BioLogic

Getting Started with EC-Lab®:

Electrochemical Impedance Spectroscopy

Getting Started EC-Lab: EIS

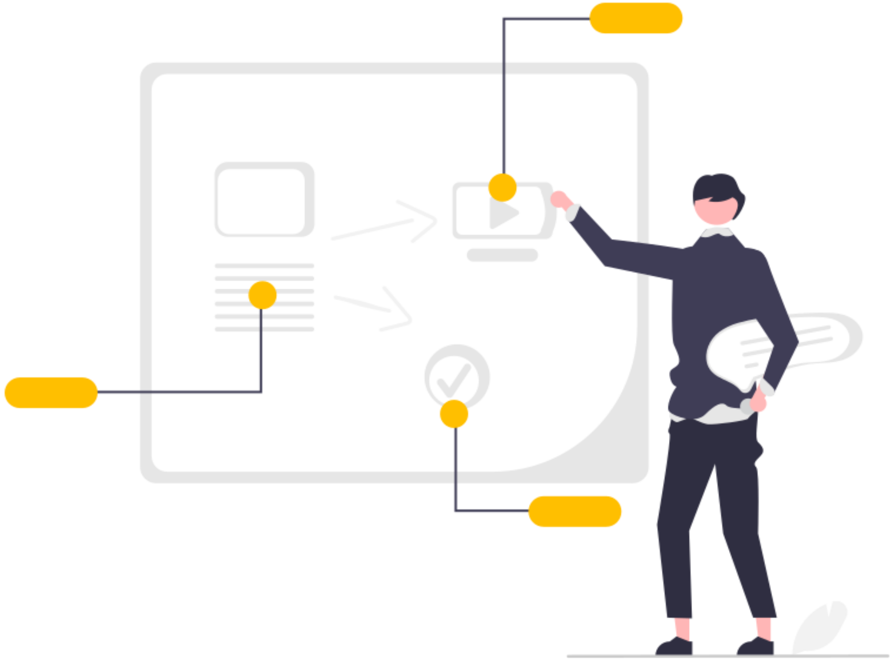
V1

March 2024

Overview and quick access

- Procedure
  - Launch the experiment
    - Step 0: Connect instrument and select channel
    - Step 1: Add EIS technique
    - Step 2: Set EIS parameters
    - Step 3: Optimize the measurement
    - Step 4: Set general parameters
    - Step 5: Launch the measurement
    - Step 6: Add additional experiments
  - Investigate the result
    - Step 7: Read the graph
    - Step 8: Analyse the data with Z Fit
- Find out more
  - For supplementary information
  - Need help?
  - FAQ

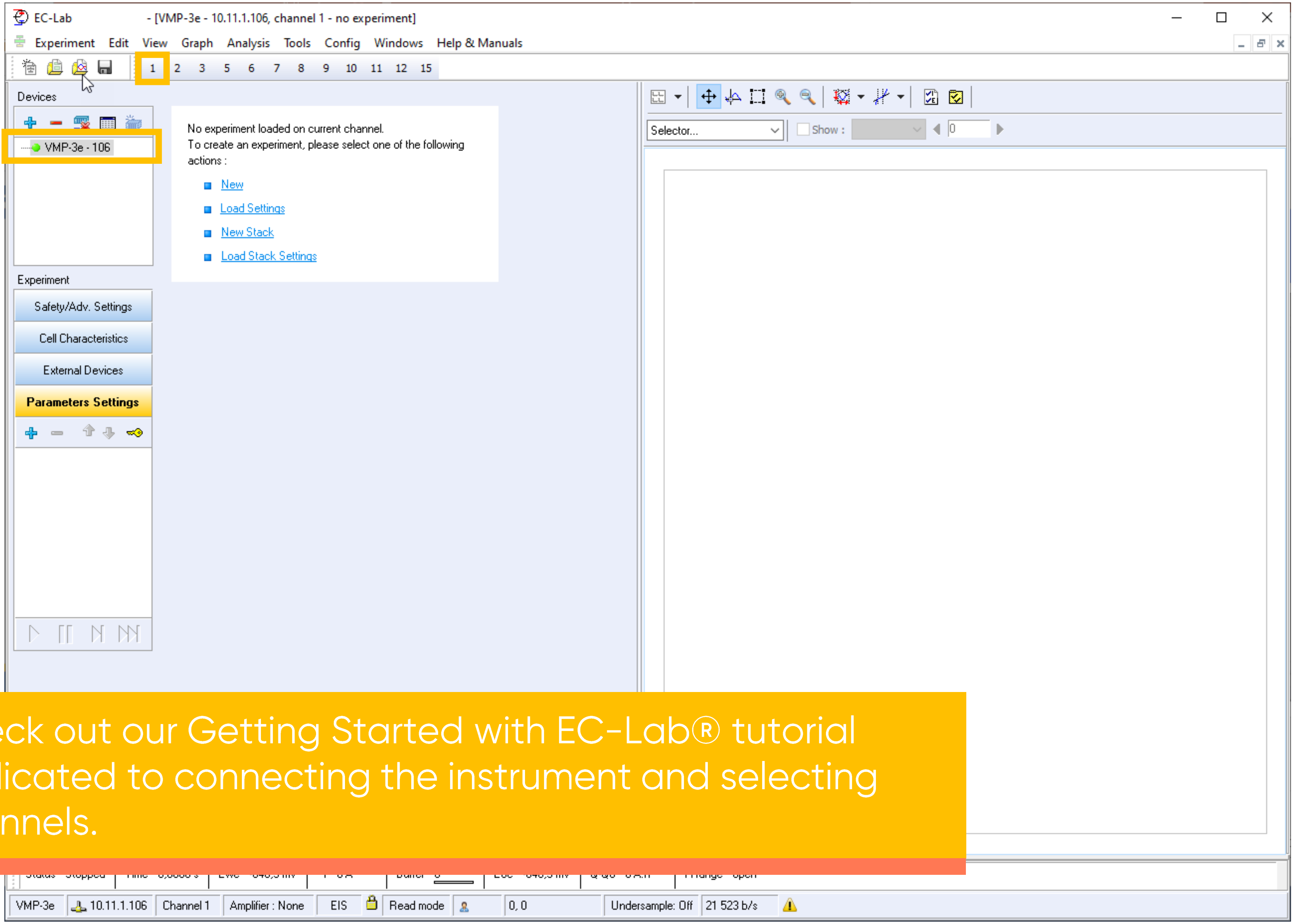
Note: Go back to this slide by clicking on the logo on the top left corner



Procedure

Step 0: Connect instrument and select channel

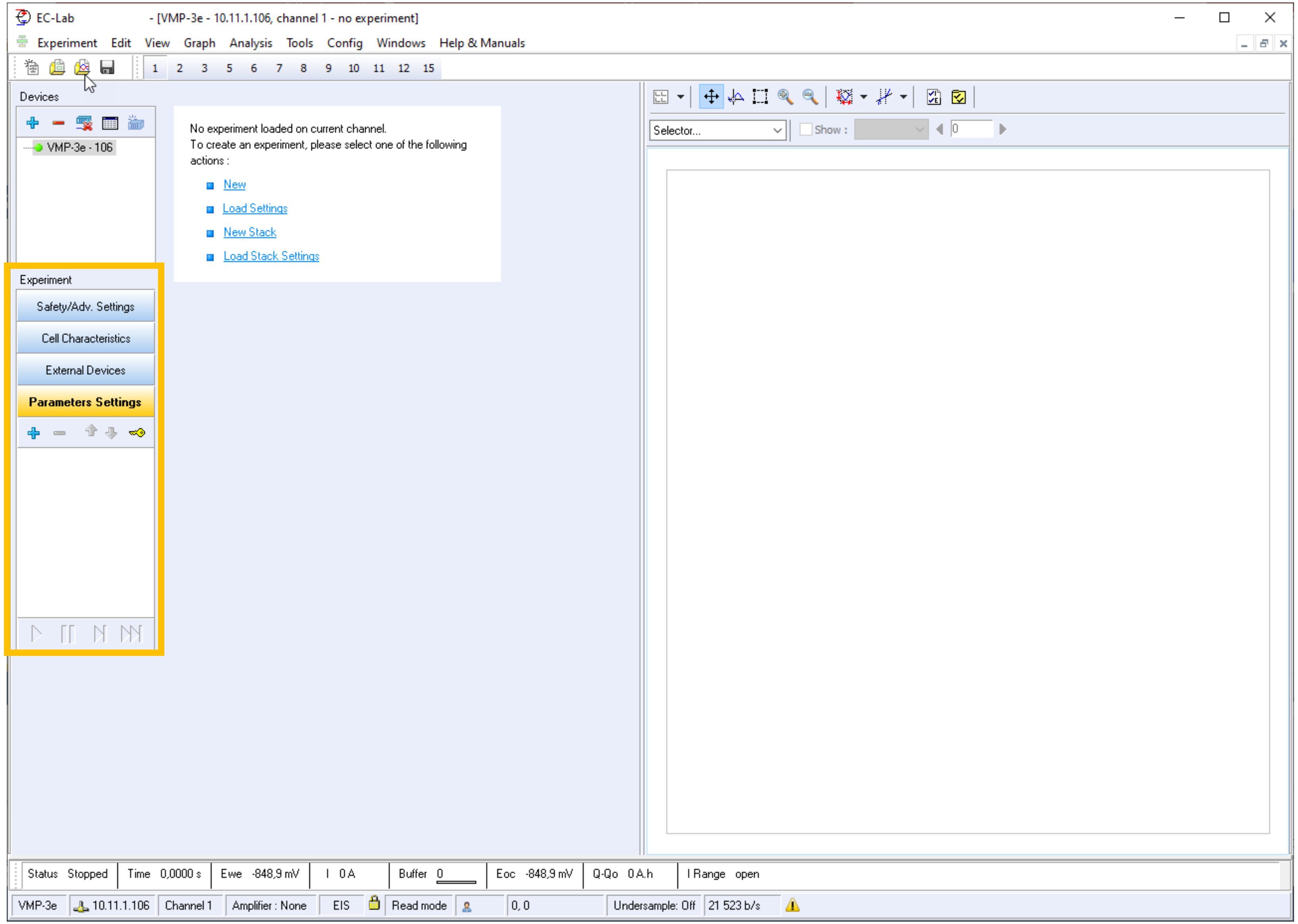
- Connect instrument and select channel



Check out our Getting Started with EC-Lab® tutorial dedicated to connecting the instrument and selecting channels.

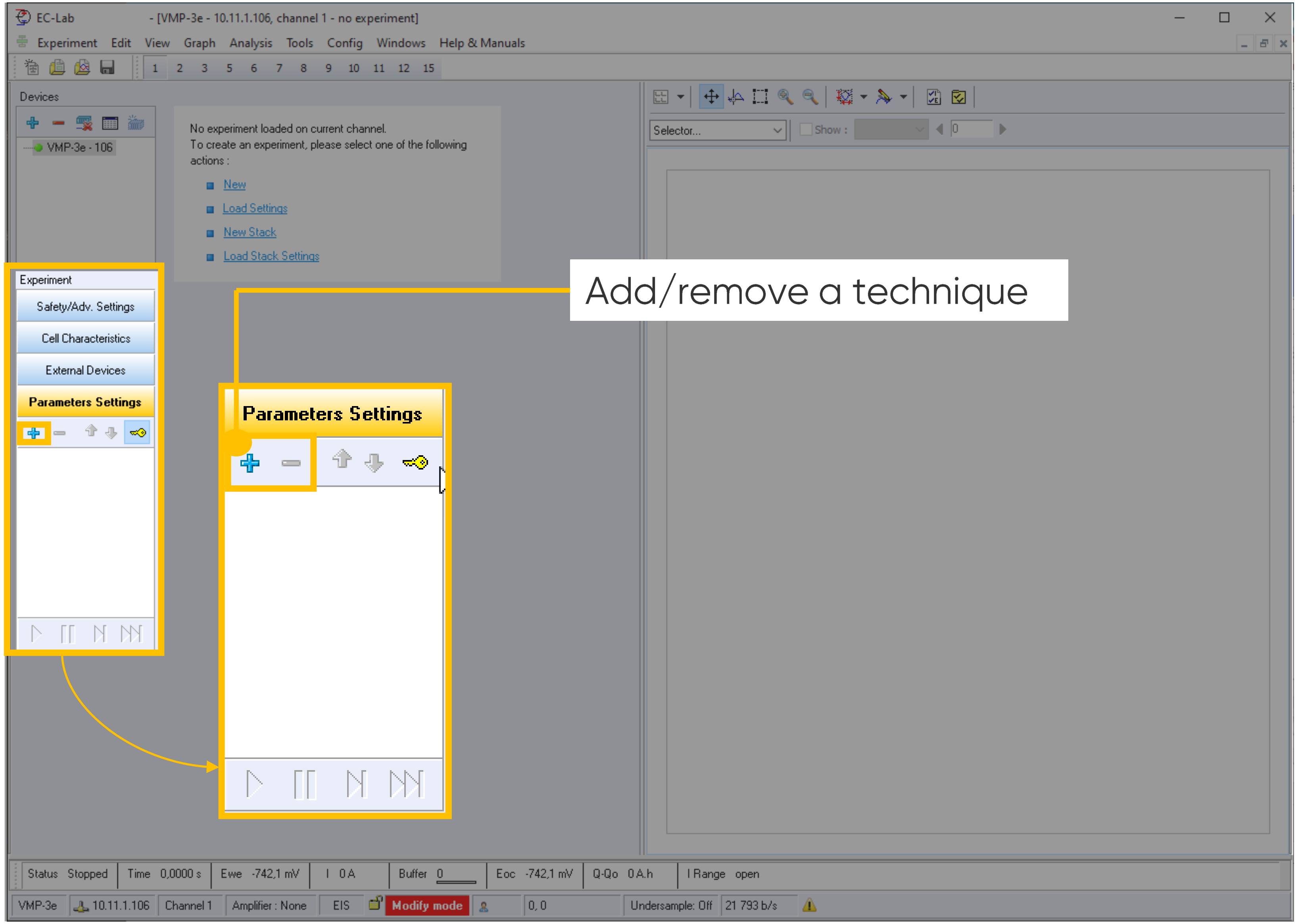
Step 0: Connect instrument and select channel

- When the instrument and channel are selected, the user can set-up the experiment



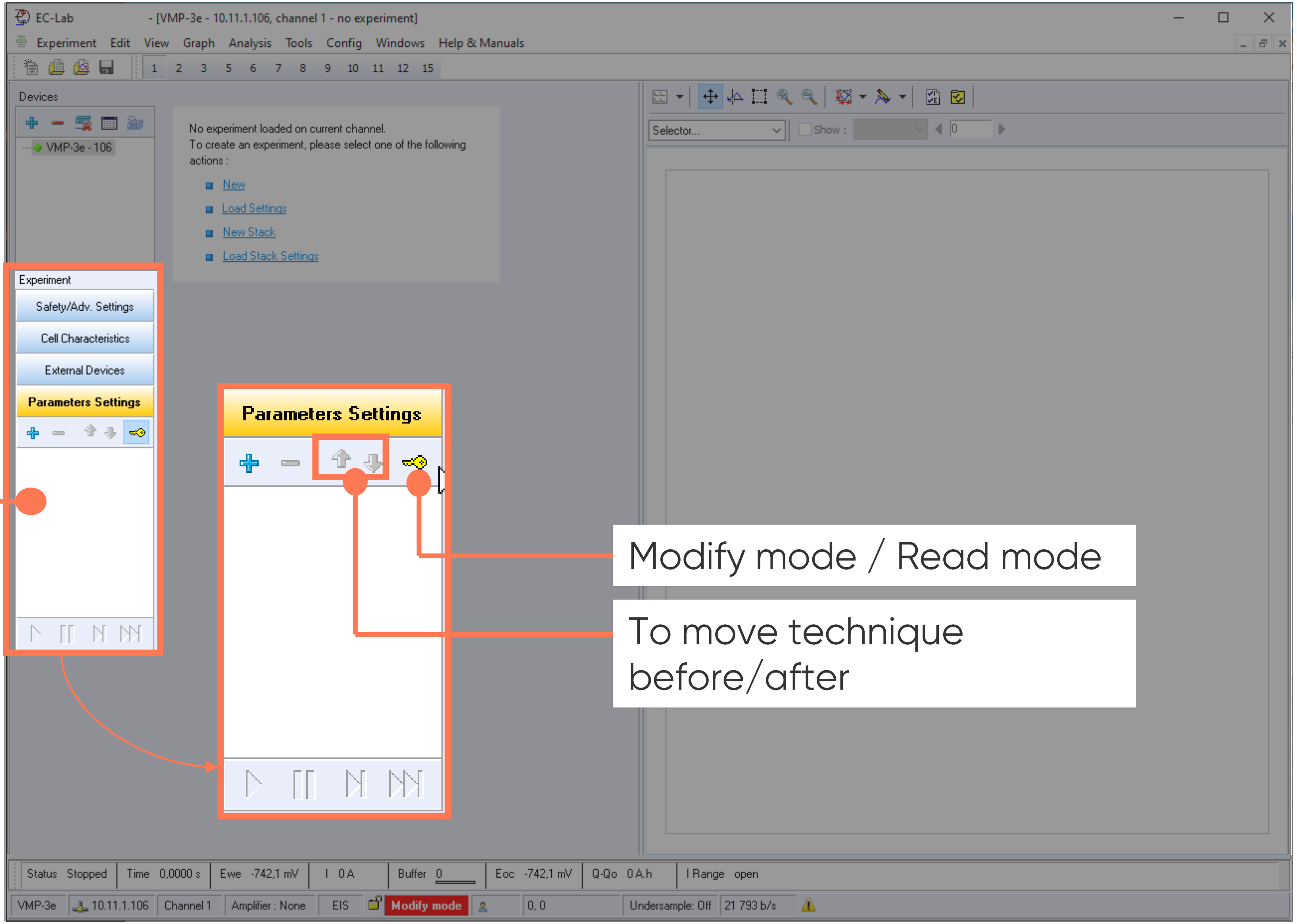
Step 1: Add EIS technique

- Click on + to add a technique in the list



Step 1: Add EIS technique

Empty window:
no loaded technique



Modify mode / Read mode

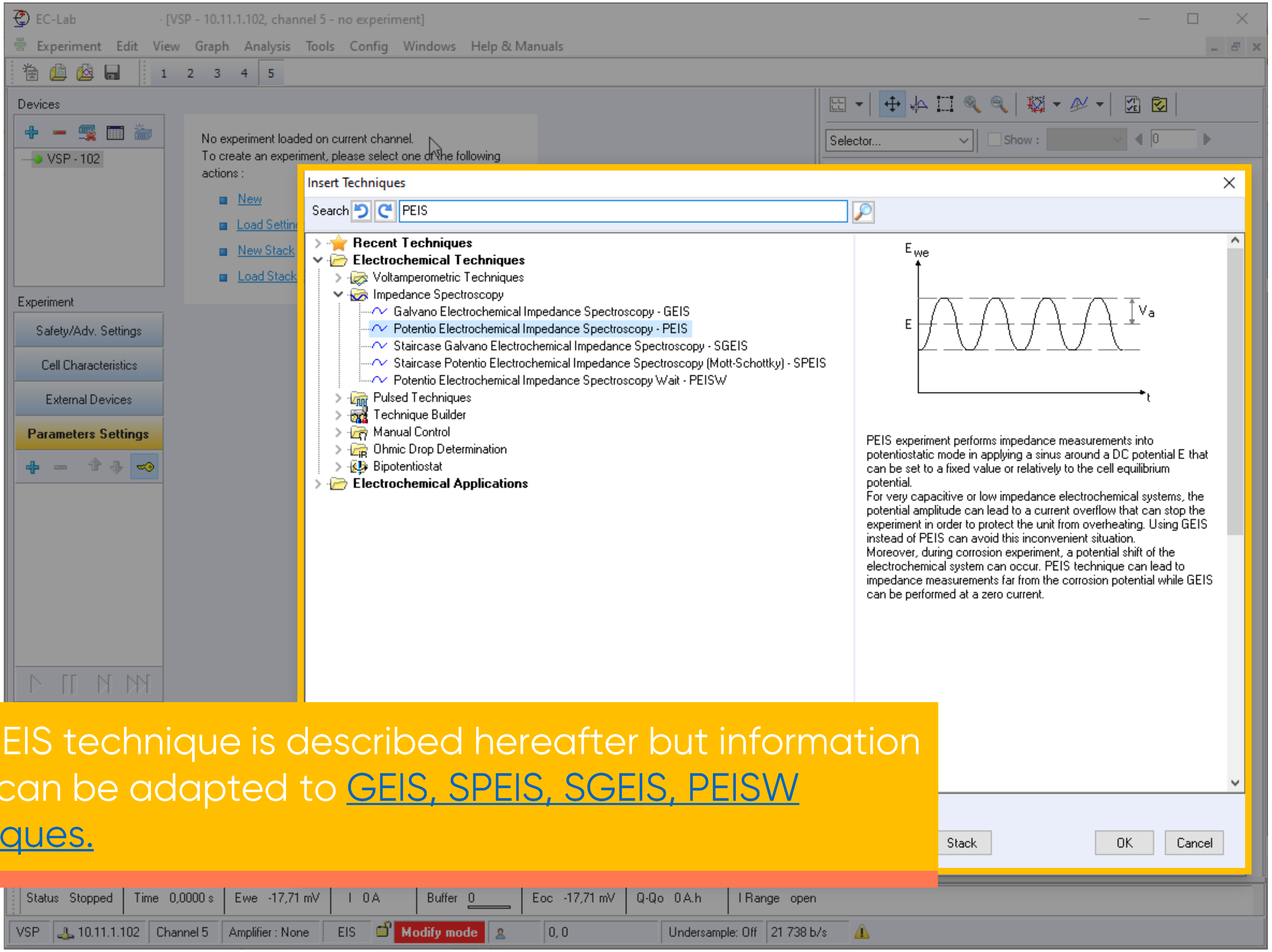
To move technique before/after

Step 1: Add EIS technique

- Select PEIS technique

  It is in the Impedance Spectroscopy folder

- Click on OK to validate

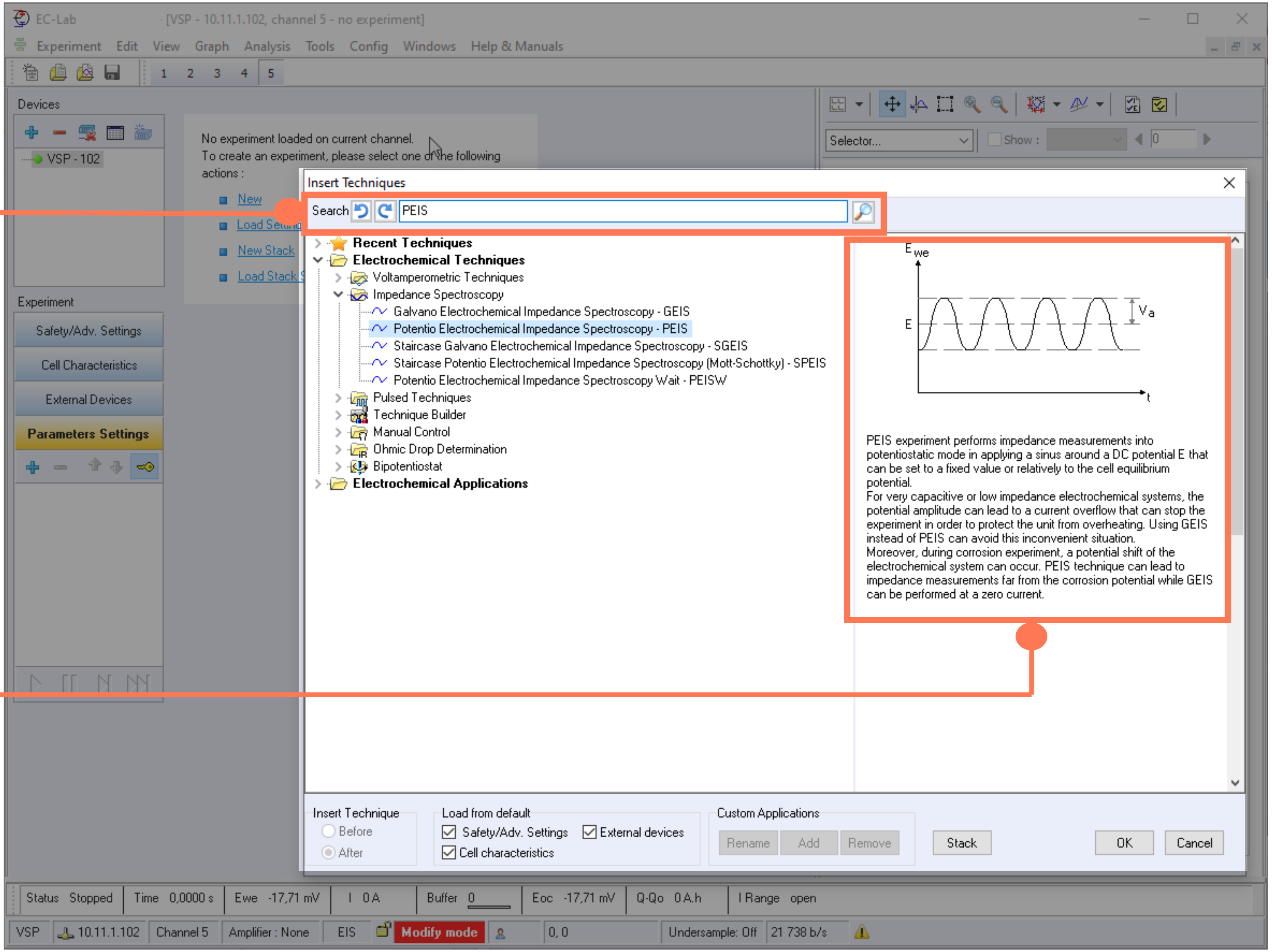


Only PEIS technique is described hereafter but information given can be adapted to GEIS, SPEIS, SGEIS, PEISW techniques.

