Doubling the spectrum of TD IP by harmonic de-noising, drift correction, spike removal, tapered gating, and data uncertainty estimation

Gianluca Fiandaca, Esben Auken, Per-Ivar Olsen,
Jakob Jull Larsen, Anders Vest Christiansen, Torleif Dahlin

HydroGeophysics Group
Aarhus Geoscience, Aarhus University, Denmark
Lunds University, Sweden
www.hgg.au.dk

HydroGeophysics Group
AARHUS UNIVERSITY

Outline

- **3D setup**
- **Full decay processing**

Motivation

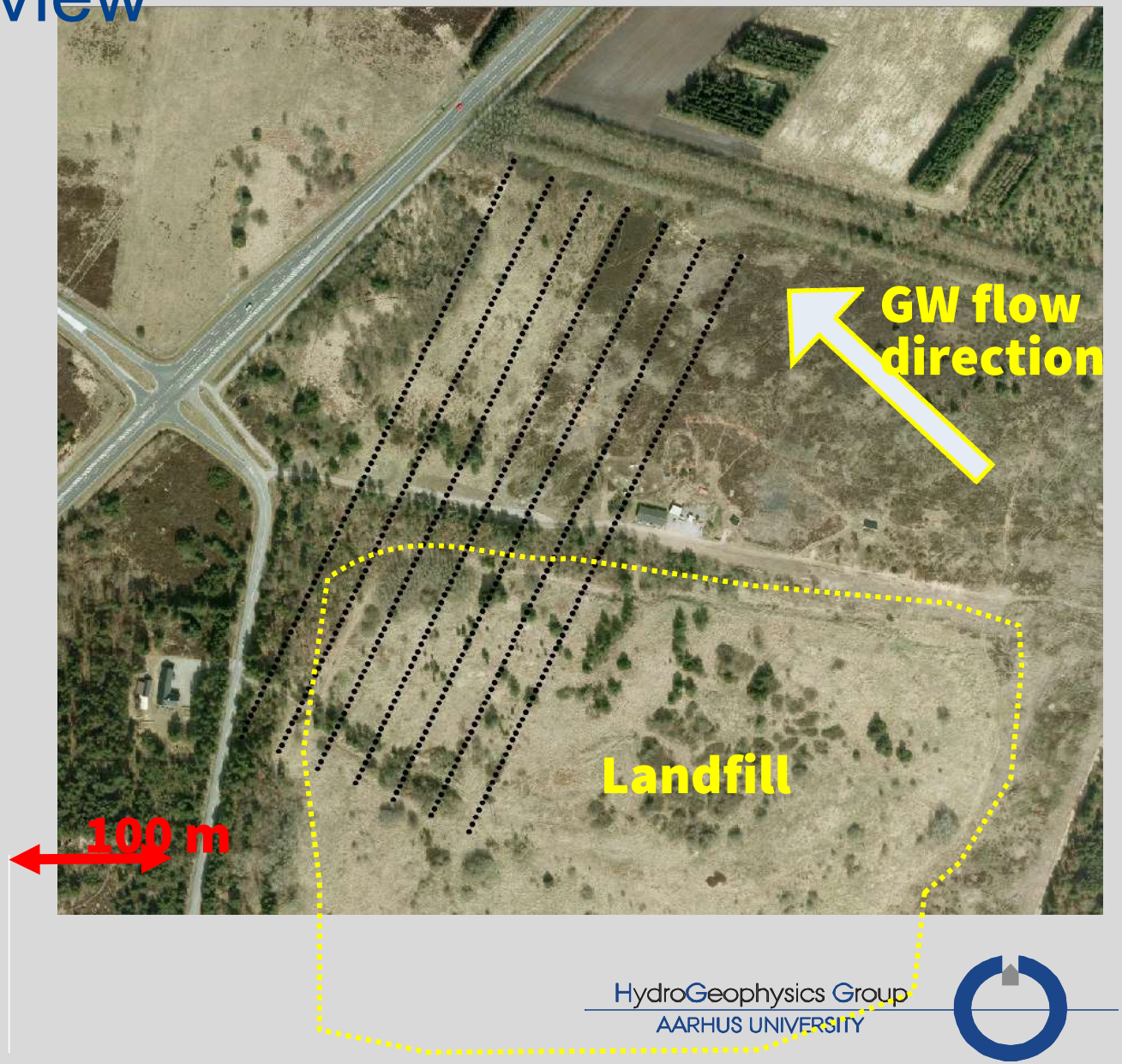
- **Full-waveform TD IP data are collected by commercial instruments**
- **High sampling rates allows for retrieving early gates, down to a few milliseconds**
- **Wider TD IP acquisition ranges increase the spectral content of the data**
- **Improved signal processing is necessary for retrieving reliable increased time-ranges**

Large time range

- **Direct inversion for Cole-Cole or constant Phase parameters directly in the time domain**
- **Greatly enhanced resolution of the parameters**

3D setup - Overview

- 441 electrodes
- 7 lines (each 4 cables)
- 25 m line spacing
- 5 and10 m elect. spacing
- Area: 410 m x 150 m

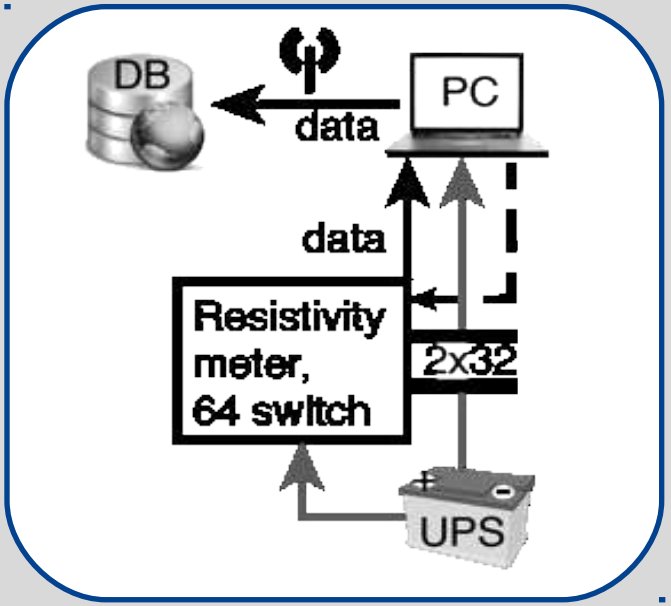


Instrumentation

- **3.6 kHz sampling**
- **1.6 kHz antialiasing**
- **4 s sampling length**
- **100 % or 50 % duty cycle – constant current transmitter**
- **Multi-electrode setup**

3D setup - Hardware

- **Fully automatic acquisition**



3D setup

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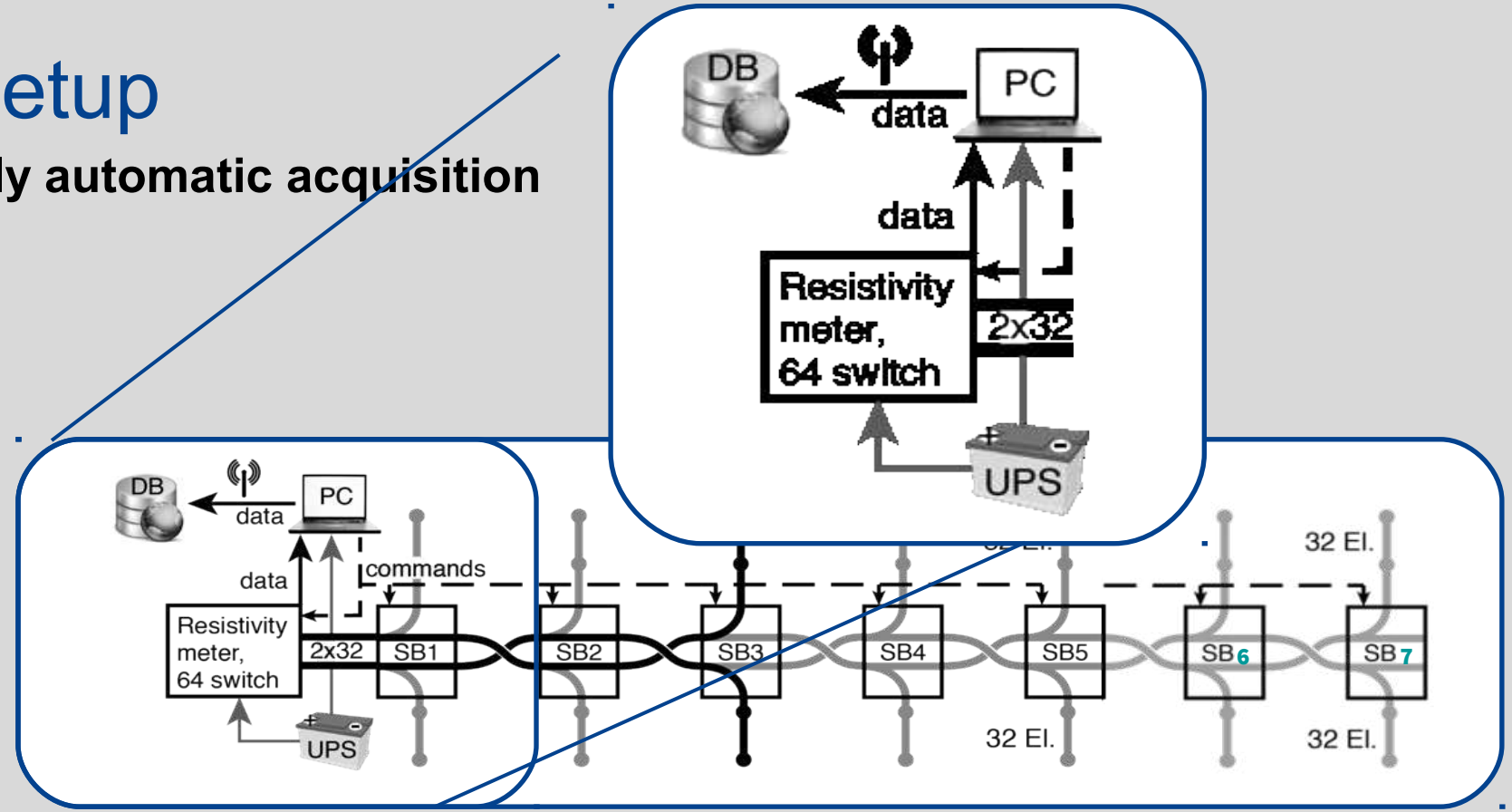

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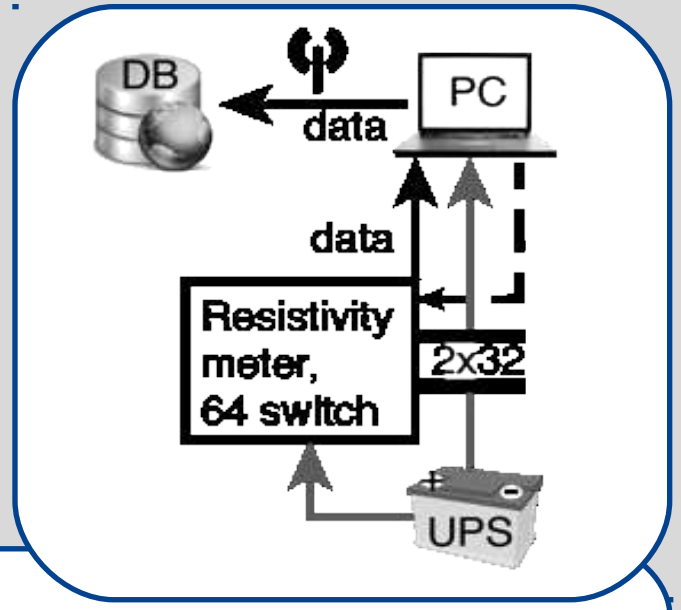
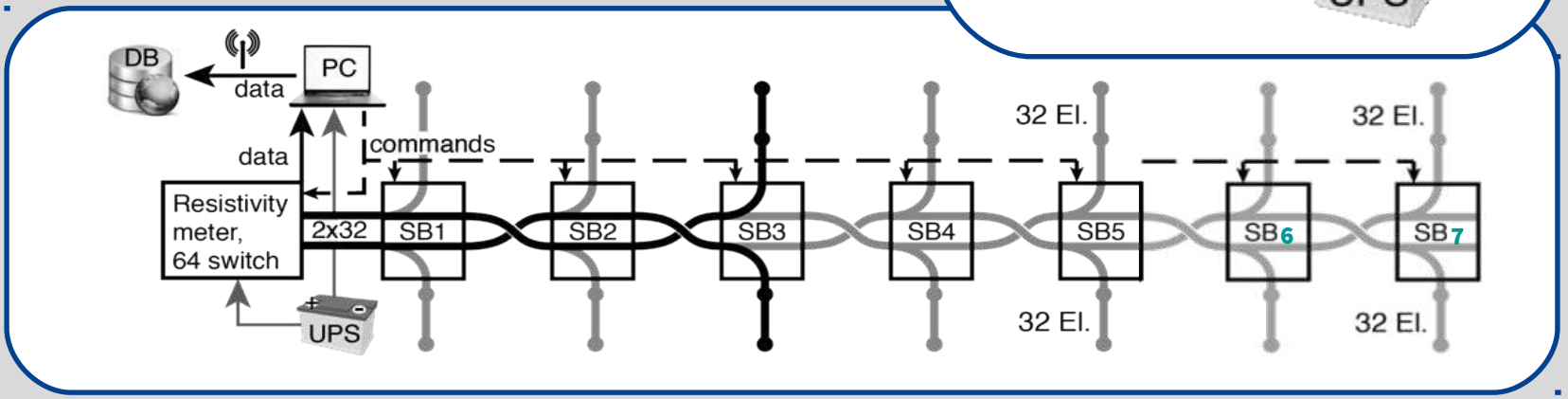
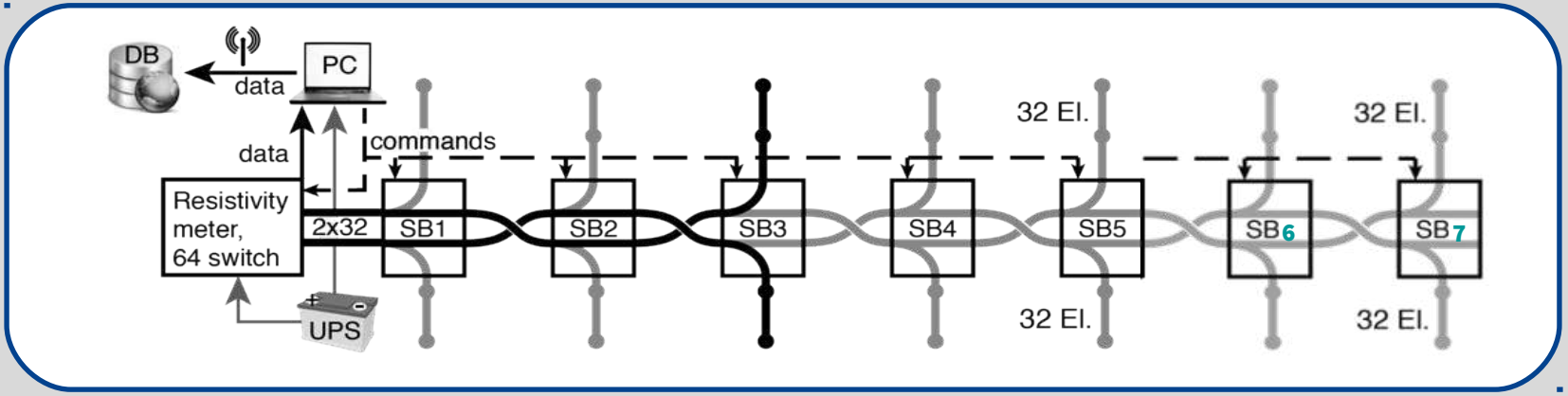




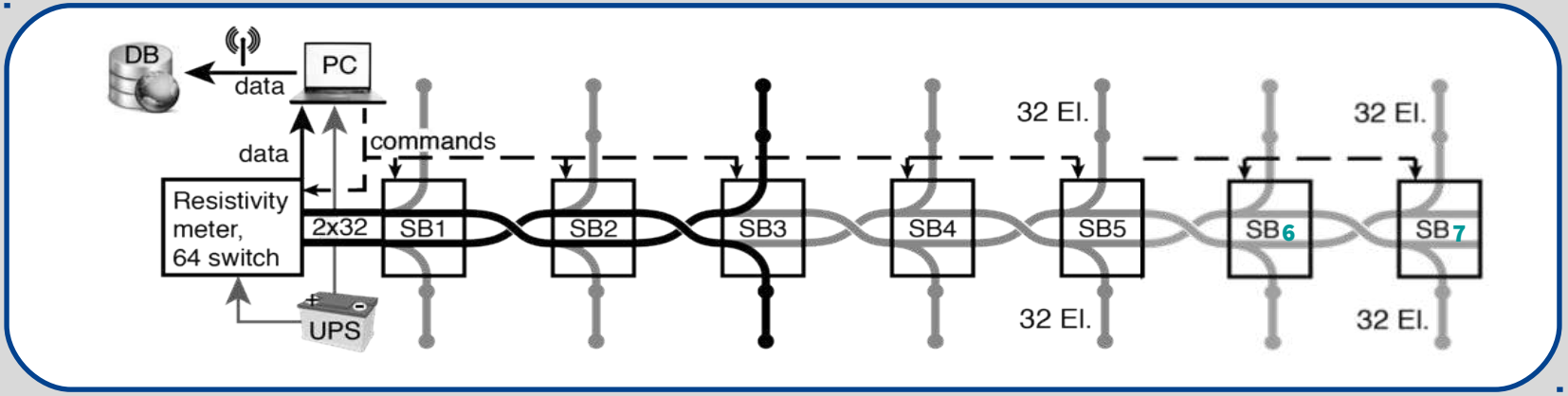
3D setup - Hardware

- **Fully automatic acquisition**
- **Custom-made switch boxes (SB1-7)**



3D setup - Hardware

- **Fully automatic acquisition**
- **Custom-made switch boxes (SB1-7)**
- **2 cables (63 elect.) active at any time**
- **In-line and crossline measurements**



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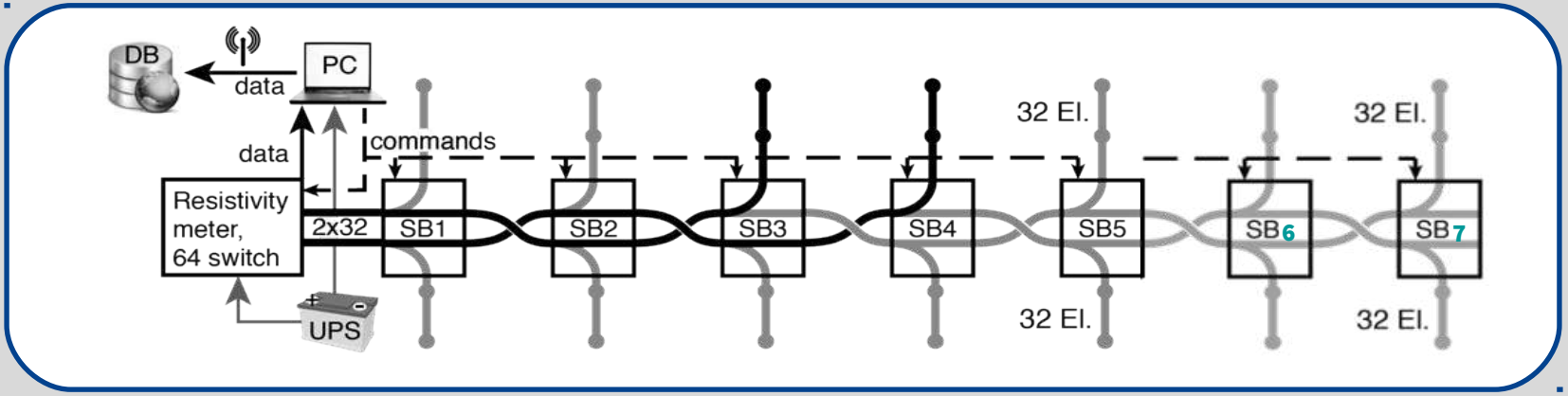

3D setup - Hardware

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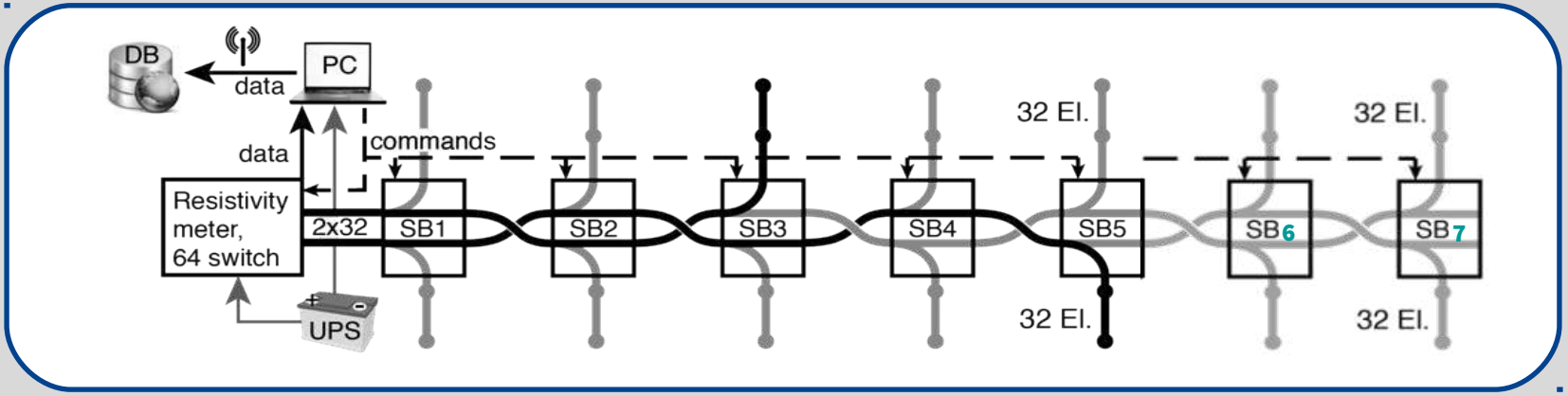
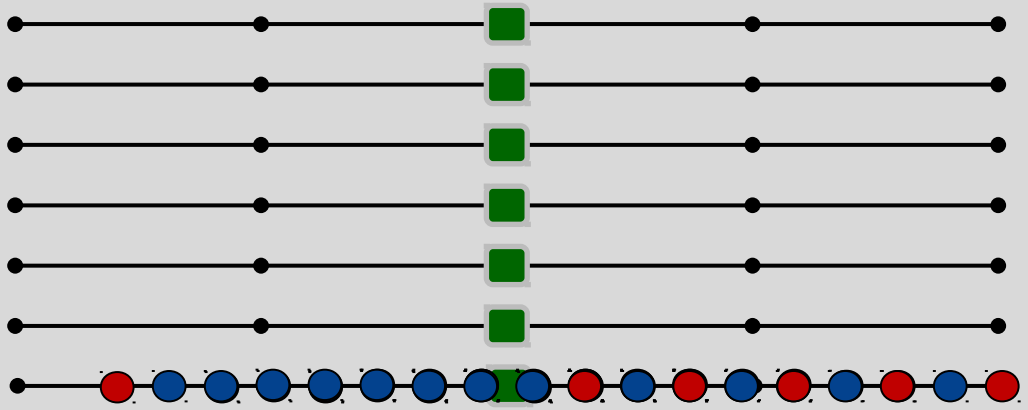
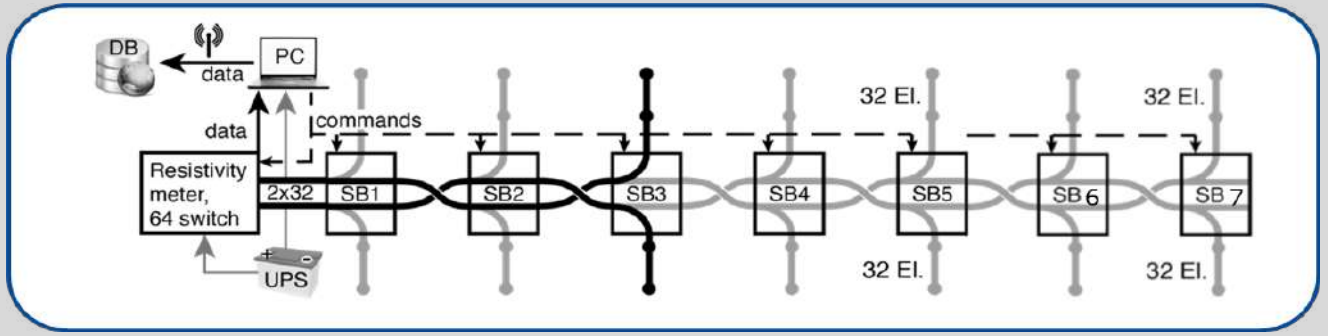


