

MultiTrace 4

Version 4.5

User Manual



In case of problems

First make sure to check the “Troubleshooting” section in this manual and on our website: www.palmsens.com/troubleshooting/

Also, please make sure your software and firmware are up-to-date.

In case of persistent problems, please do not hesitate to contact us at info@palmsens.com.

Try to describe the problem as detailed as possible. Sending us the relevant method files, data files and screenshots can be helpful.

Alternatively, you can contact us one of the following ways:

Use the contact form: www.palmsens.com/contact/

Or give us a call: +31 30 2459211

Please have your instrument model and serial numbers available, as well as any applicable software and firmware version.

Disclaimers

PalmSens BV cannot guarantee that its instruments will work with all computer systems, operating systems, and third-party software applications hardware/software. The information in this manual has been carefully checked and is believed to be accurate as of the time of compiling. However, PalmSens BV assumes no responsibility for errors that might appear.

See Appendix A for CE declarations of conformity.

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1 Getting Started

With MultiTrace you have full control over MultiPalmSens, MultiEmStat (multi-channel instruments), and EmStat-4WE (polypotentiostat) instruments. MultiTrace works multi-threaded, meaning it is optimized to use multiple processor cores in parallel for optimal performance.

1.1 Requirements

The system requirements for MultiTrace are:

- Windows 7, 8, 10 or 11
- 1 GHz or faster 32-bit (x86) or 64-bit (x64) processor with at least 2 processor cores (4 or more cores recommended)
- 2 GB RAM (32-bit) or 4 GB RAM (64-bit)
- .NET 4.7.2 framework installed
- Screen resolution of at least 1280 x 768 pixels (higher is recommended)

1.2 Installation

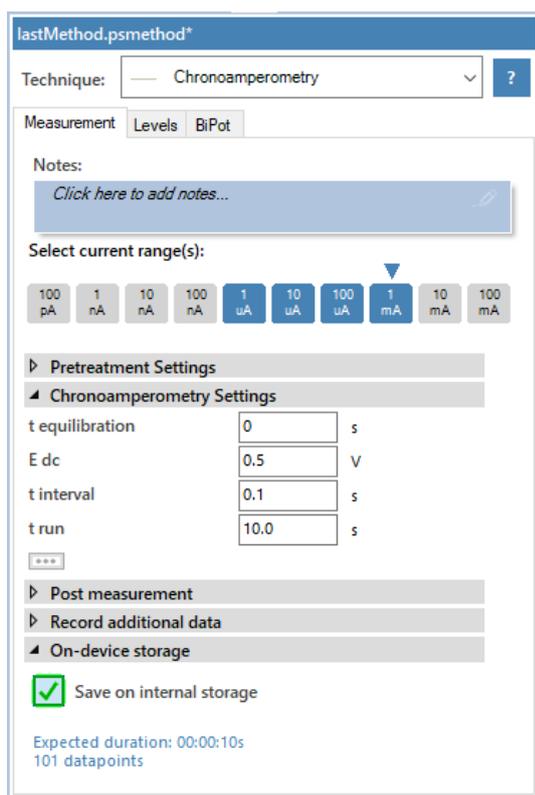
Install MultiTrace by running the setup program from the USB stick or when downloaded; from the location where the downloaded ZIP file was extracted. All required device drivers, prerequisites (like .NET), and demo files will be installed during the installation process. A desktop icon and Start Menu items will be created as well.

1.3 MultiTrace basic principles and terminology

It is strongly advised to read this section if you do not have any experience with PSTrace, MultiTrace, and/or instruments from PalmSens.

Methods

MultiTrace uses 'Methods' as a starting point for a measurement. A Method contains all measurement parameters like which *Technique* (Linear Sweep Voltammetry, Square Wave Voltammetry, Electrochemical Impedance Spectroscopy, etc.) is used and information about post-measurement actions such as data smoothing and peak searching. All these parameters can be edited in the Method Editor which is found at the left-hand side of the MultiTrace in both the Individual and Simultaneous mode.



Method Editor

The parameters can be saved to and loaded from a '.psmethod' file using the menu: 'Method'. These files do not include any measurement data and only contain the measurement parameters settings as shown in the Method Editor.

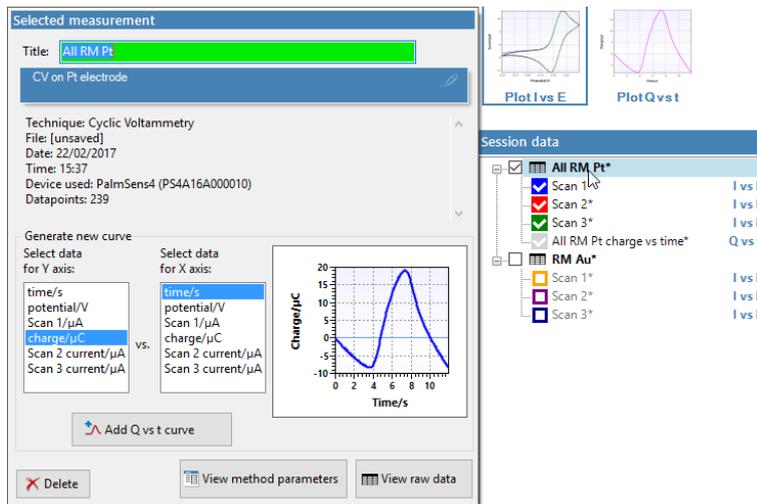
Switching between techniques or changes parameters in the Method Editor does not affect anything that has already been measured and is displayed in the Plot.

Measurement data

As soon as a measurement is started a new 'Measurement' item appears in the Legend containing the default Curve for the corresponding technique. The Measurement contains the following information:

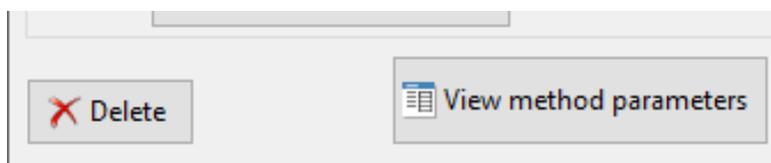
- Method parameters (as was defined in the Method Editor)
- Raw measurement data
- One or more curves

By clicking the Measurement in the Legend, the following window is shown:



Pop-up window shown when clicking a Measurement in the Legend

The window allows for changing the Measurement title and notes directly. The notes shown here are a copy of the original Method used for this measurement. Also, the window allows for adding new curves to the plot generated from the available Measurement data.

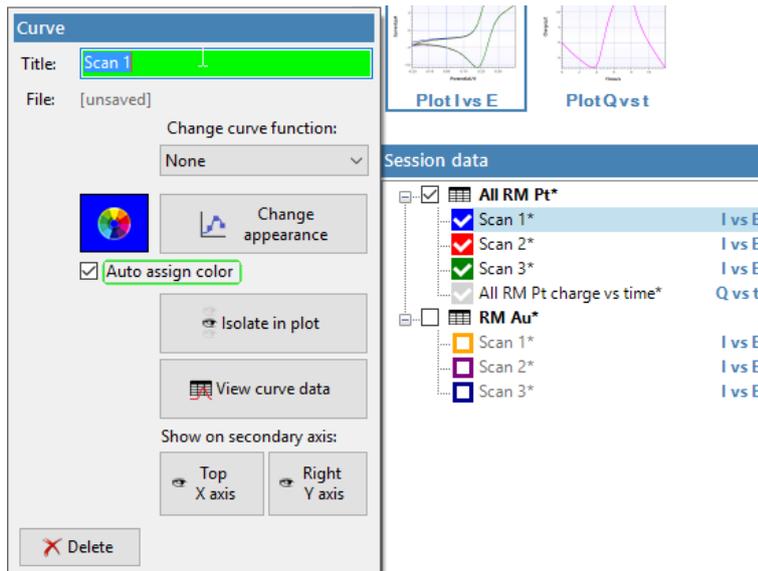


'View method parameters' button

The 'View method parameters' button shows the original Method used for this Measurement. This Method is a copy from the original Method defined in the Method Editor the moment the measurement was started.

Curves

A measurement can contain one or more Curves. By clicking a Curve in the Legend, a window is shown with information about the Curve. It allows you to directly change the title of the Curve as shown in the Legend or change its appearance or view the Data used for this curve.



Pop-up window shown when clicking a Curve in the Legend

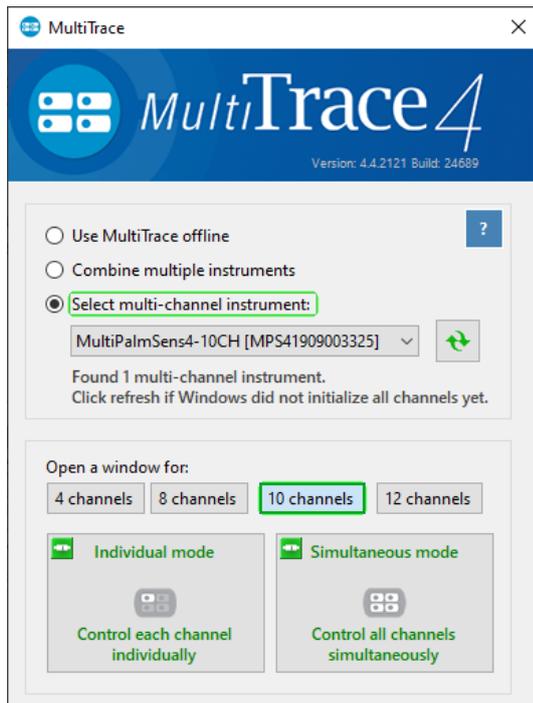
The 'Auto assign color' checkbox determines if a curve automatically gets a unique color when loaded next time. If the checkbox is disabled the color of the curve will be left unchanged when loading the data (.pssession file) the next time.

Saving your data

All available Measurement data and curves as well as the Method as shown in the Method Editor can be saved to a single 'Session' file (.pssession). Use the menu 'Data' to save and load Sessions. Any titles changed or customized Curve appearances like color and symbol used are saved as well.

1.4 MultiTrace Start window

When starting MultiTrace, the Start window is shown first:



MultiTrace Start window scanning for available channels

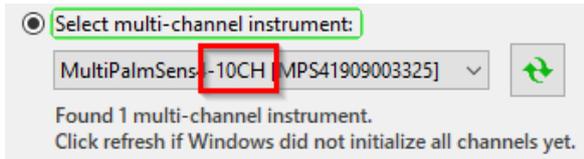
In this window the following options are available:

- **Use MultiTrace offline:** when selected you can start MultiTrace in Individual Mode or in Simultaneous Mode without being connected to any instrument.
- **Combine multiple instruments:** when selected, you can use MultiTrace to control different single and/or multi-channel instruments simultaneously. See section [Combining different instruments](#) on page 8 for more information.
- **Select multi-channel instrument:** when selected the software will automatically detect which multi-channel instruments are present and select the appropriate number of channels to show in the Simultaneous or Individual mode.

Detection of multi-channel instruments in Windows

When the instrument is connected to a Windows PC for the first time, Windows needs to initialize all channels. This might take up to a few minutes. MultiTrace will automatically select the appropriate button for the number of channels available. If a 12 channel is available but the user only wants the interface to show options for the first 4 or 8 channels this is also possible. Use the 'Combine multiple instruments' option to change channel names or use a custom selection of channels.

The text in the instrument-selection box shows how many channels were detected.



Number of channels detected

In case the number of channels is too low, click the refresh button (with the two green arrows).

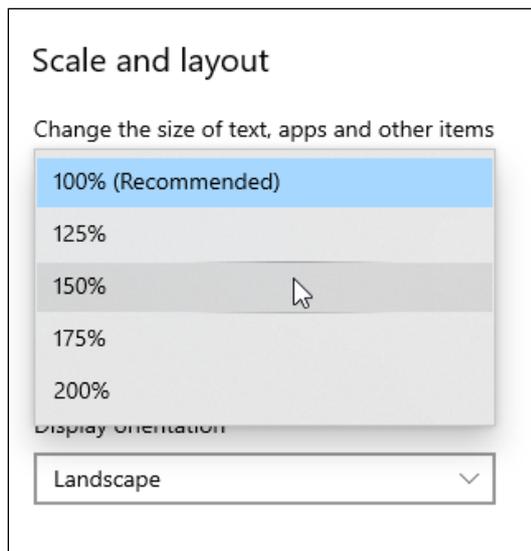
Display scaling in Windows 10

On some laptops or PCs with a high resolution, Windows 10 might have a setting active to scale-up text and apps. In that case, a warning is shown in the MultiTrace Start window.



MultiTrace Start window showing a warning to change your Display setting

You can check the scaling setting in the Display Settings window (Windows 10).



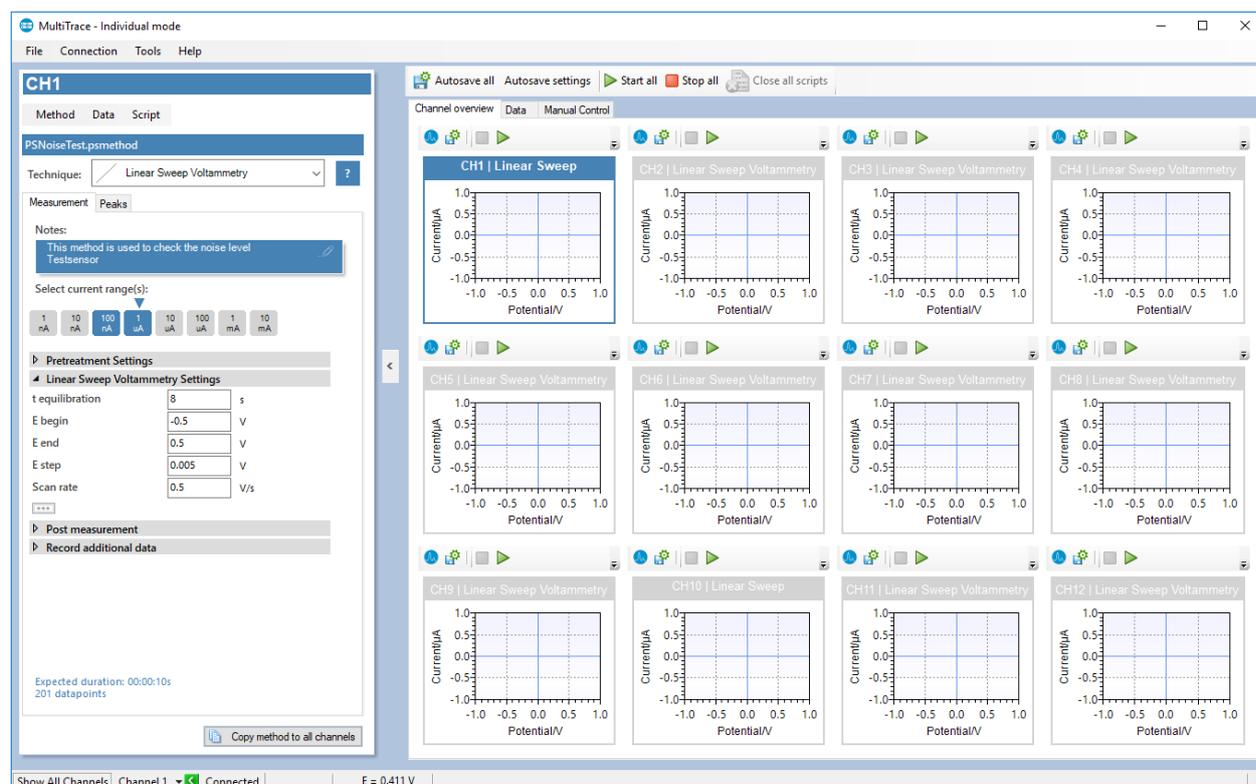
Windows 10 Scale and layout settings

If this setting is >100%, make sure to lower it or even set it to 100%, depending on your screen resolution. The reason for this is that Windows 10 cannot scale up Win32 applications, like MultiTrace, properly and will just stretch it. This will result in a poor resolution with little workspace for your channels.

Modes

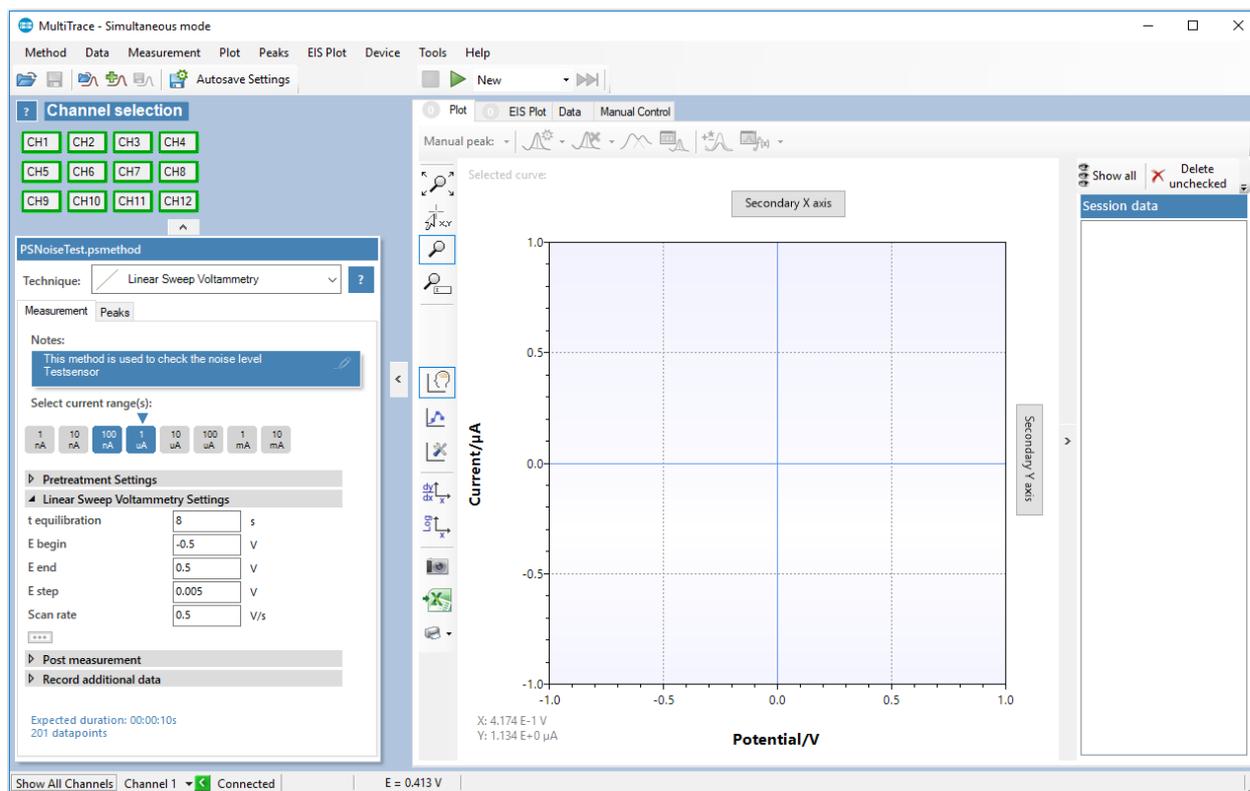
MultiTrace has two different modes; the Individual mode and the Simultaneous mode.

The Individual mode shows all channels in one overview. Each channel has its own plot and functions as an individual potentiostat. Different techniques or scripts can be run simultaneously on all channels. A complete set of methods, with different parameters for each channel, can be loaded from and saved to a single file (Method Set). Double-clicking on a channel opens a fully featured window for that specific channel. See also section [Individual mode](#) on page 10.



MultiTrace Individual mode with a 12-channel MultiEmStat connected

On clicking the 'Simultaneous mode' button in the Start window, the Simultaneous mode window is shown.



MultiTrace showing Simultaneous mode with a 12-channel MultiEmStat connected

The Simultaneous mode is used for controlling all channels simultaneously using one method. All results are presented together in a single plot. See also section [Simultaneous mode](#) on page 19.

This mode can also be used with the polypotentiostat **EmStat3-4WE**, see next section.

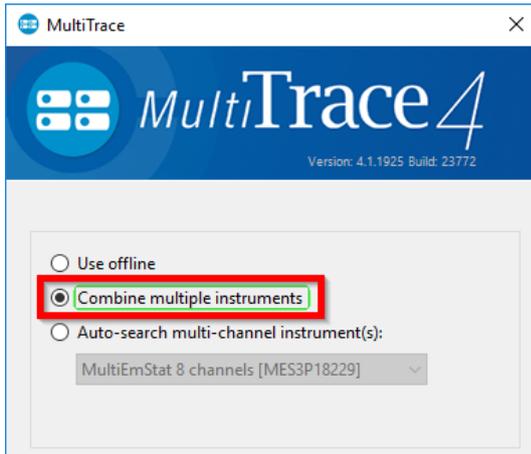
EmStat3-4WE / Polypotentiostat

If a polypotentiostat is detected, the Individual mode is disabled. The reason for this is that the additional WE's (shown as channels) are controlled by the main potentiostat and therefore do not function as individual channels. All working electrodes share the counter and reference electrode of the main potentiostat. The additional working electrodes can be used at a constant potential or follow the working electrode at a fixed potential offset. Each channel can automatically select the optimal current range for itself.

See section [EmStat3-4WE hardware description](#) on page 255 for more information about the EmStat3-4WE.

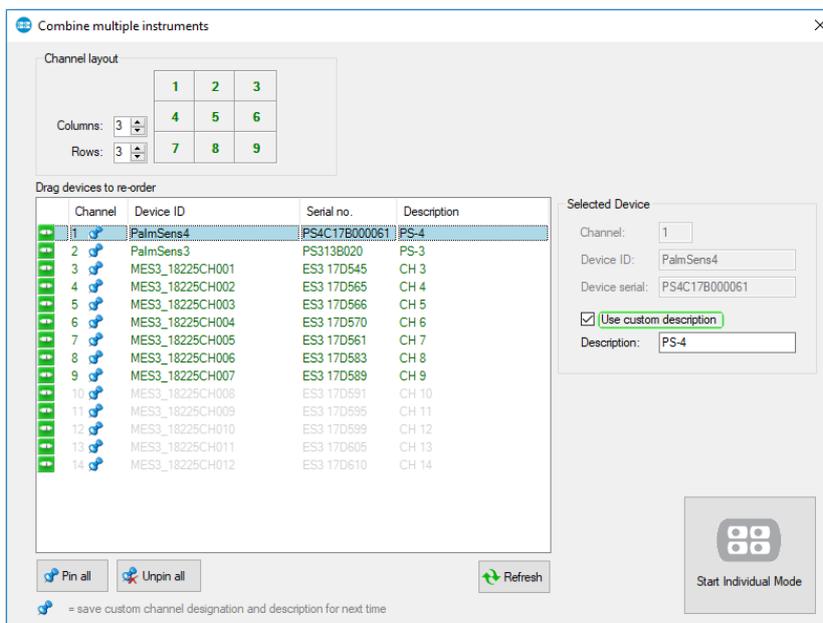
1.5 Combining different instruments

MultiTrace works with all main instruments provided by PalmSens BV. A collection of different instruments can be combined for control by MultiTrace in both Individual and Simultaneous mode. Either multiple multi-channel or single-channel instruments can be combined. To do this, make sure the option 'Combine multiple instruments' is checked before choosing a mode in the Start window.



MultiTrace Start window - the 'Combine multiple instruments' option

Clicking one of the mode buttons opens the compose channels dialog. This window allows the user to choose the channels to be included and the layout of the channels by setting the number of columns and rows. The channels will be arranged as shown in the list. The devices can be re-arranged by dragging and dropping. Each instrument can be given a custom description which is used throughout the program to identify the channel/instrument. Pinning the instrument (double-clicking on the particular row) in the list makes sure that the channel number and description are saved for the next time the 'Combine instruments' window is opened. The 'pin all' option helps to save custom channel designation and description for all the channels. If an instrument is pinned but not connected it will appear in grey. The user is then expected to click on the 'Refresh' button after unpinning the channel or after connecting/disconnecting an instrument.



Individual mode with combined instruments (PalmSens4, PalmSens3, MultiEmStat) - Compose channels screen

If an instrument is pinned but not connected it will appear in grey:

	11	MES3_18225CH011	ES3 17D605	CH 11
	12	MES3_18225CH012	ES3 17D610	CH 12
	13	PalmSens3	PS313B020	CH 13

PalmSens3 pinned in the list as channel 13, but not connected

1.6 Individual mode

Use the Individual mode when each channel is used independently. For example, each channel can be set up using a similar technique, but each with slightly different parameters. Or each channel can run an entirely different method or script.

The screenshot displays the MultiTrace software interface in Individual mode. On the left, a menu bar (1) is visible. Below it, the active channel menu bar (2) shows 'CH1'. The method editor (3) is open for 'PSNoiseTest.psmethod', showing settings for 'Linear Sweep Voltammetry'. On the right, a toolbar (4) contains 'Autosave all', 'Autosave settings', 'Start all', 'Stop all', and 'Close all scripts'. Below the toolbar, individual channel control panels (5) are shown for CH1, CH2, CH5, CH9, and CH10, each displaying a 'Current/µA' vs 'Potential/V' plot. At the bottom, the status bar (6) shows 'Show All Channels', 'Channel 1', 'Connected', and 'E = 0.409 V'.

MultiTrace showing a part of the screen in Individual mode

1.6.1 Menu

File	
Load method set	Loads a .psproject file containing references to method files for each channel.
Save method set	Saves a .psproject file with references to a method file for each channel.
Save all data	Opens a save dialog to save the data on all channels to one .psession file.

See also section [Files](#) on page 225.

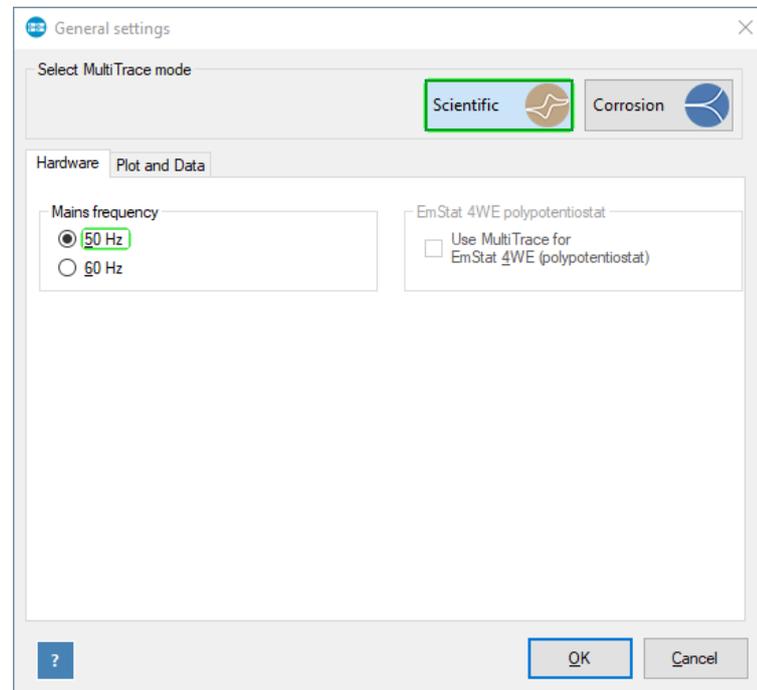
Connection

Disconnect/Reconnect

These menu items should not be necessary but can be useful in case the instrument needs to be connected to another USB port on the same PC for example. These menu items can not be used for connecting to a different instrument.

Tools

General settings



General settings – Hardware settings for MultiTrace

Scientific mode

The Scientific mode is the default mode of MultiTrace. This mode supports all relevant measurements and generic tools for curve analysis.

Corrosion mode

The Corrosion mode of PStTrace translates the supported techniques to naming conventions generally used with

Corrosion Analysis. Secondly, a tab with analytical tools is added to the user interface for:

- Linear polarization, from which the polarization resistance is obtained;
- Tafel plots, from which the corrosion rate is obtained;
- and Impedance data analysis using equivalent circuit fitting for determining values like polarization resistance and corrosion rate.

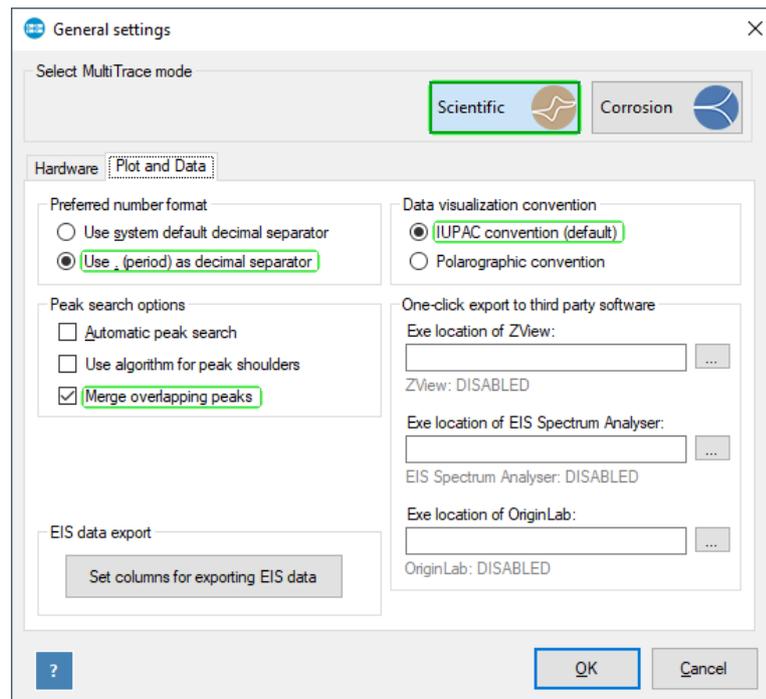
For more information see section [Corrosion mode](#) on page 211

Mains frequency

The Mains Frequency setting is used by the potentiostats to eliminate noise-induced by electrical appliances for low measurement intervals.

EmStat3-4WE polypotentiostat

‘Use MultiTrace for EmStat 4WE (polypotentiostat)’: This option is enabled only in the Simultaneous mode as the Individual mode is disabled if a polypotentiostat is detected.



General Settings – Plot and data settings for MultiTrace

Preferred number format

In case the local decimal separator is a comma instead of a point, the checkbox 'Use local default decimal separator' can be used to enforce the use of the local preference.

Peak search options

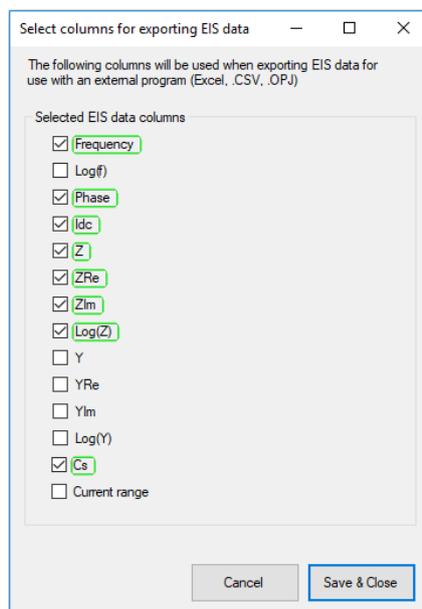
- 'Automatic peak search': If checked, automatic peak search is done on measured data immediately after the measurement has finished, or when data is loaded from a file.
- 'Inversed axes': If checked, the plot axes are always in a positive direction, also with a negative scan direction.
- 'Use alternative peak search algorithm': If checked, a different peak search algorithm is used which performs better on curves on a steep slope with no clear valleys.



Peaks found with the Alternative Peak Search option enabled.

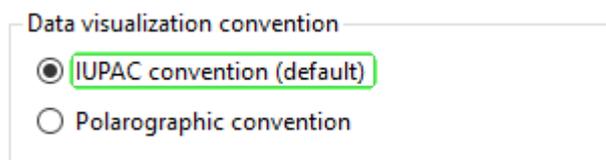
EIS data export

Set columns for exporting EIS data: Opens a dialog that allows the user to select the columns for exporting EIS data.



Plot and data settings – Set columns for exporting EIS data

Data visualization convention



There are two common conventions for Voltammetric plots both of which are supported in PStTrace:

- The IUPAC (International Union of Pure and Applied Chemistry) makes sure that anodic currents are plotted in a positive direction and cathod currents in a negative direction.
- If the Polarographic convention (also known as the North American, Polarographic, or Classic convention) is used, anodic currents will be plotted in a negative direction and cathodic currents in a positive direction.

Export data to ZView

Measured EIS data can be exported with one click to ZView. The location for ZView is detected automatically. If for some reason MultiTrace cannot detect the location of ZView automatically, browse to the location of the .exe file manually. Please note that MultiTrace has an excellent [built-in Equivalent Circuit editor and fitting tool](#) on page 137.

	<h3>Export data to EIS Spectrum Analyser</h3> <p>Measured EIS data can be exported with one click to the free program EIS Analyser. To use the 'one-click-export' button next to the plot, the location of this program needs to be set manually.</p> <p>Please note that MultiTrace has an excellent built-in Equivalent Circuit editor and fitting tool on page 137.</p> <h3>Export data to Origin</h3> <p>Measured data can be exported with one click to Origin. To use the one-click-export button next to the plot, the location of this program needs to be set manually.</p>
Peripheral Settings	See section Peripheral settings on page 44.
Autosave Settings	See section Autosaving measured data in Individual mode on page 39.

1.6.2 Selected channel menu bar

The menu at the top of the Method Editor applies to the currently selected channel as shown in blue.

CH1

Method Data Script

Channel control menu items

Method		
	Load	Loads a .psmethod file containing method parameters for the selected channel.
	Save	Saves all parameters of the active method to the existing .psmethod file in the Method Editor.
	Save As	Opens a save dialog to save all parameters of the active method in the Method Editor to a new .psmethod file.
Data		
	Load data	Loads data for the plot window of this channel.
	Load data from PalmSens4 internal storage...	This is enabled only for a MultiPalmSens4 device. Loads data from the internal storage of individual channels of a MultiPalmSens4.
	Add data	Adds data from a .psession file to the plot of this channel.

 Save data	Saves all the data for this channel to a .pssession file.
Export data to CSV file...	Opens a save dialog to save all the data for this channel to a .csv file for use in third-party software, like Excel.
Export data to OriginLab file...	Opens a save dialog to save all the data for this channel to a .opj file for OriginLab.

Script

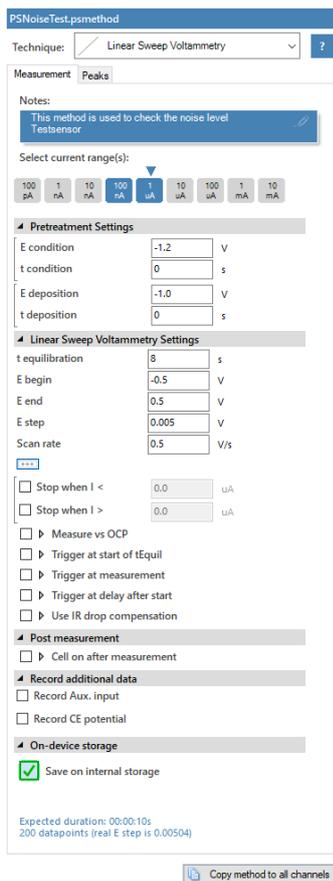
 Show script	<p>Opens a script window for this channel. This window can be closed during the running of the script, without stopping the actual script. Clicking the 'Show script' button again will show the active window with the running script again. This button can also be found in the small window with the plot for each channel while the script is active.</p>  <p><i>Show script button at the top of individual channel plot</i></p> <p>See for more information Using scripting in MultiTrace on page 235.</p>
 Copy script to all idle channels	Copies the script to all channels where no measurement is running.
 Close script	Closes and de-activates the script.

The recent method files and data files can be seen right below the menu options in the method menu and data menu respectively.

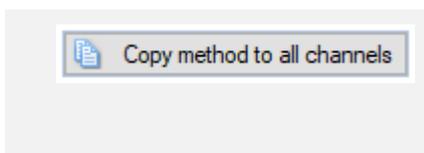
See also section [Files](#) on page 225.

1.6.3 Method Editor

The Method Editor shows the parameters for the selected channel. See for more information about the Method Editor section [Setting up a measurement](#) on page 33.

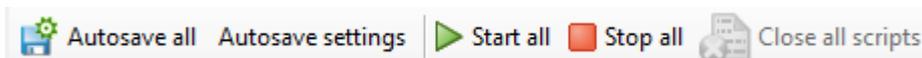


Method Editor



Copies the parameters for this channel to all other available channels. This can specifically be useful in combination with the 'Start all' button.

1.6.4 Toolbar for all channels

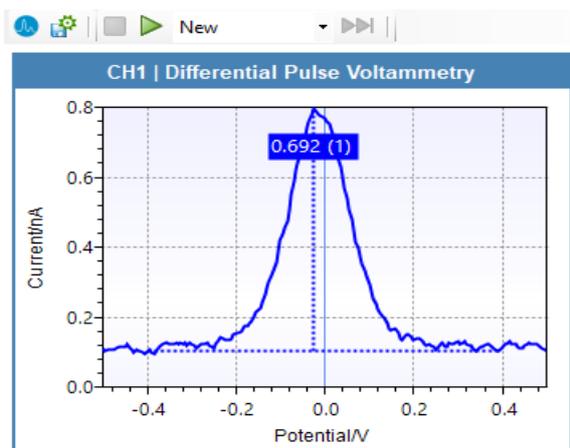


General toolbar applying to all channels

 Autosave all	<p>Enables automatic saving (as soon as a measurement is finished) for all available channels. The autosave feature can also be enabled/disabled separately for each channel using the  button found above each plot.</p>
Autosave settings	<p>Opens an 'Autosave Settings' window where the locations and formats for the autosaved data can be specified.</p>
 Start all	<p>Starts a measurement or script on all channels which are idle (connected, not running any measurement or script). A script will be started on channels that have the scripting window active.</p>

 Stop all	Stops any measurement/script running on all channels.
 Close all scripts	Closes all the active scripts.

1.6.5 Individual channel control



Individual plot with a toolbar for each channel

The toolbar contains the following buttons:

	Opens a fully featured window for this channel.
	If checked: use autosave for this channel.
	Controls measurements on this channel. Disabled when scripting is active.
	Becomes visible in the toolbar if a script is active for this channel. See also section Scripting on page 235.
	Closes the script window for this channel. Becomes visible in the toolbar if a script is active for this channel. See also section Scripting on page 235.
	Copies the script to all channels where no measurement is running.

1.6.6 Status bar

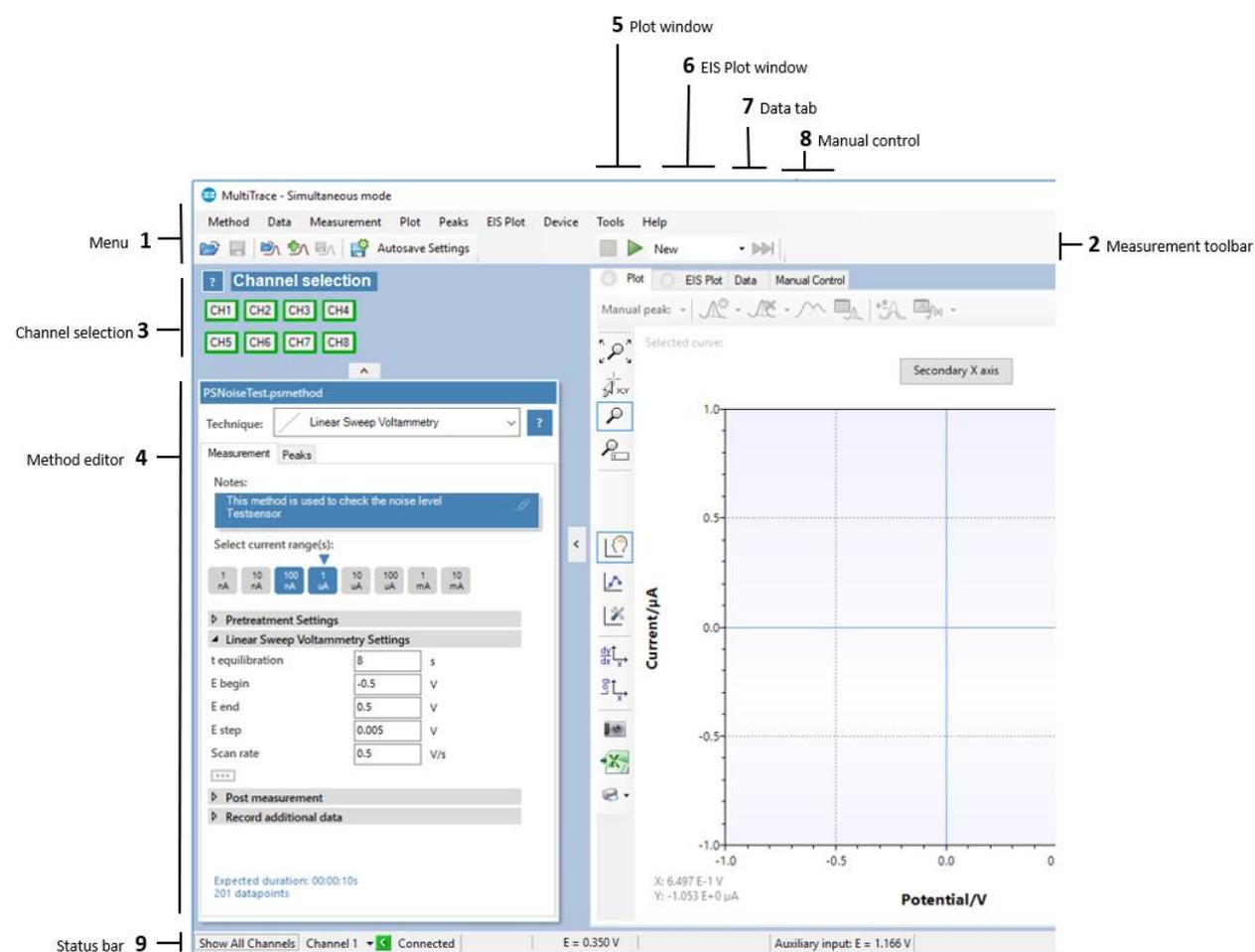


The status bar showing the status of channel one with the cell on

<p>Show All Channels</p>	<p>Gives an overview of readings for all channels.</p>  <p><i>Overview of readings during measurement on all channels</i></p>
<p><input type="checkbox"/> Do not show automatically</p>	<p>If checked, the status of all channels is not shown automatically when starting measurement on all channels using “Start all”.</p>
<p>Channel 1 Connected</p>	<p>Gives the actual status of the selected channel and allows selecting a different channel to view in the status bar. Clicking a plot will also change the selected channel shown on the status bar.</p>
<p>Underload</p>	<p>Shows if the cell readings are OK, in underload, or overload. See also section Resolution and optimal range selection on page 35.</p>
<p>E = 0.505 V I = 0.0010 * 1 uA</p>	<p>The potential and current readings for the selected channel. Current is shown in yellow in case of an underload and red in case of an overload.</p>
<p>Noise: 0.001</p>	<p>The noise bar is shown when the cell is on. See also section Noise on page 54.</p>
<p>Auxiliary input: E = 1.159 V</p>	<p>The auxiliary input. This value is ‘floating’ if nothing is attached to the auxiliary input of the connected channel.</p>

1.7 Simultaneous mode

The **Simultaneous mode** combines all channels in a single plot. This mode is used for multi-channel instruments to work on all channels simultaneously, each with its own working, reference, and counter electrodes (except in the case of a polypotentiostat like the EmStat3-4WE).



MultiTrace showing a part of the screen in Simultaneous mode

1.7.1 Menu

Method		
		Load
		Save
		Save As
		Exit

Loads a .psmethod file for the selected channel.

Saves all parameters of the active method to the existing .psmethod file in the Method Editor.

Opens a save dialog to save all parameters of the active method in the Method Editor to a new .psmethod file.

Exits the application

Data	
 Load data	Loads data for the plot window of this channel.
 Load data from PalmSens4 internal storage...	This is enabled only for channels of a (Multi)PalmSens4 instrument. Loads data from the 8 GB internal storage present on each channel.
 Add data	Adds data from a .psession file to the plot of this channel.
 Save data	Saves all the data for this channel to a .psession file.
Export data to CSV file...	Opens a save dialog to save all the data for this channel to a .csv file for use in third-party software, like Excel.
Export data to OriginLab file...	Opens a save dialog to save all the data for this channel to a .opj file for OriginLab.
 Use autosave	Automatically saves every measured curve to the location and with the prefix as specified in Autosave settings.
Autosave settings	Opens a window where the autosave location and file prefix can be specified.

Measure	
 Start F5	Starts the measurement with the parameters as specified in the Method Editor.
 Skip phase	Skips the current pretreatment phase (depositing, conditioning, or equilibrating).
 Abort F6	Abort the running measurement.
Overlay	If checked the next measurement will be added to the plot.

See section [Running a measurement](#) on page 37.

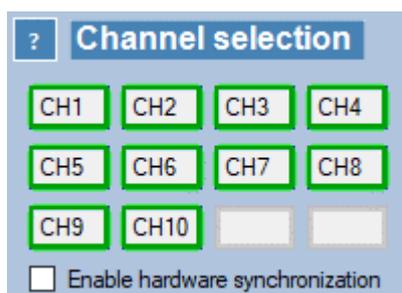
Plot	
	See section Plot, curves and data on page 177.

Tools	
	Same as settings window for Individual Mode on page 10.

1.7.2 Measurement toolbar

See section [Running a measurement](#) on page 37.

1.7.3 Channel selection



This panel gives a button for each available channel and allows channels to be left out with a measurement.

Double-clicking on a channel button will enable only that button and disable all the rest.

The checkbox to enable **hardware synchronization** is visible if the connected instrument supports it. When the checkbox for hardware synchronization is checked, the active channels will all be controlled by the hardware timer of channel 1, instead of their own timers. This gives a perfectly synchronized measurement across all enabled channels.

See also section [Using your multi-channel instrument as a polypotentiostat](#), on page 24.

1.7.4 Method Editor

See section [Setting up a measurement](#) on page 33.

1.7.5 Plot window

See section [Plot, curves and data](#) on page 177.

1.7.6 EIS Plot window

See section [Plot, curves and data](#) on page 177.

1.7.7 Data tab

Shows all data points measured for each channel. The button 'Copy to clipboard' can be used to copy/paste the table as plain text in any other program, like Excel or Notepad.

Select data: CH1: Linear Sweep Voltammetry Copy to clipboard

index	time/s	potential/V	current/ μ A	current range	current status	charge/ μ C
1	0.000	-0.500	8.437E-005	100 nA	Underload	0.000E+000
125	1.240	0.120	8.437E-005	100 nA	Underload	1.006E-004
126	1.250	0.125	9.062E-005	100 nA	Underload	1.015E-004
14	0.130	-0.435	8.437E-005	100 nA	Underload	1.016E-005
127	1.260	0.130	7.812E-005	100 nA	Underload	1.024E-004
128	1.270	0.135	9.062E-005	100 nA	Underload	1.032E-004
129	1.280	0.140	8.437E-005	100 nA	Underload	1.041E-004
130	1.290	0.145	9.062E-005	100 nA	Underload	1.049E-004

Data grid showing raw measurement data

1.7.8 Manual Control tab

See section [Manual Control](#) on page 207.

1.7.9 Status bar

Show All Channels	CH1 Connected	OK	E = 0.501 V	I = 0.394 * 10 nA	Noise: 0.048	Aux.In: E = 0.969 V
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The status bar showing for channel 1 with the cell on

	Gives an overview of readings for all channels.
Connected	Gives the actual status of the selected channel and allows selecting a different channel to view in the status bar. Clicking a plot will also change the selected channel shown on the status bar.
OK	Shows if the cell readings are OK, in underload, or overload. See also section Resolution and optimal range selection on page 35.
E = 1.000 V I = 1.002 * 1 μ A Noise: 0.001	The potential and current readings for this channel. The noise bar is shown when the cell is on. The current is shown in yellow in case of an underload and in red in case of an overload. See also section Noise on page 54.
Aux.In: E = 0.967 V	The auxiliary input. This value is 'floating' if nothing is attached to the auxiliary input pin of the connected channel.

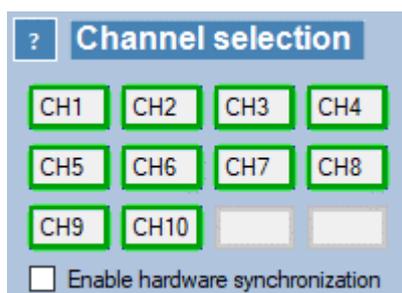
1.8 Using your instrument as a polypotentiostat

Supported instrument: MultiPalmSens4 and MultiEmStat4

In case your multi-channel instrument supports hardware synchronization, it allows for starting measurements exactly at the same time and performs the synchronized data sampling across multiple channels.

Hardware synchronization is supported in the Simultaneous mode of Multitrace.

**The synchronization is achieved at the hardware level,
no software overhead influences the timing.**



Checkbox for enabling hardware synchronization in the Simultaneous mode.

Using hardware synchronization, you can use your multi-channel instrument as a polypotentiostat, which means a potentiostat with one RE and one CE but multiple working electrodes in a cell. This functionality requires the grounds of all channels to be connected.

Should you have a model with galvanic isolation, just connect the green plugs of every channel and the one in the housing to the same conducting object, for example, your Faraday cage.

You connect the first channel as usual (RE, CE and WE). For the other channels, you just connect the working electrode. The reference and counter electrodes of each channel are connected, so RE2 to CE2, RE3 to CE3, etc. Please make sure not to mix the electrodes of different channels.

Prepare all channels to perform the same technique with the same parameters. This is easily done in the Simultaneous mode. When you trigger all channels, they will synchronize and start at the same time. Channel 1 will operate as usual, but all the other channels will follow channel 1's working electrode and perform the same measurement.

See also section [galvanic isolation](#) on page 257 about using multiple channels in the same cell.

2 First measurements

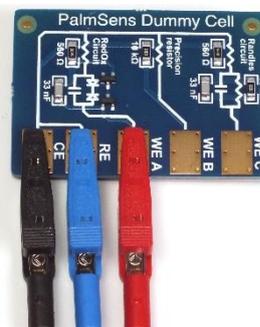
To get acquainted with the instrument, a TestSensor or Dummy Cell (since late 2017) is supplied to perform reproducible measurements.

2.1 Which dummy cell do I have

Before proceeding, please make sure to verify which dummy cell you have:



"PalmSens TestSensor A" (shipped until late 2017)



PalmSens Dummy Cell

PalmSens TestSensor A

The old PalmSens 'TestSensor A' has three stripped wires to connect to the electrodes using the croc clips. This test sensor simulates a RedOx circuit. This circuit contains two diodes in series in opposite direction with a cap in parallel and a series resistor. It simulates a non-diffusion limited RedOx system with a formal potential of 0 V. This circuit delivers i -E-curves, for example with Linear Sweep Voltammetry, that show an S-shape. That means the curve follows the Nernst equation. This circuit is prone to noise and thus can be used to investigate the noise in your measuring environment.

PalmSens Dummy Cell

The PalmSens Dummy cell offers three different circuits to check your system. To use the dummy cell, connect the croc clips to the corresponding connection pads on the dummy cell. The counter electrode (CE, black) and the reference electrode (RE, blue) are always connected to the same pads labelled CE and RE. The working electrode (WE, red) should be combined with the sense electrode (S, yellow/white) if present. For connecting the WE there are three different options.

The WE A pad connects the working electrode to the same RedOx simulating circuit as found on the old TestSensor A. This circuit contains two diodes in series in opposite direction with a cap in parallel and a series resistor. It simulates a non-diffusion limited RedOx system with a formal potential of 0 V. This circuit delivers i-E-curves, for example with Linear Sweep Voltammetry, that show an S-shape. That means the curve follows the Nernst equation. This circuit is prone to noise and thus can be used to investigate the noise in your measuring environment.

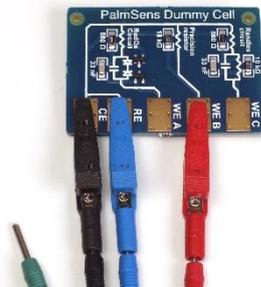
The WE B pad connects the working electrode to a 10 kOhm resistor. This resistor delivers a straight line as i-E-curves, for example as a result of a Linear Sweep Voltammetry measurement, following Ohm's law.

The WE C pad connects the working electrode to a simplified Randles circuit. This circuit will show in a Nyquist plot of an Electrochemical Impedance Spectroscopy (EIS) experiment a semi-circle, which is characteristic for an RC system (resistor and capacitor in parallel).

2.2 First measurement on the Dummy Cell

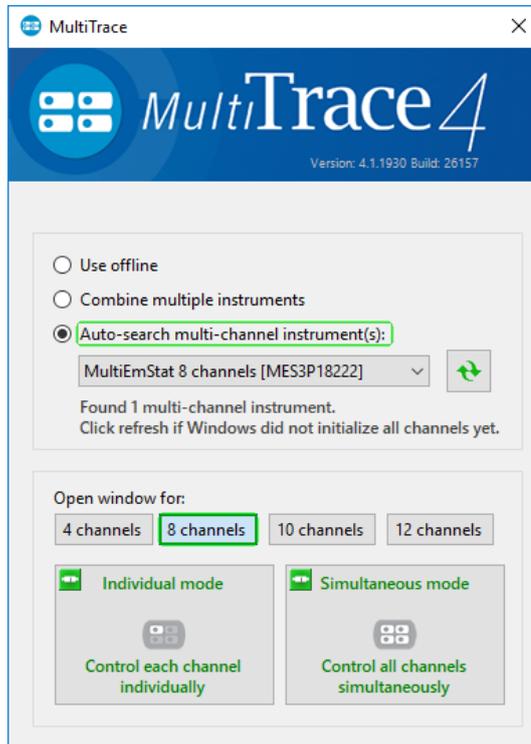
This section describes how to do the first measurements with any multi-channel instrument from PalmSens BV using the PalmSens Dummy Cell.

Please follow these steps if you have a PalmSens Dummy Cell:

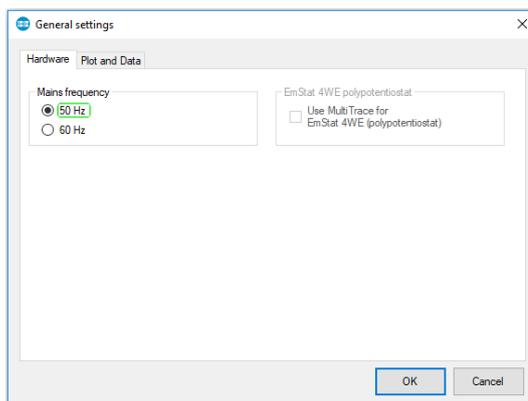


1. Make sure the instrument is on and connected to the PC using the supplied USB cable.
2. Open MultiTrace.

- The Start screen appears.
Connect the instrument and wait until all channels are detected. Click the refresh button (two green arrows) if the number of channels found does not correspond to the number of available channels on the instrument.

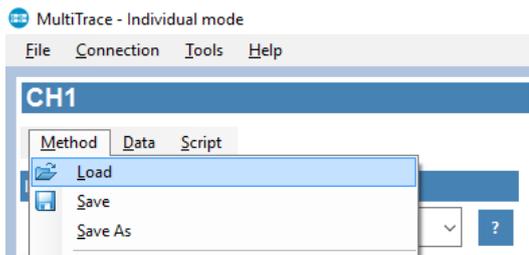


- Choose Individual Mode.
The following window shows at the first run:



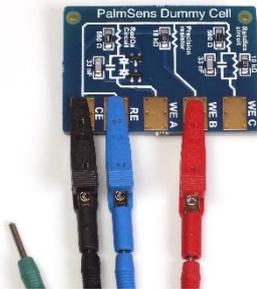
It is important for sensitive measurements to select the appropriate mains frequency.

5. Load the method file 'PSDummyCell_LSV_2V.psmethod' for channel one.



The file can be found in '[USER]\Documents\PSData\'.

6. Connect the Dummy Cell to channel one. Use the croc clips as shown here:

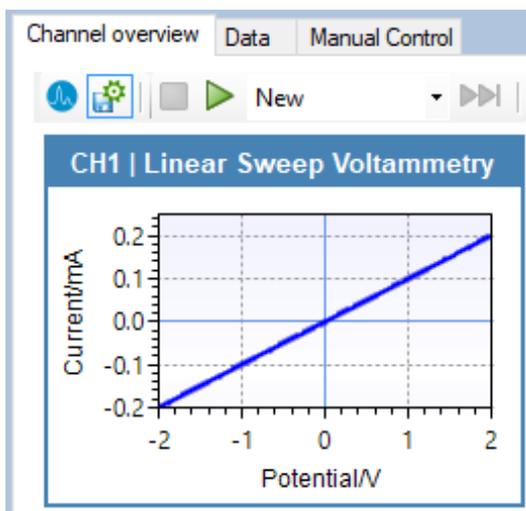


Connect CE, RE to the corresponding pads and WE to pad WE_B (10k resistor). If your instrument has a WE sense lead (S), make sure to join it with the WE lead.

7. Start measurement by clicking the "start measurement" button in the channel toolbar:



8. The result should be a straight line like this:



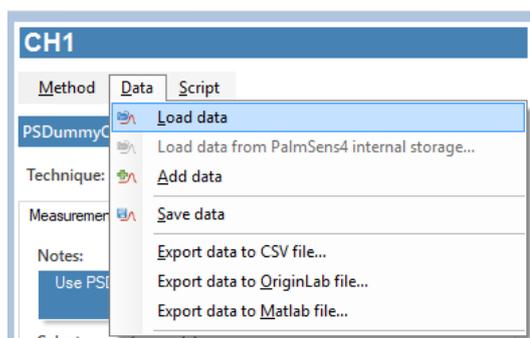
2.3 First EIS measurement on the Dummy Cell

Please follow these steps if you have a MultiPalmSens4 or MultiEmStat4 instrument licensed for EIS and a PalmSens Dummy Cell:

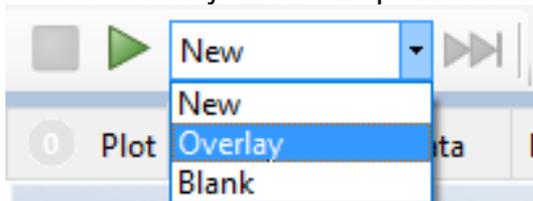


MultiEmStat4 (LR or HR), MultiPalmSens4 and PalmSens Dummy Cell

1. In case you haven't already, please follow steps 1-4 of the previous section first.
2. For channel one; load the data file
 '[USER]\Documents\PSData\EIS examples\
EIS on PS Dummy Cell WE_C.psession'



3. Connect the Dummy Cell using the croc clips. Connect the black CE lead to the CE pad, the blue RE lead to the RE pad and the red WE lead to WE_C. In case you are using a MultiEmStat4 HR with Sense; make sure to join the Sense and WE connectors.
4. Select 'Overlay' in the drop-down next to the green Start button:

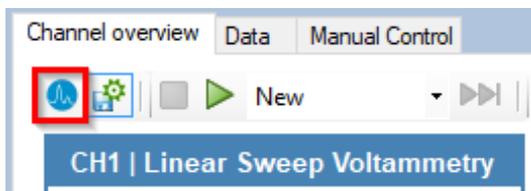


5. Start measurement by clicking the green Start button in the same toolbar.

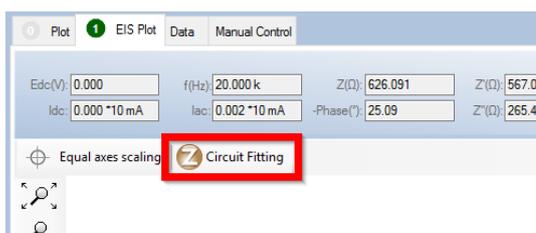
2.3.1 Fitting your data

Follow these additional steps to fit an equivalent circuit to your measurement data.

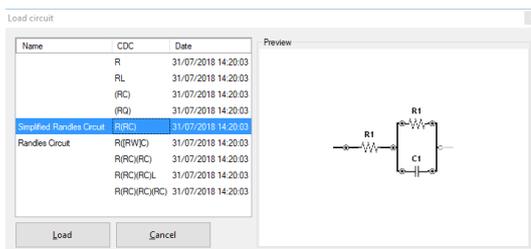
- When the EIS measurement is finished, double-click on the plot of channel 1, or click the blue PSTrace icon to open the Channel-window.



- Click the 'Circuit Fitting' button in the channel window:



- In the menu click 'Circuit' → 'Load' and select the 'Simplified Randles Circuit':



Click the 'Load' button.

- Now click the 'Fit Mode' button:



- Click the 'Fit' button:



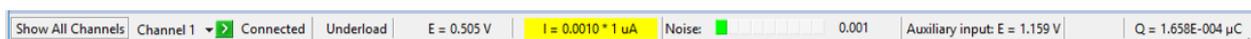
11. The found results should be close to these values:

Element	Fitted Value	Min Value	Max Value	Unit	Error%
R 1	557.5	1.00E-6	1.00E+12	Ω	0.065
R 2	9966	1.00E-6	1.00E+12	Ω	0.035
C 1	0.033	1.00E-6	1.00E+3	μF	0.064
Chi-Squared:	4.60E-6	Iterations:	26		

For more information about impedance measurements (EIS) see section: [Electrochemical Impedance Spectroscopy](#) on page 117.

2.4 Readings

The status bar always shows the measured potential and the current as well as the noise if the cell is on.



Status bar

Underloads and overloads

The box showing the status is used to note whether the instrument does not show current overload, current underload, or voltage overload.

Measured current values are wrong when a current overload warning is shown in red. This occurs when the current is out of the range of the selected current range. However, the warning is given already in orange at values that are close to overload.

If currents are below 5% of the selected current range, a current underload warning is given, since a lower current range can be applied. An underload will yield measurements with a low resolution. Select lower current ranges if available to increase the current resolution.

See section [Resolution and optimal current range selection](#) on page 35 for more information.

The noise bar shows the noise level at the current range in use. In case the bar shows orange or red, it is advised to look for ways to limit the noise level. Please refer to section [Noise](#) on page 54.

Voltage overload means that the impedance between the counter and the reference electrode is too high. This can be found when:

- the counter or the reference electrode is not properly connected,
- the conductivity of the solution is too low, which is overcome by adding an electrolyte,
- an air bubble isolates the reference electrode from the solution.

3 Measuring

MultiTrace provides not only the standard techniques as the voltammetric techniques or measuring current as a function of time but also complex methods like stripping chronopotentiometry (SCP) or PSA. Techniques are explained briefly in this chapter.

For information about impedimetric measurements, see chapter [Impedance Spectroscopy \(EIS\)](#) on page 117.

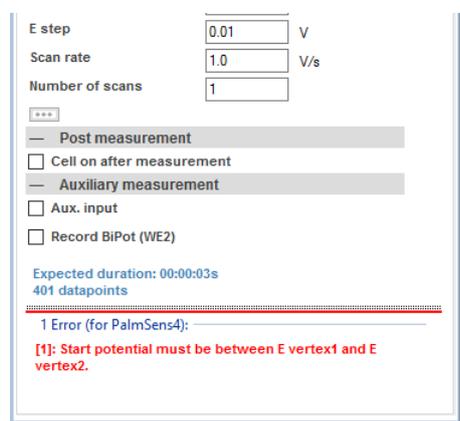
More theoretical background information can be found in:

- Christopher M.A. Brett and Ana Maria Oliveira Brett, Electroanalysis (Oxford Chemistry Printers, 64) Oxford Science Publications, ISBN-13: 978-0198548164
- Joseph Wang, Analytical Electrochemistry 3rd ed, John Wiley & Sons, ISBN-13 978-0471678793

3.1 Setting up a measurement

The 'Measurement' tab contains all the method parameters.

With each change of parameters, the validation of the method is checked. Errors or incompatibilities are shown instantly at the bottom of the measurement tab.



Method editor showing an error

Technique

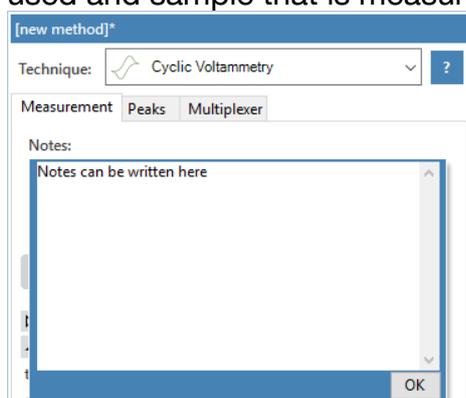
The techniques list shows the currently selected technique and allows the user to change the selected technique. If an instrument is connected, the techniques list will be

updated to show only the techniques supported by the instrument. Changing program mode will also filter out techniques that are not supported by the selected mode. If no device is connected and the default Scientific Mode is active, all techniques are shown in the list.

The parameters for each technique are saved when switching to another technique. This allows the user to switch between techniques without the need to change parameters each time.

Sensor and sample

The Notes textbox can be used to describe information for example about the sensor used and sample that is measured.



The notes box in the Method editor.

Current range



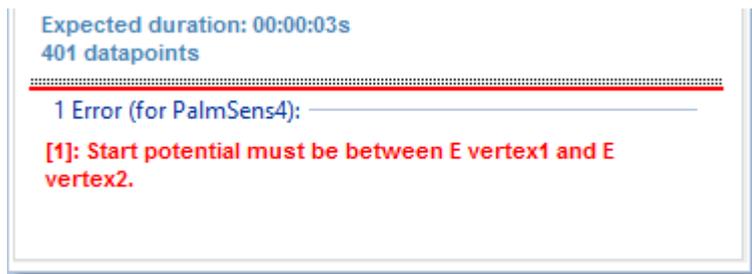
The current range selection buttons determine which range(s) are used for the measurement. See for more information next section [Resolution and optimal current range selection](#) on page 35. The small arrow hovering above one of the selected ranges determines at which current range the measurement starts. The starting range can be changed by means of clicking above one of the other selected current ranges changes.

Method settings

Entered values for each method setting should be within the absolute limits any instrument by PalmSens BV can handle. If values are not supported by the instrument connected this is shown at the bottom of the method editor. See the next chapter for a description and allowed values of each parameter.

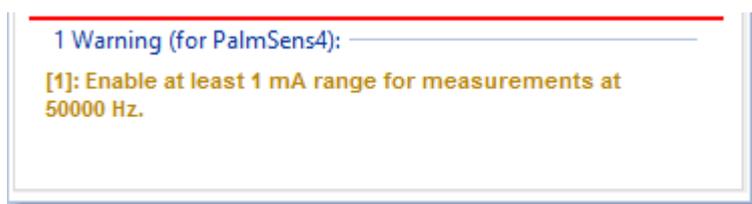
Validation

In case a value entered is invalid, an error message at the bottom is shown. Errors are shown in red and warnings are shown in orange. In case of a warning, this can be ignored by the user and the measurement can be started. In case of an error, the values need to be changed first to a value with the limits of the instrument to start the measurement.



Error shown in the method editor

A warning is shown in orange. Warnings can be ignored but, on most occasions, this will result in a bad measurement due to wrong settings.



Warning shown in the method editor

In case a value for the step potential is given which cannot exactly be met by the instrument because of its hardware-determined resolution, the actual value is shown at the bottom as 'real E step'.



Real E step shown in the method editor

3.2 Resolution and optimal range selection

The Method Editor shows one or two rows of buttons for the current and potential ranges. The potential ranges are only visible when a galvanostatic technique is selected.

With the range-buttons, the applicable current range(s) and potential range(s) during the measurement can be selected. If more than one button is selected, the instrument will select the most optimal range automatically (auto-ranging).

A measurement starts at the range with the small arrow above it.



Selection of applicable current and potential ranges shown for Potentiometry

The starting range can be changed by means of clicking above one of the other selected current ranges changes.

Double-clicking a range button will select only this range.

Automatic range selection / auto-ranging

During equilibration, the most appropriate range will be selected. If during a measurement the current or potential approaches a range limit, the instrument will switch automatically to a more suitable current or potential range (lower or higher). When a measurement exceeds the upper threshold (generally at 80% of the range), a higher range is selected within the range of selected ranges.

Likewise, when a measured current or potential falls repeatedly below the lower threshold (generally at 5% of the range) repeatedly, a lower range is selected if enabled by the user.

Because auto-ranging takes some time (in the order of milliseconds) this feature is only available at lower scan rates. For techniques at very high scan rates automatic ranging is not available. This is always shown as an error in the Method Editor if this is the case.

The following minimum and maximum measured currents apply for each instrument:

Instrument:	Maximum measured current:
EmStat1, 2 and 3(+)	± 2 * selected range
PalmSens1 and 2	± 2 * selected range
PalmSens3	± 3 * selected range
PalmSens4	± 6 * selected range
EmStat4 LR and HR	± 3 * selected range
EmStat Pico	± 0.6 * selected range

For instruments that support multiple potential ranges, the following applies:

Instrument:	Maximum measured potential:
PalmSens4	± 10 * selected range
EmStat4 LR	± 3 * selected range
EmStat4 HR	± 6 * selected range

Spikes and jumps

Please note that auto-ranging can cause spikes in the measurement curve, especially during fast measurements and/or measurements with high Faradic currents. Spike or jumps may occur due to a short interruption or change in measurement interval when switching between the ranges.

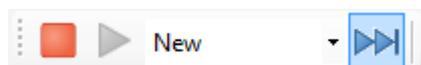
If auto-ranging is not needed it is always better to enable a single current range to prevent spikes or jumps in your curves.

If auto-ranging is not needed it is always better to enable a single current range to prevent spikes or jumps in your curves.

3.3 Running a measurement

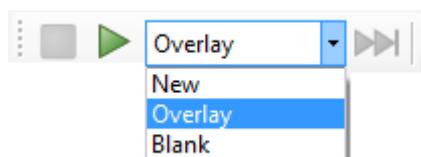
Measurements can be started and stopped with the buttons in the measurement tool strip or the 'Measure' menu.

The steps conditioning, deposition, and equilibration can be skipped each using the skip button: ▶▶



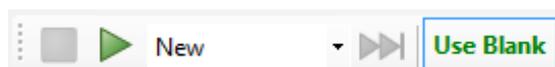
Skip button

Next to the start button, you can choose to make a 'New' graph for the measurement. If 'Overlay' is selected, the measured curve will be added to existing curves in the plot. Or measure a 'Blank' curve as a background scan to subtract it later.



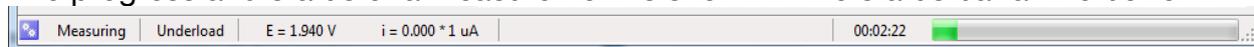
Options for the next measurement

If a blank curve is present an additional button is shown, see below. By enabling this button, the blank will be subtracted automatically after the measurement is finished.



Use Blank button

The progress and status of a measurement is shown in the status bar at the bottom.



Status bar

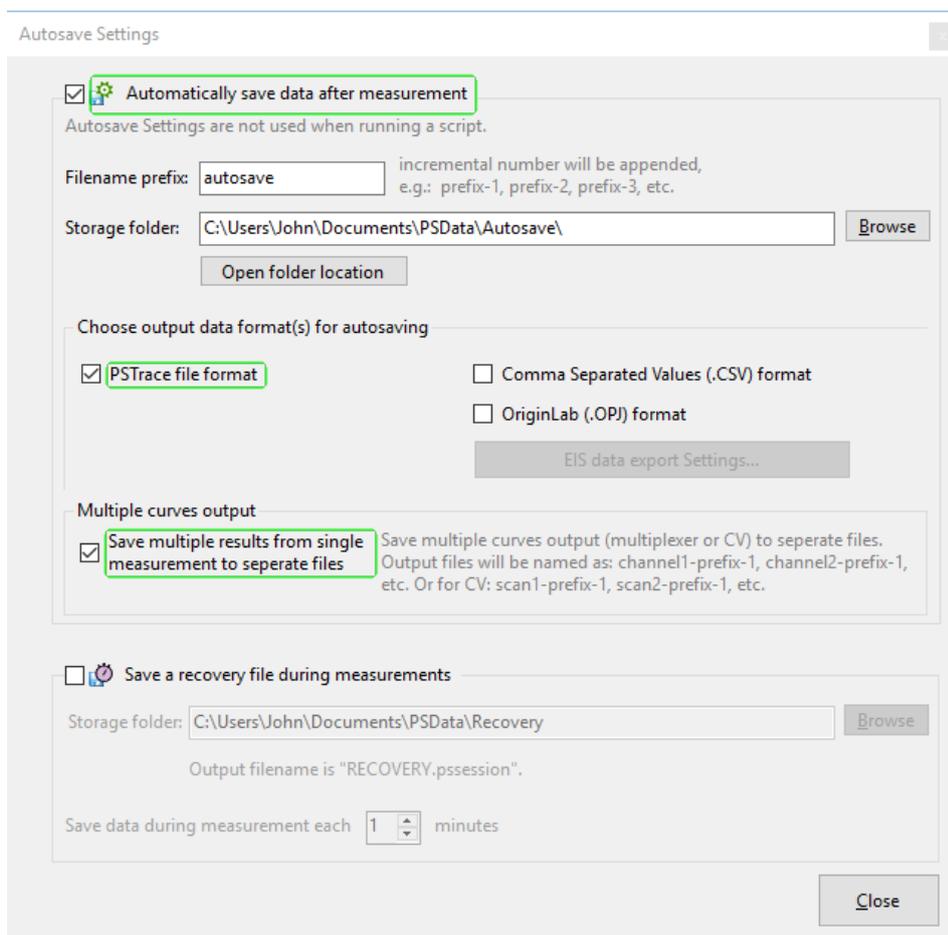
3.3.1 Autosaving measured data in Simultaneous mode

If autosave is enabled, every single measurement will be saved automatically in the corresponding format (see section [Files](#) on page 225) after the measurement has finished or is aborted.



Enabling autosave

The autosave output can be configured in the Autosave settings window.



The Autosave Settings window in Simultaneous mode of MultiTrace

Output settings

The output file gets the prefix followed by a sequential number. This number is based on the number of existing files with the given prefix in the storage folder specified and therefore increments with each new file added to the folder.

Output data formats

The output file can be stored in different formats. The MultiTrace format will store the file in a format that can be loaded in MultiTrace again. See also section [File types](#) on page 225.

A CSV file is a comma-separated file and can easily be imported into third party programs like Excel and Origin.

As a third option, it is possible to store the data in a native Origin file format. The latter will also include a graph (except for EIS data).

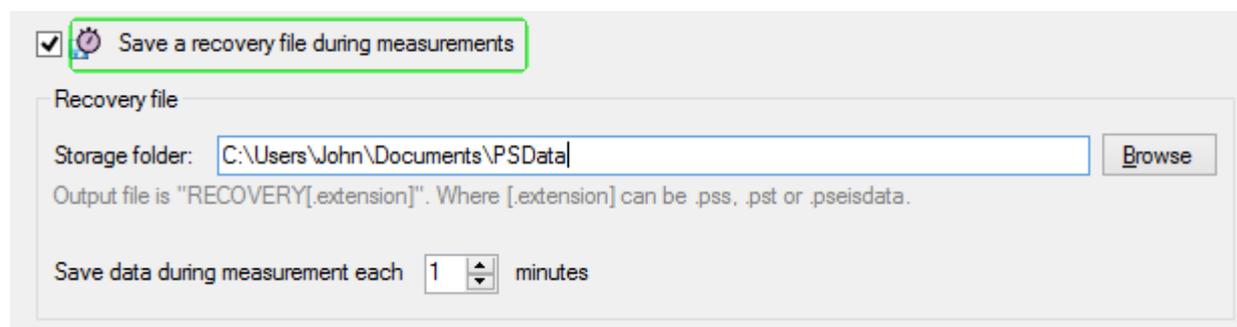
EIS data export settings

The button 'EIS data export settings' allows which columns are exported to the non-MultiTrace file formats.

Multiple curves output

Some measurements produce multiple curves, like a Cyclic Voltammetry measurement with multiple scans or a measurement done with a multiplexer. Enabling the checkbox will save the output of each separate curve to a single file instead of to a single file containing the data of all curves.

3.3.2 Recovery file in Simultaneous mode



Recovery file settings in Simultaneous mode of MultiTrace

The 'Autosave settings' window also shows options for keeping a recovery file during measurements. This option can be useful for long term measurements. In case of a PC crash or power outage, the most recent measurement data will still be available. The recovery file is overwritten for each new measurement.

3.3.3 Autosaving measured data in Individual mode

If autosave is enabled, every single measurement will be saved automatically in the corresponding format (see section [Files](#) on page 225) after the measurement has finished or is aborted.

Using the 'Autosave all' button, all autosave buttons are enabled for each channel. You can specify to use Autosave per channel separately.



The autosave output can be configured in the Autosave settings window.



The Autosave settings window in Individual mode of MultiTrace

Filename prefix

The filename prefix is the first part of the output filename and is appended with an incremental number.

Storage folder

The storage folder specifies where the data should be stored. If “Automatically add ‘channel #’” is checked, each data file is put in a channel-specific sub-directory.

Locations for each channel

For each channel the default location (specified at the top) or a specific location can be used (next to the channel), to save the data acquired for that particular channel.

Output format

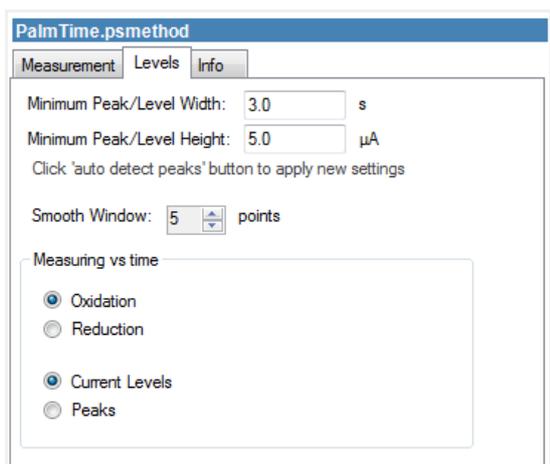
The output format is in PSTrace file format by default. Other options are to save the measured data as Comma Separated Values (CSV) or in OriginLab file format. CSV files

are a common file format that is supported by many programs like Excel and OpenOffice Calc.

3.3.4 Recovery file in Individual mode

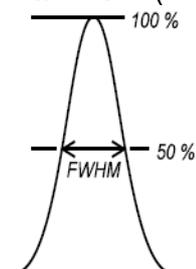
Enabling the 'Autosave during measurements' checkbox will make sure data is saved during measurements at the specified interval. The output file will be overwritten every time a new measurement is started. This feature ensures that measured data during long measurements will not be lost in case of a power failure or computer crash.

3.4 Peaks and levels



Peak/Level parameters tab (showing options for a technique as a function of time)

Minimum Peak Width determines the minimum peak width. Peaks with a lower width may not be detected. The peak width is the Full Width at Half Maximum (FWHM).



Minimum Peak Height determines the minimum peak height. Peaks lower than this value are neglected.

