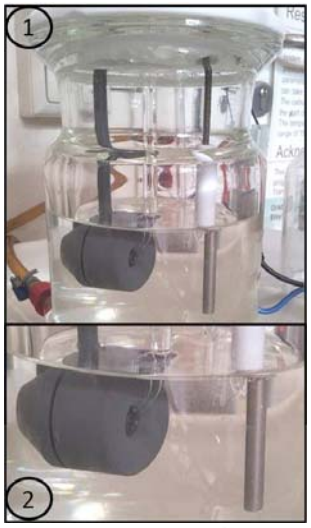
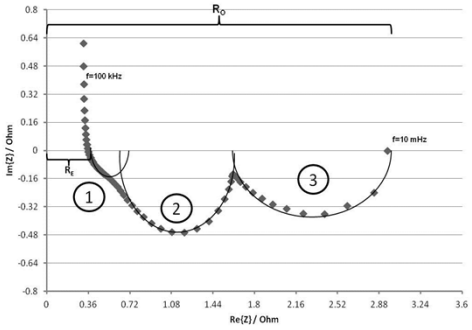
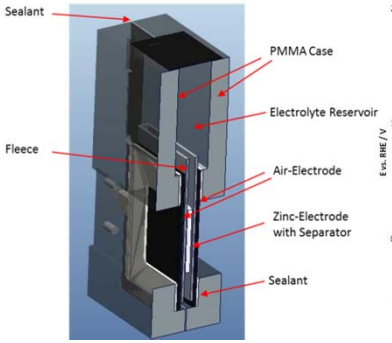
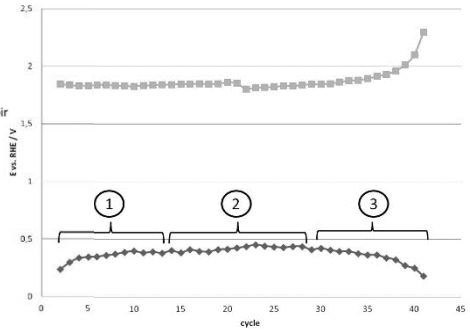
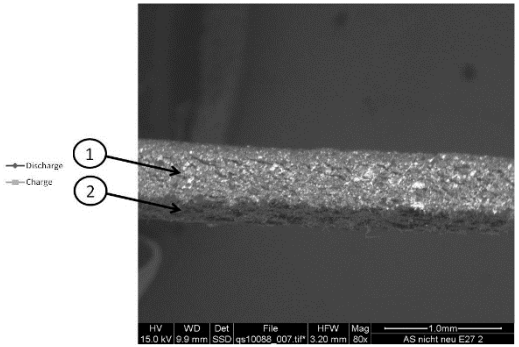
CEET Research Activities
ANNEX 27











Outlook

- Introduction
- Standard Characterisation Techniques
- Online Monitoring Techniques
  - State of Art Real Time Techniques (VM, CVM, EIS)
  - Current Mapping (CM)
  - Single Frequency Impedance Monitoring (sEIS)
  - Total Harmonic Distortion Analysis (THDA)
- New Approaches at TU Graz
  - Spatial Impedance Spectroscopy
  - Spatial THDA
- Conclusion

Reasons for Advanced Online Analysis

- Basis for improved Real Time Control Concepts
  - Static loads ➔ Dynamic loads
- Avoiding critical states improves lifetime
  - No Flooding ➔ Less Carbon Corrosion
  - No Drying ➔ Increased Membrane Lifetime
- Advanced RT Analysis enables very efficient operation of fuel cells
  - Dead end operation ➔ Higher fuel efficiencies
- Enables improved cell/stack design (Spatial information)
- Scientific Interests
  - What happens in a fuel cell stack?
  - Spatial information could be compared with simulation results

