.0s
  c8   | 3.161v  | 3.110v | 3.228v | -0.252v| -0.9s | -0.9s | -0.9s | 0.0s
  c9   | 3.146v  | 3.095v | 3.212v | -0.268v| -1.0s | -1.0s | -1.0s | 0.0s
  c10  | 3.143v  | 3.092v | 3.210v | -0.270v| -1.0s | -1.0s | -1.0s | 0.0s
  c11  | 3.156v  | 3.105v | 3.223v | -0.258v| -0.9s | -0.9s | -0.9s | 0.0s
  c12  | 3.162v  | 3.110v | 3.229v | -0.252v| -0.9s | -0.9s | -0.9s | 0.0s
  c13  | 3.443v  | 3.387v | 3.515v | 0.029v | +0.1s | +0.1s | +0.1s | 0.0s
  c14  | 3.403v  | 3.348v | 3.475v | -0.011v| +0.0s | +0.0s | +0.0s | 0.0s
  c15  | 3.475v  | 3.419v | 3.549v | 0.061v | +0.2s | +0.2s | +0.2s | 0.0s
  c16  | 3.401v  | 3.364v | 3.473v | -0.013v| +0.0s | +0.0s | +0.0s | 0.0s
  c17  | 3.463v  | 3.407v | 3.536v | 0.049v | +0.1s | +0.1s | +0.1s | 0.0s
  c18  | 3.399v  | 3.344v | 3.471v | -0.015v| +0.0s | +0.0s | +0.0s | 0.0s
  c19  | 3.146v  | 3.095v | 3.212v | -0.268v| -1.0s | -1.0s | -1.0s | 0.0s
  c20  | 3.152v  | 3.101v | 3.219v | -0.262v| -1.0s | -1.0s | -0.9s | 0.1s
  c21  | 3.156v  | 3.105v | 3.223v | -0.258v| -0.9s | -0.9s | -0.9s | 0.0s
  c22  | 3.163v  | 3.111v | 3.229v | -0.251v| -0.9s | -0.9s | -0.9s | 0.0s
  c23  | 3.162v  | 3.111v | 3.229v | -0.251v| -0.9s | -0.9s | -0.9s | 0.0s
  c24  | 3.146v  | 3.095v | 3.212v | -0.268v| -1.0s | -1.0s | -1.0s | 0.0s
```

```bash
bmse> show thermistors
```
```
The show thermistors command displays thermistor measurements.
```

```bash
bmse> show th
```
```
ltc | T1 | T2 | T3 | T4 | T5
----|----|----|----|----|----
  1 | 16C | 18C
  2 | 18C | 17C
  3 | 19C | 18C
  4 | 17C | 17C
```

If the thermistor value shown is

| blank | the thermistor is enabled but not connected |
| NC   | the thermistor is not enabled but connected |
| SHORT | the thermistor is enabled but shorted |

-27-
the thermistor is reading a temperature < 0°C
otherwise, the thermistor temperature is given.

After the thermistor temperature, there may be an “+”, which indicates whether the thermistor reading is greater than \( \text{thmax} \).

**set**
The **set** command sets the configurable parameters. If **set** is entered without parameters, **show config** will be displayed.

```
bmsc> set
    id    : 1
    lvc   : 2.400v
    hvcc  : n/a
    bvc   : n/a
    bvmin : n/a
    thmax : 50°C
    options : canterm (CAN termination resistor enabled)
```

**set id**
The **set id** command sets the bmsc id, which can be from 1 to 4. By default the bmsc id is set to 1. Multiple bmsc devices may be present in an EV, typically to support packs with more than 96 cells. When the bmsc id is 1, then the command prompt is “bmsc>”. If the bmsc id is from 2 to 4, then the command prompt changes (to “bmsc2”, etc).

```
bmsc> set id 2
bmsc2>
```

**set hvc**
The **set hvc** sets the High Voltage Cutoff.