Smooth Window determines to which degree the measured curve is smoothed. The specified number is used to smoothen the data using the Savitzky-Golay method. Please note that too many points will influence the shape of the curve

Extra options for time methods:

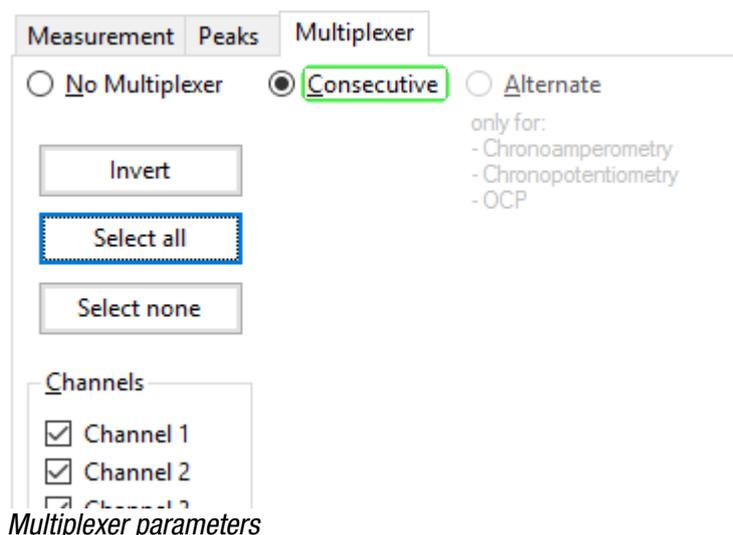
Oxidation or Reduction determines whether peaks or current levels are positive (Oxidation) or negative (Reduction).

Current Level or Peaks determines whether peaks or current levels are measured

3.5 Multiplexer

In the Multiplexer tab, it can be specified which multiplexer channels are measured and whether they should be measured consecutive (one by one) or scanned alternately (all channels simultaneously).

When the 'Consecutive' mode is chosen, any channel can be selected. In case 'Alternate' is checked, the manual selection of channels is limited to successive channels. So, it is possible to measure 2 to 8 or 2 to 16 successive channels, depending on the type of multiplexer in use.



Consecutive measurements

When doing Consecutive multiplexer measurements, the active multiplexer channel will switch to the next and be started after the entire measurement as defined in the Measurement tab has finished. This mode is available for every technique.

Alternate measurements

When doing Alternate multiplexer measurements all selected channels will be switched as fast as possible during each measurement interval. The switching time is ± 31 ms which means that the lower limit of the interval time is defined as (number of channels selected) * 0.031 s. For alternating between 8 channels the minimum interval time is 0.25 seconds.

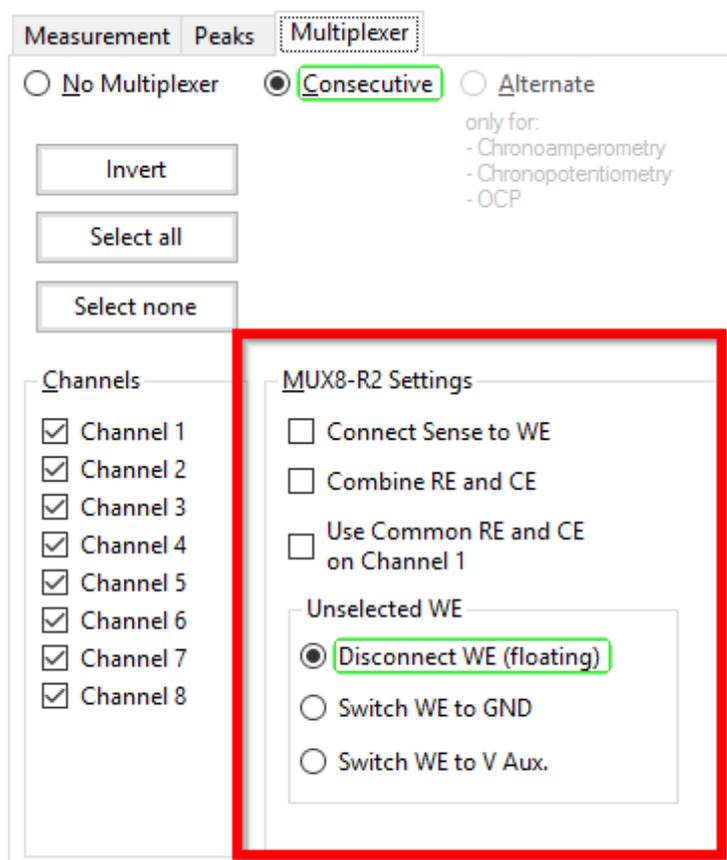
The following techniques support the Alternate multiplexer mode:

- Chronoamperometry;
- Chronopotentiometry;
- Open Circuit Potentiometry;
- and (Galvanostatic) Electrochemical Impedance Spectroscopy.

MUX8-R2 settings

The MUX8-R2 hardware configuration settings can be defined in software and will become visible in the multiplexer tab if the MUX8-R2 is either detected upon connection or selected in the General Settings window.

See also section [MUX8-R2 multiplexer](#) on page 295 for more technical information and a functional diagram.

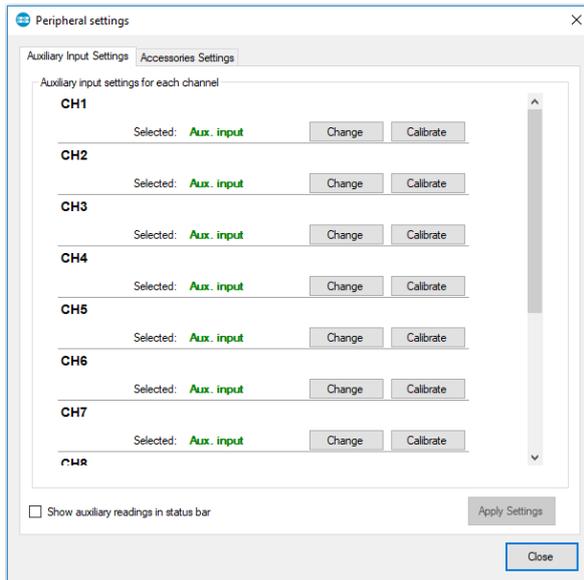


Multiplexer MUX8-R2 hardware configuration settings

When switching techniques, the initial MUX8-R2 settings will be taken from the Default settings as defined in the settings window of MultiTrace. However, when saving a method to either a .psmethod file or .psession file the settings will be saved as present in the 'Multiplexer' tab.

3.6 Peripheral settings

The peripheral settings window can be found in the menu of both Individual and Simultaneous modes in 'Tools' → 'Peripheral settings'.



MultiTrace Peripheral Settings - Auxiliary Input Settings tab

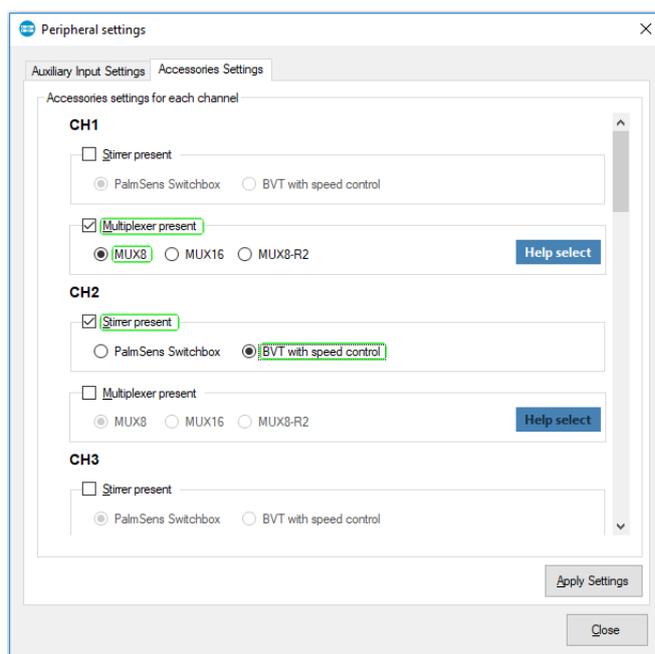
Auxiliary Input Settings

Both EmStat and PalmSens have an auxiliary input that can be used to measure an external signal simultaneously with a measurement. See section [Auxiliary port pin-outs](#) on page 269

In the case of the Simultaneous mode, each auxiliary input has an extra checkbox to toggle whether the input should be measured in case the 'Record Aux. input' is checked in the Method Editor.

Accessories Settings

PalmSens or EmStat can be used with a stirrer which is activated during the conditioning and deposition phase of a measurement. It can also be controlled manually in the [Manual Control tab](#) on page 207. The stirrer is normally controlled using a Switchbox from PalmSens BV. In case the BVT stirrer is used, its speed can be specified in the Manual Control tab for the channel.



MultiTrace Peripheral settings – Accessories settings

Check the 'Multiplexer present' checkbox if you are using a MUX multiplexer on the specific channel. All multiplexers can either be in the form of an accessory with the potentiostat or have an integrated EmStat potentiostat.

Use the button 'Help select' to see which model you are using.

3.7 Recording an auxiliary input

Supported by all instruments with an auxiliary input port.

To record an auxiliary value, like analog input voltage, temperature or cell potential, this needs to be enabled in the Method Editor in the section 'Record additional data':

▲ Record additional data

Record Aux. input

Whether or not recording additional data is supported depends on a combination of the connected instrument and the selected technique.

If the checkbox 'Record Aux. input' is checked, the voltage of the corresponding analog input pin on the physical auxiliary port of the corresponding channel is recorded. The auxiliary input value can also be translated to another value, like temperature, RPM (For an RRDE) or pH, depending on what is connected.

See also section [Using the auxiliary ports](#) on page 229.

3.8 Recording the cell potential

Supported by a selection of techniques with (Multi)PalmSens4,
(Multi)EmStat4 and EmStat Pico.

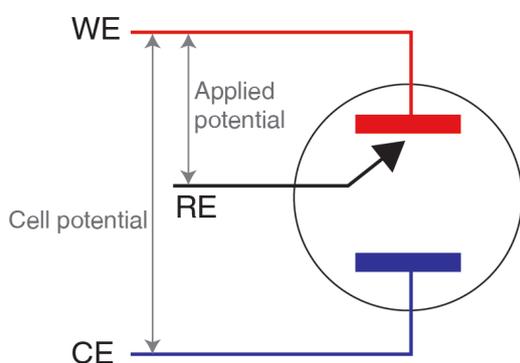
Recording the cell potential can be enabled in the Method Editor in the section ‘Record additional data’:

▲ Record additional data

Record Aux. input

Record cell potential

The ‘cell potential’ is the potential between the working and the counter electrode and thus the potential applied to the whole cell. In other words, this is the working electrode’s potential versus the counter electrode’s potential.



Cell potential

Sometimes it is interesting to calculate the potential of the counter electrode versus the reference electrode. This can be easily calculated with the applied potential and the cell potential. As is visible from picture above the cell potential is calculated by

$$\text{Cell Potential} = E(\text{WE}) - E(\text{CE})$$

By rearranging the potential of the counter electrode $E(\text{CE})$ can be calculated by

$$E(\text{CE}) = E(\text{WE}) - \text{Cell Potential}$$

3.9 Recording the WE potential

Supported by a selection of techniques with (Multi)PalmSens4 and (Multi)EmStat4.

Recording the WE potential can be enabled in the Method Editor in the section 'Record additional data':

▲ Record additional data

- Record Aux. input
- Record cell potential
- Record WE potential
- Record BiPot (WE2)

The 'WE potential' is the applied potential between the working and the reference electrode. This option can be enabled to measure the applied potential during supported potentiometric techniques on supported devices and can be used to determine if the instrument was able to apply the requested potential.

3.10 Recording the WE current

Supported by a selection of techniques with (Multi)PalmSens4 and (Multi)EmStat4.

Recording the WE current can be enabled in the Method Editor in the section 'Record additional data':

▲ Record additional data

- Record Aux. input
- Record WE current

The 'WE current' is the applied current between the working and the reference electrode. This option can be enabled to measure the applied current during supported galvanostatic techniques on supported devices. The current will be measured in the applied current range. In the case of an OCP measurement, the current will be measured in the current range as specified in the 'Select current range(s) selection' bar.

3.11 Using a BiPot

Supported by instruments with bi-potentiostat functionality for using a second working electrode (WE2).

In case one of the channels has a BiPot module present, this will be detected automatically.

An additional tab 'BiPot' will become visible in the method editor. This tab contains the settings for the use of the second working electrode (WE2).

The screenshot shows the 'BiPot' tab in the Method Editor. At the top, there are three tabs: 'Measurement', 'Peaks', and 'BiPot'. Below the tabs, the 'E WE2' field is set to '0.5' with a unit of 'V'. There are two radio button options: 'Potential is offset from WE1' (unselected) and 'Potential is fixed' (selected). Below these is a 'WE2 current range' section with a list of radio button options: '10 mA', '1 mA', '100 uA' (selected), '10 uA', '1 uA', '100 nA', '10 nA', and '1 nA'. At the bottom, there is a checkbox labeled 'Plot i(WE2) vs E(WE1)' which is currently unchecked.

The additional BiPot tab in the Method Editor.

The E WE2 is the potential set on the WE2. The options to choose if this potential is either an offset from WE1 or fixed is only shown for a BiPot with the PalmSens3 and PalmSens4.

The BiPot can be used with the following methods:

- Linear Sweep Voltammetry
- Cyclic Voltammetry
- Amperometric Detection
- Multistep Amperometry
- Multistep Potentiometry

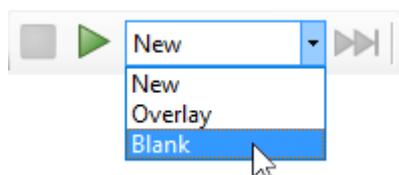
Plot i(WE2) vs E(WE1)

The plot window will show the current obtained for WE1 as well as for WE2 or Auxiliary. In case the checkbox 'Plot i(WE2) vs E(WE1)' is checked the i(WE2) curve will always be shown as an overlay in the plot, also when WE2 was maintained at a fixed potential.

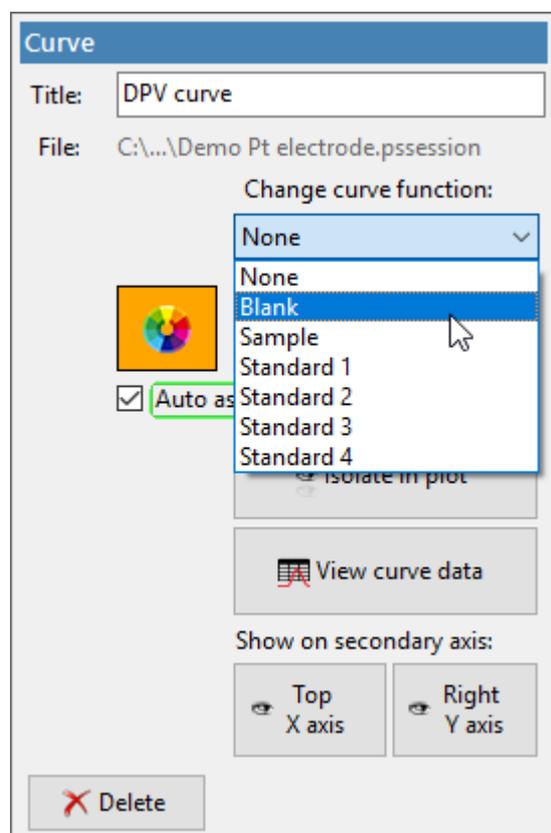
3.12 Using Blank subtraction

Blank subtraction can be used by first running a measuring as 'Blank' using the dropdown list next to the Start button. Or an existing curve can be designated as a Blank curve by clicking on this curve in the plot legend.

In the Simultaneous Mode of MultiTrace, the Blank option is not available in the dropdown list. So in this mode, a curve can **only** be designated as Blank using the curve tool window in the plot legend.



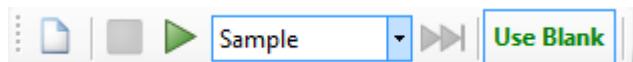
Select 'Blank' to measure a Blank curve for Blank subtraction before clicking the Start button.



By changing the curve function in the [curve tool window](#) on page 180, which is accessed by clicking on a curve in the plot legend.

When a Blank has become available, the 'Use Blank' button appears next to the measurement controls in the bar on the top of the screen.

When enabling the Use Blank button, the available Blank curve is subtracted immediately after the measurement from the measured curve. The Blank Curve is always shown in gray in the plot.



Button for Blank subtraction

3.13 Stop when E or i reaches a specified value

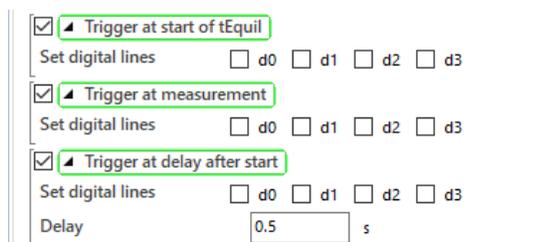
The settings for current and potential limits are found under the [...] button for advanced settings:



The limits entered here apply to the entire measurement excluding the pretreatment stages.

3.14 Trigger at ...

The settings for hardware triggering are found under the [...] button for advanced settings:



Hardware trigger settings

In case 'Trigger at ...' is set, the selected digital line(s) on the AUX port of the instrument will be set high when triggered. They will remain high until the end of the measurement. Refer to section [Auxiliary port pin-outs](#) on page 269 for more information about the position of the digital pins on your instrument's auxiliary port.

In case 'Trigger at delay after start' is used, the delay will be rounded to the applicable interval time between each measured data point.

3.15 On-device storage

The PalmSens4 and EmStat4-series are equipped with additional hardware for on-board data storage. In case the option 'Save on internal storage' is checked, the measurement will be stored on-board the instrument in a folder with the name of the day's date.



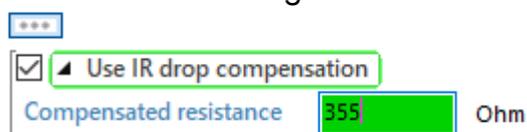
Save on internal storage in the Method Editor of MultiTrace

The on-board data can be browsed and downloaded using the menu: 'Data' → 'Load data from internal storage...'

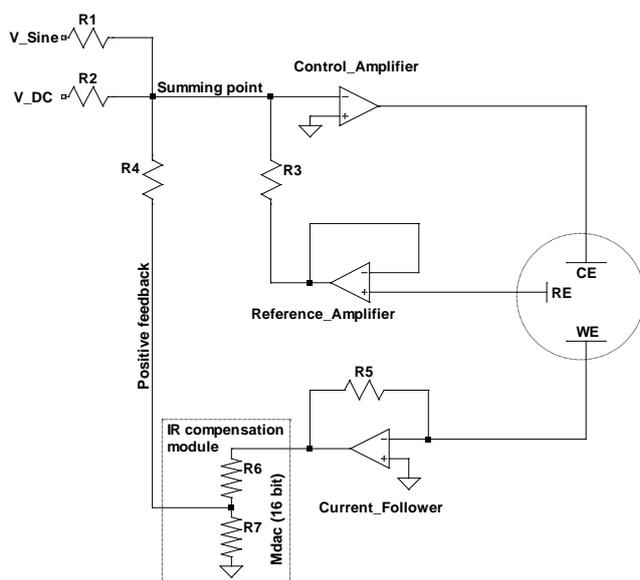
**For PalmSens4:
The following techniques are excluded for this functionality:
EIS, MultiStep and MixedMode.**

3.16 Using iR compensation

The resistance to compensate for can be entered directly in the Method Editor in PSTrace. The setting is found under the [...] button for advanced settings:



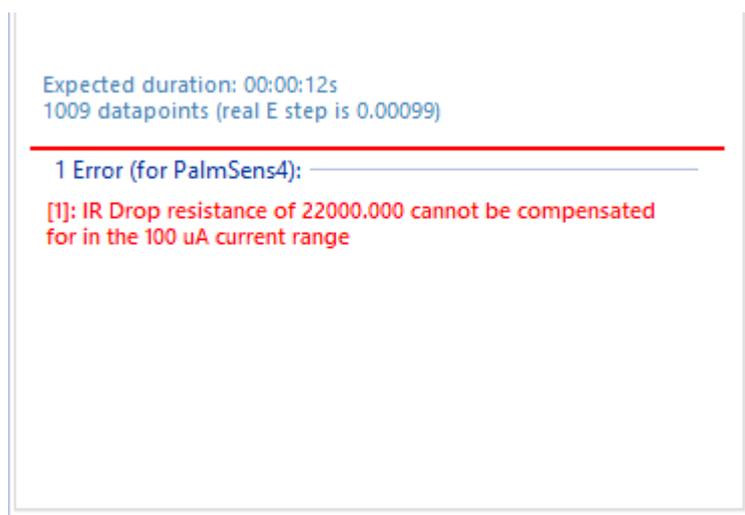
iR compensation for PalmSens4 is available as an in-factory add-on module. The resistance between the reference electrode and the double layer of the specimen can cause a significant potential drop, decreasing the applied potential where it is required. The module provides positive feedback to compensate for the iR drop between the Reference electrode and the outside of the double layer of the electrochemical cell. The PalmSens4 iR compensation module works by means of Positive Feedback. This is achieved using a 16-bit MDAC in the module which scales the output of the current follower opamp to provide a positive feedback voltage that is proportional to the current through the cell. The compensation voltage is added to the summing point before the control amplifier and thus increases the applied potential to counteract the iR drop.



The schematics for iR compensation as applied in the PalmSens4

Positive feedback allows for fast scan rates up to 10 V/s, depending on the characteristics of the cell. If the potential error to compensate for becomes close to the value set for E applied, the system might become unstable. Using iR compensation limits the measurement bandwidth to 10 kHz.

If auto-ranging is not allowed for the compensation used in combination with the selected current ranges, this is shown in the Method Editor:



Error message shown in the Method Editor

Make sure a single current range is selected in these circumstances.

Supported Techniques

The following techniques are supported for use with iR compensation:

- Linear Sweep Voltammetry
- Cyclic Voltammetry
- Square Wave Voltammetry
- Differential Pulse Voltammetry

- Normal Pulse Voltammetry
- ChronoAmperometry
- Multistep Amperometry

3.17 Noise

Electrochemical sensors and cells are susceptible to noise. If noise is interfering with your measurement, the solving strategies are rather numerous, but the sources for noise are also numerous. Here we describe the most successful and common methods for noise reduction.

Your power grid is usually using an alternating current. This undulating current influences the measured currents. PSTrace and PStouch have a filter setting for this mains frequency. Check in the Tools menu under General Settings if the mains frequency is set correctly.

Our environment is filled with electrical fields. Some of them are created by devices around us as side effects or in case of wireless communication on purpose. Although it is a bad idea to measure directly next to an electric arc furnace, it is usually not possible to have a workspace free of electrical fields, especially not during point-of-care measurements. A Faraday cage is usually sufficient to create a field-free environment. A metal box or cage out of metal mesh is a good Faraday cage. Even a shield out of aluminum foil can help. Place your electrochemical cell inside the Faraday cage and connect the cage to the ground lead (green) of the potentiostat. The cable delivered with your EmStat or PalmSens has an inbuilt shield and should protect your signal outside the Faraday cage. This is one of the most effective methods to reduce noise.

Cables should not be unnecessarily long, since they act as antennas for noise, but the cable delivered with your EmStat or PalmSens has an inbuilt shield and if you use the original cable, there is little reason to worry about cable induced noise.

Ground your measurement equipment. The best way to connect your equipment is star-shaped, that is all parts are connected with the ground at the same point. In an electrochemical lab that point is usually one small space of the faraday cage. This way earth loops that induce noise are avoided.

Check if the contacts are corroded. If so, remove the stains, for example with sandpaper.

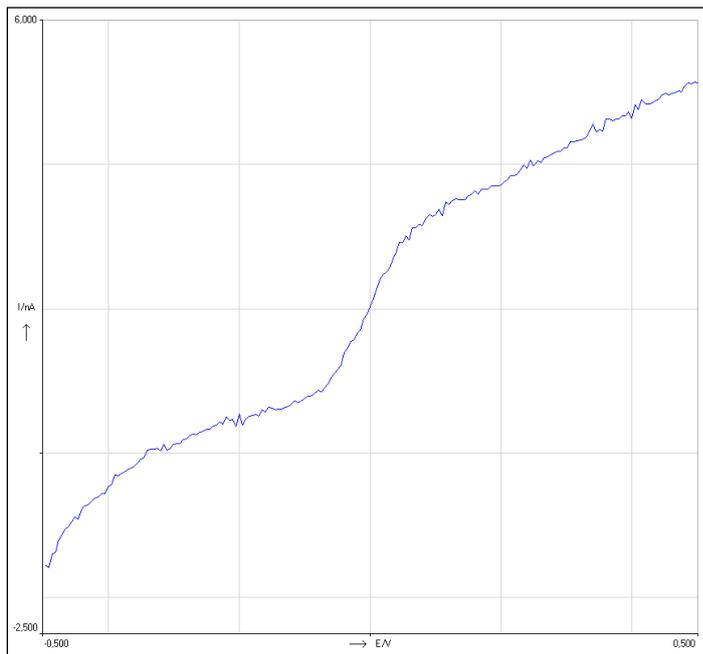
The Readings window (shown during the time the cell is on) displays the potential and the current and shows the noise level. The background color shows whether the noise might deteriorate the measurement. In case the noise level is higher than 0.1 times the selected current range, the bar will turn orange. In case the noise level exceeds 0.5 times the selected current range, the bar turns red. It is strongly advised to prevent measurements under such conditions.

In case the noise levels remain too high, the use of a Faraday cage (a simple metal cage or box may be sufficient) is required. Connect the metal cage or box to the safety ground or the green connector of the sensor cable. Place the cell or sensor together with the leads inside the cage.

3.18 Measuring the noise level of the instrument

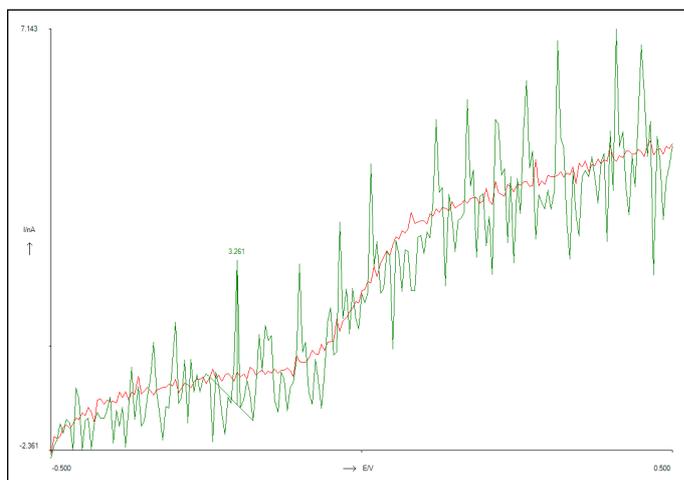
To determine the environmental noise levels, make sure the (green) test sensor is connected or the (blue) PS Dummy Cell is connected on pads RE, CE and WE A.

1. Load method file 'PSNoiseTest.psmethod'.
2. Start measurement.
3. Repeat the measurement but with a scan rate of 0.05 V/s. Note that the noise level is lower because the current sampling time is longer now. This decreases the measured noise level.



The curve shown in the figure above is a typical curve measured using the unmodified PSNoiseTest method and a PalmSens2. The sensor and connections are housed inside a grounded Faraday Cage.

Curves measured with an EmStat may show higher noise levels than with a PalmSens. In case the noise level is too high this is due to a noisy power supply of the USB ports and therefore the use of a USB Hub with its own ac-adapter between the PC or laptop and EmStat is advised.



The green (noisy) and red curves are both measured with the same conditions as before and with the same EmStat. The red curve is obtained when EmStat is connected to a USB hub instead of directly to a USB port of the PC.

The instrument can be controlled manually using the 'Manual Control' tab. To evaluate noise levels in the Manual Control tab click 'Cell On'. Change the applied potential from $E = 0.000$ V to $E = 0.500$ V by manipulating the horizontal scrollbar or entering the value in the textbox. Select the current range of 10 nA. The measured values of the potential and current as well as the noise are shown.

If the noise bar shows orange or red, the noise level is high. You are advised to see the effect of placing the test sensor in a Faraday cage.

Please refer to section [Noise](#) on page 54.

3.19 Available techniques

MultiTrace supports the following techniques in the (default) Scientific Mode.

Voltammetric techniques:

- | | |
|----------------------------|-----|
| ▪ Linear Sweep Voltammetry | LSV |
| ▪ Cyclic Voltammetry | CV |
| ▪ Fast Cyclic Voltammetry | FCV |
| ▪ AC Voltammetry | ACV |

Pulsed techniques:

- | | |
|----------------------------------|-----|
| ▪ Differential Pulse Voltammetry | DPV |
| ▪ Square Wave Voltammetry | SWV |
| ▪ Normal Pulse Voltammetry | NPV |

Amperometric techniques:

- | | |
|---|------|
| ▪ Chronoamperometry | CA |
| ▪ Zero Resistance Amperometry | ZRA |
| ▪ MultiStep Amperometry | MA |
| ▪ Fast Amperometry | FAM |
| ▪ Pulsed Amperometric Detection | PAD |
| ▪ Multiple-Pulse Amperometric Detection | MPAD |

Galvanostatic techniques:

- | | |
|---------------------------------|-----------------|
| ▪ Linear Sweep Potentiometry | LSP |
| ▪ Chronopotentiometry | CP |
| ▪ MultiStep Potentiometry | MP |
| ▪ Open Circuit Potentiometry | OCP |
| ▪ Stripping Chronopotentiometry | SCP (or
PSA) |

Coulometric techniques:

- | | |
|--------------------|----|
| ▪ Chronocoulometry | CC |
|--------------------|----|

Other:

- | | |
|--|------|
| ▪ Mixed Mode | MM |
| ▪ Electrochemical Impedance Spectroscopy | EIS |
| ▪ Galvanostatic Electrochemical Impedance Spectroscopy | GEIS |

All the above-listed techniques are described in this section, except EIS/GEIS. See section [Electrochemical Impedance Spectroscopy](#) on page 117 for more information about EIS/GEIS.

3.19.1 Linear Sweep Voltammetry (LSV)s

Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

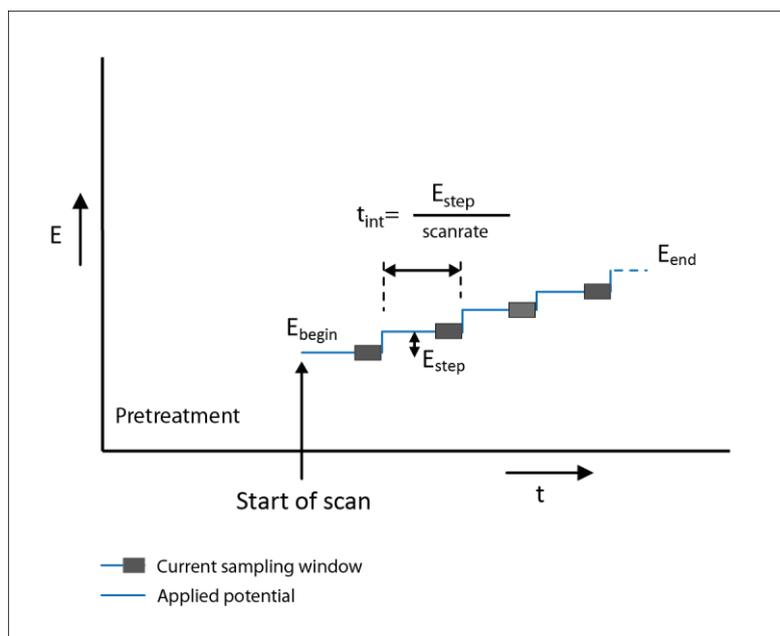
Description

In Linear Sweep Voltammetry a potential scan is performed from the begin potential, E_{begin} , to the end potential E_{end} . The scan is not really linear, but small potential steps (E_{step}) are made. The current is measured (sampled) during the last 25% interval period of each step. So, the number of points in the curve of the current versus potential is $(E_{end} - E_{begin}) / E_{step} + 1$.

The scan rate is specified in V/s, which determines the time between two steps and thus the sampling time. The interval time is $E_{step} / \text{scan rate}$. So, when E_{step} is 0.005 V and the scan rate 0.1 V/s the interval time is 0.05 s.

Measuring

In some applications, it is important that the current does not get too high. This might ruin the working electrode. If the potential at which this will occur is not known, it is possible to specify a maximum current value at which the scan stops. In this case, the end potential specified by the user is not reached.

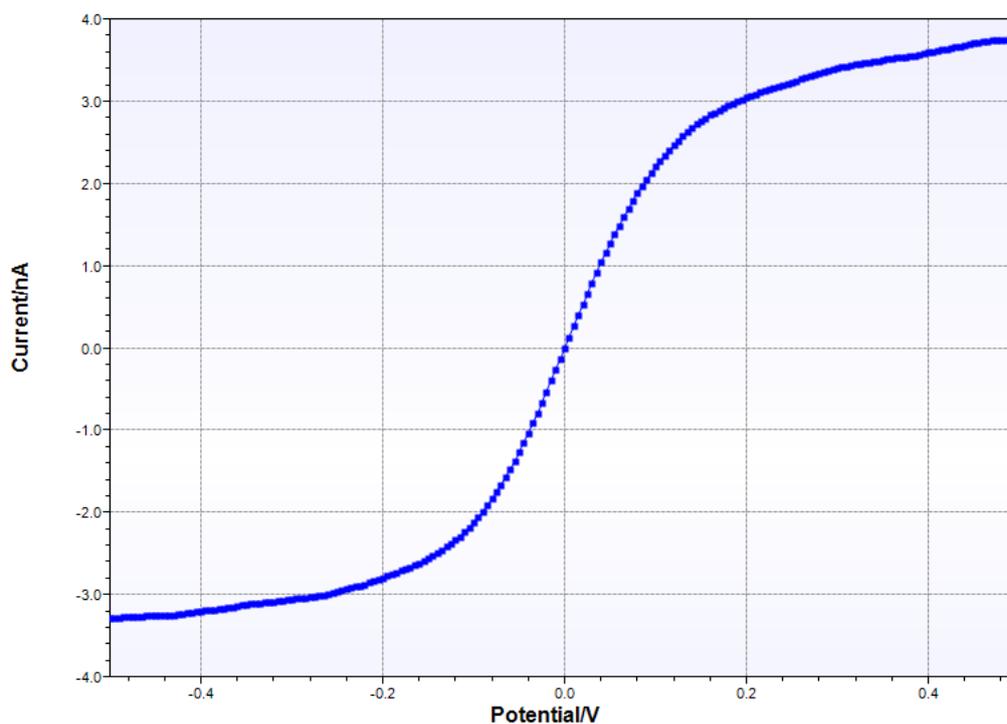


Potential applied during Linear Sweep Voltammetry

During the measurement, the curve is shown on the screen in real-time. It is possible to abort a measurement, by pressing the abort button above the plot.

During a measurement, the use of the 'Pause' button will halt the scan until the same button is used again. This button is not available at higher scan rates.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.



Typical LSV plot for a non-diffusion limited redox system and the WE_A of the PalmSens Dummy Cell.

Technique specific parameters

E begin	The potential where the measurement begins at.																		
E end	The potential where the measurement stops at.																		
	<p>The applicable potential range of each instrument:</p> <table> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table> <p>See also section EmStat Pico limitations for each mode on page 113.</p>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
E step	<p>The potential step size.</p> <p>The applicable step range for each instrument:</p> <table> <tr> <td>PalmSens1 and 2</td> <td>1 mV to 250 mV</td> </tr> <tr> <td>PalmSens3</td> <td>0.15 mV to 250 mV</td> </tr> <tr> <td>PalmSens4</td> <td>0.075 mV to 250 mV</td> </tr> <tr> <td>EmStat1 and 2</td> <td>0.1 mV to 250 mV</td> </tr> <tr> <td>EmStat3(+)</td> <td>0.125 mV to 250 mV</td> </tr> <tr> <td>EmStat4 LR</td> <td>0.1 mV to 250 mV</td> </tr> <tr> <td>EmStat4 HR</td> <td>0.183 mV to 250 mV</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV</td> </tr> </table>	PalmSens1 and 2	1 mV to 250 mV	PalmSens3	0.15 mV to 250 mV	PalmSens4	0.075 mV to 250 mV	EmStat1 and 2	0.1 mV to 250 mV	EmStat3(+)	0.125 mV to 250 mV	EmStat4 LR	0.1 mV to 250 mV	EmStat4 HR	0.183 mV to 250 mV	EmStat Pico	High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV		
PalmSens1 and 2	1 mV to 250 mV																		
PalmSens3	0.15 mV to 250 mV																		
PalmSens4	0.075 mV to 250 mV																		
EmStat1 and 2	0.1 mV to 250 mV																		
EmStat3(+)	0.125 mV to 250 mV																		
EmStat4 LR	0.1 mV to 250 mV																		
EmStat4 HR	0.183 mV to 250 mV																		
EmStat Pico	High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV																		
Scan rate	<p>The applied scan rate. The applicable range depends on the value of E step since the data acquisition rate is limited by the connected instrument.</p> <p>The applicable scan rates for each instrument:</p> <table> <tr> <td>PalmSens1 and 2</td> <td>1 mV/s (1 mV step) to 25 V/s (5 mV step)</td> </tr> <tr> <td>PalmSens3</td> <td>0.02 mV/s (0.15 mV step) to 500 V/s (5 mV step)</td> </tr> <tr> <td>PalmSens4</td> <td>0.02 mV/s (0.075 mV step) to 500 V/s (10 mV step)</td> </tr> <tr> <td>EmStat1 and 2</td> <td>0.02 mV/s (0.1 mV step) to 5 V/s (5 mV step)</td> </tr> </table>	PalmSens1 and 2	1 mV/s (1 mV step) to 25 V/s (5 mV step)	PalmSens3	0.02 mV/s (0.15 mV step) to 500 V/s (5 mV step)	PalmSens4	0.02 mV/s (0.075 mV step) to 500 V/s (10 mV step)	EmStat1 and 2	0.02 mV/s (0.1 mV step) to 5 V/s (5 mV step)										
PalmSens1 and 2	1 mV/s (1 mV step) to 25 V/s (5 mV step)																		
PalmSens3	0.02 mV/s (0.15 mV step) to 500 V/s (5 mV step)																		
PalmSens4	0.02 mV/s (0.075 mV step) to 500 V/s (10 mV step)																		
EmStat1 and 2	0.02 mV/s (0.1 mV step) to 5 V/s (5 mV step)																		

EmStat3(+)	0.025 mV/s (0.125 mV step) to 5 V/s (5 mV step)
EmStat4 LR	0.01 mV/s (0.1 mV step) to 500 V/s (200 mV step)
EmStat4 HR	0.01 mV/s (0.183 mV step) to 500 V/s (200 mV step)
EmStat Pico	0.01 mV/s to 10 V/s (10 mV step)

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

3.19.2 Cyclic Voltammetry (CV)

Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

Description

In Cyclic Voltammetry a cyclic potential scan is performed between two vertex potentials E vertex1 and E vertex2. The scan might start (E start) at one of these vertex potentials or anywhere in between.

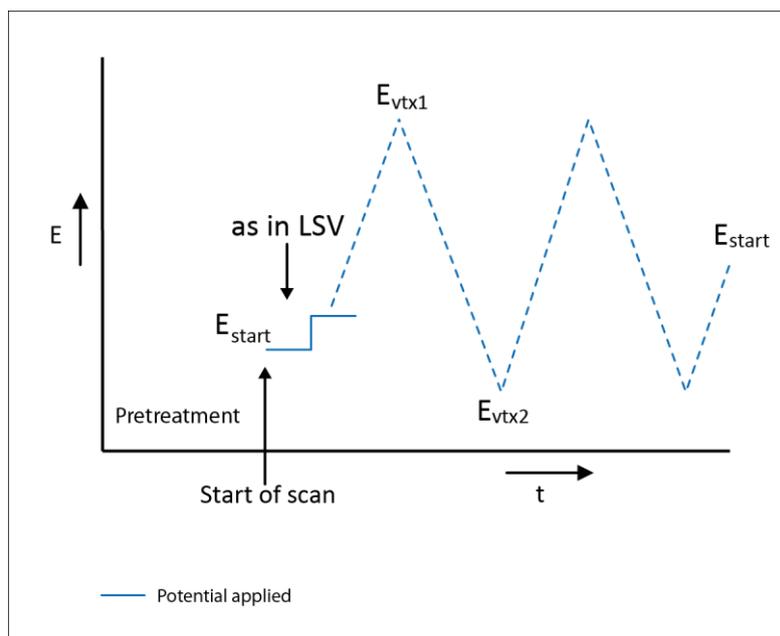
The scan is again not really linear, but small potential steps (E step) are made. The current is measured (sampled) during the 25% interval period of each step. So the number of points per scan of the current versus potential curve is $(2 * (E \text{ end} - E \text{ begin}) / E \text{ step}) + 1$.

The scan rate is specified in V/s, which determines the time between two steps and thus the sampling time. The interval time is E step / scan rate. So, when E step is 0.005 V and the scan rate 0.1 V/s the interval time is 0.05 s.

Fast CV

A CV becomes a Fast CV if the scan rate in combination with E step results in a rate of over 2500 points / second ($E \text{ step} / \text{scan rate} > 2500$).

See next section for more information.



Potential applied during Cyclic Voltammetry

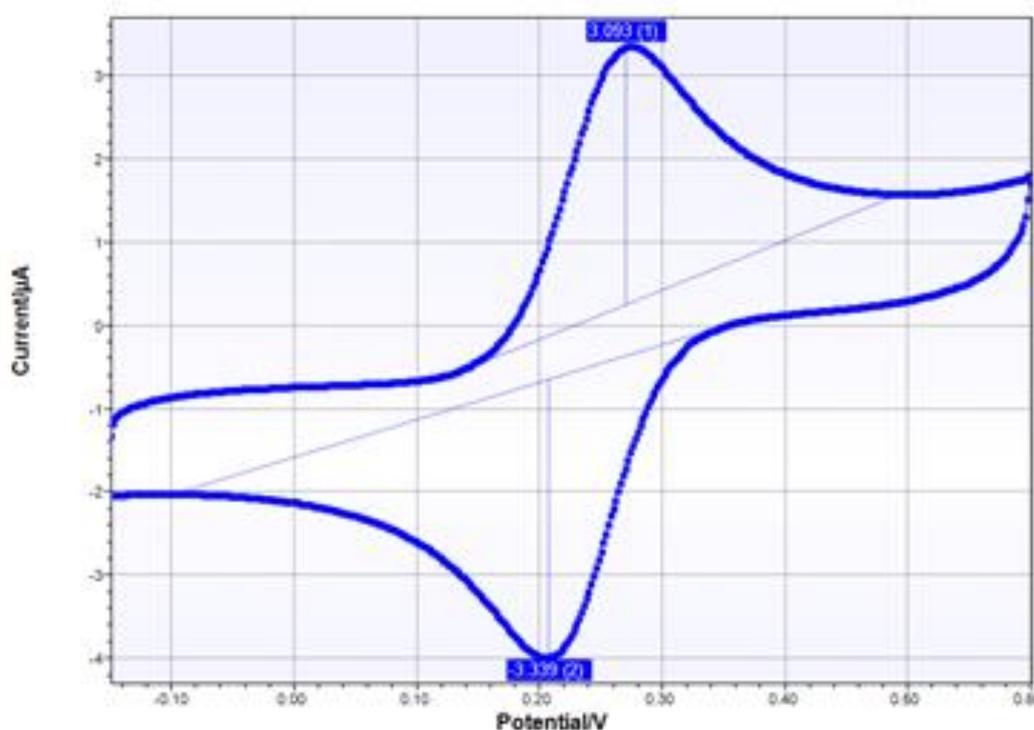
Measuring

As in LSV it is sometimes important that the current does not get too high. This might ruin the working electrode. If the potential at which this will occur is not known, it is possible to specify a maximum current value at which the scan direction will reverse. The user can also interactively determine where the scan direction is reversed, using the button 'Reverse'. In these cases, the specified vertex potential by the user is not reached.

During the measurement, the curve is shown on the screen in real-time. It is possible to abort a measurement, by pressing the abort button above the plot.

During a measurement, the use of the 'Pause' button will halt the scan until the same button is used again. This button is not available at higher scan rates.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.



Typical CV plot for a free diffusing redox species

Technique specific parameters

E start	The potential where the scan starts and stops at.																		
E vertex1	The first potential where the scan direction reverses.																		
E vertex2	The second potential where the scan direction reverses.																		
	The applicable potential range of each instrument:																		
	<table border="0"> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
	See also section EmStat Pico limitations for each mode on page 113.																		
E step	The potential step size.																		
	The applicable step range for each instrument:																		
	<table border="0"> <tr> <td>PalmSens1 and 2</td> <td>1 mV to 250 mV</td> </tr> </table>	PalmSens1 and 2	1 mV to 250 mV																
PalmSens1 and 2	1 mV to 250 mV																		

	PalmSens3 PalmSens4 EmStat1 and 2 EmStat3(+) EmStat4 LR EmStat4 HR EmStat Pico	0.15 mV to 250 mV 0.075 mV to 250 mV 0.1 mV to 250 mV 0.125 mV to 250 mV 0.1 mV to 250 mV 0.183 mV to 250 mV High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV
Scan rate	The applied scan rate. The applicable range depends on the value of E step. The applicable scan rates for each instrument:	
	PalmSens1 and 2 PalmSens3 PalmSens4 EmStat1 and 2 EmStat3(+) EmStat4 LR EmStat4 HR EmStat Pico	1 mV/s (1 mV step) to 25 V/s (5 mV step) 0.02 mV/s (0.15 mV step) to 500 V/s (5 mV step) 0.02 mV/s (0.075 mV step) to 500 V/s (10 mV step) 0.02 mV/s (0.1 mV step) to 5 V/s (5 mV step) 0.025 mV/s (0.125 mV step) to 5 V/s (5 mV step) 0.01 mV/s (0.1 mV step) to 500 V/s (200 mV step) 0.01 mV/s (0.183 mV step) to 500 V/s (200 mV step) 0.01 mV/s to 10 V/s (10 mV step)
Number of scans	The number of repetitions for this scan.	

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

3.19.3 Fast Cyclic Voltammetry (FCV)

Supported instruments:

- PalmSens series

Description

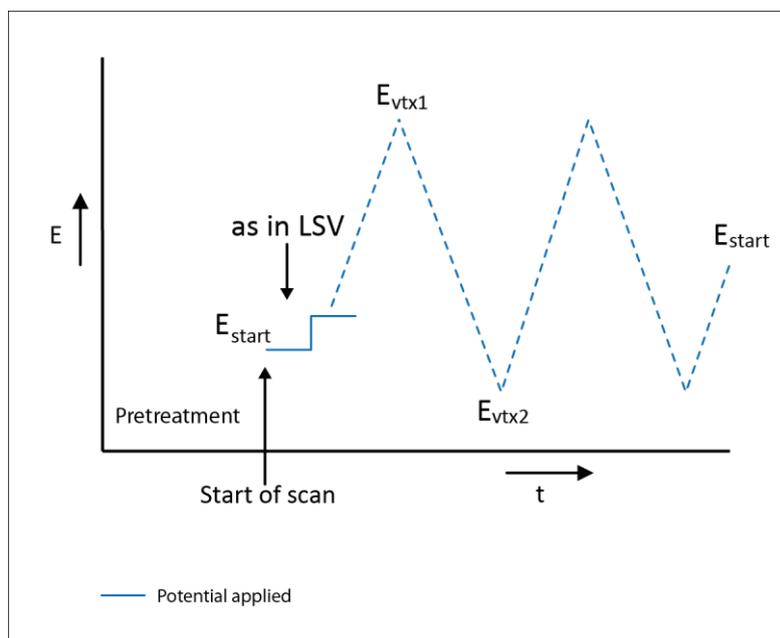
(See also previous section: Cyclic Voltammetry)

In Cyclic Voltammetry a cyclic potential scan is performed between two vertex potentials E vertex1 and E vertex2. The scan might start (E start) at one of these vertex potentials or anywhere in between.

A CV becomes a Fast CV if the scan rate in combination with E step results in a rate of over 2500 points / second ($E \text{ step} / \text{scan rate} > 2500$).

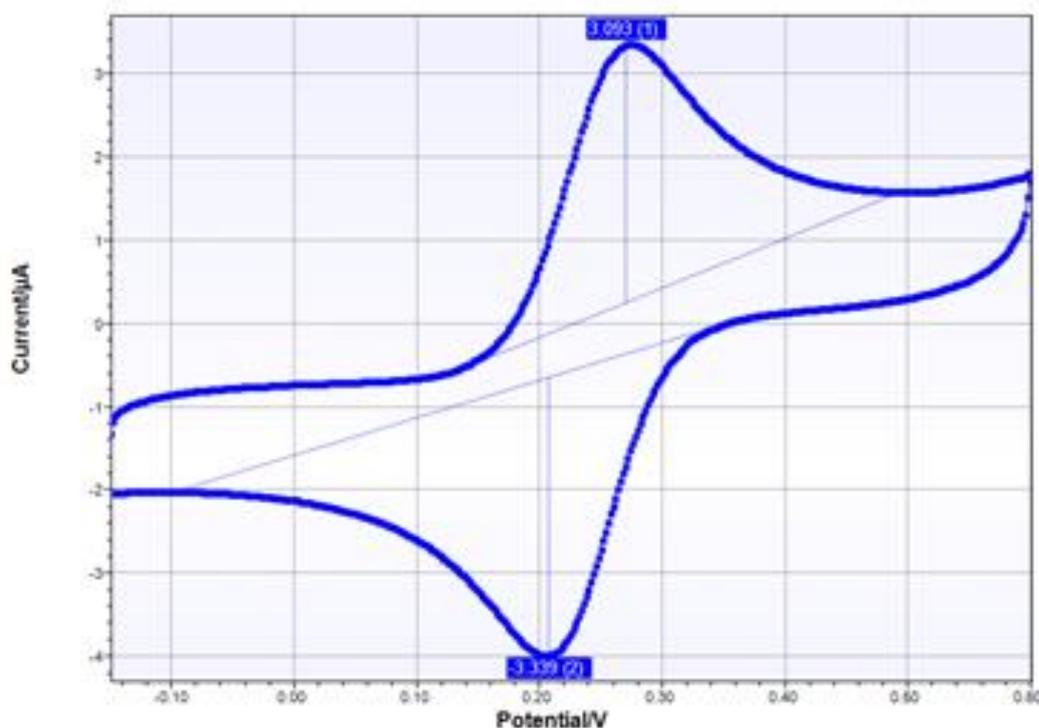
Additional options for Fast CV compared to a normal CV include averaging multiple scans and using equilibration scans. This technique can be particularly useful for very noisy measurements. Of course, it would be preferable to eliminate noise at the source first.

Auto-ranging cannot be used at these high speeds, so only one current range should be selected.



Potential applied during (Fast) Cyclic Voltammetry

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.



Typical CV plot for a free diffusing redox species

Technique specific parameters

E start	The potential where the scan starts and stops at.																		
E vertex1	The first potential where the scan direction reverses.																		
E vertex2	The second potential where the scan direction reverses.																		
	The applicable potential range of each instrument:																		
	<table> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
	See also section EmStat Pico limitations for each mode on page 113.																		
E step	The potential step size.																		
	The applicable step range for each instrument:																		
	<table> <tr> <td>PalmSens1 and 2</td> <td>1 mV to 250 mV</td> </tr> </table>	PalmSens1 and 2	1 mV to 250 mV																
PalmSens1 and 2	1 mV to 250 mV																		

	PalmSens3 PalmSens4 EmStat1 and 2 EmStat3(+) EmStat4 LR EmStat4 HR EmStat Pico	0.15 mV to 250 mV 0.075 mV to 250 mV 0.1 mV to 250 mV 0.125 mV to 250 mV 0.1 mV to 250 mV 0.183 mV to 250 mV High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV
Scan rate	The applied scan rate. The applicable range depends on the value of E step. The maximum scan rates for each instrument: PalmSens1 and 2 25 V/s (5 mV step) PalmSens3 500 V/s (5 mV step) PalmSens4 500 V/s (10 mV step)	
Number of scans	The number of repetitions for this scan.	
n averaged scans	The number of scans repetitions for averaging. In case 'Number of scans' is set to a value of more than 1, each scan in the plot is the result of an average of multiple scans, where the number of scans averaged is specified with this value.	
n equil. scans	The number of equilibration scans. During these scans, no data is recorded.	

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

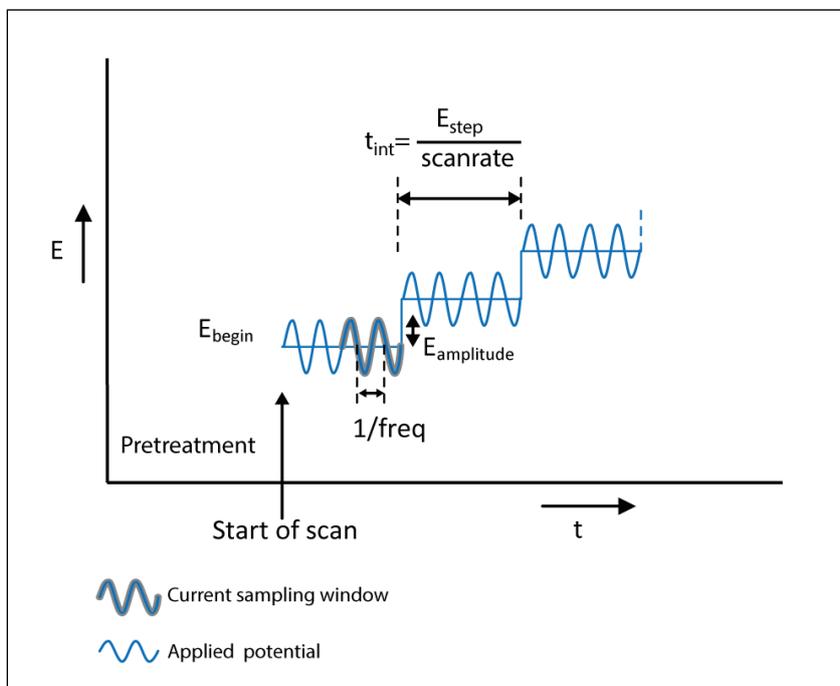
3.19.4 AC Voltammetry (ACV)

Supported instruments:

- PalmSens series

Description

In AC Voltammetry a potential scan is made with a superimposed sine wave which has a relatively small amplitude (normally 5 – 10 mV) and a frequency of 10 – 250 Hz. The AC signal superimposed on the DC-potential results in an AC response (I_{ac}). The resulting AC response is plotted against the potential.



Signal applied during AC Voltammetry

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Technique specific parameters

E begin	The potential where the measurement starts at.																		
E end	The potential where the measurement stops at.																		
	The applicable potential range of each instrument:																		
	<table border="0"> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
	See also section EmStat Pico limitations for each mode on page 113.																		
E step	The step potential size.																		
	The applicable step range for each instrument:																		
	<table border="0"> <tr> <td>PalmSens1 and 2</td> <td>1 mV to 250 mV</td> </tr> <tr> <td>PalmSens3</td> <td>0.15 mV to 250 mV</td> </tr> <tr> <td>PalmSens4</td> <td>0.075 mV to 250 mV</td> </tr> </table>	PalmSens1 and 2	1 mV to 250 mV	PalmSens3	0.15 mV to 250 mV	PalmSens4	0.075 mV to 250 mV												
PalmSens1 and 2	1 mV to 250 mV																		
PalmSens3	0.15 mV to 250 mV																		
PalmSens4	0.075 mV to 250 mV																		

	EmStat1 and 2 0.1 mV to 250 mV EmStat3(+) 0.125 mV to 250 mV EmStat4 LR 0.1 mV to 250 mV EmStat4 HR 0.183 mV to 250 mV EmStat Pico High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV
E ac	The amplitude (half peak-peak) of the applied sine wave as RMS value. <i>Applicable amplitude range: 1 mV to 250 mV</i>
Frequency	The frequency of the applied ac signal. The applicable frequency range for each instrument: PalmSens1 and 2 0.12 Hz to 250 Hz PalmSens3 1 Hz to 2000 Hz PalmSens4 1 Hz to 2000 Hz
Scan rate	The applied scan rate. The applicable range depends on the value of E step. The applicable scan rates for each instrument: PalmSens1 and 2 1 mV/s (1 mV step) to 25 mV/s (5 mV step) PalmSens3 0.2 mV/s (1mV step) to 50 mV/s (5 mV step) PalmSens4 0.2 mV/s (1mV step) to 50 mV/s (5 mV step)
Measure DC current	When checked, the direct current (DC) will be measured separately and added to the plot as an additional curve.

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

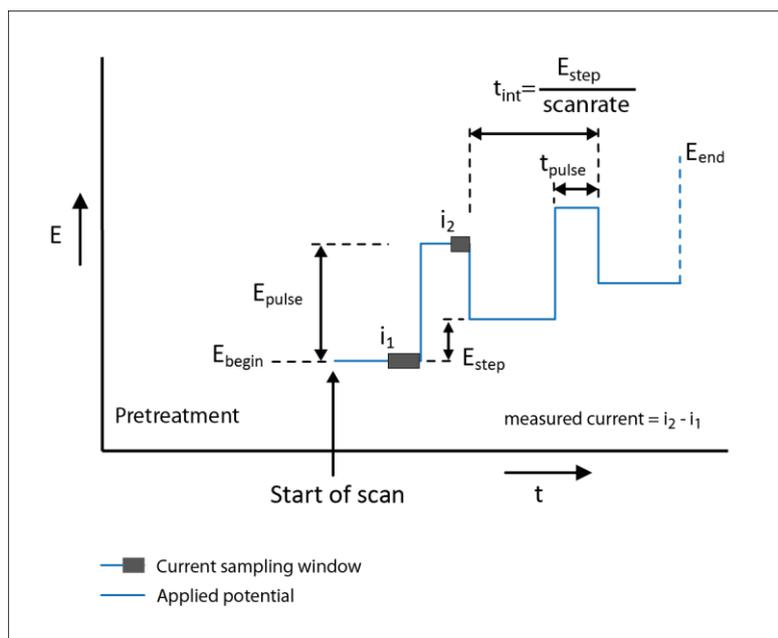
3.19.5 Differential Pulse Voltammetry (DPV)

Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

Description

In Differential Pulse Voltammetry a potential scan is made using pulses with a constant amplitude of E pulse superimposed on the dc-potential. The amplitude is mostly in the range of 5 – 50 mV.



Potential applied during Differential Pulse Voltammetry

The interval time between the pulses is equal to $E_{\text{step}} / \text{scanrate}$.

The current is sampled twice in each step: one time just before applying the pulse and one time at the end of the pulse. The difference between these two current samples is plotted versus the potential.

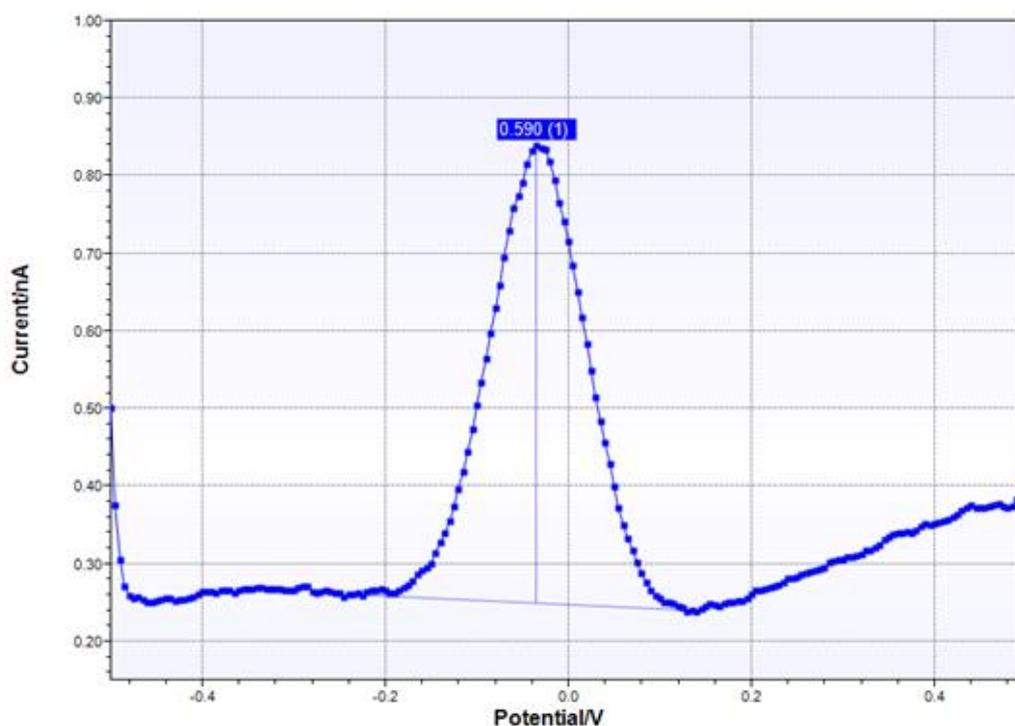
The obtained current is proportional to the derivative of the curve obtained using linear sweep or normal pulse voltammetry. A DPV thus has a peak-shaped curve. The peak height is (normally) proportional to the concentration in the solution. Be aware that the peak is not the redox potential! $E_{\text{peak}} = E_{1/2} - E_{\text{pulse}} / 2$.

Measuring

As in Normal Pulse Voltammetry (NPV) the diffusion layer thickness increases with pulse time, the current will be lower when the pulse time is increased. However, a short pulse time will result in an increased capacitive current and therefore give a higher (non-linear) baseline.

In trace analysis, it is important to apply pulses with optimal pulse times. In general, the optimal value must be found by varying the pulse time.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.



Typical DPV plot

Technique specific parameters

E begin	The potential where the measurement starts at.																		
E end	The potential where the measurement stops at.																		
	The applicable potential range of each instrument:																		
	<table border="0"> <tbody> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </tbody> </table>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
	See also section EmStat Pico limitations for each mode on page 113.																		
E step	The potential step size.																		
	The applicable step range for each instrument:																		
	<table border="0"> <tbody> <tr> <td>PalmSens1 and 2</td> <td>1 mV to 250 mV</td> </tr> <tr> <td>PalmSens3</td> <td>0.15 mV to 250 mV</td> </tr> <tr> <td>PalmSens4</td> <td>0.075 mV to 250 mV</td> </tr> </tbody> </table>	PalmSens1 and 2	1 mV to 250 mV	PalmSens3	0.15 mV to 250 mV	PalmSens4	0.075 mV to 250 mV												
PalmSens1 and 2	1 mV to 250 mV																		
PalmSens3	0.15 mV to 250 mV																		
PalmSens4	0.075 mV to 250 mV																		

	<p>EmStat1 and 2 0.1 mV to 250 mV EmStat3(+) 0.125 mV to 250 mV EmStat4 LR 0.1 mV to 250 mV EmStat4 HR 0.183 mV to 250 mV EmStat Pico High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV</p>
Scan rate	<p>The applied scan rate. The maximum scan rate depends on the value of E step and t pulse. The scan rate must be $< (E \text{ step} / 2 / t \text{ pulse})$.</p> <p><i>For PalmSens1 and 2:</i> <i>In case the scan rate is so low that the time between two measured points is longer than approx. 0.05 s, the measured data points are displayed during the measurement. In other cases, the measurement is completed before the points are shown.</i></p> <p>The applicable scan rates for each instrument:</p> <p>PalmSens1 and 2 0.2 mV/s (0.1 mV step) to 50 mV/s (5 mV step) PalmSens3 0.02 mV/s (0.15 mV step) to 25 V/s (0.25 V step) PalmSens4 0.02 mV/s (0.07 mV step) to 25 V/s (0.25 V step)</p> <p>EmStat1 and 2 0.02 mV/s (0.1 mV step) to 5 V/s (5 mV step) EmStat3 0.025 mV/s (0.125 mV step) to 5 V/s (5 mV step) EmStat3+ 0.025 mV/s (0.125 mV step) to 5 V/s (5 mV step) EmStat4 LR 0.1 mV/s (0.1 mV step) to 1 V/s (5 mV step) EmStat4 HR 0.1 mV/s (0.183 mV step) to 1 V/s (5 mV step) EmStat Pico 0.01 mV/s to 10 V/s (10 mV step)</p>
E pulse	<p>The pulse potential height.</p> <p>The applicable pulse potential range for all instruments:</p> <p>E pulse 1 mV to 250 mV</p>
t pulse	<p>The duration of the potential pulse. This duration needs to be set shorter than $0.5 * \text{interval time}$ where the interval time is equal to $E \text{ step} / \text{Scan rate}$.</p>

The applicable pulse time range for each instrument:

PalmSens1 and 2	10 ms to 1 s
PalmSens3	0.2 ms to 1 s
PalmSens4	0.4 ms to 1 s
EmStat1, 2 and 3(+)	5 ms to 1 s
EmStat4 LR and HR	0.4 ms to 0.3 s
EmStat Pico	2 ms to 0.3 s

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

3.19.6 Square Wave Voltammetry (SWV)

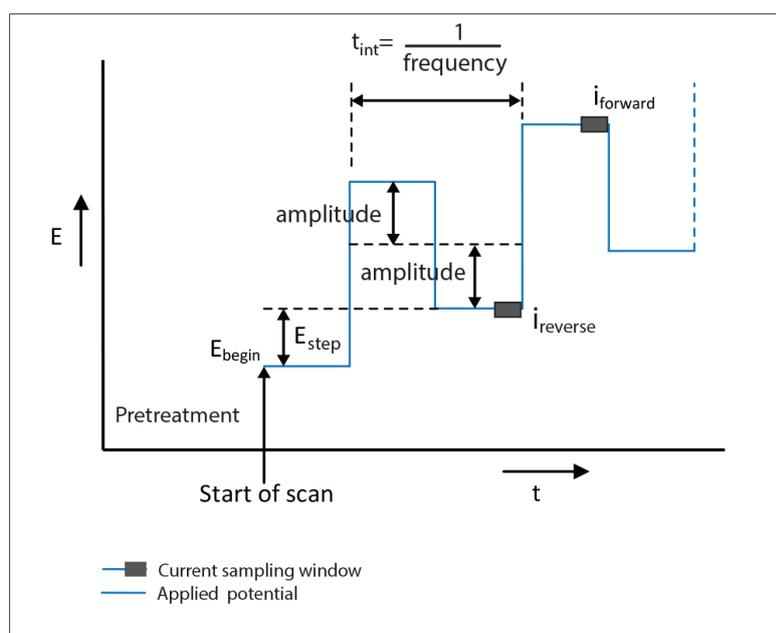
Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

Description

Square wave Voltammetry is in fact a special version of DPV.

DPV is SWV when t pulse is equal t interval/2 (see DPV). The interval time is the inverse of the frequency (Freq): t interval = $1/\text{Freq}$. As in DPV, the pulse amplitude is also normally in the range of 5 - 25 or 50 mV.



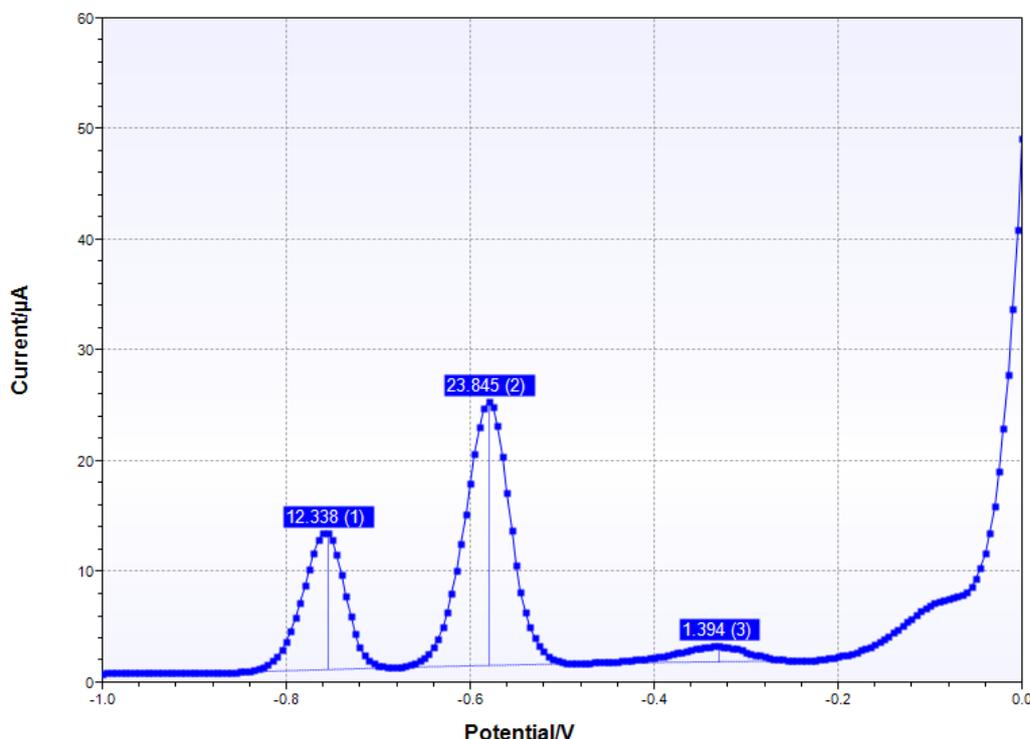
Potential applied during Square Wave Voltammetry

Measuring

In trace analysis, it is important to apply a frequency with optimal values. As in DPV the optimal value must be found by varying the frequency.

SWV is sometimes used to measure the reaction rate of the electrode reaction. In this case, a plot of the currents observed in the positive potential pulses are plotted next to the currents measured in the negative potential pulses (forward and reverse currents). The shape of these curves shows how reversible or how fast the electrode reaction is.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.



Typical SWV plot

Technique specific parameters

E begin	Potential where scan starts.
E end	Potential where measurement stops.
	The applicable potential range of each instrument:
	PalmSens1 and 2 -2 V to +2 V
	PalmSens3 -5 V to +5 V
	PalmSens4 -10 V to +10 V
	EmStat1 and 2 -2 V to +2 V
	EmStat3 -3 V to +3 V
	EmStat3+ -4 V to +4 V
	EmStat4 LR -3 V to +3 V
	EmStat4 HR -6 V to +6 V
	EmStat Pico High Speed mode: -1.7 V to +2 V
	Low Speed mode: -1.25 V to +2 V

	See also section EmStat Pico limitations for each mode on page 113.																
E step	<p>Step potential</p> <p>The applicable step range for each instrument:</p> <table> <tr> <td>PalmSens1 and 2</td> <td>1 mV to 250 mV</td> </tr> <tr> <td>PalmSens3</td> <td>0.15 mV to 250 mV</td> </tr> <tr> <td>PalmSens4</td> <td>0.075 mV to 250 mV</td> </tr> <tr> <td>EmStat1 and 2</td> <td>0.1 mV to 250 mV</td> </tr> <tr> <td>EmStat3(+)</td> <td>0.125 mV to 250 mV</td> </tr> <tr> <td>EmStat4 LR</td> <td>0.1 mV to 250 mV</td> </tr> <tr> <td>EmStat4 HR</td> <td>0.183 mV to 250 mV</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV</td> </tr> </table>	PalmSens1 and 2	1 mV to 250 mV	PalmSens3	0.15 mV to 250 mV	PalmSens4	0.075 mV to 250 mV	EmStat1 and 2	0.1 mV to 250 mV	EmStat3(+)	0.125 mV to 250 mV	EmStat4 LR	0.1 mV to 250 mV	EmStat4 HR	0.183 mV to 250 mV	EmStat Pico	High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV
PalmSens1 and 2	1 mV to 250 mV																
PalmSens3	0.15 mV to 250 mV																
PalmSens4	0.075 mV to 250 mV																
EmStat1 and 2	0.1 mV to 250 mV																
EmStat3(+)	0.125 mV to 250 mV																
EmStat4 LR	0.1 mV to 250 mV																
EmStat4 HR	0.183 mV to 250 mV																
EmStat Pico	High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV																
Amplitude	<p>The amplitude of the square wave pulse. Values are half peak-to-peak.</p> <p><i>The amplitude range for all instruments: 0.1 mV to 250 mV</i></p>																
Frequency	<p>The frequency of the square wave.</p> <p>The applicable frequency range of each instrument:</p> <table> <tr> <td>PalmSens1 and 2</td> <td>1 Hz to 400 Hz</td> </tr> <tr> <td>PalmSens3</td> <td>1 Hz to 1250 Hz</td> </tr> <tr> <td>PalmSens4</td> <td>1 Hz to 1250 Hz</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>1 Hz to 500 Hz</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>1 Hz to 2500 Hz</td> </tr> <tr> <td>EmStat Pico</td> <td>1 Hz to 500 Hz</td> </tr> </table>	PalmSens1 and 2	1 Hz to 400 Hz	PalmSens3	1 Hz to 1250 Hz	PalmSens4	1 Hz to 1250 Hz	EmStat1, 2 and 3(+)	1 Hz to 500 Hz	EmStat4 LR and HR	1 Hz to 2500 Hz	EmStat Pico	1 Hz to 500 Hz				
PalmSens1 and 2	1 Hz to 400 Hz																
PalmSens3	1 Hz to 1250 Hz																
PalmSens4	1 Hz to 1250 Hz																
EmStat1, 2 and 3(+)	1 Hz to 500 Hz																
EmStat4 LR and HR	1 Hz to 2500 Hz																
EmStat Pico	1 Hz to 500 Hz																
Measure i forward/reverse	<p>If this option is enabled the plot will show two separate curves for the measured forward and reverse current.</p> <p><i>Not supported by PalmSens1 and PalmSens2.</i></p>																

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

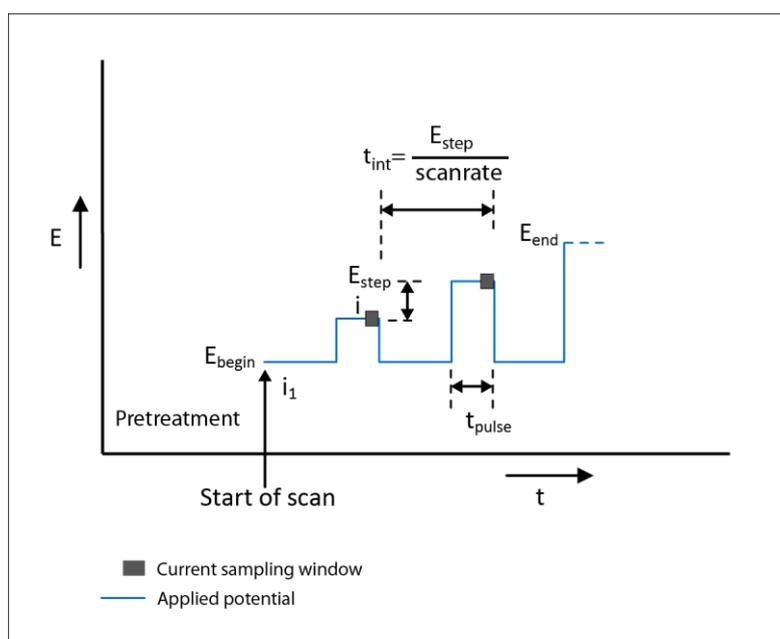
3.19.7 Normal Pulse Voltammetry (NPV)

Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

Description

With Normal Pulse Voltammetry the influence of diffusion limitation on your I-E curve (Cottrel behavior) is removed. In Normal Pulse Voltammetry (NPV) a potential scan is made by making constantly larger potential steps of pulse. NPV is normally more sensitive than LSV, since the diffusion layer thickness will be smaller, resulting in a higher faradaic current.



Potential applied during Normal Pulse Voltammetry

At the first potential step, the pulse is equal to E_{step} , at next twice the value E_{step} , until the end where the pulse is $E_{begin} + n * E_{step}$ is equal to E_{end} , where $n = (E_{end} - E_{begin}) / E_{step} + 1$.

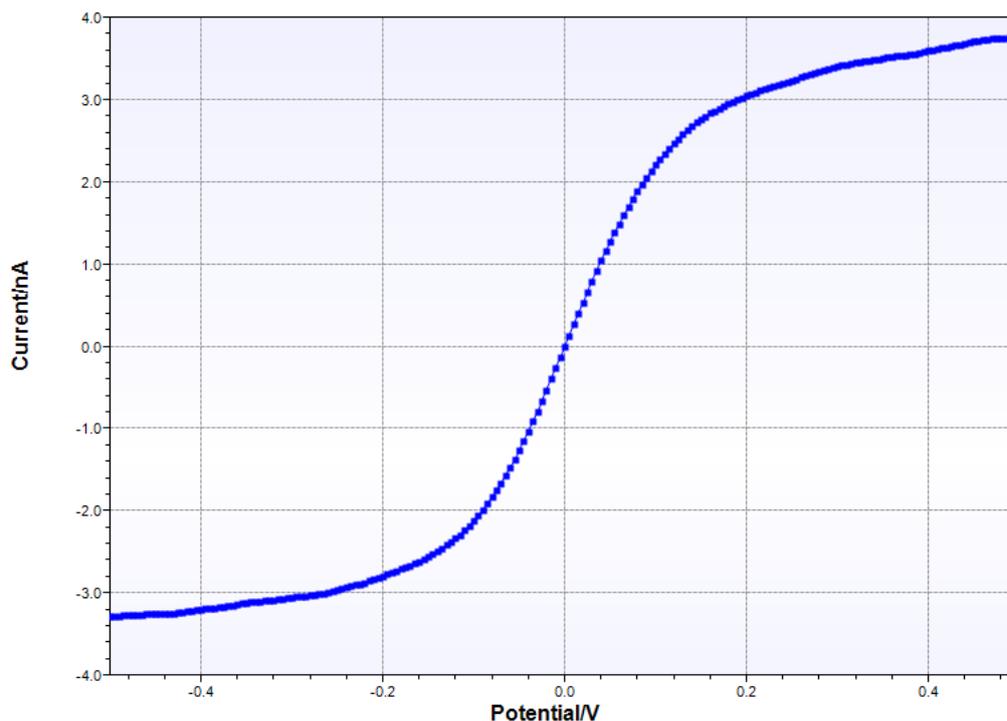
The pulse time t_{pulse} is specified by the user but must not exceed half the interval time.

So, the $t_{pulse} \leq E_{step} / (\text{scan rate} * 2)$.

Measuring

Since the diffusion layer thickness increases with time, the current will be lower when the pulse time is increased. However, a short pulse time will result in an increased capacitive current and therefore give a higher (non-linear) baseline.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.