Status

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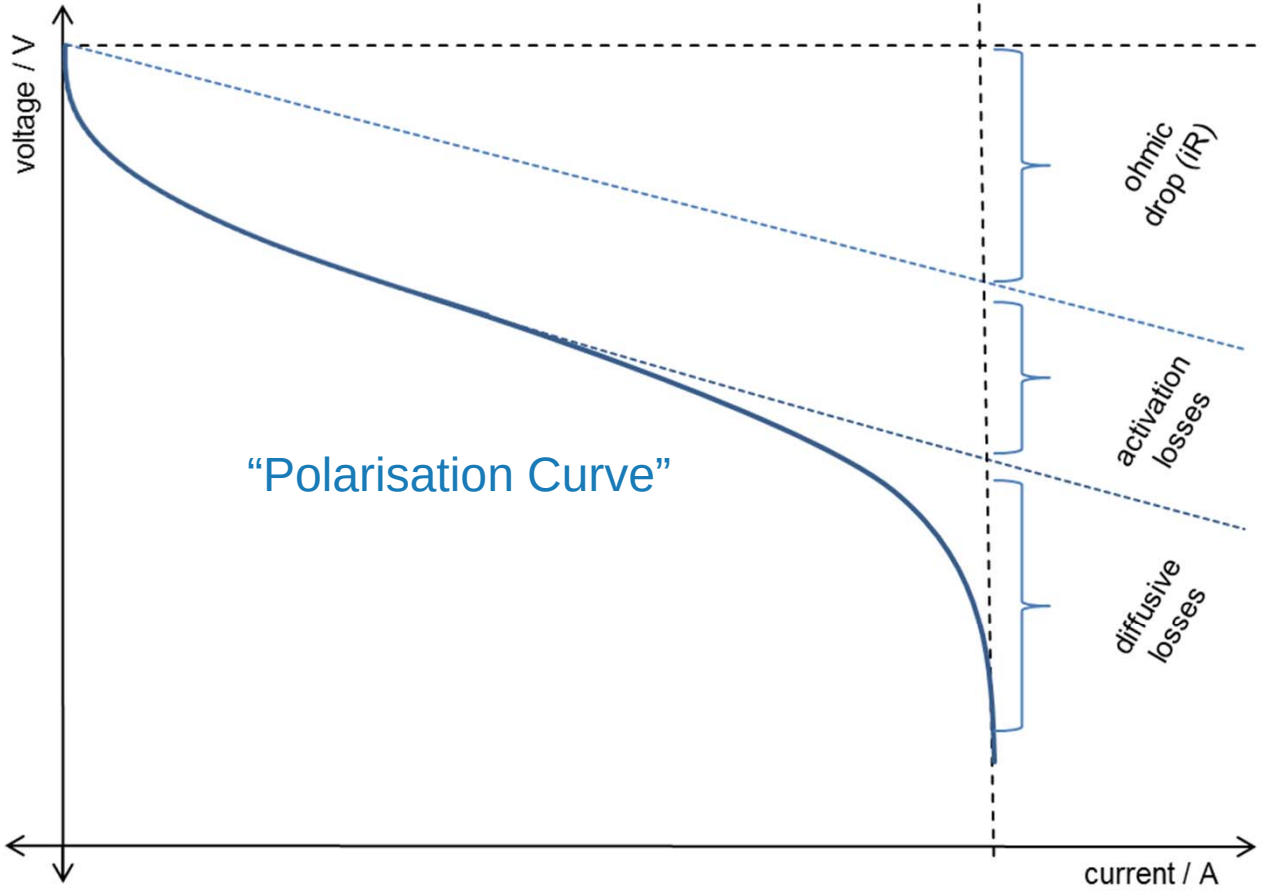
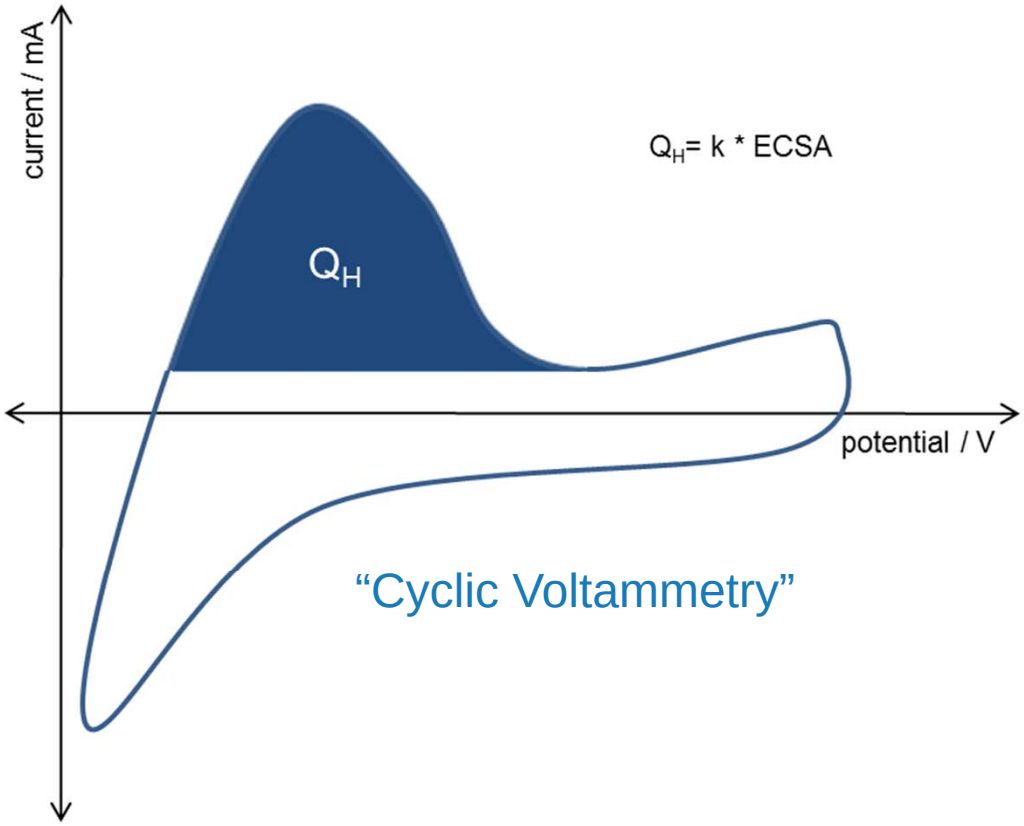
Standard Characterisation Techniques

