# MEANINGFUL CHARACTERIZATION OF BATTERY CELLS AND SYSTEMS WITH CURRENT PULSES

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#CreatingTheEnergyFuture


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Fraunhofer Institute for Solar Energy Systems ISE

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E-MOTIVE by FVA, Online Live Event, 23.09.2021

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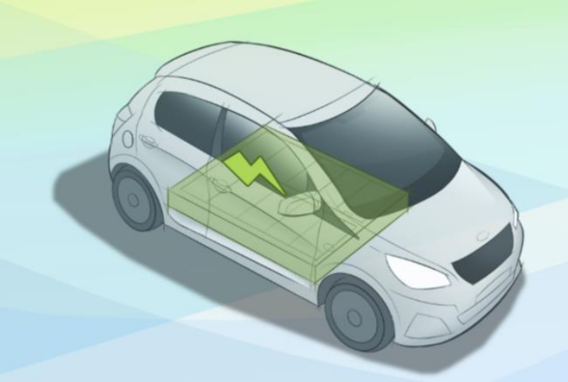
# Motivation

## Why is the characterization of batteries important?

Knowing the electric property of a specific cell or battery system is crucial for:

- Quality and safety assurance
  - Incoming components inspection
  - Service and monitoring
  - Health prediction (fast 2nd life qualification)
- Modelling and Simulation
  - Electric performance
  - System design (sizing/range, heat dissipation)
  - Analysis of aging
  - Battery management (SOC/SOH-estimation)



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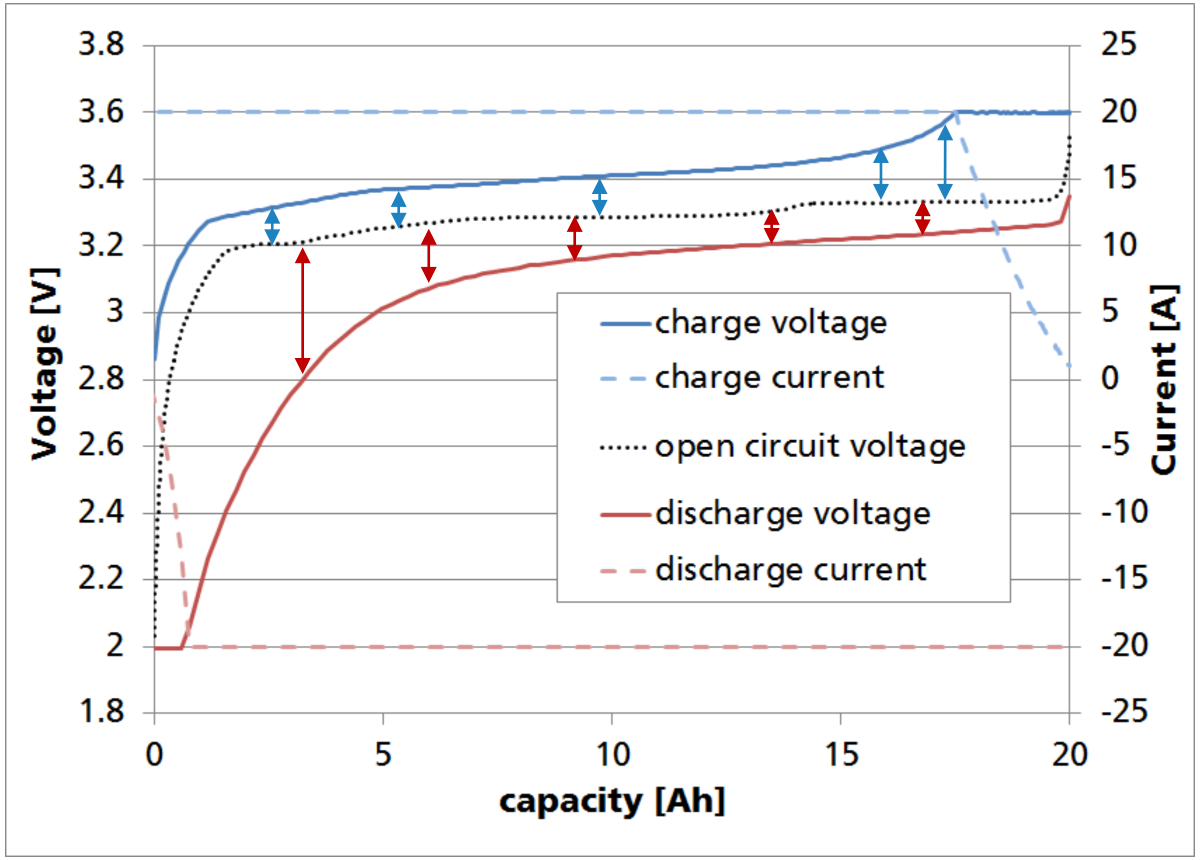
# Methods - Charge and discharge curves

## How can we characterize batteries?

- The voltage loss (discharge) or addition (charge) to the open circuit voltage (OCV) or overpotential defines the electric performance.
- Overvoltage depending on:
  - Temperature
  - Current
  - State of charge
  - Aging state





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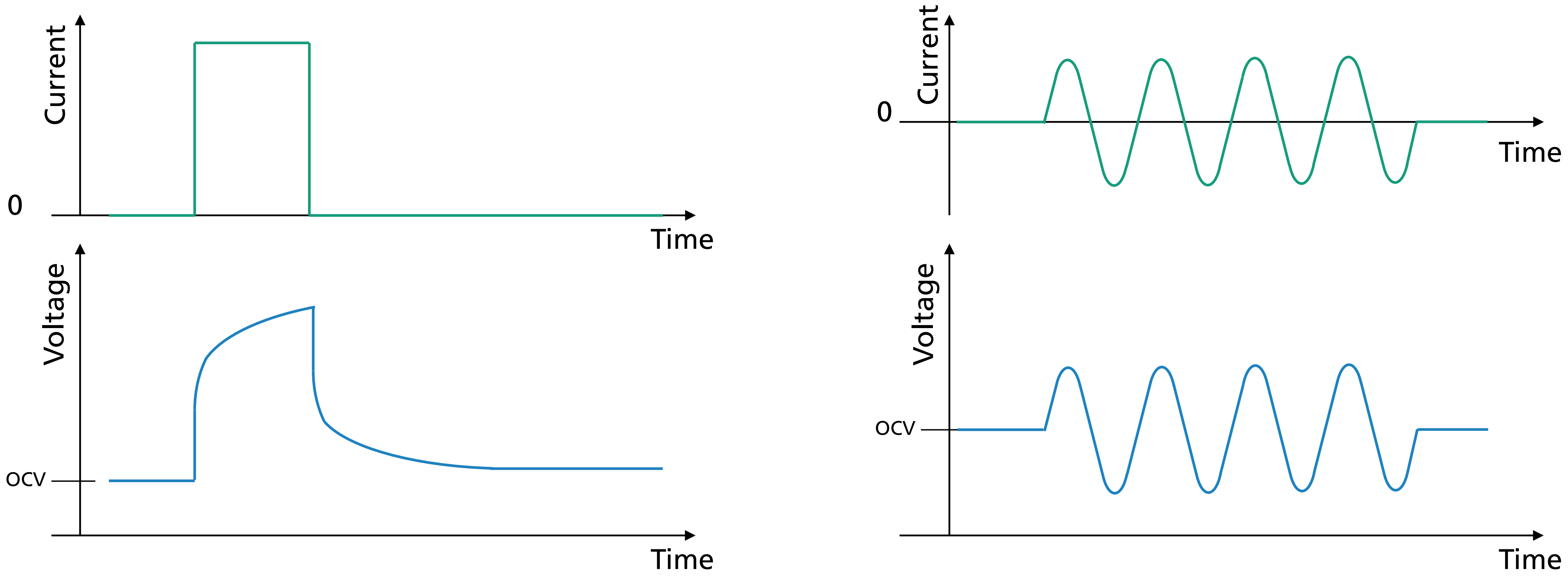
# Methods – Pulse test & Electric Impedance Spectroscopy (EIS)

How can we characterize batteries?



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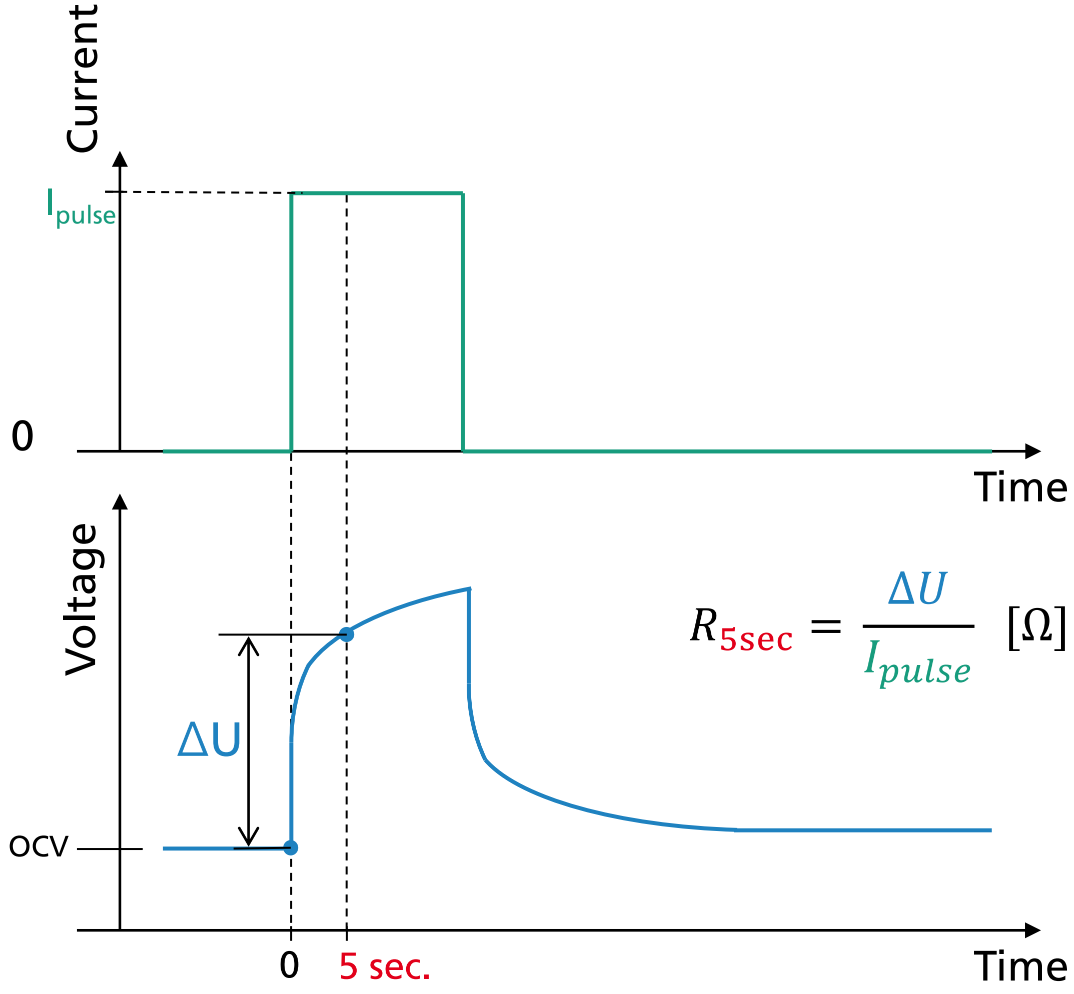


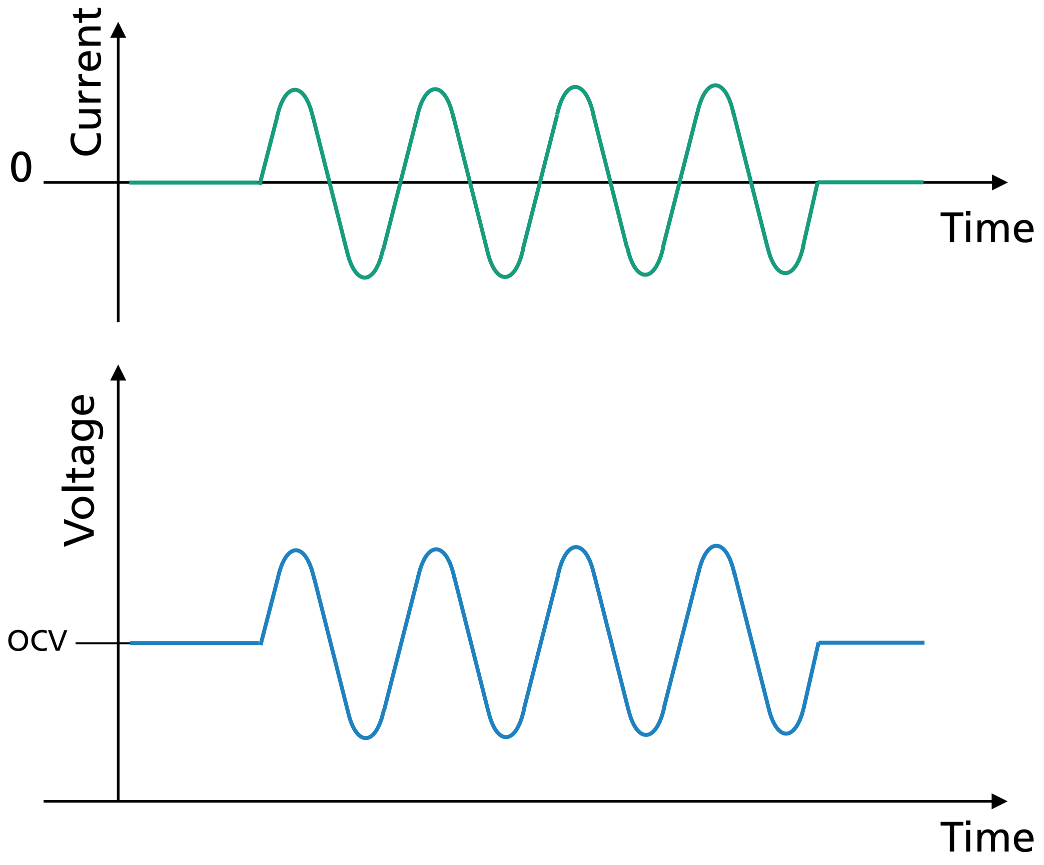




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# Methods – Pulse test & Electric Impedance Spectroscopy (EIS)

