EIS ANALYZER

DEWESoft®

SOFTWARE USER MANUAL

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY (EIS)



1. Table of contents

1. Table of contents **2**
2. About this document **4**
2.1 Legend 4
3. Electrochemical Impedance Spectroscopy (EIS) **5**
3.1 What EIS measures 5
3.2 From voltage and current to impedance 5
3.3 How the DewesoftX EIS analyzer works 8
4. Measurement setup: hardware, wiring and sample rate **8**
4.1 What is needed 8
4.2 Choosing the DAQ device and the amplifiers 9
4.3 Choosing the sample rate 10
4.4 Requirements on the excitation signal 11
4.5 Wiring and polarity 11
5. The EIS analyzer module **11**
5.1 Adding the module 11
5.2 The setup screen 12
5.3 Cell configuration 13
5.4 Frequency detection 15
5.5 Frequency mode: Frequency step or Sweep 17
5.6 Axis definition 19
5.7 Output spectra 20
5.8 Test duration estimation 21
5.9 Settings summary 21
6. Measuring and displaying the results **22**
6.1 Running a measurement 22
6.2 Nyquist plot (XY recorder) 23
6.3 Bode plot (2D graph) 24
6.4 Table, recorder and meters 25
6.5 Storing and offline recalculation 25
7. Battery cell demo setup without hardware **26**
7.1 The setup file 26
7.2 Settings used 27
7.3 Result 27
7.4 Things to try 27
8. Interpreting EIS results **28**
8.1 General EIS analysis 28
9. Troubleshooting **28**
10. Warranty information **29**
10.1 Calibration 29
10.2 Support 29
10.3 Service/repair 30
10.4 Restricted Rights 30

10.5 Copyright 30
10.6 Trademarks 30
11. Safety instructions 30
11.1 Safety symbols in the manual 30
11.2 General Safety Instructions 31
11.2.1 Environmental Considerations 31
11.2.2 Product End-of-Life Handling 31
11.2.3 System and Components Recycling 31
11.2.4 General safety and hazard warnings for all Dewesoft systems 31
12. Documentation version history 35

2. About this document

The purpose of this document is to provide the user with all the necessary information on how to use the **EIS Analyzer Plugin** in DewesoftX ensuring correct measurement and analysis results from your test setup and specimen (electrolyzer, fuel cell or battery cell).

The most recent version of this reference manual can be downloaded from our homepage. If you would like to learn more about the solutions offered by Dewesoft for other applications, please refer to the download section of our website for more information.

2.1 Legend

The following symbols and formats will be used throughout the document.



Important
It gives you important information about the subject. Please read carefully!



Hint
It gives you a hint or provides additional information about a subject.



Example
Gives you an example of a specific subject.



Caution
Calls attention to a procedure, practice, or condition that could possibly cause damage to equipment or permanent loss of data.

3. Electrochemical Impedance Spectroscopy (EIS)

3.1 What EIS measures

Electrochemical cells in electrolyzer stacks, fuel cells, supercapacitors and batteries are central components of electric vehicles and of energy storage and conversion systems. Electrochemical Impedance Spectroscopy (EIS) is an established, non-destructive technique that characterizes such a cell by its complex impedance as a function of frequency. The impedance spectrum separates processes that happen at different speeds inside the cell. The ohmic resistance of electrolyte, electrodes and contacts, the charge-transfer kinetics at the electrode surfaces, and the slow diffusion of ions. EIS is used from material science and prototype testing to end-of-line quality control, operational inspection and predictive maintenance. In battery technology the spectrum is used to estimate the state of charge (SoC) and to quantify the state of health (SoH) with equivalent-circuit models.

EIS works by superimposing a small sinusoidal signal of constant amplitude on the operating point of the system under test. The frequency of the sine is varied over a wide range, typically from several kHz down to a few mHz, and at every frequency the amplitude and phase of the response are compared with the excitation.
Two ways of excitation are common:

- Galvanostatic EIS (GEIS): a sinusoidal current is injected and the voltage response is measured. This is the usual choice for batteries, fuel cells and electrolyzers, where the current is easier to control. The current amplitude is typically a few percent of the nominal current, so that the cell stays in its linear region.
- Potentiostatic EIS (PEIS): a sinusoidal voltage is applied and the current response is measured. It is common in corrosion and coating studies.

The DewesoftX EIS analyzer works with either kind of excitation. It measures voltage and current and computes the impedance from the two, while the excitation itself comes from separate hardware (section 4.1). The frequency is detected from the current channel, so the current must carry a clean sine at every frequency.

3.2 From voltage and current to impedance

At one excitation frequency f the current and the voltage response are sine waves of the same frequency (Figure 3-1):

$$i(t) = I_0 \cdot \sin(2\pi f t)$$
$$u(t) = U_0 \cdot \sin(2\pi f t + \varphi)$$

The impedance is the complex ratio of the two phasors:

$$Z(f) = \frac{U(f)}{I(f)} = |Z| \cdot e^{j\varphi} = R + jX$$

- $R = Re(Z)$ is the resistance (in-phase part),
- $X = Im(Z)$ is the reactance (quadrature part): $X < 0$ for capacitive behaviour, $X > 0$ for inductive behaviour,
- $|Z| = \sqrt{R^2 + X^2}$ is the magnitude and φ the phase angle.

The unit of Z, R and X is Ω (Ohm). For a single cell the values are in the $m\Omega$ range, so the AC voltage response is only a few mV on top of a cell voltage of several volts. The data acquisition system has to resolve these few mV on the full cell voltage (chapter 4).

The spectrum is usually shown in two ways:

- Nyquist plot: Negative reactance (-X) is plotted against resistance (R), one point per frequency (Figure 3-2). The sign is inverted by convention so that the capacitive arc of a cell appears in the upper half plane. High frequencies are at the left (small R), low frequencies at the right. Inductive behaviour of cables and cell tabs at the highest frequencies shows as a tail below the real axis.
- Bode plot: |Z| (or R and -X) and the phase angle against frequency on a logarithmic frequency axis (Figure 3-3).

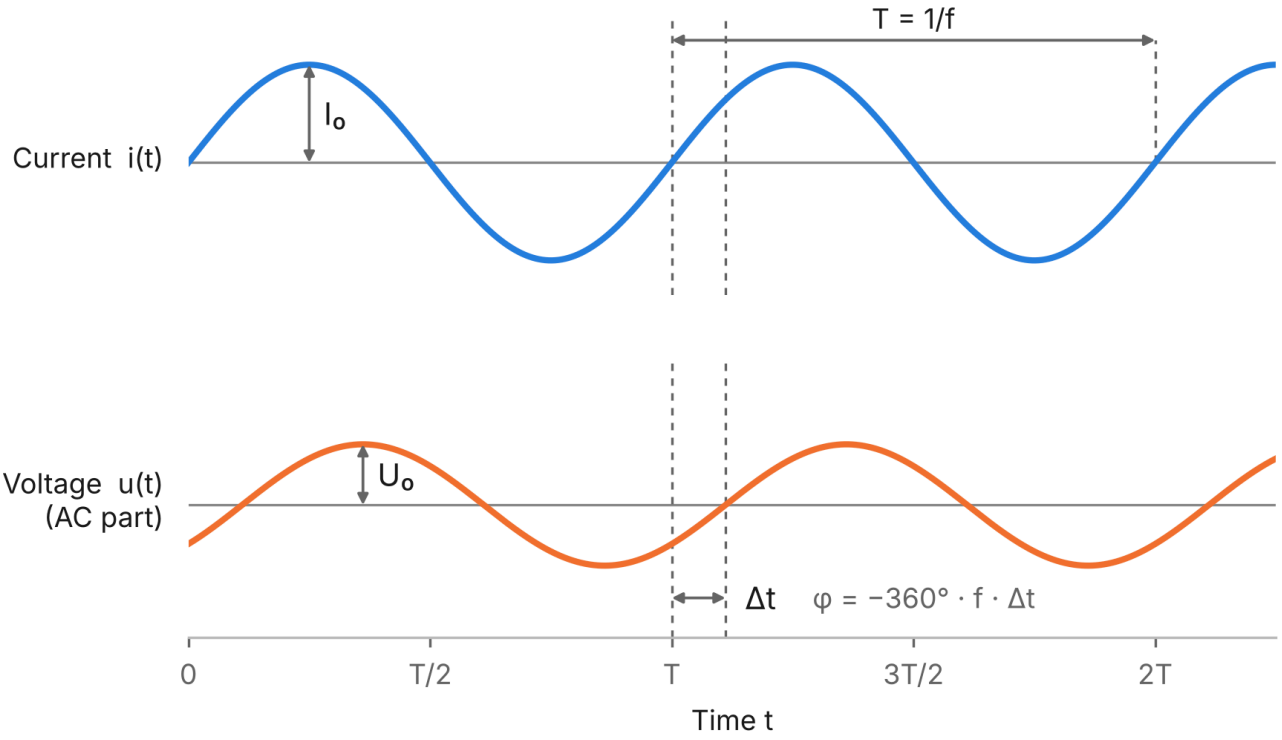


Figure 3-1: Excitation current i(t) and voltage response u(t) at one frequency. The voltage is shown without its DC level. With capacitive behaviour the voltage lags the current by the phase angle φ (φ < 0).

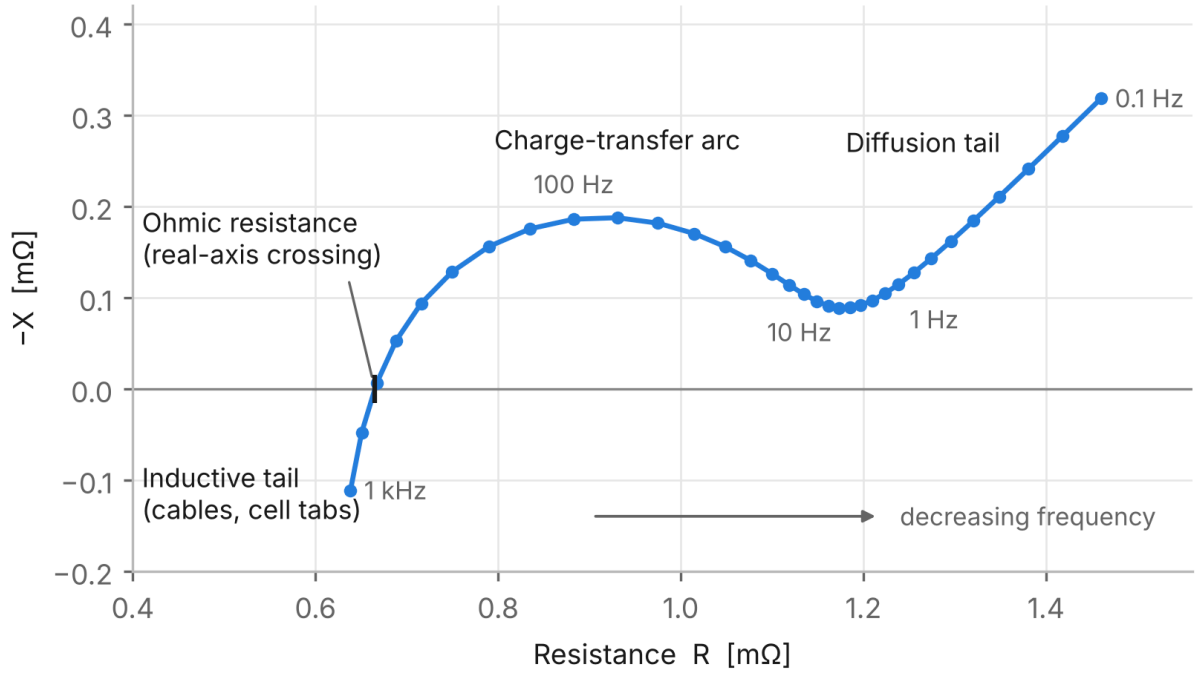


Figure 3-2: Nyquist plot of a lithium-ion cell (equivalent-circuit model), one point per frequency. High frequencies are at the left, low frequencies at the right.