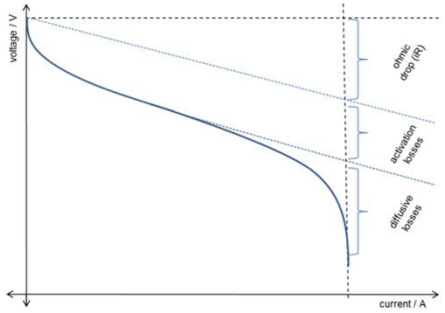


- performance
- efficiency

Standard Characterisation Techniques

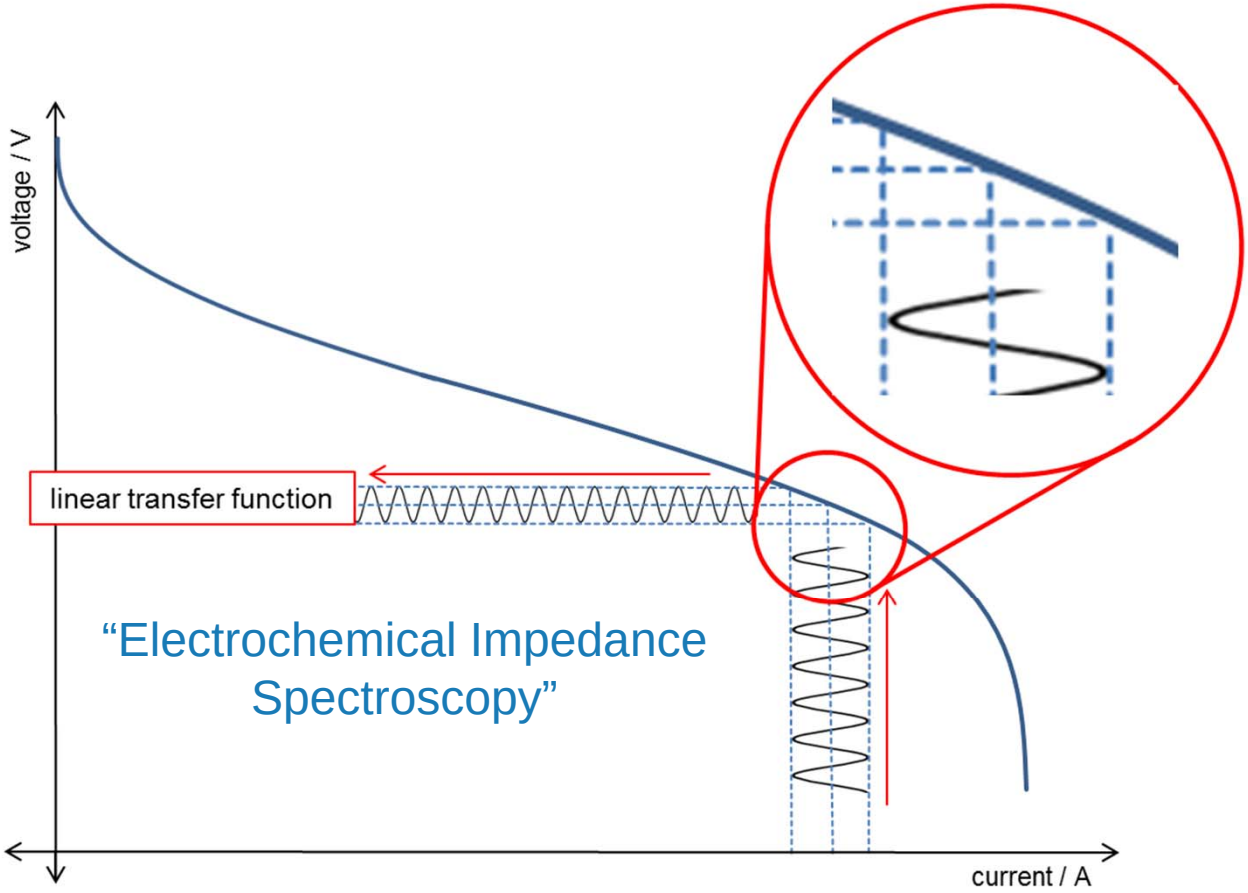


"Cyclic Voltammetry"

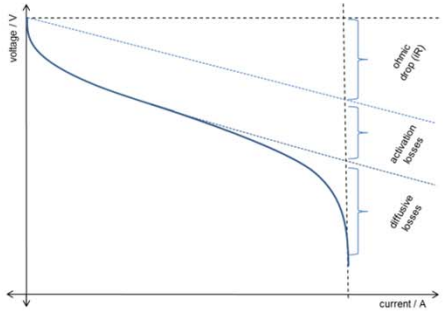


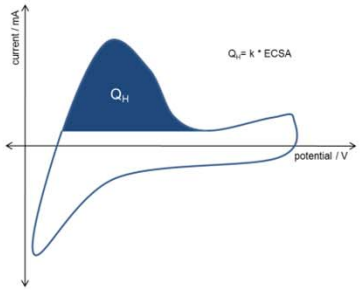
- surface properties (ECSA, catalytic activity…)

Standard Characterisation Techniques



"Electrochemical Impedance Spectroscopy"



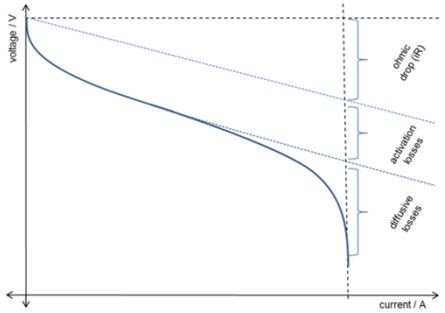


- quantification of loss mechanisms (lab)
- possible within FC operation

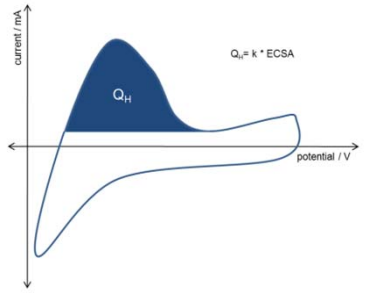
Standard Characterisation Techniques

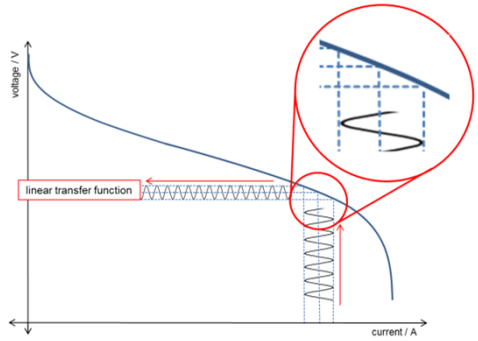
What are the most applicable methods for online/real time analysis of Fuel Cell Stacks?

What is the benefit of that method?



	Method	Information	Usability
S-O-A	Polarisation curve	performance, efficiency	laboratory
S-O-A	Cyclic Voltammetry (CV)	surface properties (ECSA, catalytic activity)	laboratory
S-O-A	Cell Voltage Monitoring (CVM)	single cell voltages	laboratory, during operation
A-A	**Electrochemical Impedance Spectroscopy (EIS)**	**quantification of loss mechanisms**	**laboratory, during operation**
A-A	**Total Harmonic Distortion Analysis (THDA)**	**detection of critical states**	**laboratory, during operation**





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State of Art Online Techniques

Voltage Monitoring (VM)

- ✓ The simplest method for real time monitoring
- ✓ Sudden changes in voltage cannot be assigned to a certain phenomena

Cell Voltage Monitoring (CVM)

Impedance Spectroscopy (EIS)

State of Art Online Techniques

Voltage Monitoring (VM)

Cell Voltage Monitoring (CVM)

- ✓ Very simple method for real time monitoring
- ✓ Sudden changes in voltage can be assigned to a certain cell
- ✓ Reason for voltage change stays unknown
- ✓ Increased efforts for wiring necessary

Impedance Spectroscopy (EIS)

VM
✓ Easiness ✓ RT Monitoring ✓ Low Information

[AVL]

State of Art Online Techniques

Voltage Monitoring (VM)

Cell Voltage Monitoring (CVM)

Impedance Spectroscopy (EIS)

- ✓ High information content
- ✓ Possible during operation (Online)
- ✓ Too time consuming for real time monitoring

VM

- ✓ Easiness
- ✓ RT Monitoring
- ✓ Low Information

CVM

- ✓ Easiness
- ✓ RT Monitoring
- ✓ Low Information
- ✓ Wiring

State of Art Online Techniques

Voltage Monitoring (VM)

Cell Voltage Monitoring (CVM)

Impedance Spectroscopy (EIS)

