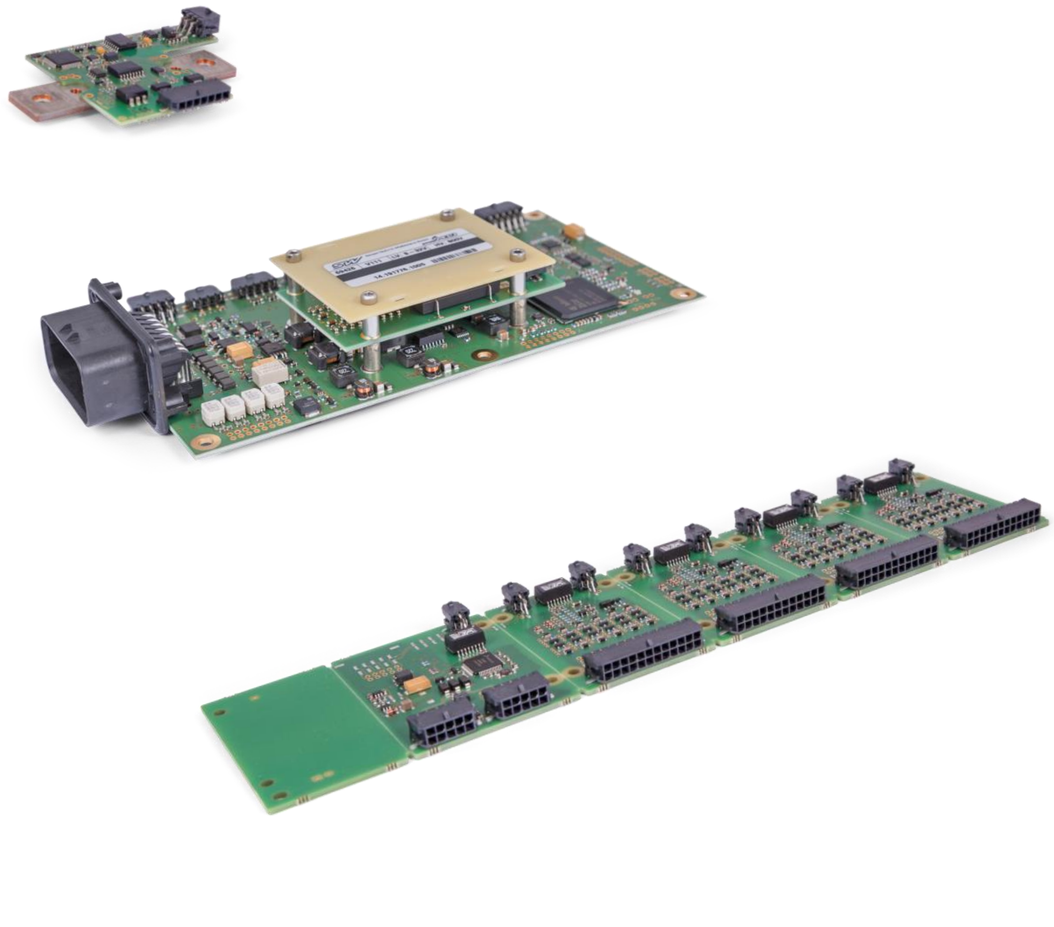
Sensor-Technik Wiedemann GmbH
Mobile Controllers and Measurement Technologies

mBMS Hardware Guide



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Document History:

Version	Date	Name	Change	Ticket
V1.2	27.07.2015	F.-J. Schuster	New PMB variants description added New BMS variants description added	15260 15261
V1.1	14.12.2015 15.12.2015 16.12.2015 21.12.2015	F.-J. Schuster	“Battery-CAN” renamed to “Sensor-CAN” Documentation standard inserted Chapter “BMS configuration” created Chapter “Interlock” created	12874 13541 12636 13526
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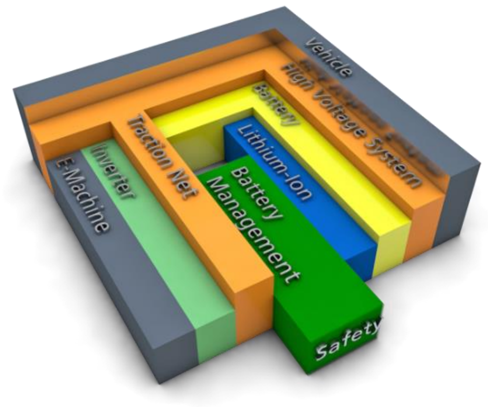
1 Copyright Notice

2 Introduction

2.1 Scope

The Battery Management System mBMS [1] is an essential part of the high voltage battery in an electric vehicle [2]. It ensures safe operation of the lithium-ion battery cells and it interacts with the vehicle's high voltage DC network (traction net) and the vehicle's bus system.



The mBMS key functions are:

- Enter Safe state by disconnecting the battery from the traction net in case of:
  - Cell Over voltage events
  - Cell Under voltage events
  - Cell Over temperature events
  - Over Current events
  - Loss of interlock signal
- Battery Health Measures:
  - Keep all cells in a balanced state
  - Prevent battery abuse
- Determination of the battery's state:
  - Self-diagnostics including insulation monitoring
  - State of Charge (SOC)
  - Inner resistance determination and prediction of deliverable power
  - Battery capacity
- Vehicle interfacing:
  - Controlled pre-charge of inverter's capacitance
  - Determination of vehicle's insulation status
  - Optional interlock signal generation
  - Communication via the ESS-CAN bus

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[1] *This document describes the 2nd generation of STW's mBMS*

[2] *The term "vehicle" is used throughout this document, although the mBMS may be part of a high voltage battery system of a non-vehicle application.*

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2.2 Documents

You can find the latest release of this document and related documents online:

- STW Cloud: https://cloud.sensor-technik.de/
- Download area on www.sensor-technik.de

Related documents include:

- mBMS Toolchain Guide
- ESS-CAN Matrix (in .dbc format and as an export in .xlsx format)
- Diagrams describing:
  - basic interconnections
  - detailed wiring and
  - Master/slave wiring
- Pin assignment of key components: BMS, PMB, CSC
- Component drawings

2.3 General Rules

This document was created to give the ambitious technician a compact set of information. Please take the time to read this issue carefully to prevent the setup from malfunction and the environment/user from harmful injuries or death.

- Building a battery system means working on voltages present.
- This should be done only by specially trained personnel.
- Even if a single cell has a low voltage, the current can be very high in short circuit condition.
- Use insulated tools.
- Pay attention towards the separation of high- and low voltage parts. For creeping and clearance, refer to related normative standards like EN 60664.
- If the component is used in a manner not specified, the protection supported by the component may be impaired.

Most components of this system are bare electronic devices without a cover. Therefore, they are sensitive to electric discharge. Personal ESD protection and an ESD protected area are necessary.