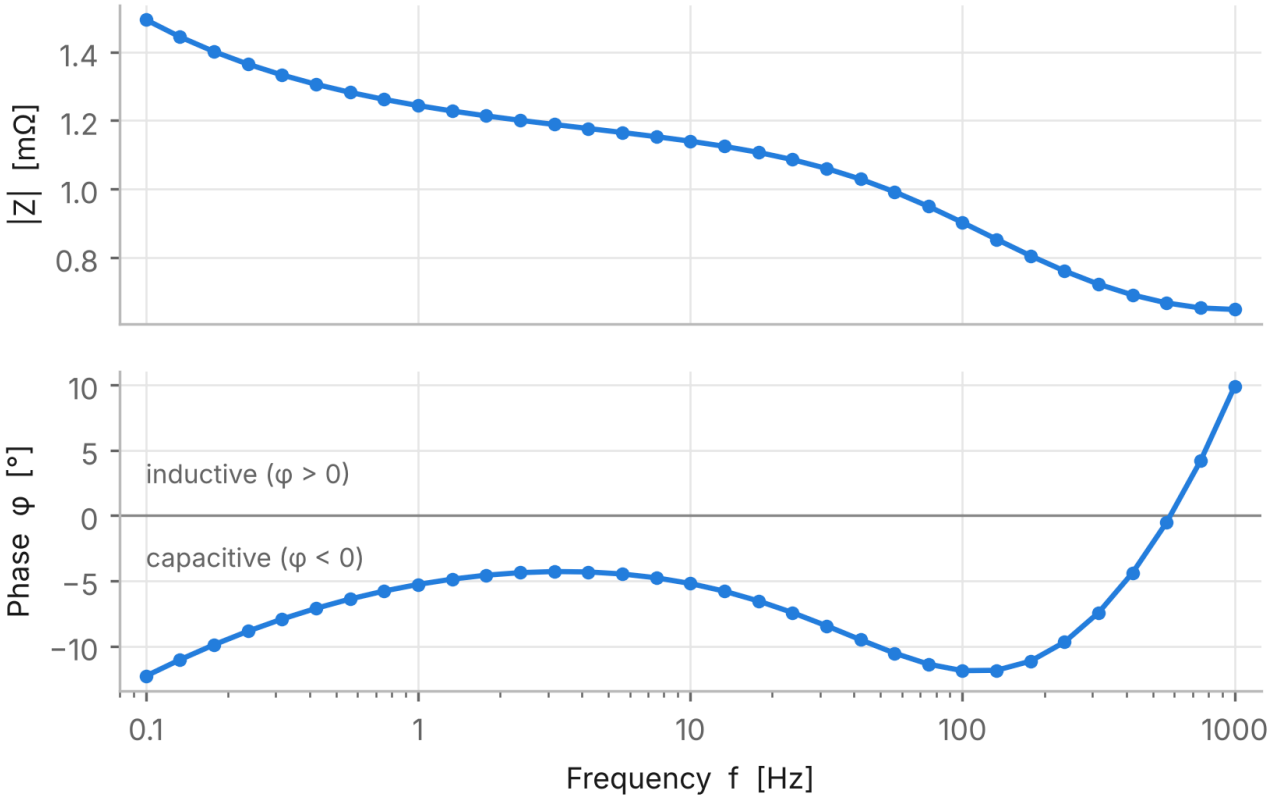


Figure 3-3: Bode plot of the same cell: magnitude |Z| (top) and phase angle φ (bottom) against frequency.

3.3 How the DewesoftX EIS analyzer works

The EIS analyzer works as a plugin in DewesoftX software. This means that the data conditioned and acquired by one of our DAQ devices, transferred to DewesoftX is made available to the EIS plugin, which then performs the analysis and outputs the results. It is important to note, that the EIS plugin only performs the analysis, it does not provide the excitation signals to the device under test, or control signals to the amplifier exciting the device under test. The excitation has to come from an external source, a power supply with a modulation input, a current amplifier or a similar device. The module processes the measured voltage and current as follows:

1. Frequency detection. The current channel is monitored by a zero-crossing detector with hysteresis (Figure 5-5). A new period starts every time the current crosses the Trigger level upwards after it has first fallen below the Rearm level. The inverse of the period duration is the detected frequency, which is available as the output channel Frequency.
2. Frequency tracking. In Frequency step mode the module waits until the detected frequency has settled on a new value (a frequency step) and then evaluates the periods at that frequency. In Sweep mode it expects the frequency to change continuously and evaluates period after period while following it. See section 5.5.
3. Harmonic estimation. For every evaluated period a harmonic estimator computes the phasor of the fundamental component of the voltage and of the current at the detected frequency. The estimator keeps only the fundamental component, so harmonics and the DC offset are filtered out and noise is strongly attenuated.
4. Impedance Z = U/I is computed from the two phasors and split into R and -X.
5. The result is written to the frequency line of the Axis definition that is closest to the detected frequency. Several periods evaluated at one line are averaged, and the number of periods is reported in the Period count channel. Lines between measured lines can be filled by interpolation. The resulting vectors Z, R, -X (and the harmonic estimates of U and I) are the spectra that the Nyquist and Bode displays plot.

The module runs online during the measurement, so the Nyquist plot builds up line by line while the excitation sweeps through the frequencies. It can also be recalculated offline on a stored data file with changed settings (section 6.5).

4. Measurement setup: hardware, wiring and sample rate

4.1 What is needed

An EIS measurement with DewesoftX consists of three parts displayed in Figure 4-1:

- An excitation source that superimposes a sinusoidal current (GEIS) or voltage (PEIS) of controllable frequency on the operating point of the cell. The source has to **step** or **sweep** through the frequency range of interest on its own. For example a programmable power supply or amplifier with an analog modulation input driven by a function generator.
- A Dewesoft data acquisition system that measures the cell voltage and the cell current synchronously with sufficient bandwidth, resolution and isolation.
- DewesoftX with the EIS analyzer module (part of the Opt-Power option), which detects the excitation frequency, computes the impedance and displays it.

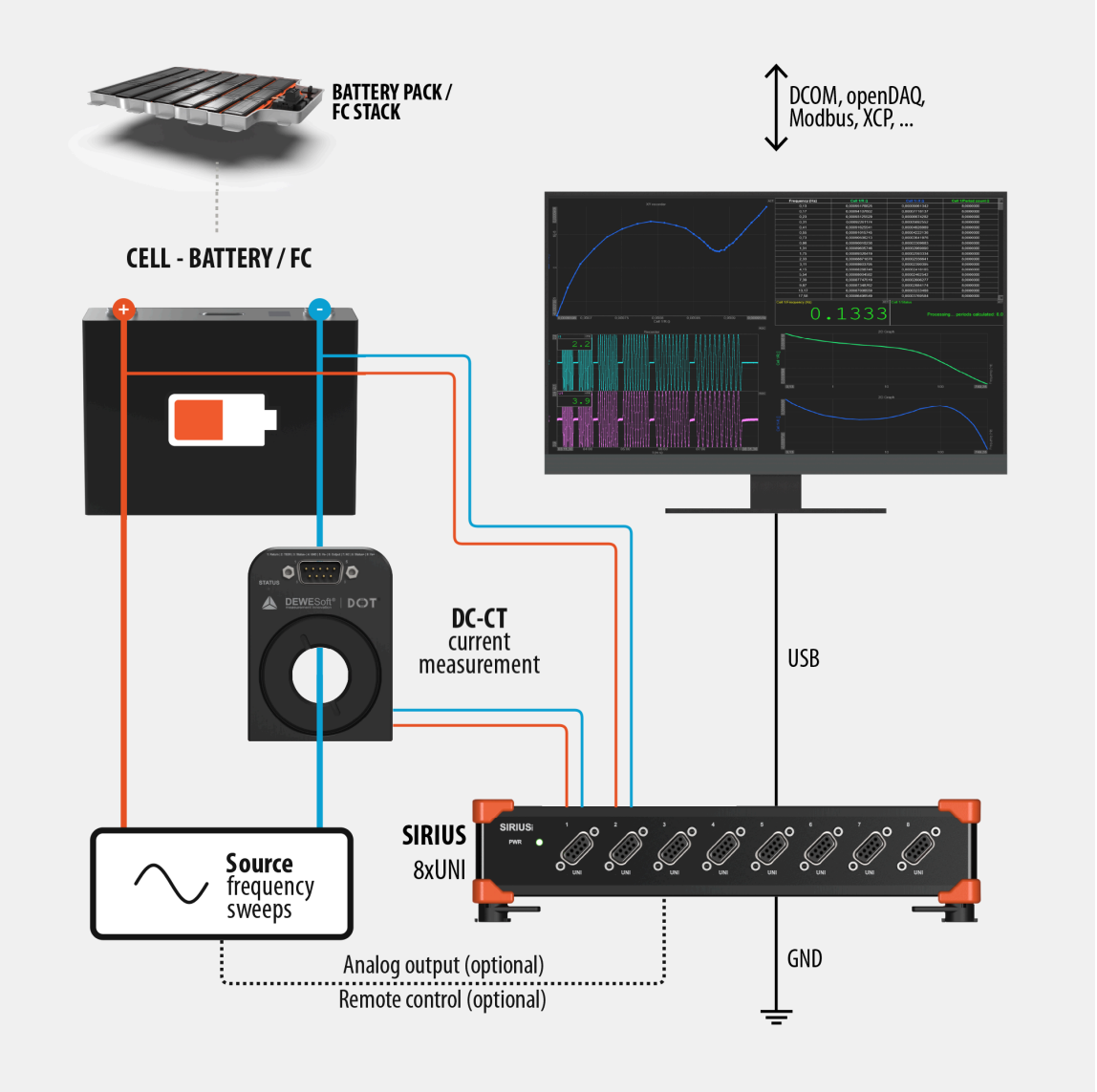


Figure 4-1: EIS measurement of a battery cell with a Dewesoft data acquisition system

4.2 Choosing the DAQ device and the amplifiers

The requirements on the acquisition hardware follow from the signal levels and from the highest frequency of the sweep:

Requirement	Why	What to use
Isolated voltage inputs	Cells in a stack sit on a high common-mode voltage. The current shunt or transducer is on a different potential than the cell terminals.	SIRIUS, IOLITE, or OBSIDIAN isolated analog inputs (LV, UNI, STG amplifiers).
High resolution on the analog inputs	The AC response of a single cell is a few mV on a DC level of 3 to 4 V (or more for stacks). The	Amplifiers use 18-24bit AD converters, use the smallest input range that fits the cell

	input range has to hold the DC level while the mV response is resolved.	voltage.
Accurate current measurement with known phase	Impedance (Z) angle depends on the phase between U and I. A phase error of 1 degree at 1 mOhm produces an error of 17 µOhm in -X.	Precision shunt measured with an isolated voltage input, DC-CT current transducer that has bandwidth well above the highest EIS frequency. Avoid current clamps with low-bandwidth or large phase displacement.
Bandwidth and sample rate for the highest EIS frequency	The zero-crossing detector and the harmonic estimator need enough samples per period.	Use acquisition rate that offers at least 20 samples per period on the highest expected EIS frequency
Synchronous channels	U and I must be sampled on the same clock otherwise the phase and therefore X are wrong, more and more so with higher frequency.	With a single Dewesoft DAQ unit all channels are synchronous. Distributed systems should be synchronized by sync line, IRIG or PTPv2.

Additional sensors (cell temperature, pressure, flow, CAN data from the BMS) can be acquired in the same setup and correlated with the spectra

.

