Practical application of impedance measurement with minimalistic instrumentation

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Outline

Instrumentation for measuring impedance

Impedance detection based on time domain method

Our choice: **step answer with common stimulus**

Data reduction

Practical solution with minimalistic approach

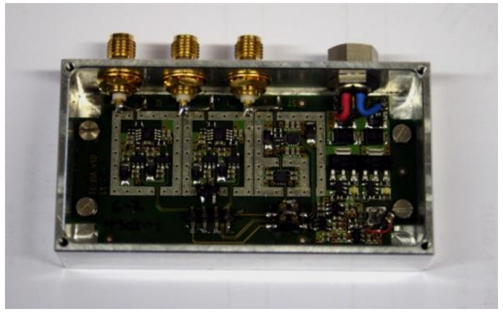
Summary

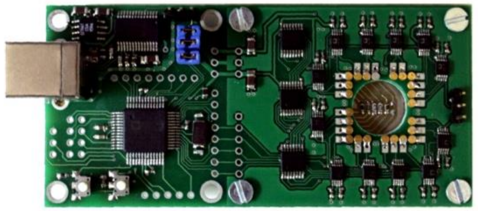
Impedance instrumentation

impdance analyzer software → front-end / multiplexer → electrode system

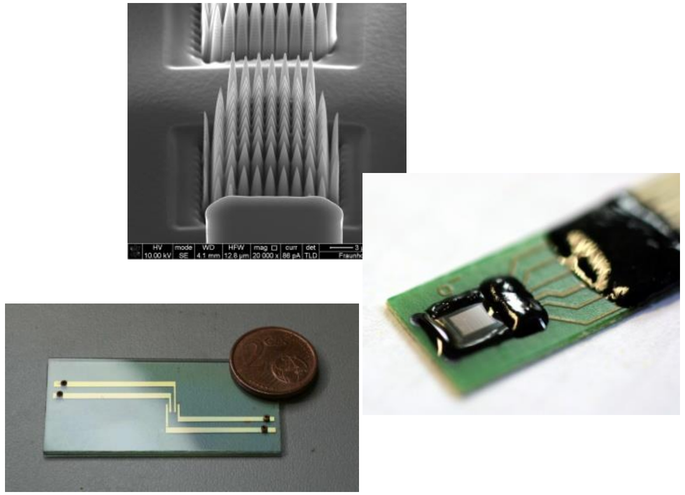
high-end

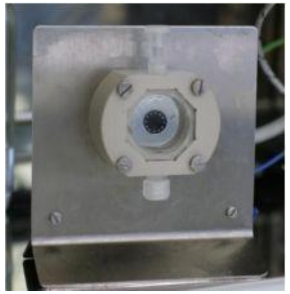
low-cost





nano-structured





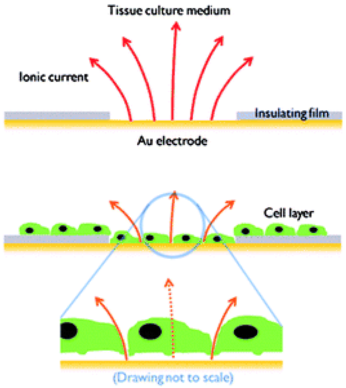
macrsocopic

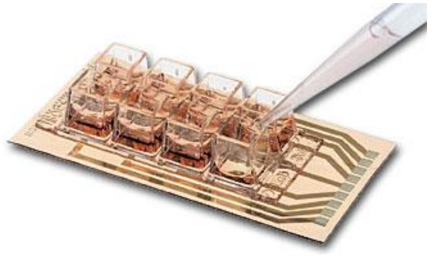
Low cost solution - one or few frequencies, but no spectrum

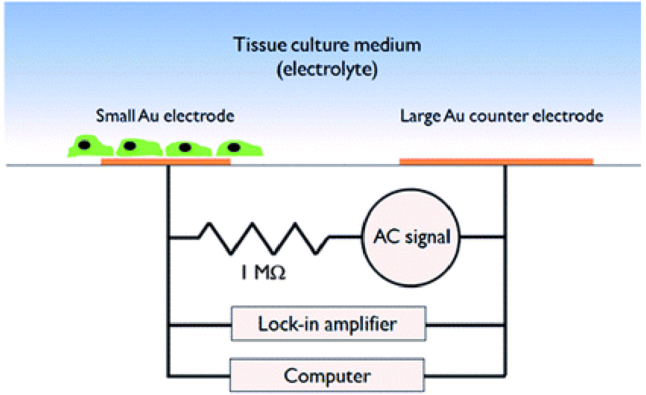
Aber Instruments yeast monitor

Measuring Frequency:	312KHz
Measuring Ranges:	0 to 400 pF/cm 0 to 100% Viable Yeast Spun Solids 0 to $5x10^9$ Cells/ml Conductivity range of 0.75 to 10 mS/cm
Cell Concentration Range:	Depends on cell sizes but typically: Yeast (6 µm): 10^6 cells/ml to 10^{10} Cells/ml

cell detection on electrodes (ECIS)







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Can we have impedance spectroscopy simple and cheap?

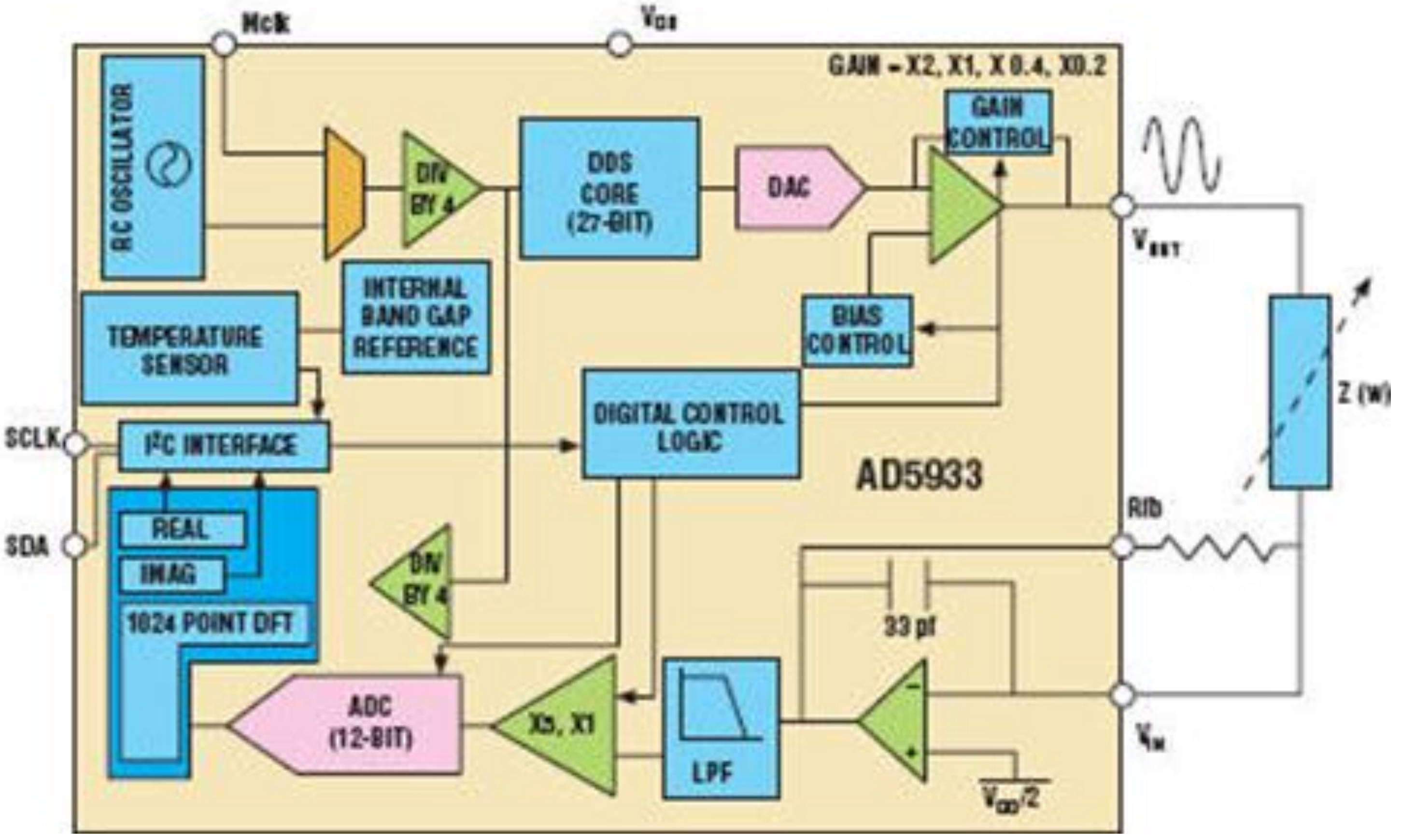
This means:

- Extremely low cost of the equipment
  single use application possible (special ASIC?)

- Extremely low energy consumption
  Possible powering via RF-link (RFID)???

Single chip solution: AD5933 / AD5934

But it is limited to narrow measurement condition



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Frequency sweep is slow and equipment is expensive

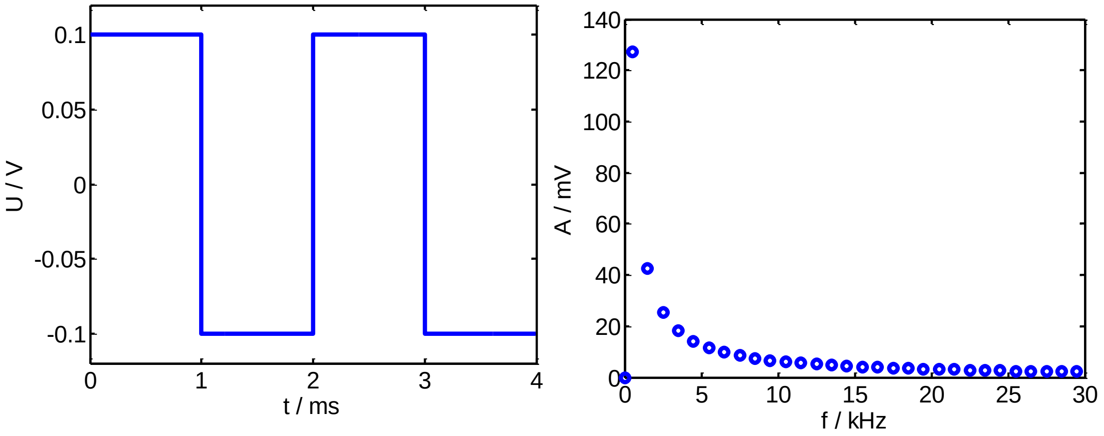
What can we do **better** ?

