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An Intelligent BMS with Cell Individual In-Situ Impedance Measurement for State-of-Charge Estimation in a Battery Pack

Prof. Christoph Weber
Hannes Rathmann
Institute of Mechatronics
University of Applied Sciences
Kiel, Germany

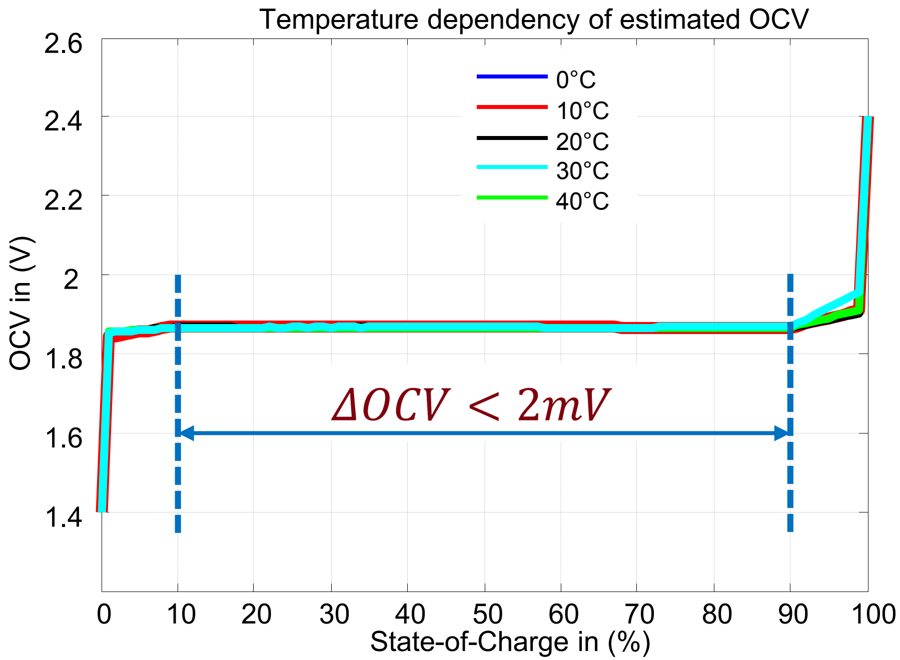
Prof. Wolfgang Benecke
Chrstian-Albrechts-University Kiel
Fraunhofer Institute for Silicon Technology ISIT
Itzehoe, Germany

Agenda

- Problem: Special battery-cell chemistries result in flat OCV-curves therefore State-of-Charge to OCV referencing isn't practicable.
- Idea: Using the dependency of the cell impedance and the actual State-of-Charge for charge estimation
- Design of the Algorithm: Implementation of an Genetic Algorithm for individual State-of-Charge estimation
- Implementation: In-Situ impedance measurement with the developed BMS
- Results
- Summary

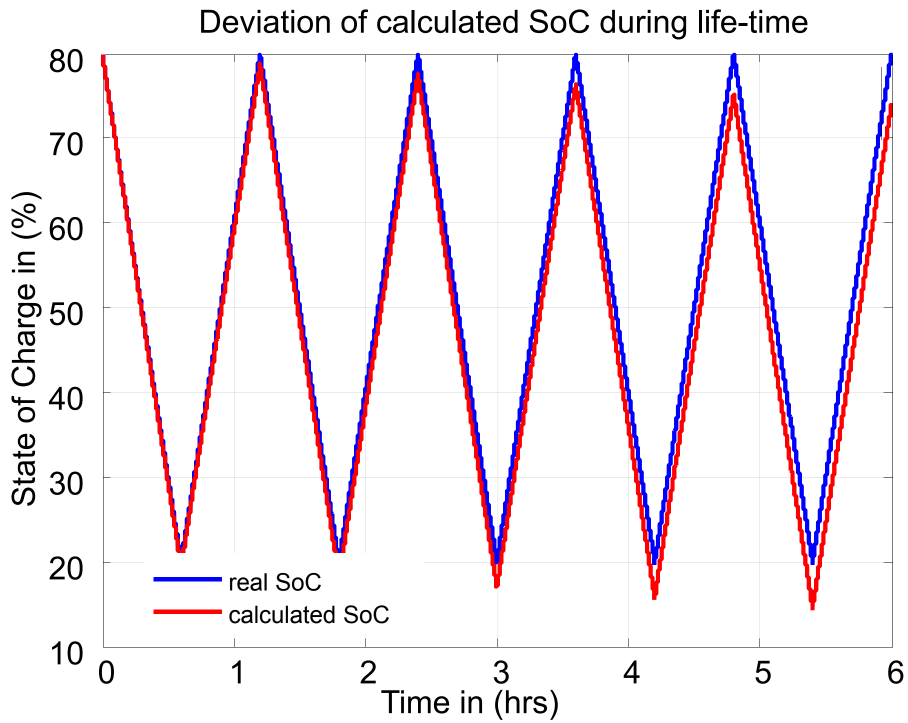
Problem:
Flat OCV curves prohibit State-of-Charge estimation