Typical NPV plot

Technique specific parameters

E begin	The potential where the measurement starts at.																		
E end	The potential where the measurement stops at.																		
	The applicable potential range of each instrument:																		
	<table> <tbody> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </tbody> </table> <p>See also section EmStat Pico limitations for each mode on page 113.</p>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
E step	The potential step size.																		
	The applicable step range for each instrument:																		
	<table> <tbody> <tr> <td>PalmSens1 and 2</td> <td>1 mV to 250 mV</td> </tr> <tr> <td>PalmSens3</td> <td>0.15 mV to 250 mV</td> </tr> <tr> <td>PalmSens4</td> <td>0.075 mV to 250 mV</td> </tr> </tbody> </table>	PalmSens1 and 2	1 mV to 250 mV	PalmSens3	0.15 mV to 250 mV	PalmSens4	0.075 mV to 250 mV												
PalmSens1 and 2	1 mV to 250 mV																		
PalmSens3	0.15 mV to 250 mV																		
PalmSens4	0.075 mV to 250 mV																		

	<p>EmStat1 and 2 0.1 mV to 250 mV</p> <p>EmStat3(+) 0.125 mV to 250 mV</p> <p>EmStat4 LR 0.1 mV to 250 mV</p> <p>EmStat4 HR 0.183 mV to 250 mV</p> <p>EmStat Pico High Speed mode: 0.395 mV to 250 mV</p> <p> Low Speed mode: 0.537 mV to 250 mV</p>
t pulse	<p>The duration of the potential pulse. This duration needs to be set shorter than $0.5 * \text{interval time}$ where the interval time is equal to $E \text{ step} / \text{Scan rate}$.</p> <p>The applicable pulse time range for each instrument:</p> <p>PalmSens1 and 2 10 ms to 1 s</p> <p>PalmSens3 0.2 ms to 1 s</p> <p>PalmSens4 0.4 ms to 1 s</p> <p>EmStat1, 2 and 3(+) 5 ms to 1 s</p> <p>EmStat4 LR and HR 0.4 ms to 0.3 s</p> <p>EmStat Pico 2 ms to 0.3 s</p>
Scan rate	<p>The applied scan rate. The maximum scan rate depends on the value of E step and t pulse.</p> <p>The scan rate must be $< (E \text{ step} / 2 / t \text{ pulse})$.</p> <p><i>For PalmSens2:</i></p> <p><i>In case the scan rate is so low that the time between two measured points is longer than approx. 0.05 s, the measured data points are displayed during the measurement. In other cases, the measurement is completed before the points are shown.</i></p>

3.19.8 Chronoamperometry (CA)

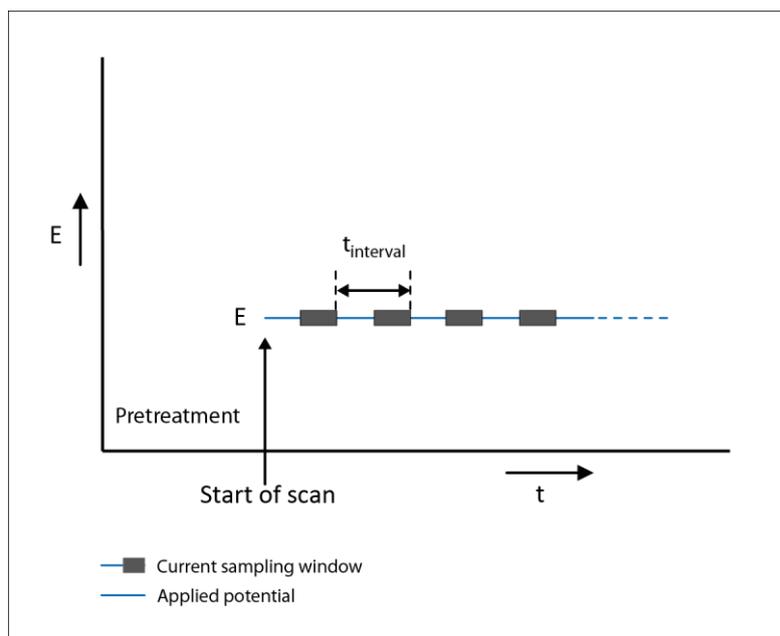
Also known as Amperometric Detection

Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

Description

The simplest, but widely used measurement technique is Chronoamperometry (or Amperometric Detection). Many sensors, like those for glucose or oxygen, require this technique.



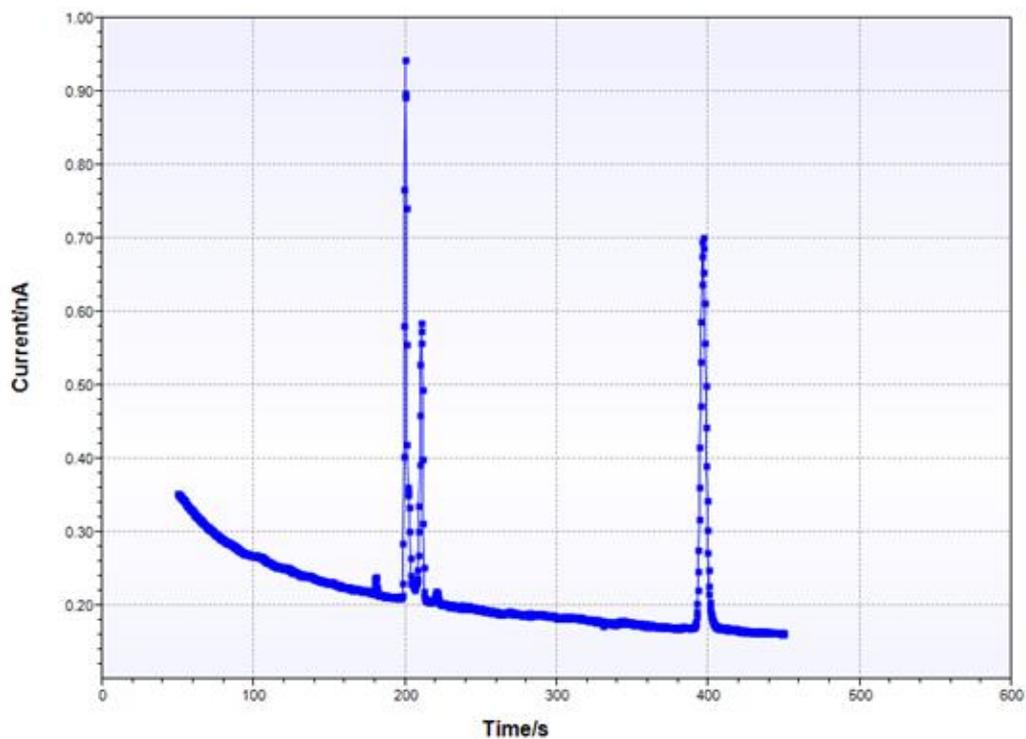
Signal applied during Chronoamperometry

Measuring

The instrument applies a constant dc-potential (E_{dc}) and the current is measured with constant interval times. By dividing the obtained current by a calibration factor the concentration of a specific analyte in the sample is calculated. Such applications allow the design of a very compact instrument like the 'glucose pen', with disposable sensors.

The technique is also applied when electrochemical detection is used with a flow cell or flow injection cell (FIA). While batch measurements result in current levels, which depend on the concentration, a FIA setup shows peaks in the current.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.



Typical CA curve obtained using capillary electrophoresis.

Cottrell plot

For more information about showing a Cottrell plot, see section [Cottrell plot](#) on page 182.

Technique specific parameters

E dc	<p>The potential applied during the measurement. The applicable potential range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table> <p>See also section EmStat Pico limitations for each mode on page 113.</p>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
t interval	<p>The time between two current samples.</p> <p>The applicable time interval range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>1 ms to 300 s</td> </tr> <tr> <td>PalmSens3</td> <td>0.2 ms to 300 s</td> </tr> <tr> <td>PalmSens4</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>1 ms to 300 s</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat Pico</td> <td>1 ms to 300 s</td> </tr> </table>	PalmSens1 and 2	1 ms to 300 s	PalmSens3	0.2 ms to 300 s	PalmSens4	0.4 ms to 300 s	EmStat1, 2 and 3(+)	1 ms to 300 s	EmStat4 LR and HR	0.4 ms to 300 s	EmStat Pico	1 ms to 300 s						
PalmSens1 and 2	1 ms to 300 s																		
PalmSens3	0.2 ms to 300 s																		
PalmSens4	0.4 ms to 300 s																		
EmStat1, 2 and 3(+)	1 ms to 300 s																		
EmStat4 LR and HR	0.4 ms to 300 s																		
EmStat Pico	1 ms to 300 s																		
t run	<p>The total run time of the measurement.</p> <p>The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)</p>																		

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

3.19.9 Zero Resistance Amperometry (ZRA)

Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

Use the technique Chronoamperometry in our software to perform ZRA measurements.

Description

All our potentiostats can be used as a Zero Resistance Ammeter (ZRA). A ZRA measures the current flowing through it without adding any resistance. This means the current is measured without the ZRA influencing the current.

Setup

If a potentiostat is used as a ZRA, in most setups it needs to be floating. The potentiostat's ground cable, is used for the ZRA setup and if the potentiostat is grounded additionally elsewhere the current could flow through that connection instead of the required path.

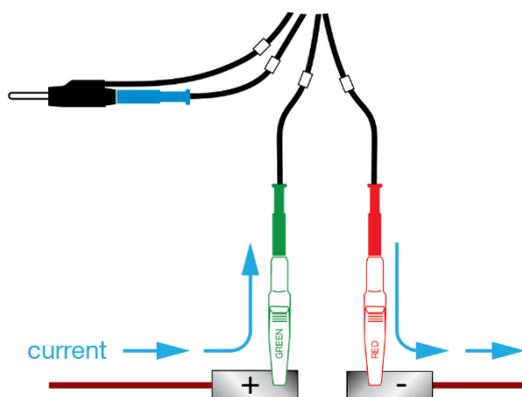
There are two options for a setup with a floating potentiostat.

1. Using Bluetooth and battery for communication and power. This means the potentiostat has no connection to ground.
2. Using a galvanic isolation dongle, which is inserted between the USB port of the computer and the potentiostat, makes the potentiostat float. This way you have a USB connection for communication and power, but no ground connection.

Connections

The reference electrode (blue) and counter electrode (black) connections of the potentiostat need to be short-circuited and left disconnected to anything else.

The current flows through the working electrode (red) and the ground (green). The Working Electrode is connected to the – input of the current follower and the + input is connected to Ground. The voltage difference between the Working Electrode and ground is zero and the current will be measured. See the following picture for a schematic representation.



Electrode connections for a ZRA measurement

Recording ZRA currents in our software

If you just want to see the current without recording, it is sufficient to go to the Manual Control tab and switch on the Cell.

If you want to record the values, you can start a Chronoamperometry measurement. The applied potential doesn't matter, because the reference and counter electrode of the ZRA is not part of the measured circuit.

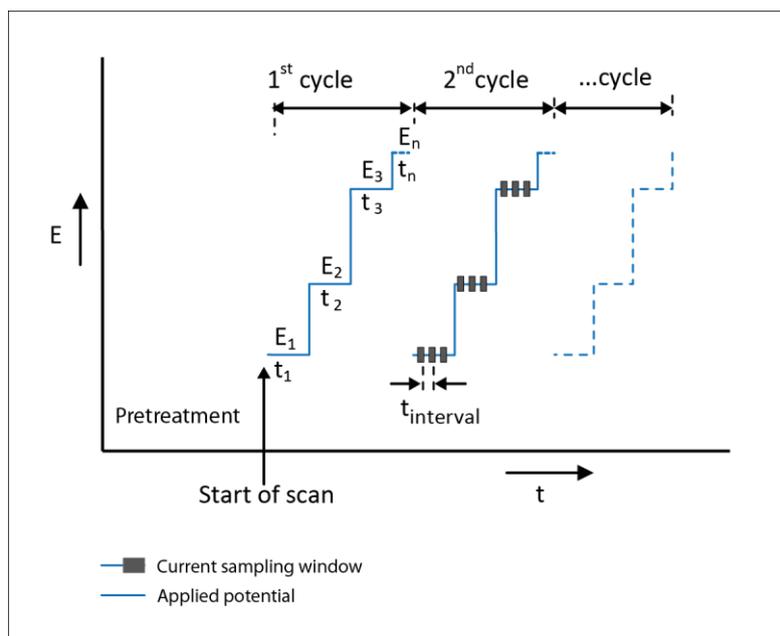
3.19.10 MultiStep Amperometry (MA)

Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

Description

Multistep amperometry simply allows the user to specify the number of potential steps they want to apply and how long each step should last. The current is continuously sampled with the specified interval time. A whole cycle of steps can be repeated several times.



Signal applied during Multistep Amperometry

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Technique specific parameters

t interval	<p>The time between two current samples.</p> <p>The applicable time interval range of each instrument:</p> <table border="0"> <tbody> <tr> <td>PalmSens1 and 2</td> <td>1 ms to 300 s</td> </tr> <tr> <td>PalmSens3</td> <td>0.2 ms to 300 s</td> </tr> <tr> <td>PalmSens4</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>1 ms to 300 s</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat Pico</td> <td>1 ms to 300 s</td> </tr> </tbody> </table>	PalmSens1 and 2	1 ms to 300 s	PalmSens3	0.2 ms to 300 s	PalmSens4	0.4 ms to 300 s	EmStat1, 2 and 3(+)	1 ms to 300 s	EmStat4 LR and HR	0.4 ms to 300 s	EmStat Pico	1 ms to 300 s
PalmSens1 and 2	1 ms to 300 s												
PalmSens3	0.2 ms to 300 s												
PalmSens4	0.4 ms to 300 s												
EmStat1, 2 and 3(+)	1 ms to 300 s												
EmStat4 LR and HR	0.4 ms to 300 s												
EmStat Pico	1 ms to 300 s												
Cycles	The number of cycles (repetitions).												
Levels	<p>The number of potentials to apply within a cycle. Switching between levels adds an overhead time.</p> <p>The average overhead time for each instrument:</p> <table border="0"> <tbody> <tr> <td>PalmSens1 and 2</td> <td>~80 ms</td> </tr> <tr> <td>PalmSens3</td> <td>~80 ms</td> </tr> <tr> <td>PalmSens4</td> <td>~80 ms</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>~80 ms</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>~1 ms</td> </tr> <tr> <td>EmStat Pico</td> <td>~1 ms</td> </tr> </tbody> </table>	PalmSens1 and 2	~80 ms	PalmSens3	~80 ms	PalmSens4	~80 ms	EmStat1, 2 and 3(+)	~80 ms	EmStat4 LR and HR	~1 ms	EmStat Pico	~1 ms
PalmSens1 and 2	~80 ms												
PalmSens3	~80 ms												
PalmSens4	~80 ms												
EmStat1, 2 and 3(+)	~80 ms												
EmStat4 LR and HR	~1 ms												
EmStat Pico	~1 ms												

E level [n]	<p>The potential level at which the current is recorded.</p> <p>The applicable potential range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table> <p>See also section EmStat Pico limitations for each mode on page 113.</p>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
t [n]	<p>The duration of the applied potential.</p> <p>The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)</p>																		

Additional options can be enabled using the  button:

Use limits for each level	Adds additional fields to each E level block for proceeding to the next level if a specified current is reached.
Select for which levels to record data	Adds additional 'Record' checkboxes to each E level block. If the 'Record' checkbox is not checked, the specified potential will be applied for the given time, without recording the current.
Use triggers	Adds additional digital trigger settings to each E level block. See for more information section Digital triggers.

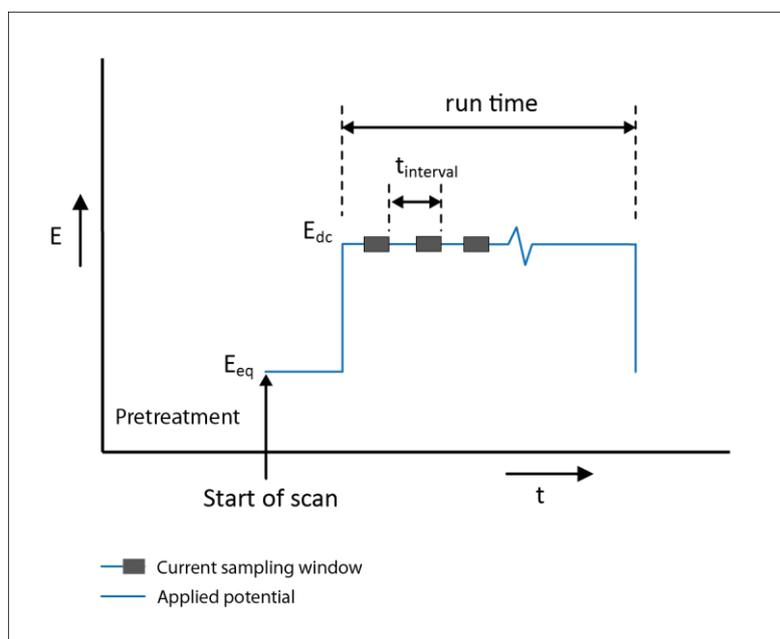
3.19.11 Fast Amperometry (FAM)

Supported instruments:

- PalmSens series

Description

Fast amperometry is a form of amperometric detection with very high sampling rates or respectively very short interval times



Signal applied during Fast Amperometry

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Technique specific parameters

E equilibration	Equilibration potential at which the measurement starts.
E dc	Potential of the pulse. Note that this value is not relative to E equilibration, given above. The current is continuously sampled during this stage.
	The applicable potential range for PalmSens series:
	PalmSens1 and 2 -2 V to +2 V
	PalmSens3 -5 V to +5 V
	PalmSens4 -10 V to +10 V
t run	Total run time of the measurement. Applicable run time: 1 ms to 30 s

t interval The time between two current samples.

Minimum interval times:

PalmSens1 and 2	0.25 ms
PalmSens3	0.01 ms
PalmSens4	0.02 ms

3.19.12 Pulsed Amperometric Detection (PAD)

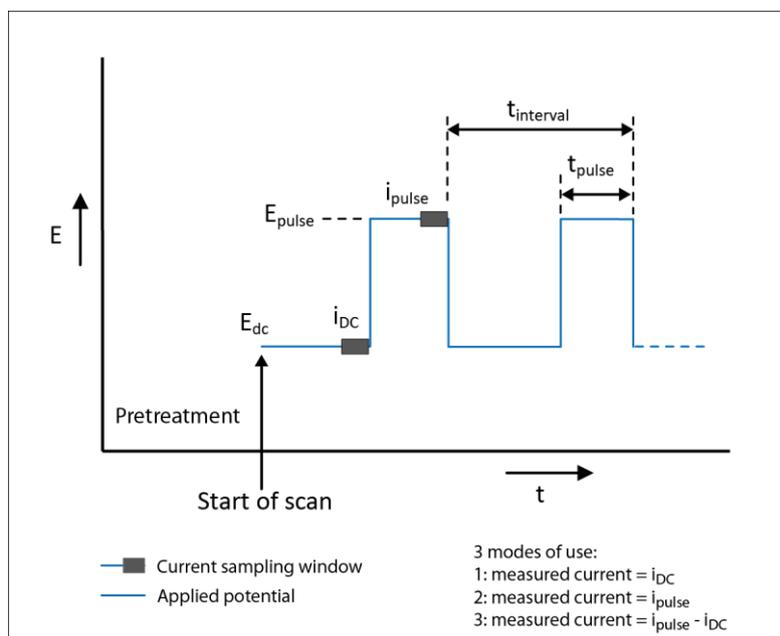
Also known as *Pulsed Amperometry*

Supported instruments:

- PalmSens series
- EmStat series (except Pico)

Description

With Pulsed Amperometric Detection a series of pulses (pulse profile) is periodically repeated. Pulsed Amperometric Detection can be used when higher sensitivity is required. Using pulses instead of constant potential might result in higher faradaic currents. PAD is also used when the electrode surface has to be regenerated continuously, for instance, to remove adsorbents from the electrode surface.



Signal applied during Pulsed Amperometric Detection

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Technique specific parameters

E dc	<p>The dc or base potential.</p> <p>The applicable potential range of each instrument:</p> <table> <tbody> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </tbody> </table> <p>See also section EmStat Pico limitations for each mode on page 113.</p>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
E pulse	<p>Potential in pulse. Note that this value is not relative to E dc, given above.</p> <p>The applicable pulse potential range of each instrument:</p> <table> <tbody> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> </tbody> </table>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V						
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
t pulse	<p>The pulse time.</p> <p>The applicable pulse time range for each instrument:</p> <table> <tbody> <tr> <td>PalmSens1 and 2</td> <td>10 ms to 1 s</td> </tr> <tr> <td>PalmSens3</td> <td>0.2 ms to 1 s</td> </tr> <tr> <td>PalmSens4</td> <td>0.4 ms to 1 s</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>5 ms to 1 s</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>0.4 ms to 0.3 s</td> </tr> <tr> <td>EmStat Pico</td> <td>2 ms to 0.3 s</td> </tr> </tbody> </table>	PalmSens1 and 2	10 ms to 1 s	PalmSens3	0.2 ms to 1 s	PalmSens4	0.4 ms to 1 s	EmStat1, 2 and 3(+)	5 ms to 1 s	EmStat4 LR and HR	0.4 ms to 0.3 s	EmStat Pico	2 ms to 0.3 s						
PalmSens1 and 2	10 ms to 1 s																		
PalmSens3	0.2 ms to 1 s																		
PalmSens4	0.4 ms to 1 s																		
EmStat1, 2 and 3(+)	5 ms to 1 s																		
EmStat4 LR and HR	0.4 ms to 0.3 s																		
EmStat Pico	2 ms to 0.3 s																		

Mode	DC: $i(\text{dc})$ measurement is performed at potential E_{dc} pulse: $i(\text{pulse})$ measurement is performed at potential E_{pulse} differential: $i(\text{dif})$ measurement is $i(\text{pulse}) - i(\text{dc})$
t run	Total run time of the measurement. The minimum and maximum duration of a measurement: $5 * \text{interval time}$ to 1,000,000 seconds (ca. 278 hours)
t interval	The time between two current samples.

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

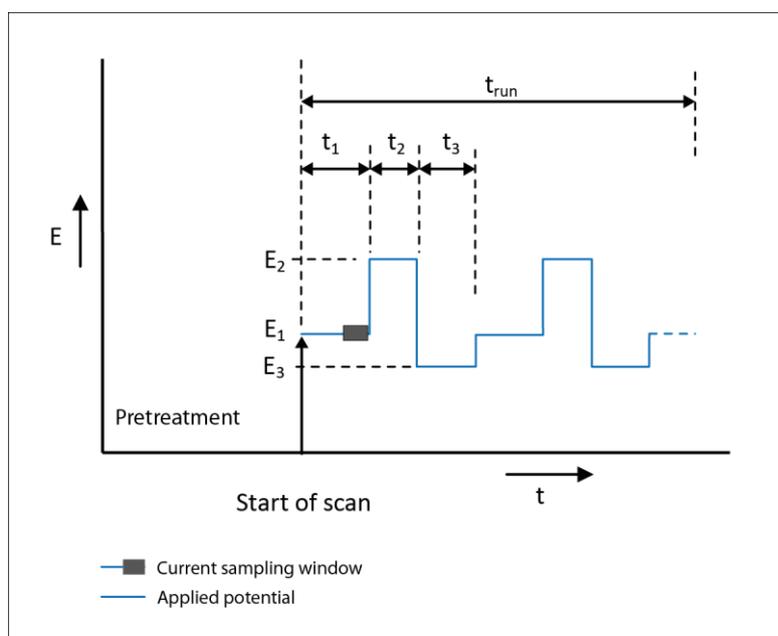
3.19.13 Multiple Pulse Amperometry (MPAD)

Supported instruments:

- PalmSens series
- EmStat1, 2 and 3(+)

Description

Multiple Pulse Amperometry can be used when higher sensitivity is required. Using pulses instead of constant potential might result in higher faradaic currents. MPAD is used when the electrode surface must be regenerated continuously, for instance, to remove adsorbents from the electrode surface.



Signal applied during Multiple Pulse Amperometry

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Technique specific parameters

E1(measure)	The first potential level in which the current is recorded																		
E2	The second applied potential level																		
E3	The third applied potential level																		
	The applicable potential range of each instrument:																		
	<table> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
	See also section EmStat Pico limitations for each mode on page 113.																		
t1	The duration of the first applied potential																		
t2	The duration of the second applied potential																		
t3	The duration of the third applied potential																		
	Values t1, t2 and t3 can be 0.1 to 2 s																		
t run	Total run time of the measurement.																		
	The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)																		

3.19.14 Open Circuit Potentiometry (OCP)

Supported instruments:

- PalmSens series
- EmStat series
- Sensit series

Description

For Open Circuit Potentiometry the current is zero and the so-called open circuit potential (OCP) is obtained.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Technique specific parameters

t run	<p>Total run time of the measurement.</p> <p>The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)</p>												
t interval	<p>The time between two potential samples.</p> <p>The applicable time interval range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>1 ms to 300 s</td> </tr> <tr> <td>PalmSens3</td> <td>0.2 ms to 300 s</td> </tr> <tr> <td>PalmSens4</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>1 ms to 300 s</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat Pico</td> <td>1 ms to 300 s</td> </tr> </table>	PalmSens1 and 2	1 ms to 300 s	PalmSens3	0.2 ms to 300 s	PalmSens4	0.4 ms to 300 s	EmStat1, 2 and 3(+)	1 ms to 300 s	EmStat4 LR and HR	0.4 ms to 300 s	EmStat Pico	1 ms to 300 s
PalmSens1 and 2	1 ms to 300 s												
PalmSens3	0.2 ms to 300 s												
PalmSens4	0.4 ms to 300 s												
EmStat1, 2 and 3(+)	1 ms to 300 s												
EmStat4 LR and HR	0.4 ms to 300 s												
EmStat Pico	1 ms to 300 s												

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

3.19.15 Chronopotentiometry (CP)

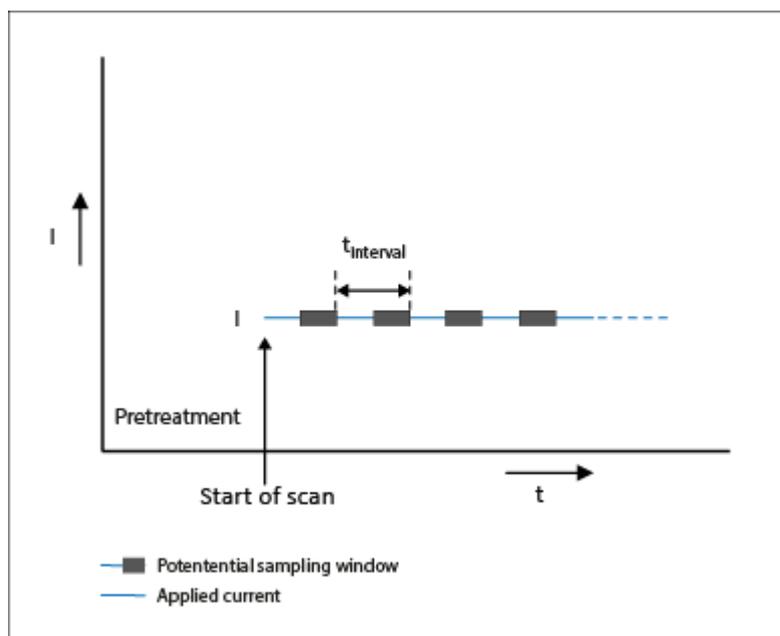
Supported instruments:

- PalmSens series
- EmStat4 LR and HR

Description

In this technique, the potential versus time is recorded. The PalmSens instruments can be used as a galvanostat. With a galvanostat, it is possible to specify the current to be applied while recording the potential response.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.



Signal applied during Chronopotentiometry

Technique specific parameters

i applied	<p>The current to apply. The unit of the value is the selected current range, so if 10 μA is selected and 1.5 is given as a value, the applied current will be 15 μA.</p> <p>The applicable applied currents for each instrument:</p> <table border="1"> <thead> <tr> <th></th> <th>Applied</th> <th>Available Ranges (CR)</th> </tr> </thead> <tbody> <tr> <td>PalmSens2</td> <td>-2 to 2 * CR</td> <td>1 μA to 10 mA</td> </tr> <tr> <td>PalmSens3</td> <td>-3 to 3 * CR</td> <td>1 μA to 10 mA</td> </tr> <tr> <td>PalmSens4</td> <td>-6 to 6 * CR</td> <td>1 nA to 10 mA</td> </tr> <tr> <td>EmStat4</td> <td>-3 to 3 * CR</td> <td>10 nA, 1 μA, 100 μA, 10 mA</td> </tr> <tr> <td>LR</td> <td></td> <td></td> </tr> <tr> <td>EmStat4</td> <td>-3 to 3 * CR</td> <td>1 μA, 100 μA, 10 mA and 100 mA</td> </tr> <tr> <td>HR</td> <td></td> <td></td> </tr> </tbody> </table>		Applied	Available Ranges (CR)	PalmSens2	-2 to 2 * CR	1 μA to 10 mA	PalmSens3	-3 to 3 * CR	1 μA to 10 mA	PalmSens4	-6 to 6 * CR	1 nA to 10 mA	EmStat4	-3 to 3 * CR	10 nA, 1 μA , 100 μA , 10 mA	LR			EmStat4	-3 to 3 * CR	1 μA , 100 μA , 10 mA and 100 mA	HR		
	Applied	Available Ranges (CR)																							
PalmSens2	-2 to 2 * CR	1 μA to 10 mA																							
PalmSens3	-3 to 3 * CR	1 μA to 10 mA																							
PalmSens4	-6 to 6 * CR	1 nA to 10 mA																							
EmStat4	-3 to 3 * CR	10 nA, 1 μA , 100 μA , 10 mA																							
LR																									
EmStat4	-3 to 3 * CR	1 μA , 100 μA , 10 mA and 100 mA																							
HR																									
t run	<p>Total run time of the measurement.</p> <p>The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)</p>																								

t interval The time between two potential samples.

The applicable time interval range of each instrument:

PalmSens1 and 2	1 ms to 300 s
PalmSens3	0.2 ms to 300 s
PalmSens4	0.4 ms to 300 s
EmStat1, 2 and 3(+)	1 ms to 300 s
EmStat4 LR and HR	0.4 ms to 300 s
EmStat Pico	1 ms to 300 s

3.19.16 Linear Sweep Potentiometry (LSP)

Supported instruments:

- PalmSens4
- EmStat4 LR and HR

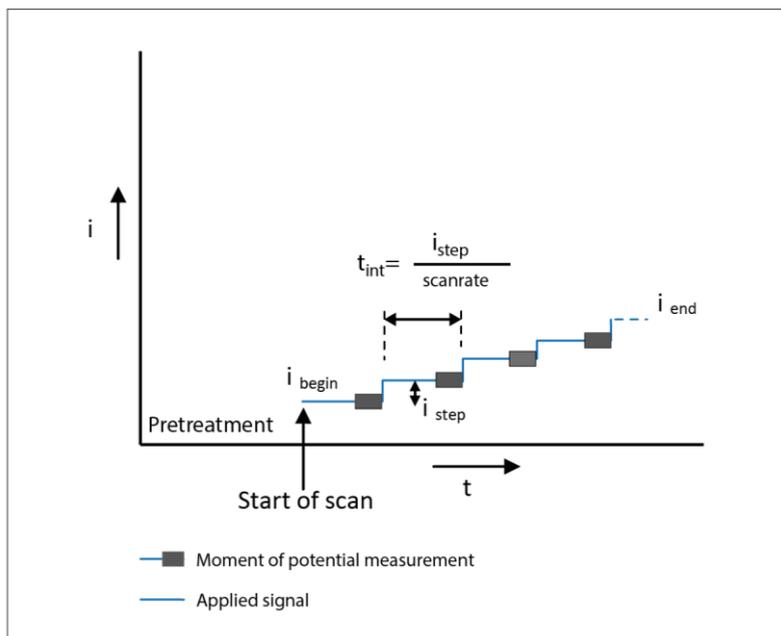
Description

In Linear Sweep Potentiometry is very similar to Linear Sweep Voltammetry, but in this case, the current is controlled, instead of the potential. A current scan is performed from the begin current, i_{begin} , to the end current, i_{end} . The scan is not really linear, but small current steps (i_{step}) are made. The potential is measured (sampled) during the last 25% interval period of each step. So, the number of points in the curve of the current versus potential is $(i_{end} - i_{begin}) / E_{step} + 1$.

The scan rate is specified in i/s , which determines the time between two steps and thus the sampling time. The interval time is $i_{step} / \text{scan rate}$. So, when i_{step} is 0.005 mA and the scan rate 0.1 mA/s the interval time is 0.05 s.

Measuring

In some applications, it is important that the potential does not get too high. This might ruin the working electrode. If the current at which this will occur is not known, it is possible to specify a maximum potential value at which the scan stops. In this case, the end current specified by the user is not reached.



Potential applied during Linear Sweep Potentiometry

During the measurement, the curve is shown on the screen in real-time. It is possible to abort a measurement, by pressing the abort button above the plot.

During a measurement, the use of the 'Pause' button will halt the scan until the same button is used again. This button is not available at higher scan rates.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Technique specific parameters

Applied current range	The applied current range. If a range of 10 μA is selected and 1.5 is given as an applied current value, the applied current will be 15 μA .	
	The applicable applied currents for each instrument:	
	Applied	Available Ranges (CR)
	PalmSens2	-2 to 2 * CR 1 μA to 10 mA
	PalmSens3	-3 to 3 * CR 1 μA to 10 mA
	PalmSens4	-6 to 6 * CR 1 nA to 10 mA
	EmStat4	-3 to 3 * CR 10 nA, 1 μA , 100 μA , 10 mA
	LR	
	EmStat4	-3 to 3 * CR 1 μA , 100 μA , 10 mA and 100
	HR	mA
i begin	Current in the selected range where scan starts at.	
i end	Current in the selected range where scan stops at.	

i step	The current step size.	
	The applicable minimum i step for each instrument:	
	PalmSens1 and 2	0.001 * CR
	PalmSens3	0.00015 * CR
	PalmSens4	0.000075 * CR
	EmStat4 LR	0.0001 * CR
	EmStat4 HR	0.000183 * CR
Scan rate	The applied scan rate. The applicable range depends on the value of i step since the data acquisition rate is limited by the connected instrument.	

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

3.19.17 MultiStep Potentiometry (MP)

Supported instruments:

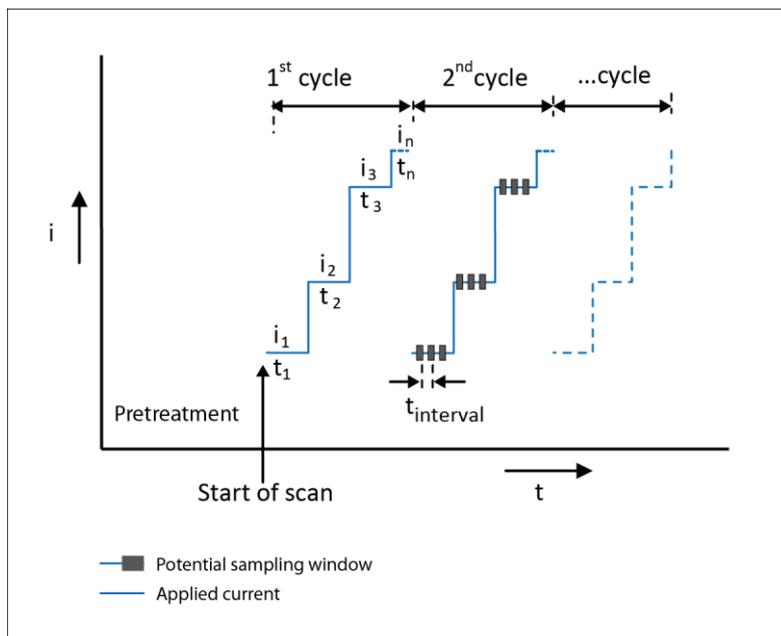
- PalmSens series
- EmStat4 LR and HR

Description

MultiStep Potentiometry simply allows the user to specify the number of current steps they want to apply and how long each step should last. The potential response is continuously sampled with the specified interval.

A whole cycle of steps can be repeated several times.

(Note: if only one current step is used, this technique is identical to Potentiometry which provide a larger range of measurement rates.)



Signal applied during Multistep Potentiometry

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Technique specific parameters

t interval	<p>The time between two potential samples.</p> <p>The applicable time interval range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>1 ms to 300 s</td> </tr> <tr> <td>PalmSens3</td> <td>0.2 ms to 300 s</td> </tr> <tr> <td>PalmSens4</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>1 ms to 300 s</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat Pico</td> <td>1 ms to 300 s</td> </tr> </table>	PalmSens1 and 2	1 ms to 300 s	PalmSens3	0.2 ms to 300 s	PalmSens4	0.4 ms to 300 s	EmStat1, 2 and 3(+)	1 ms to 300 s	EmStat4 LR and HR	0.4 ms to 300 s	EmStat Pico	1 ms to 300 s
PalmSens1 and 2	1 ms to 300 s												
PalmSens3	0.2 ms to 300 s												
PalmSens4	0.4 ms to 300 s												
EmStat1, 2 and 3(+)	1 ms to 300 s												
EmStat4 LR and HR	0.4 ms to 300 s												
EmStat Pico	1 ms to 300 s												
Cycles	The number of repetitions.												
Levels	<p>The number of potentials to apply within a cycle.</p> <p>The average overhead time for each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>~80 ms</td> </tr> <tr> <td>PalmSens3</td> <td>~80 ms</td> </tr> <tr> <td>PalmSens4</td> <td>~80 ms</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>~80 ms</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>~1 ms</td> </tr> <tr> <td>EmStat Pico</td> <td>~1 ms</td> </tr> </table>	PalmSens1 and 2	~80 ms	PalmSens3	~80 ms	PalmSens4	~80 ms	EmStat1, 2 and 3(+)	~80 ms	EmStat4 LR and HR	~1 ms	EmStat Pico	~1 ms
PalmSens1 and 2	~80 ms												
PalmSens3	~80 ms												
PalmSens4	~80 ms												
EmStat1, 2 and 3(+)	~80 ms												
EmStat4 LR and HR	~1 ms												
EmStat Pico	~1 ms												

i level [n]	The current level at which the potential is recorded.		
	The applicable applied currents for each instrument:		
		Applied	Available Ranges (CR)
	PalmSens2	-2 to 2 * CR	1 μ A to 10 mA
	PalmSens3	-3 to 3 * CR	1 μ A to 10 mA
	PalmSens4	-6 to 6 * CR	1 nA to 10 mA
t [n]	EmStat4 LR	-3 to 3 * CR	10 nA, 1 μ A, 100 μ A, 10 mA
	EmStat4 HR	-3 to 3 * CR	1 μ A, 100 μ A, 10 mA and 100 mA
	The duration of the applied current.		
	The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)		

Additional options can be enabled using the  button:

Use limits for each level	Adds additional fields to each i level block for proceeding to the next level if a specified potential is reached.
Select for which levels to record data	Adds additional 'Record' checkboxes to each i level block. If the 'Record' checkbox is not checked, the specified current will be applied for the given time, without recording the potential.
Use triggers	Adds additional digital trigger settings to each i level block. See for more information section Digital triggers.

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

3.19.18 Stripping Chronopotentiometry (SCP)

Also known as Potentiometric Stripping Analysis (PSA)

Supported instruments:

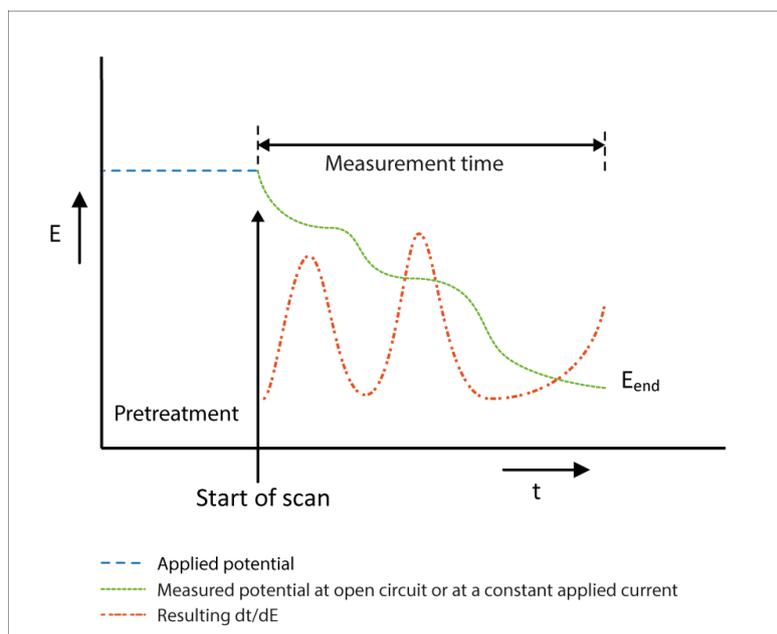
- PalmSens series

Description

Chronopotentiometric Stripping or Stripping chronopotentiometry is a sensitive analytical technique.

Before the SCP measurement starts a deposition stage at the deposition potential E_{dep} is required.

After this stage, the potential versus time is recorded. In this stage, the potentiostat is switched off and the measurement starts.



Stripping chronopotentiometry (SCP).

Measuring

The actual measurement can be done in two modes:

- Chemical stripping, using a chemical oxidant (or reductant)
- Using the instrument as a galvanostat and applying a constant stripping current.

In both cases, the potential versus time (E vs t) is measured. The resulting curve is re-calculated to the inverse derivative, so dt/dE (in s/V) vs E .

In case a component was deposited at the electrode surface, it requires current to oxidize or reduce. The higher the amount of absorbed component, the more electrical charge (time integral of the current) it requires, so the longer it takes to change the electrode potential.

The plot of dt/dE vs E therefore will show a peak the potential where the oxidation or reduction occurs.

The direction of the stripping current depends on the end potential (E_{end}) minus deposition potential ($E_{deposition}$). In case no deposition time was used, the sign is determined by the end potential (E_{end}).

The sequence of a stripping chronopotentiometry measurement:

1. Apply E condition, the conditioning potential, if t condition is not zero.
2. Apply E deposition, the deposition potential, if t deposition is not zero.
3. Apply E deposition and wait t equilibration seconds.
4. If Stripping Current = 0 then the cell is switched off, otherwise, the specified constant current is applied. The measurement with a rate of 40 kHz starts. The measurement stops when either the measured potential is below E_{end} or the run time is exceeded.

Technique specific parameters

E end	<p>Potential where measurement stops.</p> <p>The applicable potential range for PalmSens series:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> </table>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V
PalmSens1 and 2	-2 V to +2 V						
PalmSens3	-5 V to +5 V						
PalmSens4	-10 V to +10 V						
Stripping Current	<p>If specified as 0, the method is called chemical stripping otherwise it is constant current stripping.</p> <p>The direction of the stripping current is determined by E end minus E deposition.</p> <p>The applicable stripping current and potential range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>$\pm 0.001 \mu\text{A}$ to $\pm 2 \text{ mA}$. -2 V to +2 V.</td> </tr> <tr> <td>PalmSens3</td> <td>$\pm 0.001 \mu\text{A}$ to $\pm 30 \text{ mA}$. -5 V to +5 V.</td> </tr> <tr> <td>PalmSens4</td> <td>$\pm 1 \text{ nA}$ to $\pm 30 \text{ mA}$. -10 V to +10 V</td> </tr> </table>	PalmSens1 and 2	$\pm 0.001 \mu\text{A}$ to $\pm 2 \text{ mA}$. -2 V to +2 V.	PalmSens3	$\pm 0.001 \mu\text{A}$ to $\pm 30 \text{ mA}$. -5 V to +5 V.	PalmSens4	$\pm 1 \text{ nA}$ to $\pm 30 \text{ mA}$. -10 V to +10 V
PalmSens1 and 2	$\pm 0.001 \mu\text{A}$ to $\pm 2 \text{ mA}$. -2 V to +2 V.						
PalmSens3	$\pm 0.001 \mu\text{A}$ to $\pm 30 \text{ mA}$. -5 V to +5 V.						
PalmSens4	$\pm 1 \text{ nA}$ to $\pm 30 \text{ mA}$. -10 V to +10 V						
Measurement time	<p>The maximum measurement time. This value should always exceed the required measurement time. It only limits the time of the measurement. When the potential response is erroneously and E end is not found within this time, the measurement is aborted.</p>						

3.19.19 Chronocoulometry (CC)

Supported instruments:

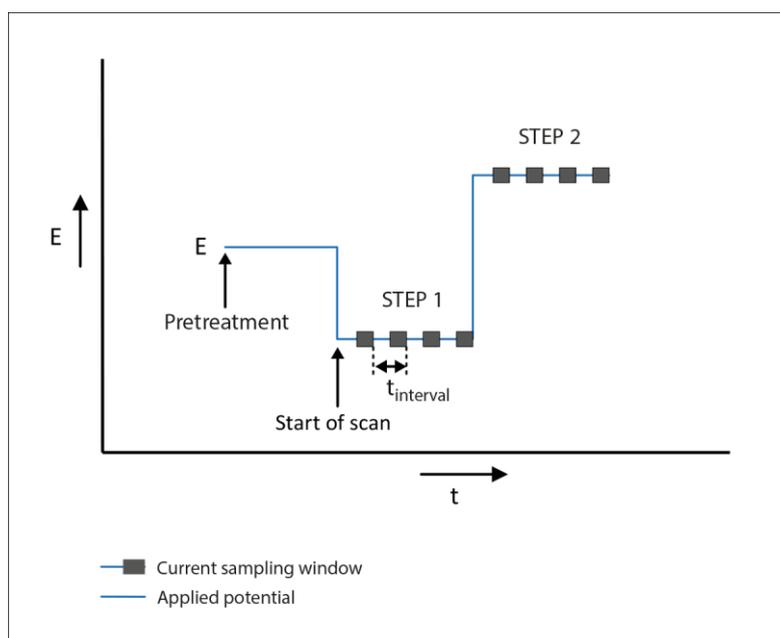
- PalmSens3 and PalmSens4
- EmStat series
- Sensit series

Description

Chronoamperometry (CA) and chronocoulometry (CC) have the same potential waveform but are used for different purposes. In CA, the current is monitored as a function of time, whereas in CC, the charge is monitored as a function of time. This means that in essence, the potentiostat performs the same experiment as in CA, recording the current as a function of time. However, the current is displayed in the software as a charge versus time. The charge is calculated by integrating the current. While the measured current in the CA shows a linear correlation with the reaction rate, the charge measured in CC shows a linear correlation with the number of converted reactants. This is described in Faraday's law. This makes CC useful during deposition or electrochemical synthesis. For the characterization of batteries, CC is also helpful.

In analytical chemistry, CC is used to determine the adsorbed number of active species in a solution of free diffusing active species. Multiplying the Cottrell equation with t delivers that the charge Q of the free diffusing species' reaction is proportional to $t^{1/2}$. The total charge also includes the contribution of the charge stored in the electrochemical double layer and the charge due to reactions of adsorbed species. These two effects are a lot faster than the reaction of free diffusing species. Plotting Q versus $t^{1/2}$ (Anson plot) delivers (ideally) a jump in charge followed by a linear increase. When the linear part is extrapolated, the intersection with the charge axis delivers the contribution of the double layer and adsorbed species. A previous blank measurement allows the determination of the double layer contribution and thus the calculation of the adsorbed species contribution.

To make sure the charge step, in the beginning, is recorded this measurement is performed in two steps. The first step at a reaction-free potential followed by the step where the reaction is initiated, just like the classic Cottrell experiment.



Signal applied during Chronocoulometry

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

Anson plot

For more information about the Anson plot, see section [Anson plot](#) on page 183.

Technique specific parameters

t interval	<p>The time between two current samples.</p> <p>The applicable time interval range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>1 ms to 300 s</td> </tr> <tr> <td>PalmSens3</td> <td>0.2 ms to 300 s</td> </tr> <tr> <td>PalmSens4</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat1, 2 and 3(+)</td> <td>1 ms to 300 s</td> </tr> <tr> <td>EmStat4 LR and HR</td> <td>0.4 ms to 300 s</td> </tr> <tr> <td>EmStat Pico</td> <td>1 ms to 300 s</td> </tr> </table>	PalmSens1 and 2	1 ms to 300 s	PalmSens3	0.2 ms to 300 s	PalmSens4	0.4 ms to 300 s	EmStat1, 2 and 3(+)	1 ms to 300 s	EmStat4 LR and HR	0.4 ms to 300 s	EmStat Pico	1 ms to 300 s						
PalmSens1 and 2	1 ms to 300 s																		
PalmSens3	0.2 ms to 300 s																		
PalmSens4	0.4 ms to 300 s																		
EmStat1, 2 and 3(+)	1 ms to 300 s																		
EmStat4 LR and HR	0.4 ms to 300 s																		
EmStat Pico	1 ms to 300 s																		
E step 1	<p>Potential applied during the first potential step.</p> <p>The applicable potential range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table> <p>See also section EmStat Pico limitations for each mode on page 113.</p>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
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PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		
t 1	<p>Duration of the first potential step.</p> <p>The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)</p>																		
E step 2	<p>Potential applied during the second potential step.</p> <p>The applicable potential range of each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </table>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
EmStat3+	-4 V to +4 V																		
EmStat4 LR	-3 V to +3 V																		
EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		

	See also section EmStat Pico limitations for each mode on page 113.
t 2	Duration of the second potential step. The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)

Additional options can be enabled using the  button. For more information, see section [Advanced settings](#) on page 110.

3.19.20 Mixed Mode (MM)

Supported instruments:

- PalmSens series
- EmStat series (limited)
- Sensit series (limited)

Description

Mixed Mode is a flexible technique that allows for switching between potentiostatic, galvanostatic, and open circuit measurements during a single run.

See section [Measurement Sequence](#) on page 108 for information about pretreatment and post measurement settings.

The Mixed Mode uses different stages similar to the levels during Multistep Amperometry or Potentiometry, but each stage can be galvanostatic or potentiostatic independent of the previous stage.

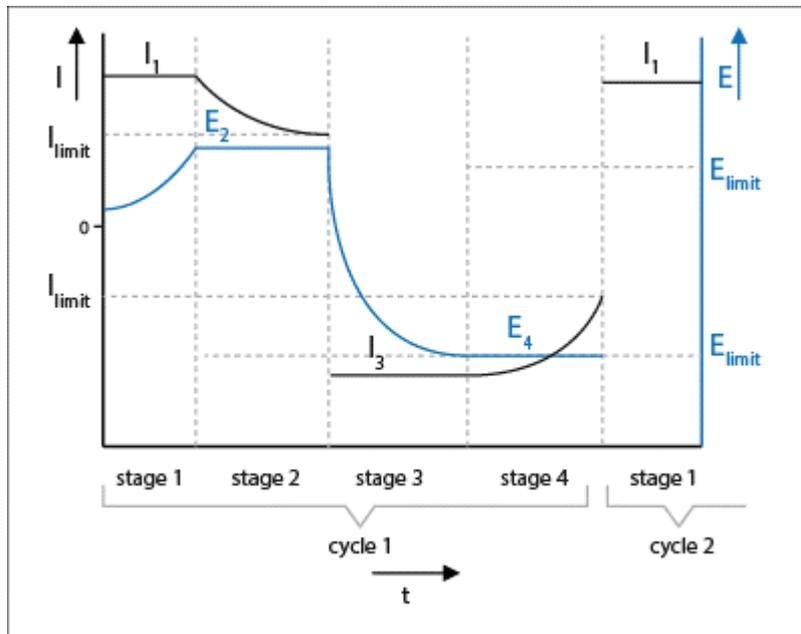
The available stage types are ConstantE, ConstantI, SweepE, OpenCircuit and Impedance. SweepE offers a linear sweep of the potential. During an Impedance stage the impedance is measured by applying a small AC potential superimposed with a DC potential. This corresponds to EIS with a single frequency.

Each stage can use the previous stage's potential as a reference point, for example, a constant current is applied for a fixed period and afterward, the reached potential is kept constant for a fixed period.

Furthermore, each stage can end, because a fixed period has elapsed, or certain criteria are met. At the moment, available criteria are reaching a maximum current, minimum current, maximum potential, and minimum potential.

These modes are useful especially for energy conversion and storage research, i.e. battery, solar cell, or supercapacitors research. A classic test for batteries is to charge and discharge them in several cycles. A constant current is applied, and the potential change is recorded. If a certain potential is reached, the next stage is triggered, which is usually applying the inverted constant current. This is repeated for multiple cycles.

While this method could be performed with Multistep Potentiometry, as soon as further steps are introduced the Mixed Mode is necessary. For example, to determine the capacity you would like to discharge a battery but you need to take care that the terminal potential isn't crossed. First the battery is charged. You can apply a constant current until a set potential is reached, e.g. the termination potential. After that, the termination potential is kept constant until a current limit is reached or the time has elapsed. Then this process is repeated with a negative current to discharge the battery.



Scheme of the potential and current profile during the above-described example.

Mixed Mode Settings

t interval: s

Cycles:

Stage 1: Constant I

I applied: *

t run: s

Proceed when E < V

Proceed when E > V

Stage 2: Constant E

E dc: V

t run: s

E vs previous E

Proceed when |I| < uA

Proceed when |I| > uA

Stage 3: Constant I

I applied: *

Part of the Method needed to perform the above-described method.

Another example is to study how well a supercapacitor stores charge. First, the capacitor is charged with a fixed current followed by observing the OCP of the supercapacitor.

Technique specific parameters

t interval	The time between two current samples.
	The applicable time interval range of each instrument:
	PalmSens1 and 2 1 ms to 300 s
	PalmSens3 0.2 ms to 300 s
	PalmSens4 0.4 ms to 300 s
	EmStat1, 2 and 3(+) 1 ms to 300 s
	EmStat4 LR and HR 0.4 ms to 300 s
EmStat Pico 1 ms to 300 s	
Cycles	The number of repetitions.

Parameters for Constant E stage

E dc	Potential during measurement.
	The applicable potential range of each instrument:
	PalmSens1 and 2 -2 V to +2 V
	PalmSens3 -5 V to +5 V
	PalmSens4 -10 V to +10 V
	EmStat1 and 2 -2 V to +2 V
	EmStat3 -3 V to +3 V
	EmStat3+ -4 V to +4 V
	EmStat4 LR -3 V to +3 V
	EmStat4 HR -6 V to +6 V
EmStat Pico High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V	
See also section EmStat Pico limitations for each mode on page 113.	
t run	The run time of the stage.
	The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)

Parameters for Constant I stage

i applied	<p>The current to apply. The unit of the value is the selected current range at the top. So, if 10 uA is selected and 1.5 is given as a value, the applied current will be 15 uA.</p> <p>The applicable applied currents for each instrument:</p> <table border="1"> <thead> <tr> <th></th> <th>Applied</th> <th>Available Ranges (CR)</th> </tr> </thead> <tbody> <tr> <td>PalmSens2</td> <td>-2 to 2 * CR</td> <td>1 μA to 10 mA</td> </tr> <tr> <td>PalmSens3</td> <td>-3 to 3 * CR</td> <td>1 μA to 10 mA</td> </tr> <tr> <td>PalmSens4</td> <td>-6 to 6 * CR</td> <td>1 nA to 10 mA</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 to 3 * CR</td> <td>10 nA, 1 μA, 100 μA, 10 mA</td> </tr> <tr> <td>EmStat4 HR</td> <td>-3 to 3 * CR</td> <td>1 μA, 100 μA, 10 mA and 100 mA</td> </tr> </tbody> </table>		Applied	Available Ranges (CR)	PalmSens2	-2 to 2 * CR	1 μ A to 10 mA	PalmSens3	-3 to 3 * CR	1 μ A to 10 mA	PalmSens4	-6 to 6 * CR	1 nA to 10 mA	EmStat4 LR	-3 to 3 * CR	10 nA, 1 μ A, 100 μ A, 10 mA	EmStat4 HR	-3 to 3 * CR	1 μ A, 100 μ A, 10 mA and 100 mA
	Applied	Available Ranges (CR)																	
PalmSens2	-2 to 2 * CR	1 μ A to 10 mA																	
PalmSens3	-3 to 3 * CR	1 μ A to 10 mA																	
PalmSens4	-6 to 6 * CR	1 nA to 10 mA																	
EmStat4 LR	-3 to 3 * CR	10 nA, 1 μ A, 100 μ A, 10 mA																	
EmStat4 HR	-3 to 3 * CR	1 μ A, 100 μ A, 10 mA and 100 mA																	
t run	<p>The run time of the stage.</p> <p>The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)</p>																		

Parameters for Open Circuit stage

t run	<p>The run time of the stage.</p> <p>The minimum and maximum duration of a measurement: 5 * interval time to 1,000,000 seconds (ca. 278 hours)</p>
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Parameters for Sweep E stage

E begin	Potential where scan starts.																		
E end	Potential where measurement stops.																		
	<p>The applicable potential range of each instrument:</p> <table border="1"> <tbody> <tr> <td>PalmSens1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>PalmSens3</td> <td>-5 V to +5 V</td> </tr> <tr> <td>PalmSens4</td> <td>-10 V to +10 V</td> </tr> <tr> <td>EmStat1 and 2</td> <td>-2 V to +2 V</td> </tr> <tr> <td>EmStat3</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat3+</td> <td>-4 V to +4 V</td> </tr> <tr> <td>EmStat4 LR</td> <td>-3 V to +3 V</td> </tr> <tr> <td>EmStat4 HR</td> <td>-6 V to +6 V</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V</td> </tr> </tbody> </table> <p>See also section EmStat Pico limitations for each mode on page 113.</p>	PalmSens1 and 2	-2 V to +2 V	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat1 and 2	-2 V to +2 V	EmStat3	-3 V to +3 V	EmStat3+	-4 V to +4 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V
PalmSens1 and 2	-2 V to +2 V																		
PalmSens3	-5 V to +5 V																		
PalmSens4	-10 V to +10 V																		
EmStat1 and 2	-2 V to +2 V																		
EmStat3	-3 V to +3 V																		
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EmStat4 HR	-6 V to +6 V																		
EmStat Pico	High Speed mode: -1.7 V to +2 V Low Speed mode: -1.25 V to +2 V																		

E step	<p>Step potential</p> <p>The applicable step range for each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>1 mV to 250 mV</td> </tr> <tr> <td>PalmSens3</td> <td>0.15 mV to 250 mV</td> </tr> <tr> <td>PalmSens4</td> <td>0.075 mV to 250 mV</td> </tr> <tr> <td>EmStat1 and 2</td> <td>0.1 mV to 250 mV</td> </tr> <tr> <td>EmStat3(+)</td> <td>0.125 mV to 250 mV</td> </tr> <tr> <td>EmStat4 LR</td> <td>0.1 mV to 250 mV</td> </tr> <tr> <td>EmStat4 HR</td> <td>0.183 mV to 250 mV</td> </tr> <tr> <td>EmStat Pico</td> <td>High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV</td> </tr> </table>	PalmSens1 and 2	1 mV to 250 mV	PalmSens3	0.15 mV to 250 mV	PalmSens4	0.075 mV to 250 mV	EmStat1 and 2	0.1 mV to 250 mV	EmStat3(+)	0.125 mV to 250 mV	EmStat4 LR	0.1 mV to 250 mV	EmStat4 HR	0.183 mV to 250 mV	EmStat Pico	High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV
PalmSens1 and 2	1 mV to 250 mV																
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EmStat3(+)	0.125 mV to 250 mV																
EmStat4 LR	0.1 mV to 250 mV																
EmStat4 HR	0.183 mV to 250 mV																
EmStat Pico	High Speed mode: 0.395 mV to 250 mV Low Speed mode: 0.537 mV to 250 mV																
Scan rate	<p>The applied scan rate. The applicable range depends on the value of E step since the data acquisition rate is limited by the connected instrument.</p> <p>The applicable scan rates for each instrument:</p> <table border="0"> <tr> <td>PalmSens1 and 2</td> <td>1 mV/s (1 mV step) to 25 V/s (5 mV step)</td> </tr> <tr> <td>PalmSens3</td> <td>0.02 mV/s (0.15 mV step) to 500 V/s (5 mV step)</td> </tr> <tr> <td>PalmSens4</td> <td>0.02 mV/s (0.075 mV step) to 500 V/s (10 mV step)</td> </tr> <tr> <td>EmStat1 and 2</td> <td>0.02 mV/s (0.1 mV step) to 5 V/s (5 mV step)</td> </tr> <tr> <td>EmStat3(+)</td> <td>0.025 mV/s (0.125 mV step) to 5 V/s (5 mV step)</td> </tr> <tr> <td>EmStat4 LR</td> <td>0.01 mV/s (0.1 mV step) to 500 V/s (200 mV step)</td> </tr> <tr> <td>EmStat4 HR</td> <td>0.01 mV/s (0.183 mV step) to 500 V/s (200 mV step)</td> </tr> <tr> <td>EmStat Pico</td> <td>0.01 mV/s to 10 V/s (10 mV step)</td> </tr> </table>	PalmSens1 and 2	1 mV/s (1 mV step) to 25 V/s (5 mV step)	PalmSens3	0.02 mV/s (0.15 mV step) to 500 V/s (5 mV step)	PalmSens4	0.02 mV/s (0.075 mV step) to 500 V/s (10 mV step)	EmStat1 and 2	0.02 mV/s (0.1 mV step) to 5 V/s (5 mV step)	EmStat3(+)	0.025 mV/s (0.125 mV step) to 5 V/s (5 mV step)	EmStat4 LR	0.01 mV/s (0.1 mV step) to 500 V/s (200 mV step)	EmStat4 HR	0.01 mV/s (0.183 mV step) to 500 V/s (200 mV step)	EmStat Pico	0.01 mV/s to 10 V/s (10 mV step)
PalmSens1 and 2	1 mV/s (1 mV step) to 25 V/s (5 mV step)																
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PalmSens4	0.02 mV/s (0.075 mV step) to 500 V/s (10 mV step)																
EmStat1 and 2	0.02 mV/s (0.1 mV step) to 5 V/s (5 mV step)																
EmStat3(+)	0.025 mV/s (0.125 mV step) to 5 V/s (5 mV step)																
EmStat4 LR	0.01 mV/s (0.1 mV step) to 500 V/s (200 mV step)																
EmStat4 HR	0.01 mV/s (0.183 mV step) to 500 V/s (200 mV step)																
EmStat Pico	0.01 mV/s to 10 V/s (10 mV step)																

Parameters for EIS stage

Frequency	The applied frequency in Hz.
E dc	The dc potential applied during the EIS scan.
E ac	The amplitude of the E ac signal has a range of 0.0001 V to 0.25 V (RMS). In many applications, a value of 0.010 V (RMS) is used. The actual amplitude must be small enough to prevent a current response with considerable higher harmonics of the applied ac frequency.
t run	The total run time of a scan.
t. Min. sampling	Each measurement point of the impedance spectrum is performed during the period specified by minimum sampling time 't Min sampling'. This means that the number of measured sine waves is equal to t Min sampling * frequency. If this value is less than 1 sine wave, the sampling is extended to 1 / frequency. So, for a measurement at a frequency, at least one complete sine wave is measured. Reasonable values for the sampling are in the range of 0.1 to 1 s.
t. Max equilibration	The impedance measurement requires a stationary state. This means that before the actual measurement starts, the sine wave is applied during 't Max equilibration' only to reach the stationary state. The maximum number of equilibration sine waves is however 5. The minimum number of equilibration sines is set to 1, but for very low frequencies, this time is limited by 't Max equilibration'. The maximum time to wait for a stationary state is determined by the value of this parameter. A reasonable value might be 5 seconds. In this case, this parameter is only relevant when the lowest frequency is less than 1/ 5 s so 0.2 Hz.

3.19.21 MethodSCRIPT Sandbox

Supported instruments:

- EmStat4 LR and HR
- EmStat Pico
- Sensit series

MethodSCRIPT™ is a scripting language designed for developers.

Description

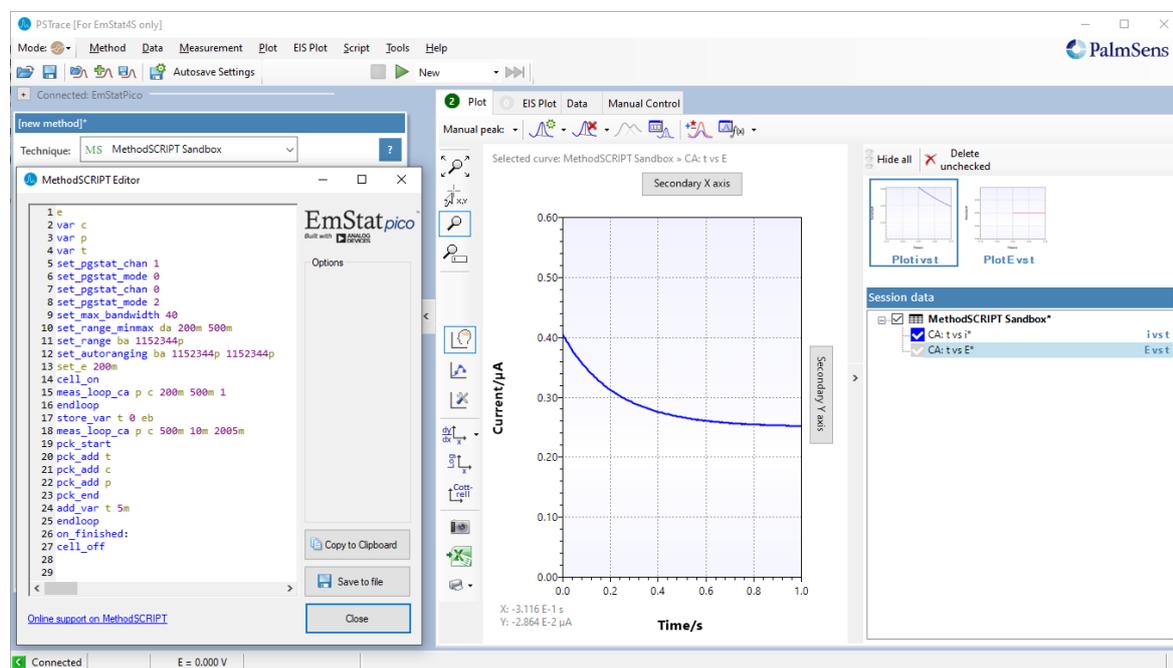
The MethodSCRIPT Sandbox allows you to write your own MethodSCRIPT and run them conveniently in PStTrace.

The MethodSCRIPT™ language allows developers to program a human-readable script directly into the potentiostat. The simple script language allows for running electrochemical techniques supported by a potentiostat and makes it easy to combine different measurements and other tasks.

More script features include:

- Use of variables
- (Nested) loops
- Logging results to an SD card
- Digital I/O for example for waiting for an external trigger
- Reading auxiliary values like pH or temperature
- Going to sleep or hibernate mode

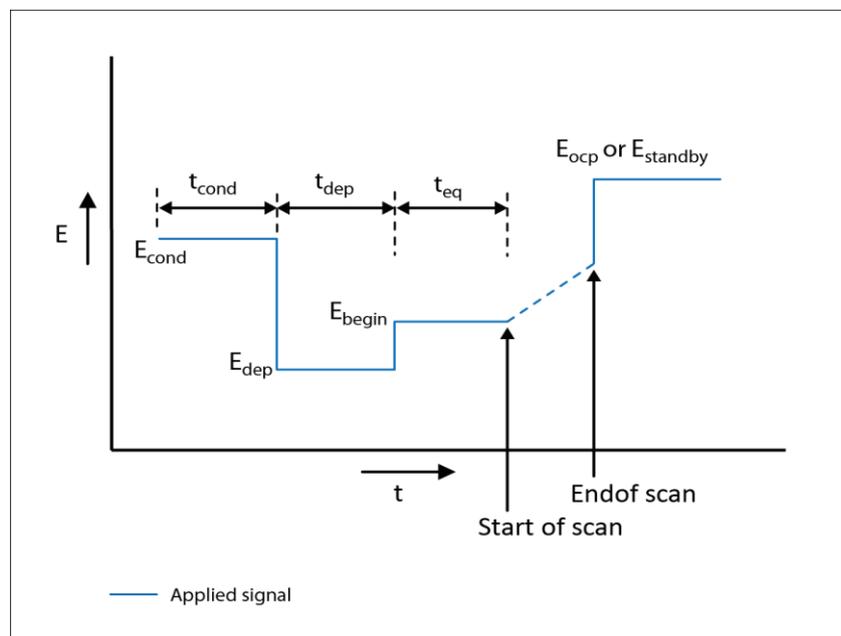
See for more information: www.palmsens.com/methodscript



PSTrace parses and stores the variables sent in pcks. Curves are generated automatically for each meas_loop that defines a pck with two or more variables, scripts with multiple meas_loops will generate multiple curves. The first variable in the pck will be set as the x-axis and a curve is created for each subsequent variable in the pck. Please note that to plot data versus time you will need to a variable with the time to the pck.

3.20 Measurement sequence

Voltammetric measurements have the following sequence.



Normal measurement sequence

The sequence of a voltammetric measurement (except for stripping chronopotentiometry) is:

1. In case Measure vs OCP is enabled: determine the OCP.
2. Apply E condition, the conditioning potential, if t condition is not zero.
3. Apply E deposition, the deposition potential, if t deposition is not zero.
4. Apply E begin and wait t equilibration seconds
5. Start measurement at E start and continue until E end with steps E step, with the specified scan rate. In CV the scan is continued by reversing the scan direction. The current range is set automatically however with the constraints as specified.
6. Depending on the potentiostat model, the measurement is plotted during the measurement or when the measurement is finished.
7. If the cell must remain switched on, E standby is applied; otherwise, the cell is switched off.

The sequence of an amperometric measurement:

1. In case Measure vs OCP is enabled: determine the OCP.
2. Apply E condition the conditioning potential, if t condition is not zero.
3. Apply E deposition the deposition potential, if t deposition is not zero.
4. Apply E or E equilibration and wait t equilibration seconds
5. Start the measurement.

Cell on after measurement

A standby potential can be set in the 'Post measurement' section in the Method Editor. This potential is applied for a certain amount of time or indefinitely after the measurement has finished. The duration can be set using the 'For specified period' checkbox.

Cell on after measurement
 E standby V
 For specified period
 t standby s

Using cell on after measurement.

3.21 Measuring versus OCP

Voltammetric measurements can be done by specifying the potential scan with respect to the Open Circuit Potential (OCP) or with absolute values versus the reference electrode.

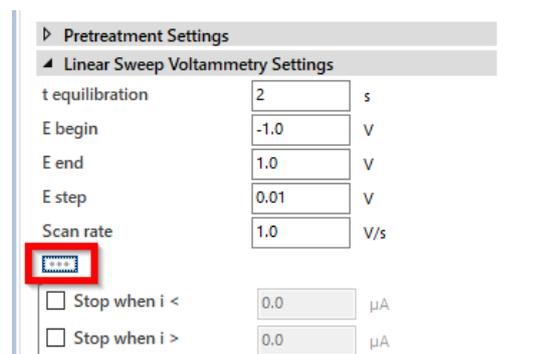
In case one or more potentials are specified with respect to the OCP, the open circuit potential must be determined before the actual measurement is done. This OCP measurement requires a variable time, which is determined by the drift of the open circuit potential and the maximum time to measure the OCP value. The OCP value is set as soon as the drift is lower than the specified value for the 'Stability criterion' or when the 't Max. OCP' has elapsed.

Stop when I < μA
 Stop when I > μA
 Measure vs OCP
 E begin versus OCP
 E end versus OCP
 t Max. OCP s
 Stability criterion mV/s

OCP parameters

3.22 Advanced settings

Additional settings for each technique can be found under the  button.



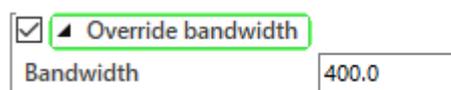
The advanced settings button in the Method Editor.

3.22.1 Stop when E or i reaches a specified value

The limits entered here apply to the entire measurement excluding the pretreatment stages.

3.22.2 Override bandwidth

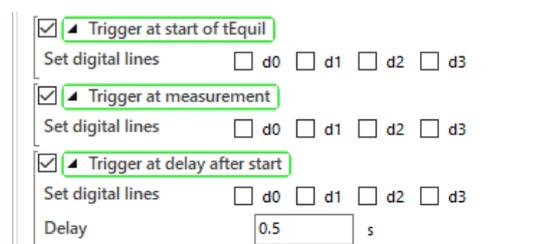
This function is only supported and visible when a MethodSCRIPT-enabled device like EmStat Pico or (Multi)EmStat4 is connected.



Normally the filters of the potentiostat are set optimally for the required bandwidth. In some exceptional cases it is useful to override the automatically determined bandwidth setting.

When the 'Override bandwidth' checkbox is set, the setting will be overridden with the value given in Hertz.

3.22.3 Digital triggers



Setting digital triggers during a measurement

In case "Trigger at ..." is set, the selected digital line(s) on the AUX port of the instrument will be set high when triggered. They will remain high until the end of the measurement. Refer to section [Auxiliary port pin-outs](#) on page 269 for more information about the position of the digital pins on your instrument's auxiliary port.

In case “Trigger at delay after start” is used, the delay will be rounded to the applicable interval time between each measured data point.

3.22.4 On-device storage

The following techniques are not supported for on-device storage with the PalmSens4: EIS, MultiStep and MixedMode.

Some potentiostat models are equipped with internal data. In case the option “Save on internal storage” is enabled, the measurement will be stored on-board the instrument in a folder with the name of the day’s date.



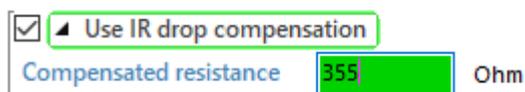
The on-board data can be browsed and downloaded using the menu: “Data” → “Load data from internal storage...”.

3.22.5 Use iR compensation

iR Compensation is optionally available for some potentiostat models, including the PalmSens4 and EmStat4X.

The resistance between the reference electrode and the double layer of the specimen can cause a significant potential drop, decreasing the applied potential where it is required. The module provides positive feedback to compensate for the iR drop between the Reference electrode and the outside of the double layer of the electrochemical cell.

The resistance to compensate for can be entered directly in the Method Editor in PSTrace:



If auto ranging is not allowed for the compensation used in combination with the selected current ranges, this is shown in the Method Editor:

Expected duration: 00:00:12s
1009 datapoints (real E step is 0.00099)

1 Error (for PalmSens4):

[1]: IR Drop resistance of 22000.000 cannot be compensated for in the 100 uA current range

Make sure a single current range is selected in these circumstances.

See section [PalmSens4 specifications](#) on page 266 for more information about the iR compensation hardware in the PalmSens4.

Supported Techniques

The following techniques are supported for use with iR compensation:

- Linear Sweep Voltammetry
- Cyclic Voltammetry
- Square Wave Voltammetry
- Differential Pulse Voltammetry
- Normal Pulse Voltammetry
- ChronoAmperometry
- Multistep Amperometry

3.23 Limitations and extra options for EmStat Pico

The EmStat Pico module has some limitations for each technique which are explained in this section. This section also applies to instruments based on the EmStat Pico like the Sensit Smart and Sensit BT.



Sensit Smart and Sensit BT based on EmStat Pico module

EmStat Pico Development Board

3.23.1 EmStat Pico limitations for each mode

The EmStat Pico can be used in two different (PGStat) modes; Low Speed and High Speed.

Each mode has different limitations for potential ranges. The table below shows which ranges are applicable for each mode.

Low Speed mode		
Mode property	Value min	Value max
EIS frequency	Not supported	Not supported
SWV frequency	1 Hz	50 Hz
Data acquisition rate	0.001 points/s	100 points/s
Potential range	-1.25 V	2.0 V
Dynamic potential window*	2.2 V	2.2 V

High Speed mode		
Mode property	Value min	Value max
EIS frequency	0.016 Hz	200k Hz
SWV frequency	1 Hz	500 Hz
Data acquisition rate	0.001 points/s	1000 points/s
Potential range	-1.7 V	2.0 V
Dynamic potential window*	1.214 V	1.214 V

*Dynamic potential window

The dynamic potential window is the available range that can be used during a single scan/sweep within the available potential range. In the Low Speed mode, a Linear Sweep Voltammetry scan can for example have the following parameters:

E Begin = -1.0 V

E End = 1.2 V

or:

E Begin = -0.2 V

E End = 2.0 V

which both are within the maximum dynamic potential window of 2.2 V.

The same limitations apply to the High Speed mode which has a more limited dynamic potential window.

3.23.2 Overriding EmStat Pico potentiostat modes

If an EmStat Pico is connected additional functions become visible when expanding the advanced options for a technique in the Method Editor

Override potentiostat mode
 Potentiostat mode: Low Speed
 Potentiostat channel: Channel 0
 Override E range
 Min E range override: 0.0
 Max E range override: 0.0

Advanced options for EmStat Pico

Override potentiostat mode

When enabled, the software doesn't choose the best mode for the EmStat Pico but uses the one specified here.

Potentiostat channel

The EmStat Pico is equipped with two channels each with their own RE, CE and WE. Here you can specify on which channel the measurement should be performed.

Override E range

To apply the desired potential between WE and RE, a potentiostat applies a potential between WE and CE. This potential is generally higher than the potential requested between WE and RE. The maximum potential the potentiostat can apply on the CE is called the compliance potential.

On the EmStat Pico, the potential range is configurable. This potential range dictates the potentials that can be applied within the measurement, and this directly affects the available compliance potential. Normally PStace automatically selects the potential range based on the measurement potentials. These potentials are defined as WE vs RE.

In some cases, the WE vs CE potential needs to be relatively high compared to the WE vs RE potential. In these cases, the automatically generated potential range may not be optimal, as the required CE potential is not known to PStace. If this is the case, the compliance potential range can be shifted to the potentials expected at WE vs CE using the "Override E range" option.

A way to verify that the compliance potential is exceeded is to measure the CE lead (black) versus the GND lead (green). If the potential reaches 2.8V vs GND, the lower (negative) limit of the potential range should be extended. If the potential reaches 0.2V vs GND, the upper (positive) limit of the potential range should be extended.

4 Electrochemical Impedance Spectroscopy

Impedance measurements are done in potentiostatic mode or galvanostatic mode if the instruments allow for it. For regular impedance measurements in potentiostatic mode, a sine wave is superimposed on the specified dc-potential, so $E = E_{dc} + E_{ac}$. This results in a dc-current with a superimposed ac-current, $I = I_{dc} + I_{ac}$.

An introduction can be found in for instance the textbook **Electrochemical Methods: Fundamentals and Applications**, written by Allen J. Bard and Larry R. Faulkner, ISBN-13: 978-0471043720

Supported instruments:

- PalmSens3
- (Multi)PalmSens4
- (Multi)EmStat4 LR and HR
- EmStat Pico

4.1 Introduction

MultiTrace provides different modes of EIS measurements:

- a frequency scan at a fixed dc-potential
- frequency scans at each potential in a potential scan
- frequency scans at specified time intervals (time scan)
- a single frequency applied at each potential in a potential scan
- a single frequency at specified time intervals

For Galvanostatic EIS (GEIS) the modes are:

- a frequency scan at a fixed dc-current
- frequency scans at each current in a current scan
- frequency scans at specified time intervals (time scan)
- a single frequency applied at each current in a current scan
- a single frequency at specified time intervals

The measured data can be presented in different plot formats.

For fitting EIS data on an equivalent circuit, see section [Equivalent Circuit Fitting](#) on page 137.

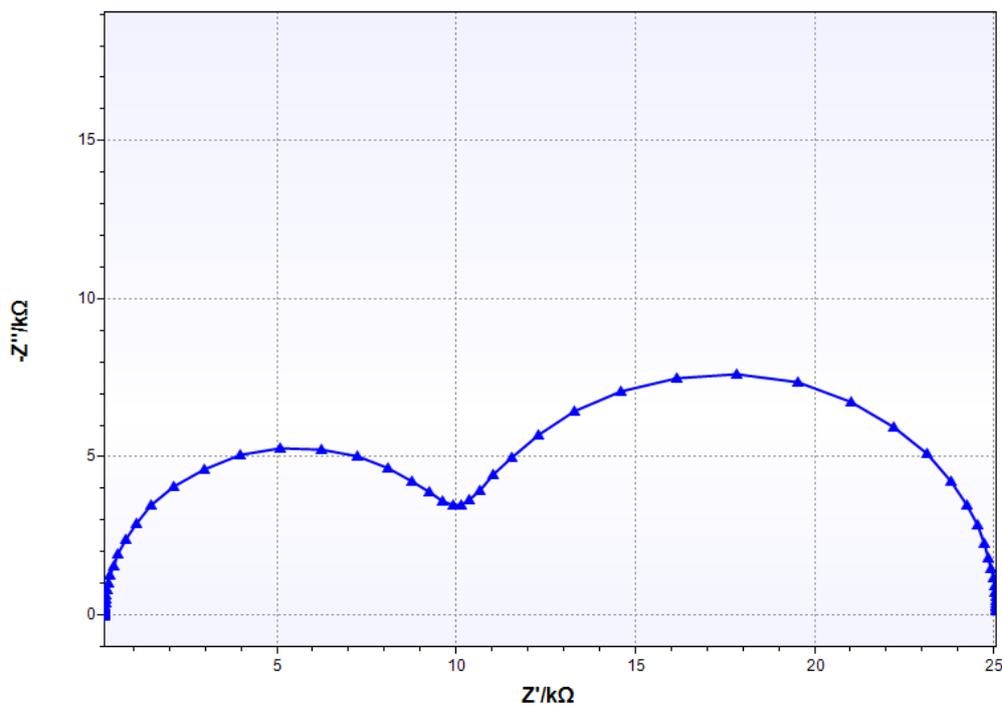
The measurements yield the impedance defined by $Z(\omega) = E_{ac}(\omega) / i_{ac}(\omega)$.