VM

- ✓ Easiness
- ✓ RT Monitoring
- ✓ Low Information

CVM

- ✓ Easiness
- ✓ RT Monitoring
- ✓ Low Information
- ✓ Wiring

EIS

- ✓ High Information
- ✓ Online Monitoring
- ✓ Time Consuming
- ✓ FT EIS

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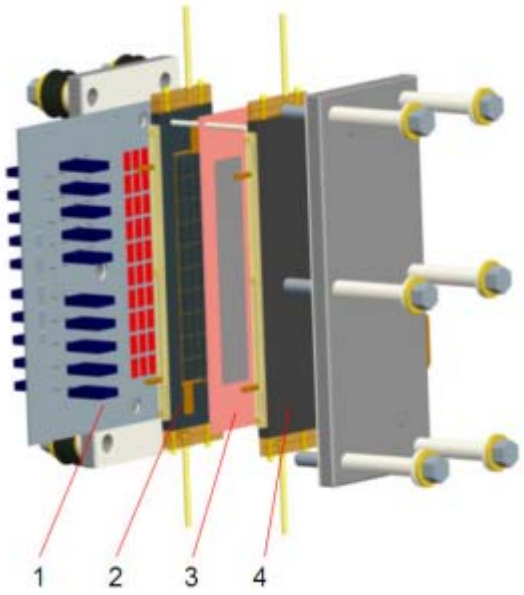
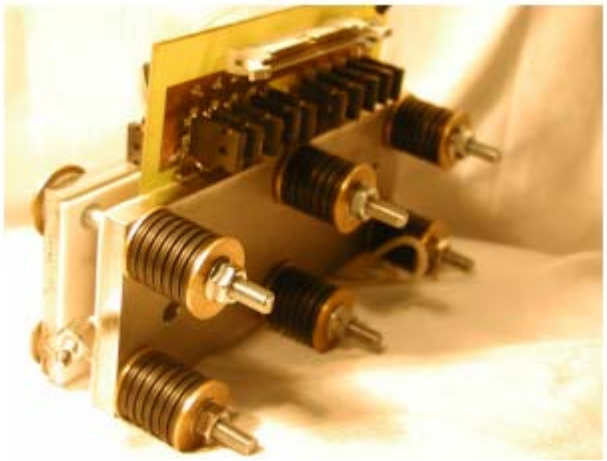
Current Mapping





Air IN → | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | ↩
↪ | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | ↩
↪ | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | → Air Out

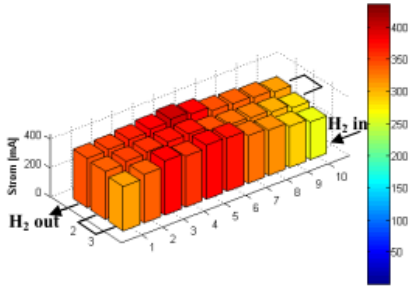


Abbildung 26: Versuchsreihe „A 1": 0 Zyklen: Stromverteilung während der Aufnahme der UI-Kennlinie bei 400mA/cm²

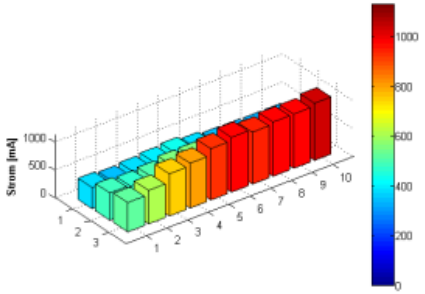


Abbildung 29: Versuchsreihe „A 1“: Stromverteilung während eines Starvation-Intervalls bei Zyklus 0 bis 100

[Baumgartner, TU Graz]
[Geymeyer, TU Graz]

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Single Frequency Impedance Spectroscopy

- The electrochemical impedance at one distinctive frequency is monitored
  - ➔ Improved acquisition time
  - ➔ Lower information than in common EIS
  - ➔ Control variable?

- Changes in the stack/cell voltage may be assigned to certain phenomena

- Parallel superposition of a few frequencies and evaluation of the frequency response after FT is also possible

