EL-CELL®
electrochemical test equipment

User Manual
EL-Software

Release 1.03

Software for PAT battery testers

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1 What is EL-Software?

EL-Software is a software platform to control all EL-CELL battery testers. It covers all relevant steps of:

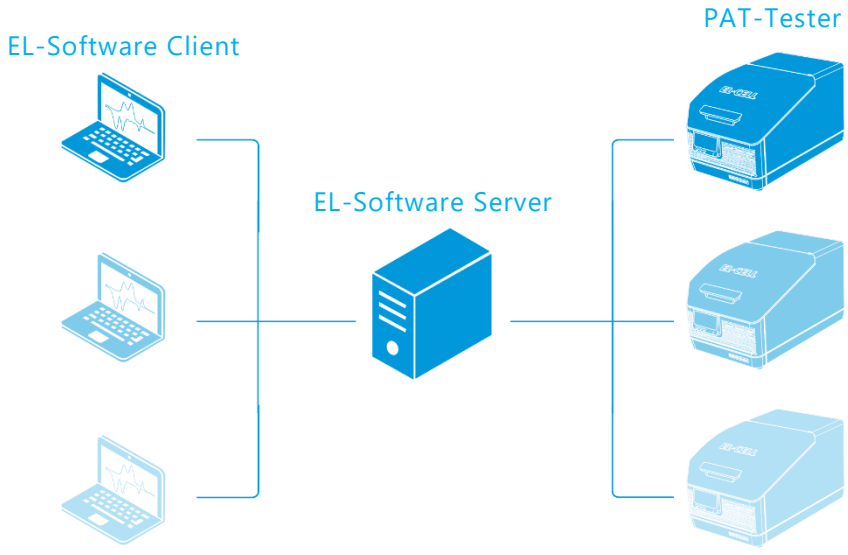
- Experiment setup
- Defining of test procedures
- Controlling and monitoring of connected battery testers and running experiments
- Viewing test results

2 Setting up EL-Software

EL-Software consists of two separate applications, a server and a client component. The server component communicates with the connected PAT-Tester devices and hosts the database. The client component offers the graphical user interface for setting up and controling experiments and for data exchange with the server.

Example for medium to large scale applications: Setup with dedicated server

The following image shows the recommended and probably most typical hardware setup for EL-Software.

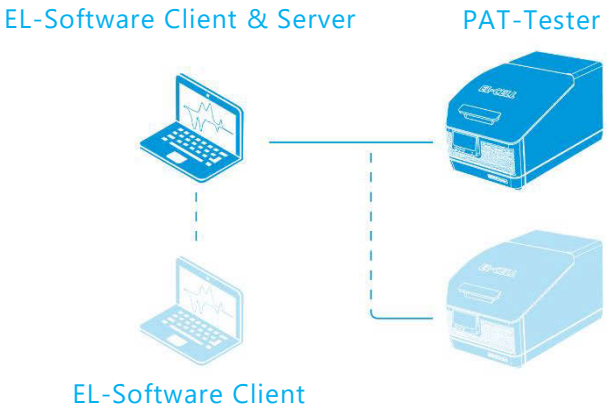


A dedicated PC hosts the server application. It controls one or more PAT-Tester devices and offers access for multiple PCs running the client application. This setup is easily scalable and recommended for a multiuser, multidevice environment.

Example for small scale applications: Setup without dedicated server

In this setup, the server and client application are installed on the same PC. This setup is suitable for smaller setups with a small numbers of channels connected. It is basically possible to connect additional PAT testers and client PCs in this configuration, but we only recommend it to a limited extent, as it can quickly lead to performance limitations.

Please note that the PC that hosts the server application needs to be permantely accessible while an experiment is running.



2.1 Requirements for running EL-Software

General requirements

Network configuration

The PC running the EL-Software server application needs a permanent ethernet connection with at least 1 GBit to the connected PAT-Tester devices. It is strongly advised to use an ethernet switch for these connections. A direct connection between the ethernet ports of the PC and the PAT-Tester is not supported.

The client PCs only need a network connection to the server application. They do not need a connection to the PAT-Tester devices.

All devices need an IPv4 address, either as static address or dynamically assigned via DHCP.

If using a firewall, the following ports need to be opened:

Server application:

TCP: 4711

UDP: 1900

PAT-Tester:

TCP: 4712, 2113, 1113, 22

UDP: 1900

Server application

Minimum hardware requirements:

- CPU: Recent x86/AMD64 processor
- System memory: 8 GB RAM
- Storage: 1 TB HDD
- System availability: Requires continuous availability during ongoing experiments
- Virtualization: Supported
- 1 Gbit LAN connection to PAT-Tester via ethernet switch

Minimum software requirements:

- Windows Server 2012 or newer, Windows 10 version 1809 or newer or Linux Ubuntu 18.04 (only for use as dedicated server)
- Microsoft .NET Framework 4.7.2 if using a Windows operating system

Client application

Minimum hardware requirements:

- CPU: Recent x86/AMD64 processor
- System memory: 4 GB RAM
- Storage: 200 MB HDD
- Virtualization: Supported
- Monitor with 1366 pixel x 768 pixel screen resolution

Minimum software requirements:

- Windows Server 2012 or newer, Windows 10 version 1809 or newer
- Microsoft .NET Framework 4.7.2

2.2 Server Hardware Recommendations for EL-Software

Battery tests can lead to very different requirements on the server hardware used, depending on the selected test procedure and chosen settings for recording data. Normal cyclisation of a test cell usually generates much less load than, for example, a PEIS/GEIS measurement over a longer period of time, since much more data points are generated.

Our recommendations should therefore be regarded as a general guideline.

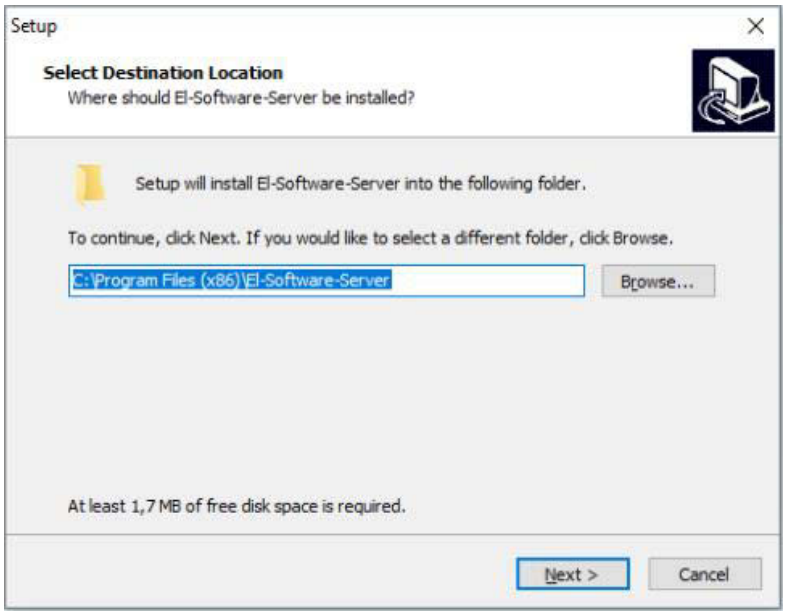
Number of Test channels	**Low record settings (e.g. usual battery cycling)**	**High record settings (e.g. for frequent GEIS/PEIS)**
1 (e.g. PAT-Tester-x with single PAT-Channel)	Single-Core CPU / 8 GB RAM / 1 TB HDD	Dual-Core CPU / 8 GB RAM / 1 TB HDD
8 (e.g. PAT-Tester-x fully equipped)	Dual-Core CPU / 8 GB RAM / 1 TB HDD	Quad-Core CPU / 8 GB RAM / 1TB SSD
16 (e.g. PAT-Tester-i-16 fully equipped)	Quad-Core CPU / 8 GB RAM / 1 TB HDD	Eight-Core CPU / 8 GB RAM / 1 TB SSD

3 Installing and Deinstalling EL-Software

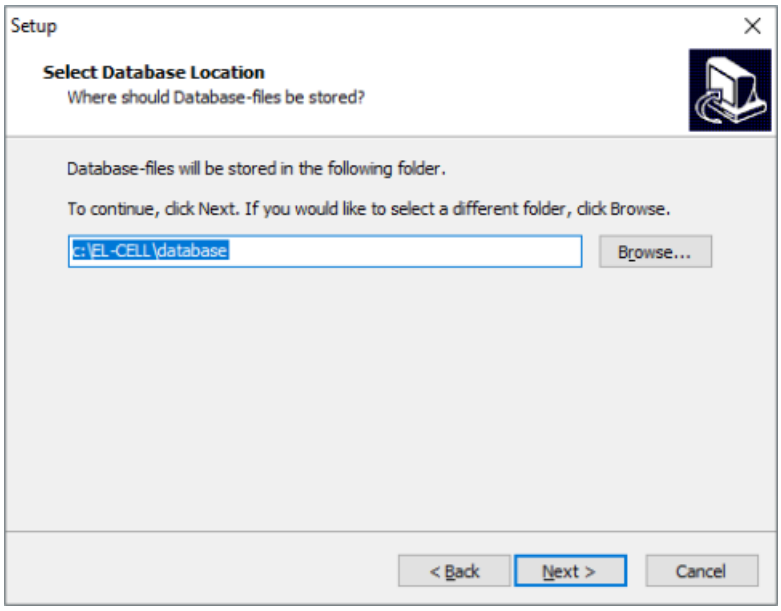
3.1 Installing EL-Software on Microsoft Windows

1. Install the EL-Software server component by doubleclicking the provided Setup-elsoftware.server.exe.

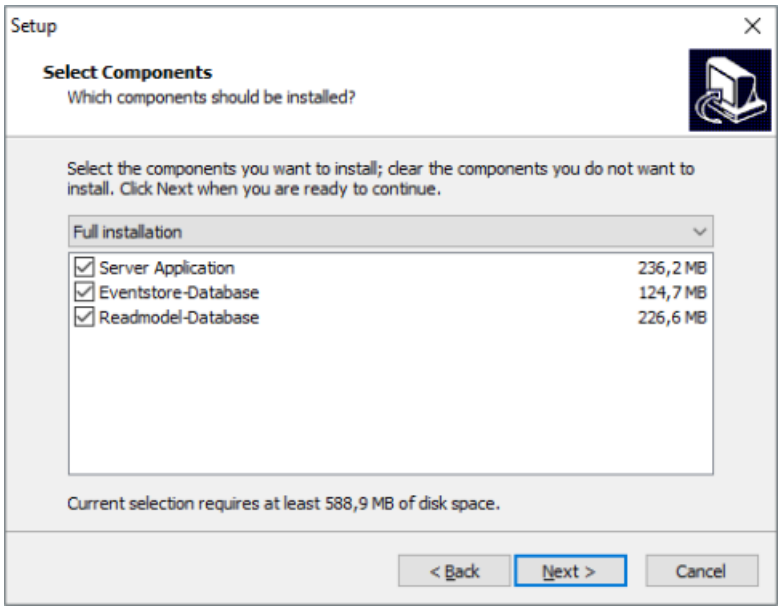
1.1 Choose the destination folder for the software installation or use the default setting.



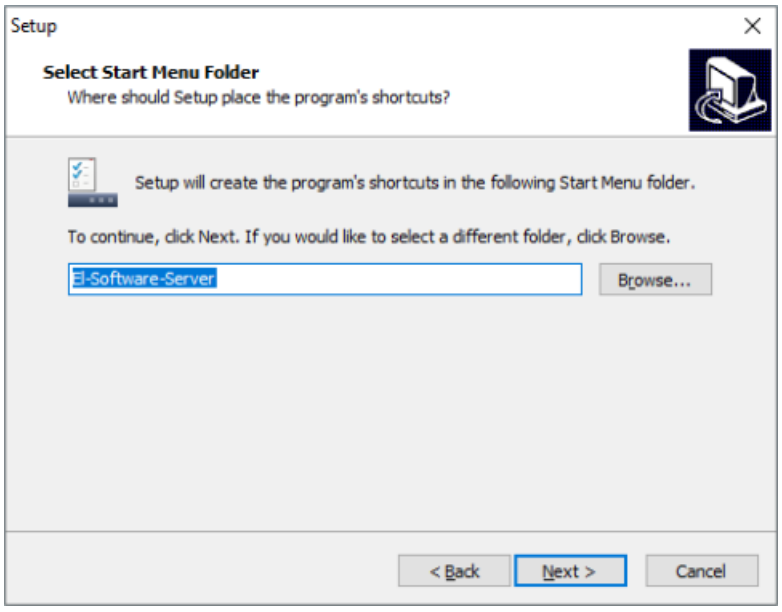
1.2 Choose the destination folder for the database installation or use the default setting.



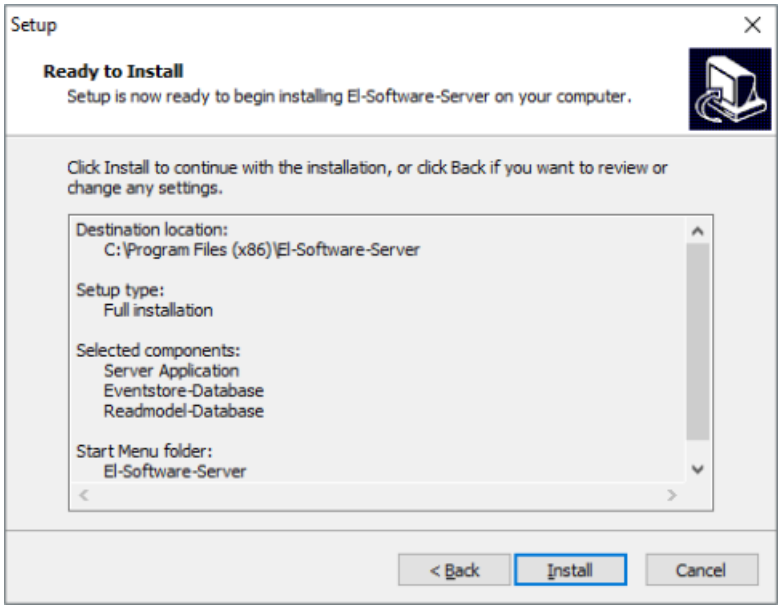
1.3 Confirm the installation of the selected components. If you are installing EL software on this machine for the first time, you must select "Full Installation" and leave all options enabled.



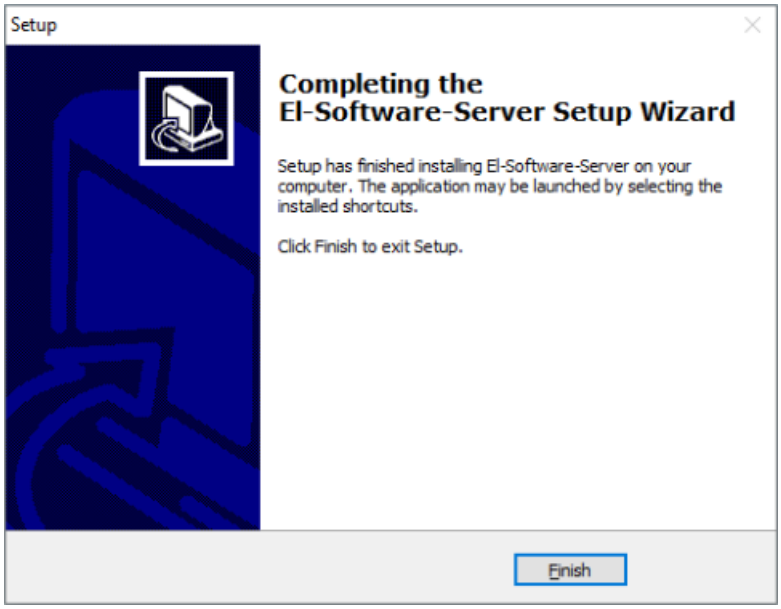
1.4 Select the name you want to use for the EL-Software server in the Start menu or leave it at the default value.



1.5 Click “Install” to start the installation process.



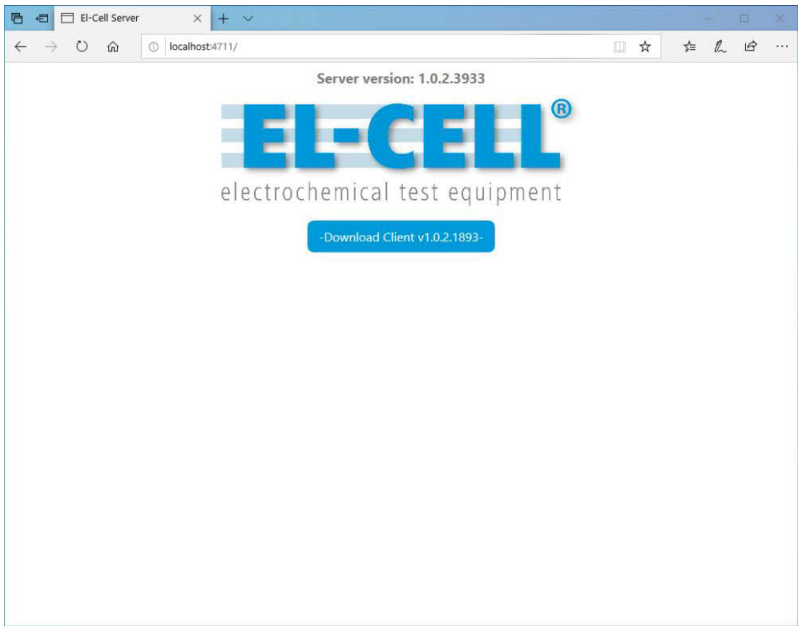
1.6 Click on “Finish” once the installation is complete.