4.3 Choosing the sample rate

The dynamic acquisition rate is set in the Analog in tab (Figure 4-3). Choose it from the highest frequency of the sweep:

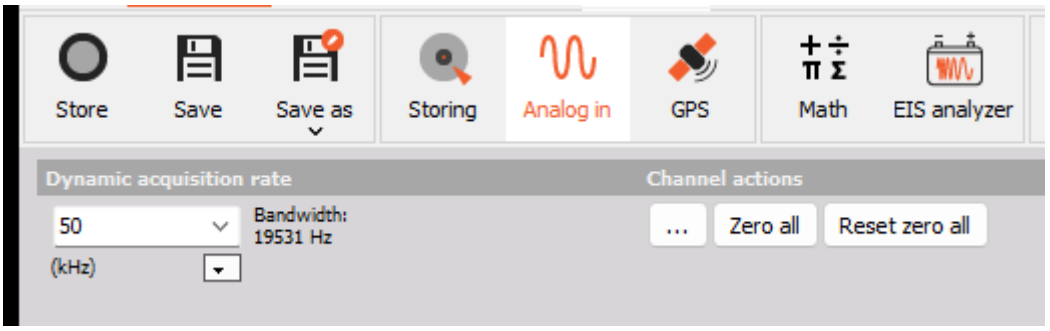


Figure 4-3: Dynamic acquisition rate in the Analog in tab (e.g. 50 kHz for a sweep up to 1 kHz)

- Rule of thumb: sample rate ≥ 20 × upper frequency, better 50 x. The frequency detector locates the zero crossings on the sampled current, and the harmonic estimator integrates over the whole period. With only a few samples per period both become inaccurate. If the sample rate is too low for the set upper frequency, the module reports "Calculation with set Upper frequency requires sample rate above ..." instead of calculating.
- The lowest frequency determines how long the sweep takes. Every frequency line has to be excited for at least the number of periods that the harmonic estimator should use (section 5.8). A line at 10 mHz with 3 periods takes 5 minutes.

- At 50 kS/s the voltage and current channels produce about 0.4 MB/s, i.e. 24 MB per minute of recording. Keep the Storing type "Always fast" so that the full-rate data is available for an offline recalculation.

4.4 Requirements on the excitation signal

The analyzer evaluates what the excitation source produces, so the quality of the result also depends on the excitation:

- Single sine, one frequency at a time. Multi-sine or noise excitation is not supported. The frequency estimator needs one clean fundamental in the current.
- Constant amplitude at every frequency. The amplitude must be larger than the hysteresis of the frequency detector (Trigger level minus Rearm level, section 5.4) and small enough to keep the cell linear. A few percent of the nominal current, or an AC voltage response of a few mV per cell, is typical.
- Enough periods per frequency. Each frequency step should last at least the number of periods set in Test duration estimation plus a few periods for the detector to lock. With 10 periods per step, 7 to 8 periods are typically evaluated.
- A frequency plan that matches the axis. The excitation frequencies should coincide with the lines of the Axis definition (section 5.6), for example 8 frequencies per decade between 1 kHz and 0.1 Hz for an axis with 8 lines per decade and the same limits. Otherwise results are written to the nearest line.
- Sweep or step direction is not important. It is usually high to low. The short high-frequency steps are finished quickly and the long low-frequency steps come last. The analyzer accepts both directions and also a continuous sweep (section 5.5).

4.5 Wiring and polarity

- Measure the voltage directly at the cell terminals with separate sense leads (four-wire connection), not at the current-carrying cables, so that the cable resistance and inductance do not add to the cell impedance.
- Keep the sense leads short. The inductive tail at high frequencies comes mostly from the loop area of the leads.
- The impedance is computed as Z = U/I with the measured signs. If R comes out negative, one of the two channels is inverted - either voltage or current. Swap the polarity of the current channel (or scale it by -1 in the channel setup).

5. The EIS analyzer module

5.1 Adding the module

1. Open DewesoftX and go to the Ch. setup tab.
2. Click More... in the toolbar and select EIS analyzer in the Electrical measurements group (Figure 5-1).
3. The module appears as a new tab EIS analyzer in the setup toolbar. The first instance is named EIS analyzer 1. As with other plugins, more instances can be added with the + button next to the instance tab.

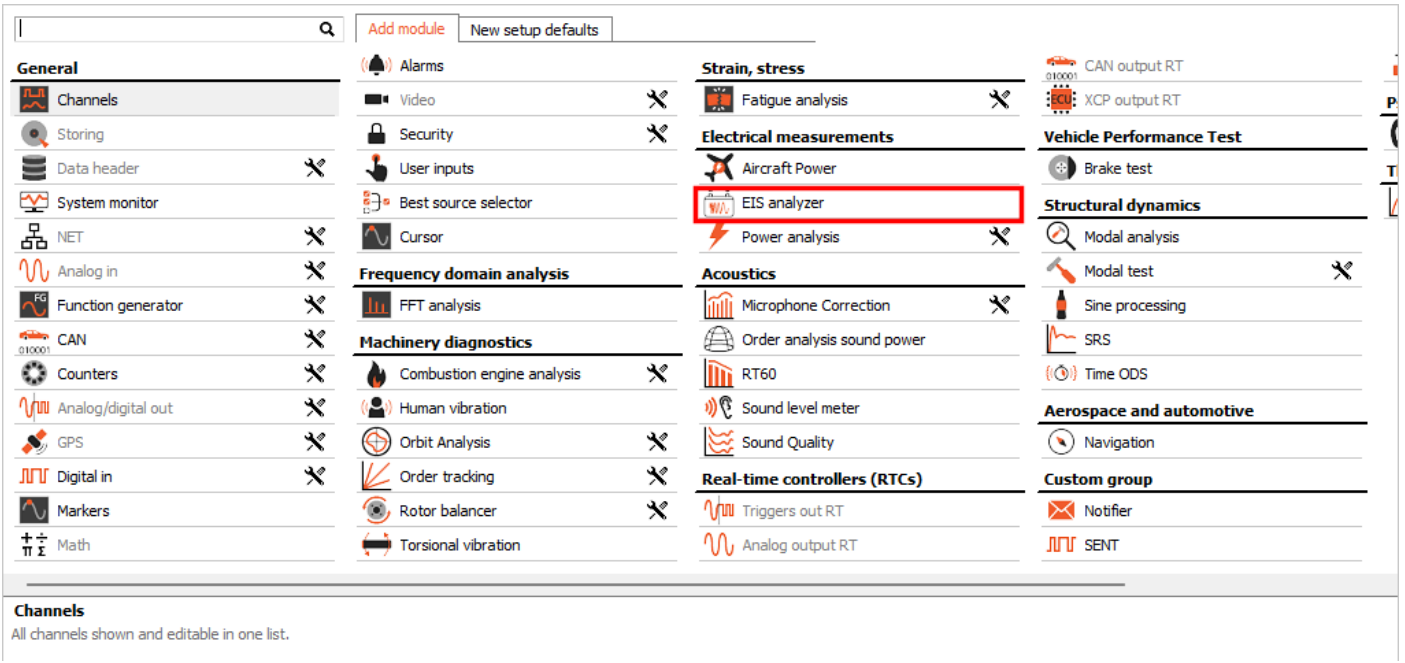


Figure 5-1: Adding the EIS analyzer module via More... > Electrical measurements

5.2 The setup screen

The setup screen is divided into five groups (Figure 5-2):

1. **Cell configuration:** how many cells are measured and which channels carry their voltage and current.
2. **Frequency detection:** how the excitation frequency is detected and whether the excitation is stepped or swept.
3. **Axis definition:** the frequency range and the frequency lines of the output spectra.
4. **Output spectra:** which spectra are calculated.
5. **Test duration estimation:** the minimum duration of a sweep or steps over the defined axis.

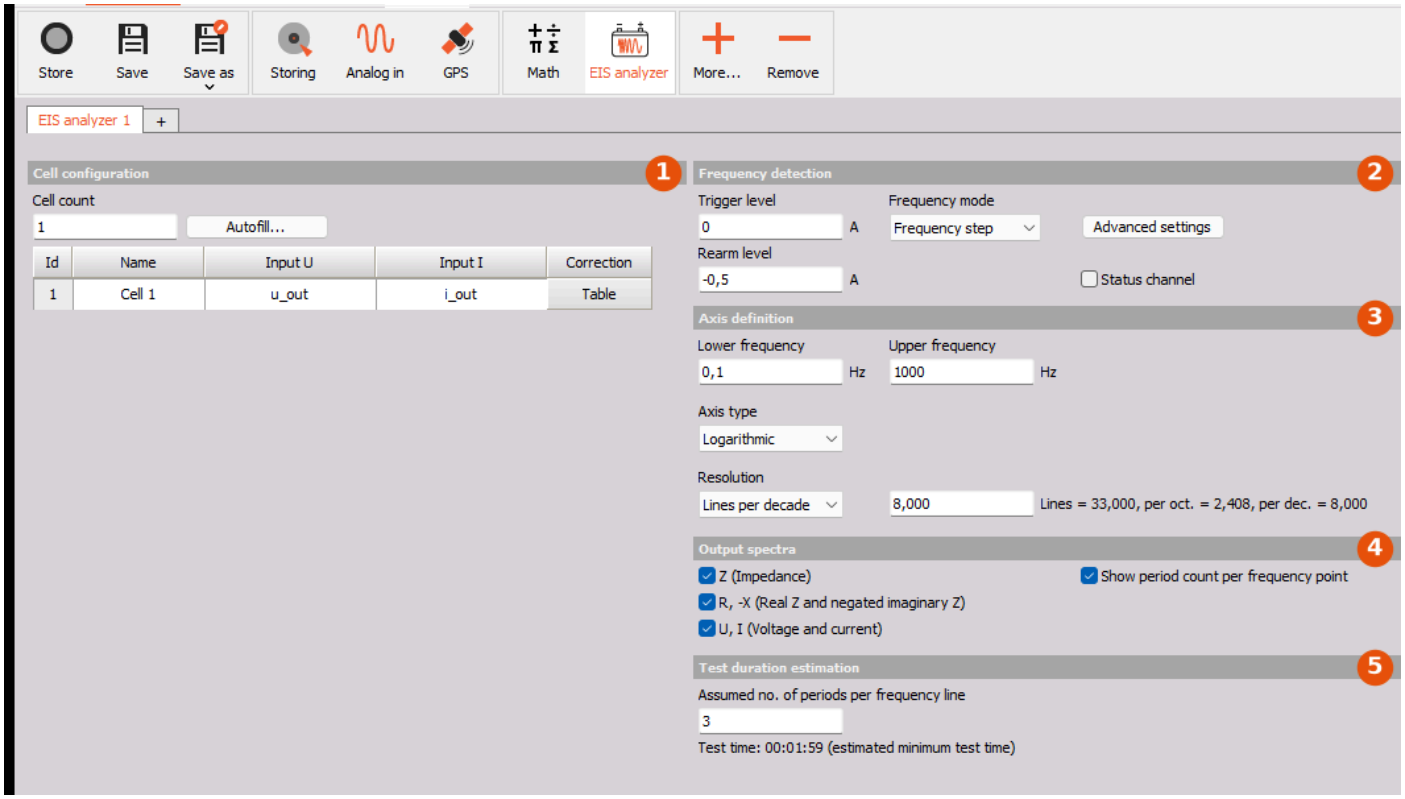


Figure 5-2: EIS analyzer setup screen with the settings of the battery demo

5.3 Cell configuration

Cell count sets the number of cells (or stack sections) that are analyzed in parallel. Every cell has one row in the configuration grid:

Column	Meaning
Id	Running number of the cell.
Name	Name of the cell; it is used as prefix of the output channels (Cell 1/Z, Cell 1/R, ...). Click the cell to rename it.
Input U	Analog input or math channel with the voltage of this cell.
Input I	Analog input or math channel with the current through this cell. Several cells of a stack can share the same current channel.
Correction	Opens the correction table of the cell (see below).

Autofill... (Figure 5-3) fills the grid for many cells at once. Select the first voltage channel and the first current channel, the number of cells and the position increment (the distance in the channel list from one cell's channel to the next). Add creates the rows.