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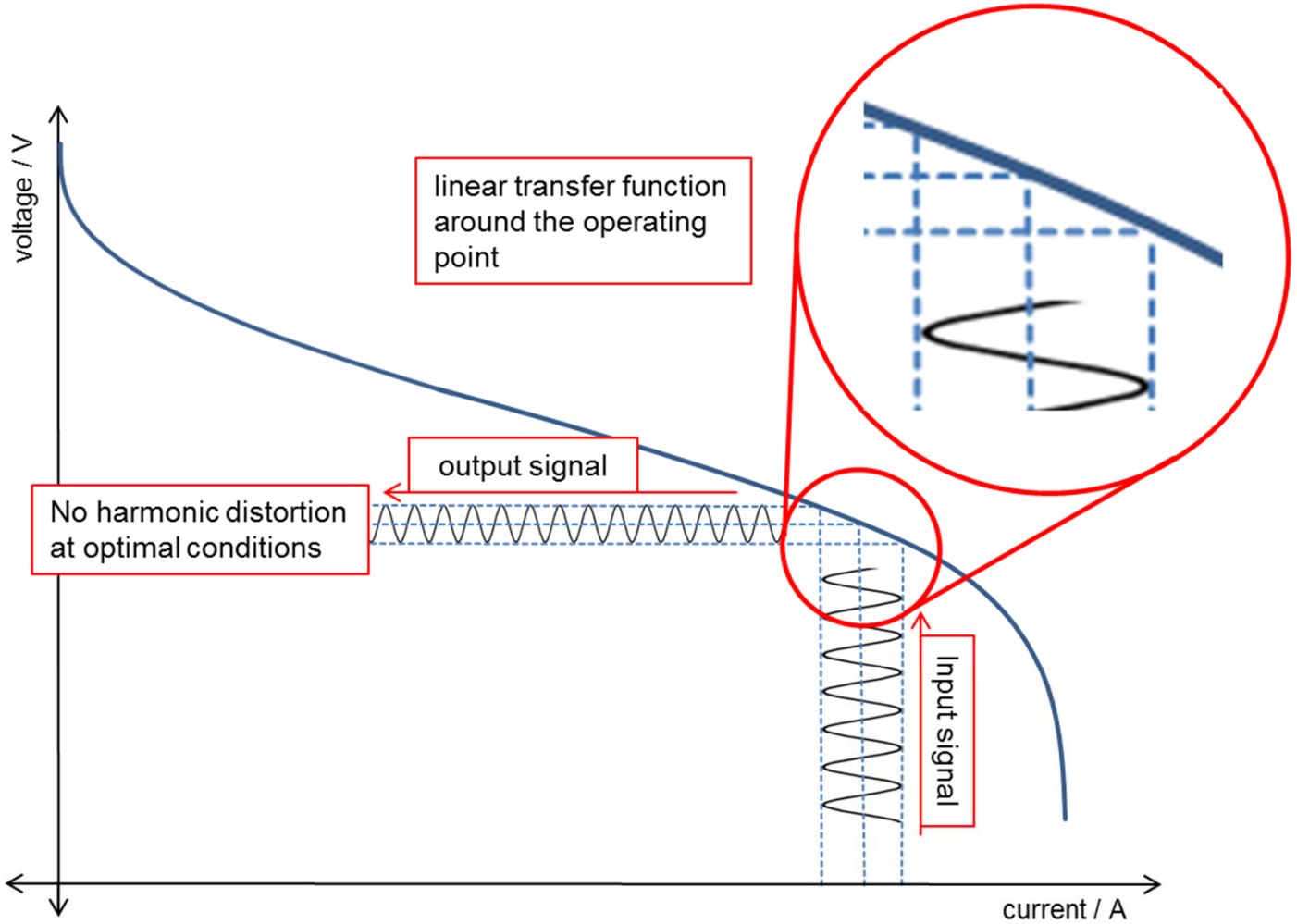
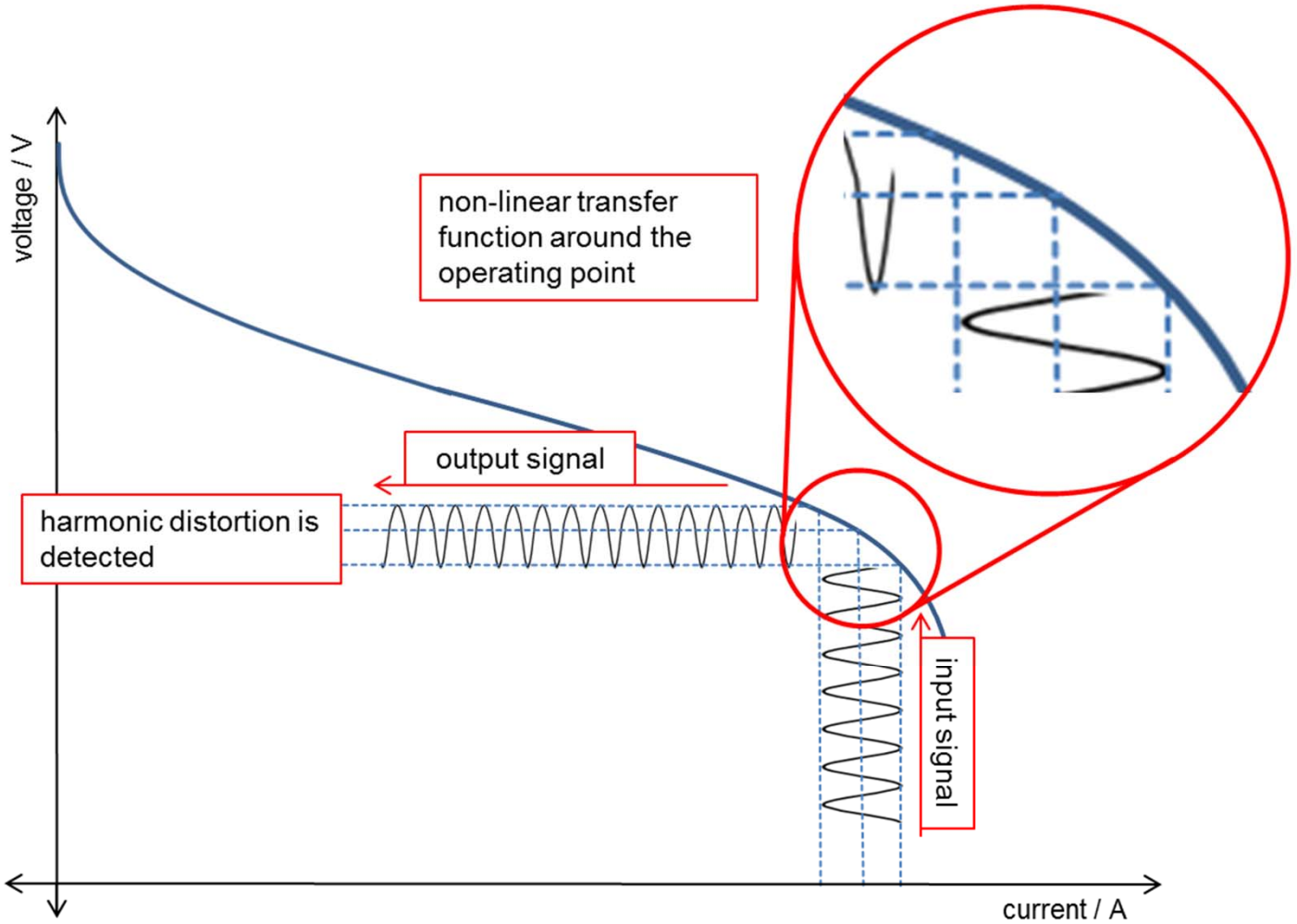
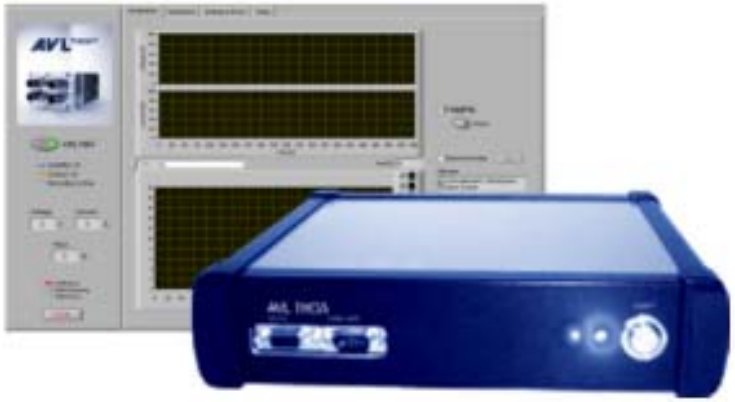
Total Harmonic Distortion Analysis (THDA)