- Depending of the used cell chemistry the Open-Circuit-Voltage is difficult to measure precisely enough.
- To reference to the State-of-Charge during steady state phases of the battery is not practicable.
- Example:
  OCV of a $LiFePO_4$-$Li_4Ti_5O_{12}$ cell



Problem:
Measurement errors distort State-of-Charge estimation

- Normally Coulomb-Counting would result the exact State-of-Charge.
- Measurement errors are always present.
- During run-time the calculated SoC will deviate from real SoC.
- Example:
  1% Offset error in current measurement

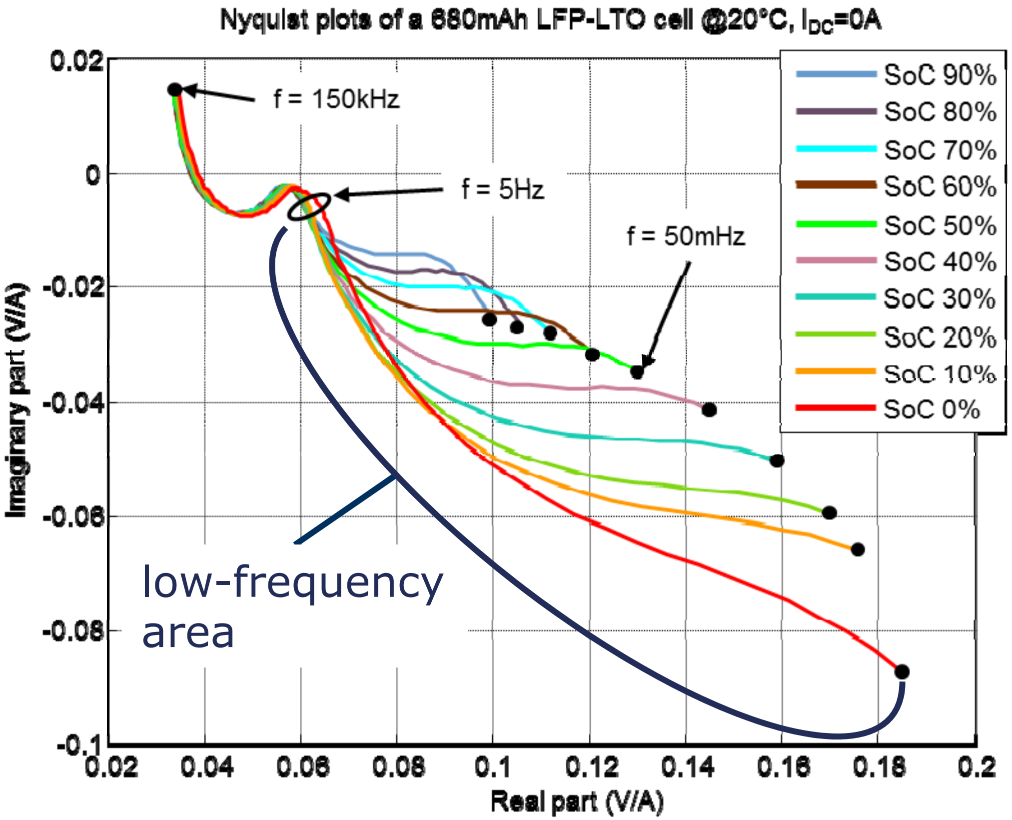


Idea: Overview of the dependency between the cell impedance and the State-of-Charge

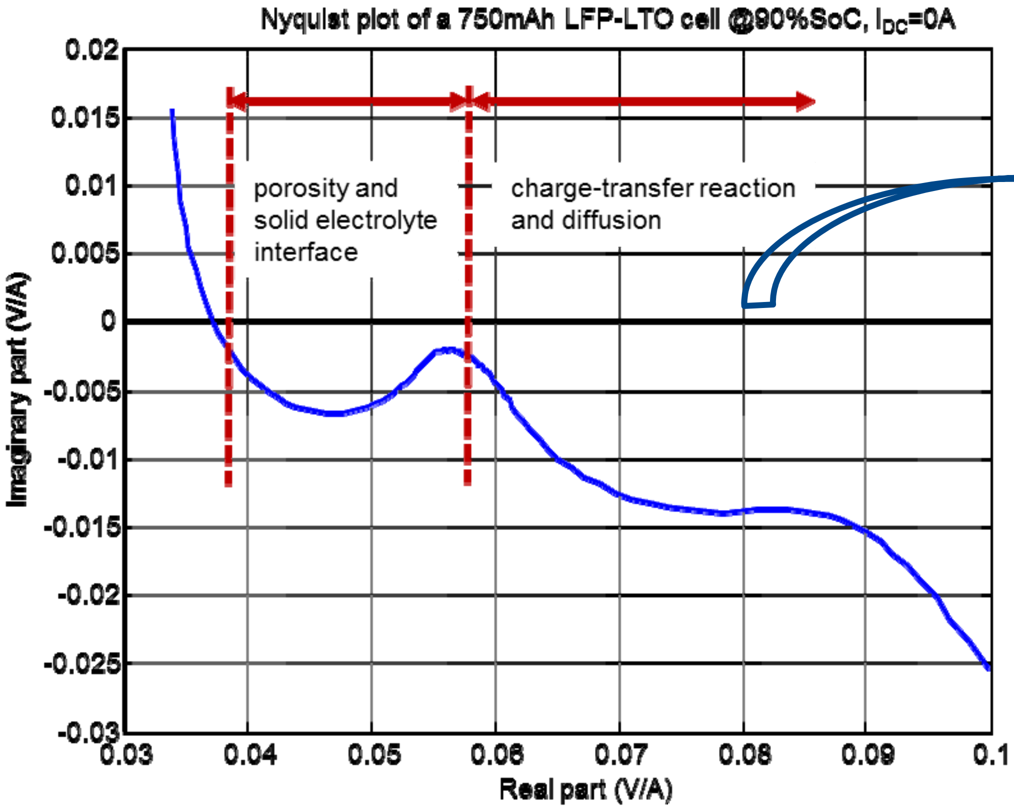
Laboratory Measurements show the dependence between the actual State-of-Charge and the complex impedance.