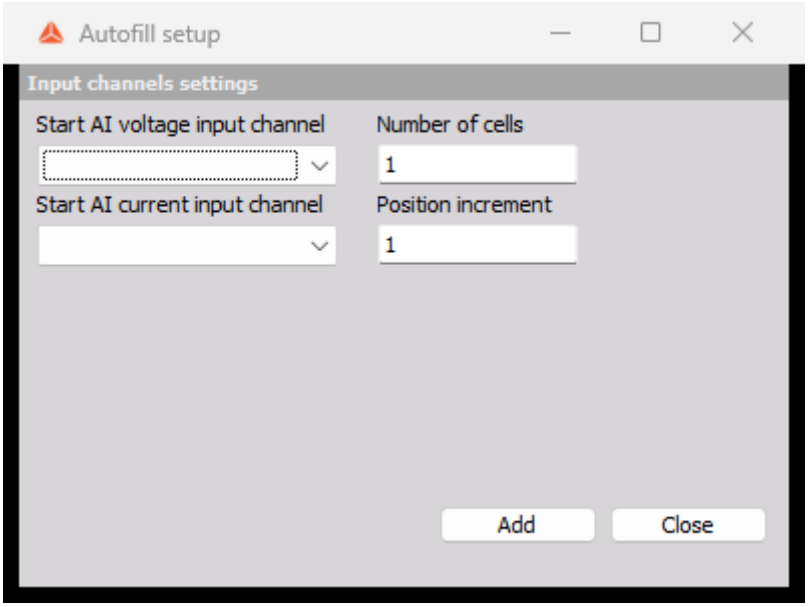


Figure 5-3: Autofill dialog

Correction table. The Table button in the Correction column opens a table with one row per frequency line of the axis (Figure 5-4). For each line a resistance R (real) and a reactance -X (imag) can be entered. These values are applied to the calculated impedance of that cell at that line. Use it to compensate for the impedance of the fixture, cables or shunt that is measured in series with the cell. To get the estimation of the correction factors, you can measure once with the cell replaced by a short, copy the resulting R and -X values into the table. The table has as many rows as the axis has lines, so define the axis first.

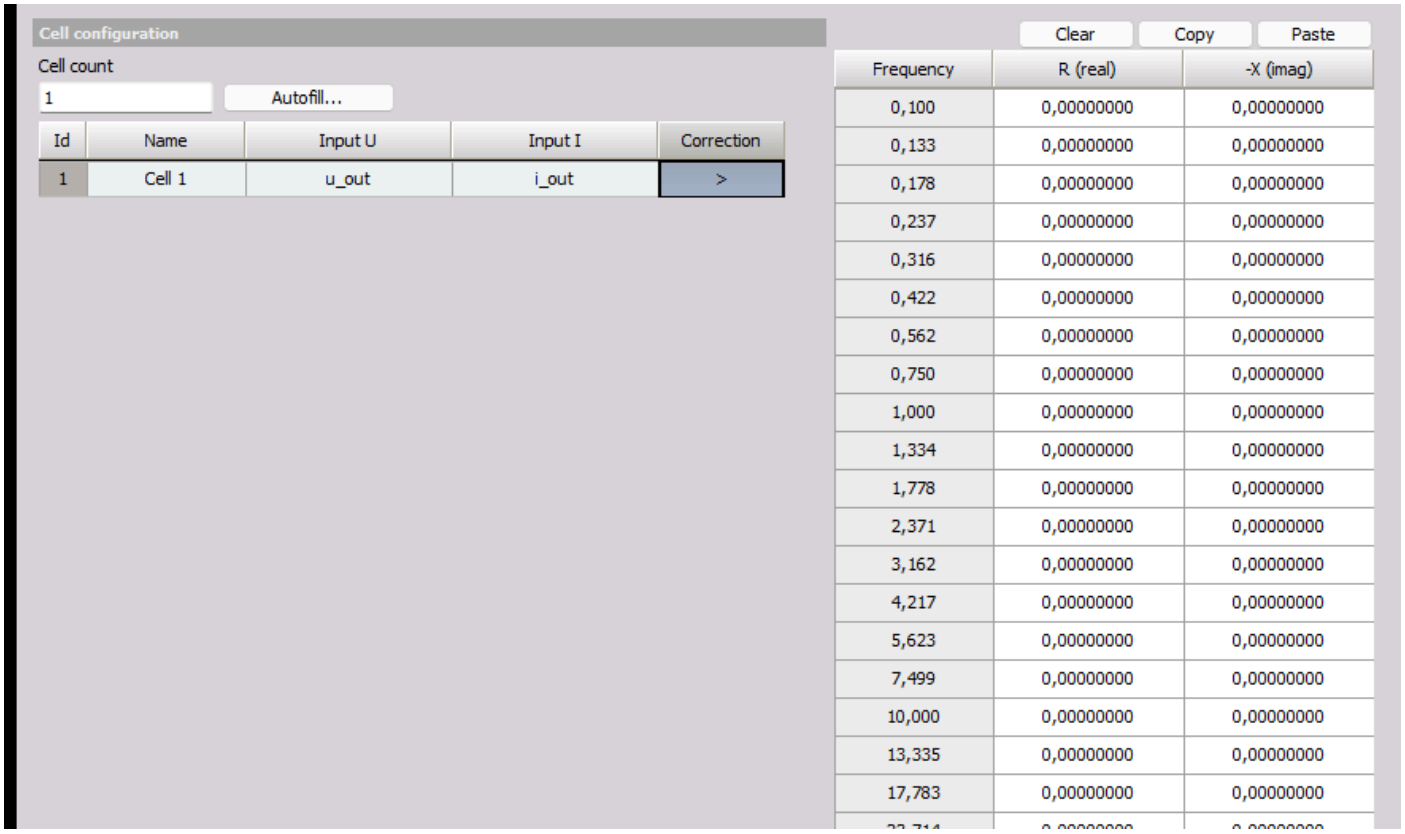


Figure 5-4: Correction table of a cell with the 33 lines of the demo axis

5.4 Frequency detection

Setting	Meaning
Trigger level [A]	Level of the current at which a new period starts (upward crossing). Set it to the DC level of the current during the excitation, usually 0 A for a pure AC excitation or the DC bias for an excitation on top of a bias.
Rearm level [A]	The current has to fall below this level before the next trigger is accepted. The difference between Trigger level and Rearm level is the hysteresis that keeps noise from producing false periods. Rearm level must not be positive relative to the trigger. set it to about 30 to 50 % of the smallest excitation amplitude below the trigger level.
Frequency mode	Frequency step or Sweep, see section 5.5.
Status channel	Adds a text channel that reports the state of the detector: "Waiting for trigger...", “Frequency step detected”, "Processing... periods calculated: ...", Useful while setting up the trigger levels.

Advanced settings	Opens the dialog of Figure 5-6.

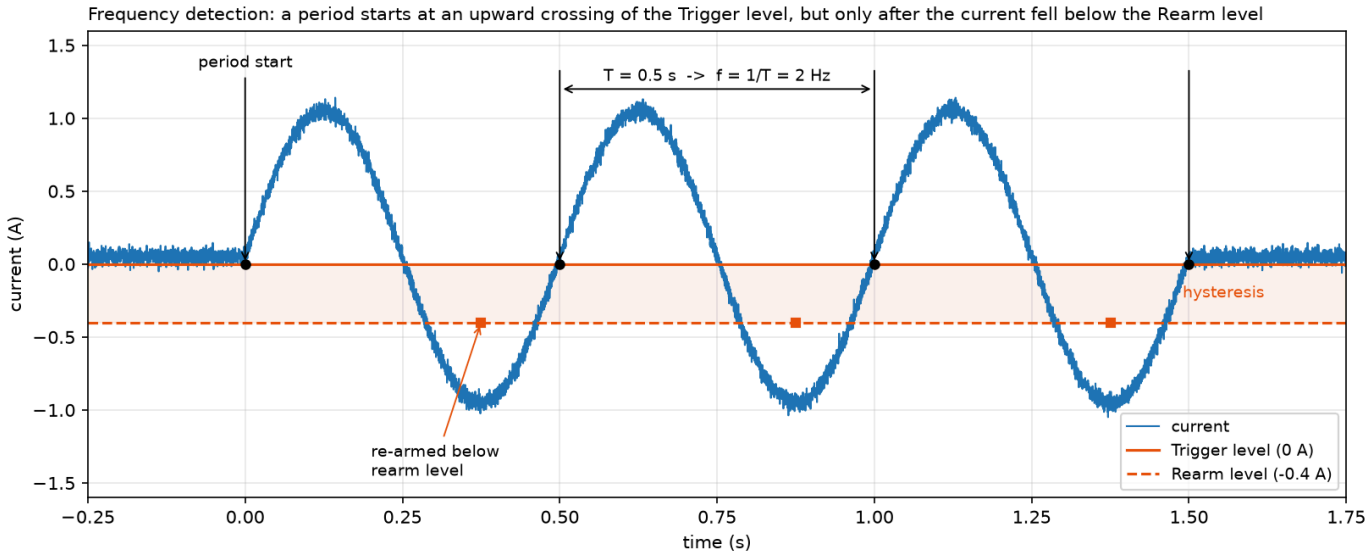


Figure 5-5: Frequency detection with Trigger level and Rearm level. The hysteresis between the two levels keeps noise from producing false periods

Example: the battery demo (chapter 7) excites with 0.5 to 2.1 A peak around a small DC current. Trigger level 0 A and Rearm level -0.2 A work for all bursts. With Rearm level -0.5 A the first burst, whose troughs reach only -0.43 A, never re-arms the detector. Its line stays empty and the Nyquist plot shows a line through the origin.

The Advanced settings dialog (Figure 5-6) contains:

- **Filter data for frequency calculation:** low-pass filters the current before the zero-crossing detection. Enable it when the current is noisy or distorted and the detector produces too many or irregular periods. The filtered signal is used only for the frequency detection, not for the impedance.
- **Use interpolation between frequency calculation points:** lines of the spectrum for which no result exists yet are interpolated between the neighbouring measured lines, so that the Nyquist and Bode plots are continuous even if the excitation skips lines. Lines outside the measured range (before the first and after the last measured line) stay at zero.
- **Set min. amplitude change to help detect frequency step (Frequency step mode only):** a frequency step is also recognized when the amplitude of the current changes by more than Min. amplitude change (default 20 %) although the frequency stays the same. Enable it when the source repeats a frequency with a different amplitude or when the amplitude ramps at the beginning of a sweep.

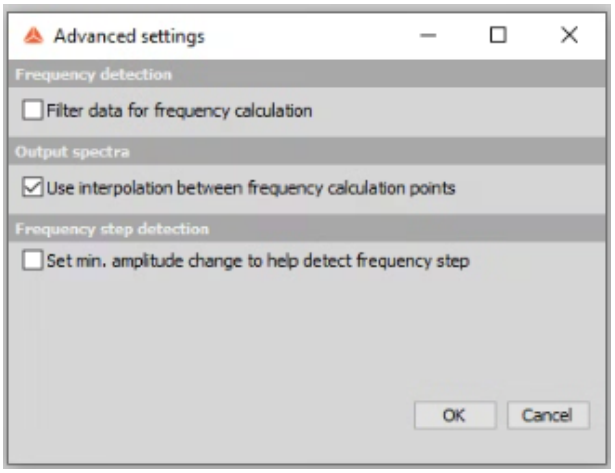


Figure 5-6: Advanced settings in Frequency step mode (left) and in Sweep mode (right)

5.5 Frequency mode: Frequency step or Sweep

The two modes describe how the excitation source moves through the frequencies, and the analyzer has to be told which one it is (Figure 5-7).