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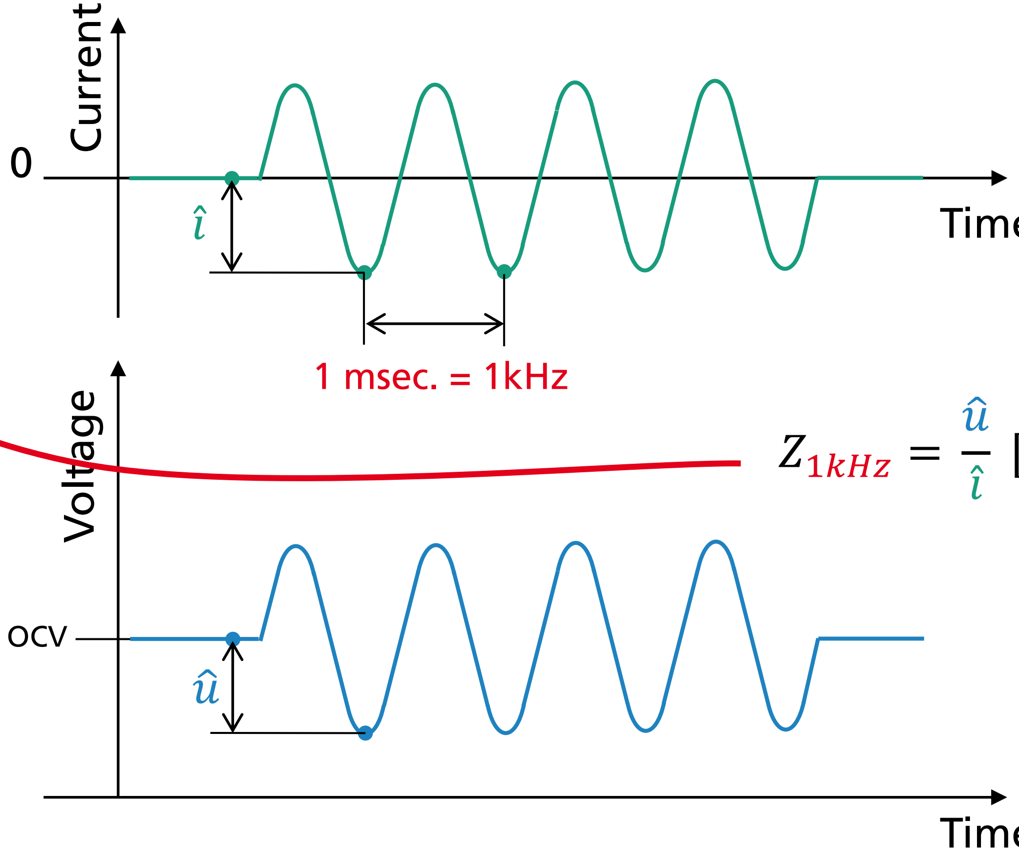


$$Z_{1kHz} = \frac{\hat{u}}{\hat{\imath}} \; [\Omega]$$



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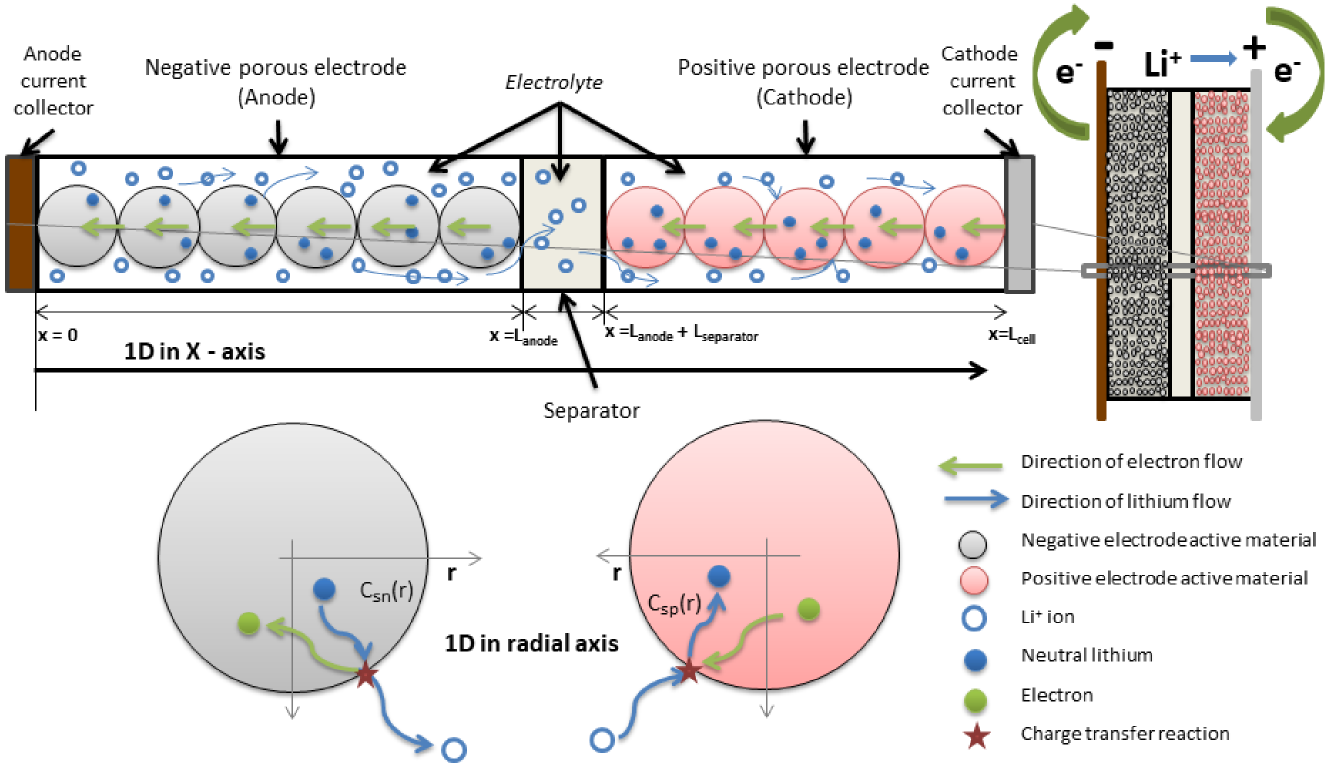
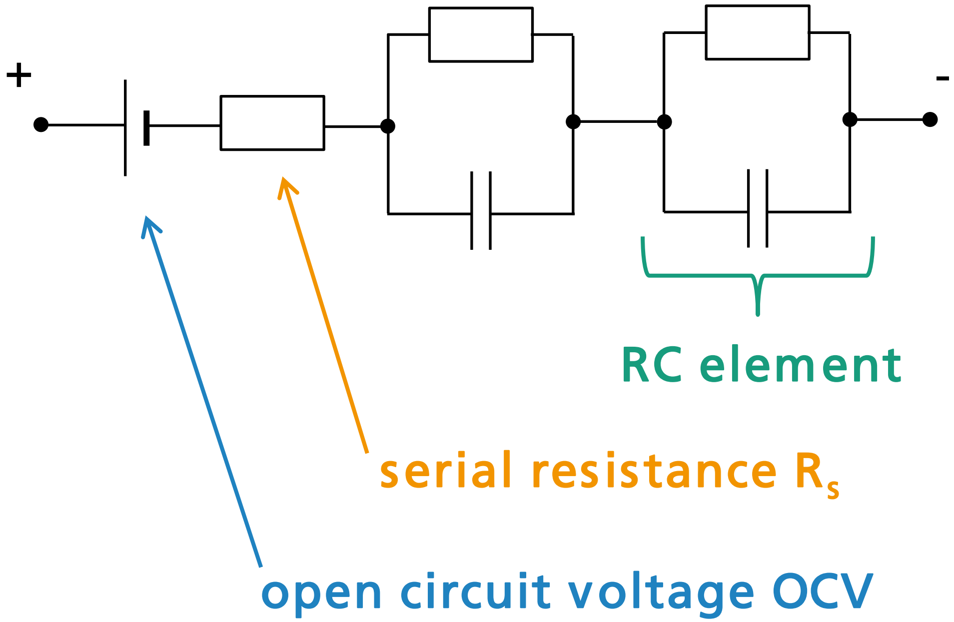
# Modelling

## Two general methods: Theoretic & empirical



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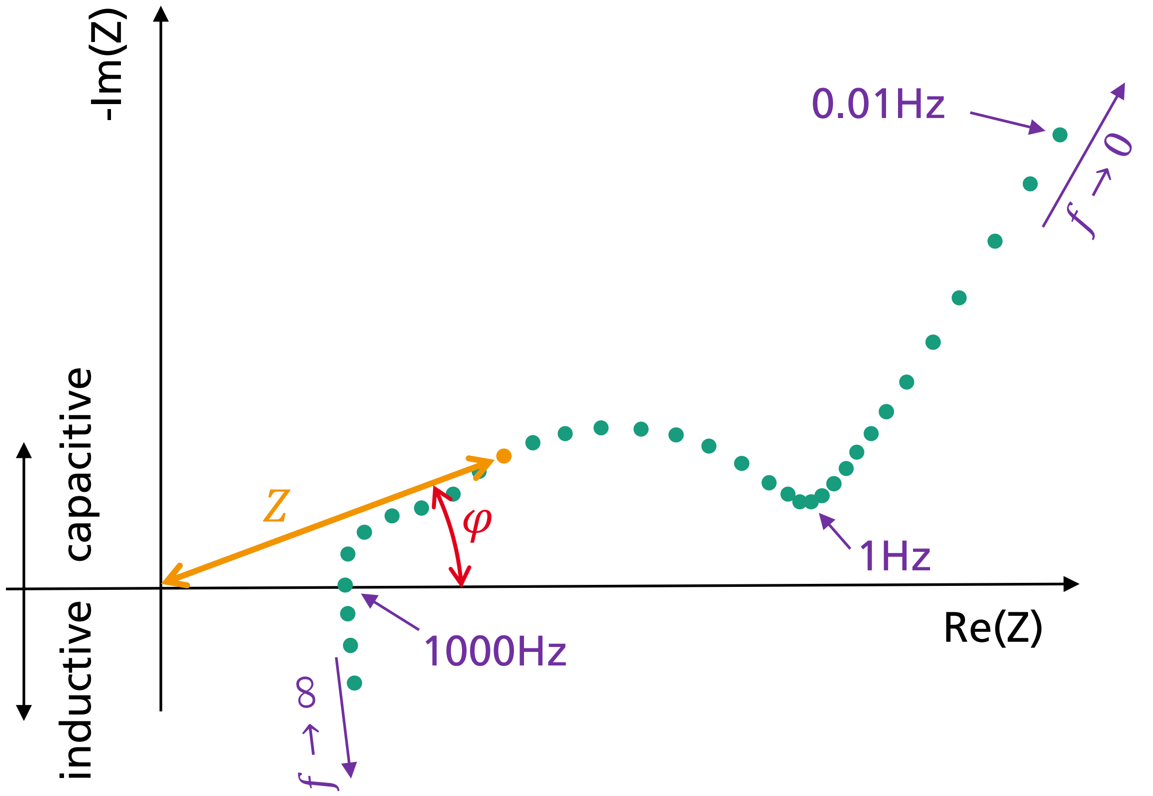
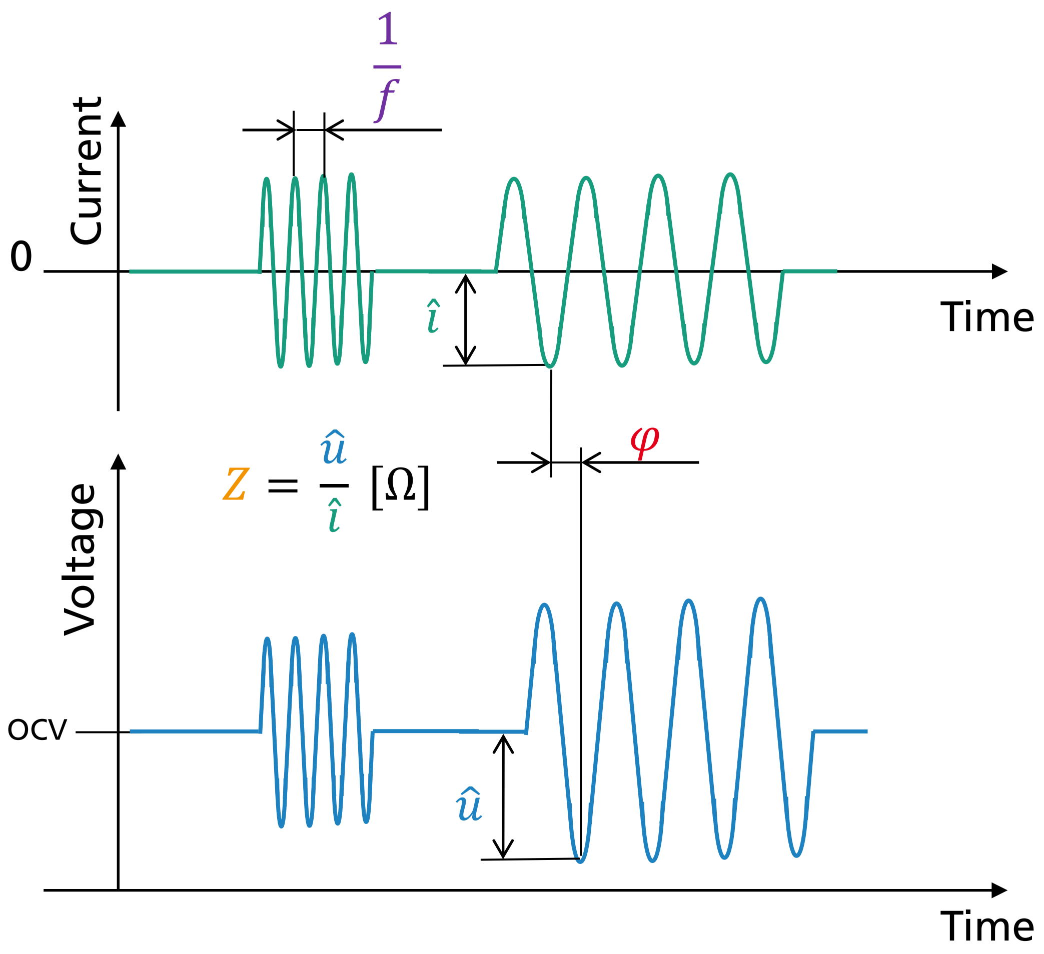
# Methods – Electric Impedance Spectroscopy (EIS)