The impedance is a complex number $Z(\omega) = Z'(\omega) - jZ''(\omega)$, where Z' is the real part and Z'' the imaginary part of the impedance and $\omega = 2 \pi f$, where f is the applied frequency. The phase shift φ is defined as $\tan(\varphi) = -Z'' / Z'$. (Note: we do not use (ω) from here anymore)

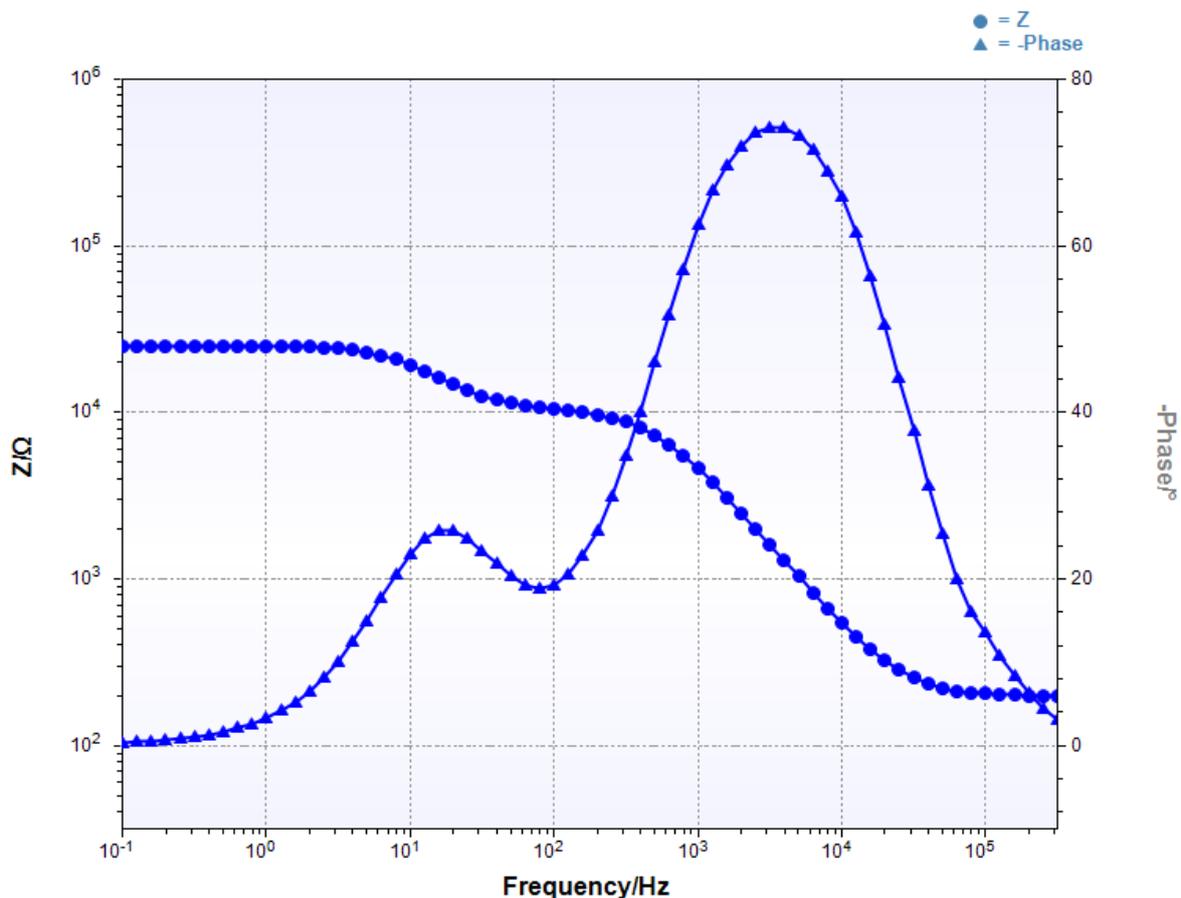
The impedance data are often presented in the Nyquist plot, with Z'' vs Z' or in a Bode plot, with the decimal logarithm of the magnitude of Z and phase shift versus the logarithm of the frequency.

The magnitude Z is defined as

$$|Z|^2 = (Z')^2 + (-Z'')^2.$$

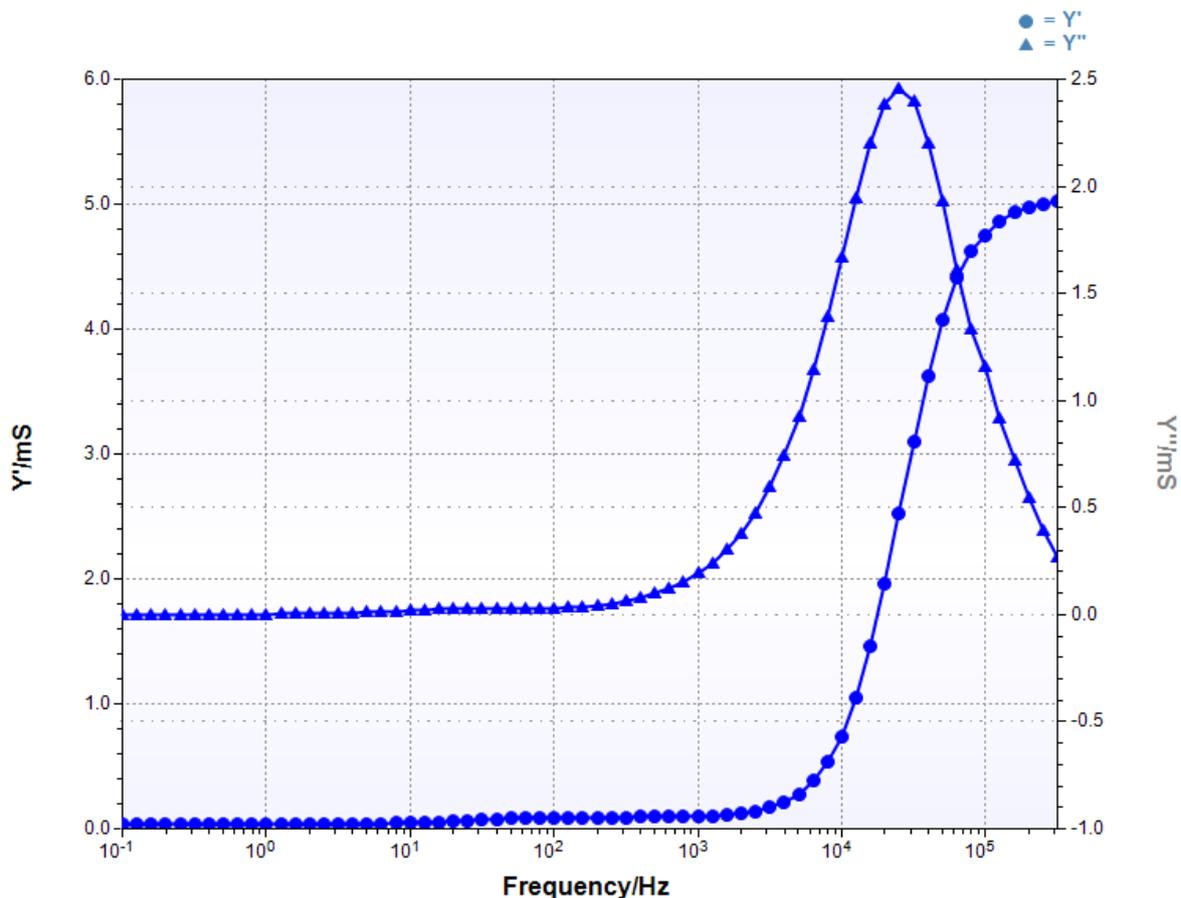


Example of a Nyquist plot.



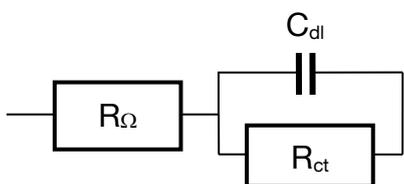
Example of a Bode plot.

The inverse of the impedance is the admittance, which is also a complex number $Y = Y' + jY''$,
 where $Y = 1 / Z$, $Y' = Z' / (Z'^2 + Z''^2)$ and $Y'' = Z'' / (Z'^2 + Z''^2)$.
 Sometimes impedance measurements are represented in a plot of Y vs $\log(f)$ or Y'' vs Y' .



Example of an admittance plot

The example shown in the plots above represents a measurement of an ideal working electrode at which a faradaic reaction occurs. The equivalent circuit for such a simple system is shown in the figure below.



Equivalent circuit

Where R_{Ω} is the ohmic resistance of the electrolytic solution, C_{dl} the capacitance of the double layer of the working electrode and R_{ct} is the resistance due to the electron transfer of the faradic reaction.

At high frequencies, the impedance is dominated by the value of R_{Ω} , so $Z = R_{\Omega}$, with a phase shift of 0° .

At low frequencies the impedance of the double layer is so high that it can be neglected, so the impedance is equal to $R_{\Omega} + R_{ct}$ and the phase shift is again 0° .

At intermediate frequencies the influence of the capacitance of the double layer (which has an impedance of $Z = -j / (\omega C_{dl})$) results in a phase shift and a measured impedance between the two limits of R_{Ω} and $(R_{\Omega} + R_{ct})$.

4.2 Setting up an impedance measurement

The Measurement tab contains all the method parameters. The Notes textbox can be used to describe the sensor used and sample that is measured.

With each change, the validation of the method is checked. Errors or incompatibilities are shown instantly at the bottom of the measurement tab.

Current ranges



With the current range buttons at the top, the applicable current range(s) during the measurement can be selected. If more than one button is selected (blue), the instrument will select the most optimal current. The highest current to be enabled is determined by the lowest impedance value and equal to $1 / Z$ (lowest value) as well as the highest obtained value for the dc-current. The lowest enabled current range is determined by the highest impedance to be measured and equal to $1 / Z$ (highest) and again the lowest value to the dc-current.

So, if the lowest impedance is in the order of 100 Ohm or lower, enable 10 mA and if the highest impedance is in the order of MOhm, enable current ranges down to 1 μ A or 100 nA.

In general, it is best to enable all current ranges for EIS. The instruments can select the proper current range automatically.

A measurement starts at the highest selected current range.

Auto current ranging in Galvanostatic EIS

Since the current follower is in the controlled loop, current range switching is not possible while measuring. Auto current ranging is therefore not supported in galvanostatic mode.

Pretreatment settings

Pretreatment is always done in potentiostatic mode, also for Galvanostatic EIS. Before a measurement starts, the working electrode or sensor can be pretreated according to the specified values for E condition1 and 2 and related times. Each time a new dc-potential is applied, the equilibration time is used before the impedance measurements start.

Frequency scan settings

A frequency scan starts at the highest specified frequency and ends at the lowest frequency. The frequency distribution can be logarithmic, linear or custom. If frequency

distribution is logarithmic, a fixed number of frequencies per decade are applied. In general, a suitable number of frequencies is 10 per decade (order of magnitude). So if a scan to be made from 10 kHz down to 100 Hz, the number of frequencies can be 2 decades times 10 + 1, so 21 frequencies. The actual applied number of frequencies can be entered or the number of frequencies per decade.

n frequencies 21 = 10 / dec. **Edit**

Max. frequency 10000.0 Hz

Min. frequency 100.0 Hz

Edit applied frequencies

Max. frequency 10000.0 Hz

Min. frequency 100.0 Hz

Logarithmic Linear Custom

n frequencies 21 = 10 / decade

Generate list

Double click on the cells to edit frequencies

Index	Frequency (Hz)
1	10000
2	7943
3	6310
4	5012
5	3981
6	3162
7	2512
8	1995
<
>	

Saved frequency lists

preset name Add

<<< Load selected Delete

Cancel Save and Close

Edit applied frequencies window

The list of frequencies is shown by clicking the Edit button in the method editor. It opens a dialog which allows the user to choose a mode (Logarithmic, linear, or custom) to generate the frequency list. Any edits made to the frequency list turns it in to a custom list which is written back to the method. The modified list can also be saved in the application settings to be used later if needed.

4.3 Parameters for EIS

Impedance Spectroscopy (EIS) parameters

Scan type

- Potential scan: defined by the E begin, E end, and E step values. At each dc potential, a single, fixed frequency is applied, or a frequency scan is made.
- Time scan: defined by E dc and t run and interval values
- Fixed potential: defined by the E dc value.

Parameters for *Scan type = Potential scan:*

E begin	<p>The potential at which the measurement starts.</p> <p>The applicable potential range for each instrument:</p> <table style="margin-left: 20px;"> <tr><td>PalmSens3</td><td>-5 V to +5 V</td></tr> <tr><td>PalmSens4</td><td>-10 V to +10 V</td></tr> <tr><td>EmStat4 LR</td><td>-3 V to +3 V</td></tr> <tr><td>EmStat4 HR</td><td>-6 V to +6 V</td></tr> <tr><td>EmStat Pico</td><td>-1.25 V to +2 V</td></tr> </table> <p>See also section EmStat Pico limitations for each mode on page 113</p>	PalmSens3	-5 V to +5 V	PalmSens4	-10 V to +10 V	EmStat4 LR	-3 V to +3 V	EmStat4 HR	-6 V to +6 V	EmStat Pico	-1.25 V to +2 V
PalmSens3	-5 V to +5 V										
PalmSens4	-10 V to +10 V										
EmStat4 LR	-3 V to +3 V										
EmStat4 HR	-6 V to +6 V										
EmStat Pico	-1.25 V to +2 V										
E step	<p>The potential step size.</p> <p>The applicable step range for all instruments</p> <table style="margin-left: 20px;"> <tr><td>PalmSens3</td><td>0.15 mV to 250 mV</td></tr> <tr><td>PalmSens4</td><td>0.075 mV to 250 mV</td></tr> <tr><td>EmStat4 LR</td><td>0.1 mV to 250 mV</td></tr> <tr><td>EmStat4 HR</td><td>0.183 mV to 250 mV</td></tr> <tr><td>EmStat Pico</td><td>0.537 mV to 250 mV</td></tr> </table>	PalmSens3	0.15 mV to 250 mV	PalmSens4	0.075 mV to 250 mV	EmStat4 LR	0.1 mV to 250 mV	EmStat4 HR	0.183 mV to 250 mV	EmStat Pico	0.537 mV to 250 mV
PalmSens3	0.15 mV to 250 mV										
PalmSens4	0.075 mV to 250 mV										
EmStat4 LR	0.1 mV to 250 mV										
EmStat4 HR	0.183 mV to 250 mV										
EmStat Pico	0.537 mV to 250 mV										
E end	The potential at which the scan ends. on page 113										

Parameters for *Scan type = Time scan:*

t run	<p>The total run time of a scan.</p> <p>Run time for each instrument: <1 s to 1,000,000 s</p>
t interval	<p>The minimum interval time between each data point (Frequency type=Fixed) or between each frequency scan (Frequency type=Scan). The interval time cannot be lower than the required time to measure the data point or perform the frequency scan + overhead time.</p>

Parameters for all scan types:

E dc	The dc potential applied during the EIS scan.
E ac	The amplitude of the E ac signal has a range of 0.0001 V to 0.25 V (RMS). In many applications, a value of 0.010 V (RMS) is used. The actual amplitude must be small enough to prevent a current response with considerable higher harmonics of the applied ac frequency.
Frequency type	Fixed: a single frequency is applied for the given duration or at each potential step or time interval. Scan: a frequency scan is performed starting at the given Max. frequency to the given Min. frequency.
Frequency	The applied frequency (in case of Frequency type=Fixed).

Parameters for *Frequency type = Scan*:

n frequencies	The number of frequencies to apply between the given Max. frequency and Min. frequency.
Max. frequency	The frequency to start the frequency scan on.
Min. frequency	The frequency to end the frequency scan on.
Measure vs OCP	If enabled, the Open Circuit Potential will be determined first as a reference point for applied dc potentials.

See also:

- “Frequency scan settings” in the section [Setting up an impedance measurement](#) on page 121.
- Section [Measuring versus OCP](#) on page 109.

Advanced parameters under [...] button:

Pretreat each scan	The potentials set in the “Pretreatment Settings” will be applied before each frequency scan is started
Force max stability filter	Applies to PalmSens4 only. Overrides the frequency-dependent stability filter to its maximum value, can prevent a shift in impedance due to 100uA to 10uA CR switch.
t. Min. sampling	Each measurement point of the impedance spectrum is performed during the period specified by minimum sampling time ‘t Min sampling’. This means that the number of measured sine waves is equal to t Min sampling * frequency. If this value is less than 1 sine wave, the sampling is extended to 1 / frequency. So, for a measurement at a frequency, at least one complete sine wave is measured. Reasonable values for the sampling are in the range of 0.1 to 1 s.
t. Max equilibration	The impedance measurement requires a stationary state. This means that before the actual measurement starts, the sine wave is applied during ‘t Max equilibration’ only to reach the stationary state. The maximum number of equilibration sine waves is however 5. The minimum number of equilibration sines is set to 1, but for very low frequencies, this time is limited by ‘t Max equilibration’. The maximum time to wait for a stationary state is determined by the value of this parameter. A reasonable value might be 5 seconds. In this case, this parameter is only relevant when the lowest frequency is less than 1/ 5 s, or 0.2 Hz.

Parameters applicable for PalmSens3 only:

Allow AC coupled measurements > 200 Hz	Enables the use of ac-coupled measurements when reading the current during measurements above 200 Hz. This option increases accuracy, but also increases sensitivity to noise and might introduce a ‘jump’ around 200 Hz.
Disable use of High Stability mode	The High Stability Mode is enabled by default for measurements at frequencies below 400 Hz. This mode filters out high-frequency noise and increases the stability of the measurement. If a small jump in phase shift is observed in a measurement around 400 Hz, it is advised to disable this mode.
Sensitivity mode	Determines the maximum gain used and therefore resolution in the measurements. If measured signals in the scope window seem too noisy, a lower sensitivity might be helpful.

4.4 Parameters for Galvanostatic EIS

In galvanostatic-EIS (GEIS) the current through the cell is controlled rather than the potential across the cell as with standard EIS. In some cases, it's preferred to perform the EIS measurement in galvanostatic mode e.g. when using low impedance cells. To prevent large currents on low impedances low amplitudes are used in potentiostatic mode, however, the cell impedance may change during the measurement giving unexpected change in currents. In Galvanostatic mode, the current amplitude is controlled and set by the user.

Galvanostatic Impedance Spectroscopy (GEIS) parameters

Scan type

- Current scan: defined by the *i* begin, *i* end and *i* step values. At each dc current, a single, fixed frequency is applied or a frequency scan is made.
- Time scan: defined by *i* dc and *t* run and interval values
- Fixed current: defined by the *i* dc value.

Parameters for Scan type = Current scan:

Applied current range	The range in which the specified current values (such as <i>i</i> begin, <i>i</i> end and <i>i</i> step) will be applied.															
	Applicable applied currents for each instrument:															
	<table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;"></th> <th style="width: 30%; text-align: center;">Applied</th> <th style="width: 40%; text-align: center;">Available Ranges (CR)</th> </tr> </thead> <tbody> <tr> <td>PalmSens3</td> <td style="text-align: center;">-3 to 3 * CR</td> <td style="text-align: center;">1 μA to 10 mA</td> </tr> <tr> <td>PalmSens4</td> <td style="text-align: center;">-6 to 6 * CR</td> <td style="text-align: center;">1 nA to 10 mA</td> </tr> <tr> <td>EmStat4 LR</td> <td style="text-align: center;">-3 to 3 * CR</td> <td style="text-align: center;">10 nA, 1 μA, 100 μA, 10 mA</td> </tr> <tr> <td>EmStat4 HR</td> <td style="text-align: center;">-3 to 3 * CR</td> <td style="text-align: center;">1 μA, 100 μA, 10 mA and 100 mA</td> </tr> </tbody> </table>		Applied	Available Ranges (CR)	PalmSens3	-3 to 3 * CR	1 μ A to 10 mA	PalmSens4	-6 to 6 * CR	1 nA to 10 mA	EmStat4 LR	-3 to 3 * CR	10 nA, 1 μ A, 100 μ A, 10 mA	EmStat4 HR	-3 to 3 * CR	1 μ A, 100 μ A, 10 mA and 100 mA
	Applied	Available Ranges (CR)														
PalmSens3	-3 to 3 * CR	1 μ A to 10 mA														
PalmSens4	-6 to 6 * CR	1 nA to 10 mA														
EmStat4 LR	-3 to 3 * CR	10 nA, 1 μ A, 100 μ A, 10 mA														
EmStat4 HR	-3 to 3 * CR	1 μ A, 100 μ A, 10 mA and 100 mA														
<i>i</i> begin	Current at which the scan starts expressed in the Applied current range.															
<i>i</i> step	The current step size.															
	The applicable minimum <i>i</i> step for each instrument:															
	<table style="width: 100%; border-collapse: collapse;"> <tbody> <tr> <td style="width: 30%;">PalmSens1 and 2</td> <td style="width: 30%; text-align: center;">0.001 * CR</td> <td style="width: 40%;"></td> </tr> <tr> <td>PalmSens3</td> <td style="text-align: center;">0.00015 * CR</td> <td></td> </tr> <tr> <td>PalmSens4</td> <td style="text-align: center;">0.000075 * CR</td> <td></td> </tr> <tr> <td>EmStat4 LR</td> <td style="text-align: center;">0.0001 * CR</td> <td></td> </tr> <tr> <td>EmStat4 HR</td> <td style="text-align: center;">0.000183 * CR</td> <td></td> </tr> </tbody> </table>	PalmSens1 and 2	0.001 * CR		PalmSens3	0.00015 * CR		PalmSens4	0.000075 * CR		EmStat4 LR	0.0001 * CR		EmStat4 HR	0.000183 * CR	
PalmSens1 and 2	0.001 * CR															
PalmSens3	0.00015 * CR															
PalmSens4	0.000075 * CR															
EmStat4 LR	0.0001 * CR															
EmStat4 HR	0.000183 * CR															
<i>i</i> end	Current at which the scan ends expressed in the Applied current range.															

Parameters for Scan type = Time scan:

t run	Total run time of the scan. <i>Run time for each instrument: <1 s to 1,000,000 s</i>
t interval	The minimum interval time between each data point (Frequency type=Fixed) or between each frequency scan (Frequency type=Scan). The interval time cannot be lower than the required time to measure the data point or perform the frequency scan + overhead time.

Parameters for all scan types:

i dc	The dc current applied during the EIS scan is expressed in the Applied current range.
i ac	The amplitude is in the RMS value as a factor of the used current range. The maximum factor is 0.4 per current range except for the 10 mA current the max factor is 0.2 x 10 mA.
Frequency type	Fixed: a single frequency is applied for the given duration or at each potential step or time interval. Scan: a frequency scan is performed starting at the given Max. frequency to the given Min. frequency.
Frequency	The applied frequency (in case of Frequency type=Fixed).

Parameters for Frequency type = Scan:

n frequencies	The number of frequencies to apply between the given Max. frequency and Min. frequency.
Max. frequency	The frequency to start the frequency scan on. In galvanostatic mode, the bandwidth of the current follower affects the stability of the system. For this reason, the maximum frequency is limited to 100 kHz for the Palmsens4.
Min. frequency	The frequency to end the frequency scan on.

See also “Frequency scan settings” in the section [Setting up an impedance measurement](#) on page 121.

Advanced parameters under [...] button:

t. Min. sampling	Each measurement point of the impedance spectrum is performed during the period specified by minimum sampling time 't Min sampling'. This means that the number of measured sine waves is equal to t Min sampling * frequency. If this value is less than 1 sine wave, the sampling is extended to 1 / frequency. So, for a measurement at a frequency, at least one complete sine wave is measured. Reasonable values for the sampling are in the range of 0.1 to 1 s.
t. Max equilibration	The impedance measurement requires a stationary state. This means that before the actual measurement starts, the sine wave is applied during 't Max equilibration' only to reach the stationary state. The maximum number of equilibration sine waves is however 5. The minimum number of equilibration sines is set to 1, but for very low frequencies, this time is limited by 't Max equilibration'. The maximum time to wait for a stationary state is determined by the value of this parameter. A reasonable value might be 5 seconds. In this case, this parameter is only relevant when the lowest frequency is less than 1/ 5 s or 0.2 Hz.

4.5 Running an EIS measurement

The sequence of the measurement depends of course on the specified parameters.

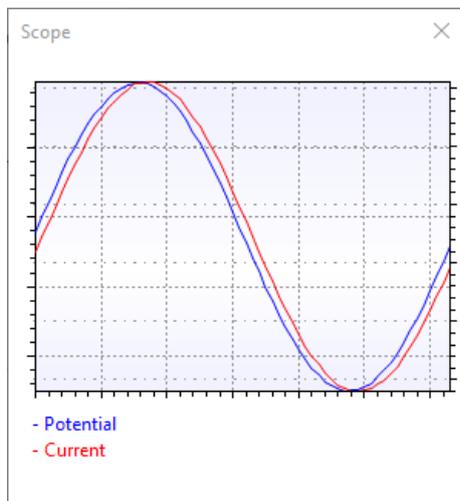
1. In case Measure vs OCP is enabled: determine the OCP.
 - If 't condition 1' > 1 apply E condition1 and wait the specified time
 - If 't condition 2' > 1 apply E condition2 and wait the specified time
 - Apply the dc-potential at which the impedance has to be measured and wait 't equilibration' seconds.
 - Apply sine wave and wait for the stationary state, using the parameters as described above.
 - Sample the impedance value by measuring at least one complete sine wave, but during at least the specified 't Min. sampling'.
 - Perform the necessary calculations and present them in the 'EIS Plot' window.
 - The next measurement is now done by stepping back to step 1, step 3 or step 4:
 - step1: if the checkbox 'Pretreat each frequency' or 'Pretreat each scan'
 - step 3: if the next dc-potential has to be applied
 - step 4: if another frequency has to be applied and the checkbox 'Pretreat each frequency' has NOT been checked.
 - Note: In case a 'Time scan' is made, the program waits until the 't interval' has been completed.

This sequence can be preceded by the measurement of the open circuit potential E OCP.

Measurement results

During the measurement the measured response is presented. The rough measurement yields a sinewave which is displayed in the 'Scope' window.

The EmStat Pico and EmStat4-series do not support the Scope window shown during measurements.



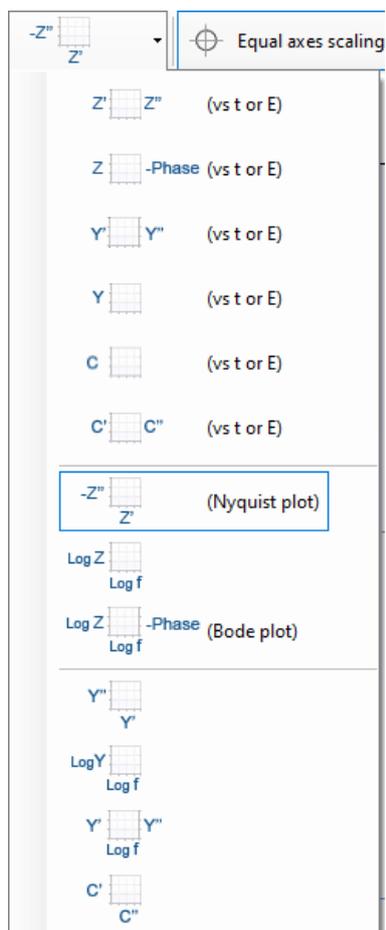
Scope window

This window is used to check that the response is not distorted by higher harmonics or noise (especially 50/60 Hz from mains) and whether the current is not measured in an overload situation.

The presented numerical results are:

- dc current
- ac current, both in units of the applied current range
- Impedance amplitude Z and phase shift in degrees
- Real or in-phase impedance Z' and imaginary or out-of-phase impedance Z''

The measured data are can graphically be presented in different ways.



Impedance plot options

For a frequency scan:

- $-Z''$ vs Z' , or Nyquist plot
- $\text{Log } |Z|$ vs $\text{log } f$
- $\text{Log } |Z|$ and $-\text{Phase}$ (shift) vs $\text{log } f$, or Bode plot
- Y'' vs Y'
- $\text{Log } Y$ vs $\text{Log } f$
- Y' and Y'' vs $\text{Log } f$
- C' vs C''

For a time or potential scan:

- Z' and Z'' vs time (t) or potential (E)
- Z and $-\text{Phase}$ (shift) vs t or E
- Y' and Y'' vs t or E
- Y vs t or E
- C vs t or E
- C' and C'' vs t or E

Please note that if a plot of Y vs potential is made, the plot in fact is an ac-voltammogram.

The numerical values of impedance, phase shift, and admittance are shown in the Data tab.

The series capacitance $|C|$ is $1 / (j * f * 2 * \pi * Z'')$ where the imaginary component j can be ignored as there is no real part to contribute to the magnitude. The real and imaginary capacitance are calculated as follows $C' = Z'' / (f * 2 * \pi * |Z|^2)$ and $C'' = Z' / (f * 2 * \pi * |Z|^2)$.

RRCRC_0V
Copy to clipboard

Index	Frequency/Hz	Z/Ohm	ZRe/Ohm	ZIm/Ohm	-Phase/Degr	Cs/F	CR
1	10000	669.882	661.115	-108.025	9.28	1.473E-07	1 mA
2	7943.28	769.209	707.219	-302.53	23.16	6.623E-08	1 mA
3	6309.57	909.844	750.994	-513.639	34.37	4.911E-08	1 mA
4	5011.87	1101	800.139	-756.39	43.39	4.198E-08	1 mA
5	3981.07	1354	873.853	-1034	49.8	3.866E-08	1 mA
6	3162.28	1680	971.615	-1371	54.67	3.672E-08	1 mA
7	2511.89	2080	1104	-1763	57.93	3.595E-08	1 mA
8	1995.26	2585	1319	-2223	59.33	3.588E-08	1 mA
9	1584.89	3206	1641	-2754	59.22	3.646E-08	1 mA
10	1258.93	3962	2122	-3346	57.61	3.779E-08	1 mA

Data tab showing the raw measured data

4.6 Fitting measured EIS data in PSTrace

PSTrace comes with an advanced Equivalent Circuit fitting tool. See section [Equivalent Circuit Fitting](#) on page 137 for more information.

4.7 Export for analysis and circuit fitting

PSTrace comes with an advanced Equivalent Circuit fitting tool. However, PSTrace also allows exporting EIS data to Scribner's ZView and the free program EIS Spectrum Analyser. Measured data in PSTrace can be opened or added to ZView with a one-click action.

4.7.1 Free EIS Spectrum Analyser

Data can be saved in a file that is loaded in the third party program (free of charge) EIS Spectrum Analyzer, written by Alexander S. Bondarenko and Genady A. Ragoisha and is available from <http://www.palmsens.com/eisspectrumanalyser>.

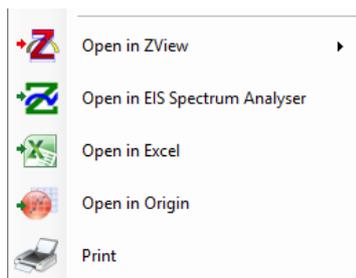
This program allows users to fit the measured data to specific equivalent circuits and for instance obtain the best values of the elements in the equivalent circuit, for instance, R_{Ω} , R_{ct} and C_{dl} .

The file can be saved using the button in the toolbar left from the plot:



Or from the EIS Plot menu:





EIS plot menu

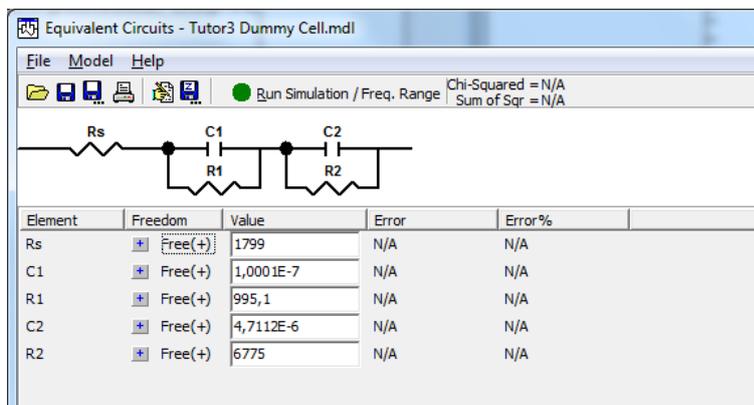
For detailed instructions consider the manual of EIS Spectrum Analyser.

4.7.2 ZView

If ZView 3.3 or later is installed, PSTrace will detect this automatically. A one-click-export button will appear next to the plot. The measurement selected in the Legend will be exported to ZView.



ZView one-click-export button



Equivalent circuit model in ZView

Multiple measurements can be run from PSTrace and fitted on the active circuit model in ZView with a single click from PSTrace.

For detailed instructions consider the manual of ZView.

4.7.3 Origin

Origin from OriginLab is scientific graphing and data analysis software widely used at universities.

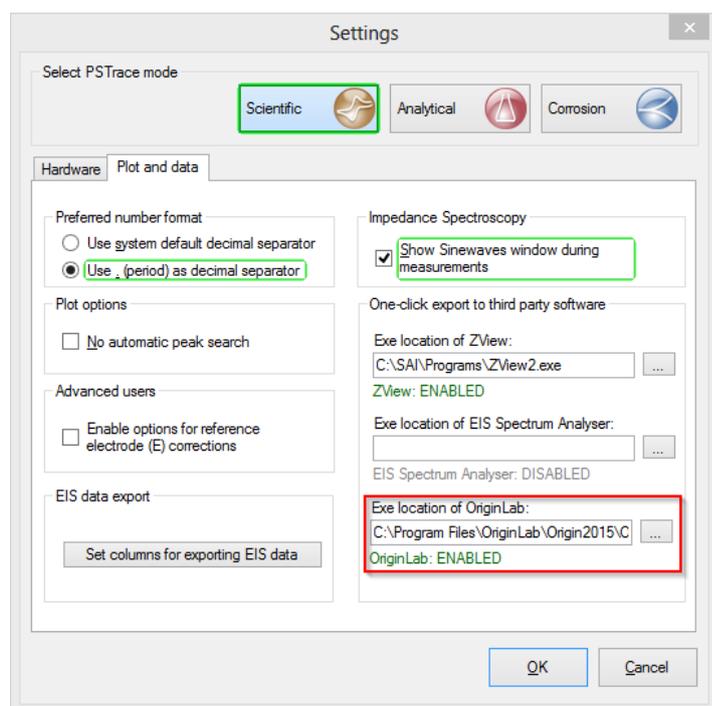
See for more information: <http://www.originlab.com/>

If Origin is installed on the PC where PSTrace is running on an extra button appears in the toolbar next to the plot:



When clicking this button, Origin will be opened showing the selected EIS data directly in a Work sheet.

If the button is not showing and Origin is installed, open the General settings window in the menu (Tools → General settings...) and check in the 'Plot and data' tab if the location for Origin is properly set.



Location for Origin specified in the Settings window.

To change the exported columns for EIS data, click the button 'Set columns for exporting EIS data' on the left-hand side of the Settings window.

4.8 Limitations for EIS on EmStat Pico

This section also applies to EmStat Pico powered instruments including the Sensit BT and Sensit Smart.

Electrochemical Impedance Spectroscopy (EIS) measures the change of the complex impedance over a frequency range (spectrum). The common way to calculate the complex impedance is by dividing the complex voltage by the complex current. The ADUCM355 has only 1 ADC so it is not possible to measure both signals (voltage and current) at the same time, the proposed solution to enable EIS measurement using only

the current signals is a 3-stage measurement. The total EIS measurement for one single frequency point is split up into three measurements on three different impedances:

1. Zcell + Rload
2. Rload (load resistor in the WE signal path)
3. Rcall (calibration reference resistor)

Since all three measurements are performed under the same conditions and Rcall is a reference resistor of known value, the final complex impedance of Zcell can be calculated having only the complex currents of the three measurements.

Complex voltage correction

For the plain ADuCM355 the conditions for the 3 measurements are equal, for the Emstat Pico the measurement on the Zcell+Rload is performed using external RE-buffers introducing a complex transfer function for the applied AC voltage on the Zcell+Rload. This complex voltage transfer function is modeled by an electronic circuit simulation of the gain and phase behavior of the transfer function.

Time-domain sinewave

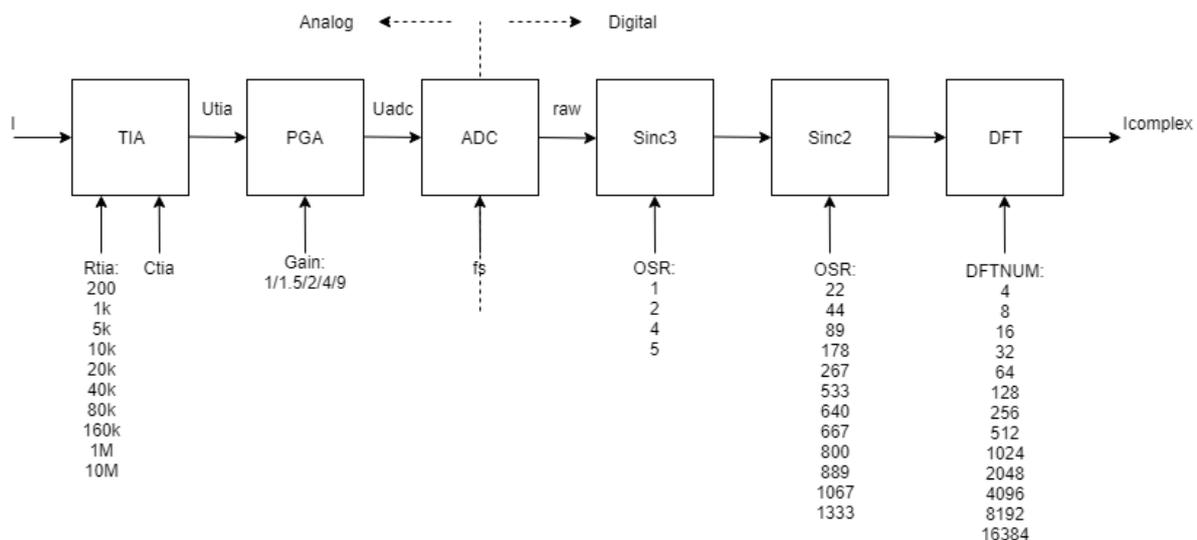
The Emstat Pico integrates a DFT calculation block enabling onboard complex current calculations. In contrast to other PalmSens devices having the EIS feature, the raw ADC signal is not available and therefore the time-domain signal cannot be shown in a host application (PSTrace, PStouch)

Measurement duration

The accuracy of the complex current depends on the number of the applied frequency cycles presented to the DFT process. For higher frequencies, the time to measure multiple cycles is relatively short in contrast to the lower frequencies. For example, measuring 8 cycles of 1 Hz takes 8 seconds resulting in a 24 seconds measurement duration for a complete 3-stage measurement.

Current ranges

Since the conditions must be the same, all 3 measurements must be performed using the same current range. Rload (~100 Ω) and the Rcall (1 k Ω or 100 k Ω) are fixed values, however the complex current measurements are frequency depended due to parasitic effects of the signals path. The changes of Zcell vs frequency can be so large that it cannot be covered by staying in the same current range. Auto current ranging dynamically changes the current range (in combination with the PGA) to cover the frequency range in the EIS measurement.



DFT signal path block diagram for EmStat Pico

More details can be found in the ADuCM355 Hardware Reference Manual- UG-1262 p137-p143.

5 Equivalent Circuit Fitting

The Circuit Editor can be used to build, simulate, and fit equivalent circuits on your Electrochemical Impedance Spectroscopy data. The following chapters present an overview of the circuit editor's options and features.

For more detailed information on fitting equivalent circuits electrochemical impedance spectroscopy measurement the following literature is recommended:

Electrochemical Impedance Spectroscopy. Chapter 23: An Integrated Approach to Impedance Spectroscopy. Mark E. Orazem & Bernard Tribollet, ISBN: 978-0-470-04140-6.

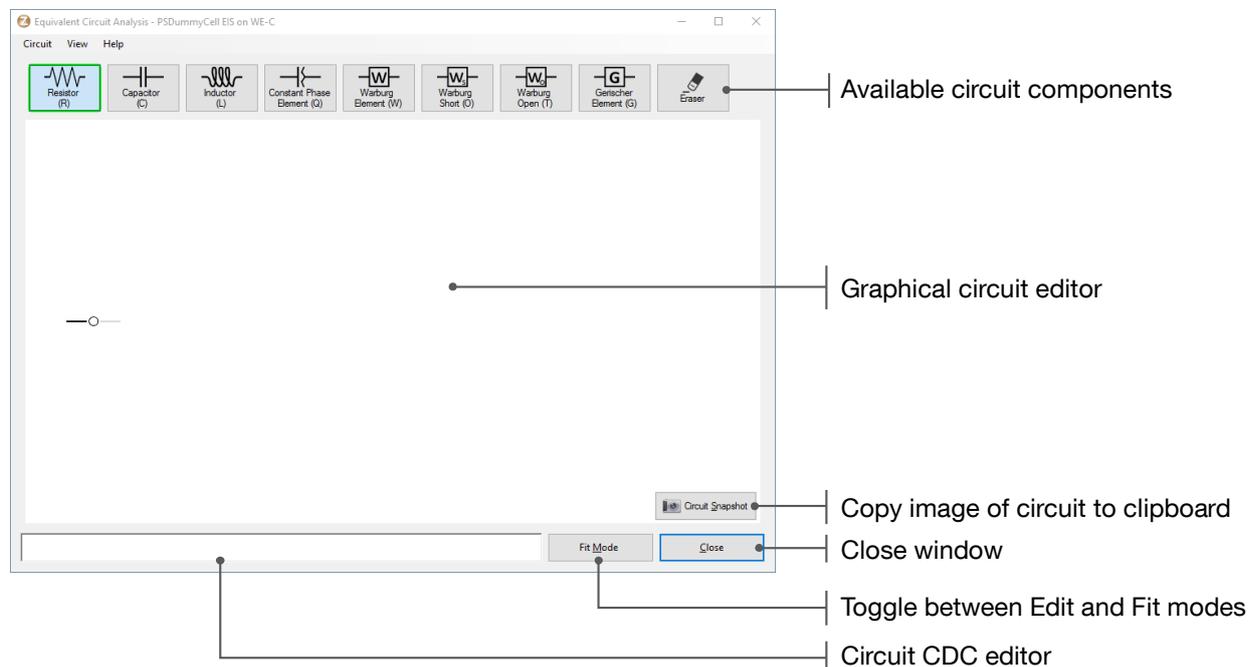
Electrochemical Impedance Spectroscopy and its Applications. Chapter 14: Modeling of Experimental Data. Andrzej Lasia, ISBN: 978-1-4614-8932-0.

5.1 Overview

The circuit editor can be used in two different modes:

- Edit mode: draw the circuit or type CDC circuit
- Fit mode: fit the EIS data on the circuit or simulate the circuit

Circuit Edit Mode



Circuit Editor main window in Edit Mode.

Circuit Fit Mode

Plot selector

Preview plot

Open fitted data in Excel

Set frequency range for fitting

Component values

Undo / redo last action

Copy results to clipboard

Do fit on model

Toggle between Edit and Fit modes

Component values

Found	Element	Fitted Value	Min Value	Max Value	Unit	Error%
<input type="checkbox"/>	R 1	556.6	1.00E-6	1.00E+12	Ω	
<input type="checkbox"/>	R 2	9991	1.00E-6	1.00E+12	Ω	
<input type="checkbox"/>	C 1	0.033	1.00E-6	1.00E+3	μF	

Circuit Editor main window in Fit Mode.

5.2 Opening the circuit editor

The circuit editor can be opened from the EIS Plot tab in MultiTrace. To fit a circuit the measurement to fit on must be selected from the Session Manager first. When no measurement is selected it is only possible to simulate circuits.

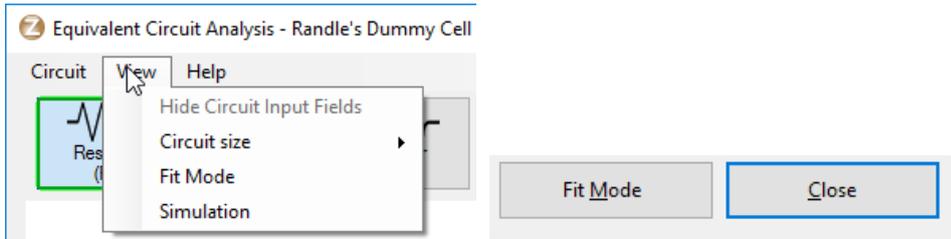
Button for opening Circuit Fitting window

5.3 Switching between Edit mode and Fit mode

The circuit editor has two modes.

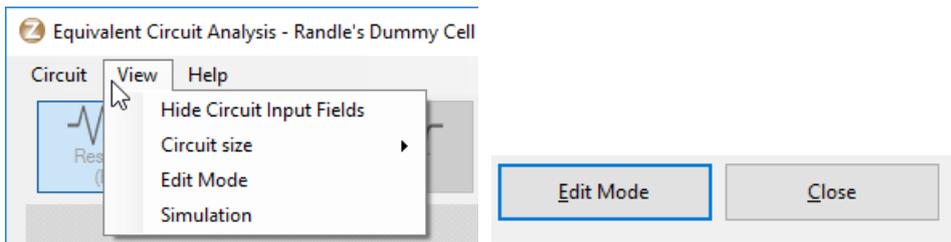
1. In **Edit mode** circuits can be built, edited, loaded and saved.
2. In **Fit mode** the circuit built in the Edit Mode can be simulated or fit on the electrochemical impedance spectroscopy data. (Note: Fitting is only possible when a measurement was selected in the Session Manager while opening the circuit editor.)

To switch from the edit mode to the fit mode either press the Fit Mode button or select Fit Mode from the view menu.



Switching between the two modes

To switch from the fit mode to the edit mode either press the Edit Mode button or select Edit Mode from the view menu.



Switching between the two modes

5.4 Building a circuit

There are two ways to build an equivalent circuit.

1. Using the graphical circuit editor.
2. Using the CDC editor.

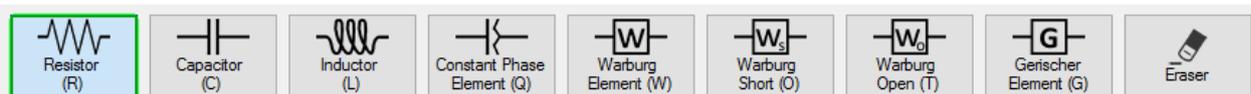
To build a circuit the circuit editor must be in edit mode.

Graphical circuit editor

Circuits can be built graphically using the circuit components and the graphical circuit editor.

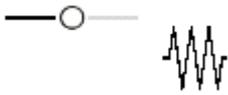
Selecting a circuit component

By default the resistor is selected. To select another circuit component click on it. The eraser is used to remove components from the circuit.



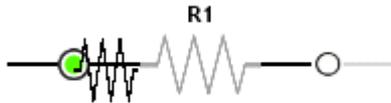
Adding a component to the circuit

Components can be added in series or in parallel with other components. The first component is added by hovering the mouse cursor over the open connector in the graphical circuit editor and clicking the left mouse button.



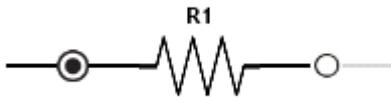
The open connector

When hovering the mouse cursor over a connector it will turn green and a grey preview of the component is displayed.



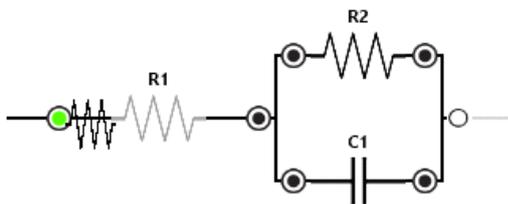
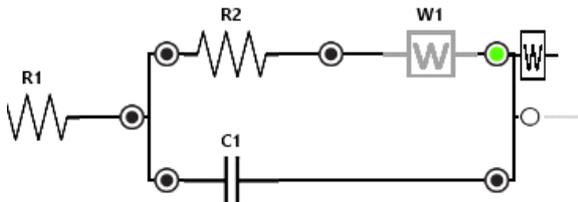
Preview of the component

By clicking the left mouse button the component is added to the circuit.



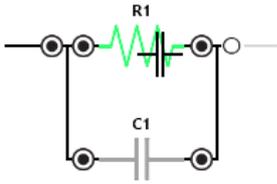
The inserted component.

To add components in serial the mouse cursor must hover over a connector. Clicking on the left mouse confirms the placement of the component.

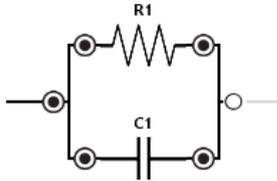


Adding components in series

Components can be added in parallel to other components by hovering the mouse cursor over the component it must be placed parallel to. When hovering the mouse cursor over another component it will turn green to indicate that it is selected and a preview parallel component is shown in grey. Click the left mouse button to confirm the placement of the component in the circuit.



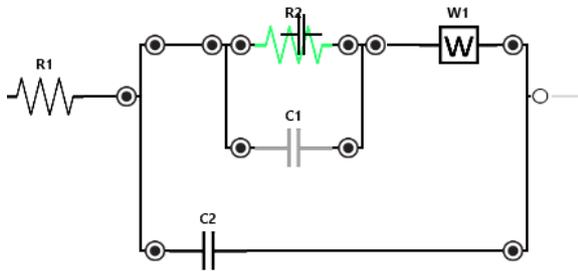
Preview of a parallel component



Component added in parallel

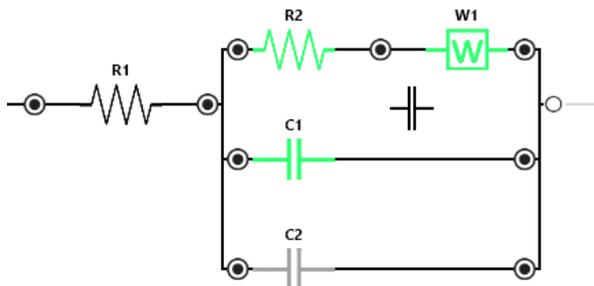
When creating larger circuits it is useful to know that components can be added in parallel within or over a parallel group in the circuit.

To place a component in parallel to a component within a parallel group directly hover the mouse cursor over the other component and click on the left mouse button.



Placing a component in parallel to a component within a parallel group

To place a component in parallel to the entire group hover the mouse cursor over the group. This will select the entire group (i.e. all its components will turn green). Clicking on the left mouse button will confirm the placement of the component.



Placing a component in parallel to the entire parallel group

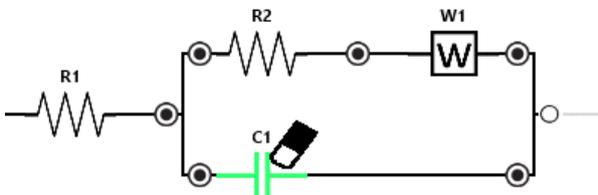
Removing components from the circuit

Components can be removed from the circuit using the eraser tool. To remove a component, select the eraser tool.

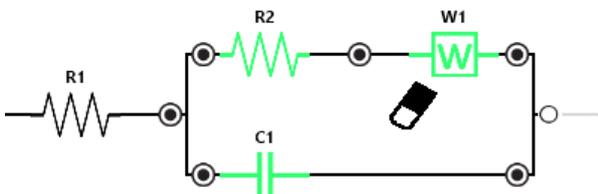


Eraser tool

To remove a component or a group of parallel components hover the mouse cursor over it. The component(s) will turn green indicating that they are selected. Clicking the left mouse button will remove the selected components from the circuit.



Removing a single component



Removing a group of components

CDC circuit editor

The CDC circuit editor is located at the bottom of the circuit editor. To build a circuit using the CDC circuit editor click on it and type the circuits CDC code. If the CDC code is valid the circuit is updated directly in the graphical circuit editor. The CDC code is described by Boukamp in:

Boukamp BA (1986) A package for impedance/admittance data analysis. *Solid State Ionics* 18 & 19, 136-40.

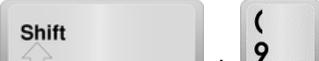


Field for entering CDC directly

Supported CDC characters

The following characters and controls are supported by the CDC circuit editor.

R Inserts a resistor.

-  Inserts a capacitor.
-  Inserts an inductor.
-  Inserts a Warburg impedance.
-  Inserts a constant phase element.
-  Inserts a parenthesis defining the beginning of a parallel group.
-  Inserts a parenthesis defining the end of a parallel group.
-  Inserts a bracket defining the beginning of a series group.
-  Inserts a bracket defining the end of a series group.

Supported CDC controls

The following controls are supported by the CDC circuit editor.

The mouse cursor places the text cursor in the CDC editor by clicking the left mouse button. It can also be used to select text in the CDC editor by holding down the left mouse button and dragging the cursor over the CDC characters it should select.

  The arrow keys move the text cursor left and right respectively. In

combination with  they select CDC code.

 /  Home and end move the cursor to the beginning or end of the CDC code

respectively. In combination with  they select CDC code.

 Backspace removes the CDC character to the left. Backspace cannot be used to remove a selection of CDC characters.

 Delete removes the CDC character to the right. Backspace cannot be used to remove a selection of CDC characters.

 +  Control + A selects all of the CDC code.

 +  Control + C copies the selected CDC code to the clipboard.

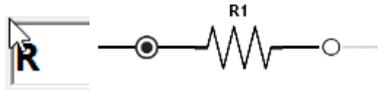
 +  Control + X cuts the selected CDC code and sends it to the clipboard.



Control + V pastes the contents of the clipboard to the location of the text cursor.

Adding components

Components are added to the circuit by typing the keys of the supported characters.



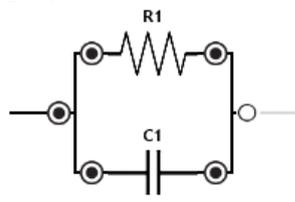
Pressing R will add a resistor to your circuit

To add components in parallel parenthesis must be used. After opening the parenthesis the CDC editor will turn red indicating the CDC code is invalid at the moment. Ignore this and add the components that should be placed parallel to each other.

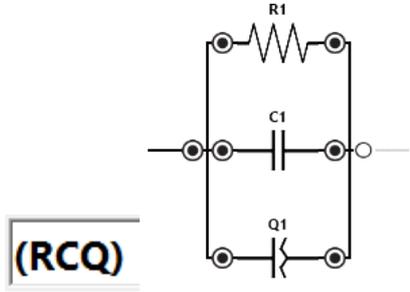
1. (
2. (RC
3. (RC)

Entering CDC code for components parallel to each other

As soon as the parenthesis are closed the CDC code will become valid again and the graphical circuit editor will display the circuit as well.



Graphical representation of the (RC) circuit in the graphical circuit editor

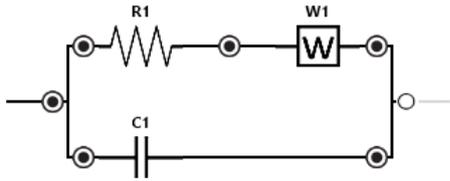


Example of a CDC code with three components parallel to each other

Within a group of components parallel to each other brackets must be used to add a component in series to one of the components. After opening the brackets the CDC editor will turn red indicating the CDC code is invalid at the moment. Ignore this and add the components that should be placed series to each other.

1. ([RC)
2. ([RWC)
3. ([RW]C)

Entering CDC code for components in series within a parallel group



Graphical representation of the $([RW]C)$ circuit in the graphical circuit editor

In some cases it is easier to copy and paste parts of the CDC code to quickly build a large circuit. This can be done using the supported CDC controls.

1. `R(RC)`
2. `R(RC)`
3. `R(RC)(RC)`

Copying and pasting in the CDC editor

Removing components

Components can be removed from the circuit with the CDC circuit editor by placing the text cursor next to the component that should be removed and using the supported CDC circuit editor controls. Pressing backspace or delete removes the CDC character to the left or right of the text cursor respectively. The changes to the circuit are directly visible in the graphical circuit editor.

1. `R(RQC)`
2. `R(RC)`

Backspace removes the constant phase element to the left of the text cursor

1. `R(RQC)`
2. `R(RQ)`

Delete removes the capacitor to the right of the text cursor

Removing a parenthesis or bracket from a valid CDC code will invalidate it. The CDC circuit editor will indicate this by turning red. This happens typically when you want to remove a parallel or series group from a circuit.

1. `R(R(RC))`
2. `R(R(RC))`
3. `R(R(R))`
4. `R(R())`
5. `RR`

Removing a parallel group from a circuit using backspace

In this example the parentheses around the second resistor are removed as they no longer have any meaning.

A selection of CDC characters can be removed by cutting or deleting it with control + x, backspace or delete. The selection can also be replaced by pasting data from the clipboard, control + v, or replacing it with any of the supported characters.

1. `R(RC)(RC)`
2. `R(R)`

Invalid CDC code

In the case of an invalid CDC code the CDC circuit editor indicates this by turning red. The graphical circuit editor is not updated until the CDC code is valid again, this is indicated by the CDC circuit editor turning white again.

When adding or removing a parallel or series group from a circuit using the CDC circuit editor ignore that the code is invalid, as it will be valid again once the entire parallel or series group has been added or removed.

When using the graphical circuit editor in combination with the CDC circuit editor hovering the mouse over the graphical representation will remove any invalid CDC code in the CDC circuit editor.

R(C[R]W]

Invalid placement of closing parenthesis

Here the invalid CDC code can be resolved by removing the closing parenthesis between the resistor and Warburg impedance and placing it at the end of the CDC code.

R(C[RW])RC)

Unbalanced amount of opening and closing parentheses or brackets

Here the invalid CDC code can be resolved by adding an opening parenthesis or removing a closing parenthesis, as the amount of opening and closing parenthesis is unbalanced in this example.

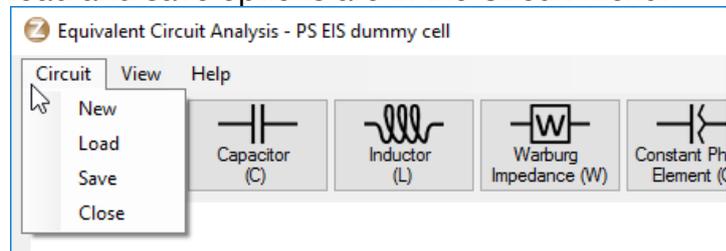
R(RCfewfe)

Unsupported CDC characters have been pasted into the CDC circuit editor

This code is invalid because unsupported CDC characters were pasted into the CDC circuit editor from the clipboard. To resolve this, the unsupported CDC characters must be removed.

5.5 Loading and saving circuits

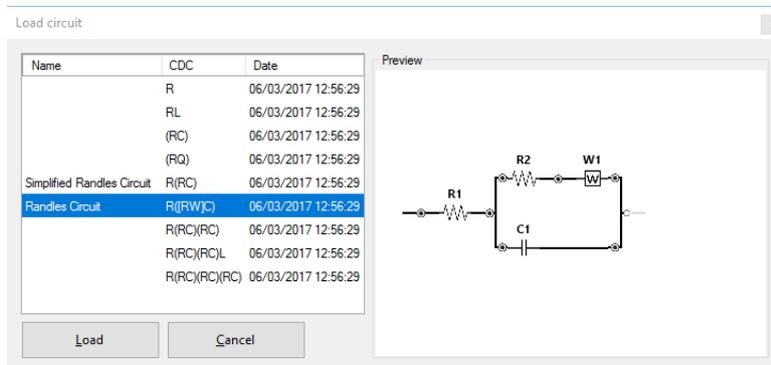
Circuits can be stored in and retrieved from the circuit database on your computer. The load and save options are in the Circuit menu.



To load or save a circuit the circuit editor must be in edit mode.

Loading a circuit

To load a circuit, open the load circuit screen by selecting load in the Circuit menu. In this screen the available circuits stored on your computer are listed in the circuit browser on the left. A preview of the selected circuit is presented in the preview panel on the right.

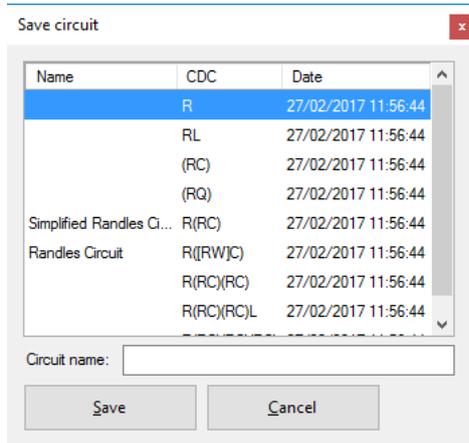


Load circuit window

The selected circuit can be loaded by pressing on the Load button or double-clicking on the circuit.

Saving a circuit

Circuits can be saved using the save circuit screen. To open the save circuit screen select save in the Circuit menu. The option to save a circuit is only available if there is a circuit containing at least one component in the editor. The save circuit screen contains a circuit browser and a field to input the name of circuit that is being saved.



Save circuit window

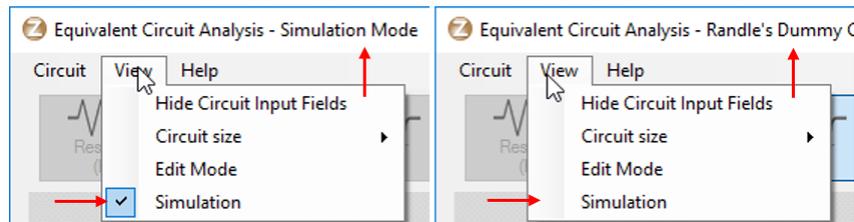
To save the circuit press the save button. Optionally a name can be assigned to the circuit in the circuit name input field.

5.6 Fitting or simulating a circuit

After an equivalent circuit has been built or loaded into the circuit editor in Edit Mode it can be simulated or fit onto the data of the electrochemical impedance spectroscopy measurement.

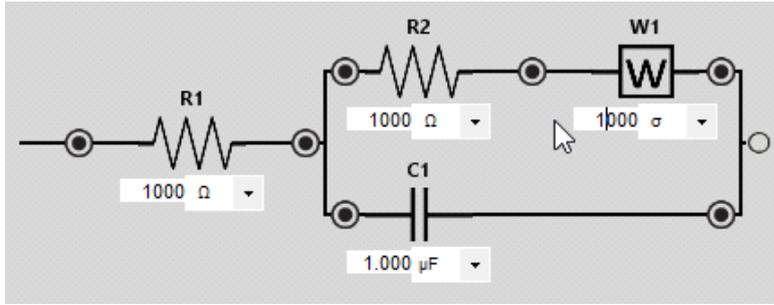
Simulating a circuit

The impedance of circuits can be simulated using the circuit editor. When simulating the fit options are disabled. Check the title of the circuit editor or the view menu to see whether the circuit editor is set to simulation mode.



Circuit editor set to simulation mode and fit mode. In fit mode the name of the measurement is visible in the title bar and the simulation is not checked in the view menu.

Values of the components can be changed in the circuit table and the graphical circuit editor. Changing the value of a component in either the graphical circuit editor or the table will automatically update the value in the other. The effects of these changes will appear directly in the preview plot.

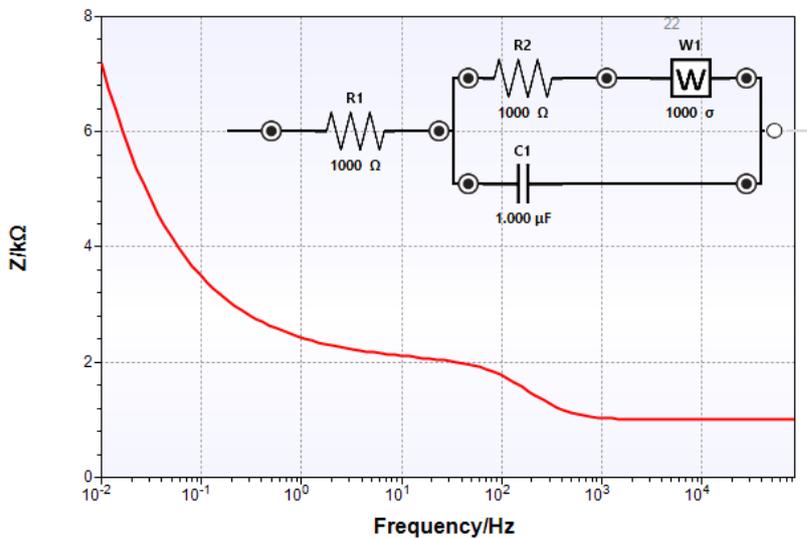


Changing the value of the Warburg Coefficient for a Warburg Impedance in the graphical circuit editor.

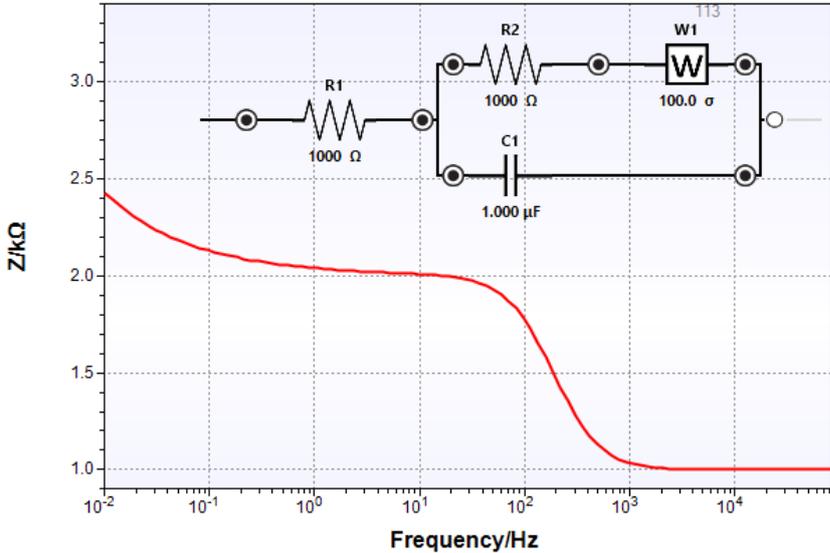
Element	Fitted Value	Unit	Error%
R 1	1000	Ω	
R 2	1000	Ω	
W 1	1000	σ	
C 1	1.000	μF	

Changing the value of the Warburg Coefficient for a Warburg Impedance in the circuit table.

For example, changing the value of the Warburg Coefficient to 100 will lower the impedance at the lower frequencies.

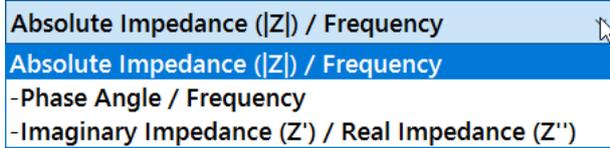


Simulation of the absolute impedance over frequency of a Randle's circuit using the default values.



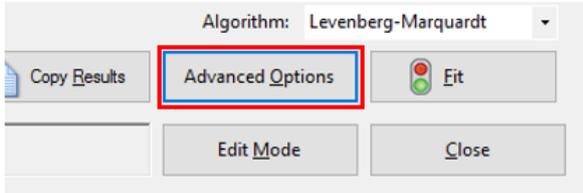
Simulation of the absolute impedance over frequency of a Randle's circuit with the value of the Warburg Coefficient lowered to 100.

Using the plot selector, it is possible to view the effects of lowering the Warburg Coefficient to 100 on the negative phase angle over frequency and the Nyquist plot as well.

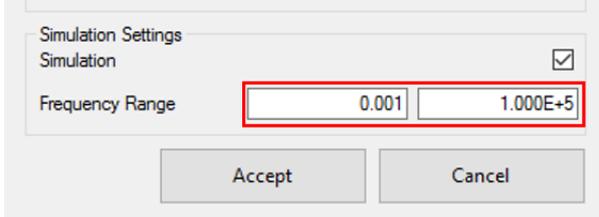


Setting the simulation's frequency range

The frequency range of the simulation can be set in the Advanced Options menu which can be accessed by clicking on the Advanced Options button.

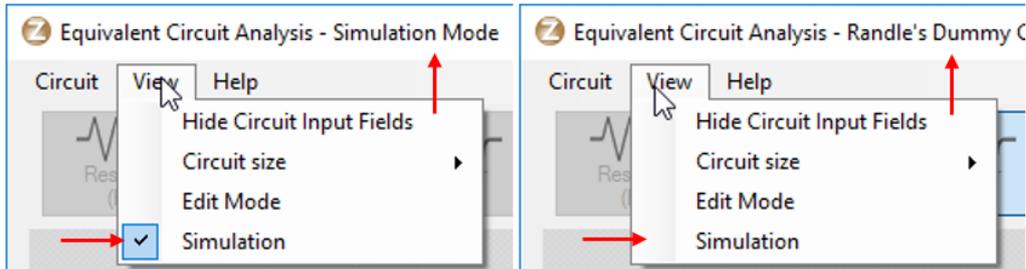


The simulations frequency range (Hz) can be specified in the simulation settings, by default this is 0.01 to 100000 Hz.



Fitting a circuit

Before fitting the circuit, it is important to check whether the circuit editor is in simulation or fit mode. Check the title of the circuit editor or if the simulation option is checked in the view menu.



Circuit editor set to simulation mode and fit mode. In fit mode the name of the measurement is visible in the title bar and the simulation is not checked in the view menu.

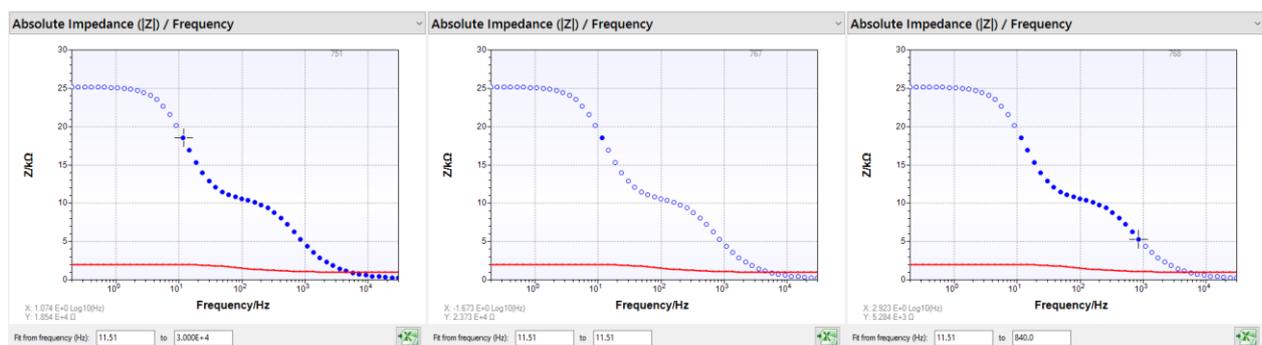
To ensure a good fit on a measurement it is important to build the right equivalent circuit. It is often possible to achieve a good fit with different but similar circuits. Although these other circuits can provide a good fit, they are not necessarily an accurate representation of the cell that was measured. Selecting appropriate initial values for the components in the models is also recommended, as in some cases the fitting algorithm will get stuck in a local minimum and the quality of the fit is not optimal.

Fitting on a specific frequency range

The frequency over which you desire to fit the circuit can be specified either by clicking in the plot or by entering the values in the corresponding textboxes.

Note: Specifying the frequency range over which to fit the data is only possible when in fit mode. To specify the frequency for a simulation please refer to the help section on simulating a circuit. Specifying the fitting frequency range is only possible in the plots that also show the measured data (i.e., the blue dots).

Specifying fitting frequency with the mouse is done by moving your mouse over the sample from where you would like to start or end your fit, then clicking on that sample (blue dot) twice. Then move your mouse to the data point where you would like to respectively end/start your fit and click on it once. The frequency range selected for fitting is indicated by the solid blue dots.



Specifying the frequency range for fitting. **Left:** First move your mouse to the data point from which you would like to start the fit and click on it. **Middle:** Click on it again, now it will be the only data point selected (in this case the sample at 11.51 Hz). **Right:** Then move your mouse to the data point where you would like fitting to end and click

on it. The selected frequency range is now indicated by the solid blue dots and the values in the text boxes below the plot.

Excluding outliers

To exclude outliers from a fit hold down the control button on your keyboard and left click on the outlier with your mouse to deselect it. Left clicking on that point again while holding down control will reselect it. While holding down both the control button and the left mouse button it is possible to (de)select all points in the specified area.

Fixate a component's value

When necessary, it is possible to fixate the value of any given component in the model by checking its checkbox in the Fixed column.

Fixed	Element	Fitted Value	Min Value	Max Value	Unit	Error%
<input checked="" type="checkbox"/>	R 1	540.0	1.00E-6	1.00E+12	Ω	
<input type="checkbox"/>	R 2	9982	1.00E-6	1.00E+12	Ω	
<input type="checkbox"/>	C 1	0.033	1.00E-6	1.00E+3	μF	
Chi-Squared:		0.0001	Iterations:		6	

Undo/Redo changes to component values

The undo/redo buttons allow you to revert unwanted changes to the model's component values either due to an incorrect fit or a mistake when entering the values.

Fixed	Element	Fitted Value	Min Value	Max Value	Unit	Error%
<input type="checkbox"/>	R 1	707.4	1.00E-6	1.00E+12	Ω	22.25
<input type="checkbox"/>	R 2	1.000E+12	1.00E-6	1.00E+12	Ω	3.004E+9
<input type="checkbox"/>	C 1	1000	1.00E-6	1.00E+3	μF	37.75
Chi-Squared:		0.8852	Iterations:		51	

Fixed	Element	Fitted Value	Min Value	Max Value	Unit	Error%
<input type="checkbox"/>	R 1	556.3	1.00E-6	1.00E+12	Ω	28.30
<input type="checkbox"/>	R 2	9970	1.00E-6	1.00E+12	Ω	3.013E+17
<input type="checkbox"/>	C 1	0.033	1.00E-6	1.00E+3	μF	1.142E+6
Chi-Squared:		0.8852	Iterations:		51	

In the case of a poor fit the values of a previous fit can be recovered by clicking on the undo button.

In the next chapter and the example brief instructions are given on selecting the components for the circuit. However, further reading on the topic is recommended:

<http://www.consultsr.net/resources/eis/index.htm>

Electrochemical Impedance Spectroscopy. Chapter 23: An Integrated Approach to Impedance Spectroscopy. Mark E. Orazem & Bernard Tribollet, ISBN: 978-0-470-04140-6.

Electrochemical Impedance Spectroscopy and its Applications. Chapter 14: Modelling of Experimental Data. Andrzej Lasia, ISBN: 978-1-4614-8932-0.

5.7 Batch-fitting a circuit on multiple curves

When multiple EIS curves are available, a single equivalent circuit can be fitted on multiple curves.

The screenshot shows the 'Equivalent Circuit Analysis - EIS 2' software. A red box highlights a panel titled 'Select (G)EIS data to fit' which contains a list with 'EIS 1' checked. To the right, a plot shows '-Z' / kΩ vs Z' / kΩ with a red curve. Below the plot is a 'Results' table:

Fixed	Element	Fitted Value	Min Value	Max Value	Unit	Error%
<input type="checkbox"/>	R 1	183.2	1.00E-6	1.00E+12	Ω	1.284
<input type="checkbox"/>	R 2	1.004E+4	1.00E-6	1.00E+12	Ω	0.456
<input type="checkbox"/>	C 1	32.47	1.00E-3	1.00E+6	nF	0.361
<input type="checkbox"/>	R 3	1.491E+4	1.00E-6	1.00E+12	Ω	0.870
<input type="checkbox"/>	C 2	1032	1.00E-3	1.00E+6	nF	1.315
Chi-Squared:		0.0002	Iterations:	140		

Panel for selecting multiple EIS curves

When this panel is visible, the 'Fit' button applies to the checked curves only. The table showing the fit results and the results shown in the equivalent circuit apply to the curve selected in the same list.

After fitting, the checkboxes can be used to show or hide the results in the Plot with the EIS data curves and fitted curves.

The initial component values used for fitting can be copied to all curves in the list, using the button 'Copy values to selected items'.

5.8 Overview of circuit components

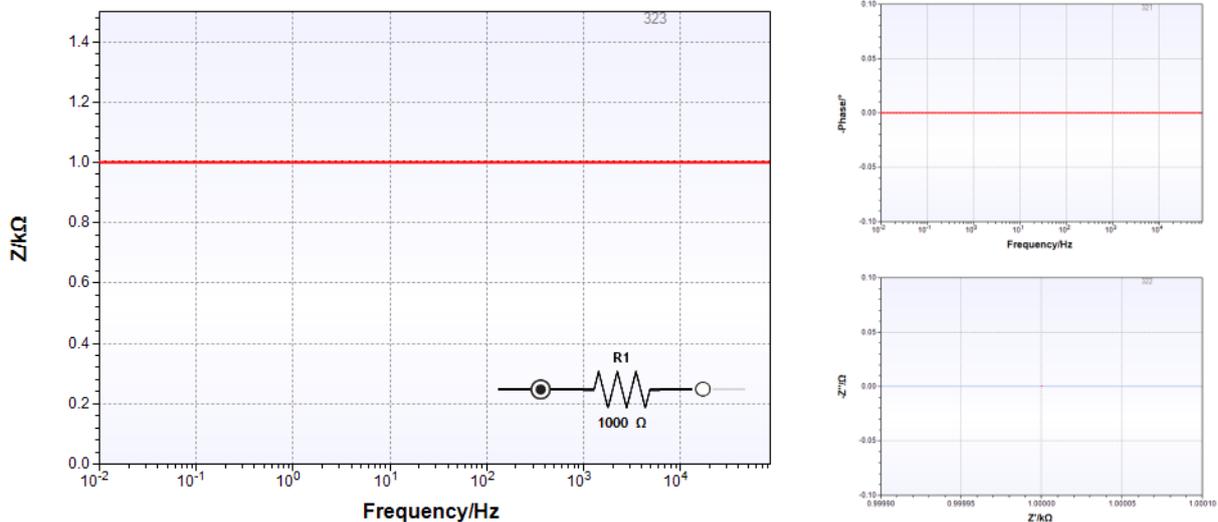
The following components can be used to build equivalent circuits in the circuit editor. The two chapters after this chapter provide two examples of selecting the components for an equivalent circuit, setting/adjusting their values to obtain a good fit, and interpreting the quality of the fit.

Resistor

$$Z_R = R$$

The impedance of a resistor is independent of frequency, and it only contributes to the real component of impedance. Hence it does not affect phase shift and it is represented by a single dot in the Nyquist plot. By default, resistors are 1000 Ω in the circuit editor.

When modeling an electrochemical impedance measurement on a cell a resistor can be used to model the solution resistance (resistance between the working electrode's surface and the tip of the reference electrode).