- Inverters cause high electromagnetic fields.
- Inside the housing, communication wires (CAN, CSC-Bus) should be a pair of twisted wires (at least).
- Outside the housing, use shielded wires suitable for high voltage wiring.

The pre-charge resistor, the shunt and as well the cell sensor circuit might get hot during operation.

3 Overview

3.1 Topologies

Lithium-ion batteries are the preferred energy storage system (ESS) for modern electric drive systems. The mBMS permits safe operation of lithium-ion batteries up to 800 volts.

The mBMS supports various ESS topologies – single battery systems as well as multi battery systems for larger installations.

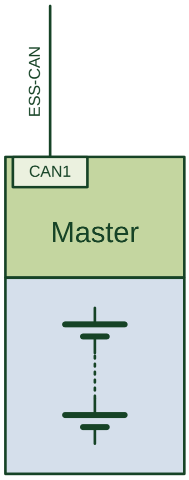


Figure 1 – single battery topology

The single battery approach (standalone) is the most common system topology consisting of one serially connected string of battery cells. A stack comprises one or more cell modules with cell sensor circuits (CSC), a single current sensor (PMB), a single main supervisor (BMS) and a pair of main switches.

For an ESS with a high demand for energy, power, availability or maintainability, it may be more appropriate to connect multiple batteries in a parallel topology.

See chapter 5 for further information.

3.2 Key components

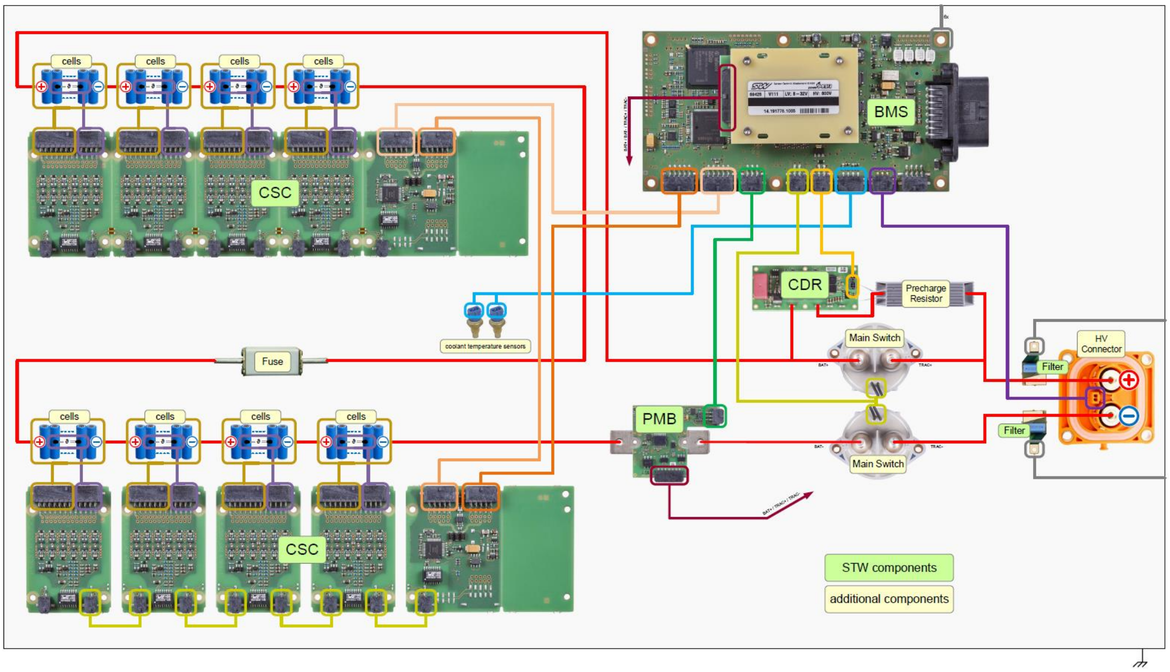


Figure 2 – Connection overview

Figure 2 shows the devices for a battery management system and their interconnection. This diagram can be found as a separate file in a larger format and higher resolution. The key components (marked green) can only be purchased from STW. The additional components (marked yellow) may be obtained from 3rd parties.

3.2.1 BMS – Battery Main Supervisor

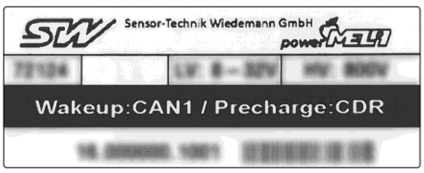
The BMS is the main device of the battery system. It contains three controllers for a maximum of reliability and safety. It collects all information from its sensors, determines the state of the battery system and decides whether main switches are allowed to be close or need to be opened. An insulation measurement device may be installed as a piggy-pack to the BMS.

It´s very important for the function of the insulation measurement device that the mounting hole of the BMS is connected to the chassis of the system (car body, system rack, etc.) in a low impedance way.

There are four hardware variants of the BMS.

- CAN Wakeup or KL15 Wakeup (Imprint on nameplate: CAN1 or KL15)
- Precharge with Relay or with CDR-Module (Imprint on nameplate: RELAY or CDR)

Exemplary imprint on the nameplate:



3.2.2 PMB – Power Measurement Board / current sensor

The PMB measures the current (shunt resistor) which flows in or out of the battery, the voltage value of the battery stack and the traction net. The PMB is equipped with a unique redundant safety circuit which enables the PMB to directly signal a current limit violation.

Do not mount the shunt on conductive surfaces/materials.

Choose the mounting position of the shunt carefully because it´s getting hot during operation at high currents. The dissipated power is $P_D = I^2 * 100\mu\Omega$.

There are two hardware variants of the PMB: PMB1000 and PMB2000.
The PMB2000 is designed for higher currents than the PMB1000. For details, see the chapter Technical Data.
Exemplary imprint on the nameplate:

3.2.3 CSC – Cell Sensor Circuit

The CSC is directly contacted to the cells of the battery. It measures the cell voltages and temperatures and converts this data in a way suitable for the BMS. Each CSC is equipped with a passive discharge path for balancing the charges of the battery cells.

- While balancing, the CSC is getting hot.
- To prevent overheating, the CSC will reduce the balancing current

3.2.4 Filter

Optional filter devices reduce the electrical noise originating from the power converters on the traction net. They include special Y-Capacitors for EMC suppression.

- Filters should be mounted directly on the battery output (near HV connector).
- Filters have to be connected with low impedance (short wires) to chassis ground.

3.3 Additional components

3.3.1 Main switches

The main switches are connecting and disconnecting the power source or load to/from the battery. They must be able to interrupt the flowing current in short circuit situation to prevent uncontrollable situations.

It´s important to use the correct fixing torques at the contacts to ensure good connection and low connecting resistances. For the EV200 the torque should be 10Nm. Refer to the owner's manual if different main switches are used.

The BMS supports main switches with 12V or 24V coils as well as types without internal power reduction (economizer). Please keep in mind that the BMS has to be provided at least with the lowest voltage level the main switches require for closing.