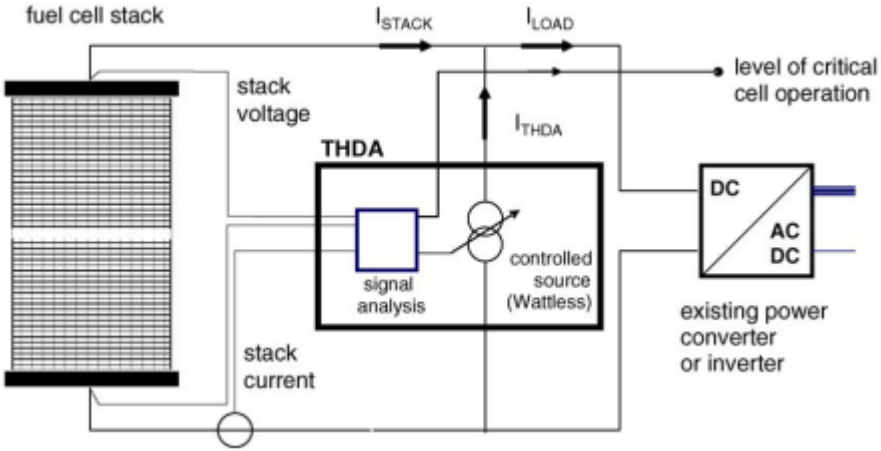


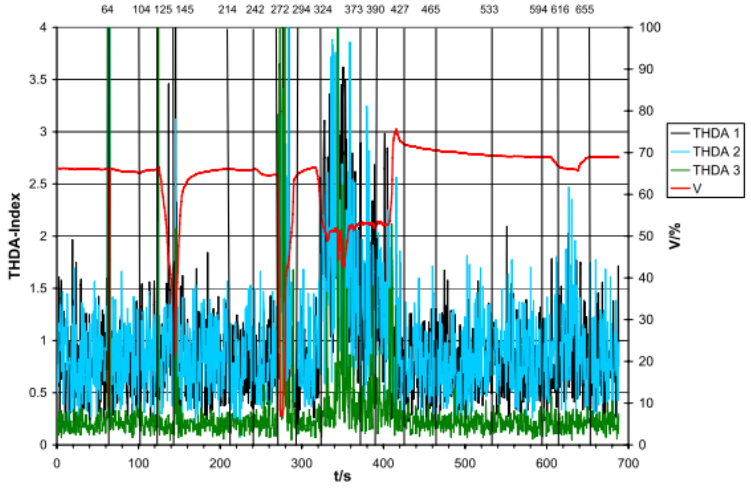
Total Harmonic Distortion Analysis (THDA)



Total Harmonic Distortion Analysis (THDA)







➔ THDA (nonlinear response)
➔ FT EIS (linear response)

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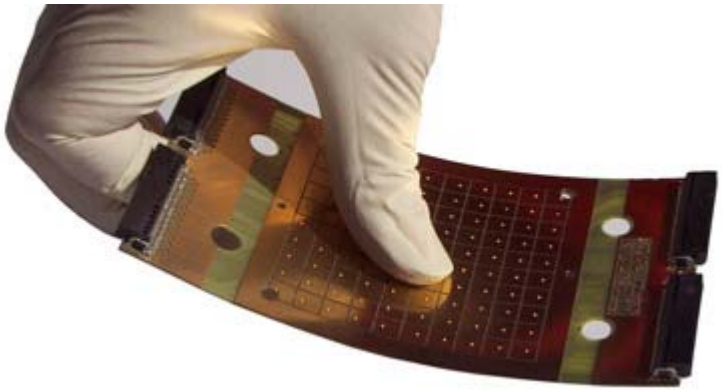
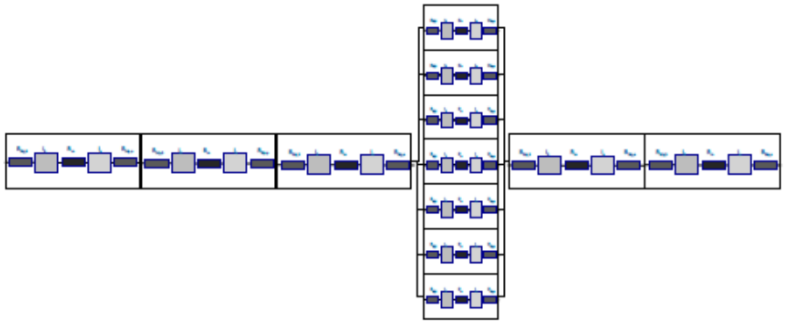
Spatial Approaches

- Based on a previous THDA project a new hardware device is developed and tested at TU Graz
- The basic idea is to extend the THDA and EIS approach from 0D to 2D and consequently to 3D
- Therefore a special data acquisition hardware is necessary
- Two sensor plates plus two different hardware interfaces for preprocessing
- Signal is imposed on the whole stack