- The low frequency area is the most significant area for SoC estimation

Battery Laboratory FH-Kiel



Idea: Overview of the dependency between the cell impedance and the State-of-Charge



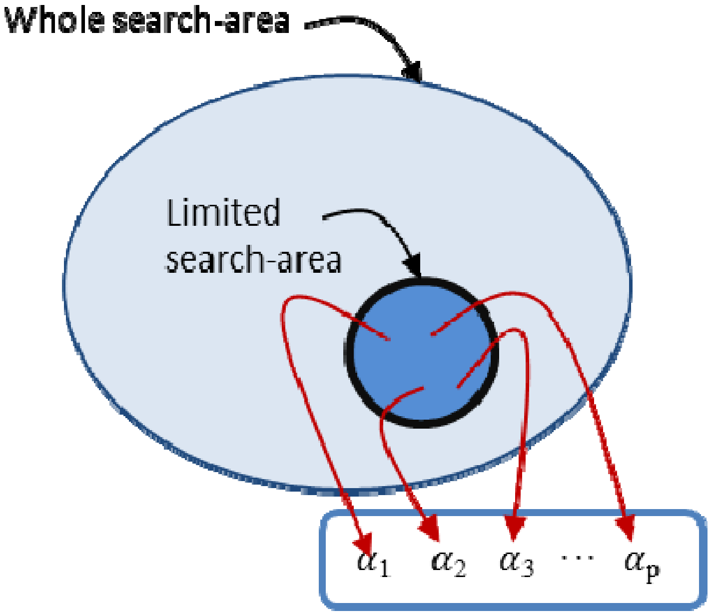
An equation for the significant low frequency area (50mHz-5Hz) can be deduced.

Model equation for charge-transfer and diffusion [Troeltzsch]

$$Z_{cell} = R_S + \frac{R_D}{j\frac{\omega}{\omega_g} + \frac{1}{1 + \left(\frac{k\omega_g}{j\omega}\right)^{\alpha}\sqrt{2}}}$$

Gen vector: $\vec{g_1} = \begin{pmatrix} R_S \\ R_D \\ \alpha \\ k \\ \omega_g \end{pmatrix}$

Design of the Genetic Algorithm: Just seven steps



$$\vec{g}_1 = \begin{pmatrix} 0{,}001\Omega \\ 0{,}001\Omega \\ 0{,}05 \\ 10^{-6} \\ 0{,}1s^{-1} \end{pmatrix} \dots \vec{g}_u \dots \vec{g}_p = \begin{pmatrix} 1\Omega \\ 0{,}1\Omega \\ 0{,}9 \\ 10^{-2} \\ 100s^{-1} \end{pmatrix}$$

1) Definition of the external limits of the interested parameters.
2) Generation of a start population of **p** gen-vectors.
3) Assessment of each vector according to a prescribed fitness function.
4) Selection of the best **b** gen-vectors and propagate **p** new gen-vectors
5) Mutation of the **b** gen-vectors.
6) Replacement of the old population by the new **b** gen-vectors.
7) Repetition of step three to six until a termination condition is reaches.

Development:
Model based on parameter determination.

