



MEASUREMENT AND SENSOR
TECHNOLOGY



Department of
Electrical Engineering and
Information Technology



CHEMNITZ UNIVERSITY OF
TECHNOLOGY

Multispectral Impedance Measurement in Embedded Systems

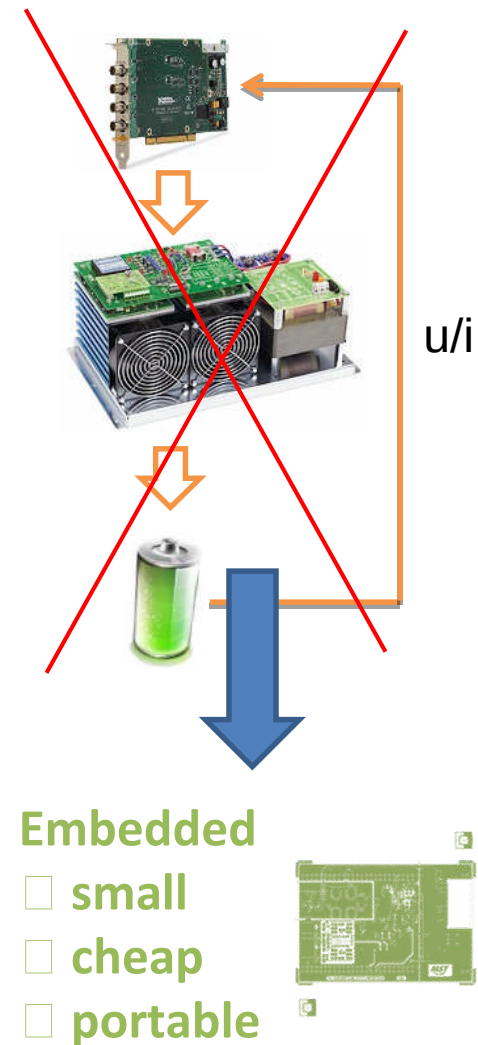
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Paul Büschel, Olfa Kanoun

10th International Symposium on
Electrochemical Impedance Analysis 2014

June 1-5, 2014 Borvets, Bulgaria

Outline

- Motivation
- System Structure
- Perturbation Sequence
- System Structure
- Calculation of Impedance Spectra
- Prototype



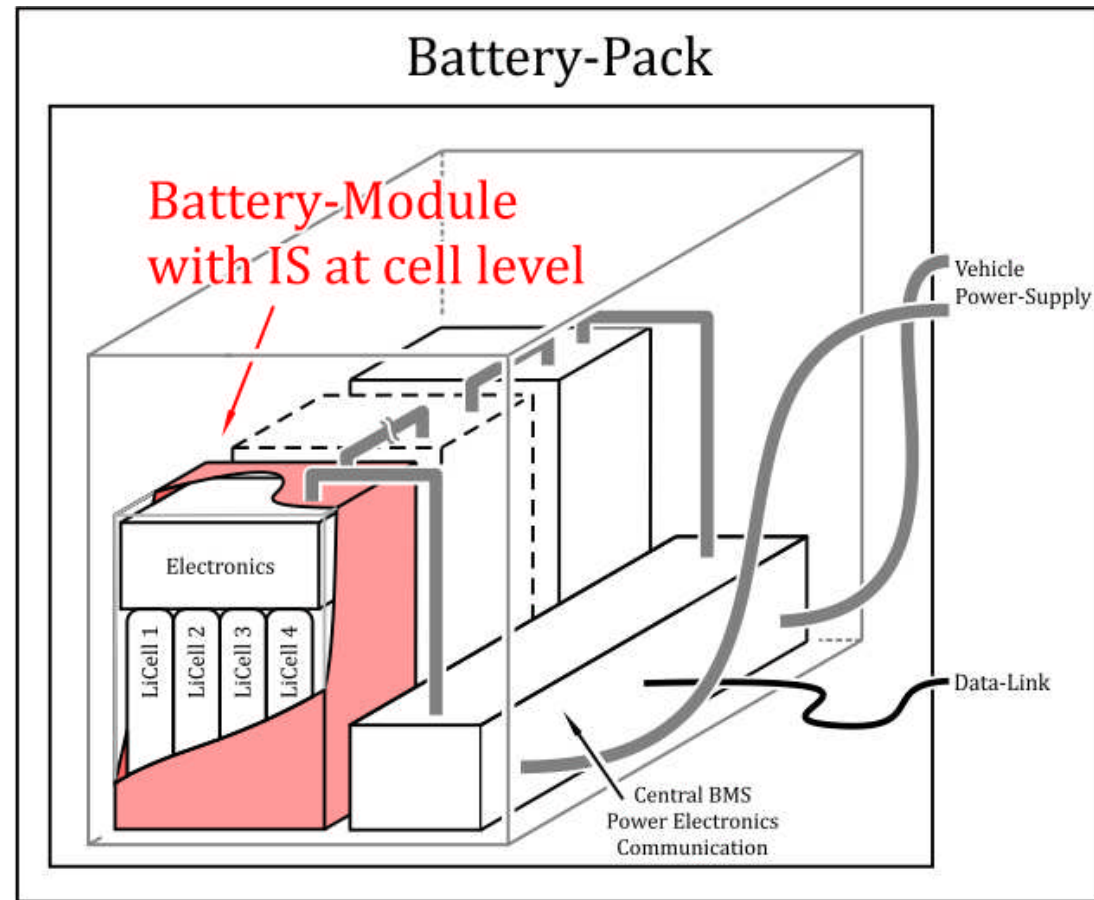
Motivation

■ Battery-Packs in cars

- One big block
- Non-modular setup
- Huge amount of data in tables (hundreds of MB)

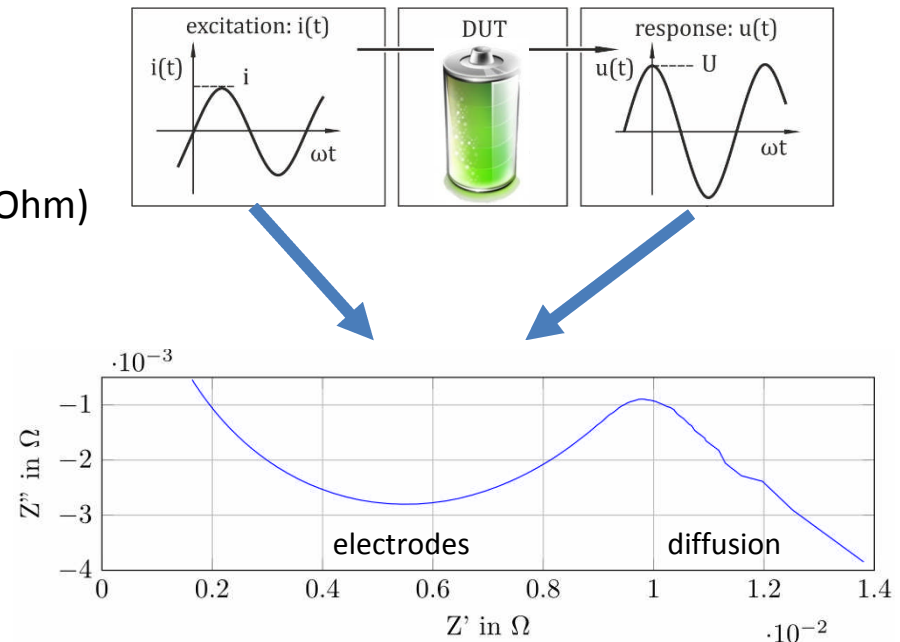
■ AIM

- Modular system structure
- Single cell observation
- Support battery management with measured data
- Usage of standard components



