CELL-INTEGRATED SENSING FUNCTIONALITIES FOR SMART BATTERY SYSTEMS WITH IMPROVED PERFORMANCE AND SAFETY

GA 957273

D4.1 BMS-SLAVE DEMONSTRATOR SUPPORTING THE READ OUT OF CELL-INTEGRATED LEVEL-1 SENSORS

LC-BAT-13-2020 - Sensing functionalities for smart battery cell chemistries

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Summary

This report presents the design for an advanced BMS-slave and sensor read-out circuit. The design can read-out a cell-integrated 5x7 resistive temperature sensor matrix and a 5x7 capacitive pressure sensor matrix (SENSIBAT Level-1 sensors), as well as the cell voltages for a module consisting of 6 series-connected cells. The design follows a modular approach, with a cell-based read-out circuit on each cell. This circuit can either work in stand-alone mode, where it is used in combination with standard lab equipment (frequency and voltage measurement), or in a mode controlled by an NXP analogue frontend IC (AFE). In this last option, the read-out circuits of every cell are all connected to a PCB with the NXP AFE, that controls the read-out circuits of 6 series-connected cells, retrieves all cell-level pressure and temperature values (2x5x7x6 values), measures all cell voltages and transfers all the measurement data to the BMS master. Additionally, it executes commands from the BMS-master, such as cell balancing.

The momentaneous unavailability of some BMS slave components increased the needed design effort to develop the BMS-Slave. In addition, drop-in replacement components were not available, and this forced the SENSIBAT project to carry out different BMS-slave design solutions to adapt to the new components. All this caused the delay of the activities to be carried out in the Task 4.1 and consequently an accumulated delay of 1 month in the present deliverable and demonstrator. The resulting delay was carefully evaluated and is unlikely to lead to further delays in the SENSIBAT project.

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Abbreviations

Symbol / Abbreviation	
3D	*3-dimesional*
AD	*Analog to Digital*
AFE	*Analog Front End*
BMS	*Battery Management System*
CLK	*Clock Signal*
IC	*Integrated Circuit*
I2C	*Inter-Integrated Circuit (digital interface bus)*
MCU	*Microcontroller Unit*
MUX	*Multiplexer*
P	*Pressure*
PCB	*Printed Circuit Board*
T	*Temperature*
ZIF	*Zero Insertion Force*

1 Introduction

The document D4.1 presents the BMS-slave demonstrator supporting the read-out of cell-integrated level-1 sensors.

The temperature and pressure sensor matrix (level-1 sensors) are processed on a single, sheet-like polyimide substrate that can be integrated inside the pouch of a Li-ion battery. Via a feed-through section in the pouch sealing, the sensors can be read-out from outside of the cell. This approach avoids the integration of electronics in the aggressive electrolyte environment inside the cell. Moreover, due to the experimental nature of this approach the accessibility of the electronics is advantageous for debugging, fine-tuning, calibration, and characterization of the circuit. As an additional feature, the read-out circuit can be operated in a stand-alone mode without a BMS master. This is useful during cell characterization and ageing tests with single cells. The circuit can be controlled by a simple clock signal, with each clock edge causing the output to be connected with the next sensor of the matrix.

This document organized in top-down approach, starting from a system-level block diagram and ending on circuit-level details.

2 Circuit design

2.1 Block Diagram

Figure 1 shows a high-level block diagram of the battery management system (BMS), including master and slave circuits for a single module setup consisting of 6 series-connected 5 Ah cells with integrated SENSIBAT level-1 sensor. The BMS follows a modular concept: it consists of a read-out circuit for every cell, an AFE circuit for every module and a BMS master.

