MILLSWOOD engineering

6S Battery Cell Monitor & Balancer

PRODUCT MANUAL

1 General Description

The 6S Battery Cell Monitor & Balancer is a precision instrument that ensures multi-cell batteries are maintained in an optimal state, improving system reliability and prolonging battery life.

Figure 1 – 6S Battery Cell Monitor & Balancer

The 6S Battery Cell Monitor & Balancer does exactly as its name suggests: it monitors cells within a 6S battery, and it balances those cells if and when they require it.

2 Features

- Transforms a "dumb" battery into a smart (self-balancing) battery.
- Supports multiple battery chemistries – LiPo, LiS and LiFe.
- Galvanically isolated CAN interface, allowing stacking (for series connected batteries).
- Battery temperature monitoring with suitable external sensor.
- User-friendly configuration software.
- Rich variety of balancing control options.
- Seamless integration with 250W PMU.
- Weight: 45g.
- Dimensions: 80 x 35 x 11.5mm.

3 Usage

The Battery Balancer plugs directly into the balance connector present on most Lithium-based batteries. In many cases, this is the only connection required. A pair of indicator lights on the front panel give a "go / no go" indication of the battery's state of balance and state of charge. More detailed battery information is available via the CAN bus.

The Battery Balancer can be used in two ways:

- As a hand-held battery verification tool, or
- Installed in a UAV, either with or without interfacing to the vehicle's CAN bus.

Installation into a UAV confers a number of operational advantages:

- Batteries do not need to be removed periodically to check for balance.
- Battery status is available instantly, either directly from the front-panel LEDs, or remotely from the telemetry data sent on the CAN bus.
- Batteries are maintained in a state of balance, improving flight-readiness.

This page intentionally left blank.

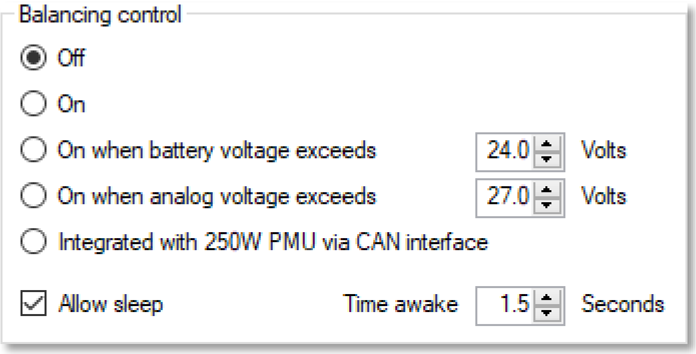
4 Contents

5 Quick Start Guide

- Download the configuration utility from www.millswoodeng.com.au/resources.html and run it.
- Connect the balancer to your PC with a micro-USB cable.
- Click on the "Connect" menu item to establish a connection with the balancer.
- Click on the "Device" menu and check that reading the balancer's configuration settings works.
- Plug a battery into the balancer.
- Click on the "Monitor" tab and check that cell voltages are being measured correctly.
- If desired, adjust the configuration settings and write these to the balancer.

5.1 Configuration examples

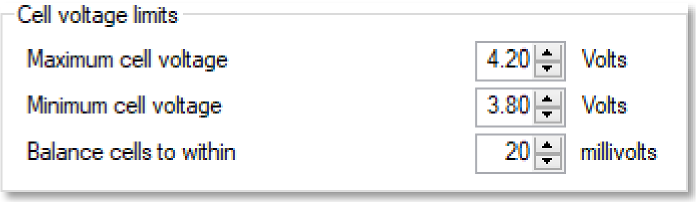
5.1.1 Hand-held battery verification tool for 6S LiPo batteries



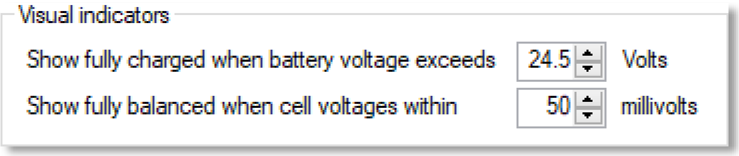
Select "Off" as the balancing control option and write this setting to the balancer.

This prevents the balancer from actually balancing, but it is still able to measure all the cell voltages and display the battery's balance and charge status.

The rest of the default settings are a good starting point for 6S LiPos, but you may wish to adjust:



Cell voltage limits – these determine when the charge LED alternates between red and green to warn that a cell voltage is out of tolerance.



Visual indicators – these determine when the balance and charge LEDs display red or green.

Plug the balancer into a 6S LiPo's balance connector, and the balance and charge LEDs will indicate its status. If the configuration software is connected and running at the same time, then the Monitor tab will show detailed information about the battery.

5.1.2 Balancer for 6S LiPo (stand-alone smart battery)

The default settings are tailored for this application. The balancer can be fitted to a "dumb" battery to turn it into a smarter (self-balancing) battery. The balancer may be left connected to the battery semi-permanently (until the battery is retired). Charging the battery with a "dumb" (non-balancing) charger will automatically enable balancing once the battery voltage rises above 24V. If the battery is not used for extended periods of time, balancing ceases once the battery voltage falls to below 24V. This prevents the battery from becoming overly discharged.

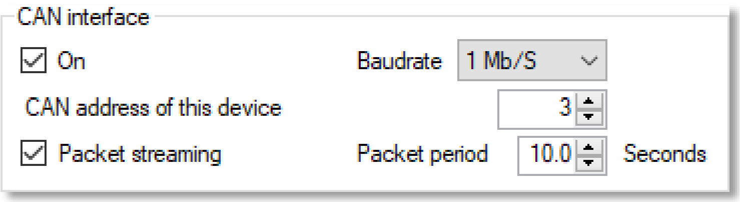
Simply plug a battery into the balancer with its default settings and you're all done.