2. Install the EL-Software Client.

2.1 Open a web browser and establish a connection to the server pc on port 4711 by entering http://*******:4711 in the address line, if you are installing the client on a separate pc (replace the asterisks by your server name). Use **http://localhost:4711** if installing the client on the same computer as the server.

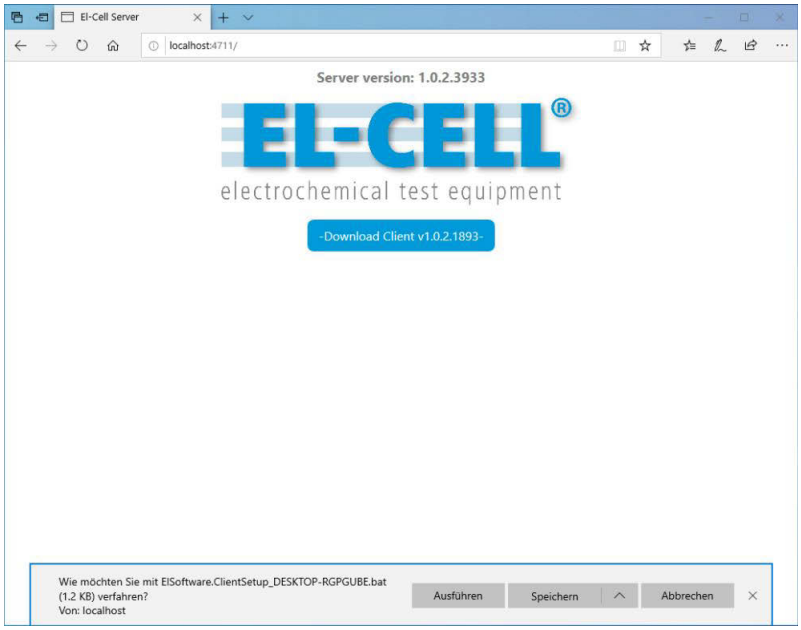
A website will appear.



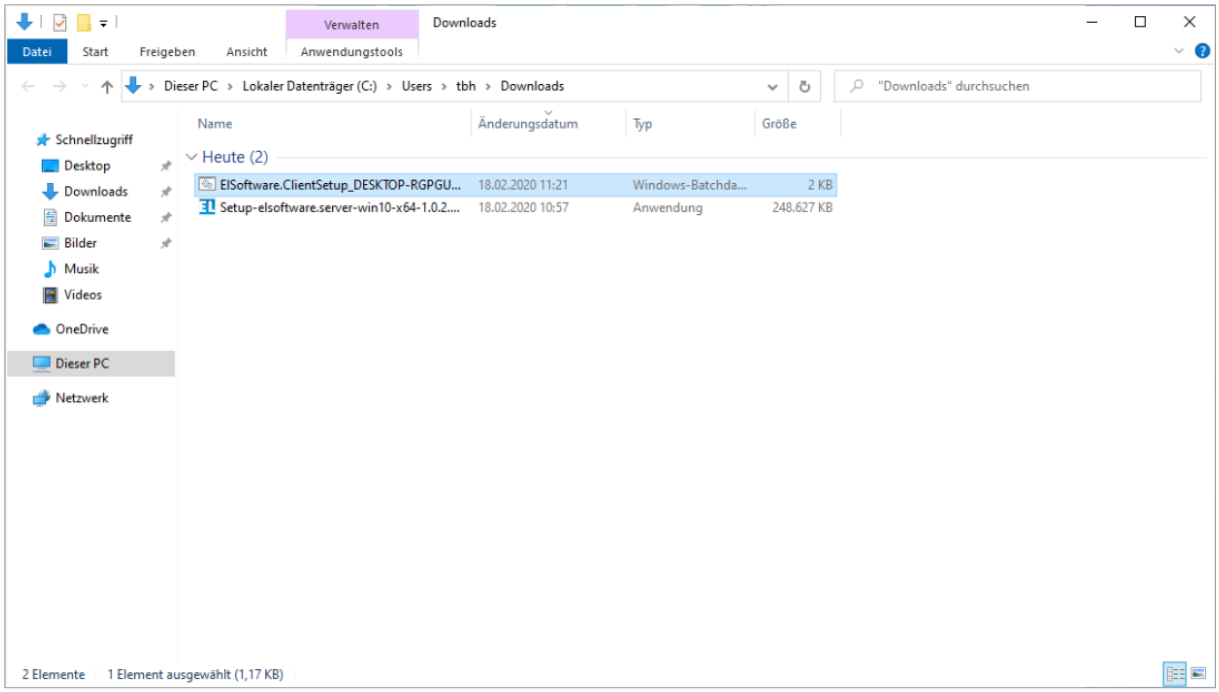
Troubleshooting:

If the connection to the server fails, check your port clearances in the firewall settings.

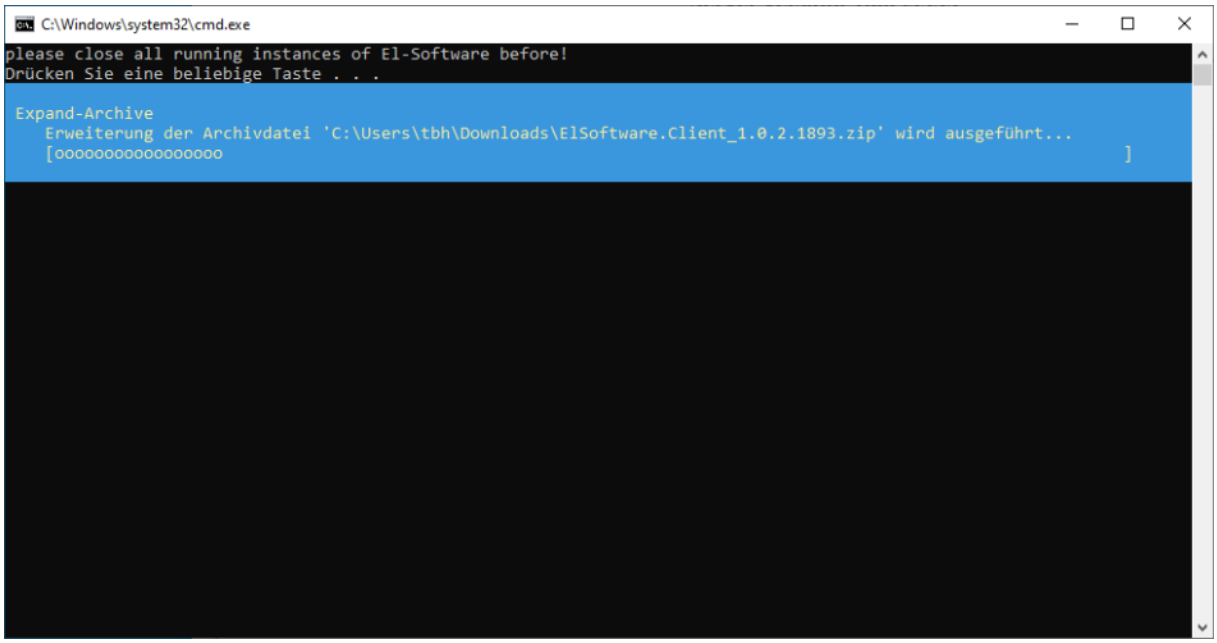
2.2 Click the button to download the installer batch file. Click on “Save”.



2.3 Open the file location and execute the downloaded installer batch (.bat) file.



2.4 The windows command console opens. Press any key to start the installation process.



Troubleshooting:

If you have problems installing the client, check the settings of your virus scanner. We recommend you to disable your virus scanner temporarily before installing the software, otherwise it might block the execution of the batch file or installed progam files.

2.5 The EL-Software client will start automatically once the installation is complete.

3.2 Deinstalling EL-Software on Microsoft Windows

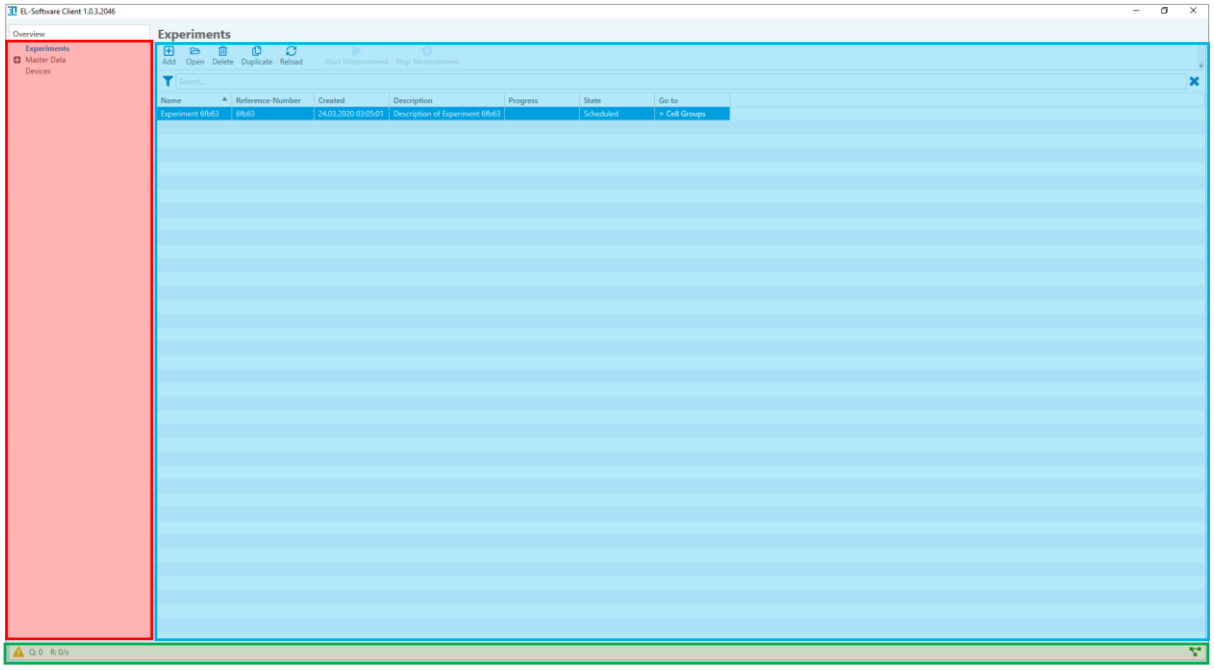
In order to remove EL-Software from your computer:

1. Navigate to the following folder: *C:\Users\YOUR_USER_NAME\AppData\Local*
2. Delete the folder "ElSoftware.Client_VERSIONNUMBER" and all its content.
3. Navigate to the folder *C:\Users\YOURUSERNAME\AppData\Roaming\Microsoft\Windows\Start Menu\Programs*
4. Delete the "EL-Software YOUR_SERVER_NAME" link file to remove the entry in the windows start menu.

4 EL-Software User Interface

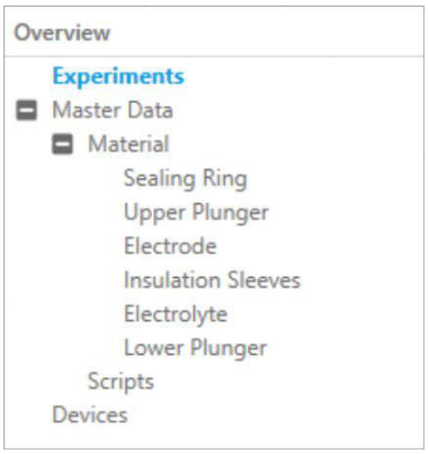
The user interface is organized into different areas.

- The Overview (red) on the left is used for navigating between the main views of the software.
- The content area (blue) to the right shows the selected view content. All commands inside a view are executed either by using the toolbar at the top or directly in the content area. If a content section comprises several pages, these can be selected via a tab-based navigation.
- The status bar (green) shows error logs, tooltips and the network connectivity status.



4.1 Overview

Experiments: Display all experiments. It is used to setup and monitor experiments.



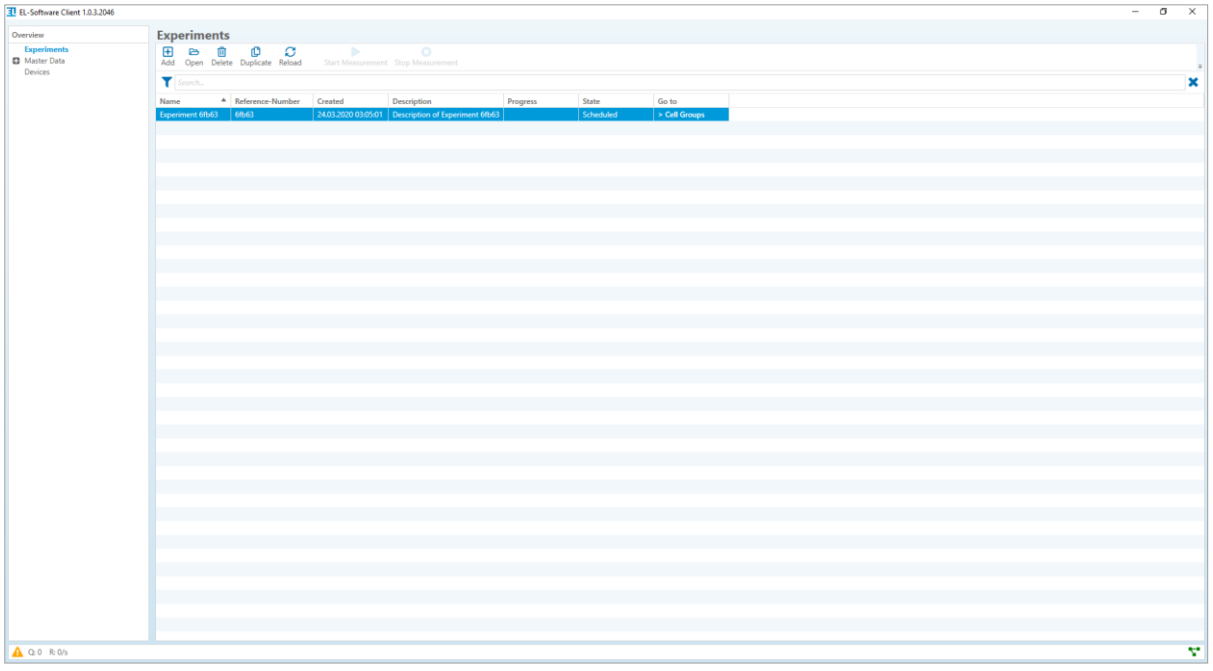
Master Data: Display the Master Data view. Master Data is the database of EL-Software.

Material: Contains records of cell components needed for building a test cell.

Scripts: Contains all saved test procedures.

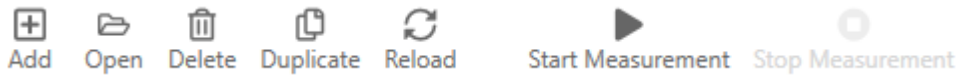
Devices: Display the device view for managing the connected testing devices.

4.2 Experiments View

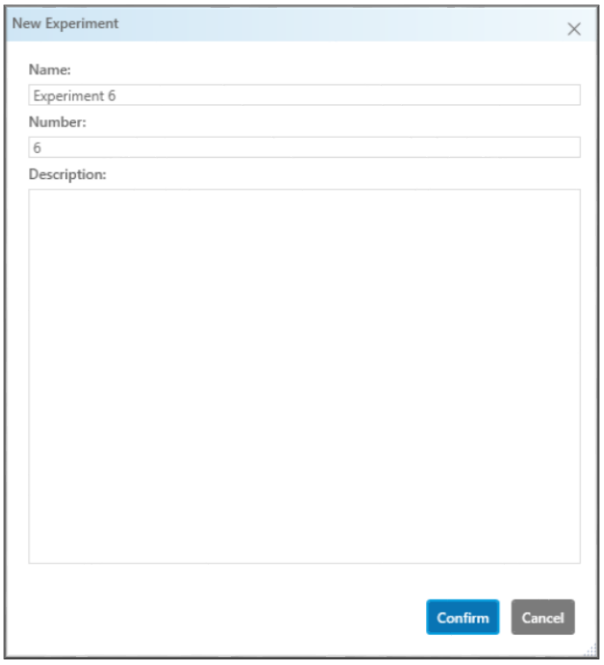


The experiments view lists all created experiments showing their progress and status.

Experiments list toolbar options:



Add: Open a dialog for creating a new experiment:



Name (required): Enter a custom name for the experiment. (3-50 characters)

Number: Default shows a automatically generated number.

Description: Enter a description of the experiment.

Open: Open a selected experiment from the list. Changes to the experiment details view.

Delete: Delete the selected experiment.

Duplicate: Create a duplicate of the selected experiment. (Test cells need new assignment in order to start this new experiment)

Reload: Refresh the list.

Start Measurement: Start the selected experiment if all requirements are met.