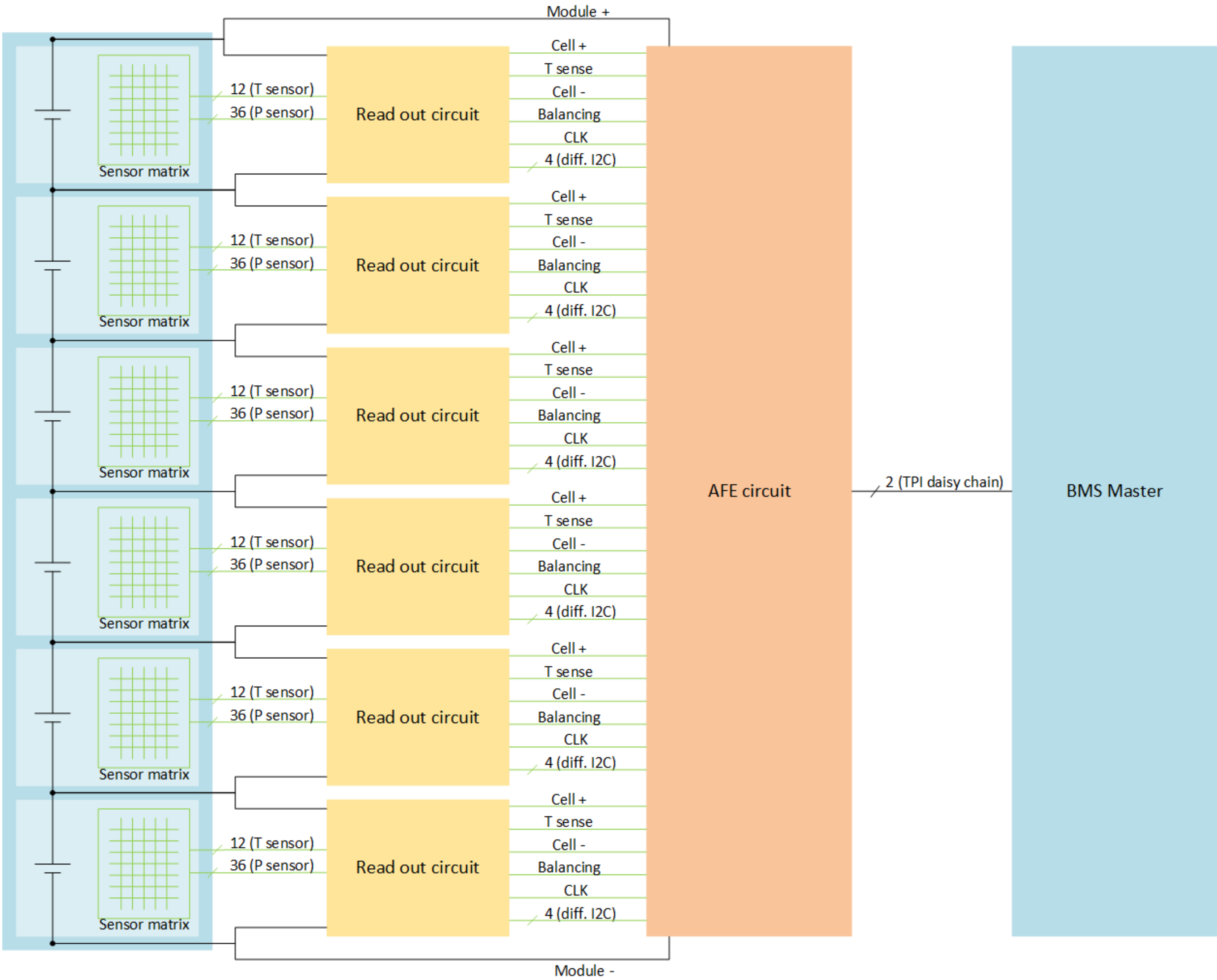

Figure 1: Battery system block diagram

Every cell is equipped with a 5x7 resistive temperature sensor matrix and a 5x7 capacitive pressure sensor matrix. For the temperature sensor, a connection to every matrix column and row is fed to the outside of the cell (i.e., 5+7=12 traces). The capacitances of the pressure sensor are all referenced to the same potential, i.e., one electrode is connected to a common signal and the remaining electrode is left floating. The common signal as well as the floating electrodes are fed through to the outside of the cell (i.e., 5 * 7 + 1 = 36 traces). In total, 48 traces are available on the outside of each cell. The technology details of the level-1 sensors are described in D3.1 "Report on adaptation of level 1 sensors for incorporation into battery cells". Further details on the level-

1 sensors for the 5Ah cell will be found in D3.4 Report on prototyping of 20x 5Ah baseline pouch battery cells with integrated level 1 sensors.

The sensor matrices are connected to the read-out circuit via zero insertion force (ZIF) type connector. This kind of connector does not require a counterpart on the sensor matrix.

Apart from the sensor matrix connections, also the cell voltage (cell positive and negative terminals) need to be connected to the read-out circuit. The read-out circuits of every cell are connected to a PCB with the NXP AFE, that controls the read-out circuits, retrieves pressure and temperature values, measures cell voltages and, transfers all the measurement data to the BMS master. The BMS master collects the data and controls the complete data acquisition via the daisy chain.

Figure 2 shows a high-level block diagram in the stand-alone configuration of the sensor read-out circuit. Again, all signals fed to the outside of the cell are connected. In order to minimize the impact of the read-out circuit on cell characterization measurements, a separate 5V supply can be added to minimize self-discharge rate (available as HW/SW variant). This set-up allows for stand-alone characterization of a single cell including its integrated level-1 sensors without needing access to and control signals from the NXP AFE circuit. This allows various partners within the SENSIBAT project to do laboratory characterization of level-1 5Ah cells.