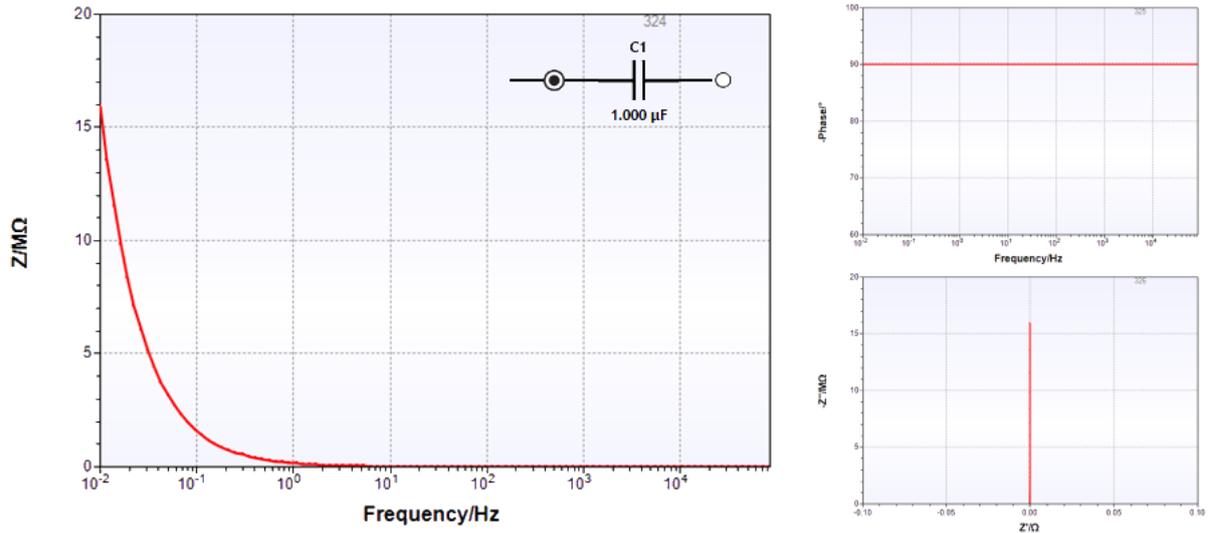


Left: The absolute impedance of a resistor plotted against frequency. Top right: Phase shift of a resistor over frequency. Bottom right: In the Nyquist plot a resistor is seen as a single dot (little red dot in the center of the plot).

Capacitor

$$Z_c = 1/j\omega C$$

A capacitor's effect on impedance pertains to its imaginary component and decreases with increasing frequency. On its own a capacitor causes a phase shift 90° independent of frequency. As it only effects the imaginary component of impedance it is represented by a vertical line in the Nyquist plot. The default value of a capacitor is 1 μF in the circuit editor.



Left: The absolute impedance of a capacitor plotted against frequency. Top right: Phase shift of a capacitor over frequency. Bottom right: Nyquist plot of capacitor.

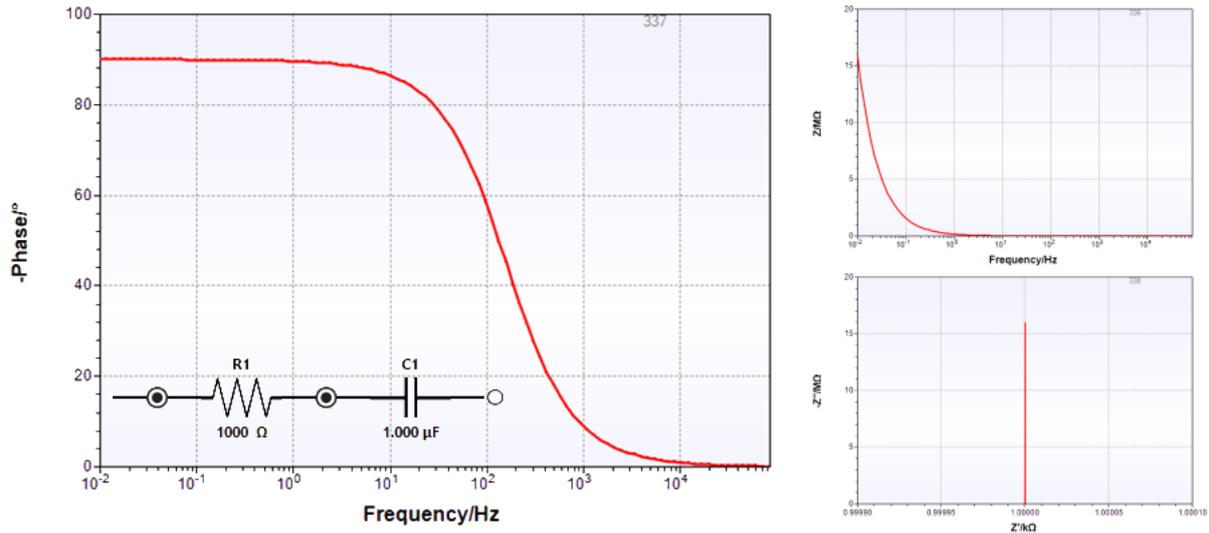
When a capacitor is placed in series with a resistor the circuit's phase shift becomes frequency dependent. At low frequencies, it approaches 90° and at high frequencies it approaches 0° . Thus, at high frequencies the capacitor's effect on the circuit's impedance and phase shift becomes negligible and the circuit effectively behaves as a single resistor. The Nyquist plot below shows that the real component of the impedance remains $1\text{ k}\Omega$ regardless of frequency.

A resistor and capacitor in series model the impedance of an ideally polarized liquid electrode / blocking electrode, i.e., an electrode that does not transfer charge with the surrounding solution. In this model, the resistor represents the solution resistance, and the capacitor represents the product of the real surface of the electrode and its double layer capacitance. With increasing frequency there is less time for the electrochemical double layer to charge and its effects on impedance and phase shift diminish.

Another application of a resistor and capacitor in series is modeling an ideal coating. Again, the resistor represents the solution resistance. But in this model, the capacitor represents the coating capacity. A coating's capacity depends on the coating's thickness, surface area, and dielectric constant.

For more information on modeling corrosion, we recommend reading:

Electrochemical Impedance Spectroscopy and its Applications. Chapter 11: Coatings and Paints. Andrzej Lasia, ISBN: 978-1-4614-8932-0.



Left: The phase shift of a resistor and capacitor in series plotted against frequency. Top right: Absolute impedance over frequency. Bottom right: Nyquist plot.

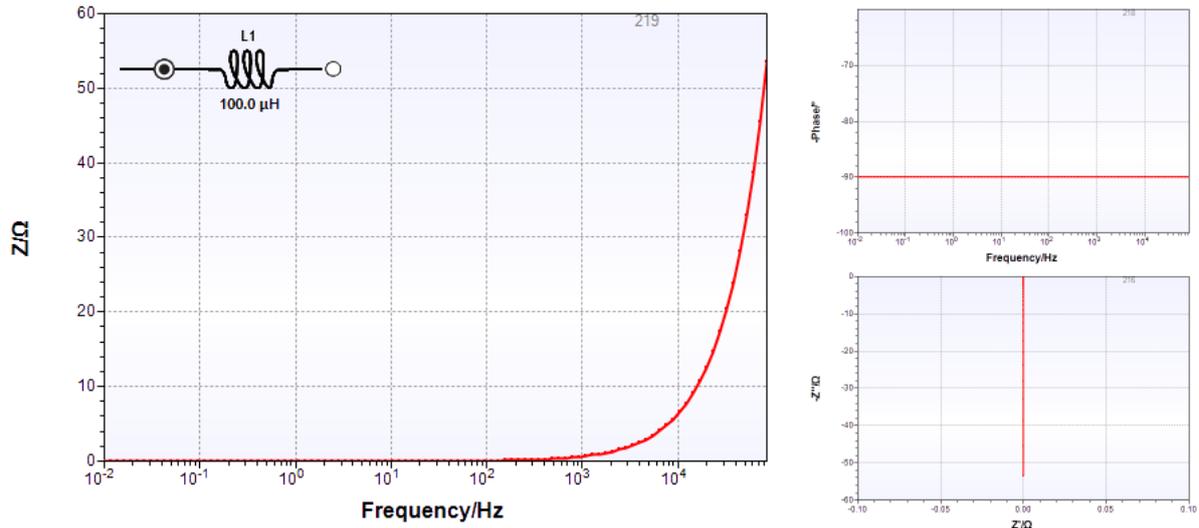
Inductor

$$Z_L = j\omega L$$

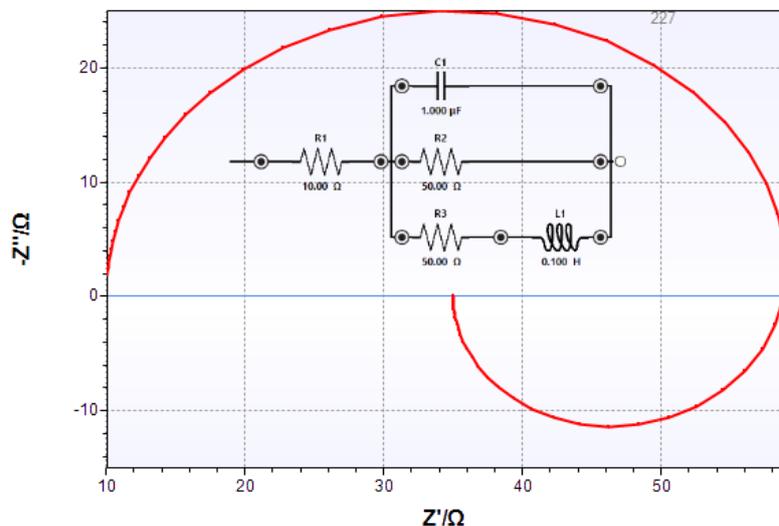
An inductor is the reciprocal of a capacitor its effect also pertains to the imaginary component of impedance. However, in contrast to a capacitor, the impedance of an inductor increases with frequency and its phase shift is -90° . It is also represented by a vertical line in the Nyquist plot, but in the opposite direction. In the circuit editor, the default value of an inductor is 100 μH.

An example of a model where an inductor is used is a model of a faradaic reaction involving adsorption of one or more species. In certain cases, on the Nyquist plot inductive loops can be observed together with capacitive loops and it is possible to model inductance as the product of the resistance of the charge transfer squared and the absorption pseudocapacitance. For further reading see:

Electrochemical Impedance Spectroscopy and its Applications. Chapter 5: Impedance of the faradaic reactions in the presence of adsorption. Andrzej Lasia, ISBN: 978-1-4614-8932-0.



Left: The absolute impedance of an inductor plotted against frequency. Top right: Phase shift of an inductor over frequency. Bottom right: Nyquist plot of Inductor.

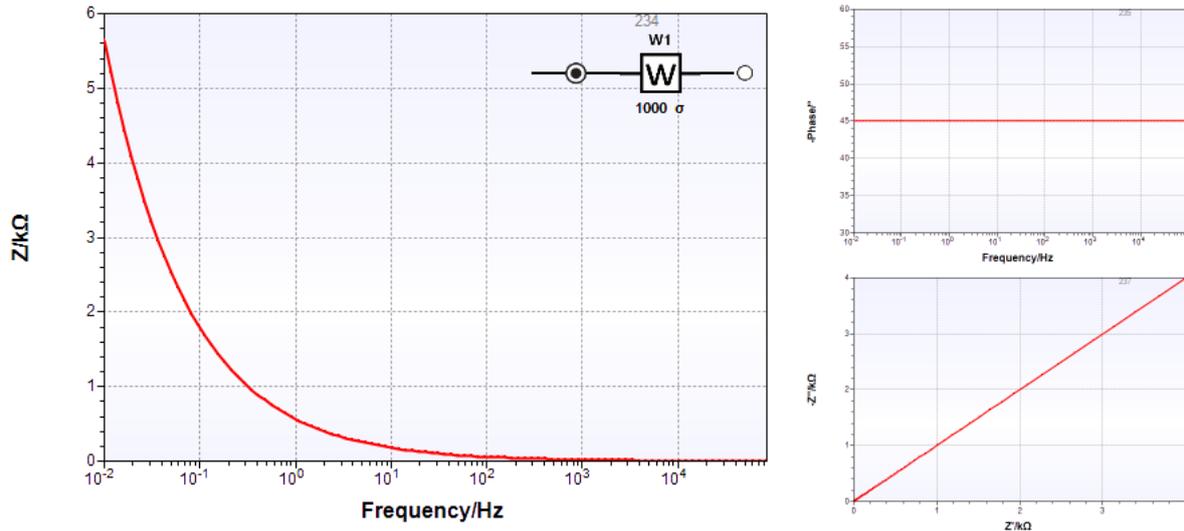


Nyquist plot of a circuit that can model faradaic reactions involving adsorption and subsequent desorption of a species.

Warburg impedance

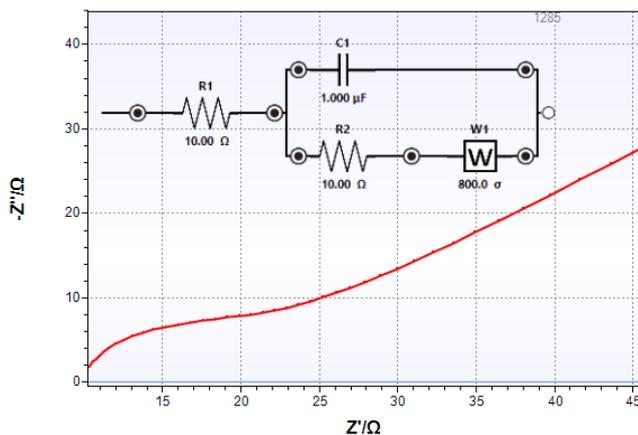
$$Z_W = \frac{\sigma}{\sqrt{\omega}} - j \frac{\sigma}{\sqrt{\omega}}$$

A Warburg element is a component used to model the transfer of charge between the electrode and a redox species in the solution and the depletion of the diffusion layer's inner layer. This Warburg element assumes there is a semi-infinite linear diffusion layer. Both the real and imaginary components of impedance increase equally with frequency. The equal decrease in real and imaginary impedance can be seen in the Nyquist plot and results in a constant phase shift of 45° . The unit of the Warburg coefficient, σ , is Ohm to the power -0.5. The default value of the Warburg coefficient in the circuit editor is 1000.

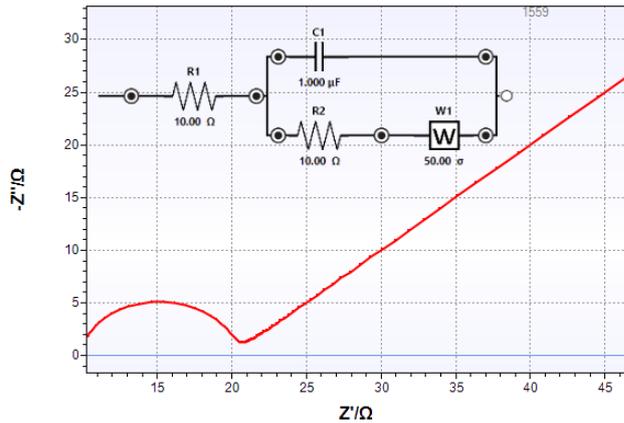


Left: The absolute impedance of a Warburg element plotted against frequency. Top right: Phase shift of a Warburg element over frequency. Bottom right: Nyquist plot of Warburg element.

The Randle's circuit is often used to model the transfer of charge between the electrode and a redox species solution. The Randle's circuit consists of two resistors, a capacitor, and a Warburg element. The first resistor is in series and represents the solution resistance. The electrode's double-layer capacitance is represented by a capacitor parallel to a resistor that represents the charge transfer resistance and the Warburg element. At high concentrations of the oxidant, the semicircle and the diffusion are separated and at low concentrations, they overlap.



Nyquist plot of a Randle's circuit with a large value for the Warburg coefficient of the Warburg element. This represents the transfer of charge between the electrode and redox species with a low concentration of the oxidant (overlap of semicircle and diffusion).



Nyquist plot of a Randle's circuit with a small value for the Warburg coefficient of the Warburg element. This represents the transfer of charge between the electrode and redox species with a high concentration of the oxidant (no overlap of semicircle and diffusion).

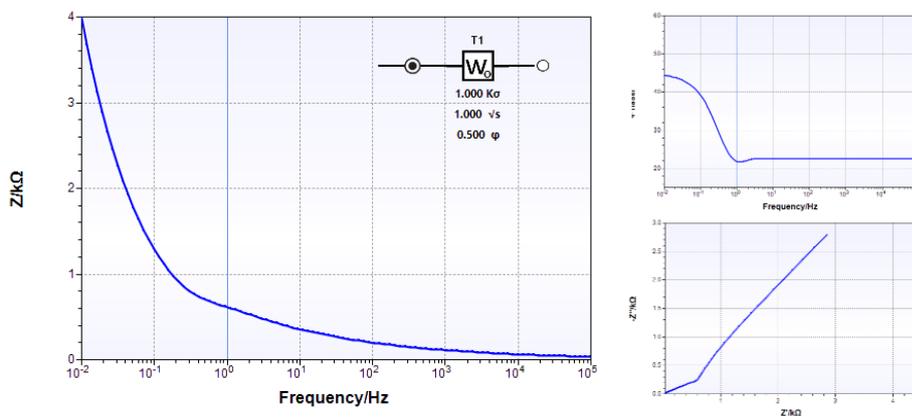
Warburg Short/Open

In contrast to the Warburg element, the Warburg short/open do not assume semi-infinite diffusion.

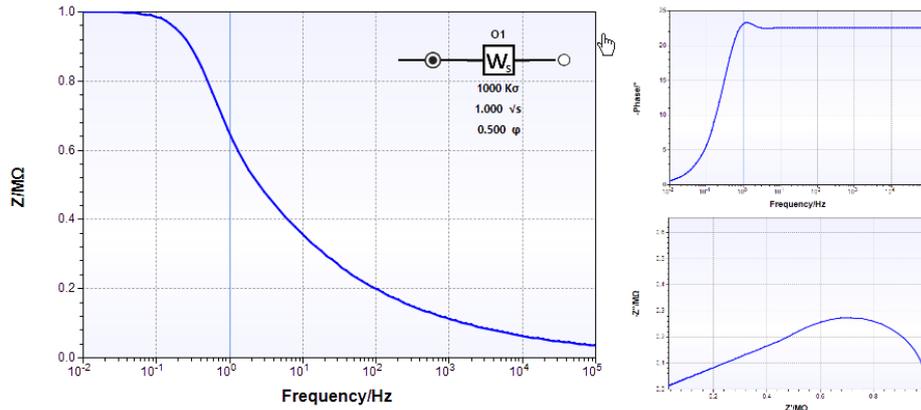
$$Z_O = \frac{\sigma B}{(B\sqrt{j\omega})^\phi} \tanh(B\sqrt{j\omega})^\phi$$

$$Z_T = \frac{\sigma B}{(B\sqrt{j\omega})^\phi} \coth(B\sqrt{j\omega})^\phi$$

Respectively the Warburg short (O) and Warburg open (T) model the transmissive and reflective boundaries of a diffusion layer. B represents the thickness (l) in meters (m) and the diffusion coefficient (D) of the diffusion layer in square meters per second (m²/s), $B = l/\sqrt{D}$. The experimental parameter (ϕ) has a maximum value of 1 when diffusion is uniform and is smaller when diffusion is nonuniform. The default values for the Warburg coefficient, B, and the experimental parameter are 1000 σ , 1 \sqrt{s} and 0.5 respectively.

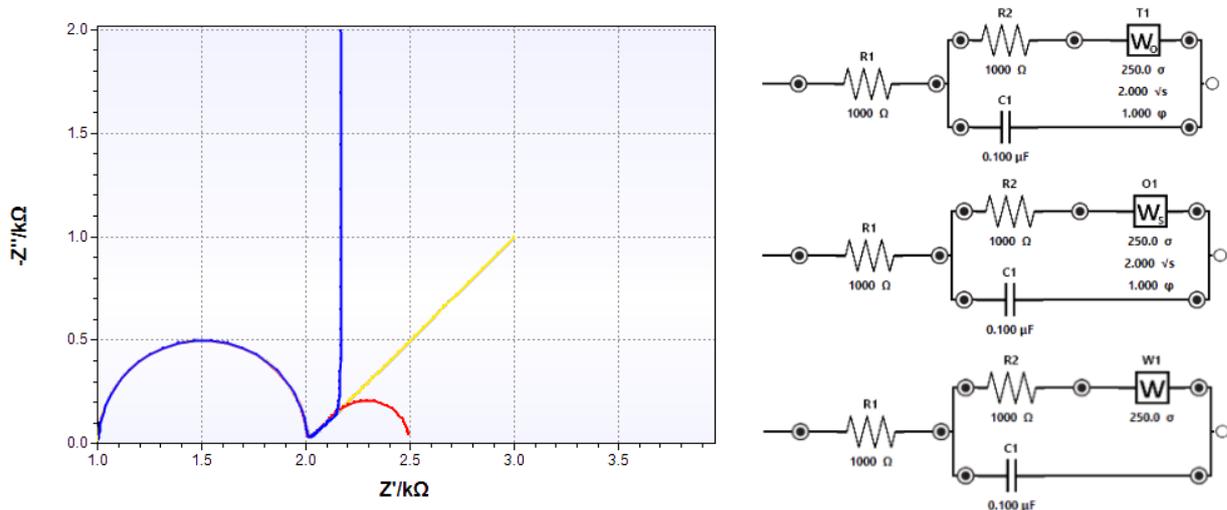


Left: The absolute impedance of a Warburg open plotted against frequency. Top right: Phase shift of a Warburg open over frequency. Bottom right: Nyquist plot of Warburg open.



Left: The absolute impedance of a Warburg short plotted against frequency. Top right: Phase shift of a Warburg short over frequency. Bottom right: Nyquist plot of Warburg short.

The circuits in the figure below model show the differences in the transfer of charge between the electrode and a redox species a solution, assuming finite diffusion transmissive/reflective boundary or semi-infinite diffusion.

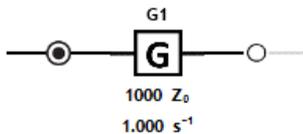
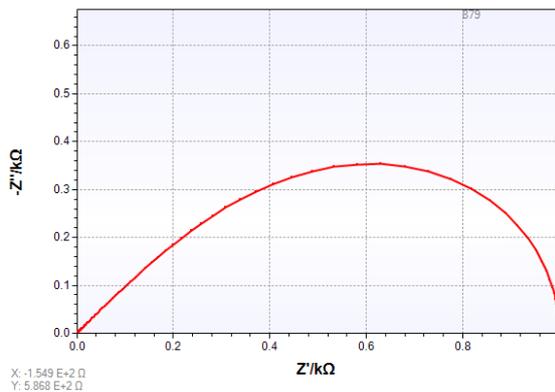
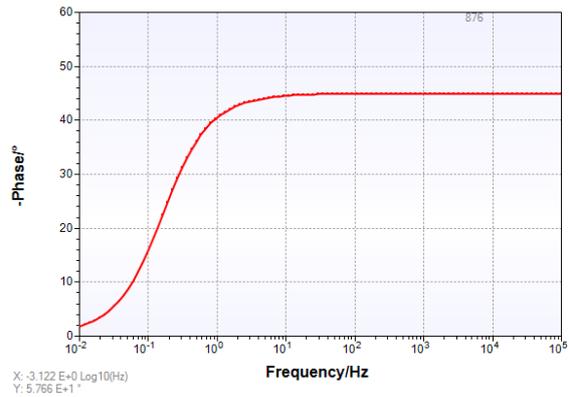
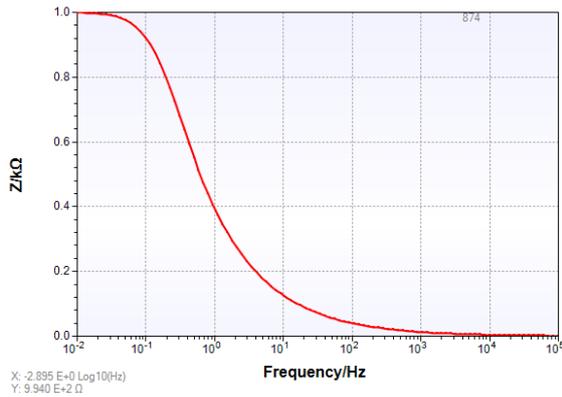


Nyquist plot demonstrating the differences in diffusion at low frequencies for a Randle's circuit (yellow line and bottom circuit), an electrode with a reflective boundary (blue line and top circuit) and an electrode with a transmissive boundary (red line and middle circuit).

Gerischer element

$$Z_G = \frac{Z_0}{\sqrt{k + j\omega}}$$

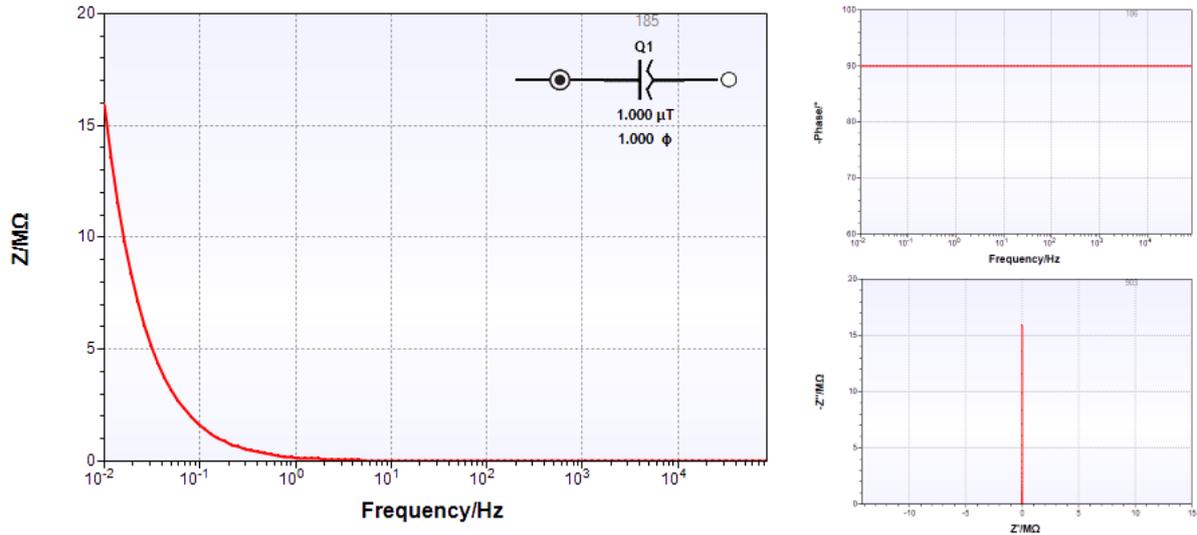
The effects of a Gerischer element are similar to those of a Warburg open. However, the parameters of the model are different, Z_0 is the magnitude of the impedance at $\omega = 1$ rad/s and k is a rate constant. It is designed to model the effect of an electrochemical species reacting with something to form an inactive substance or absorbed species during the diffusion process.



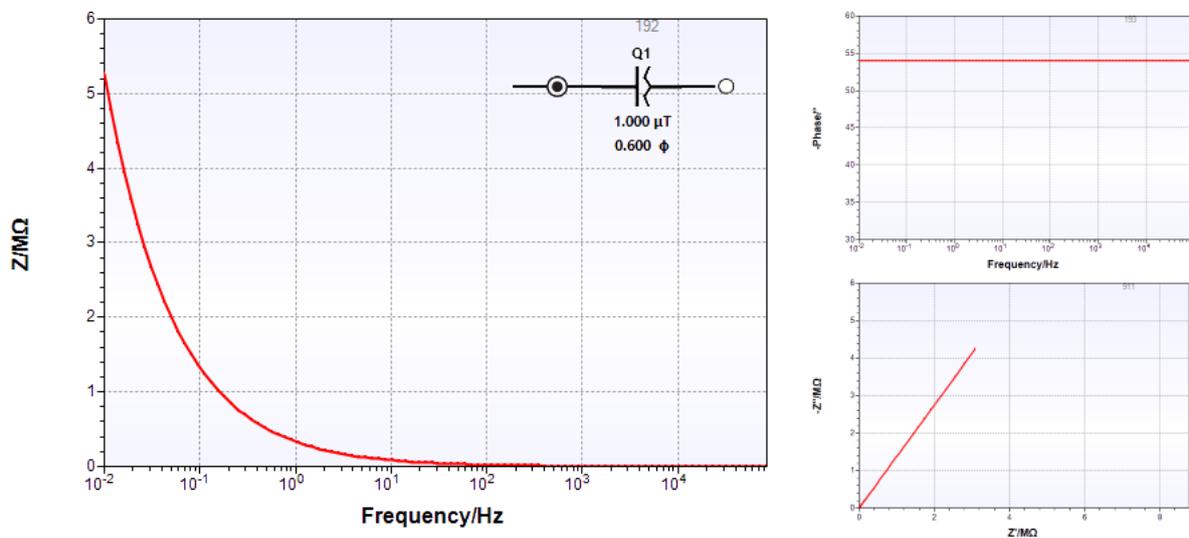
Constant phase element

$$Z_{CPE} = 1/T(j\omega)^\phi$$

A constant phase element is similar to a capacitor, but unlike a capacitor, it can also model frequency dispersion and affects both the real and imaginary components of impedance. The constant phase element has two parameters: T is related to its capacitance and Φ is the constant phase exponent which is related to the deviation from a regular capacitor, the unit of T is Siemens per second to the power Φ . The value of the constant phase exponent should be between 0 and 1; it regulates the constant phase which is -90 times Φ . At a Φ of 1 the behavior of a constant phase element resembles that of a capacitor, for a Φ of 0.5 that of a Warburg element, and for a Φ of 0.0 that of a resistor. The phase shift of a constant phase element is independent of frequency, the slope of the line in the Nyquist plot corresponds to the magnitude of the phase shift specified by Φ . The default values of the constant phase element in the circuit editor are $1 \mu\text{T}$ and 1Φ .

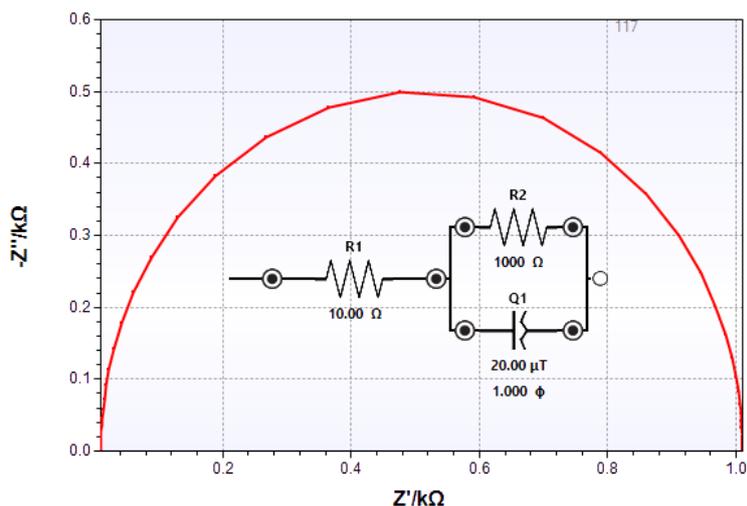


Left: The absolute impedance of a constant phase element with a constant phase exponent of 1 Φ (i.e. a capacitor) plotted against frequency. Top right: Phase shift of a constant phase element over frequency. Bottom right: Nyquist plot of constant phase element.

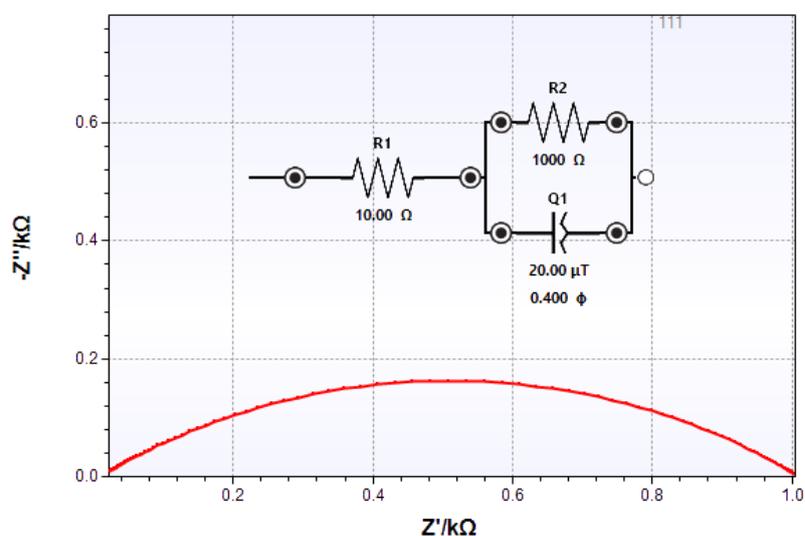


Left: The absolute impedance of a constant phase element with a constant phase exponent of 0.6 Φ plotted against frequency. Top right: Phase shift of a constant phase element over frequency. Bottom right: Nyquist plot of constant phase element.

The constant phase element is used instead of a regular capacitor to model the double layer capacitance when an electrode displays a frequency-dependent dissipation/dispersion of energy (typical for solid electrodes). When studying a redox reaction without diffusion limitations the dissipation/dispersion of energy presents as a depressed semicircle in the Nyquist. See the figure below.



Nyquist plot of a redox reaction without diffusion limitations, with a solution resistance of 10Ω , a charge transfer resistance of $1 k\Omega$ and a constant phase element that represents the double layer capacitance of an ideally polarizable liquid electrode, i.e. a constant phase element with a phase exponent of 1Φ (or a capacitor).



Nyquist plot of a redox reaction without diffusion limitations, with a solution resistance of 10Ω , a charge transfer resistance of $1 k\Omega$ and a constant phase element that represents the double layer capacitance of a solid electrode with dispersion/dissipation of energy. Here the semicircle is shifted downwards as a result of the dispersion/dissipation, modelled as a constant phase element with a phase exponent smaller than 1Φ .

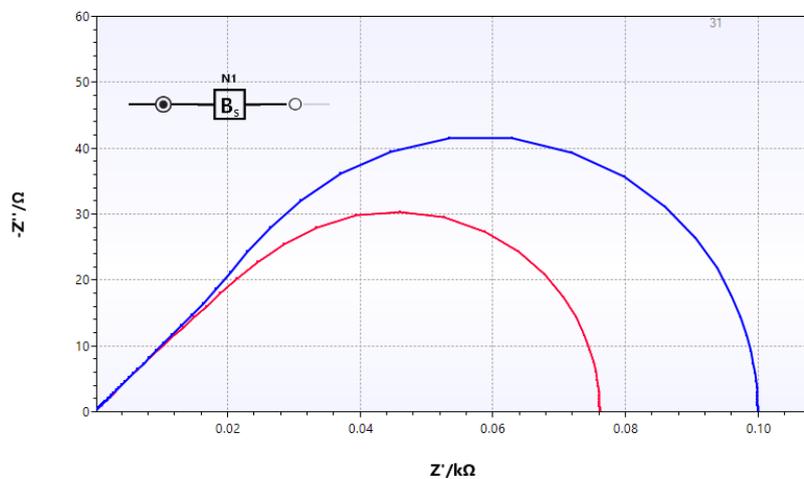
Bisquert Short/Open

$$Z_N = \sqrt{\zeta \chi} \tanh \left(L \sqrt{\frac{\chi}{\zeta}} \right)$$

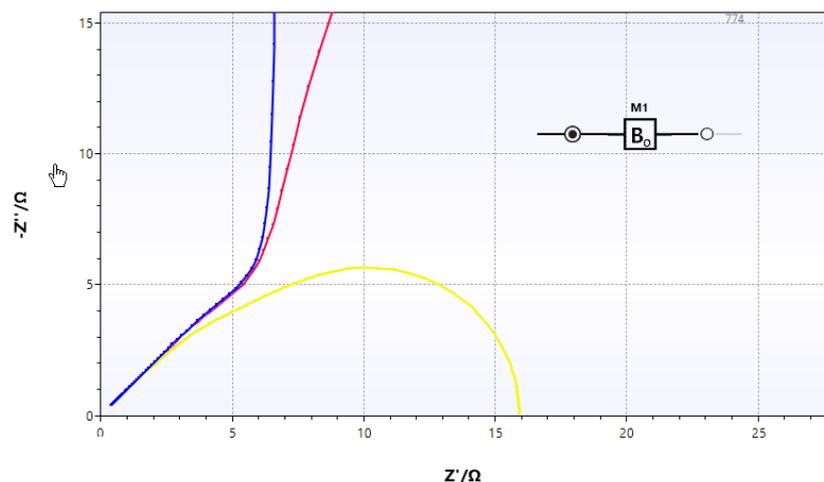
$$Z_M = \sqrt{\zeta \chi} \coth \left(L \sqrt{\frac{\chi}{\zeta}} \right)$$

where $\zeta \equiv \frac{1}{\frac{1}{Z_{R_k}} + \frac{1}{Z_{Q_m}}} = \frac{1}{R_k + T(j\omega)^\phi}$ and $\chi \equiv Z_{R_m} = R_m$

The Bisquet Short (N) and Bisquet Open (M) can be used to model porous electrodes. These electrodes have a large surface area but the pores themselves contain a limited volume affecting the rate with which ions enter and react in the pores. L is a fixed parameter that represents the depth of the pore. ζ relates to the impedance of the active porous part of the electrode, R_k models the reaction resistance and Q_m the diffusion / double-layer capacitance (a constant phase element is used to compensate for inhomogeneities of the pores). Finally, the χ relates to the impedance of the electrolyte within the pore. Both elements assume that reactions can only take place at the active porous part of the electrode. The Bisquet Short models an absorbing boundary condition where the contribution of the base electrode to the reaction can short the porous film. The Bisquet Open models a reflective boundary condition where the base electrode is insulating and cannot contribute to the reaction. For both elements the parameters are in the respective order; pore impedance (R_m), reaction resistance (R_k), diffusion of active porous area modeled by a constant phase element (T, ϕ), pore depth (L).



Nyquist plot demonstrating the differences in impedance of a porous electrode with an absorbing boundary. The blue line ($R_m = 100 \Omega$, $R_k = 1e20 \Omega$, $CPE = (1 \mu T, 1 \phi)$, $L = 1$) represents a situation where the diffusion reaction Q_m is dominant, impedance of $R_k \gg$ than R_m and Q_m . The red line ($R_m = 100 \Omega$, $R_k = 0.1 \Omega$, $CPE = (1 \mu T, 1 \phi)$, $L = 1$) where there is a homogeneous reaction with the absorbing boundary condition and a diffusion reaction.



Nyquist plot demonstrating the differences in impedance of a porous electrode with a reflecting boundary with different relations between reaction rate and diffusion rate. The blue line ($R_m = 20 \Omega$, $R_k = 1e20 \Omega$, $CPE = (0.1 \mu T, 1 \varphi)$, $L = 1$) represents a situation where there is diffusion with a reflective boundary, impedance of $R_k \gg R_m$ and Q_m . The red line ($R_m = 20 \Omega$, $R_k = 100 \Omega$, $CPE = (0.1 \mu T, 1 \varphi)$, $L = 1$) where the reaction at the active porous part is slower than the diffusion and the yellow line ($R_m = 20 \Omega$, $R_k = 10 \Omega$, $CPE = (0.1 \mu T, 1 \varphi)$, $L = 1$) where the reaction is faster than the diffusion.

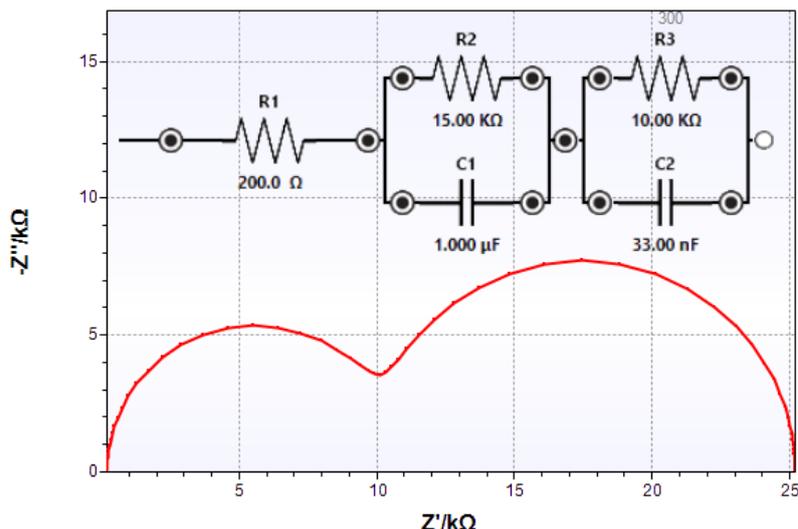
For more information, please refer to:

Theory of the Impedance of Electron Diffusion and Recombination in a Thin Layer.
 Juan Bisquert. (2002) *The Journal of Physical Chemistry B*. 106 (2), 325-333

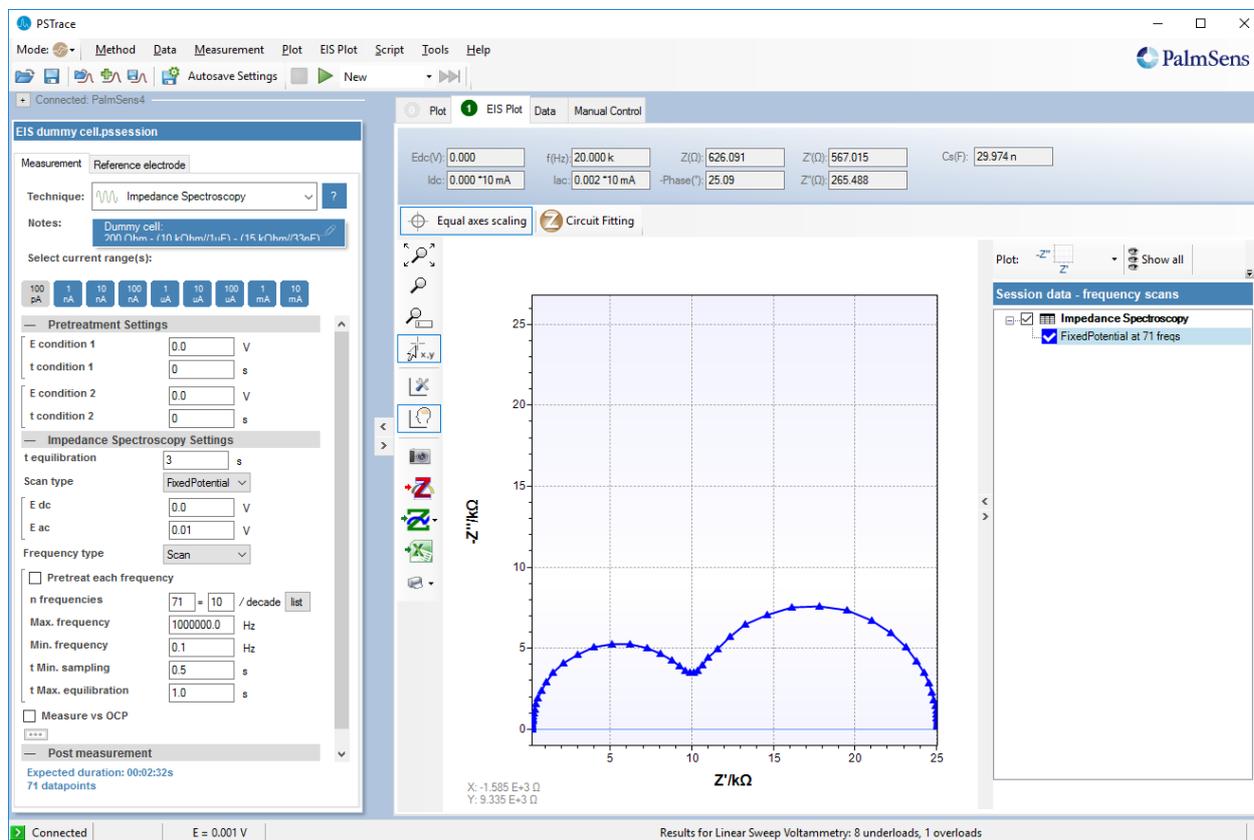
5.9 Fitting Example

This example demonstrates the fitting of an equivalent circuit on a measurement with two distinct time constants (semi-circles). The measurement used in this example was performed on a PalmSens EIS Dummy Cell described in the figure below. The figure below shows the dummy cell's circuit, the values of its components, and a simulated of a Nyquist plot of the dummy cell. Below that is the Nyquist plot of the actual measurement.

This example aims to demonstrate that three similar equivalent circuits can all fit the data accurately. Although the quality of the fit is similar the values of the components differ significantly emphasizing the importance of choosing the right equivalent circuit to interpret a measurement.



Nyquist plot of a simulation of the PalmSens EIS Dummy Cell

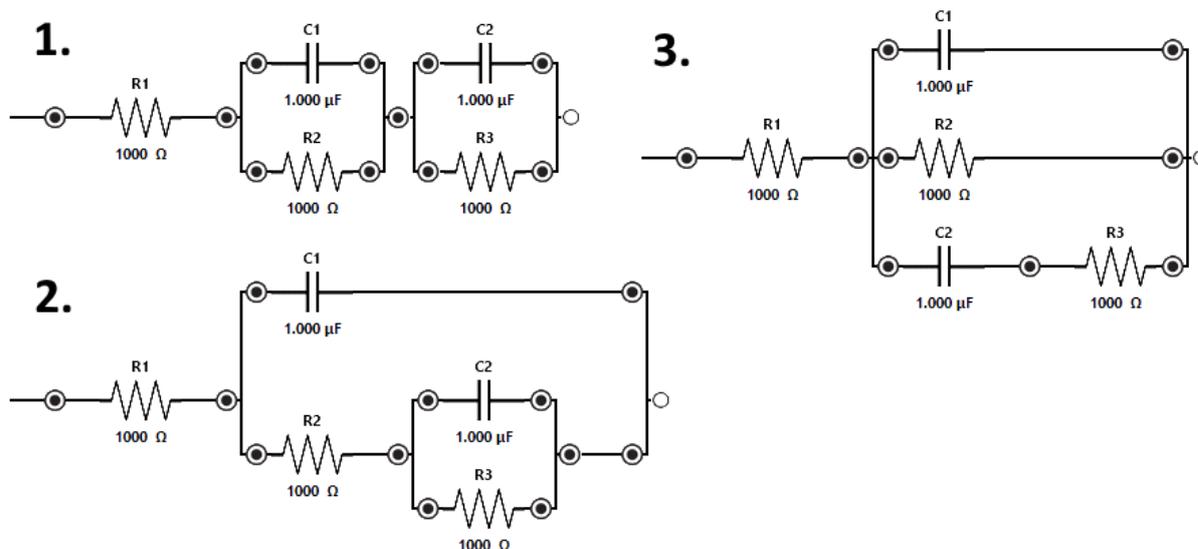


Impedance spectroscopy measurement of the PalmSens EIS Dummy Cell

Designing equivalent circuits

There are two distinct time constants (semi-circles) visible in the Nyquist plot. Time constants can be modeled by placing a capacitor or constant phase element in parallel to a resistance (and optionally a Warburg element). For this example, three different circuits will be used, (1) a circuit with a Voigt structure (the same as the circuit inside

the dummy cell), (2) a circuit with a ladder structure and (3) a circuit with a Maxwell structure. Voigt circuits are typically used for modeling the redox process on an electrode. Ladder circuits can be used when there are one or more adsorbed species. Maxwell circuits have been used to study dielectric phenomena.



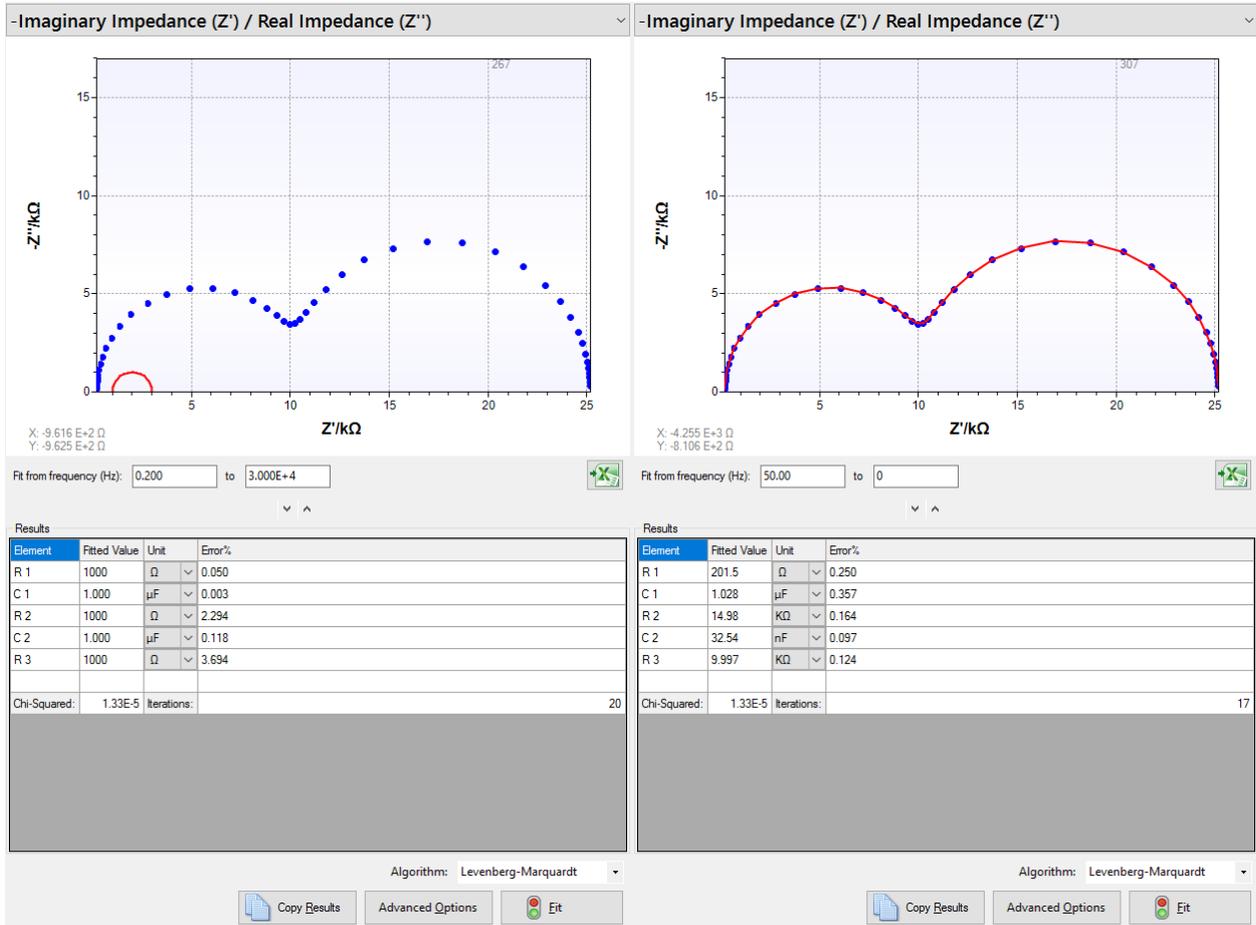
Three different circuits that can model measurements with two-time constants. 1: A Voigt circuit (the actual model of the dummy cell). 2: A ladder circuit. 3: A Maxwell circuit.

Fitting the circuits

After the circuit has been drawn the Fit mode can be opened. Often the default values of the components are sufficiently close to their actual values and the fitting algorithm will fit the circuit correctly. However, in some cases circuit fitting algorithms end up in so-called local minima, this inherits to mathematical optimization algorithms. The fitting of the three equivalent circuits on the measurement is demonstrated below. In the fit of the Maxwell circuit, some tips are also given on how to avoid getting stuck in local minima.

Voigt

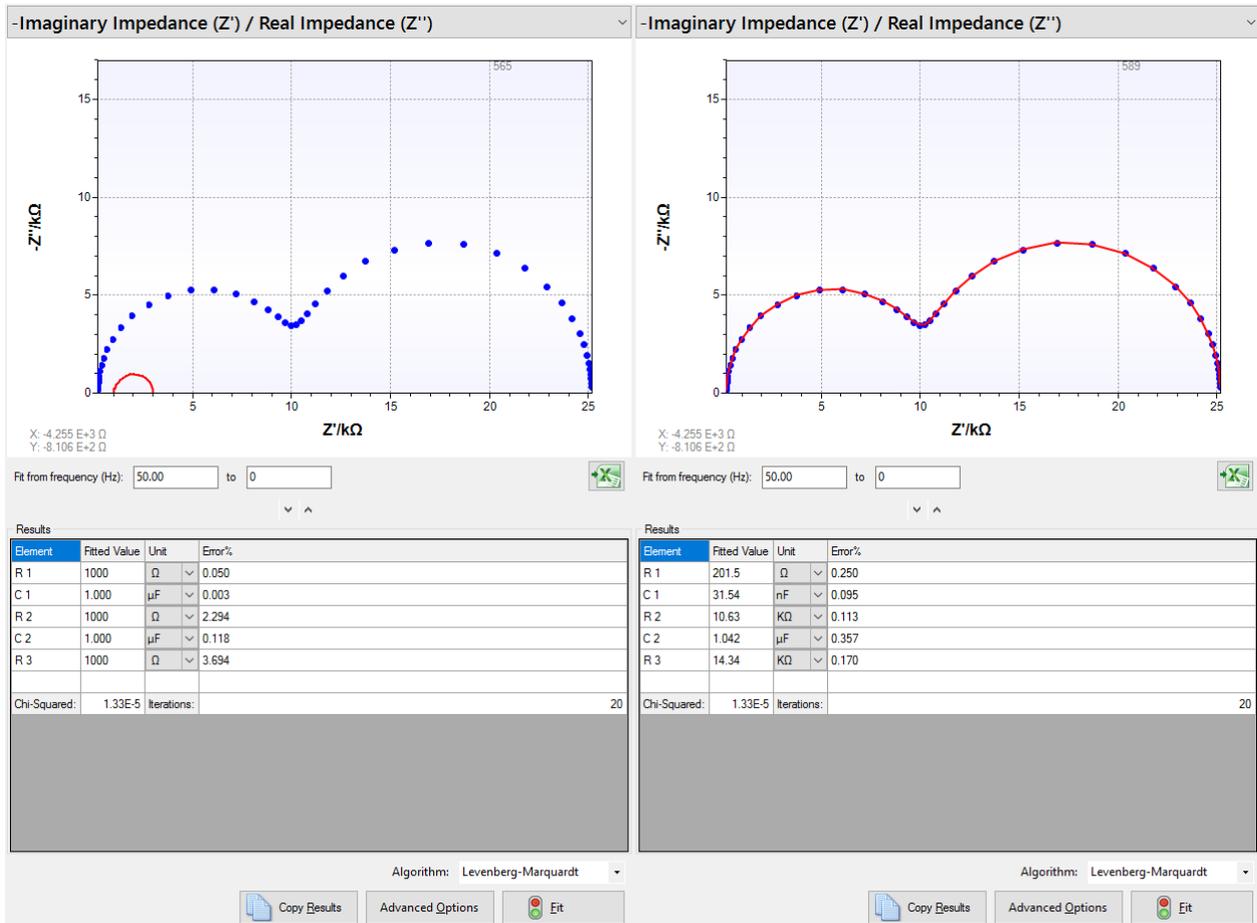
The following image shows the fitting tab with at the top a Nyquist plot of the measurement (blue dots) and a simulation of the Voigt circuit with the circuit editors default values (red line). Clicking on the fit button will fit the equivalent circuit on the measurement. Assuming the measurement was performed correctly this circuit will directly give an accurate fit with the default values of the components.



Fitting of the Voigt circuit. Left: the default values of the components result in the small red semi-circle. Right: After pressing the fit button the circuits semi-circles (time constants) no longer overlap and fit the measurement accurately.

Ladder

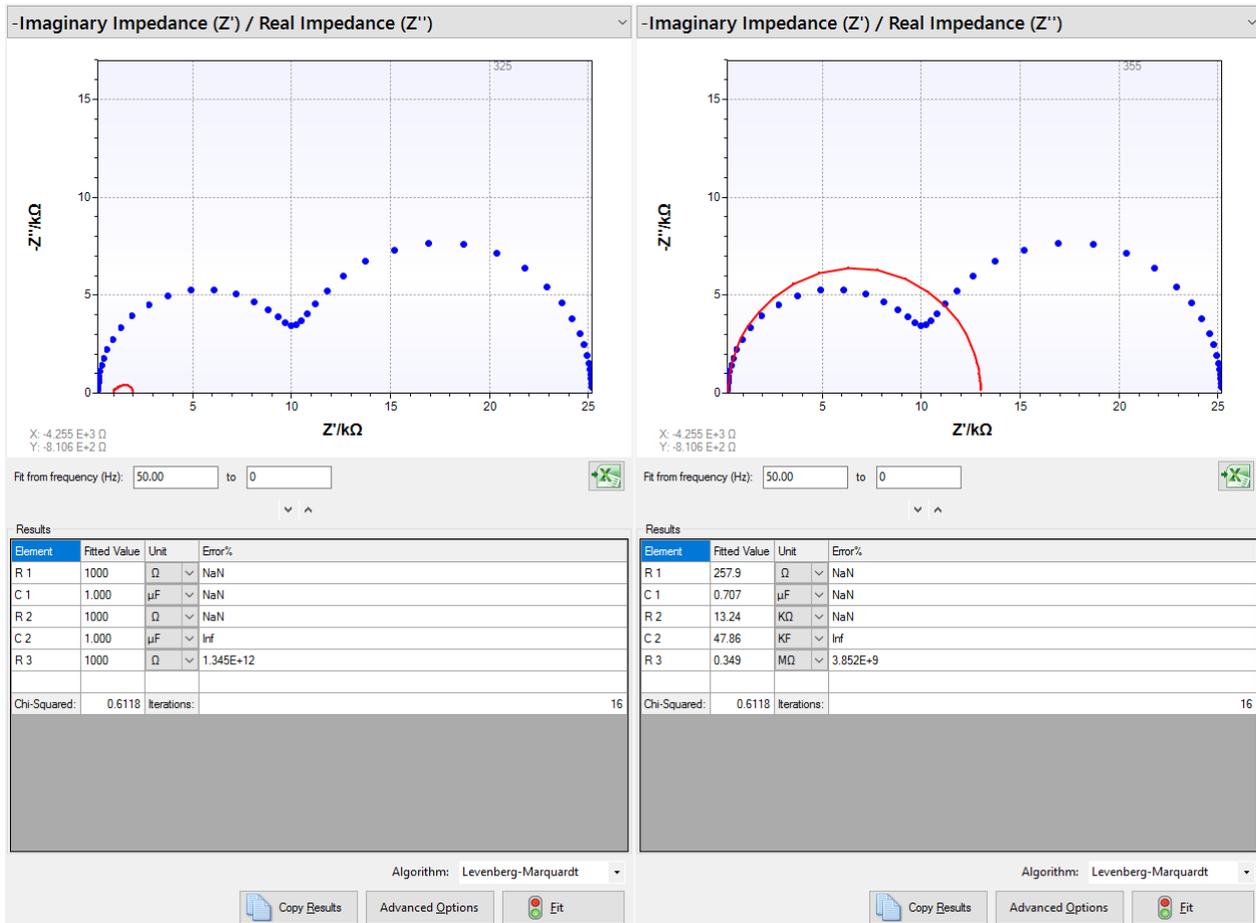
Just as the Voigt circuit the ladder circuit directly fits on the measured data without first getting stuck in a local minimum. The fitted values of the components are even quite close to those of the Voigt model. However, in the Maxwell circuit the resistor R3 is used to obtain the value of the pseudocapacitance and not for modeling the charge transfer resistance.



Fitting of the ladder circuit. Left: the default values of the components result in the small red semi-circle. Right: After pressing the fit button the circuit's semi-circles (time constants) no longer overlap and fit the measurement accurately.

Maxwell

As seen below the Maxwell circuit will not fit directly on the measurement, as it gets stuck in a local minimum. Therefore, it is necessary to refine the initial values of the circuit's components to avoid ending up in this local minimum.

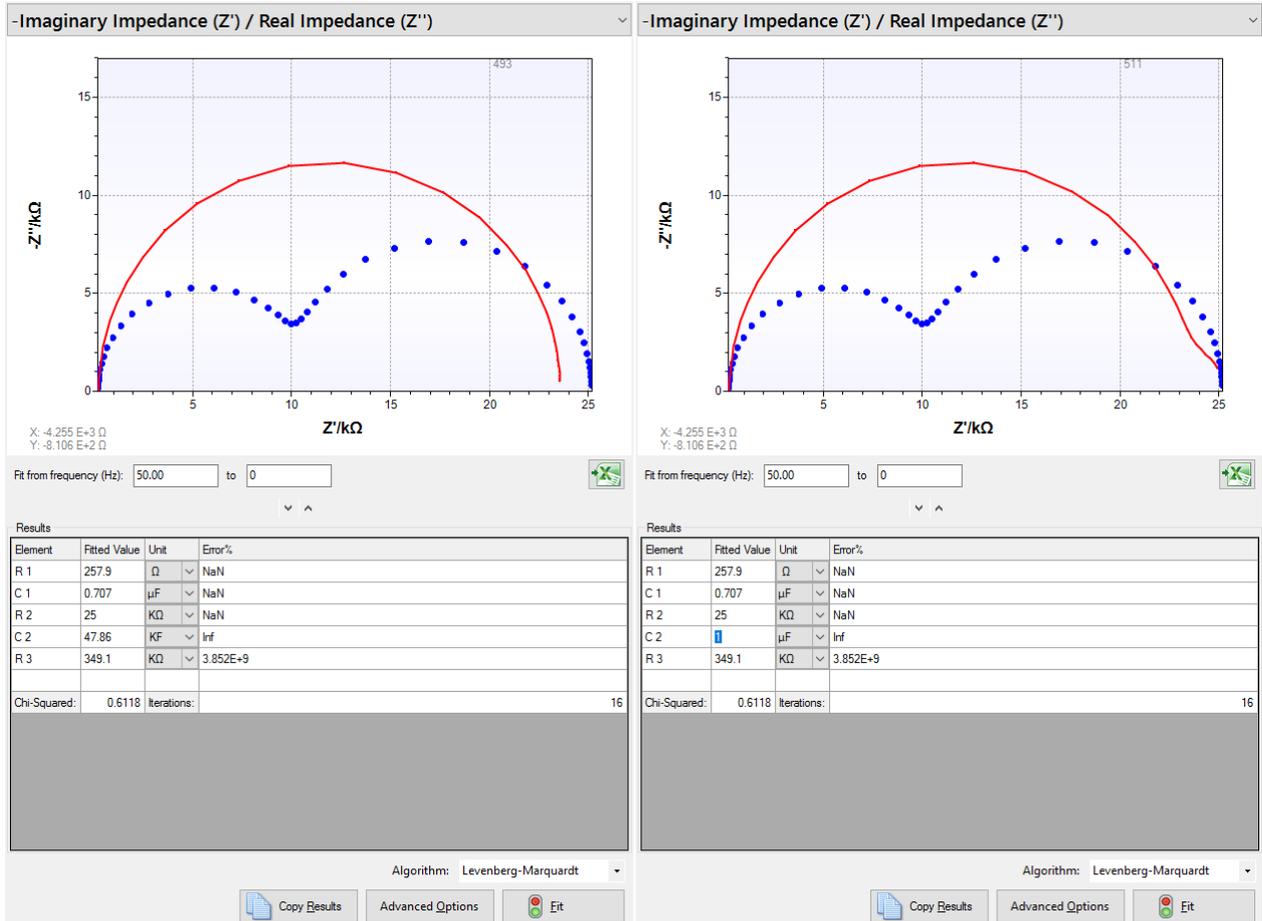


Fitting of the Maxwell circuit. Left: the default values of the components are far from the actual values as the overlapping red semi-circles (time-constants) are much smaller than the ones that were measured. Right: clicking on the fit button will result in the fitting algorithm getting stuck in a local minimum, the model of the semi-circle clearly does not overlap with the measured data also the values several components are unrealistic. Thus, values of the components must be adjusted to obtain an accurate fit.

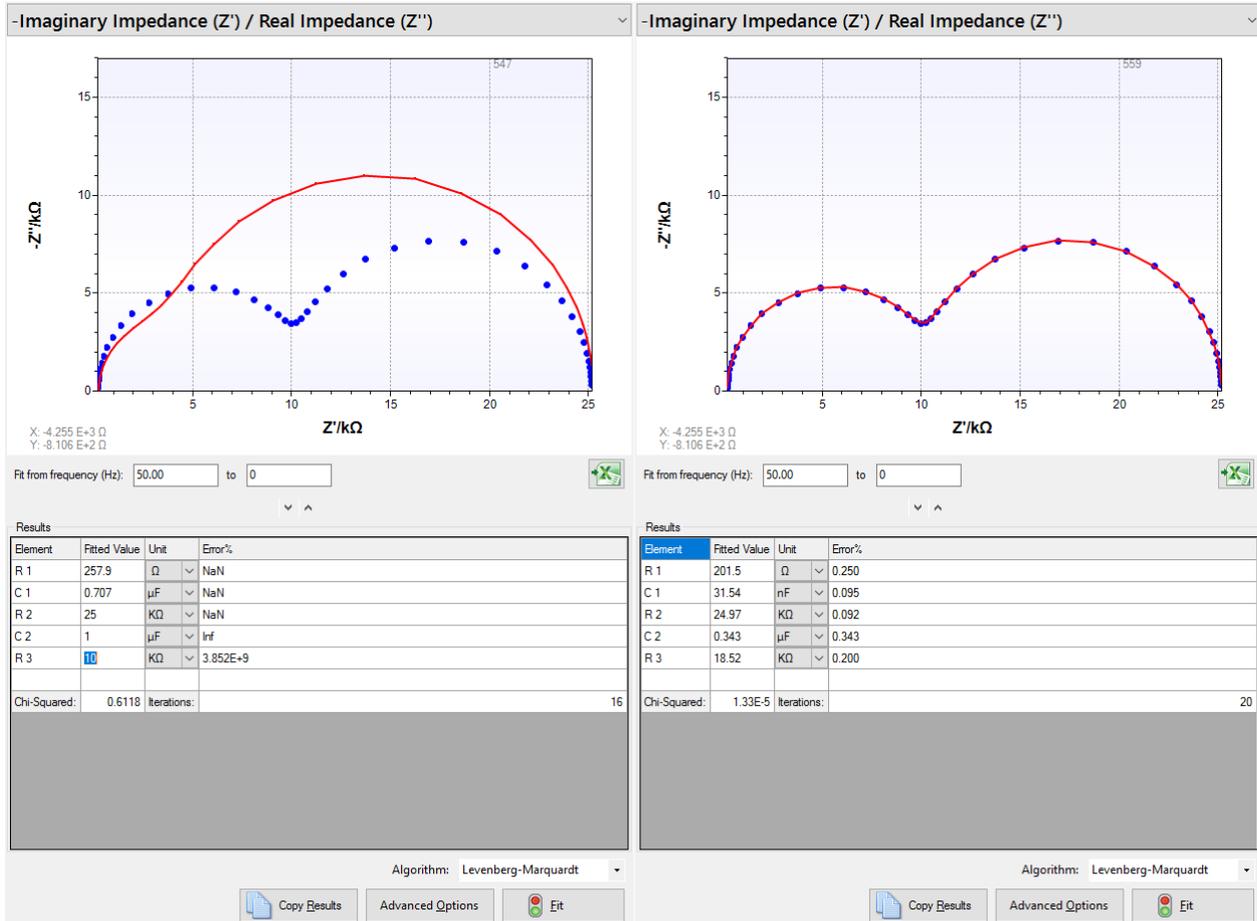
A general tip for avoiding local minima is providing a rough initial estimation in which the red semicircle(s) (i.e., the modelled time constants) approaches that of the measurement, preferably set the initial values so that the circuit's semicircles are slightly larger than the measured semi circles.

Based on the Nyquist plot the real component (x-axis) of the impedance is close to 25 k Ω at the lowest frequencies. In the Maxwell circuit resistor R2 is parallel to the second time constant (C2 and R3) and the current will primarily flow through this resistor at low frequencies, thus increasing R2 to 25 k Ω should increase the total size of the overlapping semicircles. Before we will attempt to fit again, we will change the size of the capacitors to decrease the overlap of the resistors. During the last fit, the value of C2 got stuck at 48 kF which is unrealistically large, therefore, we will change it back to 1 μF . The value of R3, 349 k Ω , is also too high, so we will set it somewhere between 0 and 25 k Ω (this is where the imaginary component (y-axis) of the impedance

approaches zero). Then, click on the fit button again and the fit should now be accurate.



Left: the value of resistor R2 is increased to match the real impedance of the circuit at low frequencies (25 $k\Omega$ as seen on the x-axis on the plot above), as a result, the semicircle is now almost as wide as the measured semi-circles. Right: The unrealistically high capacitance of C2 is lowered back to $1 \mu F$, this reduces the overlap of model's the semi-circles.



Left: The very high resistance of R3 is lowered to 10 kΩ, a value between 0 and 25 kΩ (i.e. the range of the real component of the impedance (x-axis)). This changes how the model's semi-circles overlap. Right: with the values of the components as specified in the left image the fitting algorithm now finds an accurate fit.

Inspecting the quality of the fit

The results of the fit are displayed in the table after fitting the circuit on the data. The chi-squared test is a general indication of the fit's quality. The lower the chi-squared value, the better is the fit. The square root of the chi-squared statistic gives the average error of the fit. For these fits, this is 0.4% which is very good. The individual errors of the components are also given in the table.

Although the quality of the fit is good, the values of the components for the ladder and Maxwell model cannot be interpreted correctly as the specific processes of the cell that these components represent do not comply with the actual measurement, thus it is demonstrated that blindly assuming that your model is an accurate representation, just because it fits, might lead to circuits lacking actual physical meaning.

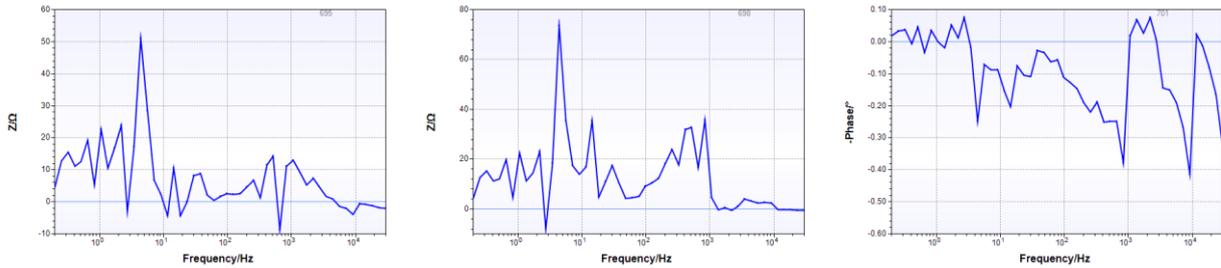
Voigt			
Element	Fitted Value	Unit	Error%
R 1	201.5	Ω	0.250
C 1	1.028	μF	0.357
R 2	14.98	$\text{K}\Omega$	0.164
C 2	32.54	nF	0.097
R 3	9.997	$\text{K}\Omega$	0.124
Chi-Squared:	1.33E-5	Iterations:	17

Ladder			
Element	Fitted Value	Unit	Error%
R 1	201.5	Ω	0.250
C 1	31.54	nF	0.095
R 2	10.63	$\text{K}\Omega$	0.113
C 2	1.042	μF	0.357
R 3	14.34	$\text{K}\Omega$	0.170
Chi-Squared:	1.33E-5	Iterations:	20

Maxwell			
Element	Fitted Value	Unit	Error%
R 1	201.5	Ω	0.250
C 1	31.54	nF	0.095
R 2	24.97	$\text{K}\Omega$	0.092
C 2	0.343	μF	0.343
R 3	18.52	$\text{K}\Omega$	0.200
Chi-Squared:	1.33E-5	Iterations:	10

Fitting results

Visual inspection of the fit's quality is also possible by changing the plot to either the error in the magnitude of the impedance over frequency, the error in the real component of impedance over frequency or the error in phase shift over frequency. These plots represent the difference in magnitude of impedance, real impedance, and phase shift between the fit of the equivalent circuit and the measured data. As seen in the figure below there are subtle discrepancies in impedance at the lower frequencies and phase shift at higher frequencies between the equivalent circuit and the measurement.



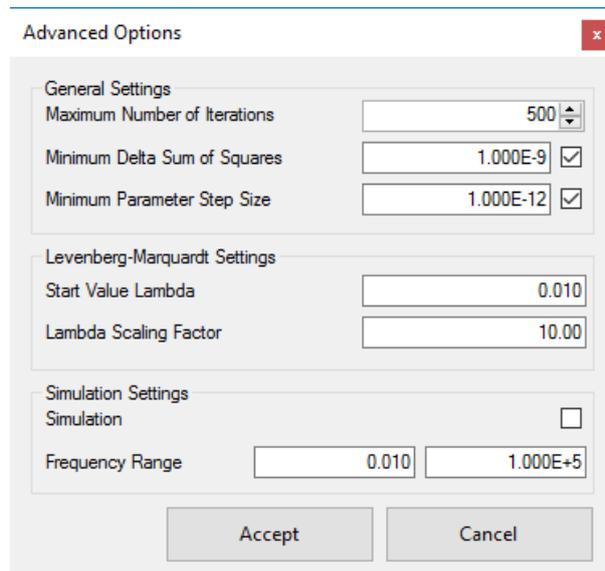
Error plots displaying the differences in impedance and phase shift between the equivalent circuit and the measurement.

Adjusting the advanced fit options

In some cases, you may wish to adjust the fitting options to obtain the type of fit that you want. In the fit tab of the circuit editor several advanced options can be set, such as selecting a frequency range over which you would like to fit your equivalent circuit and adjustments to the default parameters of the fitting algorithm.

5.10 Fitting algorithm

Currently, only the Levenberg-Marquardt algorithm is available for finding the minimum complex non-linear sum of squares. The advantages of this algorithm are that it is robust and generally quick at finding a solution. A disadvantage of the Levenberg-Marquardt algorithm is that it was not designed to work with specified minimum and maximum values for components. As a result, the algorithm sometimes ends up in local minima with unrealistic values for the components (i.e. extremely large/small or negative values). Local minima are inherent to mathematical optimization algorithms and in some cases, a good fit will require changing the default values of the components before performing the fit.



Advanced fitting options window

Maximum Iterations

Generally, it will not be necessary to increase the maximum number of iterations for fitting. As the Levenberg-Marquardt algorithm usually requires few iterations to achieve a fit. However, when the minimum step size parameters are lowered this could be necessary. When you do not achieve a good fit and see that the number of iterations was 500 in the table of the fit tab increasing the maximum number of iterations may help. Usually, it is better to carefully review the design of your circuit and enter more appropriate values for its components before fitting again.

Minimum Step Size

The minimum delta sum of squares and minimum parameter step size are the desired stopping conditions for the fitting algorithm.

The Levenberg-Marquardt algorithm attempts to reduce the sum of squares with each step, the minimum delta sum of squares specifies when further improvements become negligible. This can be lowered to achieve a more precise fit for the value of the components. For this to have an effect you will usually have to lower the minimum parameter step size as well. It is questionable whether lowering the minimum delta sum of squares will improve your fit as generally the accuracy of the fit is limited by the fact you are fitting a model which is a simplification of the actual ongoing processes in the cell and that will never fit the measurement perfectly.

As the Levenberg-Marquardt algorithm approaches the global minimum (i.e. the desired fit) or a local minimum (i.e. an undesired fit) the differences in the values of the components become smaller each step. Lowering this value is recommended if the expected component in the circuit has a value in the range of 1-10 pico Farad/Henri/Ohm etc.

Lambda

The Levenberg-Marquardt algorithm uses lambda as a damping/scaling parameter. The lambda factor increases/decreases the change in the values of the components for the next step. In the event of a successful step (i.e., the sum of squares decreases) the lambda factor decreases and becomes increasingly smaller as the algorithm approaches a minimum. In the event of an unsuccessful step, it becomes larger allowing the algorithm to approach a minimum with fewer steps.

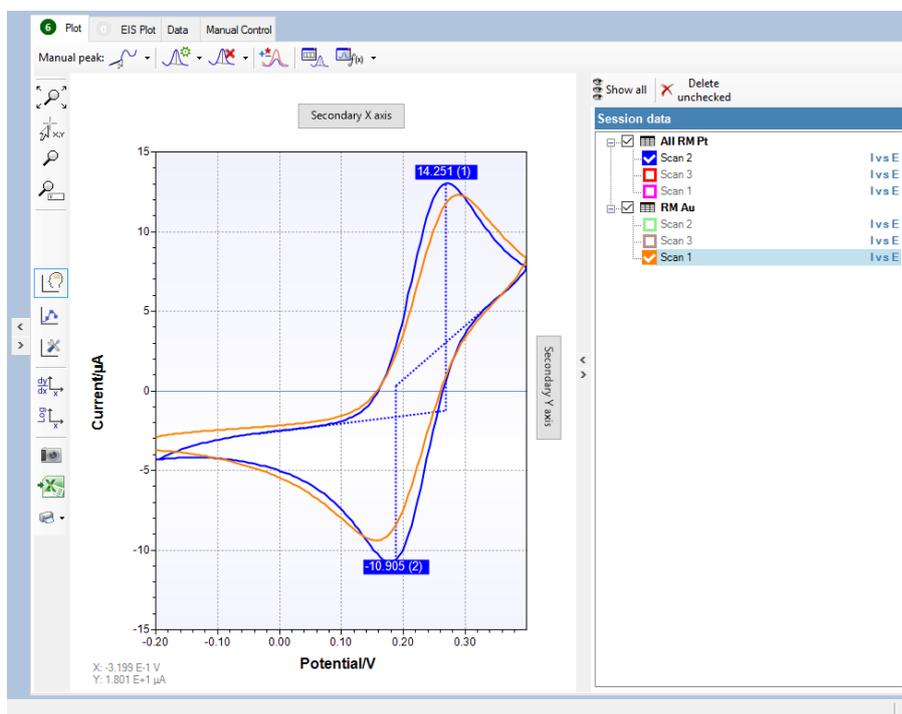
The starting lambda value can be lowered in the case you want to further optimize a fit that was already good or increased to find a minimum in fewer steps. The same holds for the lambda scaling factor reducing it will increase the number of iterations required but may be useful if further optimization is required and increasing it could decrease the number of iterations required to find a minimum or it could make the algorithm unstable.

6 Plot, curves and data

In this section, all available functions related to measured curves are explained. Since impedance data is presented differently from regular curves, please refer to chapter [Electrochemical Impedance Spectroscopy](#) on page 117 for information about working with impedance data.

6.1 Handling curves

There are two Plot tabs in MultiTrace; impedance measurement curves (EIS curves) are shown in the 'EIS Plot' tab, all other curves are shown in the 'Plot' tab.



MultiTrace window showing the Plot tab

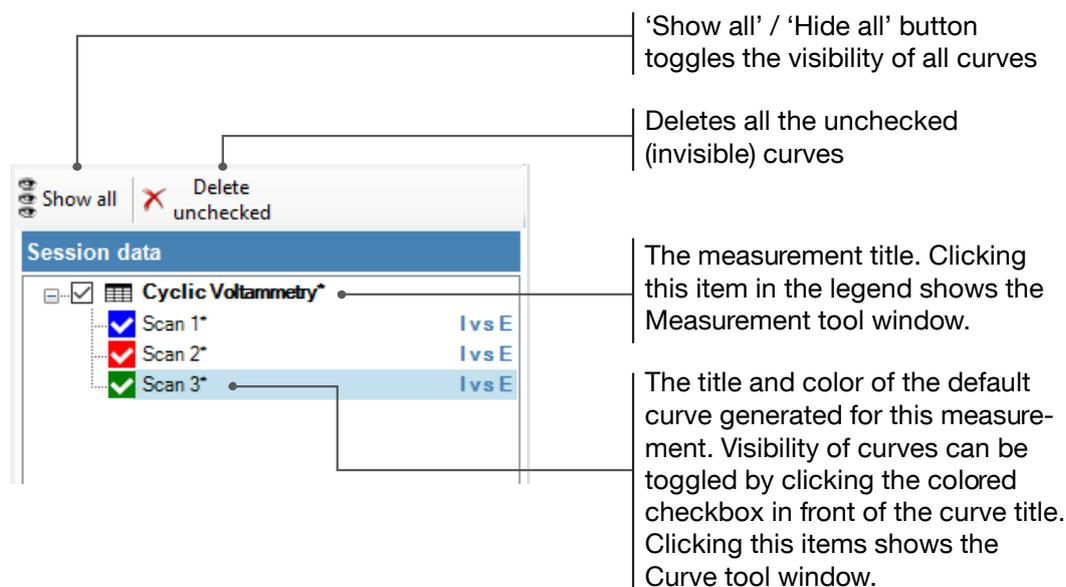
The legend next to the Plot tab shows all available measurements (session data) with corresponding curves.