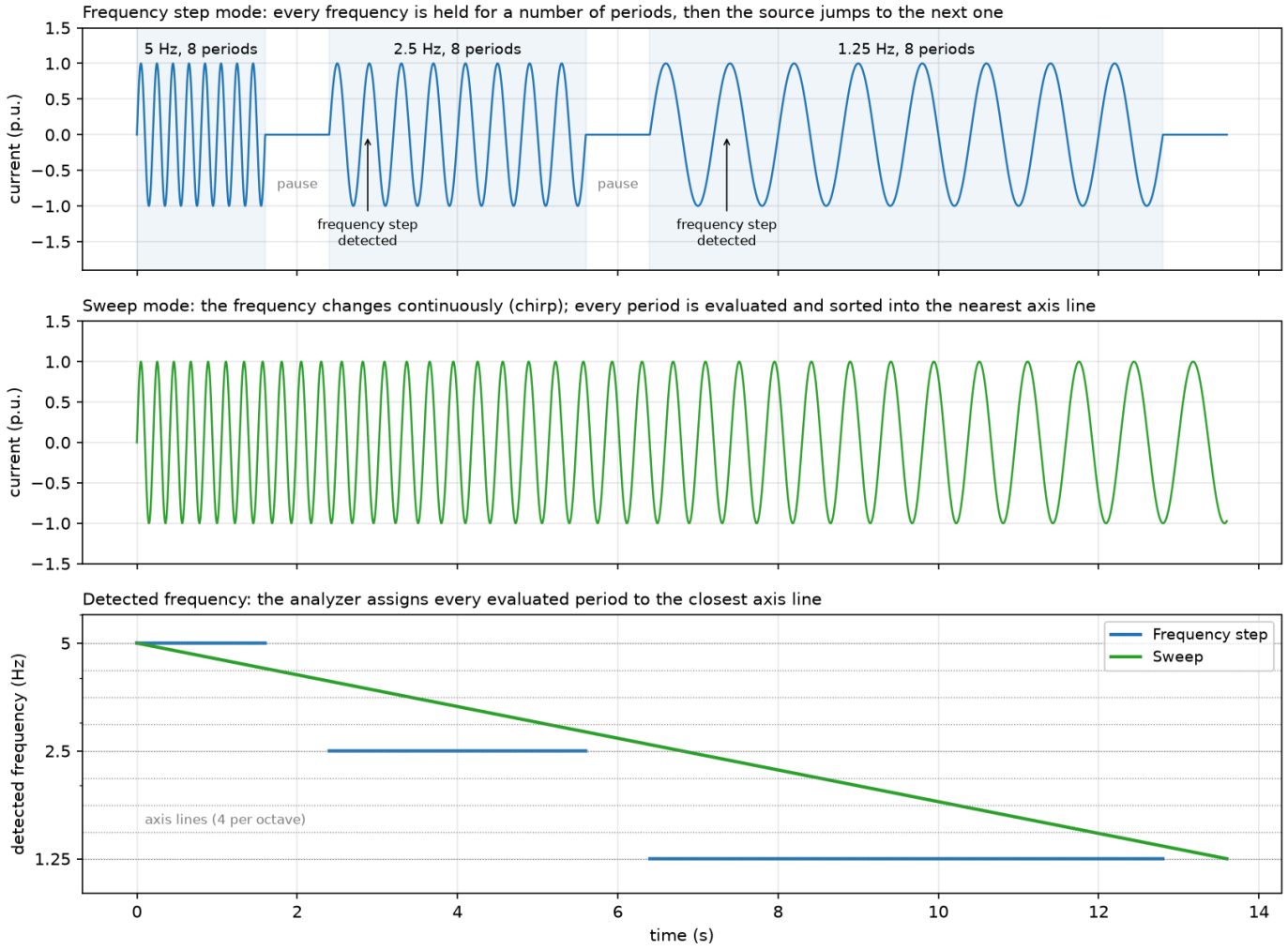


Figure 5-7: Excitation current in Frequency step mode (top) and in Sweep mode (middle); detected frequency against time and the lines of the axis (bottom)

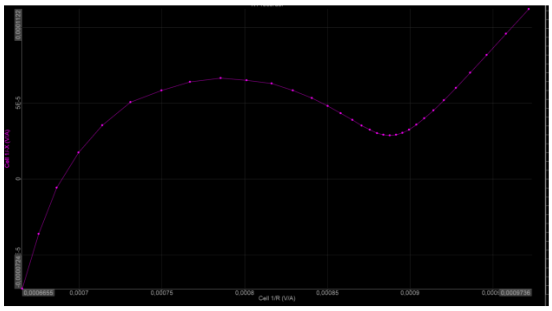
For Frequency step mode, the source holds every frequency for a number of periods and then jumps to the next one, often with a short pause in between. This is the classic EIS sequence that impedance analyzers produce. The analyzer waits until the detected frequency has settled on a new value ("Frequency step detected"), evaluates the periods of that step with the harmonic estimator, averages them and writes the result to the nearest line of the axis. The number of evaluated periods per line is reported in the Period count channel.
An example of this mode is as follows: an excitation of 10 periods at 1000 Hz, a 2.5 s pause, 10 periods at 750 Hz, a pause, 10 periods at 562 Hz and so on down to 0.1 Hz, 8 frequencies per decade. With an axis of 8 lines per decade from 0.1 Hz to 1000 Hz every burst lands exactly on one line, and Period count shows 7 to 8 periods per line (the first periods of each burst are used by the detector to lock to the new frequency).
For frequency sweep the source changes the frequency continuously, for example a logarithmic chirp from 1 kHz to 0.1 Hz over 10 minutes. There is no settling and no pause. The analyzer follows the frequency from period to period, evaluates every period and sorts the result into the nearest axis line. All periods whose frequency falls closest to the same line are averaged there. Because a line now collects periods of slightly different frequencies, use a fine axis (many lines per decade) and a slow sweep, so that several periods fall into each line.
An example of this mode is as follows: a linear sweep from 1 kHz down to 10 Hz over 100 s with an axis of 1 Hz steps. At 1 kHz one period lasts 1 ms and the frequency changes by 10 Hz per second, so about 10 periods fall into every 1 Hz line. At 10 Hz the sweep passes a line in 0.1 s, which is one period.

When choosing, consider the factors below.

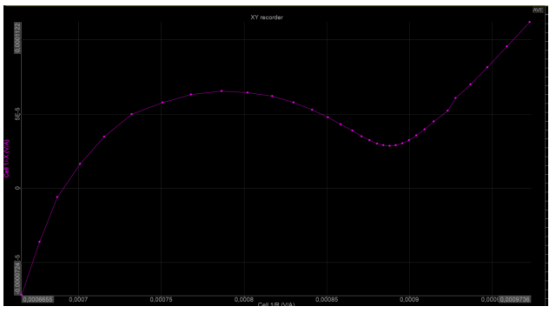
	Frequency step	**Sweep**
Accuracy	Best. Recommended for batteries and stacks	Lower at low frequencies, where only one period falls into a spectral line
Duration	Longer, since every step needs its periods plus settling	Shorter for the same frequency range

Each mode expects its own kind of signal. In Frequency step mode a continuously changing frequency never settles, so no step is detected. In Sweep mode a stepped signal is processed, but the periods during which the source switches between frequencies are evaluated as well. Figure 5-8 shows the stepped demo signal of chapter 7 recorded in Frequency step mode and recalculated in Sweep mode from the same file. The spectra are almost identical, but in Sweep mode the lowest lines collect 10 to 29 periods instead of 8, because the transition periods at the start and end of every burst and the switching between the long bursts are assigned to the nearest lines, and the values of these lines deviate by a few µOhm.

Frequency step mode (recorded live)



Sweep mode (offline recalculation of the same file)



The eight lowest lines, left: Frequency step mode, right: Sweep mode. Sweep mode also evaluates the transition periods between the bursts (period counts up to 29)

	Frequency step			Sweep		
line (Hz)	R (mOhm)	-X (uOhm)	periods	R (mOhm)	-X (uOhm)	periods
0.10	0.9718	112.4	9	0.9726	112.2	11
0.13	0.9581	95.7	8	0.9589	95.5	10
0.18	0.9464	81.6	8	0.9471	81.5	10
0.24	0.9364	69.9	8	0.9370	69.8	10
0.32	0.9278	60.0	8	0.9279	60.6	14
0.42	0.9205	51.9	8	0.9232	52.2	29
0.56	0.9143	45.2	8	0.9148	44.9	9
0.75	0.9087	39.9	8	0.9092	39.6	9

Figure 5-8: The stepped demo excitation evaluated in Frequency step mode (left) and in Sweep mode (right), with the lowest lines of the result table

5.6 Axis definition

The Axis definition fixes the frequency lines at which the spectra are calculated and stored. Every result is assigned to the line closest to the detected frequency, so the axis should contain the frequencies of the excitation.

Setting	Meaning
Lower frequency [Hz]	First line of the axis.
Upper frequency [Hz]	Last line of the axis. Must be higher than Lower frequency and compatible with the sample rate (section 4.3).
Axis type	Logarithmic (equal ratio between neighbouring lines, the usual choice for EIS) or Linear (equal distance in Hz).
Resolution	In the logarithmic axis these are Lines per decade, Lines per octave or Total Lines. In the linear axis these are Step in Hz. The label next to the value shows the resulting number of lines and, for a logarithmic axis, the equivalent lines per octave and per decade.

The lines are calculated as follows. The axis runs from the lower frequency f_low to the upper frequency f_high and spans D = log10(f_high / f_low) decades. Line k sits at the frequency f_k, with k counted from 0 at the lower frequency.
Logarithmic axis. The three resolution settings describe the same kind of axis, with a constant ratio between neighbouring lines. They differ only in how the spacing is entered:

- Lines per decade (n_d): f_k = f_low · 10^(k / n_d). Number of lines N = n_d · D + 1.
- Lines per octave (n_o): f_k = f_low · 2^(k / n_o). One decade has 3.32 octaves, so n_o lines per octave are the same as 3.32 · n_o lines per decade.
- Total Lines (N): f_k = f_low · (f_high / f_low)^(k / (N - 1)), which is (N - 1) / D lines per decade.

When the setting does not give a whole number of lines, the module rounds down, and the last line then lies a little below the upper frequency.
Example for an axis from 0.1 Hz to 1000 Hz (D = 4):

Setting	Lines per decade	Lines per octave	Number of lines
Lines per decade = 8	8	2.41	33
Lines per octave = 3	9.97	3	40 (40.86, rounded down)
Total Lines = 21	5	1.5	21

With linear axis the lines are equally spaced, f_k = f_low + k · df, with the step df entered in Hz. The number of lines is N = floor((f_high - f_low) / df) + 1. From 0.1 to 1000 Hz with a step of 10 Hz that gives 100 lines at 0.1, 10.1, 20.1, … 990.1 Hz (Figure 5-10). A linear axis suits a narrow frequency band. Over several decades it crowds the high frequencies with lines and leaves almost none at the low end.