The main switches shall be selected in accordance with the maximum system voltage, the maximum short circuit current as well as the number of cycles the main switch can do in these situations.

3.3.2 CDR – Pre-charge Module

The CDR pre-/dis-charge module may be used as an alternative solution for pre-charging traction net capacitors usually included in inverters. It is able to provide an economic replacement of a mechanical pre-charge relay (up to 800 V). The CDR combines a small mechanical relay with a semiconductor device.

3.3.3 Pre-charge relay

The pre-charge relay bypasses the positive main switch with a resistor. This is to prevent high current flows into the traction net capacity.

The pre-charge relay has to fit to the maximum pre-charge current (limited by the pre-charge resistor) and the system voltage.

Attention: When using the CDR, a special variant of the BMS (Battery Main Supervisor) has to be used.

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3.3.4 Pre-charge resistor

The pre-charge resistor has to limit the current rushing into the traction net capacitor. It must be ensured that the resistance is capable to handle the impulse energy which occurs during pre-charging. Use special “braking resistors” with high impulse energy capability.

The suitable resistance value “R” depends on the traction net capacity “C”, the pre-charge time “t”, the maximum allowed current “I_{Short}” as well as on the maximum system voltage “U”. The value “ΔU” is the voltage difference between the traction net voltage and the system voltage “U” after pre-charge time “t”.

$$R = -\frac{t}{C * \ln\left(\frac{\Delta U}{U}\right)}$$

The current I_{Short} has to be within the switching capability of the pre-charge relay.

$$I_{Short} = \frac{U}{R}$$

The impulse energy “E” for the resistor to dissipate is calculated with

$$E = \frac{1}{2} * C * U^2$$

- The pre-charge resistor gets hot during the pre-charge process.
- After one pre-charge cycle, the resistor needs a time-interval sufficiently for cooling down.
- The pre-charge resistor has to be mounted on a heat dissipation surface.
- The BMS dynamically manages the pre-charge process in order to prevent overheating.

3.3.5 HV connector

This connector is the Interface to the traction net. The HV connector may include additional contacts carrying an interlock signal.

3.3.6 Temperature sensor

The two temperature sensor inputs are intended to measure the coolant temperature. The internal look up table is configured for an NTC type with 10 kΩ and the characteristic EPCOS 8016. If you use a different type, the look up table has to be adapted to the sensor used. The adaptions necessary on mBMS side are subject to a customer specific development. Please call STW for a commercial offer.

The used temperature sensors (10 kΩ NTC, characteristic 8016) must be electrically isolated types.

3.3.7 Fuse / Service-Disconnect

Pay attention to the following items for the selection of the fuse:

- Maximum system voltage (DC voltage)
- Maximum operating current
- Temperature derating
- Short circuit current (even at low cell temperatures)
- Time / current characteristics
- Power switching rating of the main switches (if necessary, the main contactor must not open before the fuse has tripped)

It is recommended to install the fuse / service-disconnect in the electrical middle of the battery in order to split the voltage of the battery in half in case of emergency.

> The fuse / service-disconnect must not be located between cells measured by the same CSC measurement module.

4 Mounting and wiring

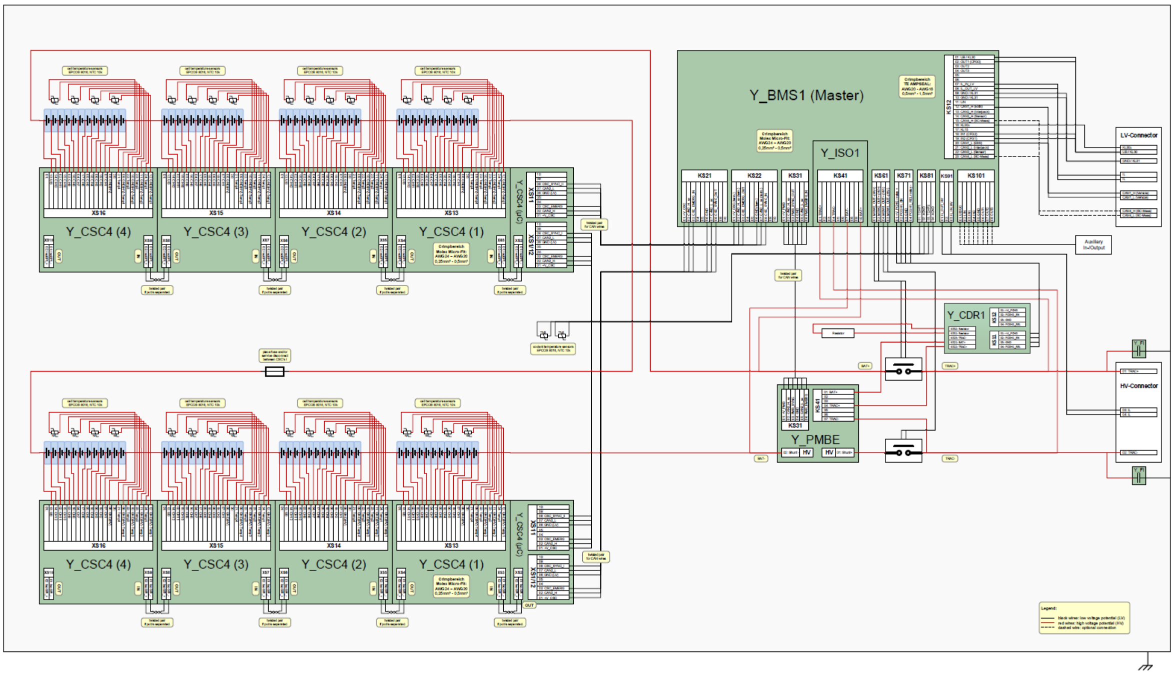

Figure 3 – Wiring diagram

Figure 3 shows the detailed interconnection of the devices. This diagram can be found as a separate file in a larger format and higher resolution.

4.1 Mounting electronic components

Device	Fixing material
BMS	M4 screws
CSC	M3 plastic screws or rivets [3]
PMB	Mounted on main switch or bus bar

The maximum torque for the plastic screws used for the CSC fixation depends on the type of screw used. Refer to the manufacturer's datasheet.

In applications exposed to vibrations, it is highly recommended to use all fixation holes of the PCBs and to apply additional fixations of the cables close to the PCB plug.

[3] *It is required to use isolated fixing materials like plastic screws, washers and mothers or plastic rivets. See chapter 3.3 for further information.*

4.2 Wire dimensions

Type of connector	Wire gauge	
Micro-Fit	AWG24 – AWG20	0.205 mm² – 0.51mm²
AMPSEAL	AWG20 – AWG16 [4]	0.51 mm² – 1.31mm²

In order to make correct crimp contacts, it is highly recommended to use the crimp tools recommended by the supplier. Use double isolated wires for safety reasons, conducting material between high voltage and low voltage needs a reinforced insulation. For wiring this can be realized with an additional tube. Figure 4 shows how this looks like. See chapter 4.3 for further information.