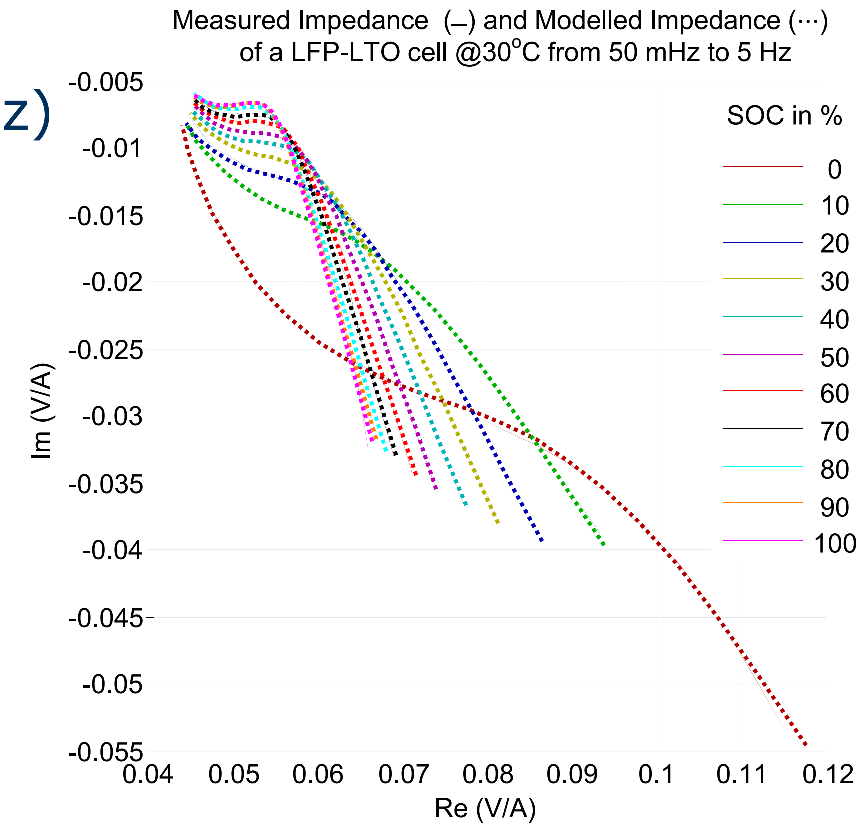
- ❑ An equation for the significant low frequency area (50mHz-5Hz) can be deduced.
- ❑ With a developed genetic algorithm five parameters are determined.

Model equation [Troeltzsch].

$$Z_{cell} = R_S + \frac{R_D}{j\frac{\omega}{\omega_g} + \frac{1}{1 + \left(\frac{k\omega_g}{j\omega}\right)^{\alpha} \sqrt{2}}}$$

Gen vector:

$$\vec{g_1} = \begin{pmatrix} R_S \\ R_D \\ \alpha \\ k \\ \omega_g \end{pmatrix}$$

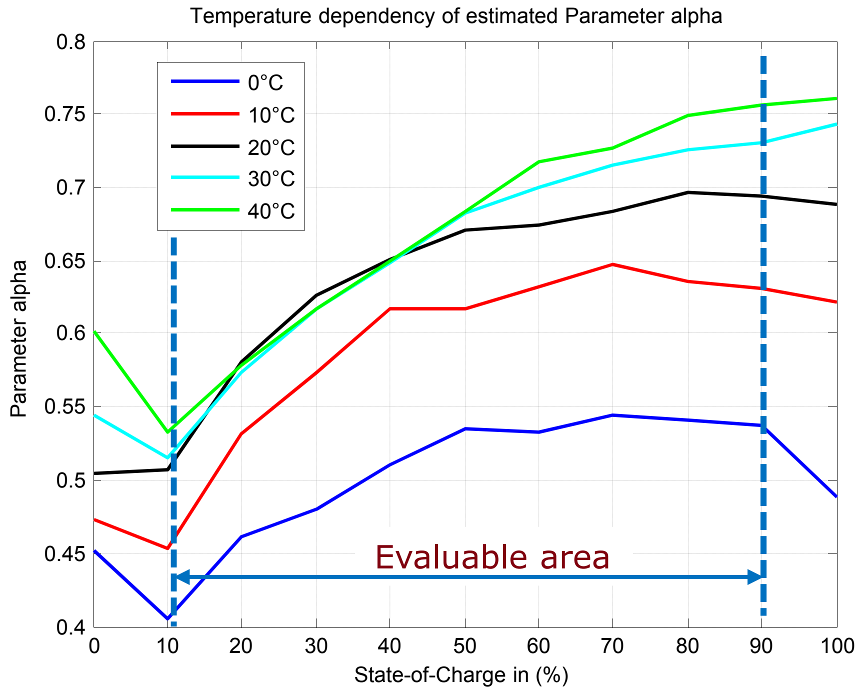


Development:
Model based parameter determination.

- The parameter α will be used to draw conclusions about the actual State-of-Charge.

- The area between 10% and 90% SoC is evaluable.