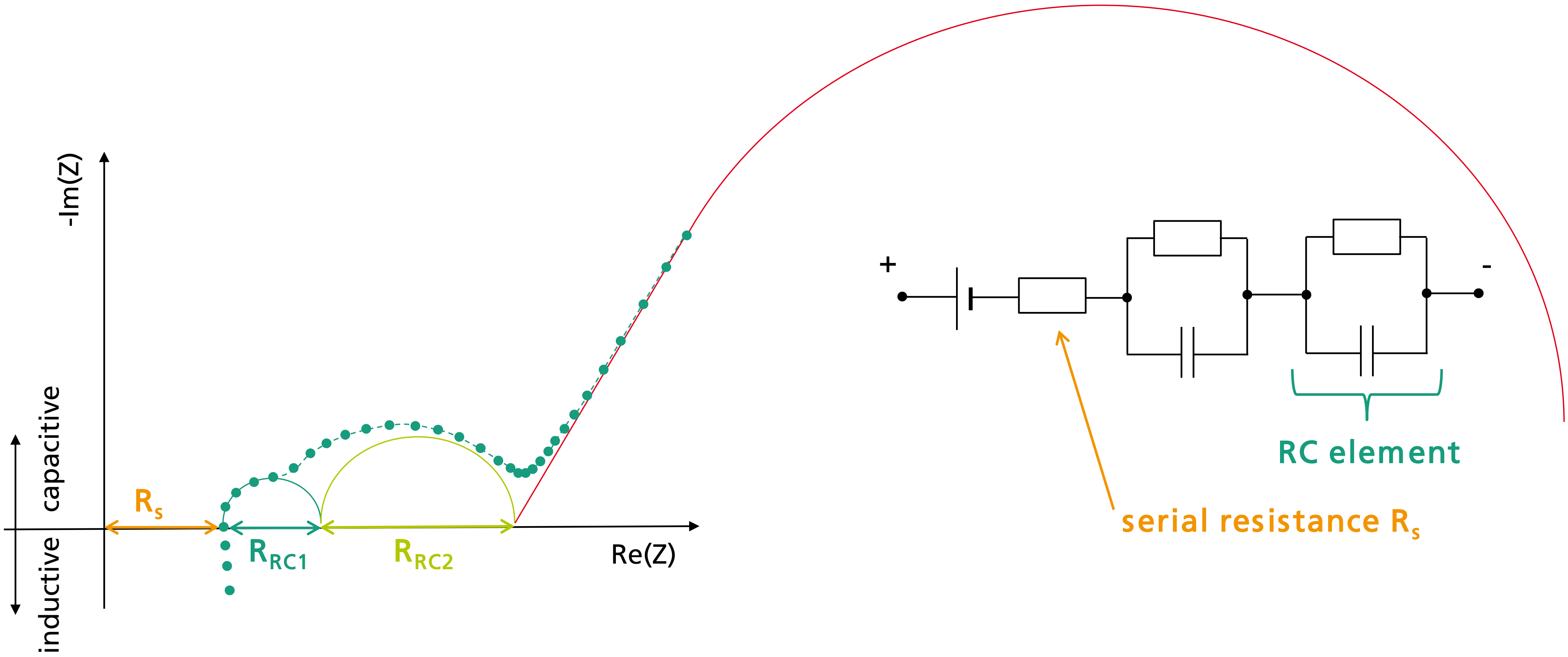
## Nyquist plot



# Methods – Electric Impedance Spectroscopy (EIS)

## Fitting EIS result



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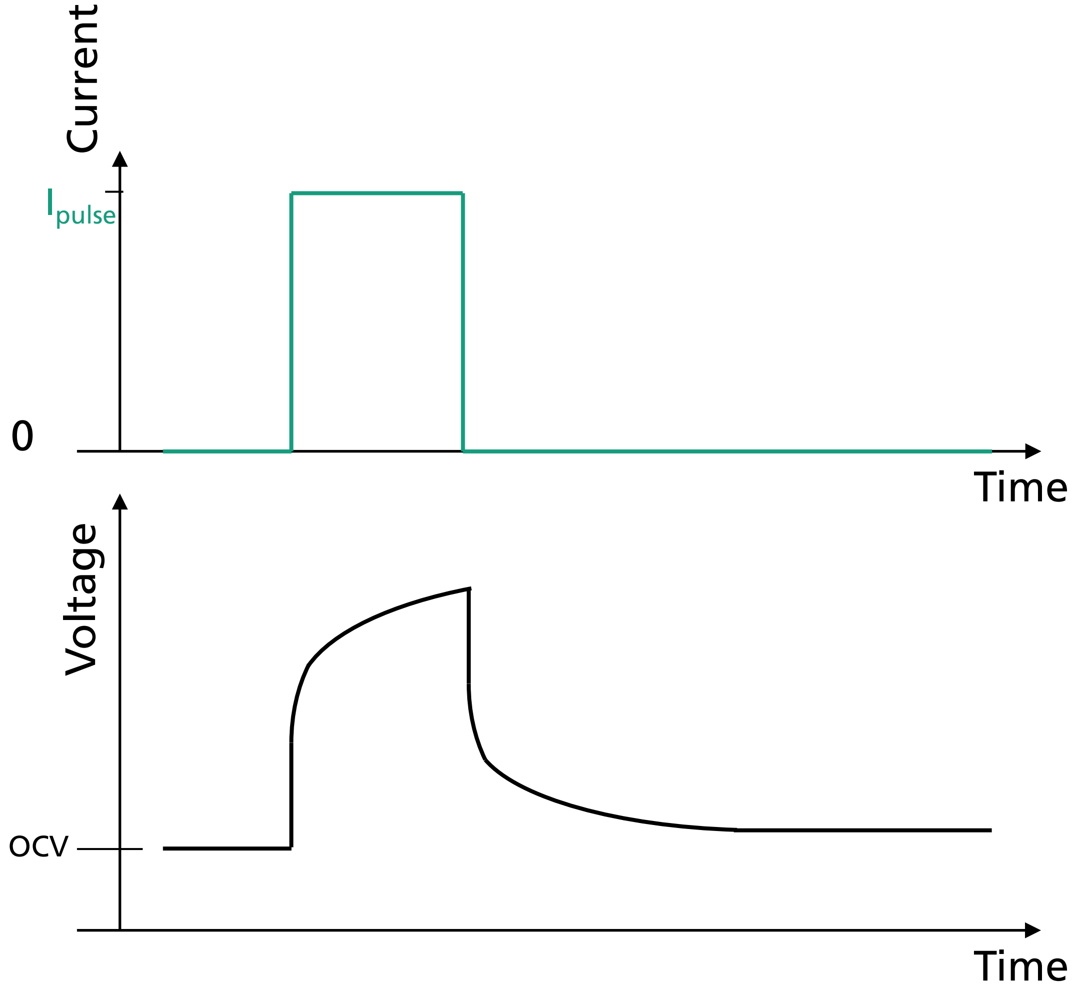
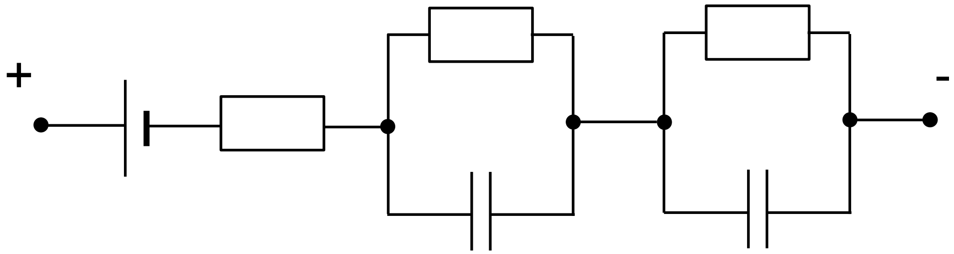
# Methods – Pulse test

How can we characterize batteries?



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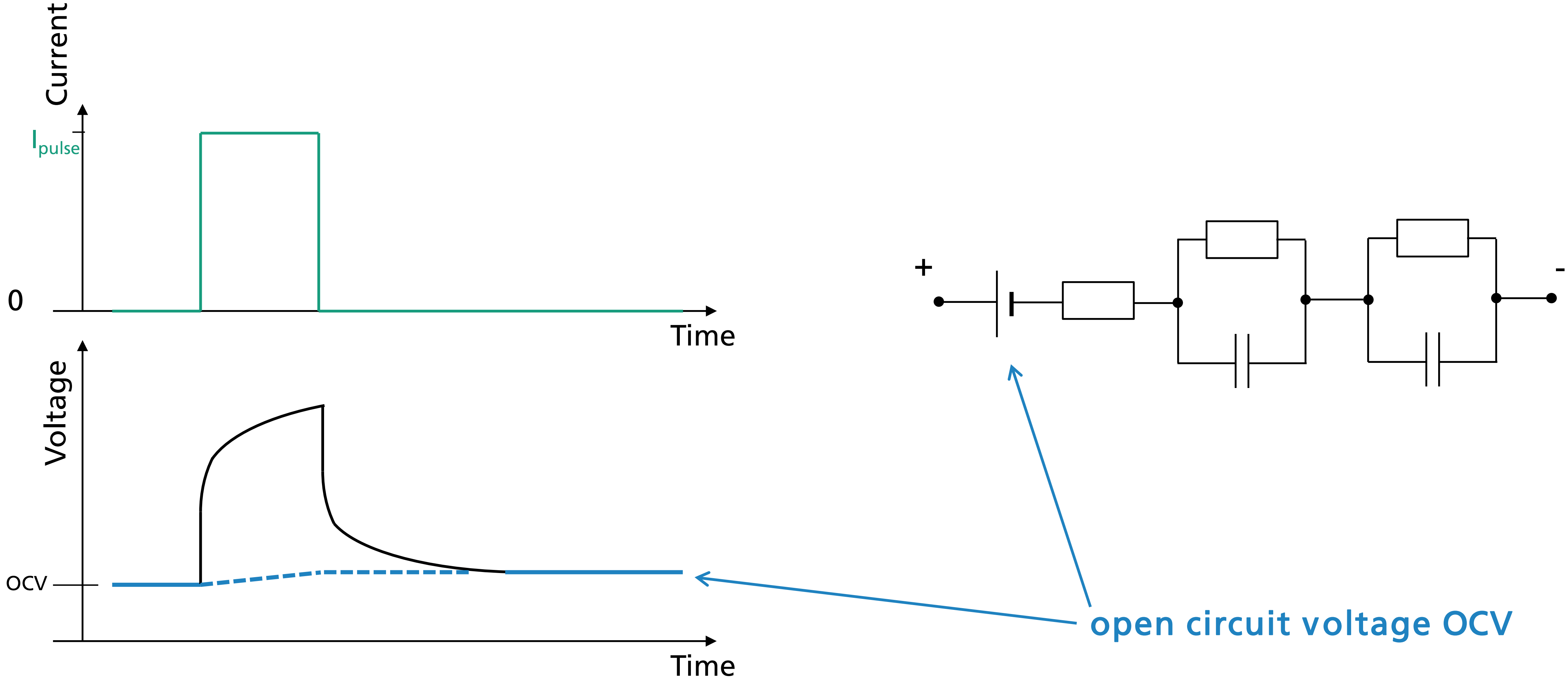




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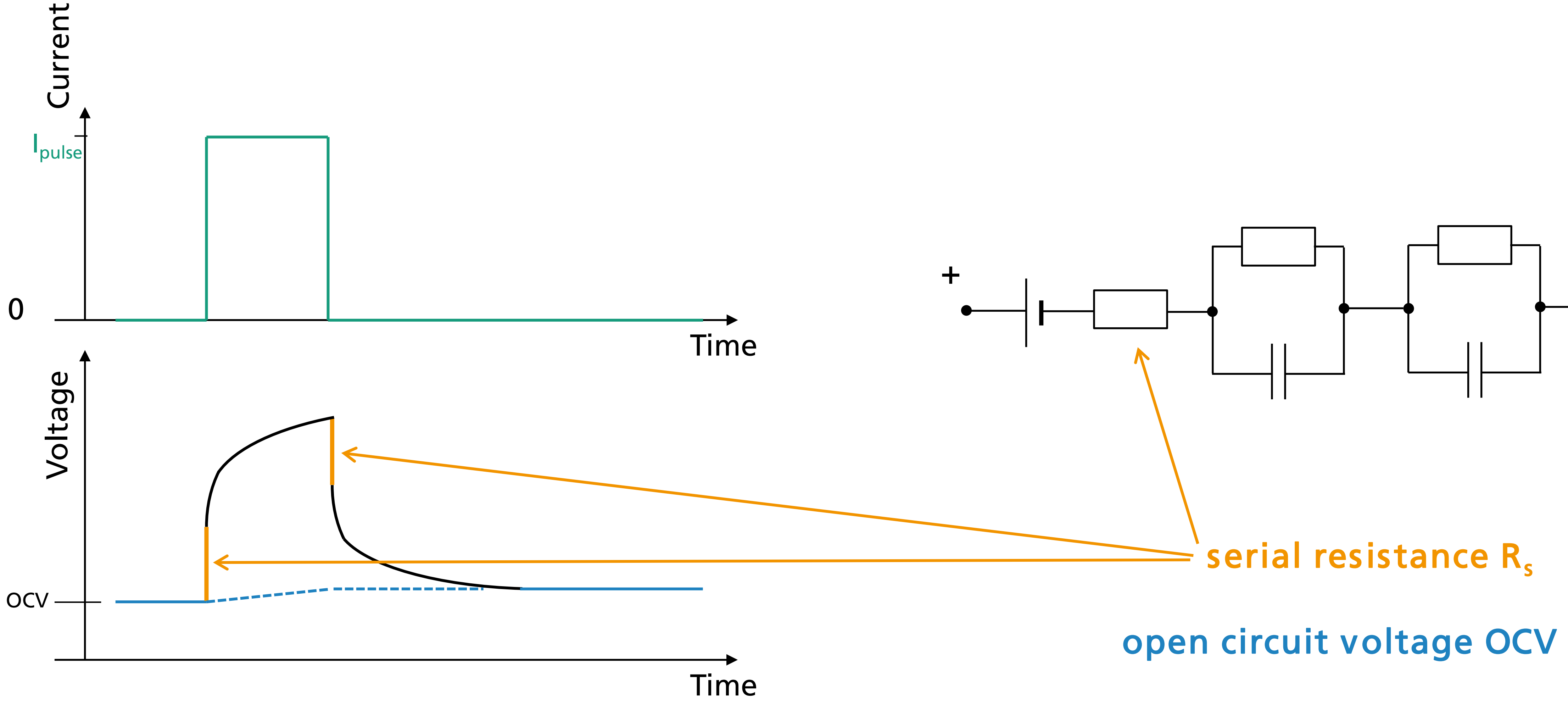

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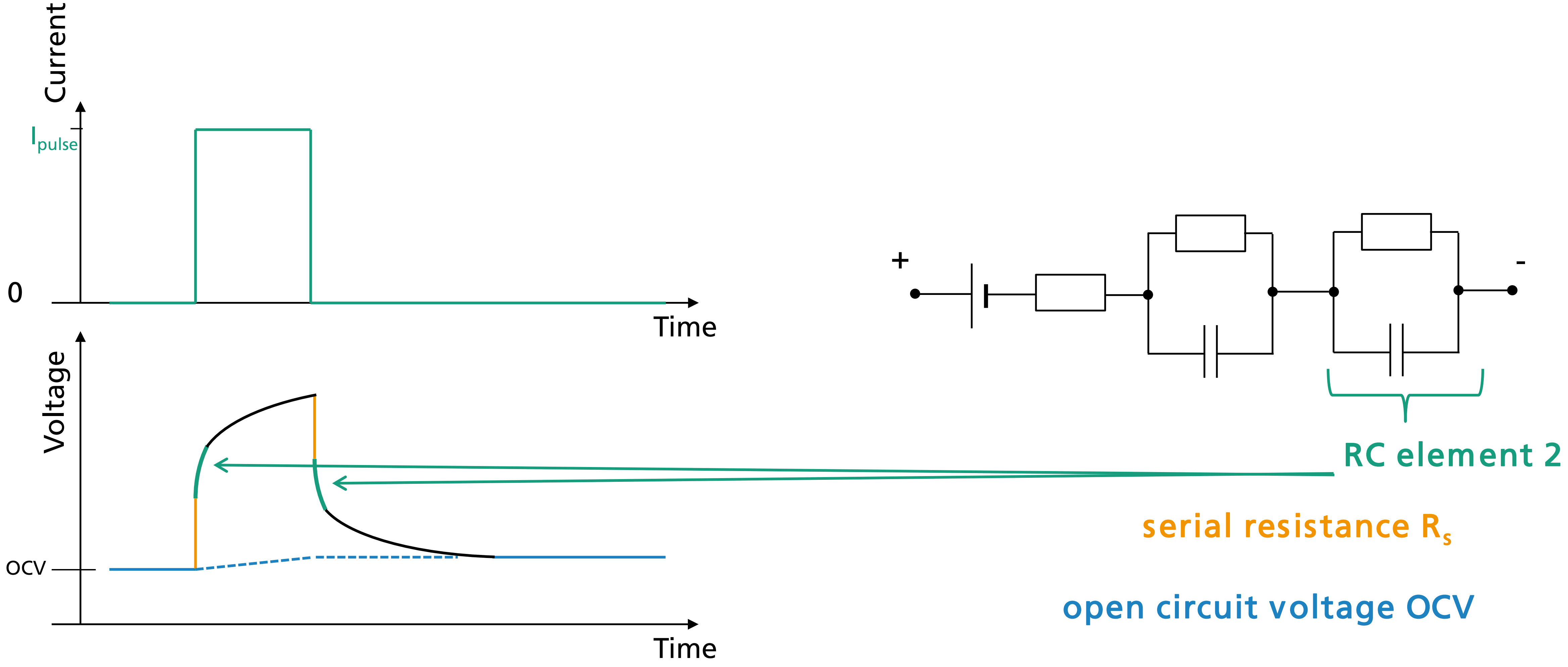