Settings that you may wish to adjust are:

- Cell voltage limits – these determine how far the balancer is allowed to modify the cell voltages, and how closely to match the cell voltages to each other.
- Visual indicators – these determine when the balance and charge LEDs display red or green.

Because the battery is constantly being monitored and balanced, it is not necessary to set a particularly tight balancing target. Larger values have the advantage of slowing the rate of self-discharge. See section 9.4.1 for further details.

5.1.3 Balancer for 6S LiPo (smart battery with CAN)



Tick the "On" checkbox in the CAN interface box and select the appropriate CAN Baudrate for your CAN bus.

The other settings in the CAN interface box are described in detail in the CAN protocol document, but the defaults are a good starting point.

Apart from the Cell voltage limits and Visual indicators settings, one other setting that is worth checking is:

- Allow sleep – if ticked, the balancer goes to sleep if idle for more than 32 seconds. [Note 1] The balancer does not report data nor respond to commands whilst asleep.

Plug a battery into the balancer and connect your CAN bus via either of the CAN connectors. The pin allocation for the CAN connectors is given in section 7.3. The minimum connections required are CAN H, CAN L and Ground. [Note 2] In non-stacked systems CAN ground may be the same as battery ground.

Note 1: "Idle" in this context means that balancing is not occurring and no CAN data addressing the balancer is present on the CAN bus. Packet streaming works with sleep enabled – streaming restarts 1 second after awakening, and so with default settings measurements are sent once every 32 seconds.

Note 2: CAN power is an optional input that can be used to dynamically enable and disable the CAN interface, as an alternative to enabling the CAN interface statically using a configuration setting. The presence of CAN power prevents sleeping.

5.1.4 Balancer for 6S LiPo integrated with 250W PMU (minimal effort)

This is essentially the same as configuring the Balancer to be a stand-alone smart battery (section 5.1.2 above); the default configuration settings are tailored for this application.

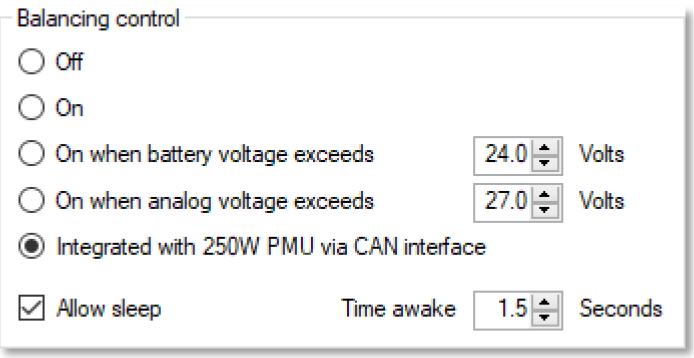
Plug a battery into the balancer with its default settings. Connect the battery's main terminals to the PMU's battery connection terminals. With dual battery systems two balancers are required – one fitted to each battery.

The PMU functions as the "dumb" charger, and the battery balances itself whenever its terminal voltage is above 24V. This generally corresponds with the battery being charged.

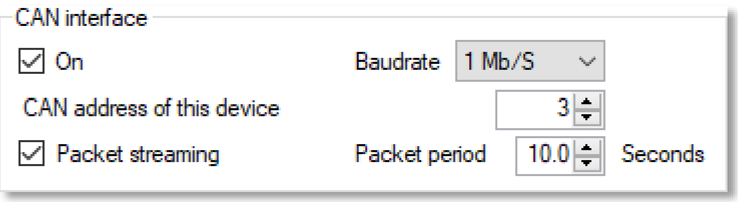
CAN reporting of data can also be added to this setup very easily, see section 5.1.3 above for details.

5.1.5 Balancer for 6S LiPo integrated with 250W PMU (fully featured)

Setting up the balancer as described below allows the balancer to control charging via the CAN bus. This allows the balancer to suspend charging if necessary, such as if a cell voltage exceeds its upper limit, or the battery temperature goes outside of its specified range.

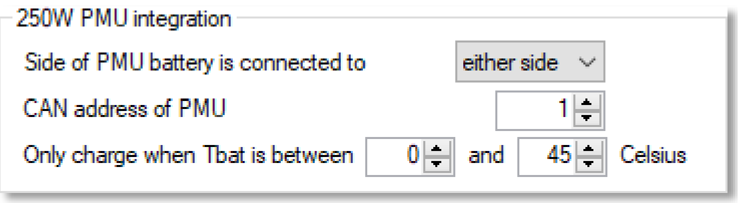


Select "Integrated with PMU via CAN interface" as the balancing control option and write this setting to the balancer.



Tick the "On" checkbox in the CAN interface box and select the appropriate CAN Baudrate for your CAN bus.

The other settings in the CAN interface box are described in detail in the CAN protocol document, but the defaults are a good starting point.



The PMU supports the connection of two batteries, designated A and B. Select "A-side" or "B-side".

The balancer also needs to know the CAN address of the PMU, so that it can communicate with it over the CAN bus. Enter the PMU's CAN address.

The final option is only relevant if a temperature sensor is connected to the balancer. Specify the range of temperatures over which the battery charging is permitted.

Plug a battery into the balancer. Connect the battery's main terminals to the PMU's battery connection terminals. With dual battery systems two balancers are required – one fitted to each battery.