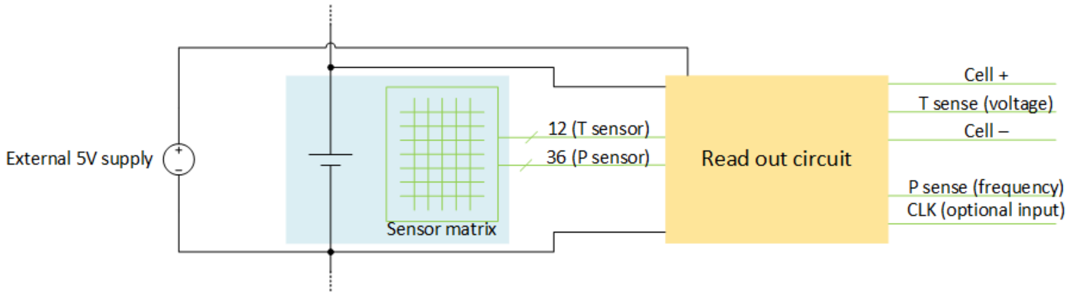

Figure 2: Block diagram of the stand-alone use case scenario of the read-out circuit

The circuit can be either controlled by an external clock or an enable signal or can run autonomously. The temperature sensor data of the selected matrix element can be retrieved as a voltage in relation to the cell voltage (voltage divider) at the output connector. The pressure sensor information is encoded as a frequency. The sensors of the matrix are connected to the outputs one by one, either controlled by an external clock signal or autonomously. This allows read-out and synchronization while stepping through all matrix elements using commonly available lab equipment.

2.2 Read-out circuit

2.2.1 Block diagram

Figure 3 shows a block diagram of the read-out circuit. The main parts are the read-out circuit for the temperature sensor matrix, the read-out circuit for the pressure sensor matrix and, a microcontroller (MCU) for control, synchronization, and transfer of the measurement information.

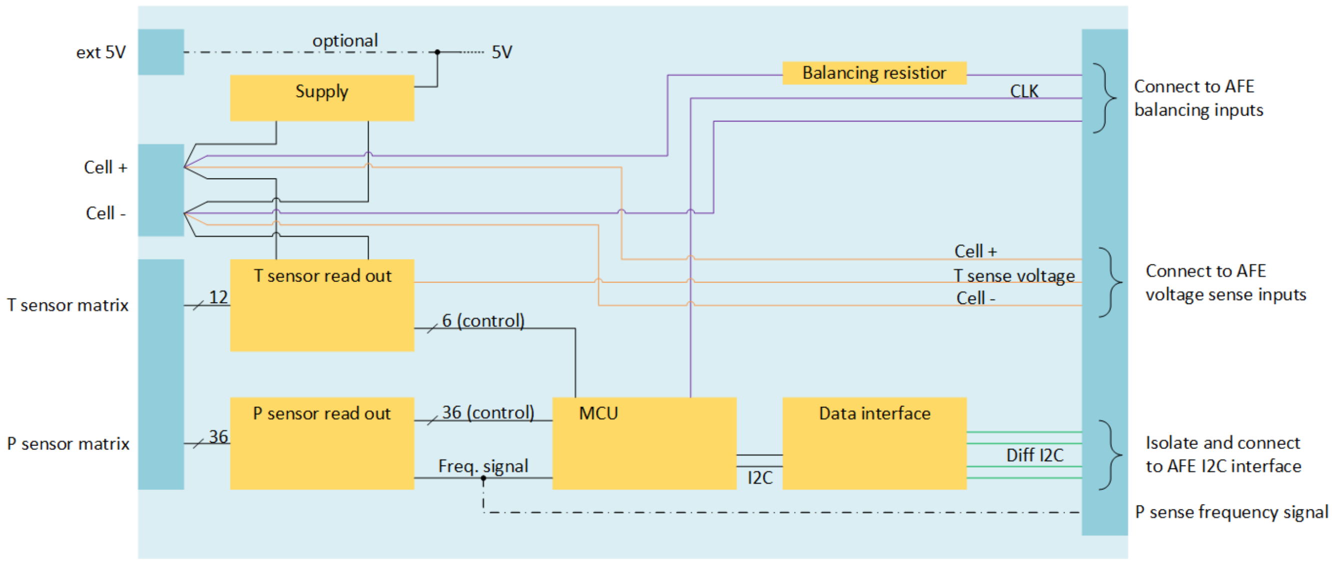

Figure 3: Block diagram of the sensor read-out circuit

The temperature sensing circuit relies on a voltage divider, supplied by the cell voltage, and made up of the temperature-dependent resistance of the sensor and a reference resistance on the read-out circuit. The voltage is not measured on the read-out circuit, but on the AFE circuit, in order to take advantage of the precision AD converter of the NXP AFE. Therefore, the three connections of the voltage divider are directly fed through to the voltage measurement inputs of the AFE and two measurement channels are used per cell, one measuring the lower half of the voltage divider and one measuring the upper half of the voltage divider. The cell voltage is measured by adding both voltages measurements. The ratio between the lower divider voltage and the cell voltage is used measure temperature matrix elements.

