REC BATTERY MANAGEMENT SYSTEM
Master – Slave configuration

Features:

- robust and small design
- Master + max 15 Slave 16S combination (max 240 cells)
- single cell voltage measurement (0.1 – 5.0 V, resolution 1 mV)
- single cell - under/over voltage protection
- single cell internal resistance measurement
- SOC and SOH calculation
- over temperature protection (up to 3 temperature sensors per Slave)
- under temperature charging protection
- passive cell balancing up to 1.3 A per cell with LED indication
- shunt current measurement (resolution 10 mA @ ± 300 A)
- 3 galvanically isolated user defined multi-purpose digital inputs/outputs
- 4 programmable relays (normally open and normally closed option)
- 12 V galvanically isolated supply (10.5 – 15 V)
- galvanically isolated RS-485 and CAN communication protocol
- error LED + buzzer indicator
- internal battery powered real time-clock (RTC)
- PC user interface for changing the settings and data-logging (optional accessory)
- LCD touch display for monitoring (optional accessory)
- hibernate switch
- one-year warranty

General Description of the BMS:

Battery management system (BMS) is a device that monitors and controls each cell in the battery pack by measuring its parameters. The capacity of the battery pack differs from one battery cell to another and this increases with number of charging/discharging cycles. Due to the different capacity this voltage is not reached at the same time for all cells in the stack. The lower the capacity the sooner this voltage is reached. When charging series connected batteries with single charger, the voltage on some cells might be higher than maximum allowed charging voltage at the end of charging. Overcharging the cell additionally lowers its capacity and number of charging cycles. The BMS equalizes cells' voltage by diverting some of the charging current from higher voltage cells – passive balancing. The device temperature is measured to protect the circuit from over-heating due to the passive balancing. Battery pack temperature is monitored by Dallas DS18B20 digital temperature sensor/s. Maximum 3 sensors per Slave unit may be used. The BMS parameters are listed in table below.

Default Parameter Table:

Table 1: Default parameter table.

Parameter	Value	Unit
balance start voltage	4.10	V
balance end voltage	4.16	V
maximum diverted current per cell	up to 1.2 (3.9 Ohm)	A
cell over voltage switch-off	4.18	V
cell over voltage switch-off hysteresis per cell	0.01	V
charger end of charge switch-off pack	4.16	V
charger end of charge switch-off hysteresis per cell	0.1	V
charger end of charge switch-off SOC hysteresis	5	%
cell under voltage protection switch-off	3.0	V
under voltage protection switch-off hysteresis per cell	0.05	V
Max cell voltage difference	0.075	V
BMS slave under voltage sleep mode	36	V
BMS over temperature switch-off	55	°C
BMS over temperature switch-off hysteresis	5	°C
cell over temperature switch-off	55	°C
under temperature charging disable	-5	°C
Slave Unit absolute maximum package voltage	60	V
Master Unit power supply voltage	11-15	V
voltage to current coefficient	10000	A/V
max DC current Relay 1-4 at 100 V DC	0.4	A
max DC current Relay 1-4 at 12 V DC	2	A
max AC current Relay 1-4 at 230 V AC	2	A
optocoupler output max voltage	62	V
optocoupler output max current	15	mA
Slave Unit stand-by power supply	< 90	mW
Slave Unit disable power supply	< 1	mW
Slave Unit cell balance fuse rating (SMD)	2	A
Master Unit stand-by power supply @ 12 V	300	mW
Master Unit disable power supply	0	mW
internal relay fuse (Master Unit)	2 slow	A
cell voltage and temp. measurement refresh rate	2	s
current measurement refresh rate	1	s
Slave Unit dimensions (w × l × h)	190 x 114 x 39	mm
Master Unit dimensions (w × l × h)	190 x 104 x 39	mm
weight	0.650	kg

System Overview:

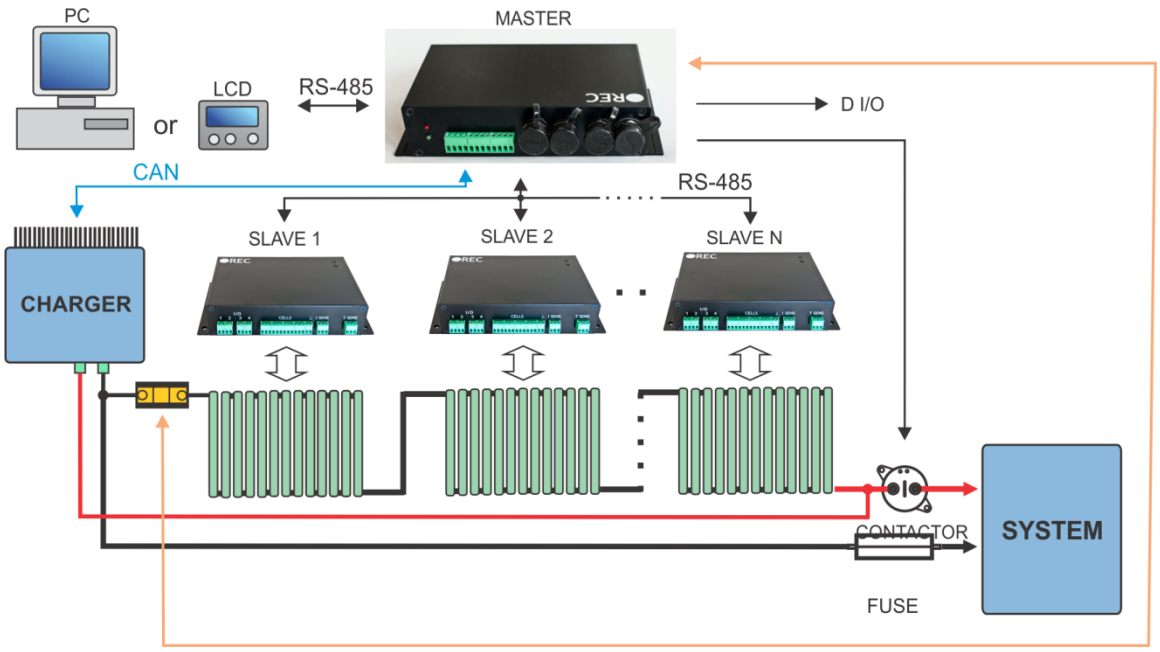

Figure 1: System overview.

Slave Unit:

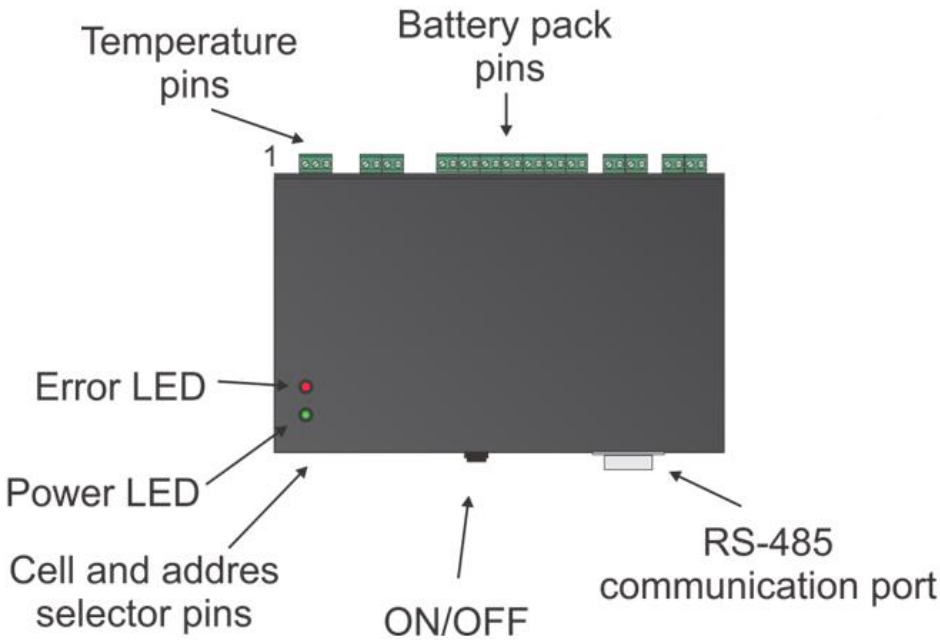

Figure 2: Slave Unit function overview.

Slave Unit Connection Table:

Table 2: Slave Unit connection table.

Pins	Connection	Description
Temp. pins		
1	DALLAS 18B20 temp. sensor pins	+5 V
2	DALLAS 18B20 temp. sensor pins	GND
3	DALLAS 18B20 temp. sensor pins	1-wire digital signal
Current. pins		
1	-	-
2	-	-
3	-	-
4	-	-
Cells pins		
1	Cell 1 ground	Analog signal
2	Cell 1 positive	Analog signal
3	Cell 2 positive	Analog signal
4	Cell 3 positive	Analog signal
5	Cell 4 positive	Analog signal
6	Cell 5 positive	Analog signal
7	Cell 6 positive	Analog signal
8	Cell 7 positive	Analog signal
9	Cell 8 positive	Analog signal
10	Cell 9 positive	Analog signal
11	Cell 10 positive	Analog signal
12	Cell 11 positive	Analog signal
13	Cell 12 positive	Analog signal
14	Cell 12 positive	Analog signal
I/O pins		
1	-	-
2	-	
3	-	-
4	-	-
5	-	-
6	-	-
7	-	-
8	-	-

Setting Number of Cells and the RS-485 Address:

Number of cells connected to the Slave Unit is selected via CELL DIP Switch pins at the back of the Unit. Binary addressing is used to enable setting up to 15 cells with 4 DIP Switches.

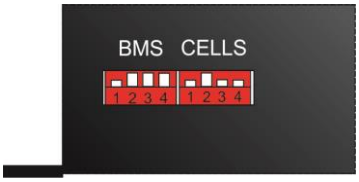

Figure 3: Address and cell selection DIP Switches.

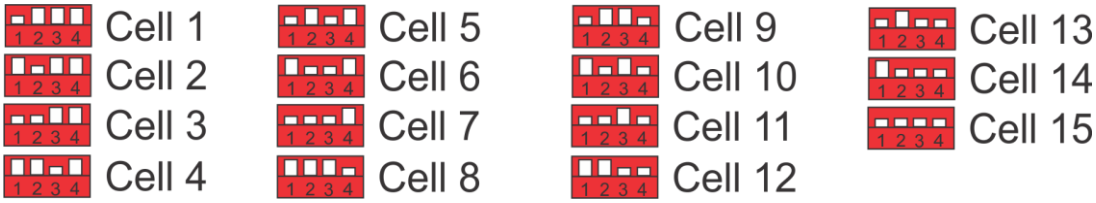

Figure 4: Number of cell selection description.