Impedance detection based on time domain method

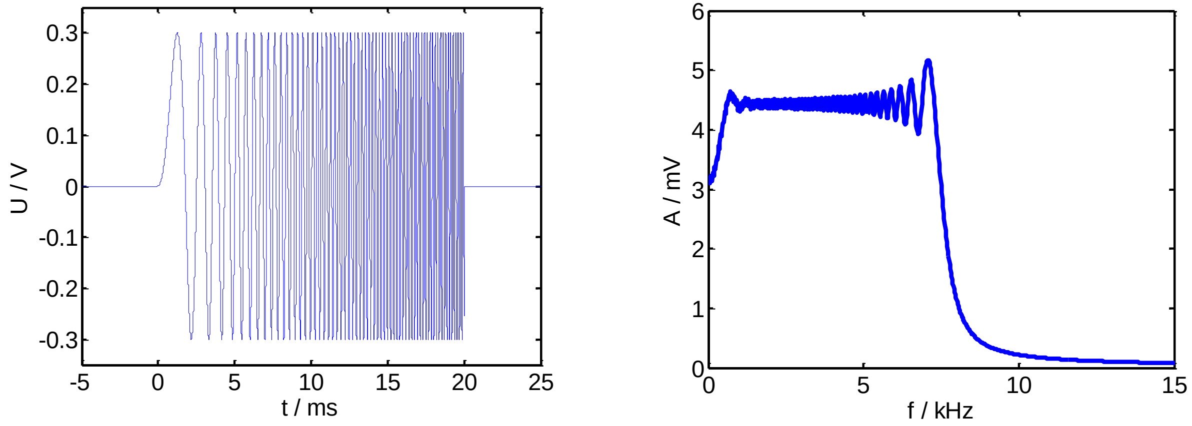
<u>Simple idea</u>: apply all frequencies at the same time and process the data to find the impedance at each single frequency

Popular excitation signals

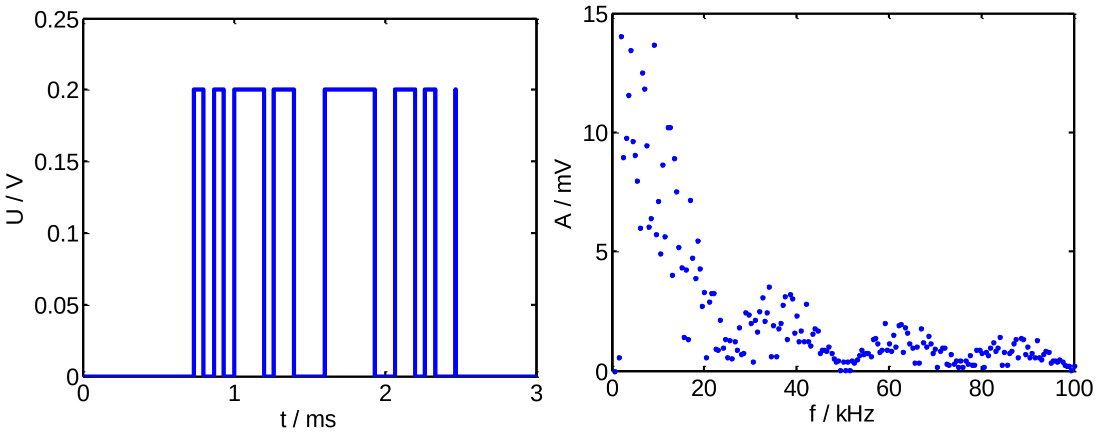
Rectangular wave



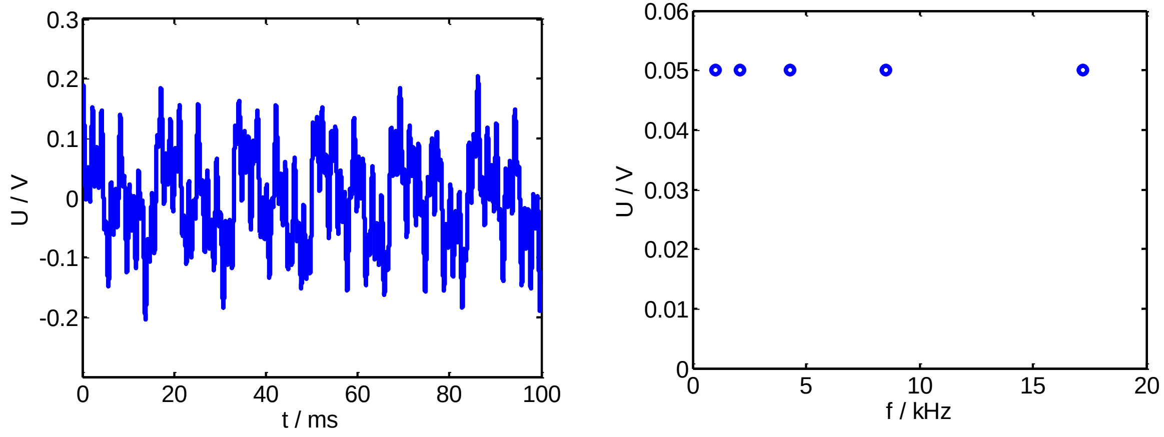
chirp



Maximum length sequence

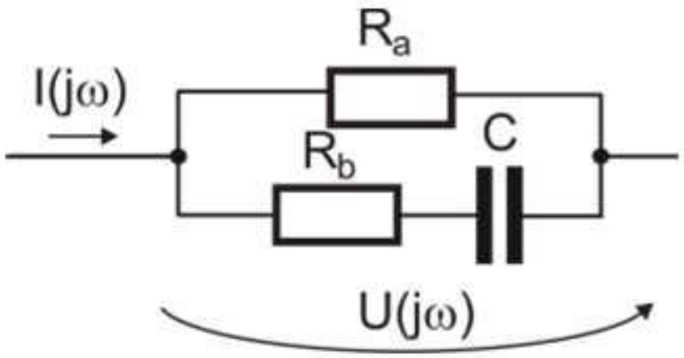


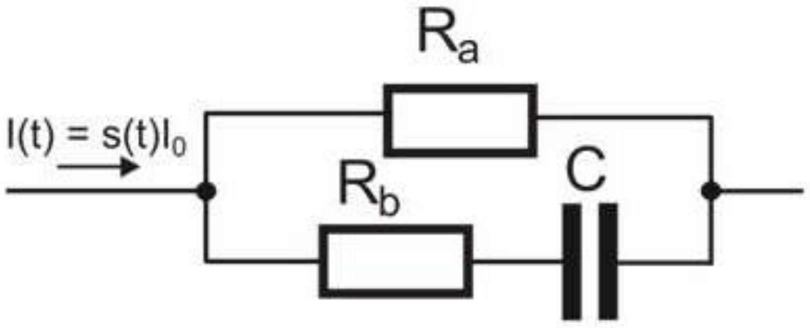
multisine



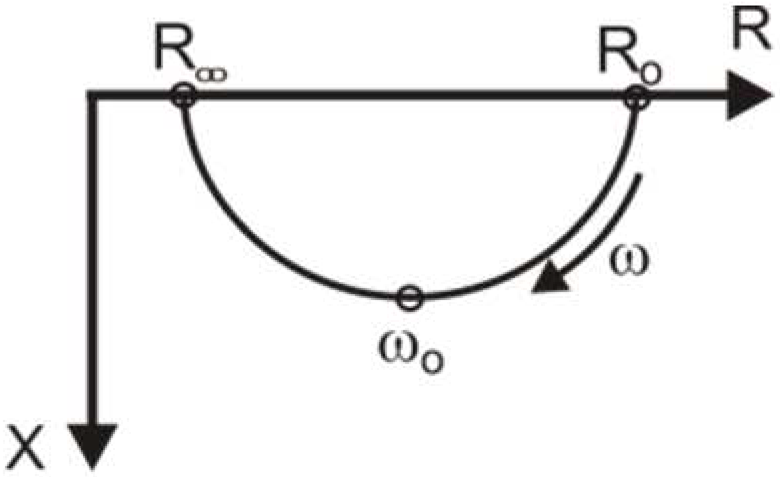
Our choice: step answer

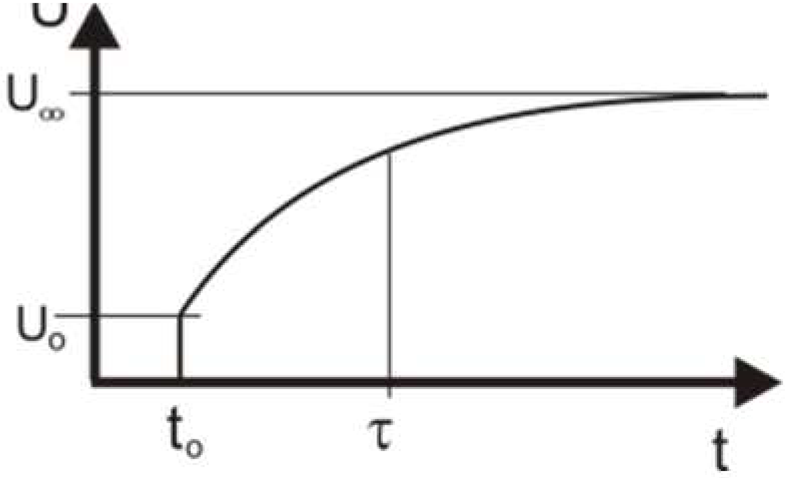
Current and voltage in frequency and time domain