A 'Session' can contain multiple measurements with curves.

See also section [Files](#) on page 225.

6.2 Session data

When a measurement is started the measurement is added in the Session data list or Legend next to the plot window and the default curve is added.



The legend showing session data

The curve selected in the curves list determines which curve is active. The active curve is used when saving a single curve, showing data in the Data tab, marking peaks or slopes, etc.

The asterisk (*) next to the titles indicates the measurement or curve is not saved yet. They will disappear when the data is saved to a session file.

When a measurement is selected in the legend, a window appears next to the legend showing all data that was recorded during the measurement together with some other information about the measurement:

Automatic naming of curves

In the case of a new measurement, the curve is named 'Curve' by default. In the case of a Cyclic Voltammetry measurement, the curve receives the name 'Scan n', where n is a sequential number. In the case of a multiplexer measurement or measurement using an auxiliary channel, it receives the name of the channel used.

6.2.1 Measurement Tool window

Selecting a Measurement item in the Legend opens the following tool window for this measurement.

The screenshot shows the Measurement Tool window for a selected measurement. The window is titled "Selected measurement" and contains the following elements:

- Title:** A text field containing "RM Au".
- Notes:** A text area with a "Click here to add notes..." link.
- Technique:** Cyclic Voltammetry
- File:** C:\... \RM Au electrode.psession
- Date:** 22/02/2017
- Start time:** 17:09
- Device used:** Unknown, EmStat2 (PS4A16A000010)
- Datapoints:** 239
- Generate new curve:** A section with two lists for selecting data for the Y and X axes. The Y-axis list includes "charge/ μC " (selected), "Scan 2 current/ μA ", and "Scan 3 current/ μA ". The X-axis list includes "time/s" (selected), "potential/V", "Scan 1/ μA ", "charge/ μC ", "Scan 2 current/ μA ", and "Scan 3 current/ μA ".
- Preview plot:** A graph showing "Charge/ μC " vs "Time/s" with a blue curve and a peak at approximately 6 seconds.
- Buttons:** "Add Q vs t curve", "Delete", "View method parameters", and "View raw data".

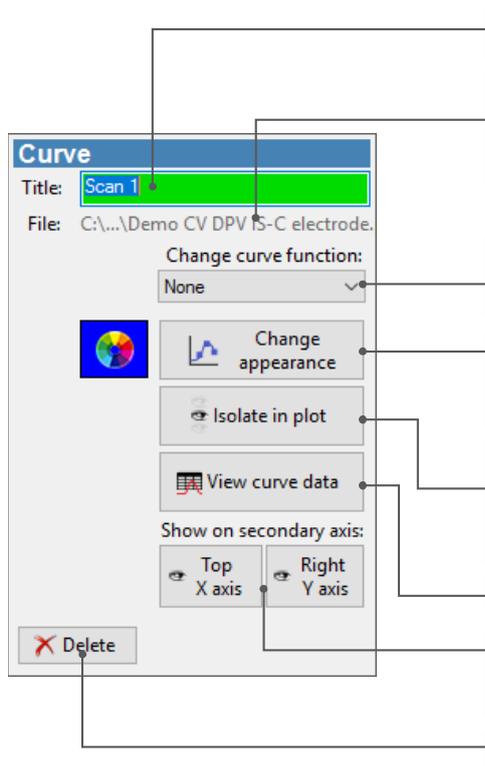
Annotations on the right side of the window provide the following descriptions:

- The measurement title as shown in the legend
- Notes as specified in the method editor before starting the measurement. Can be in this window as well.
- Preview plot of the new curve generated from the selected data.
- Add curves generated from the data recorded during the measurement.
- View the raw data recorded for this measurement in the 'Data' tab.
- View the method parameters used for this measurement. Also useful for changing automatic peaks detection settings for the curves in this measurement.
- Change appearance for all curves in this Measurement.
- Delete the recorded Measurement including all related data and information (notes, Method parameters used).

Window with measurement information shown next to the selected measurement in the legend.

6.2.2 Curve Tool window

Selecting a Curve item in the Legend opens the following Curve tool window.



The screenshot shows the 'Curve' tool window with the following components and their functions:

- Title:** Scan 1 (The title of the curve)
- File:** C:\...\Demo CV DPV IS-C electrode. (The name and location (path) of the file where this curve is stored in. Hover the mouse cursor over the path to see the full path in case it is too long for the window.)
- Change curve function:** None (Curve functions can be changed here. This can be used in the Analytical Mode to assign Sample and Standard Addition curves.)
- Change appearance:** (Buttons to change the Curve's color and the appearance of the curve (line visibility, thickness and/or symbols))
- Isolate in plot:** (Button to make all other curves invisible and the selected curve visible. Making all curves visible again is done using the 'Show all' button above the legend.)
- View curve data:** (Button to view the curve data in the Data tab)
- Show on secondary axis:** Top X axis, Right Y axis (Assign secondary axis for the curve to overlay with curves with different units or magnitudes)
- Delete:** (Delete the curve.)

Windows with tools for the selected curve shown next to the legend after selecting a curve

6.3 Plot toolbar

The plot toolbar at the left-hand side of the plot contains the following buttons.

Scaling and selection

	Automatic scaling to show all data points.
	Use pointer to select a datapoint.
	Use the pointer to drag an area that defines the new scaling boundaries.
	Enter minimum and maximum values for both axis.

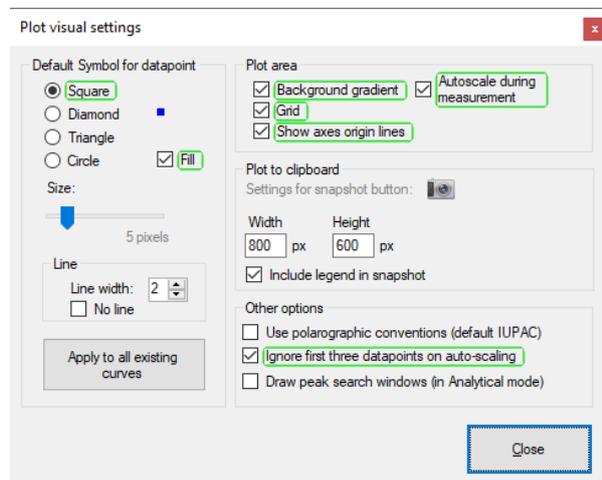
Clear helplines

	Removes all existing helplines (for example LLS or integration lines).
---	--

Plot options

	Toggle smart scaling to automatically round up / down minimum and maximum values for both axes.
	Toggle symbol visibility on each datapoint in the curve(s).
	Opens the 'Plot visual settings' window.

Plot visual settings window



The 'Plot visual settings' window

The 'Plot visual settings' window allows for changing the default appearance of the plot.

- **'Use polarographic conventions (default IUPAC)'**: There are two common conventions for Voltammetric plots both of which are supported in PStTrace:
 - The IUPAC (International Union of Pure and Applied Chemistry) makes sure that anodic currents are plotted in a positive direction and cathod currents in a negative direction.
 - If the Polarographic convention (also known as the North American, Polarographic, or Classic convention) is used, anodic currents will be plotted in a negative direction and cathodic currents in a positive direction.
- **'Ignore first three datapoints on auto-scaling'**: if enabled the first three datapoints may not be within the boundaries of the vertical axes. This can be useful if the first measured datapoints were not recorded in the correct current range.
- **'Draw peak search windows (in Analytical mode)'**: if enabled the potential windows that are assigned to an analyte are made visual in the plot. This helps the user to visually check the chosen potential windows.

Axes options

	Plots the derivative of the curve using the centred three-point method.
	Plots the second derivative of the curve.
	Plots the integral of the curve.
	Plots the logarithm (Log ₁₀) of the Y values.
	Shows the Cottrell plot (see next section for more information).
	Shows the Anson plot (see next section for more information).

6.3.1 Cottrell plot

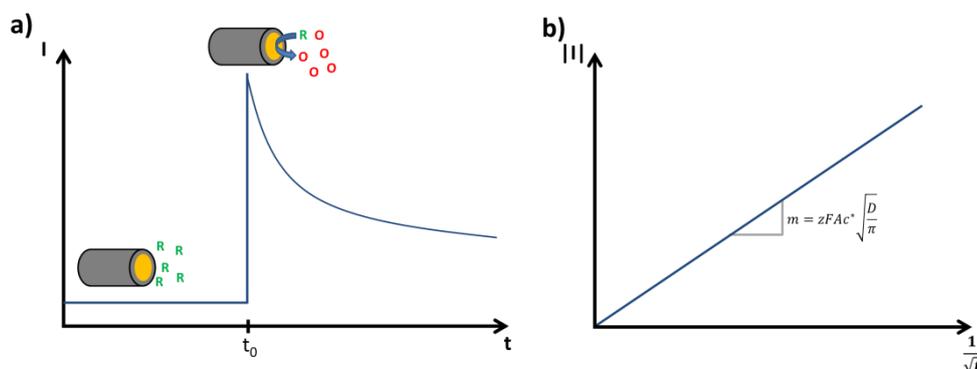
The option for displaying the Cottrell plot is only visible for current measured versus time (chronoamperometry).

The Cottrell Equation is well known in electrochemistry. It describes how the current I due to a reaction of a free diffusing species develops over time t :

$$I = zFAc^* \sqrt{\frac{D}{\pi t}}$$

Where D is the species' diffusion coefficient, z the number of electrons transferred per molecule, A the active area of the electrode, c^* the bulk concentration and F the Faraday constant.

If a potential step is performed from a reaction free potential to a potential where a reaction is no longer potential controlled, but diffusion controlled, we expect the current to look like in the figure below.



a) current response to a potential step (Cottrell experiment) **b)** linear form of a)

In the Cottrell plot the current I is plotted versus $t^{1/2}$ and according to the Cottrell equation a linear plot is expected as shown in the figure above (b). The slope m of this plot is

$$m = zFAc^* \sqrt{\frac{D}{\pi}}$$

Depending on which factors are known the Cottrell plot can be used to determine for example D , c^* or A . The challenge is to choose the right part of the Cottrell plot to perform the linear fit.

In the beginning of the curve and at the end the plot is not linear. The end of the curve is not linear, because the diffusion layer does not expand perfectly into infinity due to convection or other effects.

The end of the curve is influenced by two factors. First, it is impossible to perform an ideal potential step. Potentiostats have rise times in ns or even μ s, that is they can reach a set potential in that short period, but this is still not perfectly instantaneous. So, the beginning of the curve deviates from the ideal potential step. The second factor, the capacitive current or capacitive charging current, is caused by ions forming a capacitor at the electrochemical double layer.

6.3.2 Anson Plot

The option for displaying the Anson plot is only visible for charge measured versus time (chronocoulometry).

While measured current in the Chronoamperometry (CA) shows a linear correlation with the reaction rate, the charge measured in Chronocoulometry (CC) shows a linear correlation with the amount of converted reactants. This is described in Faraday's law. This makes CC useful during deposition or electrochemical synthesis. For characterization of batteries CC is also helpful.

In analytical chemistry CC is used to determine the adsorbed amount of active species in a solution of free diffusing active species. Multiplying the Cottrell equation with t delivers that the charge Q_{diff} of the free diffusing species' reaction is proportional to $t^{3/2}$.

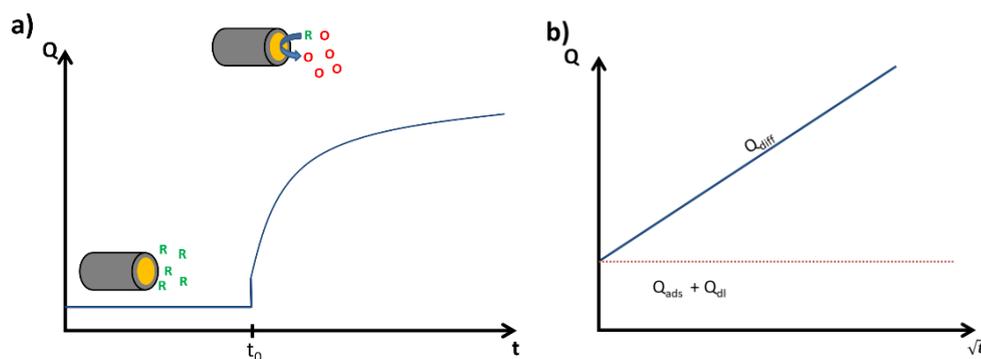
$$Q_{diff} = zFAc^* \sqrt{\frac{Dt}{\pi}}$$

Where D is the species' diffusion coefficient, z the number of electrons transferred per molecule, A the active area of the electrode, c^* the bulk concentration and F the Faraday constant.

The total charge Q during a potential step like the Cottrell experiment (see Cottrell plot) includes also the contribution of the charge stored in the electrochemical double layer Q_{dl} and the charge due to reactions of adsorbed species. Q_{ads} (see figure below)

$$Q = Q_{diff} + Q_{ads} + Q_{dl}$$

The cause of Q_{ads} and Q_{dl} are a lot faster than the reaction of free diffusing species. Plotting Q versus $t^{3/2}$, known as Anson plot, delivers (ideally) a jump in charge followed by a linear increase (see figure below).



a) current response to a potential step (Cottrell experiment) **b)** linear form of a)

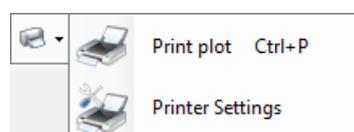
When the linear part is extrapolated the intersection with the charge axis delivers $Q_{\text{ads}} + Q_{\text{dl}}$. A previous blank measurement allows the determination of Q_{dl} and thus the calculation Q_{ads} .

Analog to the Cottrell plot the Anson plot won't show linear behavior at the beginning and the end for real experiments.

To make sure the charge step, in the beginning, is recorded CC is performed in 2 steps. The first step at a reaction-free potential is followed by the step where the reaction is initiated, just like the classic Cottrell experiment.

Plot export options

	Takes a snapshot of the plot area and copies the result to the clipboard for pasting in other software. The snapshot settings can be changed in the 'Plot visual settings' window.
	This button is only visible when exporting to Excel is enabled. See also section Exporting curves on page 205.
	This button is only visible when exporting to Origin is enabled. See also section Exporting curves on page 205.



Print buttons in the Plot toolbar

	Shows a print preview and printing options for the plot
	Opens the general printer settings window, allowing you to select the default printer for printing in MultiTrace and changing the default printer settings.

6.4 Curve toolbar

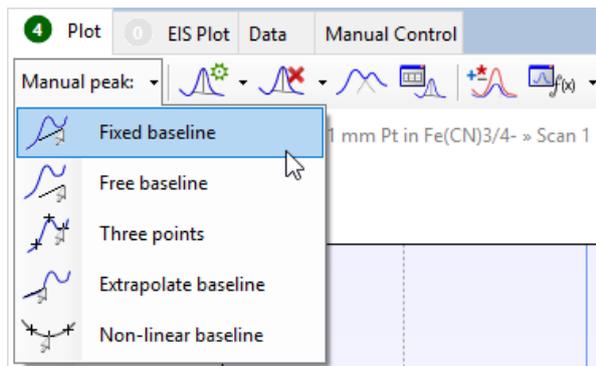
This section describes the tools found in the curve toolbar.



The Curve toolbar.

6.4.1 Marking peaks manually

The buttons to manually mark peaks in the plot can be found in the curve toolbar under the button 'Manual peak'.

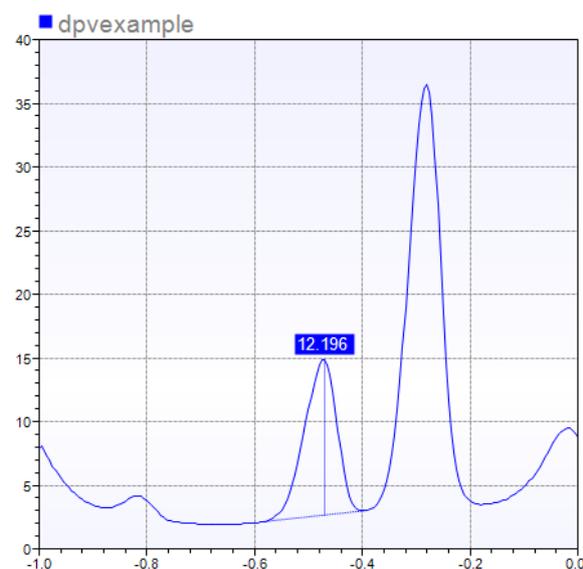


Mark peak manually

Fixed baseline



Draw a baseline fixed on the curve for peak detection.

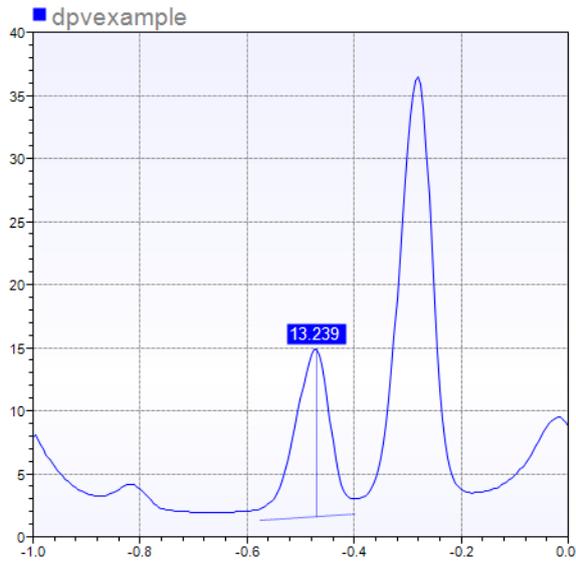


Baseline on curve

Free baseline



Draw a baseline that is not attached to the curve.

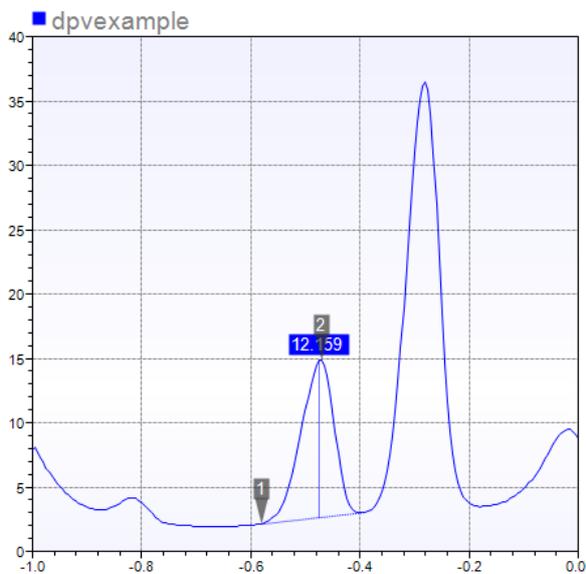


Free baseline

Three points



Mark three points on the curve to determine the left and right sides of the baseline and the top of the peak.

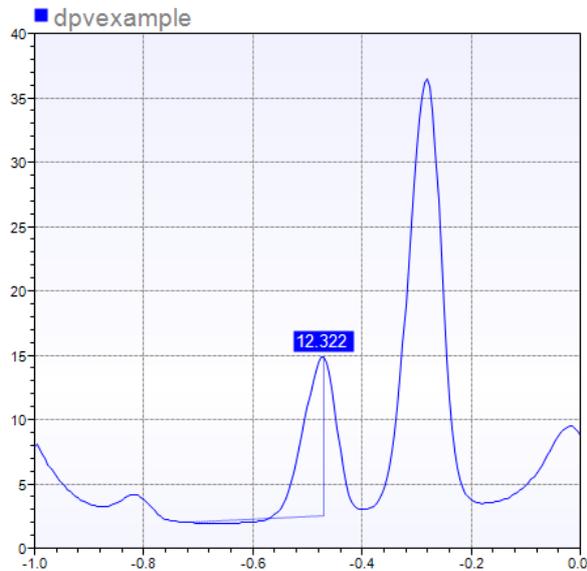


Three points determine baseline and corresponding peak

Extrapolate baseline

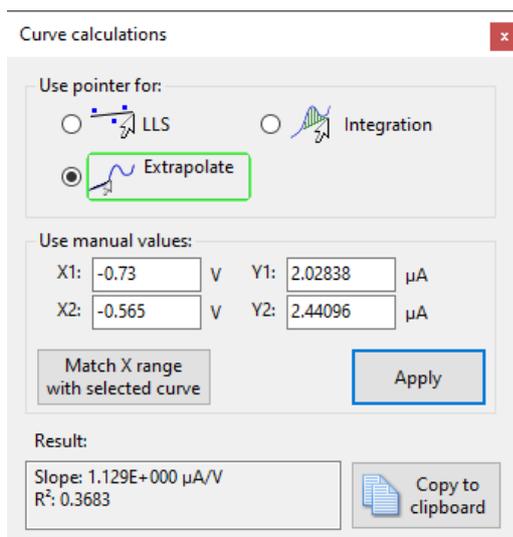


A linear slope (using linear regression) is marked on the curve from which the baseline is extrapolated.



Extrapolate from slope

As soon as the slope for the baseline line has been drawn, the Curve calculations window is shown:



Calculations window showing the properties of the slope

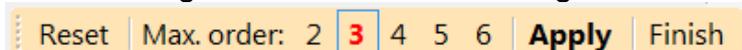
The values shown in the window can be changed manually and applied again on the curve.

Non-linear baseline



A polynomial with a specified order is fitted through the selected points on the curve.

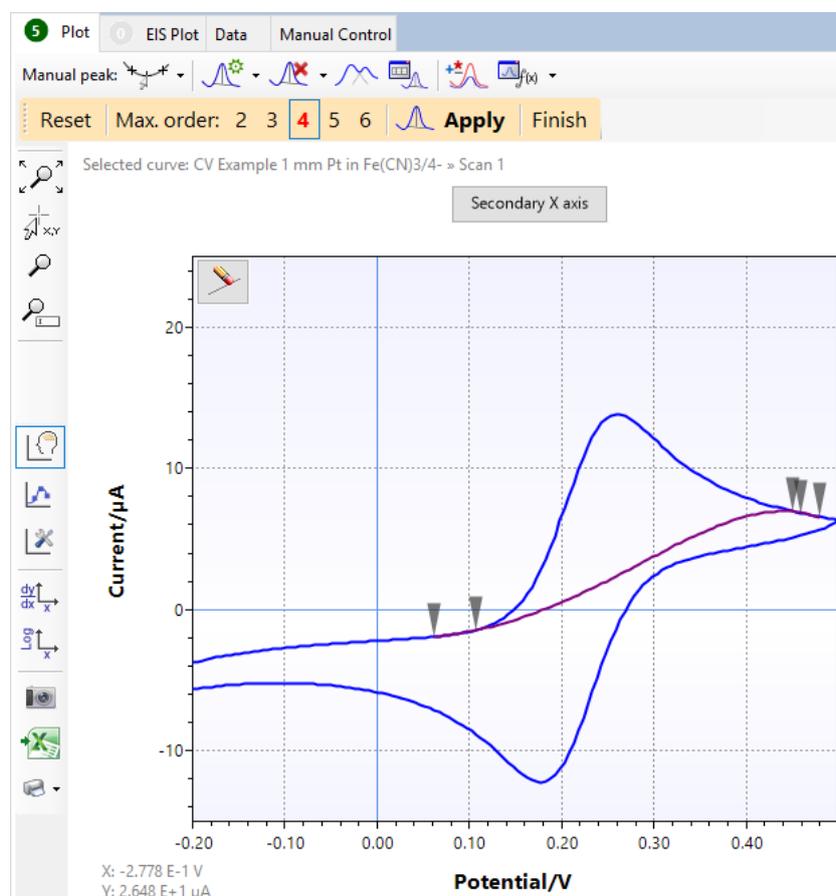
The following buttons are shown during selection:



The selected 'Max. order' defines the maximum (n) order applied for the polynomial:

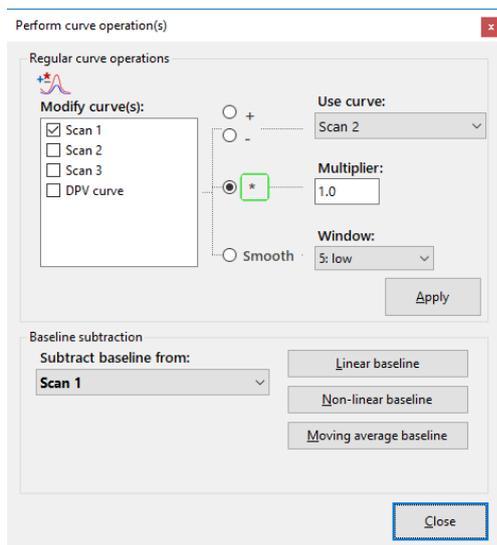
$$a_0 + a_1x + a_2x^2 + \dots + a_nx^n,$$

The number in red represents the current order n applied. When a polynomial is set, the button 'Apply' shows a preview of the peak using the polynomial as the baseline. Each time the polynomial is changed; the 'Apply' button should be clicked to mark a new peak using the changed polynomial as the baseline. The 'Close' button should be clicked when a satisfactory peak is found.



Marking a peak in a CV curve

The baselines can also be used for subtraction. This can be done in the Curve Operations Window. See section [Curve operations](#) on page 195.



Curve operations window

6.4.2 Peaks toolbar buttons

Detect peaks



Automatically detect peaks in all curves or a selected curve. A single curve can be selected using the small drop-down arrow next to the button. The settings in the [Peaks tab](#) on page 41 are used for peak finding. Results are shown in the Peaks Data window. Note: This button is replaced by the 'Find levels' button if the last measurement was versus time. This can be reversed in the Peaks tab.

Remove peaks



Remove all peaks or remove the peaks of a specific curve. Peaks in a single curve can be removed using the small drop-down arrow next to the button.

Find levels



Available if measured as a function of time and *Current Level* is checked in the Peaks tab. The settings in the Peaks tab are used for the level finding. Results are shown in the Peaks Data window.

Remove levels

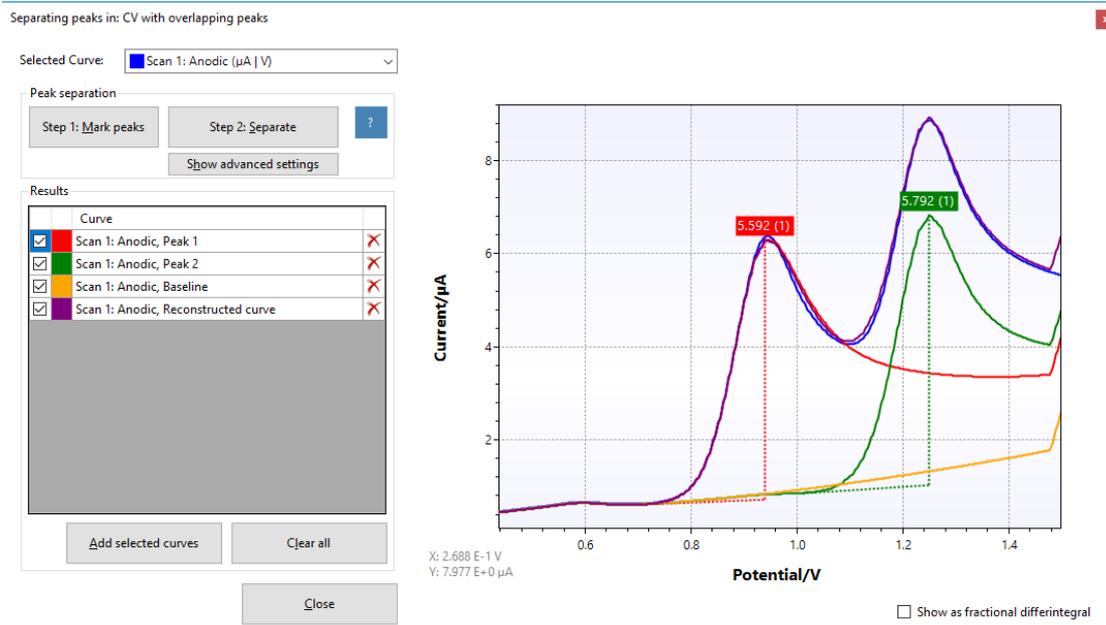


Remove all levels or remove the levels of a specific curve. Peaks in a single curve can be removed using the small drop-down arrow next to the button.

Windows



Overlapping peaks separation window.

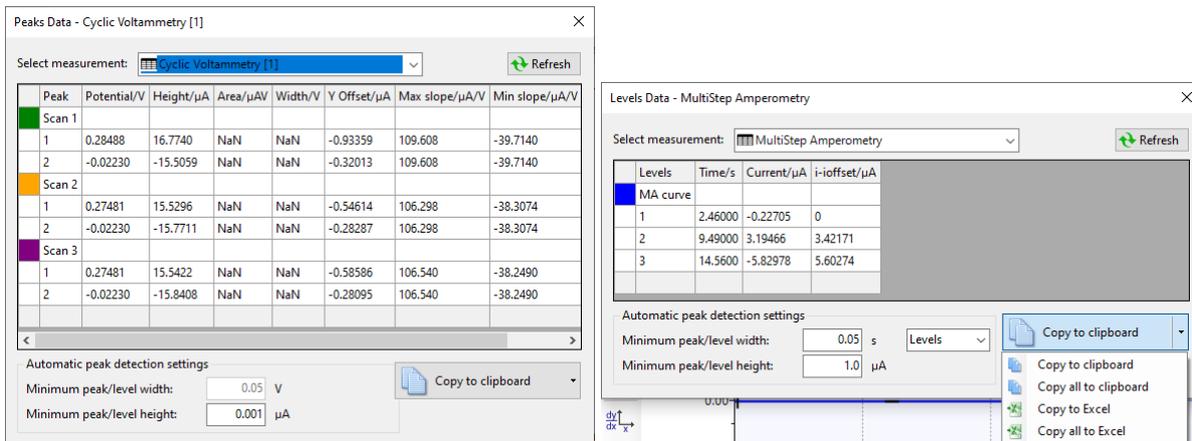


Window showing separation of overlapping peaks in a CV measurement.

The [overlapping peaks separation window](#) (see page 191) allows for the separation of two or more overlapping peaks. This tool window is only accessible for [LSV](#) (see page 57) and [CV](#) (see page 60) measurements.



Toggle peaks or levels data window.

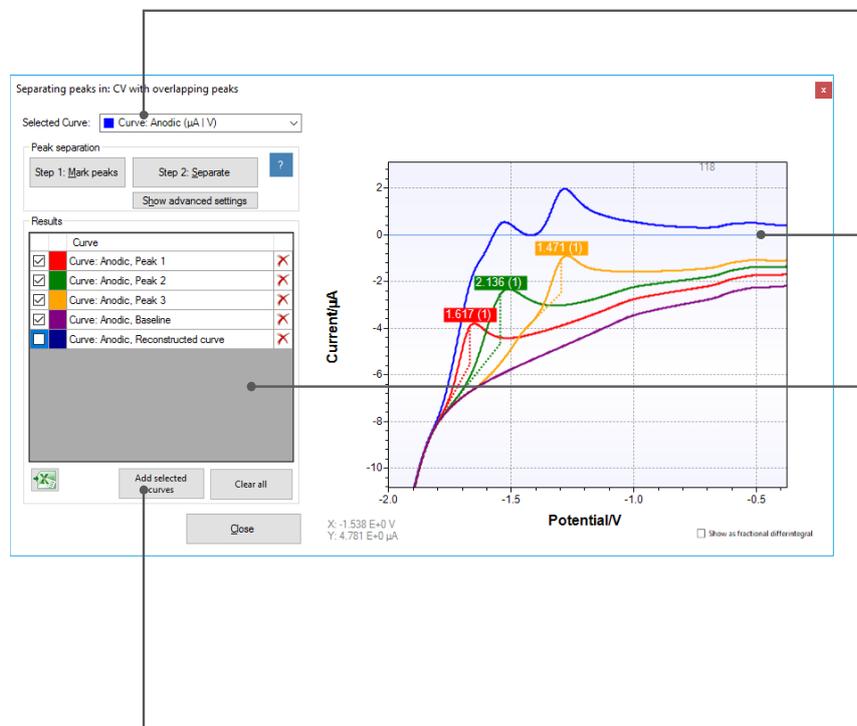


Windows showing peak (left) or level (right) data

The table shows the values for the peak potential, peak height, peak area, peak width at half-height, the value at the baseline as well as the maximum values for the ascending and descending slopes, and the sum of both values for each curve in a measurement. These results can be copied to excel or the clipboard for the selected or all measurements. The measurement's automatic peak detection parameters can be adjusted, and the automatic peak detection can be performed again. In the case of a curve plotted versus the time it is possible to switch between peak and level detection.

6.5 Separating overlapping peaks

Overlapping peaks in a cyclic or linear sweep voltammetry measurement can be separated using the peak separation window. The peak separation window can be opened from the toolbar above the plot . Peak separation works best for reversible peaks, the amount of overlap and number of overlapping peaks determine how well the peaks can be separated from each other (separating peaks is not guaranteed to work properly in all cases).



Dropdown list from which you can select the anodic or cathodic parts of the curves in the measurement.

Table and plot containing the results of the peak separation.

The blue curve is the original curve (highlighted in the top left).

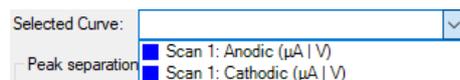
The red, green and yellow curves are the separated peaks.

The purple curve is the baseline and the dark blue curve is a reconstruction of the original curve using the three separated curves.

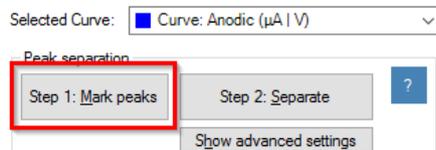
Adds the resulting curves to the main window.

Overview of the peak separation window

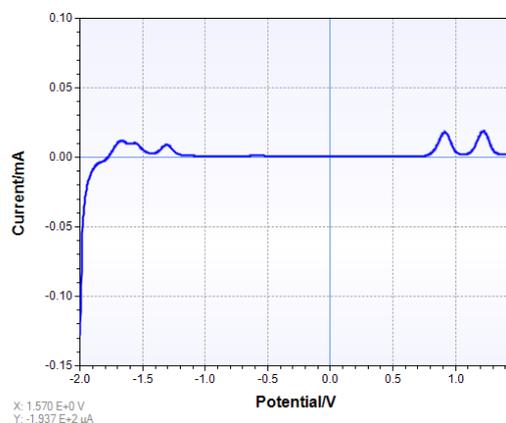
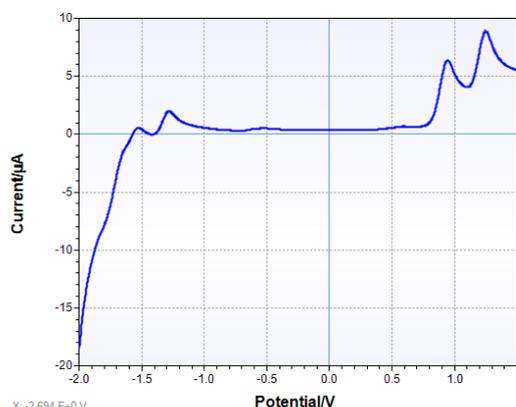
First, select the measurement that contains the curve that you would like to separate in the [legend of the Plot tab](#) on page 178 in the main window. Then the peaks or levels data window  should be opened and the  separate overlapping peaks button clicked. Select the anodic or cathodic curve that you would like to separate peaks in from the dropdown menu in the top left corner of the peak separation window.



Before you can separate the overlapping peaks, they should be marked in the plot to the right. Click on mark peaks, this will change the view in the plot to the differintegral view. The peaks are still at approximately the same potential, however, in this view, they are more distinct.

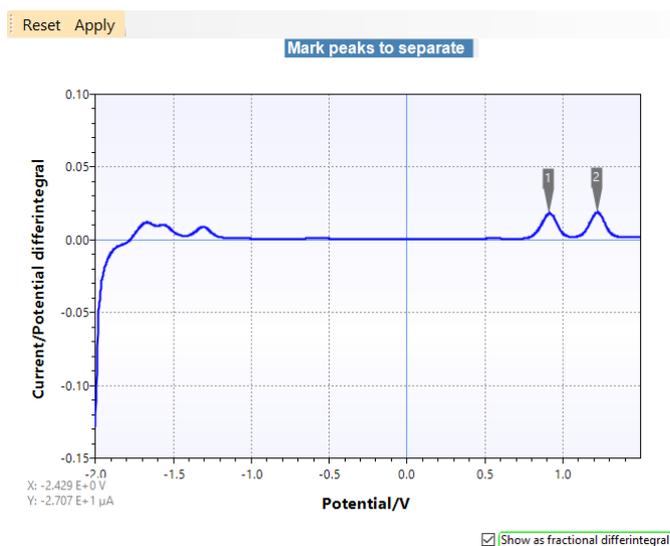


First step: Mark peaks to separate



Left: Anodic curve with several overlapping peaks. Right: Differintegral view of the same curve.

Once you selected the peaks you want to separate, click on 'Apply'. **Tip: you can zoom in by scrolling the mouse and pan using the right mouse button.** Selecting peaks that do not overlap will not work and selecting more than three peaks takes much longer to compute.

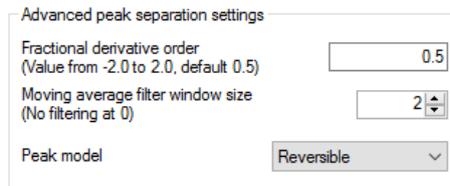


Marking the peaks in a curve

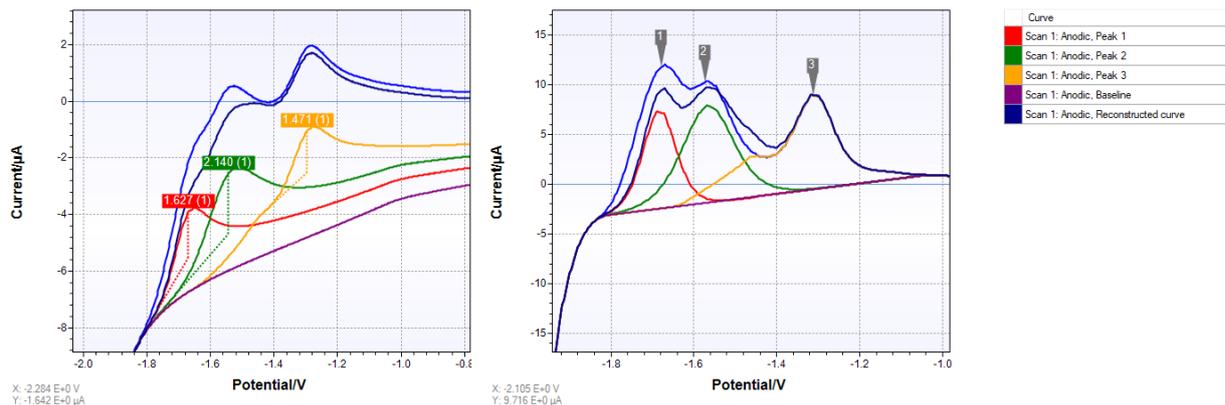
Once the peaks have been marked, they can be separated by clicking on the respective button. This will change the plot back to the regular view and display the results.

6.5.1 Advanced peak separating settings

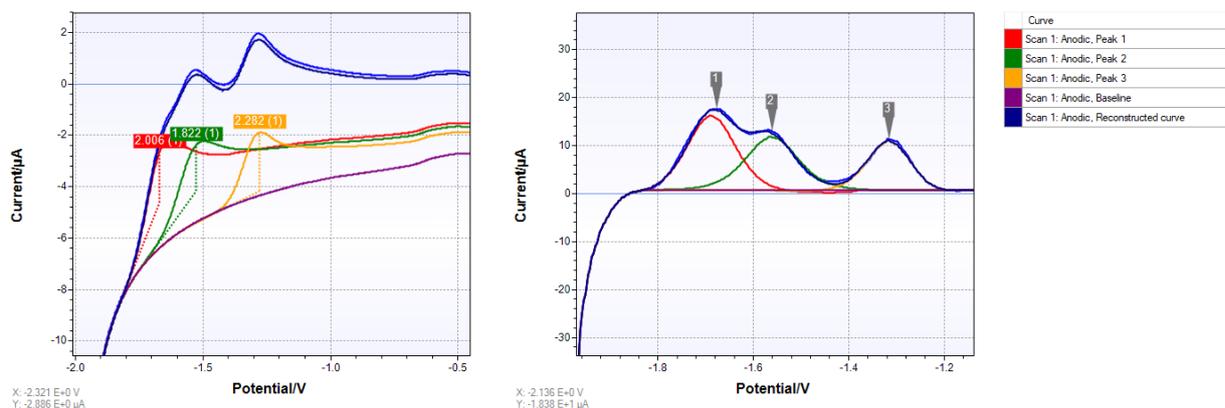
In some cases, the separation of the peaks can be improved by adjusting the default settings in the advanced settings.



The order of the differintegral is specified in the fractional derivative order text box. By default, the 0.5 semi-derivative is used to separate the peaks from each other. The peaks are best separated when they do not or barely overlap in the differintegral view and when the beginning and end of the peaks are on the same level / the baseline is not slanted.



Results of the peak separation with the default settings. Notice that the baseline (purple curve) is slanted in the differintegral view (right), this often leads to sub optimal results (the purple curve deviates from the original blue curve).



Increasing the order of the fractional derivative to 0.61 improves the separation of the peaks significantly.

The show as differintegral check box toggles between the regular and differintegral view. Toggling back to the differintegral view is useful when optimizing the separation of the peaks.

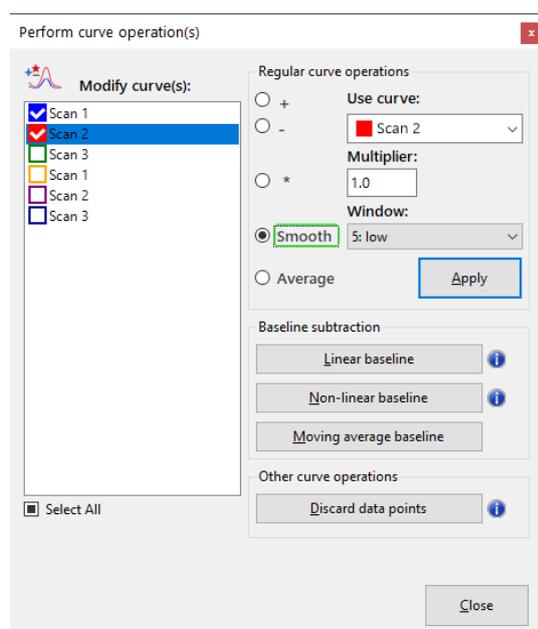
The window size of the moving average filter is used to prevent noise from interfering with the peak separation. The separation works best with smooth curves, however,

there is a trade-off between large and small window sizes. Large window sizes can result in an underestimation of the peak height and small window sizes can result in errors when separating the peaks.

Finally, depending on the type of reaction switching between the reversible and irreversible peak model can improve the peak separation. The reversible peak model works best with peaks that are symmetrical in the differintegral view and the irreversible peak model works best with asymmetrical peaks (peaks where the second half is steeper).

6.6 Curve operations

The curve operations window is available in the Curve toolbar and can be opened with the button 



Curve operations window

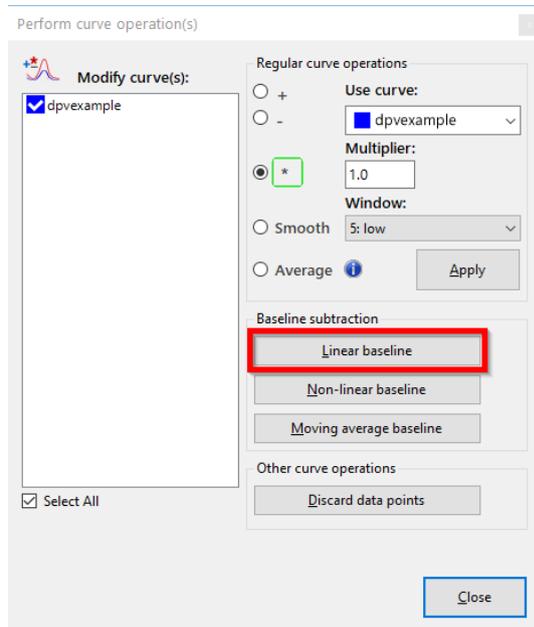
1. Select one or multiple curves to apply operations on.
2. Choose the mode of operation.

New curves will be generated and added to the corresponding measurement, based on the selected operation.

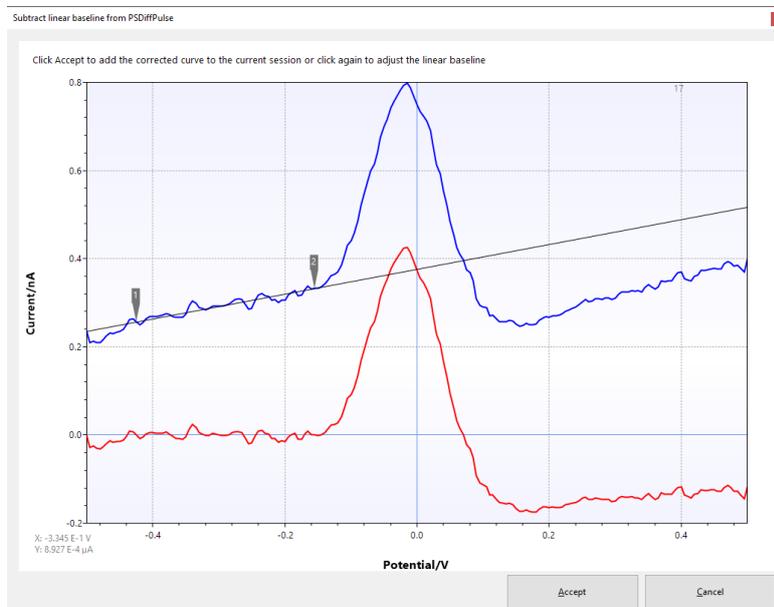
For more information about the Baseline buttons, see the following sections [Linear baseline subtraction](#) on page 196, [Non-linear baseline subtraction](#), on page 197 and [Moving average baseline](#) on page 198.

6.6.1 Linear baseline subtraction

To do a linear baseline subtraction, click on the 'Subtract linear baseline' button in the Curve Operations window. This is opened using the  in the plot toolbar. Or in the menu 'Peaks' → 'Curve operations'.



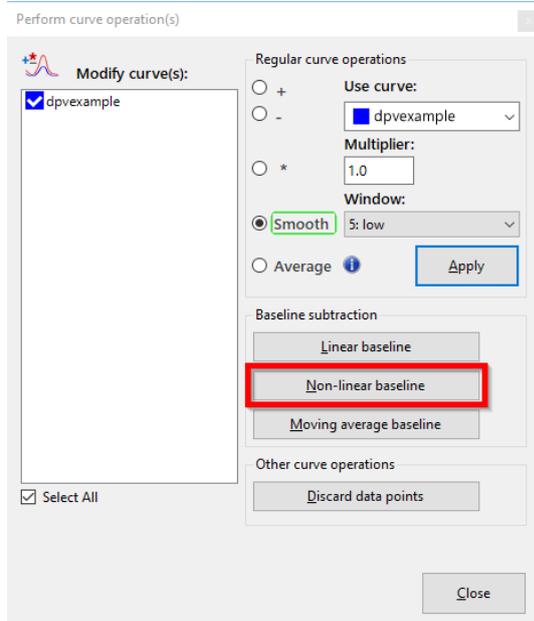
Clicking on this button will open a new window with a plot of the selected curve. Set two markers on the curve. As soon as the second marker is set, a preview is shown. A third click on the plot will remove the preview, reset the markers, and place the first one again. If the preview seems satisfactory, click 'Accept'.



Plot showing a preview of a linear baseline subtraction

6.6.2 Non-linear baseline subtraction

To do a non-linear baseline subtraction, click on the 'Subtract non-linear baseline' button in the Curve Operations window. This is opened using the  button in the plot toolbar.



The non-linear baseline button in the Curve Operations window

The following buttons are shown during selection:

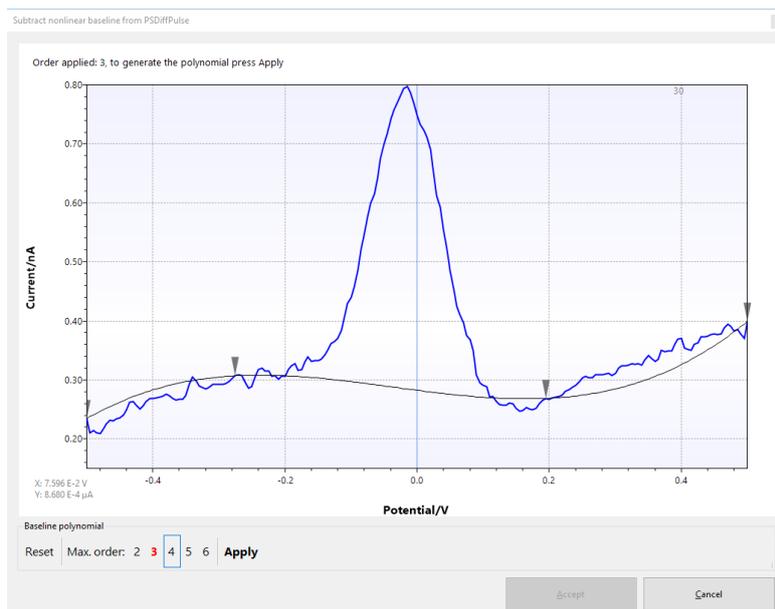


The selected 'Max. order' defines the maximum (n) order applied for the polynomial:

$$a_0 + a_1x + a_2x^2 + \dots + a_nx^n,$$

A polynomial with a specified order is fitted through the selected points on the curve. A polynomial requires a minimum of n+1 markers. So, a 3rd order polynomial requires three markers.

The number in red represents the current order n applied. When a polynomial is set, the button 'Apply' shows a preview of the subtracted curve using the polynomial as the baseline. Each time the polynomial is changed; the 'Apply' button should be clicked to update the preview. The 'Accept' button should be clicked when the preview is satisfactory.

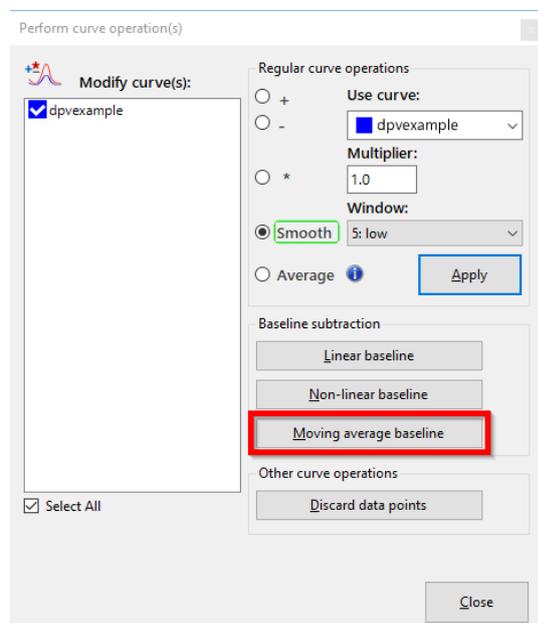


Setting markers on a DPV curve

6.6.3 Moving average baseline subtraction

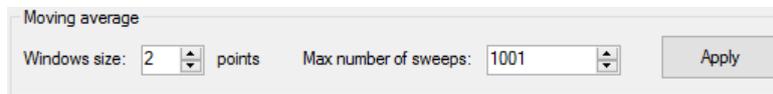
To do a moving average baseline subtraction, click on the 'Moving average baseline' button in the Curve Operations window. This is opened using the  in the plot toolbar.

Note:
Moving average baseline subtraction is not applicable for Cyclic Voltammograms.



The Moving average baseline button in the Curve Operations window

By clicking on the 'Moving average baseline' button, a preview window opens. In this window, the window size and the maximum number of sweeps can be adjusted to obtain the desired result. The grey line represents a preview of the baseline correction, it is updated instantly after changing the window size and the maximum number of sweeps.



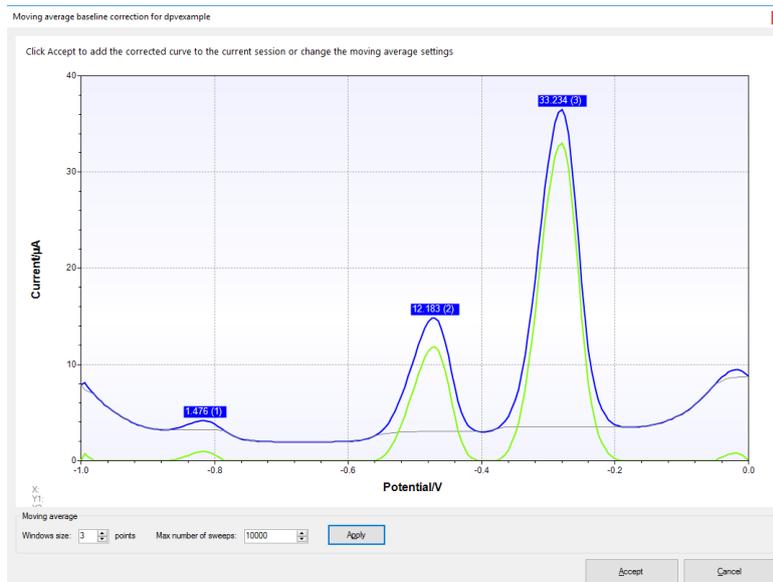
Moving average baseline settings

When performing a moving average baseline correction, it is recommended to change the window size first.

Increasing the window size will increase the number of data points that are used to determine the new value of the data points with the moving average correction. The ideal window size depends on the number of data points in your measurement and the width of the peaks. A window size that is too large will result in unwanted rounding errors.

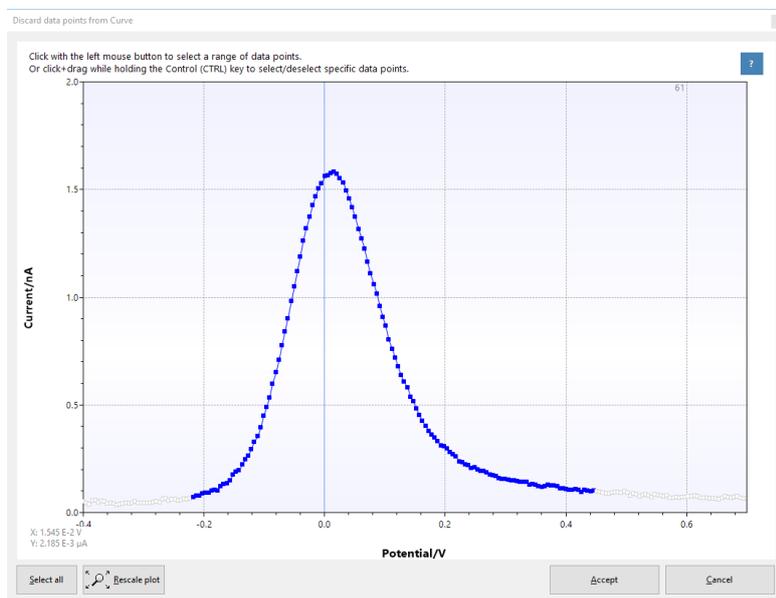
When the desired result cannot be obtained by increasing the window size the maximum number of sweeps (i.e., the iterations of the moving average correction applied to the curve) can be increased to achieve the desired effect.

To see a preview of the moving average baseline correction, click on 'Apply'. Clicking on 'Accept' will add the curve to the session manager.

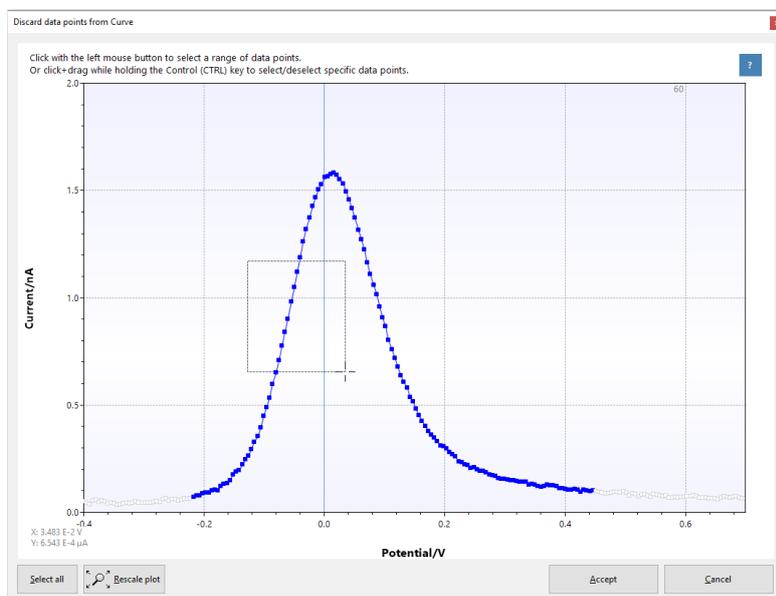


6.6.4 Discarding data points

Using this option, it is possible to create a new curve from a specific selection of a curve. Specifying the selection of the curve to keep with the mouse by moving your mouse over the sample from where you would like to start or end your selection, then clicking on that sample (blue dot) twice. Then move your mouse to the data point where you would like to respectively end/start your selection and click on it once. The selected range for the new curve is indicated by the solid markers.



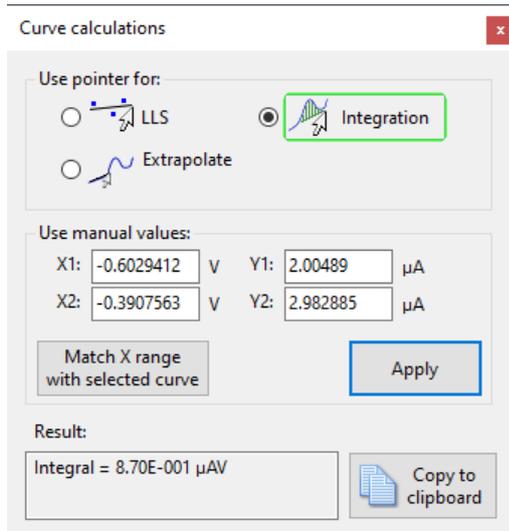
Alternatively, its single points can be (de)selected by holding down the CTRL button on your keyboard and left clicking on the outlier with your mouse. Left clicking on that point again while holding down control will reselect it. While holding down both the CTRL button and the left mouse button it is possible to (de)select all data points in the specified area.



Click 'Accept' to add the new curve based on the selection to the current session.

6.7 Curve calculations

Use the button  to open the Curve calculations window.



Curve calculations window

The values obtained by using the pointer are shown in the 'Use manual values:' window so they can be fine-tuned and re-applied. These values are saved when MultiTrace is closed.

Using the button 'Copy to clipboard' the results can be pasted (usually using Ctrl+V) as plain text into any other program.

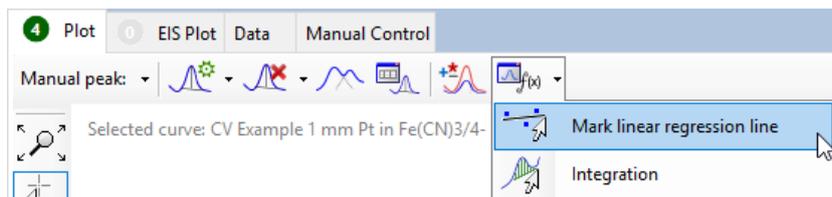
The 'Match X range with selected curve' button selects the entire range of the curve.

Extrapolate



See for more information regarding Extrapolate baseline button section [Marking peaks manually](#) on page 185.

The buttons for integration and marking a linear regression line can be found under the *Curve operations* button.

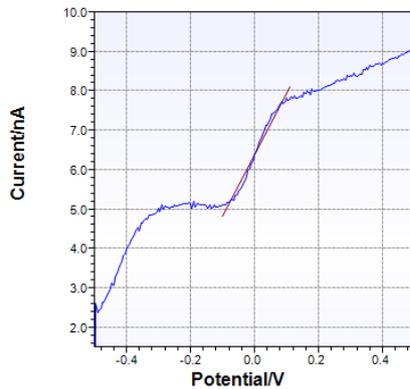


Calculations on the curve

Linear regression

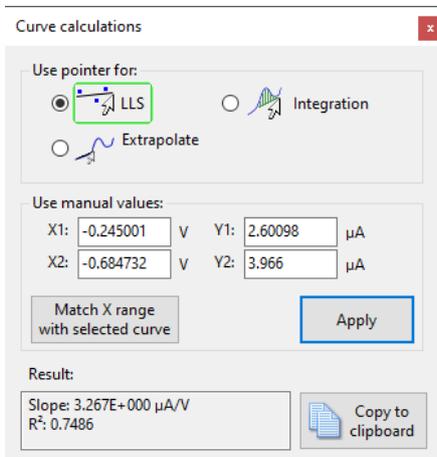


Mark begin and end on the curve for linear regression using linear least squares (LLS).



Calculation of a slope using LLS.

As soon as the line has been drawn, the Curve calculations window with the results is shown:



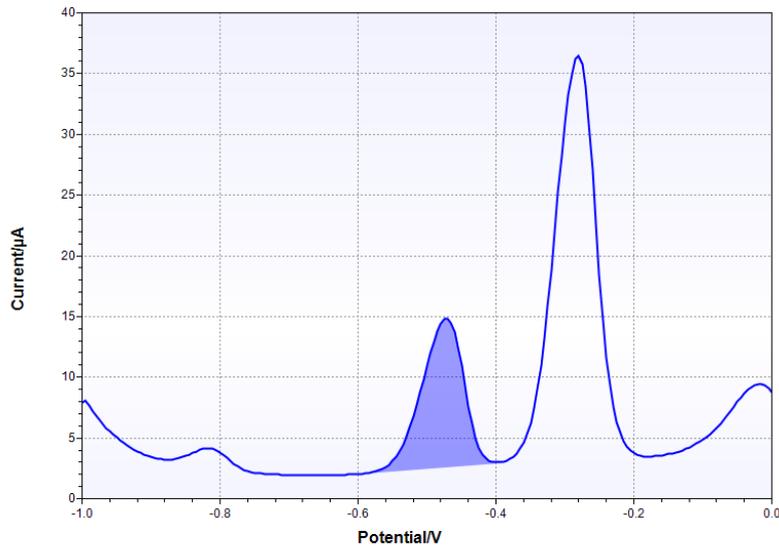
Calculations window showing the properties of the slope

The values shown in the window can be changed manually and applied again on the curve.

Integration



Draw a baseline for integration on a curve.



Result of drawing a baseline for integration

The integration result is shown in the Curve calculations window:

The screenshot shows the 'Curve calculations' window with the following details:

- Use pointer for:**
 - LLS
 - Integration
 - Extrapolate
- Use manual values:**
 - X1: -0.6029412 V Y1: 2.00489 µA
 - X2: -0.3907563 V Y2: 2.982885 µA
- Buttons:** 'Match X range with selected curve' and 'Apply'.
- Result:** Integral = 8.70E-001 µAV
- Copy to clipboard** button.

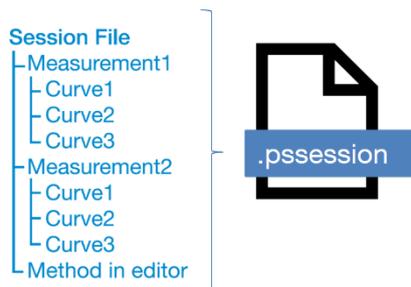
Calculations window showing the integration results in two different units

The values shown in the window can be changed manually and applied again for integration of part of the curve.

The “Match X range with selected curve” button selects the entire range of the curve. This can be useful when determining the total charge of a curve for example.

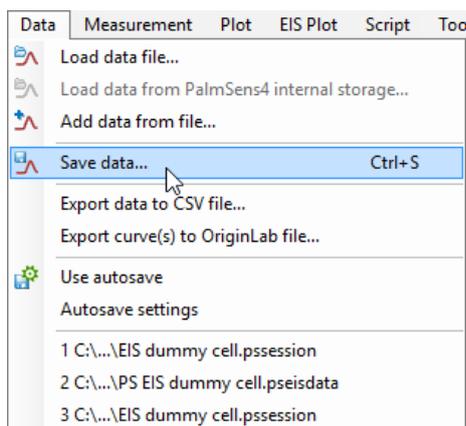
6.8 Saving data

All measurements and curves that are present in the Plot and EIS Plot tabs and the method present in the Method Editor can be saved to a single '.pssession' file.

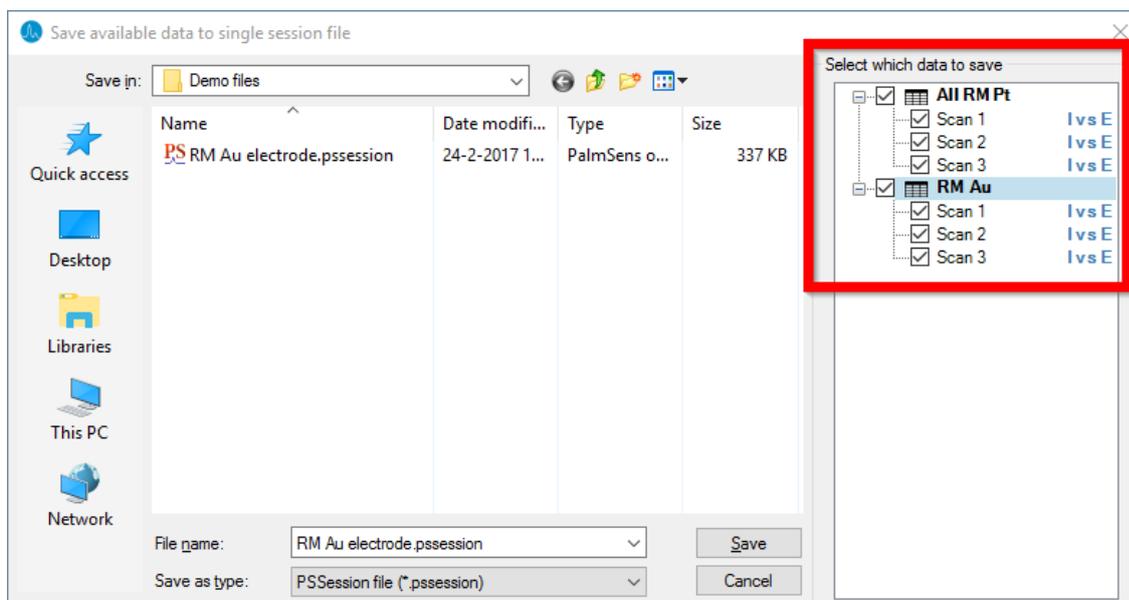


A PSSession (.pssession) file contains basically all the data available at a given moment.

Data is saved via the menu: 'Data' → 'Save data...'



Data menu



Save Data dialog for saving to a PSSession file

In the tree at the right side of the Save Data dialog window data can be selected that will be included in the PSSession file.

CSV

Files can also be exported to a CSV (Comma Separated Values) format. This is a common file format supported by many applications like Excel, OpenOffice Calc and Origin.

OriginLab

Files can be exported to a native .OPJ file for use in Origin.

See also section [Files](#) on page 225.

Legacy curve files

Since the release of PStTrace v5 and MultiTrace v4, the following file formats can no longer be used for saving data:

.pss, .pst, .mux, .psd and .pseisdata.

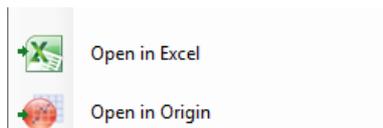
The new .pssession file format has replaced the need for keeping these different formats.

All these old file formats can still be loaded in PStTrace v5 and MultiTrace v4.

See also section [Files](#) on page 225.

6.9 Exporting curves

MultiTrace allows curves to be exported to third-party software with a single click.



Export options shown in the Plot menu

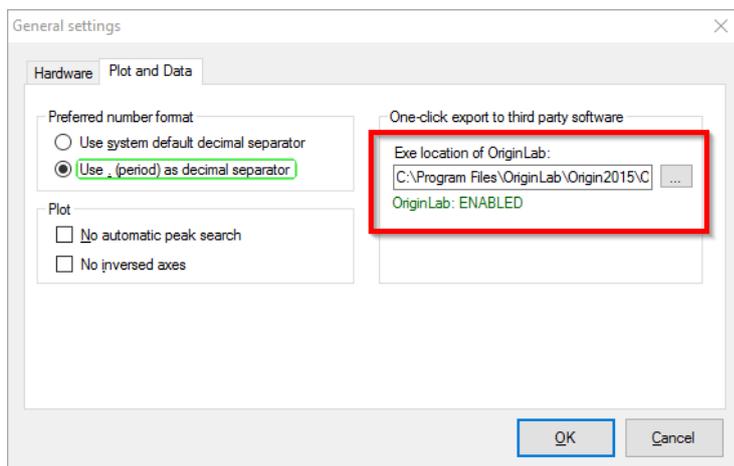
Excel

If Excel version 2007 or newer is installed an 'Open in Excel' menu item is added to the Plot menu and an extra button is added at the left-hand side of the Plot. Clicking the menu item or the button will open an Excel window and automatically export the data of all visible curves to the spreadsheet. A graph will be generated for all exported data. The template for the graph can be found in the installation folder of MultiTrace.

Origin

If Origin is installed an 'Open in Origin' menu item is added to the Plot menu and an extra button is added at the left-hand side of the Plot. Clicking the menu item or the button will open an Origin window and automatically export the data of all visible curves to a separate book and graphs will be generated for each exported curve.

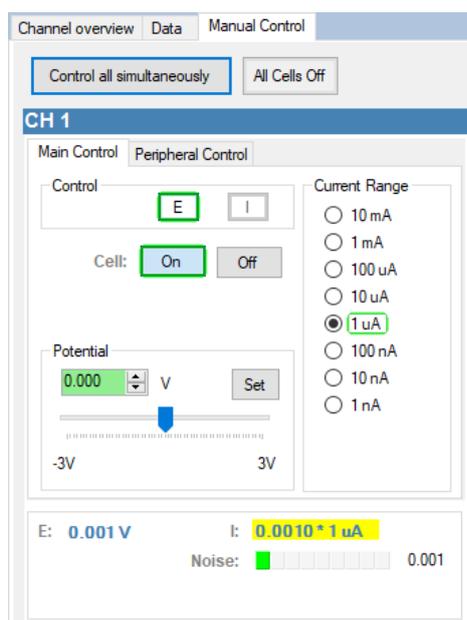
If the button is not showing and Origin is installed, open the General settings window in the menu ('Tools' → 'General settings...') and check in the 'Plot and data' tab if the location for Origin is properly set.



Location for Origin specified in the Settings window.

7 Manual control

The Manual Control tab in both the Individual and Simultaneous mode, allows the control of each individual channel. All cells can be turned on and off at once using the buttons at the top.



Manual control box with controls for individual cell control

Each box can be used to control the cell of the individual channel.

Main Control

Cell On/Off is used to connect the sensor to the channel/device. If the cell is off only the potential is measured. If the BiPot module is present, WE2 can also be switched on or off.

Control E or i is used to set the mode (potentiostatic or galvanostatic) of the device. Selecting 'E' is to set the potential and to read the current response, i.e., the instrument is used as a potentiostat. Selecting 'i' will allow to control the current and to read the potential, i.e. the instrument is set as galvanostat. In short: Potentiostat (E) or Galvanostat (i).

Potential or Current allows to set either one of these depending on the set mode with 'Control E or i'. The scrollbar and textbox are used to specify the potential or the current.

Current Range specifies the sensitivity of the measurement of the current.

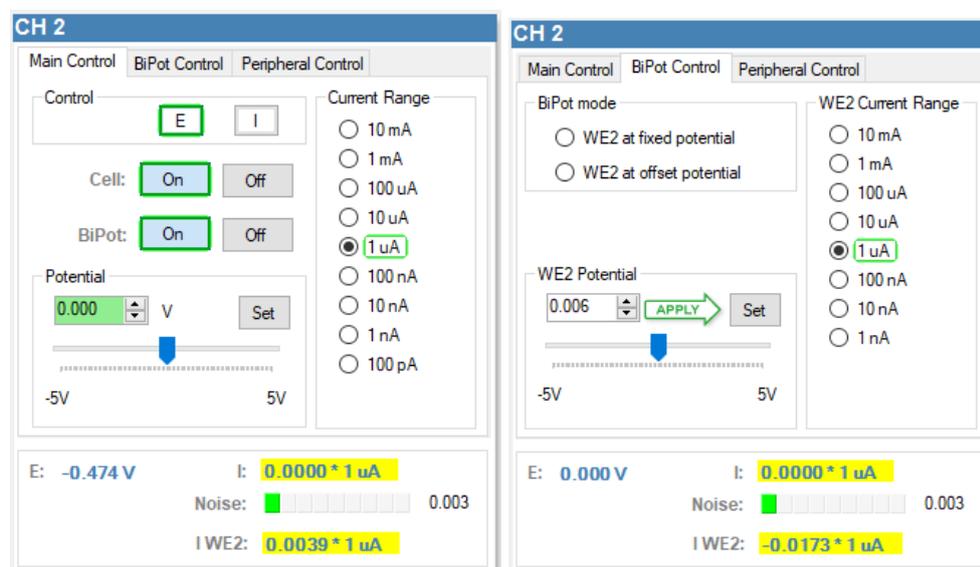
The applicable potential and current ranges can be set before turning the cell on or while the cell is on.

The readings (shown at the bottom of each of the channel's manual control window) are updated every second showing potential (E), current (i) and noise in case the cell is on. The color of the readings indicates if readings are within the current range or in underload (yellow) or overload (red). A tooltip also appears upon hovering over the measured reading indicating if the readings are OK/underload/overload.

See also sections:

- [Resolution and optimal current range selection](#) on page 35.
- [Noise](#) on page 54.

The BiPot controls are visible only on the channels that are enabled with a BiPot. While the BiPot can be turned on/off from the 'Main control' tab, the BiPot mode, the WE2 potential and current range can be set in the 'BiPot Control' tab.

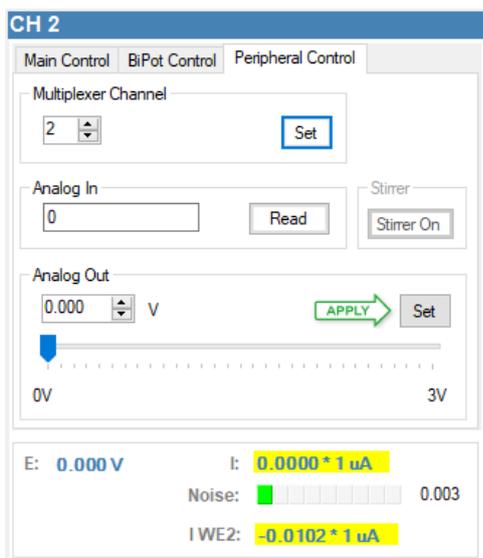


Manual control window: 'Main control' and 'BiPot Control' tabs showing BiPot controls

BiPot On/Off is used to control the on/off of WE2. The BiPot on/off are enabled only if the cell is on.

The **WE2 Potential** and **BiPot mode** frames are visible if BiPot is enabled in the device and the BiPot is turned on in the Channel's manual control – 'Main control' tab.

The manual controls for the Multiplexer, Stirrer and Analog in/out can be found in the 'Peripheral Control' tab. The Multiplexer and Stirrer have to be enabled in the 'Peripheral settings' under the 'Tools' menu in order to be used in manual control.



Manual control window: 'Peripheral control' tab with Multiplexer enabled

Multiplexer Channel is enabled if the use of a multiplexer is enabled in the Settings window. In this frame the multiplexer channel which is used for control and measurement can be selected.

Checking **Stirrer On** sets the digital ports d0 to high and d1 to low (and vice versa) of the digital outputs on the AUX port. See also section: [Auxiliary port pin-outs](#) on page 269.

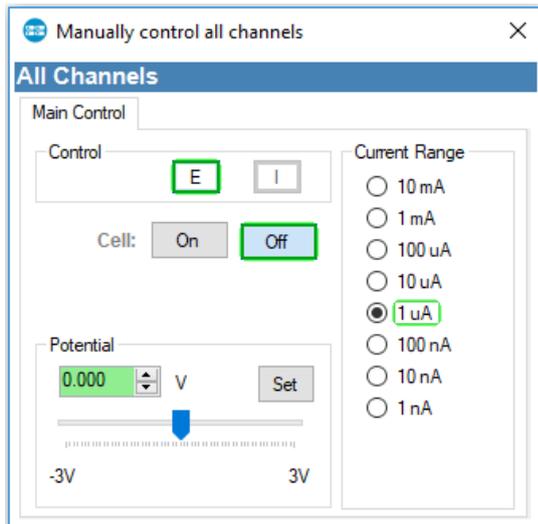
Analog In reads the voltage applied on the analog input pin of the AUX port. See also section: [Auxiliary port pin-outs](#) on page 269.

Analog Out set a specific potential on the analog output pin of the AUX port. See also section: [Auxiliary port pin-outs](#) on page 269.

In case the 'Speed control' for the stirrer is enabled, Analog Out controls the stirrer speed.

Control all simultaneously

The button 'Control all simultaneously' at the top toggles a window with controls to set the mode (potentiostatic/galvanostatic), current range or potential and control the cell On/Off of all channels simultaneously.



Manual control window to control all channels simultaneously

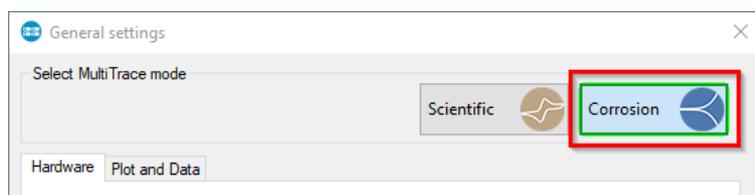
Changing the value for potential, current range or cell On/Off will have immediate effect on all channels. If all the connected devices can be operated in galvanostatic mode, then the galvanostatic mode control button is enabled.

8 Corrosion mode



The Corrosion mode in MultiTrace allows the user to run specific corrosion measurement techniques and use analytical tools for corrosion research on the measurement data.

The Corrosion mode can be enabled in the General Settings window of MultiTrace.