Step 1: Add EIS technique

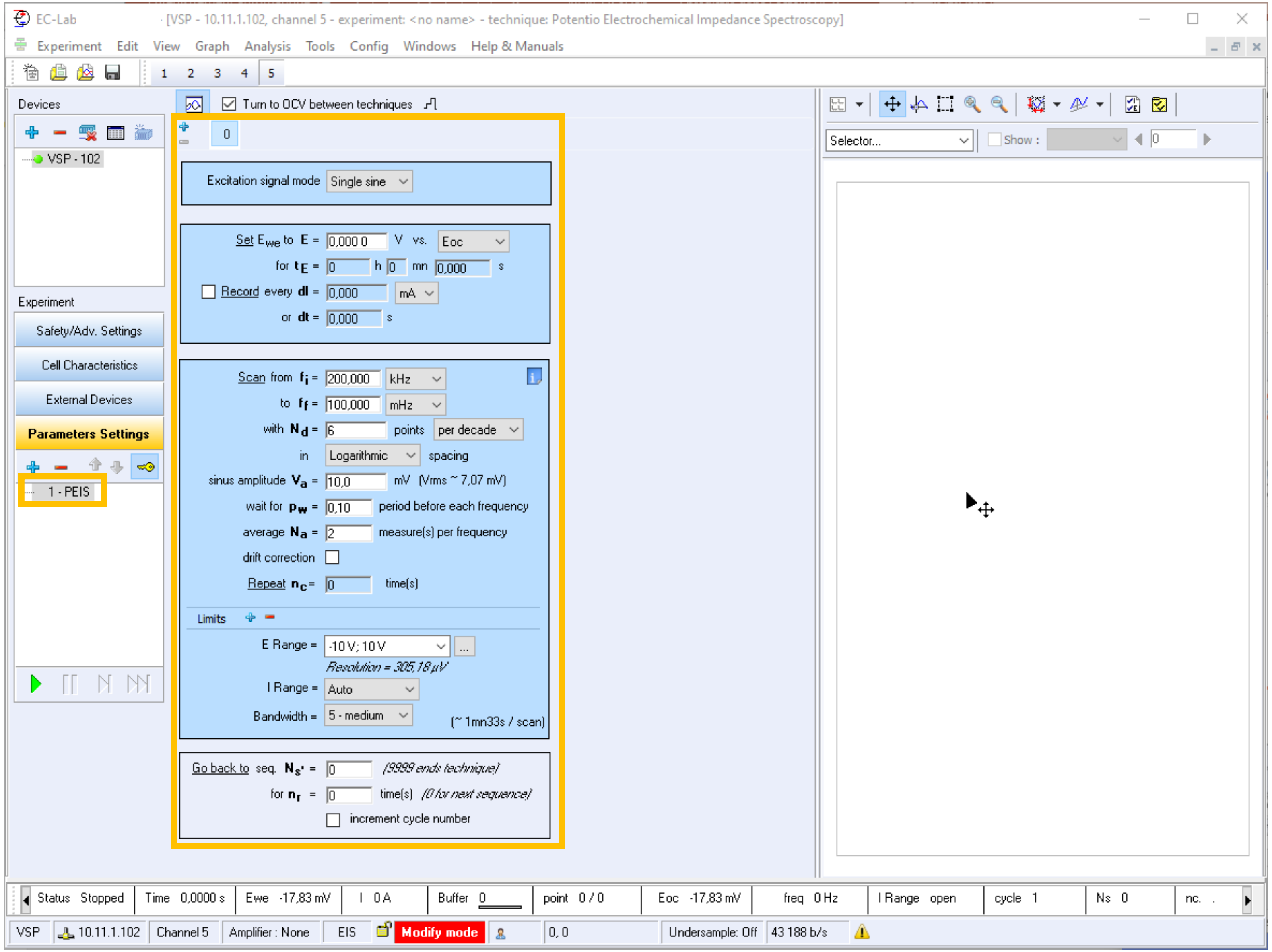
Search bar to quickly find the desired technique

Description of the settings technique and associated graph



Step 1: Add EIS technique

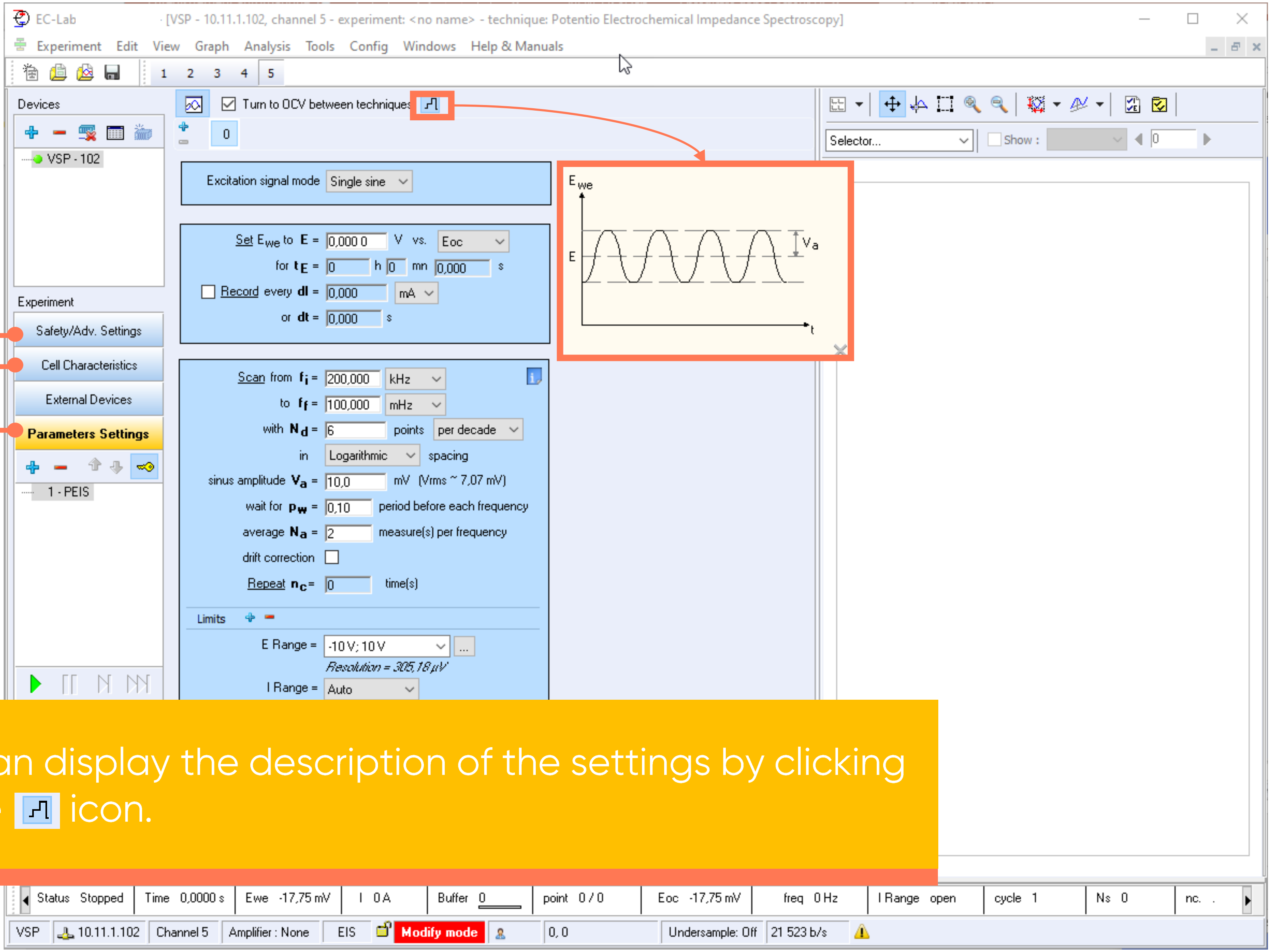
- PEIS technique is loaded in the technique list
- Corresponding PEIS parameters settings appear



Step 1: Add EIS technique

General parameters

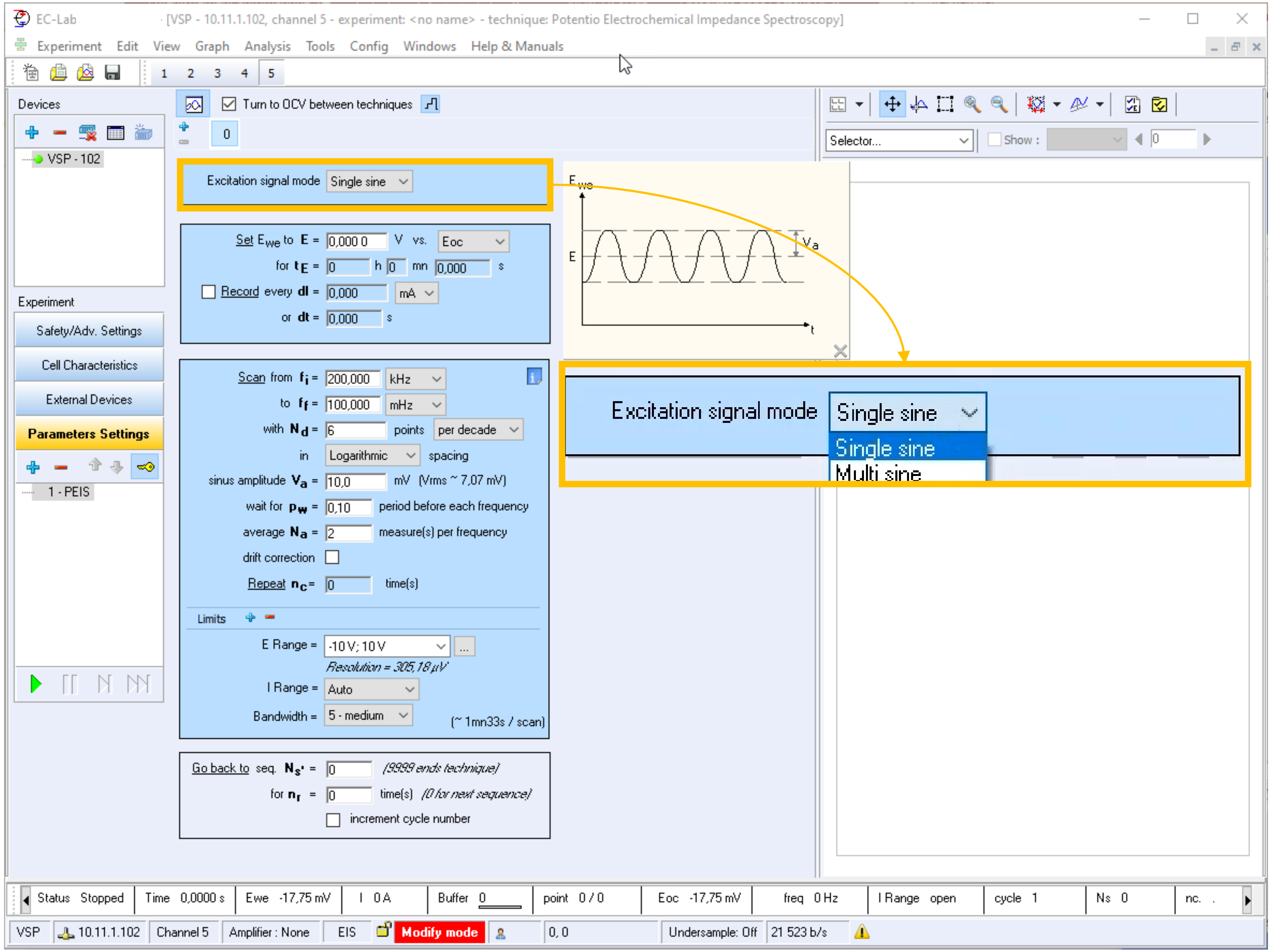
Technique parameters



You can display the description of the settings by clicking on the icon.

Step 2: Set EIS parameters

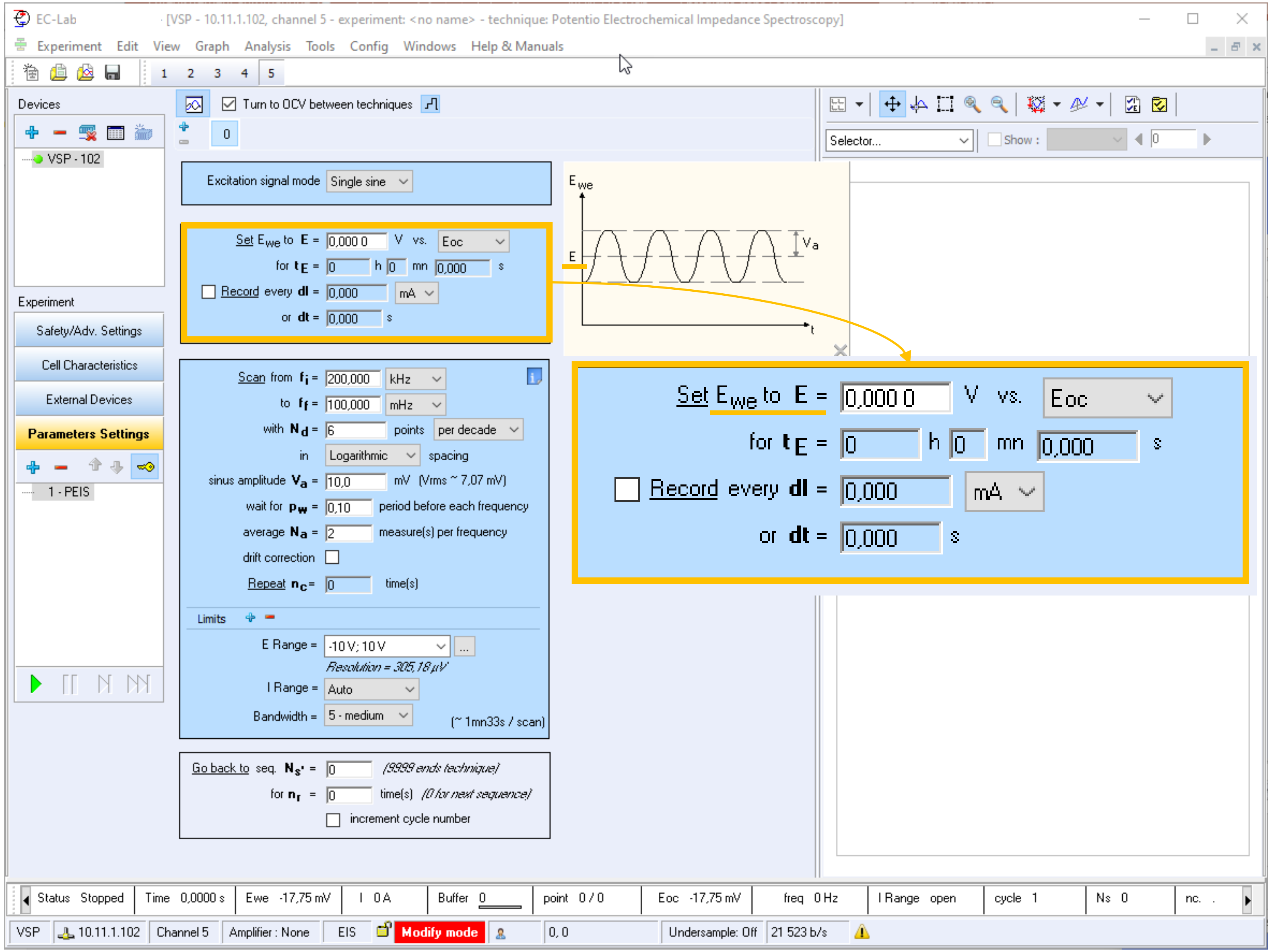
- Select Single sine



Note: Multisine can be performed (it is the sum of sinus)

Step 2: Set EIS parameters

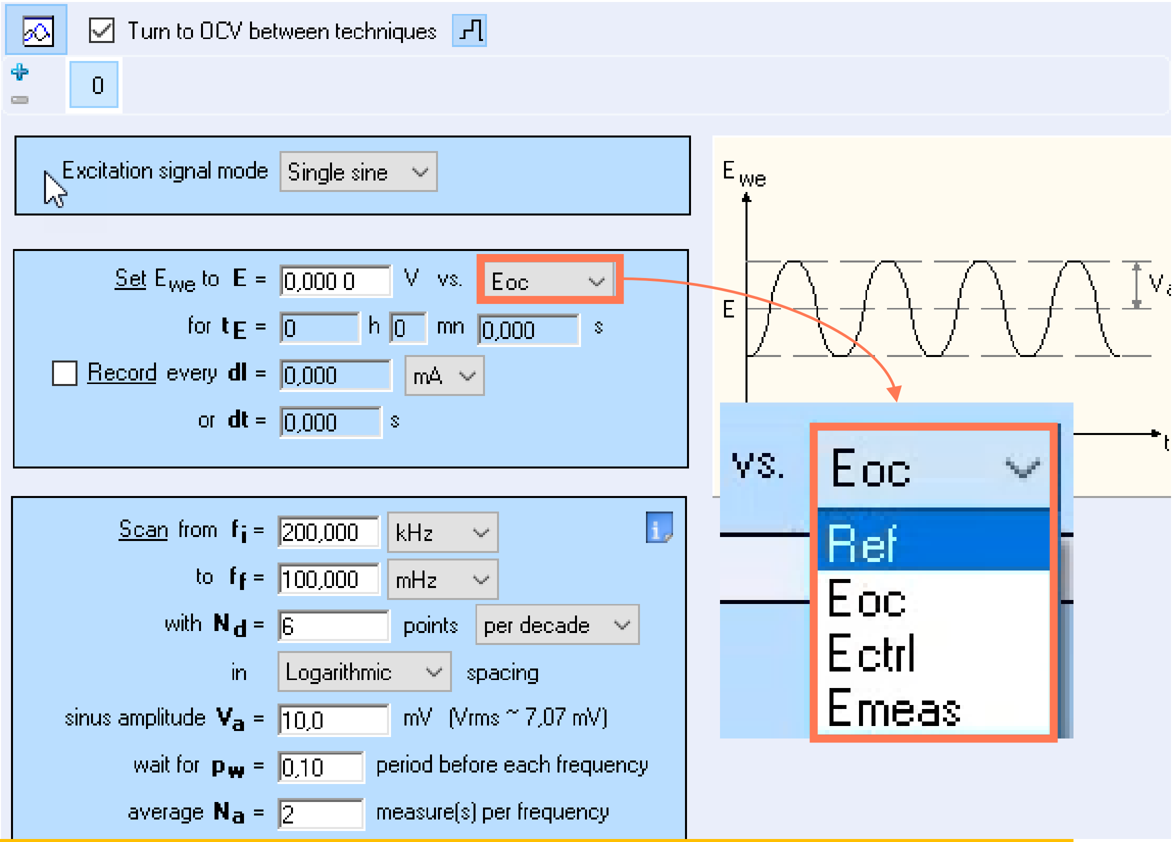
- Set E_{we} to E to define the bias voltage level
- E can be held during a time t_E before starting



Step 2: Set EIS parameters

Define E versus voltage of:

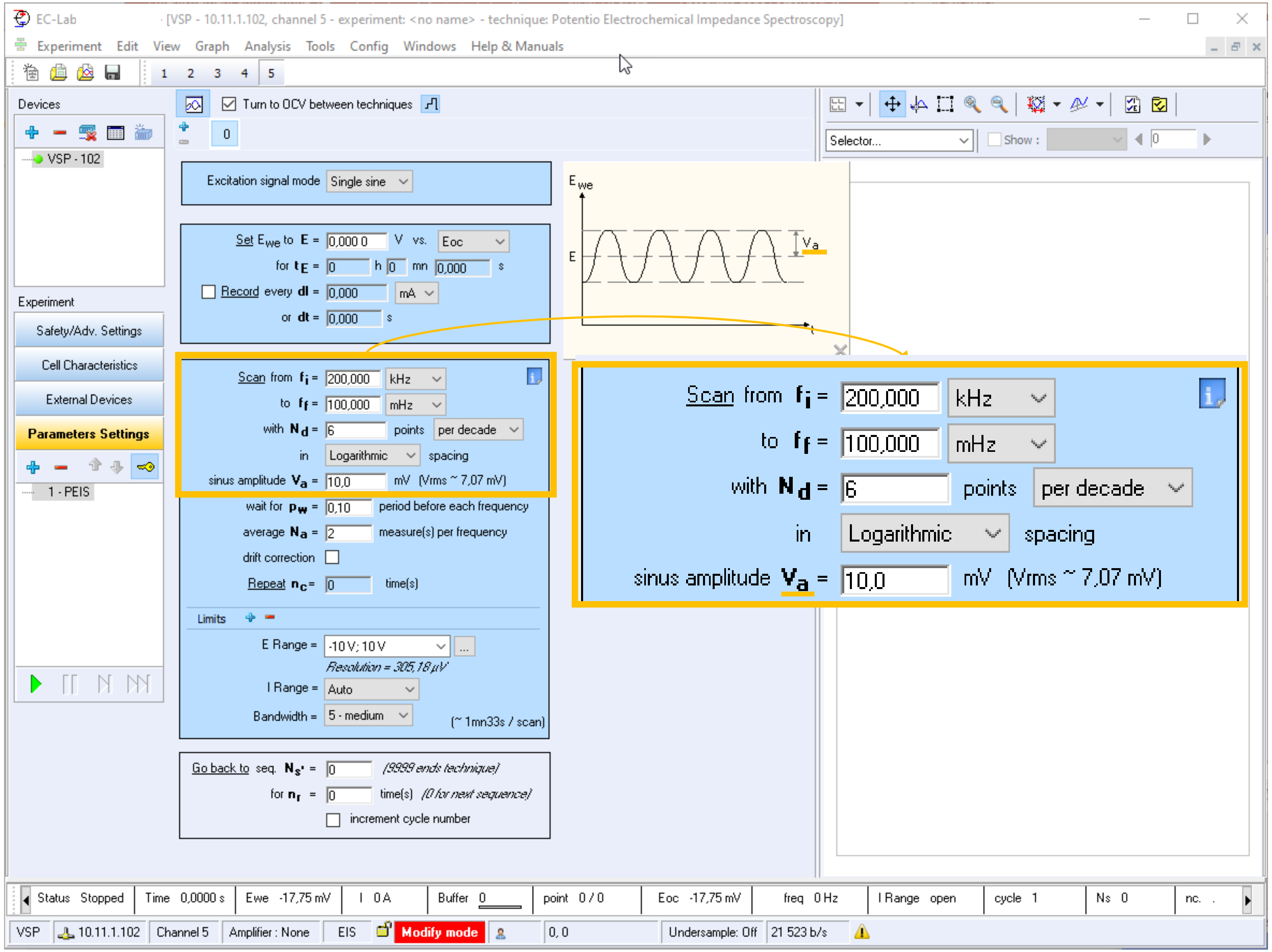
- **Ref:** the reference electrode
- **Eoc:** open circuit voltage
- **Ectrl:** the previous controlled voltage, if a technique is set before the PEIS
- **Emeas:** the previous measured voltage, if a technique is set before the PEIS



Be aware that Eoc is a relative voltage value as OCV may change. E_{Ref} is an absolute voltage value.

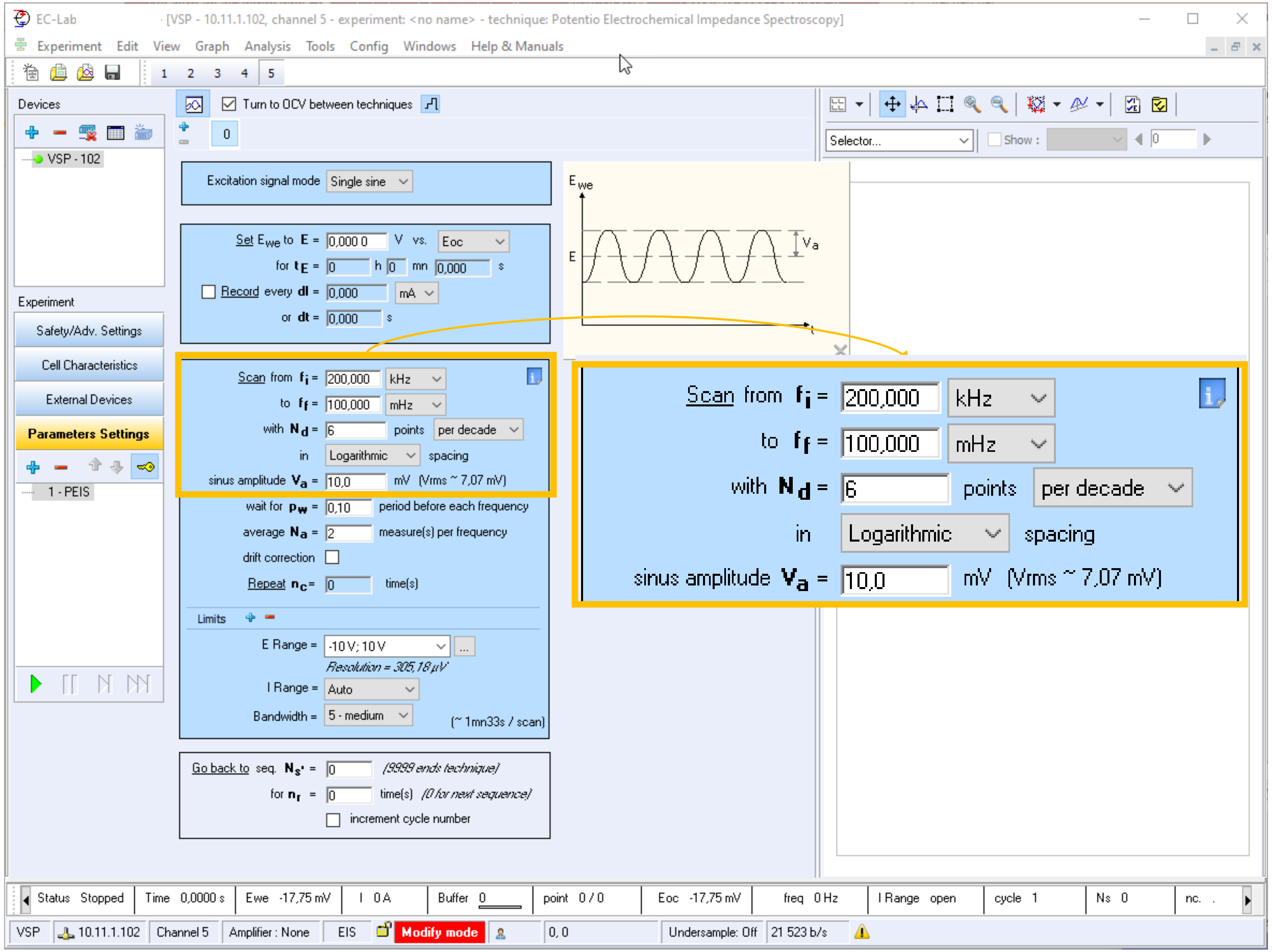
Step 2: Set EIS parameters

- Set f_i and f_f to define the frequencies range
- Set V_a to define amplitude of perturbation



Step 2: Set EIS parameters

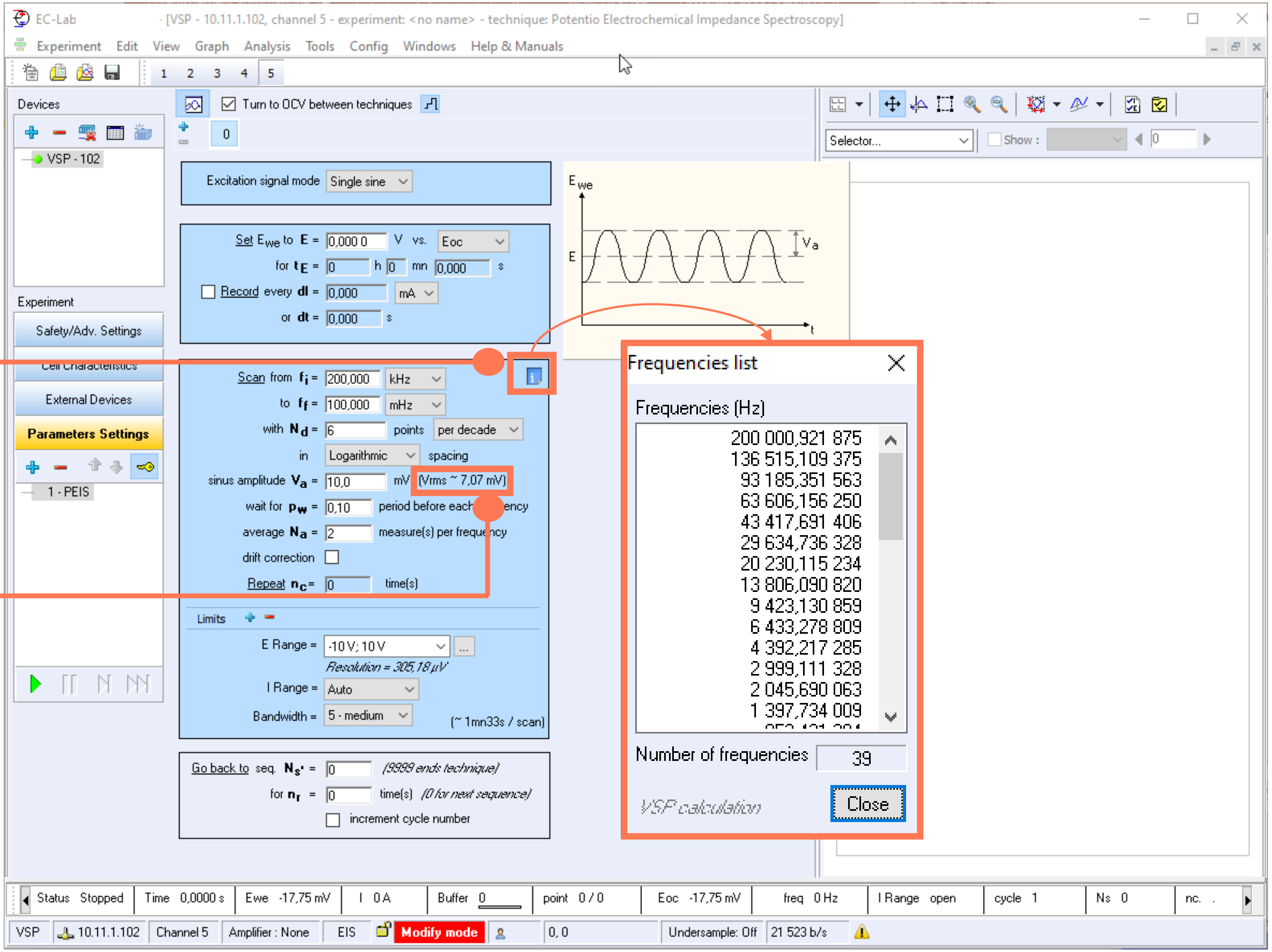
- Define data point sampling
  - Points per decade N_d
  - in log or linear spacing



Step 2: Set EIS parameters

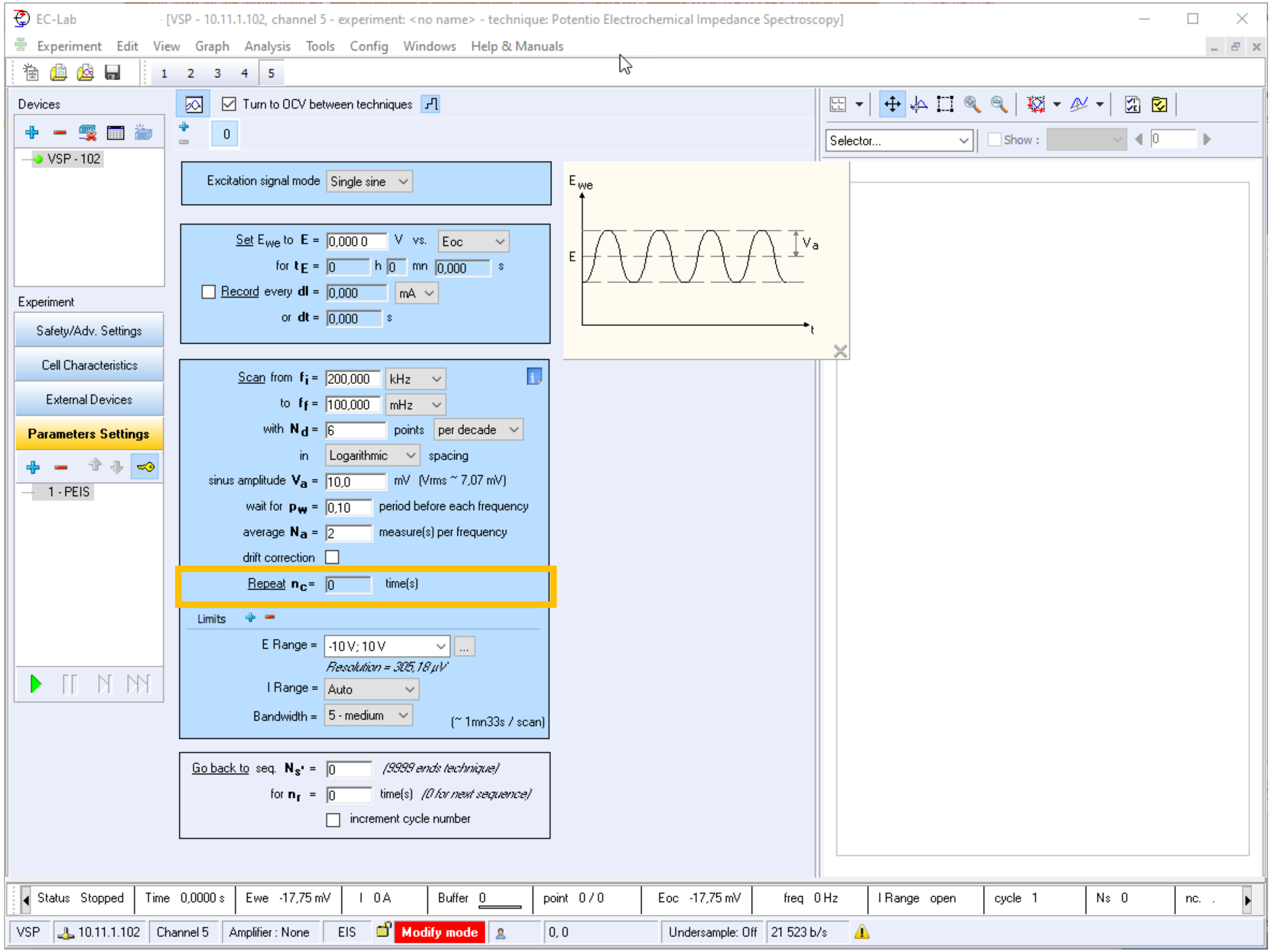
Frequencies list at which the EIS are performed