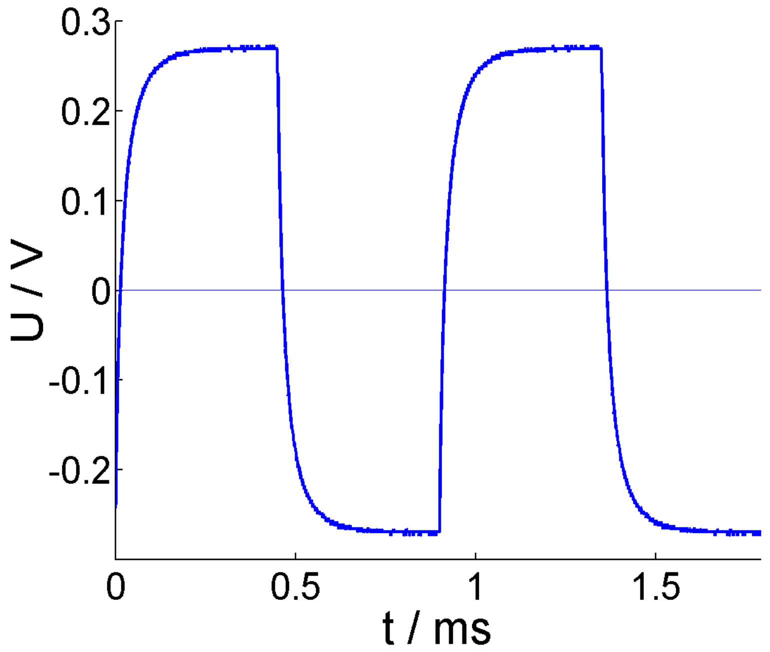


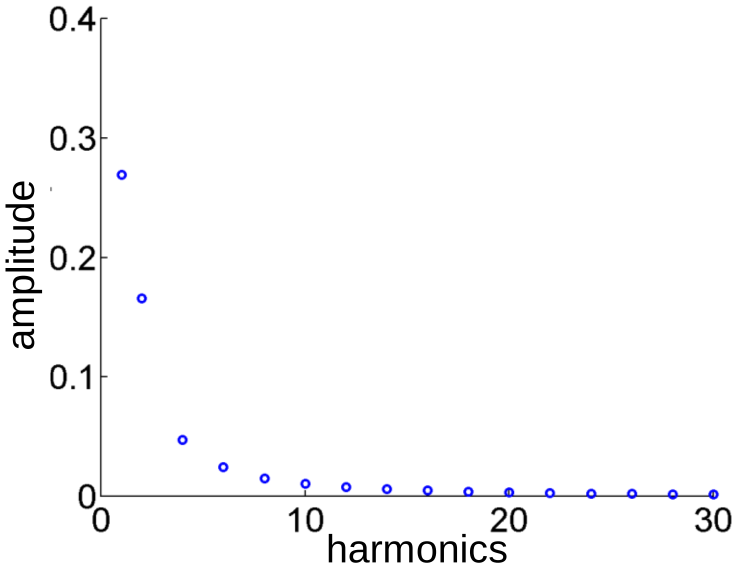
$$U(t) = I_0\left(R_a - \frac{R_a^2}{R_a + R_b} e^{-\frac{t}{\tau}}\right)$$





Processing of the step answer





$$U = \mathrm{f}(t) \xrightarrow{\text{FOURIER transformation}} U = \mathrm{f}(\omega)$$

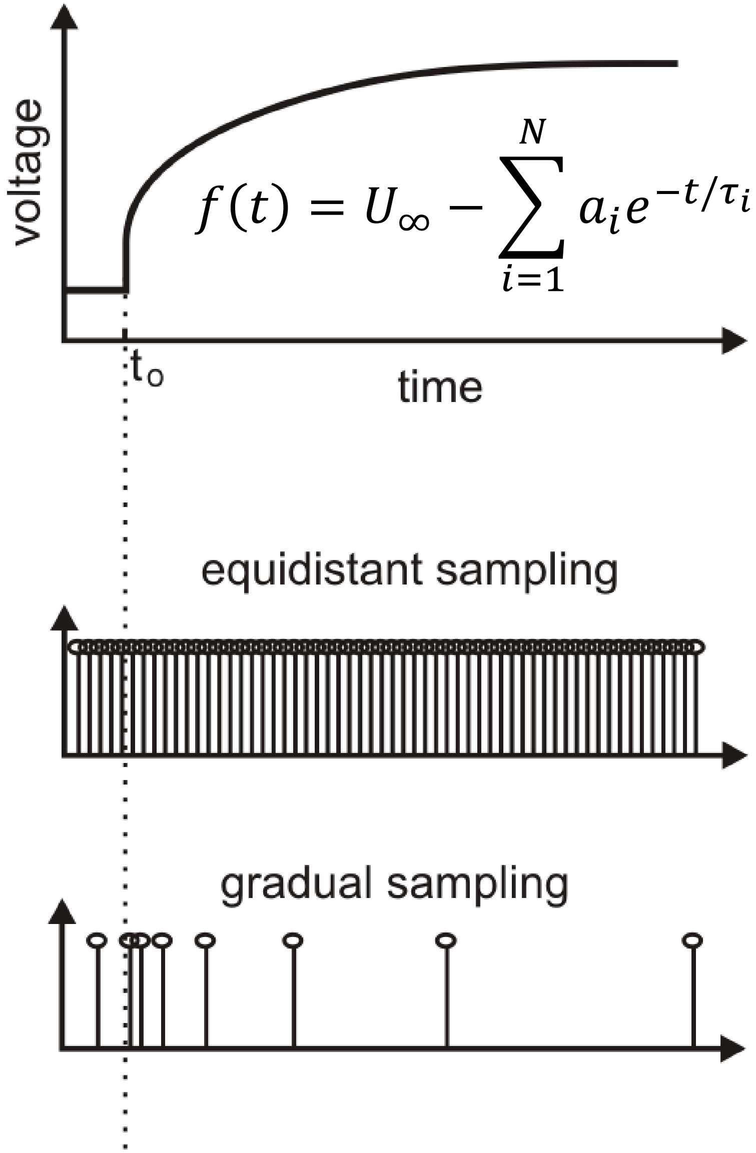
$$Z(\mathrm{j}\omega) = \mathrm{F}(U(t)) / \mathrm{F}(I(t))$$

Huge data volume for broad bandwidth spectroscopy

Example: measurement from 100 Hz – 10 MHz
requires at least 200,000 samples

Solution: excitation signals like
Dirac pulse, step function, ramp
and **gradual sampling**

Gradual Sampling of Exponential Function



optimal:

$$\Delta U_{LSB} = \Delta t_s \frac{\partial U}{\partial t}$$

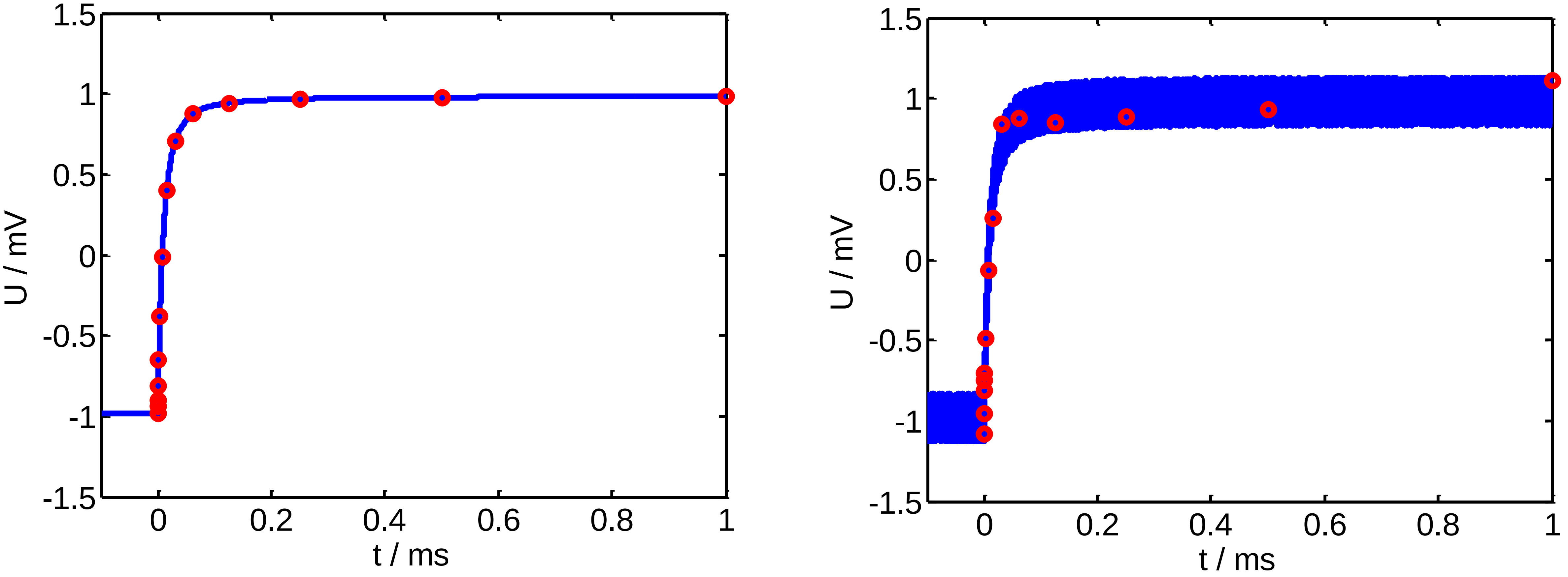
chosen for bio-impedance:

$$\Delta t_s(t) = A e^{t/B}$$

goal:

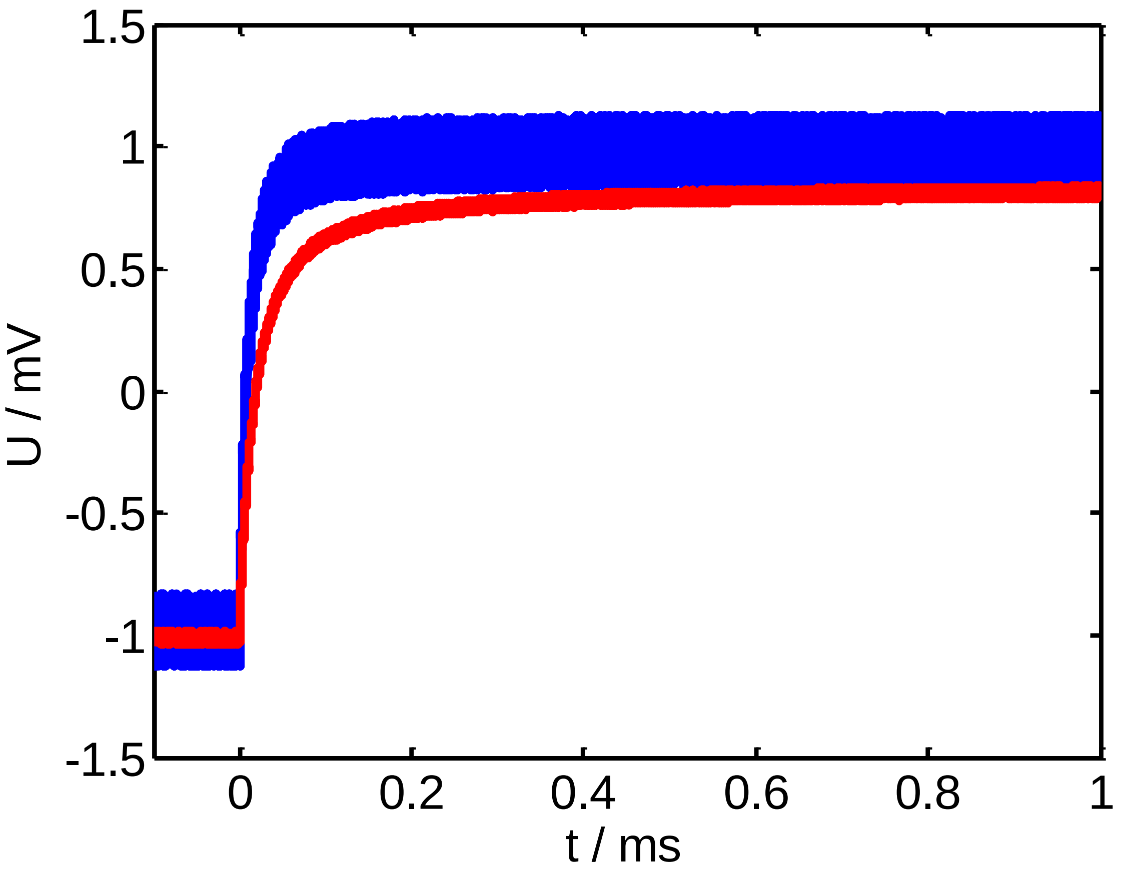
$$\Delta t_{meas} \Delta f_{meas} \approx \text{const.}$$

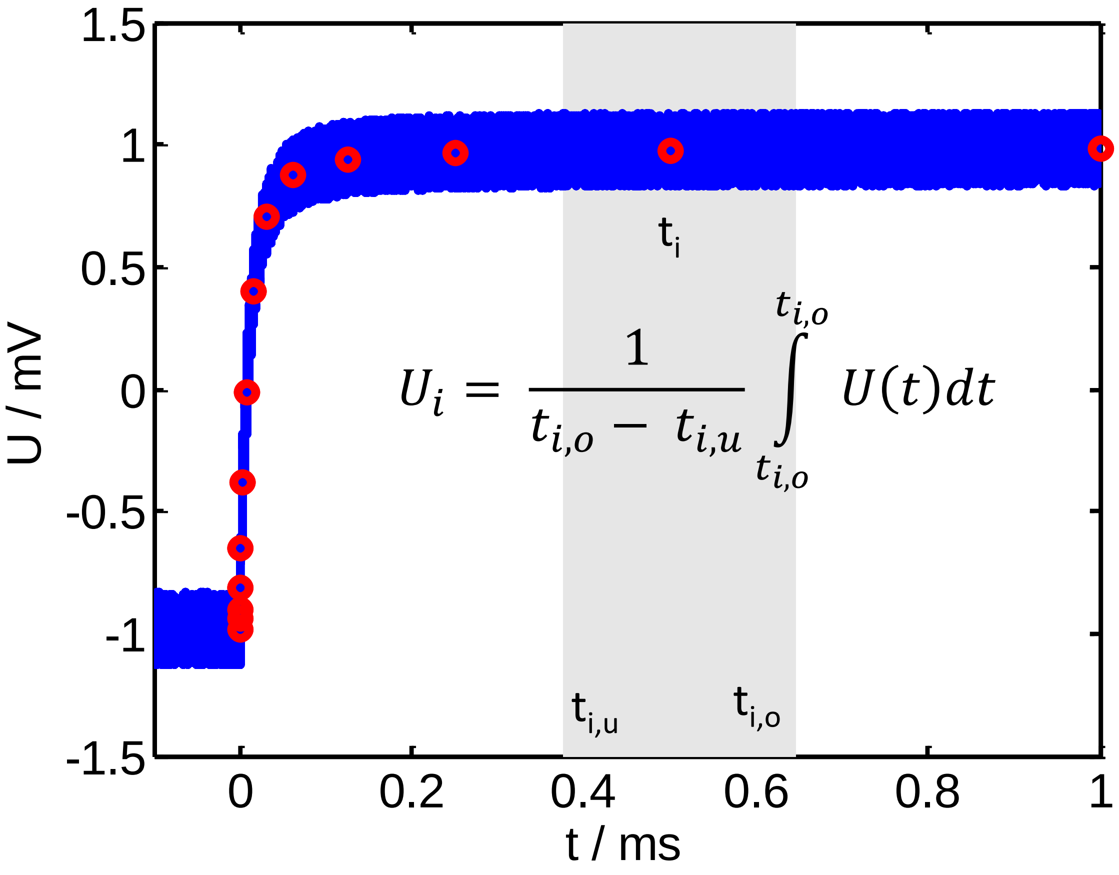
Simply sampling???



Gradual sampling is extremely noise sensitive and aliasing occurs !!!

Adding anti-aliasing filter???

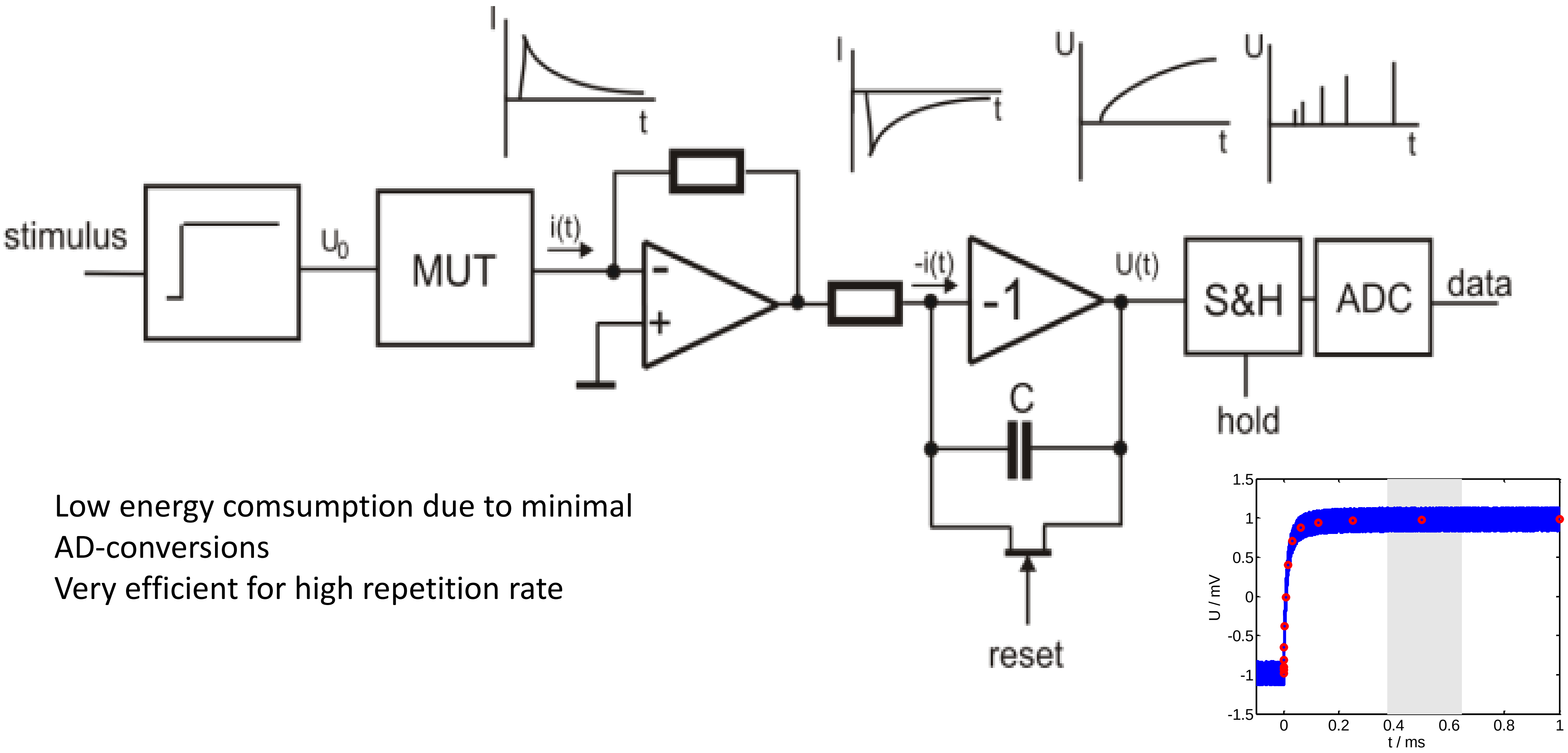




Simple filtering disturbes the signal.