Connect your CAN bus to the balancer via either of the CAN connectors. The pin allocation for the CAN connectors is given in section 7.3. The minimum connections required are CAN H, CAN L and Ground. CAN ground may be the same as battery ground.

6 Visual indicators

There are 2 LED indicators on the front panel, one for balance and one for charge. The LED colours have the following meanings:

6.1 Balance LED

GREEN	The battery is balanced.
RED	The battery is not balanced.
OFF	No battery connected (or the Battery Balancer is sleeping).

Table 1 – Balance LED states

The balancing LED flashes when balancing is occurring.

6.2 Charge LED

GREEN	The battery is fully charged.
RED & GREEN	The battery is fully charged, but one (or more) cells are over or under voltage.
RED	The battery is not fully charged.
OFF	No battery connected (or the Battery Balancer is sleeping).

Table 2 – Charge LED states

The charge LED is only valid when the battery current is zero (i.e. not being charged and not under load).

The thresholds for both the charge and balance LEDs are user-configurable.

7 Connectors

The Battery Balancer has 5 external connectors: a battery balance connector, a micro-USB connector, a pair of CAN connectors, and an auxiliary connector. Use of the CAN and auxiliary connectors is entirely optional.

7.1 Battery balance connector

Connects directly to a 6S battery's balance connector. The mating connector is a 7-way JST XH series connector, part number XHP-7. The pin allocation is:

Pin	Name	Type	Description
1	Cell 6+	Power input	Connects to positive terminal of cell 6
2	Cell 5+ / Cell 6-	I/O	Connects to junction of cells 5 and 6
3	Cell 4+ / Cell 5-	I/O	Connects to junction of cells 4 and 5
4	Cell 3+ / Cell 4-	I/O	Connects to junction of cells 3 and 4
5	Cell 2+ / Cell 3-	I/O	Connects to junction of cells 2 and 3
5	Cell 1+ / Cell 2-	I/O	Connects to junction of cells 1 and 2
6	Cell 1-	Ground	Connects to negative terminal of cell 1

Table 3 – Balance connector pin allocations

7.2 Micro-USB connector

Used to connect the Battery Balancer to a PC. This connection is only required when configuring the Battery Balancer, although it may also be useful for displaying a battery's cell voltages and temperature in real-time.

Be aware that the USB connector is referenced to the connected battery's negative terminal. Exercise caution with systems that have series-connected batteries, as ground on the micro-USB connector may not be the same as system ground.

7.3 CAN connectors

Used to interface to a CAN bus. The mating connector is a 4-way JST GH series connector, part number GHR-04V-S or GVHRSF-04V-S. The pin allocation is:

Pin	Name	Type	Description
1	CAN power	Power input	Nominally 0 and +5 VDC
2	CAN H	I/O	CAN data, high side
3	CAN L	I/O	CAN data, low side
4	Ground	Ground	Ground reference for CAN connections

Table 4 – CAN connector pin allocations

The CAN interface is DC isolated from the battery so that multiple batteries can be connected in series. All pins on both CAN connectors are fully-floating as a group. CAN signals should all be referenced to a common ground, usually the most negative battery terminal.

Two CAN connectors are provided so that one may be used as a "CAN IN", and the other as a "CAN OUT", simplifying wiring when connecting batteries in series. The two CAN connectors are physically identical and wired in parallel.

The CAN interface is not terminated internally.

The CAN power pin is only used to enable the CAN interface; no power is drawn or sourced from this pin. The balancer stays awake whenever CAN power is present.

7.4 Auxiliary connector

Used to connect a battery temperature sensor and/or an analog voltage. The mating connector is a 4-way JST GH series connector, part number GHR-04V-S or GVHRSF-04V-S. The pin allocation is:

Pin	Name	Type	Description
1	Analog voltage	Input	Sensing range: 0 to +33 VDC
2	Ground	Ground	Ground reference for analog voltage
3	Temperature sensor	Input	10k NTC thermistor
4	Ground	Ground	Ground reference for temperature sensor

Table 5 – Auxiliary connector pin allocations

The analog input is used to turn balancing on and off, if configured to do so. It may be driven by a logic-level signal if its switching threshold is configured appropriately.

Be aware that the analog input is referenced to the connected battery's negative terminal. Exercise caution with systems that have series-connected batteries, as ground on the Auxiliary connector may not be the same as system ground.

The temperature sensor input is designed for a 10k NTC thermistor. Devices with a beta of 3950K will give the most accurate results (typically within +/-1 degree from -20 to +65C), but any 10k NTC thermistor will work acceptably well. Connect the thermistor between pins 3 and 4, either polarity.

8 Configuration Software

The configuration utility is a Windows application that allows configurable settings to be read from and written to the Battery Balancer. Settings can also be saved to file and retrieved for later use. The file format is XML, and so Battery Balancer settings files can be inspected using any browser or text editor.

The configuration utility may be downloaded from www.millswoodeng.com.au/resources.html

To configure the Battery Balancer, simply connect it to a PC with a micro-USB cable and run the configuration utility. Be aware that some micro-USB cables intended for charging do not have the data lines connected. These cables do not work.

Be aware that the USB connector is referenced to the connected battery's negative terminal. Exercise caution with systems that have series-connected batteries, as ground on the micro-USB connector may not be the same as system ground.

The Battery Balancer will power itself from the USB connection.

The main page of the configuration utility consists of tabbed pages, and there is a menu across the top. The "Connection" menu allows selection of the serial port to which the Battery Balancer is connected. Once connected successfully, the "Device" menu will become accessible. This menu allows reading and writing to the Battery Balancer, as well as viewing its serial number and upgrading its firmware.