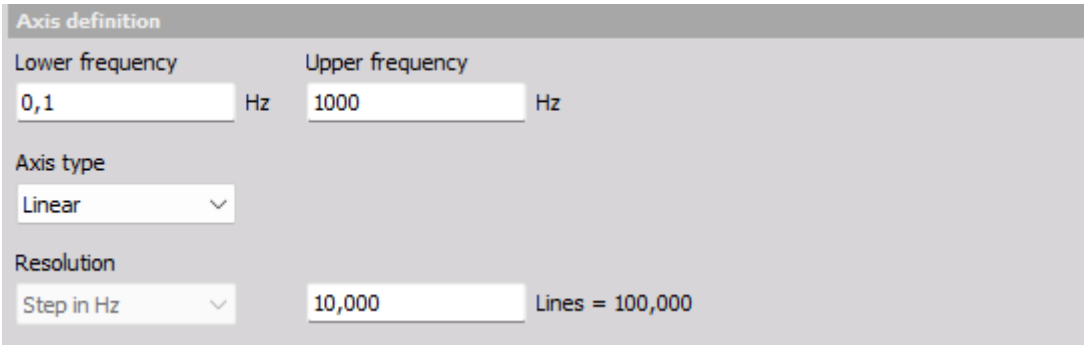


Figure 5-9: The same frequency range with 8 lines per decade (top), 3 lines per octave (middle) and 21 total lines (bottom); the label shows the resulting resolution
Figure 5-10: Linear axis with a step of 10 Hz

5.7 Output spectra

The checkboxes select which spectra the module outputs. Each one is a vector channel over the frequency lines of the axis, per cell:

Checkbox	Output channels	Content
Z (Impedance)	Cell n/Z [V/A]	Magnitude of the impedance

		per line.
R, -X (Real Z and negated imaginary Z)	Cell n/R, Cell n/-X [V/A]	Resistance and negated reactance per line. The input of the Nyquist plot.
U, I (Voltage and current)	Cell n/<U channel>/Harmonic estimator [V], Cell n/<I channel>/Harmonic estimator [A]	Amplitude of the fundamental of voltage and current per line, as computed by the harmonic estimator. Use them to verify that the excitation amplitude is constant over frequency.
Show period count per frequency point	Cell n/Period count [-]	Number of periods that were evaluated for each line. Zero means that the line has not been measured (or was interpolated).

Two channels are always present. Cell n/Frequency [Hz], the frequency detected from the current (a scalar channel that is updated with every period), and, if enabled in Frequency detection, the status channel.

5.8 Test duration estimation

Assumed no. of periods per frequency line is the number of periods the source is expected to hold at every line. The module multiplies it with the sum of the periods of all lines and shows the result as Test time. The minimum duration of one complete sweep over the axis, without pauses and settling.

5.9 Settings summary

Group	**Setting**	**Options / unit**
Cell configuration	Cell count	integer >= 1
	Name, Input U, Input I	channel selection
	Correction	table of R and -X per line
Frequency detection	Trigger level	A
	Rearm level	A, not positive relative to the trigger
	Frequency mode	Frequency step, Sweep
	Status channel	on/off
Advanced settings	Filter data for frequency calculation	on/off
	Use interpolation between	on/off

	frequency calculation points	
	Set min. amplitude change to help detect frequency step	on/off, %
Axis definition	Lower frequency, Upper frequency	Hz
	Axis type	Linear, Logarithmic
	Resolution	Total Lines, Lines per octave, Lines per decade (log); Step in Hz (linear)
Output spectra	Z; R, -X; U, I; Show period count	on/off
Test duration estimation	Assumed no. of periods per frequency line	integer

6. Measuring and displaying the results

6.1 Running a measurement

Start the measurement with going into Measure. The module starts in the state "Waiting for trigger..." until the current crosses the trigger level. From then on the Frequency channel shows the detected frequency, and every completed frequency step adds a point to the spectra. The analyzer accepts the excitation in any order. A sweep can be repeated and the lines are overwritten with the new values. When the module is added, DewesoftX creates a display Cell 1/Nyquist plot for every cell (Figure 6-1). It contains the preset displays with widgets that are described below and can be edited like any other display.

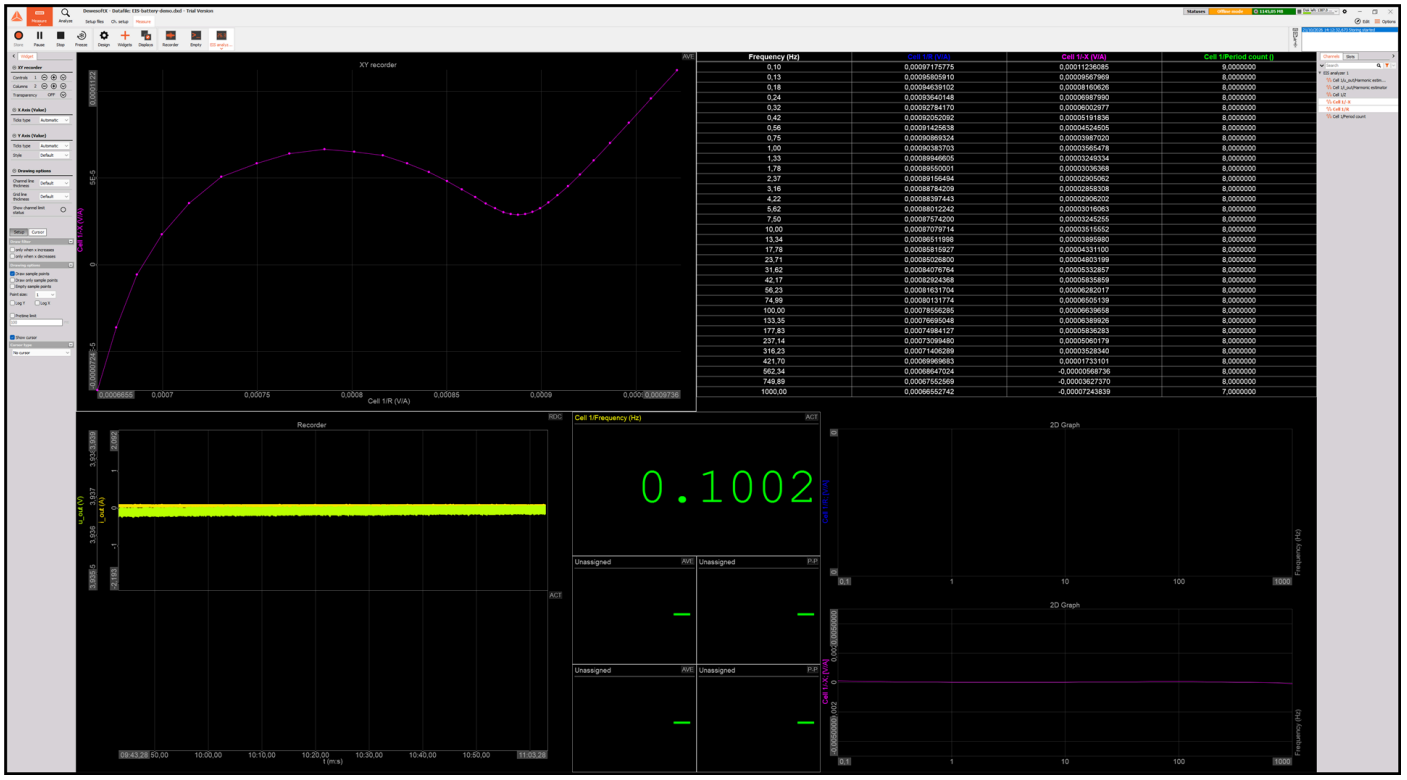


Figure 6-1: The generated Nyquist plot display of the demo during the sweep: XY recorder (Nyquist), table of R, -X and period count per line, recorder of U and I, detected frequency and Bode graphs of R and -X

6.2 Nyquist plot (XY recorder)

The Nyquist plot is an XY recorder with Cell 1/R on the x axis and Cell 1/-X on the y axis (Figure 6-2). Both are vector channels, so the recorder draws one point per frequency line and joins consecutive lines. Two settings in the widget properties matter:

- Draw only sample points (Drawing options): shows the measured points without the joining lines. Can be used while the sweep is running. Every line that has no result yet holds (0, 0), and the joining line would run through the origin.
- Scaling: use a fixed scale once the expected range is known so that the plot does not rescale with every new point.

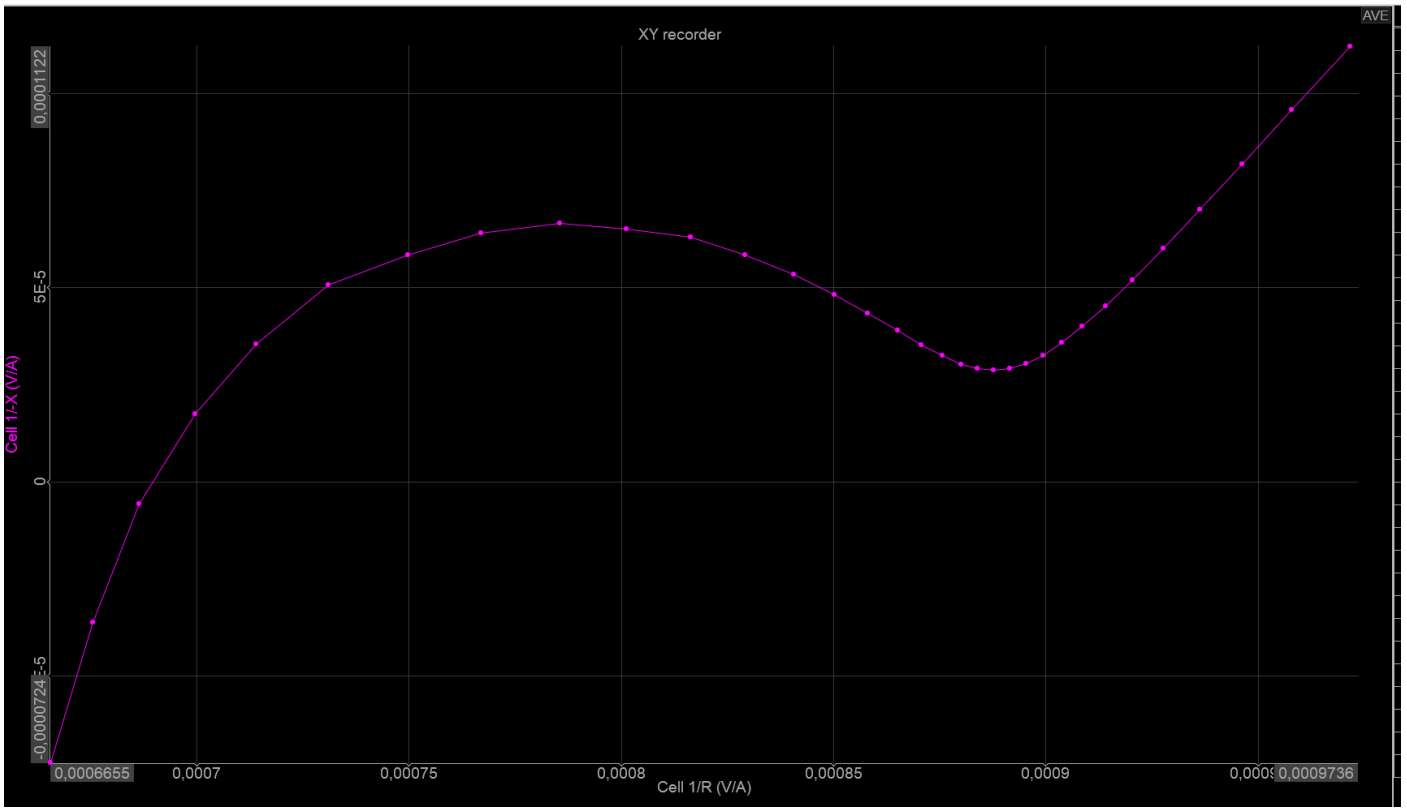


Figure 6-2: Nyquist plot of the demo cell after the complete sweep

6.3 Bode plot (2D graph)

A 2D graph with Cell 1/Z, Cell 1/R or Cell 1/-X shows the spectrum against frequency. Set the x axis type to Log and the y axis Auto scale to Per channel or All channels in the widget properties to obtain the usual Bode representation. The Frequency (Hz) axis then spans the axis definition of the module. The phase angle can be computed from R and -X with a formula channel (phi = atan2(-(-X), R)). Figure 6-3 shows the magnitude and the phase of the demo cell computed from the measured R and -X of Figure 6-2.