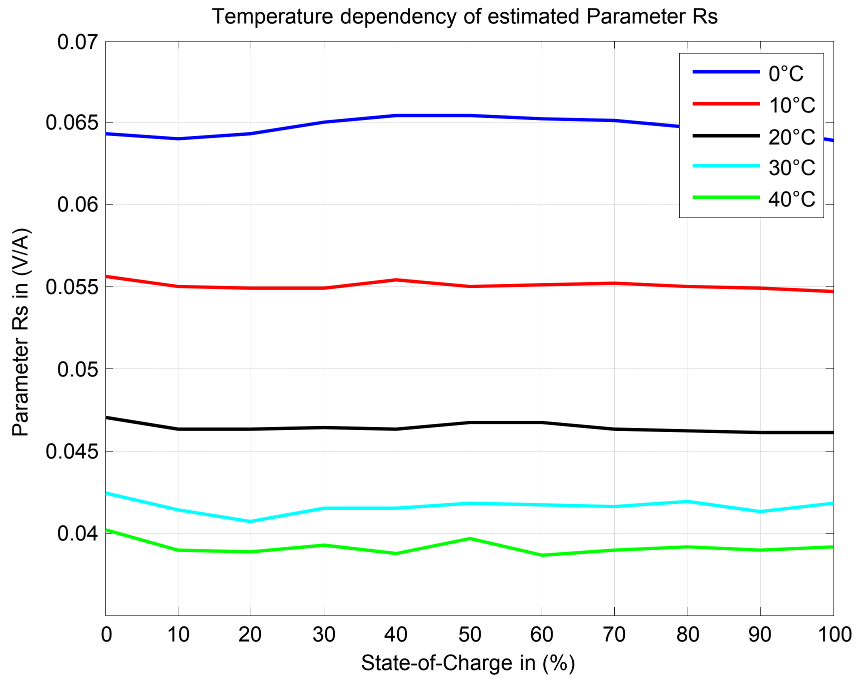
- The temperature dependence has to be taken into consideration.



Development:
Model based parameter determination.

- The parameter R_s show quasi-constant behavior over the whole State-of-Charge.

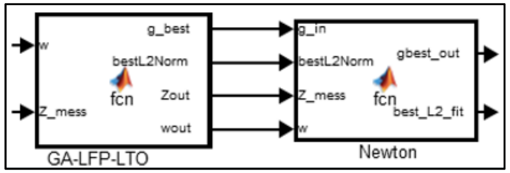
- Pointing out:
  The parameter Rs can be used to draw conclusions about the actual cell temperature for a new cell!



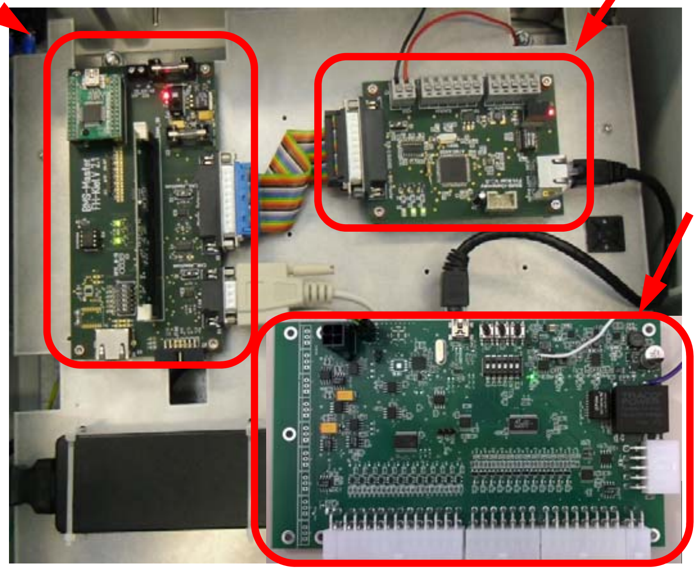
Implementation:
Developed Battery-Management-System.

BMS-Master

- TMS320F28335
- Safety
- Intelligence
- Analyzing:
  - Model based parameter determination



- Estimation algorithms based on parameters e.g.
  - SoH
  - SoC



BMS-Gateway

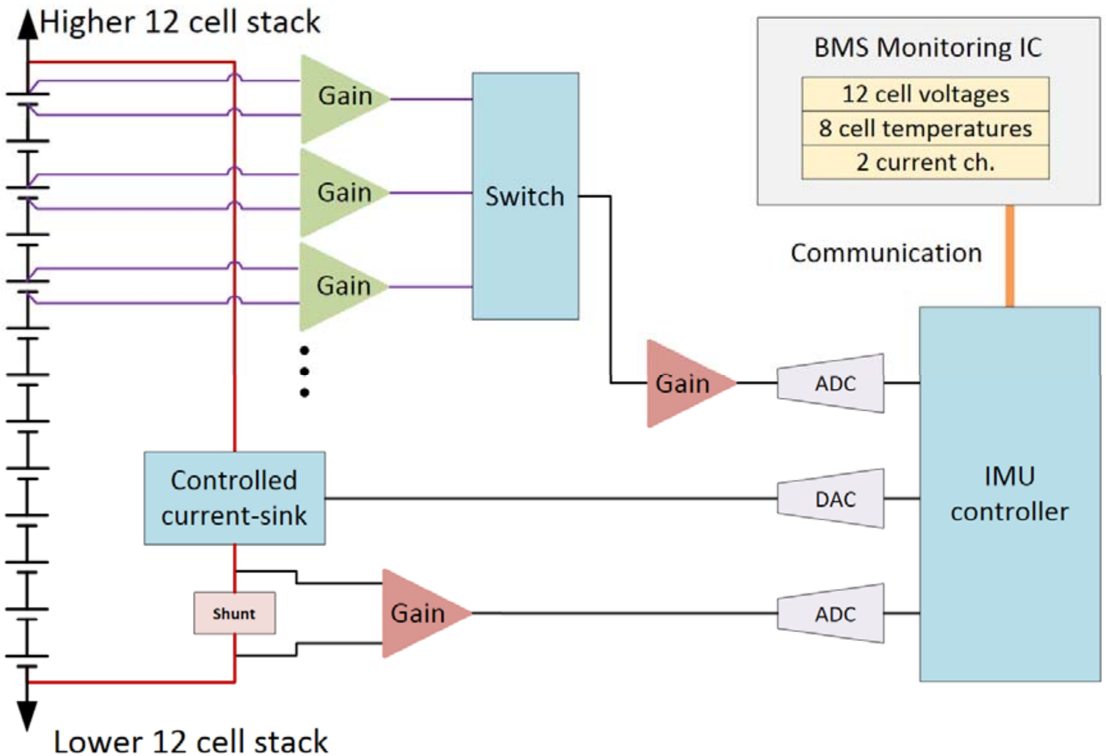
- Communication
  - to BMS-Master
  - to BMS-Slave
  - external signals