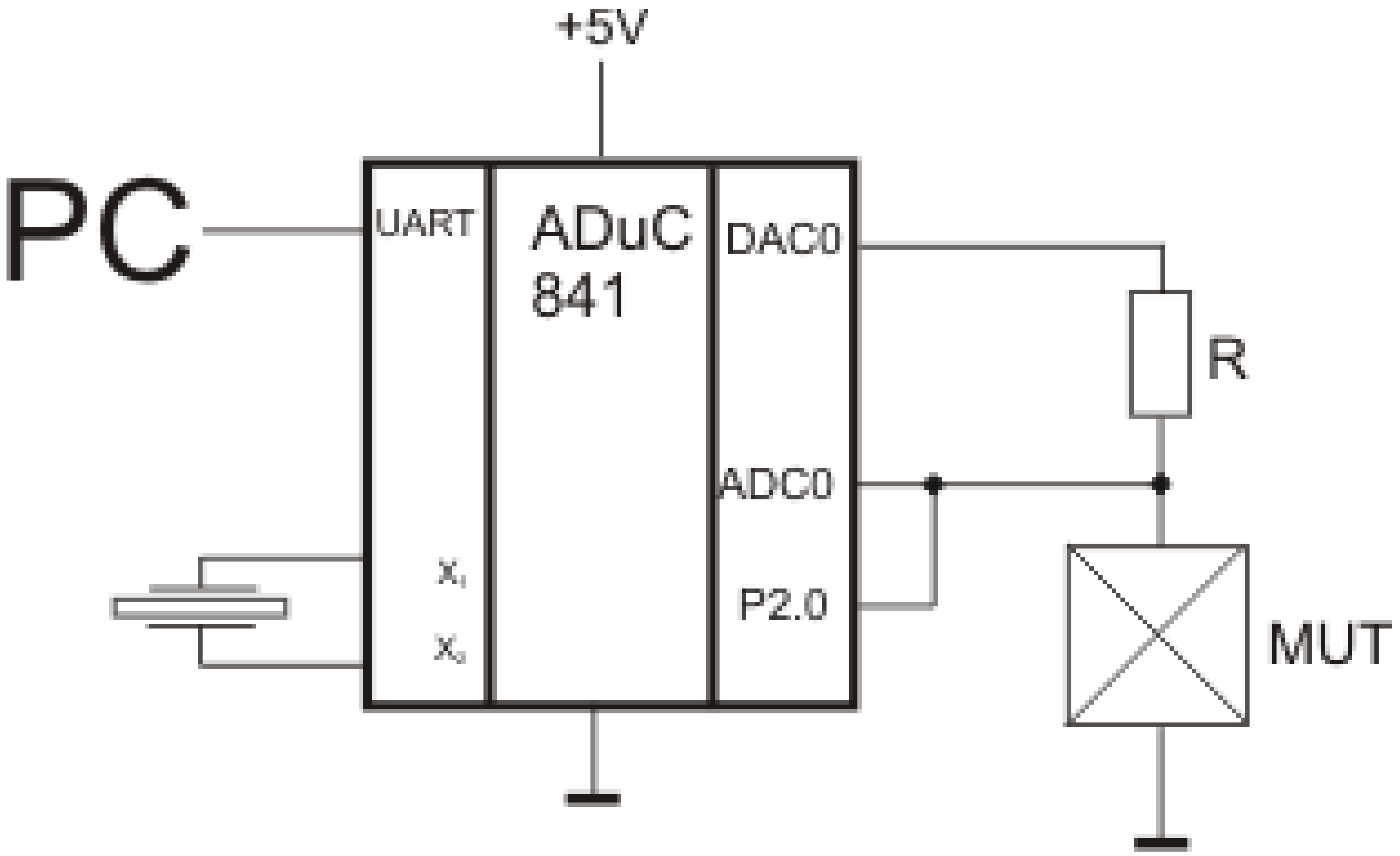
Solution: integration between sampling point → adaptive low pass filtering

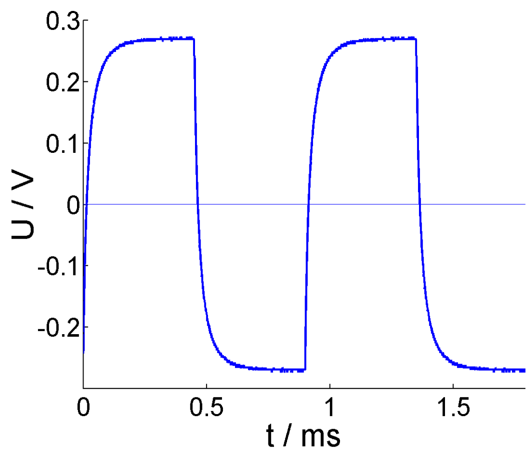
Practical solution

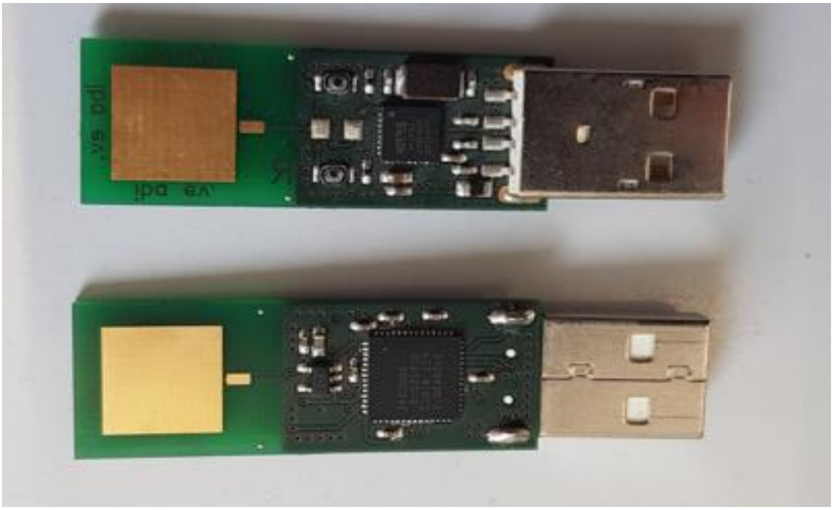


Low energy comsumption due to minimal
AD-conversions
Very efficient for high repetition rate