```
bmsc> set hvc 3.5
bmsc> show config
    id    : 1
    lvc   : 2.800v
    hvcc  : 3.500v
    hvc   : n/a
    bvc   : n/a
    bvmin : n/a
    thmax : 50°C
    options : canterm (CAN termination resistor enabled)
```

**set lvc**
The **set lvc** command sets the Low Voltage Cutoff.

```
bmsc> set lvc 2.75
bmsc> show config
    id    : 1
    lvc   : 2.750v
    hvcc  : 3.400v
    hvc   : n/a
    bvc   : n/a
    bvmin : n/a
```
thmax : 50C
options : canterm (CAN termination resistor enabled)

**set hvcc**
The `set hvcc` command sets the High Voltage Balance Cutoff Clear threshold. When the BMS has detected a cell in HVC then it will not clear the HVC alert until the cell drops below the configured hvcc value.

If this value is configured to be 0, then the feature is disabled and its value will display as *n/a*.

**set bvc**
The `set bvc` command sets the Charge Balance Voltage Cutoff. When a cell voltage exceeds this threshold, a CAN message is sent to the EVCC to lower the charge current.

If this value is configured to be 0, then the feature is disabled and its value will display as *n/a*.

**set bvmin**
The `set bvmin` command sets the Automatic Minimum balancing voltage. This parameter is used during automatic cell balancing. A cell voltage must be higher than this threshold in order to allow balancing.

If this value is configured to be 0, then the feature is disabled and its value will display as *n/a*.

**set map**
The `set map` is used to set the ltc to cell group mapping. The syntax of this command is

```
set map <ltc> <pack> <group>
```

where `<ltc>` is from 1 to 8, `<pack>` is from 1 to 8 and `<group>` is from 1 to 8.

**set thmax**
The `set thmax` command sets the Thermistor Maximum temperature, in Centigrade.

```
bmsc> set thmax 42
bmsc> show config
id     : 1
lvc    : 2.400v
hvc    : 3.400v
hvcc   : n/a
bvc    : n/a
bvmin  : n/a
thmax  : 42C
```

**reset**

**reset config**
The `reset config` command sets all configuration parameters to the defaults.

Example:

```
bmsc> reset config
```

**reset stats**
The `reset stats` command clears out the statistics.
Example:
```
bmsc> reset stats
```

declare | disable

declare balance
The **enable balance** command activates automatic balancing. By default, automatic balancing is disabled.
The **disable balance** command disables automatic balancing.

Examples:
```
bmsc> enable balance
bmsc> disable balance
```

declare canterm
The **enable canterm** command enables the programmable CAN termination resistor. By default, the termination resistor is NOT enabled.
The **disable canterm** command disables the programmable CAN termination resistor.

Examples:
```
bmsc> enable canterm
bmsc> disable canterm
```

declare thermistor
The **enable thermistor** is used to enable thermistor operation. The command **disable thermistor** disables thermistor operation. The list of which thermistors are enabled can be determined by the command **show config**.

If a thermistor is enabled then if the measured value of the thermistor is greater than **thmax** then the BMS will generate an alert: (1) A message will be printed, (2) an alert will present (and available through **show**), (3) the LED blink will change, and (4) the cell loop will be opened, and (5) the CAN status will be updated.

The syntax of these commands is
```
**enable thermistor** <ltc> <therm_number>
**disable thermistor** <ltc> <therm_number>
```

where **<ltc>** is from 1 to 8, and **<therm_number>** is from 1 to 5.

Examples:
```
bmsc> en th 1 1
bmsc> en th 1 2
bmsc> en th 2 1
bmsc> en th 2 2
bmsc> en th 3 1
bmsc> en th 3 2
bmsc> en th 4 1
bmsc> en th 4 2
bmsc> show thermistor
---|T1 | T2 | T3 | T4 | T5
----|------------------------
1 | 16C  18C  ---  ---  ---
2 | 18C  17C  ---  ---  ---
3 | 19C  18C  ---  ---  ---
4 | 17C  17C  ---  ---  ---
```
**lock**
The **lock** command is used to configure the discovered configuration.