Slave Unit address is selected via Address DIP Switch pins (BMS) at the back of the Unit. Binary addressing is used to enable setting up to 15 addresses with 4 DIP Switches. **! If multiple Slave Units are used distinguished addresses should be set to avoid data collision on the RS-485 communication bus!**

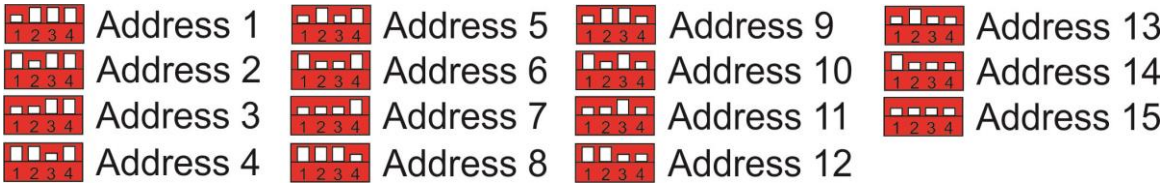

Figure 5: Slave Unit address selection description.

Slave Unit Cell Connector:

Connect each cell to the Slave Unit cell connector plug. Use silicon wires with cross section of 0.25-1 mm^2.
! Before inserting the cell connector check voltages and polarities with voltmeter of each connection!

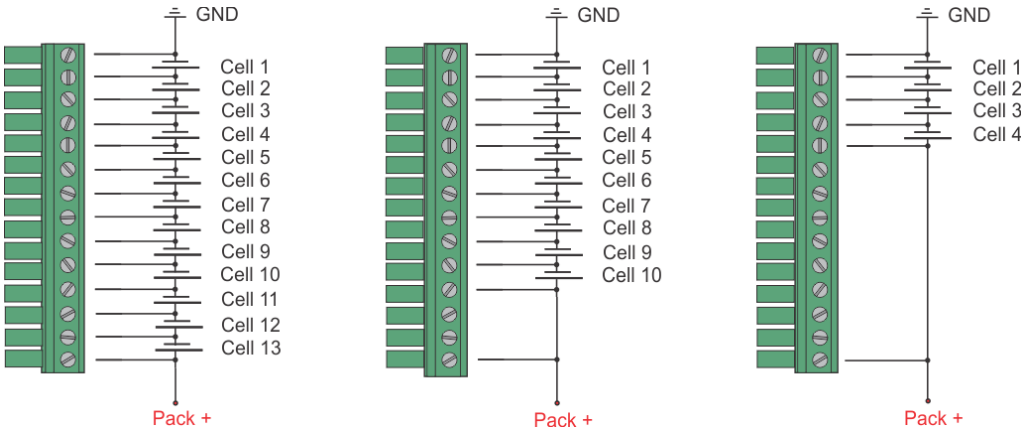

Figure 6: Slave unit power supply.

Slave Unit is always supplied from the 13-th cell connection. **! When less than 13 cells are used in the battery pack, an additional wire with Pack + voltage should be connected to the cell 13 connector!**

If multiple Slave Units are used in series, care should be taken how to connect each. Two separate wires should be wired to the same cell: first wire for the lower Slave Unit as the end-cell voltage potential, and second wire as GND potential for the higher Slave Unit. See Fig. 7 ! **Do not bypass the higher cell!**

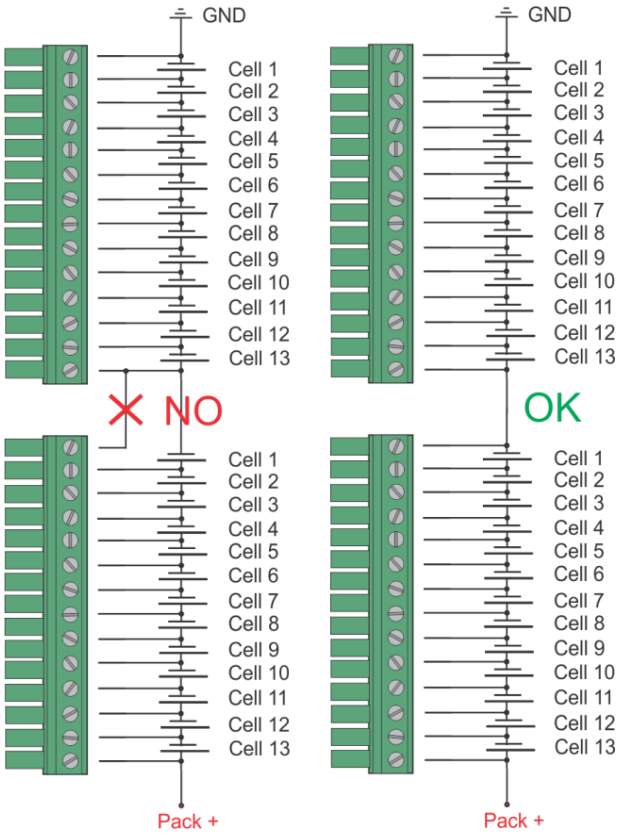

Figure 6: Multiple Slave Units for series cell connection.

Slave Unit Connection Instructions:

Connect the Slave Unit to the system by the following order described in Fig. 8. It is important to disable all the BMS functions by turning enable switch OFF before plugging any connectors. **All cells should be connected second to last and simultaneously**. When all the system components are plugged in, the enable switch can be turned ON and the Slave Unit starts the test procedure.