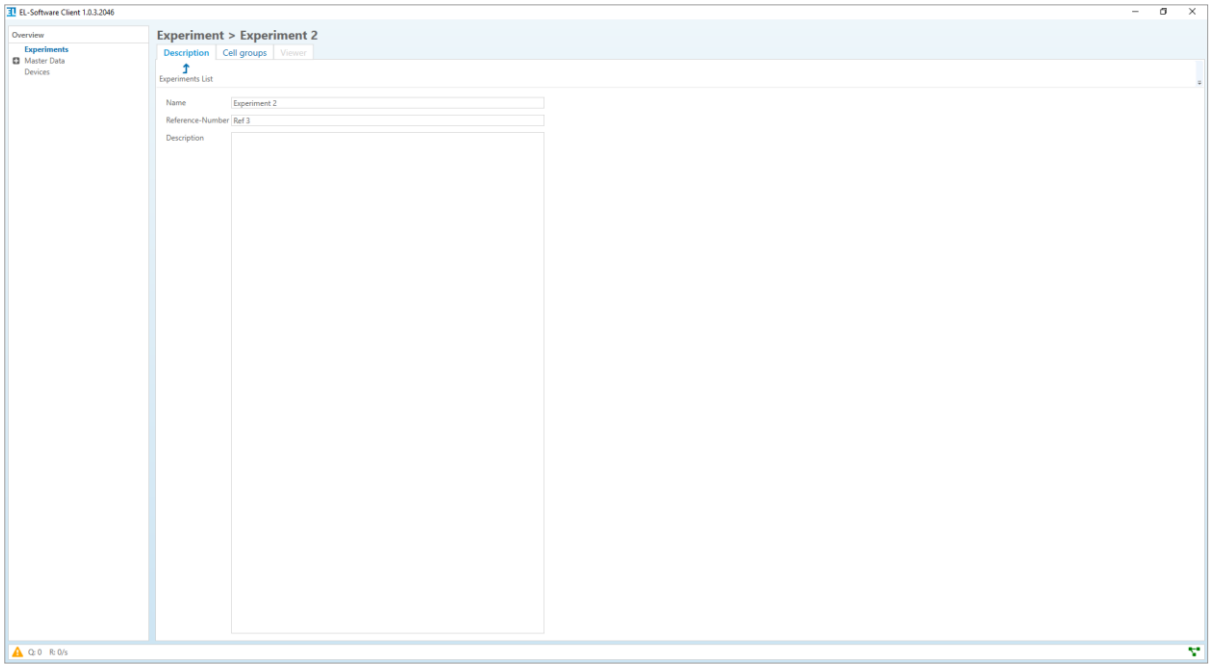
Stop Measurement: Stop a running experiment.

4.2 Experiments \

4.2.1 Experiment Details

The Experiment Details view contains all relevant information of a selected experiment. It also offers all options for setting up a new experiment and monitoring the test cells once the experiment has started. Its content is organised in three tabs.

4.2.1.1 Description tab



The Description Tab shows editable information of the experiment.

Description tab toolbar options:

Experiments list: Return to the experiments list view.

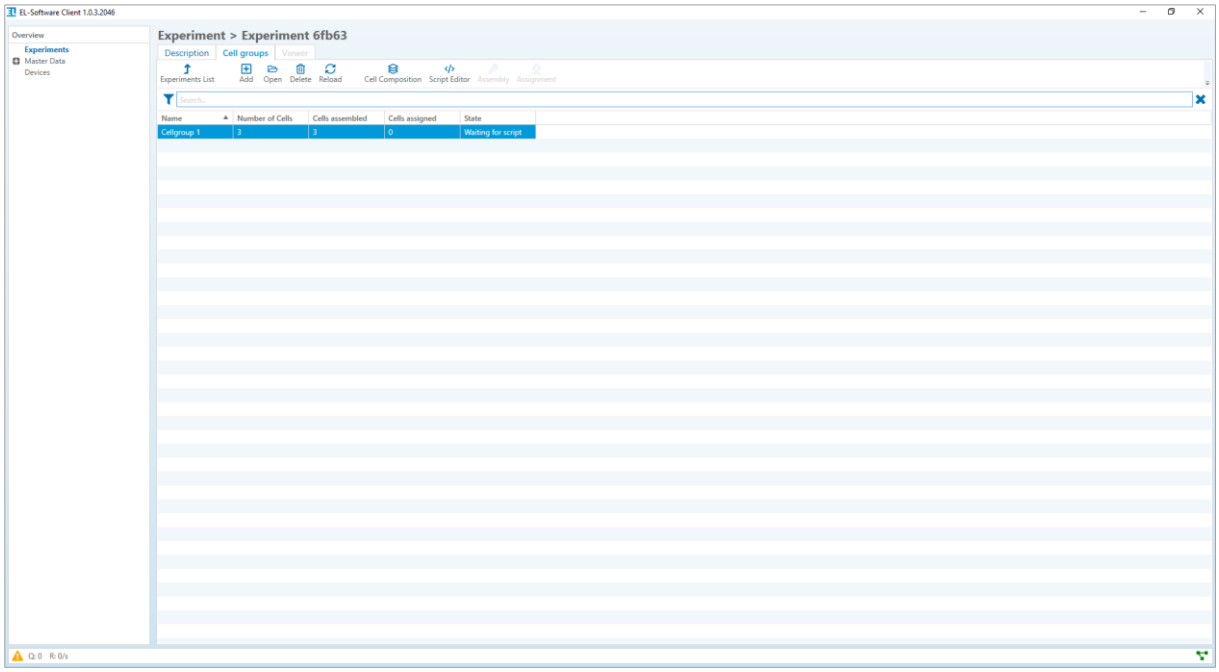
Content parameters:

Name (required): Enter a custom name for the experiment. (3-50 characters)

Number: Enter a number or leave the automatically generated number.

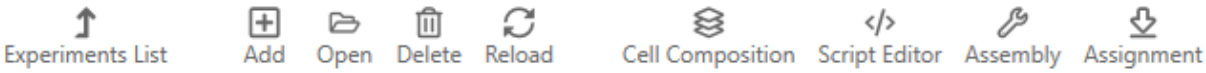
Description: Enter an optional description of the experiment.

4.2.1.2 Cell Groups tab



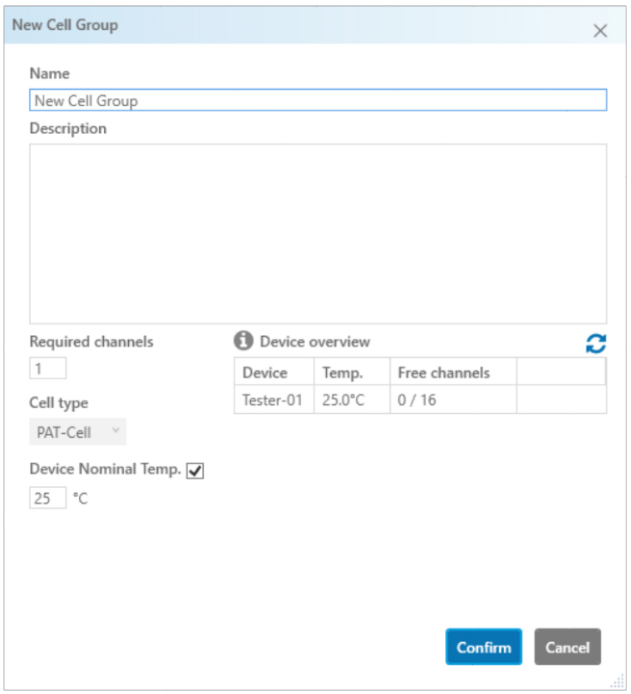
The Cell Groups tab shows a list of all cell groups of the experiment. In general, this tab covers all options of the definition and management of cell groups.

Cell Groups toolbar options:



Experiments list: Return to the experiments list view.

Add: Open a dialog for creating a new experiment:



Name (required): Enter a custom name for the cell group. (3-50 characters)

Description: Enter a description of the cell group.

Required channels (required): Enter a number for the required test channels for this cell group.

Cell type: Choose the cell type for this cell group.

Device Nominal Temp.: If checked, the measurement will only be started, if the given temperature agrees with the setpoint of the corresponding PAT-Tester channel.

If unchecked, the temperature of the test channels will not be taken into account.

Device overview: Shows all available testing devices, their current temperature and free test channels.

Open: Open the selected cell group.

Delete: Delete the selected cell group.

Reload: Reload this view.

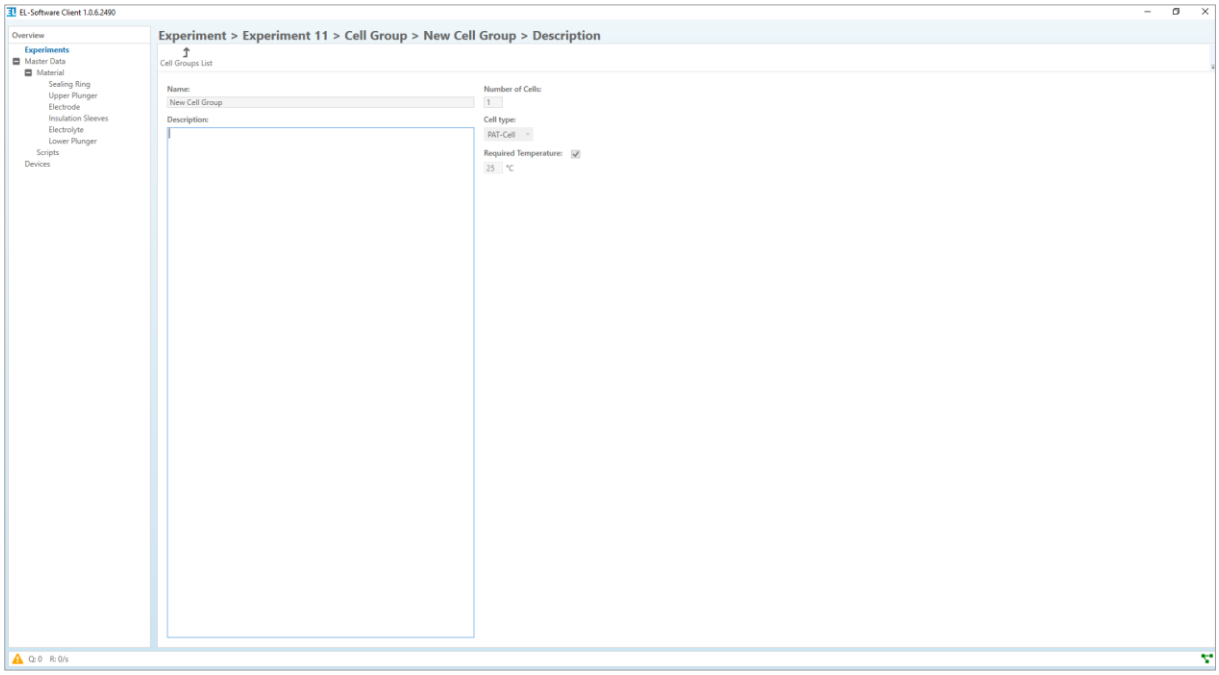
Cell Composition: Open to the cell composition view for defining the cell components for all test cells of this group.

Script Editor: Open the Script Editor for assigning test procedures for this cell group.

Assembly: Open the assembly view for entering electrode weights of the test cells of this cell group.

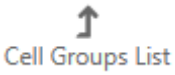
Assignment: Open the Assignment list for assigning the cells of the cell group to free test channels.

4.2.1.2.1 Cell Groups List



The Cell Groups List offer general information about the selected Cell Group of an experiment.

Cell Groups List toolbar options:



Cell Groups List: Return to the Cell Groups list view.

Content parameters:

Name: Display the name of the Cell Group specified during creation (Read-only).

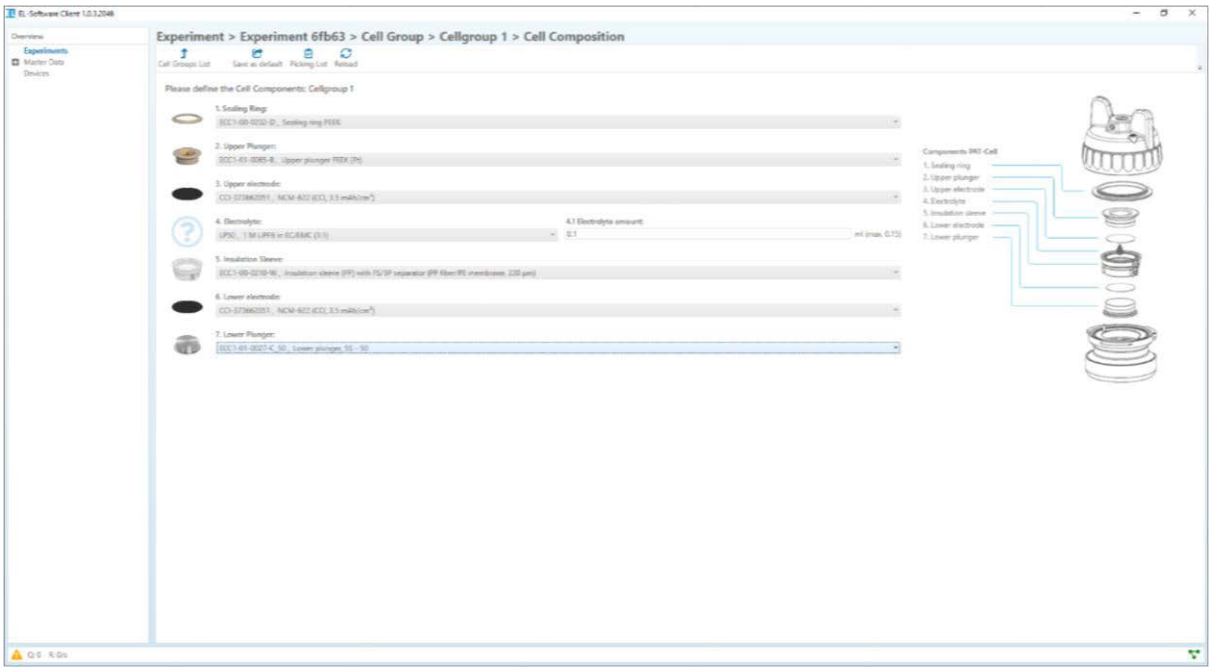
Description: Enter an optional description of the experiment.

Number of Cells: Display the number of cell in this Cell Group (Read-only).

Cell type: Display the cell type used in this Cell Group (Read-only).

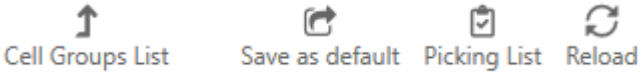
Required Temperature: Show the temperature requirements for this Cell Group as specified in the creation dialog (Read-only).

4.2.1.2.2 Cell composition



The required components of the test cells are specified in the Cell Composition view.

Cell composition toolbar options:



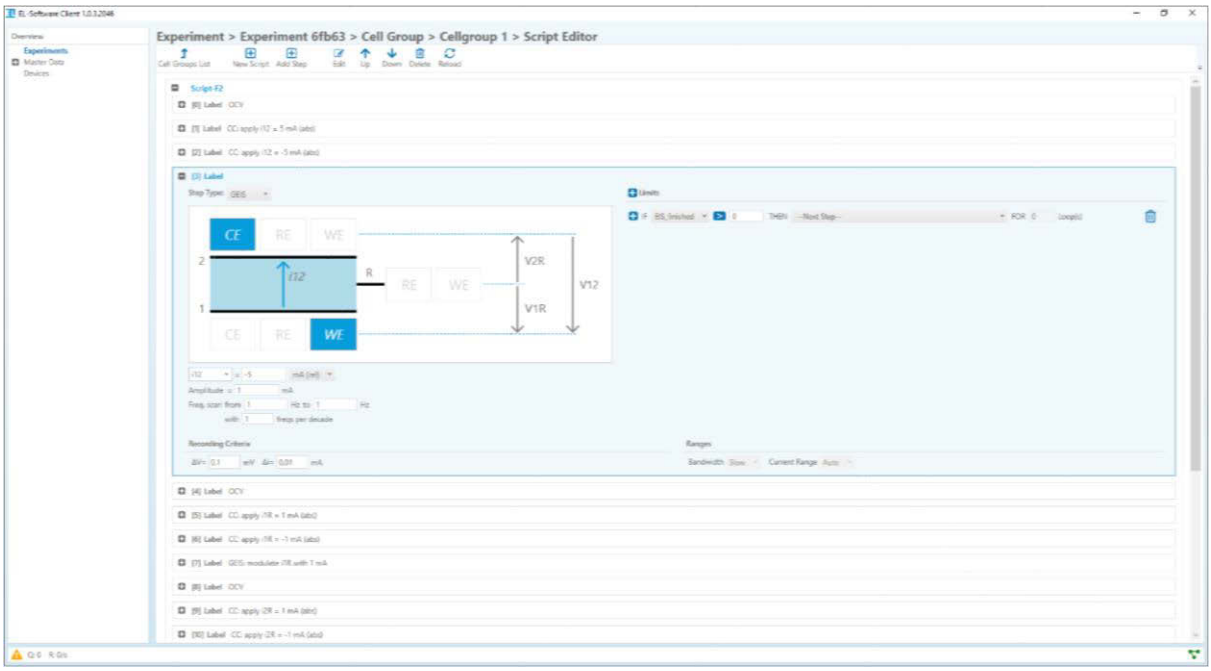
Cell Groups List: Return to the Cell Groups list view.

Save as default: Specify the current selection of cell components as global default.

Picking List: Open a html list in an external web browser with the required cell components for this cell group.

Reload: Reload this view.

4.2.1.2.3 Script Editor



The Script Editor is used to create test procedures for the selected cell group. Test procedures can be saved as templates for further use with other cell groups or experiments.

The Script Editor can be entered from inside an experiment or from the Master Data, and differs slightly in functionality.

If entered from inside an experiment, the created test script will be automatically attached to the opened experiment. It is not automatically stored to the data base, but can be exported to Master Data for future use. Furthermore it is possible to create multiple scripts inside the editor to create very complex procedures.

If entered from the Master Data, the created script is stored in the data base. It can be used as an template for future use and can attached to any experiment. It is only possible to create a single script.

For further informations about the test procedures creation, see chapter 5.

Script editor toolbar options (opened from the experiment view):

Cell Groups List: Return to the Cell Groups list view.

New Script: Open the New Script dialog. Read more about it here.

Add step: Add a new step at the end of the selected script.

Edit: Change the label of the selected item. You may need to refresh the view ("Reload" button) in order to see the changes.