BMS-Slave

- Measurement
  - Cell voltage
  - Cell temperature
  - String current
  - Cell individual impedance 50mHz to 5Hz
  - Passive balancing

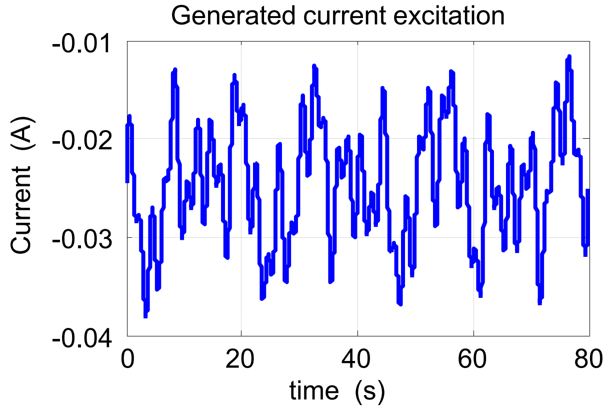
Implementation:
Developed BMS-Slave with Impedance-Measurement-Unit.

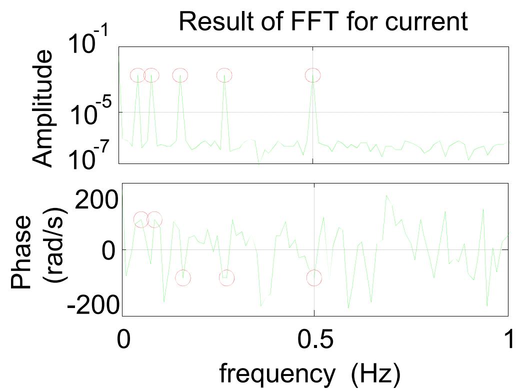
- Sinusoidal Current
- Current-sink:
  up to 1A amplitude
  up to 1A offset
- Single frequency measurement
- Special algorithm with multi frequency measurement to reduce test time

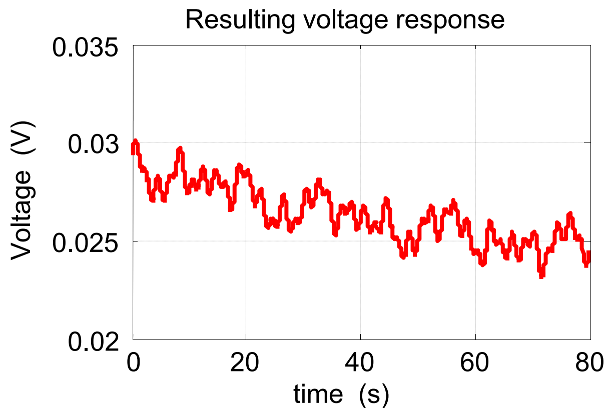


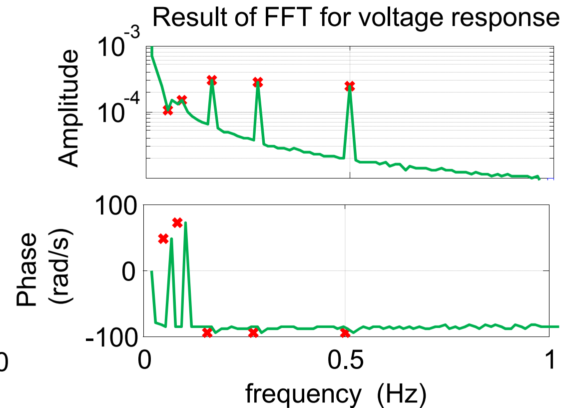
Results:
Developed BMS-Slave with Impedance-Measurement-Unit.