The pressure sensing circuit relies on a precision timer (NA555) to convert the capacitances in an according frequency signal. The frequency is measured by a timer of the MCU and transferred to the AFE circuit via an isolated I2C interface. As every read-out circuit is referenced to the negative potential of its according cell, the isolation is necessary to connect all read-out circuits to a single I2C bus controlled by the AFE.

The MCU also allows the synchronization between the AFE and the read-out circuit, by reading in the status of the unused balancing channel from the AFE (CLK signal).

2.2.2 Temperature sensing circuit

Figure 4 shows the schematic of the temperature sensing circuit, including the sensor matrix.

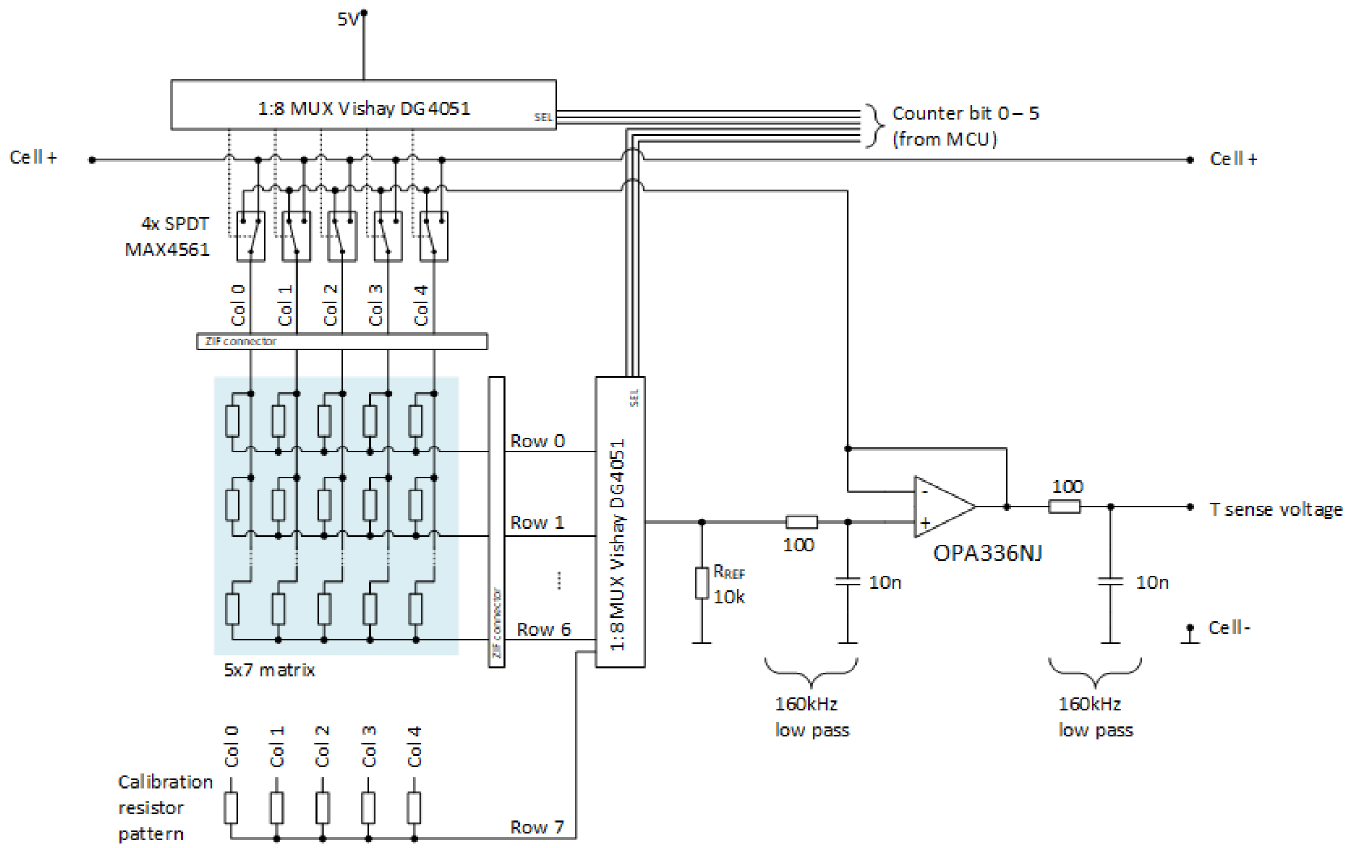

Figure 4: Read-out circuit for the temperature sensor matrix

Temperature sensing is based on the temperature-dependent resistors. The sensors are read-out using a voltage divider consisting of the temperature sensor and a reference resistor to divide the cell voltage. To measure the cell voltage and the divided cell voltage, two measurement channels of the AFE are needed. In the temperature sensor matrix, all sensors in a line as well as all sensors in a column are connected, resulting in the need of selection switches i.e., multiplexers (MUX), for addressing single sensors. The selected column is connected to the positive cell voltage and the selected row is connected to the reference resistor forming the second part of the voltage divider.

To minimize the influence of parallel connections over multiple series connections on the selected sensor, the un-selected columns are supplied with the voltage divider output voltage. A voltage buffer ensures that the feedback circuit has minimal influence on the voltage divider output. The principles of this approach are discussed in detail in [1].

A 6bit binary counter output provided by the MCU, where the lower 3 bits control the row-selecting MUX and the higher 3 bits control the column-selecting MUX, is used to address every single sensor of the matrix one by one. For calibration and easy identification of the current sensor position, an additional row of reference resistors is added. These resistors can form an easily identifiable pattern in the measurement data (as shown in Figure 5) that can be used to correlate the measurement values to the correct sensor positions.

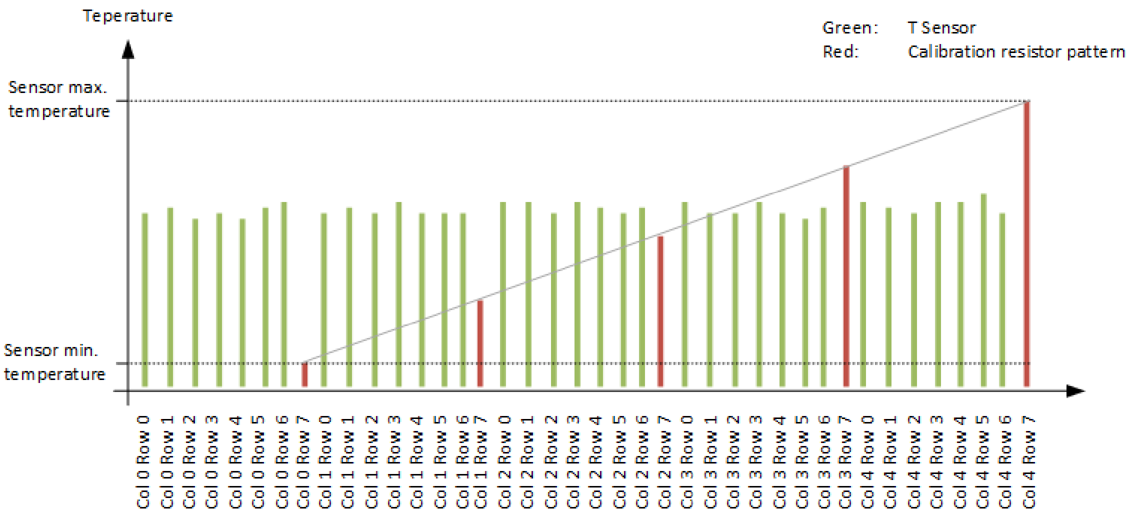

Figure 5: Plot showing the calibration resistor pattern

2.2.3 Pressure sensing circuit

Figure 6 shows the schematic of the pressure sensing circuit, including the sensor matrix.