3D setup - Protocols

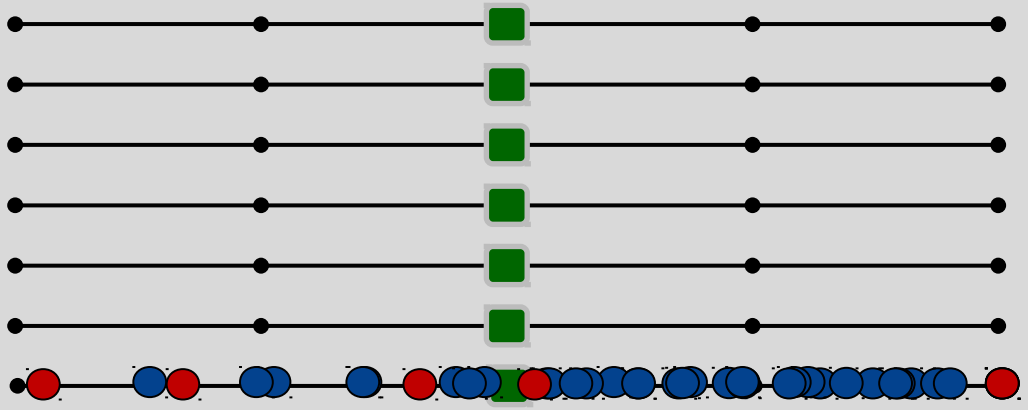
- **2D and 3D coverage**
  - Limited time!
- **In-line gradients**

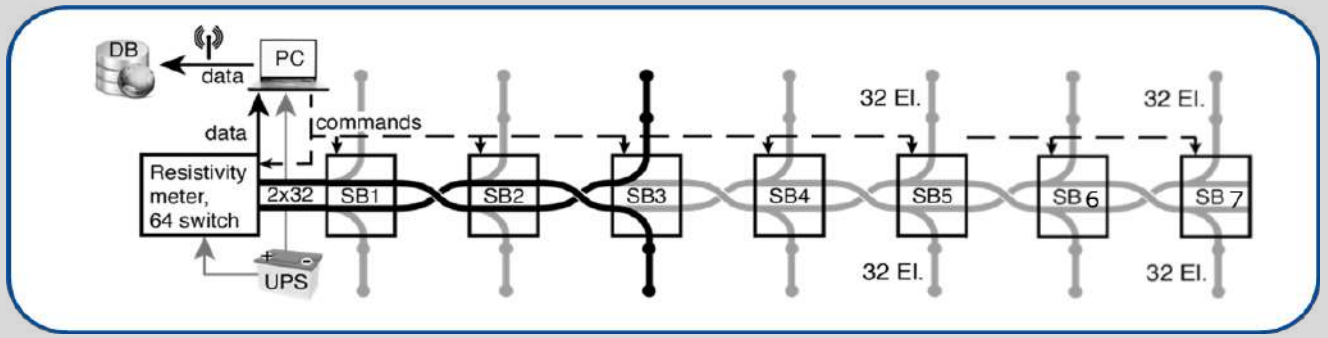




3D setup - Protocols

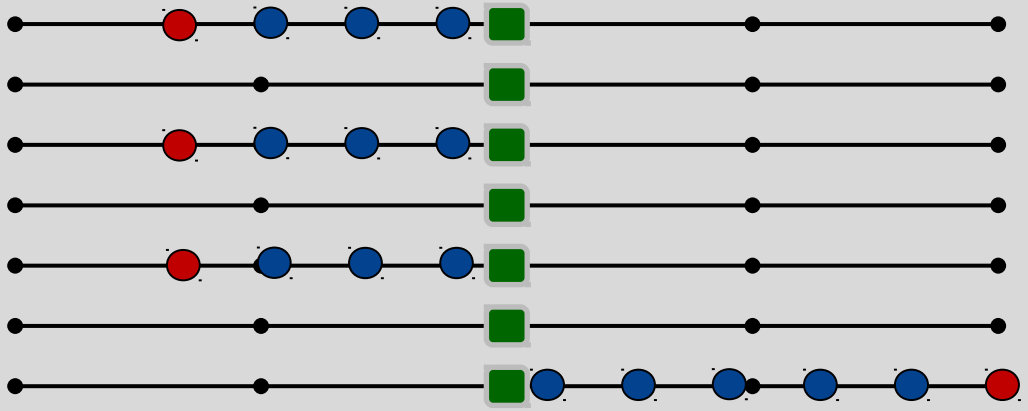
- **2D and 3D coverage**
  - Limited time!
- **In-line gradients**
  - 763 quadrapoles per line (109 current injections)
  - Total 5341 data points

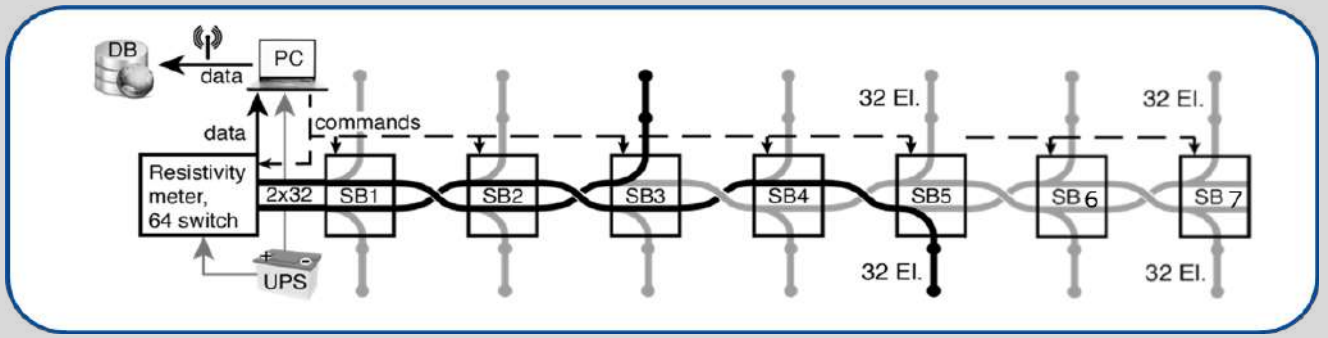




3D setup - Protocols

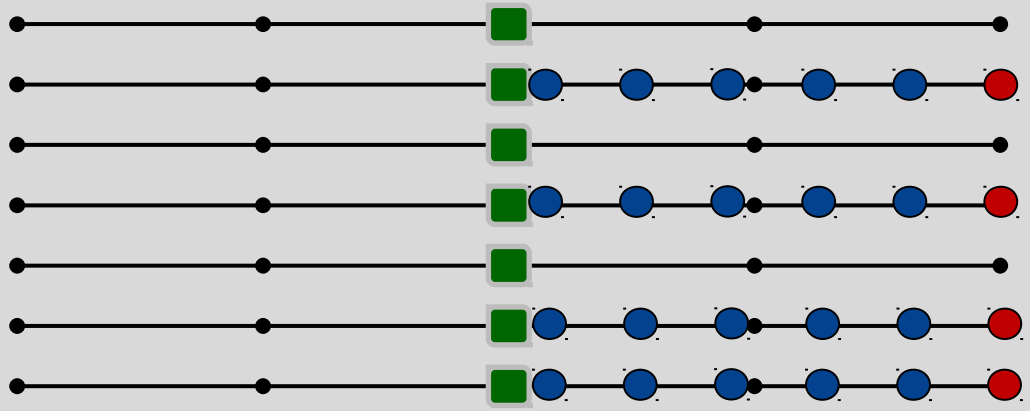
- **2D and 3D coverage**
  - Limited time!
- **Cross-line gradients**
  - Total 1680 datapoints

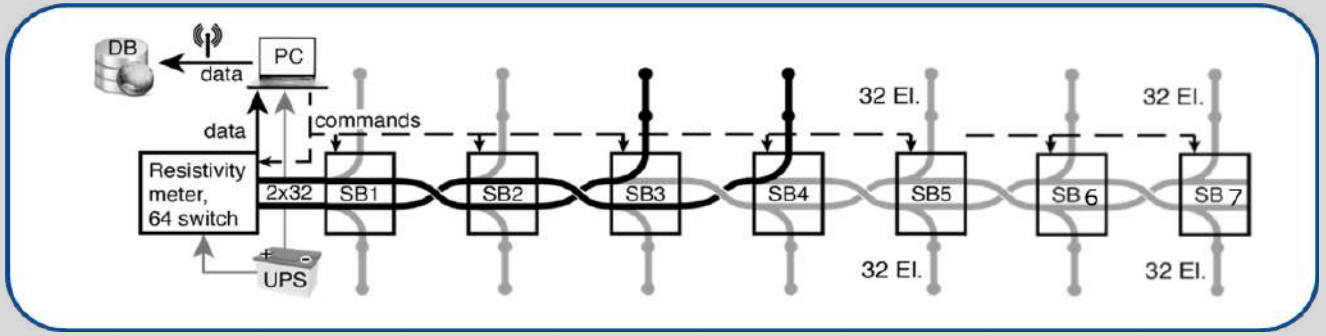




3D setup - Protocols

- **2D and 3D coverage**
  - Limited time!
- **Equatorial dipole-dipole**
  - Total 2640 datapoints