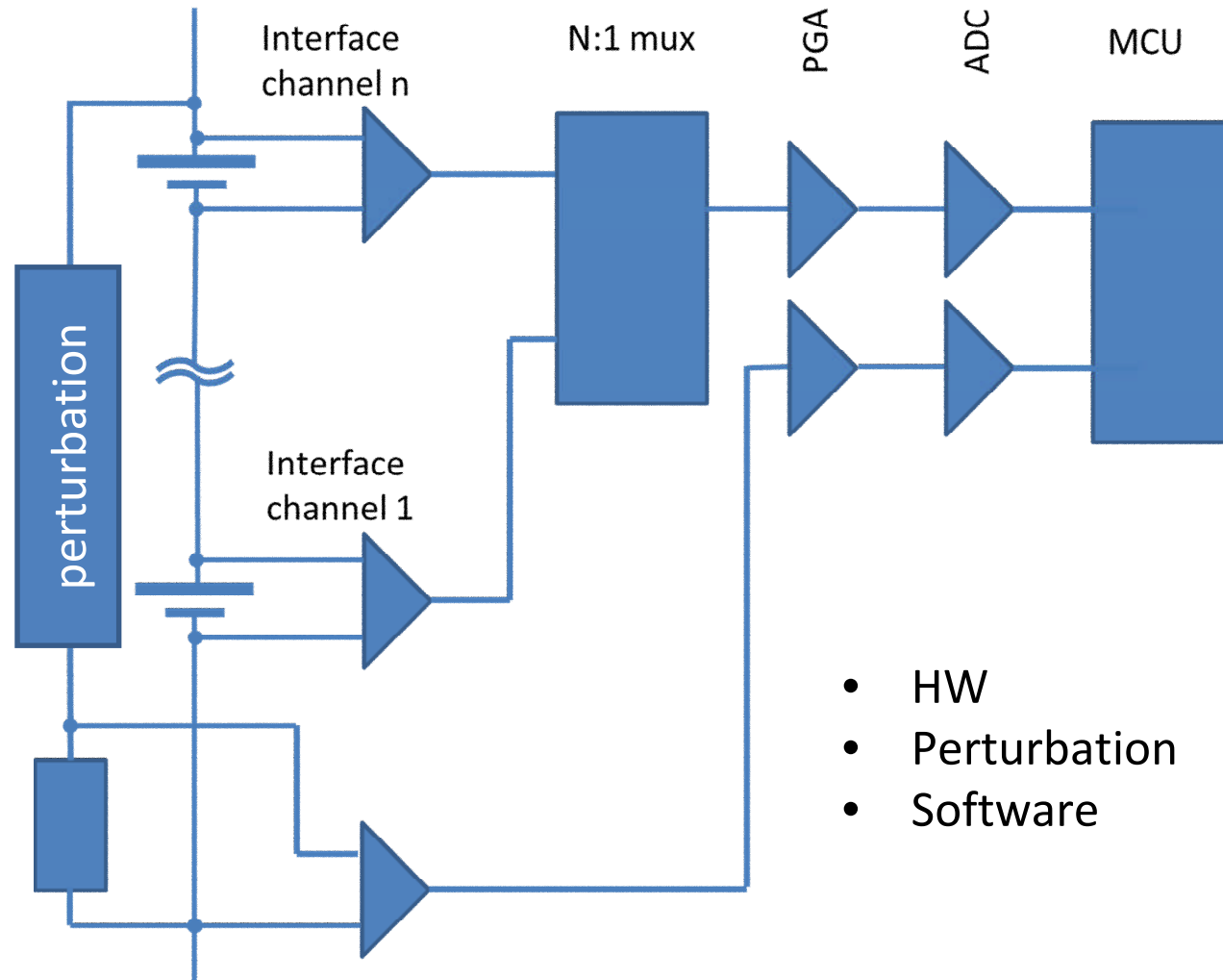
Motivation – Requirements

- Measure electrode and diffusion effects
 - Information is in the ac behavior
 - Measure in a wide frequency range approx. (10mHz up to 1kHz)
 - Battery is a low ohmic device (approx. 5mOhm)
- MCU is very limited
 - performance
 - memory
- Data Analysis
 - High noise immunity
 - Simultaneous to the measurement
- General (customer)
 - Short measurement time ≤ 5 minutes
 - Low sample-rate (approx. 1kHz)
 - Low HW complexity



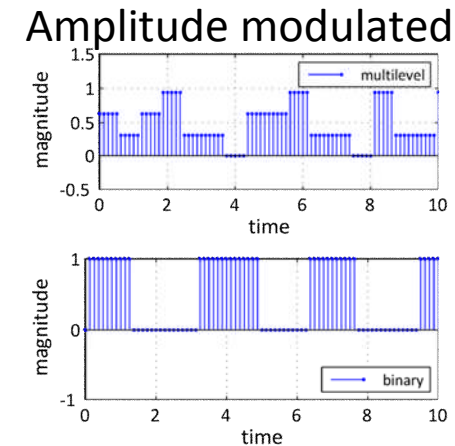
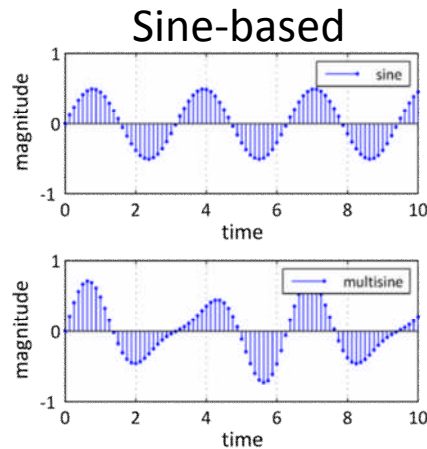
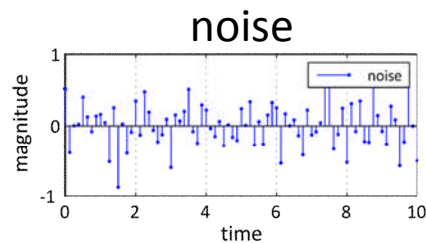
- Determination/Tracking of states
- Simulation in time domain