The corresponding RMS value is indicated



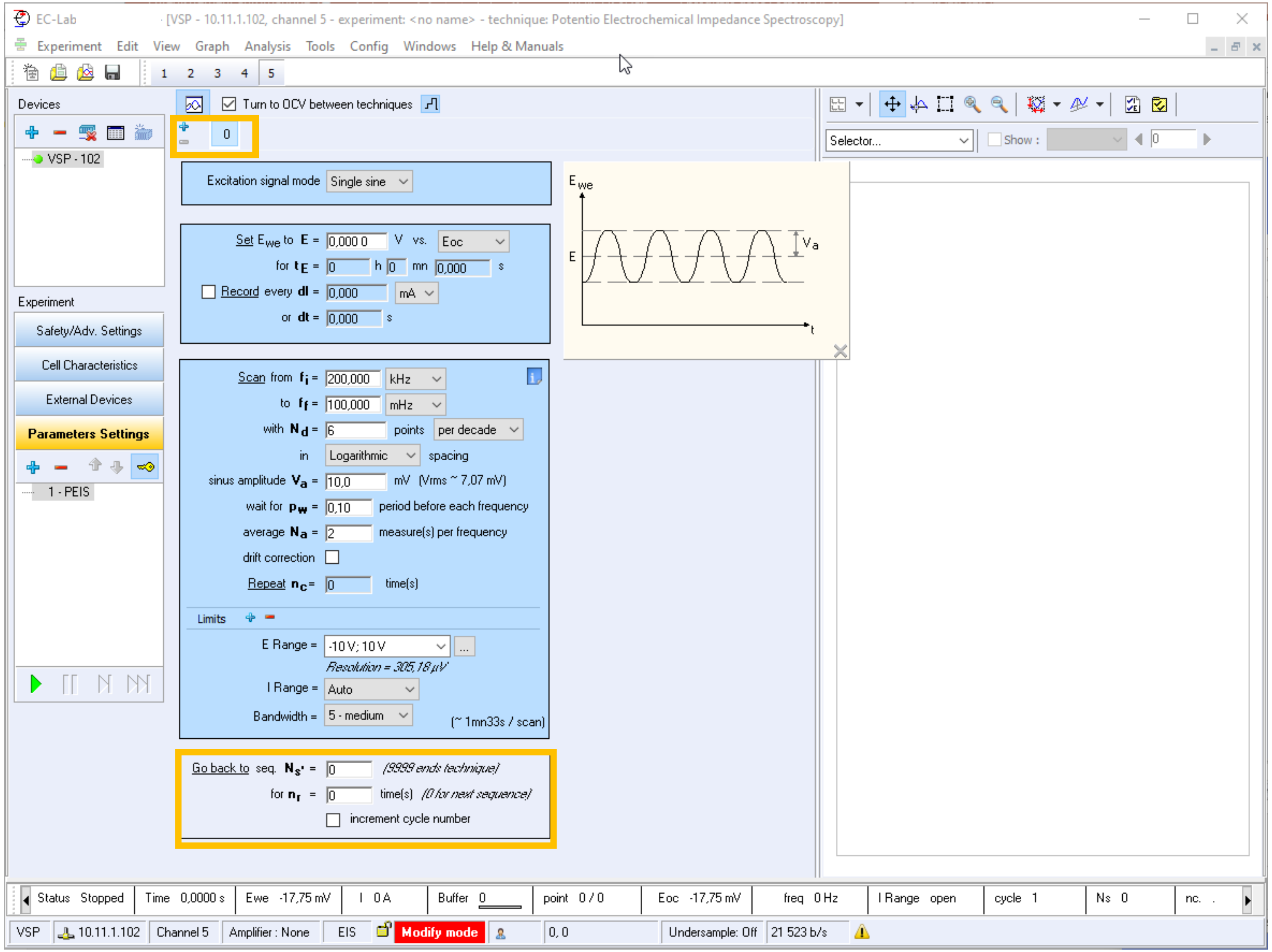
Step 2: Set EIS parameters

- Set n_c to repeat the sweep of frequencies



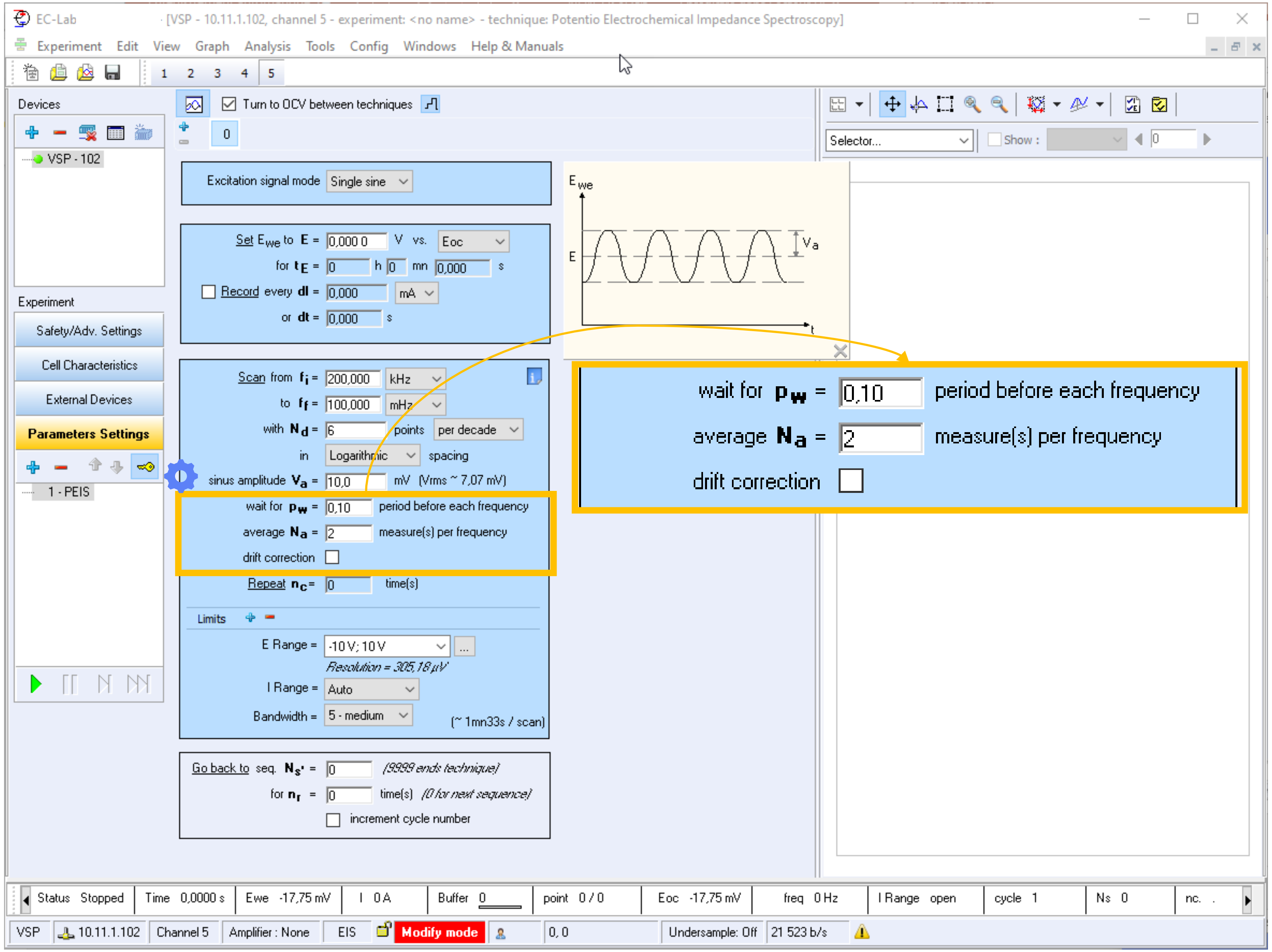
Step 2: Set EIS parameters

- Sequences can be added
- Go back to a desired cycle or sequence



Step 3: Optimize the measurement

- A delay p_w can be added before the measurement for each frequency

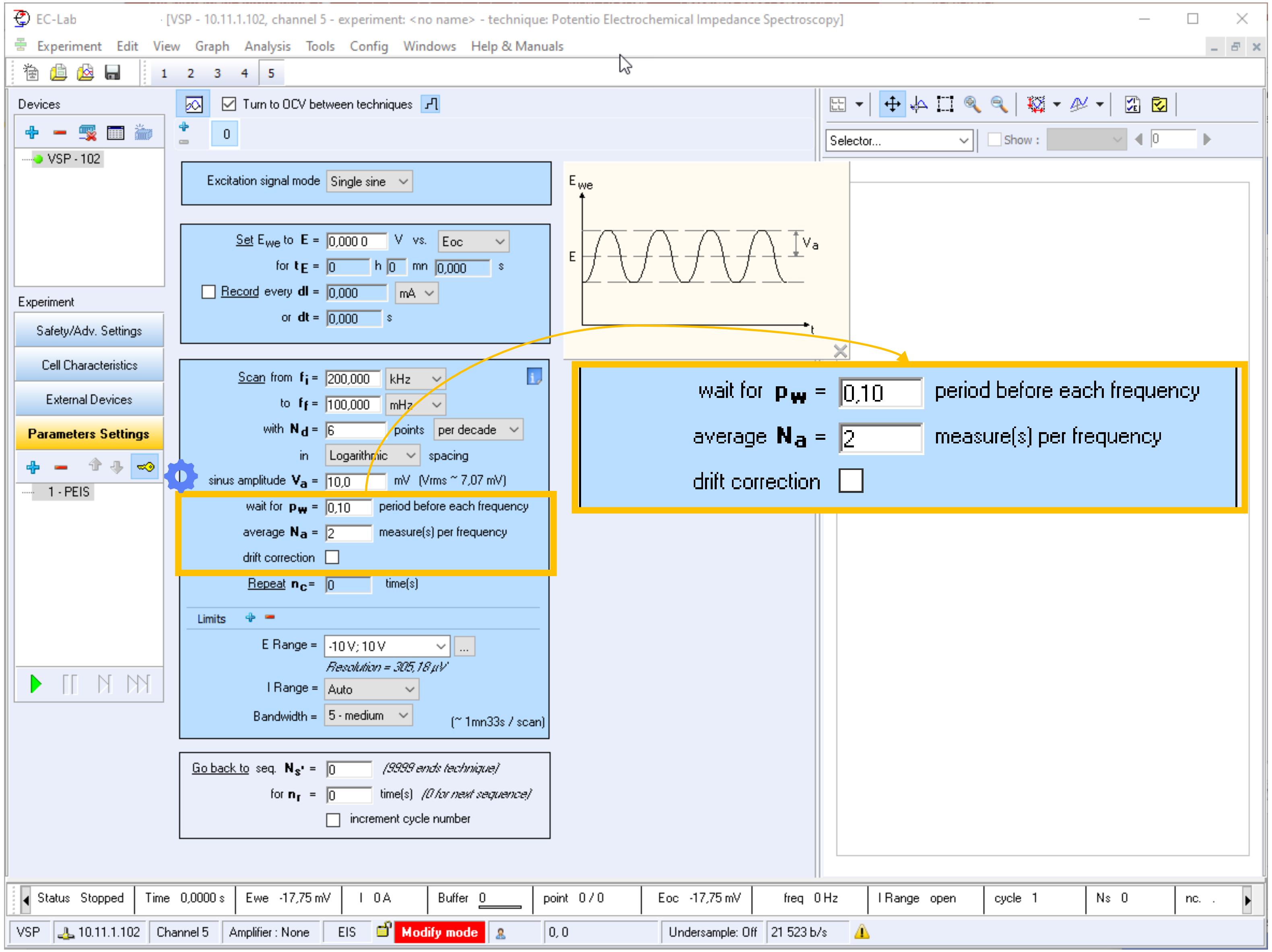


It is important to activate when there is a big gap between two frequencies. Delay is longer for low frequencies.

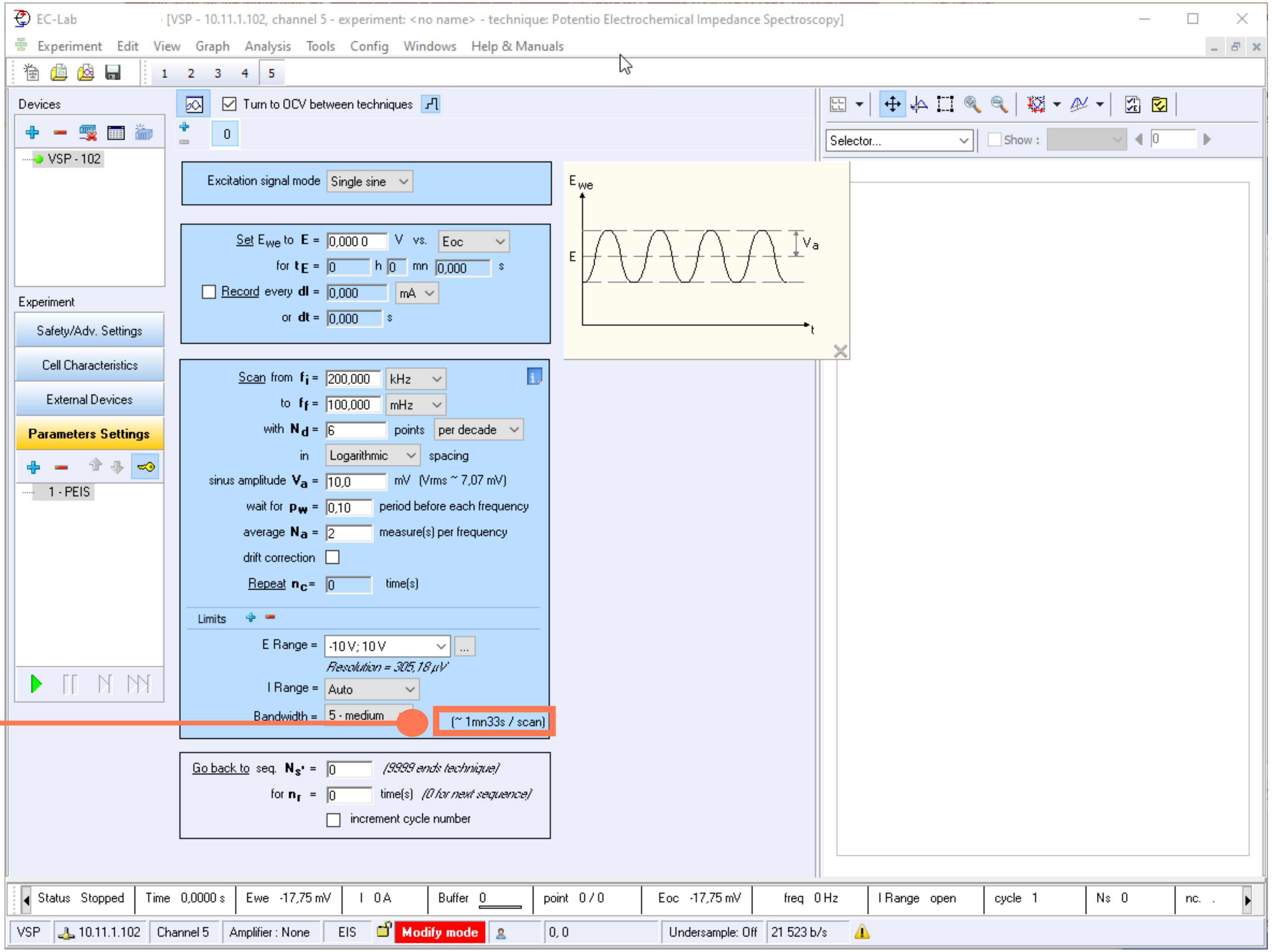
Step 3: Optimize the measurement

- Set N_a to repeat measurements at each frequency and average the values

This average process smooths the random error of the measurement, but the experiment lasts longer.



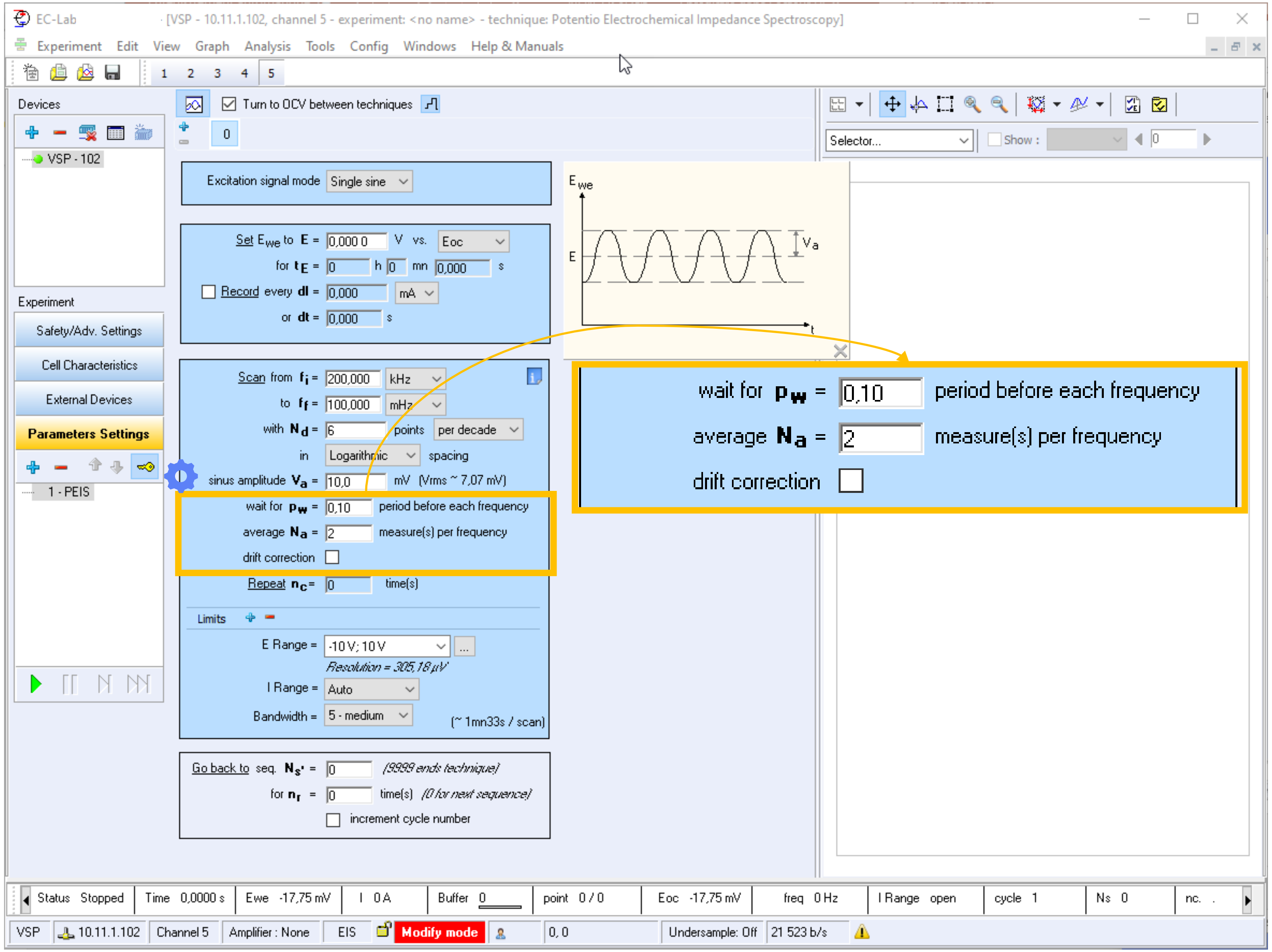
Step 3: Optimize the measurement



The duration of the experiment is indicated. It depends on frequency range, sampling and averaging N_a

Step 3: Optimize the measurement

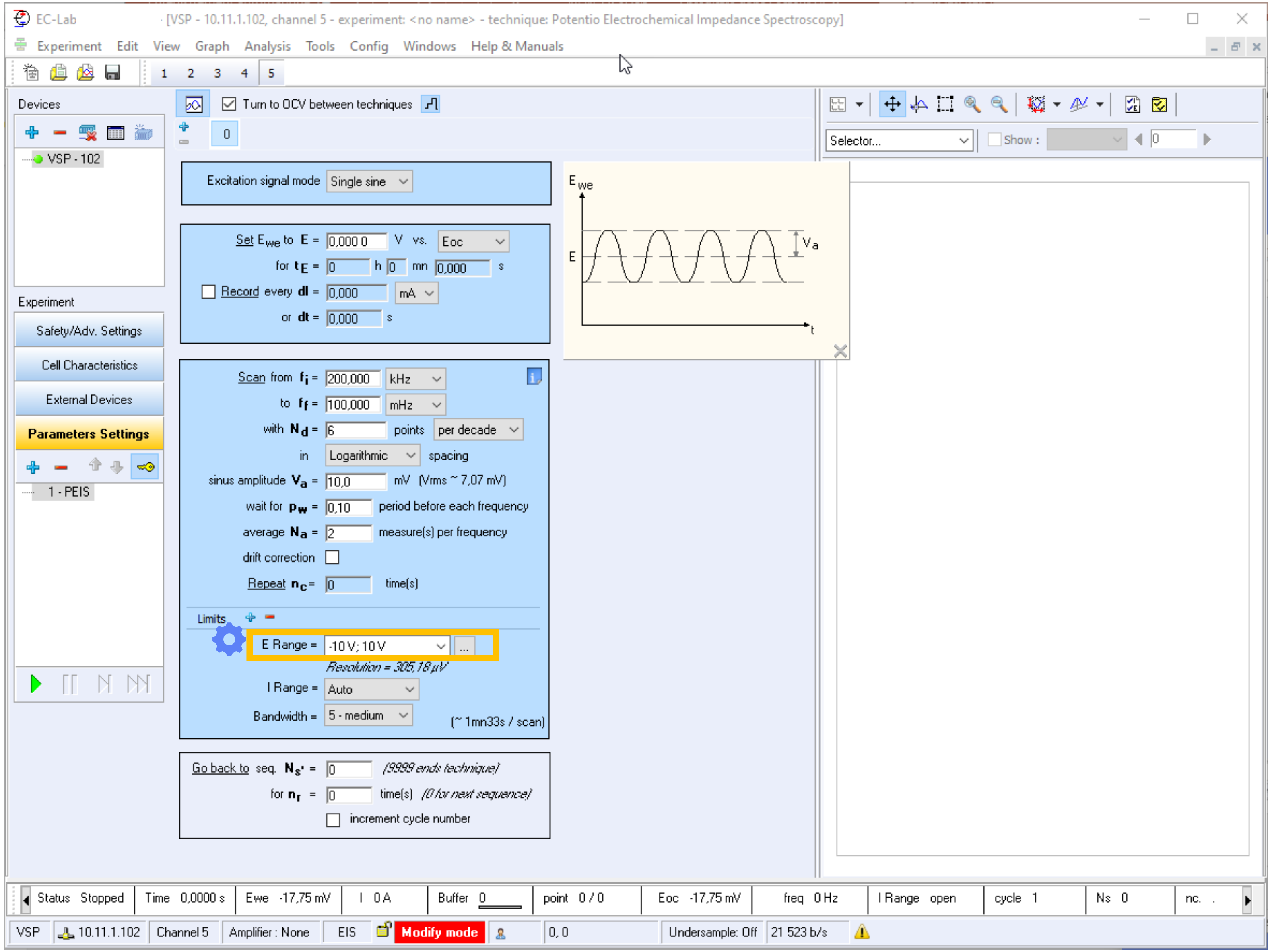
- Drift correction corrects non stationarity



This has to be activated for measurements on slow systems which has not reached steady state conditions

Step 3: Optimize the measurement

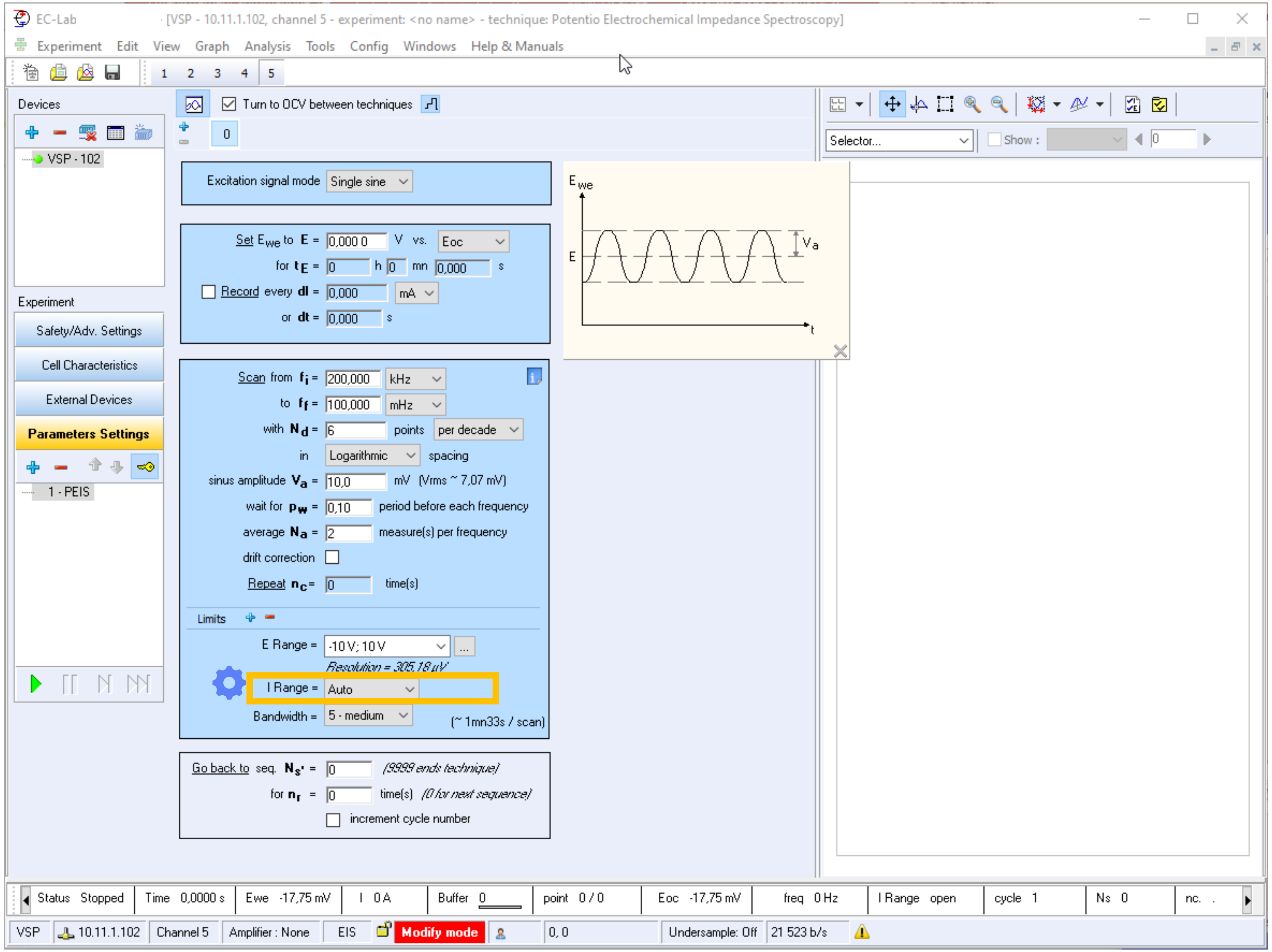
- E Range is the range of expected voltage



E Range has to be wide enough to be in the range of the operating voltage but narrow enough to get an optimized resolution in voltage measurement / control

Step 3: Optimize the measurement

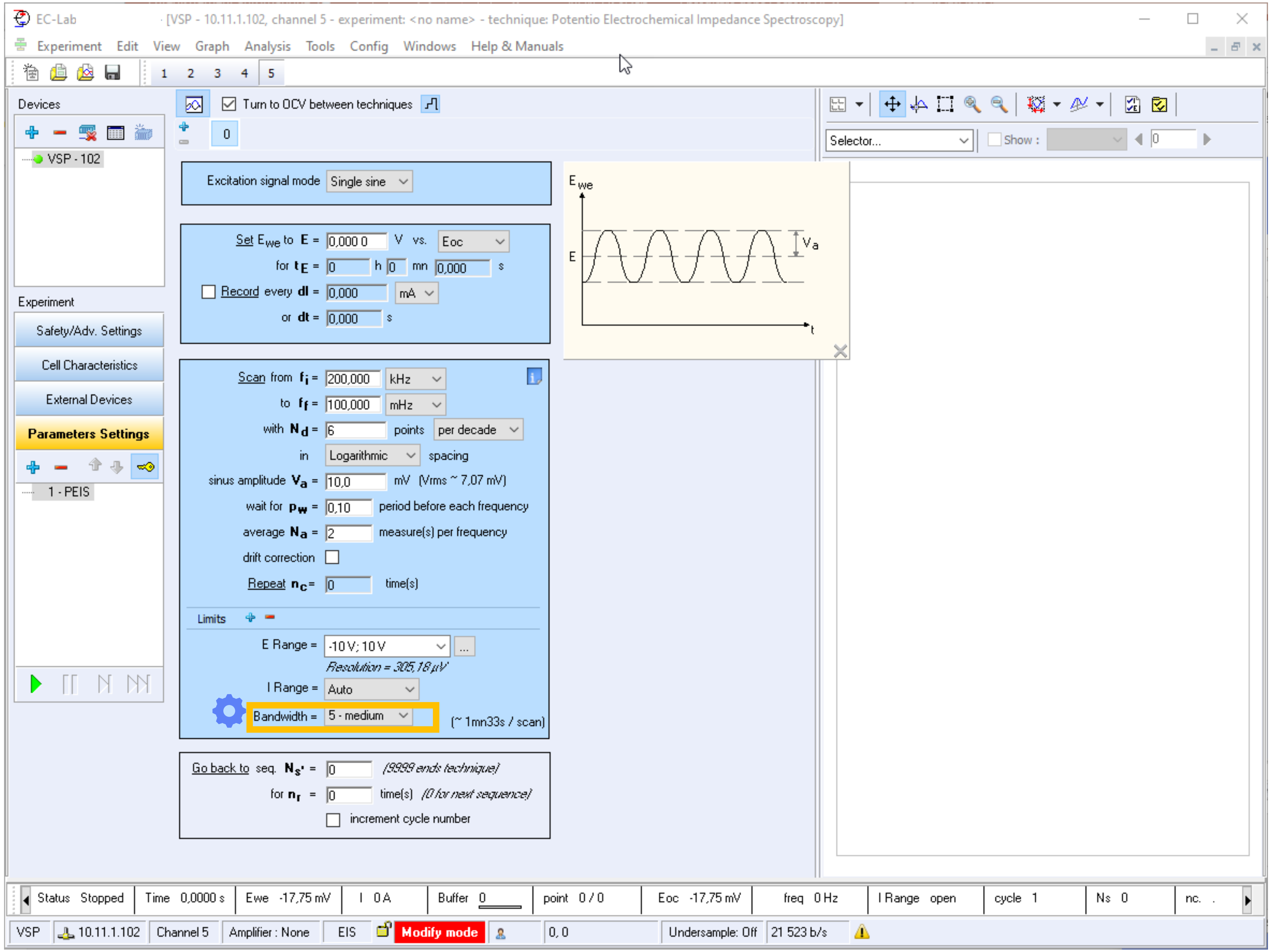
- I Range is the range of expected current
- Autorange is available