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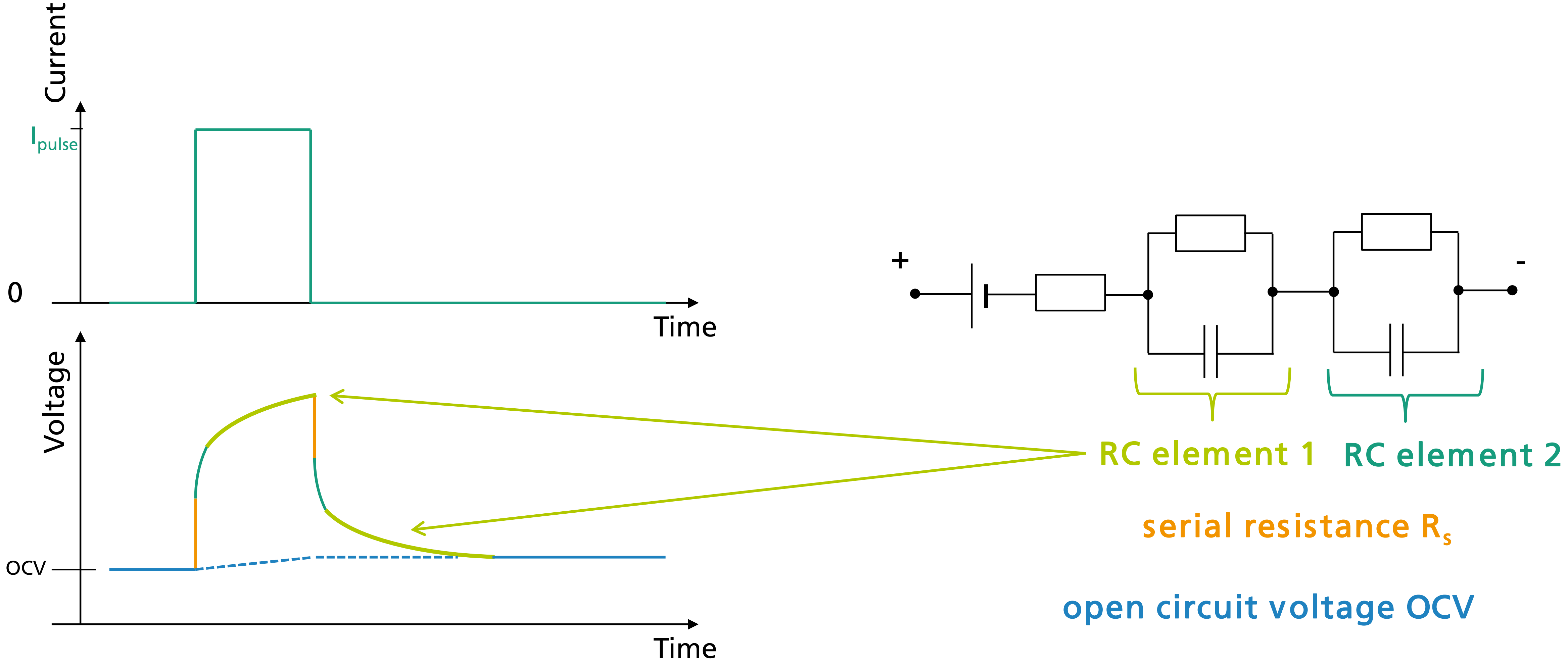


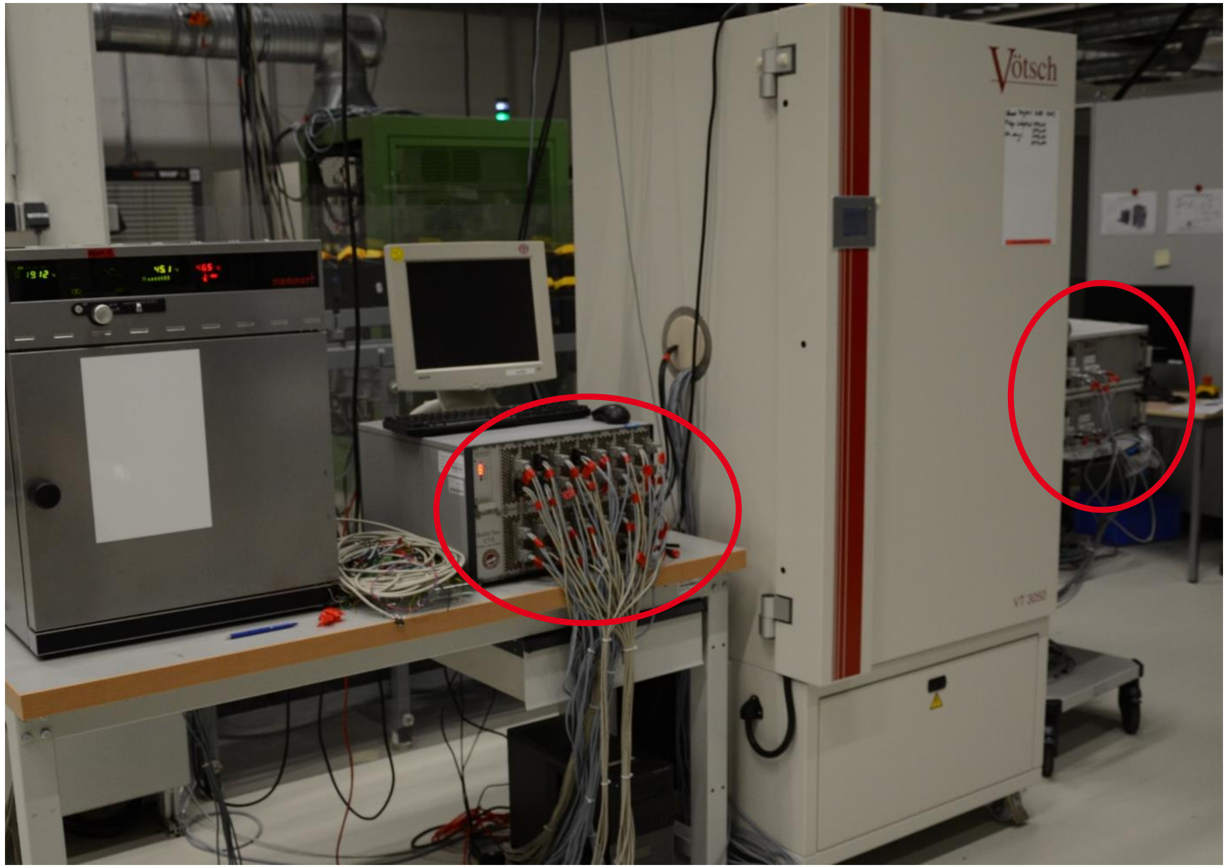
# Pulse test vs. EIS

Advantage pulse test:

- Conductible with all test channels & no switching of connection / measu. channels
- Slow diffusion measurable

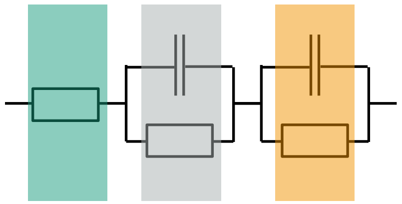
Disadvantage pulse test:

- Most hardware is not suited for measuring fast el.chem. effects
- El. chem. effects are difficult to separate
- Result difficult to visualize
- Results of fitting procedures are often ambiguous and unprecise

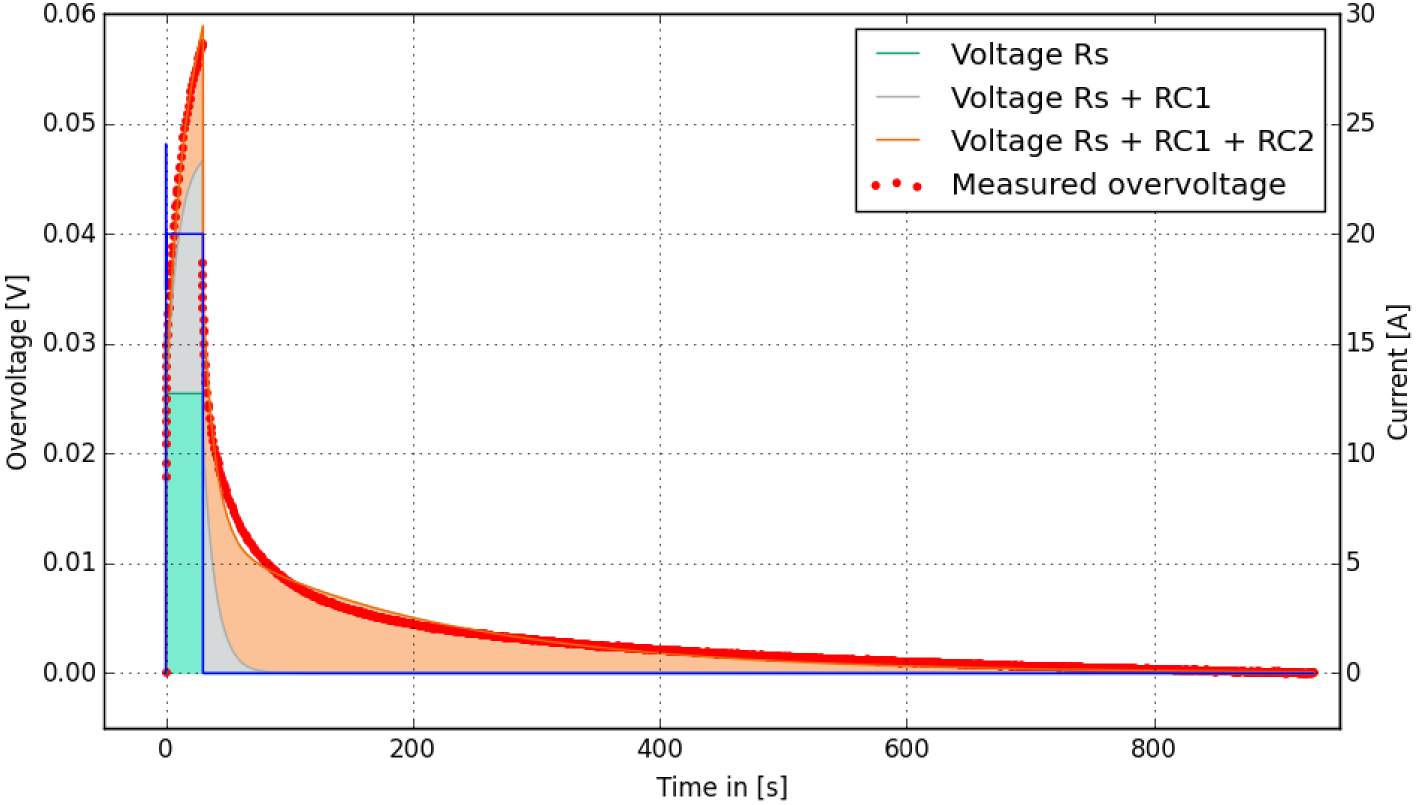


# Pulse test fitting problems

## What are the problems with pulse test fitting?



- Not clear how much RC elements are detectable:
  Under or over fitting problem!



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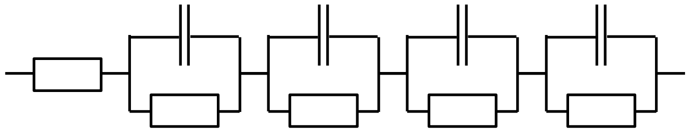

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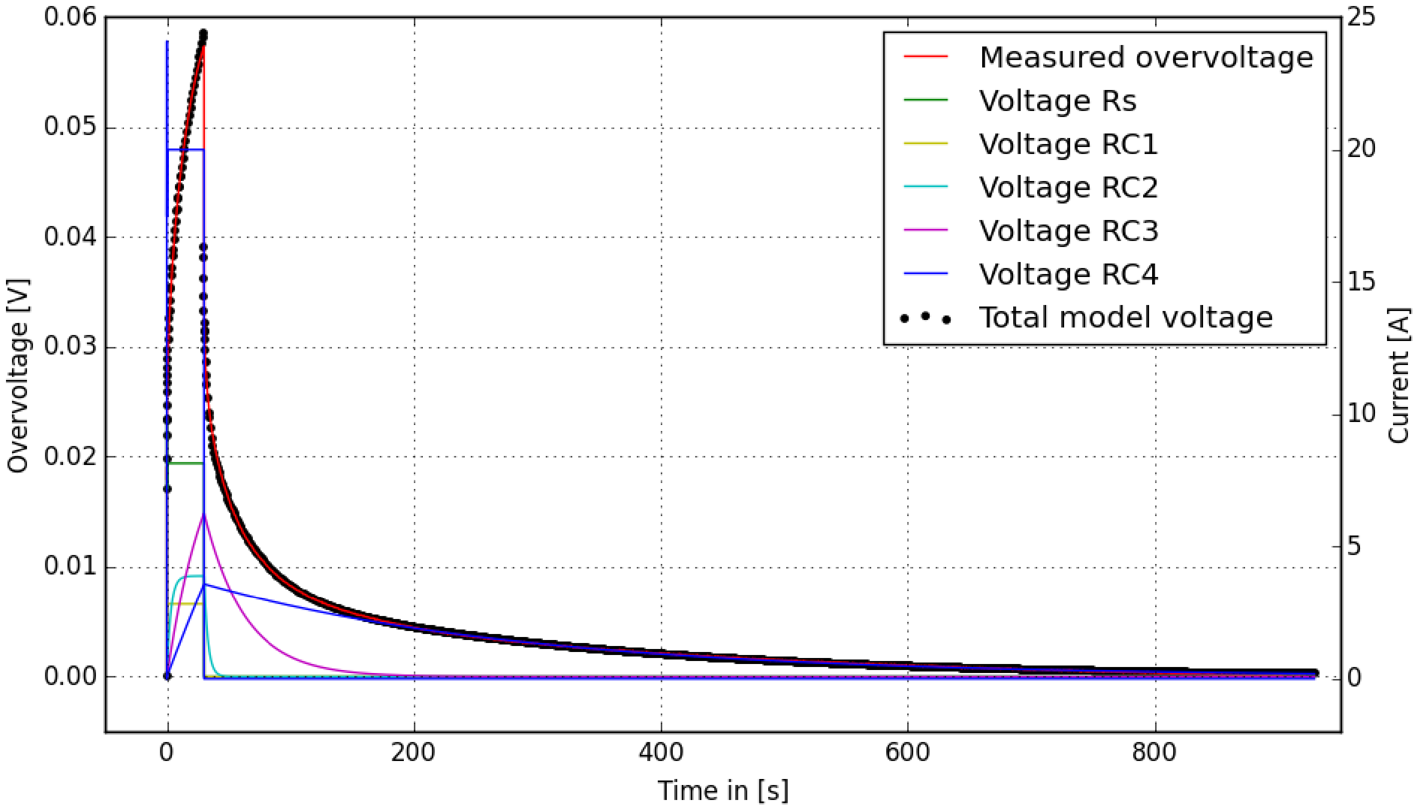