System Structure



Perturbation Sequence

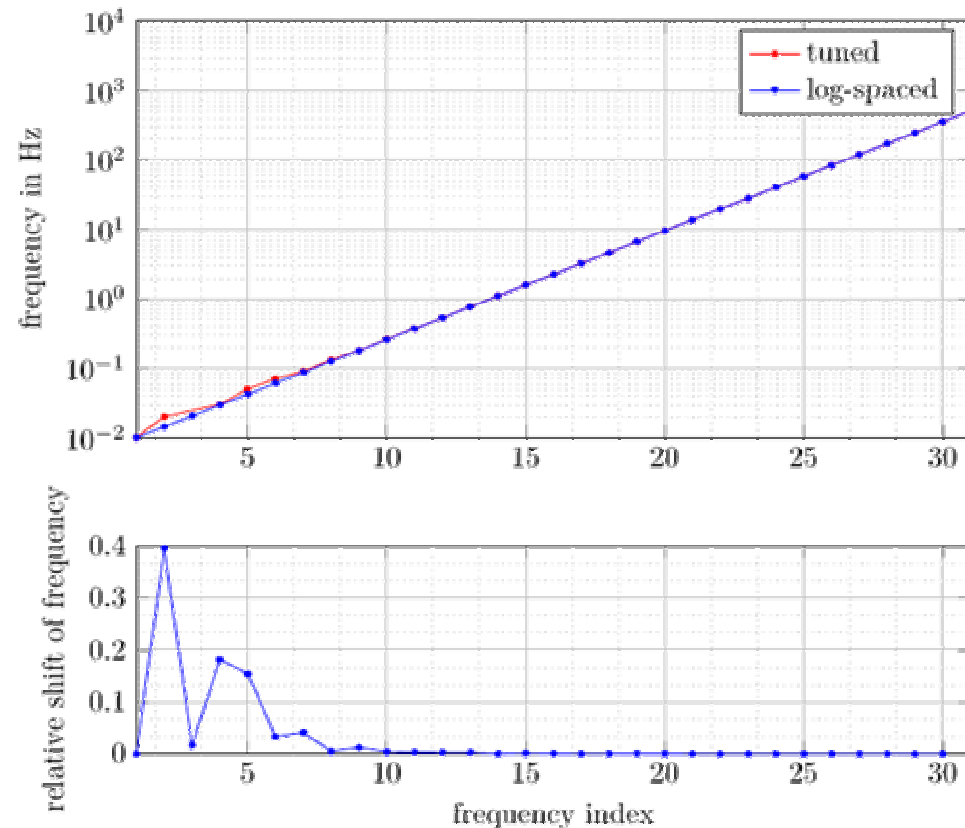
- In Lab 3 main classes of signals for system identification



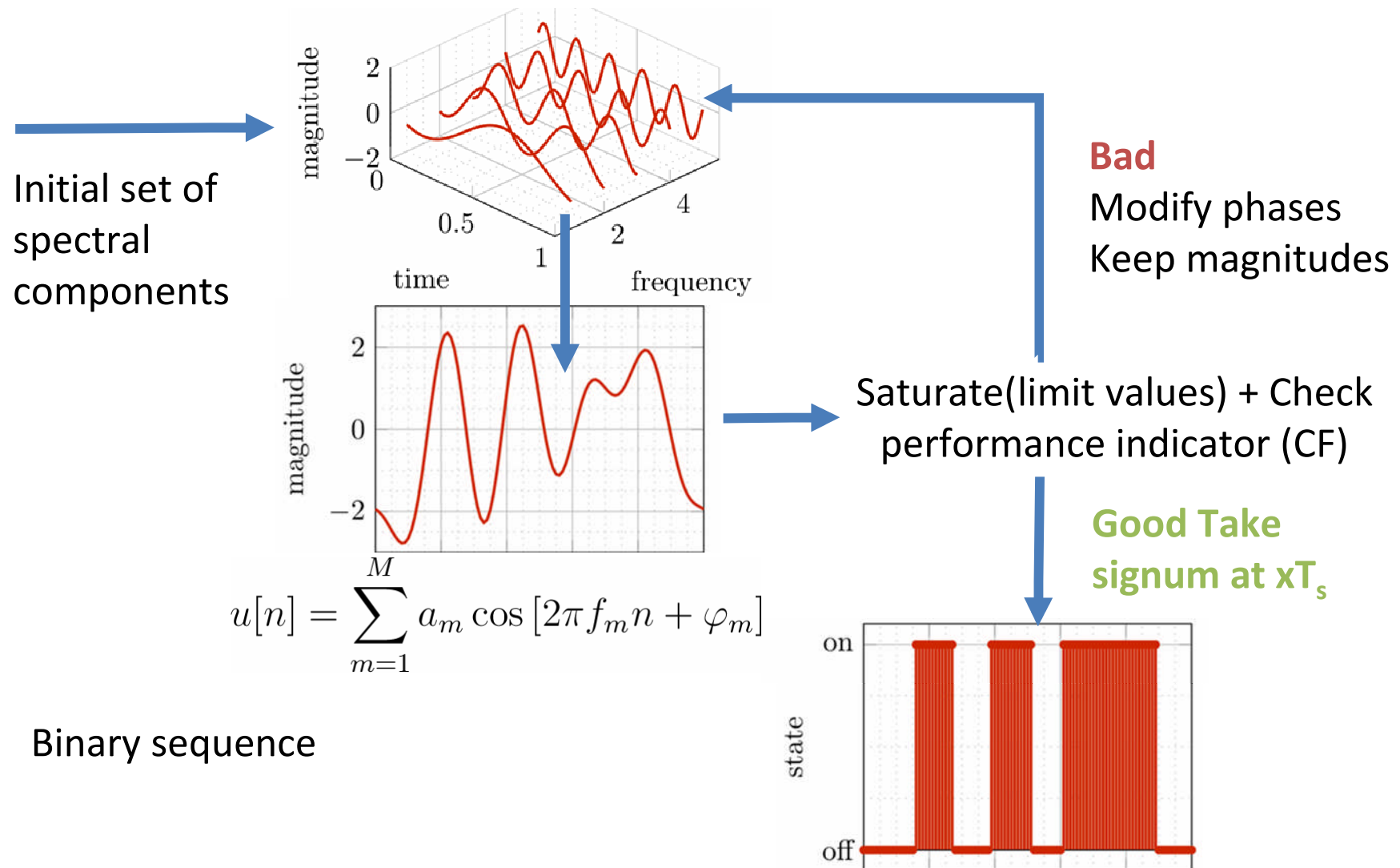
- Important criteria for the experiment
 - Tuned spectral properties (perturb frequencies of interest only)
 - Short measurement time
 - Small magnitude (linearity)
 - Easy to modulate

Perturbation Sequence

- Selection of frequencies for perturbation (30 in total; planned to increase)
- Equally distributed in $\log(f)$
- Avoid leakage → Integral multiplies of smallest frequency