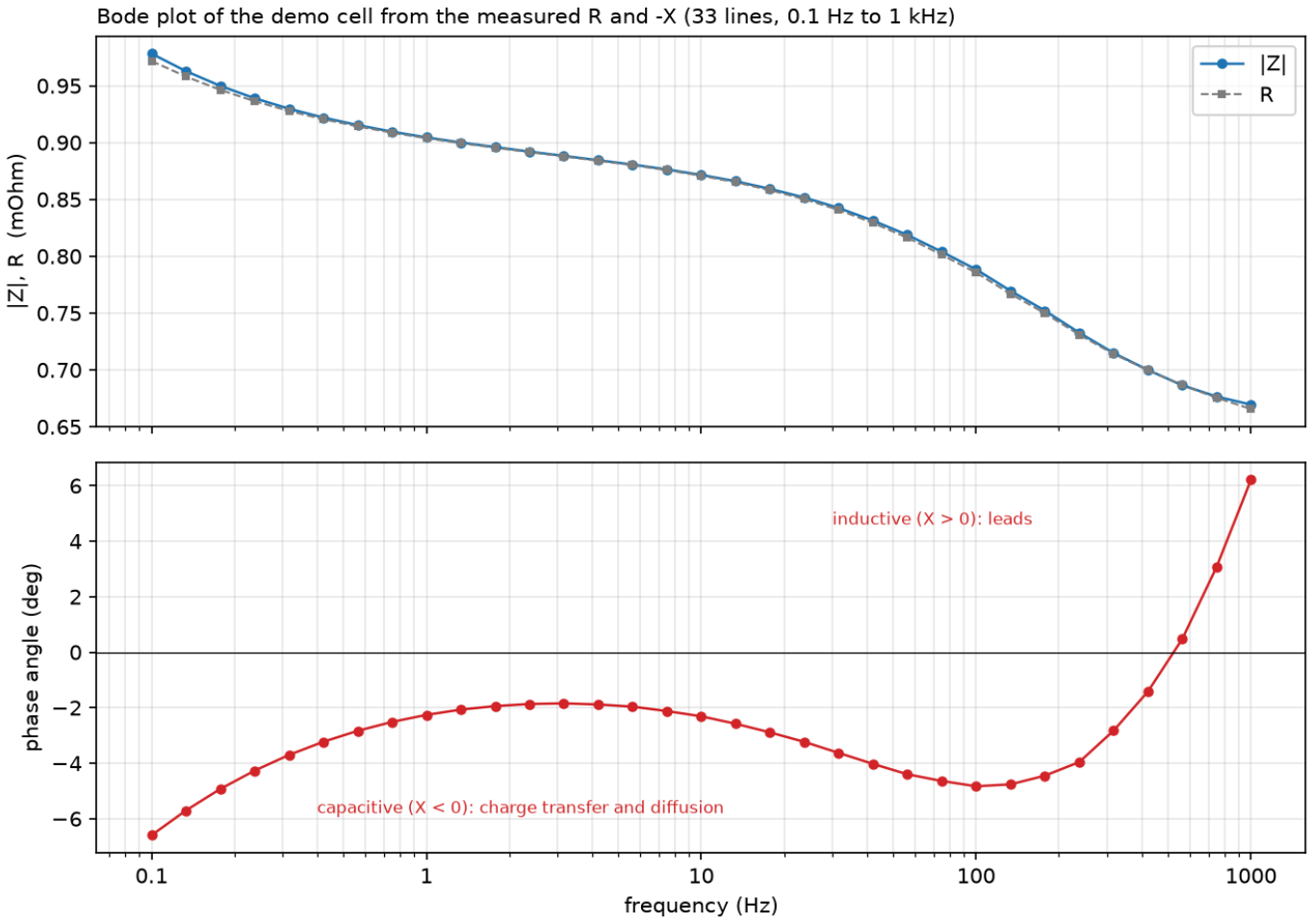


Figure 6-3: Bode representation of the demo cell: |Z| and R (top) and phase angle (bottom) against frequency

6.4 Table, recorder and meters

- A table with Frequency, R, -X and Period count lists every line of the axis. The Period count column shows at a glance which lines have been measured and how many periods went into them.
- A recorder with the voltage and the current channels shows the excitation and the response in the time domain. Use it to set the trigger and rearm levels and to check that the current amplitude is constant.
- A digital meter with Cell 1/Frequency shows the detected frequency live.

6.5 Storing and offline recalculation

Store the measurement as a data file with the full-rate voltage and current channels (Storing type "Always fast"). In Analyze mode the file can be opened, the settings of the EIS analyzer can be changed in Ch. setup (for example the frequency mode, the trigger levels or the axis), and the spectra are recalculated from the stored signals with Recalculate. This makes it possible to optimize the settings after the test without repeating the excitation, and to export the spectra (R, -X, Z, Period count per line) with the usual export functions.

7. Battery cell demo setup without hardware

7.1 The setup file

The setup EIS-battery-demo.dxs, that can be downloaded from our download center, contains a complete EIS measurement that runs without hardware. A C++ script math module (Figure 7-1) generates the current excitation and the voltage response of a lithium-ion cell as a real impedance analyzer produced them in a reference recording. Sine-current bursts of 10 periods from 1 kHz down to 0.1 Hz, 8 frequencies per decade, 2.1 A peak (the first bursts ramp up from 0.5 A), with 2.5 s of rest between the short bursts and two periods of rest between the long ones. The cell model is an equivalent circuit with an ohmic resistance, series inductance, a depressed charge-transfer arc and a diffusion element, fitted to the reference measurement.

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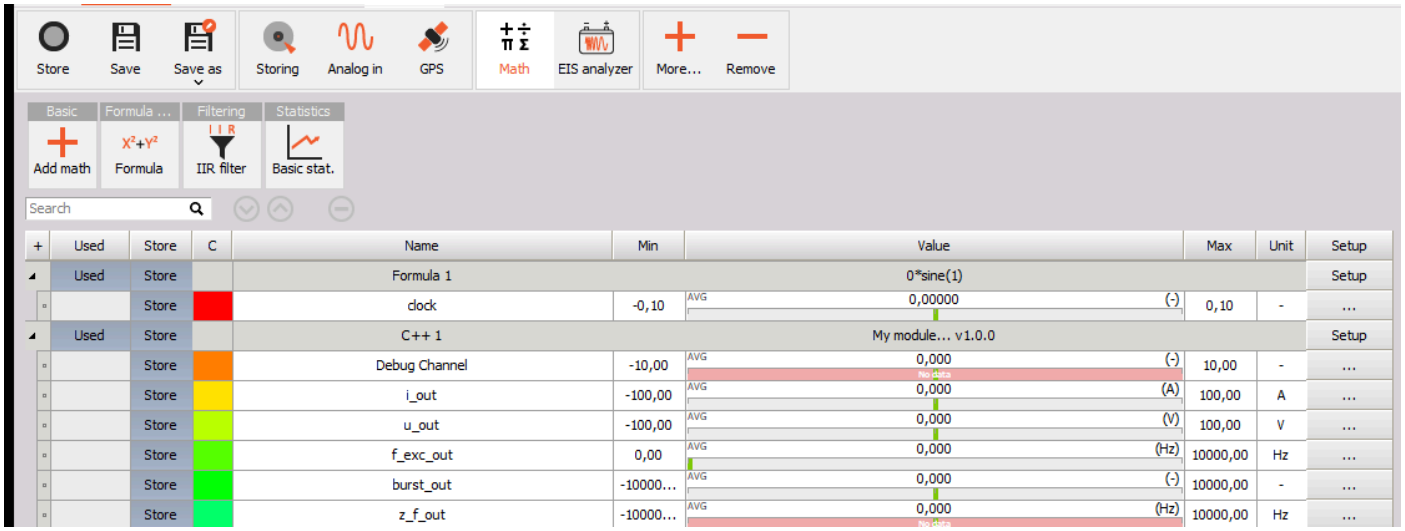


Figure 7-1: Math tab of the demo: the clock formula and the C++ script with its output channels

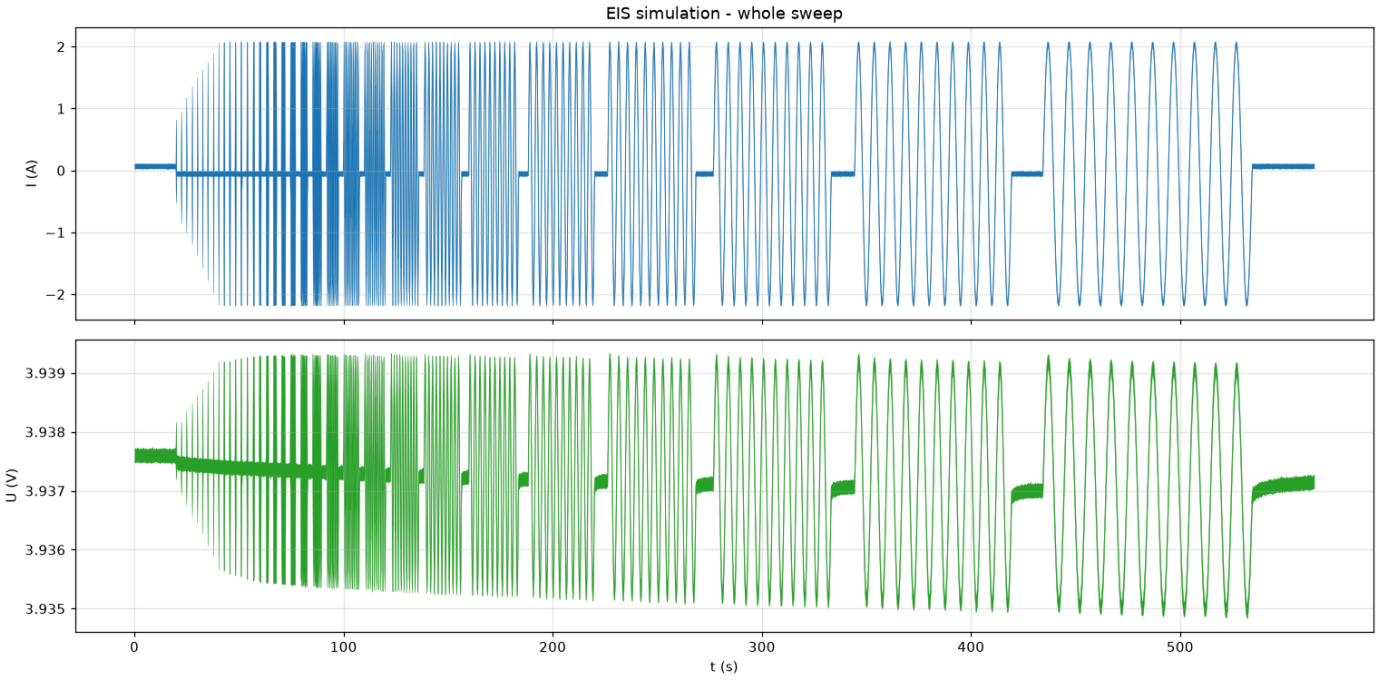


Figure 7-2: The generated current (top) and voltage (bottom) of the whole sweep. The current bursts get longer towards low frequencies; the voltage response is a few mV on the DC cell voltage

The published variables of the script (frequency range, points per decade, periods per burst, amplitude, rest times, the cell model parameters and the noise levels) can be changed in the Configure tab of the script module, so the demo can be adapted to other cells and sweep plans.

7.2 Settings used

Setting	Value	Reason
Dynamic acquisition rate	50 kHz	50 samples per period at the highest frequency of 1 kHz (section 4.3).
Input U, Input I	u_out, i_out	The outputs of the script; with hardware these are the analog input channels.
Trigger level, Rearm level	0 A, -0.2 A	The smallest burst has 0.5 A amplitude, so a rearm level of -0.2 A re-arms on every pass.
Frequency mode	Frequency step	The source holds every frequency for 10 periods with a pause in between.
Axis	Logarithmic, 0.1 to 1000 Hz, 8 lines per decade	Equal to the frequency plan of the source, so every burst lands on its own line (33 lines).
Output spectra	all, with period count	Period count verifies that every line received about 8 periods.