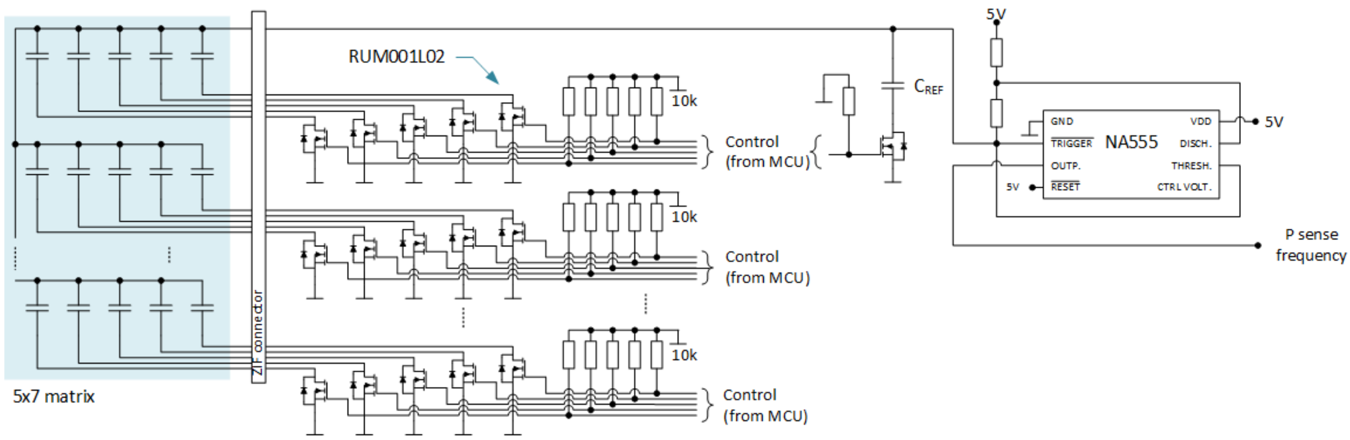

Figure 6: Read-out circuit for the pressure sensor matrix

Pressure sensing is based on the pressure-dependent variation of the capacitance on the addressed matrix position. The capacitance is measured using a precision NA555 type timer, that outputs a frequency signal depending on the connected capacitance. The timer circuit follows the standard implementation for astable operation.

One electrode of every sensor is connected to a common potential, whereas the other electrode can be individually shorted to ground when that matrix cell is selected or left floating by a MOSFET. The common potential is connected to the input of the timer circuit.

By comparing the resulting frequencies when the MOSFET is ON and OFF allows for the calculation of the capacitance of the according sensor. This requires using a MOSFET with a low output capacitance, that is well below the sensor capacitance. For calibration, an additional channel with a known and fixed capacitance is added.

The control of the MOSFET and the read-out of the frequency signal is done by the MCU.

2.2.4 Communication, and power supply circuit

Figure 7 shows the schematic of the power supply circuit.

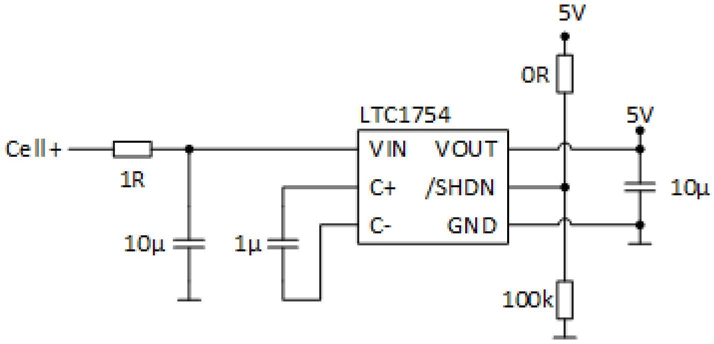

Figure 7: Voltage supply of the read-out circuits

All circuit parts are supplied with 5 V generated from the corresponding cell voltage. This allows operation independent of the connected cell's voltage level. If the circuit needs to be supplied by an external source, 5 V can then be supplied directly via a connector (requires simple hardware reconfiguration). This prevents draining the characterized cell by the read-out electronics.

Figure 8 shows the schematic of the isolation circuit for the I2C communication.

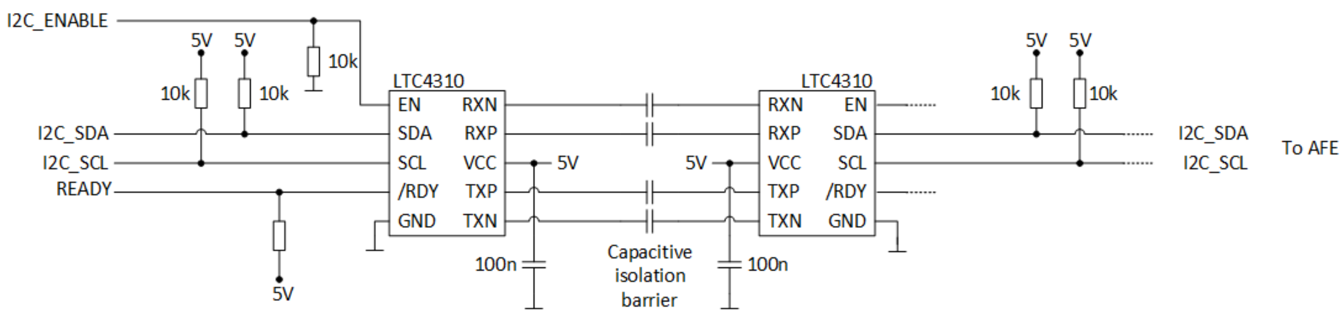

Figure 8: Isolation circuit for the I2C communication interface

The MCU provides an I2C interface, that is used to communicate with the NXP AFE. The isolation is realized by translating the signal into a differential signal. This signal can be transferred over an isolating capacitive barrier. After the isolating capacitors, the differential signal is transformed back to a single-ended, standard I2C signal, which can be interfaced by the AFE.