Select autorange as the level of current at low and high frequency may be very different

Step 3: Optimize the measurement

- Adjust bandwith to make sure potentiostat control the cell in stable and fast way

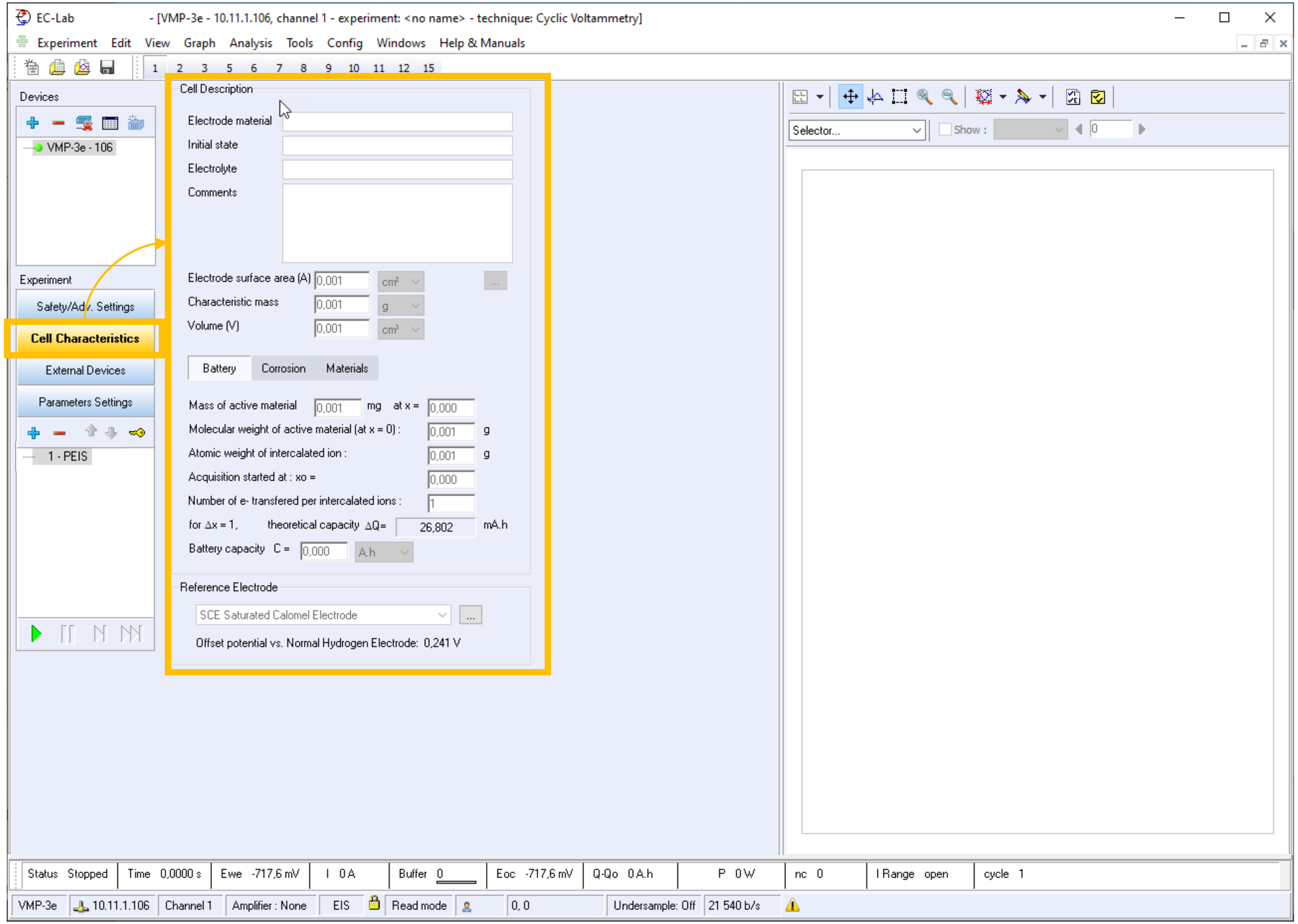


For EIS measurements at high frequencies, the regulation loop has to be fast, so a fast bandwidth is required

- 7-fast for Essential
- 9-fast for Premium

Step 4: Set general parameters

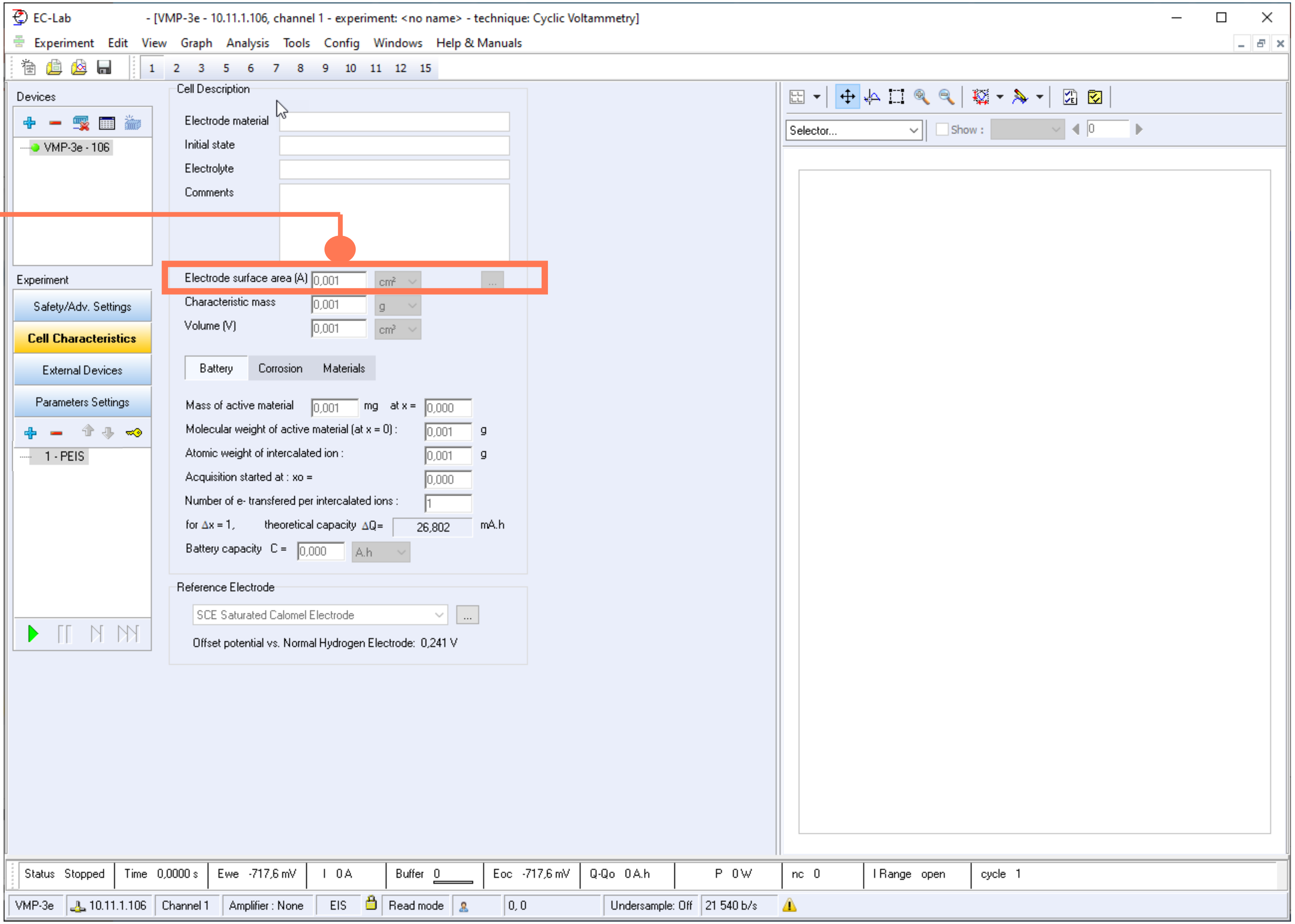
- Add information and comments about the cell



Note: All this information is store in the data file

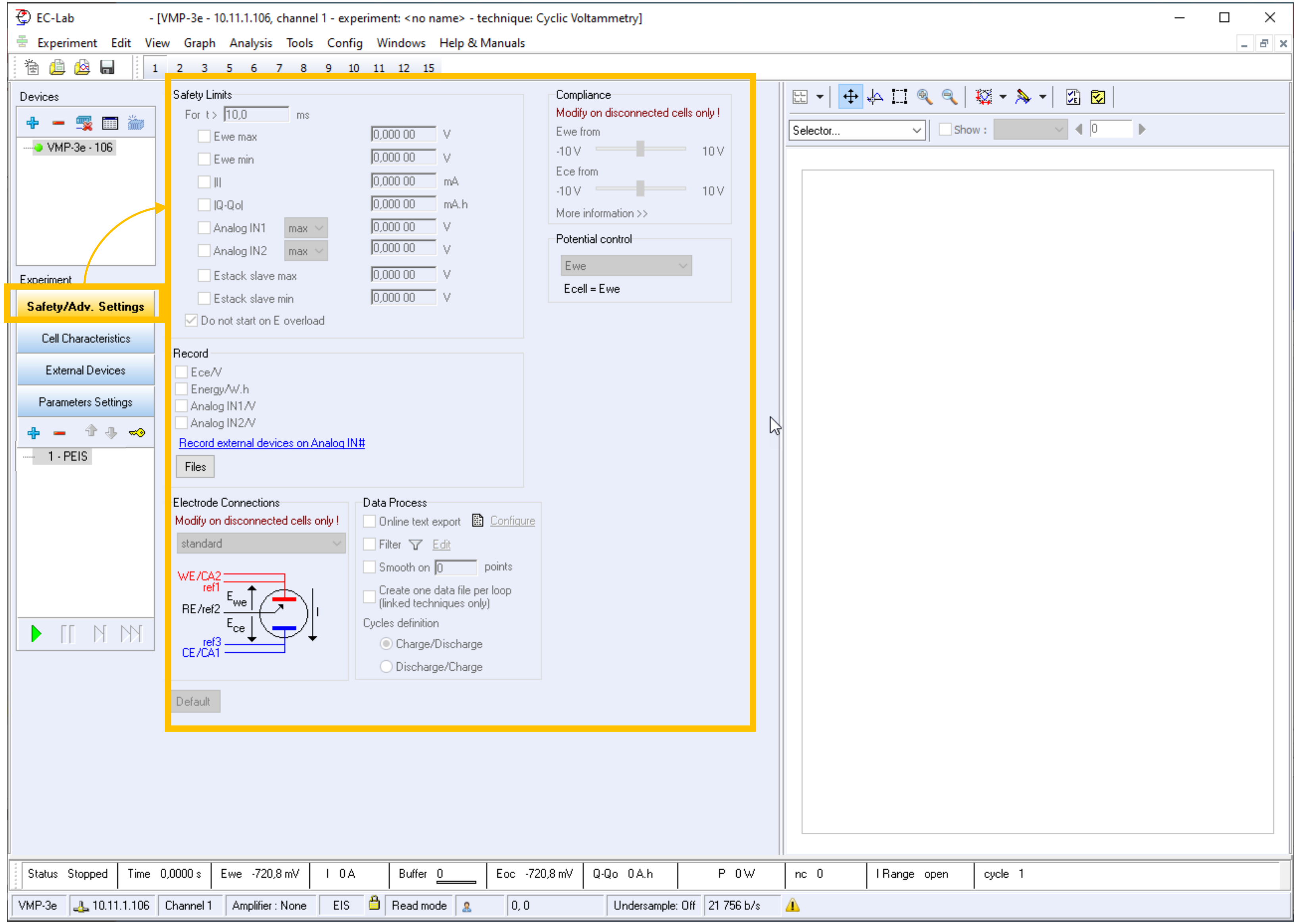
Step 4: Set general parameters

Electrode surface area has to be set if the user wants to work with volumic/surfacic resistance (Ω/ cm^3 or cm^2) instead of resistance (Ω)



Step 4: Set general parameters

- Safety and Advanced Settings are available here

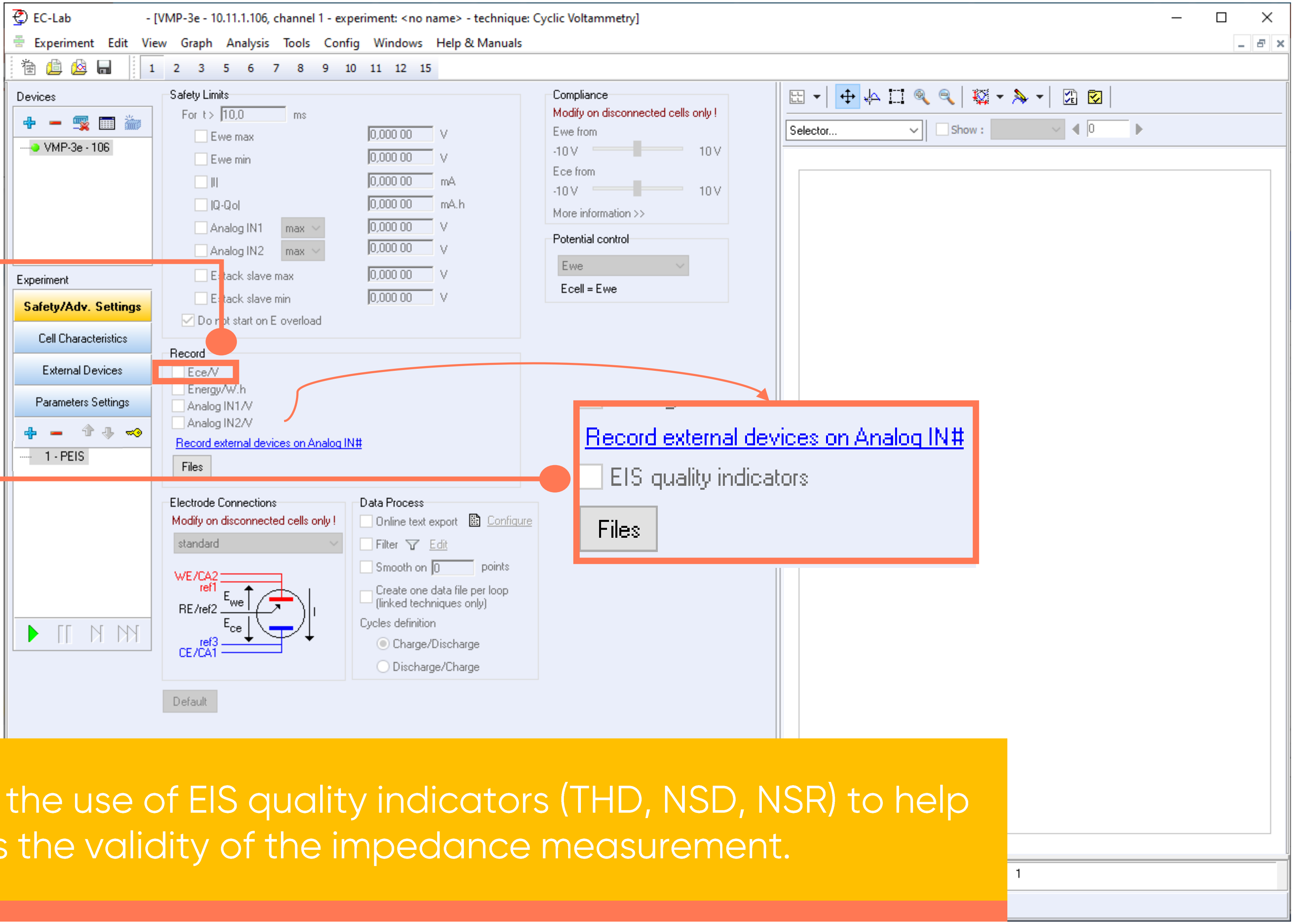


Note: This windows is different for the Essential and Premium instruments.

Step 4: Set general parameters

Record the impedance of the CE in addition to the impedance of the WE

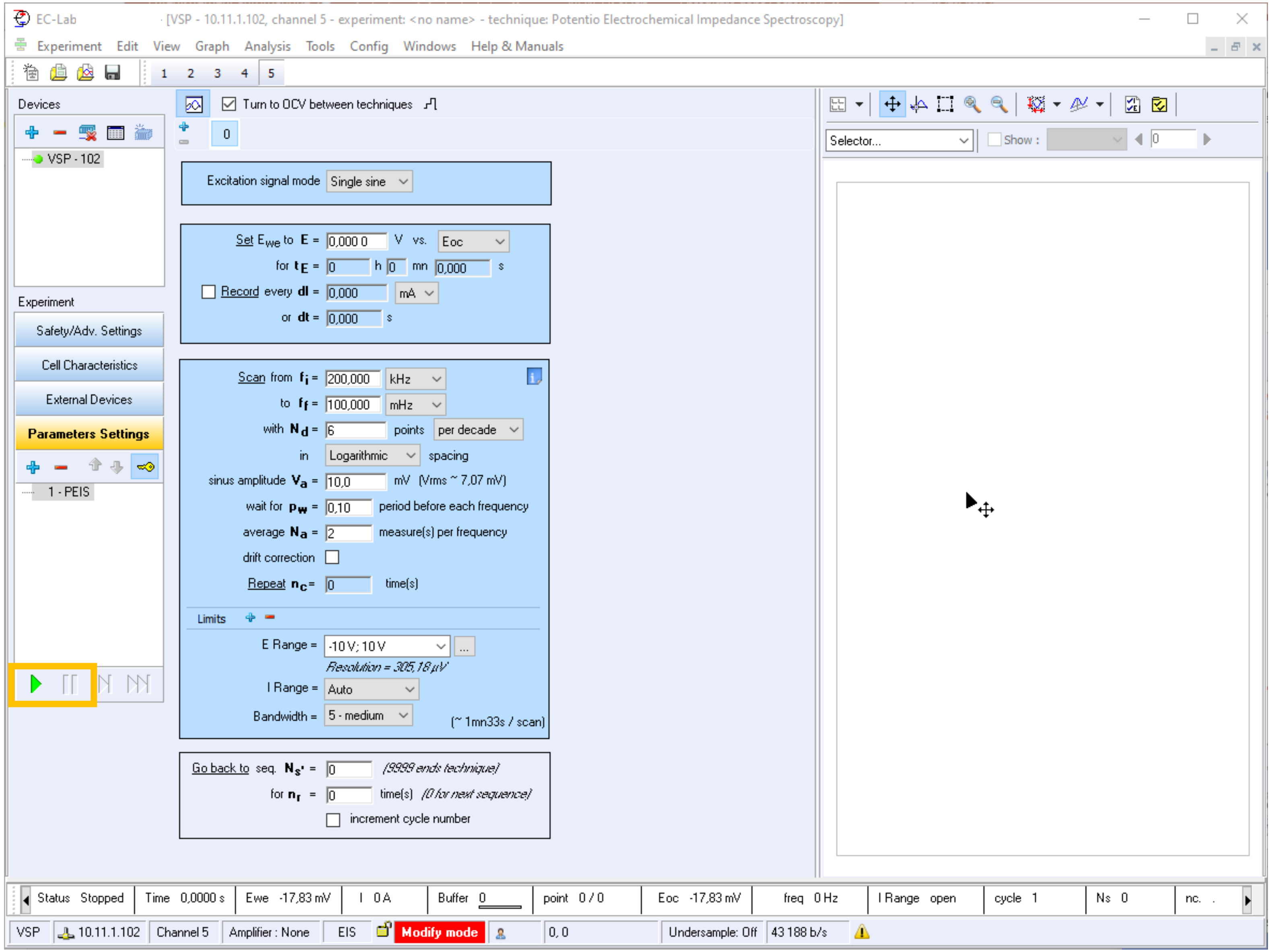
Activate EIS quality indicators
(available on Premium or e-board potentiostats)



We recommend the use of EIS quality indicators (THD, NSD, NSR) to help to quickly assess the validity of the impedance measurement.