Up and **Down**: Shift the selected item one position upwards or downwards.

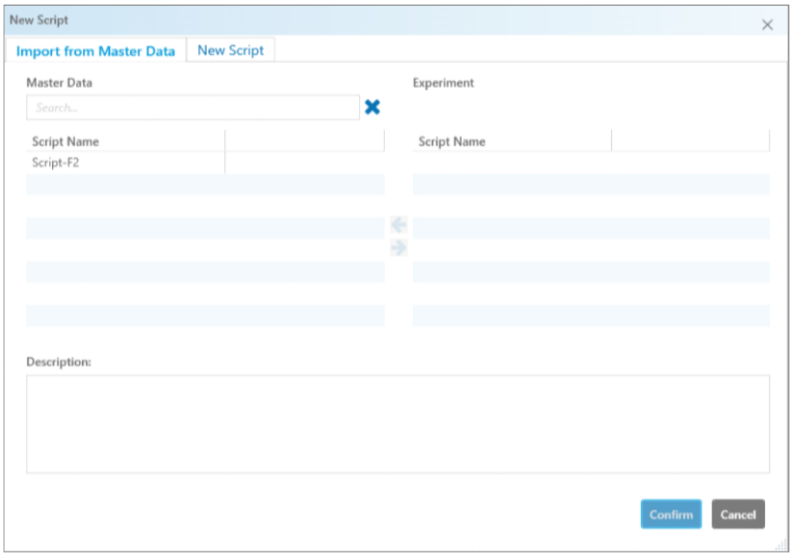
Export to Master Data: Store the script to the data base, so it can be reused in other experiments.

Delete: Delet the selected script or step.

Reload: Refresh the view.

4.2.1.3 Script Editor: How to add a new script

New Script \ **Import from Master Data tab:**



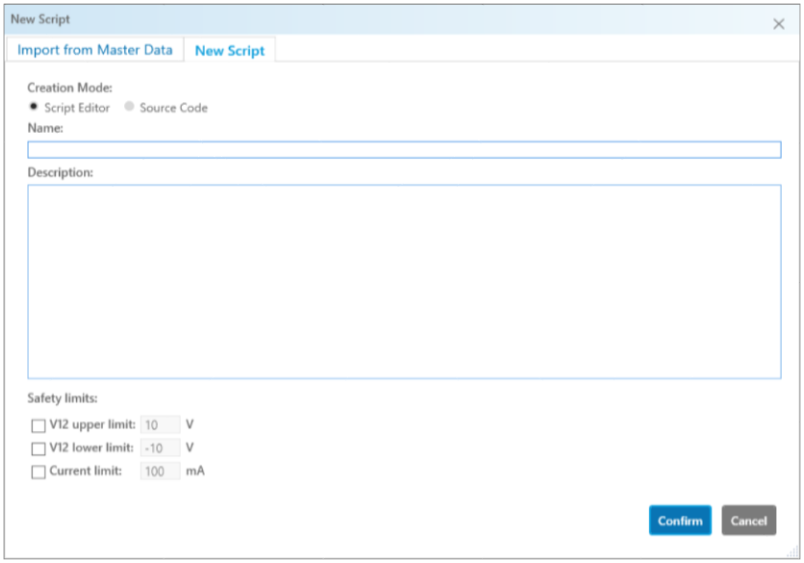
In this tab you can import a template script from the master data. The imported script will be attached to the cell group as a duplicate. To alter the original script, you need to open it in the script editor found under Master Data\Scripts.

The list on the left side shows all scripts, that are stored in the Master Data. The list on the right side shows the scripts attached to the active Cell Group.

To import a template script from the Master Data or to remove it from the experiment list, doubleclick it, or use the arrow buttons between the two lists.

New Script \ **Create Script tab:**

Creation Mode: Script Editor: Creates a new empty script



Creates a new empty script that is attached to the active Cell Group.

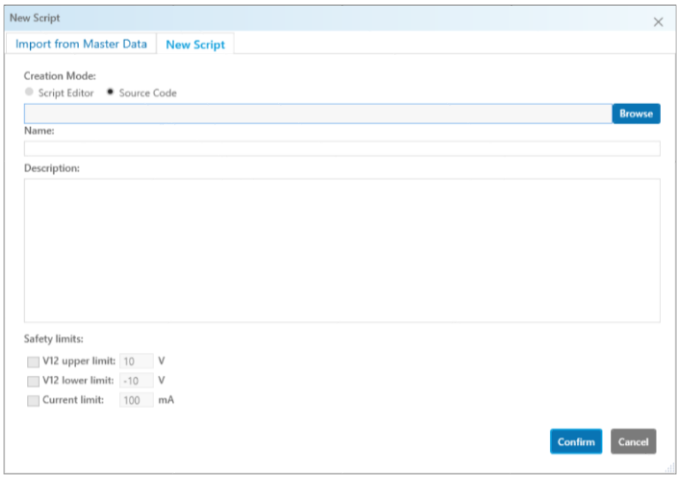
Name (required): Enter a custom name for the cell group. (3-50 characters)

Description: Enter a description of the cell group.

Safety limits: Enable and adjust limits for the script.

New Script \ **Create Script tab:**

Creation mode: Source Code: Import a Lua script that was written outside of EL-Software.



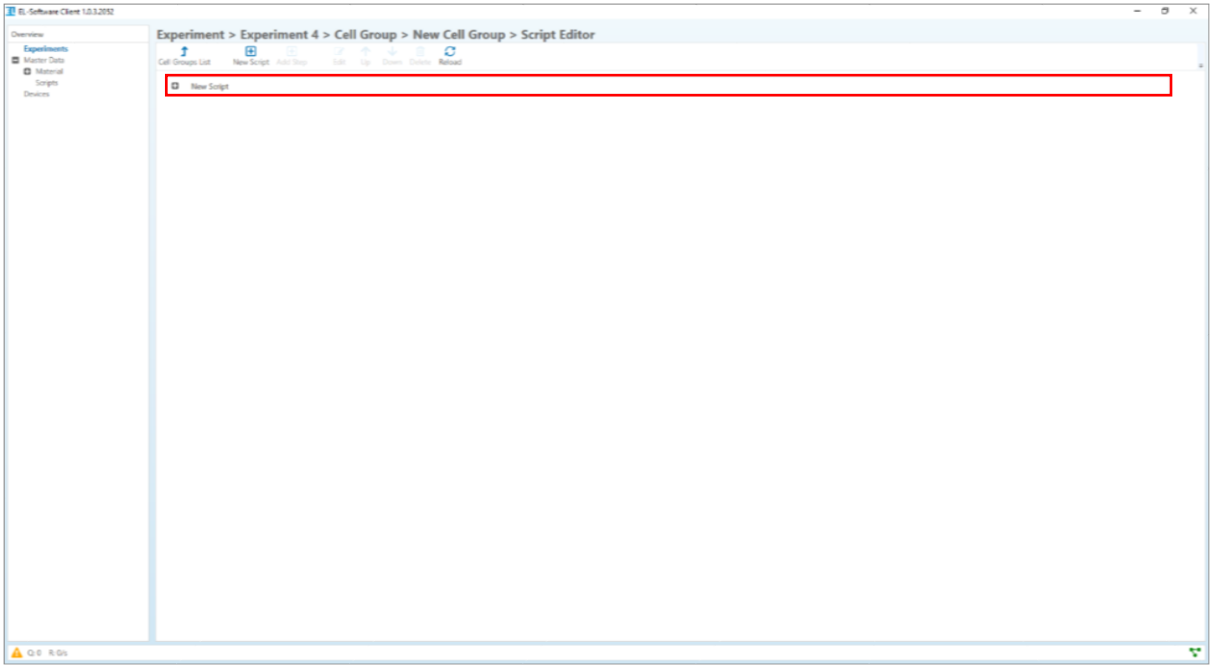
Browse: Choose a lua script file to import.

Name (required): Enter a custom name for the cell group. (3-50 characters)

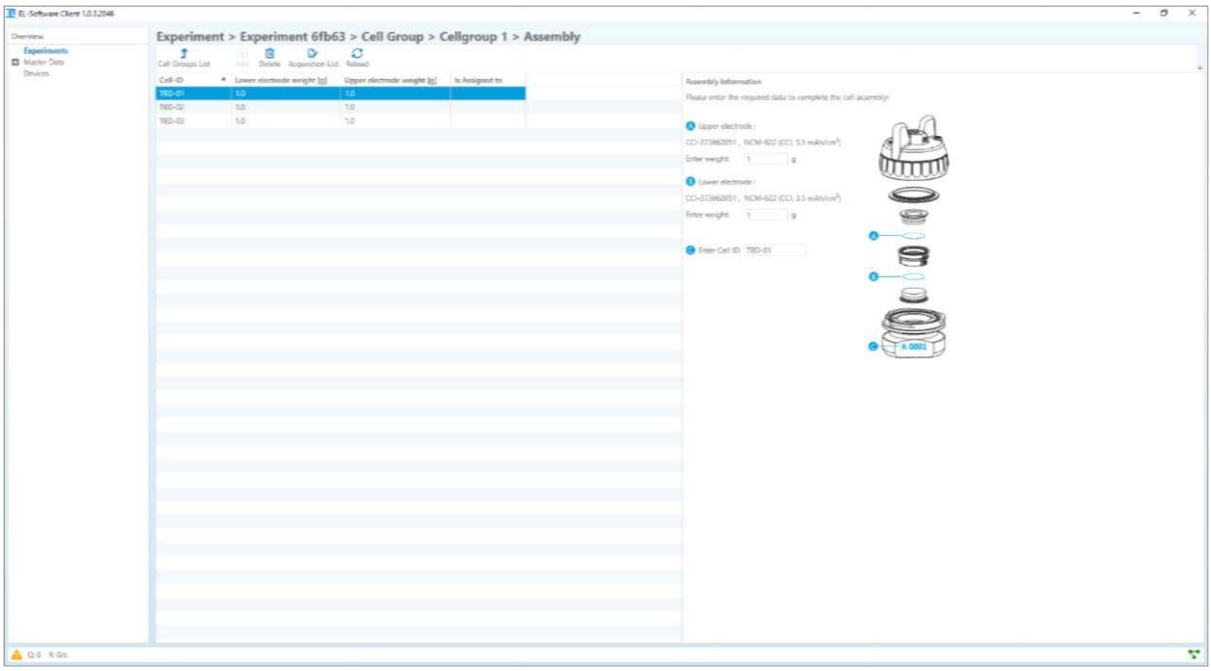
Description: Enter a description of the cell group.

Safety limits: Enable and adjust limits for the script.

After confirming the dialog, a new script container item will appear in the editor.



4.2.1.2.4 Assembly



The assembly view collects data about the electrode weights and cell IDs of the used test cells.

Assembly toolbar options:

Cell Groups List: Return to the Cell Groups list view.

Add: Add a cell to the list, up to the number of cells specified for this cell group.

Delete: Delete the chosen cell from the list.

Acquisition List: Open a html list in an external web browser. Electrode weights and Cell IDs can be entered in this list.

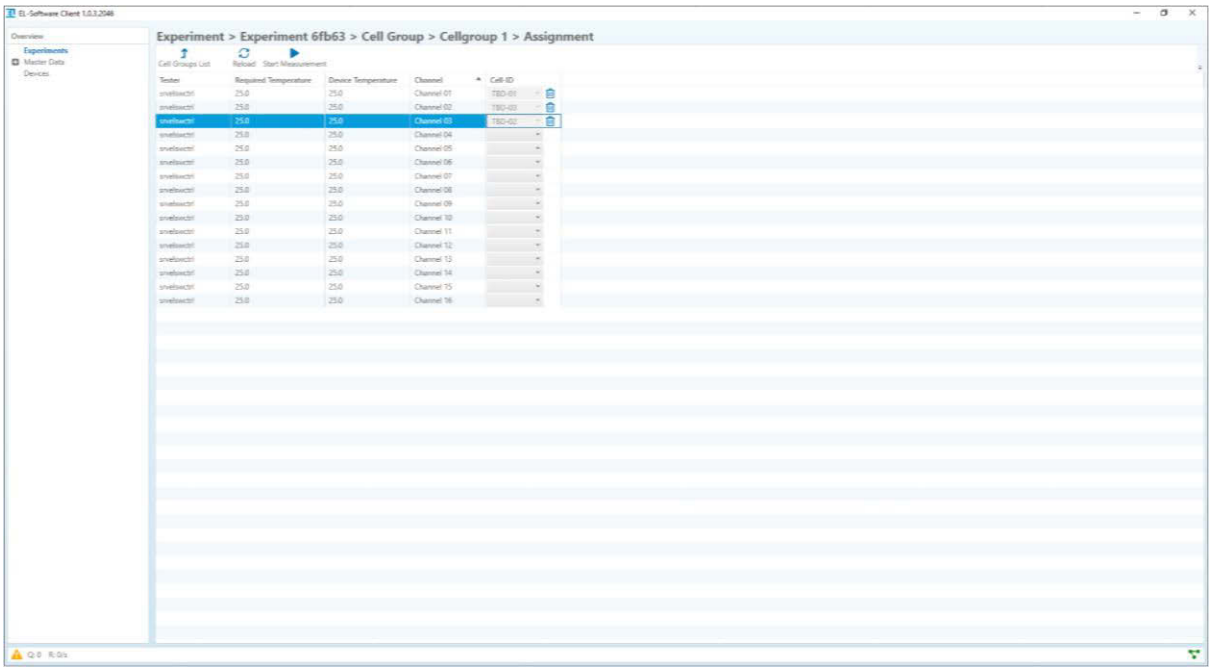
Reload: Refresh the view.

Content parameters

Enter weight (electrode 1 and 2): Set the electrodes weight, this number is used for correct interpretation of testing data. Accepts a value between >0 and 1.

Enter cell ID: Replace the placeholder name of the cell (TBD-xx) with the real cell ID for a better representation inside the software.

4.2.1.2.5 Assignment



In the Assignment view test cells are assigned to the available test channels shown in the list. After the assignment of all cells inside the experiment, the measurement can be started directly from this view.

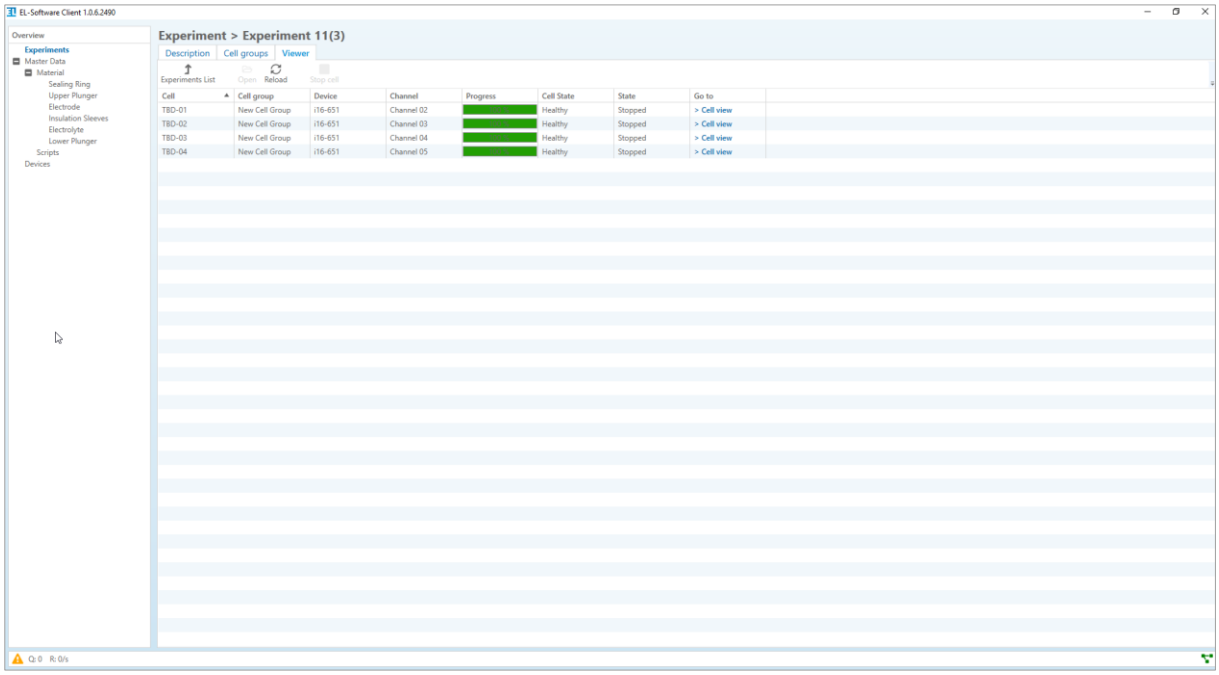
Assignment toolbar options:

Cell Groups List: Return to the Cell Groups list view.

Reload: Refresh the view.

Start Measurement: Start the measurement. It is required that all test cells in all cell groups of the experiment are assigned to available channels before this option is enabled.

4.2.1.3 Viewer tab



The Viewer tab offers the possibility to graphically display and evaluate the measurement data of the individual test cells during and after an experiment. It is especially useful for performing life checks of the test cells in a running experiment.

When opening the Viewer tab, a list of all test cells of an experiment is displayed first. With the option Open or by double-clicking on an entry, the actual Cell Viewer is started.

Assignment toolbar options:

Experiment List: Return to the Experiments list view.

Open: Open the Cell Viewer with the currently selected test cell

Reload: Refresh the view.

Stop cell: Stop the measurement on the selected cell. Only available when the experiment is running.