8.1 Configure tab

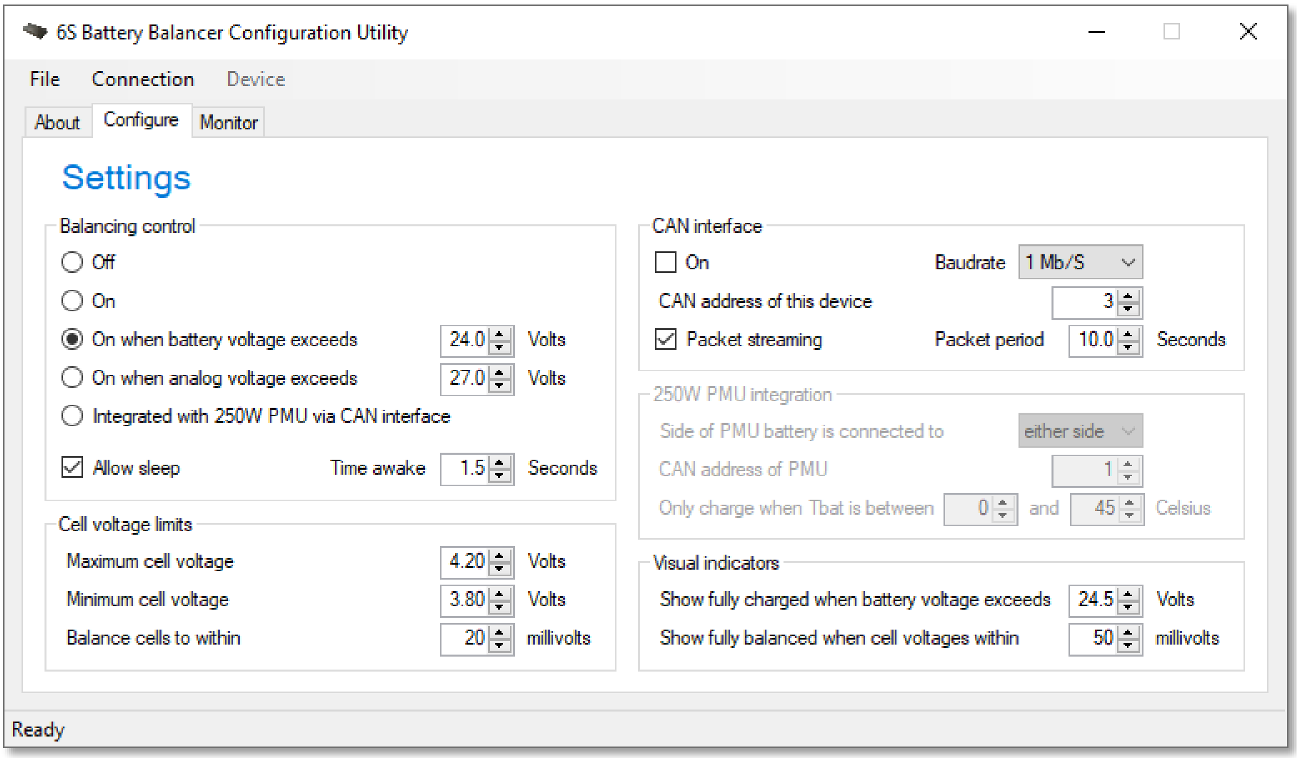


Figure 2 – Configure tab

When written to the Battery Balancer, settings are stored in non-volatile memory and are retained after power is removed.

8.1.1 Balancing control

Select one of the 5 control options:

- **Off:** Balancing is disabled.
- **On:** Balancing is enabled and occurs whenever:
    - the cell voltage spread (max – min) exceeds the cell balancing target, or
    - a cell's voltage exceeds the maximum permitted cell voltage.
- **On when battery voltage exceeds:** Balancing is enabled whenever the battery voltage is above the threshold specified.
- **On when analog voltage exceeds:** Balancing is enabled whenever the analog input voltage is above the threshold specified.
- **Integrated with PMU via CAN interface:** Balancing is enabled whenever the battery is being charged by the PMU. This is described in more detail in section 8.1.4 below.

If "**Allow sleep**" is checked, after 32 seconds of inactivity the Battery Balancer will go to sleep. It will wake every 32 seconds to re-measure the battery voltages and temperature and check for any CAN activity (if the CAN interface is enabled). If balancing needs to be performed the Battery Balancer will remain awake to do this, and then go back to sleep again afterwards.

When the Battery Balancer goes to sleep, the 2 LEDs will glow green very faintly. This is normal and does not draw any appreciable current.

The Battery Balancer will wake (and remain awake) if connected to a PC or if CAN power is present. It will also remain awake if CAN packets addressed to the Battery Balancer are present on the CAN bus.

The "**Time awake**" setting may need to be increased if waking due to CAN activity is required and CAN messages are infrequent.

8.1.2 Cell voltage limits

- **Maximum cell voltage:** The maximum safe voltage for cells to be charged up to. Cells with voltage exceeding this limit will be discharged until they reach this limit.
- **Minimum cell voltage:** Cells will never be discharged below this voltage.
- **Balance cells to within:** The target cell voltage spread that the Battery Balancer will attempt to reach by discharging cells with higher voltages. There is 10mV of hysteresis, so that once the target is reached balancing will not resume until the spread between cells exceeds the target plus 10mV.