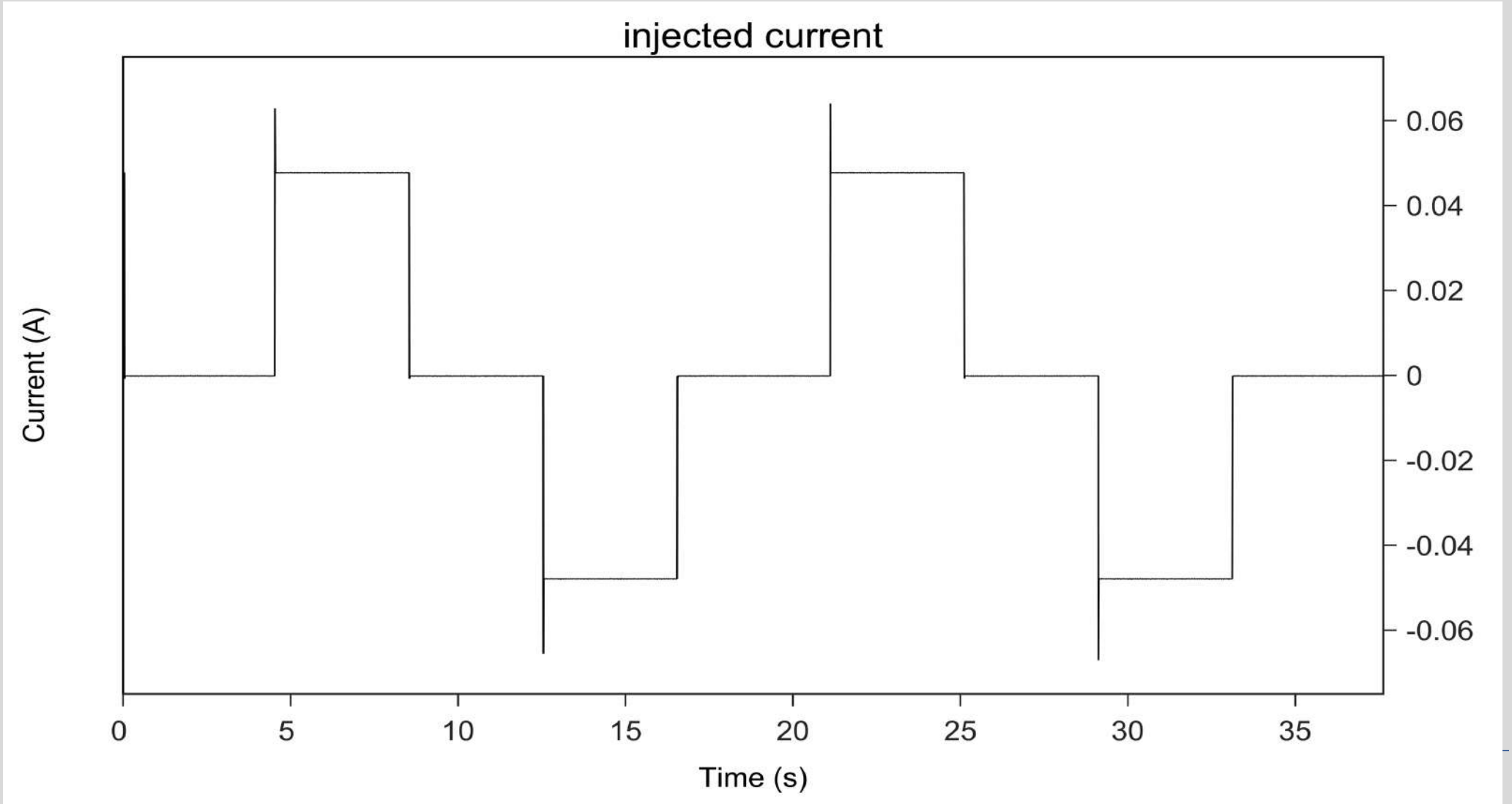




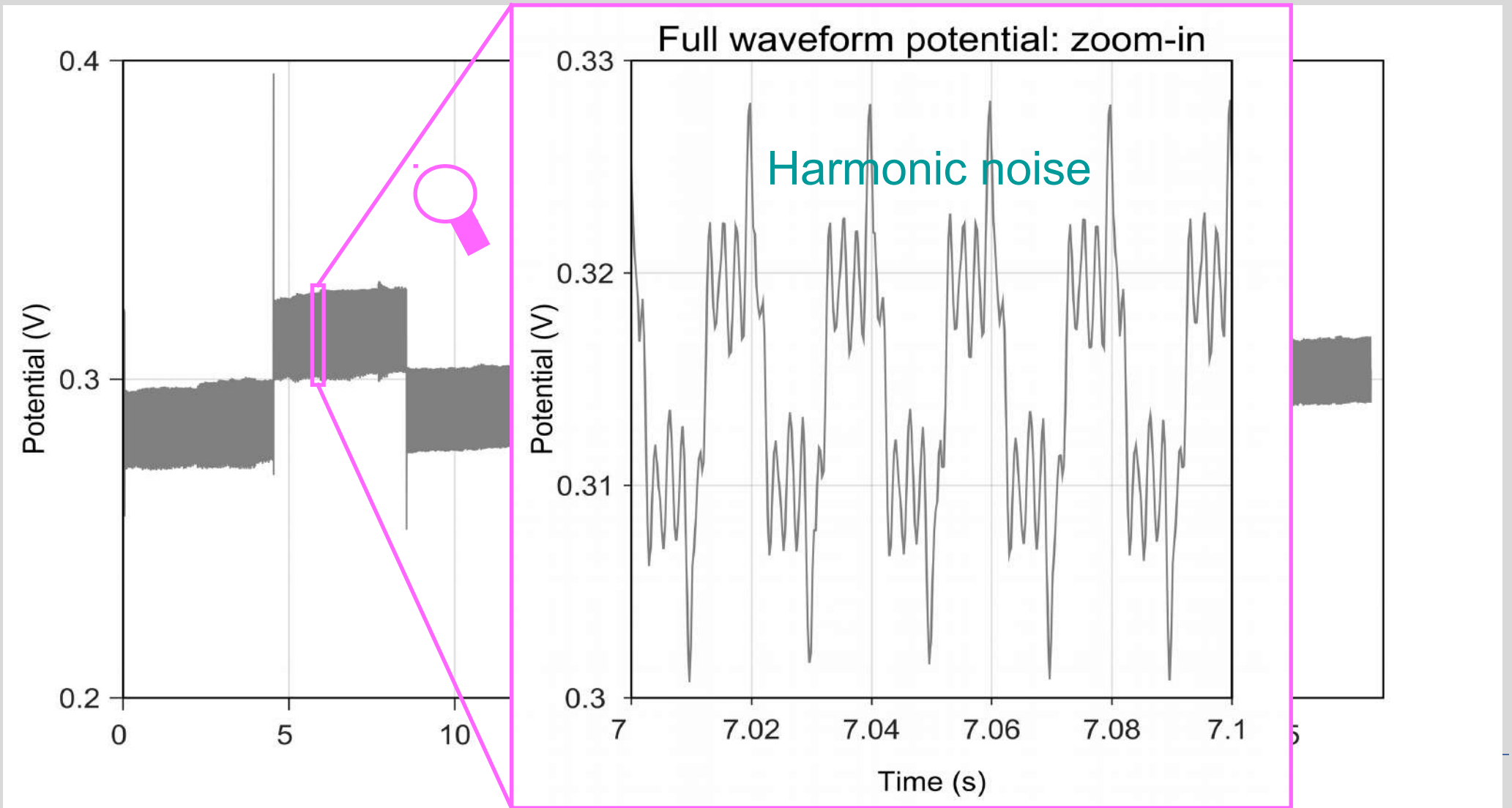
Outline

- **3D setup**
- **Full decay processing**

Real current injection



Real potential measurement



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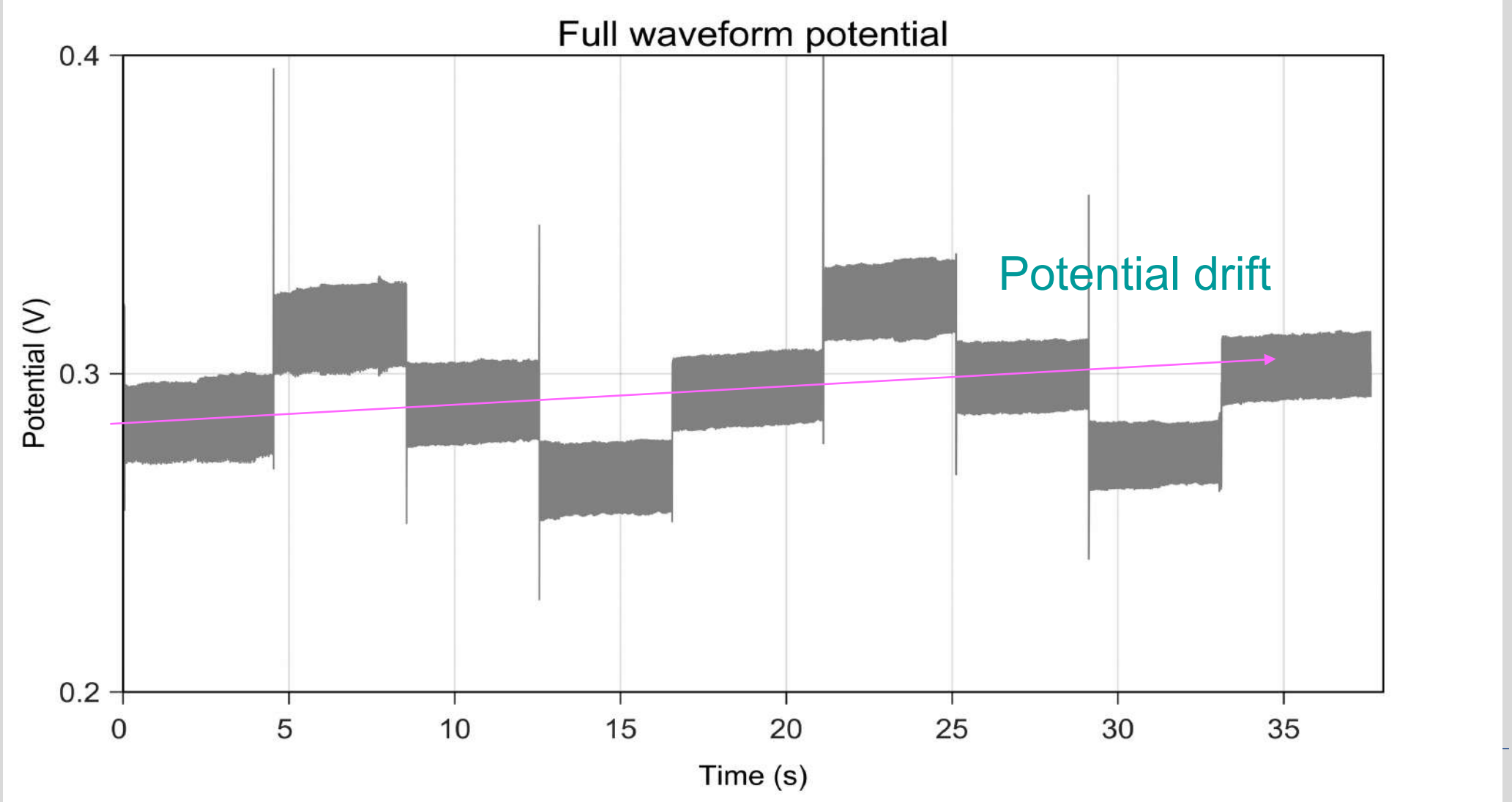
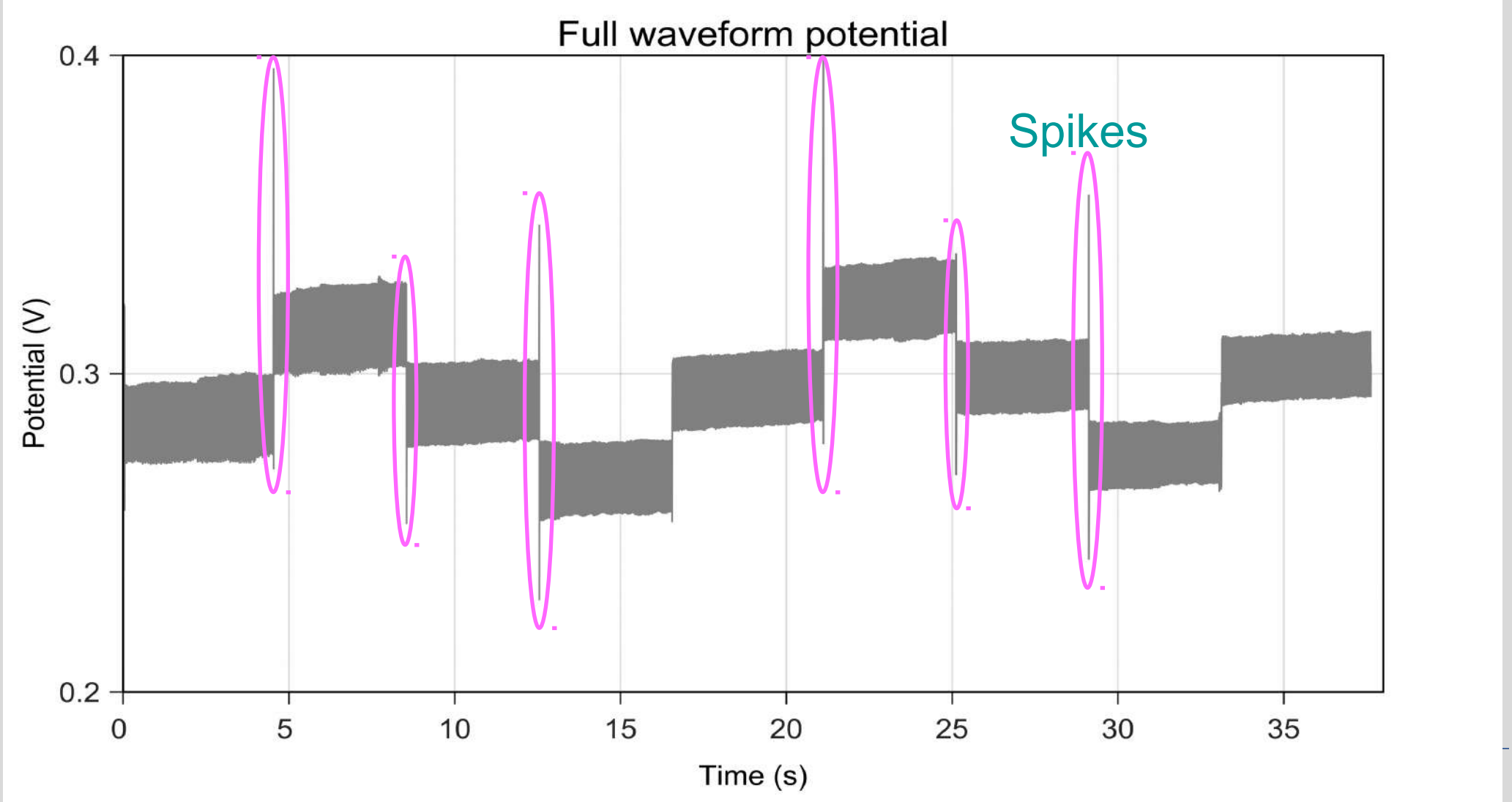
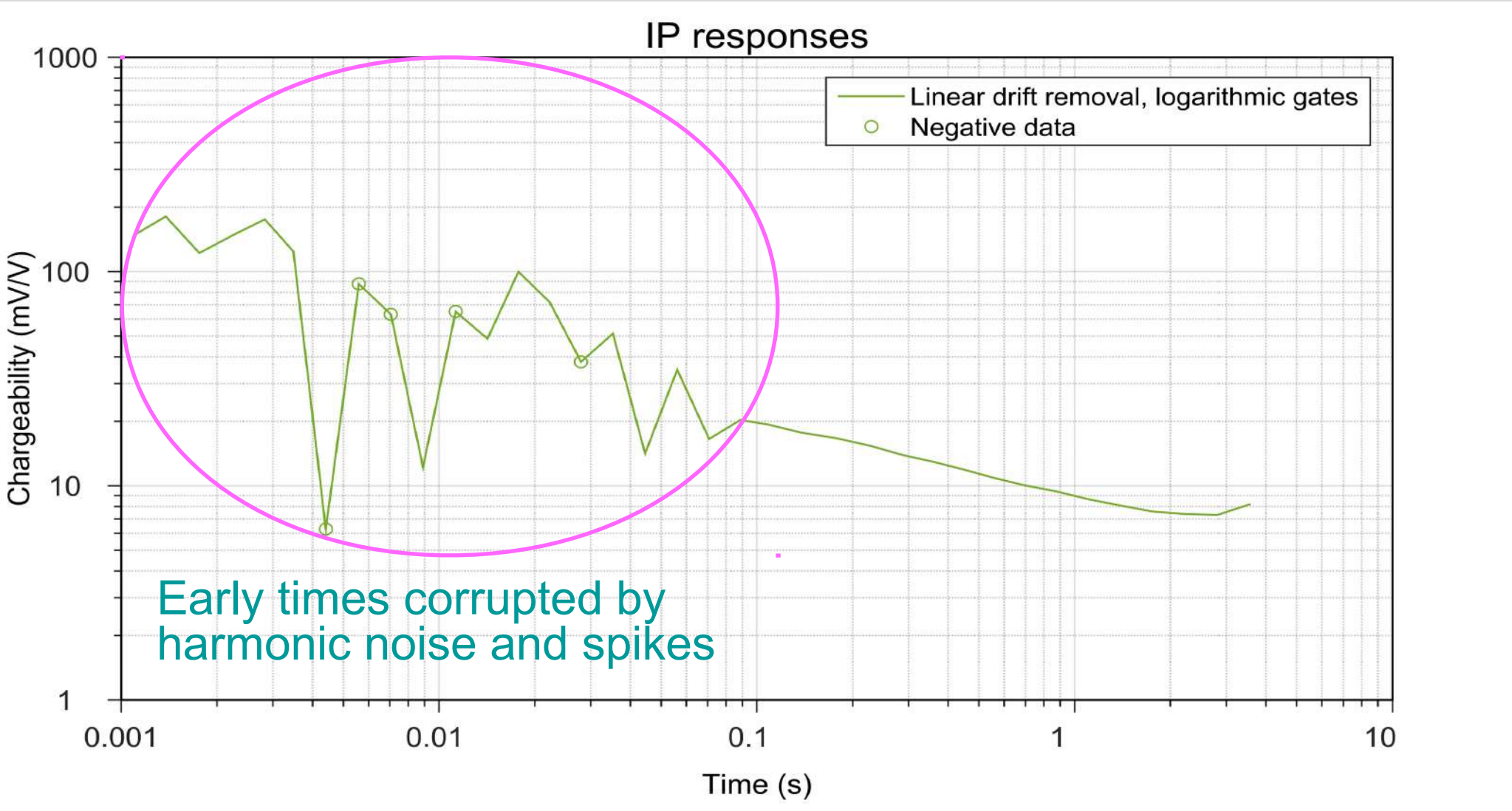


Real potential measurement



Gating the full waveform data



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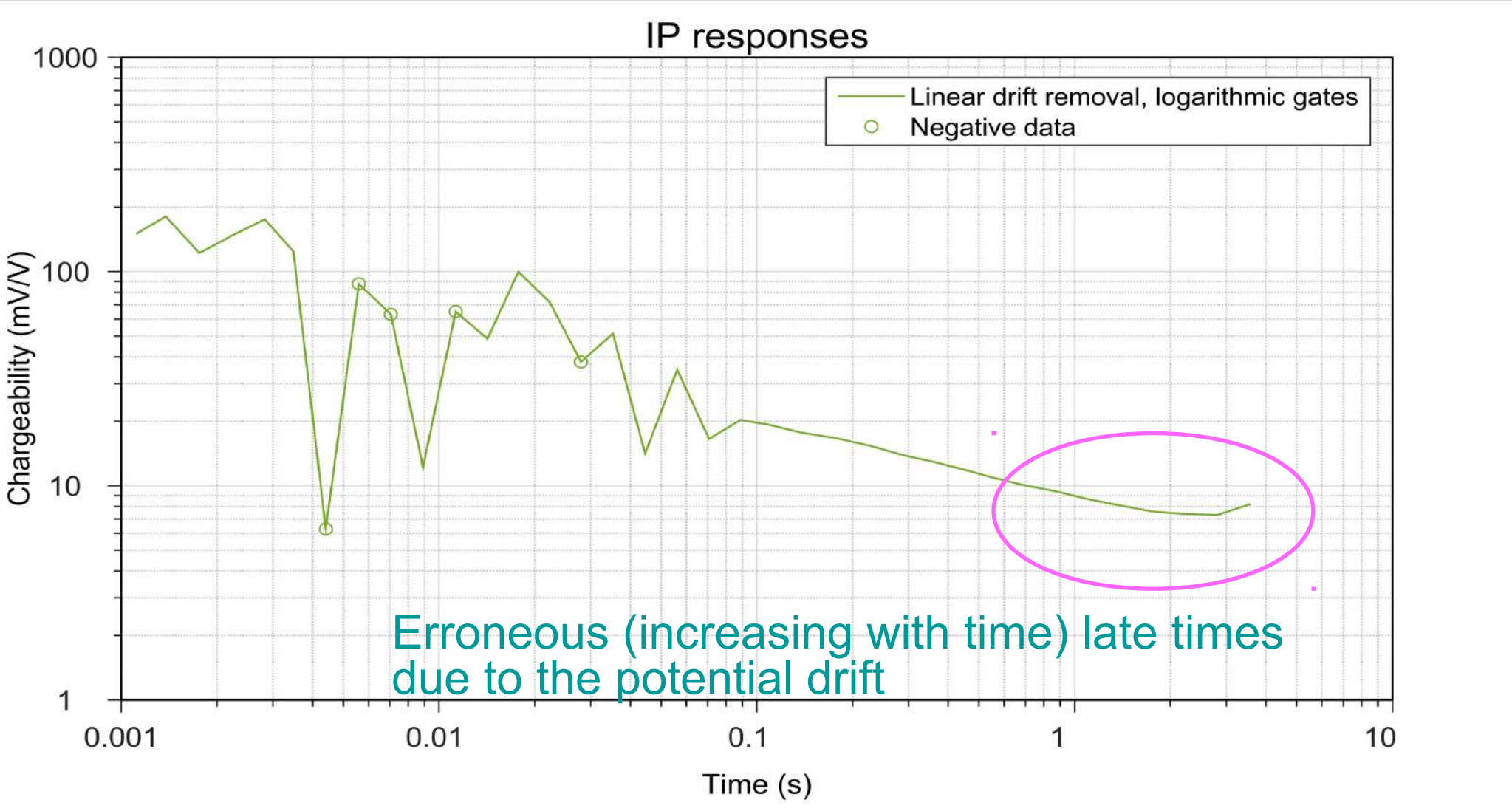

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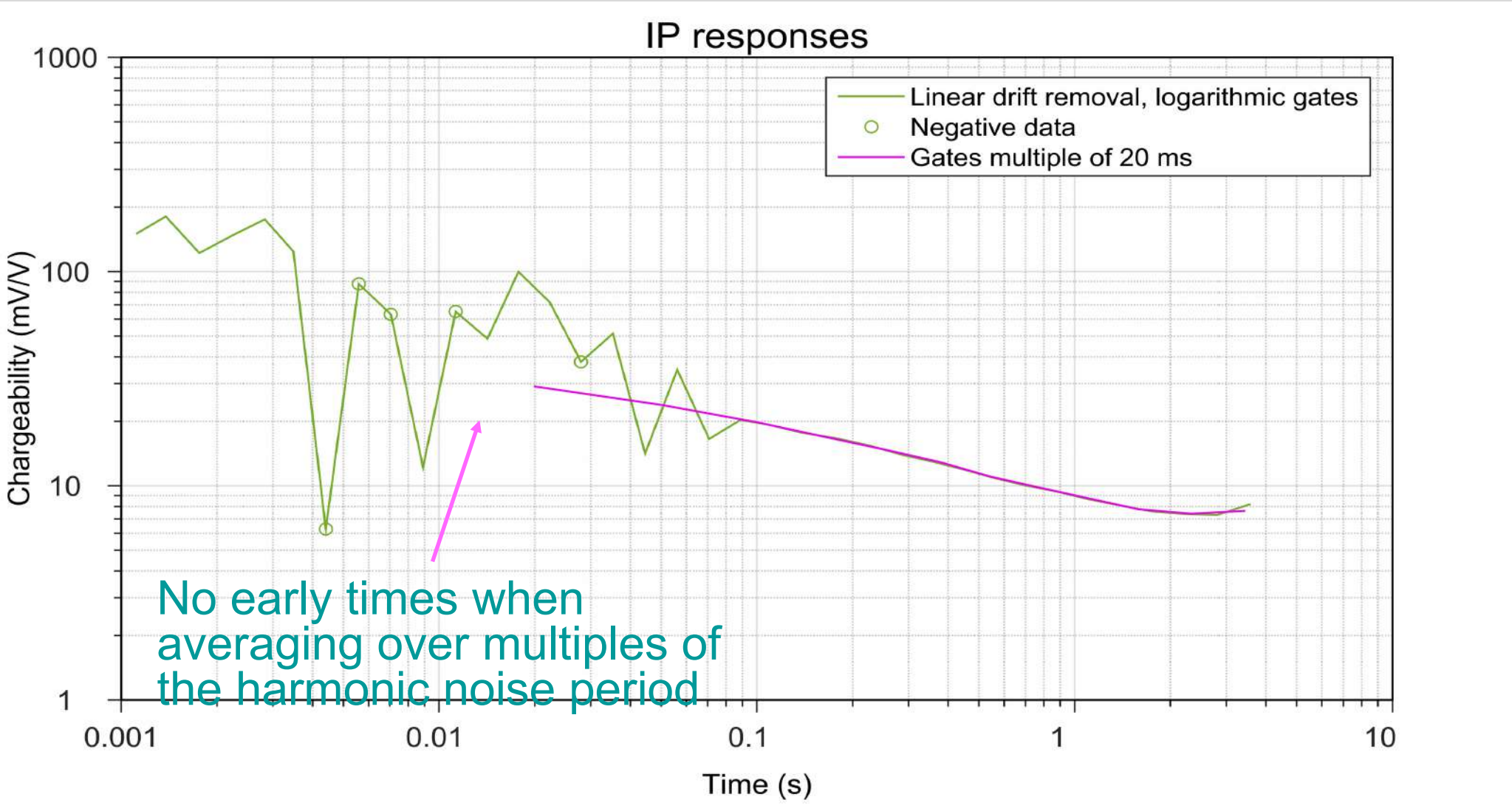

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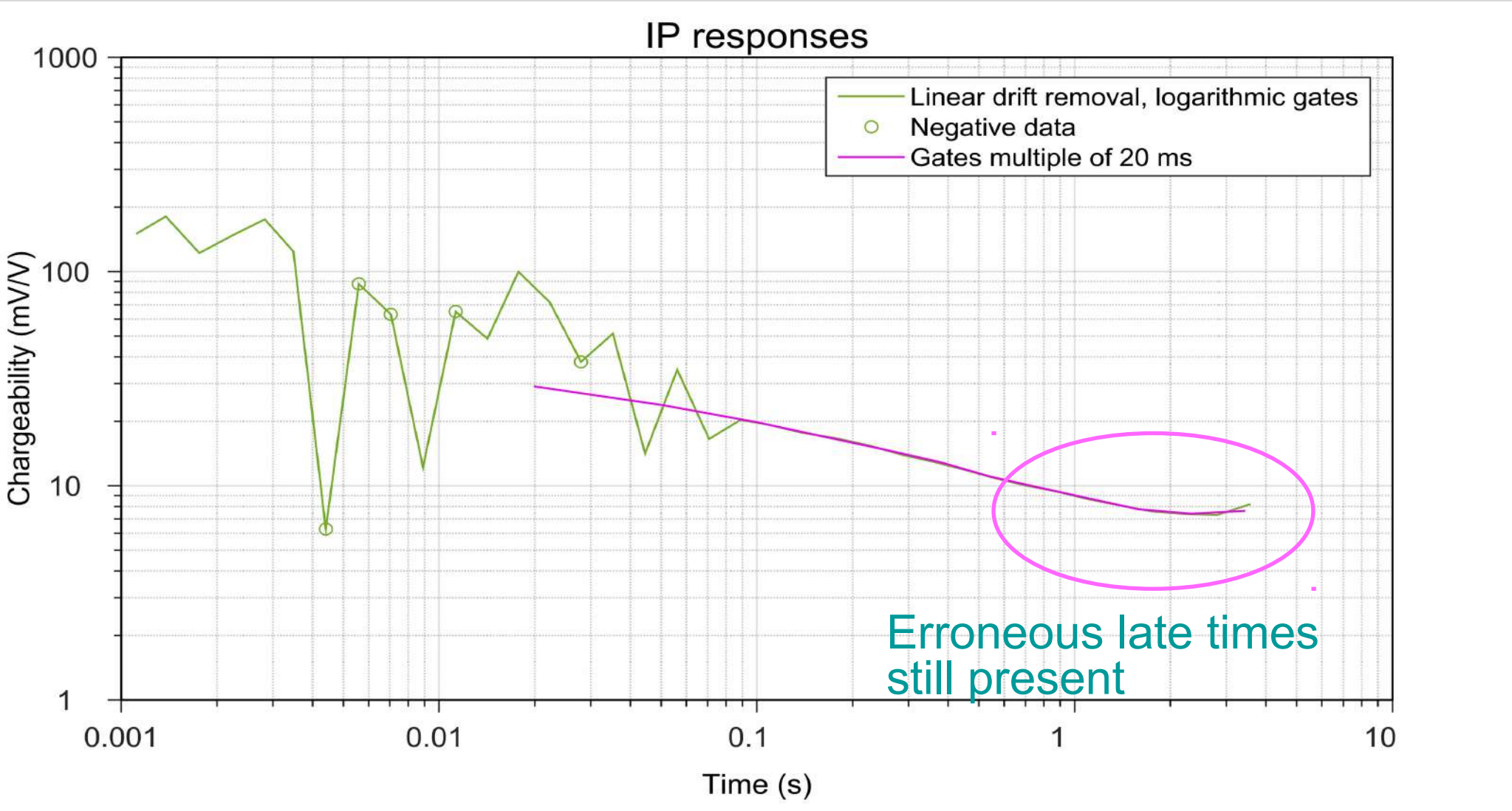
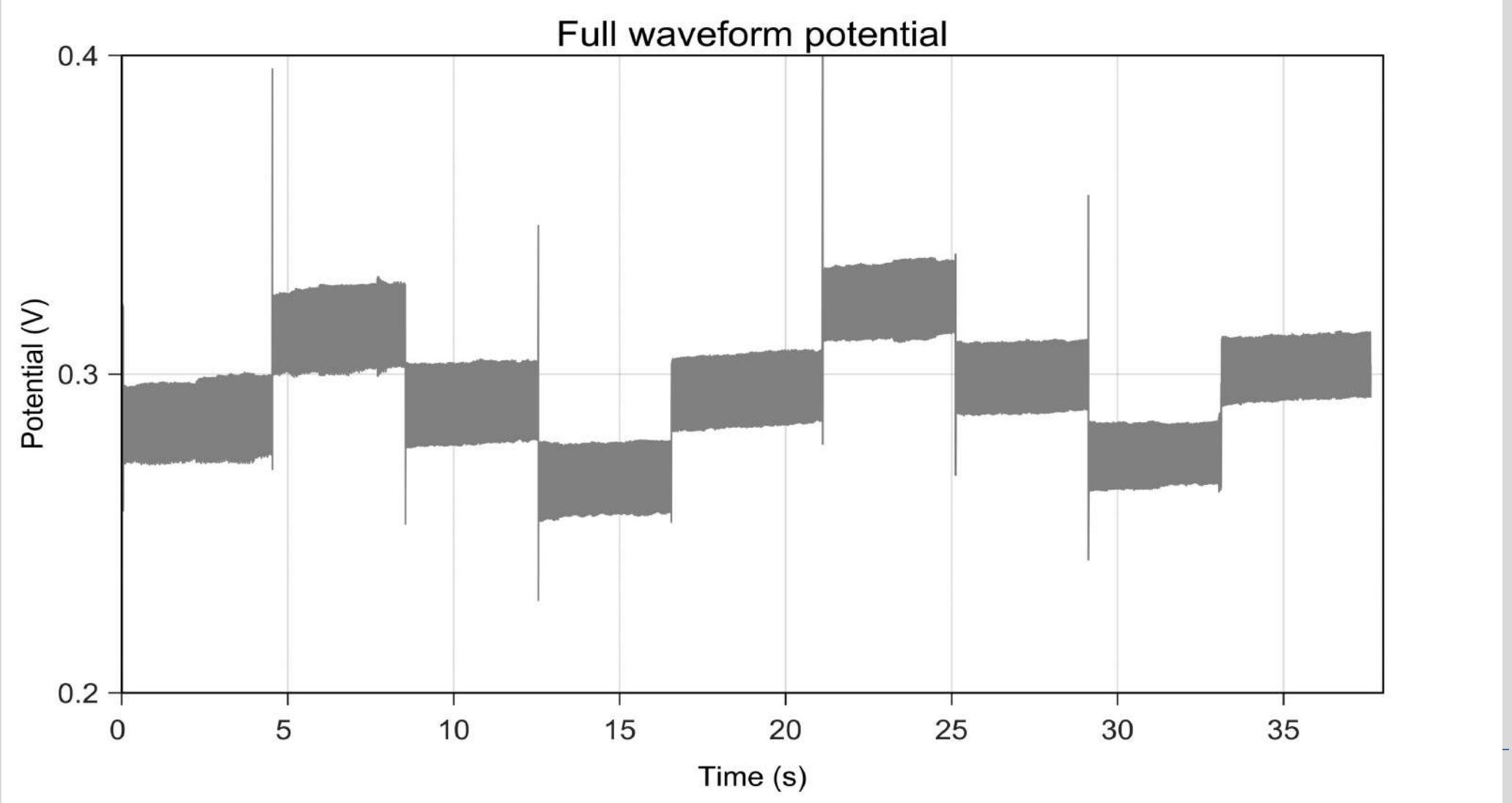


Processing steps

- **Enhanced drift removal**
- **De-spiking**
- **Harmonic de-noising**
- **Tapered gating**
- **Uncertainty estimation**