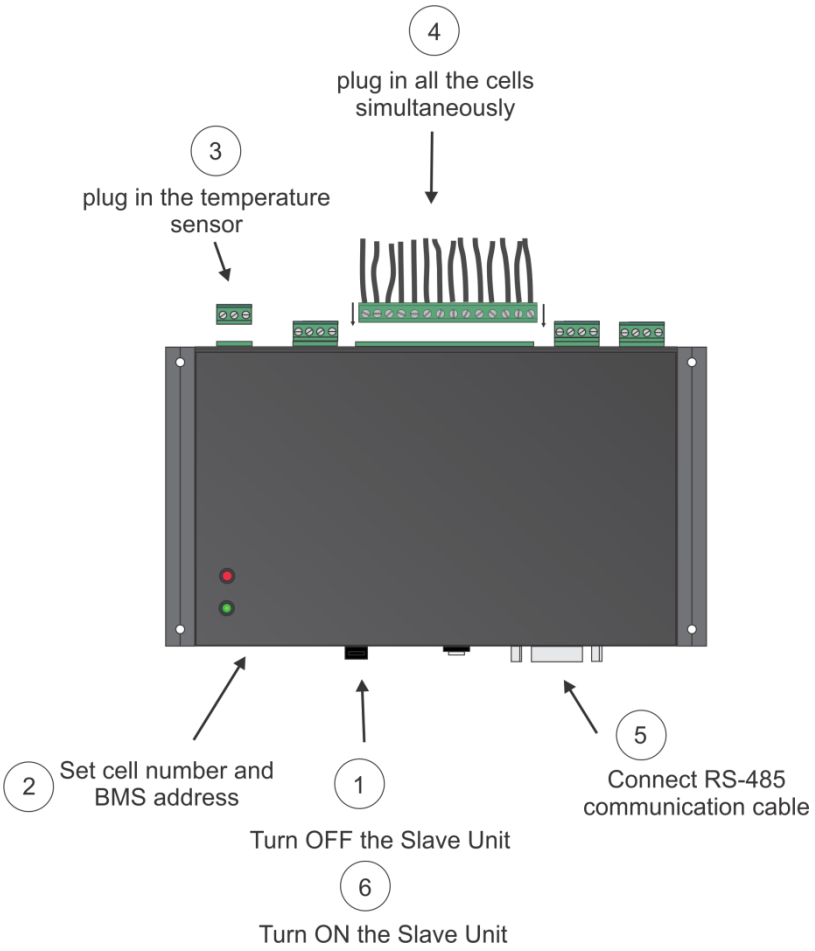

Figure 8: BMS connection order.

When disconnecting the Slave Unit from the battery pack, the procedure should be followed in reverse order.

Slave Unit Test procedure:

When the Slave Unit is turned ON it commences the test procedure. Red error LED turns on to signal the system's test procedure. The procedure starts by testing Slave Unit balancing switches. The test completes in 12 seconds, red LED turns off and the Slave Unit starts working in normal mode. Slave Unit goes to idle mode to conserve power consumption and waits for the Master Unit instructions.

Slave Unit LED indication:

While the Slave Unit measures the cell voltage, current, cell temperature and BMS temperature Power LED (green) is turned on at each Slave module simultaneously. Error LED (red) is turned on in case of system error.

Master Unit:

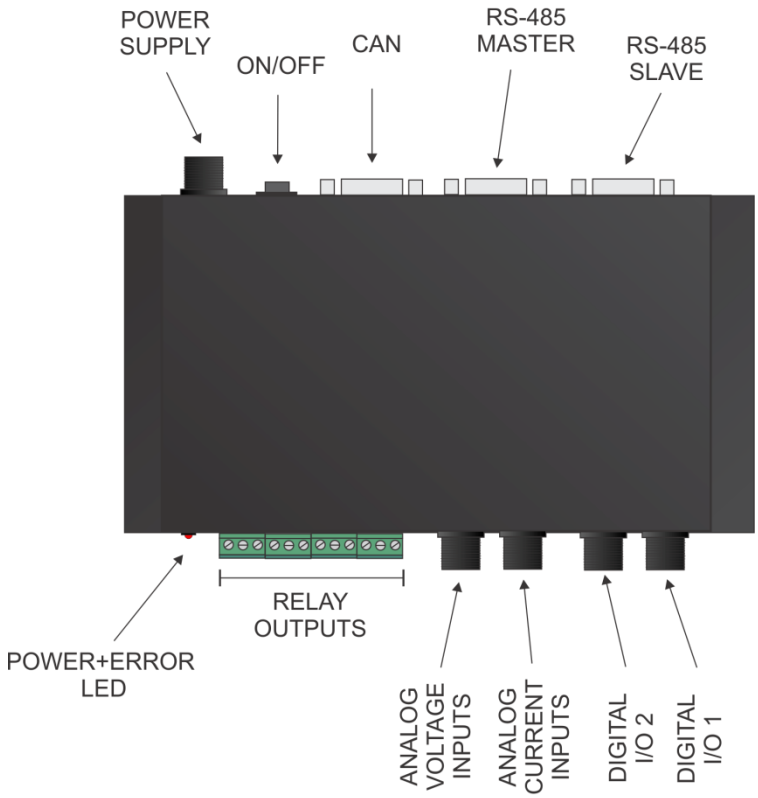

Figure 9: Master Unit function overview.

Table 3: Digital I/O 1.

Pin	I/O	Connection	DESCRIPTION
1	2	LOW SOC	Open collector output – HIGH if SOC<30 %
2	1	AGND	AGND output
3	1	LOW SOC	Open collector output – HIGH if SOC<40 %
4	2	AGND	AGND output

Table 4: Digital I/O 2.