2.3 Connection to AFE circuit

As previously described, the two voltage measurement channels of the AFE are used for each cell (e.g. CT2 and CT1 for cell 0, as shown on the left-hand side in Figure 9; normally the NXP AFE can be used with 14 cells and cell0 would have been connected between CT1 and CT0), to read-out the cell voltage and the temperature sense voltage over a voltage divider formed by the sensing resistor R(t) and the reference resistor R(REF). The cell voltage can be calculated by adding the voltage reading of both channels, e.g. $V_{Cell0}=V(CT0,CT1)+V(CT1,CT2)=V(R_{REF})+V(R_{(T)})$.

As two measurement channels are used for each cell, there are two balancing channels available per cell (e.g. CB1C and CB2H for cell 0, see right-hand side in Figure 9). The additional balancing channel is used as a CLK signal for synchronization of the temperature measurements. With every e.g., rising edge on CLK, the counter controlling the MUX of the T-sensor read out is incremented and the read-out circuit shifts to the next sensor matrix position. The CLK signal can also serve as a wake-up signal for the MCU (if no edge is visible for a certain time (i.e., time-out), the MCU goes to sleep).

Figure 9 shows how the read-out circuit outputs are connected to the AFE.

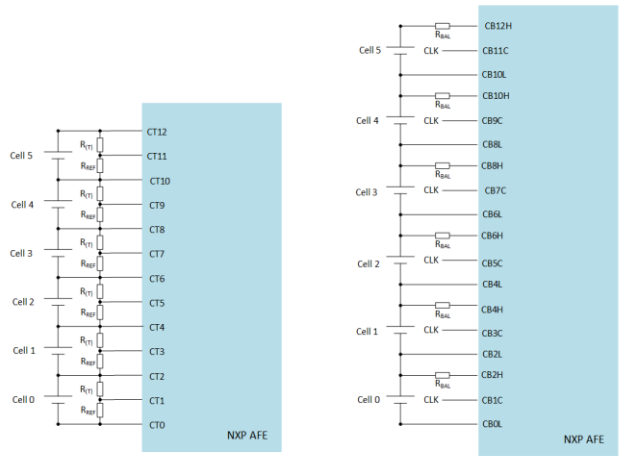

Figure 9: Connection scheme for connection of the SENSIBAT cell with read-out circuit to the NXP AFE

3 Demonstrator

Figure 10 shows a 3D visualisation of the read-out PCB (50x80mm) showing the circuit parts discussed before.