8.1.3 CAN interface

- **On:** Enables the CAN interface. The CAN interface is also enabled whenever CAN power is applied to the CAN connectors, regardless of the state of this checkbox.
- **Bit rate:** Select the same bit rate for all devices sharing the CAN bus.
- **CAN address of this device:** Choose a unique 16-bit address for the Battery Balancer. The Battery Balancer will respond to this address and also to the global address of 65535 (FFFF Hex).
- **Packet streaming:** Enables the regular transmission of measured data. Data may also be requested (polled) from the Battery Balancer.
- **Packet period:** Sets how often measured data is transmitted, if packet streaming is enabled.

The CAN protocol is described in detail in the CAN protocol document.

8.1.4 PMU integration

These settings are only relevant if the balancing control option selected is "Integrated with PMU via CAN interface". When this option is selected the balancer communicates with the PMU via CAN in order to manage balancing and charging.

- **Side of PMU battery is connected to:** In order to perform these tasks the balancer needs to know which side (A or B) of the PMU it is connected to, so that it can turn the appropriate charging circuit off and on.
- **CAN address of PMU:** The balancer also needs to know the CAN address of the PMU that is charging its battery, so that it can identify the data it needs and direct commands to the appropriate CAN device.
- **Only charge when Tbat is between:** The balancer also needs to know the temperature range over which the battery may be charged and balanced. If no temperature sensor is fitted, the balancer recognises this and allows charging and balancing to occur regardless of the temperature.

The balancer inspects the data on the CAN bus to determine when battery charging is occurring, and requests this information periodically if it is not already present. No special configuration of the PMU is necessary. If communication with the PMU cannot be established or is lost, battery management halts until communication is re-established.

The balancer stops balancing and turns charging off if the battery is outside the specified temperature range. Charging is turned on again when the temperature returns to within the specified limits. To prevent excessive on/off cycling, 5 degrees of hysteresis is applied to the temperature limits.

If cell overvoltage occurs whilst charging, the balancer will halt charging and discharge the cell to a safe value before continuing. Charging may cycle on and off for this reason.

The balancer terminates charging when the battery is fully charged (average cell voltage within 50mV of the maximum permitted, corresponding to a state of charge of 95% for Lithium polymer batteries). The balancer restarts charging when the average cell voltage falls to below this level.

8.1.5 Visual indicators

- **Show fully balanced when cell voltages within:** This is the threshold for determining the colour of the balance LED. If the cell voltage spread is less than this threshold, the balance LED will be green.
- **Show fully charged when battery voltage exceeds:** This is the threshold for determining the colour of the charge LED. If the battery voltage is above this threshold, the charge LED will be green.

These thresholds apply only to the visual indicators; they do not affect operation of the Battery Balancer in any way.

Note that with default configuration settings, the charge LED is only valid at zero current. When under any significant load the charge LED will be red, but this does not mean that the battery is flat.

The reasons are complex; a rough explanation is given here.

The Battery Balancer is first and foremost a balancer, and as such does not require a current sensor to do its job. A current sensor adds complexity, cost, size and weight and is not included for these reasons.

However, determining state of charge accurately requires a knowledge of battery current, and so the only way of doing this without a current sensor is to ensure that the current is zero. The default charge LED threshold of 24.5V (4.08V/cell) was chosen to correspond to a state of charge of 90% for a 6S LiPo at no load. See Graph 2 – LiPo cell voltage versus state of charge at 23 °C.

It is entirely possible to choose a non-zero load current and set the charge LED threshold accordingly, however this requires a knowledge of cell voltage versus discharge current for the specific battery being used.

For example, using the data given in Graph 2, at 1.0C discharge current the cell voltage corresponding to 90% of full capacity is 3.84V/cell, and so setting the charge LED threshold to 23.0V (6 x 3.84V) would be the appropriate threshold.

8.2 Monitor tab

The configuration utility is able to display a battery's cell voltages and temperature in real-time.