Pin	I/O	Connection	DESCRIPTION
1	4	High cell temperature	Open collector output – HIGH if Cell temperature>55°C
2	3	-	Internal buzzer
3	3	-	
4	4	AGND	AGND output

Digital outputs use Darlington optocouplers and reverse protection Schottky diode. Signal can be pulled down up to 0.95V.

Table 5: Analog current measurement connections.

Pin	Connection	DESCRIPTION
1	Shunt +	Shunt positive
2	Shunt -	Shunt negative
3	-	(+5 V optinal for Hall sensor)
4	Shield and Shunt +	Shield + AGND from Shunt +

Table 6: Analog voltage measurement connections (optional-not programmed).

Pin	Connection	DESCRIPTION
1	Vin 2 +	On-board voltage positive
2	Vin 1 -	System voltage negative
3	Vin 1 +	System voltage positive
4	Vin 2 -	On-board voltage negative

Table 7: Relay Outputs (other relays functions are enabled by additional software).

Pin	Connection	Polarity	Protection
1	Main Contactor Control	NO	
2	Main Contactor Control	Signal	Fuse 2A Slow
3	-	NC	
4	Inverter Control	NO	
5	Inverter Control	Signal	Fuse 2A Slow
6	-	NC	
7	Cooling Fan Control	NO	
8	Cooling Fan Control -	Signal	Fuse 2A Slow
9	-	NC	
10	Heating Control	NO	
11	Heating Control	Signal	Fuse 2A Slow
12	-	NC	

Power Supply:

Connect the power supply at the back side of the Master Unit. Supply voltage is limited to 10.5 – 15 V DC by internal protection circuit. Power consumption differs according to the switched on relays or I/O. If no relay is turned on, the BMS Master Unit consumes about 300 mW of power @ 12 V. Power supply entry is isolated from the rest of the circuit by internal isolative DC-DC converter.

Figure 7: Master Unit back plate power supply pins.

Table 8: Master Unit power supply connections.

Pin	Connection	Protection
1	GND	
2	+ 12 DC (10.5 – 15 V)	Under-voltage/overvoltage + over-current protection

Master Unit Shunt Connection:

A low-side shunt resistor current measurement is used. A 4-wire Kelvin connection is used to measure the voltage drop. As short as possible **shielded cable** should be used to connect the power shunt and BMS. The battery pack current is measured every second. A high precision ADC is used to filter out the current spikes. The first current measurement is timed at the beginning of the cell measurement procedure for a proper internal DC resistance calculation. Shunt connection is shown in Fig. 10.

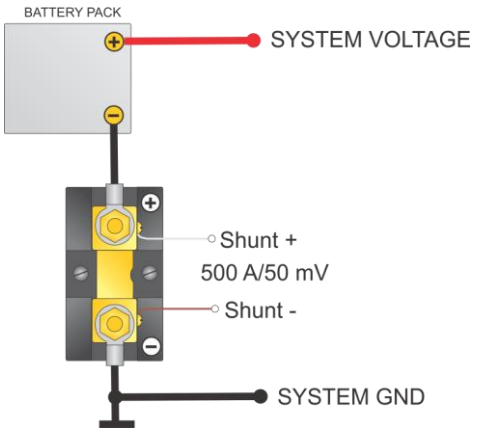

Figure 10: Shunt resistor connection.

Table 9: Current measurement connections.

Connector	Connection
1	Shunt +
2	Shunt + and shield
3	Shunt -

Shunt + voltage determines BMS Master ground potential. Since the Master Slave RS-485 communication signals use the same ground potential it is important to make the smallest possible loop. **Put the cables of the shunt and first BMS Slave's communication as close as possible.**

Voltage-to-current Coefficient:

Different size and resistance shunts can be used, since the voltage-to-current coefficient can be changed in the BMS Control software as 'I','R','E','F',' ','xxxxx'

Current is calculated by the voltage drop at the shunt resistor. 1 LSB of the 18 bit ADC represents different current values according to the shunt resistance. The LSB coefficient can be calculated as $k_{LSB}=I_{CURRENT}/U_{DROP}$, where the U_{DROP} represents the voltage drop on shunt resistor at current $I_{CURRENT}$.

ADC has a pre-set gain of 8. With a maximum input voltage difference of 0.256 V.

Master Unit Analog Voltage Inputs:

Master Unit has two separate analog voltage inputs that are able to measure up to maximum 450 V DC each. Input voltages are subtracted and translated to circuit ground. Input impedance toward the internal ground is 1 MOhm at both poles. Signal is filtered by low-pass filter (-3dB @ 0.6 Hz).

Battery Pack SOC Determination:

SOC is determined by integrating the charge in-to or out of the battery pack. Different Li-ion chemistries may be selected:

Table 10: Programmed Chemistry types.

Number	Type
1	Li-Po High power
2	Li-Po High capacity
3	Winston/Thunder-Sky/GWL
4	A123

Temperature and power correction coefficient are taken into consideration at the SOC calculation. Li-Po chemistry algorithms have an additional voltage to SOC regulation loop inside the algorithm. Actual cell capacity is recalculated by the number of the charging cycles as pointed out in the manufacturer's datasheet.

SOC is reset to 100% at the end of charging and Power LED turns ON until charger hysteresis is present.

System Error Indication:

System errors are indicated with red error LED by the number of ON blinks, followed by a longer OFF state. Red LED switch-off indicator turns on in case of:

Table 11: System error description.