Step 5: Launch the measurement

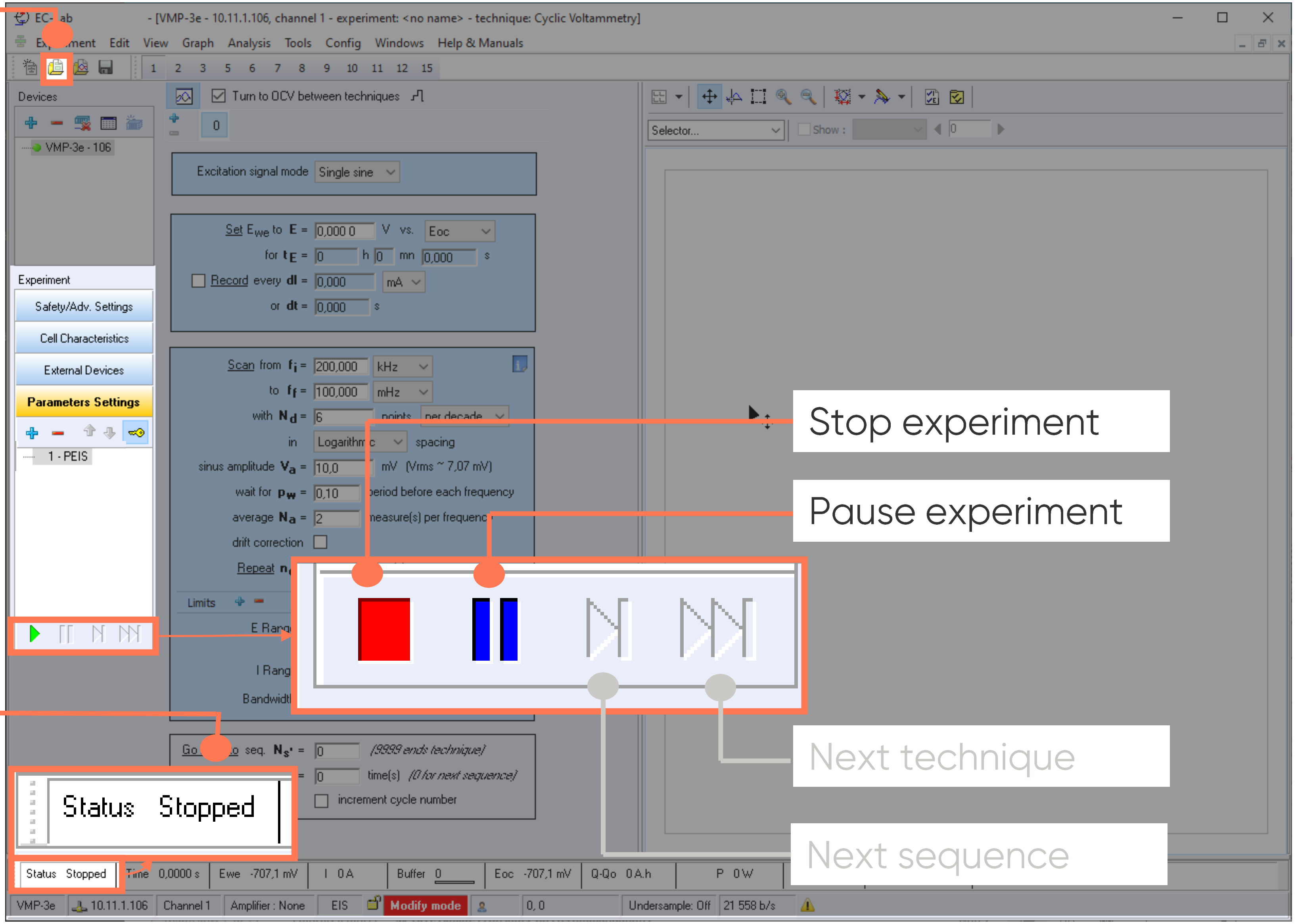
- Click on ▷ to launch experiment



Note: All the settings may be changed during the experiment (Modify on the fly) except Irange, Erange, bandwidth and single sine / multisine

Step 5: Launch the measurement

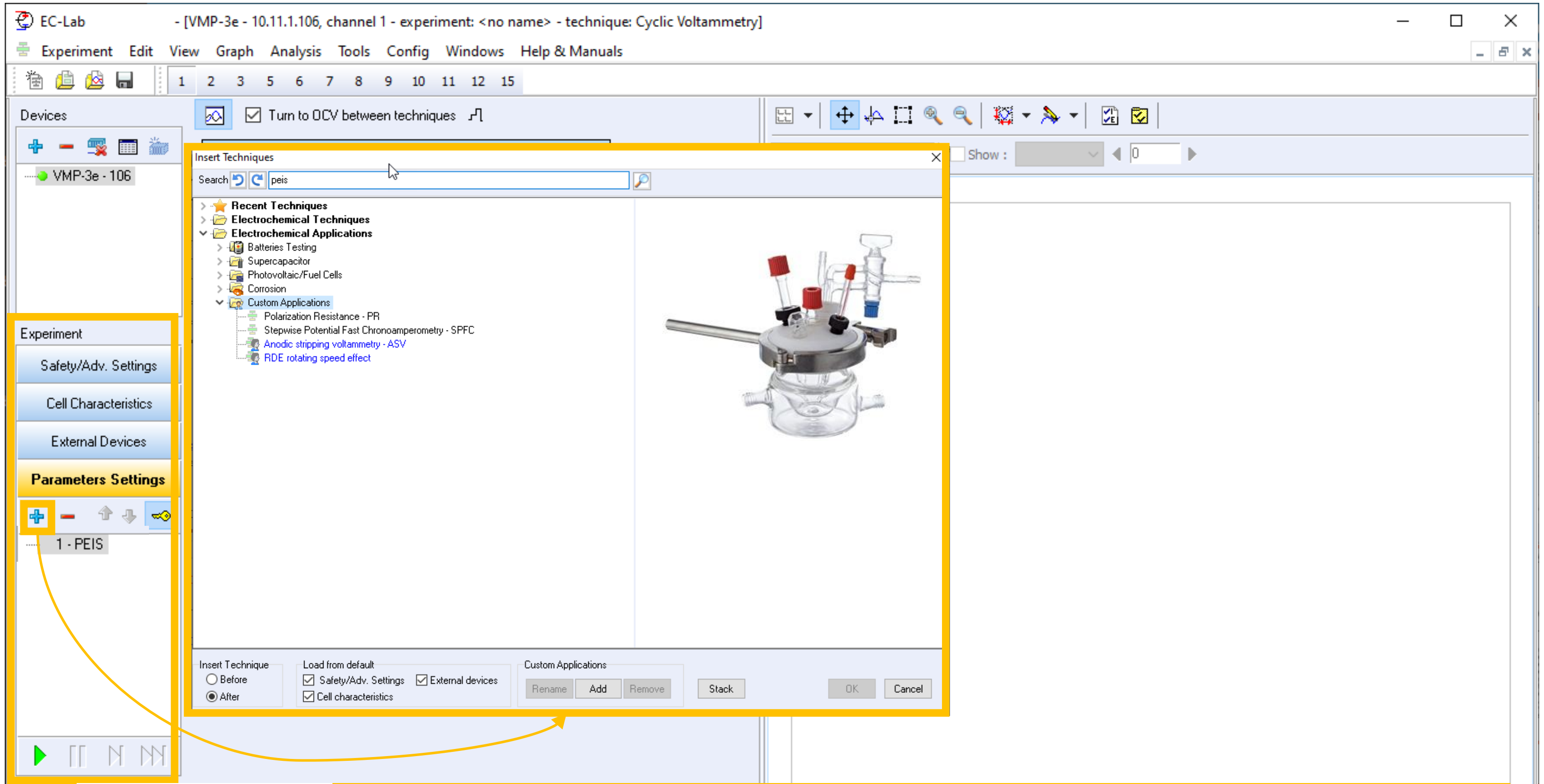
Load techniques with same settings using a .mps file created when launching the experiment



Status of experiment is displayed (Stopped, Paused, Relax...)

Step 6: Add additional experiments

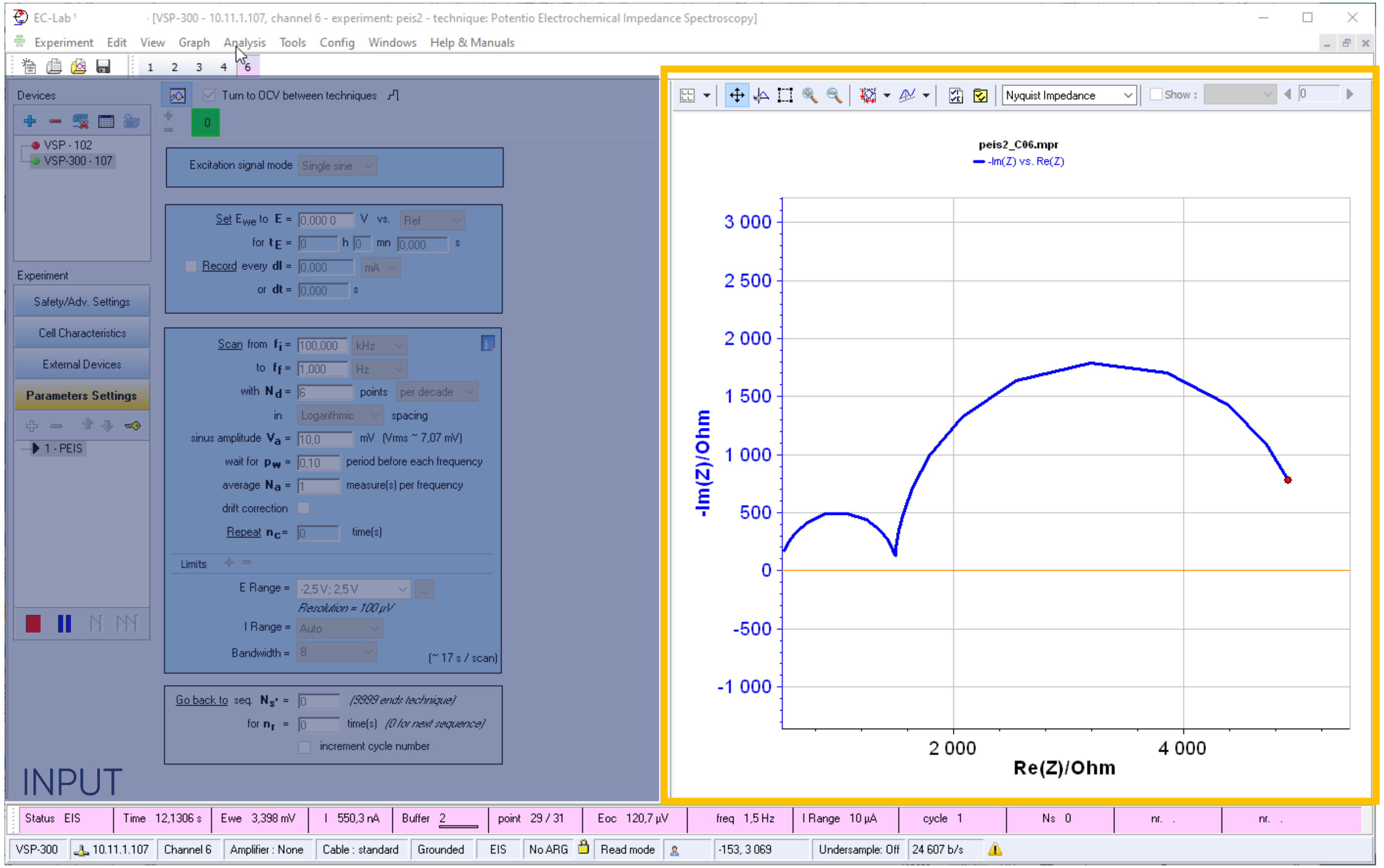
- Click on + button to add more techniques
- Order of execution appears in the technique list



You can save **personalized protocol** to technique list with **Save As Custom Application...** (in the main bar menu Experiment) and find it under Electrochemical Application - Custom Applications **My protocol**

Step 7: Read the graph

- Graphics are displayed in real time
- Data are saved in .mpr file

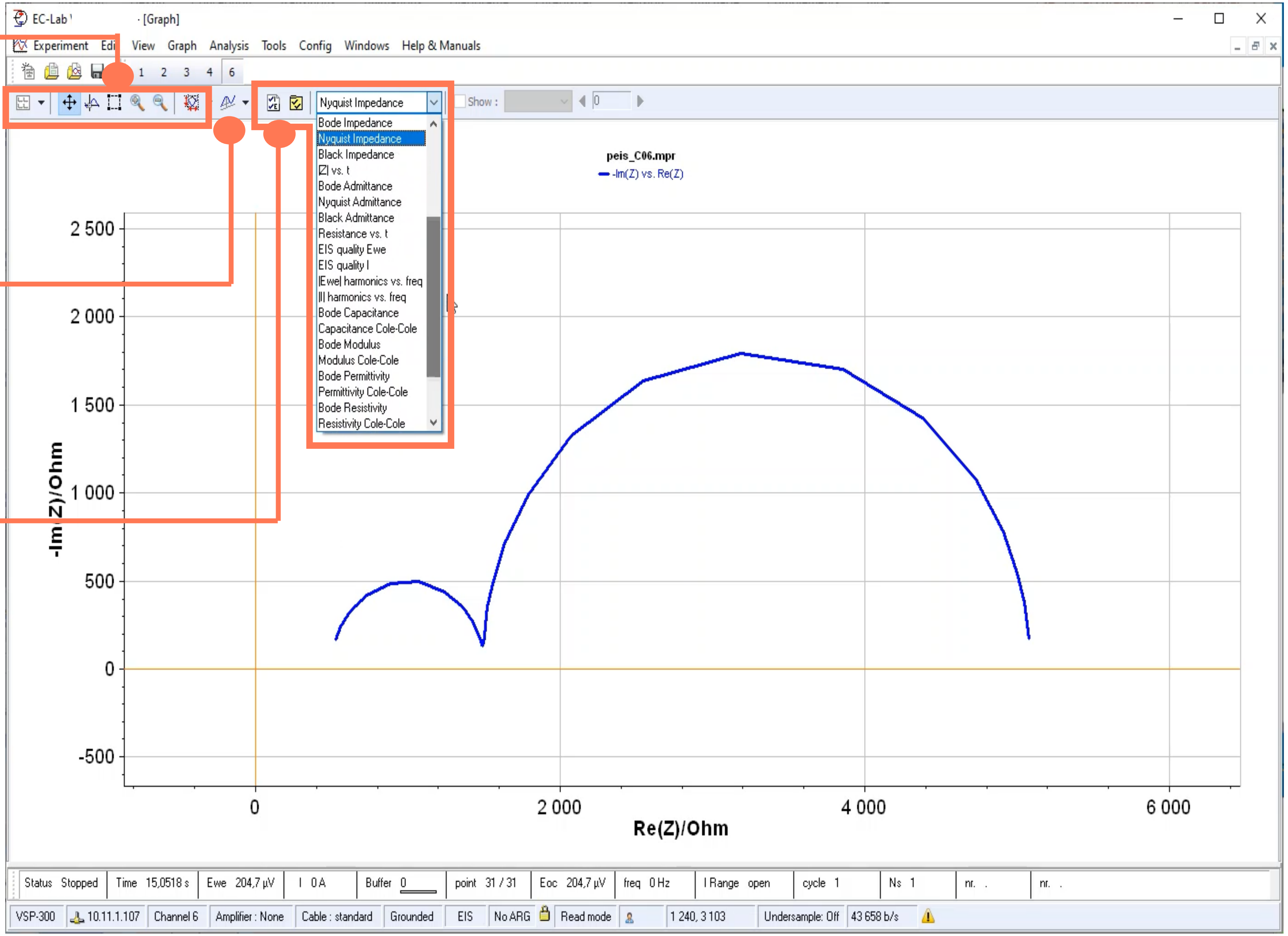


Step 7: Read the graph

Browse though the graph
(Filter, Scroll, Cursor, Selection, Zoom +, Zoom –, Autoscale)

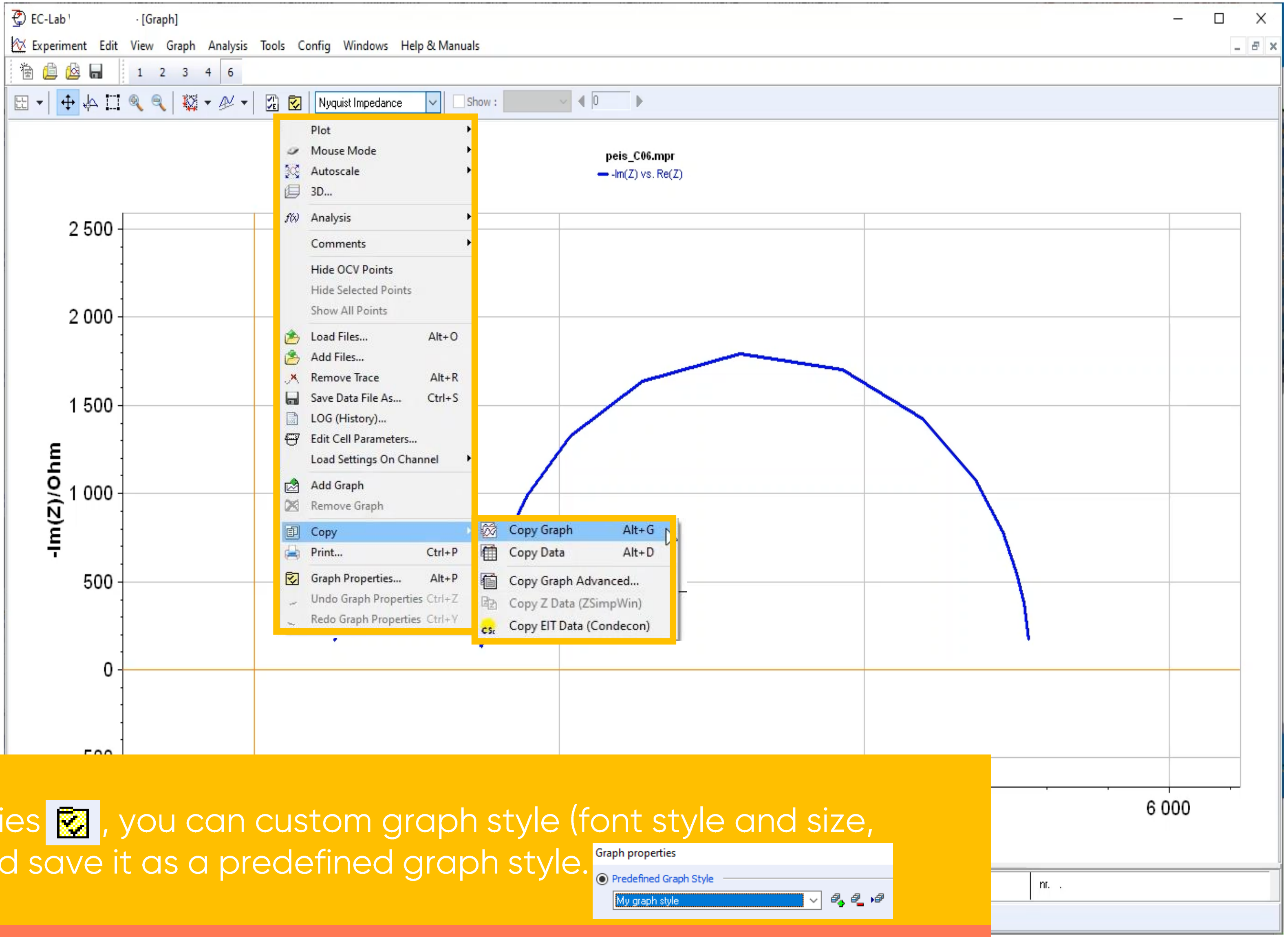
Modify the graph
(Selector, graphic properties, representations)

Show only selected cycle



Step 7: Read the graph

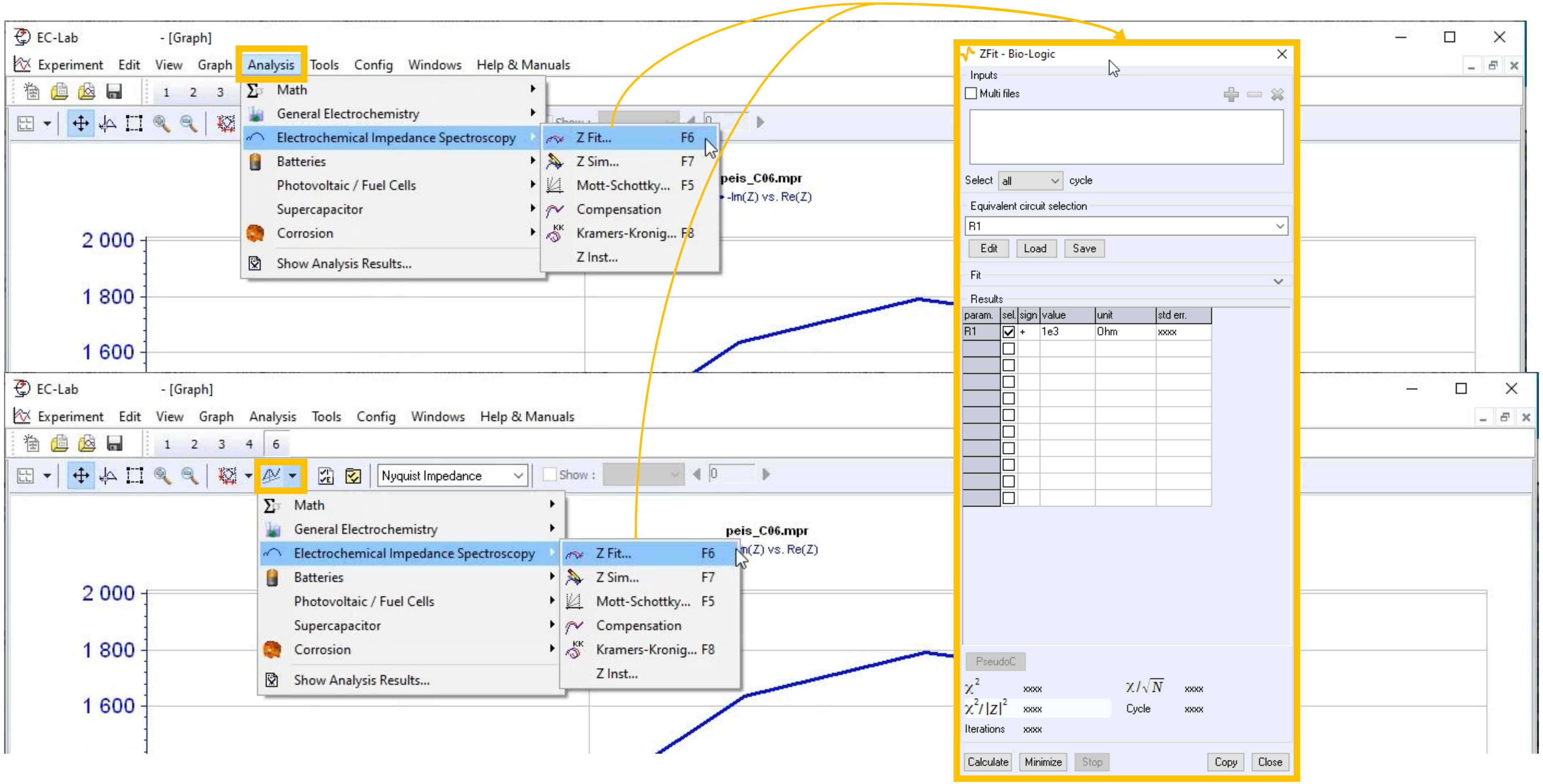
- Copy graph as a picture with a right click on the graph



In graph properties, you can custom graph style (font style and size, traces, grid...) and save it as a predefined graph style.