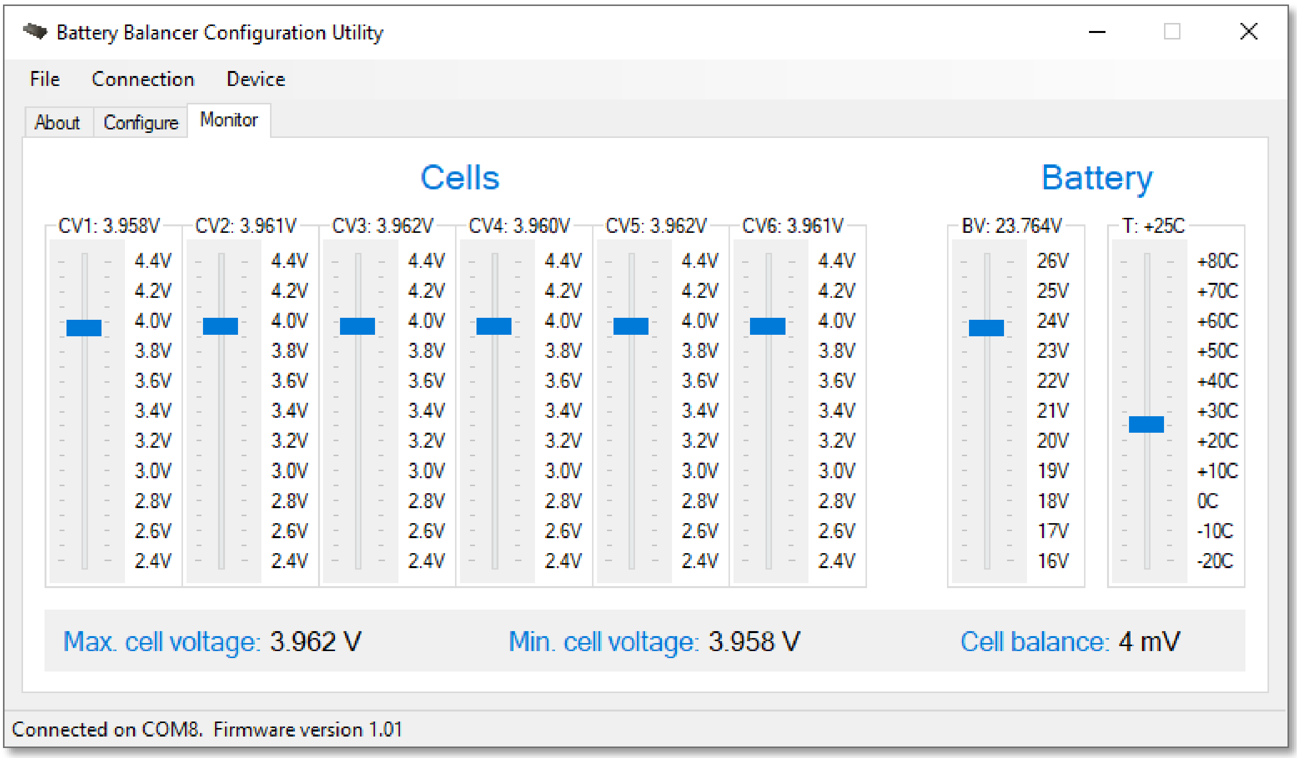


Figure 3 – Monitor tab

All of this data is also available via the CAN interface. The CAN protocol is described in detail in the CAN protocol document.

9 Specifications

9.1 Absolute Maximum Ratings

Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

Symbol	Parameter	Min	Max	Unit
V_{BAT}	Battery voltage (Cell 6+ with respect to Cell 1-)	-0.3	+36	V_{DC}
V_{CELL}	Cell voltage	-0.3	+9	V_{DC}
V_{ANALOG}	Analog input voltage	-5	+50	V_{DC}
V_{T_SENSE}	Temperature sensor input voltage	0	+3.6	V_{DC}
V_{CAN_POWER}	CAN power input voltage (with respect to CAN ground)	-25	+30	V_{DC}
V_{CAN_L}, V_{CAN_H}	CAN L and H voltage (with respect to CAN ground)	-36	+36	V_{DC}
V_{CAN_ISO}	CAN interface isolation voltage (with respect to battery negative terminal)	-200	+200	V_{DC}
T_{INT}	Internal temperature	-55	+105	°C

Table 6 – Absolute Maximum Ratings

9.2 Recommended Operating Conditions

Symbol	Parameter	Min	Max	Unit
V_{BAT}	Battery voltage (Cell 6+ with respect to Cell 1-)	6.0	26.4	V_{PP}
V_{CELL}	Cell voltage	1.4	4.4	V_{DC}
V_{ANALOG}	Analog input voltage	0	33	V_{DC}
V_{CAN_POWER}	CAN power input voltage (with respect to CAN ground)	0	5	V_{DC}
T_{INT}	Internal temperature	-40	+85	°C

Table 7 – Recommended Operating Conditions

9.3 Electrical Specifications

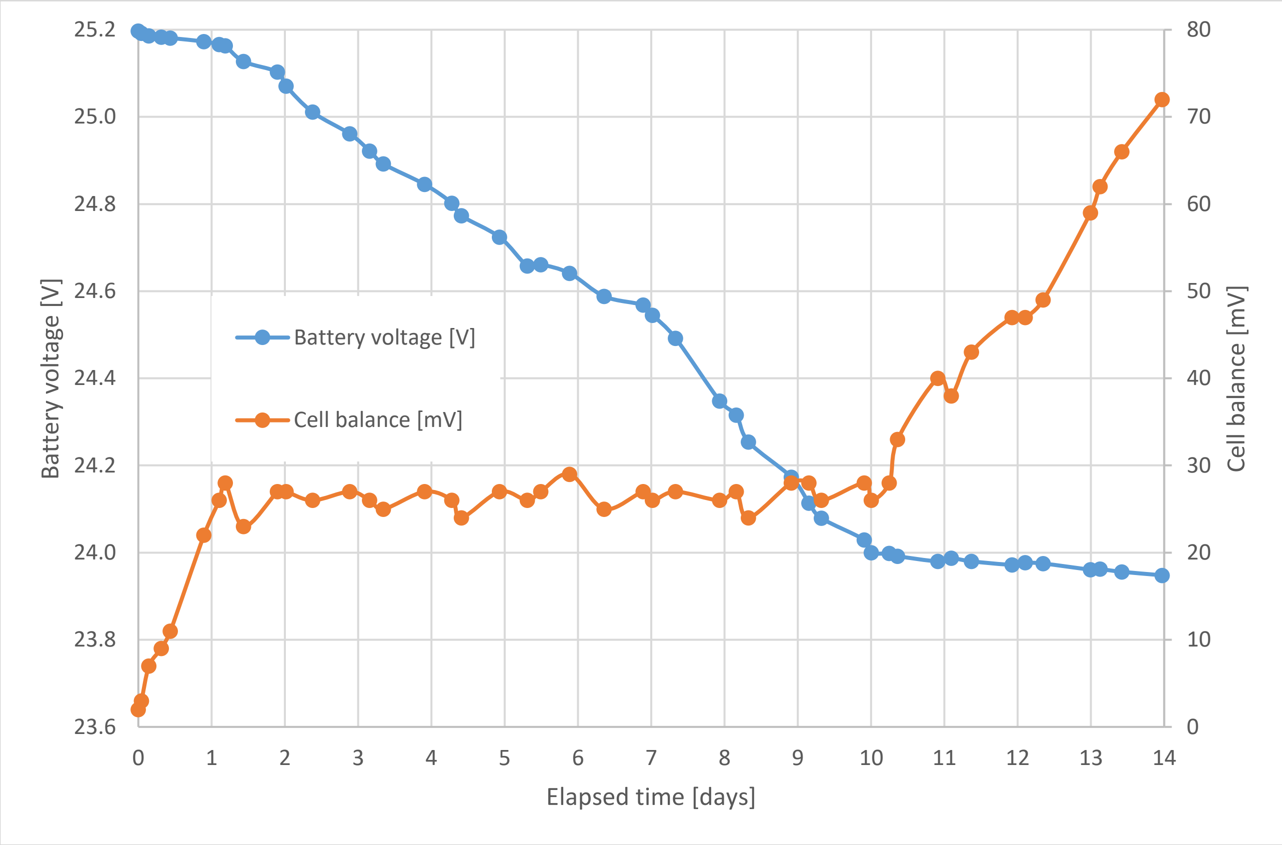
Minimum and maximum limits apply across the range of values given in the recommended operating conditions. Typical values are measured with T_{INT} = +25°C.