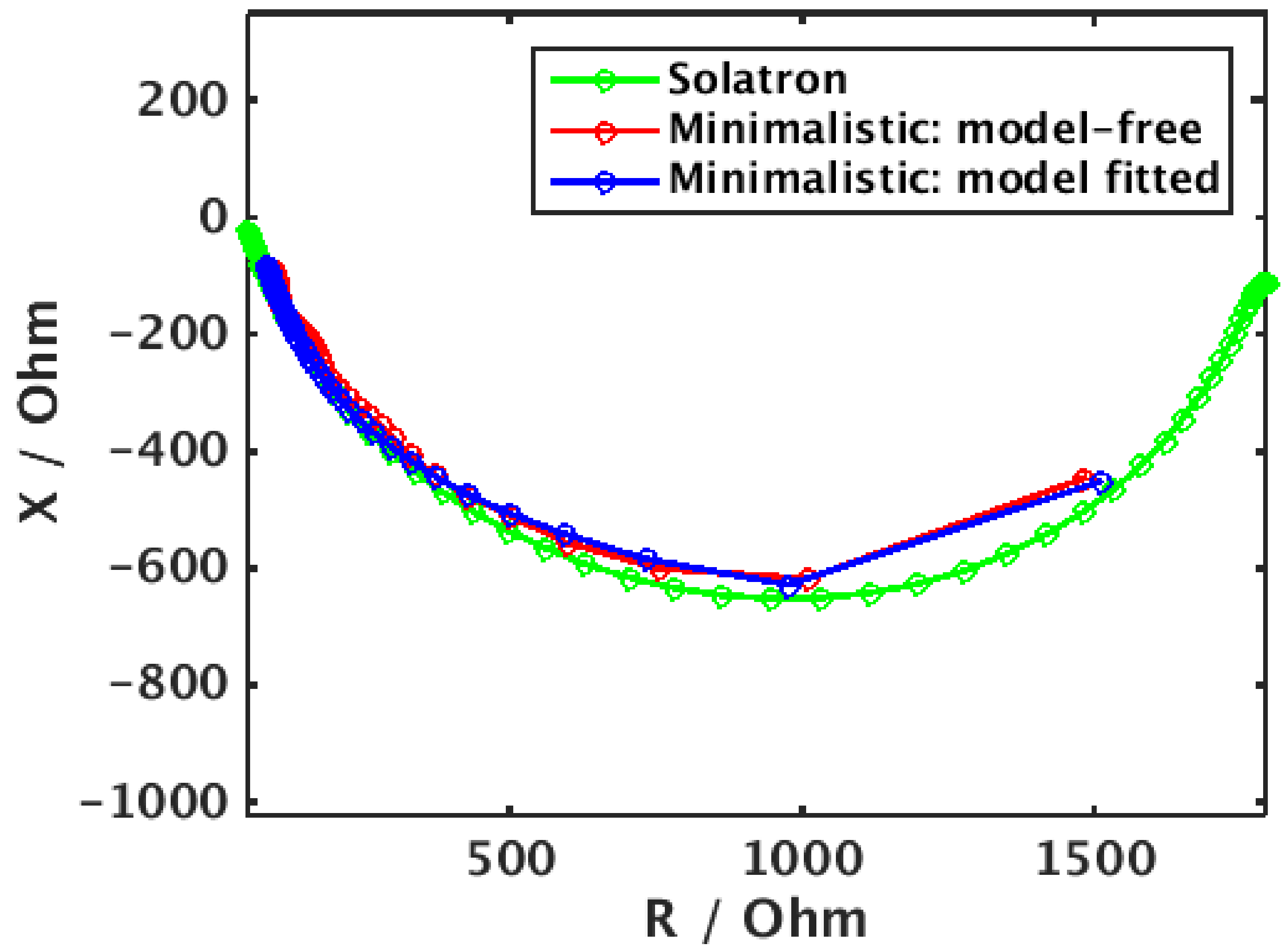
Minimalistic hardware





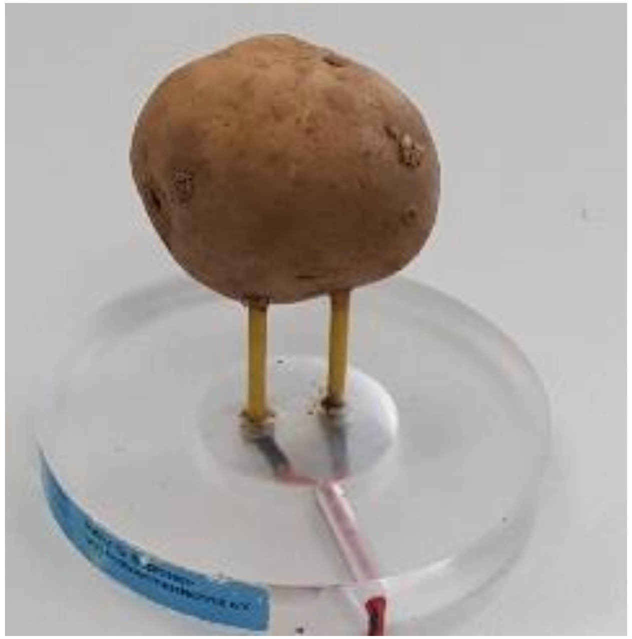


Comparison minimalsitic – impedance analysator

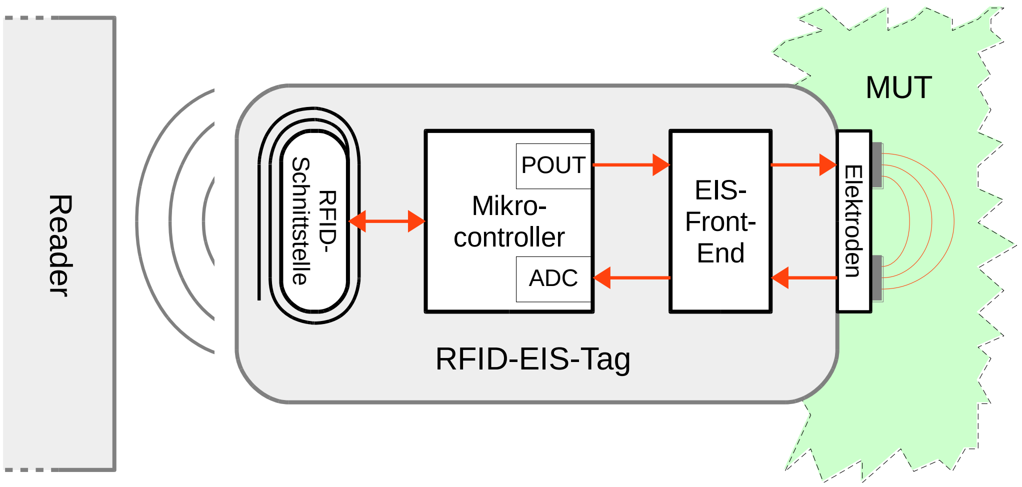


potato stickung on at needle electrodes

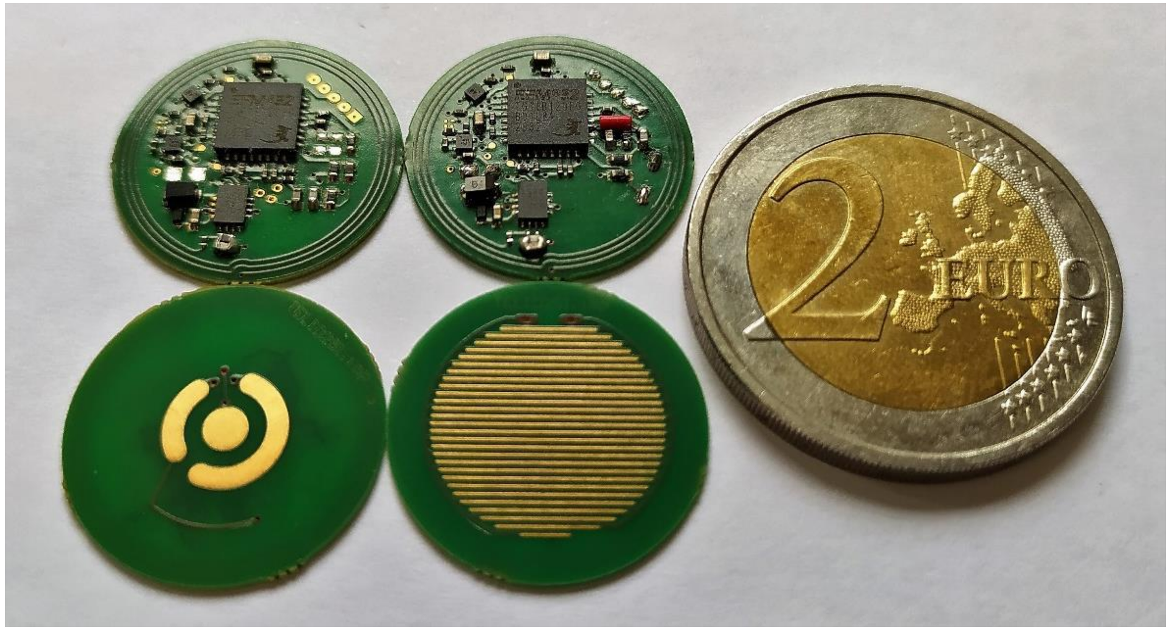
Stainless steel
25 mm long, 20 mm apart, Ø 2mm



Merging RFID und EIS



Schematic of the RFID-EIS-Tag



Two versions of the FRID-measurement chip

possible applications

- wound monitoring
- monitoring of lubricants
- biofilms in watertubing
- moreover: quality of honey,
  asphalt-aging,

extremely low power
low data volume
but – still high dynamic range and broad bandwidth

Fortune of fast measurements with low data rate

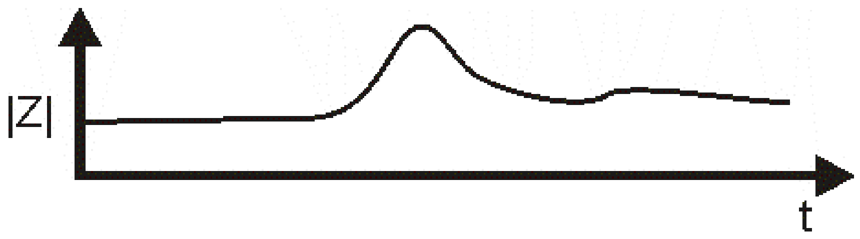
High repetition rate:

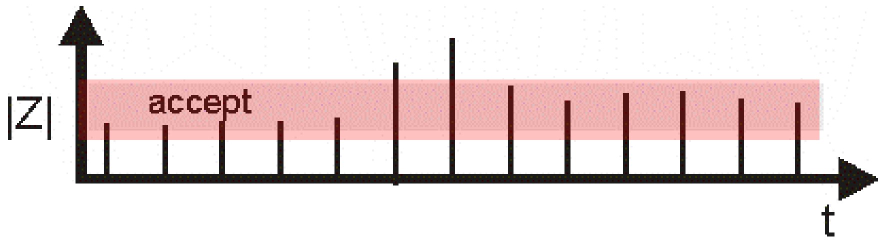
‘snap shot‘ maybe not signifikant

Simple solution: averaging over several measurments

→ More precise measurement but less time resolution

better: selection of probable values and rejection of artefacts

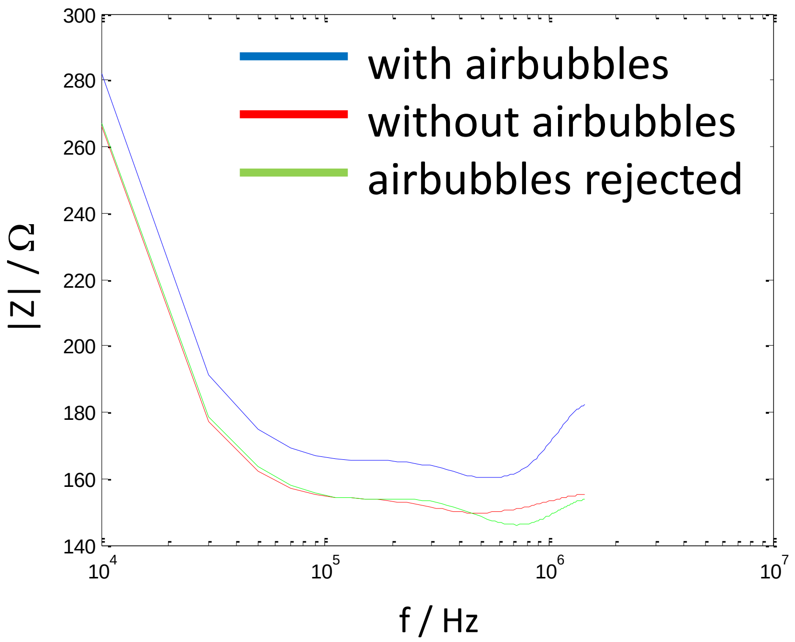




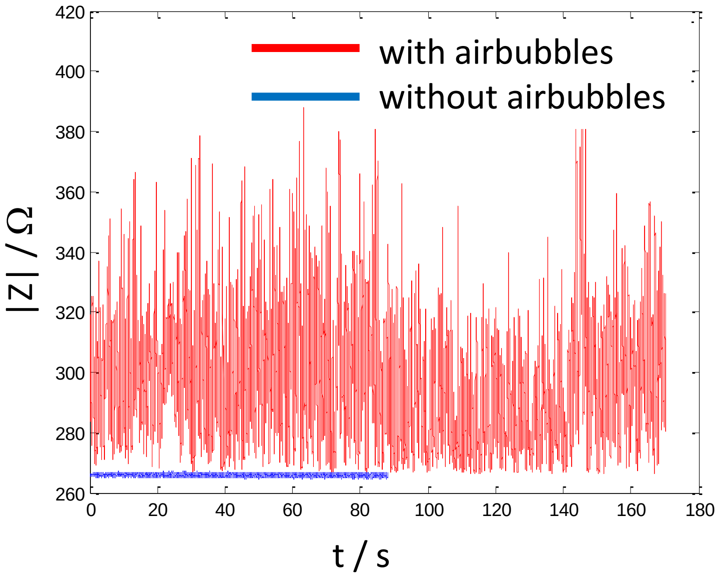
Rejection of artefacts

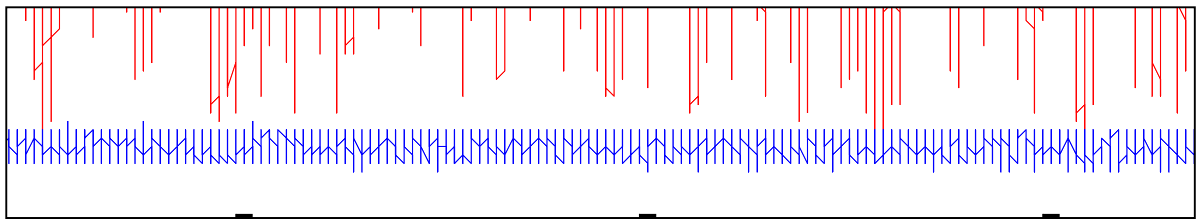
Measurement of suspension conductivity in a channel in the presence of cells and bubbles