Step 8: Analyse the data with Z Fit

- Analyse with Z Fit

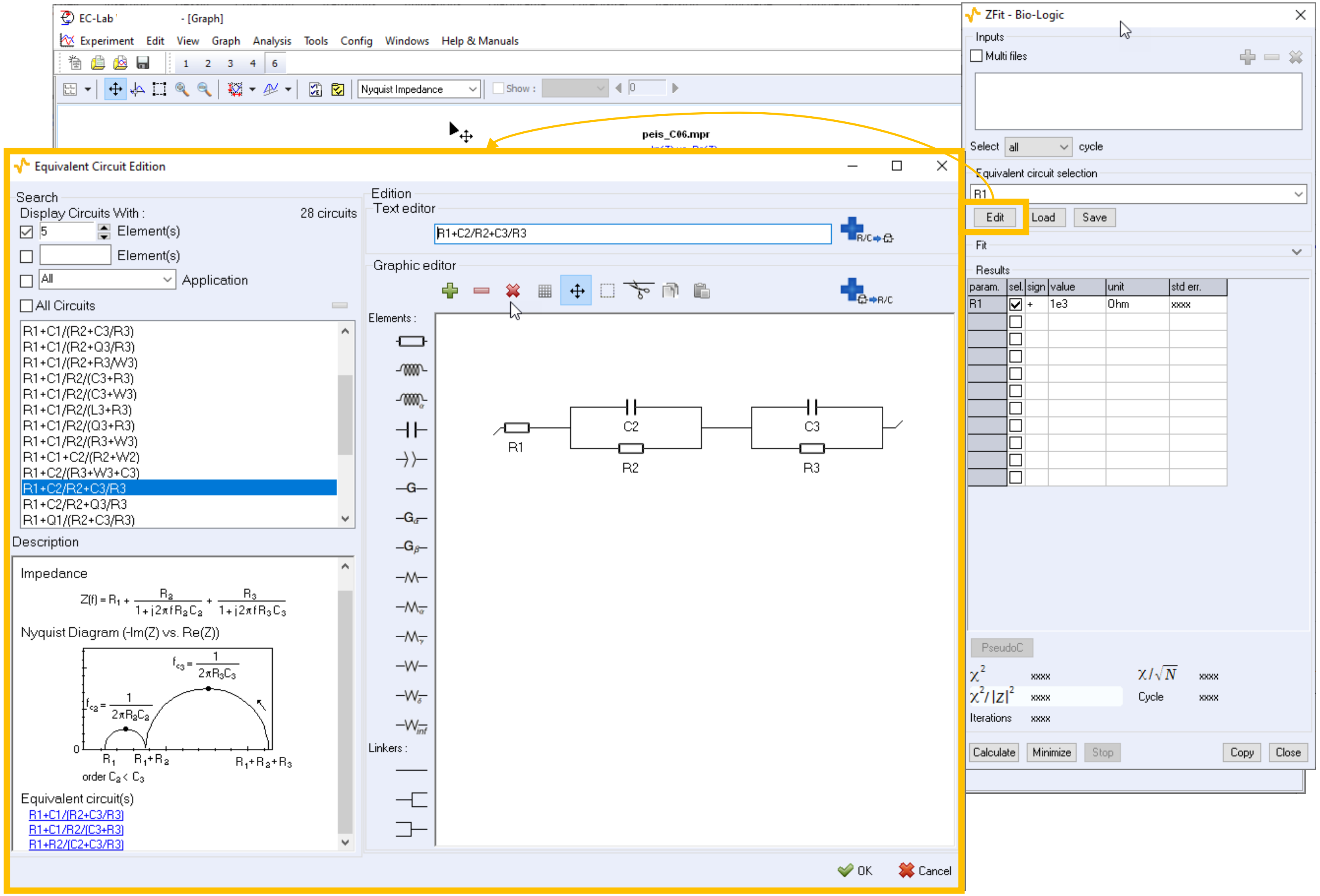


Note: Analysis is available either in the main tool bar or as a shortcut in the graph bar or with F6

Did you know? Z Sim (available in Analysis) is a powerful impedance simulation tool. It can be helpful to learn more about equivalent circuits.

Step 8: Analyse the data with Z Fit

- Click on Edit to select the equivalent circuit



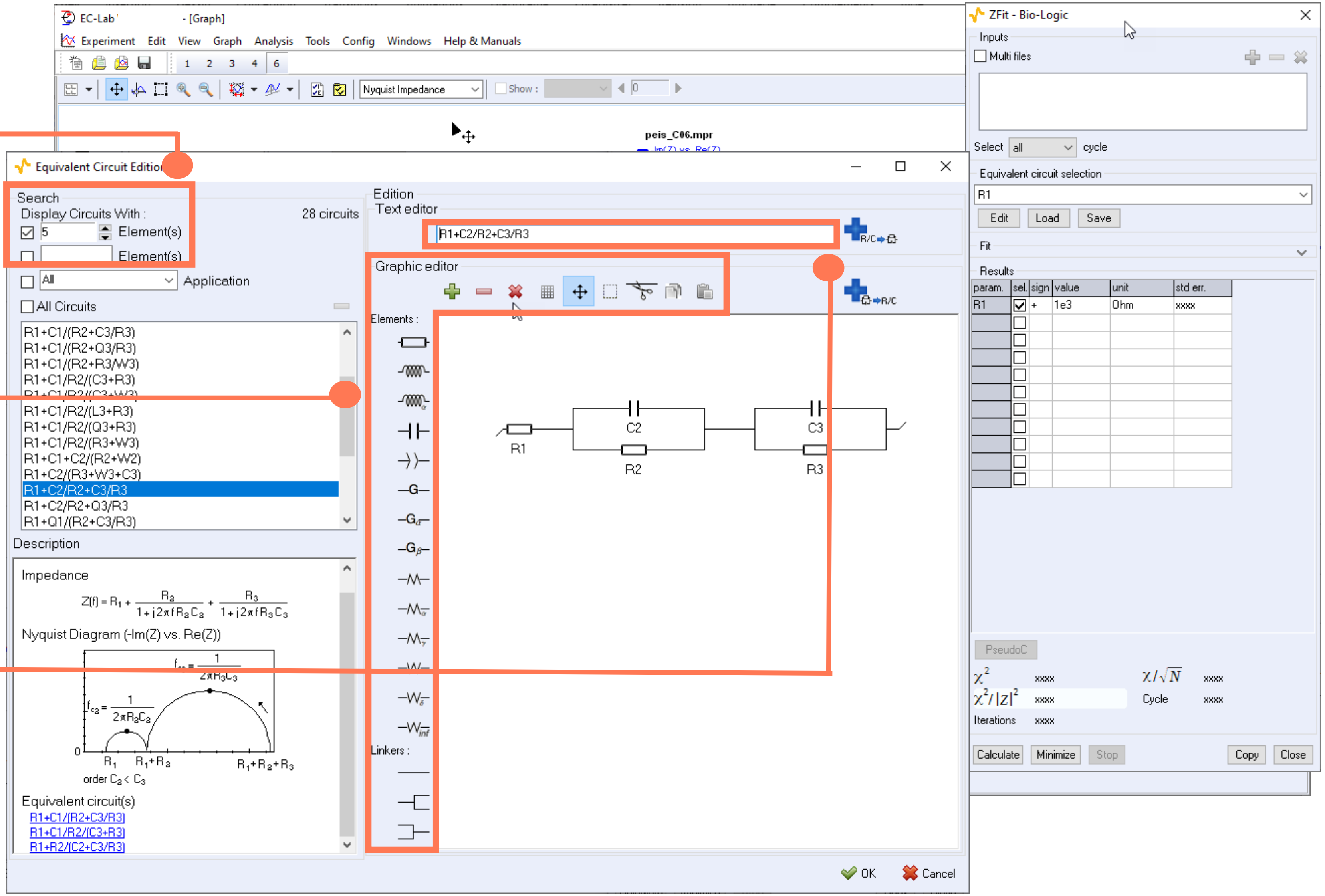
Step 8: Analyse the data with Z Fit

Sort the circuit in the list

Build the circuit

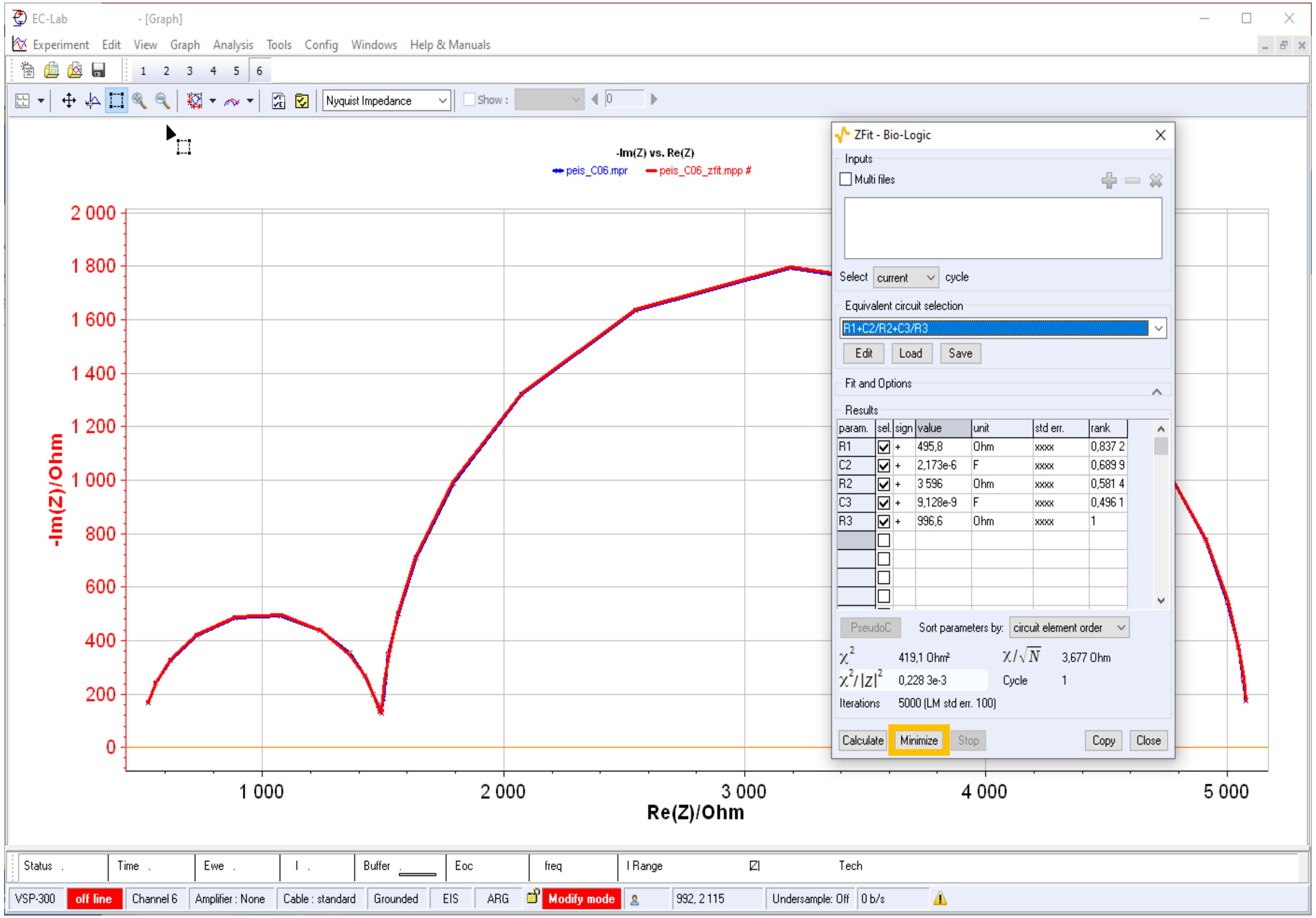
Write the circuit

+: elements in series
/: elements in parallel
(): several elements in series or in parallel with each other



Step 8: Analyse the data with Z Fit

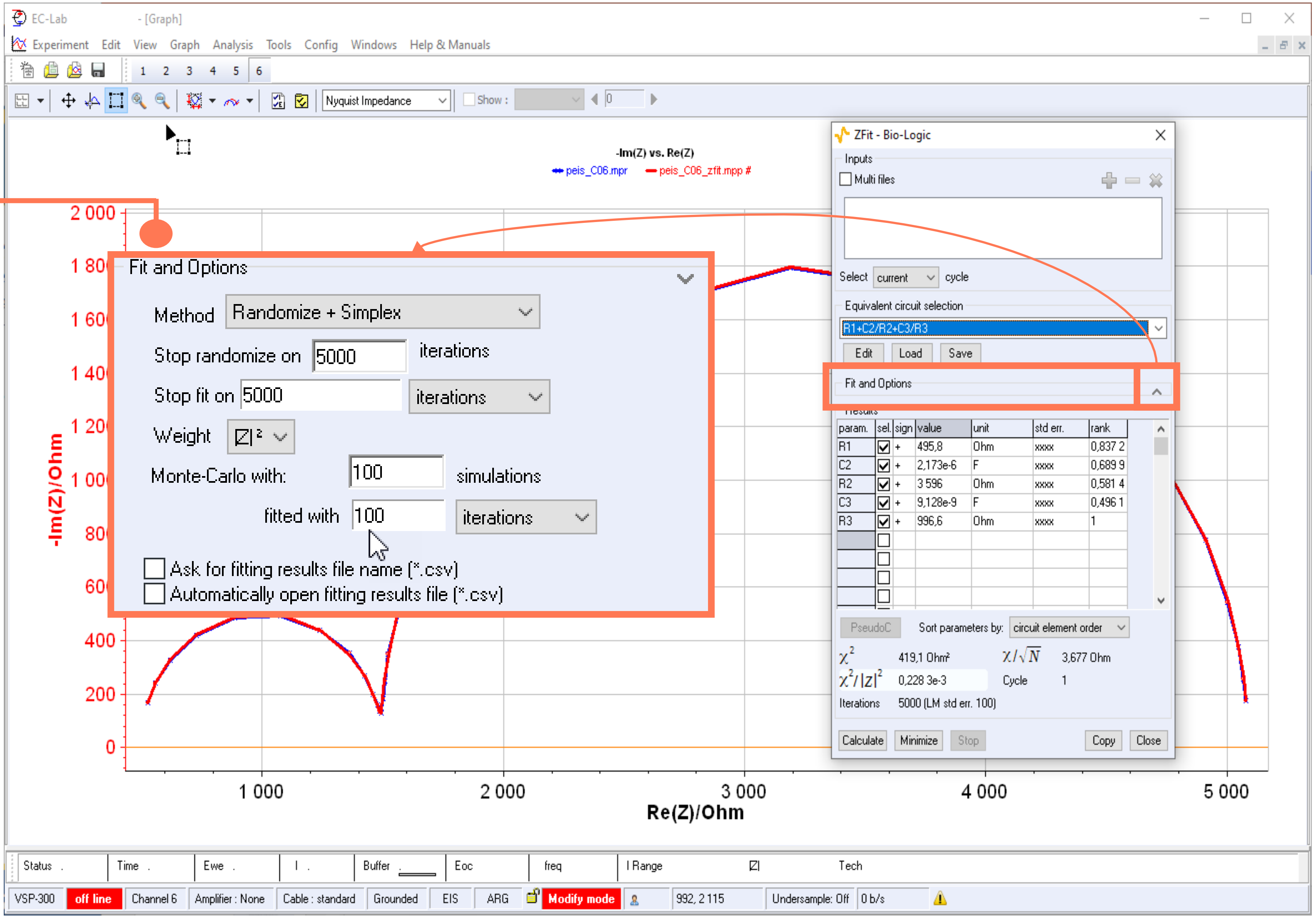
- Click on minimize to fit the data



Note: xx_zfit.mpp temporary file is generated. It can be saved as .mpr file

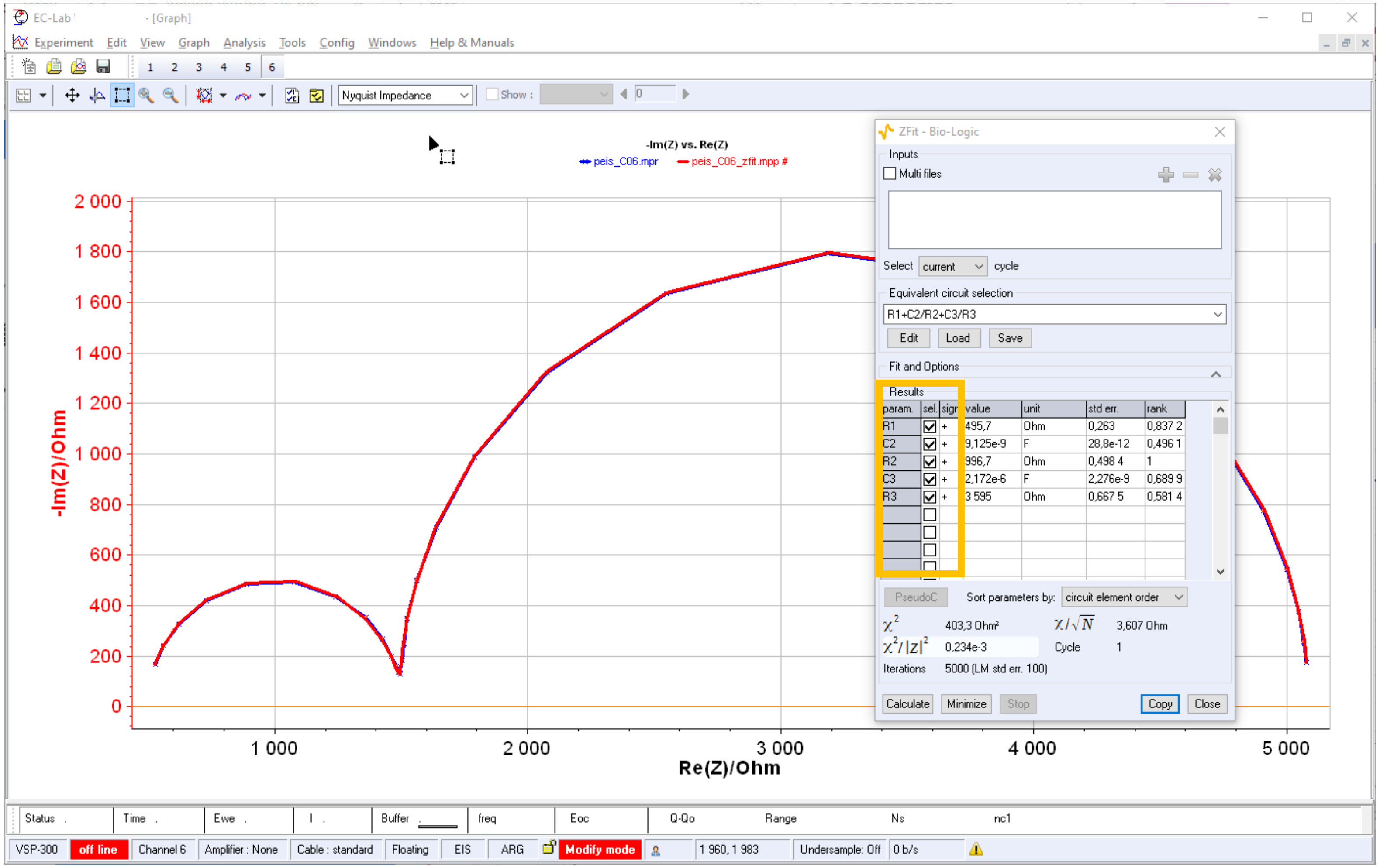
Step 8: Analyse the data with Z Fit

3 kinds of method to fit and a randomize to find initial values of the fit



Step 8: Analyse the data with Z Fit

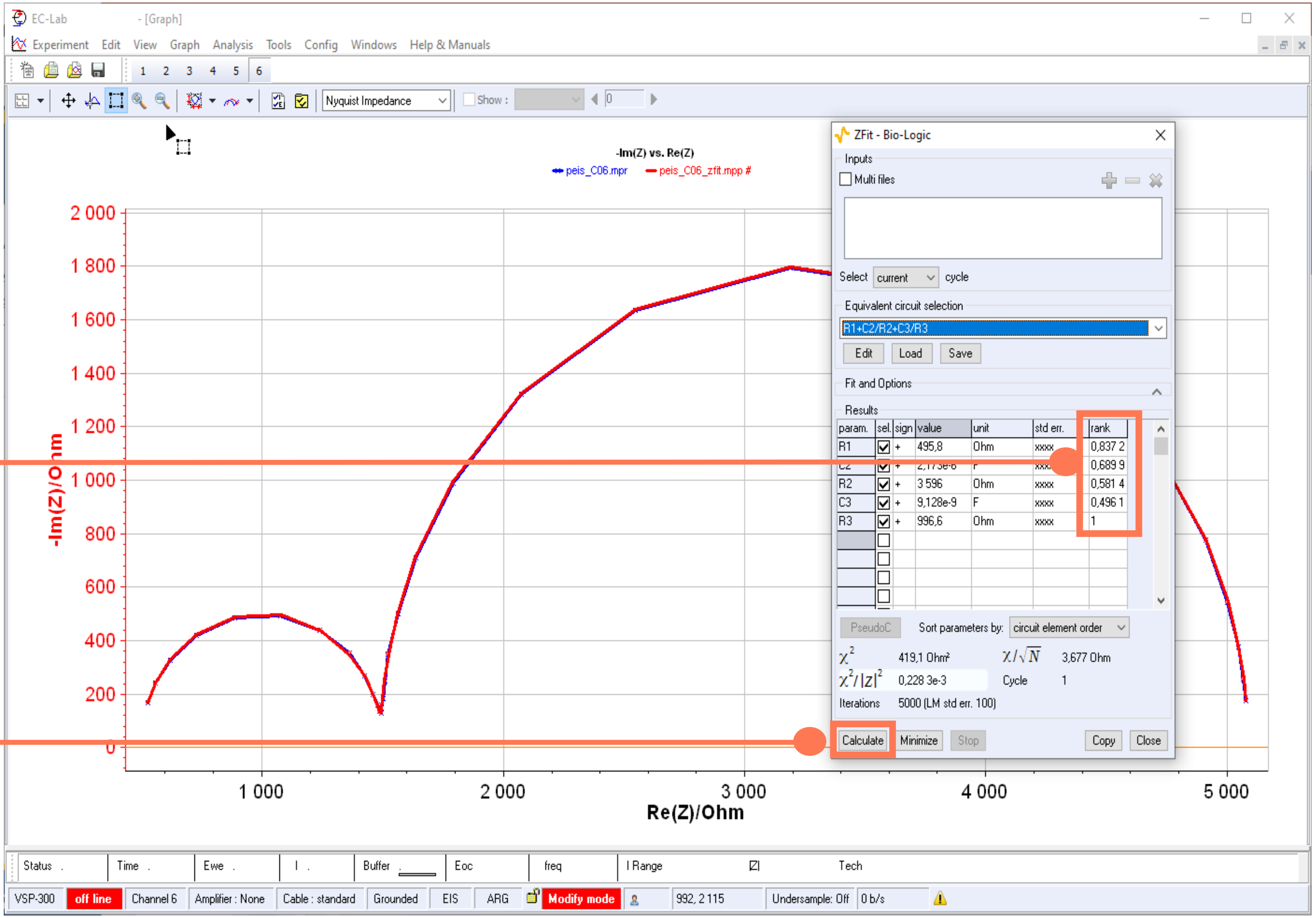
- Take over the results during fitting process
  - Unchecked “Sel” to keep a value in the table
  - Choose +/- to force sign of a value