	Min	Typ	Max	Unit
Battery parameters				
Measurement accuracy		±20	±50	mV
Cell parameters				
Discharge resistance		10		Ω
Measurement accuracy		±3	±8	mV
Balancing hysteresis		+10		mV
Analog input				
Measurement accuracy		±150	±300	mV
Input impedance	100			kΩ
CAN power input				
Low level			2.3	V
High level	2.7			V
Temperature (using 3950K 10k NTC)				
Measurement accuracy (-20 to +65°C)		±0.5	±1	°C

Table 8 – Electrical Specifications

9.4 Typical Characteristics

9.4.1 Quiescent discharge of 1.8Ah 50C 6S LiPo with balancer connected



Graph 1 – Quiescent discharge of 1.8Ah 50C 6S LiPo with balancer connected

Some explanation of the graph shown above is warranted.

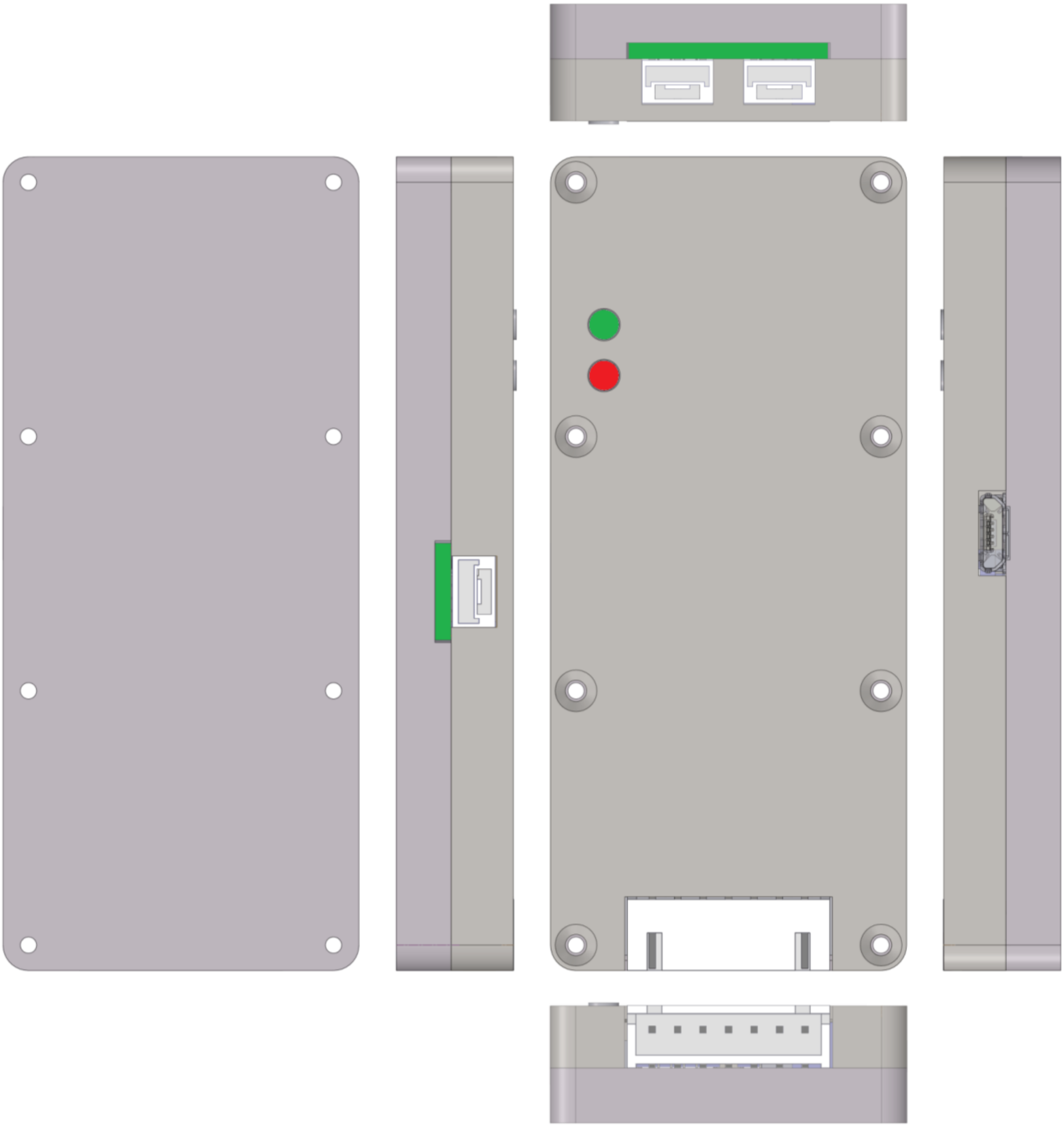
A near-new 1.8Ah 50C 6S LiPo battery was charged up to 4.2V/cell and balanced. It was then connected to a Battery Balancer configured with default settings and allowed to self-discharge for 14 days.