Number of ON blinks	ERROR	BMS	TO-DO
1	Single or multiple cell voltage is too high (cell over voltage switch-off).	BMS will try to balance down the problematic cell/cells to safe voltage level (2 s error hysteresis cell over voltage switch-off hysteresis). Main contactor is connected, charger is disabled.	• Wait until the BMS does its job.
2	Single or multiple cell voltage is too low (cell under voltage protection switch-off).	BMS will try to charge the battery (2 s error hysteresis + cell under voltage hysteresis is applied). Main contactor is disconnected, charger is enabled.	• Plug in the charger.
3	Cell voltages differs more than allowed (cells differ more than set).	Main contactor is connected, charger is enabled.	
4	Cell temperature is too high (over temperature switch-off).	Cells temperature or cell inter-connecting cable temperature in the battery pack is/are too high. Main contactor is disconnected, charger is disabled.	• Examine the battery pack if this occurs frequently.
5	BMS temperature is too high (BMS over temperature switch-off).	Due to extensive cell balancing the BMS temperature rose over upper limit (2 s error hysteresis + 5 °C temperature hysteresis). Main contactor is connected charger is disabled.	• Wait until the BMS cools down.
6	Number of cells, address is not set properly.	Number of cells at the back of the Slave Unit was changed from the default manufacturer settings. Main contactor is disconnected charger is disabled.	• Set the proper number of cells, address.

7	The temperature is too low for charging (under temperature charging disable).	If cells are charged at temperatures lower than operating temperature range, cells are aging much faster than they normally would, so charging is disabled. (2 °C temperature hysteresis). Main contactor is connected, charger is disabled.	• Wait until the battery's temperature rises to usable range.
8	Temperature sensor error.	Temperature sensor is un-plugged or not working properly. Main contactor is disconnected, charger is disabled.	• Turn-off the Master and Slaves Units by enable switch and try to re-plug the temperature sensor connector. Turn Slave Unit back ON and restart the Master Unit. If the BMS still signals error 8, contact the service. The temperature sensors should be replaced.
9	Communication error.	Main contactor is disconnected, charger is disabled.	• Turn OFF Master and all Slave Units. Turn ON Slave Units and Master Unit. • Check the Master –Slave connection cable + remote ON/OFF cable • Check the Slave Unit voltage (is it below set threshold voltage) • If the error repeats, contact the service.
10	Cell in short circuit or BMS measurement error.	Single or multiple cell voltage is close to zero or out of range, indicating short circuit, blown balance fuse or measuring failure. Main contactor is disconnected, charger is disabled.	• Restart the Slave and Master Unit. • Check the cells connection to the BMS Slave Units. • If the same error starts to signal again contact the service.
11	Tyco main relay is in short circuit.	If the main relay should be opened and current is not zero or positive the BMS signals error 11. When the error is detected, the BMS tries to un-shorten the main relay by turning it ON and OFF for three times. Main contactor is disconnected charger is disabled.	• Restart the Master Unit
12	Error measuring current.	Current sensor is disconnected or not working properly. Main contactor is disconnected, charger is disabled.	• Turn-off the BMS by enable switch and try to re-plug the current sensor connector. Turn BMS back ON. If the BMS still signals error 12, contact the service.
13	Wrong cell chemistry selected.		• Use PC interface to set proper cell chemistry

RS-485 Communication Protocol:

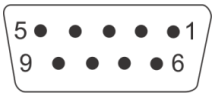

Figure 12: RS-485 DB9 male connector front view.

Table 12: RS-485 DB-9 connections.

Pin	Designator
1	-
2	A + 1200 Ohm termination (both ends)
3	B + 1200 Ohm termination (both ends)
4	AGND
5	-
6	-
7	-
8	-
9	+5 V

BMS Unit is programmed as a Slave Unit and responds only when asked. Galvanically isolated RS-485 (EN 61558-1, EN 61558-2) serves for logging and changing BMS parameters. Dedicated PC software BMS Master control or another RS-485 device may be used for the communication.

Messages are comprised as follows:

- STX, DA, SA, N, INSTRUCTION- 4 bytes,16-bit CRC, ETX
- STX start transmition <0x55> (always)
- DA - destination address <0x01> to <0x10> (set as 6)
- SA - sender address <0x00> (always 0)
- N – number of sent bytes
- INSTRUCTION 4 bytes for example.: 'L','C','D','1','?', - (combined from 4 ASCII characters, followed by '?', if we would like to receive the current parameter value or ' ','xx.xx' value if we want to set a new value
- 16-bit CRC, for the whole message except STX in ETX
- ETX- end transmition <0xAA> (always)

Dataflow:

- Bit rate: 56k
- Data bits: 8
- Stop bits: 1
- Parity: None
- Mode: Asynchronous