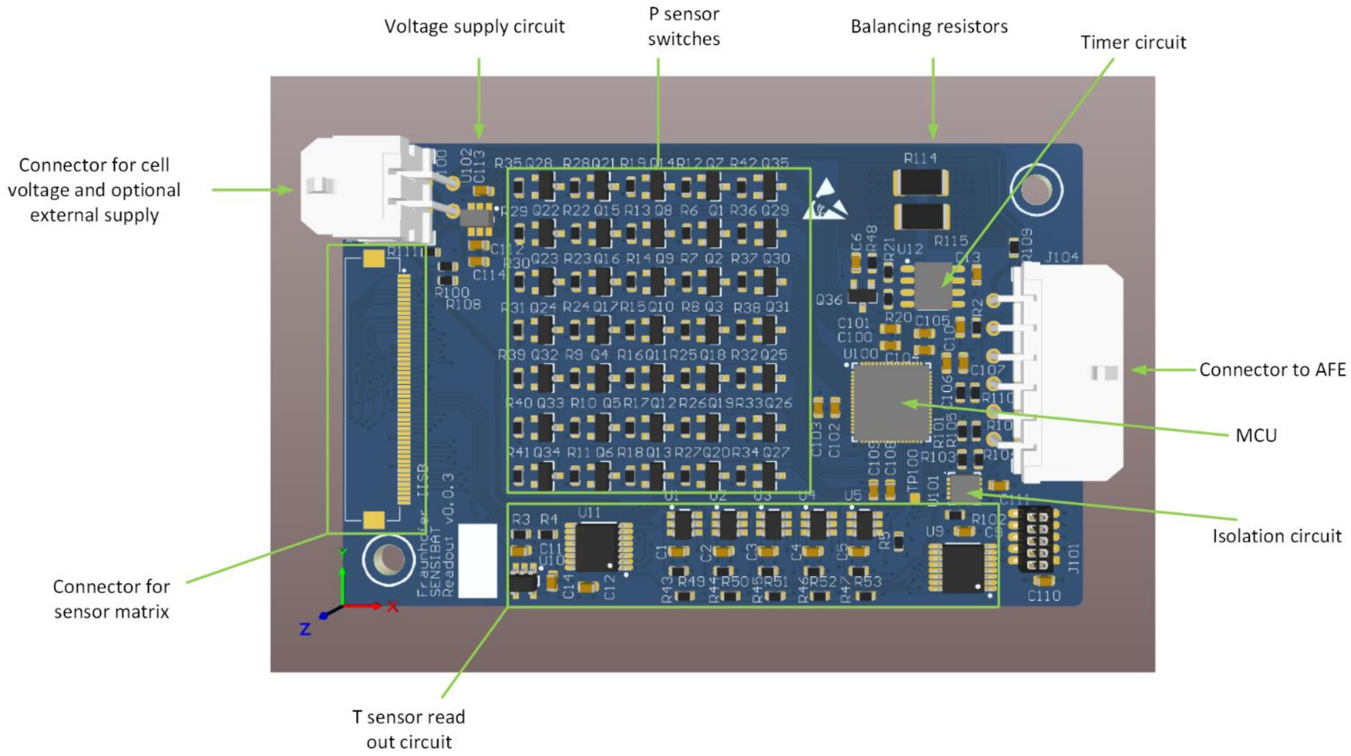

Figure 10: Read-out circuit PCB (3D rendering)

Figure 11 shows a photograph of the prototype PCB.

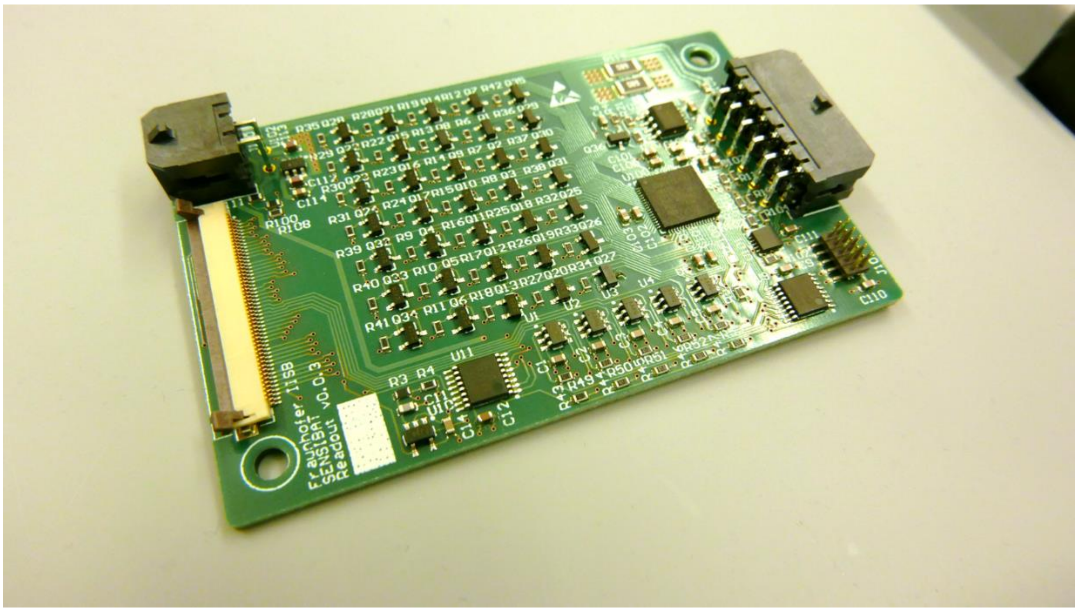

Figure 11: Read-out circuit PCB prototype

4 Discussion & Conclusion

This document shows how the objective of Task 4.1 and D4.1, which requires the demonstration of a BMS-slave supporting the read-out of cell-integrated level-1 sensors for a module with six series-connected 5 Ah cells was achieved.

As described in this document, the developed BMS slave can be integrated at both cell or module level, together with the needed laboratory equipment or master BMS subsequently, to read-out the cell voltages for a module consisting of 6 series connected cell, cell-integrated level-1 sensors with 35 temperature and pressure reading, transfer all the measurement data to the BMS master and execute commands from the BMS-master, such as cell balancing.

The current situation of disrupted worldwide supply chains has also had an impact on the development of the BMS slaves. In some cases, the originally planned implementations had to be replaced by work-around solutions causing increased effort and delay of 1 month. At this time, however, we do not expect significant further delays in the SENSIBAT project.

5 References

[1] L. Shu, X. Tao and D. D. Feng, "A New Approach for Readout of Resistive Sensor Arrays for Wearable Electronic Applications," in *IEEE Sensors Journal*, vol. 15, no. 1, pp. 442-452, Jan. 2015, doi: 10.1109/JSEN.2014.2333518

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