As can be seen from the graph, the Battery Balancer maintained balance within 30mV (default target of 20mV plus 10mV of hysteresis) for the first 10 days, at which point the battery voltage had fallen to 24V and so balancing ceased.

24V corresponds to 4.0V/cell, which is approximately 78% of full capacity for a LiPo with no load (see section 11.1). This means that the average rate of discharge was 2.2% per day.

Most UAVs will use batteries of significantly higher capacity than 1.8Ah, and so discharge rates will be correspondingly lower. A 5Ah battery could reasonably be expected to lose less than 1% per day with the default configuration settings.

9.5 Mechanical Characteristics



Dimensions:
80 x 35 x 11.5mm

Mass: 45g
(excluding mating wiring harnesses)

10 Document version history

10.1 0.9 -> 1.0

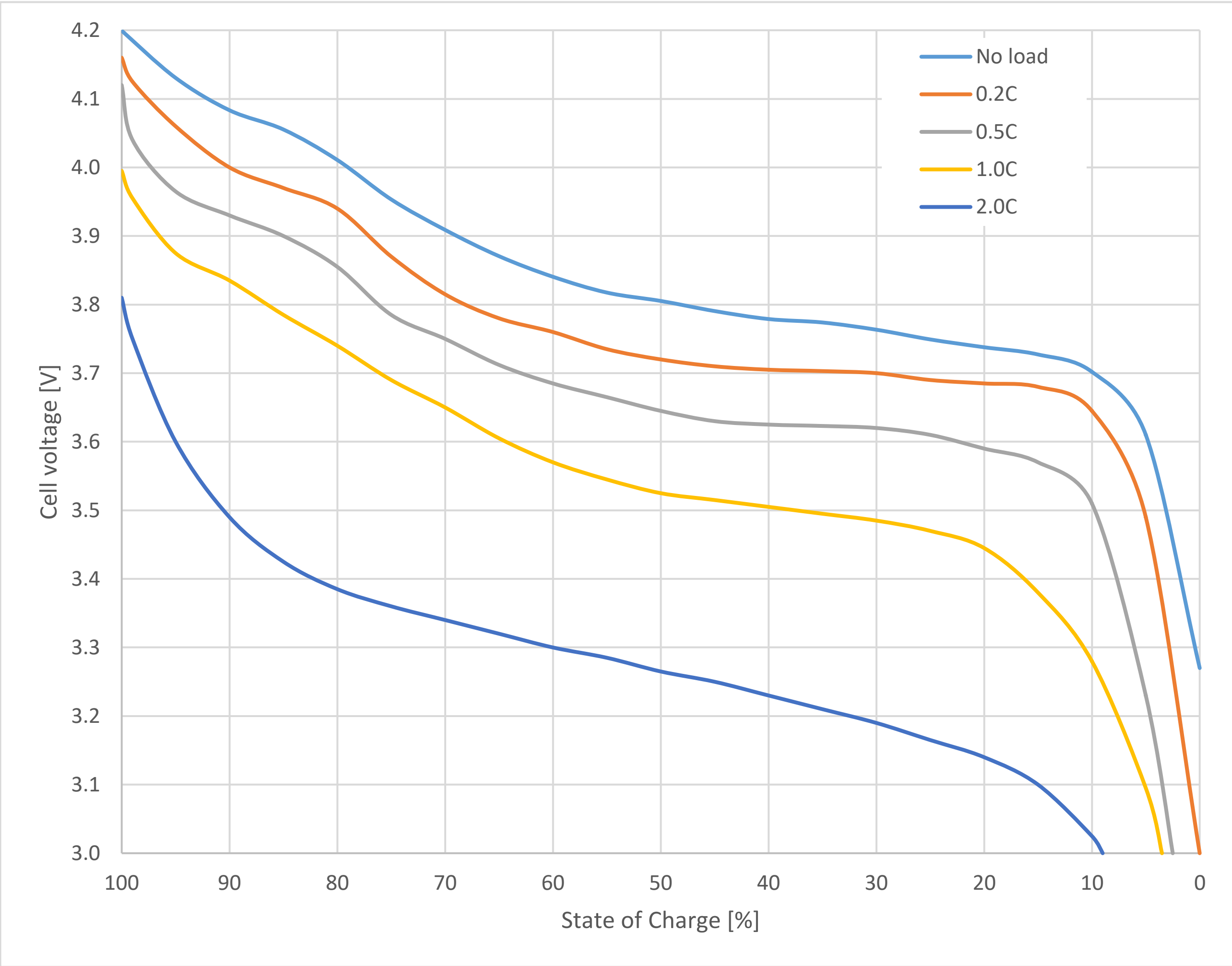
- Initial release.

10.2 1.0 -> 1.1

- Image updated.

11 Reference data

11.1 Typical Lithium polymer characteristics at 23 °C



Graph 2 – LiPo cell voltage versus state of charge at 23 °C

With regard to Graph 2, the no load curve is the average of a large number of datasets. It is the only curve that applies to LiPo cells in general. The loaded curves vary significantly between batteries because manufacturers use different criteria to determine their C ratings.