Table 13: **RS-485 instructions description.**

INSTRUCTION	DESCRIPTION	BMS ANSWER
'*','I','D','N','?'	Identification	Answer "REC - BATERY MANAGEMENT SYSTEM"
'L','C','D','1','?'	Main data	Returns 7 float values LCD1 [0] = min cell voltage, LCD1 [1] = max cell voltage, LCD1 [2] = current, LCD1 [3] = max temperature, LCD1 [4] = pack voltage, LCD1 [5] = SOC (state of charge) interval 0-1 -> 1=100% and LCD1 [6] = SOH (state of health) interval 0-1 -> 1=100%
'C','E','L','L','?'	Cell voltages	BMS first responds with how many BMS units are connected, then it sends the values of the cells in float format
'P','T','E','M','?'	Cell temperatures	BMS first responds with how many BMS units are connected then it sends the values of the temperature sensors in float format
'R','I','N','T','?'	Cells internal DC resistance	BMS first responds with how many BMS units are connected then it sends the values in float format
'B','T','E','M','?'	BMS temperature	BMS first responds with value 1, then it sends the values of the BMS temperature sensor in float format
'E','R','R','O','?'	Error	Responds with 4 bytes as follows ERRO [0] = 0 – no error, 1 – error ERRO [1] = BMS unit ERRO [2] = error number (1-13) in ERRO [3] = number of the cell, temp. sensor where the error occurred
'B','V','O','L', '?'/ 'B','V','O','L', ' ','xxx'	Cell END balancing	Returns float voltage [V]
'C','M','A','X','?'/ 'C','M','A','X',' ','xxx'	Max allowed cell voltage	Returns float voltage [V]
'M','A','X','H', '?'/ 'M','A','X','H', ' ','xxx'	Max allowed cell voltage hysteresis	Returns float voltage [V]
'C','M','I','N', '?'/ 'C','M','I','N', ' ','xxx'	Min allowed cell voltage	Returns float voltage [V]
'M','I','N','H', '?'/ 'M','I','N','H', ' ','xxx'	Min allowed cell voltage hysteresis	Returns float voltage [V]
'T','M','A','X', '?'/ 'T','M','A','X', ' ','xxx'	Maximum allowed cell temperature	Returns float temperature [°C]
'T','M','I','N', '?'/ 'T','M','I','N', ' ','xxx'	Minimum allowed temperature for charging	Returns float temperature [°C]
'B','M','I','N', '?'/ 'B','M','I','N', ' ','xxx'	Balancing START voltage	Returns float voltage [V]
'C','H','A','R', '?'/ 'C','H','A','R', ' ','xxx'	End of charging voltage per cell	Returns float voltage [V]
'C','H','I','S', '?'/ 'C','H','I','S', ' ','xxx'	End of charging voltage hysteresis per cell	Returns float voltage [V]
'I','O','F','F','?'/ 'I','O','F','F',' ','xxx'	Current measurement zero offset	Returns float current [A]
'T','B','A','L','?'/ 'T','B','A','L',' ','xxx'	Max allowed BMS temperature	Returns float temperature [°C]

'B','M','T','H','?'/ 'B','M','T','H',' ','xxx'	Max allowed BMS temperature hysteresis	Returns float temperature [°C]
'V','M','A','X','?'/ 'V','M','A','X',' ','xxx'	Number of exceeded values of CMAX	Returns integer value
'V','M','I','N','?'/ 'V','M','I','N',' ','xxx'	Number of exceeded values of CMIN	Returns integer value
'T','H','I','S','?'/ 'T','H','I','S',' ','xxx'	Number of exceeded values of TMAX	Returns integer value
'C','Y','C','L','?'/ 'C','Y','C','L',' ','xxx'	Number of battery pack cycles	Returns integer value
'C','A','P','A','?'/ 'C','A','P','A',' ','xxx'	Battery pack capacity	Returns float capacity [Ah]
'I','O','J','A','?'/ 'I','O','J','A',' ','xxx'	Voltage to current coefficient	Returns float value
'R','A','Z','L','?'/ 'R','A','Z','L',' ','xxx'	Package cell difference	Returns float voltage [V]
'C','H','E','M', '?'/ 'C','H','E','M', ' ','xxx'	Li-ion chemistry	Returns unsigned char value
'P','A','R','V', '?'/ 'P','A','R','V',' ','xxx'	Number of parallel branches	Returns unsigned char value
'O','P','1','L','?'/ 'O','P','1','L',' ','xxx'	Optocoupler 1 SOC level	Returns float value [0,1]
'O','P','2','L','?'/ 'O','P','2','L',' ','xxx'	Optocoupler 2 SOC level	Returns float value [0,1]
'O','P','4','L','?'/ 'O','P','4','L',' ','xxx'	Optocoupler 2 max cell temperature	Returns float temperature [°C]
'R','E','2','L','?'/ 'R','E','2','L',' ','xxx'	Relay 2 SOC inverter control	Returns float value [0,1]
'R','E','2','H','?'/ 'R','E','2','H',' ','xxx'	Relay 2 SOC inverter control hysteresis	Returns float value [0,1]
'R','E','3','L','?'/ 'R','E','3','L',' ','xxx'	Relay 3 cell temperature cooling control	Returns float temperature [°C]
'R','E','3','H','?'/ 'R','E','3','H',' ','xxx'	Relay 3 cell temperature cooling control hysteresis	Returns float temperature [°C]
'R','E','4','L','?'/ 'R','E','4','L',' ','xxx'	Relay 4 cell temperature heating control	Returns float temperature [°C]
'R','E','4','H','?'/ 'R','E','4','H',' ','xxx'	Relay 4 cell temperature heating control hysteresis	Returns float temperature [°C]
'S','Y','S','V','?'	System voltage-read only	Returns float voltage [V]
'B','R','D','V','?'	On-Board voltage-read only	Returns float voltage [V]
'C','H','S','H','?'/ 'C','H','S','H',' ','xxx'	SOC charging hysteresys	Returns float value [0,1]

Parameter accepted and changed value is responded with 'OK' answer.

Example: proper byte message for 'LCD1?' instruction for BMS address 1 is:
<0x55><0x01><0x00><0x05><0x4C><0x43><0x44><0x31><0x3F><0x01><0xD9><0xAA>
RS-485 message are executed when the microprocessor is not in interrupt routine so a timeout of 350 ms should be set for the answer to arrive. If the timeout occurs, the message should be sent again.