4.2.1.3.1 Cell Viewer

The Cell Viewer shows detailed information, e.g. event log, live voltages, measurement data about the test cells of an experiment. All recorded measurement data can be easily displayed and plotted using the freely configurable graphs. The Cell Viewer always shows the information of a single cell at the moment.

The Cell Viewer is organized in 4 main areas:

Cell Viewer toolbar (1)

Header area (2)

Info pane (3)

Graph pane (4)

Cell Viewer toolbar options:

Previous cell: Go to the previous cell in the experiment.

Cells List: Return to the Cells List view in the Viewer Tab.

Next cell: Open the next the cell in the experiment.

Stop cell: Stop the measurement on the selected cell. Only available during a running experiment.

Add graph: Open the graph settings dialogue to add a new graph. See here for more information.

Graph settings: Open a dialog to change the settings of the currently selected graph.

Delete: Remove the selected graph.

Move up and **Move Down**: Change the position of the selected graph.

Sync Charts: When active, couples the zoom factor of a selected graph with all graphs that share the same data parameter (e.g. time) on the x-axis.

Autoscroll: When Autoscroll is enabled, the charts are automatically rescaled to display all newly incoming data. To view all data from the current experiment (including historical data that is not currently displayed), double-click inside the graph. If you double-click on the x or y axis, this autoscaling function is only applied to the given axis.

Time Range: Click to define the time range of the displayed measurement data for all graphs.

Graph Layout: Change the number of graph. Choose Auto columns to adjust the displayed columns in relation to the available screen resolution or choose a manual setting.

Header area options:

Script navigation: Use the arrows keys to switch the data display to another script. Only applicable if more than one script were created for this cell group.

Cell name: Shows the name of the currently displayed test cell **(Read only)**.

Cell Group name: Shows the name of the currently displayed cell group **(Read only)**.

Info pane: Contains several expandable menues.

Step type: Shows a live view of the connection matrix and the current script step during an experiment.

Live data: See the voltages of the test cell during a running experiment.

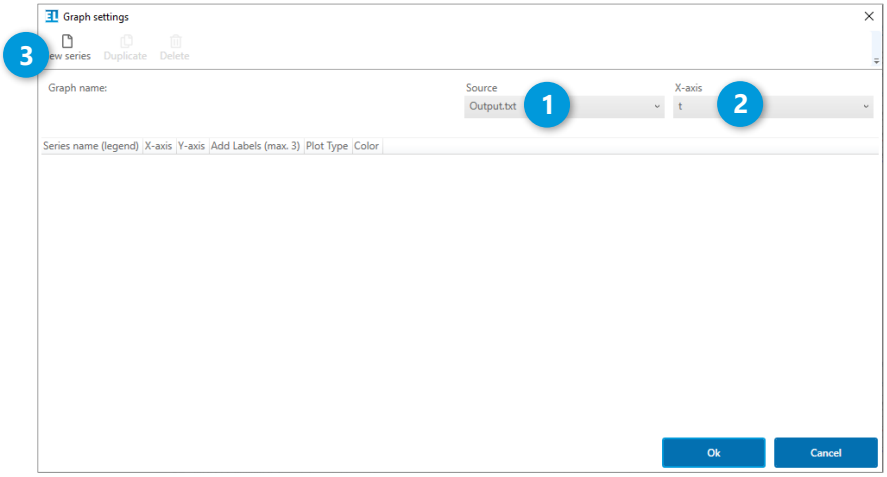
Info: Technical information about the testing device and progress of the currently viewed script.

Channel log: Displays all events of the currently selected channel.

Graph pane: Contains a freely configurable number of graphs, showing the measurment data of the currently selected test cell.

4.2.1.3.1 Cell Viewer: How to set up a graph

1. Add a graph by clicking the Add Graph button. This will create an empty graph and opens the Graph settings dialog. You can also enter the dialog by selecting an existing graph and using the Grap Settings button.

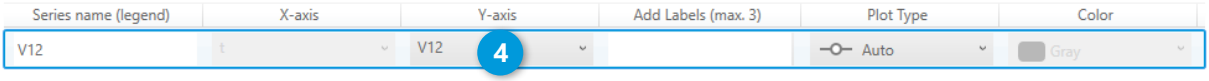


2. Choose the data source (1).

Select the source file for the data to be processed. The output.txt is set as default. You will find an overview of the contents of the different output files in chapter 6.

3. Select the data type of the x-axis (2).

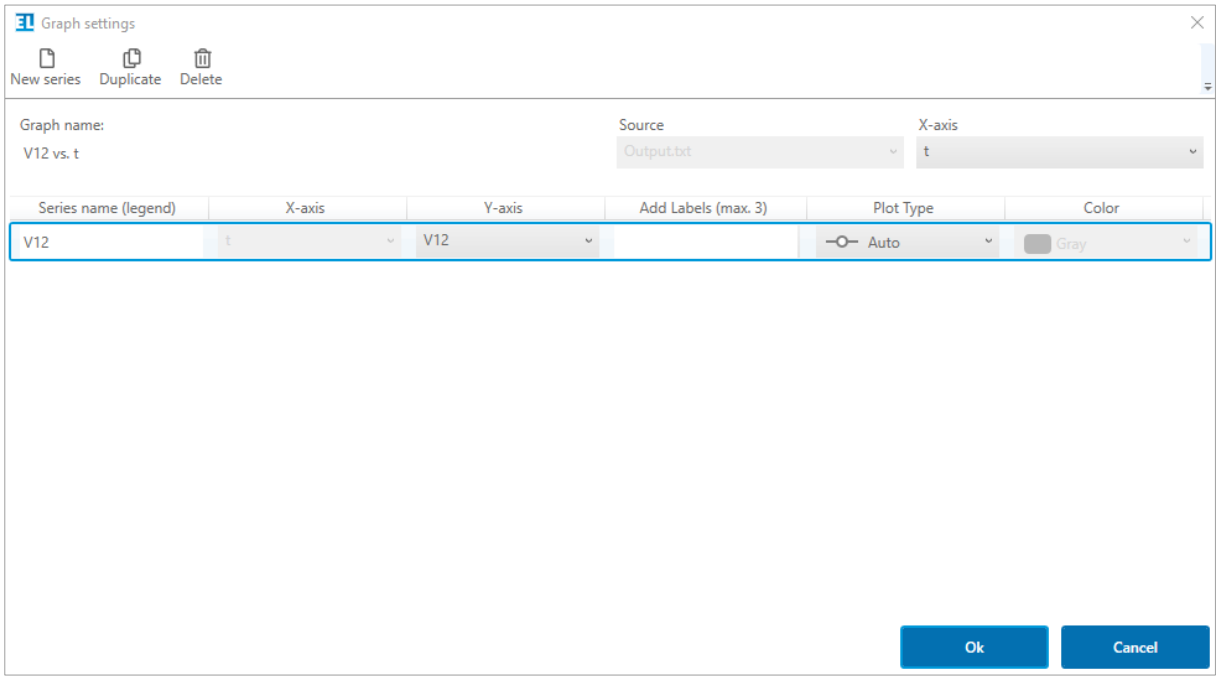
4. Add a data series by pressing the New series button (3).



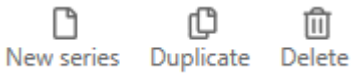
5. Select the data type for the y-axis (4).

6. Press ok to confirm.

4.2.1.3.1.1 Graph settings dialog



Assignment toolbar options:



New series: Create a new data series.

Duplicate: Duplicate the selected series.

Delete: Delete the selected series.

Content parameters:

Graph name: Displays the name of this graph **(Read only)**. The name is automatically generated from the selected data types.

Source: The source file from which the graph loads its measurement data is selected here. See chapter 6 for more details.

X-axis: Define the data type for the x-axis. Available data types are:

t	time
t_cycle	cycle time
t_step	step time
over	overload flag (!i or !v)
cycle	cycle number
step	step number
type	step type (OC, CC, CV, VS, PEIS, GEIS)
p/g	PGStat mode (p: potentiostatic, g: galvanostatic)
c/d	charge or discharge (c: charge, positive current, d: discharge, negative current)
con	connection between PGStat and test cell (1vs2, 1vsR, 2vsR, Rvs1, Rvs2)
I-Range	current range (1: 100 mA, 2: 10 mA, 3: 1 mA, 4: 100 µA)
V12	cell voltage (1 vs 2)
V1R	positive half cell voltage (1 vs R)
V2R	negative half cell voltage (2 vs R)
I12	cell current (between 1 and 2)
I1R	current between 1 and R
I2R	current between 2 and R
Qcd	charge (Q) accumulated during charge and discharge, set to zero at end of cycle
Qc	Q accumulated during charge, set to zero during discharge
Qd	Q accumulated during discharge, set to zero during charge
Q1	total Q of electrode 1
Q2	total Q of electrode 2
QR	total Q of electrode R
P	instantaneous power I12 * V12
W12	energy
Vaux	auxiliary analog signal (e.g. pressure signal)
T	temperature (cell or device)
buf	channelboard internal buffer

Series list parameters:

Series name (legend): Display name in the legend, automatically generated from the selected data type of the y-axis. It can also be assigned manually.

X-axis: Can only modified per graph **(Read only)**.

Y-axis: Set the data type for the y-axis. Available types are the same as for the x-axis.

Add Labels: Choose up to three data typen, that will be additionally displayed in the graphs data tooltip.

Plot type: Set the display type for the series. Available plot types are:

Auto: The best visualization type is automatically determined based on the graph's zoom level.

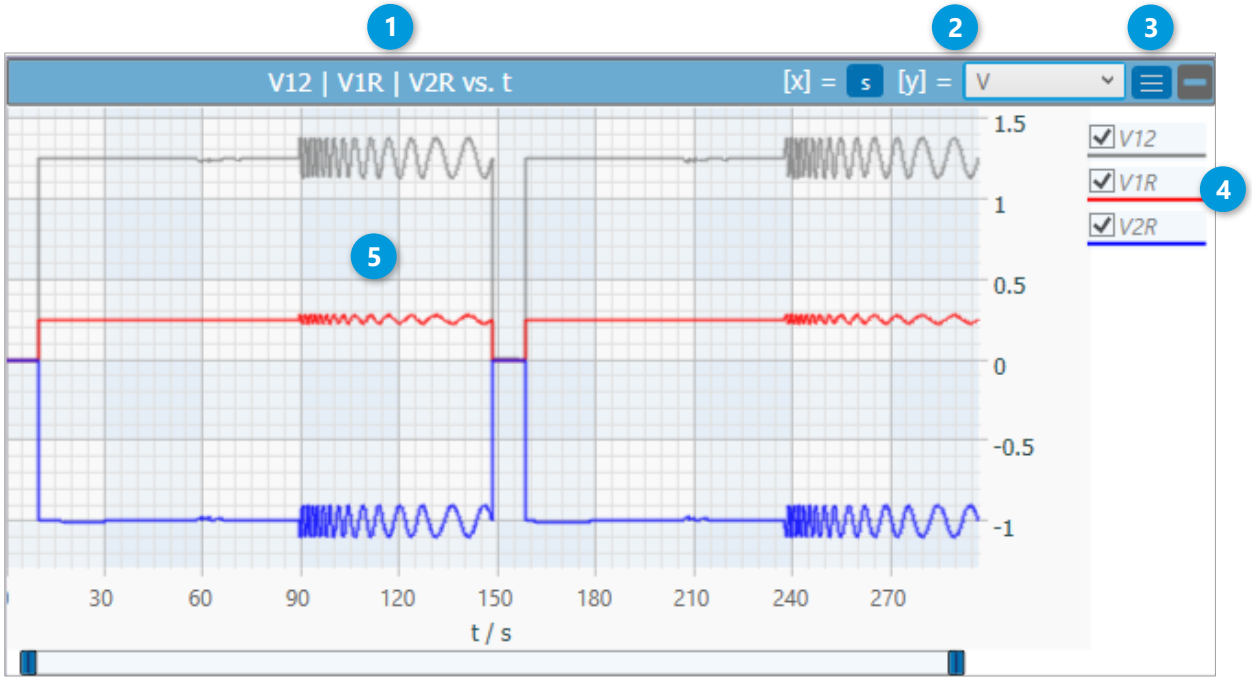
Line: Data values are shown as a connected line

Point: Data values are shown as points

Point and Line: Data values are shown as points and connected line.

Color: Displays the color of the series **(Read only)**.

4.2.1.3.1.2 Graph options



Content parameters:

Graph name (1): Automatically created name of the graph **(Read-only)**

Axis unit settings (2): Use these controls to change the displayed unit system for each axis.

Advanced display settings (3):

1:1 aspect ratio: Scales both axes equally so that 1 Ohm on the x-axis is the same length as 1 Ohm on the y-axis. Available for Nyquist diagrams only.

x log scale (log|x|): Plots log|x| on x-axis.

y log scale (log|y|): Plots log|y| on y-axis.

x axis inverted: Plots -x on x-axis

y axis inverted: Plots -y on y-axis

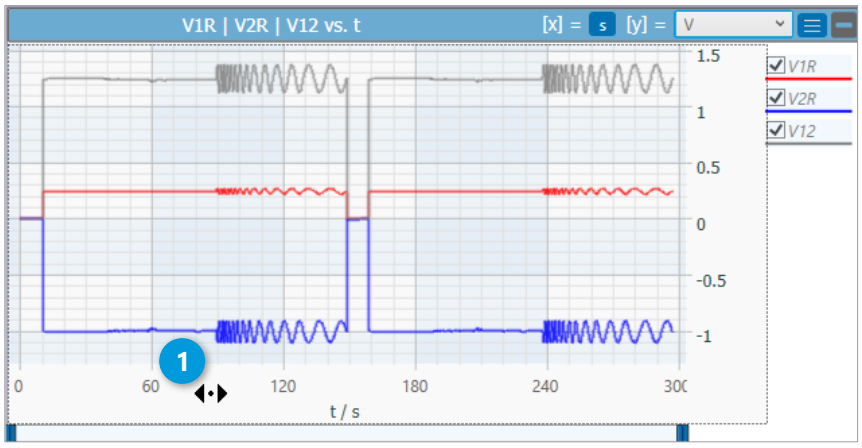
show zero point: Scales the diagram so that it contains the data point x = y = 0

Graph legend (4): Toggle the display of a series by clicking the checkbox.

Graph area (5): Shows the measurement data. See

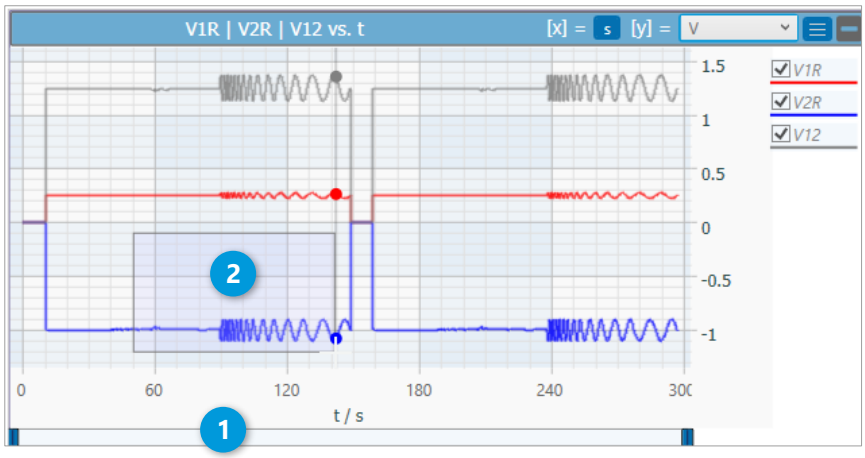
4.2.1.3.1.2 Graph area: How to use the navigation controls

1. Panning:



To move the display area of the series along an axis, place the mouse cursor near the respective axis label. The mouse symbol will change (1). By holding down the left mouse button and moving the mouse you can now move the display. Reset an axis by using the right mouse button.

2.Zooming:

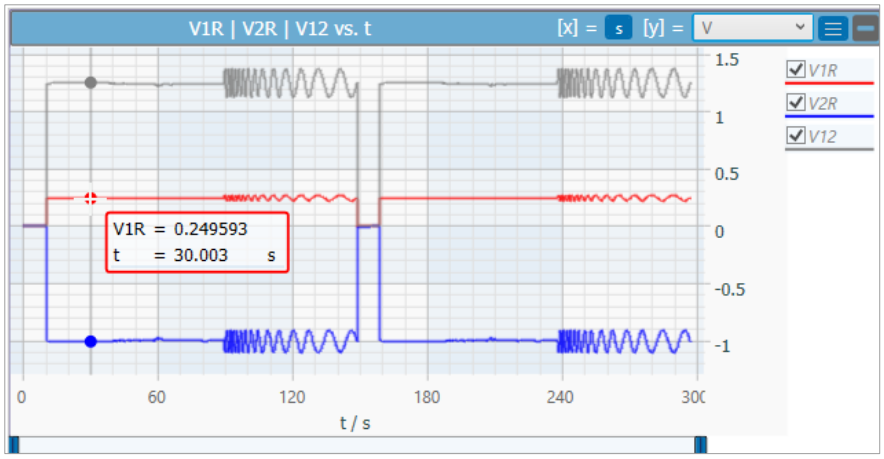


Per default, the graph will show the entire data range. Use the slider beneath the graph to zoom in on the x-axis by changing the scope (1) .You can also use the scroll wheel to zoom in and out.