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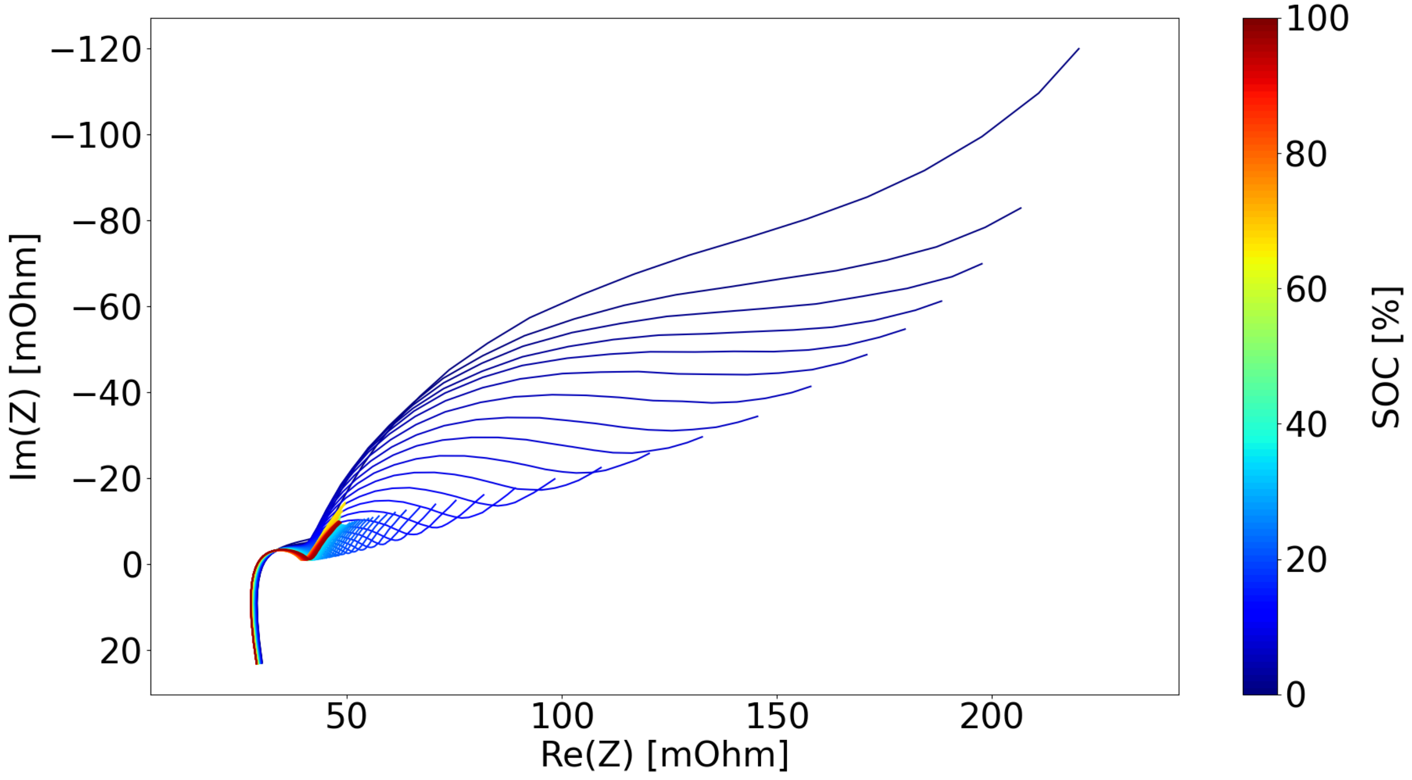




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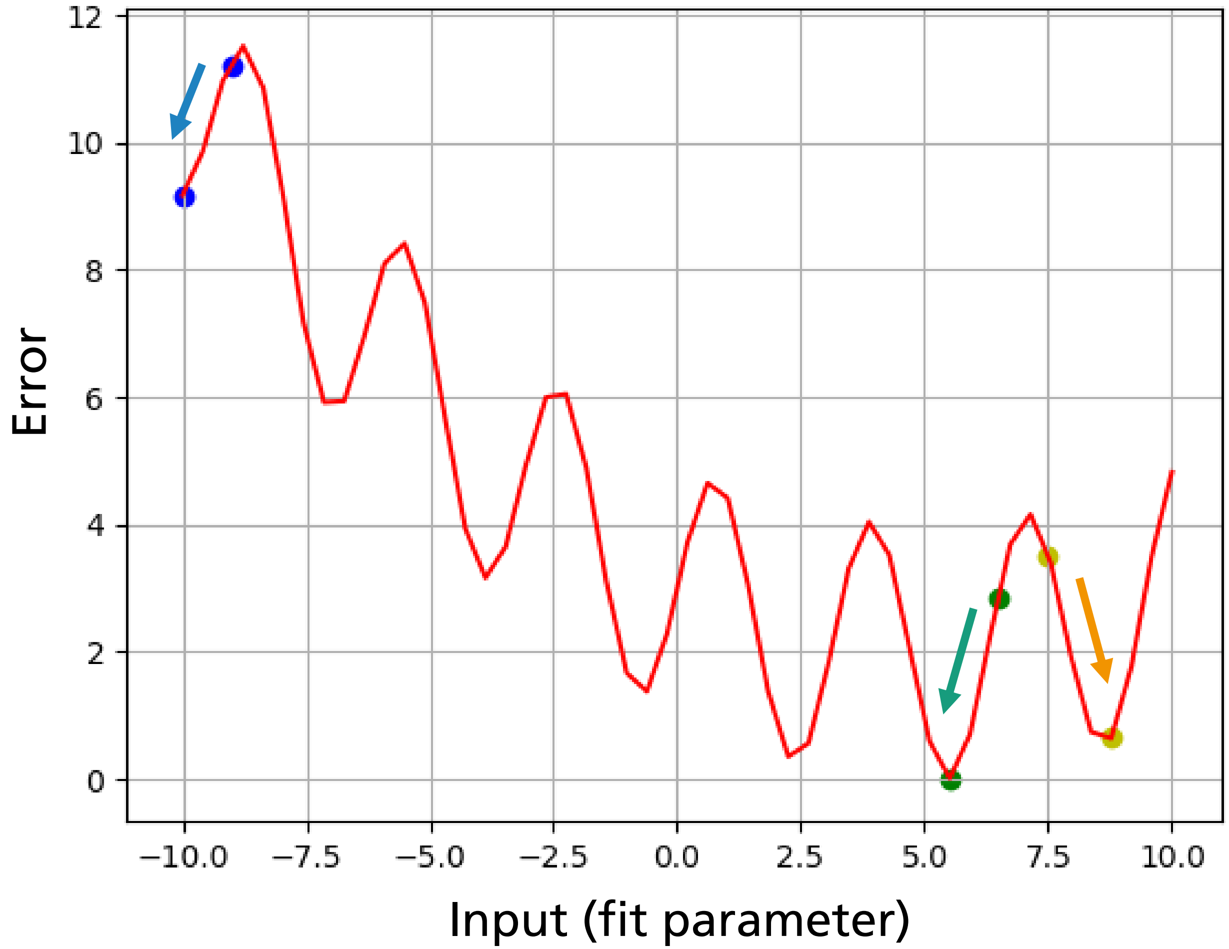
# Pulse test fitting problems

## What are the problems with pulse test fitting?

- Not clear how much RC elements are detectable:
  Under or over fitting problem!
- Search for numerous parameter with least-square algorithm (local optimizer)
  - Initial guess values required
  - Outcome may be a local minima/optimum



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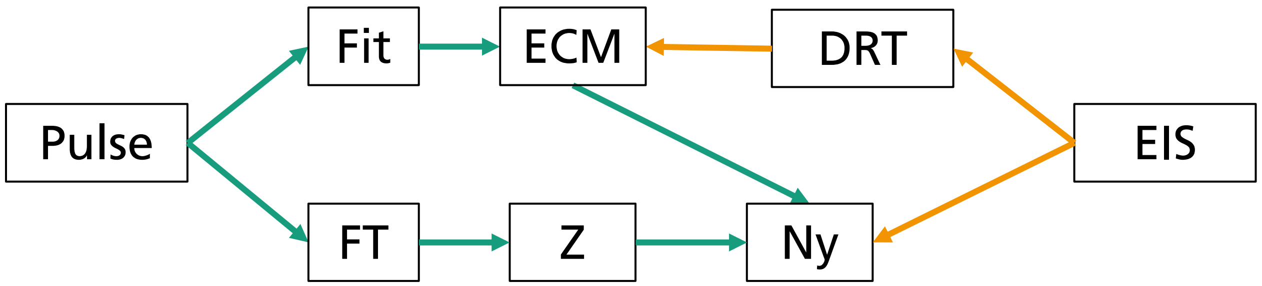
# Solution for pulse analysis

What can we do?

- Successive pulse fitting:
  Fitting one RC element at a time starting form the end of relaxation (highest time constant).
  Publication: https://doi.org/10.1016/j.jpowsour.2021.229513
- Fourie transformation:
  Transform the pulse response into frequency domain and use the impedance workflow (e.g. DRT analysis).
  Publication: coming soon




ECM = equivalent circuit model

FT = Fourier transform

Z = Impedance

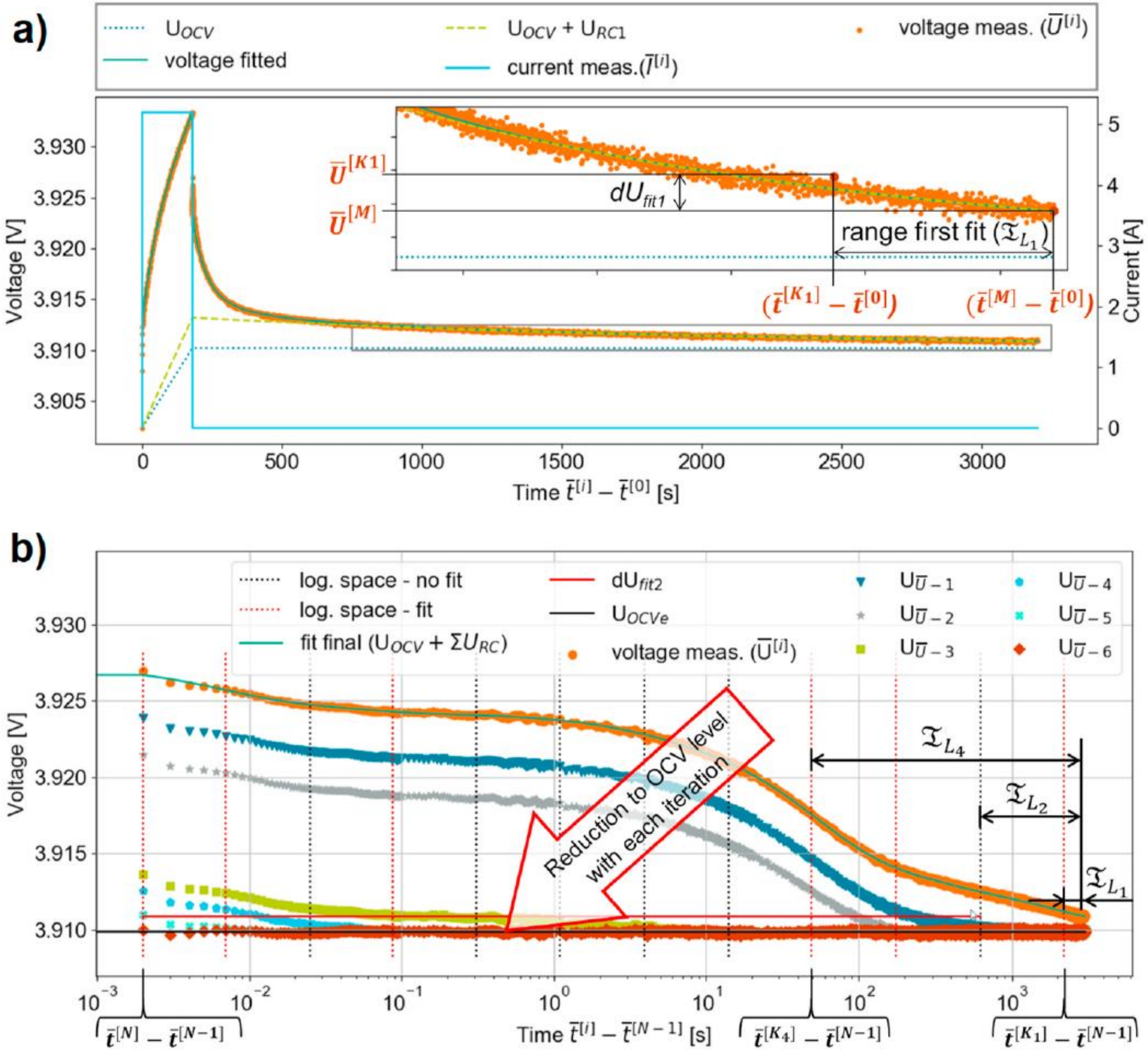
Ny = Nyquist plot

DRT = Distribution of relaxation times

# Successive pulse fitting

How does it work?