Drift removal



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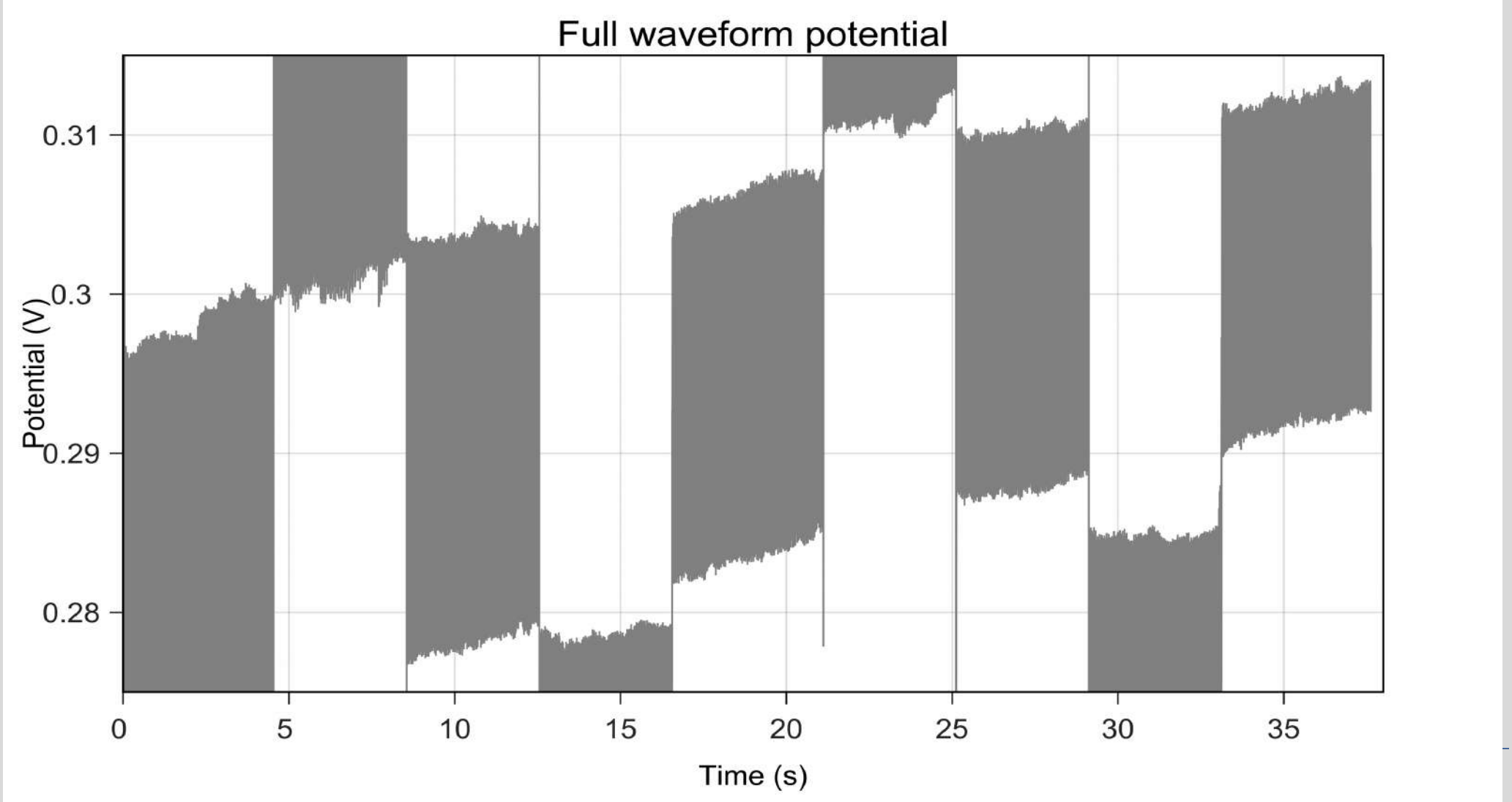
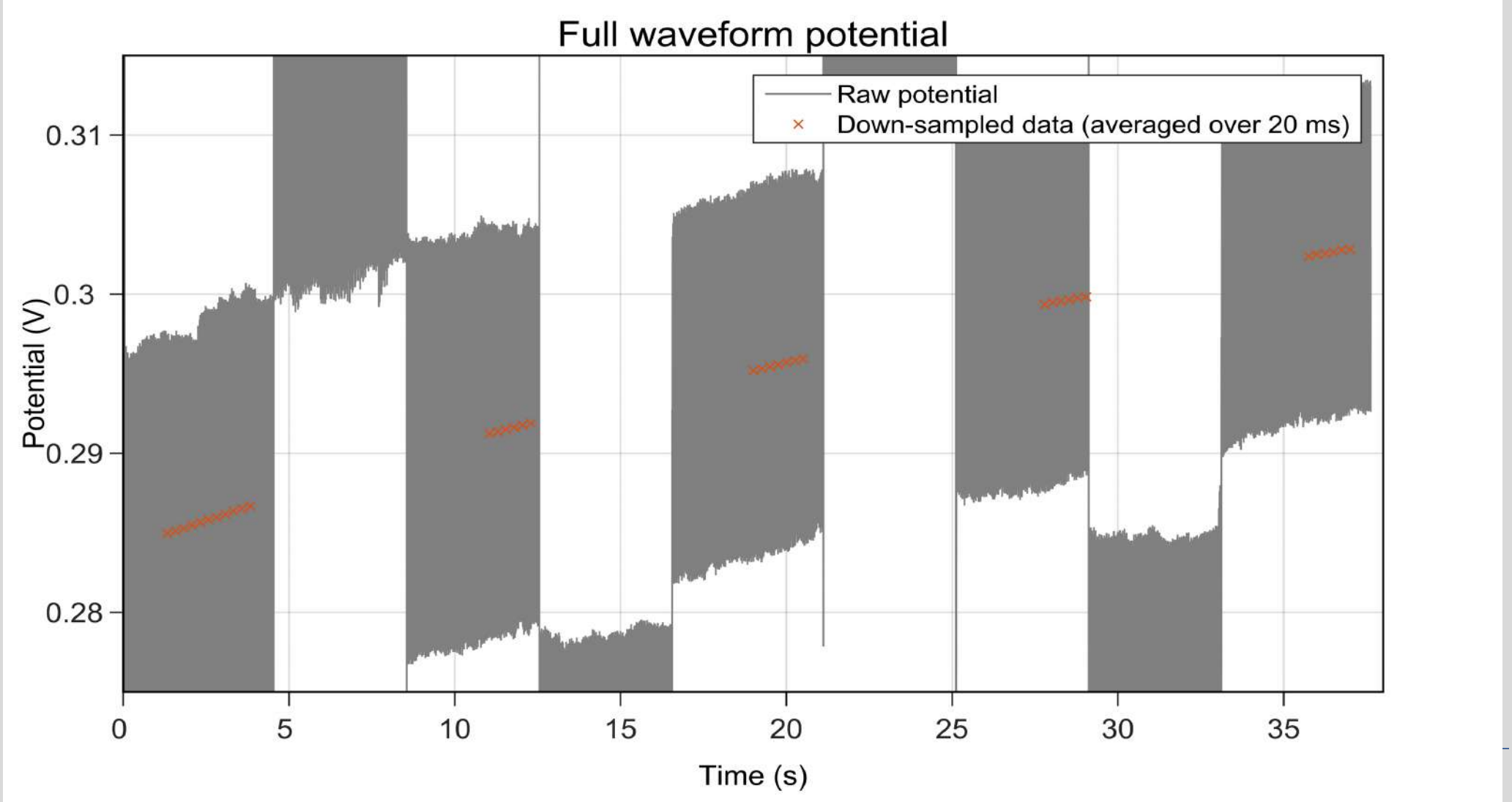
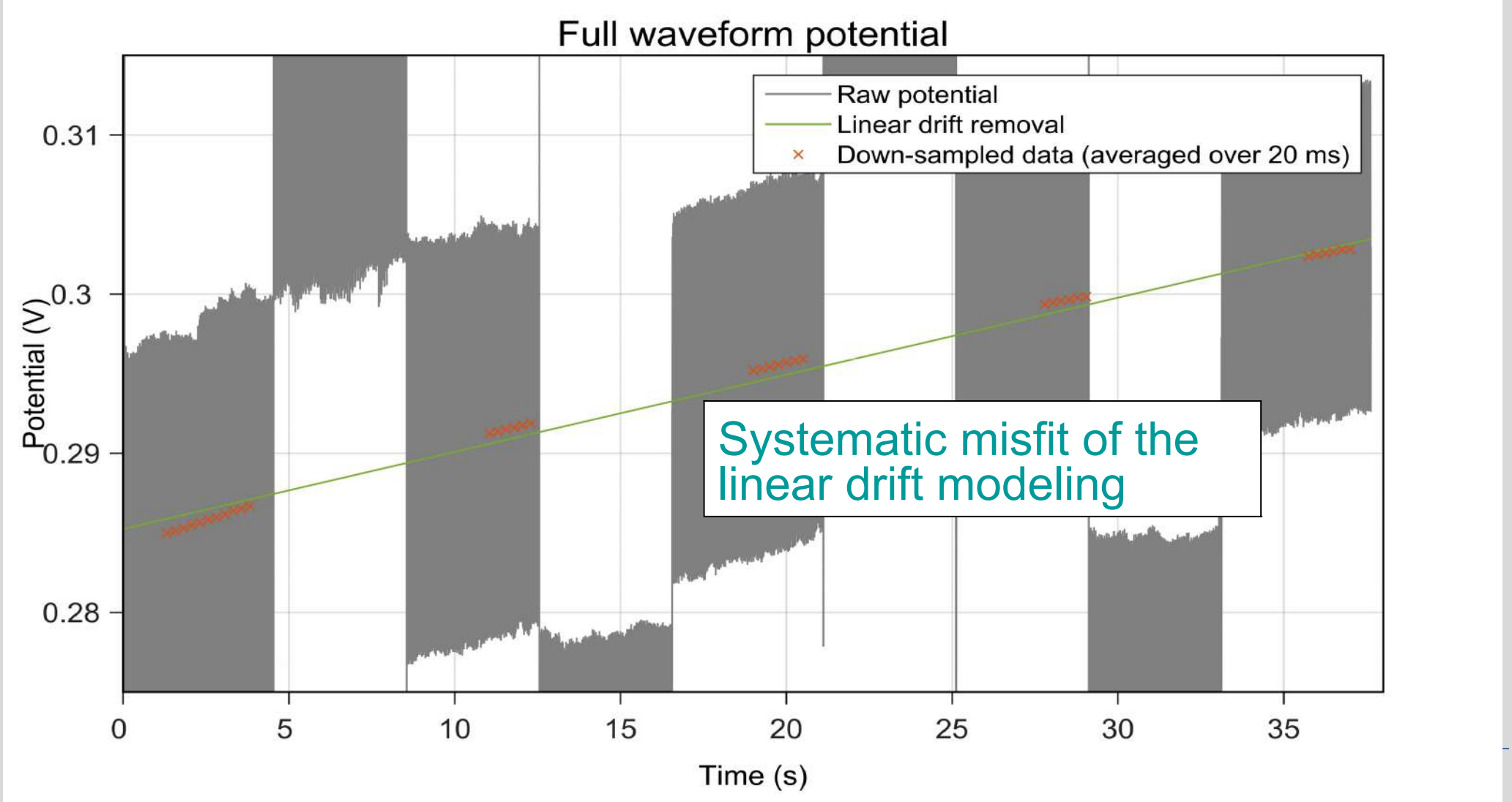


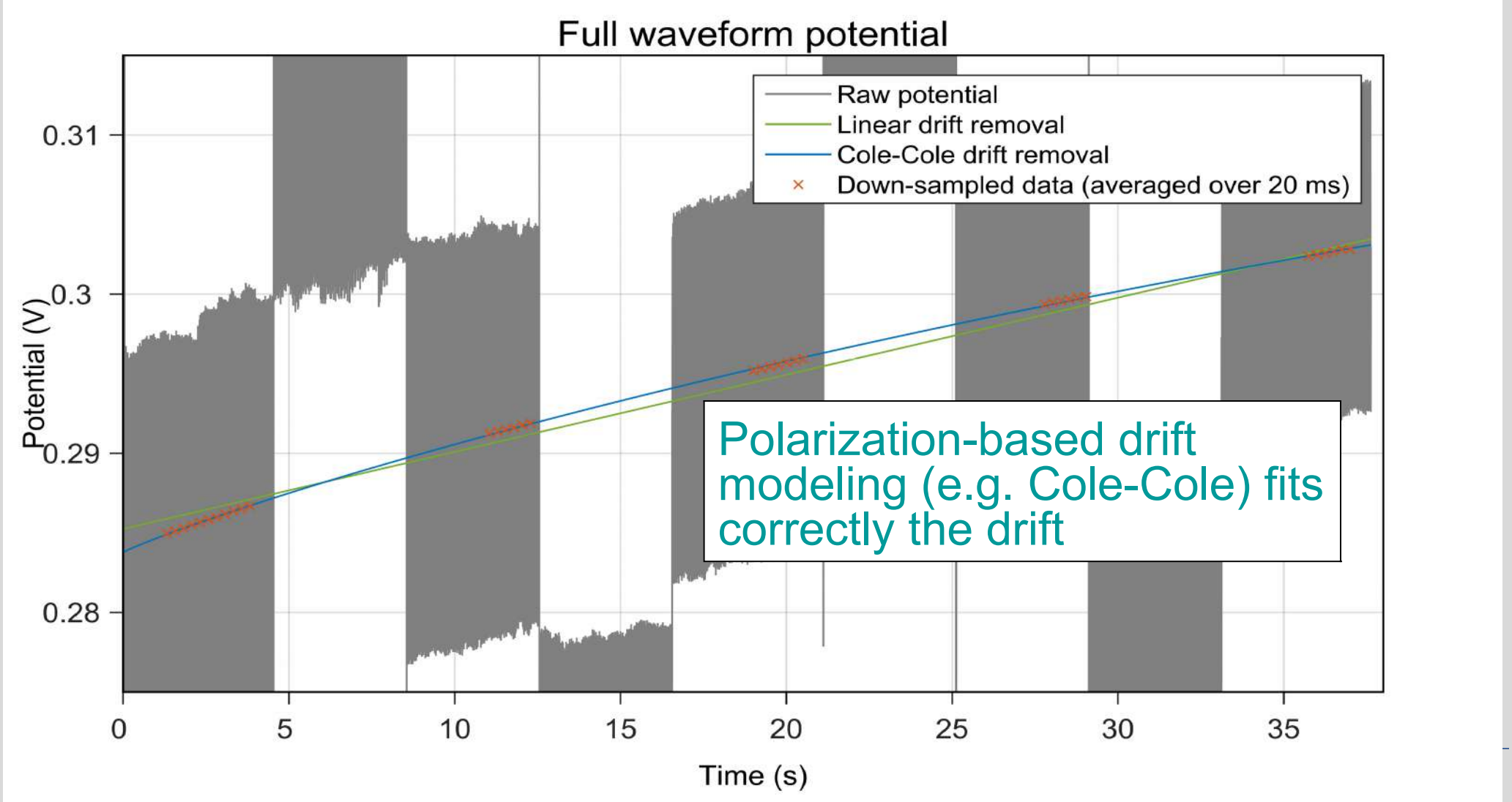
Drift removal



Drift removal



Drift removal



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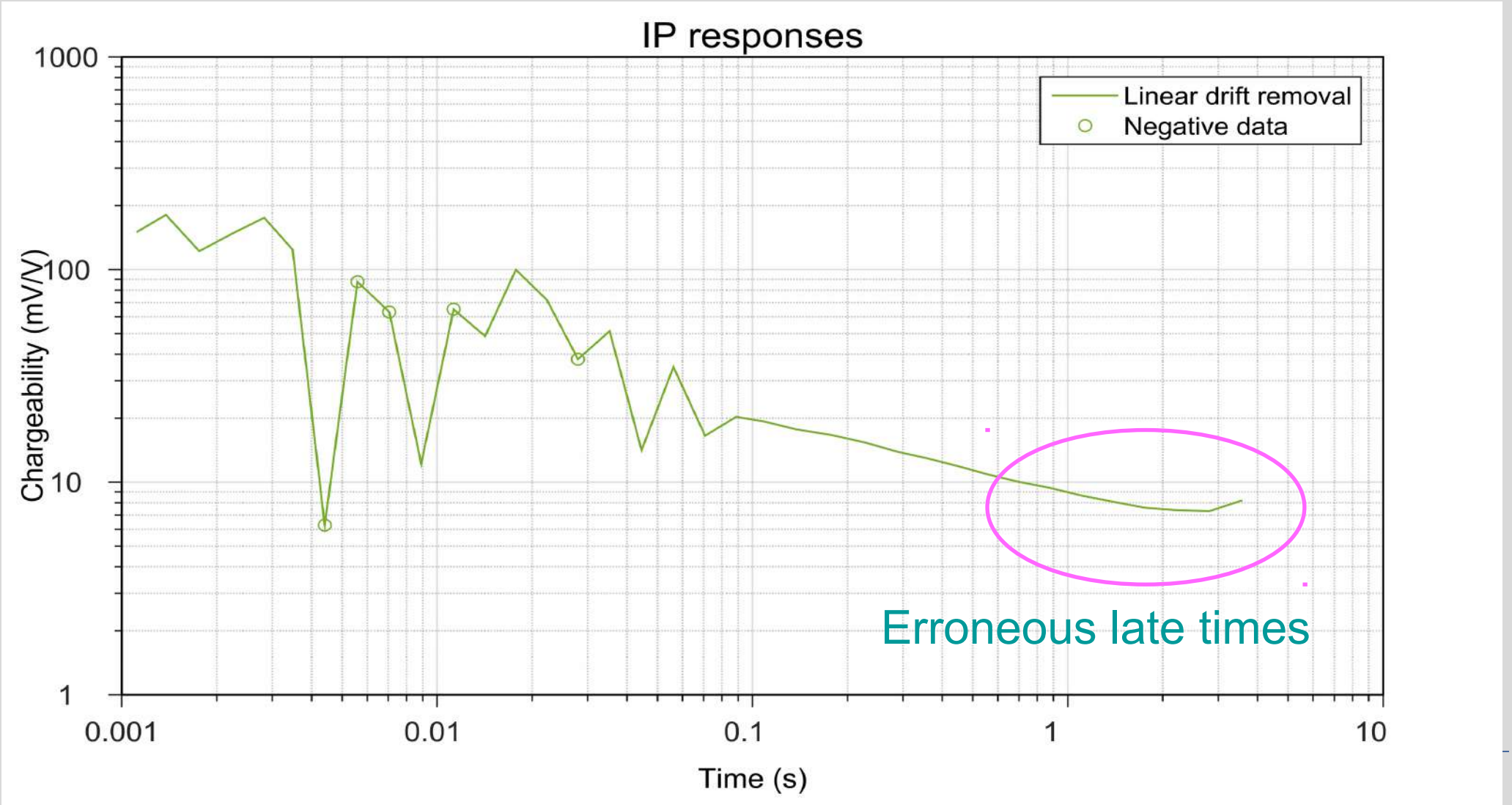
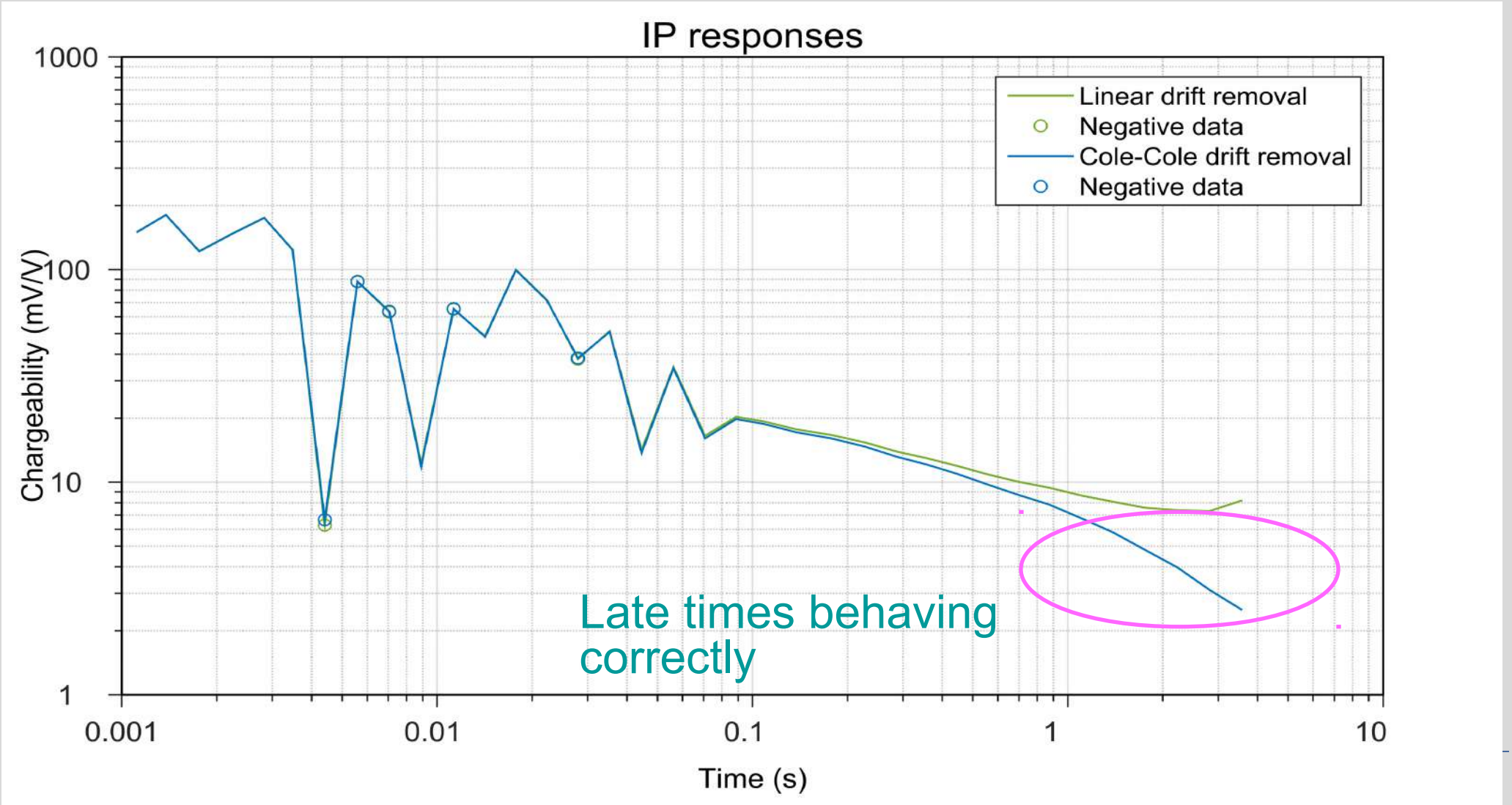
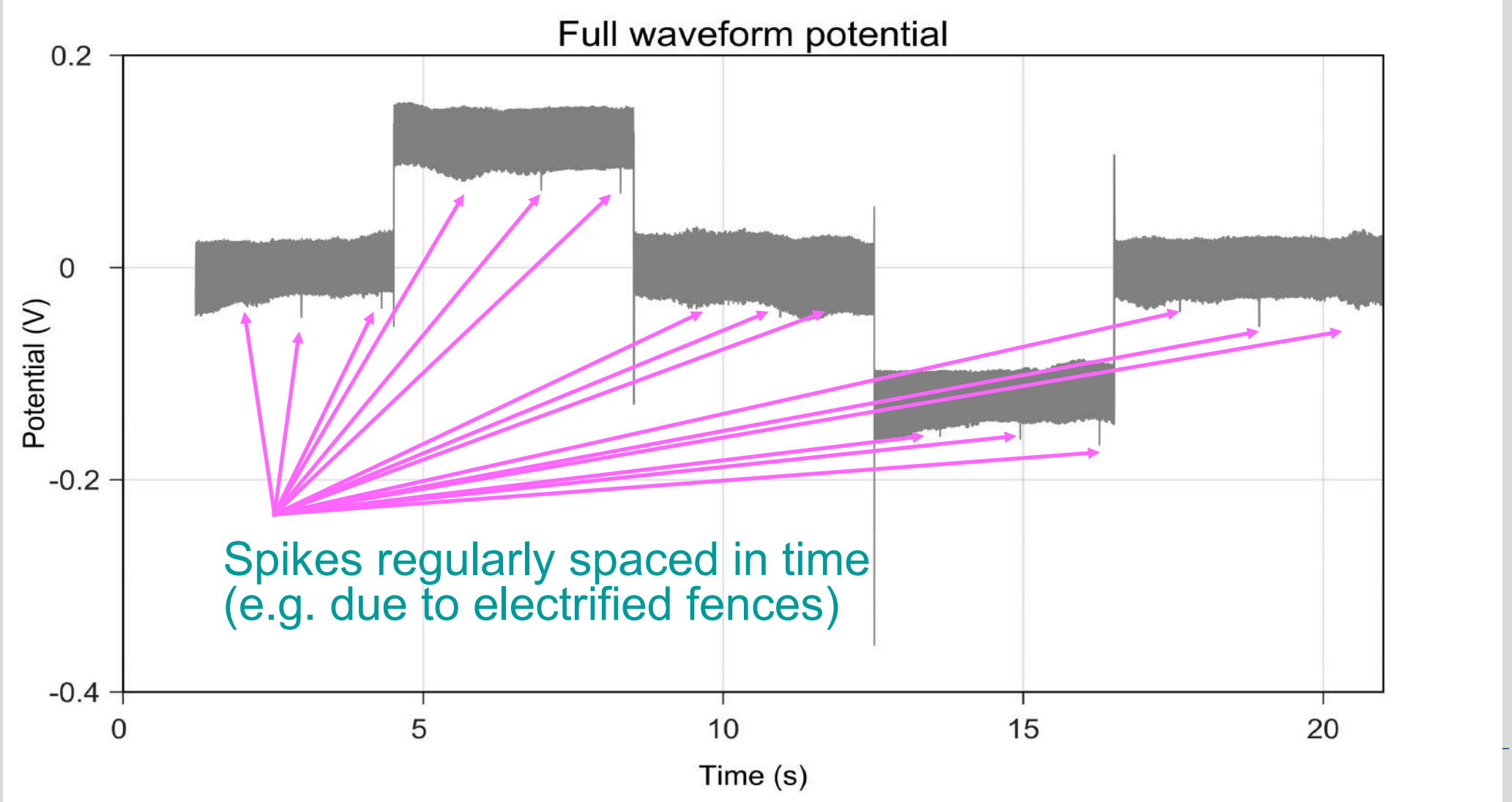