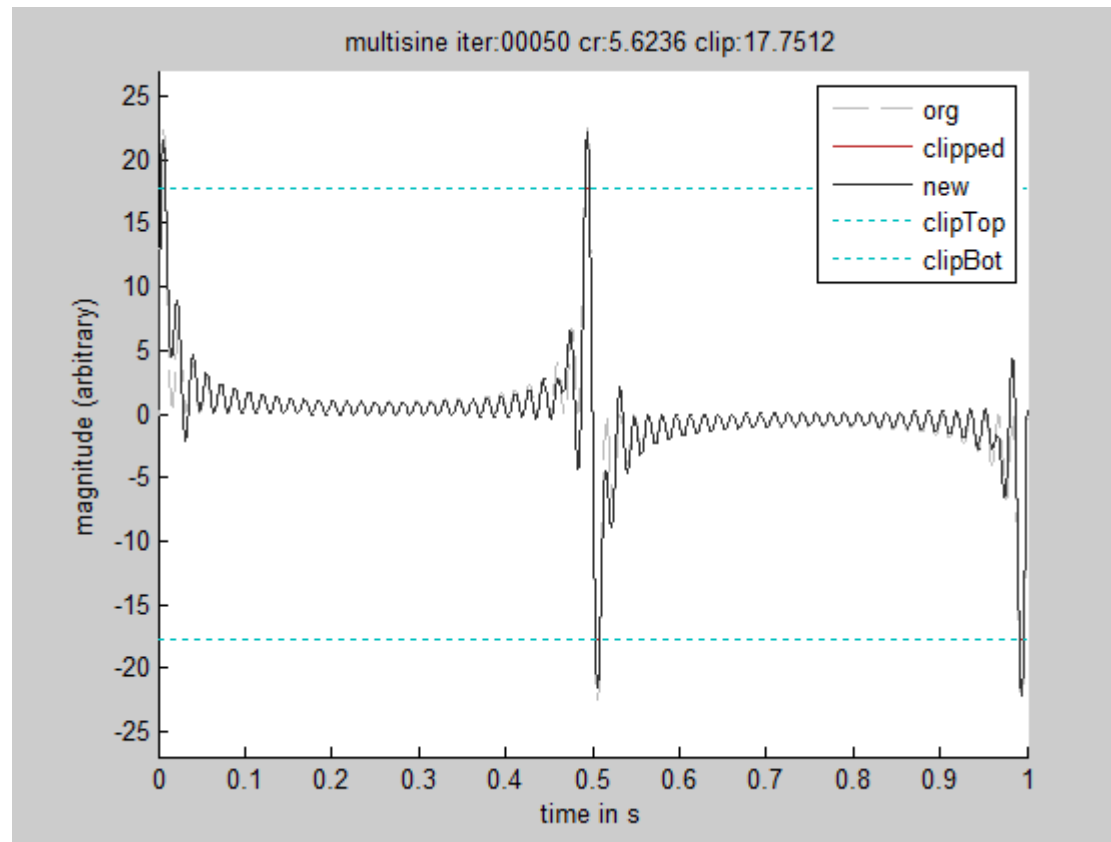


Perturbation Sequence



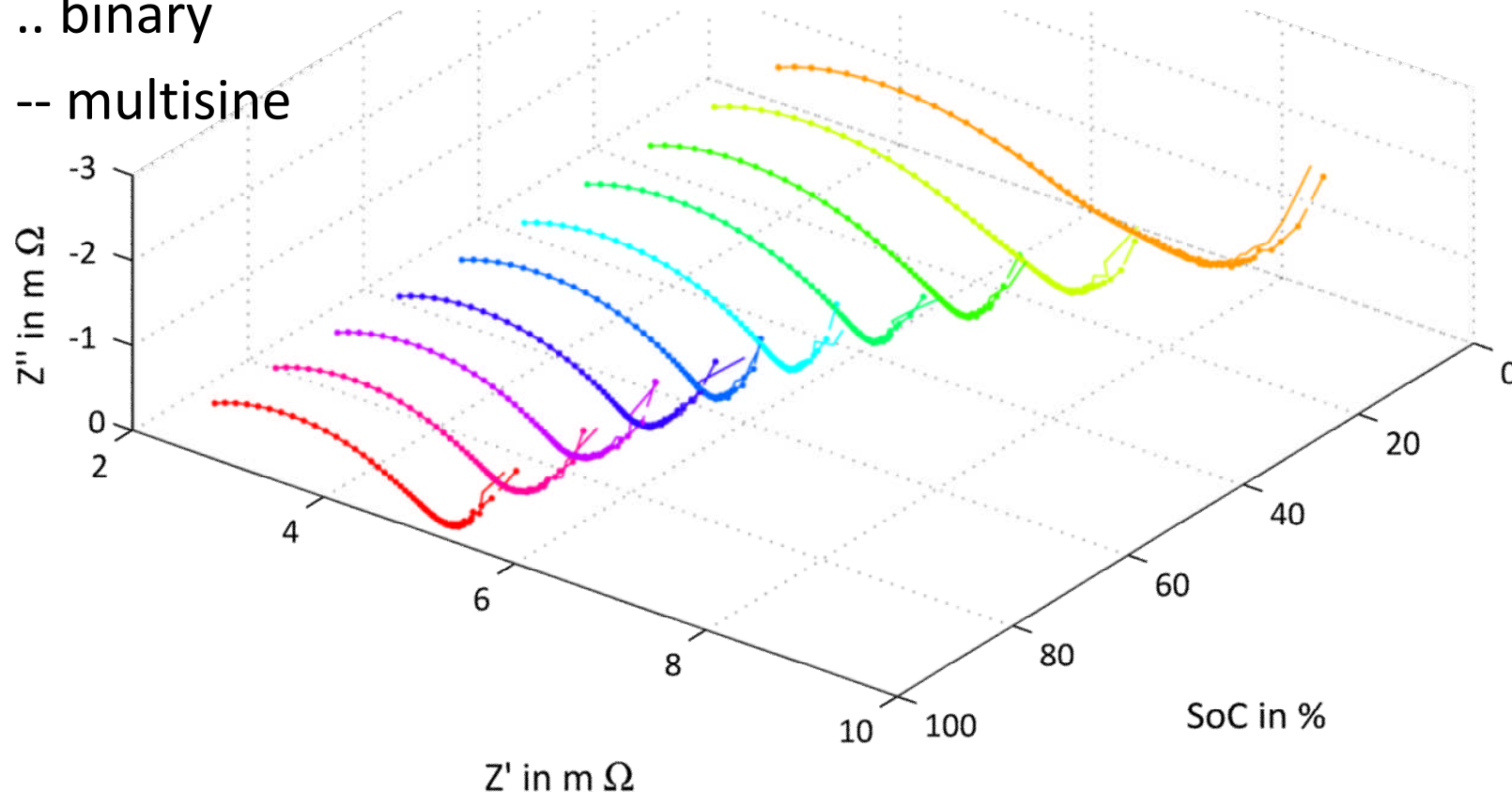
Perturbation Sequence

- Iterative offline optimization of multisine
- CF of a 50% PWM-signal is approx. 1.4



Perturbation Sequence – conclusion

- .. binary
- -- multisine



- measurement of impedance spectra possible with the optimized binary signals

Perturbation Sequence – conclusion

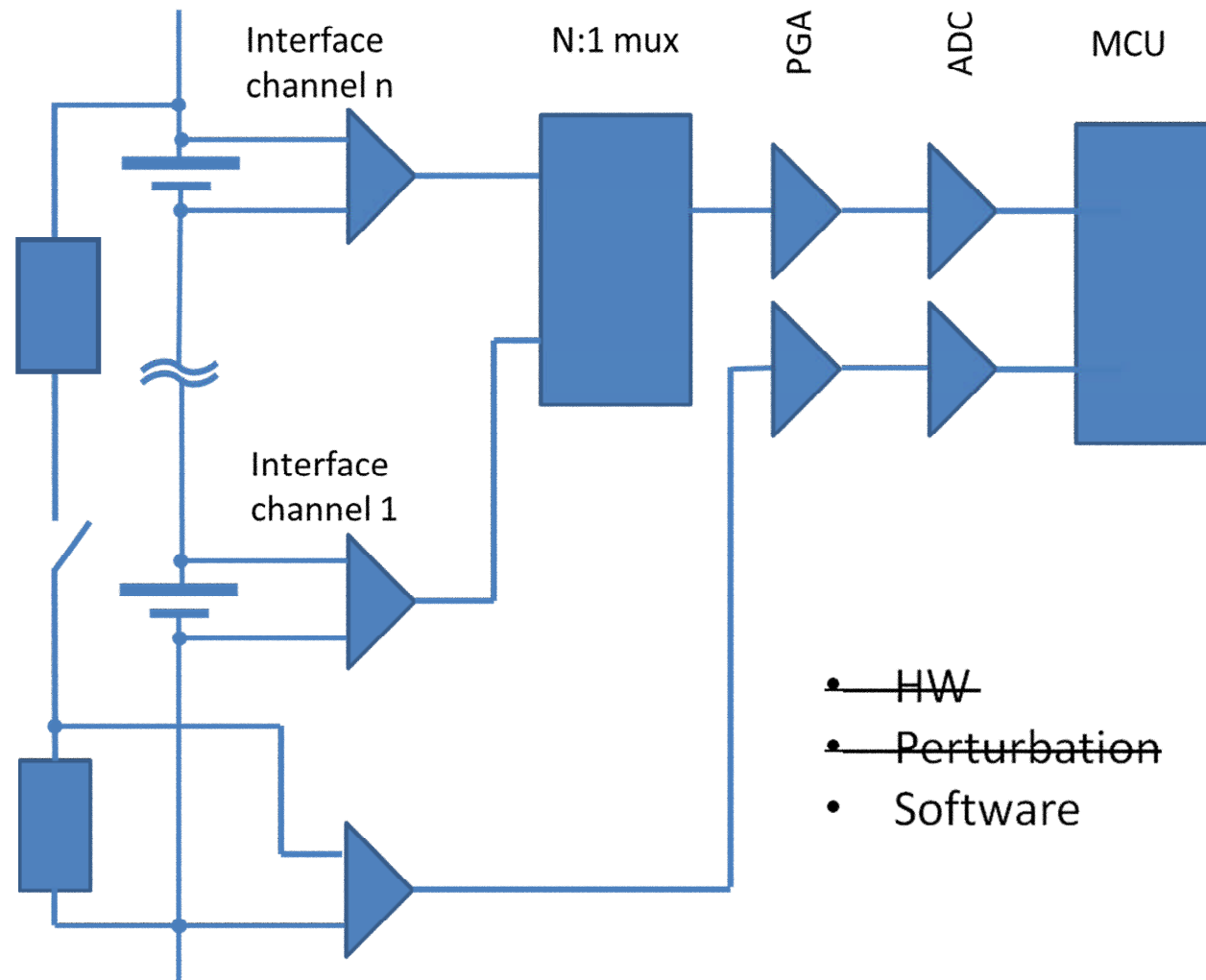
- Design is a high dimensional optimization problem
 - 30 dimensions (planned to increase later)
- Frequencies (and magnitudes) freely selectable
- Offline optimization allows high signal “quality”
- Storage of final sequence in MCU with high compression