CAN Communication Protocol:

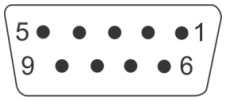

Figure 13: CAN DB9 connector front view.

Bitrate: 500 kbs
29-bit extended identifier: 0x618
8 byte message structure

Terminate the CAN line by shorting PIN 1 and 2 at the BMS Master side and add a 120 Ohm resistor across CANL and CANH at the last CAN device.

Table 14: CAN DB9 connector pin designator.

Pin	Designator
1	TERMINAL
2	CANL + TERMINAL
3	GND
4	
5	-
6	GND
7	CANH
8	-
9	

Table 15: CAN message 0x618structure description.

Byte	Description	Type	
0	State	bit	Bit 7: Enable (1)/Disable (0) Bit 6: Clear Error latch 0->1 Bit 5: Ventilation (1)/no ventilation(0) Bit 4-0: n/a
1	Max charging current high byte	signed integer	0-500, LSB….0.1 A
2	Max charging current low byte		
3	Max Charging voltage high byte	signed integer	0-10000, LSB….0.1 V
4	Max Charging voltage low byte		
5	Max charging current high byte	signed integer	0-1500, LSB….0.1 A
6	Max charging current low byte		

CAN messages are sent every 200 ms with refreshed values on 2 s.

Charging current is decreased when the first cell reaches end of charge voltage. When all the cells reach end of charge voltage, SOC is set to 100% and charging voltage + charging SOC hysteresis are set. Both values can be changed with PC user interface.

Slave Unit Dimensions:

BMS Slave Unit can be supplied without the enclosure if an application is weight or space limited. The dimensions of the BMS without the enclosure are 160 mm x 110 mm x 27 mm. A sufficient contact surface for balancing resistors should be provided. The PCB has four 3.2 mm mounting holes. The enclosure is made of black anodized aluminum.

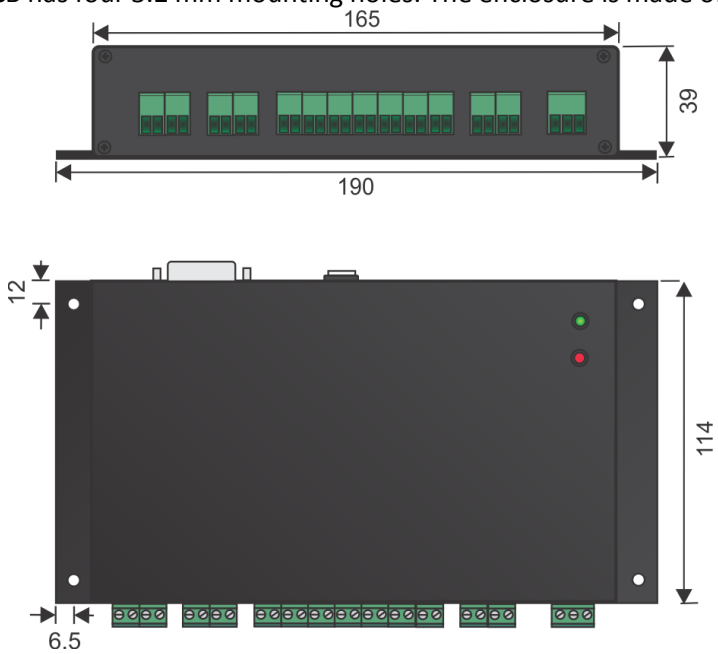

Figure 15: BMS Slave Unit dimensions.

BMS Master Unit Dimensions:

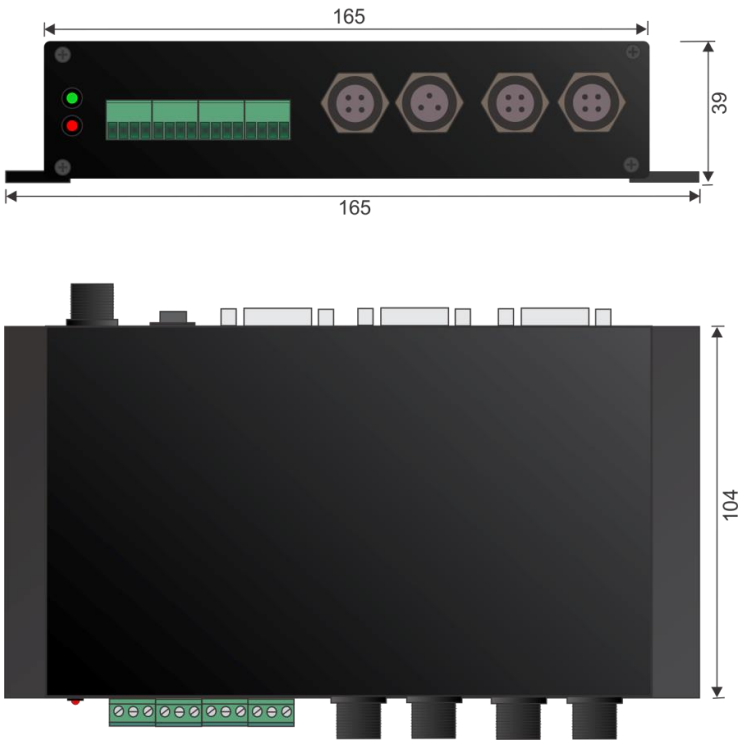

Figure 16: BMS Master Unit dimensions.