- First fit at the end of the relaxation (RC1, OCV)
- Subtract voltage of RC1 and divide voltage response in logarithmic sections.
- Loop: fit in the section and subtract respective RC element´s voltage





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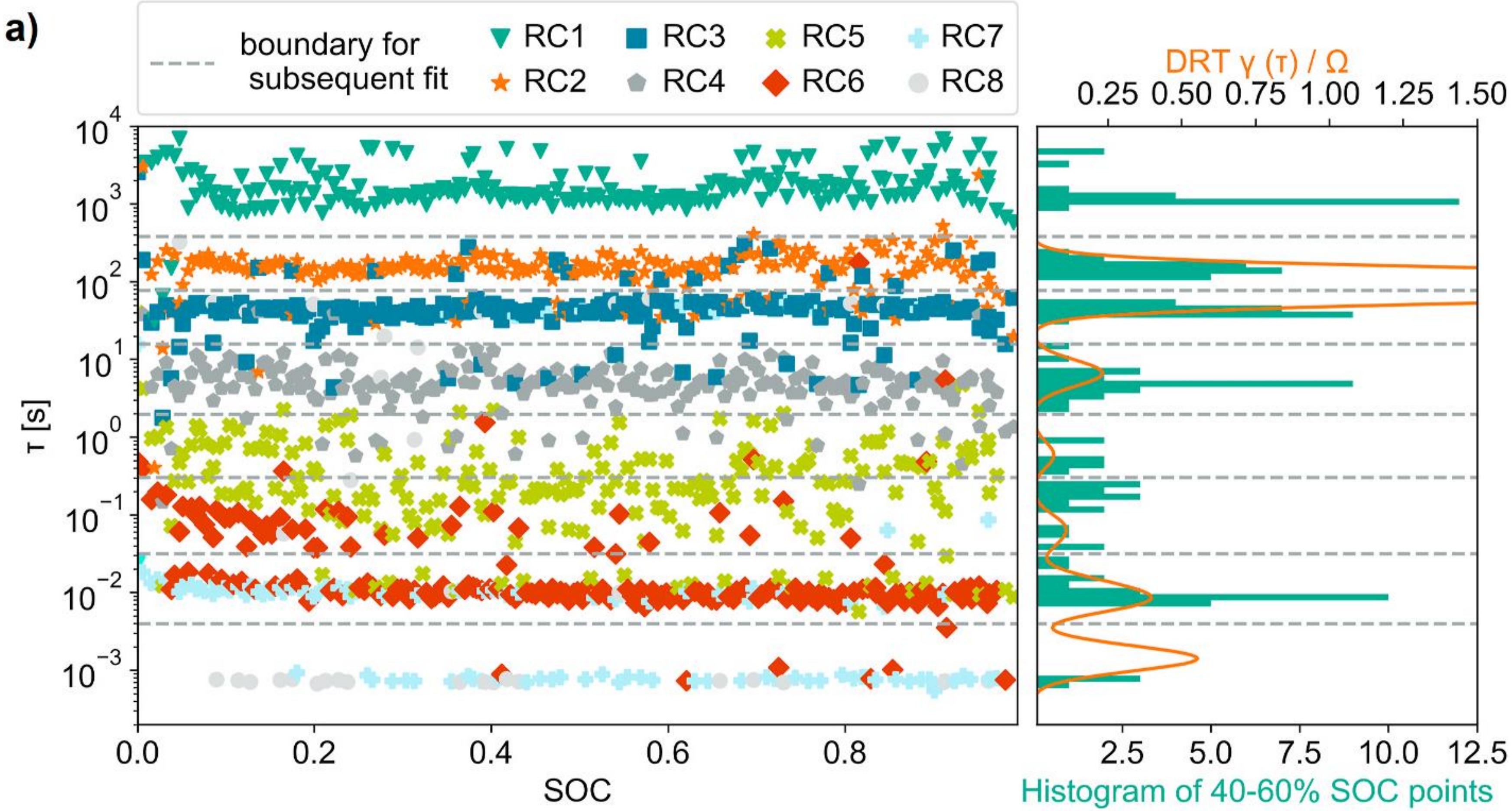
# Successive pulse fitting

Results for a battery cell





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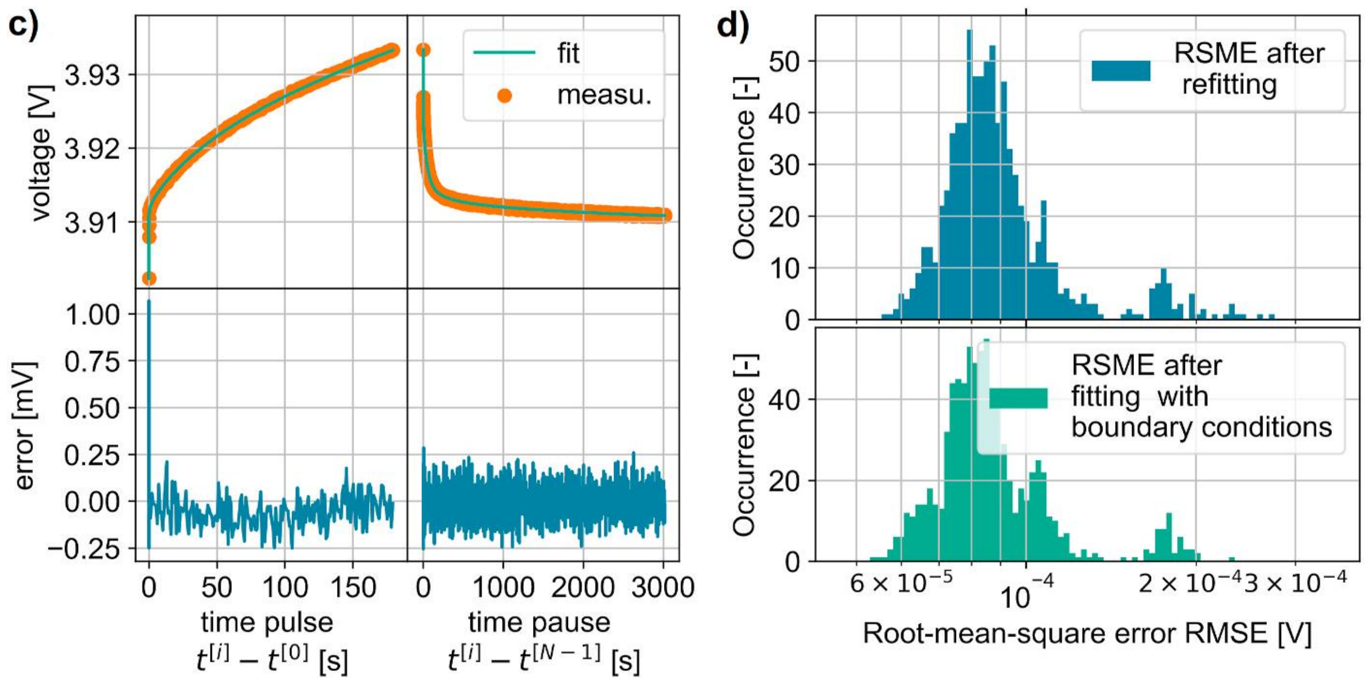
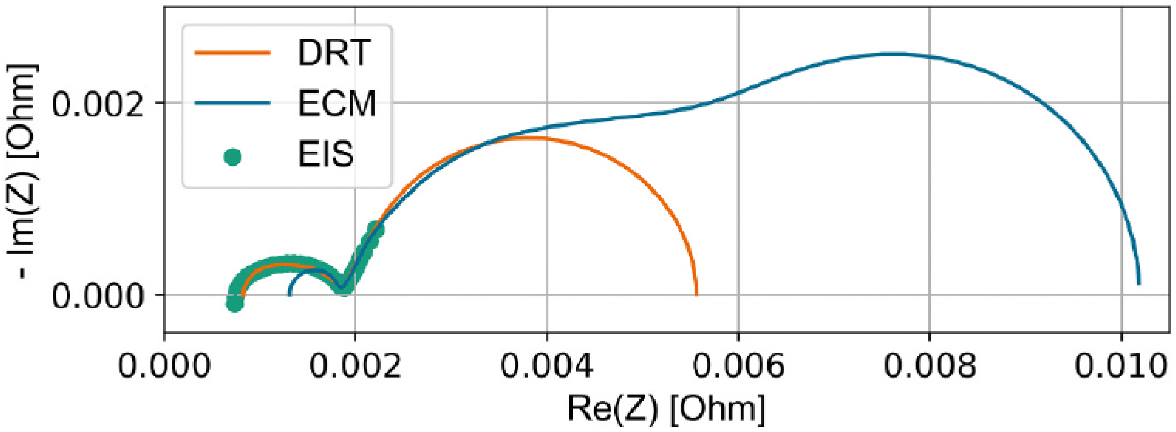
# Successive pulse fitting

## Results for a battery cell

- One current pulse response can be perfectly modeled with RC elements. Error = noise
- The time constants match with EIS-DRT-analysis, impedance in Nyquist plot
- The data acquisition rate of battery tester needs to increase 10-20 kHz (and logarithmic logging)







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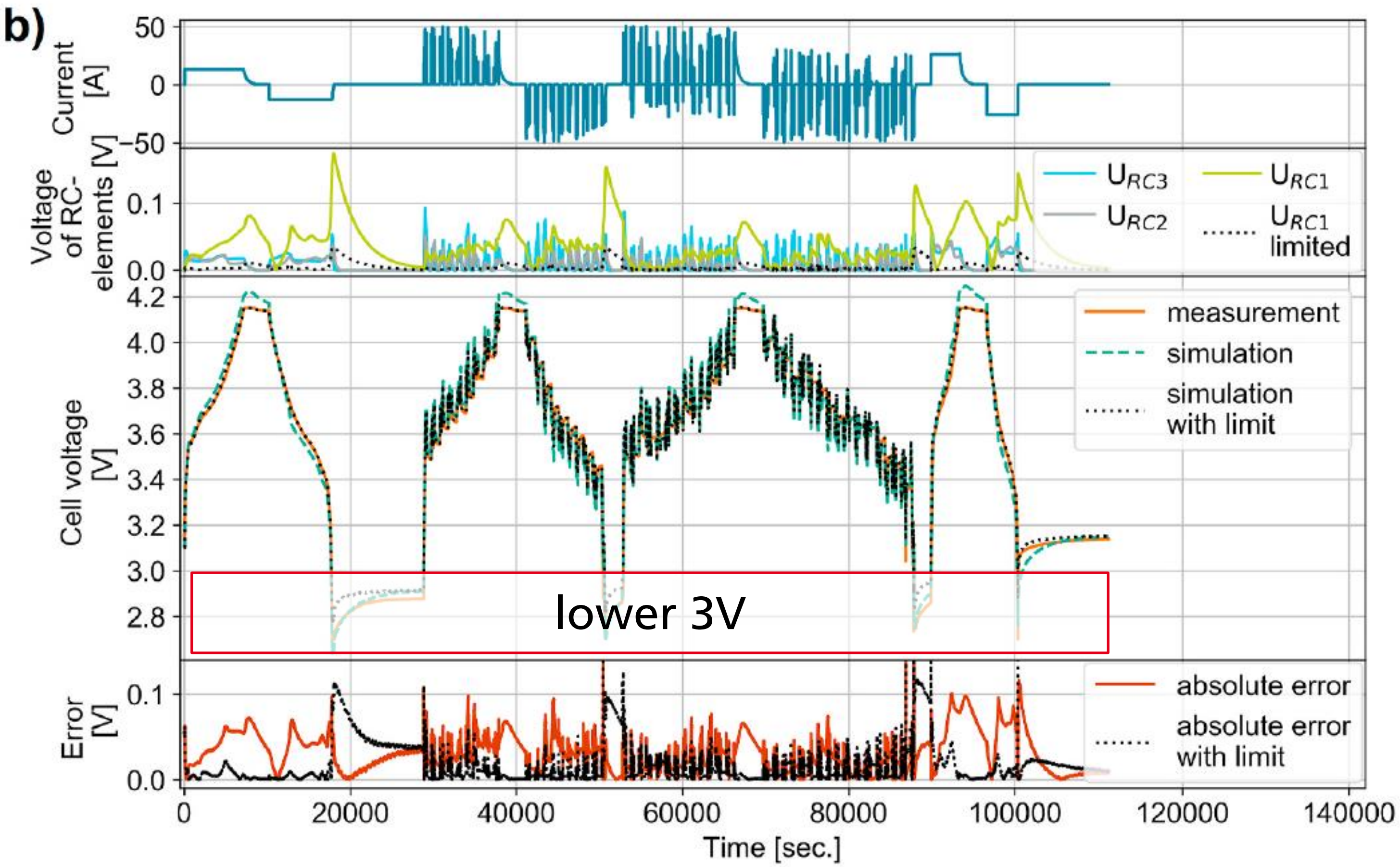
# Battery cell model

## Verification of fitted ECM parameter

- Voltage limit for RC with highest time constant

$$U_{RC1\ limit} = R_1\ I_{pulse} \left(1 - e^{\frac{-t_{pulse}}{\tau_1}}\right)$$

- Good result:
  - RMSE 33.2 mV // NRMSE 2.27%
  - RMSE 19.0 mV // NRMSE 1.30% (for voltages over 3V)







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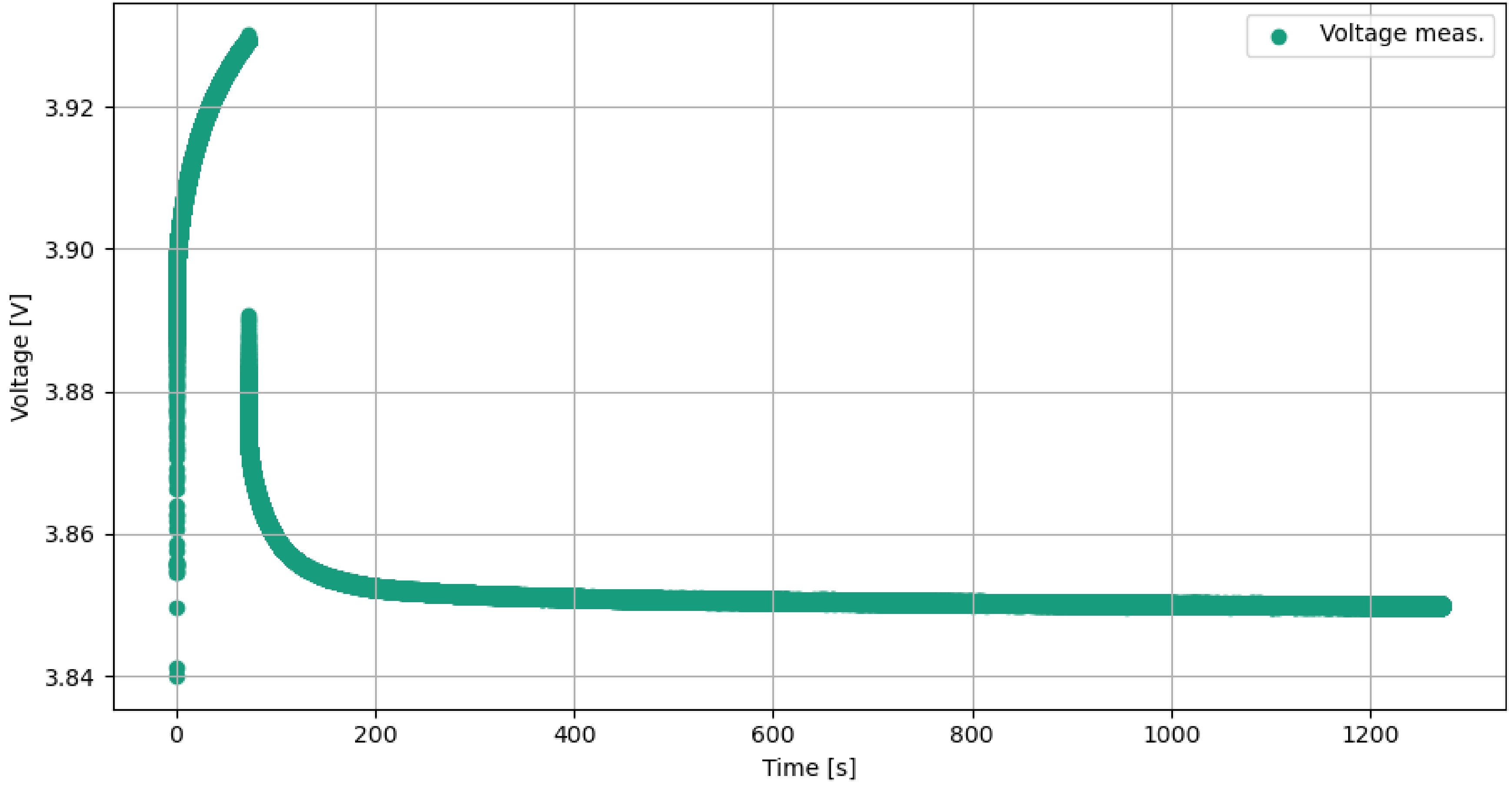
# Pulse test

Can a pulse test be as meaningful as EIS?