- High intrinsic compression by data representation (minimum by 24)
 - (12) 16 to 24 due to magnitude values
 - 8 using bit-packing
- Very low computational load during perturbation
 - No calculation of analogue values
 - No complicated methods underlying (like in DDS)
 - Masking and shifting only (1cycle operations)

- Most simple binary pulse-forming method (1resistor + 1switch)

- But: measurement discharges
 - approx. 0,042 Ah → 0.21% discharge during measurement (20Ah cell)

System Structure



Calculation of Impedance Spectra

- The classical way

- Measure a sequence for $u(t)$ and $i(t)$
- Compute its spectral components using Fourier-transform

$$F(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} f(t) \cdot e^{-i\omega t} dt$$

- Calculate impedance spectra using the complex fourier coefficients
- Need to save the entire sequence (MB of measurement data)

- But

- The frequencies are known
- Perturbation and measurement fully synchronized

Calculation of Impedance Spectra

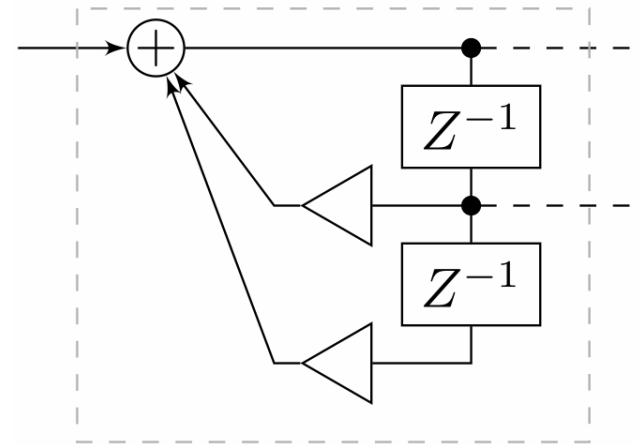
Fourier-transform

$$F(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} f(t) \cdot e^{-i\omega t} dt$$

- Time-domain signal multiplied with complex oscillation
- Oscillations reformulated as transition matrix yields to IIR-filter
- Standard FFT computes for unperturbed components
- Matrix-representation with twiddle factors still needs full/reordered sequence



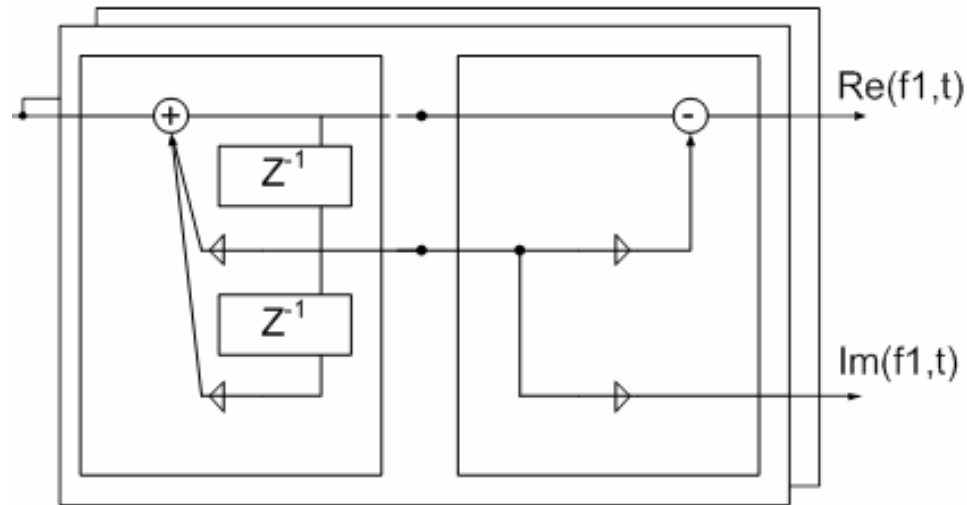
IIR-Approach (Goertzel-filter)



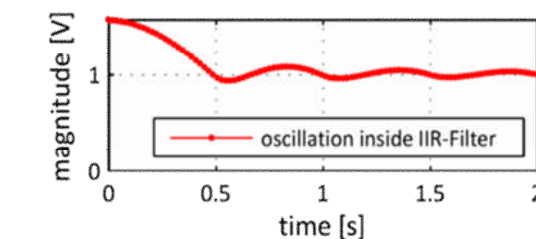
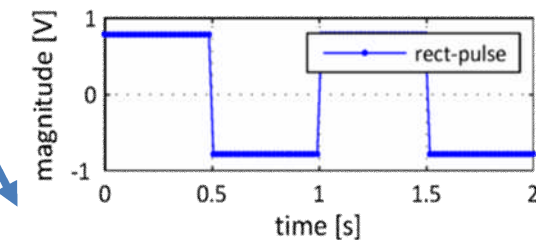
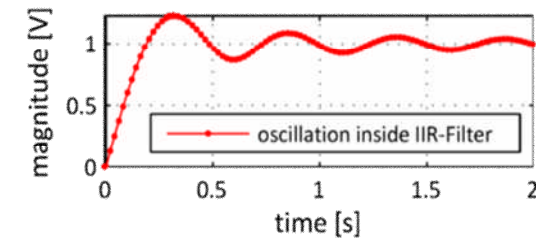
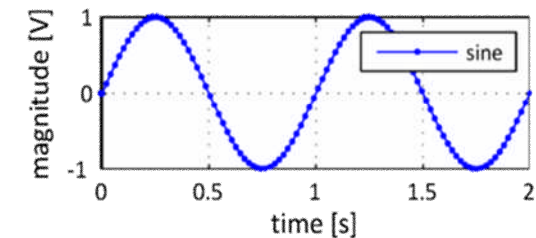
- Computation for needed spectral components only
- Operates on streamed data → computation simultaneous to measurement
- Noise immune
- “operational-gain” usage of simple ADC