- Multi frequency current excitation of 12 cells in series.
- Five frequencies in 80s: 50mHz, 87,5mHz, 162,5mHz, 275mHz and 500mHz.
- The resulting voltage response of each single cell is measured.
- Fast-Fourier-Transform is used to calculate the impedance at each frequency step.





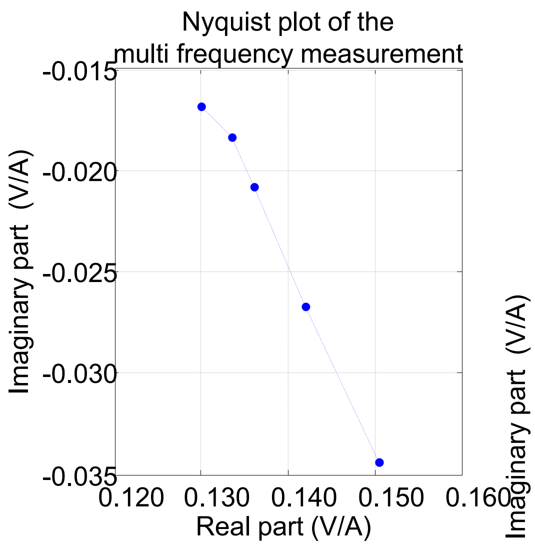




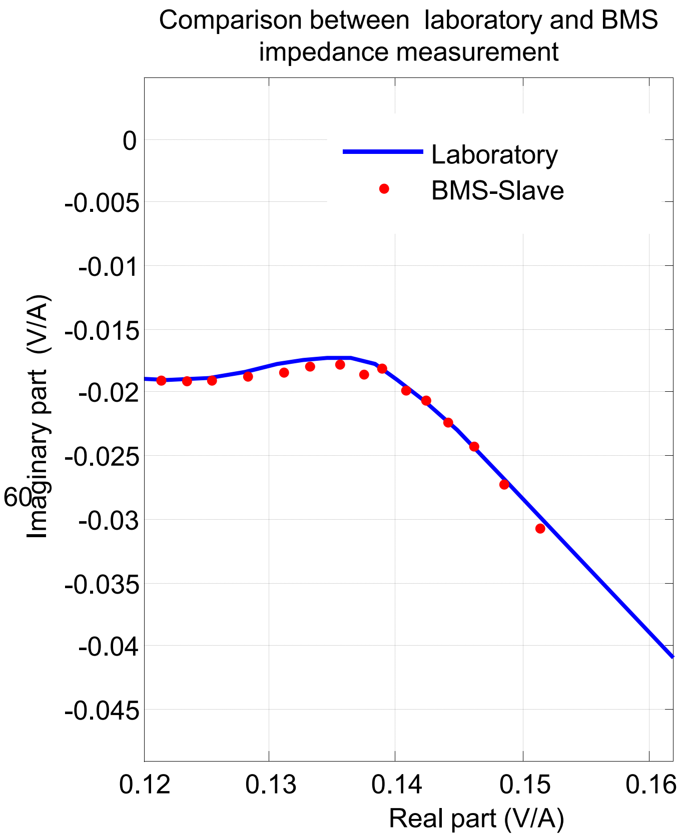
Results:
Developed BMS-Slave with Impedance-Measurement-Unit.

The results are adequate to draw conclusions for SoC estimation.