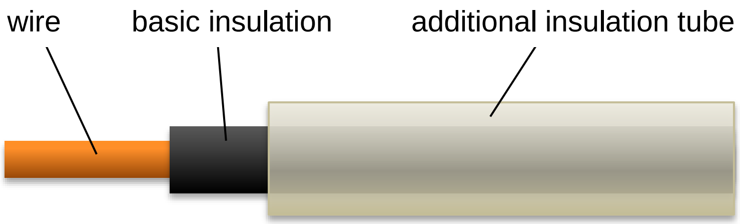

Figure 4 – reinforced insulation of wiring

4.3 Insulation coordination

The components are designed for safe separation between low voltage and high voltage potentials. The design follows pollution degree 2 according to EN60664.
The following tables shows the creeping and clearance distances between low voltage and high voltage potentials according to EN60664 for a withstand voltage of 2.4 kV and a battery voltage of maximal 800 V.

4.3.1 Clearance distances

Insulation	Clearance distances [5]	Clearance distances (for 5000 m above sea level) [6]
Basic insulation HV – HV	≥ 1.5 mm (59 mil)	≥ 2.25 mm (89 mil)
Reinforced insulation LV – HV	≥ 3.0 mm (118 mil)	≥ 4.5 mm (177 mil)

[4] To reduce power dissipation on the supply lines, biggest possible wire dimensions are recommended.
[5] see EN 60664-1 table F.2
[6] correction factor 1.48, see EN 60664-1 table A.2

4.3.2 Creeping distances

Insulation	Creeping distances for printed wiring material	Creeping distances		
	All material groups except IIIb CTI ≥ 175	Material group I CTI ≥ 600	Material group II 400 ≤ CTI < 600	Material group III 100 ≤ CTI < 400
Basic insulation HV – HV	≥ 4.0 mm (157 mil)	≥ 4.0 mm	≥ 5.6 mm	≥ 8.0 mm
Reinforced insulation LV – HV	≥ 8.0 mm (315 mil)	≥ 8.0 mm	≥ 11.2 mm	≥ 16.0 mm

The exact values have to be taken from the normative standards and depend on the material used.

4.4 Achieving EMC compliance

Please follow these rules:

- Wires should be as short as possible.
- Housing of battery, inverter and engine must be connected with low impedance.
- Backward/forward lines forming electrical loops shall be installed close together.
- Filters as shown below should be mounted at the poles of the traction net connector inside the battery housing.
- Traction net and communication lines should be shielded and separated by at least 100 mm.
- Shielding should be connected with respect to low impedance.
- Installation of unused CAN wires (for example diagnosis buses) should be avoided or terminated (stubs). See chapter 4.8 CAN-Interfacing.

4.5 BMS configuration

As already mentioned the mBMS supports various ESS topologies – single battery systems as well as multi battery systems for larger installations (see chapter 5 for further information).

Therefore, the role of the BMS has to be defined within the mBMS network. This is done by cable configuration in the low voltage interconnection.

The network address is determined by the state of the following pins.
For detailed description, see document “mBMS2 master slave wiring.pdf”.

Configuration	IN1 (CFG2)	IN2 (CFG1)	OUT1 (CFG0)
Master	UB	UB	UB
Slave 1	UB	UB	GND
Slave 2	UB	GND	UB
Slave 3	UB	GND	GND
Slave 4	GND	UB	UB
Slave 5	GND	UB	GND
Slave 6	GND	GND	UB
Slave 7	GND	GND	GND

The BMS within a single battery system network should be configured as Master.

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4.6 CSC configuration

4.6.1 Configuration rules

The CSC is able to sense and balance a maximum of 48 cells. Each CSC has up to four measurement modules with each module being able to sense up to twelve cell voltages and up to four cell temperatures.

The CSC may be configured in various ways according to these rules:

§1 The consecutive numbering of the cells, used in the application software, starts at the first connected CSC on the lowest cell. Nevertheless, different numbering is possible, but is not very practical in view of servicing.
§2 Each module can measure up to twelve cells and four temperatures.
§3 Unused cell inputs should be connected to the highest voltage on the module or left open. It is recommended, to connect them to the highest module voltage for EMI reasons.
§4 The minimum voltage per module (pin 8 to pin 13) must be in any case higher than 11 V.
§5 Unused modules can be left unconnected or can be removed.
§6 A module can be used as a single temperature measuring module without sensing cell voltages, if the module is powered from the related cells on which the temperature should be measured (pin 8 and pin 13 (U = 11 V … 55 V)). These temperature sensors are “grounded” to pin 8 of the module. With one CSC, a maximum of 16 cell temperatures can be measured.
§7 In order to adapt to geometrical restrictions or in order to optimize wiring, a CSC may be split mechanically into four separate modules and a controller board. The separation needs to be prepared and carried out by STW. The bus connections among the separated boards need to be carried out with twisted pair wires.
§8 The free PCB area next to the controller board in connection with the controller board itself, have the same dimension as two CSC modules. Therefore it is easily possible to build vertical stacks of PCBs. For this mechanical variant, non-conductive spacers have to be used.

It is recommended to establish the cell connections to the CSC module sequentially, beginning with lowest cell potential - the minus pole of the stack.

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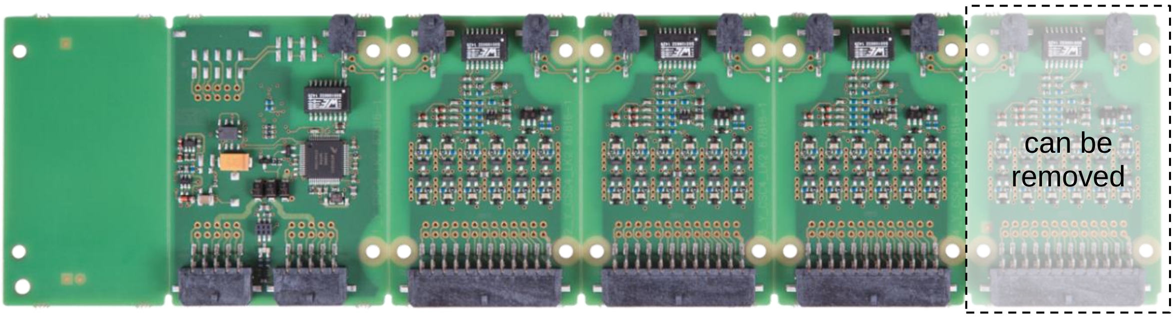
4.6.2 Example 1

CSC board has to sense 36 cells

Related rules: §2, §5

⇨ For 36 cells, use the first three measuring modules on the CSC and leave the last one unconnected.