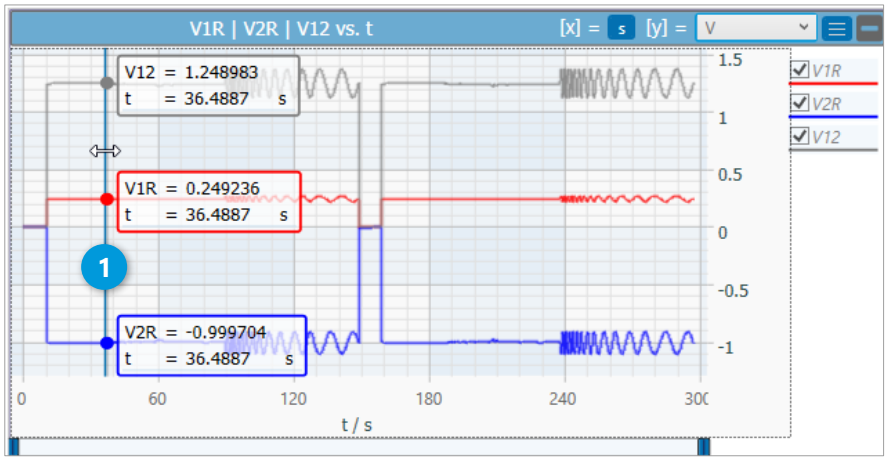
To enlarge a certain area, you can also left click into the graph area and draw a selection area by holding down the left mouse button (2) . By releasing the button, the view will zoom in to show the selected area.

To reset the display to default simply doubleclick into the graph area.

3. Data labels



Mouse the mouse cursor on a series to display a data label showing the axis values at this point, or also additional values, if you defined them in the graph settings dialog.



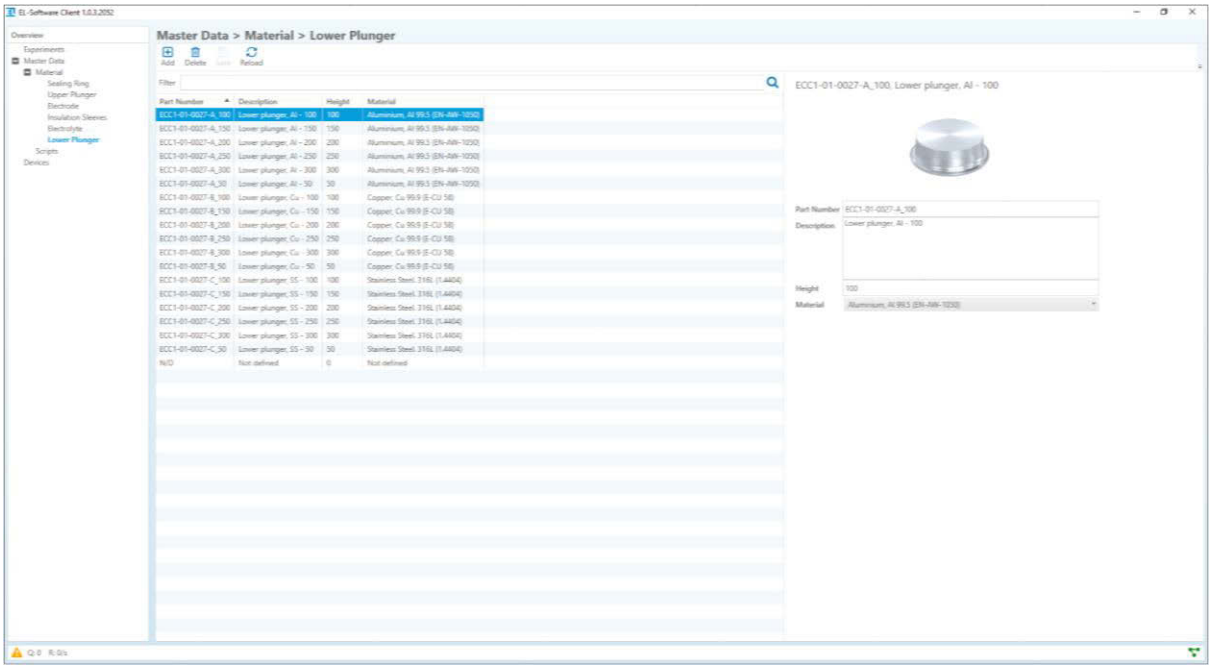
Click on a series using the left mouse button to show the data labels for all series in the graph. Click anywhere inside the graph area to hide the data labels.i

Click and hold the left mouse button while hovering over the line (1) to move along the data series with data labels activated.

4.3 Master Data

Information about all required components of an experiment is stored in this central data base.

4.3.1 Material



The Material section lists all cell components sorted by category. Items can be added, modified or removed from the data base.

Material toolbar options:

Add: Creates a new entry to selected category.

Delete: Delete the selected item fron the data base.

Save: Saves the newly created item to the data base.

Reload: Refreshes the view.

Content parameters:

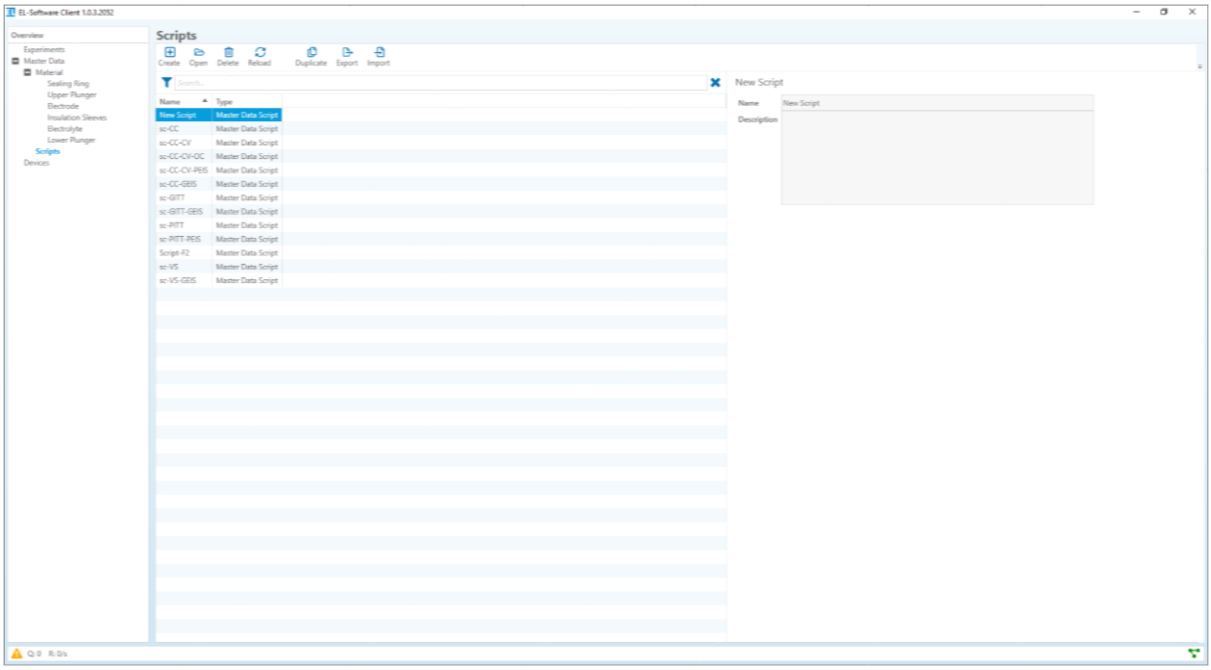
Part Number: Reference number of the item.

Description: Optional description of the item.

Height (only in Lower Plunger category): EL-CELL Height number of the lower plunger.

Consists Of: Pulldown list with available materials to choose from.

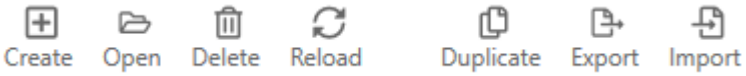
4.3.2 Scripts



In the Scripts section, default and user created test prodcedures are stored for further use in experiments.

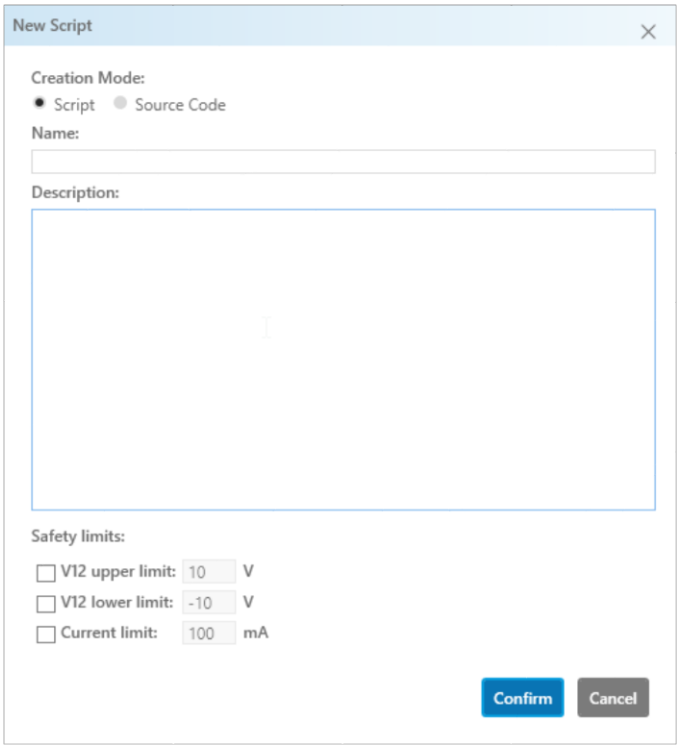
In contrary to the script creation inside the experiment view, these scripts are not bound to a specific experiment and can be used directly or as templates for new experiments.

Scripts toolbar options:



Create: Creates a new script.

Creation mode: Script: Creates a new empty script

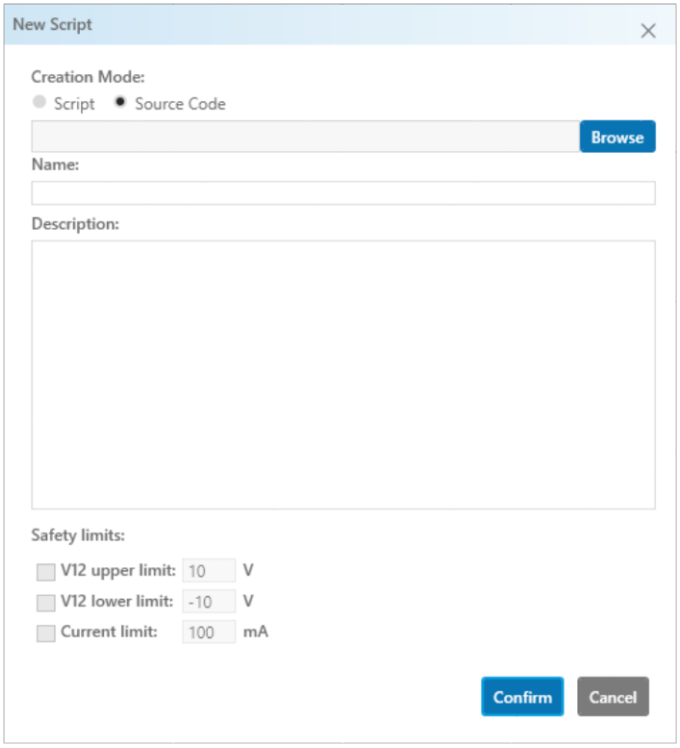


Name (required): Enter a custom name for the cell group. (3-50 characters)

Description: Enter a description of the cell group.

Safety limits: Enable and adjust limits for the script.

Creation mode: Source Code: Import a Lua script that was written outside of EL-Software.



Browse: Choose a lua script file to import.

Name (required): Enter a custom name for the cell group. (3-50 characters)

Description: Enter a description of the cell group.

Safety limits: Enable and adjust limits for the script.

Open: Opens the selected script in the Script Editor.

Delete: Removes the selected script from the list.

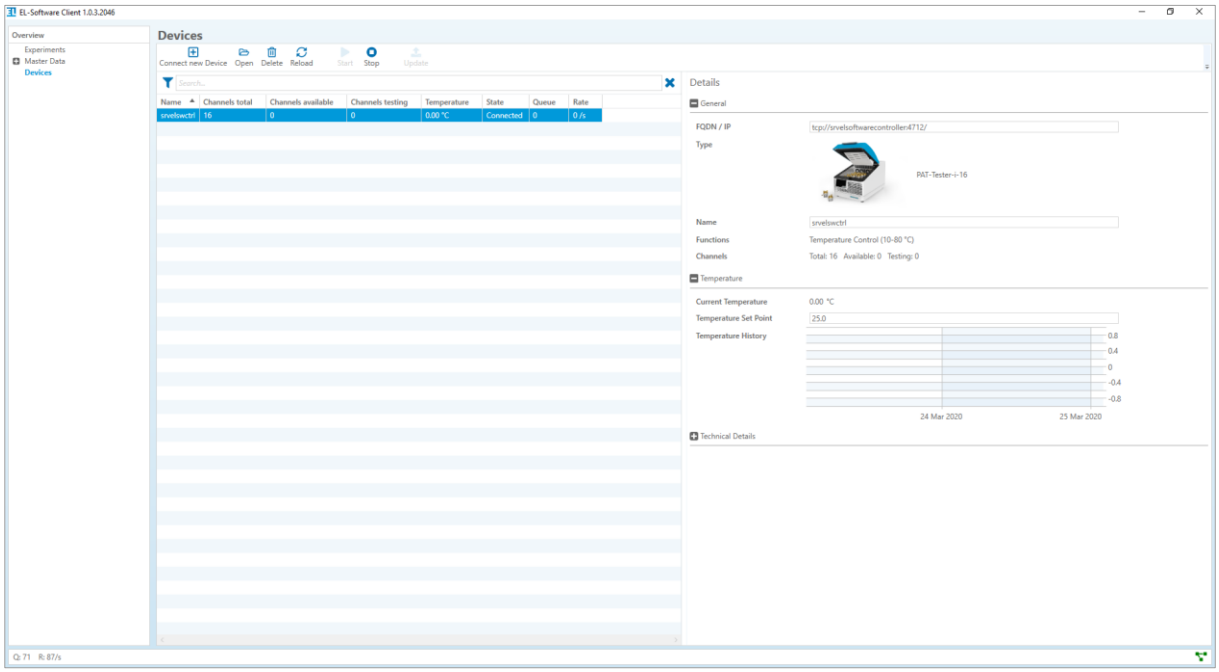
Reload: Refreshes the view.

Duplicate: Creates a duplicate of the selected script.

Export: Export a script as an .elc file.

Import: Import an .elc file into the data base.

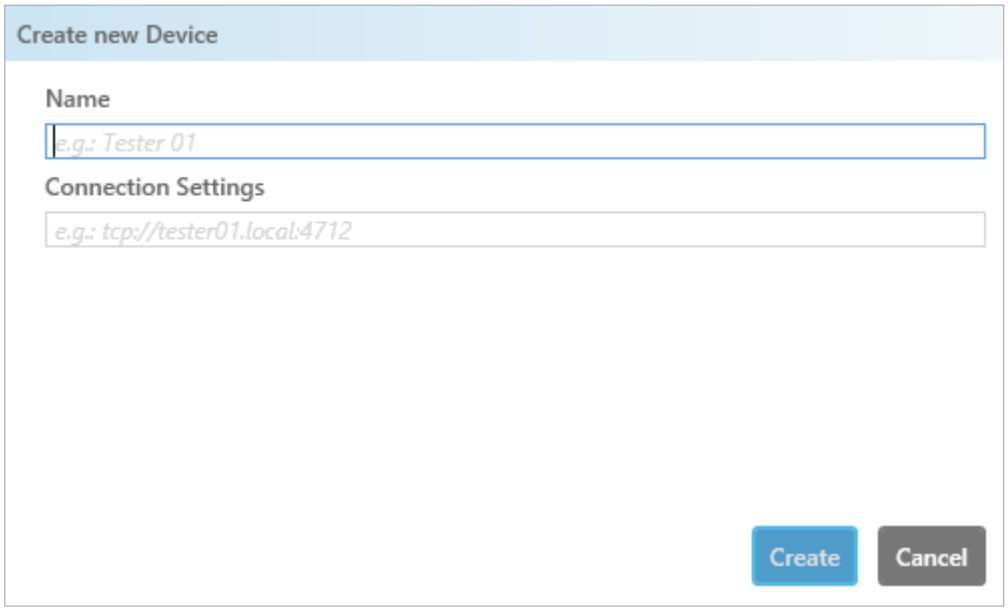
4.4 Devices



The Device view offers all relevant details about the connected testing devices.

Devices toolbar options:

Connect new Device: Add a new battery tester in order to control it with EL-Software



Name: Enter a name for the device

Connection Settings: Enter the FQDN or IP address of the device to connect it.

Open: Open the channel view of the selected device

Delete: Close the connection and deletes the device from the list.

Reload: Refreshes the view.

Stop: Disconnect the selected device.

Start: Connect the selected device.

Update: Update the controller software version on the selected device.

Content parameters:

General parameters:

FQDN/IP: The current adress of the device. Changes can be entered here.

Type: The device type

Name: The current name of the device as it appears in EL-Software. Changes can be entered here.

Functions: Lists special functionalities of the device, e.g. temperature control

Channels: Displays the curent status of the device channels

Temperature parameters (if temperature control is available):

Current temperature: Shows the current temperature inside the device cell chamber.