frequency spectrum

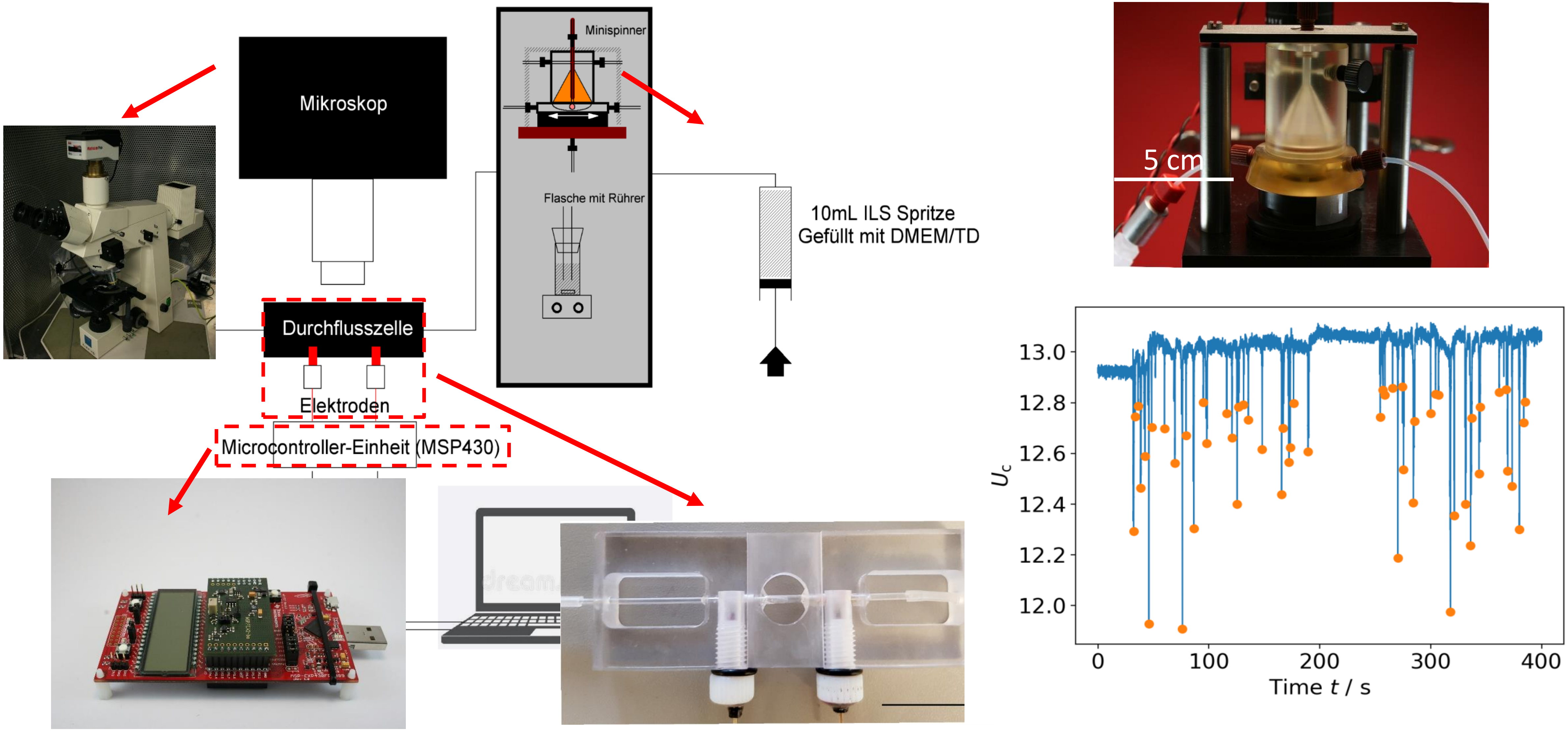


magnitude at 10 kHz





Impedance flow cytometer - requires fast measurement

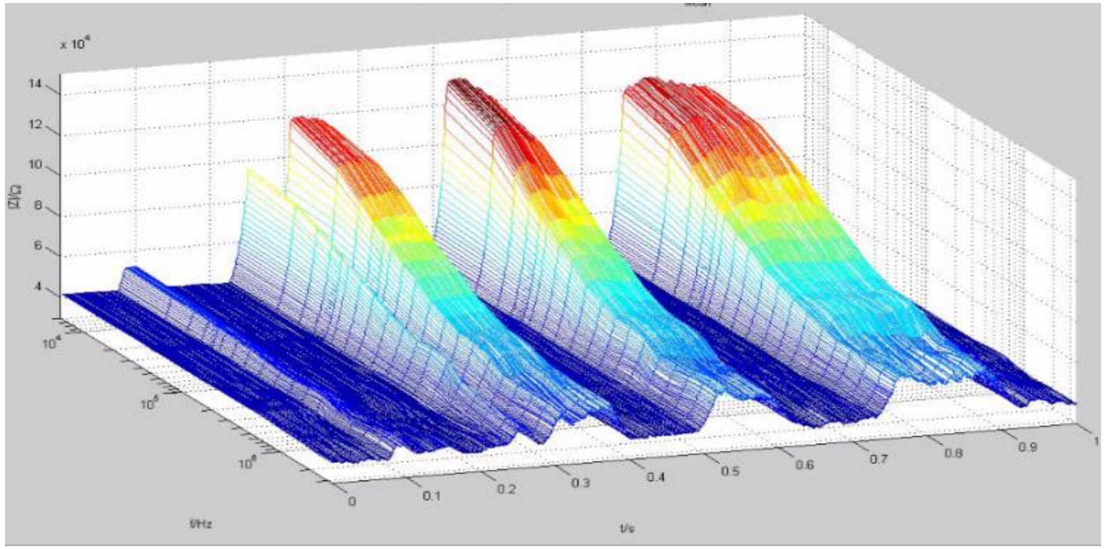


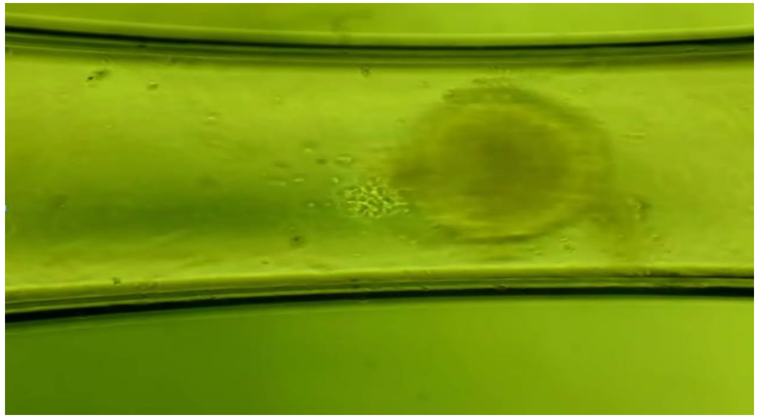
Continous flow in capillary

Impedance flow cytometer

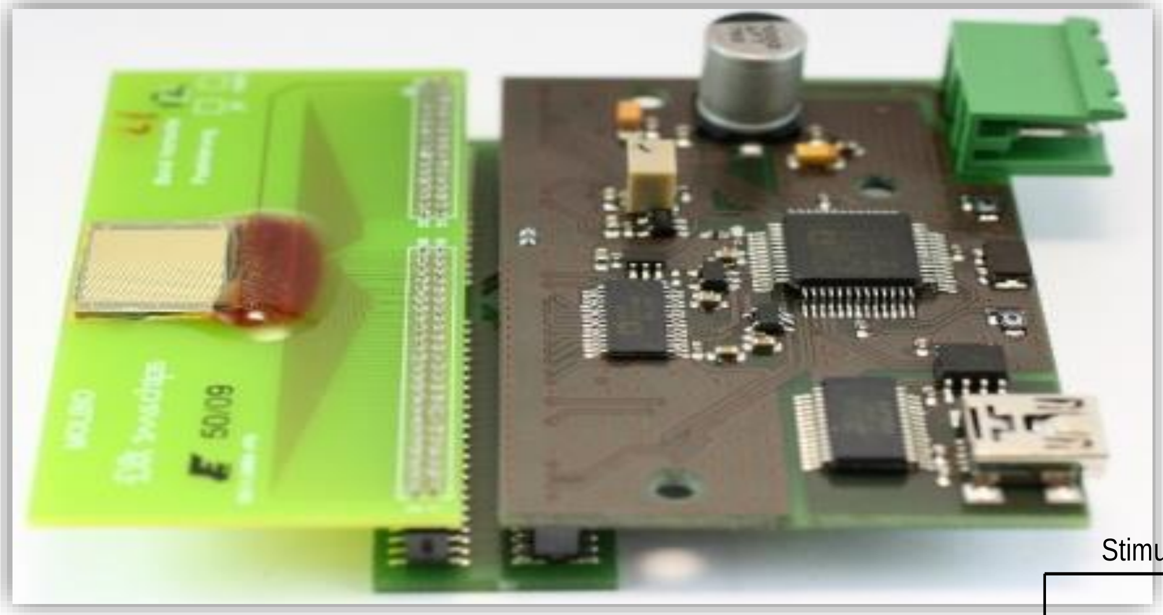
- Monitoring over several hours
- 60 frames per second
- Flow speed: 20 µl/min
- size of sphäroids: 150-400 µm