12 cells

Pin	Signal Name	Cell connection
1	--	n. c.
2	CH11	Cell 11+
3	CH9	Cell 9+
4	CH7	Cell 7+
5	CH5	Cell 5+
6	CH3	Cell 3+
7	CH1	Cell 1+
8	GND	Cell 1-
9	GND T4	
10	GND T3	
11	GND T2	
12	GND T1	
13	UB	Cell 12+
14	CH12	Cell 12+
15	CH10	Cell 10+
16	CH8	Cell 8+
17	CH6	Cell 6+
18	CH4	Cell 4+
19	CH2	Cell 2+
20	--	n. c.
21	Temp 4	
22	Temp 3	
23	Temp 2	
24	Temp 1	

12 cells

Pin	Signal Name	Cell connection
1	--	n. c.
2	CH11	Cell 23+
3	CH9	Cell 21+
4	CH7	Cell 19+
5	CH5	Cell 17+
6	CH3	Cell 15+
7	CH1	Cell 13+
8	GND	Cell 13-
9	GND T4	
10	GND T3	
11	GND T2	
12	GND T1	
13	UB	Cell 24+
14	CH12	Cell 24+
15	CH10	Cell 22+
16	CH8	Cell 20+
17	CH6	Cell 18+
18	CH4	Cell 16+
19	CH2	Cell 14+
20	--	n. c.
21	Temp 4	
22	Temp 3	
23	Temp 2	
24	Temp 1	

12 cells

Pin	Signal Name	Cell connection
1	--	n. c.
2	CH11	Cell 35+
3	CH9	Cell 33+
4	CH7	Cell 31+
5	CH5	Cell 29+
6	CH3	Cell 27+
7	CH1	Cell 25+
8	GND	Cell 25-
9	GND T4	
10	GND T3	
11	GND T2	
12	GND T1	
13	UB	Cell 36+
14	CH12	Cell 36+
15	CH10	Cell 34+
16	CH8	Cell 32+
17	CH6	Cell 30+
18	CH4	Cell 28+
19	CH2	Cell 26+
20	--	n. c.
21	Temp 4	
22	Temp 3	
23	Temp 2	
24	Temp 1	

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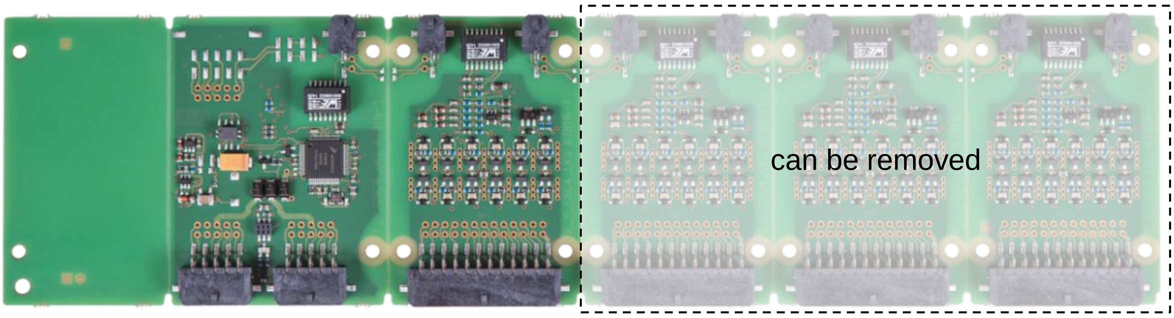
4.6.3 Example 2

CSC has to sense 7 cells

Related rules: §2, §3, §5

⇨ It is recommended to connect the unused cell voltage inputs of the CSC and the “UB”-Input. The UB connection has to be connected to the highest voltage of the module, here Cell 7+.



7 cells

Pin	Signal Name	Cell connection
1	--	
2	CH11	Cell 7+
3	CH9	Cell 7+
4	CH7	Cell 7+
5	CH5	Cell 5+
6	CH3	Cell 3+
7	CH1	Cell 1+
8	GND	Cell 1-
9	GND T4	
10	GND T3	
11	GND T2	
12	GND T1	
13	UB	Cell 7+
14	CH12	Cell 7+
15	CH10	Cell 7+
16	CH8	Cell 7+
17	CH6	Cell 6+
18	CH4	Cell 4+
19	CH2	Cell 2+
20	--	
21	Temp 4	
22	Temp 3	
23	Temp 2	
24	Temp 1	

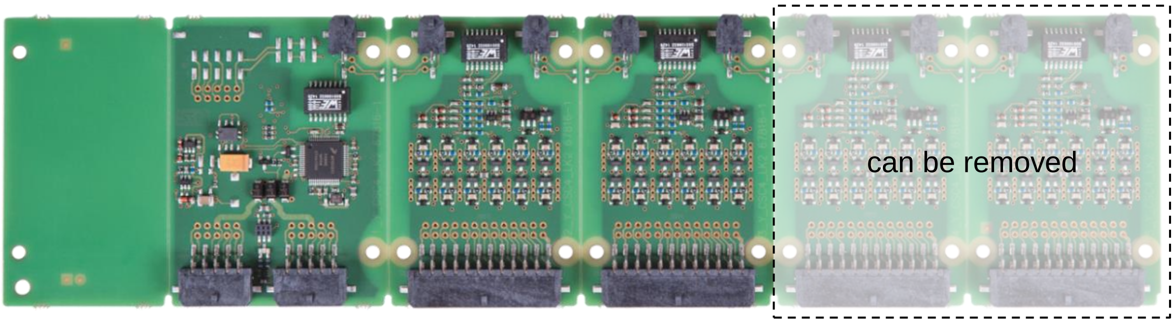
connected together

4.6.4 Example 3

CSC board has to sense 13 cells

Related rules: §2, §3, §5

⇨ Reduce the utilization to two measuring modules. This could be done in this manner: seven cells to the first module, six to the second. Do not connect less than four cells to one measuring board (the voltage level between pin 8 and 13 must be higher than 11V in any case.)



6 cells

Pin	Signal Name	Cell connection
1	--	
2	CH11	Cell 6+
3	CH9	Cell 6+
4	CH7	Cell 6+
5	CH5	Cell 5+
6	CH3	Cell 3+
7	CH1	Cell 1+
8	GND	Cell 1-
9	GND T4	
10	GND T3	
11	GND T2	
12	GND T1	
13	UB	Cell 6+
14	CH12	Cell 6+
15	CH10	Cell 6+
16	CH8	Cell 6+
17	CH6	Cell 6+
18	CH4	Cell 4+
19	CH2	Cell 2+
20	--	
21	Temp 4	
22	Temp 3	
23	Temp 2	
24	Temp 1	