Calculation of Impedance Spectra

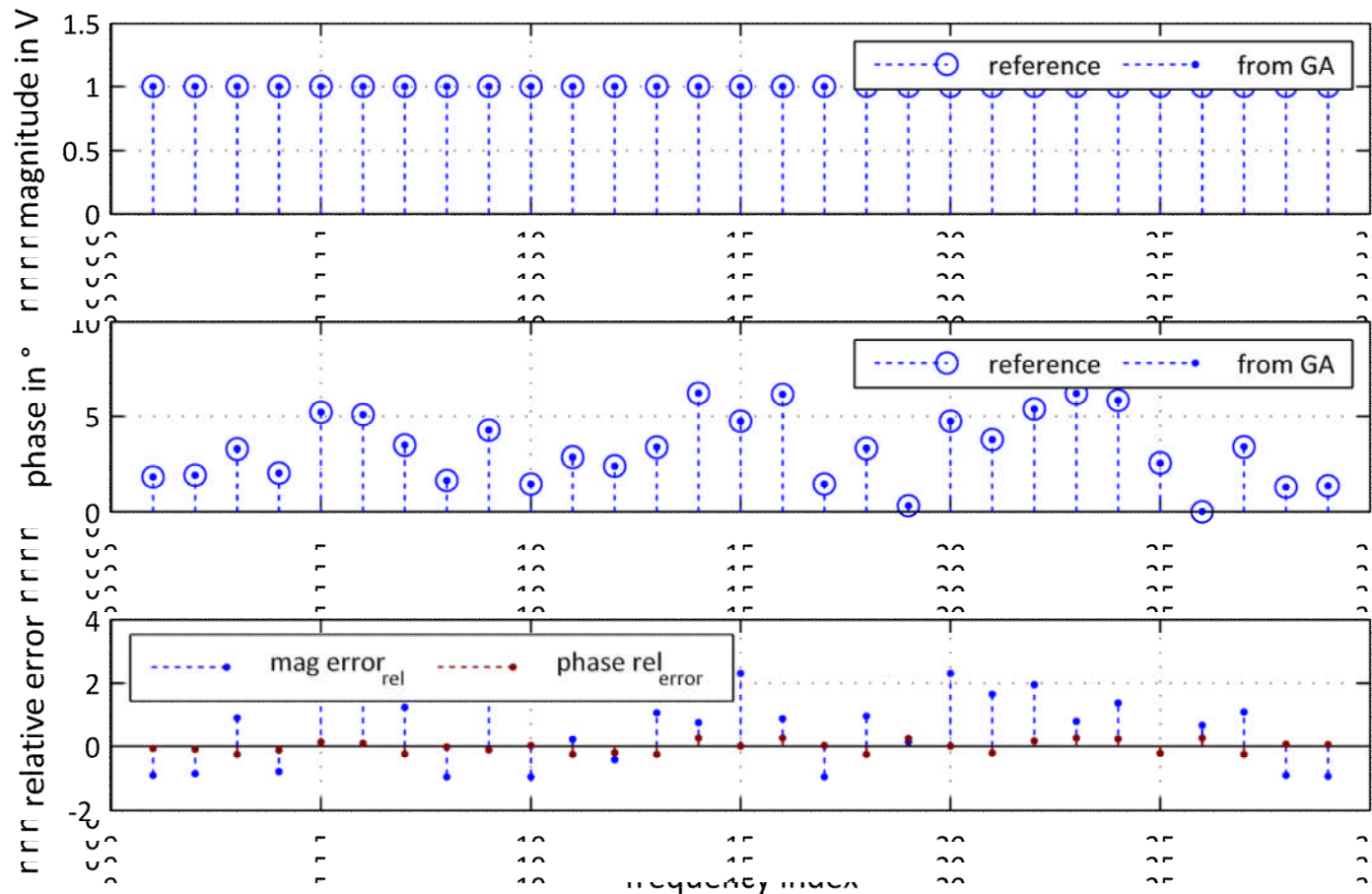
- One filter per frequency and measurement channel



- Left: updated after each measurement
- Right: once after measurement
- Less than 5k RAM in total