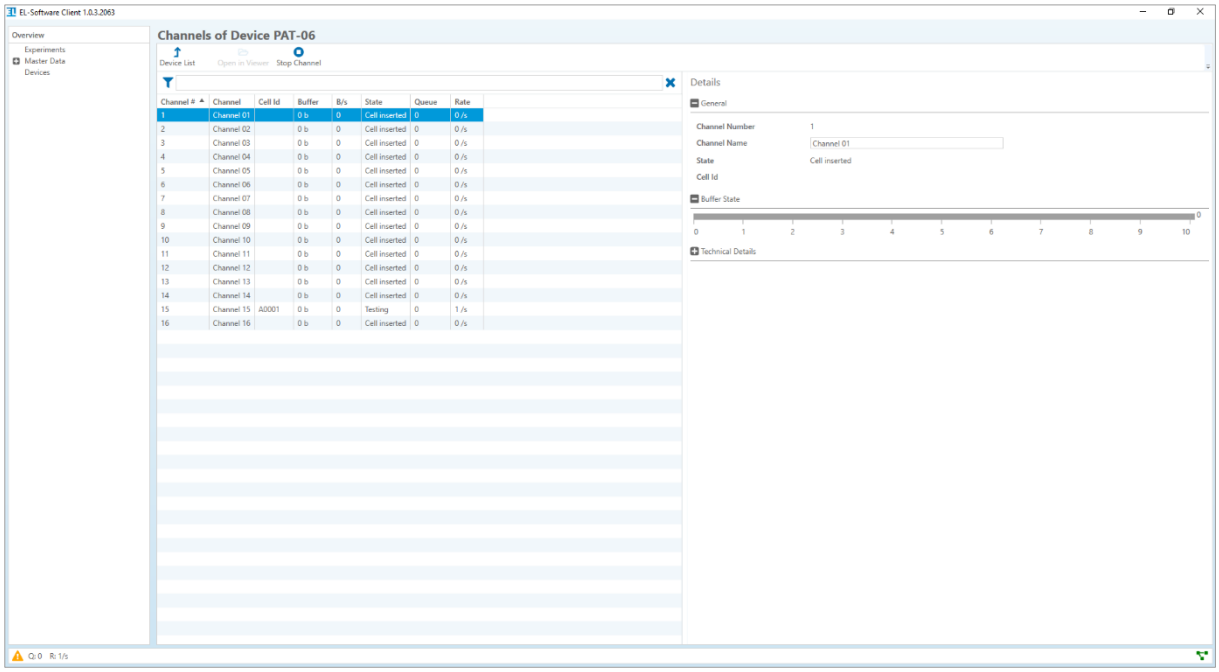
Temperature set point: Enter a number to change the temperature set point for the device.

Temperature history: Diagram view of the temperature curve

Technical details: This section shows minor details depending on the selected device

4.4 Devices \

4.4.1 Channels of device view



This view lists all channels of the device with their current status. Doubleclicking of a running channel will open the cell viewer.

List parameters:

Channel #: Shows the channel number.

Channel: Shows the channel name.

Cell ID: Display the cell ID of the inserted and assigned cell.

Buffer: Channel board buffer size

B/s: Channel board reading rate

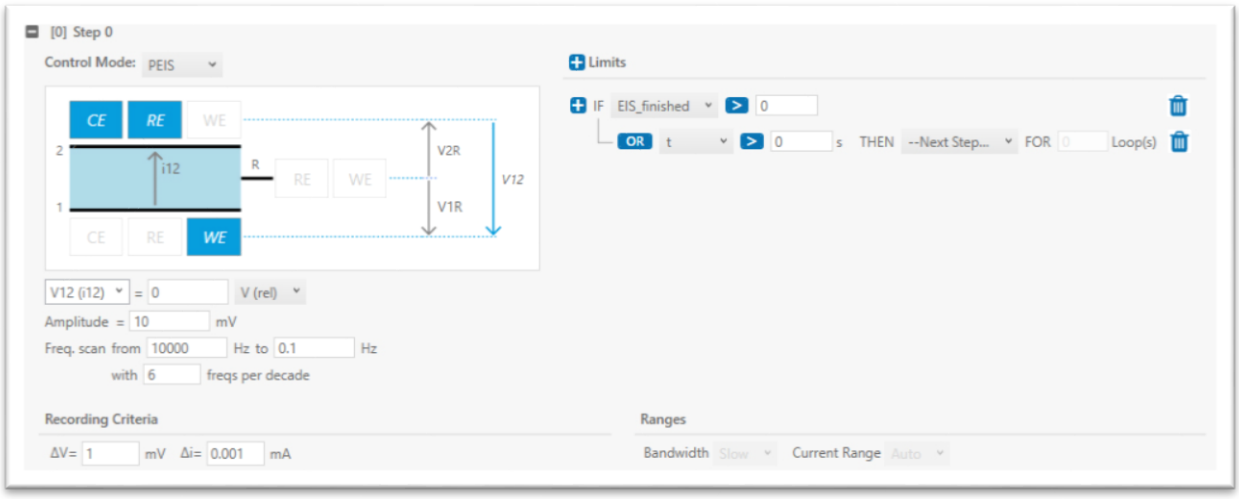
State: The current state of the channel.

Queue: Controller buffer size

Rate: Controller reading rate

5 Working with the Script Editor

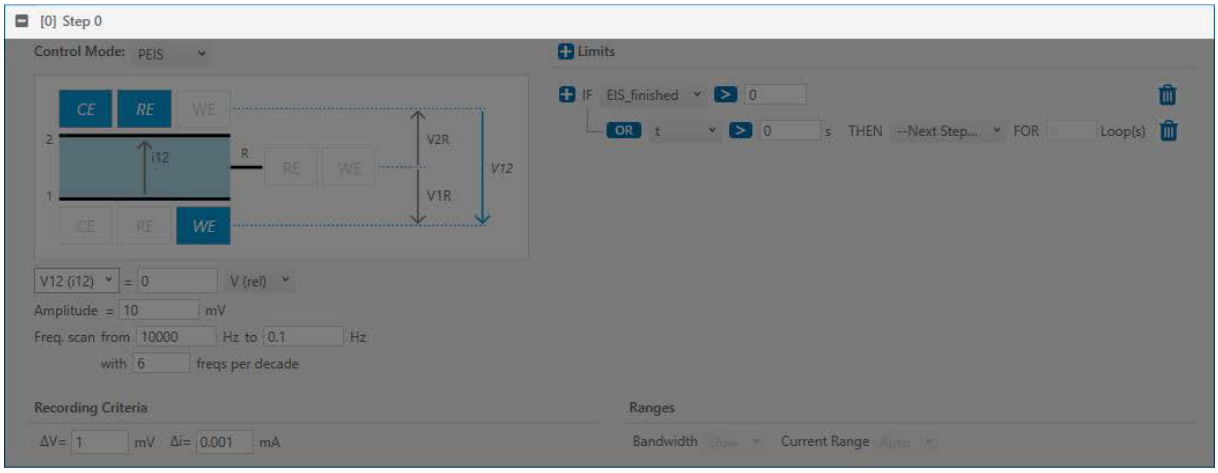
5.1 The Script Step



Each test script inside EL-Software contains one or multiple steps. They are processed in a user defined order during the experiment.

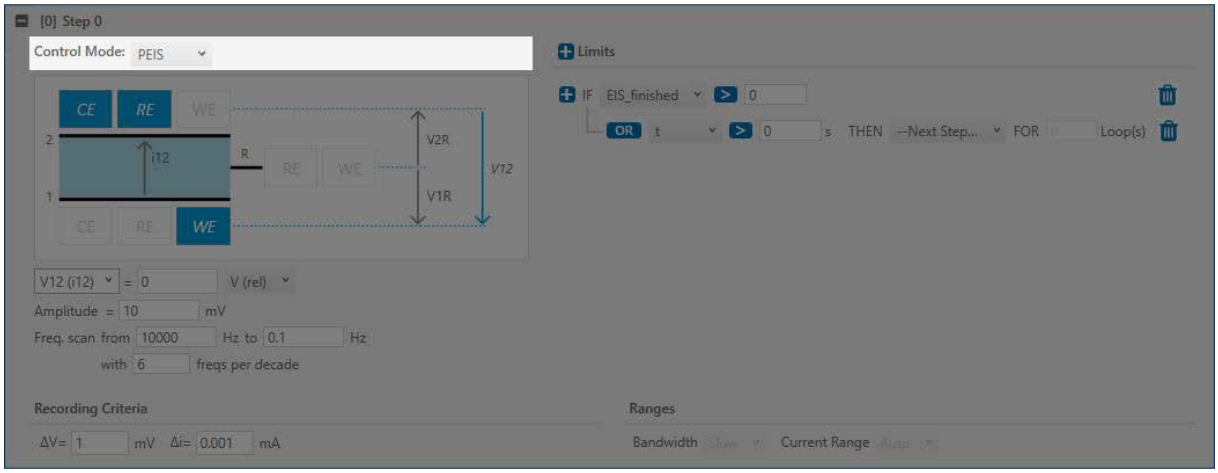
Each step is defined by a measurement mode such as CC (constant current) or CV (constant voltage), and one or more limits. After reaching this limit, the script will perform a loop through the same step again or jump to another step.

Step label:



The position of each step in the script is shown in square brackets. In addition, an extract of the set parameters appears in collapsed state. A label text can also be defined for each step. This is done via the *Edit button* in the menu bar.

Control mode:

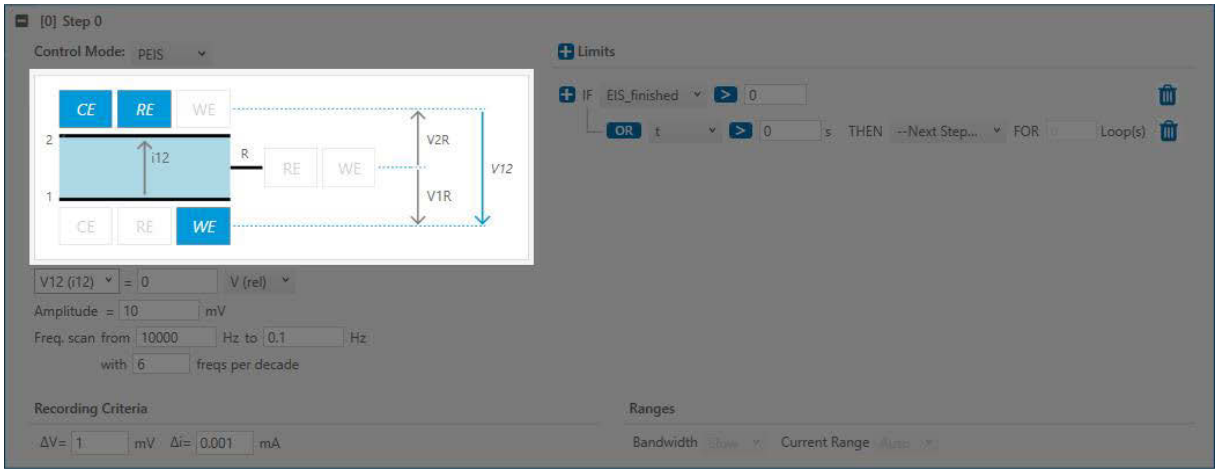


The working mode of the PGStat (potentiostat/ galvanostat). The following modes are available:

- Off
- Open Circuit (OC)
- Constant Voltage (CV)
- Constant Current (CC)
- Voltage Scan (VS)
- PEIS
- GEIS

See chapter 5.2 for further details.

Connection matrix:



The connection matrix is an interactive graphical representation of the electrical connection between the three electrodes of the test cell (1, 2, R) and the three terminals of the PGStat (WE, CE, RE). Depending on the step type, various connections are available, from which the user can select by clicking on the elements WE, CE and RE in the connection matrix, or by direct entry into the corresponding field.

Note: The individual electrodes cannot be active in several places at the same time. Therefore, you must first deactivate them by clicking on them to make them available elsewhere. Then you can activate them at the new position.

During a galvanostatic step, the current between two (of the three) electrodes is controlled. The following galvanostatic control modes are available:

	WE	**CE**	**Current control**
i12	1	2	1 to 2
i1R	R	1	R to 1
i2R	R	2	R to 2

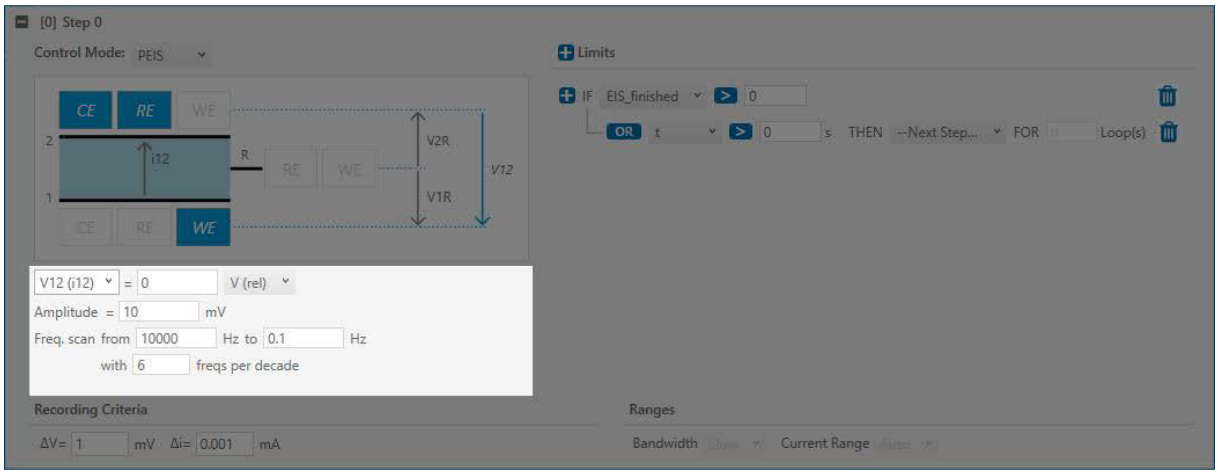
Most common is to apply a current i12 between electrodes 1 and 2, and so to leave electrode R unaffected. However, sometimes a current should also flow over electrode R, e.g. to check its state of health or to plate it galvanically. The above settings i1R and i2R serve this purpose.

During a potentiostatic step, the voltage between two (of the three) electrodes is controlled. The corresponding current can flow between the same two electrodes between which the voltage is controlled, or between two other electrodes. The user can select between the following potentiostatic control modes:

	WE	**CE**	**RE**	**Voltage control**
V12 (i12)	1	2	2	full cell 1 vs 2
V1R (i12)	1	2	R	half cell 1 vs R
V2R (i12)	2	1	R	half cell 2 vs R
V1R (i1R)	R	1	1	R vs 1
V2R (i2R)	R	2	2	R vs 2

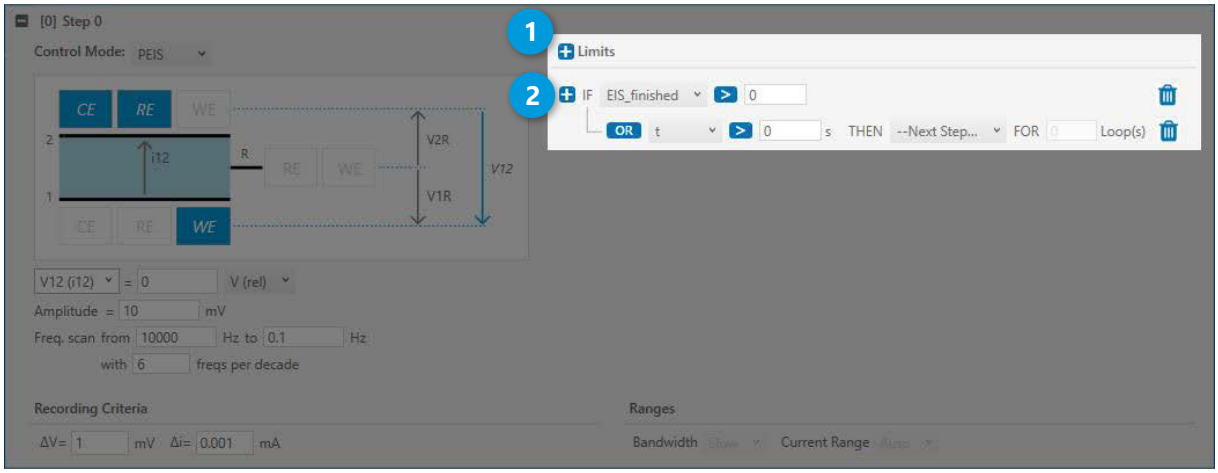
Again, it is most common to apply the current between electrodes 1 and 2, while electrode R is left uncharged. This can be done in three different potentiostatic modes: Either the voltage V12 of the full cell is controlled, or the voltage V1R or V2R of one of the two half cells. Sometimes the current should also flow over the R electrode during potentiostatic control, e.g. to check the impedance of the R electrode by a PEIS measurement. The above potentiostatic settings V1R(i1R) and V2R(i2R) serve this purpose.

Control mode parameters:

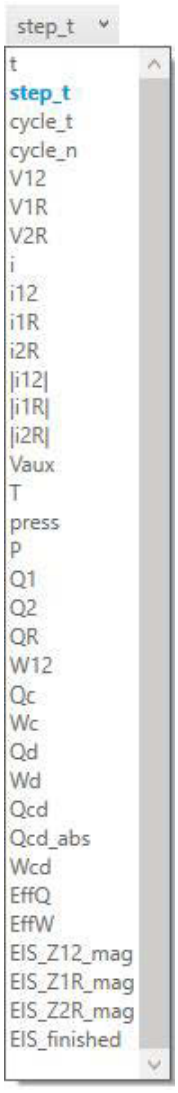


Depending on the control mode, additional parameters can be set here. See chapter 5.2 for further details.