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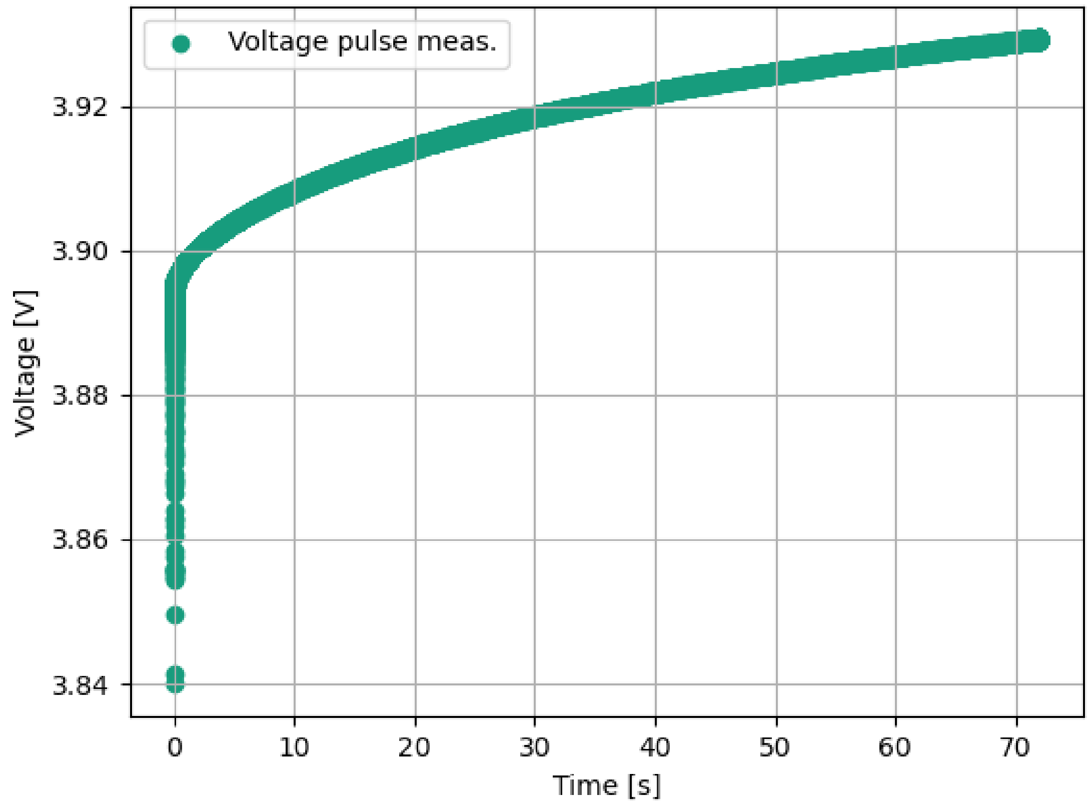


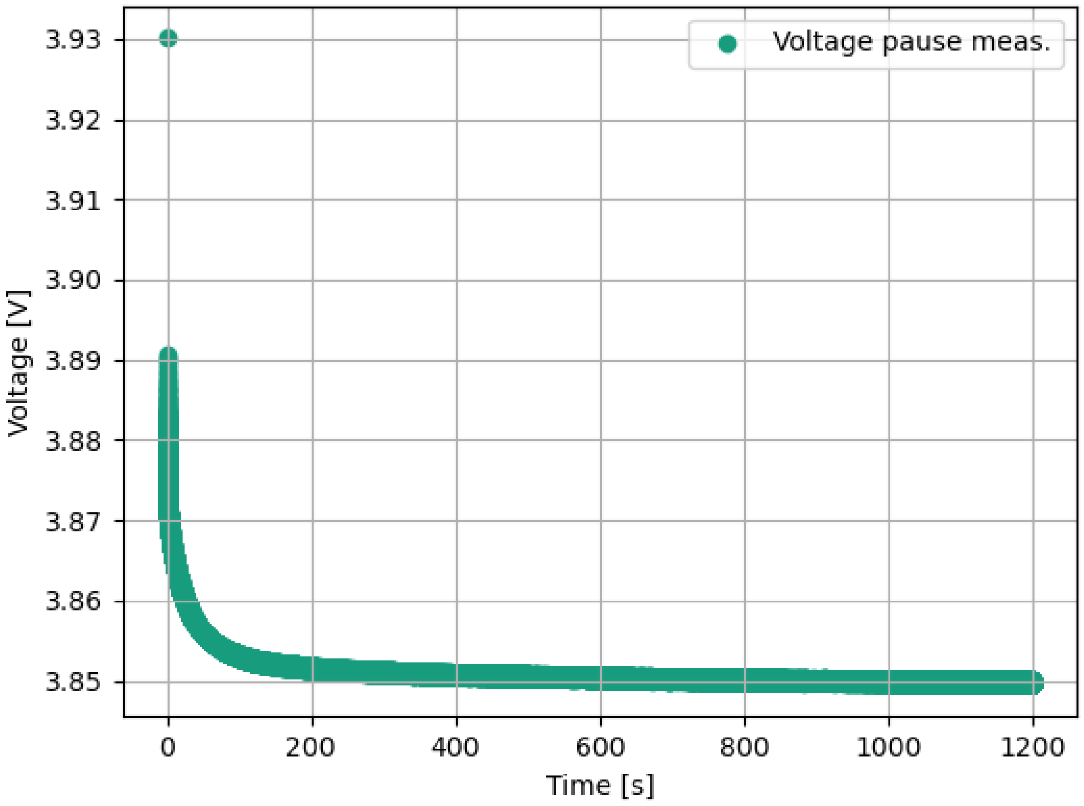

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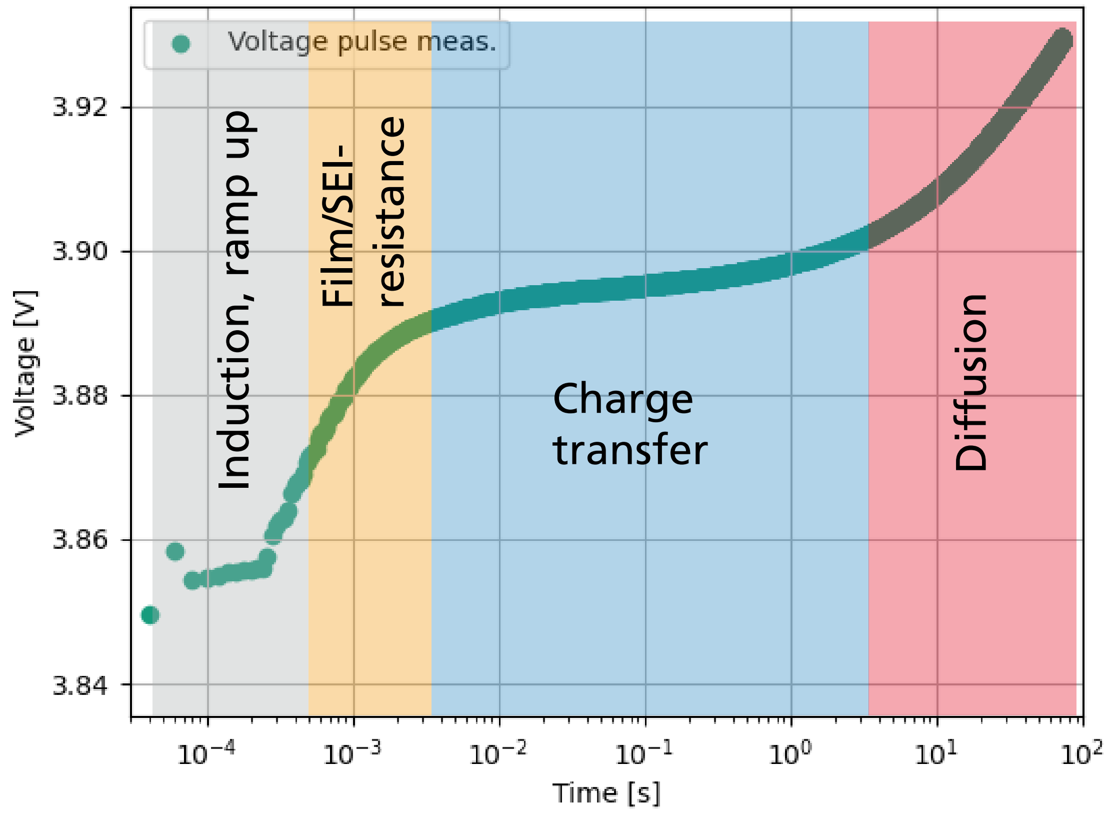
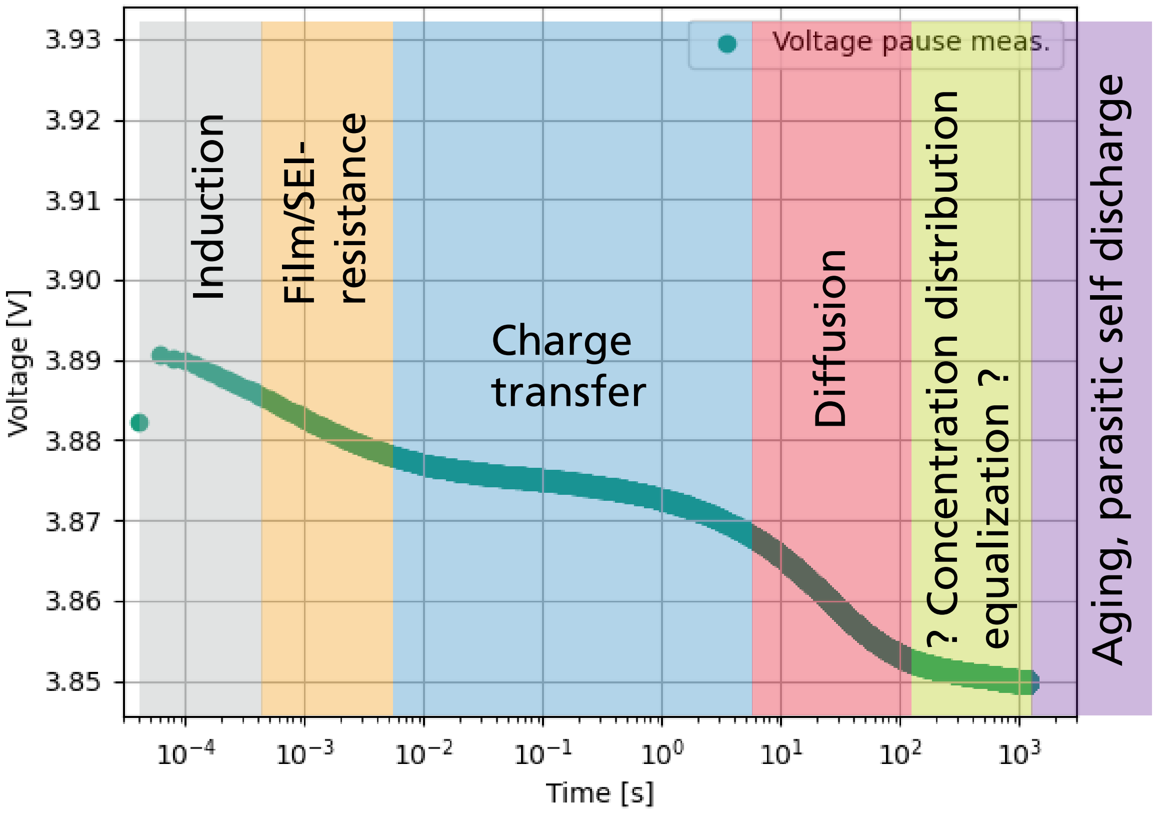
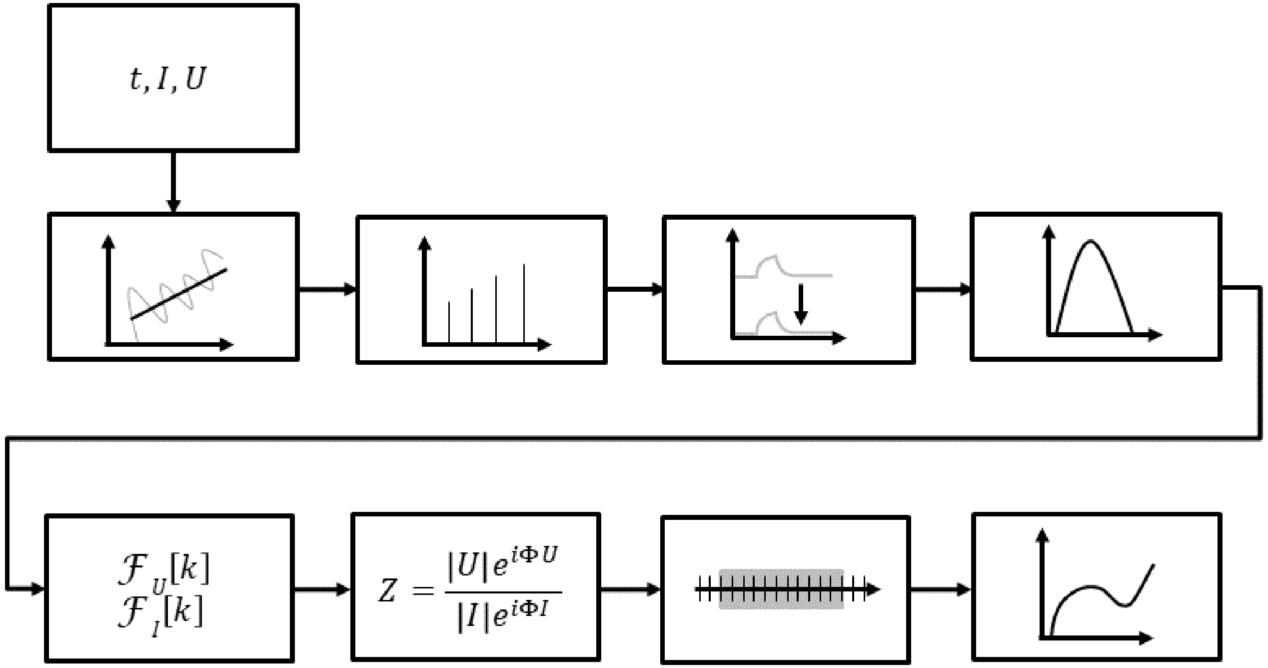
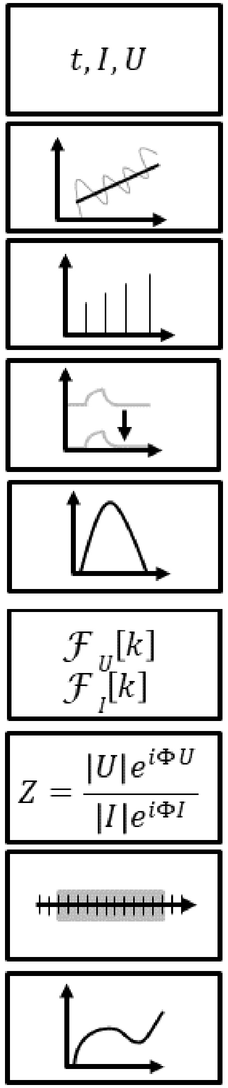