Impedance spectra vs. time





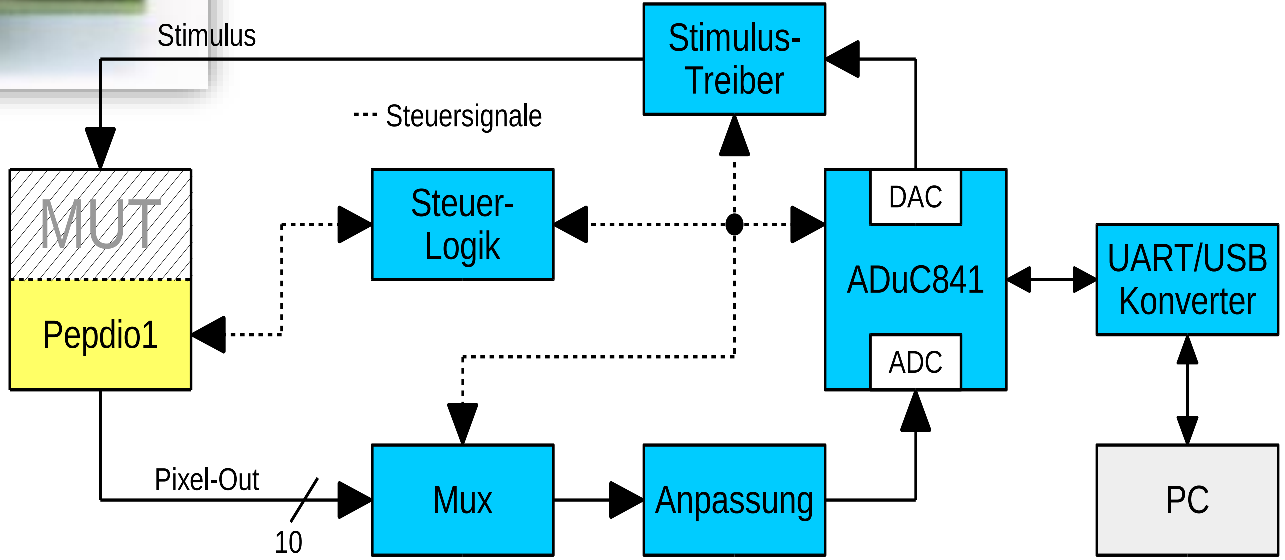
Multichannel impedance sensor



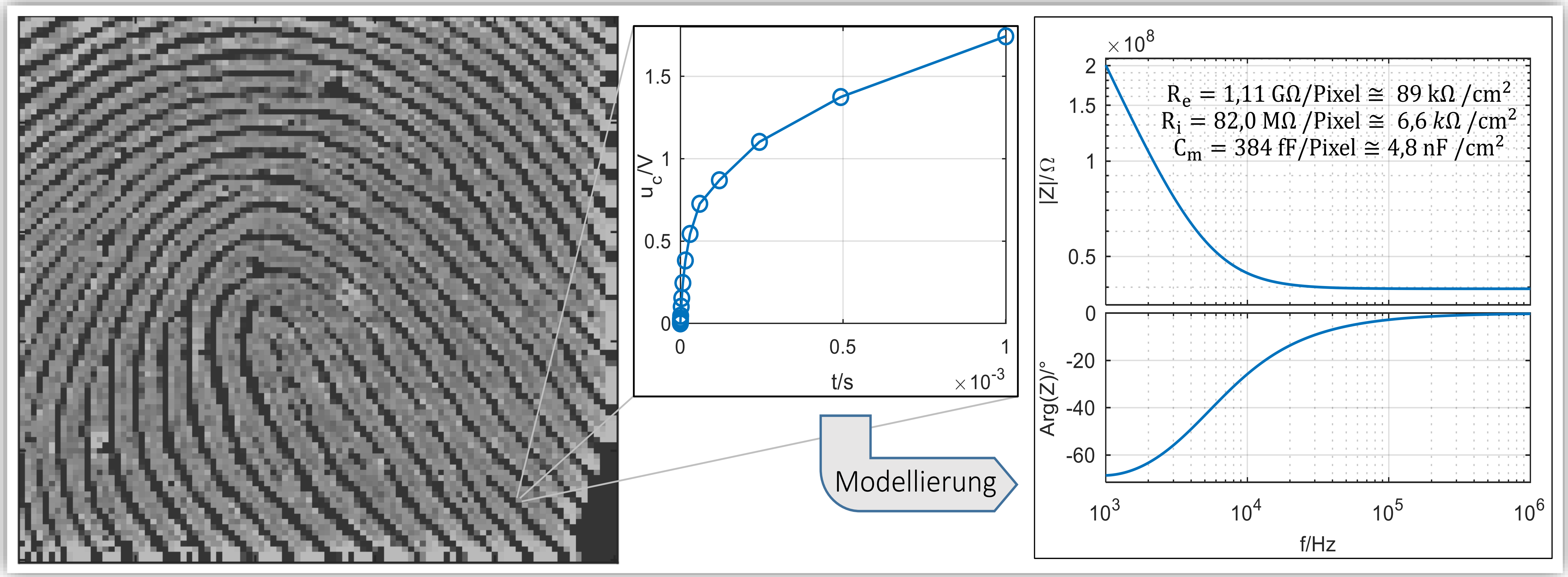
100 x 100 electrodes

Coverage of the entire frequency spactrum for all 10.000 electrodes within 500 ms

Manufacturer of MEA: IMS Chips, Stuttgart, Germany



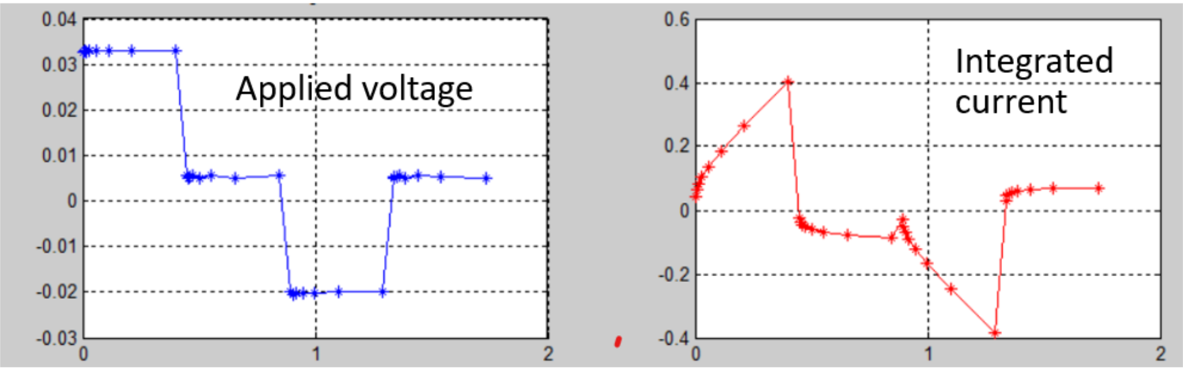
Multichannel impedance sensor



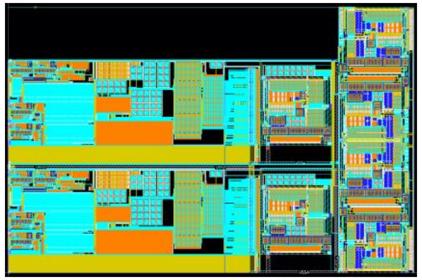
Finger print with complete frequency spectrum for each pixel

Whole impedance measurement system at a single chip.

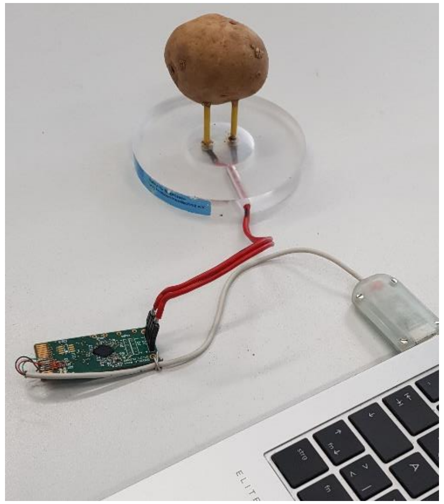
Single chip solution
- cheap devices
- single use applications
- minimial instrumentation



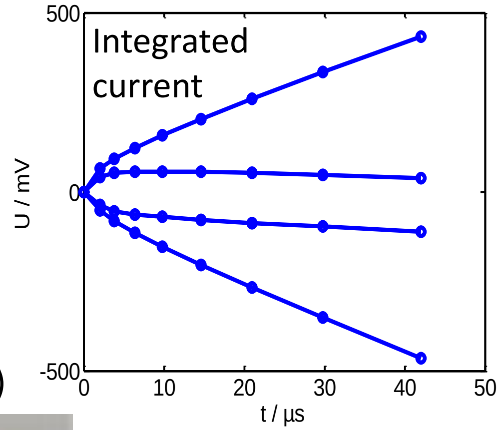
Chip layout 3x2 mm

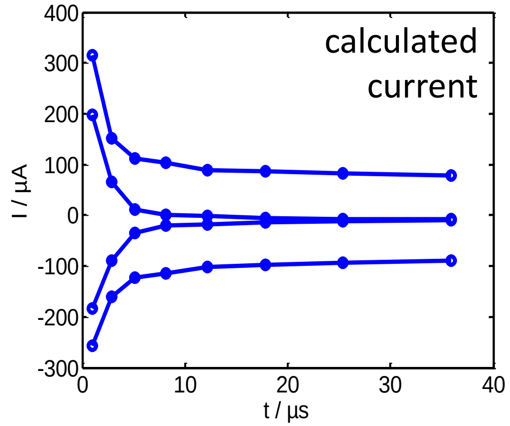


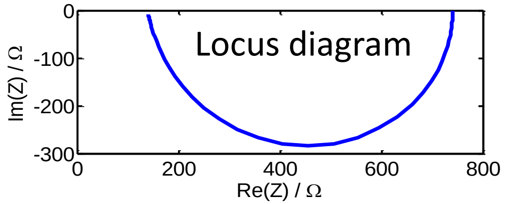
Potato at electrodes



Chip on testboard (no further compounds)







Summary

Unique features of step response are the basics for fast measurements with minimal hardware requirements

Suitable for high channel, low power systems

Adaptive sampling of step response reduced data volume dramatically

Low data volume without information loss is essential for many use cases