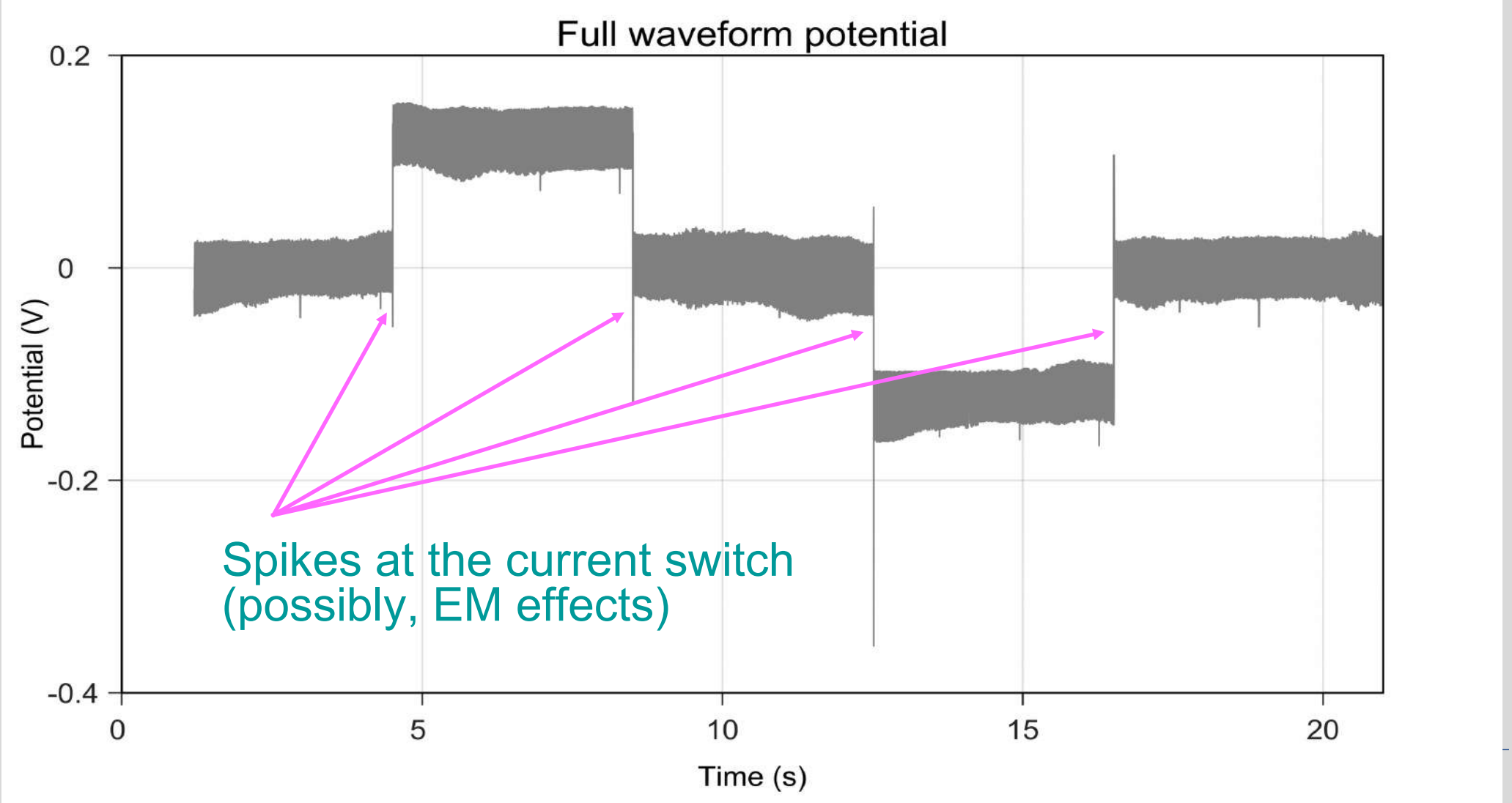
Drift removal



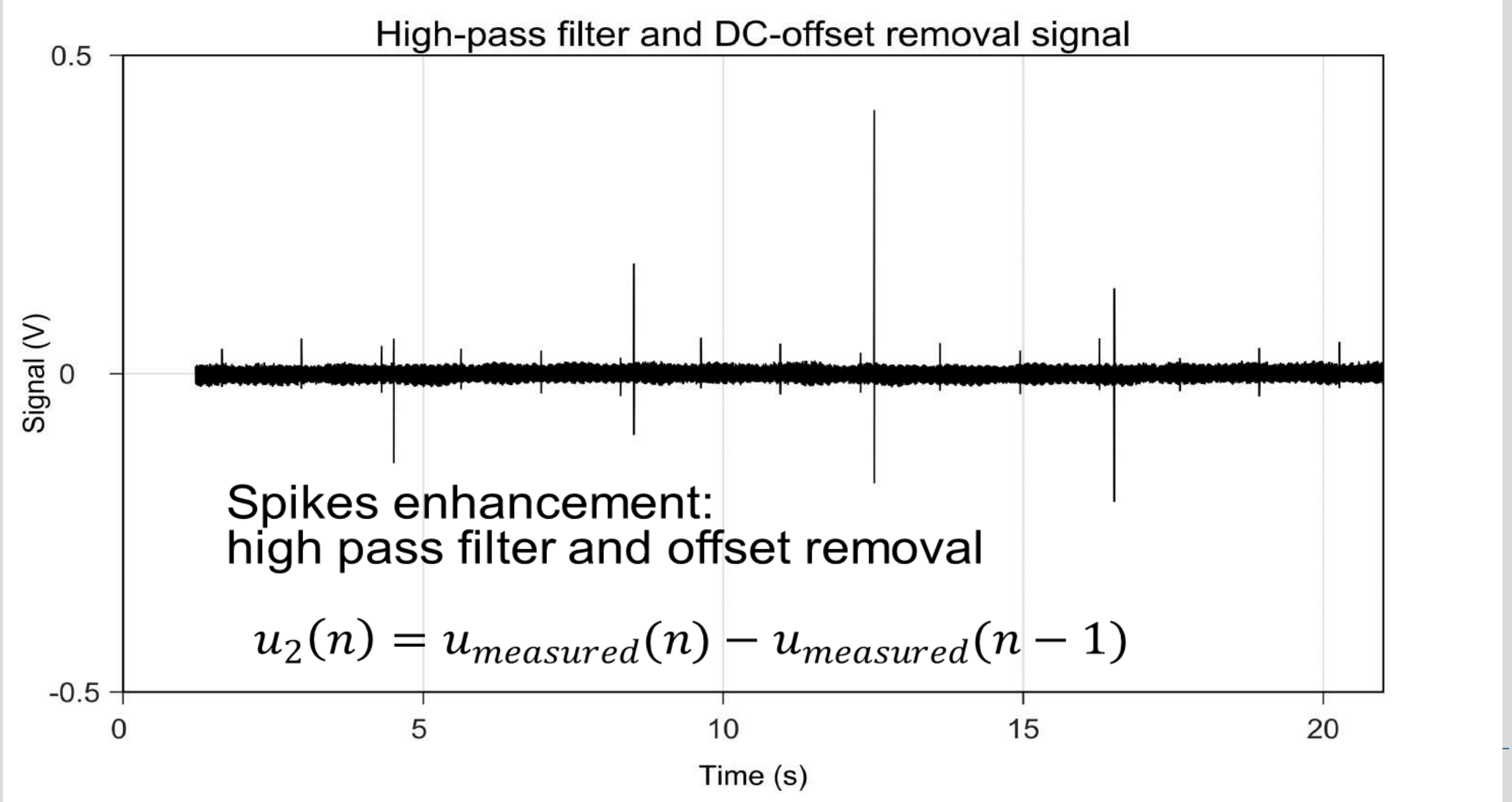
De-spiking


Full waveform potential
0.2
0
-0.2
-0.4
Potential (V)
0
5
10
15
20
Time (s)
Spikes regularly spaced in time
(e.g. due to electrified fences)

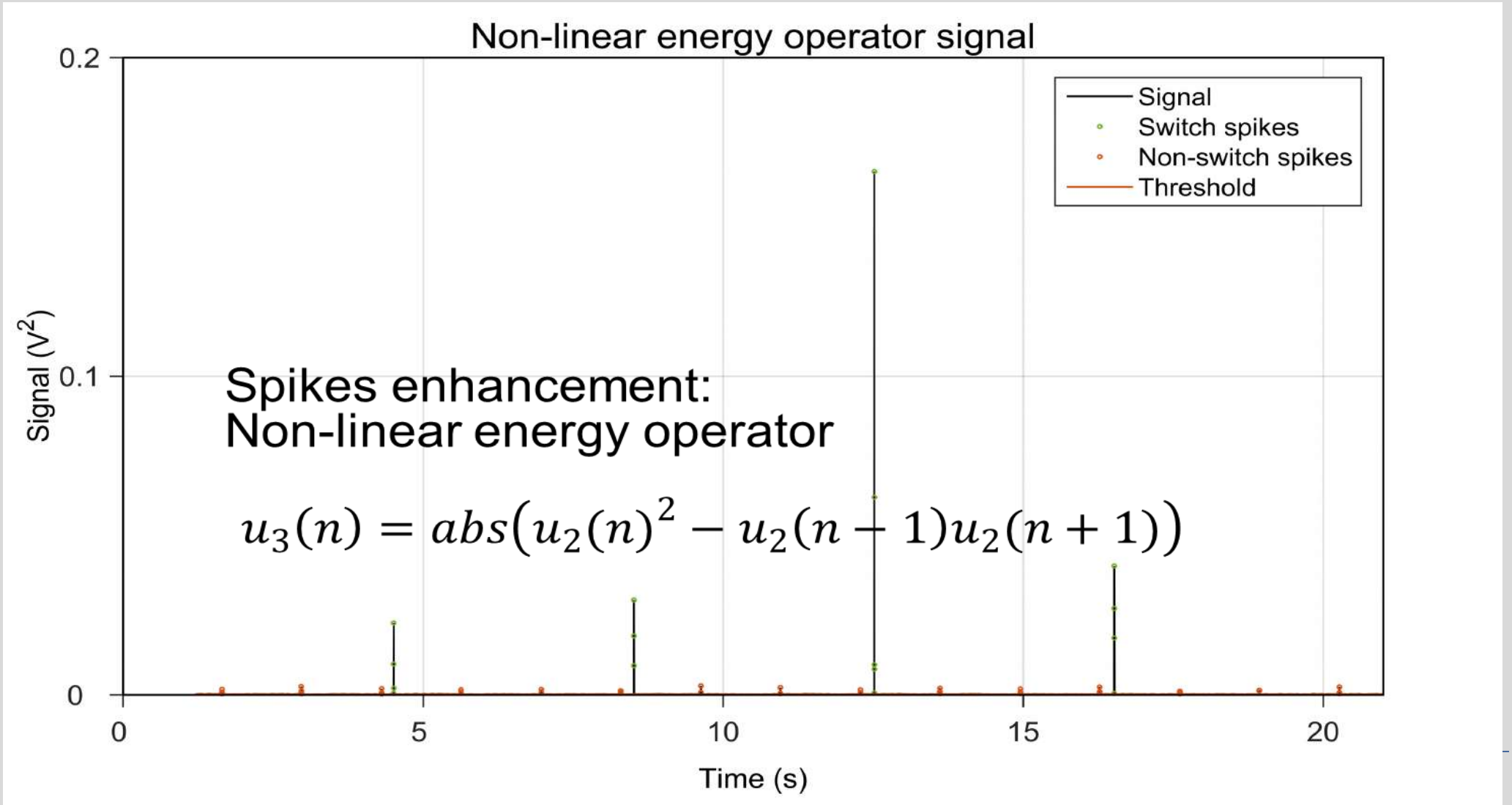
De-spiking


Full waveform potential
0.2
0
-0.2
-0.4
Potential (V)
0
5
10
15
20
Time (s)
Spikes at the current switch
(possibly, EM effects)

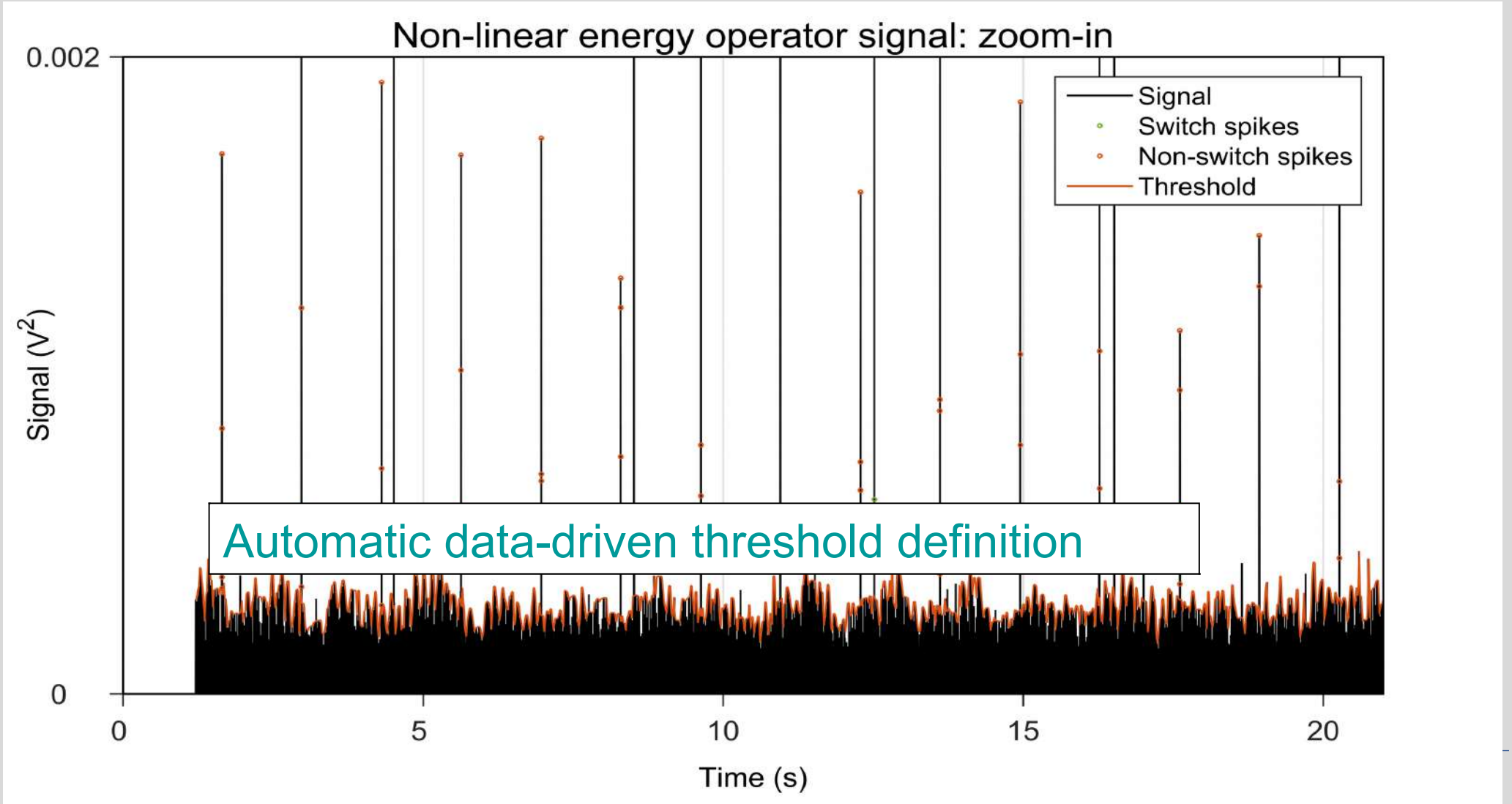
De-spiking


High-pass filter and DC-offset removal signal
0.5
0
-0.5
Signal (V)
0
5
10
15
20
Time (s)
Spikes enhancement:
high pass filter and offset removal
$u_2(n) = u_{measured}(n) - u_{measured}(n-1)$

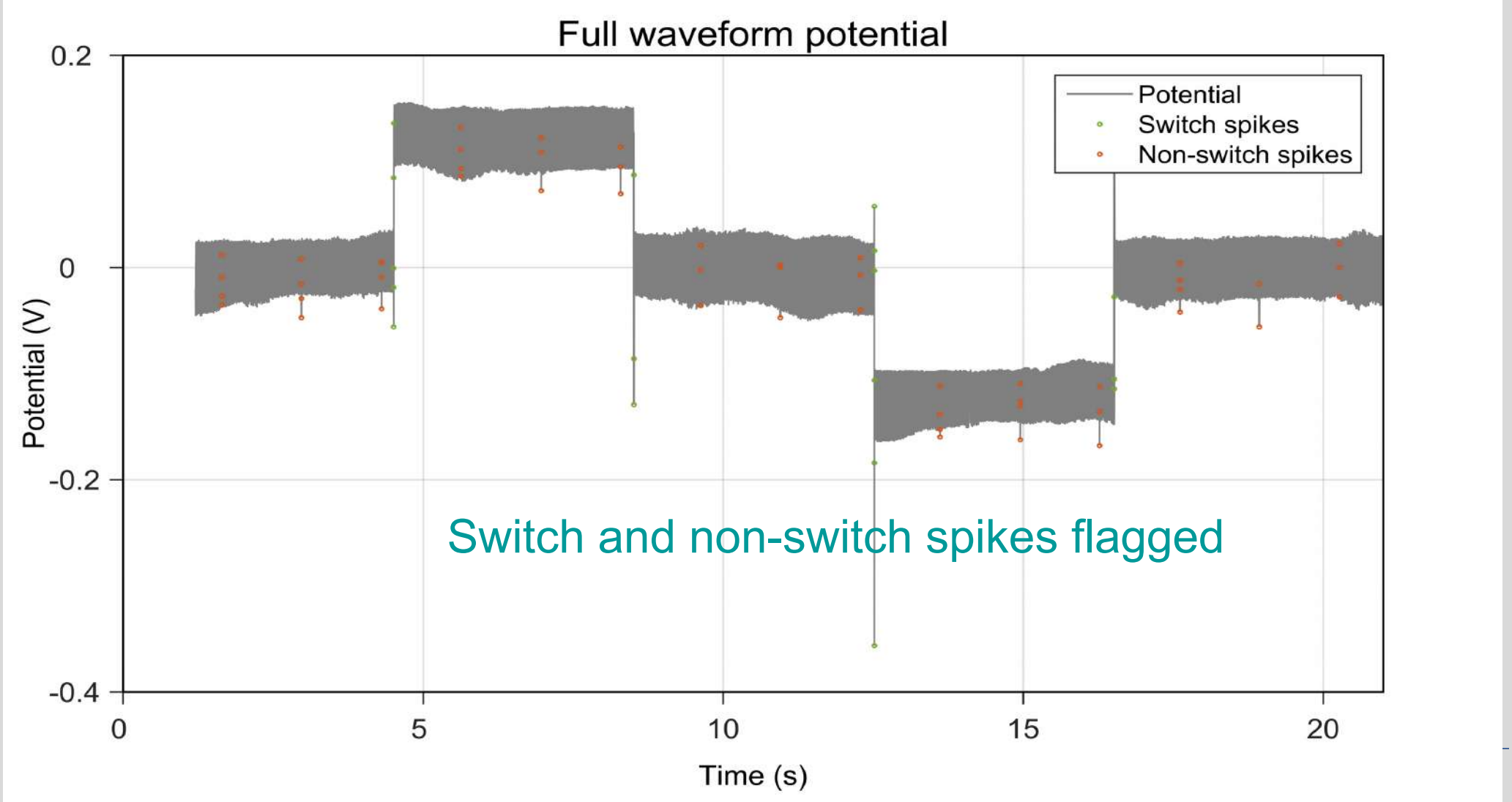
De-spiking


Non-linear energy operator signal
Signal
Switch spikes
Non-switch spikes
Threshold
Signal (V^2)
0.2
0.1
0
0
5
10
15
20
Time (s)
Spikes enhancement:
Non-linear energy operator
$u_3(n) = abs\left(u_2(n)^2 - u_2(n-1)u_2(n+1)\right)$

De-spiking


Non-linear energy operator signal: zoom-in
0.002
0
Signal (V^2)
0
5
10
15
20
Time (s)
Signal
Switch spikes
Non-switch spikes
Threshold
Automatic data-driven threshold definition