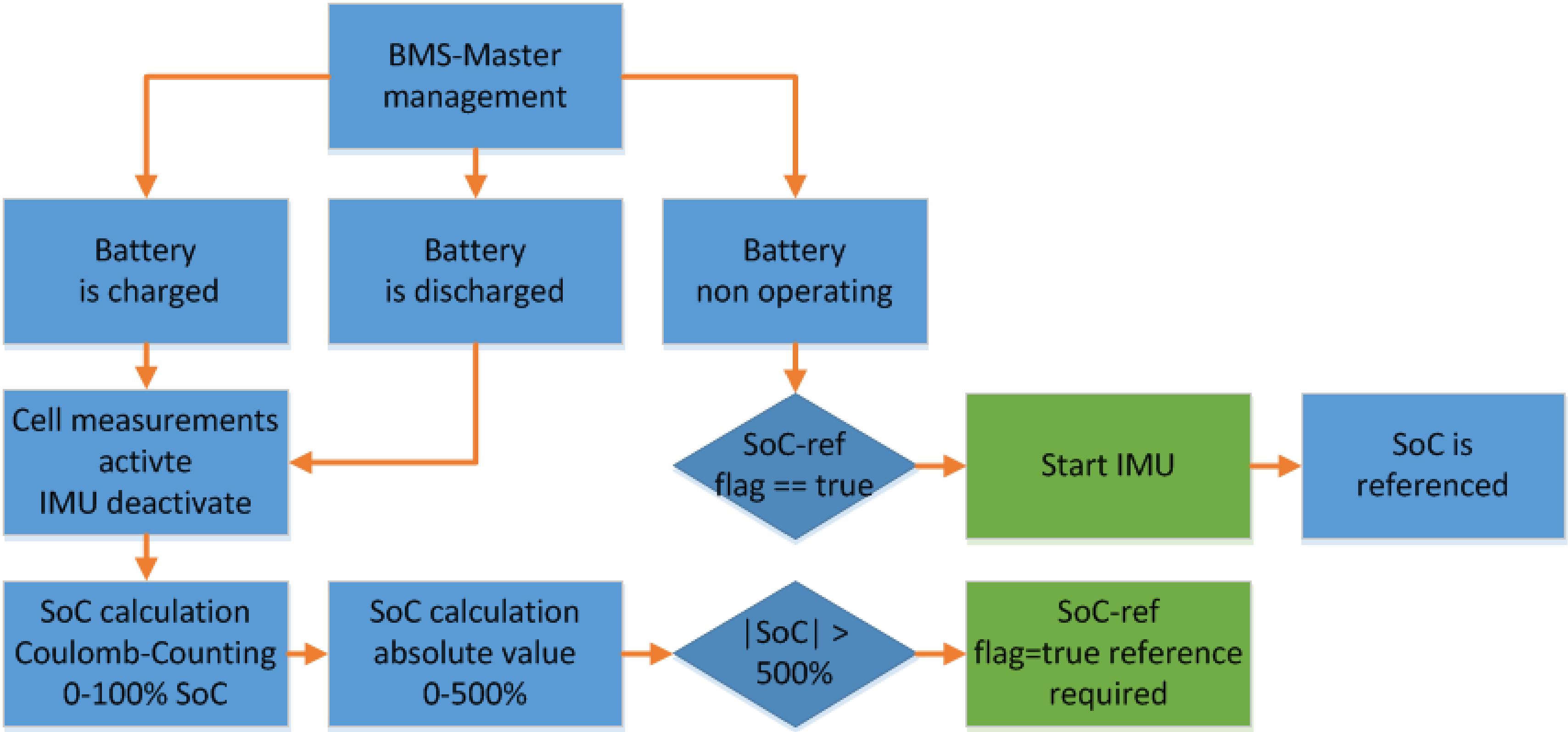
- The GA can be used to synchronize the calculated SoC from coulomb count or observers during steady state phases of the battery.



3 multi frequency measurements

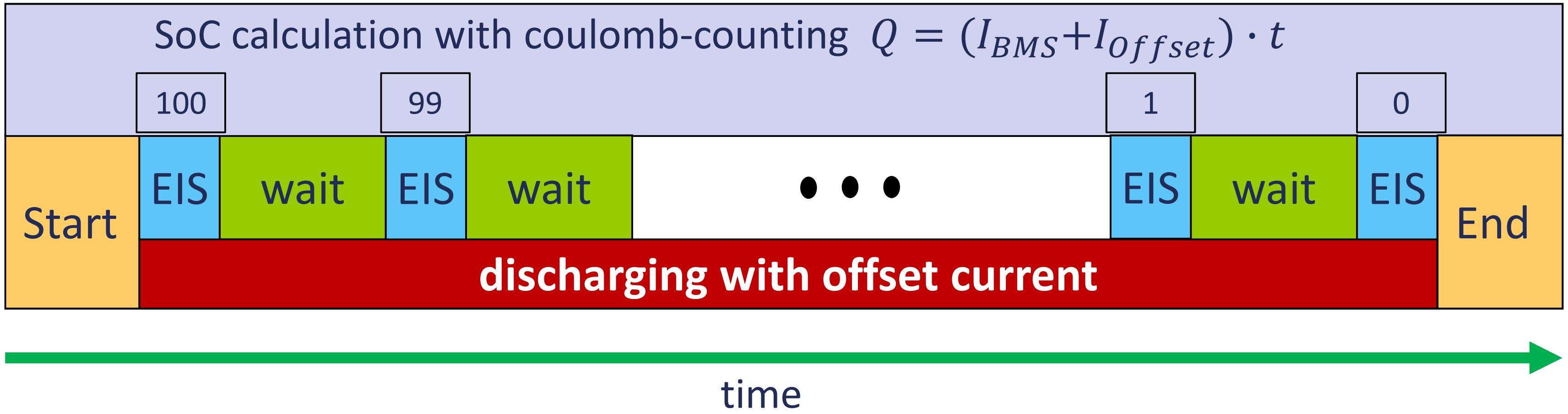


Procedure of the Operation of the BMS: State-of-Charge estimation with this new BMS.



Due to manufacturing tolerances a Self-Calibration-Cycle with this new BMS is necessary.

- Starting after battery pack is constructed.
- Set offset current (discharge) approx. 1/24C – rate.
- Battery is discharged continuously with offset current.
- Each 1% SoC step an impedance measurement is performed.
- End of SCC when battery discharge condition is reached.



Summary

- A method for State-of-Charge estimation based on impedance measurements was developed.
- The impedances were analyzed for identify significant model based parameters.
- A BMS which is capable to measure the impedance by a self developed electronic circuit was developed.
- The algorithm and measurement technique was tested on real battery cells.
- A Self-Calibrating-Cycle was illustrated

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Thank you very much for your attention!