Calculation of Impedance Spectra

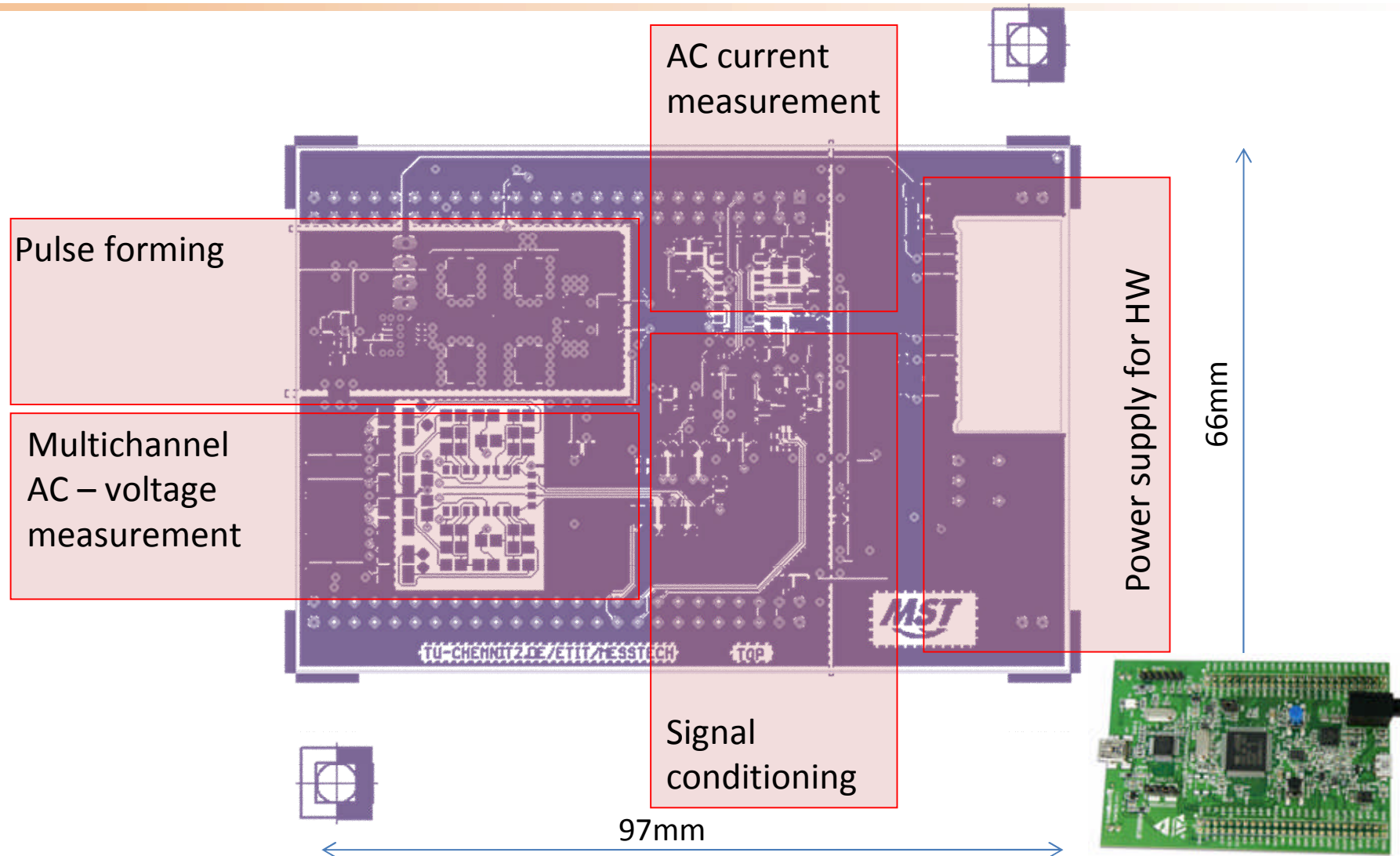


- Goertzel filter bank can be used instead of FFT based methods

Calculation of Impedance Spectra – Conclusion

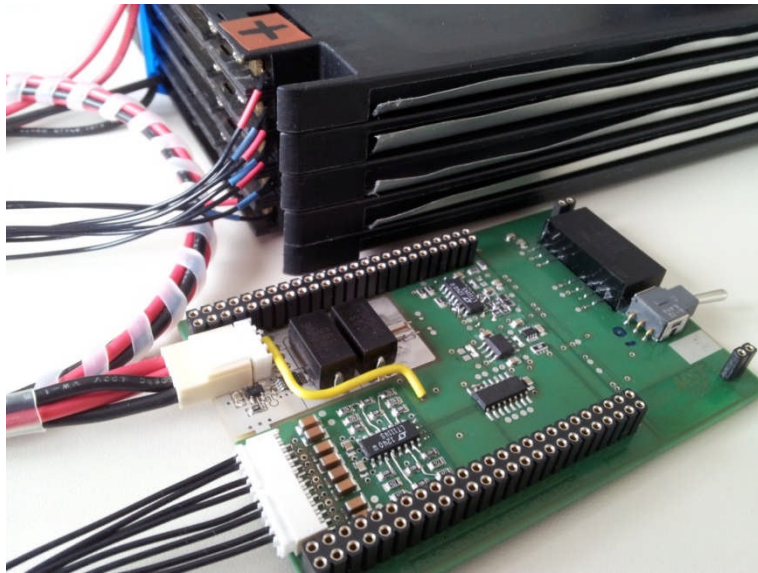
- Update of all filter banks @ MCU in $< .6\text{ms}$ at 1ms cycle time (4x voltage, 1xcurrent, 30 frequencies each)
- Further speedup by > 10 (SIMD extensions + data type optimization)
- Filter-bank approach can be used as alternative for FFT

Prototype – Version 1



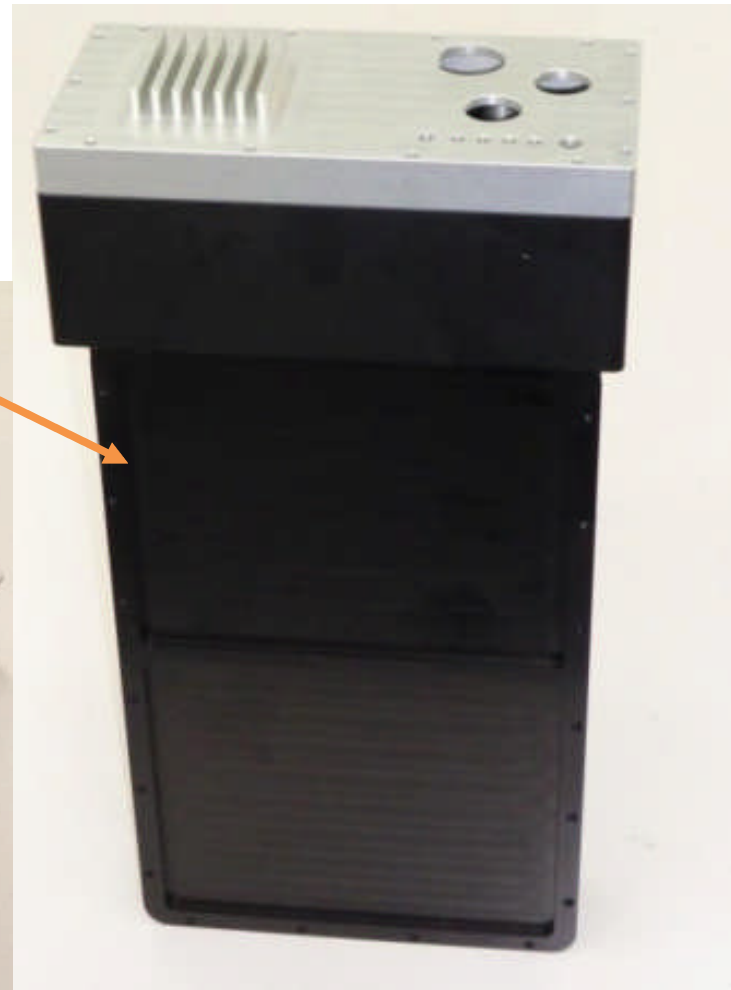
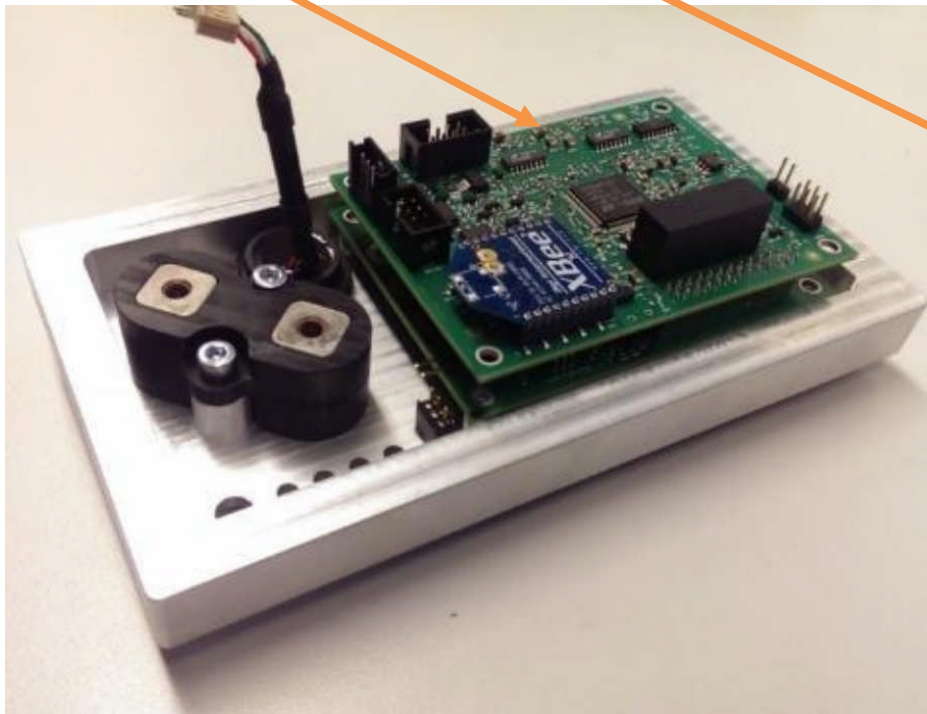
Prototype – Version 1