Step 8: Analyse the data with Z Fit

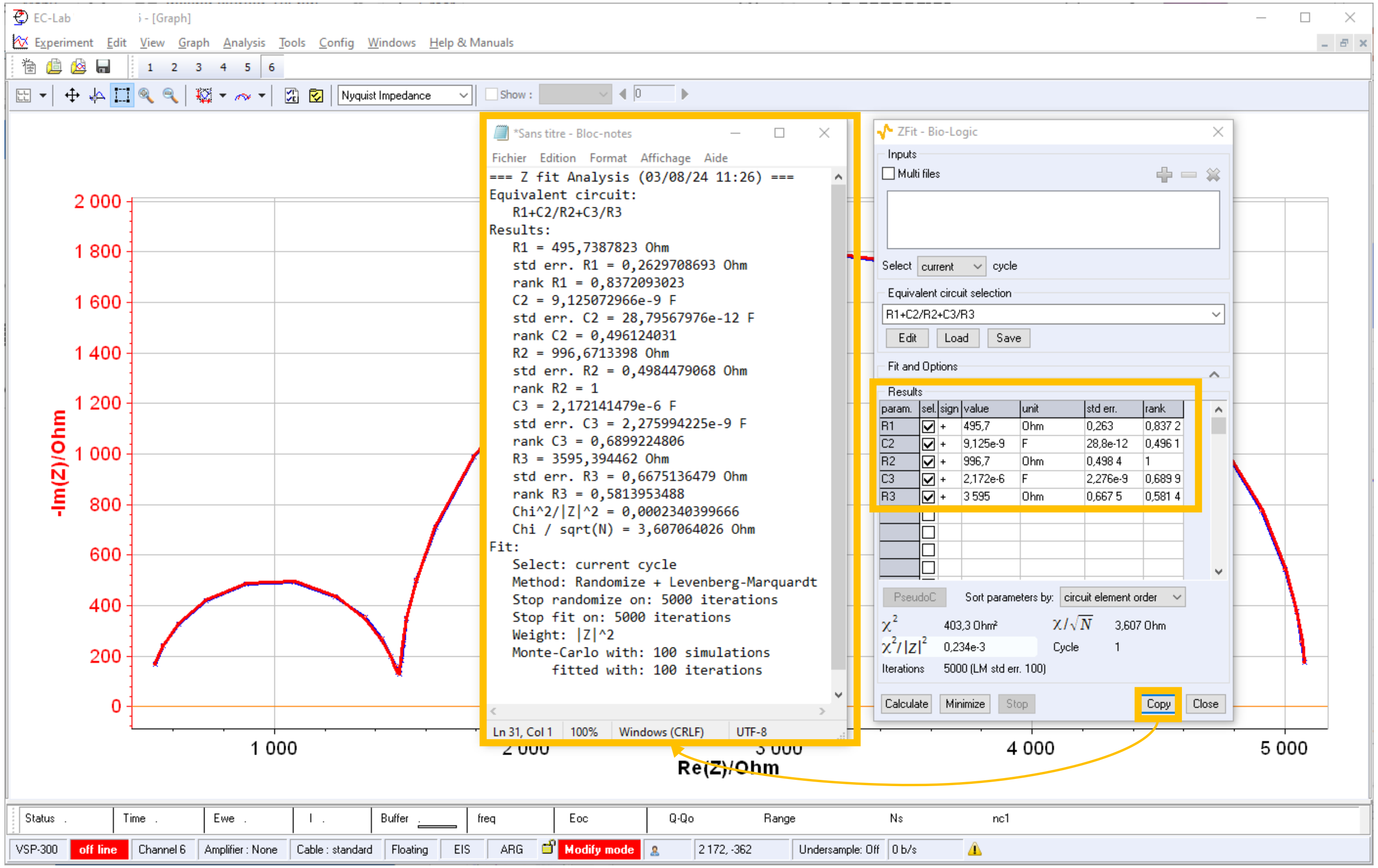
Rank the importance of the element in the fit

Calculate (no fitting) using parameters entered in table



Step 8: Analyse the data with Z Fit

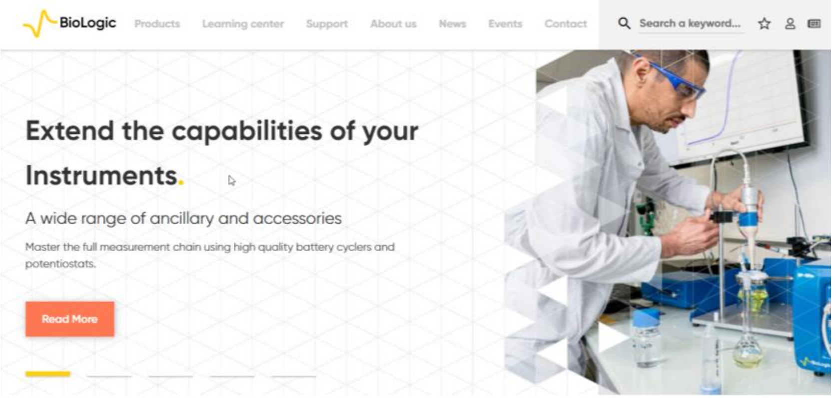
- Save the results with copy/paste

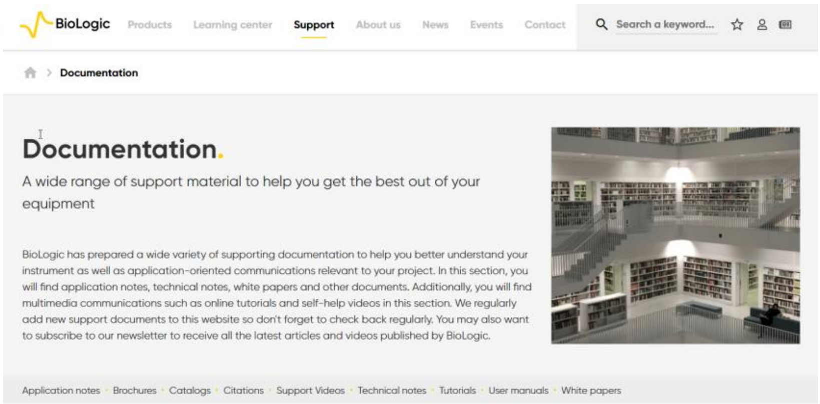


Find out more

For supplementary information

Visit our website!





www.biologic.net

- Documentation list
  - What is EIS? (article)
  - How to make reliable EIS measurements? (article)
  - Application Notes
  - EC-Lab Techniques and Applications (manual)
  - EC-Lab Analysis and Data Process (manual)

Did you know? **Free update of EC-Lab® are available on our website.**

Need help?

Contact us!

[Contact - BioLogic]

- Helpful information to get when contacting support center:
  - Serial number of the instrument (located on the rear panel of the device)
  - Software and hardware version you are currently using (on the Help menu, About on EC-Lab)
  - Operating system on the connected computer
  - Connection mode (Ethernet, LAN, USB) between computer and instrument

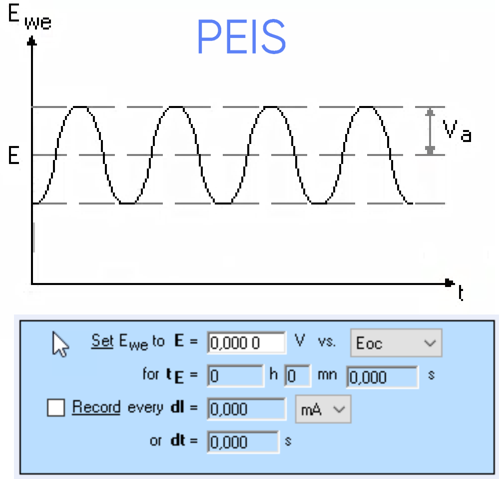
FAQ

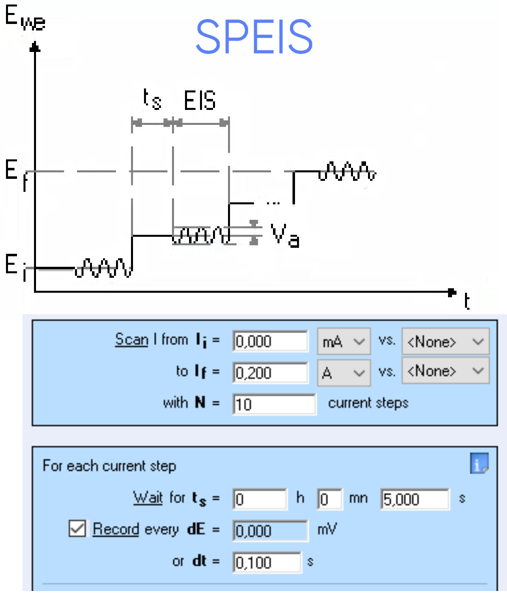
- How to adapt presented PEIS parameters on other EIS techniques?
- What is the difference between PEIS, GEIS and GEIS AA?
- What are the advantages of using multisine ?
- How to optimize the setup?
- How to ensure the reliability of the measurements?
- How to select an equivalent circuit?
- How to measure impedance on stack cell?

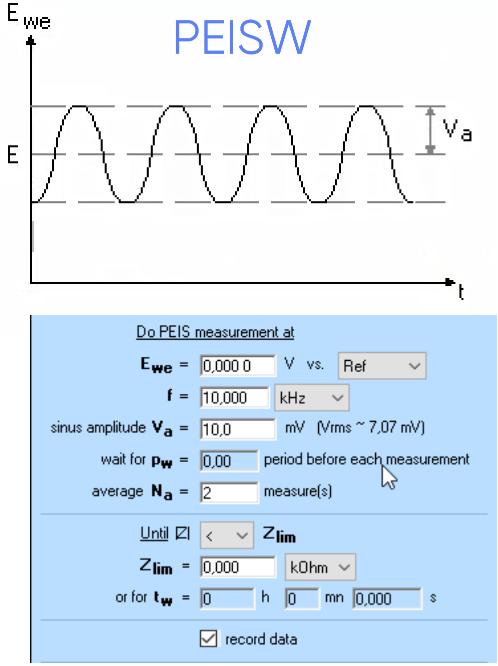
How to adapt presented PEIS parameters on other EIS techniques?

- EIS techniques are design in a similar way
- As control modes differ (potentio or galvano), related parameters have to be adapted

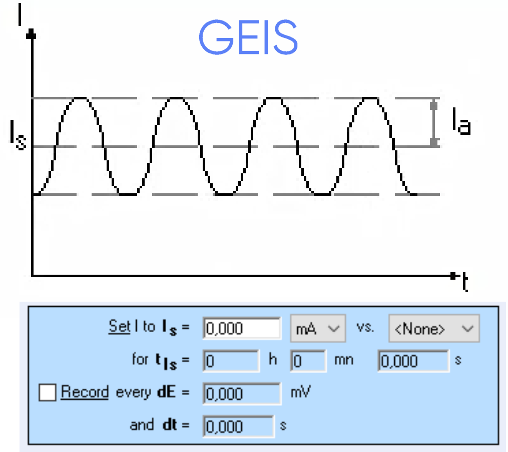
Potentio

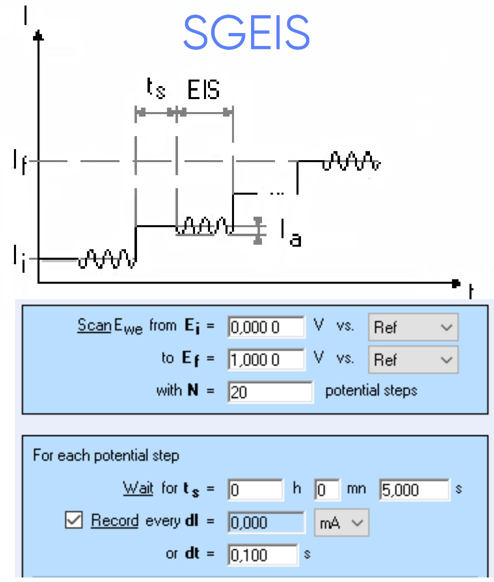






Galvano





What is the difference between PEIS, GEIS and GEIS AA?

- In most cases, performing measurements in potentio or galvano control are equivalent. One of the difficulties comes from finding the right sine amplitude:
  - High enough to induce a significant amplitude of the response
  - Small enough to keep the linear behavior of the cell

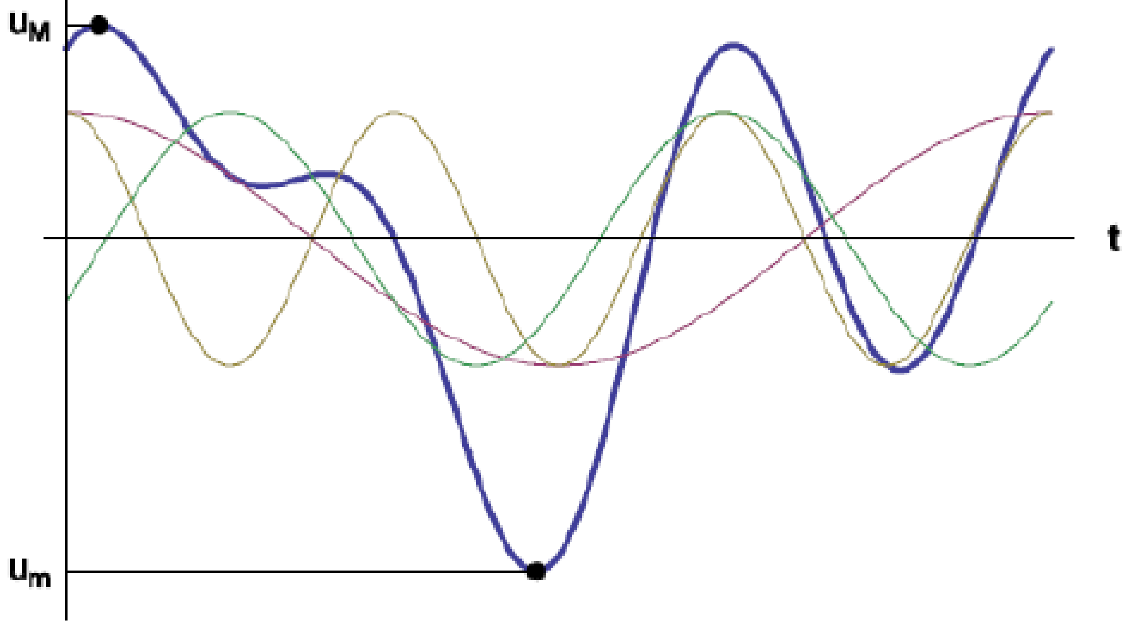
	PEIS	GEIS	GEIS-AA
Control mode	Potentio	Galvano	Galvano (with amplitude adaptation)
Sinus amplitude to set	Input Va (mV)	Input Ia (mA)	Output Va (mV)
Sinus amplitude value	5-20 mV (small amplitude)	*Small* current amplitude (depends on the system). Rule of thumb 10% of the discharge/charge current for batteries	5-20 mV (small amplitude). Automatic modulation of input current amplitude to output voltage amplitude.
Use	Most applications	Low impedance system, system that change with time (battery, corrosion…)	Avoid non-linear behavior

Note: To go further, refer to PEIS or GEIS or GEIS-AA? (article), AN#49, AN#09

What are the advantages of using multisine ?

- Multisine is a sum of sinus. The advantages are:
  - Reduce time of the measurement
  - Avoid drifts for non-steady state system on measurement at low frequency

$$u(t) = A\sum_{k=1}^{N}\cos(2\Pi f_k t + \Phi_k) \text{ with the phase } \Phi_k = \Phi_1 - 2\Pi\sum_{n=1}^{k-1}\frac{(k-n)}{N}$$



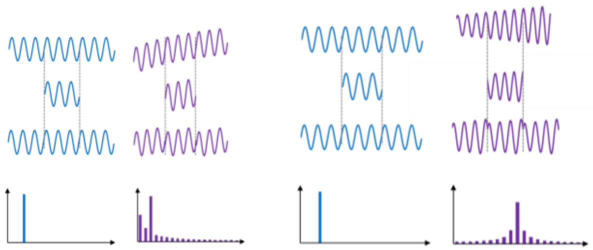
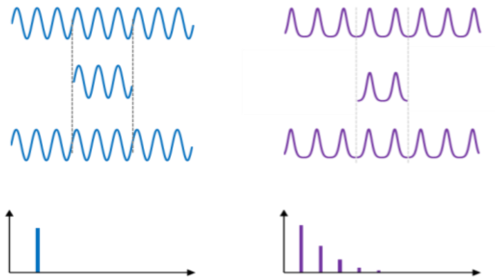
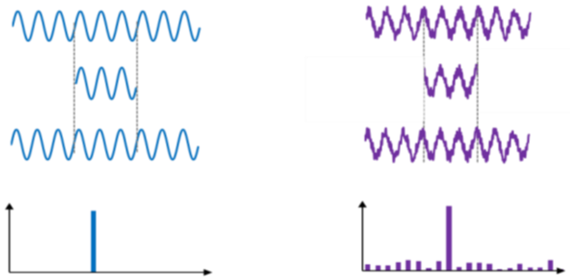
Note: To go further, refer to AN#19

How to optimize the setup?

- Verify the impedance measurement accuracy of the setup
(To go further, refer to AN#54)
- Add booster (for system with low impedance) or low current option (for system with high impedance) if needed
- Use a Faraday cage (connected to the ground of the potentiostat) to protect the cell from any external disturbance (especially for low current measurements)
- Avoid extended cable (capacity of the extra cable is added and affect impedance measurement at high frequencies, bandwidth is affected too)
- Use 4-point measurements (contact resistance not negligible for low impedance system)

Note: To go further, refer to AN#05

How to ensure the reliability of the measurements?

Criteria to respect	System is stationary	System is linear	Limited Noise
Explanation Actual signal Time record Assumed response Amplitude spectrum	 *Steady -state* · ***NON*** *Steady-state* · *Time* ***in****variant* · *Time* ***variant***	 *Linear* · ***NON****-linear*	 ***Without*** *noise* · ***With*** *noise*
Quality Indicators to check	**NSD** (Non-Stationary Distortion) has to be low	**THD** (Total Harmonic Distortion) has to be low	**NSR** (Noise to Signal Ration) has to be low
Possible actions to take	$\nearrow P_W$ Use multisine Use drift correction	$\searrow V_a$	$\nearrow V_a$ $\nearrow N_a$

Note: To go further, refer to AN#64, AN#65, AN#69 and AN#17

Check the value of the AC (|I| and |E|) and DC (<I> and <E>) current and potential in the graph selector (unchecked "hide additional variables").

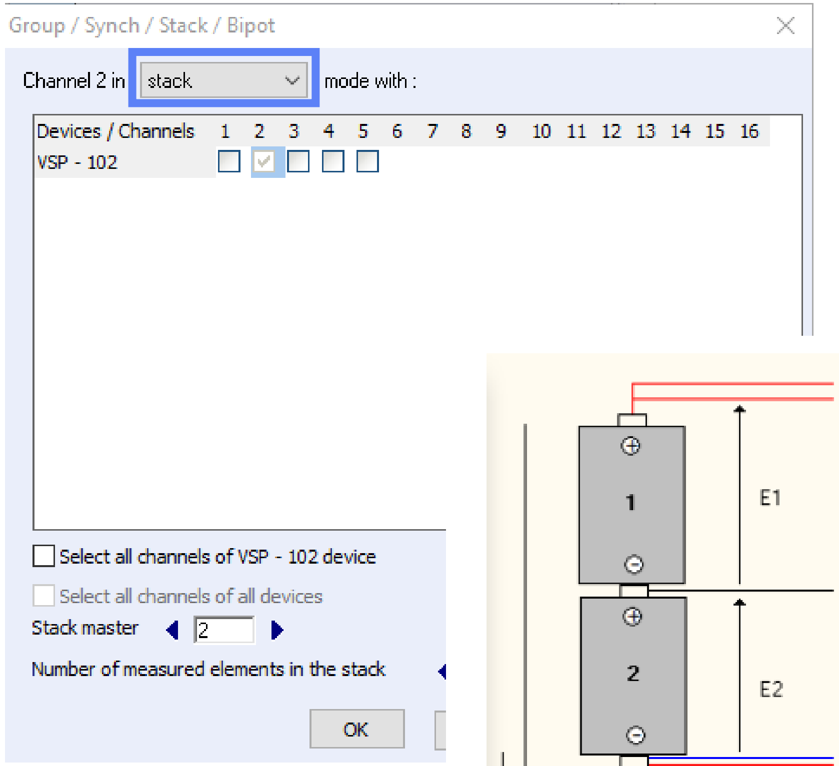
How to select an equivalent circuit?

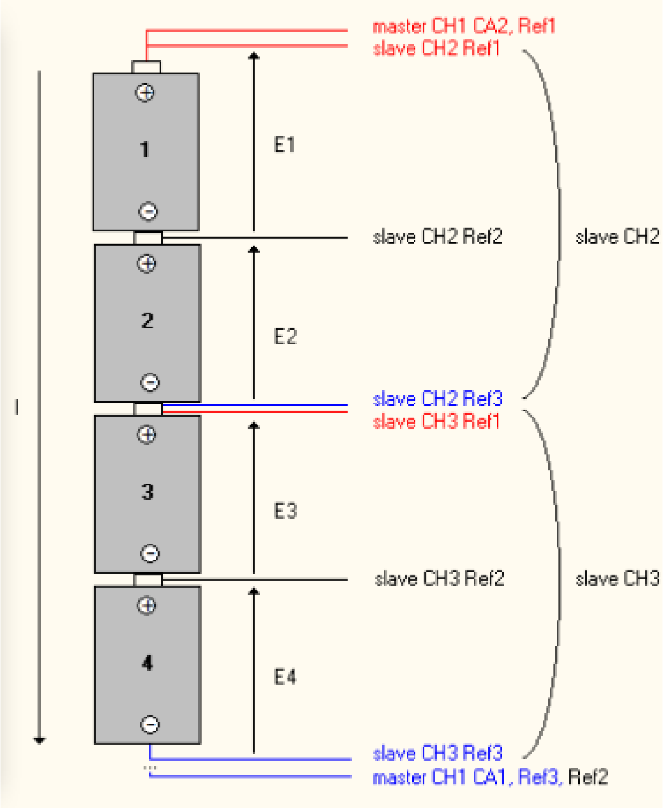
- There are many different electrical equivalent circuits which correspond one impedance diagram
- The effectiveness of the process is dependent on the ability to choose the best circuit representing the physical reality of the system being studied
- A sensitivity feature, « Rank » in the results of Z Fit, was developed to help to assess the importance of each element in the fit. *Generally the less elements in the circuit, the better it is.*

Note: To go further, refer to Z Fit tutorials (videos), How to choose the proper equivalent circuit (articles), AN#14, AN#45

How to measure impedance on stack cell?

- Simultaneously assess a whole stack and each cell behavior with stack mode (in Edit menu)
- Connect leads to master (stack) and slave channels (each elements)
- Impedance of the stack is the sum of the impedance of each element





Note: To go further, refer to AN#59 and TN#27

BioLogic

www.biologic.net

contact@biologic.net

BioLogic

Thank you for choosing us!