De-spiking

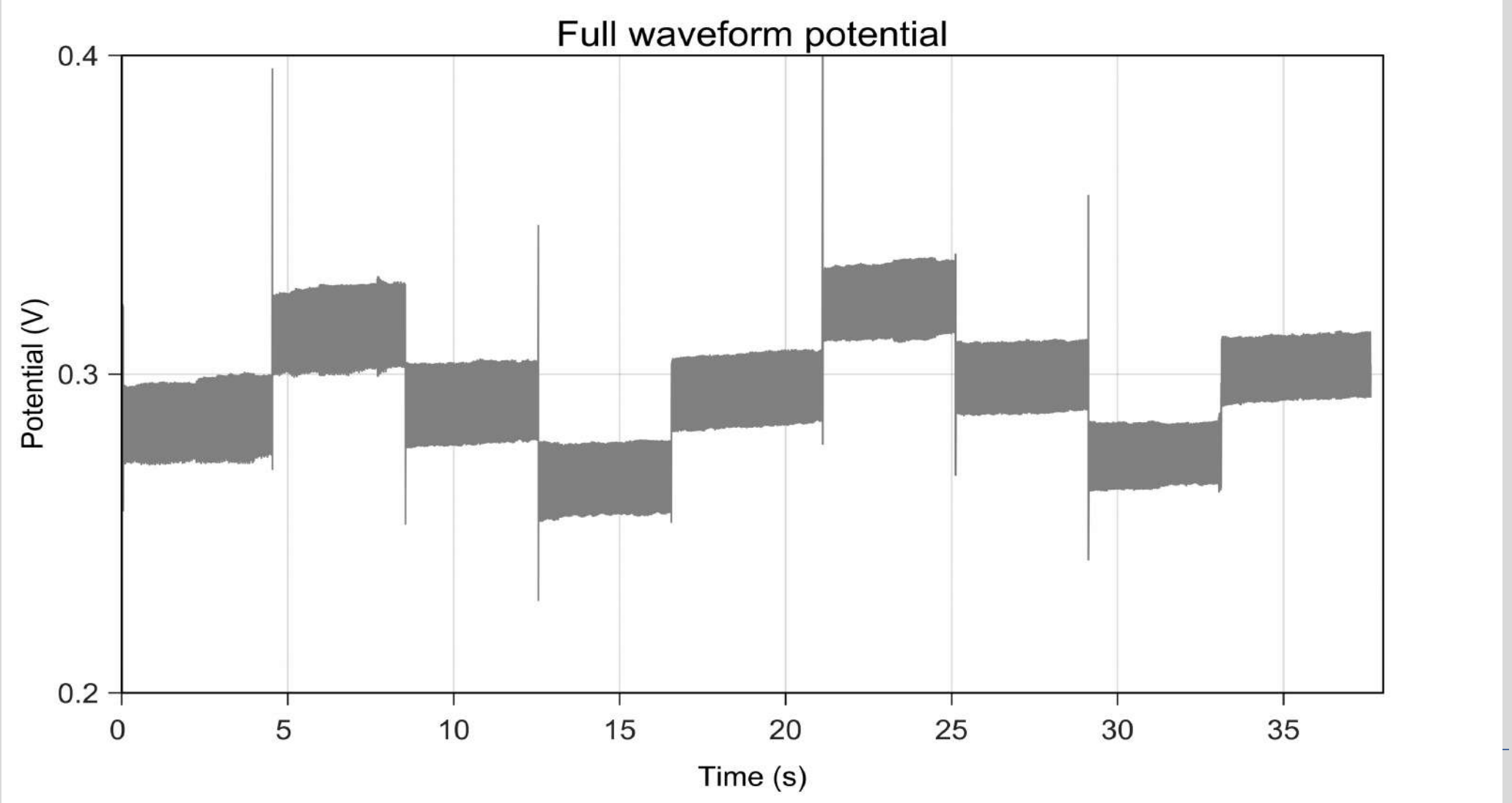

Full waveform potential
Potential
Switch spikes
Non-switch spikes
0.2
0
-0.2
-0.4
Potential (V)
0
5
10
15
20
Time (s)
Switch and non-switch spikes flagged

De-spiking

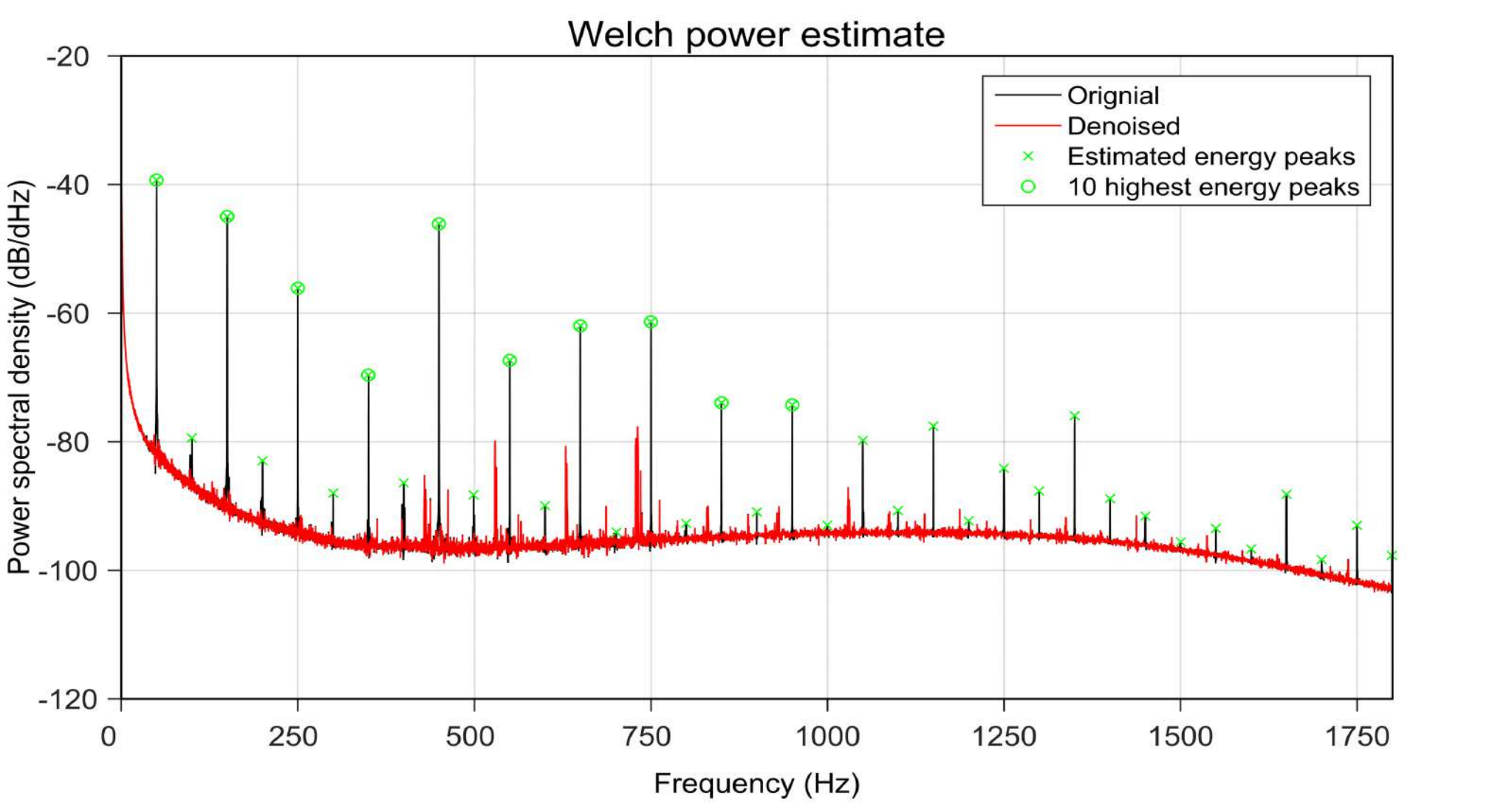
- **Gates containing switch spikes are considered outliers**

- **Non-switch spike-flagged samples are replaced with the median of their 8 neighbouring samples (4 on each side)**

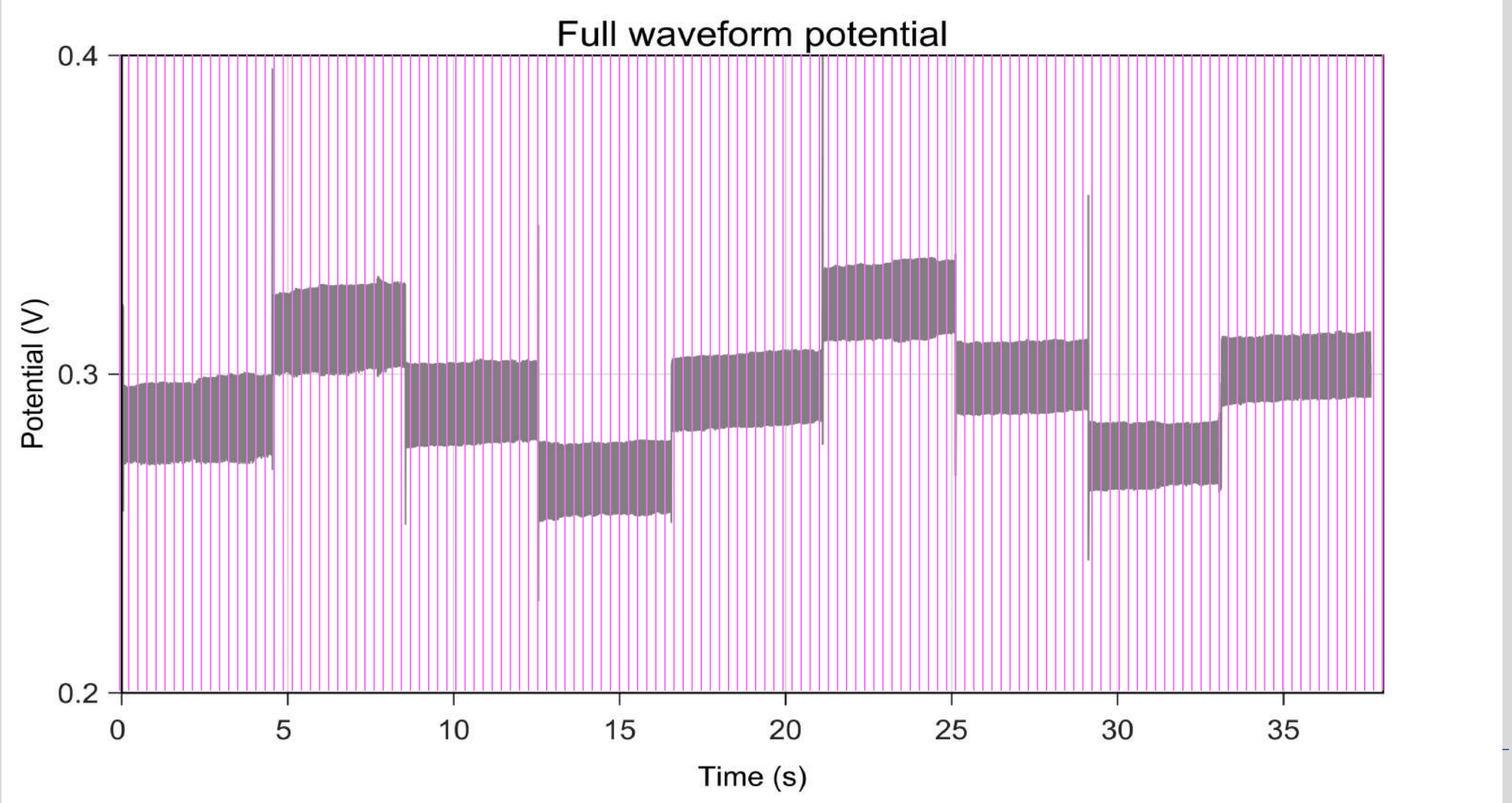
Harmonic de-noising



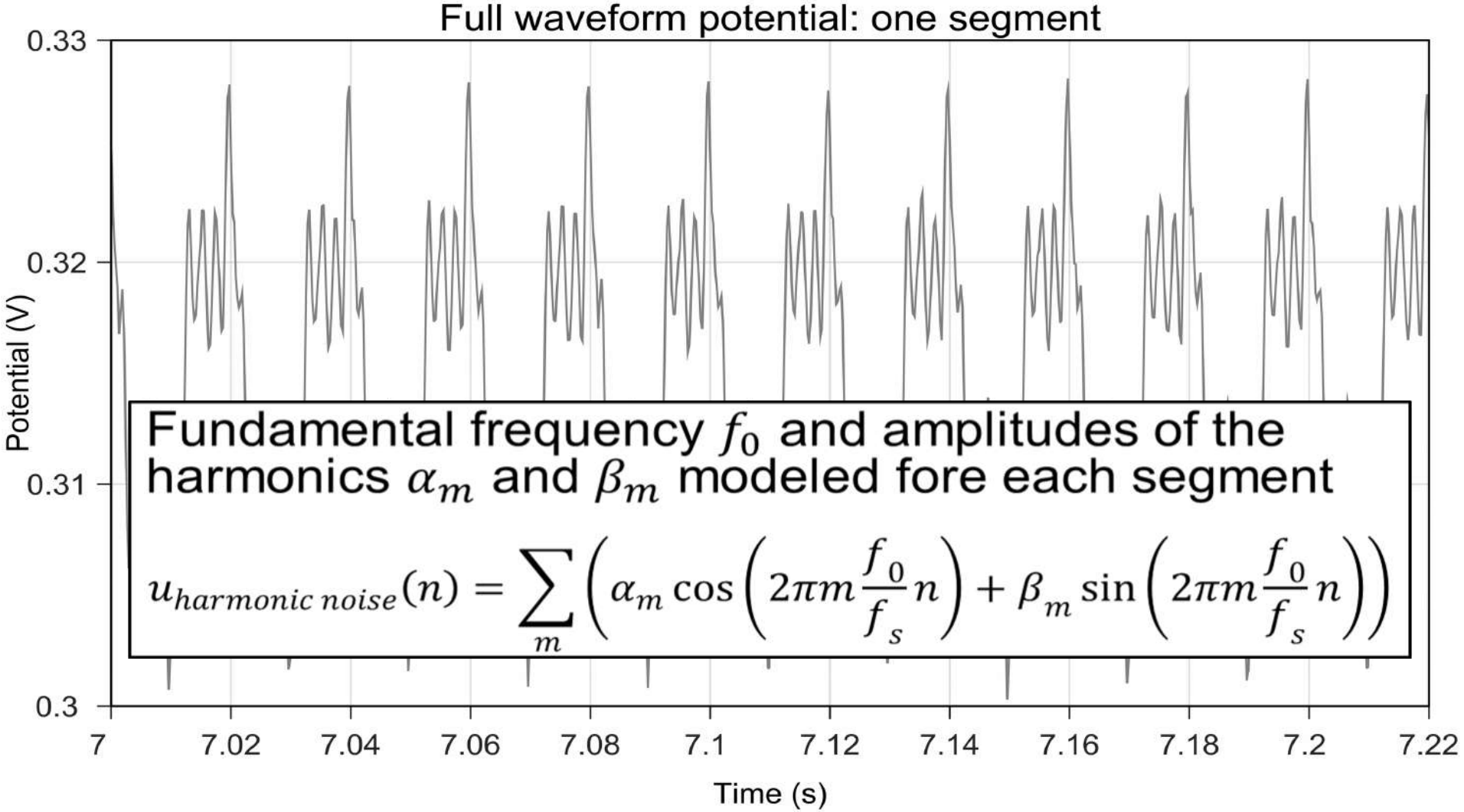
Harmonic de-noising



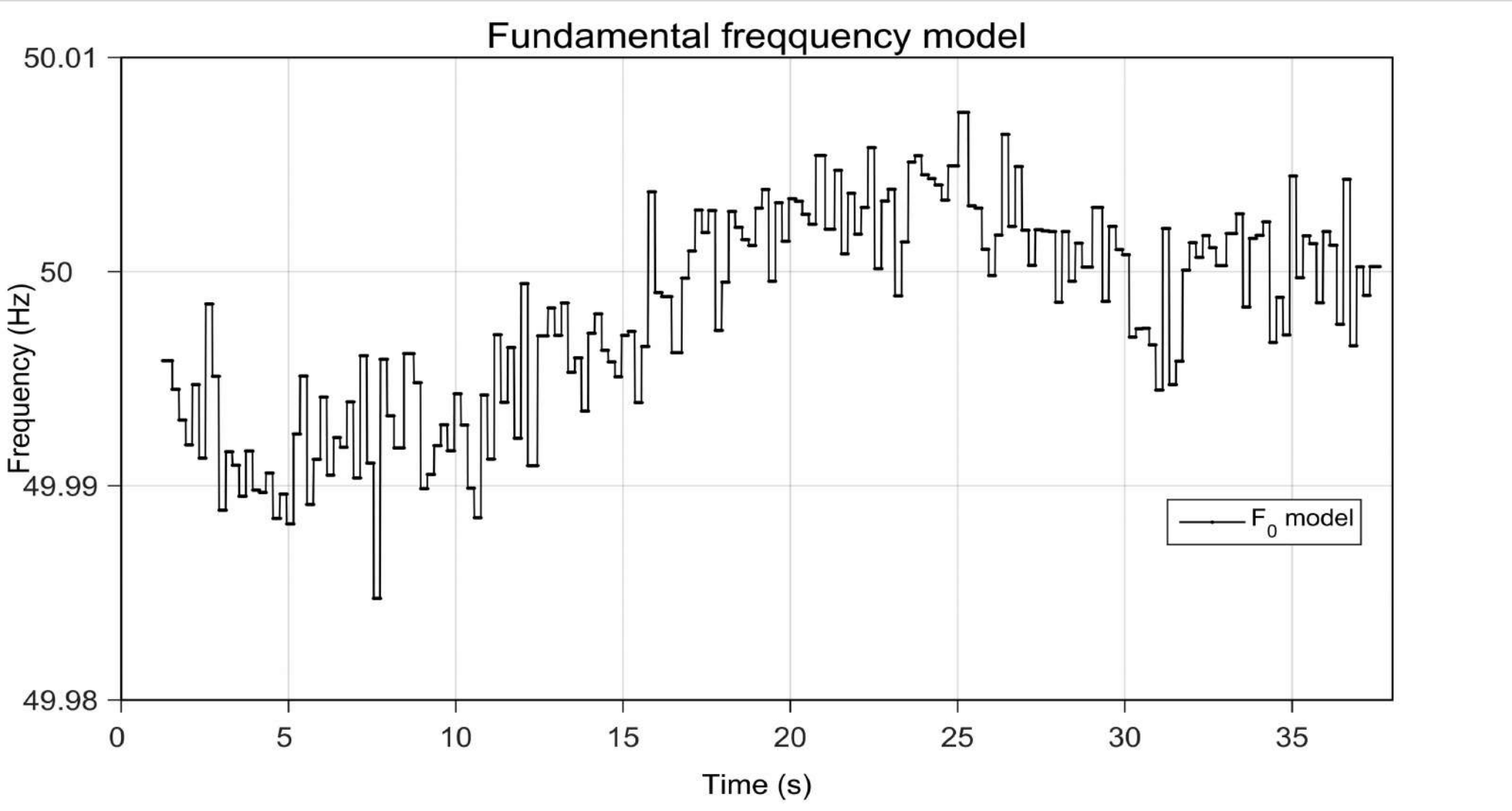
Harmonic de-noising: segmentation



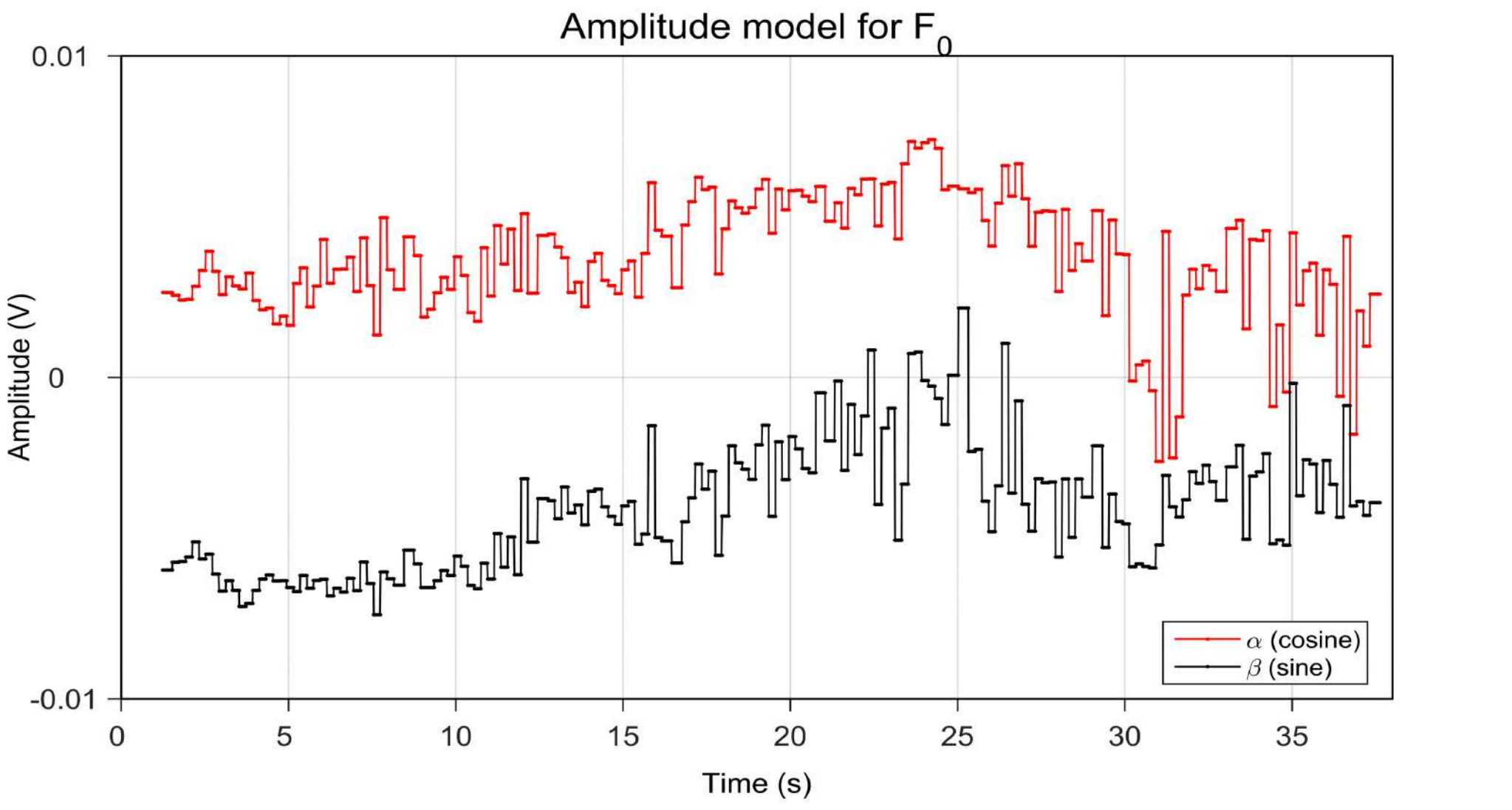
Harmonic de-noising: noise modeling



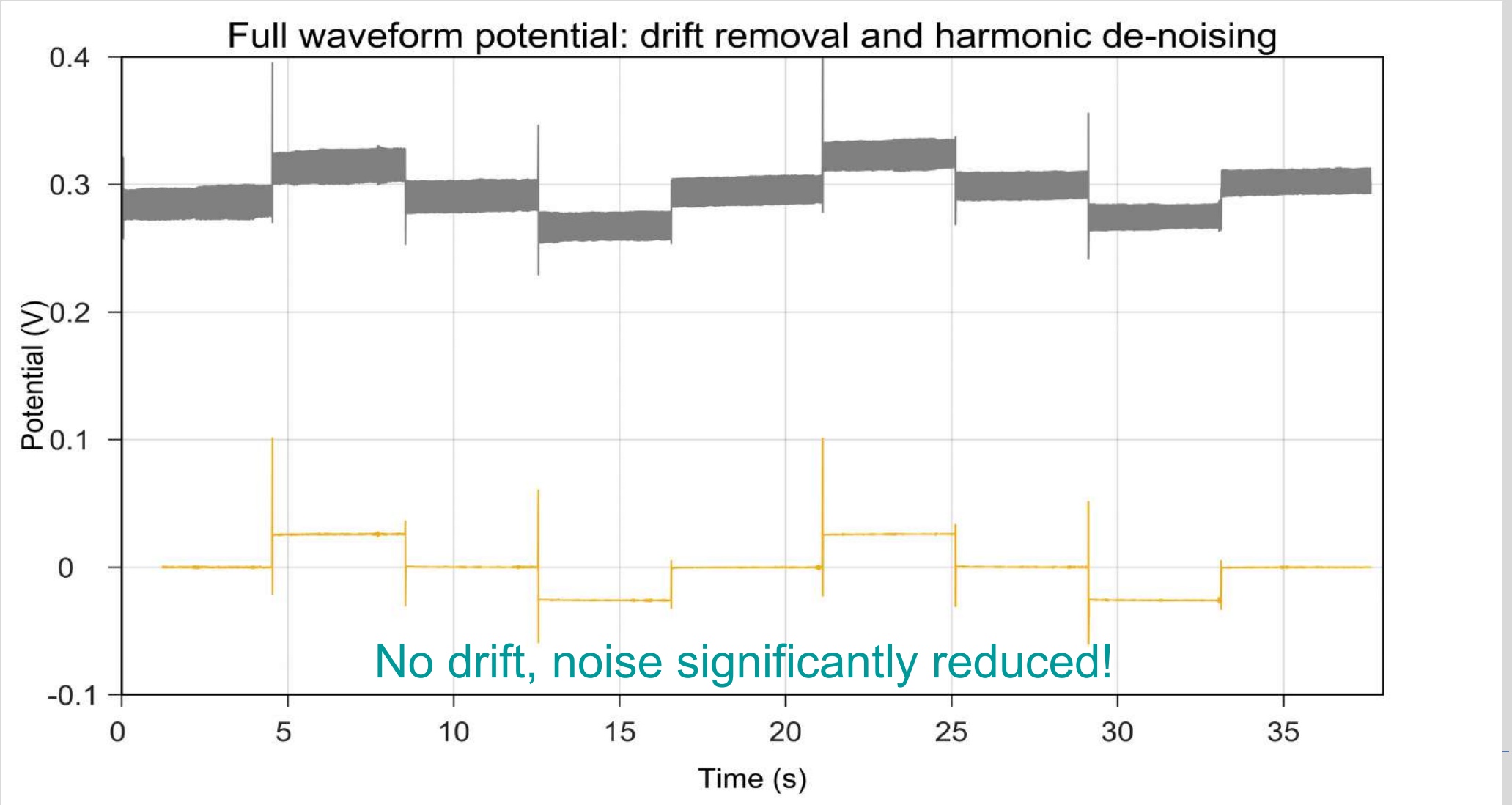
Harmonic de-noising: frequency variation