7 cells

Pin	Signal Name	Cell connection
1	--	
2	CH11	Cell 13+
3	CH9	Cell 13+
4	CH7	Cell 13+
5	CH5	Cell 11+
6	CH3	Cell 9+
7	CH1	Cell 7+
8	GND	Cell 7-
9	GND T4	
10	GND T3	
11	GND T2	
12	GND T1	
13	UB	Cell 13+
14	CH12	Cell 13+
15	CH10	Cell 13+
16	CH8	Cell 13+
17	CH6	Cell 12+
18	CH4	Cell 10+
19	CH2	Cell 8+
20	--	
21	Temp 4	
22	Temp 3	
23	Temp 2	
24	Temp 1	

connected together same signals

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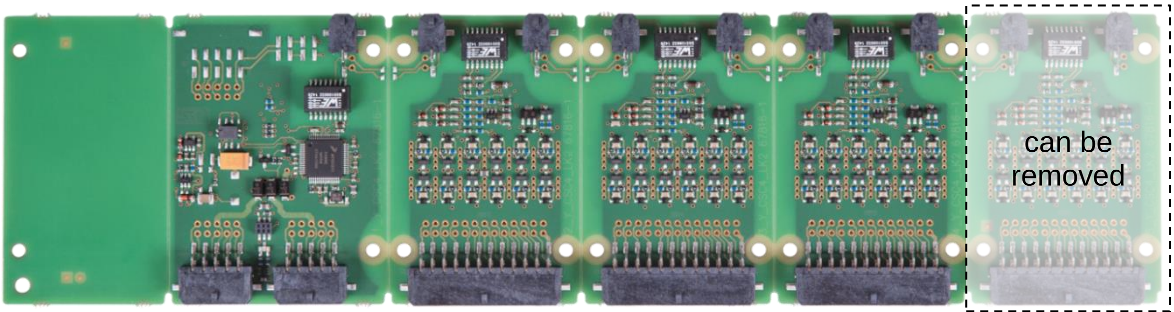
4.6.5 Example 4

CSC board has to sense 12 cells (incl. temperature of each cell)

Related rules: §2, §4, §5, §6

⇨ In early steps of battery system development, the developer wants to know the voltage and the temperature of each cell in the system. In further steps, the amount of sensors will be reduced. These development steps can be handled with one and the same CSC board. With one CSC board it is possible to sense 16 cells and 16 temperatures. The example here shows a system of 12 cells and 12 temperatures.



12 cells / 4 temperatures

Pin	Signal Name	Cell connection
1	--	n. c.
2	CH11	Cell 11+
3	CH9	Cell 9+
4	CH7	Cell 7+
5	CH5	Cell 5+
6	CH3	Cell 3+
7	CH1	Cell 1+
8	GND	Cell 1-
9	GND T4	Temp4-
10	GND T3	Temp3-
11	GND T2	Temp2-
12	GND T1	Temp1-
13	UB	Cell 12+
14	CH12	Cell 12+
15	CH10	Cell 10+
16	CH8	Cell 8+
17	CH6	Cell 6+
18	CH4	Cell 4+
19	CH2	Cell 2+
20	--	n. c.
21	Temp 4	Temp4+
22	Temp 3	Temp3+
23	Temp 2	Temp2+
24	Temp 1	Temp1+

4 temperatures

Pin	Signal Name	Cell connection
1	--	n. c.
2	CH11	n. c.
3	CH9	n. c.
4	CH7	n. c.
5	CH5	n. c.
6	CH3	n. c.
7	CH1	n. c.
8	GND	Cell 1-
9	GND T4	Temp8-
10	GND T3	Temp7-
11	GND T2	Temp6-
12	GND T1	Temp5-
13	UB	Cell 12+
14	CH12	n. c.
15	CH10	n. c.
16	CH8	n. c.
17	CH6	n. c.
18	CH4	n. c.
19	CH2	n. c.
20	--	n. c.
21	Temp 4	Temp8+
22	Temp 3	Temp7+
23	Temp 2	Temp6+
24	Temp 1	Temp5+

4 temperatures

Pin	Signal Name	Cell connection
1	--	n. c.
2	CH11	n. c.
3	CH9	n. c.
4	CH7	n. c.
5	CH5	n. c.
6	CH3	n. c.
7	CH1	n. c.
8	GND	Cell 1-
9	GND T4	Temp12-
10	GND T3	Temp11-
11	GND T2	Temp10-
12	GND T1	Temp9-
13	UB	Cell 12+
14	CH12	n. c.
15	CH10	n. c.
16	CH8	n. c.
17	CH6	n. c.
18	CH4	n. c.
19	CH2	n. c.
20	--	n. c.
21	Temp 4	Temp12+
22	Temp 3	Temp11+
23	Temp 2	Temp10+
24	Temp 1	Temp9+

voltage supply for the module is necessary

- The temperature sensors used (10kΩ NTC, characteristic 8016) must be electrically isolated types.
- Electrical contact of the temperature sensor element and the HV or LV voltages will damage the CSC board.

4.7 Interlock

The BMS provides an interlock detector (DET) and generator (GEN) considering the requirements of the “LV123” specification. The generator can be disabled per software configuration if there is an external interlock signal generated by another system component.

The interlock identifies unauthorized access into the HV system, which may enable access to live parts, and provides a suitable reaction to protect against access to live HV parts.

The following sketch clarifies: Remote HV plugs may be supervised across LV plugs.

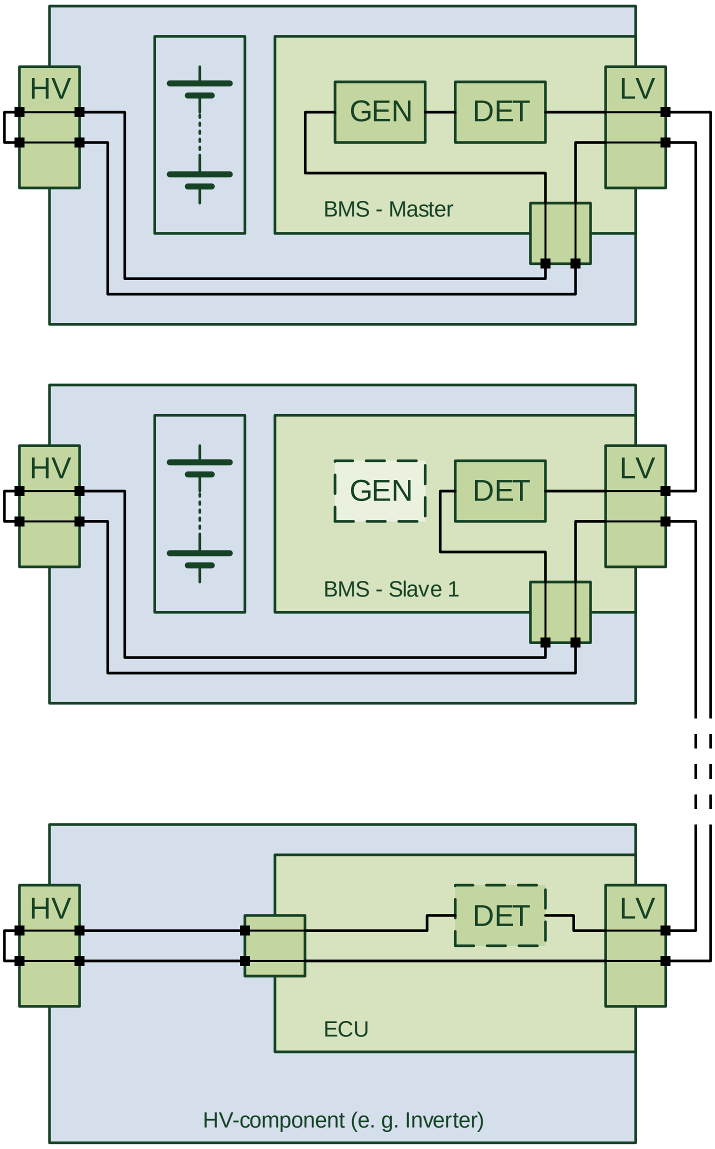


Figure 5 – Interlock distribution

4.8 CAN-Interfacing

On the LV-Connector there are four CAN busses using a baud rate of 500 kBit/s.