```plaintext
bmsc> lock
configuration locked
bmsc>
```

**upgrade**

```plaintext
bmsc> upgrade

***
*** Starting BMSC Upgrade ***
*** 1) Exit from the terminal application ***
*** 2) Start the bootloader and download a new .hex file ***
*** 3) Restart the BMSC ***
```
CAN Dictionary

// Dilithium Design CAN Message Definitions

#if 0
#define byte unsigned char;   // 8 bits
#define word unsigned int;   // 16 bits
#endif

// DD_BMS_STATUS_IND
// This message is periodically sent by the BMS to indicate BMS health.
//
#define DD_BMS_STATUS_IND 0x01dd0001

// BMS status flag definitions
#define BMS_FLAG_CELL_HVC 0x01  // at least one cell v is >HVC
#define BMS_FLAG_CELL_LVC 0x02  // at least one cell v is <LVC
#define BMS_FLAG_CELL_BVC 0x04  // at least one cell v is >BVC

// BMS flag definitions
#define BMS_FAULT_NOT_LOCKED 0x01  // configuration not locked
#define BMS_FAULT_CENSUS 0x02    // not all cells present
#define BMS_FAULT_OVERTEMP 0x04   // thermistor overtemp

typedef struct tDD_BMS_StatusInd
{
    byte bBmsStatusFlags;
    byte bBmscid;         // bmsc id (0..3)
    byte bBmascFault;
    byte bLtcFault;       // bit mask; 1 indicates error
    byte bLtcCount;       // number of LTCs
} tDD_BMS_StatusInd;

// DD_BMS_CVCUR_REQ
// DD_BMS_CVCUR_C1_TO_C4_RSP
// DD_BMS_CVCUR_C5_TO_C8_RSP
// DD_BMS_CVCUR_C9_TO_C12_RSP
//
// These messages request Current Cell Cell data from the BMSs
//
// The message is of the form 0x01dexxxxx
//
// where xxxx = <group>
//    <bmsc id>
//    <ltc id>
//
//     <group> = 08 - request
//     = 09 - reply, cells 1 to 4
//     = 0a - reply, cells 5 to 8
//     = 0b - reply, cells 9 to 12
//
//     <bmsc id> = 0 to 3 (for bmsc 1 to 4)
//     <ltc id> = 0 to 7 (for LTC 1 to 8)
//
// Example: To request the cell voltage data for bmsc1:ltc3,
// the <bmsc id> is 0 and the <ltc id> is 2.
The following id must be sent:
0x01de0802

The BMSC will then reply with three CAN messages with the following ids:
0x01de0902
0x01de0a02
0x01de0b02

The reply message will have a payload using the structure tDD_BMS_RawData, which contains four cell voltage values.

#define DD_BMS_CVCUR_REQ 0x01de0800
#define DD_BMS_CVCUR_C1_TO_C4_RSP 0x01de0900
#define DD_BMS_CVCUR_C5_TO_C8_RSP 0x01de0a00
#define DD_BMS_CVCUR_C9_TO_C12_RSP 0x01de0b00

#define DD_BMSC_MASK 0x0030 // 2 bits of bmsc idx (0 - 3)
#define DD_LTC_MASK 0x0007 // 3 bits of ltc idx (0 - 7)

// tDD_BMS_RawData
typedef struct tDD_BMS_RawData {
    word wData[4]; // cell voltages in tenths of mv
} tDD_BMS_RawData;
Warrantee and Support

The BMSC and BMSS are warranted to be free from defects in components and workmanship under normal use and service for a period of 1 year.

The product is intended for non-commercial use by hobbyists. The warranty does not apply to defects arising from miswiring, abuse or negligence, accidents, or reverse engineering. Dilithium Design shall not be responsible for any incidental or consequential damages.

Dilithium Design reserve the right to make changes or improvements in design or manufacturing without assuming any obligation to change or improve products previously manufactured and / or sold.

For errors in this document, or comments about the product, contact

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Rev 1.1   Mar 2017   Initial Release