- Hardware for IS-measurements
- 4x20Ah cells



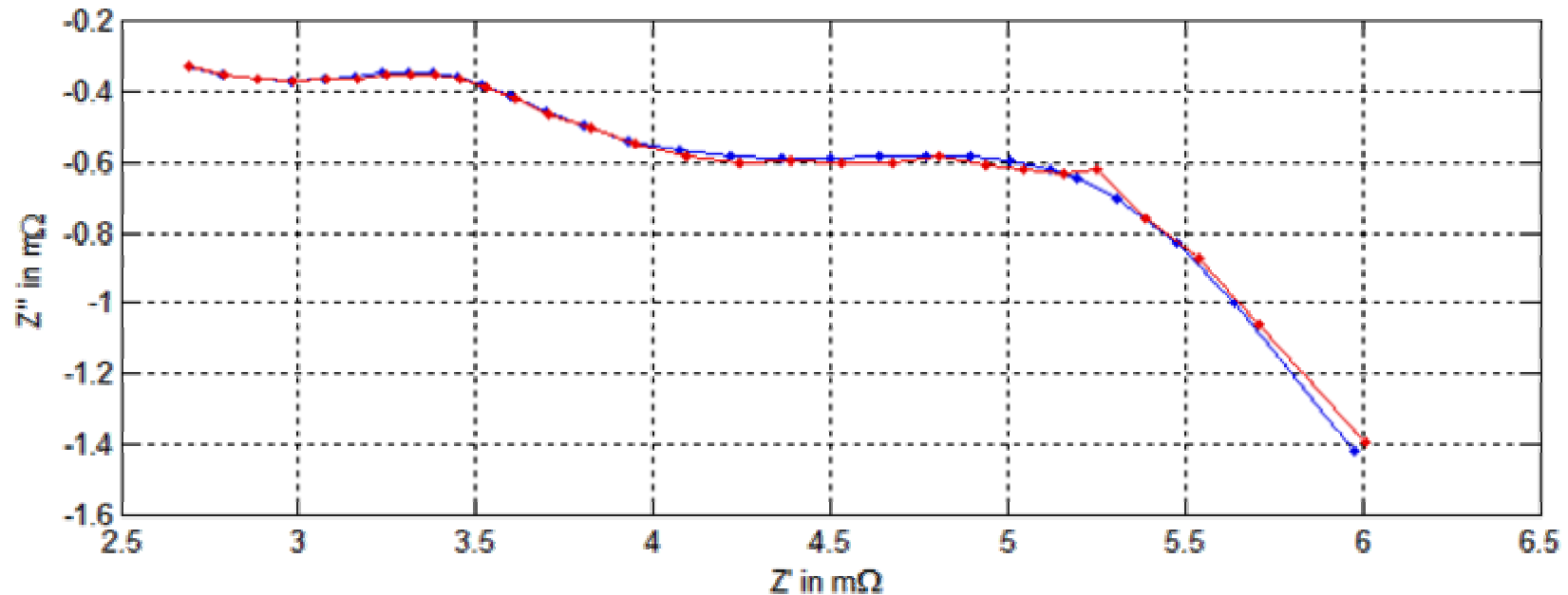
Prototype – Version 2

- Version 2 of the hardware
- Battery (4 cells; 20Ah)
- Hardware



Prototype – Data

- Obtained Impedance Spectrum using the described approach



- HW as shown before
- SW-running on Matlab

Conclusion

- Approaches for
 - Perturbation sequence (binary, high compression, < 90k ROM, 10mHz-1kHz, quasi-log-spaced)
 - Memory load (< 5k RAM during measurement)
 - Computational load (update of filter banks < 0.6ms with 1ms cycle time)
 - Impedance spectra available directly after measurement
 - Simple ADC (12bit, due to Goertzel filter, 16bit or more otherwise)
- Verification of measurements concerning perturbation
- Implementation using Matlab; porting to MCU ongoing
- Prototype using STM32f4
- Scalable to battery packs with #cells > 4
- Next:
 - IS with less discharging
 - Definition of abstract values (SoH, SoF, ...) related to Cells with extended possibilities by IS
- Supported by
 - FP-7 project „SmartLIC“ – 284879
 - ESF research group „AdAntE – 100098113

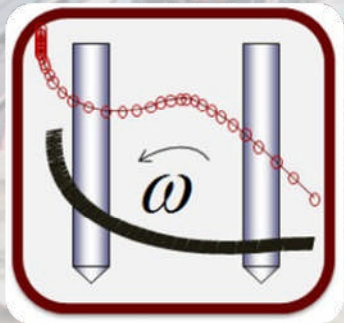


Thank you for your attention!



**5th Symposium on Environmental Instrumentation
and Measurement (IMEKO TC19)**

September 23-24 , 2014 Chemnitz/GERMANY
www.tu-chemnitz.de/imeko

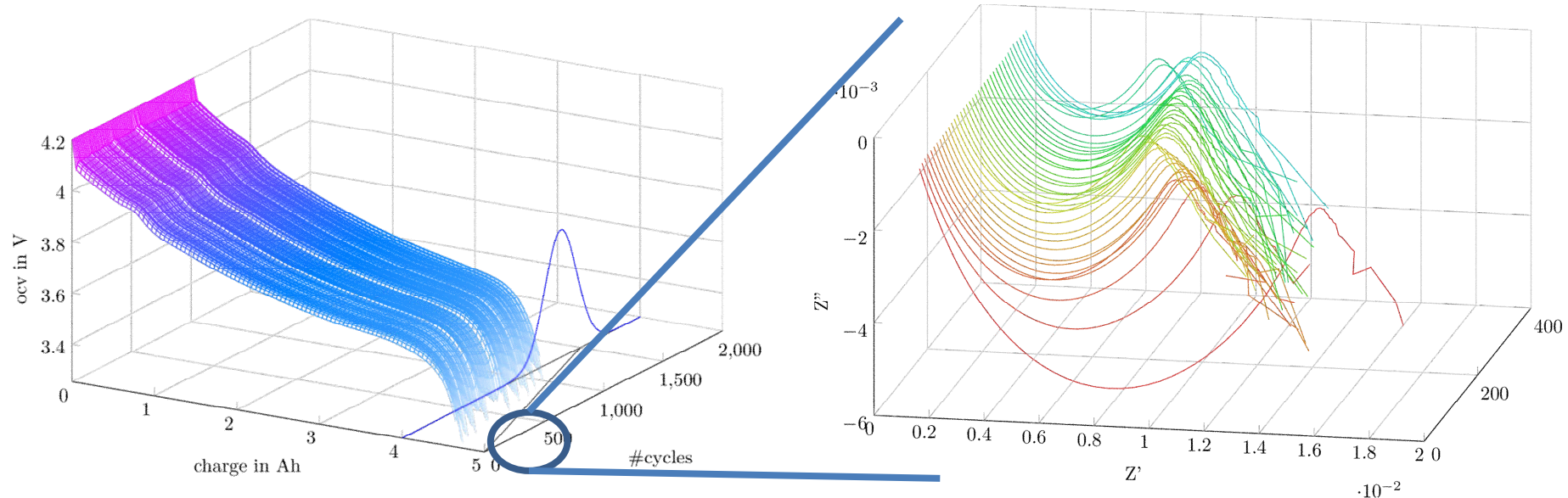


**7th International Workshop on Impedance
Spectroscopy (IWIS'14)**

September 24-26 , 2014 Chemnitz/GERMANY
www.tu-chemnitz.de/iwis

Motivation

- Interesting & reliable data are not available to BMS for now



1C – full cycles not available in the application

Impedance spectra show high sensitivity

- Lets provide data describing the dynamic behavior
- Lets provide data with high relation to internal properties
- Lets provide data gathered from measurements