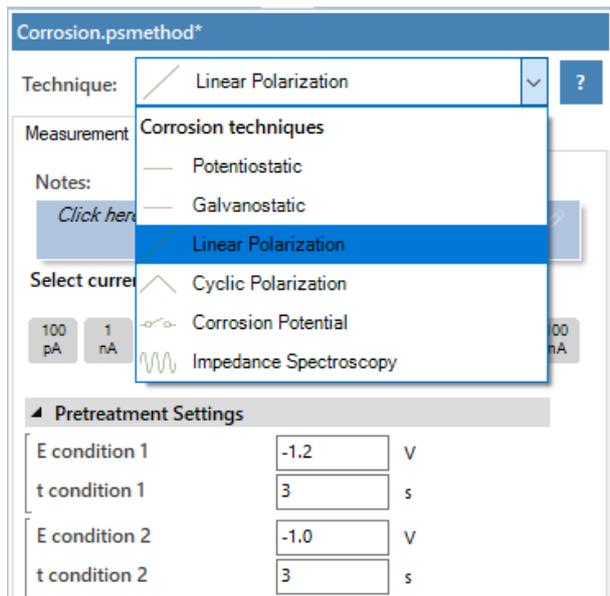


General settings window in MultiTrace

8.1 Supported techniques

The available electrochemical measurement techniques in the Corrosion mode are:

- Potentiostatic (apply constant potential)
- Galvanostatic (apply constant current)
- Linear Polarization (potential sweep)
- Cyclic Polarization (bi-directional potential sweep)
- Corrosion Potential (open circuit potential)
- Impedance Spectroscopy



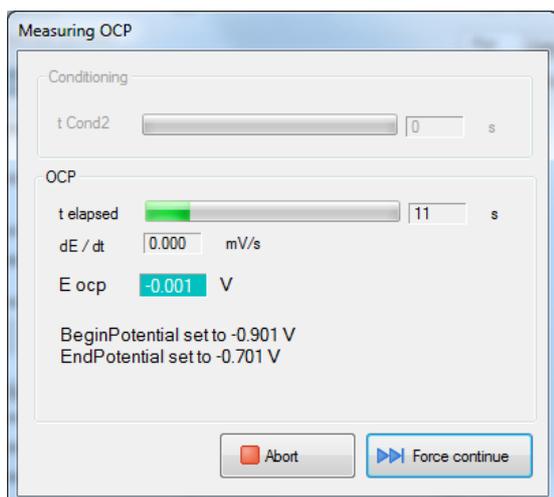
List showing available techniques

The other standard available electrochemical techniques that do not apply to corrosion research are not listed when MultiTrace is set in the Corrosion mode.

8.2 Running a corrosion measurement

The sequence of a corrosion measurement is:

1. If $t_{\text{Cond1}} > 0$ s then E_{cond1} is applied for t_{Cond1} s.
2. If $t_{\text{Cond2}} > 0$ s then E_{cond2} is applied for t_{Cond2} s.
3. The cell is switched off if the measurement of E_{oc} or OCP is required.
4. Now the value of E_{oc} is continuously measured until either 'Max. OCP time' is reached OR until the stability criterion is met OR the button 'Force continue' is pressed.
5. Now the cell is switched on at the value of E or E_{begin} for ' t_{eq} ' seconds, after which the actual measurement starts.



Waiting for the OCP to meet the stability criterion.

Measure versus OCP

Corrosion measurements can be done by specifying the potential scan with respect to the Open Circuit Potential OCP or with absolute values versus the reference electrode. In case one or more potentials are specified with respect to the OCP, the open circuit potential must be determined before the actual measurement is done. This OCP measurement requires a variable time, which is determined by the drift of the open circuit potential and the maximum time to measure the OCP value. The OCP value is set as soon as the drift is lower than the specified value for the 'Stability criterion' or when the 't Max. OCP' has elapsed.

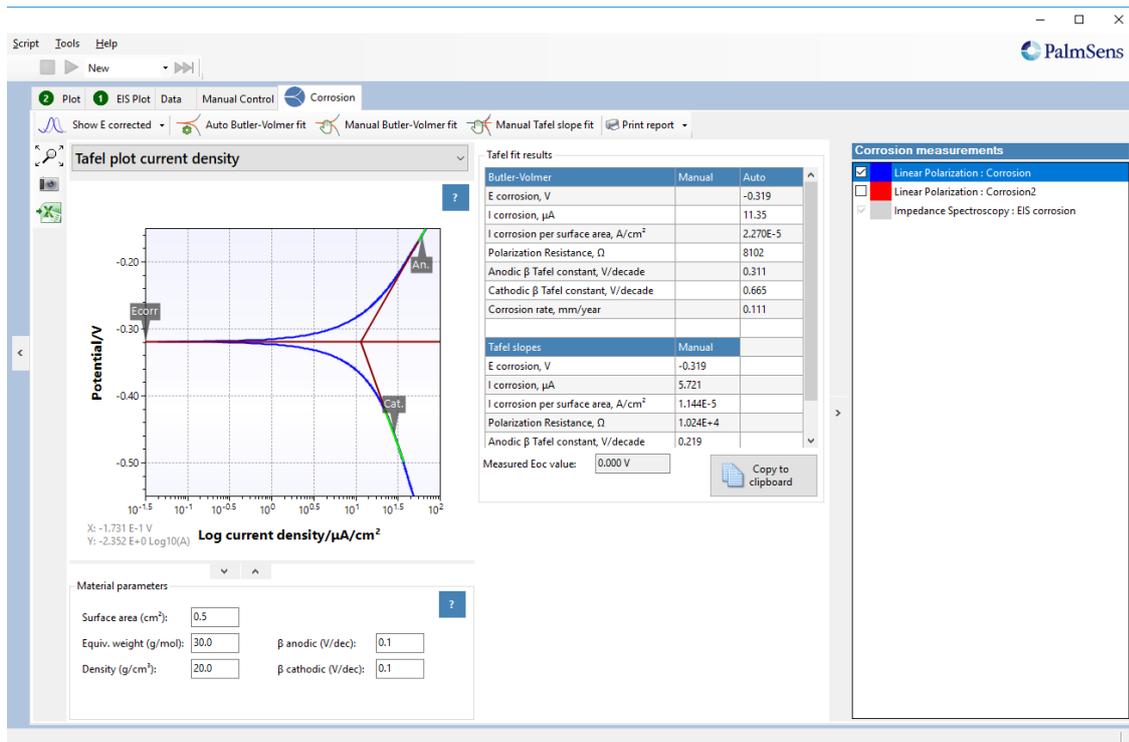


OCP parameters

It is possible to condition the electrode or the corrosion sample before this OCP is obtained. For this purpose, two potentials can be applied: 'E cond1', during a period of 't cond1' and 'E cond2' during a period of 't cond2'. In case the value of 't cond' is set to 0 s, the corresponding conditioning potential is not applied. So, if both values for 't cond' are 0, the electrode is not conditioned at all.

8.3 Result analysis

The 'Corrosion' tab in the plot window is used for analysis of linear polarization and electrochemical impedance spectroscopy measurements. The supported measurements are shown in the legend on the right and the material settings of the selected measurement are shown on the left.



The Corrosion analysis tab

8.3.1 Setting up material parameters

The material parameters required for analysis can be entered before the measurement in the Method Editor or after the measurement in the 'Corrosion' tab.

Measurement **Material**

Surface area (cm^2): 0.001

Equiv. Weight (g/mol): 0.0

Density (g/cm^3): 0.1

β anodic (V/dec): 0.1

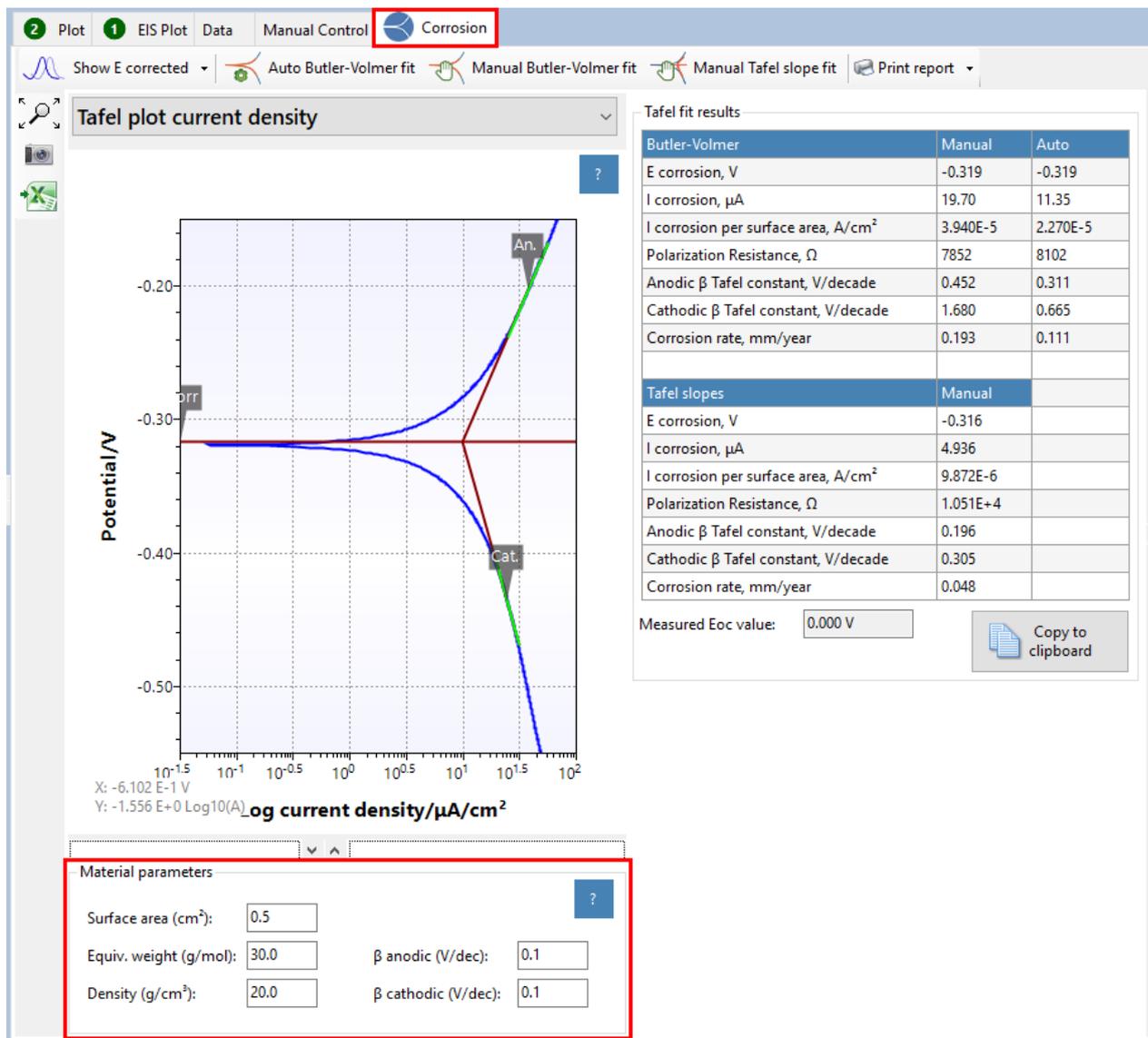
β cathodic (V/dec): 0.0

Data smoothing (Savitzky-Golay): 0: spike rejection

Tab with Material properties in the Method Editor

The values set in the 'Material' tab of the Method Editor are copied to the tab for Corrosion analysis when a measurement is started.

In the 'Corrosion' tab, the material parameter input fields are found beneath the plot.



Material parameters used for calculations in the Corrosion tab

The material parameters are required to determine the corrosion rate. Linear polarization measurements require surface area, equivalent weight and density and impedance measurements also require the anodic and cathodic Tafel slopes, β_{anodic} and $\beta_{cathodic}$.

- Surface area is the area of the sample in cm^2 .
- Equivalent weight is the equivalent mass of one mole of the sample material in g/mol.
- Density is the density of the sample material in g/cm^3 .
- β_{anodic} and $\beta_{cathodic}$ are the Tafel slope parameters for the sample material, these can be determined from a linear polarization measurement or from literature.

8.3.2 Linear polarization

Linear polarization is typically used to study the corrosion response of metallic coatings. The following analysis techniques are supported for the estimation of the corrosion rate based on linear polarization measurements:

- Auto Butler-Volmer fit: Fitting the Butler-Volmer model over an automatically detected range.
- Manual Butler-Volmer fit: Fitting the Butler-Volmer model over a manually selected range.
- Manual Tafel slope fit: Fitting Tafel slopes in the linear regions of the anodic and cathodic slopes.

Note: To achieve an accurate estimation of the corrosion rate it is recommended to use a measurement with at least one linear Tafel slope that ranges over one decade in current density. Additionally, the distance between the Tafel slope and the corrosion potential should at least be 50 mV.

The results of these analysis techniques are presented in the Tafel fit results table.

Tafel fit results		
Butler-Volmer	Manual	Auto
E corrosion, V	-0.319	-0.319
I corrosion, μA	13.17	13.99
I corrosion per surface area, A/cm^2	2.635E-5	2.797E-5
Polarization Resistance, Ω	7926	7891
Anodic β Tafel constant, V/decade	0.347	0.358
Cathodic β Tafel constant, V/decade	0.784	0.879
Corrosion rate, mm/year	0.129	0.137
Tafel slopes	Manual	
E corrosion, V	-0.312	
I corrosion, μA	5.874	
I corrosion per surface area, A/cm^2	1.175E-5	
Polarization Resistance, Ω	1.006E+4	
Anodic β Tafel constant, V/decade	0.212	
Cathodic β Tafel constant, V/decade	0.380	
Corrosion rate, mm/year	0.058	

Measured Eoc value:

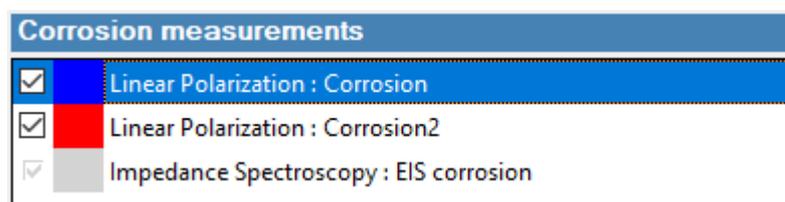
 Copy to clipboard

- The corrosion potential (E corrosion) is the potential at which the anodic and cathodic reaction rates are equal. The measured current approaches zero at the corrosion potential, because all the electrons released by the dissolving of the metal are consumed by reduction reactions. For the Butler-Volmer techniques the corrosion potential is determined as the potential where the log the measured current is the smallest. In the Tafel slope method the corrosion potential is the potential where the anodic and cathodic Tafel slopes intersect.
- The corrosion current (I corrosion) is a measure of the rate of corrosion, measuring it directly is not possible. The corrosion current can be estimated the current at which the Tafel slopes intersect or by fitting the Butler-Volmer equation on a linear polarization measurement.

- $$I = I_{corrosion} \left(e^{\frac{2.303(E-E_{corrosion})}{\beta_{anodic}}} - e^{\frac{-2.303(E-E_{corrosion})}{\beta_{cathodic}}} \right)$$
- β_{anodic} and $\beta_{cathodic}$ are the Tafel slopes, these represent the change in Volts per decade of current in the Tafel plot.
- When plotting current over potential a linear slope is equals resistance (i.e. $R=U/I$). The slope close to the corrosion potential is approximately linear, this is referred to as the polarization resistance. The polarization resistance is inversely proportional to the corrosion current, assuming that the Tafel slopes are constants (Stern-Geary equation).
- $$I_{corrosion} = \frac{\beta_{anodic} \cdot \beta_{cathodic}}{R_{polarization}(\beta_{anodic} + \beta_{cathodic})}$$
- The corrosion rate in mm/year can be calculated according to the standard practice described in the ASTM Standard G 102. To calculate this an estimation of corrosion current is needed as well as the following [material parameters](#) on page 214: equivalent weight (EW) in g/mol, the density (d) in grams/cm³, and the sample area (A) in cm² of the study sample. Combined with a constant (K) defined by the ASTM (3272 mm/(amp*cm*year)) this information is used to determine the corrosion rate in mm/year.
- $$Corrosion\ Rate = \frac{I_{corrosion} \cdot K \cdot EW}{d \cdot A}$$

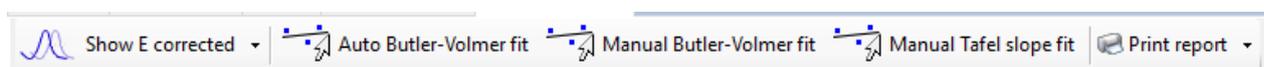
Selecting a curve for corrosion analysis

On the right-hand side of the screen is a legend which contains all compatible corrosion measurements. To perform a Butler-Volmer or Tafel slope fit select a Linear Polarization measurement from the legend. The checkbox in front of the measurements indicate whether they are also visible in the plot window.



Performing an automatic Butler-Volmer fit

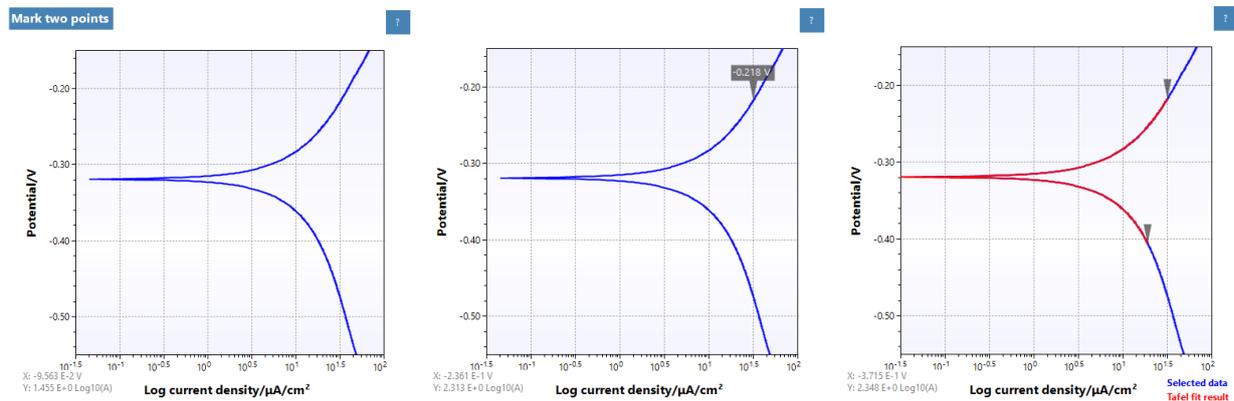
The auto Butler-Volmer fit is automatically applied after selecting a Linear Polarization curve from the legend and after changing the value of one of the material parameters. Alternatively, clicking on the Auto Butler-Volmer fit button in the toolbar above the plot also applies the fit.



Performing a manual Butler-Volmer fit

By selecting the Manual Butler-Volmer fit from the toolbar above the plot the range for the Butler-Volmer can be set manually.

Usage: click two points on the curve to mark start and end point

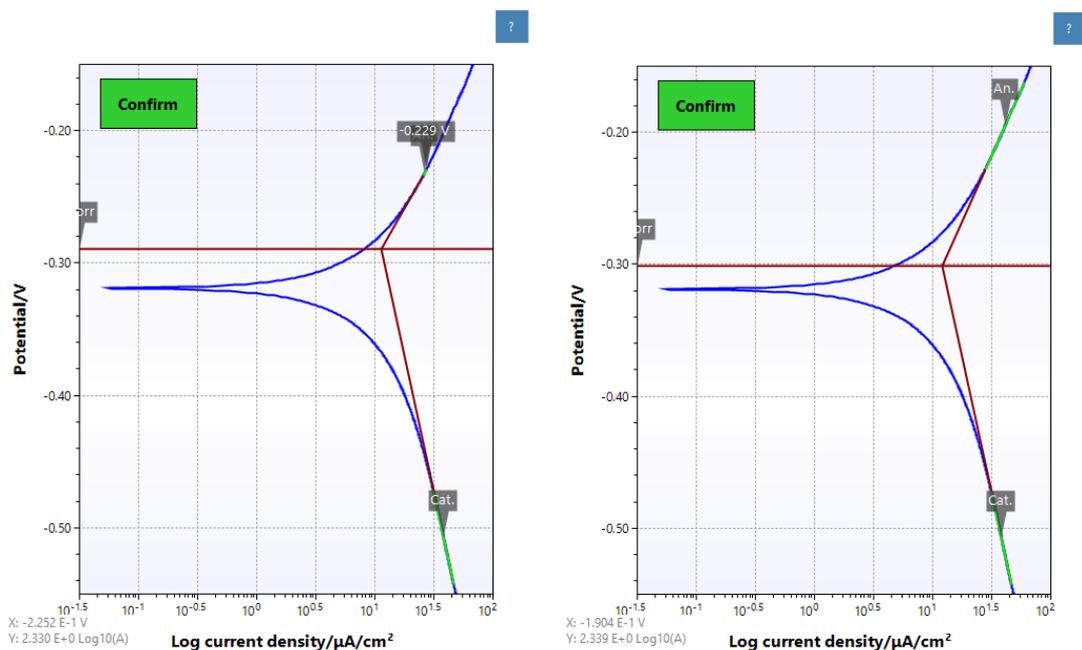


Marking two points for a logarithmic fit

Performing a Tafel slope fit

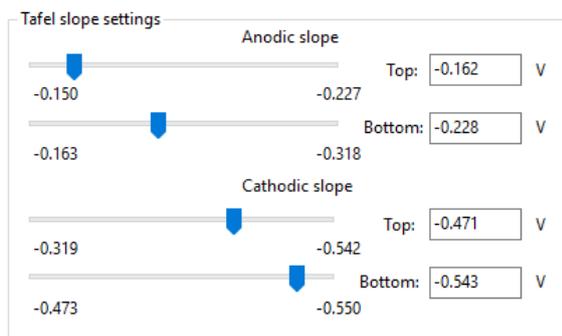
To perform a Tafel slope fit click on the Manual Tafel slope fit button in the toolbar above the plot. The Tafel slopes (Evan's diagram) are drawn in the plot, they are either fit automatically or loaded from the previous fit. The ranges of the slopes can be adjusted in two ways. The range can be specified by clicking twice on a linear section of either the anodic or cathodic part of the corrosion measurement.

Usage: mark two points for the anodic slope line and/or two points for the cathodic slope line. After selecting two points a green line is drawn representing the Tafel slope.



Setting the anodic and cathodic slope lines for Tafel plot analysis.

Alternatively, the ranges of the slopes can be adjusted using the Tafel slope settings. Either by adjusting the ranges of the slopes using sliders or by entering the potential ranges in the text boxes.

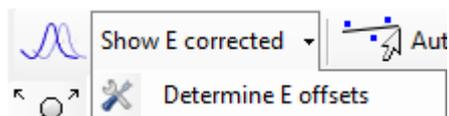


Adjustments of the Tafel slope settings

To confirm the fit of the Tafel slopes click on Confirm in the top left corner of the plot.

Correcting for the potential of the reference electrode

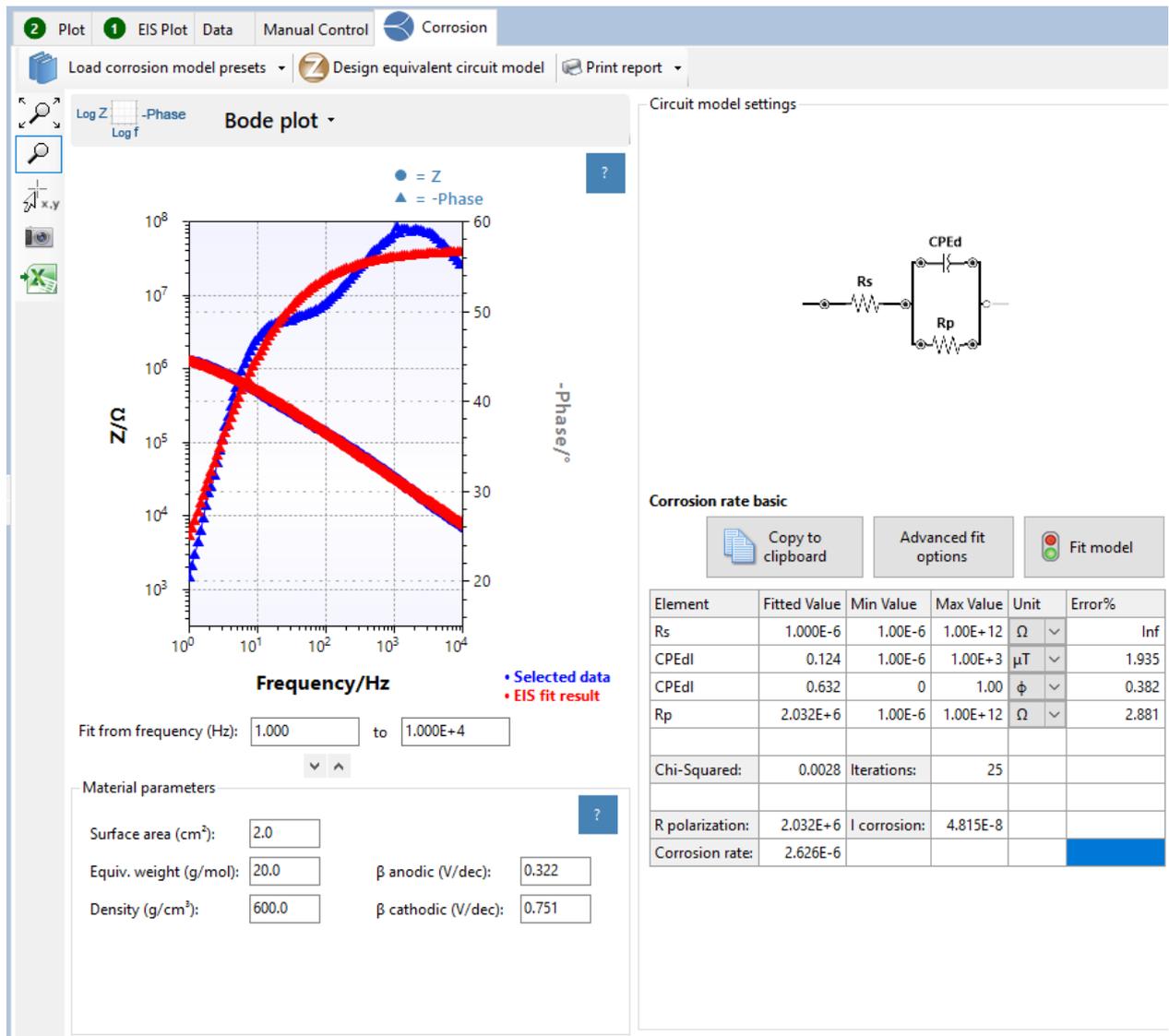
In the corrosion mode it is possible to apply a reference electrode correction to the measured potential. Click on the downward arrow of the Show E corrected button in the toolbar above the plot and select Determine E offsets.



From this menu you can select a correction for the potential of the reference electrode.

8.3.3 Impedance Spectroscopy

Electrochemical Impedance Spectroscopy (EIS) can be used to study corrosion and the effects of a wide range of coatings. For example, anodized coatings (anodized aluminium), conversion coatings (Chromate conversion coating), or organic coatings (paint). The corrosion rate and the pitting/disbanding of coatings are studied by fitting equivalent circuit models on the EIS measurement.



Fitting an equivalent circuit on measured corrosion data

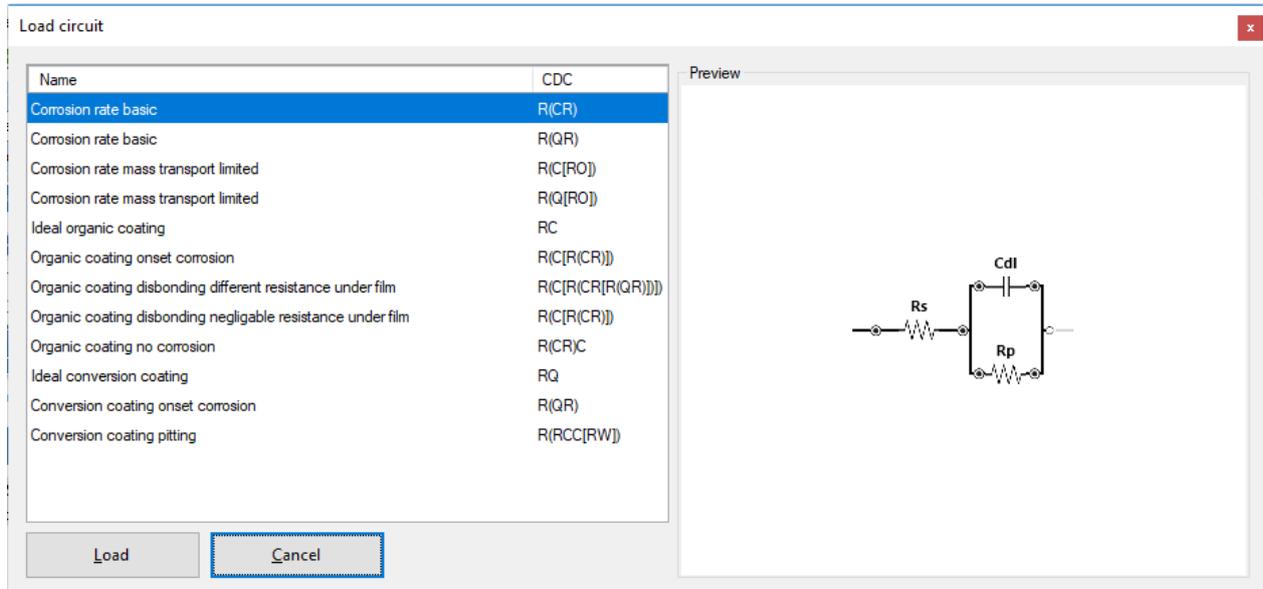
Selecting a curve for corrosion analysis

On the right-hand side of the screen is a legend which contains all compatible corrosion measurements. To perform an equivalent circuit fit select a EIS measurement from the legend. The checkbox in front of the other EIS measurements indicate whether they are also visible in the plot window.

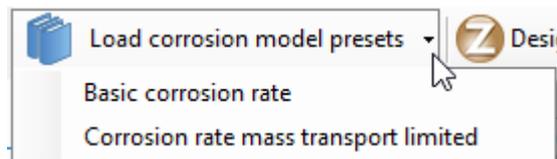
Corrosion measurements	
<input checked="" type="checkbox"/>	Linear Polarization : Corrosion
<input checked="" type="checkbox"/>	Linear Polarization : Corrosion2
<input checked="" type="checkbox"/>	Impedance Spectroscopy : EIS corrosion
<input checked="" type="checkbox"/>	Impedance Spectroscopy [1] : FixedPotential at 100 fr...

Selecting an equivalent circuit

To change the selected equivalent circuit either click on the 'Load corrosion model presets' button above the plot window to open the circuit library or click on the downward arrow of the button to quickly select a circuit.



Corrosion circuit library



Corrosion circuits quick access

Loading a circuit from the circuit library or the quick select menu will update the circuit model settings. A graphical representation of the selected equivalent circuit is displayed, below the image is a table with circuits corresponding parameters. When selecting one of the four corrosion rate circuits the corrosion parameters are added to the table: polarization resistance (R polarization in Ohm (Ω)), corrosion current (I corrosion in Ampere (A)) and corrosion rate in mm/year.

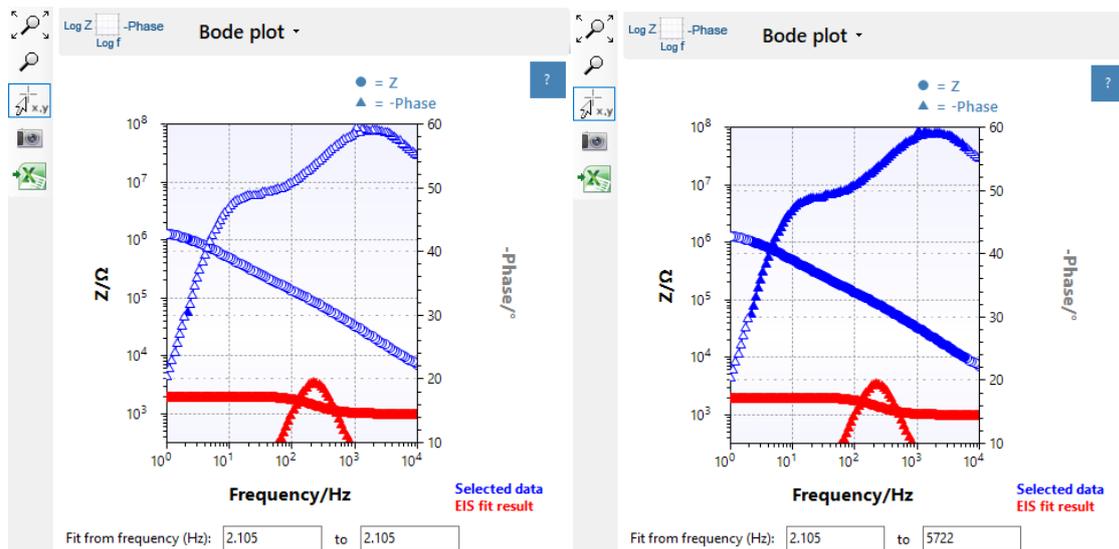
Note: for the corrosion parameters to be calculated all material parameter values must be greater than 0. See also section [Setting up material parameters](#) on page 214.

Fitting the equivalent circuit

Before fitting a circuit, the frequency range on which to perform the fit can be selected. By default, a fit is performed over the entire measurement. To select a frequency enter the desired range in frequency range text boxes below the plot.

Fit from frequency (Hz): to

Alternatively, it is possible to specify the frequency range in the plot by selecting the 'Select fit range' mouse pointer button from the toolbar left to the plot and clicking in the plot.



Selecting the fit frequency range. Double-click on a point in the plot. Then select the point to where the fit should be performed.

To fit the model on the measurement, click on the 'Fit model' button. The result of the fit is stored in your measurement, but to store the fit result it is necessary to save your measurement. Simple circuits with few components will often fit directly, but more complex circuits will require fine tuning of the circuit parameters before a good fit is obtained. To fine tune the model, you can either use your prior knowledge of the cell or you can estimate certain parameter values from the Bode and Nyquist plots. For more information on circuit fitting please refer to the help section on [circuit fitting](#) on page 165.

8.4 Exporting results

There are three ways to export the results from your Tafel or circuit fit:

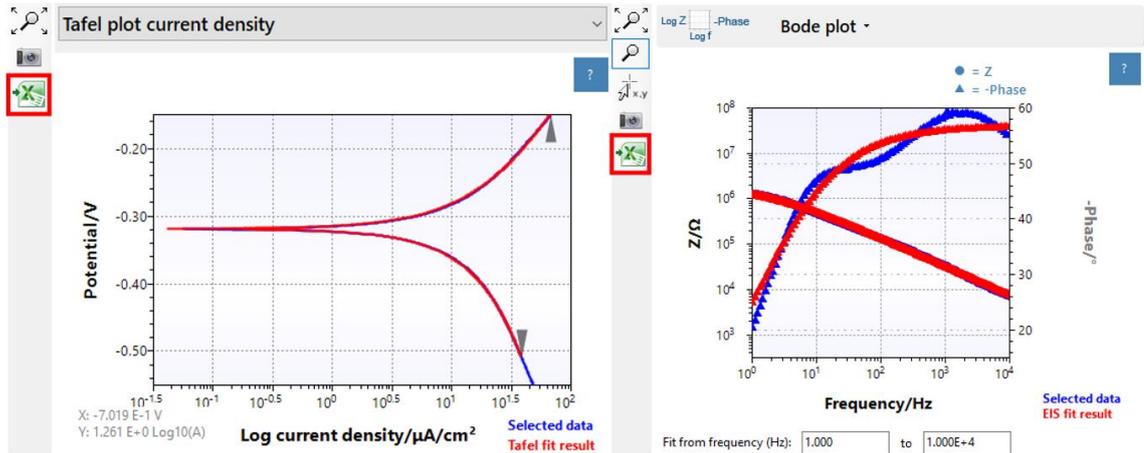
Butler-Volmer	Manual	Auto
E corrosion, V	-0.319	-0.319
I corrosion, μA	16.23	11.35
I corrosion per surface area, A/cm^2	3.246E-5	2.270E-5
Polarization Resistance, Ω	7902	8102
Anodic β Tafel constant, V/decade	0.403	0.311
Cathodic β Tafel constant, V/decade	1.103	0.665
Corrosion rate, mm/year	0.159	0.111
Tafel slopes		
E corrosion, V	-0.317	
I corrosion, μA	6.627	
I corrosion per surface area, A/cm^2	1.325E-5	
Polarization Resistance, Ω	9854	
Anodic β Tafel constant, V/decade	0.236	
Cathodic β Tafel constant, V/decade	0.416	
Corrosion rate, mm/year	0.065	

Measured Eoc value:

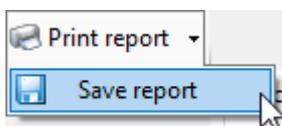
Element	Fitted Value	Min Value	Max Value	Unit	Error%
R_s	965.9	1.00E-6	1.00E+12	Ω	7.645
CPEd1	0.060	1.00E-6	1.00E+3	μT	4.940
CPEd1	0.708	0	1.00	ϕ	0.696
Rct	0.304	1.00E-12	1.00E+6	$\text{M}\Omega$	13.13
WD	4.983	1.00E-12	1.00E+6	$\text{M}\sigma$	1.893
WD	0.254	1.00E-12	1.00E+6	\sqrt{s}	3.751
WD	0.992	0	1.00	ϕ	4.573
Chi-Squared:	0.0002	Iterations:	27		
R polarization:	5.287E+6	I corrosion:	1.709E-8		
Corrosion rate:	4.149E-8				

Left: Copying Tafel fit results to clipboard. Right: Copying circuit fit results to clipboard.

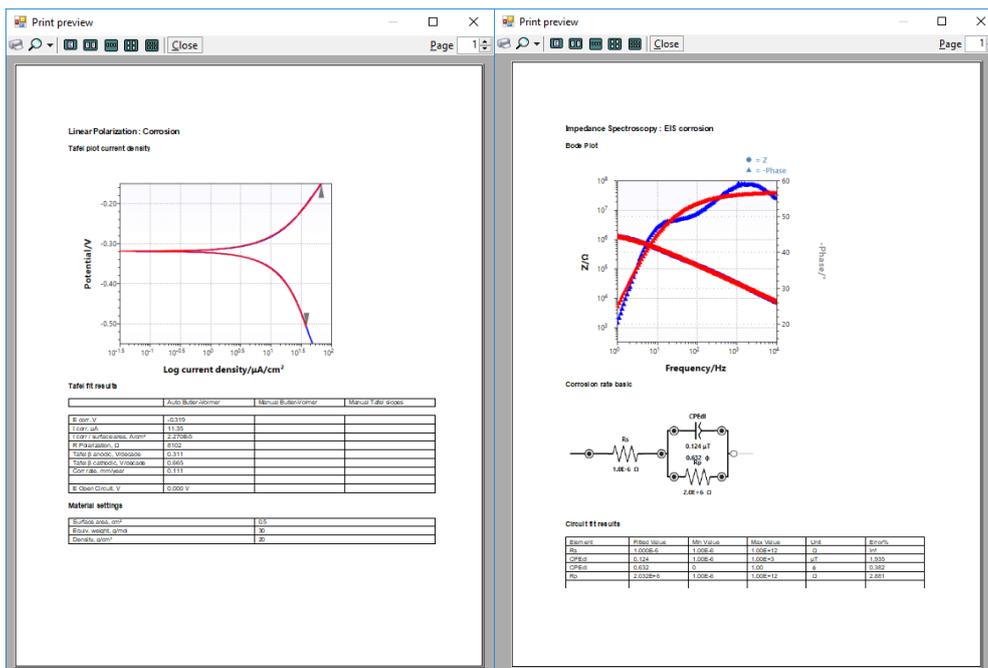
1. Exporting a Tafel plot or a circuit fit curve to Excel (Bode or Nyquist) by pressing the export to Excel button on the left-hand side of the plot.



Printing/saving a report as a .rtf file by clicking on the print report button or selecting the save report button in the toolbar above the plot.



Print and save report buttons.



Left: Tafel fit report. Right: Circuit fit report.

8.5 Example data files

The program comes with an example file stored in the default PS Data folder:
“My Documents\PSData\Corrosion mode examples\Corrosion.psession”.
You can load this file in MultiTrace using the menu ‘Data → ‘Load data file...’

9 Files

MultiTrace uses several different file formats. This section describes which file types are used.

9.1 File types

MultiTrace creates several different files in ASCII format.

The files are by default stored in the folder:
“[USER]\Documents\PSData”

The following files are currently supported by both PStTrace and MultiTrace:

Method	.psmethod
Raw measurement data, curves and methods	.psession
Script	.psscript
MultiTrace project file	.psproject

Obsolete file formats

The following list of file formats has become obsolete. They can still be loaded in latest versions of PStTrace and MultiTrace, but they can no longer be saved in this particular format.

Method	.pms (scans) or pmt (vs time)
Curve	.pss (scans) or .pst (vs time)
EIS data	.pseisdata
Multiple curves	.mux
Analysis curves	.pds

Method files

The method parameters (as shown in the Method Editor) can be saved separately to a .psmethod file or are automatically saved with (a) curve(s) when saved to a .psession file.

Saving and loading method files (.psmethod) can be done using the Method menu found in both the Individual and Simultaneous modes.

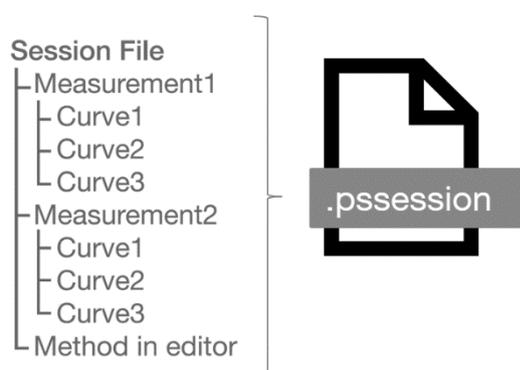
Data files (obsolete)

The old single data files (.pss, .pst and .pseisdata) as well the old multiple curves files (.mux, .pds) were always saved together with a method file (.pmt or .pms) with the same name.

The data file contains measured data of potential and current or time and current.

Session files

Session files can contain all the data available at any time in a MultiTrace session. All available measurements, corresponding curves and method, including the active method in the method editor can be stored to a single .psession file format. Session files are stored in a format that has not been designed for importing in third-party programs. For exporting data to other programs like Excel or Origin, it is advised to export to a CSV file or use the one-click export buttons in MultiTrace.



Contents of a .psession file

PSScript files

The .PSScript files are plain ASCII files containing a script that can be loaded and run in the Script window of MultiTrace. (See section [Scripting](#) on page 236)

MultiTrace project file

A .psproject file contains a references to a method file for all channels.

All corresponding method files have the same prefix in the filename as the .psproject file. For example the file 'project4channel.psproject' refers to method files in the same location with the names

- 'project4channel_1.psmethod'
- 'project4channel_2.psmethod'
- 'project4channel_3.psmethod'
- 'project4channel_4.psmethod'

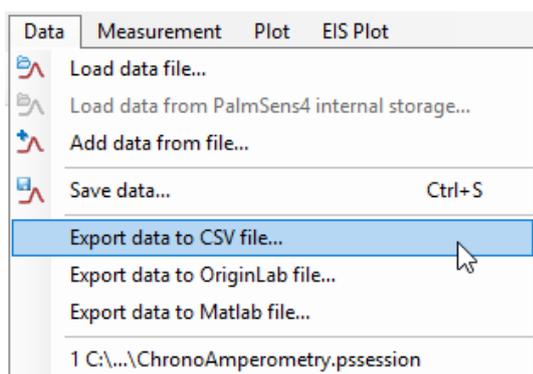
9.2 Exporting data to other file formats

Measured data can be exported to different file formats. The export options are available in the 'Data menu'.

CSV

The CSV (Comma Separated Values) is a popular format in plain ASCII, supported by many applications like Excel, OpenOffice Calc and Origin. To change the values exported for EIS data, open the 'Settings' window (menu: 'Tools' → 'General settings...') and click the 'Plot and data' tab. Then click the button:

Set columns for exporting EIS data



Data menu showing "Export data to CSV file" option

Origin

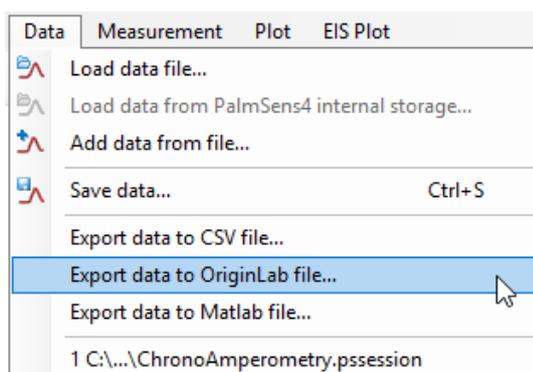
Data can be exported to a native Origin data file (.opj).

Origin from OriginLab is scientific graphing and data analysis software widely used at universities.

See for more information: <http://www.originlab.com/>

To change the values exported for EIS data, open the 'Settings' window (menu: 'Tools' → 'General settings...') and click the 'Plot and data' tab. Then click the button:

Set columns for exporting EIS data

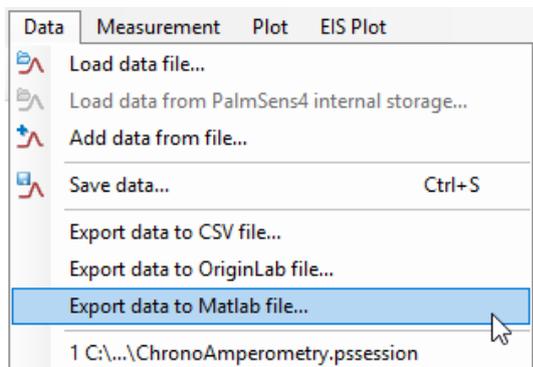


Data menu showing "Export data to OriginLab file" option

Origin does not need to be installed on the PC to export data to the Origin format.

Matlab

Matlab (Matrix laboratory) is a numerical computing environment that allows interfacing with programs written in other languages. A Mat-file stores data in binary form.



Data menu showing “Export data to Matlab file” option

10 Using the auxiliary ports

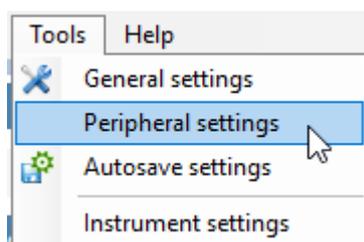
This section describes how the auxiliary ports of multi-channel instruments can be configured and used. Note that not all multi-channel instruments are equipped with an auxiliary port.

The auxiliary input can be used with the following methods:

- Linear Sweep Voltammetry
- Cyclic Voltammetry
- Chronoamperometry / Amperometric Detection
- Multistep Amperometry
- Open Circuit Potentiometry
- Chronopotentiometry
- Multistep Potentiometry

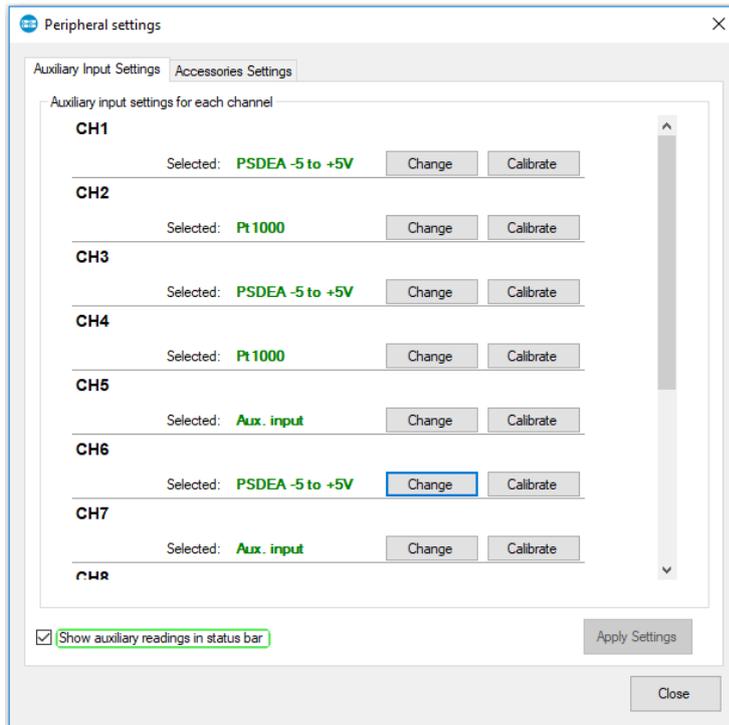
10.1 Configuring the auxiliary input ports

The window to configure the auxiliary port for each individual channel can be found in the menu: 'Tools' → 'Peripheral settings' in both the Individual and Simultaneous modes:



The 'Peripheral settings' window can be opened from the Tools menu

The 'Peripheral settings' window shows a list of the selected input for each channel.



Auxiliary input settings

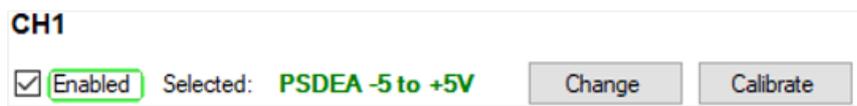
For each channel the following is shown

In Individual mode:



Channel auxiliary settings – Individual mode

In Simultaneous mode:



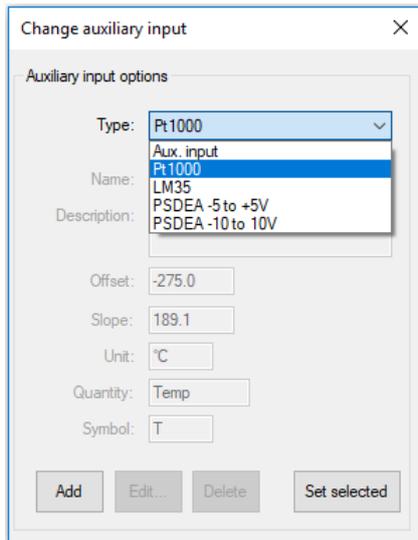
Channel auxiliary settings – Simultaneous mode

Selected input source

The selected input type can be any supported auxiliary input like Pt1000 or LM35 temperature sensor, or the Differential Electrometer Amplifier. But it can also be another external source which gives a signal between 0-3V for PalmSens3, 0-10V for PalmSens4 or between 0-4V for EmStat or PalmSens1 and 2.

Change input source

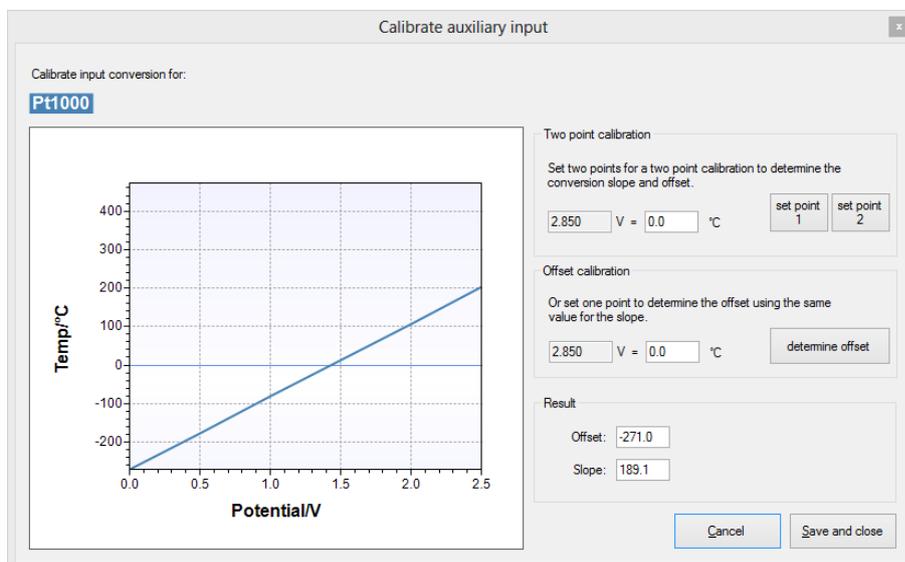
The selected input source can be changed using the 'Change' button. The following window is shown:



Auxiliary input selection window for each channel

Calibrating the input source

A custom auxiliary input can also be added. If the analog output of any external device is linear, it can be translated to any given unit. Use the 'Calibrate' button for calibration.



Auxiliary input calibration window

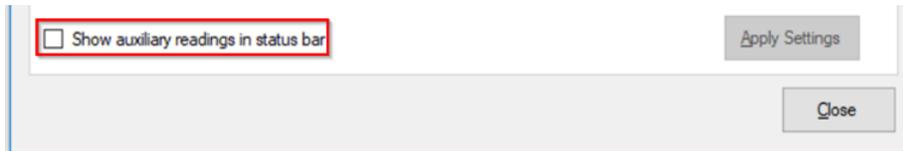
Calibration can be done by setting two points to determine both offset and slope of the linear relation, or by just adjusting the offset.

The LM35 temperature sensor for example can be put in water with a reference thermometer. Then the correct temperature can be entered in the field for Offset calibration to determine the offset.

A more precise two-point calibration can also be used. In this case a high precision thermometer can be used in a low temperature and high temperature medium to enter two different values, e.g., room temperature and 100 degrees Celsius by using the 'set point 1' and 'set point 2' buttons. This will determine both the offset and slope for the linear relation.

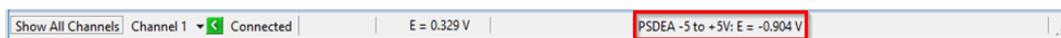
Show auxiliary readings in status bar

Make sure to enable the checkbox in the 'Auxiliary input settings' window to show auxiliary readings in the status bar on the bottom of the screen during the time channels are idle (no measurement is running).



Checkbox at the bottom of the Auxiliary input settings window.

Any selected input source can be added. The linear correlation between the source and the output signal can be manually changed for custom added sources. This linear correlation can also be changed by means of calibration.



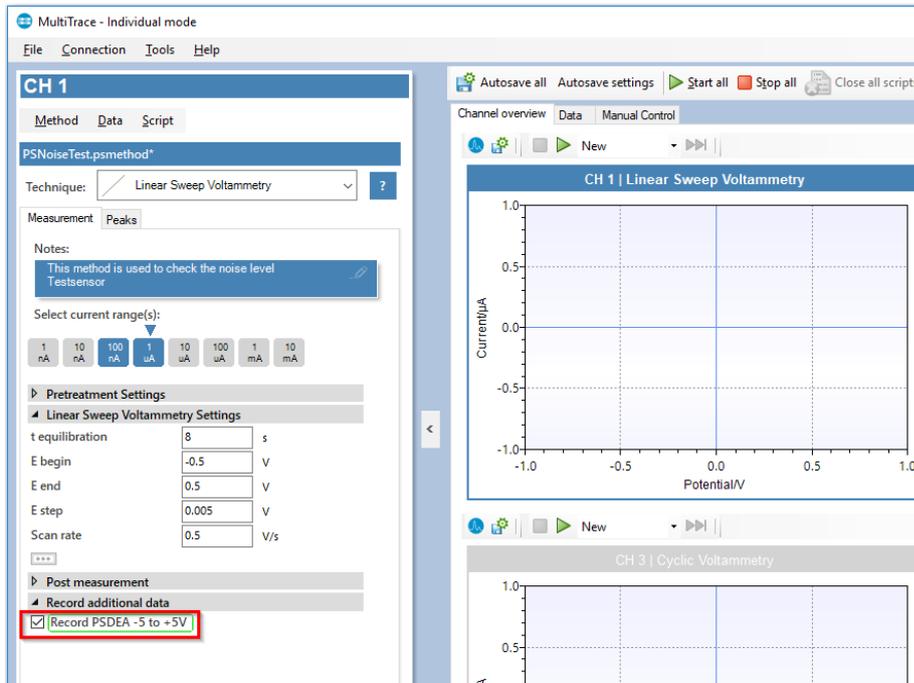
Auxiliary readings shown in the status bar in both the Individual and Simultaneous mode

10.2 Measuring auxiliary input

The auxiliary inputs can be measured in both the Individual and Simultaneous modes of MultiTrace.

Measuring the auxiliary input in the Individual mode

In the Individual mode the auxiliary input can be selected for each channel individually. The Method Editor on the left-hand side of the screen shows the active method settings for each channel. At the bottom of the Method Editor the selected auxiliary input is shown with a check box. See next figure. Ticking the check box will enable measuring of the auxiliary input with the measurement.

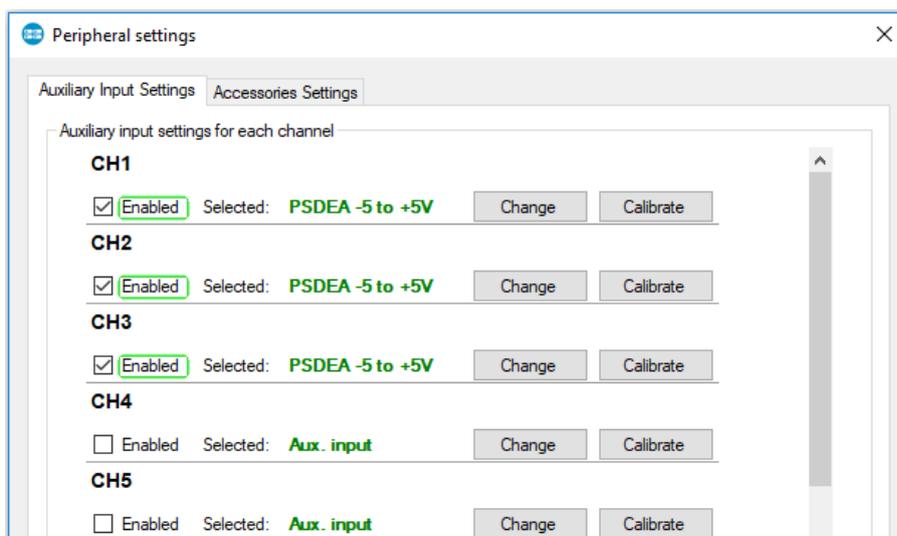


The auxiliary input source can be used with the measurement by ticking the check box

See first section of this chapter for a list of supported techniques.

Measuring the auxiliary input in the Simultaneous mode

In Simultaneous mode there is one method which is used on all channels. The Method editor therefore shows a generic checkbox 'Aux. input'. This enables or disables the use of the auxiliary input on the channels where an auxiliary input port is enabled. Auxiliary input ports can be enabled in the 'Peripheral settings' window, see menu: 'Tools' → 'Peripheral settings'.



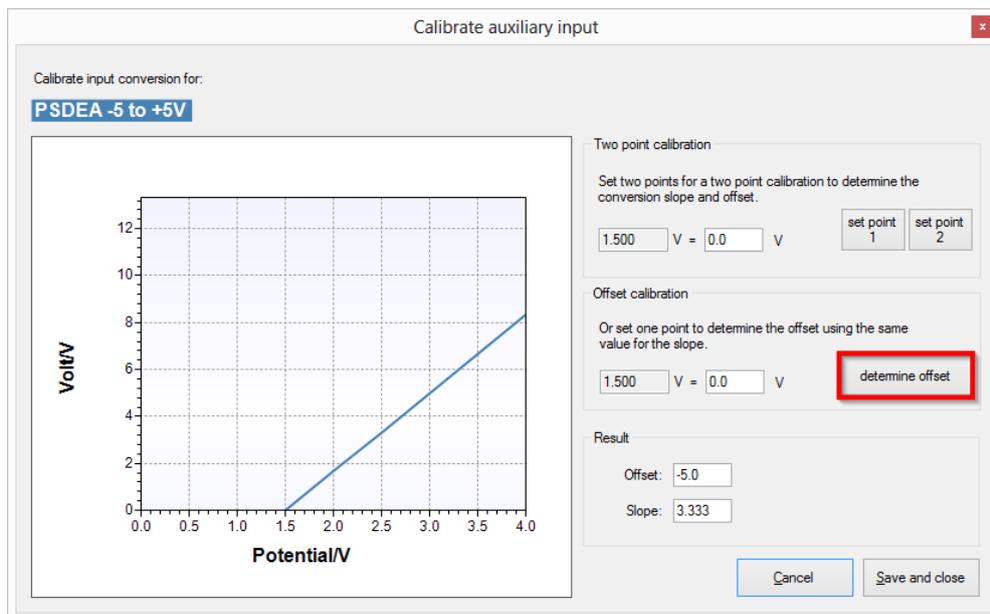
Enabling auxiliary input ports for use in the Simultaneous mode

Only the auxiliary ports on channels that are enabled in the 'Tools' → 'Peripheral Settings' → 'Auxiliary settings', will be used when the 'Aux. input' checkbox is checked in the Method editor.

10.3 Calibration of the Differential Electrometer Amplifier

The Differential Electrometer Amplifier can develop an offset potential over time. This offset can be calibrated using in the 'Calibrate auxiliary input' window. Connect the V+ and V- both to the ground lead of the sensor cable of the instrument. The potential on the DEA should now be 0V.

Click the button 'determine offset' in the Calibration window (see next figure). Then click 'Save and close'. This value will be saved in the local settings on the PC. The correction values will be taken in effect immediately after saving.



Calibrating the DEA in the 'Calibrate auxiliary input' window

11 Scripting

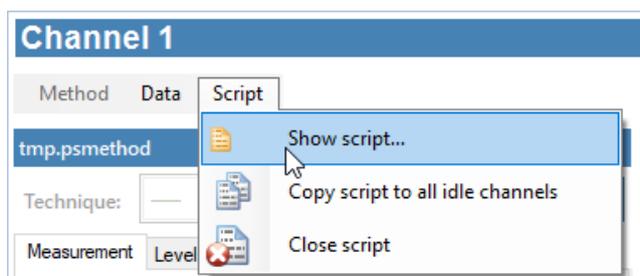
Using the scripting functionality in the Individual Mode of MultiTrace a list of commands can be executed automatically.

In the default data folder (normally 'My Documents\PSData') a script file is available as example.

11.1 Using scripting in MultiTrace

Scripting in MultiTrace is only available in the Individual Mode. Each channel can be loaded with a different script.

The Script window for a channel can be opened using the Script menu found in the menubar on the left side of the screen.

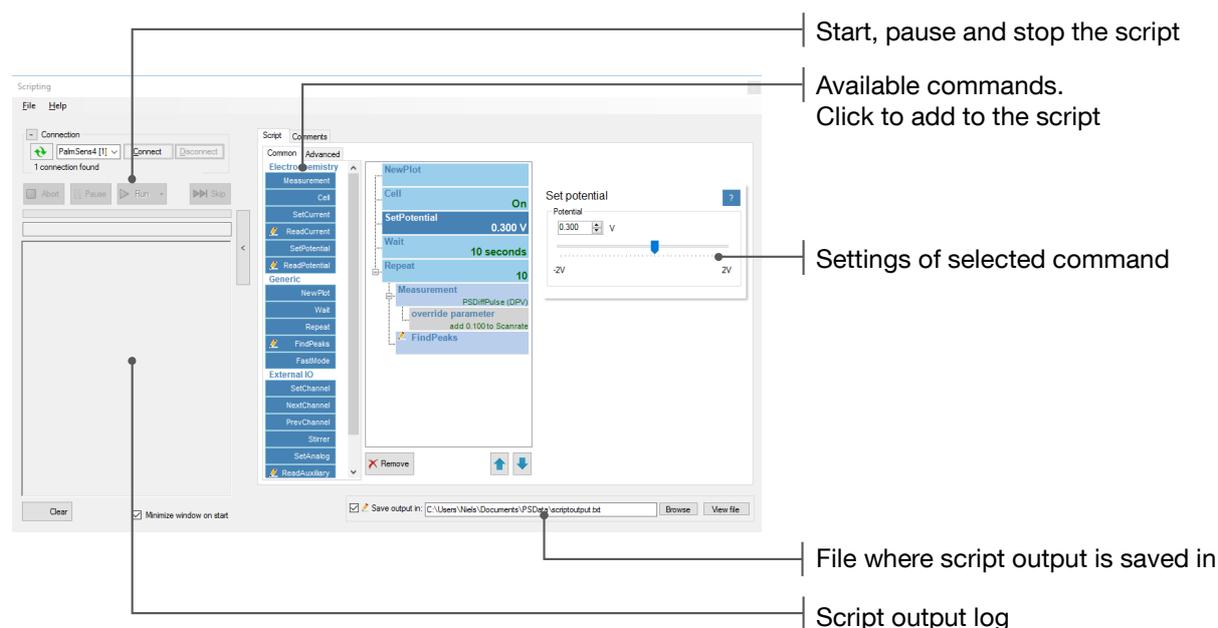


'Show script...' menu item

A script loaded for a specific channel can be copied to all other channels using the menu item 'Copy script to all idle channels' in the same menu. These scripts can then be started all simultaneously using the 'Start All' button on top of the Individual Mode window:

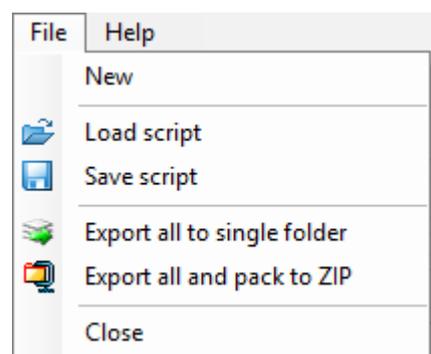


11.2 Features



Scripting main window

11.2.1 File menu



New

Clears the script present in the editor.

Load script

Loads a saved script.

Save script

Saves a script to a specific location. All the file references to method or curve files in the script will be made relative to the location of the script file. For example, if the script file is in location:

C:\directory A\script.psscript

and the script refers to files in location

```
C:\directory A\directory B\
```

the file references in the script file will be relative:

```
directory B\file1.psmethod
```

```
directory B\file2.psmethod
```

and not to the absolute path:

```
C:\directory A\directory B\file1.psmethod
```

```
C:\directory A\directory B\file2.psmethod
```

So, if the directory A including script and sub-directory is copied to another location or PC, the references will still be intact.

Export all to single folder

Copies all files that are referred to and the actual script file to the folder chosen to save the new script file into. So, if a script file is at location:

```
C:\directory A\script.psscript
```

and file references in the script are for example to:

```
C:\directory B\file1.psmethod
```

```
C:\directory C\file2.psmethod
```

All files will be copied to a single folder and all file references will be changed to this folder. This allows you to save all relevant files to a single location for back-up purposes.

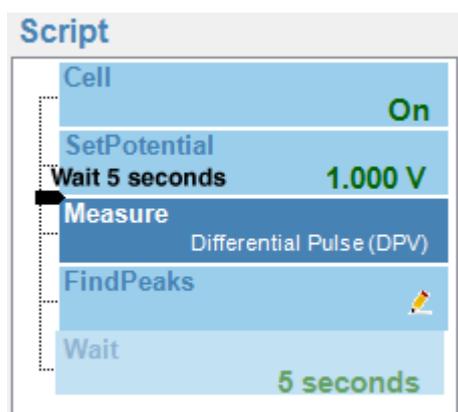
Export all and pack to ZIP

This function does the same as 'Export all to single folder' as described above, but instead of targeting a folder all files are saved to a single ZIP file.

11.2.2 Composing a script

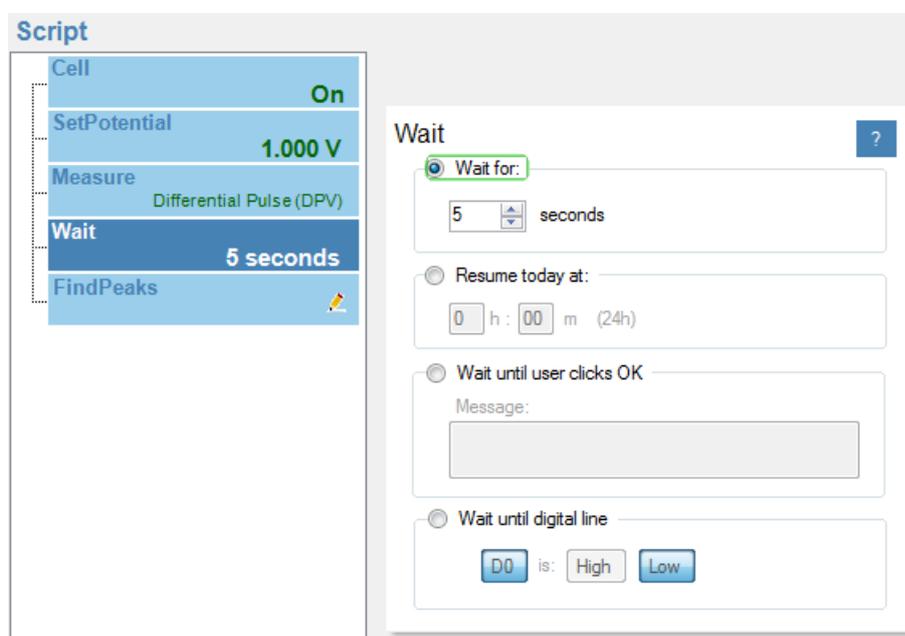
The script contains of a sequence of commands which is run from the top down. Add commands using the list of available commands shown at the left of the script. The order of the commands in the script can easily be changed by dragging and dropping them. Click and hold on the text of a command and drag the command to a location where you want. The black arrow shows where the command will be dropped.

In the picture below the Wait command is dragged above the Measure command:



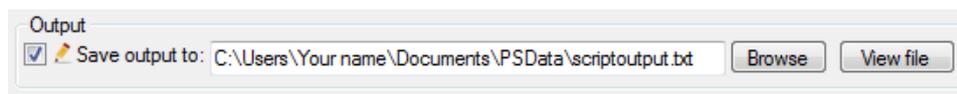
11.2.3 Changing parameters

The parameters for each command can be changed in the panel at the right side of the script. This panel shows the settings for the selected command. Click the '?' button to get help for the selected command.



11.2.4 Using the output file

The output file can be specified by typing in the textbox or using the 'Browse' button.



If one of the following commands is used in the script and the output checkbox is checked, the corresponding results are appended to the text file provided.

- ReadCurrent
- ReadPotential
- FindPeaks
- ReadAnalog
- ReadDigitalIO

The file can be read using any text editor like Notepad, or they can be loaded in Excel. The columns are separated using tabs.

11.3 Measure command

Measurement ?

Clear plot before start measurement

Load method from specified file:

C:\Users\Youname\PSData\PSDiffPulse ...

Create new method... Edit...

Subtract Blank

Load existing Blank curve:

C:\Users\Youname\PSData\PSDiffPulse. ...

Measurement using method:

C:\Users\Niels\Documents ...

Create new method... Edit...

Measurement Blank first

Save result

Prefix: dpvData

Format: PSTrace format

Save to folder: C:\Users\Youname\Documents\PSDa ...

‘Clear plot before start measurement’

If checked; the plot and legend will be cleared before the measurement is started. In case a Blank is measured first or afterwards, both the Blank and the actual measurement curve will be displayed in the plot.

‘Load method from specified file’

The specified method will be loaded for this measurement. A new method can be created and saved instantly using the ‘Create new method...’ button. The ‘Edit...’ button allows to make changes in the method file and save (overwrite) these changes to the specified file.

‘Subtract Blank’

If subtract blank is checked a Blank curve will be subtracted from the measured curve. This curve can be an existing curve (‘Load existing Blank curve’) or can be measured (‘Measure using method’).

If ‘Measure Blank first’ is checked, the method for the Blank will be loaded first and used for measurement, then the actual measurement will be done. As soon as the latter is finished, the Blank will be subtracted from the measured curve.

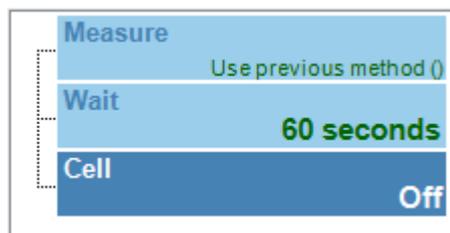
‘Save result’

When checked, the measured curve (or curves in case a Blank was used) will be saved using the prefix, followed by a number. This number automatically increments if multiple curves are saved with the same prefix. If curves are not saved from within the Script, all curves in the PSTrace plot can be saved manually to a single session file (.pssession) using the ‘Data’ menu as well.

‘Cell on after measurement’

In case a method is used with the setting ‘Cell on after measurement’ together with ‘cell off after n seconds’, the latter setting is ignored in the script so the cell can be turned off after a specific period in the script.

To keep the cell on after a measurement for a period, you should use the ‘Wait’ command in combination with the ‘Cell’ command.



11.4 Fast Mode command

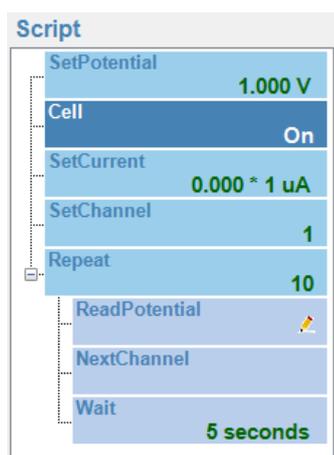
When a PalmSens or EmStat is idle, it normally sends an idle status package with voltage, current and auxiliary readings every second. If an instrument receives a command while measuring the values for the idle status package it will not be able to process the received command immediately. Setting FastMode on disables the idle packages being sent every second. This way the response time of the instrument is always optimal.

11.5 Cell command



Turns the cell on or off.

Example:

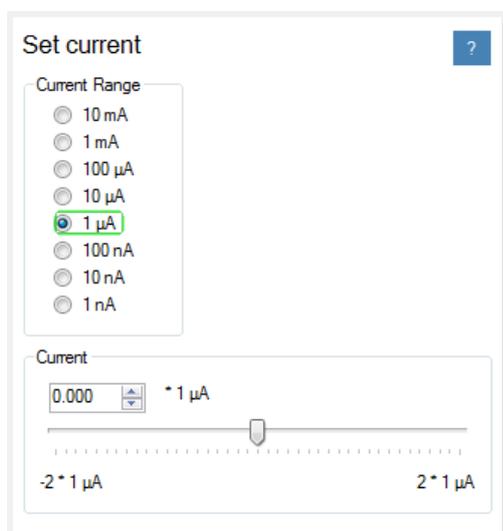


```

Script
SetPotential 1.000 V
Cell On
SetCurrent 0.000 * 1 uA
SetChannel 1
Repeat 10
  ReadPotential
  NextChannel
  Wait 5 seconds

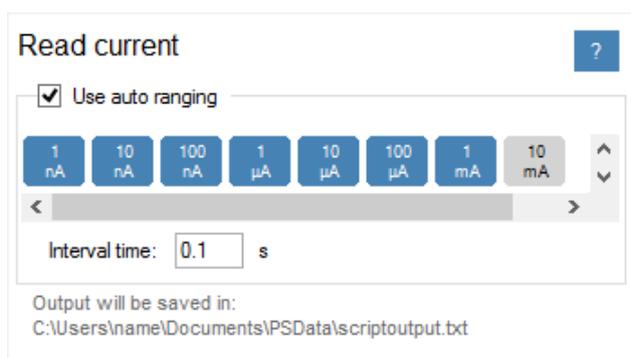
```

11.6 Set current command



Set current sets the connected device in galvanostatic mode and applies a current at the specified current range. This command is not supported by the EmStat series.

11.7 Read current command



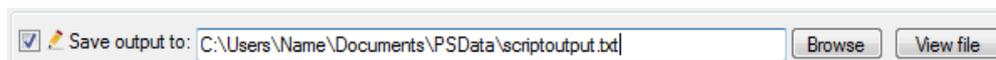
The read current command should be used when the cell is on. It reads the current and stores the value in the text file specified at the bottom of the script window.

Auto ranging

If the 'Use auto ranging' checkbox is used, the current range will be evaluated at each interval time and changed if necessary. If the correct current range has been found or the minimum or maximum range is set, the current will be read.

The first current range to evaluate is the highest current range.

If 'Use auto ranging' is not used the Read current command will leave the current range unchanged. The current range can be changed in the script using the 'Current range' command. See next section.



Output

If there is no column in the text file yet, it will add the line with columns first and then the line with values. The same columns are used for potentials.

The values are all separated by a TAB, and can be imported in Excel.

Example output:

Script output 12/07/2012 - 17:42:43:

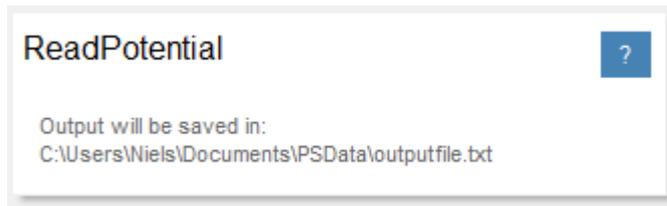
Time	Potential in V	Current in uA
12/07/2012 17:42:45		-3.313E-5
12/07/2012 17:42:46		-7.501E-6
12/07/2012 17:42:47		5.250E-5
12/07/2012 17:42:48		-4.250E-5

11.8 Set potential command



The set potential command sets the connected device in potentiostatic mode and sets the potential to the given value. The cell state (on or off) is not changed.

11.9 Read potential command



The read potential command outputs the Potential to the output file.

Output

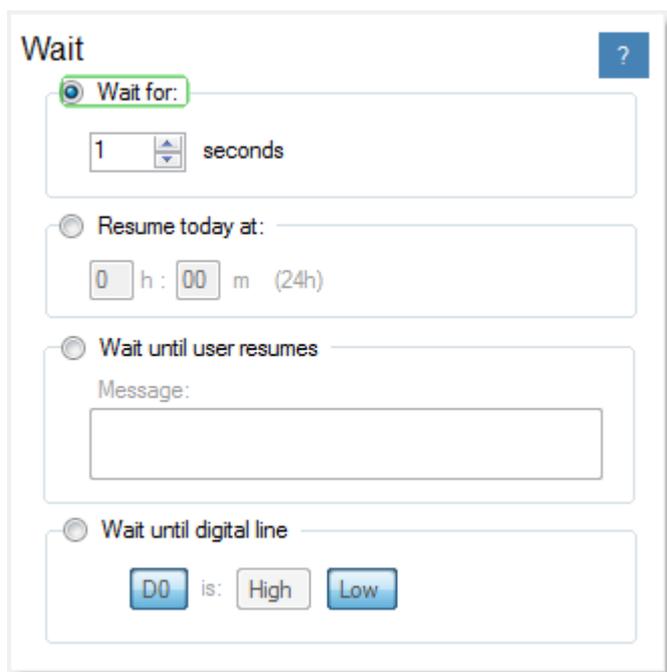
If there is no column in the text file yet, it will add the line with columns first and then the line with values. The same columns are used for currents. The values are all separated by a TAB, and can be imported in Excel.

Example output:

Script output 12/07/2012 - 17:45:59:

Time	Potential in V	Current in uA
12/07/2012 17:46:01	-1.501	
12/07/2012 17:46:02	-1.401	
12/07/2012 17:46:03	-1.299	
12/07/2012 17:46:04	-1.200	
12/07/2012 17:46:05	-1.098	

11.10 Wait command



The 'Wait' command interrupts the script for a specified period or until an event occurs.

‘Wait for:’

The script continues after the specified amount of seconds.

‘Resume today at:’

The script continues at the specified time of day (this can go on for multiple days)

‘Wait until user resumes:’

The script shows the message in the script result box (see Features) and waits until the user clicks the active Pause button to resume.

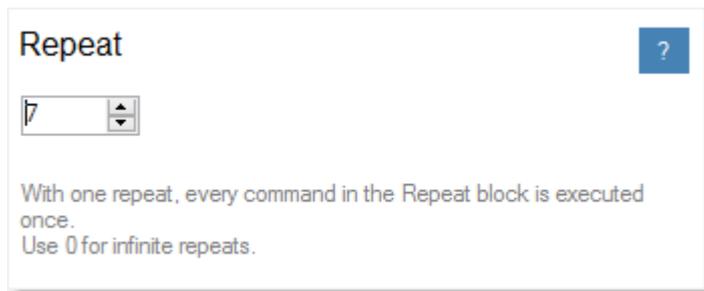
‘Wait until digital line:’

The script waits until the External IO line D0 is set high or low. This feature can be used to let an external device determine if the script can continue.