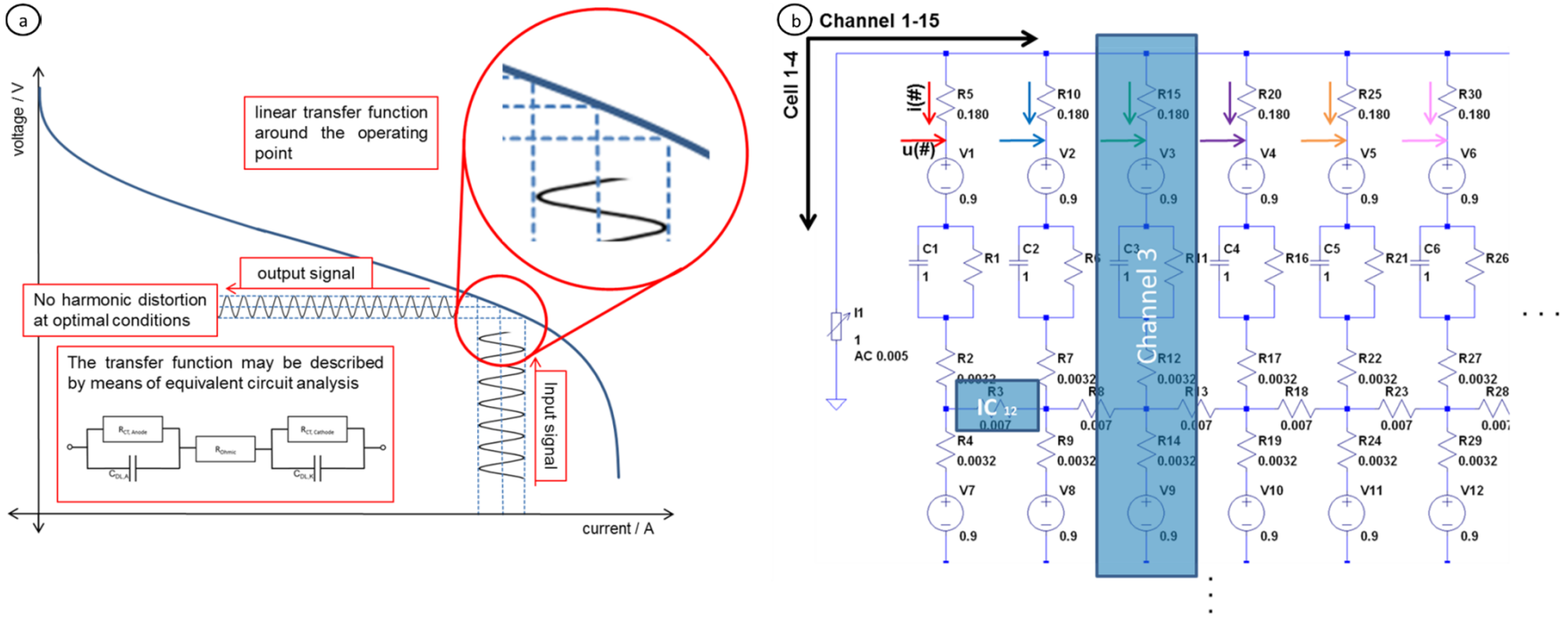




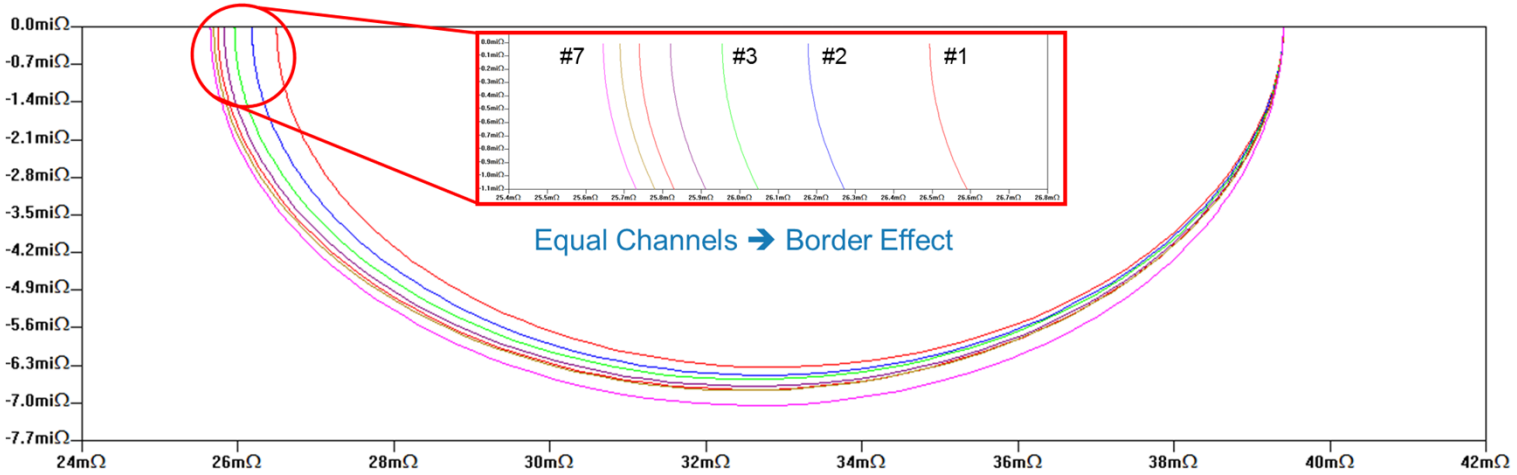
[AVL]
[S++]

Spatial Impedance spectroscopy

- Spatial approach needs a spatial equivalent circuit (lab scale)
- Online/Real Time Analysis needs an assumption of the current distribution
  - ➔ In plane conductivities have to be taken into account



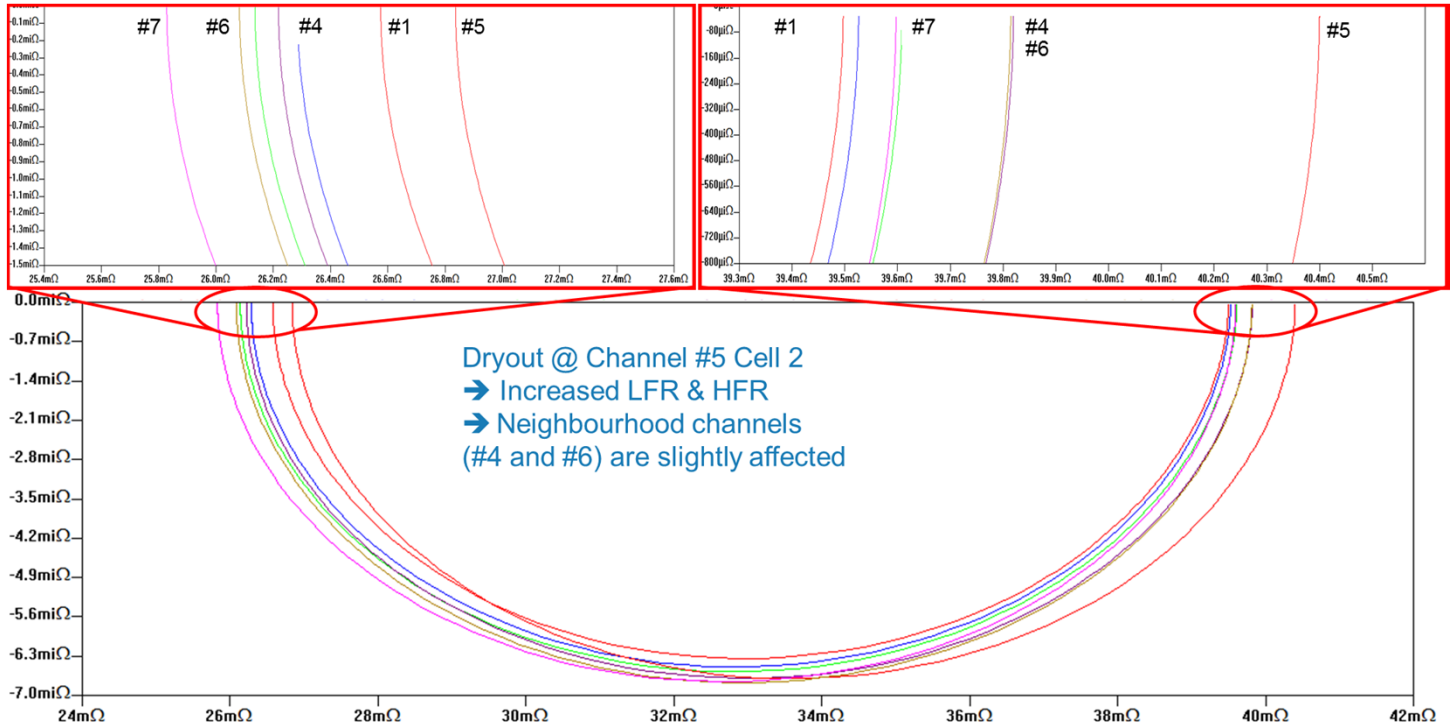
[Weinberger]