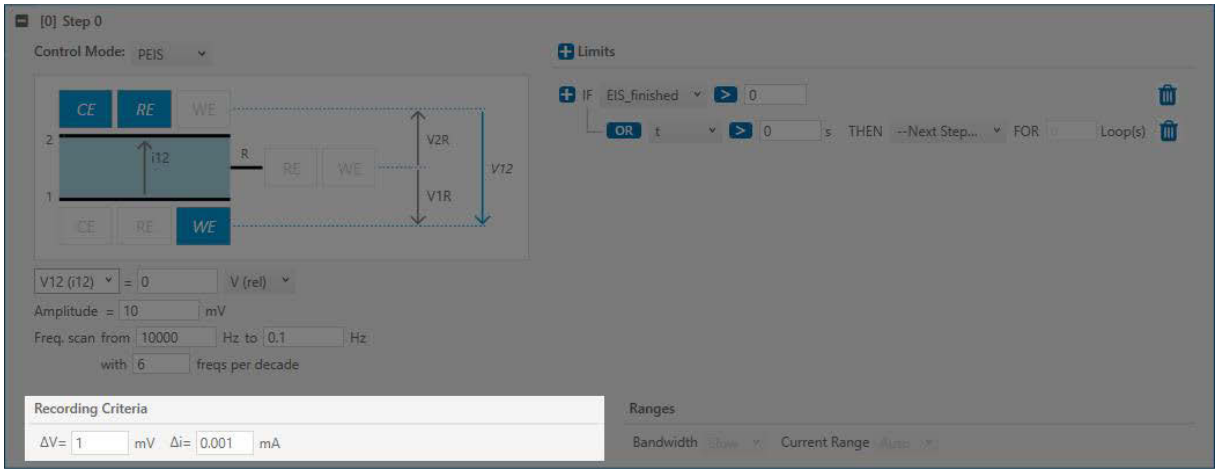
Limits:



A step ends once a step limit is reached. Multiple limits can be defined (1). In addition, each limit can contain further conditions (2) that can be linked with AND or OR. IF..THEN.. clauses can be formed using the operators > and < and a variable from the list below.

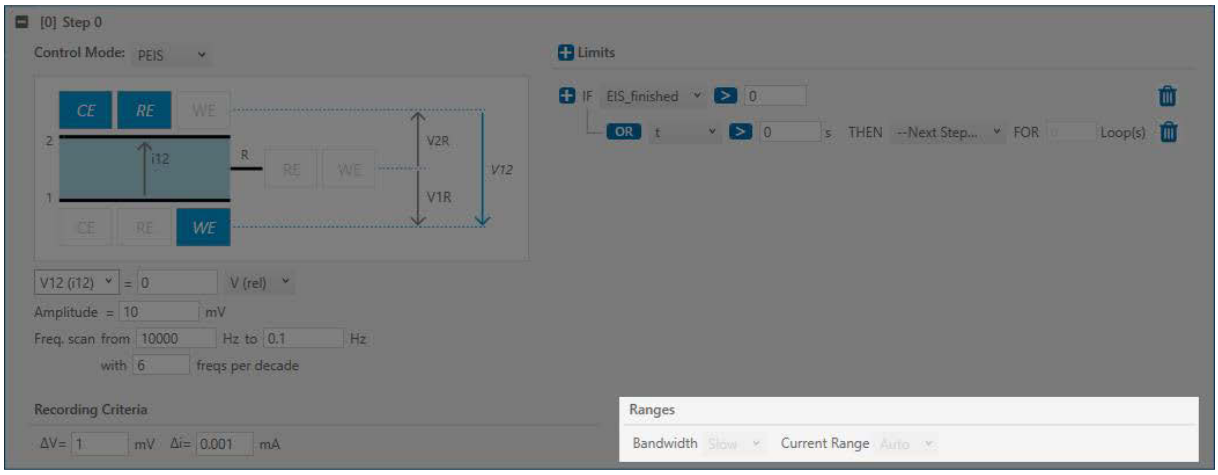


Recording Criteria:



The recording criteria ΔV and Δi aim to minimize the amount of stored data without losing much information. The special algorithm used in EL-Software is much more effective and provides much better data compression then conventional methods. In short, drawing lines between adjacent data points of the reduced data results in a curve that is always close to the original curve, with the maximum difference between the two curves defined by the recording criteria ΔV and Δi. Depending on the step type, the reduction can be applied on V(t) or i(t), or on both. For best accuracy, all continuous calculations (e.g. of capacity and energy) are performed directly on the raw data rather than the reduced data.

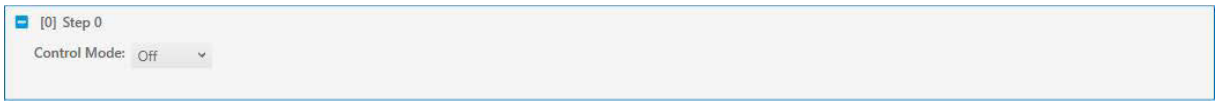
Ranges:



Autorange and 3 fixed current ranges (100 µA, 1 mA, 10 mA) are available. Autorange is the default for all step types.

5.2 Control Modes

Off

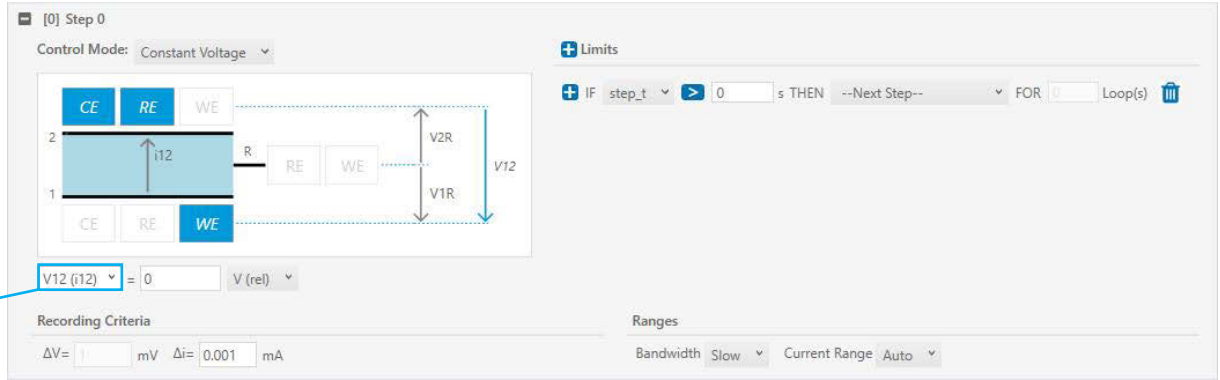


When OFF, the PGStat is disconnected from the test cell, and no data are recorded. Note that any script is ending with an OFF step, even if not explicitely set in the composer.

Open Circuit (OC)

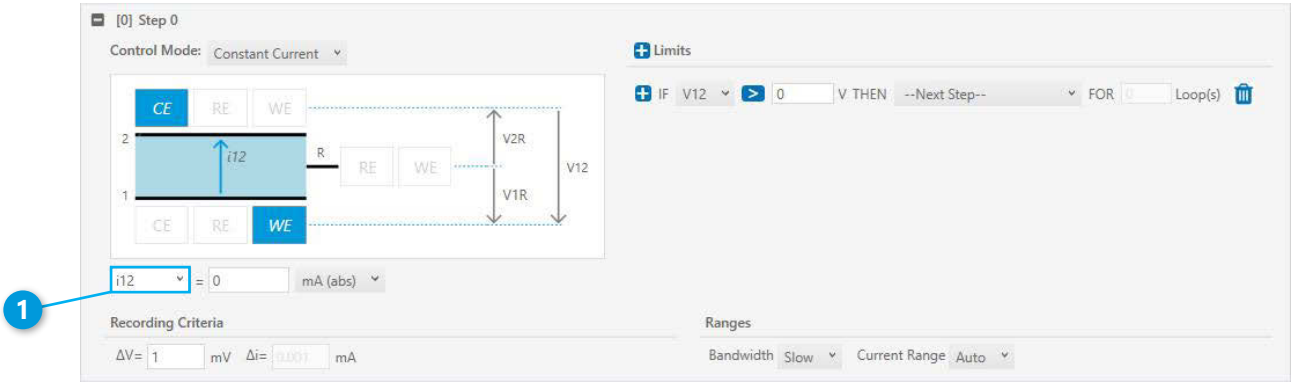
Open Circuit (OC) is the default for new steps. As a good practise, any script should begin with an OC step. In open circuit, the PGStat is disconnected from the test cell. Still, data are recorded as defined by the recording criterion ΔV.

Constant Voltage (CV)



During a CV step, the voltage between two electrodes is held constant by applying a current between the same two or different two electrodes. The desired potentiostatic control mode can be selected by clicking on the elements WE, CE and RE in the connection matrix or by direct selection from a drop down list (1). The setpoint of the control voltage is either given as an absolute value, V(abs), or relative to the last voltage measured in the previous step, V(rel). During a CV step, data are recorded as defined by the recording criterion Δi.

Constant Current (CC)

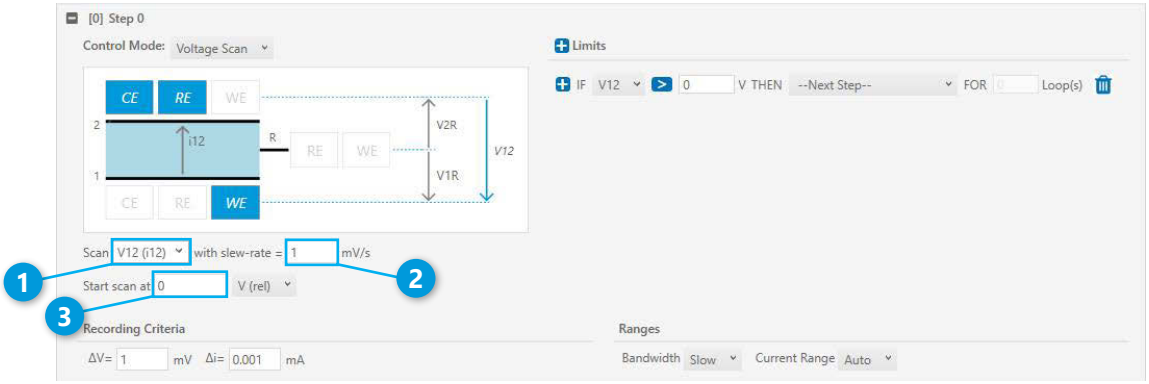


During a CC step, the current between two electrodes is held constant. The desired galvanostatic control mode can be selected by clicking on the elements WE, CE and RE in the connection matrix or by direct selection from the drop down list (1).

The setpoint of the current is given either as an absolute value (mA(abs)) or relative to the last measured current value of the previous step (mA(rel)), or relative to the weight of electrode 1 (mA/g(1)), or relative to the weight of electrode 2 (mA/g(2)).

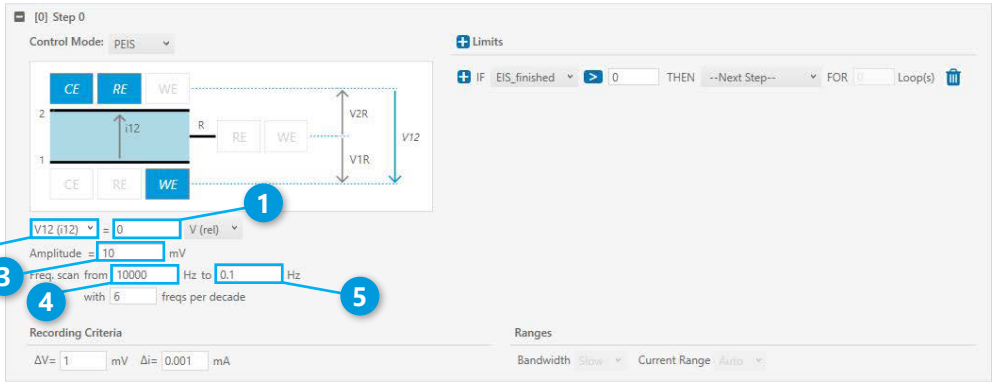
During a CC step, data are recorded as defined by the recording criterion ΔV.

Voltage Scan (VS)



During a VS step, the selected voltage (1) is increased or decreased linearly with time. The slew rate (2) defines the slope ΔV/Δt in units of mV/s. The slew rate can be positive or negative. The start point of the scan (3) can either be given as an absolute value, V(abs), or relative to the last voltage measured in the previous step, V(rel). By default, the scan starts at 0 V(rel). During a VS scan, data are recorded as defined by the recording criteria ΔV and Δi.

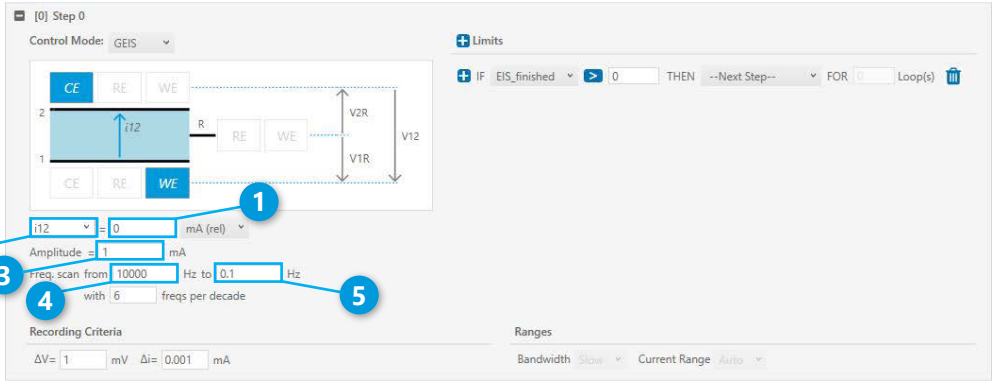
Potentiostatic Electrochemical Impedance Spectroscopy (PEIS)



During a PEIS step, the setpoint (1) of the voltage (2) is modulated with a sinoidal voltage perturbation of amplitude (3). The frequency of the sinoidal voltage can be swept between two frequency limits (4 and 5), starting from either high or low values, and with logarithmic spacing between the frequency values.

The calculated impedance data is always stored in the Output-Impedance table. In contrast, the time-wise data is only stored in the Output table at frequencies above 1 Hz and only if the recording criteria ΔV and Δi are set accordingly. This prevents too much data from being recorded.

Galvanostatic Electrochemical Impedance Spectroscopy (GEIS)



During a GEIS step, the setpoint (1) of the current (2) is modulated with a sinoidal current perturbation of amplitude (3). The frequency of the sinoidal current can be swept between two frequency limits (4 and 5), starting from either high or low values, and with logarithmic spacing between the frequency values.

The resulting impedance data is always stored in the Output-Impedance table. In contrast, the time-wise (raw) data is only stored in the Output table at frequencies above 1 Hz and only if the recording criteria ΔV and Δi are set accordingly. This prevents too much data from being recorded.

6 Data Export

For each cell and each test script txt files are created during an experiment. These files can be used for importing the test data in other applications.

6.1 Log files

Between 2 and 6 txt files are created for each cell and each test script:

- **Output.txt** and **Output-Cycles.txt** are always created.
- **Output-Impedance.txt** only for impedance measurement (PEIS and GEIS)
- **Output-C12.txt, Output-C1R.txt** and **Output-C2R.txt** only in CC and VS (Voltage Scan) steps

- **Output.txt** contains the conventional "time data":

t	time
t_cycle	cycle time
t_step	step time
over	overload flag (!i or !v)
cycle	cycle number
step	step number
type	step type (OC, CC, CV, VS, PEIS, GEIS)
p/g	PGStat mode (p: potentiostatic, g: galvanostatic)
c/d	charge or discharge (c: charge, positive current, d: discharge, negative current)
con	connection between PGStat and test cell (1vs2, 1vsR, 2vsR, Rvs1, Rvs2)
I-Range	current range (1: 100 mA, 2: 10 mA, 3: 1 mA, 4: 100 µA)
V12	cell voltage (1 vs 2)
V1R	positive half cell voltage (1 vs R)
V2R	negative half cell voltage (2 vs R)
I12	cell current (between 1 and 2)
I1R	current between 1 and R
I2R	current between 2 and R

Qcd	charge (Q) accumulated during charge and discharge, set to zero at end of cycle
Qc	Q accumulated during charge, set to zero during discharge
Qd	Q accumulated during discharge, set to zero during charge
Q1	total Q of electrode 1
Q2	total Q of electrode 2
QR	total Q of electrode R
P	instantaneous power I12 * V12
W12	energy
Vaux	auxiliary analog signal (e.g. pressure signal)
T	temperature (cell or device)
buf	channelboard internal buffer

- **Output-Cycles.txt** contains the accumulated cycle data:

t	time (s)
t_cycle	cycle time
cycle	cycle number
Qc_cyc	charge accumulated during charge of the given cycle (mAh)
Qd_cyc	charge accumulated during discharge of the given cycle (mAh)
Wc_cyc	energy accumulated during charge of the given cycle (mWh)
Wd_cyc	energy accumulated during discharge of the given cycle (mWh)
Qd/Qc	charge efficiency
Wd/Wc	energy efficiency

- **Output-C12.txt** contains the differential capacities of the full cell:

t	time (s)
cycle	cycle number
V12	full cell voltage (V)
dQ12	charge accumulated during dV12 (mAh)

|dQ12|/dV12	differential capacity of the full cell (mAh/V)

- **Output-C1R.txt** contains the differential capacities of the positive half-cell:

t	time (s)
cycle	cycle number
V1R	full cell voltage (V)
dQ12	charge accumulated during dV1R (mAh)
|dQ12|/dV1R	differential capacity of the positive half cell (mAh/V)

- **Output-C2R.txt** contains the differential capacities of the negative half-cell:

t	time (s)
cycle	cycle number
V2R	full cell voltage (V)
dQ12	charge accumulated during dV2R (mAh)
|dQ12|/dV2R	differential capacity of the negative half cell (mAh/V)