CAN-Interface	Channel	Description	bus termination on-board
ESS-CAN	CAN 1	Interface to external systems (e.g. SCU)	no
Interpack CAN	CAN 2	Interface between the battery packs (Master/Slave networking)	no
Sensor CAN	CAN 3	Internal CAN between battery sub-components (PMB, CSCs) This interface is useful for deeper battery data (Further Cell-Information)	yes [7]
SC-Meas CAN	CAN 4	Safety Controller diagnostic interface. This interface is useful for detailed safety error diagnostic (complete description system safety errors and states)	no

The wiring topology of a CAN network should be as close as possible to a single line structure in order to avoid cable-reflected waves. The termination resistors on a cable should match the nominal impedance of the cable. ISO 11898 requires a termination resistor of 120 Ω and a nominal impedance of the cable of 120 Ω. If you place multiple CAN nodes along the cable, only the nodes at the ends of the cable need termination resistors. The maximum bus length should be less than 100 m, the maximum stub length should be less than 1 m. The cable type should be twisted pair.

Figure 6 shows an example of how to terminate a high-speed network.

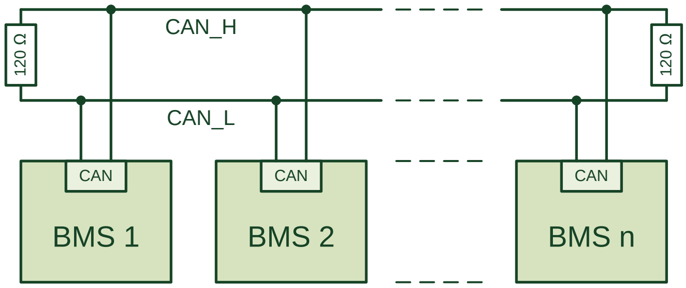


Figure 6 – CAN bus termination

[7] *The CAN bus termination resistors are placed on PMB and BMS (end of CSC-chain)*

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5 Multi battery topologies

For ESS built up from multi batteries, there are two options for interconnecting the battery management systems.

5.1 Master/Slave networking

Master/slave networking is a unique mBMS feature. In a master/slave network, all parallel batteries are connected so that one battery is the master while the others are slaves. The communication between the vehicle and the multi battery system is done via the master's ESS-CAN only. A maximum of seven slaves can be interconnected in this type of network.

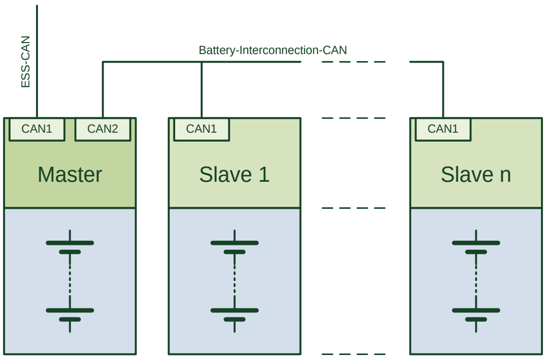

Figure 7 – Master/Slave networking topology

The functional assignment is done by cable configuration in the low voltage interconnection of the batteries. The differences of master and slaves are just in behavior, while hard- and software components remain identical. For example: a technician, servicing the system does not have to care whether a battery is a slave or a master. Replacing a battery is therefore more or less a plug and play event.

The master's additional duty is the collection and distribution of data as well as virtualizing the parallel batteries. From the vehicle's perspective, the master-slave network represents a single battery system (ESS).

For example: the master reports all necessary data from the ESS, it receives the power enabling and disabling signals, manages how and when all batteries are getting active, which battery has to be shut down if there is a system failure and it controls functions which should be done by only one BMS like pre-charging the traction net or performing insulation monitoring.

5.2 Multi master networking

If it is necessary to interconnect more than eight batteries in parallel in order to form a battery system, a multi master network topology is used. The communication between the vehicle and the multi battery system is done by the system control unit (SCU) – e.g. ESX from STW. The additional ECU has to coordinate the functions of the storage system with specific software relying on the functions and data provided by the individual batteries.

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The maximum number of parallel batteries is defined by the bus load of the respective CAN bus. Please note that sharing CAN busses among parallel batteries requires a customized CAN protocol in order to avoid collisions.

STW is able to develop such a fully customized solution on your request. Call STW for a technical and commercial offer.

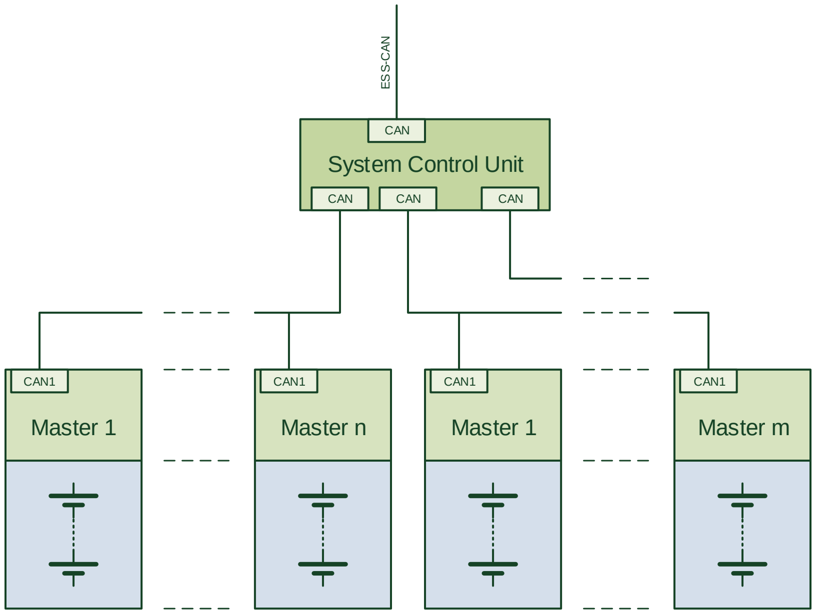

Figure 8 – Multi master networking topology

The multi master network contains a minimum of two batteries. All batteries have identical privileges and have no information about other batteries connected to the system.