Conclusion (issue: in plane conductivity):

➔Higher HFR at outer segments compared to isolated segments

➔Inner segments show less effect of in plane conductivity (equal segments)



Conclusion (issue: in plane conductivity):

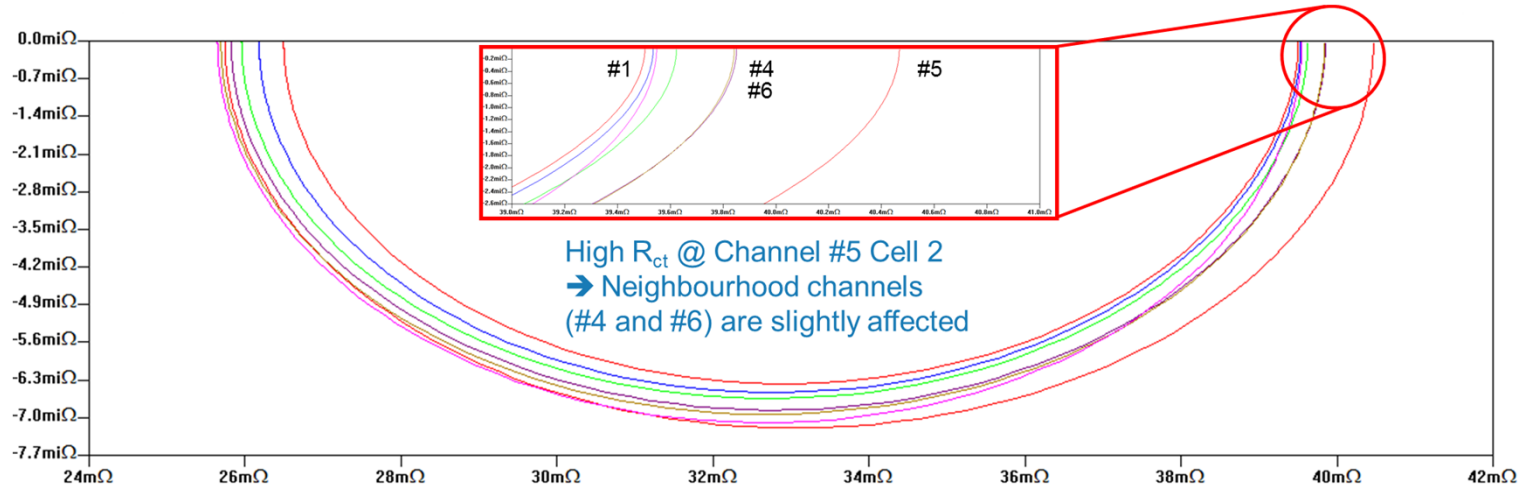
➔Higher HFR at outer segments compared to isolated segments

➔Inner segments show less effect of in plane conductivity (equal segments)

Conclusion (issue: membrane dry out):

➔Increased HFR and LFR at affected „channel“

➔Adjacent channels show a little increase at HFR and LFR



Conclusion (issue: in plane conductivity):

➔Higher HFR at outer segments compared to isolated segments

➔Inner segments show less effect of in plane conductivity (equal segments)

Conclusion (issue: membrane dry out):

➔Increased HFR and LFR at affected „channel“

➔Adjacent channels show a little increase at HFR and LFR

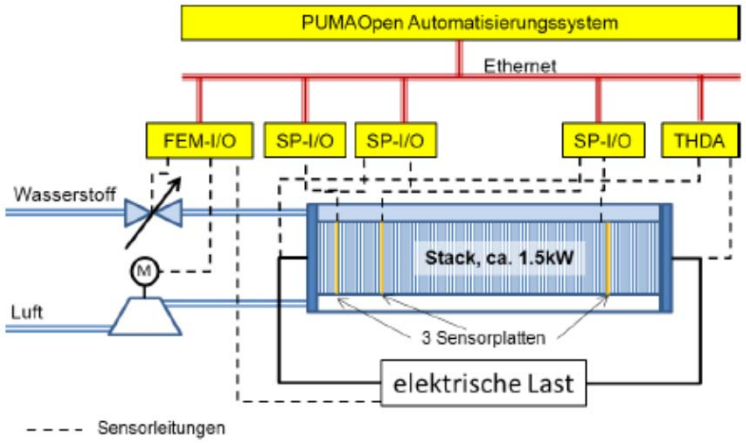
Conclusion (issue: increased charge transfer resistance):

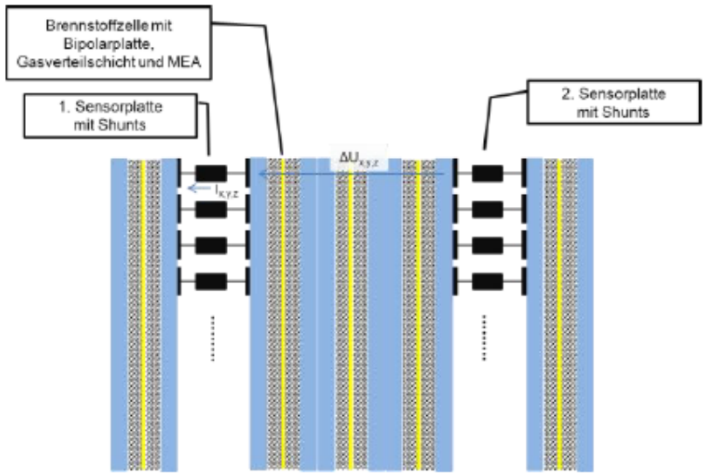
➔Increased LFR at affected „channel“

➔ Adjacent channels show a little increase at LFR

Spatial THDA

- First measurements will be conducted with an Air - Cooled stack from Intelligent Energy at TU Graz and at UCL
- 1.5 kW stack equipped with the new technology will be tested at AVL consequently
- Results coming soon





[AVL]

Conclusion

- Advanced Online Analysis leads to a better understanding of Fuel cells
  - ➔ Continuous State of Health monitoring
  - ➔ Comparison to Simulation Results
- Real Time Analysis enables very efficient operation of FCs
- Critical Operating states may be avoided
  - ➔Increased Lifetime
- Enables further improvements of stack/cell design

[AVL]

QUESTIONS?

CEET Research Activities
ANNEX 27

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Institute of Chemical Engineering and Environmental Technology
Graz University of Technology