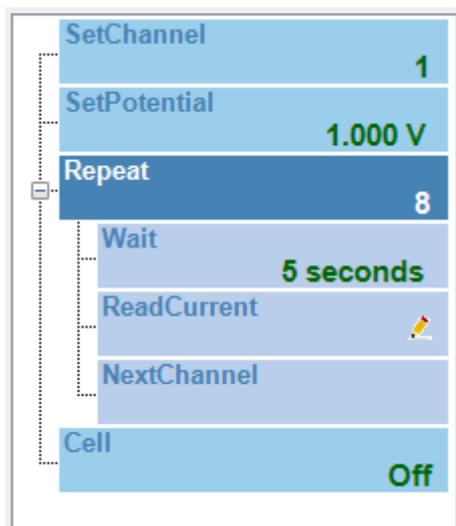
For auxiliary port pin-outs:

of (multi)PalmSens-series, see section [PalmSens Auxiliary port pin-outs](#) on page 269.
of EmStat3 and EmStat3+, see section [EmStat3 Blue auxiliary port pin-out](#) on page 282.

11.11 Repeat command

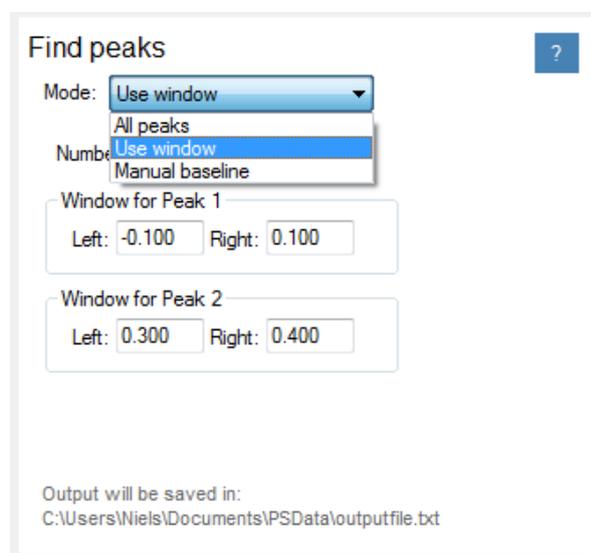


Using the repeat command, a set of commands can be repeated. The commands to repeat should be attached to the Repeat instruction in the list.
Use a value of 0 for infinite repeats.

Example:

The Repeat instruction itself cannot contain any repeats.

11.12 FindPeaks command



The FindPeaks command performs a peak search over the last measured curve available. This instruction is therefore logically preceded by the Measure command. The peaks found are written to the output file specified.

‘All peaks’

All peaks are searched using the parameters as specified in the method editor. This command always uses the default algorithm for peak search and may give different results compared to using the auto-detect peaks button in the main window.

‘Use window’

The number of peaks must be specified and for each peak the left and right of the search window must be provided.

'Manual baseline'

The provided left and right values for each peak are used as left and right of the peak baseline, therefore forcing the finding of a peak.

Output

If there are no columns set yet in the output file, a line with columns will be added first. All values are separated by a TAB and can be imported to Excel.

Script output 12/07/2012 - 16:36:02:

Curve	Peak#	Date Time	Potential/V	Height/ μ A	Area/ μ AV	Width/V	Y Offset/ μ A	Sum/ μ AV
Curve	1	12/07/2012 16:36:23	0.0280	-1.2007E-3	-6.6505E-5	0.080	6.5409E-3	1.5656E-1

11.13 SetChannel command



This command sets the channel of a CH8, MUX or MUX8-R2 multiplexer.

11.14 NextChannel command

Sets the connected CH8, MUX or MUX8-R2 multiplexer to the next channel. If the maximum available channel is exceeded, the first channel will be set.

11.15 PrevChannel command

Sets the connected CH8, MUX or MUX8-R2 multiplexer one channel lower. If the first channel is exceeded, the last channel will be set.

11.16 Stirrer command



A stirrer can be controlled by any instrument from PalmSens BV that has an auxiliary port. This command sets the stirrer on or off by using the D0 and D1 digital lines.

11.17 SetAnalog command



This command sets a potential on the Analog output of the connected device. This is pin 8 of the miniDIN port in case of a PalmSens. The output range depends on the connected instrument.

See [Auxiliary port pin-outs](#) on page 269.

11.18 ReadAuxiliary command

Reads the value for the auxiliary input port of the connected device and appends the result to the output file. The input range depends on the instrument connected and/or the auxiliary input type connected.

See for the ranges and location of the auxiliary pins: [Auxiliary port pin-outs](#) on page 269.

See for setting the type of auxiliary input: [Peripheral settings](#) on page 44.

Output example for a Pt1000 temperature sensor:

Script output 18/08/2014 - 10:00:32:

18/08/2014 10:00:32	Aux. In:	T = 29.276 °C
18/08/2014 10:01:32	Aux. In:	T = 30.275 °C
18/08/2014 10:02:32	Aux. In:	T = 30.388 °C
18/08/2014 10:03:32	Aux. In:	T = 30.497 °C
18/08/2014 10:04:32	Aux. In:	T = 30.613 °C

11.19 SetDigitalIO command



Set the digital IO ports of the connected device. Selected and highlighted buttons stand for a 1 otherwise 0, so in the example above the digital lines set are: 0101

For auxiliary port pin-outs:

of (multi)PalmSens-series, see section [Auxiliary port pin-outs](#) on page 269.

of EmStat3 and EmStat3+, see section [EmStat3 Blue auxiliary port pin-out](#) on page 282.

11.20 ReadDigitalIO command

Reads the digital input states of the 3 or 4 digital lines of the connected device and appends the result to the output file.

Output example:

```
Script output 12/07/2012 - 18:15:56:
12/07/2012 18:15:56      Digital lines:  0 0 0 0
12/07/2012 18:15:57      Digital lines:  0 0 0 1
12/07/2012 18:15:58      Digital lines:  0 0 1 0
```

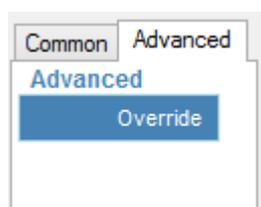
For auxiliary port pin-outs:

of (multi)PalmSens-series, see section [Auxiliary port pin-outs](#) on page 269.

of EmStat3 and EmStat3+, see section [EmStat3 Blue auxiliary port pin-out](#) on page 282.

11.21 Override parameter command

The Override parameter command is always attached to a Measure command. The value provided can either be 'Fixed' or an 'Added value'.



Advanced tab

The command can be found under the 'advanced' tab. This command is helpful, if you want to repeat the same methods in one experiment several times with different parameters each time.

'Parameter'

The method parameter to override.

'Fixed'

In case the potential is 'Fixed' the parameter of the method used with the Measure command is overridden with the value given in 'Set potential'.

'Added value'

In case 'Added value' is selected, the original parameter value from the method is added with the value given in 'New value'. In case the measure command is used within a Repeat block as shown in the example below, this means that the result of the previous iteration will be used for each new value.

If the resulting value is not valid, because it exceeds the parameter limits, the script will continue using the last valid value.

Using the override parameter for Pseudo Polarography

The override parameter can be used to change the deposition potential for each iteration in a repeat loop. In the example below the deposition potential (E dep) is read as 1.000 V in the method provided for the Measure command. The Override parameter command is attached to the Measure command. The Override parameter command adds 0.1 V with each iteration to the deposition potential. This results in a deposition potential in the first iteration of 1.100 V, in the second of 1.200 V, etc.

The screenshot displays the MultiTrace software interface. On the left, a script editor titled "Script" shows a sequence of commands: "Cell" (On), "SetPotential" (1.000 V), "Wait" (5 seconds), "Repeat" (10), "Wait" (for user to resume), "Measure" (PSDiffPulse (DPV)), "override parameter" (add 0.100 to DepositionPotential), and "FindPeaks". On the right, an "Override parameter" dialog box is open. It features a "Parameter:" dropdown menu set to "DepositionPotential". Below it, the "Original value:" is shown as "-0.5 V" and the "New value:" is shown as "0.1 V". At the bottom of the dialog, there are two buttons: "New value is fixed" and "New value is added", with the latter being highlighted with a green border.

12 Multi-channel instruments

Our multi-channel instruments are based on EmStat and PalmSens instruments in a single enclosure where each instrument is assigned to a specific channel number for simultaneous or individual control. In the case of MultiPalmSens4 and MultiEmStat4 the boards are also capable of synchronizing their measurements by means of a hardware setting which can be enabled through software.

The multi-channel instruments are used with electrochemical sensors or electrochemical cells with three or four electrodes: working electrode (optional with additional Sense), reference electrode and auxiliary or counter electrode. In the so-called two-electrode configuration the counter and reference electrodes can be combined to a single electrode. In that case the counter and reference connectors are tied together.

12.1 MultiPalmSens4 hardware description

The MultiPalmSens4 is a multi-channel potentiostat, galvanostat and optional impedance analyzer for EIS, with a minimum of 4 and a maximum of 10 channels.



MultiPalmSens4 with 10 channels

The MultiPalmSens4 channels can be extended with a bipotentiostat module (BiPot), iR compensation module, or with a multiplexer for use with up to eight or sixteen sensors or electrochemical cells. Also, each channel can be galvanically isolated so that the channels do not share grounds.

MultiPalmSens4 specifications

See [PalmSens4 specifications](#) on page 266 for potentiostat and AUX port specifications.

MultiPalmSens4 specifications	
▪ housing	15 x 25 x 25 cm ³
▪ weight	+/- 4 kg
▪ temperature range	0 °C to + 50 °C
▪ power supply	external 12 V AC/DC adapter
▪ communication	USB (type B)
▪ internal storage space	8 GB per channel or +/- 800000 measurements incl. method info (assuming 200 data points per measurement)
▪ hardware synchronization	optional via software, where channel 1 is always master
▪ galvanic channel isolation	optional in hardware (in-factory setting)

Channel status indicator

Each channel has a dual-color status indicator that can either be red or blue. Blue means that the cell is at open circuit, so no potential is applied, or current is flowing. Red means that the cell is active, and the internal feedback loop is closed for current or potential controlled mode.

12.2 MultiEmStat4 hardware description

The MultiEmStat4 is a multi-channel potentiostat, galvanostat and optional impedance analyzer for EIS, with a minimum of 4 and a maximum of 12 channels. The instrument comes in a Low Range (LR) and a High Range (HR) version.



MultiEmStat4 LR (left) and HR (right)

MultiEmStat4 specifications

The MultiEmStat4 consists of 4, 8 or 12 EmStat4 modules. This is the exact same EmStat4 module as used in the EmStat4S.

See www.palmsens.com/mes4 for more detailed specifications.

MultiEmStat4 specifications	
▪ housing	21.2 x 22.1 x 7.7 cm ³
▪ weight	+/- 3 kg
▪ temperature range	0 °C to + 50 °C
▪ power supply	external 12 V AC/DC adapter
▪ communication	USB (type B)
▪ internal storage space	500 MB per channel, equivalent to >15M datapoints
▪ channel synchronization (in hardware)	optional via software, where channel 1 is always master timing error across channels < 100 µs
▪ galvanic channel isolation	optional in hardware (in-factory setting)

Channel status indicator

Every channel has an illuminated ring in a color that represents its state. The following table explains the meaning for each color.

Color	State
Steady green	Booting
Steady blue	Cell off (at open circuit)
Steady red	Cell on
Blinking green	Uploading new firmware
Blinking orange	Error state
Blinking red	Fatal error (not responding)



MultiEmStat4 with illuminated indicator rings

12.3 MultiEmStat3 / 3+ hardware description

The MultiEmStat3 is a multi-channel potentiostat with a minimum of 4 and a maximum of 12 channels, each with its own WE, RE and CE and Sense (3+ only). The instrument comes in two versions: 3 and 3+. The MultiEmStat3 with 4 channels comes in a smaller housing, unless the system is equipped with galvanic isolation of each channel. Every system with galvanic isolation comes in the larger housing.



MultiEmStat3 / 3+ in a small 4 channels enclosure and enclosure for 8 or 12 channels

MultiEmStat3 / 3+ specifications

See [EmStat3 and 3+ specifications](#) on page 278 for potentiostat specifications.

Specifications of MultiEmStat3 / 3+ with 4 channels

▪ housing	115 mm x 85 mm x 35 mm
▪ weight	+/- 260 g
▪ temperature range	0 °C to + 50 °C
▪ power supply	external 5 V AC/DC adapter
▪ communication	USB (type B)
▪ channel synchronization	not available
▪ galvanic channel isolation	optional in hardware (in-factory setting)

Specifications of MultiEmStat3 / 3+ with 8 or 12 channels

▪ enclosure	120 mm x 210 mm x 75 mm
▪ weight	+/- 2 kg
▪ temperature range	0 °C to + 50 °C
▪ power supply	external 12 V AC/DC adapter
▪ communication	USB (type B)
▪ hardware synchronization	not available
▪ galvanic channel isolation	optional in hardware (in-factory setting)

Channel status indicator

Each channel has a dual-color status indicator that can either be red or blue. Blue means that the cell is at open circuit, so no potential is applied, or current is flowing. Red means that the cell is active, and the internal feedback loop is closed for current or potential controlled mode.

12.4 EmStat3-4WE hardware description

EmStat3-4WE is a polypotentiostat with 4 working electrodes, that makes parallel measuring of multiple electrodes in one electrochemical cell possible. With this polypotentiostat one electrochemical cell can be equipped with 1, 2, 3 or 4 working electrodes and all of these will be measured parallel.

The additional WE's can each individually be used in two different modes:

1. The potential of the additional WE has a constant dc-potential offset with respect to WE1, i.e. it is following the potential change of WE1.
2. The potential of the additional WE has an independent fixed dc-potential.

Each potentiostat has eight current ranges: 1 nA to 10 mA with a resolution of 1 pA at the lowest current range and can automatically select the optimal current range.



EmStat3-4WE

A cell can be setup with one reference and one counter electrode or one combined reference and counter electrode.

EmStat3-4WE specifications

The EmStat3-4WE consist of a standard EmStat3 potentiostat and additionally three polypotentiostat (bipotentiostat-like) modules. The instrument is used for electrochemical systems with 1, 2, 3, or 4 working electrodes (WE1 - 4) all sharing the same counter (CE) and reference electrodes (RE) or combined CE/RE. The embedded software of the EmStat3 instruments provides all relevant methods for electrochemical sensors.

All techniques supported by EmStat3 are available for the EmStat3 4WE.

EmStat3 4WE	Main potentiostat	Polypotentiostat modules
▪ dc-potential range	$\pm 3.000\text{ V}$	$\pm 3.000\text{ V}$
▪ compliance voltage	$\pm 5\text{ V}$	$\pm 5\text{ V}$
▪ dc-potential resolution	0.1 mV	0.1 mV
▪ max. dc-offset error	2 mV	3 mV
▪ potential accuracy	0.2 %	0.2 %
▪ current ranges	1 nA to 10 mA (8 ranges)	1 nA to 10 mA (8 ranges)
▪ maximum current	$\pm 20\text{ mA}$ typical and $\pm 15\text{ mA}$ minimum for the sum of WE1, W2, W3 and W4	
▪ current resolution	0.1% of current range, 1 pA at lowest current range	
▪ electrometer amplifier input	> 100 GOhm // 4 pF	> 100 GOhm // 4 pF
▪ rise time	approx. 100 μs	approx. 100 μs

Housing	
▪ dimensions	12 cm x 8.5 cm x 3.5 cm
▪ weight	250 g
▪ power	5 V external power supply
▪ interfacing	USB (type B)
▪ hardware synchronization	always enabled for all channels with channel 1 as master
▪ galvanic channel isolation	not available

Channel status indicator

Each channel has a dual-color status indicator that can either be red or blue. Blue means that the cell is at open circuit, so no potential is applied, or current is flowing. Red means that the cell is active, and the internal feedback loop is closed for current or potential controlled mode.

12.5 Chassis ground

Our multi-channel instruments have a provision for connecting a 4 mm banana connector to the chassis ground of the instrument. If the channels of the instrument are not galvanically isolated (floating), the ground leads of all individual channels will be directly connected with the chassis of the instrument. In case the multi-channel instrument has floating channels (optional), each of them will have an individual ground which is separated from the chassis.

If the MultiPalmSens4 is connected to a PC that is connected to the mains power supply with a USB cable, it is almost certain that the instrument's chassis is connected to the computer chassis which again is likely to be connected to earth ground. This is not a requirement for normal operation of the instrument; however your instrument might be susceptible to ground loops.



MultiPalmSens4 back side

See also section [Noise](#) on page 54 for more information about reducing noise interference in your measurements.

12.6 Galvanic isolation

Galvanic isolation (GI) can be translated to non-conductive separation. The part of system with GI has no connection to a common ground and in the majority of situations no other common connection to the other parts of other potentiostats. This status is also known as floating or earth / ground potential free.

The removal of the ground connection has some impacts on your measurement.

The potentiostats in one of these instruments usually use the common ground as working electrode potential, which is difficult to imagine for electrochemists. This means, multiple potentiostats will start to cross talk, if they share the ground due to a common chassis, a connection to the protection contacts in a USB plug or a power socket and try to work in the same electrochemical cell. If all potentiostats are floating, they can't cross talk, because there is no internal connection. This is the main application for floating instruments: Shared electrochemical cells / electrolytes. Without galvanic isolation it is not possible to operate multiple 2- or 3-electrode systems in the same cell.

Avoiding ground loops

Another reason to use a floating instrument is to avoid ground loops. If two points in your systems are meant to be ground, but there is a potential difference between them (the potential of the ground isn't uniform) noise is induced. For this reason, a common practice is to ground your devices "star shaped". This means all ground connection of your devices should be connected to the same spot. This is usually a point at the Faraday cage, because it has the biggest mass and doesn't charge easily. And one point at the Faraday cage means here a physical small area, so all connectors should be next to each other leading like the rays of a star away from one point. Of course, if you remove the connection to the ground (thus having a floating device), there can't be any current flow through the ground connections, because there are no ground connections.

Using your channels as ZRA

If you want to use your instrument as a ZRA (Zero Resistance Ammeter), it needs to be floating. With a ZRA you are measuring a current without changing it. You short circuit the RE and CE of the potentiostat and let the current, you want to measure, flow through WE and GND of the device. Would the ZRA share the ground with the flowing current, such a measurement wouldn't be possible.

Reduced shielding properties

There is, however, a disadvantage: The noise protection is drastically reduced. Usually all conducting shields connected to the ground act as a Faraday cage for the device and protect it against noise. If the connection between the chassis and the potentiostat is removed, the chassis no longer acts as a Faraday cage for the potentiostat. This is an important protection against environmental noise, which is removed. Additionally, the floating device can't share a Faraday cage with any other device, which might create a rather complex setup.

According to our experience most customers don't need to measure with multiple potentiostats in the same cell or use the device as a ZRA. Galvanic isolation increases the price for your multi-channel device and decreases the signal to noise ratio. Therefore, we recommend galvanic isolation only for customers, who know that they need it and are aware of the drawback.

Galvanic Isolation is needed, if you want to use your potentiostat with other potentiostats in the same cell or want to use it as a ZRA. The housing of a multi-channel instrument is no longer a Faraday cage for the potentiostat modules inside.

13 PalmSens instrument series



PalmSens is a hand-held battery powered instrument for use with electrochemical sensors or electrochemical cells. The instrument contains a microprocessor and a low noise and low-current potentiostat and galvanostat which controls the potential or current applied to the sensor and measures the current or potential response. The PalmSens3 and PalmSens4 can also optionally be equipped with FRA for impedance spectroscopy.

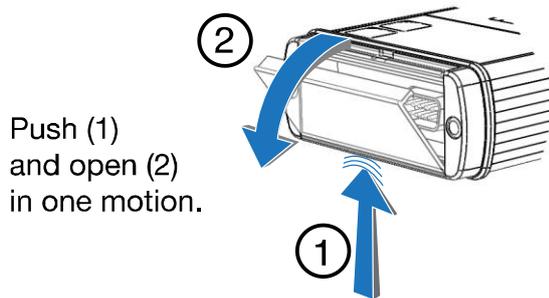
13.1 Description

In general, the PalmSens instruments are used with electrochemical sensors or electrochemical cells with three electrodes: working electrode, reference electrode and auxiliary or counter electrode. In the so-called two-electrode configuration the counter and reference electrodes can be combined to a single electrode. In that case the counter and reference connectors are tied together.

The instrument can be extended with a bipotentiostat module (BiPot) or with a multiplexer for use with up to eight or sixteen sensors or electrochemical cells.

13.2 Operating PalmSens1 or 2

Open the lid at the left-hand side of PalmSens by pressing the hinge upwards and then turning the lid.



Opening the lid of PalmSens1 or 2

Before PalmSens is used without the adapter, the batteries must be charged. Connect the adapter to the miniDIN-connector (PS1) or dc-in connector (PS2). Switch on PalmSens by pressing the power key until the display shows: “Selftest”. During the self test the voltage range of the instrument is tested and shown. The normal range for PalmSens is approx. -2.035 V to $+2.047\text{ V}$.

After the test the display will show:

```
> PalmSens
Vs. #.#
E= #.### V
FsChg
```

Default contents of the PalmSens1 and 2 LCD

If the display shows the text “FsChg”, the batteries are being charged. As soon as the display shows “PwrOK”, the batteries are full and the adapter can be disconnected. The batteries have to be recharged as soon as “LowBat” is shown and the corresponding beep is heard. PalmSens can be used with the adapter connected and the batteries charged. The adapter however might increase the noise level. The backlight of the LCD is switched on and off by using the key ▲. Please note that the backlight will reduce the battery-lifetime of PalmSens from approx. 8 hours to not more than 6 hours. PalmSens is switched off by pressing the power key until the display shows “Shutting down”.

Keypad

During the conditioning, deposition, and equilibration stage two keys of the keypad are active. When the stop button is pressed the measurement is ended. The skip key is used to step to the next stage. During a measurement only the ESC or ■ key is active.

13.3 PalmSens1 and 2 specifications



PalmSens model 1 and 2

Potentiostat (controlled potential mode)	
▪ dc-potential range	$\pm 2.000 \text{ V}$
▪ compliance voltage	$\pm 8.0 \text{ V}$
▪ dc-potential resolution	1 mV
▪ dc-offset error	2 mV
▪ accuracy	$\leq 0.2 \%$
▪ ac-potential amplitude	1 mV to 250 mV
▪ current ranges	1 nA to 10 mA (8 ranges)
▪ maximum current	$\pm 10 \text{ mA}$
▪ current resolution	0.1 % of current range 1 pA on lowest current range
▪ accuracy	$\leq 0.2 \%$ of current range at 100 nA to 1 mA $\leq 0.5 \%$ at 10 nA and $\leq 1 \%$ at 1 nA all with additional 0.2 % offset error
Galvanostat (controlled current mode)	
▪ current ranges	1 μA to 1 mA
▪ dc-current range	-2 to + 2 times selected current range
▪ dc-current resolution	0.1 % of selected current range
▪ dc-offset error	$\leq 0.2 \%$
▪ current accuracy	$\leq 0.4 \%$
▪ maximum output voltage	$\pm 8 \text{ V}$
General	
▪ electrometer amplifier input	$> 100 \text{ Gohm} // 4 \text{ pF}$
▪ rise time	approx. 50 μs
▪ Keypad	▲▶▼◀ ENTER ESC and Power (7 keys)
▪ Display	4 lines of 16 characters with backlight
▪ Dimensions	155 mm x 85 mm x 35 mm

▪ Temperature range	0° C to + 40° C
▪ Weight	0.43 kg
▪ Power	2 AA cells NiMH 2500 mAh for > 8 hours operation. Battery charger included (6 V- 1500 mA)
▪ Interfacing	Serial RS232 Default serial mode: 57600 baud, 8 bits data, no parity, 1 stopbit.
▪ External I/O	Analog: 1 input and 1 output channel (0 V - 4.096 V) Digital: 1 input and 4 output lines

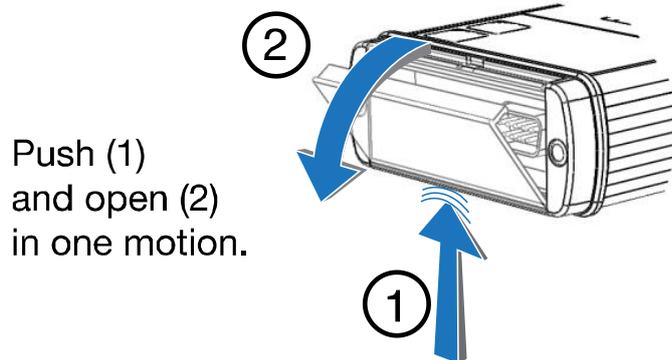
13.4 BiPot specifications for PalmSens1 and PalmSens2

The table below shows the specifications of the optional Bipotentiostat module for PalmSens1 and PalmSens2.

General	
▪ dc-potential range	± 2.000 V
▪ dc-potential resolution	1 mV
▪ dc-offset error	3 mV
▪ accuracy	≤ 0.3 %
▪ current ranges	1 nA to 10 mA (8 ranges)
▪ maximum measured current	± 10 mA
▪ current resolution	0.1 % of current range 1 pA on lowest current range
▪ accuracy	≤ 0.3 % of current range at 1 μ A to 100 μ A ≤ 0.5 % at 100 nA and ≤ 1 % at 10 and 1 nA all with additional 0.2 % offset error
▪ connection	Use requires a cable with additionally a (yellow) connector for WE2

13.5 Operating the PalmSens3

Open the lid at the left-hand side of PalmSens by pressing the hinge upwards and then turning the lid.



	<p>Power button PalmSens3 is switched on by pressing and holding the power button. If a PalmSens3 Bluetooth extension is used, make sure the Bluetooth extension is connected to the PalmSens3 auxiliary port BEFORE turning it on. PalmSens3 will detect any extensions during start-up. PalmSens3 is switched off by pressing the power button twice. If PalmSens3 is not responding, press and hold the power button for a few seconds to force it to switch off.</p>
	<p>Backlight button The backlight of the LCD is switched on by using the backlight button next to the power button. Please note that the backlight will reduce the battery-lifetime of PalmSens3. The backlight is turned off automatically after a while.</p>
	<p>Charging icon PalmSens3 is always charging when connected to a USB port. When charging the red battery icon will light up.</p>
	<p>Stop button Pushing the stop button will abort any running measurements immediately. If the instrument is in 'fast mode' it will return to normal mode.</p>
	<p>Start button Reserved for future updates.</p>
	<p>Skip button This button can be used to skip pretreatment stages and proceed to the next stage. See also section Measurement sequence on page 108.</p>

13.6 PalmSens3 specifications



PalmSens 3

Potentiostat (controlled potential mode)	
▪ dc-potential range	$\pm 5.000\text{ V}$
▪ compliance voltage	$\pm 8.0\text{ V}$
▪ dc-potential resolution	0.15 mV
▪ applied potential accuracy	$\leq 0.2\%$ with max. 2 mV offset error
▪ current ranges	100 pA to 10 mA (9 ranges)
▪ maximum measured current	$\pm 30\text{ mA}$ (typical)
▪ current resolution	0.01% of current range
▪ accuracy	$\leq 1\%$ of current range at 1 nA ($\leq 5\%$ at 100 pA) $\leq 0.5\%$ at 10 nA $\leq 0.2\%$ at 100 nA to 1 mA $\leq 0.5\%$ at 10 mA all with max. 0.2% offset error
▪ max. acquisition rate	$200\,000\text{ data points/s}$

Galvanostat (controlled current mode)	
▪ current ranges	$1\text{ }\mu\text{A}$ to 10 mA
▪ dc-current range	± 3.000 times selected current range
▪ dc-current resolution	0.01% of selected current range
▪ max. dc-offset error	$\leq 0.2\%$
▪ current accuracy (deviation)	$\leq 0.4\%$
▪ maximum output voltage	$\pm 8\text{ V}$

Impedance measurements	
▪ frequency range	$100\text{ }\mu\text{Hz}$ to 50 kHz
▪ ac- amplitude range	1 mV to 0.25 V (rms)

General

▪ electrometer amplifier input	> 100 Gohm // 4 pF
▪ rise time	programmable from min. 0.5 μ s

Other

▪ keypad	run, skip, abort, backlight and power
▪ housing	aluminium: 155 mm x 85 mm x 35 mm
▪ weight	430 g
▪ temperature range	0° C to + 40° C
▪ power supply	USB or internal Li-ion battery
▪ battery time	>9 hours idle time with Bluetooth extension
▪ communication	USB

Auxiliary port (D-Sub 15)

▪ external I/O	analog: 1 input and 1 output channel (0 V - 3 V) digital: 1 input and 4 output lines (5 V)
----------------	---

13.7 BiPot specifications for PalmSens3

The table below shows the specifications of the optional Bipotentiostat module for PalmSens3.

General

▪ dc-potential range	± 5.000 V
▪ dc-potential resolution	0.15 mV
▪ dc-offset error	3 mV
▪ accuracy	≤ 0.3 %
▪ current ranges	1 nA to 10 mA (8 ranges)
▪ maximum measured current	± 10 mA
▪ current resolution	0.01 % of current range 0.1 pA on lowest current range
▪ accuracy	≤ 0.3 % of current range at 1 μ A to 100 μ A ≤ 0.5 % at 100 nA and ≤ 1 % at 10 and 1 nA all with additional 0.2 % offset error
▪ connection	Use requires a cable with additionally a (yellow) connector for WE2

13.8 Operating the PalmSens4



Power button

PalmSens4 is switched on and off by pressing and holding the power button for a couple of seconds.

If PalmSens4 is not responding make sure to take out the USB connector and, press and hold the power button for a few seconds to force it to switch off.

13.9 PalmSens4 specifications



PalmSens4

General			
▪ dc-potential range	model	PS4.F#.05	PS4.F#.10
		±5 V	±10 V
▪ compliance voltage	±10 V		
▪ maximum current	±30 mA (typical)		
▪ max. acquisition rate	150000 points/s		
Potentiostat (controlled potential mode)			
▪ applied dc-potential resolution	75 μ V		
▪ applied potential accuracy	$\leq 0.1\%$ ± 1 mV offset		
▪ current ranges	100 pA to 10 mA (9 ranges)		
▪ measured current accuracy	$\leq 0.1\%$ at Full Scale Range		
▪ measured current resolution	0.006% of current range (5 fA on 100 pA range)		
Galvanostat (controlled current mode)			
▪ current ranges	1 nA to 10 mA (8 ranges)		
▪ applied dc-current range	± 6 times applied current range		
▪ applied dc-current resolution	0.005% of applied current range		

▪ measured dc-potential resolution	75 μ V at ± 10 V (no gain) 7.5 μ V at ± 1 V (gain 10) 0.75 μ V at ± 0.1 V (gain 100)
▪ measured dc-potential accuracy	$\leq 0.05\%$ or ± 1 mV (for $ E < \pm 9$ V) $\leq 0.2\%$ (for $ E \geq \pm 9$ V)

FRA / EIS (impedance measurements)

▪ frequency range	model PS4.F1.## PS4.F2.## 10 μ Hz to 100 kHz 10 μ Hz to 1 MHz
▪ ac-amplitude range	1 mV to 0.25 V rms, or 0.6 V p-p

Electrometer

▪ electrometer amplifier input	> 1 T Ω // 10 pF
▪ bandwidth	1 MHz

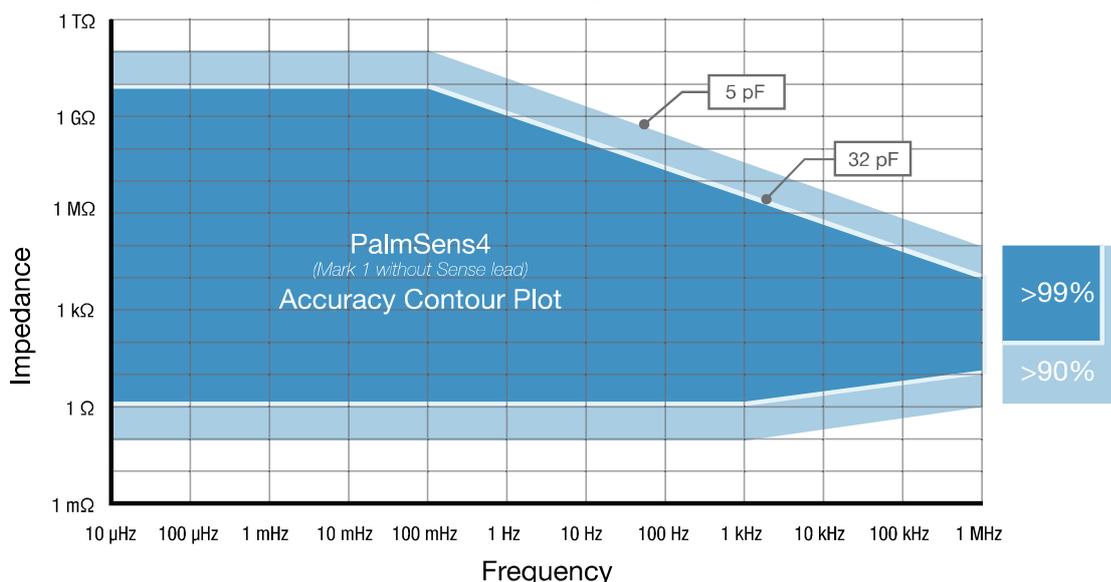
Other

▪ housing	aluminium body with rubber sleeve: 15.7 x 9.7 x 3.5 cm ³
▪ weight	+/- 500 g
▪ temperature range	0 °C to +50 °C
▪ power supply	USB or internal LiPo battery
▪ communication	USB and Bluetooth
▪ battery time	> 16 hours idle time (> 5 hours with BiPot installed) > 4 hours with cell on at max. current Extendible by means of power bank
▪ internal storage space	8 GB (or > 100 million data points)

Auxiliary port (D-Sub 15)

▪ analog input	± 10 V, 18 bit
▪ analog output	0-10 V, 12 bit (1 kOhm output impedance)
▪ 4 digital outputs	5 V
▪ 1 digital input	5 V
▪ i-out and E-out	raw output of current and potential E-out ± 10 V (1 kOhm output impedance) I-out ± 6 V (1 kOhm output impedance)
▪ power	5 V output (max. 150 mA)

13.9.1 EIS contour accuracy plot

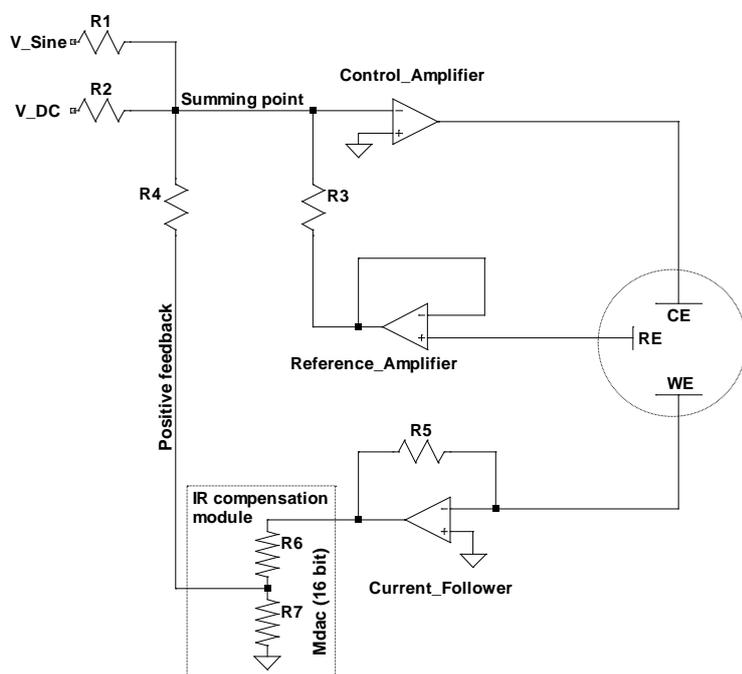


Note

The accuracy contour plot was determined under lab conditions and should be used for reference purposes. Please note that the true limits of an impedance measurement are influenced by all components in the system, e.g. cables, the environment, and the cell.

13.9.2 iR Compensation

The PalmSens4 iR Compensation module works using Positive Feedback. This is achieved using a 16-bit MDAC in the module which scales the output of the current follower opamp to provide a positive feedback voltage that is proportional to the current through the cell. The compensation voltage is added to the summing point before the control amplifier and thus increases the applied potential to counteract the iR drop.

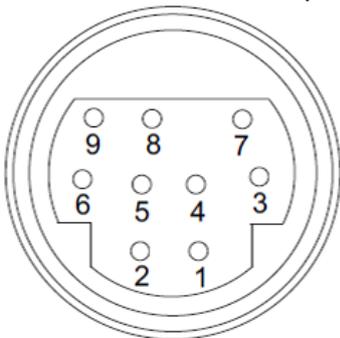


Positive feedback allows for fast scan rates up to 10 V/s, depending on the characteristics of the cell. If the potential error to compensate for becomes close to the value set for E applied, the system might become unstable. Using iR compensation limits the measurement bandwidth to 10 kHz.

13.10 Auxiliary port pin-outs

PalmSens2 AUX port pin-out

Front view of female port:



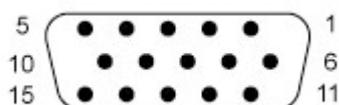
pin 1	Vadapter (6 V- 1.5 A) for serial numbers PS0201 to PS04200 and d3 digital output for PS04201 and higher
pin 2	analog ground
pin 3	d0 digital output (maximum current 5 mA source or sink)
pin 4	d1 digital output (maximum current 5 mA source or sink)
pin 5	d2 digital output (maximum current 5 mA source or sink)
pin 6	d0 digital input
pin 7	auxiliary analog input
pin 8	auxiliary analog output (advised resistive load > 10 kohm)
pin 9	5 V digital power line (maximum current 100 mA)
shield	digital ground

Maximum ratings:

Digital input and output lines:	-0.3 V to 5.3 V
Analog input and output lines:	-0.3 V to 5.3 V

PalmSens3 AUX port pin-out

Front view of female port:

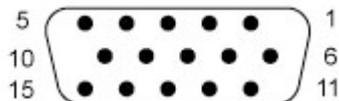


pin 1	d0 digital output (5V)
pin 2	d3 digital output (5V)

pin 3	auxiliary analog input (>0.5 Mohm input impedance)
pin 4	Rx (TTL default, or RS232 see pin 12)
pin 5	Tx (TTL default, or RS232 see pin 12)
pin 6	d1 digital output (5V)
pin 7	d0 digital input (5V)
pin 8	I out (V in current range)
pin 9	5 V digital power line (max. 50mA)
pin 10	digital ground
pin 11	d2 digital output (5V)
pin 12	Connect to pin 10 (DGND) for RS232 comm on pin 4 and pin 5
pin 13	E out (-5 to +5V)
pin 14	analog ground
pin 15	DAC out (0-3V)
shield	digital ground

PalmSens4 AUX port pin-out

Front view of female port:



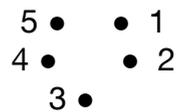
pin 1	d0 digital output (5V)
pin 2	d3 digital output (5V)
pin 3	auxiliary analog input -10 to +10 V, 18 bit, >0.5 MOhm input impedance
pin 4	RESERVED
pin 5	RESERVED
pin 6	d1 digital output (5V)
pin 7	d0 digital input (5V)
pin 8	I out (V in active current range)
pin 9	5V digital power line (max. 300mA)
pin 10	digital ground
pin 11	d2 digital output (3.3V)
pin 12	RESERVED (NC)
pin 13	E out (-10 to +10V)

pin 14	analog ground
pin 15	analog out (0 to 10 V at 12 bit)
shield	digital ground

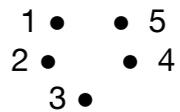
13.11 Sensor connector pin-outs

PalmSens1 and PalmSens2 sensor connector pin-out

Front view of male plug on cable:



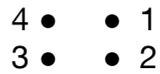
Front view of female connector on instrument:



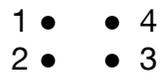
1. WE: red connector is working electrode
2. AGND: green connector is ground
3. Not connected in default plug or WE2 if BiPot is present
4. CE: black connector or counter electrode
5. RE: blue connector or reference electrode

PalmSens3 sensor connector pin-out

Front view of male plug on cable:



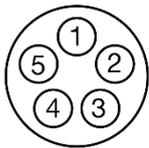
Front view of female connector on instrument:



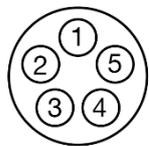
1. RE: blue connector or reference electrode
2. CE: black connector or counter electrode
3. Not connected in default plug or WE2 if BiPot is present
4. WE: red connector is working electrode
[shield] AGND: green connector is ground

PalmSens4 sensor connector pin-out

Front view of male plug on cable:



Front view of female plug on instrument:



1. RE: blue connector or reference electrode
2. RE shield
3. CE: black connector or counter electrode
4. Not connected in default plug or WE2 if BiPot is present
5. WE: red connector is working electrode
[shield] AGND: green connector is ground

IMPORTANT:

The shield of the cable must make contact with the metal case of the sensors connector.

13.12 Battery maintenance

In case the battery capacity decreases it is advised to switch on PalmSens and wait until it switches off automatically. After charging the batteries, their capacity might be restored again.

Warning: Do not charge the batteries when the ambient temperature is below 0 °C or above 40 °C.

Charging is done most efficiently in the range of 10 °C to 30 °C.

Do not store the instrument with batteries in places where the ambient temperature is below 0 °C or above 40 °C.

Do not connect the charger with reversed polarity.

Detailed instructions for battery replacement are available from PalmSens BV: send a message to info@palmsens.com

Note: the batterypack must be obtained from PalmSens BV.

Ordering codes:

- PS2BATT (for PalmSens1 or 2, old models)
- PS3BATT for PalmSens3
- PS4BATT for PalmSens4

14 EmStat instruments series



The EmStat1, EmStat2, EmStat3(+) and EmStat4S (*embedded potentiostat*) are the smallest, commercially available computer controlled potentiostats.

See section “EmStat Pico base instruments” for more information about the EmStat Pico.

14.1 Description

The EmStat instruments are used with electrochemical sensors or electrochemical cells with three or four electrodes: working electrode, reference electrode and auxiliary or counter electrode and sense electrode. In the so-called two-electrode configuration the counter and reference electrodes can be combined to a single electrode. In that case the counter and reference connectors are tied together.

The EmStats are used in different hardware configurations, see below. All these instruments incorporate the same EmStat potentiostat modules.

EmStat Blue models

The EmStat Blue models allow to connect via Bluetooth, have an integrated battery, an additional auxiliary port and connector for a wide collection of screen-printed electrodes (SPE).

Multiplexed EmStat models

The instruments (except EmStat3+) can be delivered with a 8- or 16-channel multiplexer integrated in a single housing as EmStat MUX.

Multi-channel EmStat models

The EmStats can also be configured as MultiEmStat where a single instrument contains 4, 8 or 12 individual EmStat modules. These instruments can be controlled

simultaneously or individually in a single overview with MultiTrace for Windows. Only one channel at a time can be controlled in PStace.

14.2 Operating standard EmStats

The standard EmStat is powered directly by means of the USB cable.

Status leds

LED indicators. The EmStats1, 2 and 3 have two single color LEDs. The LED colors and corresponding functions are shown in the table below.

Model	Powered	Cell On
EmStat1 and 2	Green	Red
EmStat3 and 3+	Blue	Red

The EmStat4S has a multi-color status LED with the following functions:

Function	LED state
Booting	Steady green
Idle and ready	Steady blue
Cell on	Steady red
Uploading new firmware	Blinking green
Error state	Blinking orange
Fatal error (not responding)	Blinking red

Noise considerations

Certain laptops or PC's induce a high noise level. This can be eliminated using a USB-hub with its own ac-adapter or a Galvanic Isolation USB dongle, which is available from PalmSens BV.

14.3 Operating the EmStat3 Blue

When connecting to the USB port of a PC, Bluetooth will switch off automatically unless there is Bluetooth a connection active. This allows the instrument to be charged via a PC while a Bluetooth connection is present.

	<p>Power button EmStat Blue is switched on by pressing and holding the power button. When device is on: Press short to switch Bluetooth ON or OFF.</p>
	<p>Bluetooth icon Blinking: ready to connect Steady: connected</p>
	<p>Battery icon Blinking red: battery low Blinking green: charging battery Steady green: battery fully charged</p>

14.4 EmStat1 and EmStat2 specifications

General	
▪ dc-potential range	± 2.000 V
▪ compliance voltage	± 4.5 V
▪ maximum output current	± 20 mA
Potentiostat (controlled potential mode)	
▪ dc-potential resolution	1 mV
▪ applied dc-potential accuracy	≤ 0.2 %
▪ max. dc-offset error	2 mV
▪ current ranges	1 nA to 100 µA (6 ranges) 1 nA to 10 mA (8 ranges) for EmStat2
▪ current resolution	0.1 % of current range 1 pA on lowest current range
▪ current accuracy	≤ 0.3 % of current range at 1 µA to 100 µA ≤ 0.5 % at 100 nA and ≤ 1 % at 10 and 1 nA all with additional 0.2 % offset error
Electrometer	
▪ electrometer amplifier input	> 100 Gohm // 4 pF
▪ rise time	approx. 200 µs

Other	
▪ dimensions	EmStat: 6.2 cm x 4.6 cm x (1.7 to 2.8 cm) EmStat2: 6.2 cm x 4.8 cm x (1.7 to 2.6 cm)
▪ power	5 V / 60 mA from USB connector (or ac-adaptor ¹)
▪ interfacing	USB (or RS-232 ¹)
▪ external I/O options ¹	analog: 1 input and 1 output channel (both 0 V - 4.096 V) digital: 4 input and/or output lines
▪ options	8 or 16 channel multiplexer
▪ sensor connection	shielded cable with circular connector (PalmSens compatible)

14.5 EmStat3 and EmStat3+ specifications

	EmStat ³	EmStat ³⁺
▪ dc-potential range	± 3.000 V	± 4.000 V
▪ compliance voltage	± 5 V	± 8 V
▪ applied dc-potential resolution	0.1 mV	0.125 mV
▪ applied potential accuracy	≤ 0.2 % with max. 2 mV offset error	≤ 0.3 % with max. 3 mV offset error
▪ current ranges	1 nA to 10 mA (8 ranges)	1 nA to 100 mA (9 ranges)
▪ maximum measured current	± 20 mA typical and ± 15 mA minimum	± 100 mA typical

EmStat 3 and 3+ Potentiostat (controlled potential mode)

▪ current resolution	0.1 % of current range 1 pA on lowest current range
▪ current accuracy	≤ 1 % of current range at 1 nA ≤ 0.5 % at 10 nA ≤ 0.2 % at 100 nA to 100 uA ≤ 0.5 % at 1 mA, 10 mA and 100 mA all with additional 0.2 % offset error

Electrometer / other

▪ electrometer amplifier input	> 100 Gohm // 4 pF
▪ rise time	approx. 200 μs
▪ sensor connection	shielded cable with circular connector for WE, RE, CE and Sense (100 mA for ES3+ only)

EmStat 3 and 3+ regular model

▪ housing	anodized aluminium: 6.7 cm x 5.0 cm x (1.9 to 2.8 cm)
▪ weight	85 g
▪ power supply	5 V, min. 130 mA (ES3) or 500 mA (ES3+) via USB
▪ communication	USB
▪ auxiliary port present	no

EmStat 3 and 3+ Blue model

▪ housing	anodized aluminium: 100 mm x 60 mm x (27 to 34 mm)
▪ weight	85 g
▪ power supply	USB or internal Li-Po battery 5 V, min. 130 mA (ES3) or 500 mA (ES3+)
▪ battery time	> 8 hours with cell off > 5 hours with continuous cell on at 1uA current full charge takes approx. 3 hours
▪ communication	USB or Bluetooth
▪ auxiliary port present	yes
▪ external I/O options	analog: 1 input and 1 output channel (both 0 V - 4.096 V) digital: 1 input, 4 output lines (maximum rating: -0.3 V to 5.3 V)

The EmStat3 and EmStat3+ Blue have an auxiliary port to control external accessories. The instrument is also available as OEM device for integration in instruments for specific electrochemical sensors or other applications.

14.6 EmStat3 and 3+ Blue specifications

The EmStat Blue models have similar specifications as the regular EmStat3 and 3+, but they are extended with Bluetooth connectivity, a battery and auxiliary port.

The following table shows the main differences.

	EmStat ³ and 3 ⁺	EmStat ³ and 3 ⁺ blue
		
Size (cm)	6.7 x 5.0 x 2.8	10.0 x 6.0 x 3.4
Weight	85 g	250 g
Battery	no	yes
Communication	USB	USB + Bluetooth
Auxiliary port	no	yes
Sensor connector	LEMO	LEMO + SPE

14.7 EmStat4S specifications

The EmStat4S comes in two versions: LR (Low Range) and HR (High Range). The version of your EmStat4S can easily be recognized by the color of the bottom shell. The HR has a black bottom shell, and the LR has a blue one.

The following table shows the main differences between the LR and HR versions.

		
	<i>EmStat4S LR</i>	<i>EmStat4S HR</i>
Potential range	±3 V	±6 V
Max. compliance voltage	±5 V	±8 V
Current ranges	1 nA to 10 mA (8 ranges)	100 nA to 100 mA (7 ranges)
Max. current	±30 mA	±200 mA
Electrode connections	WE, RE, CE, and ground, 2 mm banana plugs	WE, RE, CE, S, and ground, 2 mm banana plugs

See www.palmsens.com/es4s for more detailed specifications.

Meaning of status indicator colors

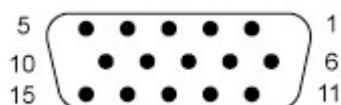
The EmStat4S has a multi-color status indicator. The following table explains the meaning for each color.

Color	State
Steady green	Booting
Steady blue	Cell off (at open circuit)
Steady red	Cell on
Blinking green	Uploading new firmware
Blinking orange	Error state
Blinking red	Fatal error (not responding)

14.8 EmStat3 Blue auxiliary port pin-out

EmStat3 or 3+ Blue

Front view of female port:

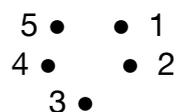


D-Sub15	Description	EmStat PCB pin (CON-PIN)
pin 1	d0 digital output (5V)	1-4
pin 2	d3 digital input/output (5V)	1-1
pin 3	auxiliary analog input (0 – 4.095 V)	2-9
pin 4	Rx (TTL comm)	2-2
pin 5	Tx (TTL comm)	2-1
pin 6	d1 digital output (5V)	1-3
pin 7	d0 digital output (5V)	1-4
pin 8	RESERVED	-
pin 9	5 V digital power line (max. 50mA)	2-12
pin 10	digital ground	2-11
pin 11	d2 digital output (5V)	1-2
pin 12	RESERVED	-
pin 13	RESERVED	-
pin 14	analog ground	1-9
pin 15	DAC out (0-3V)	2-10
shield	digital ground	-

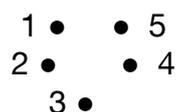
14.9 Sensor connector pin-outs

EmStat1 and EmStat2

Front view of male plug on cable:



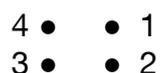
Front view of female connector on instrument:



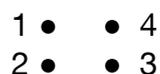
1. WE: red connector is working electrode
2. AGND: green connector is ground
3. Other (optional) use.
4. CE: black connector or counter electrode
5. RE: blue connector or reference electrode

EmStat3(Blue) and EmStat3+(Blue)

Front view of male plug on cable:



Front view of female connector on instrument:

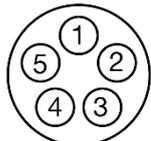


1. RE: blue connector or reference electrode
2. CE: black connector or counter electrode
3. S: Sense connector for working electrode on EmStat3+ or other (optional) use on EmStat3
4. WE: red connector is working electrode

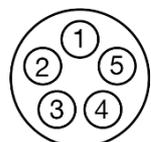
Metal casing AGND: green connector is ground

EmStat4S

Front view of male plug on cable:



Front view of female connector on instrument:



1. RE: blue connector or reference electrode
2. RE shield
3. CE: black connector or counter electrode
4. Sense (in case of EmStat4S HR only)
5. WE: red connector is working electrode [shield] AGND: green connector is ground

15 Sensit series



The Sensit Smart and Sensit BT readers for use with Screen-Printed Electrodes

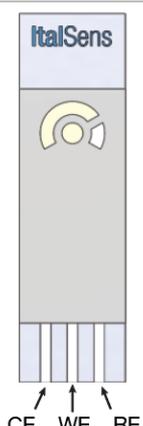
15.1 Description

The Sensit BT is ideal for electrochemical sensor applications. The Sensit BT connects via Bluetooth to your smartphone or tablet and controlled via the Android app PStouch. You can use the USB-C port to charge the Sensit BT or connect to a classic USB port on your PC and control the Sensit BT via our PC software PStace.

15.2 Operating the Sensit Smart

The Sensit Smart is communicating and is powered via the USB-C connector. If the Sensit Smart is powered, its blue LED is turned on.

The Sensit Smart can be used with Screen-Printed Electrodes with the following properties:

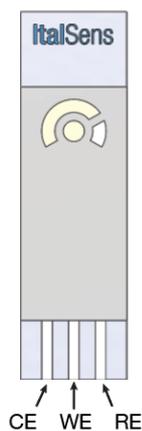
Sensor pitch	2.54 mm
Electrode connections	
Allowed sensor thickness	between 0.1 mm and 0.8 mm
Maximum sensor width	11 mm

15.3 Operating the Sensit BT

The Sensit BT comes in two different versions;

Sensit BT.SPE		Sensit BT.SNS	
			
▪ Sensor pitch	2.54 mm	▪ Cable length	40 cm
▪ Electrode connections	2x CE, WE, RE	▪ Connectors	2 mm banana
▪ Allowed sensor thickness	between 0.1 and 0.8 mm	▪ Electrode connections	RE, WE, WE2, CE
▪ Maximum sensor width	11 mm		

The Sensit BT.SPE is compatible with common screen-printed electrodes with the following electrode configuration:



15.4 Sensit BT trigger button



Trigger button on Sensit BT

The Sensit BT trigger button is not supported natively in PStTrace, but can be used with custom MethodSCRIPTs. The button can be configured in such a way that each push starts a measurement and stores the measured data on the on-board storage.

See also section [MethodSCRIPT Sandbox](#) on page 107.

15.5 Sensit Smart and Sensit BT specifications

	Low Speed Mode	High Speed Mode	Max Range Mode
▪ dc-potential range	-1.2 to +2 V	-1.7 to +2 V	-1.7 to +2 V
▪ Dynamic dc-potential range *	2.2 V	1.2 V	2.6 V
▪ Compliance voltage	-2.0 to 2.3 V		
▪ Maximum current	± 3 mA		
▪ Max. acquisition rate (datapoints/s)	100	1000	100
▪ Supports FRA/EIS	NO	YES	NO

* The dynamic range is the range that can be covered during a single scan within the full potential range. For example, a linear scan can start at -1.5 V and end at 1.1 V or vice versa, covering 2.6 V dynamic range.

See www.palmsens.com/smart and www.palmsens.com/bt for detailed technical specifications.

Compliance voltage limitation

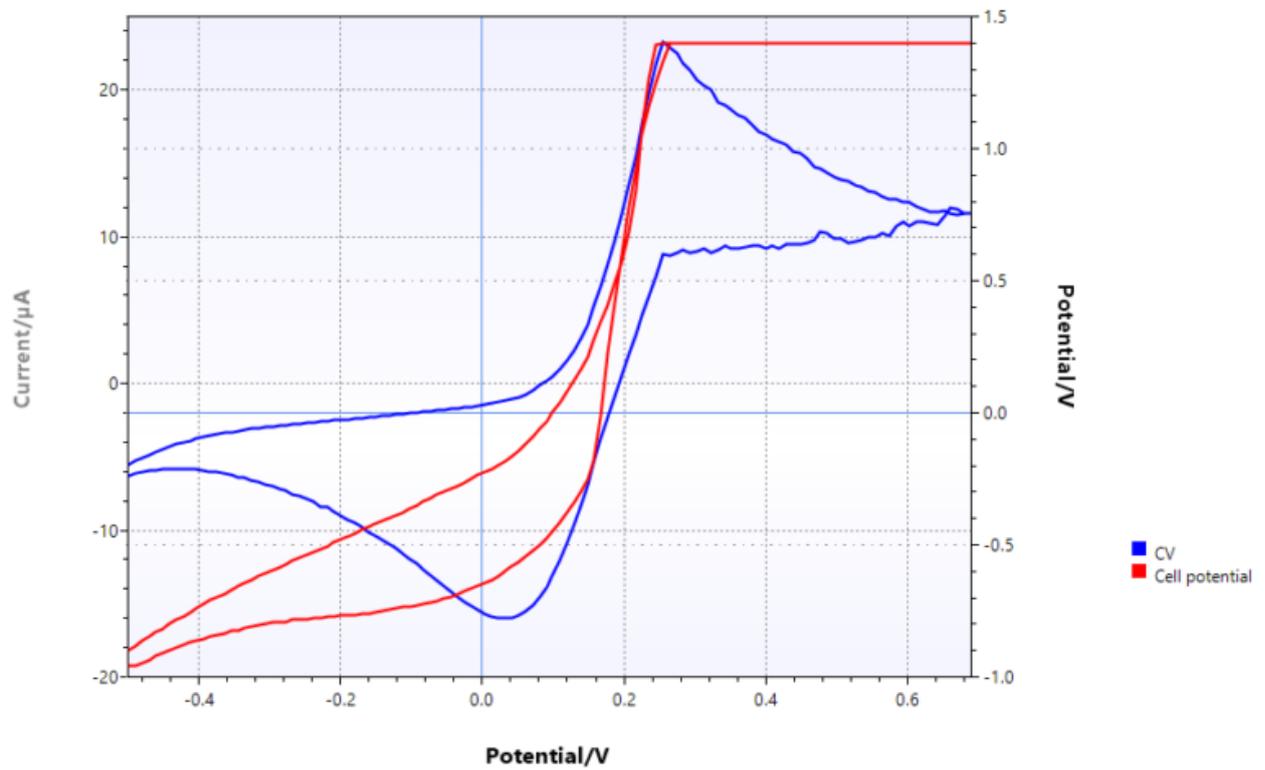
The Sensit series are based on the EmStat Pico modules which have a limited compliance voltage. The compliance voltage is the maximum voltage that can be applied between the working and counter electrode. Another name could be the maximum cell potential.

The Sensit series are based on the EmStat Pico modules which have a limited compliance voltage.

The higher the current at the working electrode, the higher the current required at the counter electrode. To increase the current the potentiostat increases the potential difference between the working and counter electrode. At some point, the maximum cell potential is reached and cannot be increased further.

This means the working electrode's potential might not be correct anymore, because the correct current cannot flow through the counter electrode anymore. The potentiostat ran into its compliance voltage. The potential of the working electrode will stay at the last value it could reach.

During DPV or SWV this means the differential is 0 and thus the curve shows a sudden drop in current and stays at 0. In a Cyclic Voltammogram reaching the compliance voltage is clearly visible. The constant potential will lead to a current following the Cottrell equation:



Typical CV showing an exceeded maximum compliance voltage

16 EmStat Pico based instruments



EmStat Pico potentiostat module

The EmStat Pico is a small potentiostat module which is available as separate product, but is also at the heart of housed instruments like the Sensit Smart and Sensit BT. EmStat Pico modules with correct license can be used with PSTrace.

16.1 EmStat Pico specifications

See www.palmsens.com/pico for EmStat Pico specifications.

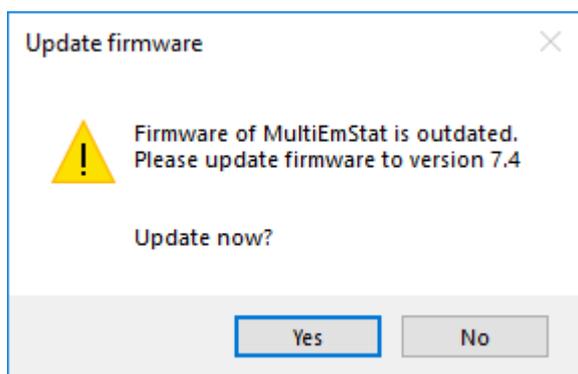
17 MultiPalmSens or MultiEmStat firmware update

The firmware which runs on MultiPalmSens or MultiEmStat might need to be updated when a new version of MultiTrace is installed. MultiTrace will automatically prompt a message and take care of the firmware update if this is necessary.

Manual firmware update

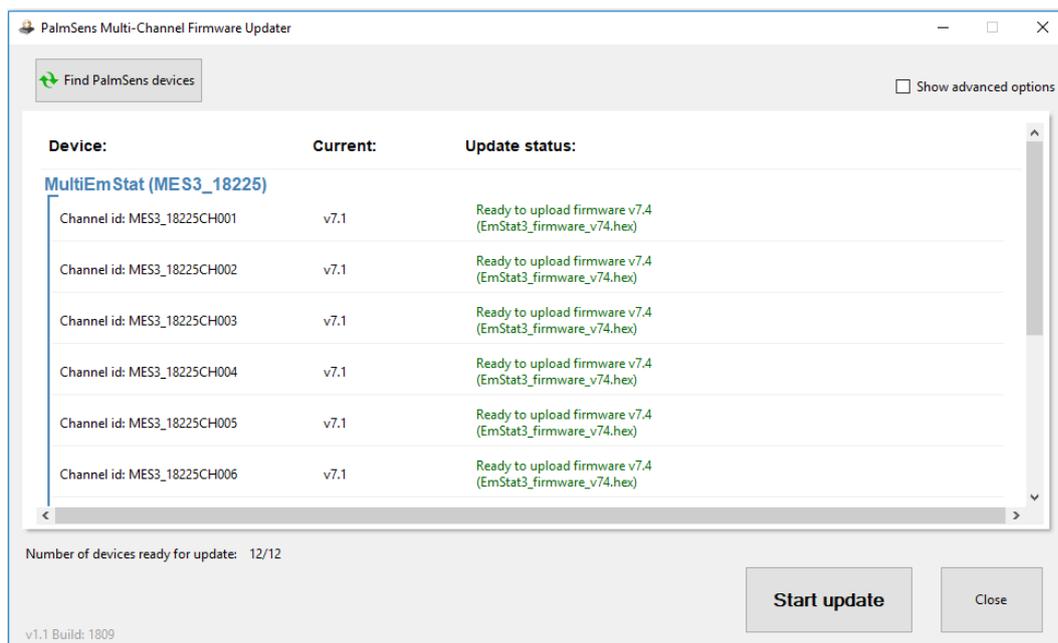
If a specific version of the firmware should be uploaded to the device, the firmware can be updated using the separate firmware update tool - MultiFirmwareUpdater.exe

Normally this should not be necessary because MultiTrace will prompt a message and take care of the firmware update if this is necessary.



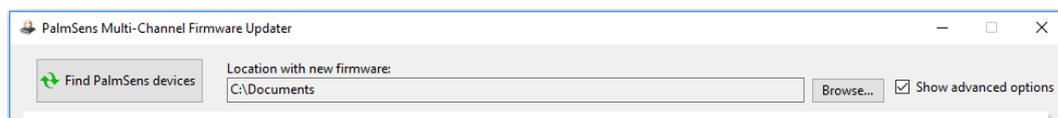
MultiTrace firmware outdated warning window

On click of 'Yes', the MultiTrace Firmware update window is shown.



Multi-channel firmware update window

If a specific version of the firmware is to be uploaded, the 'Show advanced options' checkbox has to be checked.



Multi-channel firmware updater that allows selecting the firmware file to be uploaded.

IMPORTANT:

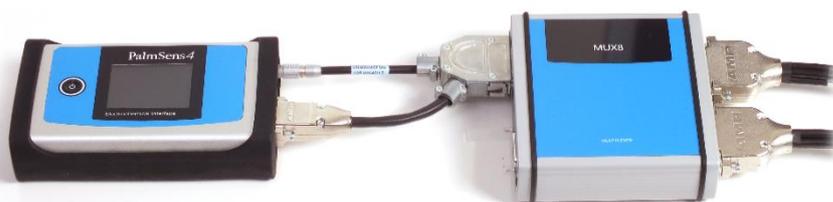
It is essential that the instrument is not switched off during the process of updating the firmware.

1. Click the 'Select firmware file' button and select the appropriate firmware file.
2. Press the 'Start update' button.
3. After completing the update, the program will show "UPDATE COMPLETE".

18 MUX8-R2 multiplexer

The MUX8-R2 multiplexer can be used to expand a PalmSens3, PalmSens4 or EmStat Blue potentiostat. Or the MUX8-R2 can have an integrated EmStat3 or EmStat3+ potentiostat.

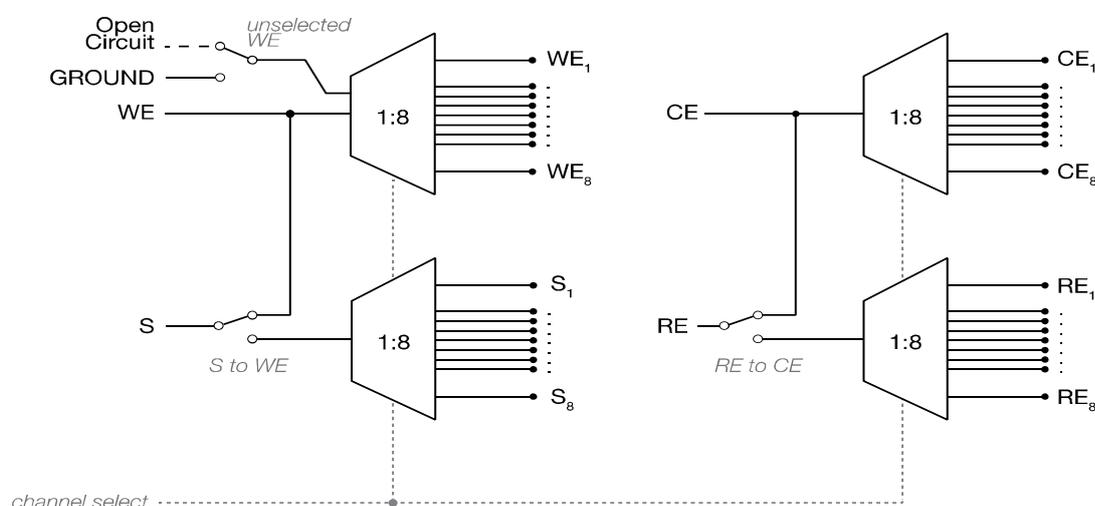
The multiplexer allows to increase productivity by automatically switching between multiple electrochemical cells each with their own WE, RE and CE electrodes.



PalmSens4 connected to MUX8-R2 multiplexer

The MUX8-R2 multiplexer is designed for up to 128 channels (by stacking a maximum of 16 MUX8-R2's) with 2- or 3- electrode sensors or cells.

18.1 MUX8-R2 Functional Diagram



18.2 Specifications

MUX8-R2 multiplexer	
▪ number of channels	8 (up to 128 channels when daisy chained)
▪ multiplexer	switches 8 x (WE, S, RE and CE)
▪ on resistance for WE	1.5 ohm typical
▪ charge injection on WE	20 pC typical
▪ leakage current	< 20 pA (5 pA typical) at 25 °C
▪ switching time	2 ms
▪ compliance voltage	±10 V

Limitations for Electrochemical Impedance Spectroscopy (EIS)	
▪ max. frequency	100 kHz when switching WE/S, RE and CE
	1 MHz when switching WE/S and RE+CE combined (2-electrode configuration)

18.3 Configurations

The MUX8-R2 multiplexer is designed for use up to 128 channels with 2- or 3-electrode sensors or cells.

The multiplexer can be used with different electrode or sensor configurations:

- 1 Eight separate cells or sensors each with a working/sense, reference and counter electrode
- 2 Eight separate cells or sensors each with a working/sense and combined reference and counter electrode
- 3 Cell or sensor array with eight working/sense electrodes sharing one reference and one counter electrode
- 4 Cell or sensor array with eight working/sense electrodes sharing one combined reference/counter electrode

In all configurations the cells can be multiplexed, leaving the non-selected working electrodes either at open circuit (individually floating) or at Ground potential.

When in configurations 3 and 4, the unselected channels are switched to Ground, they will have the working electrode's potential. This is due to the fact that the active WE is always at Ground potential.

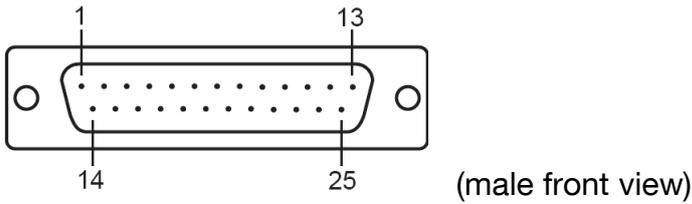
You can easily change the hardware configuration of the MUX8-R2 as part of the measurement settings in our PStace software or the PStouch app for Android.

The MUX8-R2 multiplexer settings can be changed in the Multiplexer tab.

18.4 Connections

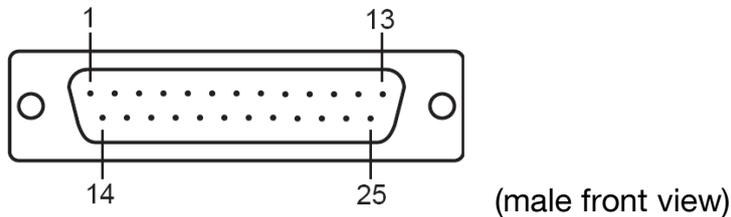
Connector	Function
Input	Y-cable connects to both potentiostat sensor connector and (digital) AUX
AUX	Can be used to measure auxiliary input like temperature or pH, and to switch external hardware using two digital control lines that can be set in PSTrace
Link	Connects to Input of next multiplexer, for daisy-chaining multiple multiplexers.
USB-C	For providing extra power in case more than 2 multiplexers are connected to a single instrument.
Channel 1-4	Connects to sensor cables 1-4
Channel 5-8	Connects to sensor cables 5-8

18.5 MUX8-R2 Pin-outs



Channel 1-4

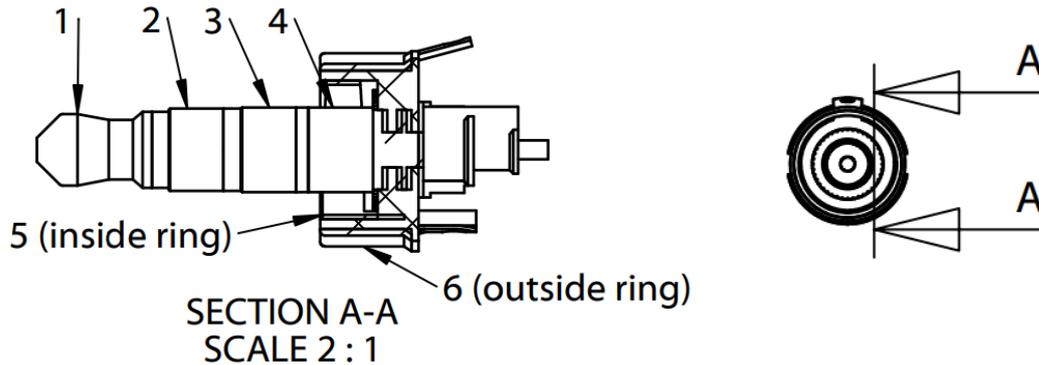
Pin	Function	Pin	Function	Pin	Function
1	CE4	11	RE1	21	AGND
2	RE4	12	RE_SHIELD1	22	SENSE2
3	RE_SHIELD4	13	NC	23	WE1
4	CE3	14	WE4	24	AGND
5	RE3	15	AGND	25	SENSE1
6	RE_SHIELD3	16	SENSE4		
7	CE2	17	WE3		
8	RE2	18	AGND		
9	RE_SHIELD2	19	SENSE3		
10	CE1	20	WE2		



Channel 5-8

Pin	Function	Pin	Function	Pin	Function
1	CE8	11	RE5	21	AGND
2	RE8	12	RE_SHIELD5	22	SENSE6
3	RE_SHIELD8	13	NC	23	WE5
4	CE7	14	WE8	24	AGND
5	RE7	15	AGND	25	SENSE5
6	RE_SHIELD7	16	SENSE8		
7	CE6	17	WE7		
8	RE6	18	AGND		
9	RE_SHIELD6	19	SENSE7		
10	CE5	20	WE6		

AUX port:



Ring	Lead color	Function
1	Red	NC
2	Black	D0 (digital I/O)
3	Yellow	Analog Input
4	White	D1 (digital I/O)
5	Green	GND
6	Blue	5V

18.6 Stacking

Each multiplexer has a Link connector which can be used to daisy chain to another MUX8-R2 multiplexer, expanding the number of channels. A maximum of 16 multiplexers can be connected in a daisy chain, giving a maximum of 128 channels. The PSTrace software detects automatically how many multiplexers are daisy chained and shows the available number of channels in the user interface.



The MUX8-R2 has magnetic feet and magnets in the top for easy stacking

19 Appendix A – CE Declarations



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 www.palmsens.com

Chamber of Commerce
 Utrecht: 55590705

EU DECLARATION OF CONFORMITY

Certificate number: PS220223D

PalmSens BV declare that the product:

PalmSens 4: (PS4 V1.4 and higher)

- Portable electrochemical analyser
- USB power and communications
- Battery power
- Bluetooth communication
- Screen display



conforms with the (EMC) Directive 2014/30/EU, 2014/53/EU (RED) and applicable standards for *Electrical equipment for measurement control and laboratory use* (standards listed below)

Standard		Class / level
EN 61326-1 (2013), EN 301 489-01 V2.1.1 & EN 301 489-03 V1.6.1	Emission	B
EN 61326-1 (2013), EN 301 489-01 V2.1.1 & EN 301 489-03 V1.6.1	Immunity	3V/m

Tests performed

Test	Test standard	Result (Pass/Fail)
Radiated emission up to 1 GHz (SAC)	EN 55032 (2015) + AC (2016)	Pass
Radiated Immunity	EN-IEC 61000-4-3 (2006) + A1 (2008) + A2 (2010)	Pass
ESD	EN-IEC 61000-4-2 (2009)	Pass

Date: 23rd of February 2022

C.J. van Velzen, CTO

Notes:

This declaration is issued under the sole responsibility of the PalmSens BV.
 Instrument must be used with the recommended shielded USB cable.



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EU DECLARATION OF CONFORMITY

Certificate number: PS220223C

PalmSens BV declare that the product:

EmStat4S HR/LR:

- Portable electrochemical analyser
- USB power and communications



conforms with the (EMC) Directive 2014/30/EU
 applicable standards for *Electrical equipment for measurement control and laboratory use*
 (standards listed below)

Standard		Class / level
EN 61326-1 (2013)	Emission	B
EN 61326-1 (2013)	Immunity	Basic EM environment

Tests performed

Test	Test standard	Result (Pass/Fail)
Radiated emission up to 1 GHz (TEM cell)	EN 55011 (2009) + A1 (2010)	Pass
Radiated Immunity	EN-IEC 61000-4-3 (2006) + A1 (2008) + A2 (2010)	Pass

Date: 23rd of February 2022

C.J. van Velzen, CTO

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EU DECLARATION OF CONFORMITY

Certificate number: PS220223E

PalmSens BV declare that the product:

Sensit BT:

- Portable electrochemical analyser
- USB power and communications
- Battery power
- Bluetooth communications



conforms with the (EMC) Directive 2014/30/EU applicable standards for *Electrical equipment for measurement control and laboratory use* (standards listed below)

Standard		Class / level
EN 61326-1 (2013)	Emission	B
EN 61326-1 (2013)	Immunity	Basic EM environment

Tests performed

Test	Test standard	Result (Pass/Fail)	Note
Radiated emission up to 1 GHz (TEM cell)	EN 55011 (2009) + A1 (2010)	Pass	
Radiated Immunity	EN-IEC 61000-4-3 (2006) + A1 (2008) + A2 (2010)	Pass	
ESD	EN-IEC 61000-4-2 (2009)	Pass	Tests conducted on EmStat Pico

Date: 23rd of February 2022

C.J. van Velzen, CTO

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EU DECLARATION OF CONFORMITY

Certificate number: PS220223F

PalmSens BV declare that the product:

Sensit Smart:

- Portable electrochemical analyser
- USB power and communications



conforms with the (EMC) Directive 2014/30/EU applicable standards for *Electrical equipment for measurement control and laboratory use* (standards listed below)

Standard		Class / level
EN 61326-1 (2013)	Emission	B
EN 61326-1 (2013)	Immunity	Basic EM environment

Tests performed

Test	Test standard	Result	Note
Radiated emission up to 1 GHz (TEM cell)	EN 55011 (2009) + A1 (2010)	Pass	
Radiated Immunity	EN-IEC 61000-4-3 (2006) + A1 (2008) + A2 (2010)	Pass	
ESD	EN-IEC 61000-4-2 (2009)	Pass	Tests conducted on EmStat Pico

Date: 23rd of February 2022

C.J. van Velzen, CTO

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EU DECLARATION OF CONFORMITY

Certificate number: PS220223A

PalmSens BV declare that the product:

EmStat Go: (V1.2 and higher)

- Portable electrochemical analyser
- USB power and communications
- Battery power
- Bluetooth communication



conforms with the (EMC) Directive 2014/30/EU applicable standards for *Electrical equipment for measurement control and laboratory use* (standards listed below)

Standard		Class / level
EN 61326-1 (2013)	Emission	B
EN 61326-1 (2013)	Immunity	Basic EM environment

Tests performed

Test	Test standard	Result (Pass/Fail)
Radiated emission up to 1 GHz (SAC)	EN 55011 (2009) + A1 (2010)	Pass
Radiated Immunity	EN-IEC 61000-4-3 (2006) + A1 (2008) + A2 (2010)	Pass
ESD	EN-IEC 61000-4-2 (2009)	Pass

Date: 23rd of Feb 2022

C.J. van Velzen, CTO

This declaration is issued under the sole responsibility of the PalmSens BV.

Instrument must be used with the recommended shielded USB cable.



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EU DECLARATION OF CONFORMITY

Certificate number: PS220524A

PalmSens BV declare that the product:

MultiPalmSens4: (MPS4)

- Multi-channel electrochemical analyser
- USB communications
- Mains adaptor power
- Galvanic isolation option



conforms with the (EMC) Directive 2014/30/EU, (LVD) (2014/35/EU) and applicable standards for *Electrical equipment for measurement control and laboratory use* (standards listed below)

Standard		Class / level
EN 61326-1 (2013)	Emission	B
EN 61326-1 (2013)	Immunity	Basic EM environment

Tests performed

Test	Test standard	Result (Pass/Fail)	Note
Radiated emission up to 1 GHz (SAC)	EN 55011 (2009) + A1 (2010)	Pass	
EFT	EFT EN61000-4-4 AC mains 1 Phase	Pass	
Radiated Immunity	EN-IEC 61000-4-3 (2006) + A1 (2008) + A2 (2010)	Pass	
ESD	EN-IEC 61000-4-2 (2009)	Pass	Performed on PS4

Date: 24th of May 2022

C.J. van Velzen, CTO

This declaration is issued under the sole responsibility of the PalmSens BV.

20 EU Waste Electrical and Electronic Equipment (WEEE) Directive



The pictogram shown above, located on the product(s) and / or accompanying documents means that used electrical and electronic equipment (WEEE) should not be mixed with general household waste. For proper treatment, recovery and recycling, please take this product(s) to designated collection points where it will be accepted free of charge.

Alternatively, in some countries, you may be able to return your products to your local retailer upon purchase of an equivalent new product. Disposing of this product correctly will help save valuable resources and prevent any potential negative effects on human health and the environment, which could otherwise arise from inappropriate waste handling. Please contact your local authority for further details of your nearest designated collection point. Penalties may be applicable for incorrect disposal of this waste, in accordance with your national legislation.

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