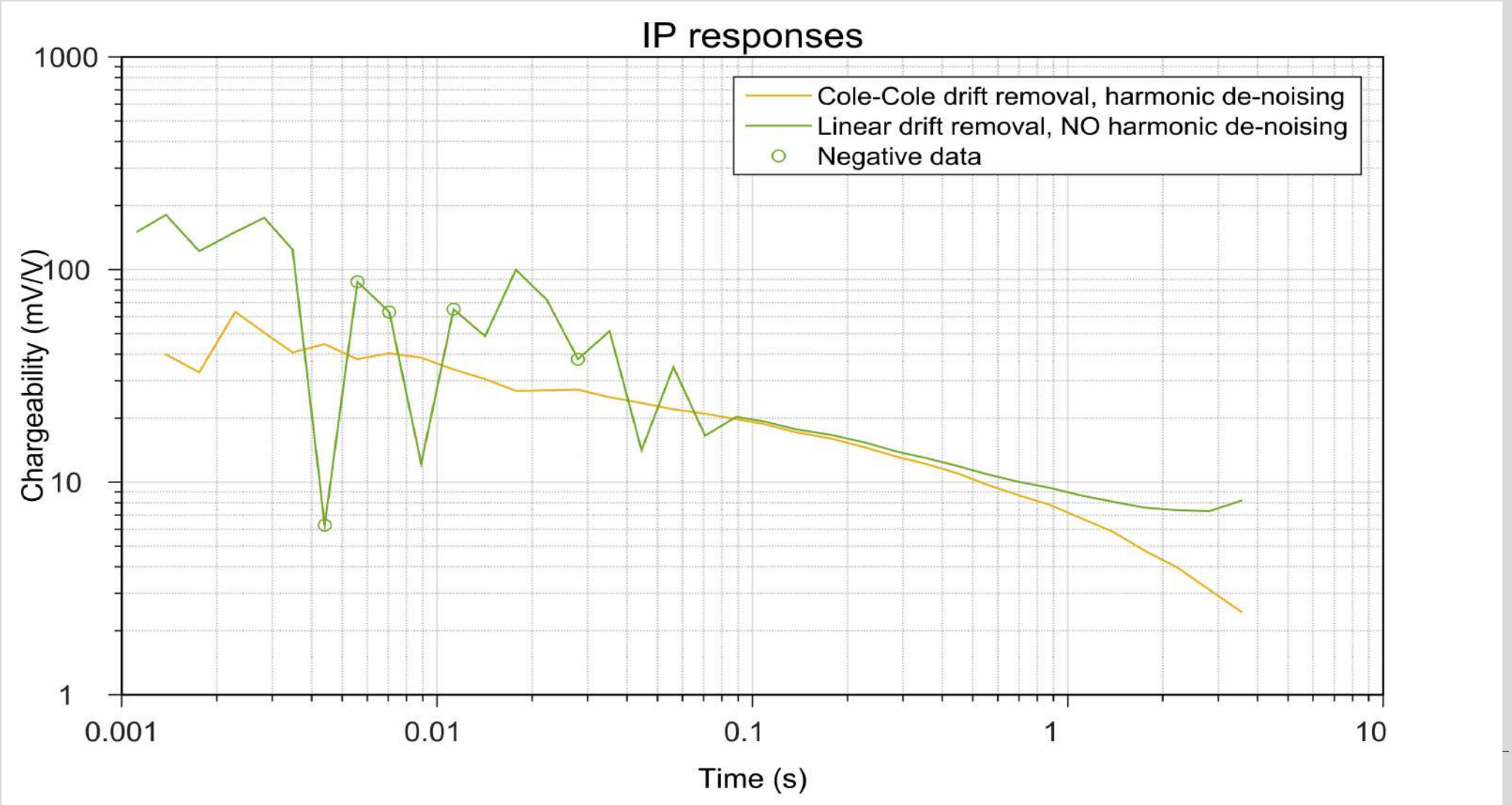
Harmonic de-noising: amplitude variation



Harmonic de-noising: corrected potential



Harmonic de-noising: IP response



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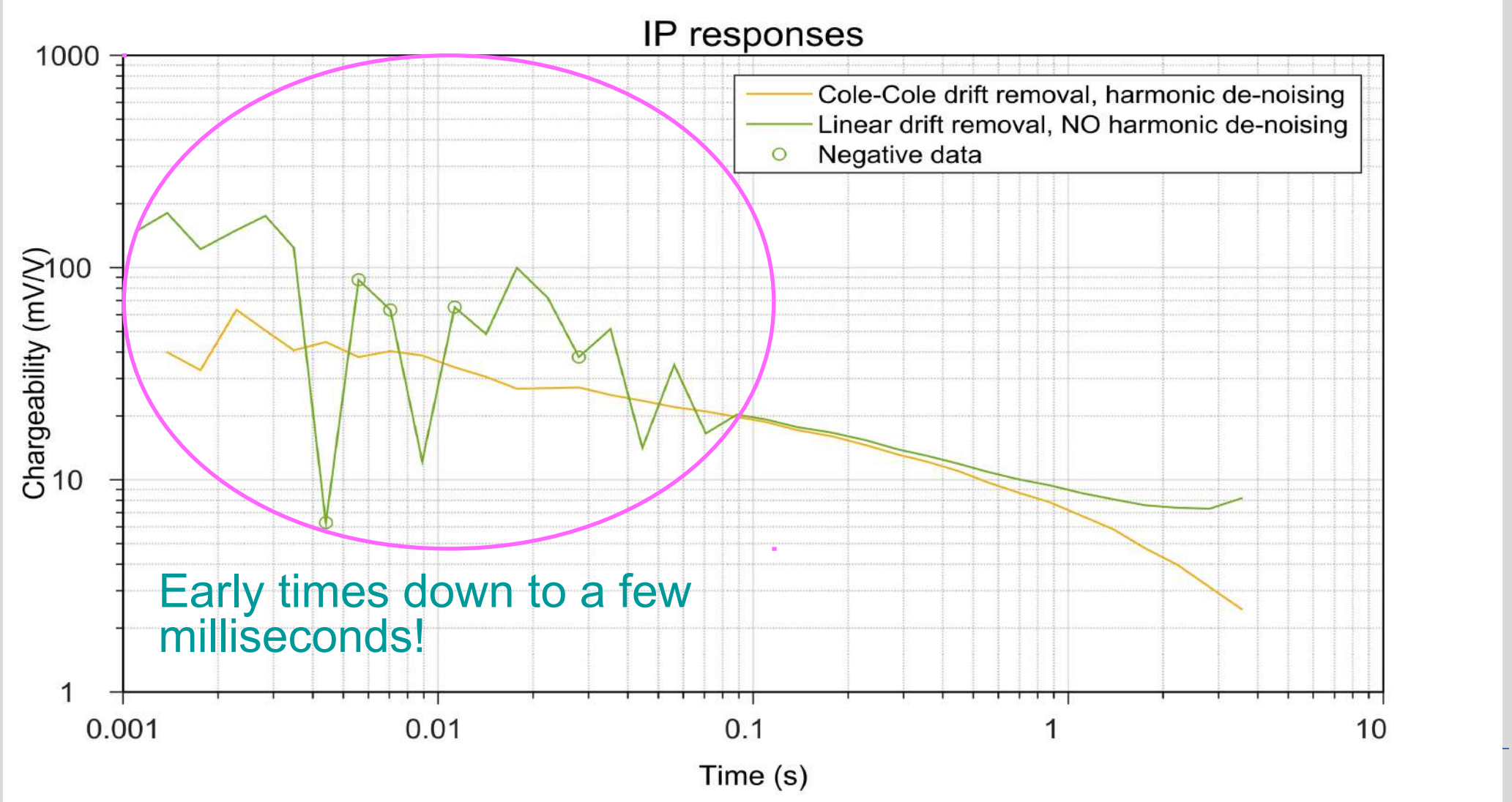
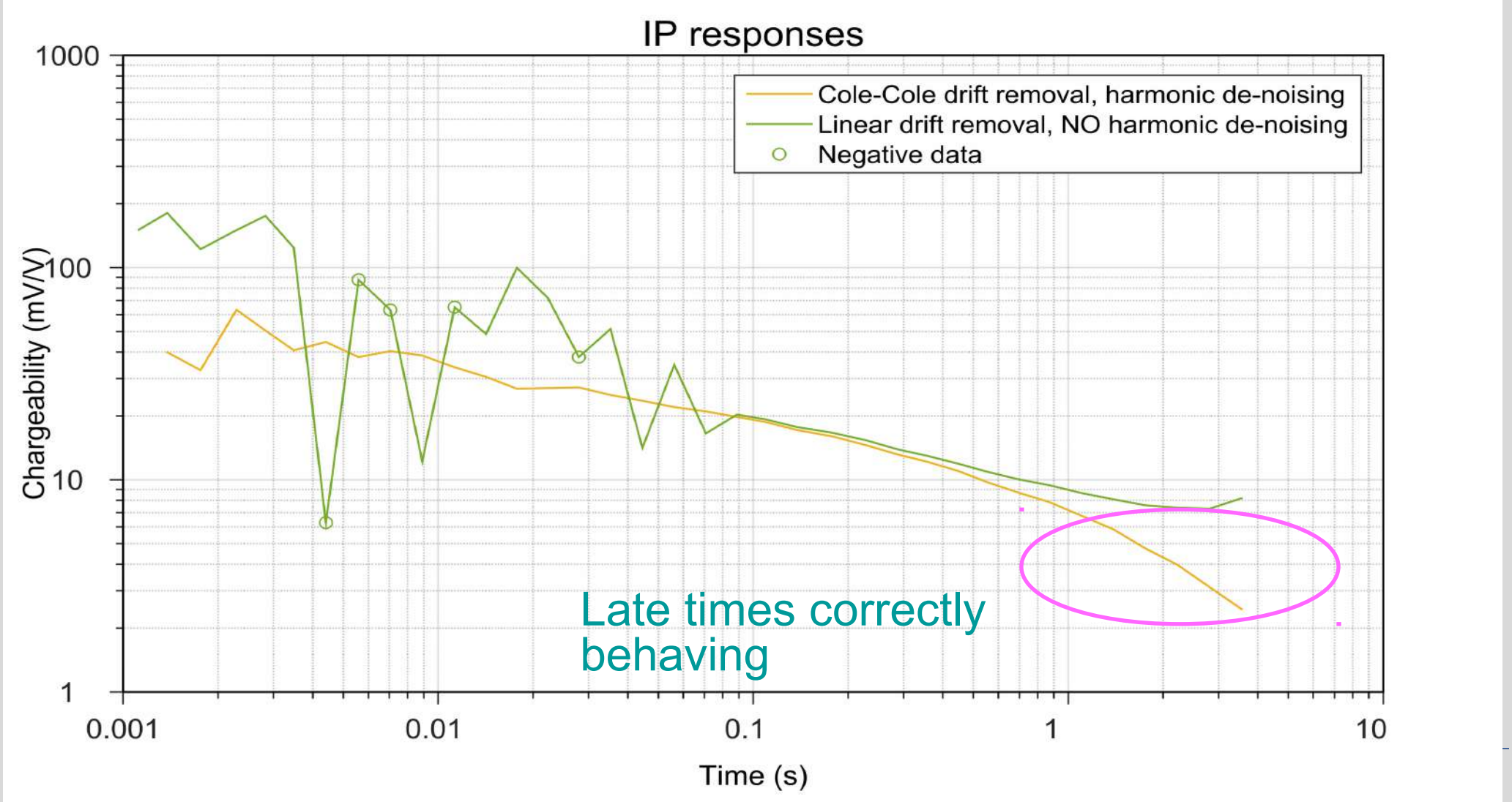


Harmonic de-noising: IP response

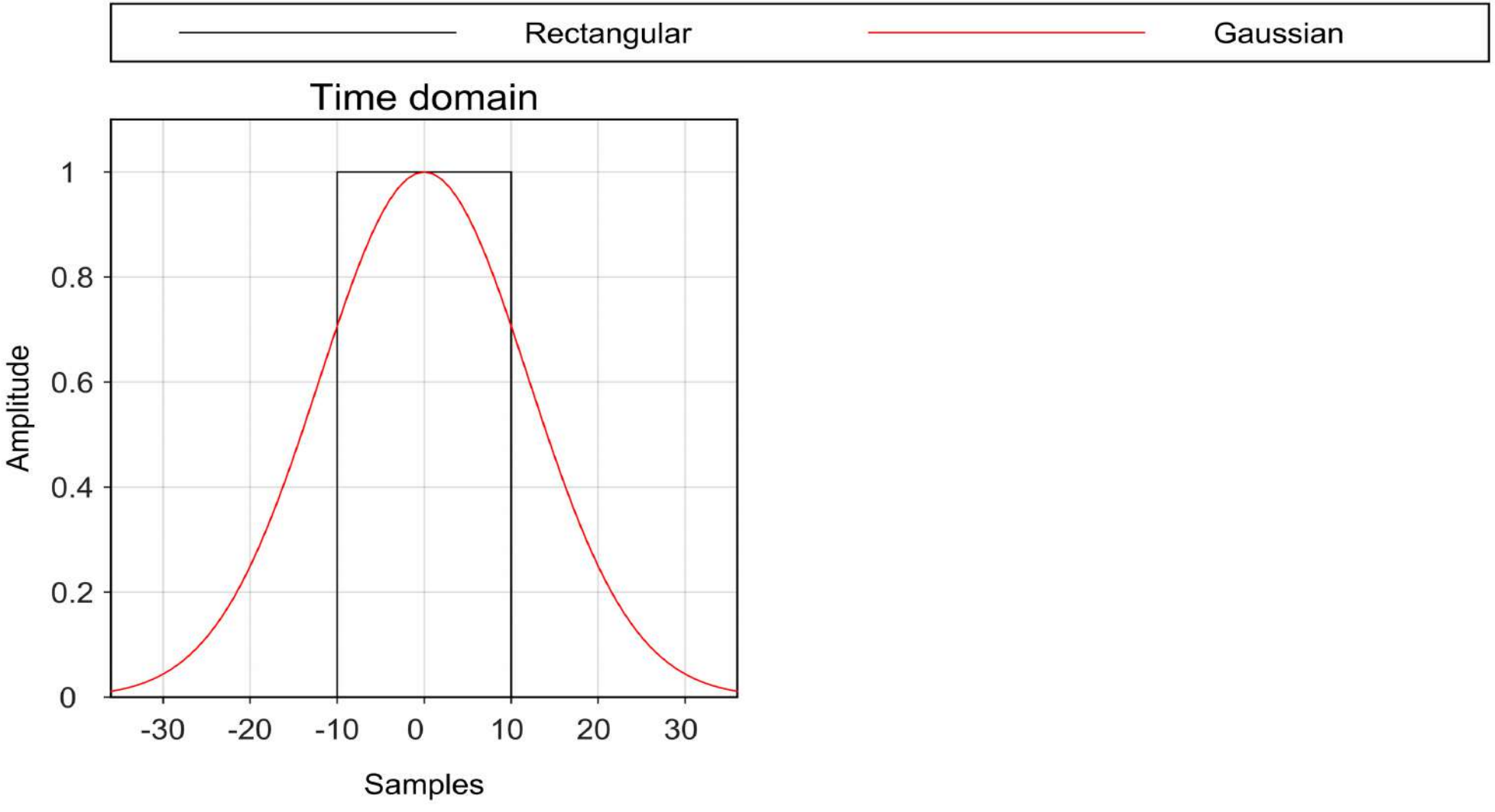


Tapered gating

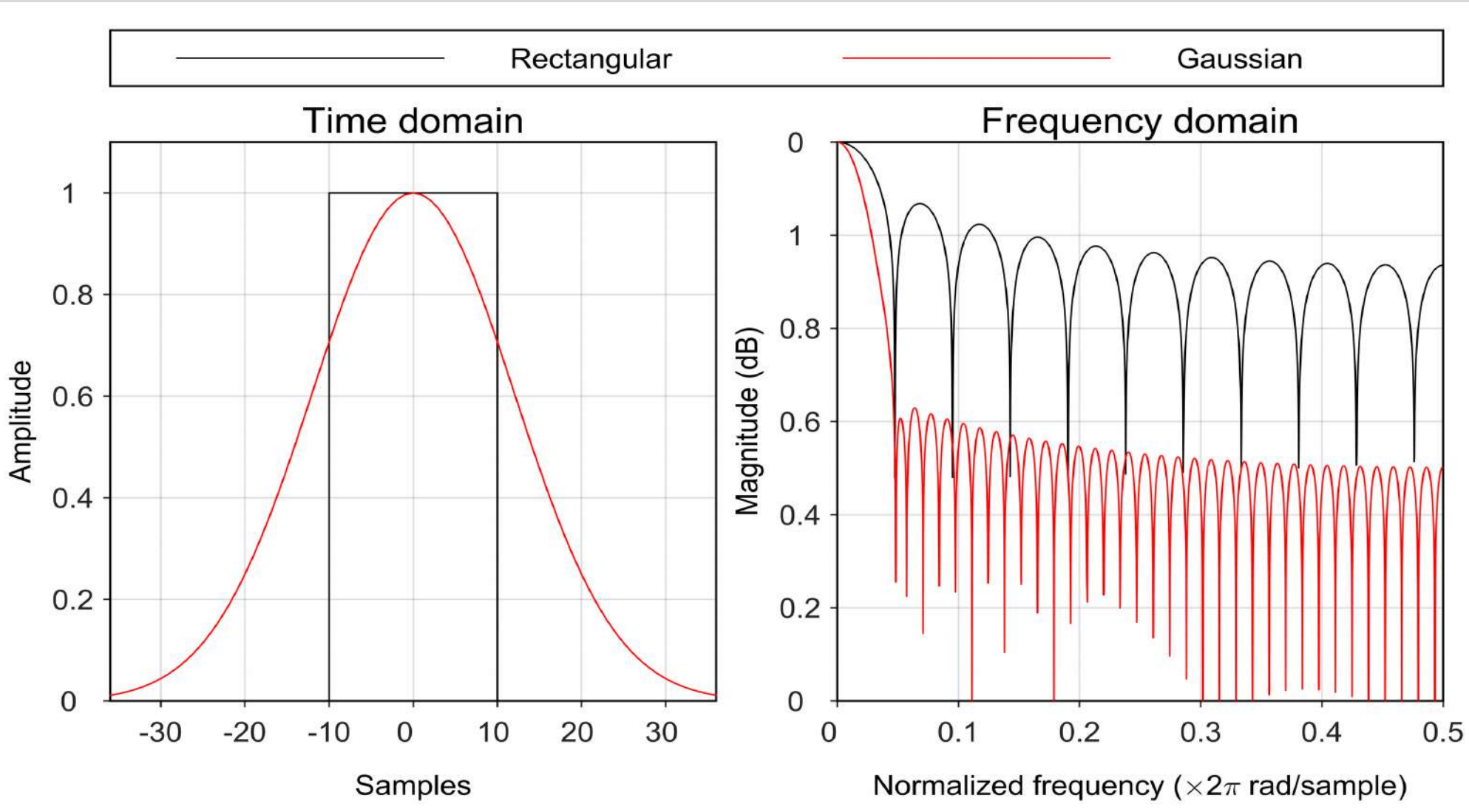
- **Usually rectangular gates are used in TD IP**

- **But tapered gates provide increased noise suppression without signal distortion**