# Fourier transform
## Can a pulse test be as meaningful as EIS?

- Workflow Fourier transformation:




*Importing measurement data*

*Fitting measurement data*

*Interpolating measurement data*

*Subtracting OCV*

*Windowing*

*Fourier transforming current and voltage signals*

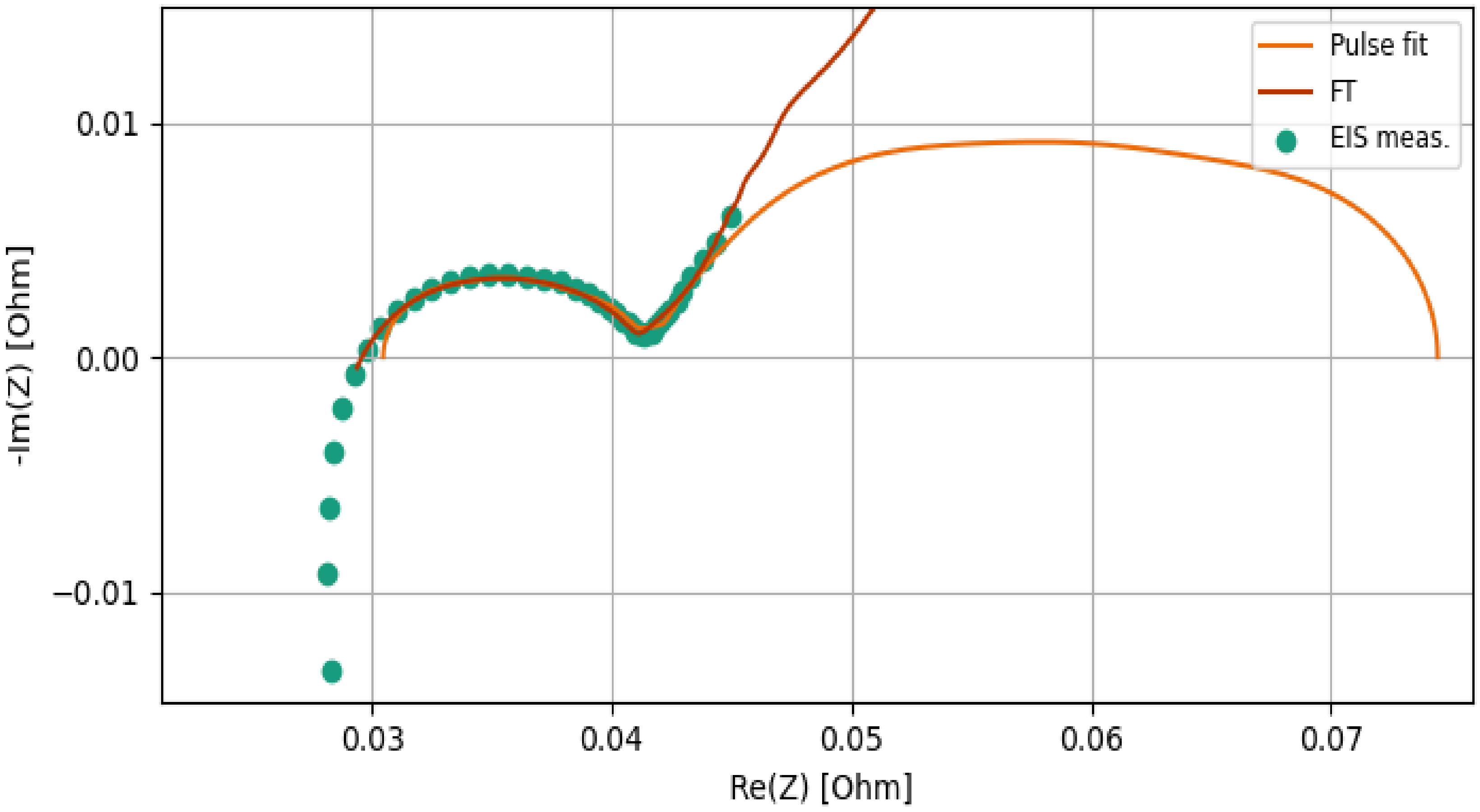
*Calculating impedance*

*Filtrating frequencies*

*Visualising via Nyquist plot*

# Pulse test

Can a pulse test be as meaningful as EIS?



# Conclusion

- Pulse testing can be as meaningful as EIS and analyze all el. chem. effects.
  - Quality and aging indicator
  - Empirical modeling
- The bad reputation of pulse testing is due to the presented problems and bad practice.
- Our pulse fitting & FT algorithms are verified by EIS (DRT, Nyquist plot), synthetic data, load profile
- Visualization of pulse response should be (also) in logarithmic scale.
- Battery test systems need to have higher measurement rates (20-50 kHz).
- Pulse tests are easily viable for cells and battery systems

# Thank You for Your Attention!


Maximilian Bruch

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# Pulse test

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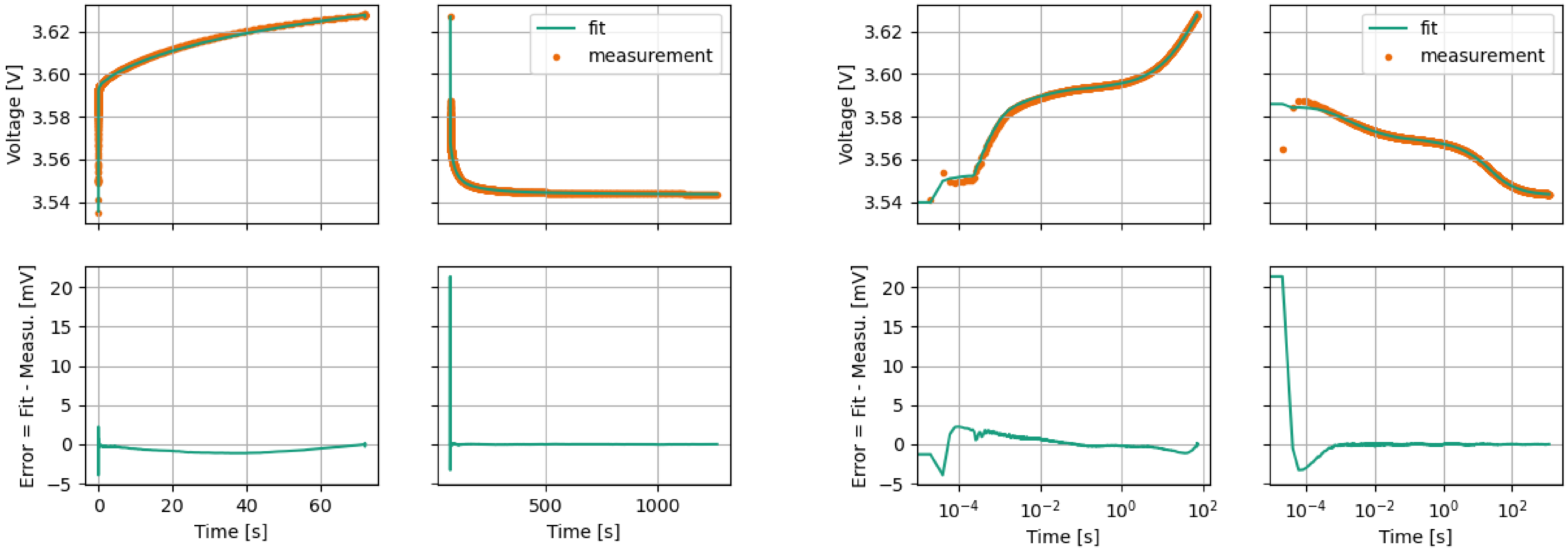






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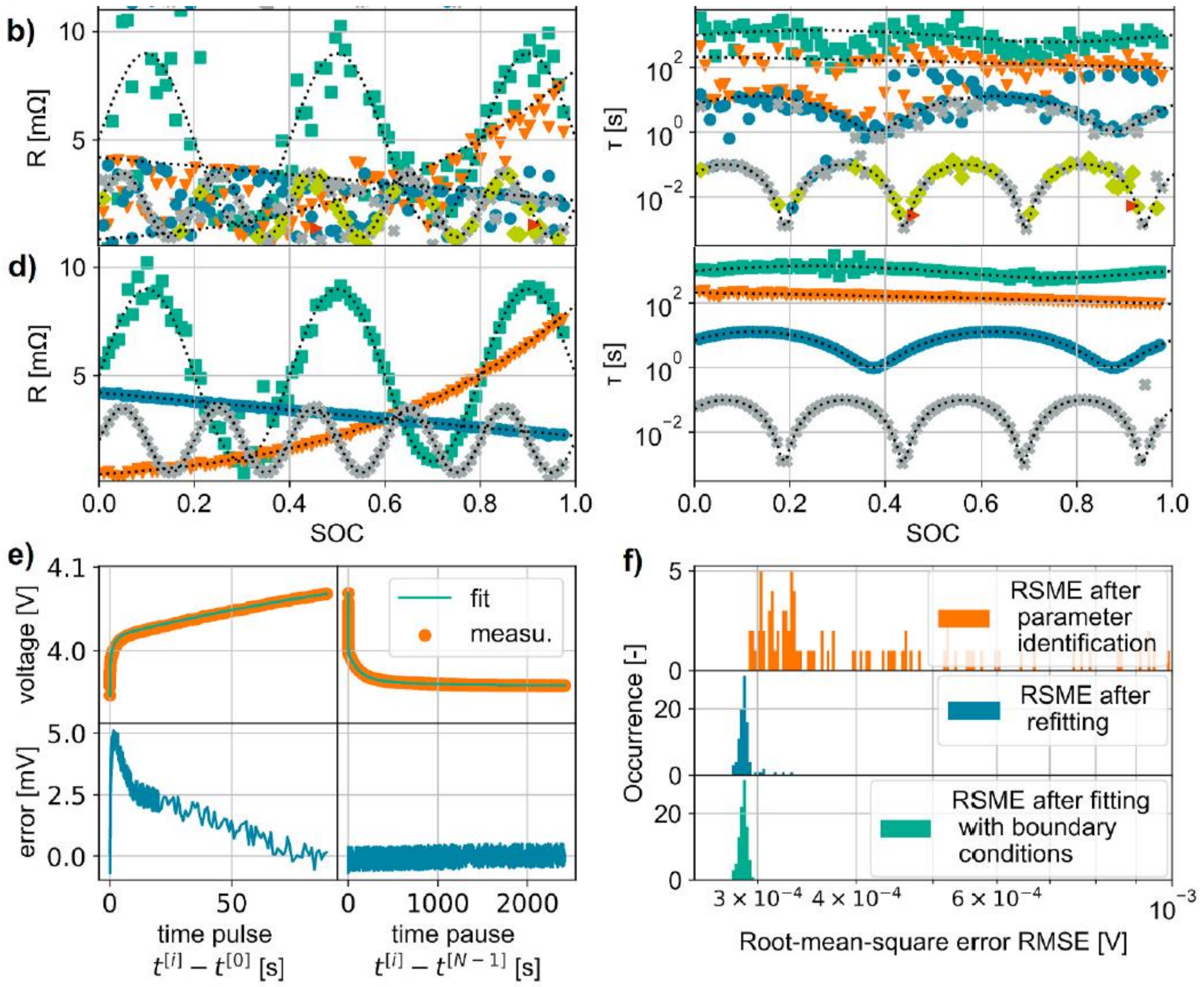
# Subsequent pulse fitting
## Verification with synthetic data

- Calculate the voltage with known parameter
- Use the algorithm on the data
- Compare, verify







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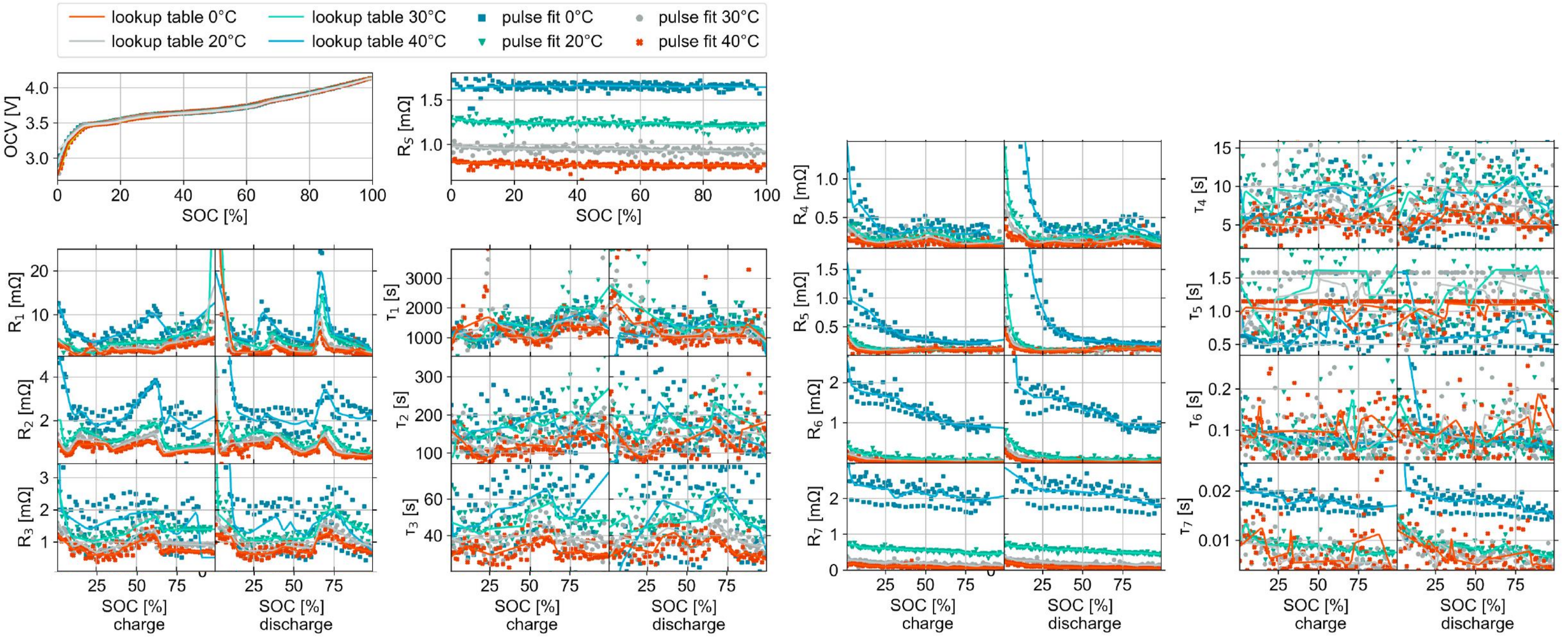






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