6 Technical Data

6.1 Maximum Ratings

Interfaces LV (low voltage)	
Power supply	32 V (load dump capability at KL30: 58V)

Interfaces HV (high voltage)			
	max. time	**PMB1000**	**PMB2000**
Current measurement	continuous 100 sec 10 sec 1 sec	230 A 390 A 600 A 1000 A	250 A 450 A 900 A 1400 A
	Conditions: Cable cross section: min. 120 mm² Ambient temperature: max. 80 °C. Further details see appendix PulseLoadDiagram-Y_PMBE.pdf		
High voltage measurement	800 V		

- When the rated current is exceeded, the circuit has to be limited or interrupted (e. g. by external switch or circuit-breaker)
- The disconnecting device should be installed next to the PMB.
- The PMB shall be mounted in a way that a manual disconnection can be done easily.

6.2 Key Data

External Interfaces (vehicle side)		
LV Connector Type	23-pole AMPSEAL (TE connectivity)	
CAN	CAN 1 - ESS-CAN CAN 2 - Interpack CAN CAN 3 - Sensor CAN CAN 4 - SC-Meas CAN	CAN 2.0 B, 500 kBit/s
Interlock	detector and generator alternating current (20 mA / 88 Hz) reaction: enter safe state (main switch off)	

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Digital output LSS	2 x 2 A, low-side, 0 % … 100 % short circuit protected, diagnostics (usable on customer spec. , ask STW for a commercial offer)	
Digital output HSS	1 x 2 A, high-side, 0 % … 100 % short circuit protected, diagnostics (usable on customer spec., ask STW for a commercial offer)	
Analog input	0 ... 36 V, 12-bit, pull-up for open-load-detection (usable on customer spec., ask STW for a commercial offer)	
Internal Interfaces (battery side)		
Connector Type	Micro-Fit (Molex)	
Indicators	on-board LEDs	
Cell voltage measurement	range: 1 V … 5 V accuracy: 2.5 mV @ 2.5 V … 4.3 V [8]	⇨ CSC
Cell temperature measurement	NTC-Sensor, 10 kΩ, characteristics: EPCOS 8016 range: -55 °C … +125 °C (-67 °F ... 257 °F) accuracy: 2 K plus sensor tolerance	⇨ CSC
Cell balancing current	120 mA @ Ucell = 3.6 V (derated at high temperature)	⇨ CSC
High voltage measurement	range: 0 V … 800 V accuracy: offset 0.1 V, gain 1 %	⇨ PMB
Current measurement	range: +/- 1000 A (PMB1000) range: +/- 2000 A (PMB2000) accuracy: offset 0.1 A, gain 1 % [8]	⇨ PMB
Coolant temperature measurement	2x input for NTC-Sensor 10 kΩ characteristics: EPCOS 8016 range: -55 °C … +125 °C (-67 °F ... 257 °F) accuracy: 2 K plus sensor tolerance	⇨ BMS
Insulation measurement	between HV (battery) and LV (vehicle chassis) range: 1 ... 4500 kΩ accuracy: 0 … -5 kΩ @ 1 … 20 kΩ 0 … -25 % @ 20 … 1000 kΩ	⇨ BMS
Main switch control	2 x 1.5 A (hold current), 5 A (pickup current)	

[8] *No in-system calibration required. Accuracy in the range +/- 300 A (PMB1000) and +/- 600 A (PMB2000)*

<table>
<tr><th colspan="3">System Data</th></tr>
<tr><td>Wake up options</td><td colspan="2">CAN1
(options: CAN2, RTC and ignition (KL15) can be made available on customer spec., ask STW for a commercial offer)</td></tr>
<tr><td>Power supply</td><td colspan="2">8 ... 32 V DC</td></tr>
<tr><td rowspan="2">Current consumption (active mode)</td><td>350 mA @ UB = 12 V (main switches off)
185 mA @ UB = 24 V (main switches off)</td><td>⇨ BMS</td></tr>
<tr><td>10 mA @ Ucell = 4.2V</td><td>⇨ CSC</td></tr>
<tr><td rowspan="2">Current consumption (sleep mode)</td><td>< 100 µA @ UB = 12 V</td><td>⇨ BMS</td></tr>
<tr><td>< 10 µA @ Ucell = 4.2V</td><td>⇨ CSC</td></tr>
<tr><td>Dimensions (approx.)</td><td colspan="2">BMS: 212 mm x 100 mm x 33 mm (8.3“ x 3.9“ x 1.3“)
PMB: 95 mm x 61 mm x 15 mm (3.7“ x 2.4“ x 0.6“)
CSC: 300 mm x 75 mm x 13 mm (11.8“ x 3.0“ x 0.5“)</td></tr>
<tr><td>Weight (approx.)</td><td colspan="2">BMS: 0.23 kg (0.51 lbs.)
PMB: 0.10 kg (0.22 lbs.)
CSC: 0.26 kg (0.57 lbs.)</td></tr>
<tr><td>Operating temperature range</td><td colspan="2">-40 °C ... +80 °C (-40 °F ... 176 °F) ambient temperature</td></tr>
<tr><td>Insulation coordination</td><td colspan="2">Reinforced insulation between HV and LV for a working voltage of 800V and a pollution degree 2 (according DIN EN 60664)
Voltage withstand: 4 kV (according DIN EN 60664)</td></tr>
</table>

<table>
<tr><th colspan="2">Applied Standards</th></tr>
<tr><td></td><td>Qualified according to applicable standards for the automotive, agricultural and construction industries.</td></tr>
<tr><td>Isolation</td><td>DIN EN 60664</td></tr>
<tr><td>EMC</td><td>CISPR 25, ISO 11452-5, ISO 7637, DIN EN 61000-6-3, DIN EN 61000-6-2 (partly)</td></tr>
<tr><td>CAN</td><td>ISO 11898</td></tr>
<tr><td>Functional Safety</td><td>the architecture permits safety functions up to SIL2 (EN 61508), ASIL B (ISO 26262)</td></tr>
</table>

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7 Terms and abbreviations

BMS *Battery Main Supervisor*
CAN *Controller Area Network*
CSC *Cell Sensor Circuit*
CTI Comparative Tracking Index
DET *Interlock Detector*
EMC *Electromagnetic Compatibility*
ESD *Electrostatic Discharge*
ESS *Energy Storage System*
GEN *Interlock Generator*
HV *High Voltage*
LV *Low Voltage*
mBMS *STW's modul Battery Management System*
NTC *Negative Temperature Coefficient Thermistors*
PCB *Printed Circuit Board*
PMB *Power Measurement* Board - Current sensor
SCU *System Control Unit*
traction net *The Vehicle's high voltage DC network*
vehicle *The application, the ESS is used in (not necessarily a mobile application)*

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