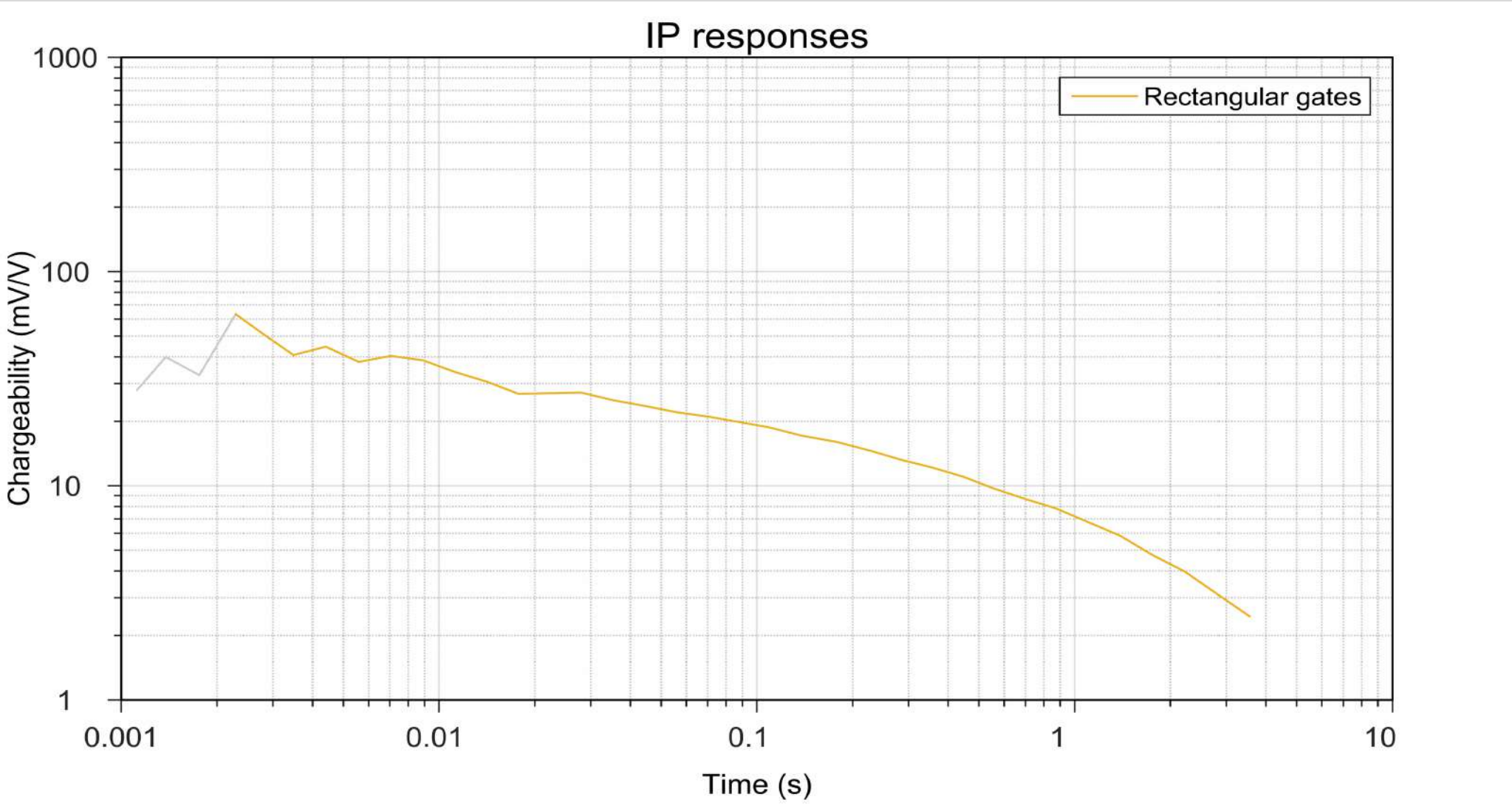
Tapered gating



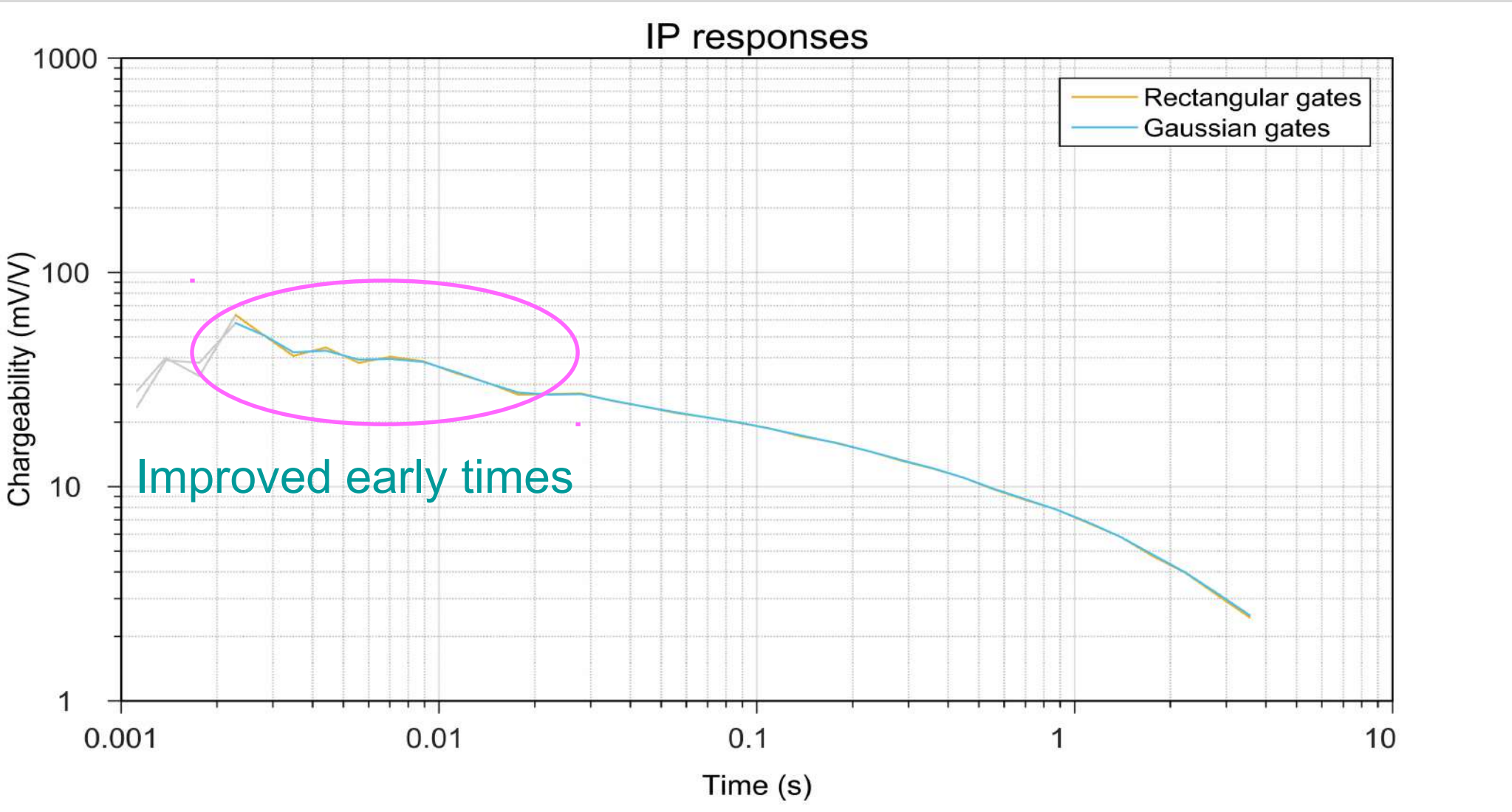
Tapered gating



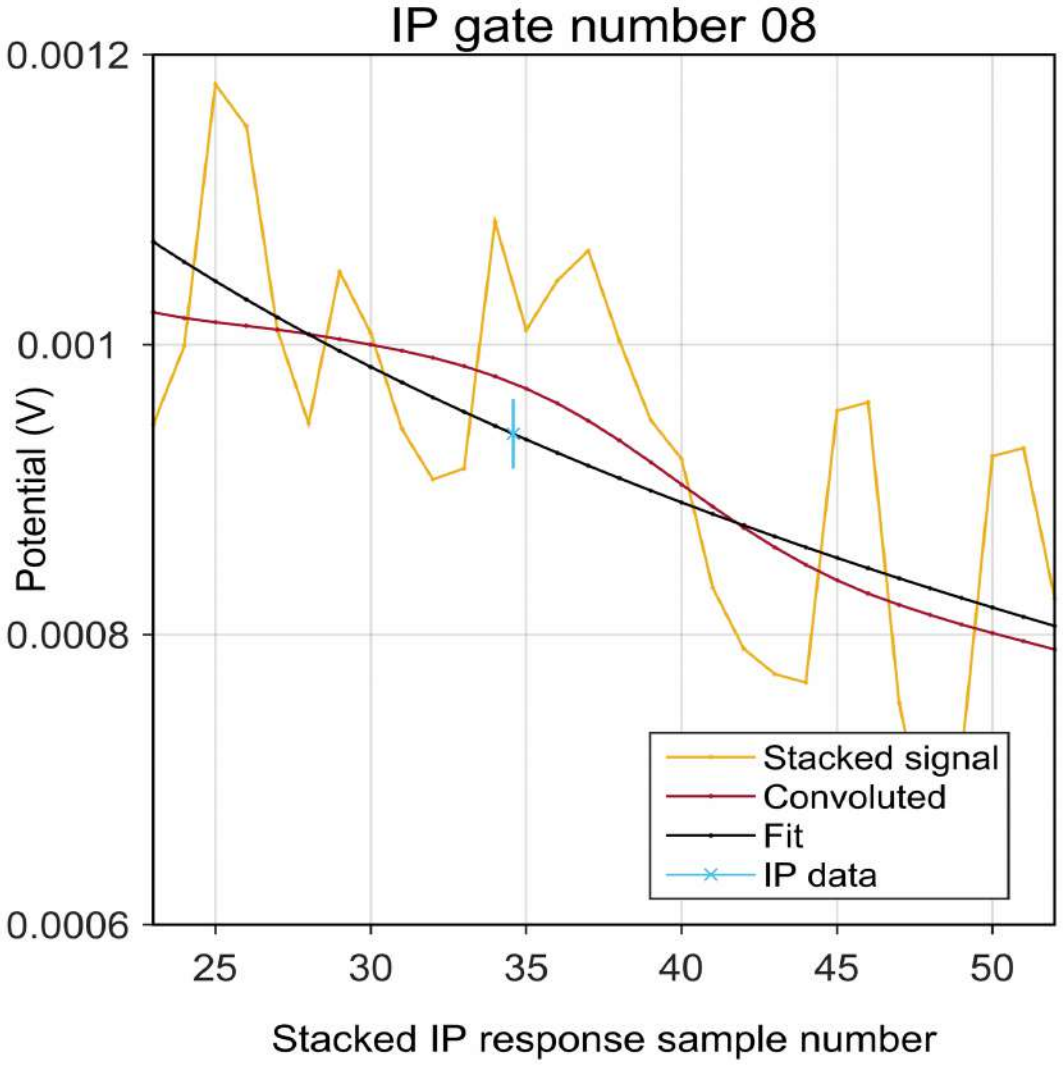
Tapered gating



Tapered gating



Uncertainty estimation



Uncertainty from a fit of the convoluted signal within the gate:

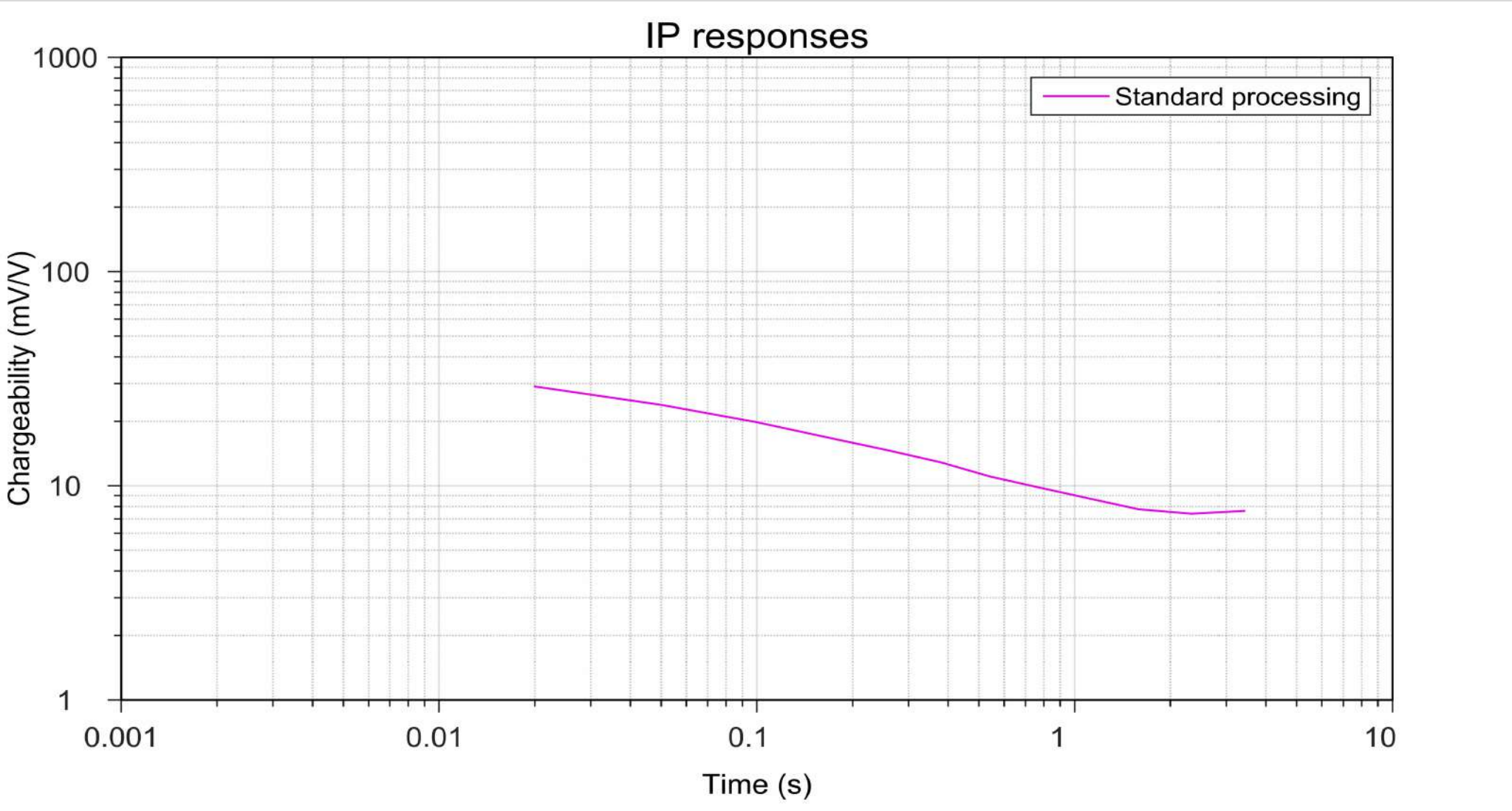
$$STD_{gating}(m) = \sqrt{\frac{1}{N_{samples}(m)} \sum_{i=1}^{N_{samples}(m)} \left(u_{IP,conv(m)}(i) - u_{IP,fit(m)}(i)\right)^2}$$

Uncertainty from the misfit of the drift model:

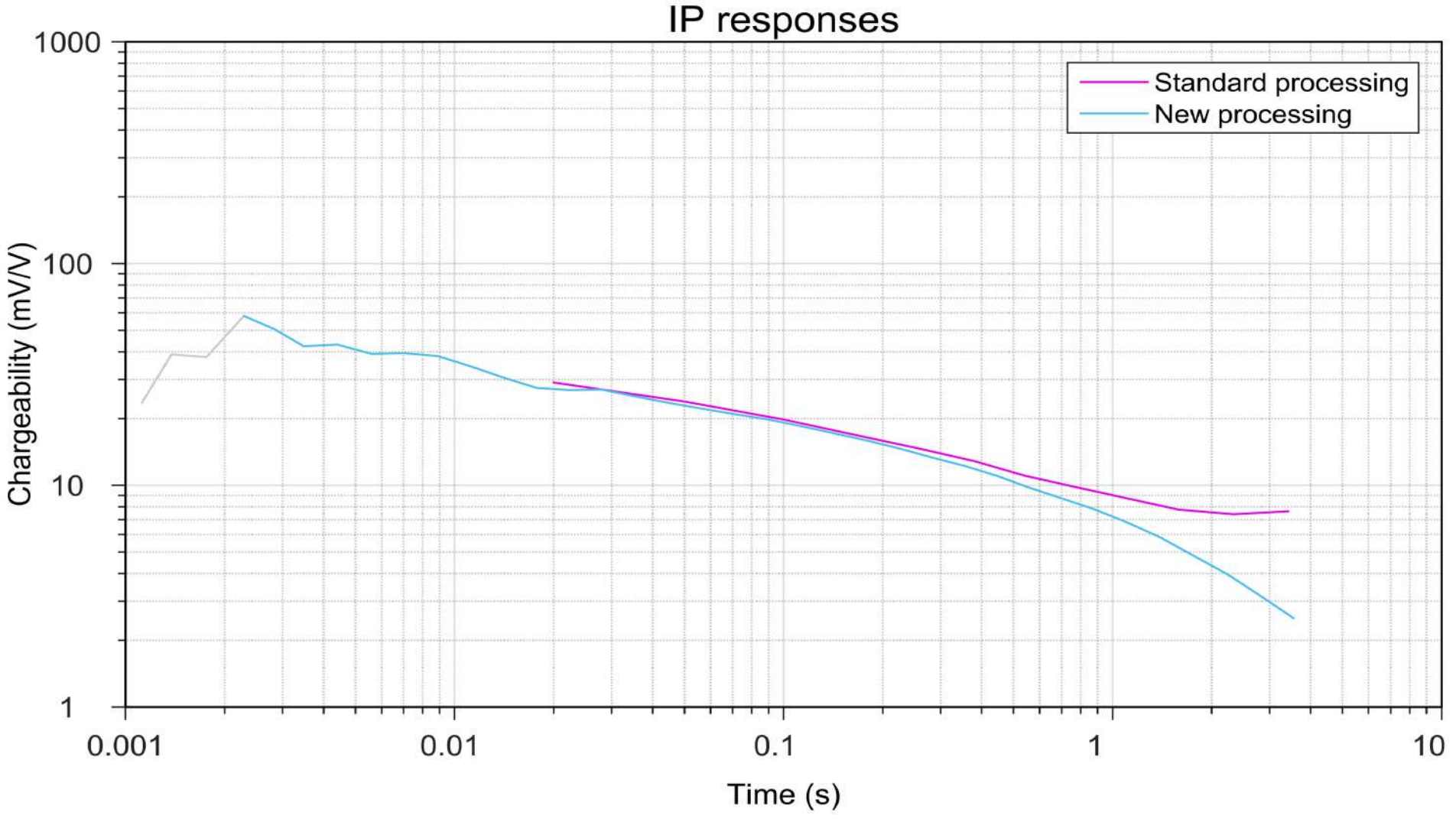
$$STD_{drift} = \sqrt{\frac{1}{N_{subset}} \sum_{i=1}^{N_{subset}} \left(u_{subset}(i) - u_{drift}(n_{drift}(i))\right)^2}$$

Plus uniform uncertainty (e.g. 5%)

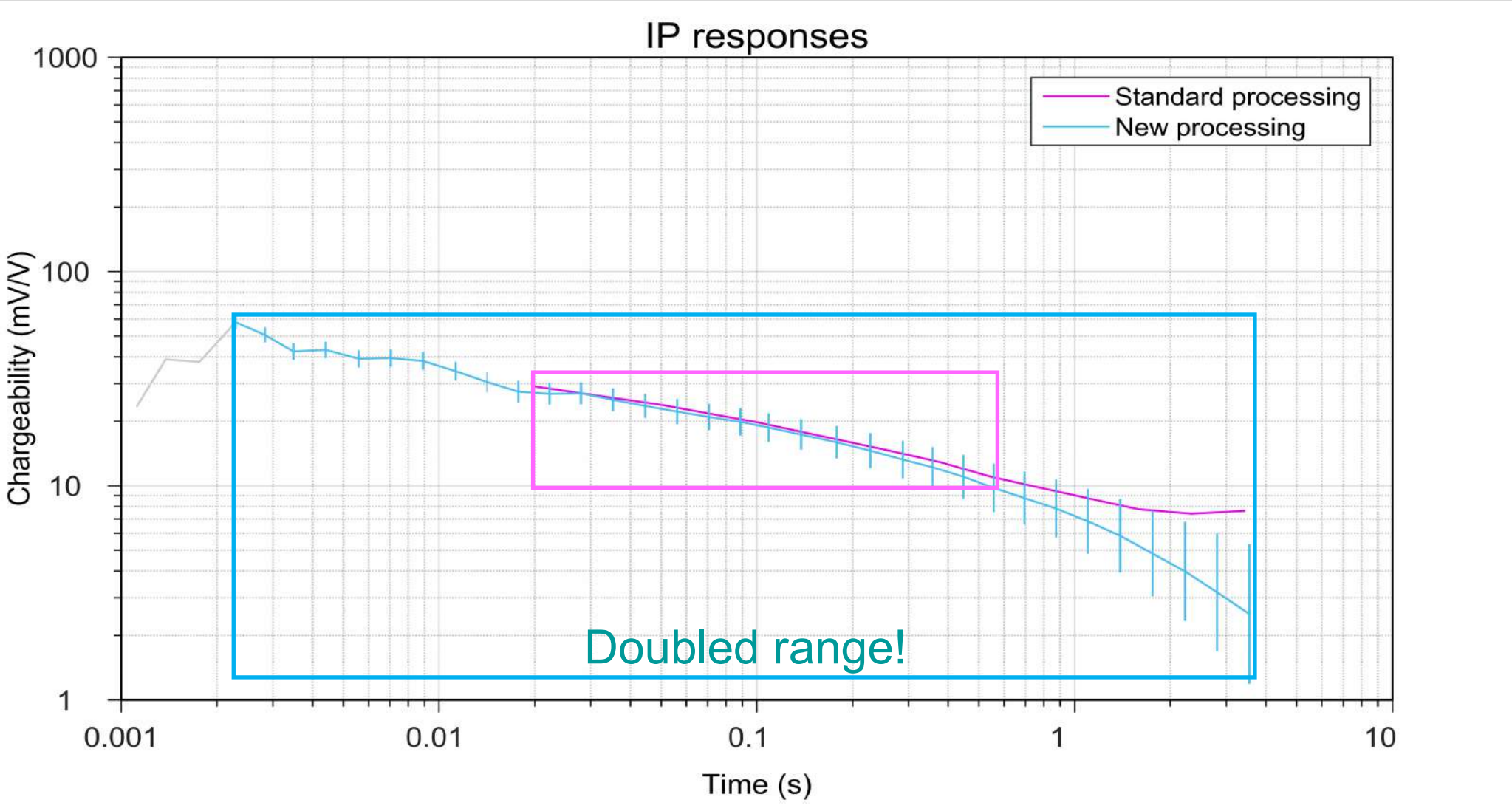
Uncertainty estimation



Uncertainty estimation



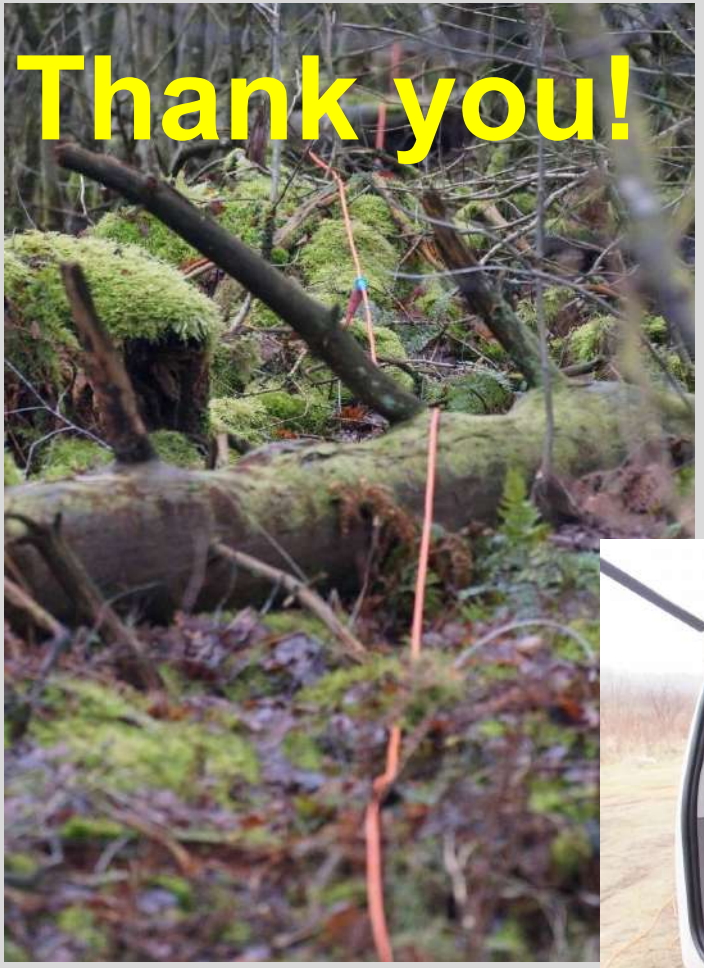
Uncertainty estimation



Conclusions

- **Early times through harmonic de-noising and de-spiking, down to 2/3 milliseconds**
- **Late times through polarization-based drift removal, up to tens of seconds**
- **Uncertainty estimation from the variability of the data within the gates and the misfit of the drift removal**
- **All together, doubled spectrum of TDIP surveying**

Thank you!



HydroGeophysics Group
AARHUS UNIVERSITY