7.3 Result

After the sweep (about 7 minutes plus 20 s of idle current at the beginning) the Nyquist plot shows the spectrum of Figure 6-2. The inductive tail below the real axis at 1 kHz, the crossing of the real axis at 0.66 mOhm, the depressed charge-transfer arc with its maximum near 100 Hz, the minimum near 3 Hz and the rising diffusion tail towards 0.1 Hz.

7.4 Things to try

- Set Rearm level to -0.5 A and run again: the 1000 Hz line is missed (period count 0) and at the end the Nyquist plot runs through the origin unless "Draw only sample points" is set.
- Set Lines per decade to 4. Most lines then receive two bursts, which are averaged, so Period count roughly doubles.
- Set Lines per decade to 16. The bursts then fall on every second line, and the lines in between are interpolated if Use interpolation between frequency calculation points is enabled (otherwise they stay at 0).
- Switch Frequency mode to Sweep on the stored file and recalculate: the stepped bursts are processed period by period, including the transitions (Figure 5-8).

8. Interpreting EIS results

8.1 General EIS analysis

EIS can be used on individual cells or multiple-cell stacks to investigate:

- Internal resistance, including ohmic resistance, charge-transfer resistance and diffusion resistance, for diagnosing losses and identifying degradation mechanisms.
- State of Health (SoH). The aging of a cell is assessed from the change of its impedance over time. High impedance correlates with reduced capacity and power.
- State of Charge (SoC). The impedance varies with the state of charge and allows its estimation under defined conditions.
- Electrochemical processes. The kinetics of the reactions at the electrodes and the rate-determining steps, such as ion diffusion through the electrolyte or charge transfer at the electrode/electrolyte interface.
- Thermal and mechanical effects. Changes caused by temperature or mechanical stress within the cell.
- Electrode and electrolyte degradation. Changes in the composition or structure of electrodes and electrolytes.

Additional math channels (formulas, statistics, filters) can be added in DewesoftX to derive further quantities from the spectra, for example the ohmic resistance as the value of R at the zero crossing of -X.

9. Troubleshooting

Symptom	Cause	Remedy
Status stays "Waiting for trigger..."	The current never crosses the trigger level, or never falls below the rearm level.	Check the current channel in a recorder. Set Trigger level to the DC level of the current and Rearm level below the troughs of the smallest excitation amplitude.
"Rearm level must not have positive value"	Rearm level above the trigger level.	Enter a rearm level below the trigger level.
"Frequency out of range"	The detected frequency is outside the Lower to Upper frequency.	Widen the axis or check the detector (noise can produce very high frequencies).
"Calculation with a set Upper frequency requires a sample rate above ..."	Sample rate too low for the upper frequency of the axis.	Increase the dynamic acquisition rate (section 4.3) or lower the upper frequency.
A line stays at 0 (period count 0), Nyquist plot runs through the origin	The burst at that frequency was not detected (rearm level too low for a small first burst, too few periods) or the excitation skipped that frequency.	Adjust the levels, set "Draw only sample points" in the XY recorder. Enable interpolation for lines inside the measured range.
R negative, Nyquist plot mirrored	Current or voltage channel inverted.	Invert the current channel polarity.

Scattered points at high frequencies	Too few samples per period or a current transducer with poor high-frequency phase.	Raise the sample rate. Use a shunt or a transducer with sufficient bandwidth.
Scattered points at low frequencies	The cell drifts (temperature, SoC) during the long low-frequency periods, or only one period per line.	Let the cell settle before the sweep. Use more periods per line. In Sweep mode slow the sweep down at low frequencies, or switch to the step mode.
Arc too large or too far right	Fixture and lead resistance included.	Four-wire sensing at the cell terminals. A correction table with a short measurement should be entered.
Spectrum changes with amplitude	Cell driven out of its linear region.	Reduce the excitation amplitude.

10. Warranty information

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Note:
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The copy of the specific warranty terms applicable to your Dewesoft product and replacement parts can be obtained from your local sales and service office. To find a local dealer for your country, please visit https://dewesoft.com/support/distributors.

10.1 Calibration

Every instrument needs to be calibrated at regular intervals. We recommend an annual cadence. Before your Dewesoft data acquisition system is delivered, it is calibrated. Detailed calibration reports for your Dewesoft system can be requested. We retain them for at least one year, after system delivery.

10.2 Support

Dewesoft has a team of people ready to assist you in case you have questions or any technical difficulties regarding the system. For any support please contact your local supplier first or Dewesoft headquarter directly.

Dewesoft d.o.o.
Gabrsko 11a
1420 Trbovlje Slovenia

Europe Tel.: +386 356 25 300
Web: http://www.dewesoft.com
Email: Support@dewesoft.com

The telephone hotline is available Monday to Friday from 07:00 to 16:00 CET (GMT +1:00)

10.3 Service/repair

Dewesoft also performs any kinds of repairs to your system to assure a safe and proper operation. For information regarding service and repairs please contact your local contact first or Dewesoft directly on https://dewesoft.com/support/rma-service.

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11. Safety instructions

Your safety is our primary concern! Please be safe!

11.1 Safety symbols in the manual



Warning
Calls attention to a procedure, practice, or condition that could cause the body injury or death



Caution
Calls attention to a procedure, practice, or condition that could possibly cause damage to equipment or permanent loss of data.

11.2 General Safety Instructions

Warning

The following general safety precautions must be observed during all phases of operation, service, and repair of this product. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the product. Dewesoft d.o.o. assumes no liability for the customer's failure to comply with these requirements.

All accessories shown in this document are available as an option and will not be shipped as standard parts.

11.2.1 Environmental Considerations

Information about the environmental impact of the product.

11.2.2 Product End-of-Life Handling

Observe the following guidelines when recycling a Dewesoft system:

11.2.3 System and Components Recycling

Production of these components required the extraction and use of natural resources. The substances contained in the system could be harmful to your health and to the environment if the system is improperly handled at its end of life! Please recycle this product in an appropriate way to avoid unnecessary pollution of the environment and to keep natural resources.



This symbol indicates that this system complies with the European Union's requirements according to Directive 2002/96/EC on waste electrical and electronic equipment (WEEE). Please find further information about recycling on the Dewesoft web site www.dewesoft.com

Restriction of Hazardous Substances
This product has been classified as Monitoring and Control equipment and is outside the scope of the 2002/95/EC RoHS Directive. However, we take care of our environment and the product is lead-free.

11.2.4 General safety and hazard warnings for all Dewesoft systems

Safety of the operator and the unit depend on following these rules.

- Use this system under the terms of the specifications only to avoid any possible danger.
- Read your manual before operating the system.
- Observe local laws when using the instrument.
- DO NOT touch internal wiring!
- DO NOT use higher supply voltage than specified!
- Use only original plugs and cables for harnessing.
- You may not connect higher voltages than rated to any connectors.
- The power cable and connector serve as Power-Breaker. The cable must not exceed 3 meters, the disconnect function must be possible without tools.

- Maintenance must be executed by qualified staff only.
- During the use of the system, it might be possible to access other parts of a more comprehensive system. Please read and follow the safety instructions provided in the manuals of all other components regarding warning and security advice for using the system.
- With this product, only use the power cable delivered or defined for the host country.
- DO NOT connect or disconnect sensors, probes or test leads, as these parts are connected to a voltage supply unit.
- Ground the equipment: For Safety Class 1 equipment (equipment having a protective earth terminal), a non-interruptible safety earth ground must be provided from the mains power source to the product input wiring terminals.
- Please note the characteristics and indicators on the system to avoid fire or electric shocks. Before connecting the system, please read the corresponding specifications in the product manual carefully.
- The inputs must not, unless otherwise noted (CATx identification), be connected to the main circuit of category II, III and IV.
- The power cord separates the system from the power supply. Do not block the power cord, since it has to be accessible for the users.
- DO NOT use the system if equipment covers or shields are removed.
- If you assume the system is damaged, get it examined by authorized personnel only.
- Adverse environmental conditions are Moisture or high humidity Dust, flammable gases, fumes or dissolver Thunderstorm or thunderstorm conditions (except assembly PNA) Electrostatic fields, etc.
- The measurement category can be adjusted depending on module configuration.
- Any other use than described above may damage your system and is attended with dangers like short-circuiting, fire or electric shocks.
- The whole system must not be changed, rebuilt or opened.
- DO NOT operate damaged equipment: Whenever it is possible that the safety protection features built into this product have been impaired, either through physical damage, excessive moisture, or any other reason, REMOVE POWER and do not use the product until the safe operation can be verified by service-trained personnel. If necessary, return the product to Dewesoft sales and service office for service and repair to ensure that safety features are maintained.
- If you assume a more riskless use is not provided anymore, the system has to be rendered inoperative and should be protected against inadvertent operation. It is assumed that a more riskless operation is not possible anymore if the system is damaged obviously or causes strange noises. The system does not work anymore. The system has been exposed to long storage in adverse environments. The system has been exposed to heavy shipment strain.
- Warranty void if damages caused by disregarding this manual. For consequential damages, NO liability will be assumed!
- Warranty void if damage to property or persons caused by improper use or disregarding the safety instructions.
- Unauthorized changing or rebuilding the system is prohibited due to safety and permission reasons (CE).
- Be careful with voltages >25 VAC or >35 VDC! These voltages are already high enough in order to get a perilous electric shock by touching the wiring.
- The product heats during operation. Make sure there is adequate ventilation. Ventilation slots must not be covered!
- Only fuses of the specified type and nominal current may be used. The use of patched fuses is prohibited.
- Prevent using metal bare wires! Risk of short circuit and fire hazard!

- DO NOT use the system before, during or shortly after a thunderstorm (risk of lightning and high energy over-voltage). An advanced range of application under certain conditions is allowed with therefore designed products only. For details please refer to the specifications.
- Make sure that your hands, shoes, clothes, the floor, the system or measuring leads, integrated circuits and so on, are dry.
- DO NOT use the system in rooms with flammable gases, fumes or dust or in adverse environmental conditions.
- Avoid operation in the immediate vicinity of high magnetic or electromagnetic fields, transmitting antennas or high-frequency generators, for exact values please refer to enclosed specifications.
- Use measurement leads or measurement accessories aligned with the specification of the system only. Fire hazard in case of overload!
- Lithium ion batteries are classified as not hazardous when used according to the recommendations of the manufacturer described in Battery Safety Data Sheet, which is available for download from this link.
- Do not switch on the system after transporting it from a cold into a warm room and vice versa. The thereby created condensation may damage your system. Acclimatise the system unpowered to room temperature.
- Do not disassemble the system! There is a high risk of getting a perilous electric shock. Capacitors still might be charged, even if the system has been removed from the power supply.
- The electrical installations and equipment in industrial facilities must be observed by the security regulations and insurance institutions.
- The use of the measuring system in schools and other training facilities must be observed by skilled personnel.
- The measuring systems are not designed for use in humans and animals.
- Please contact a professional if you have doubts about the method of operation, safety or the connection of the system.
- Please be careful with the product. Shocks, hits and dropping it from already- lower level may damage your system.
- Please also consider the detailed technical reference manual as well as the security advice of the connected systems.
- This product has left the factory in safety-related flawlessness and in proper condition. In order to maintain this condition and guarantee safety use, the user has to consider the security advice and warnings in this manual.

EN 61326-3-1:2008
IEC 61326-1 applies to this part of IEC 61326 but is limited to systems and equipment for industrial applications intended to perform safety functions as defined in IEC 61508 with SIL 1-3.

The electromagnetic environments encompassed by this product family standard are industrial, both indoor and outdoor, as described for industrial locations in IEC 61000-6-2 or defined in 3.7 of IEC 61326-1.

Equipment and systems intended for use in other electromagnetic environments, for example, in the process industry or in environments with potentially explosive atmospheres, are excluded from the scope of this product family standard, IEC 61326-3-1.

Devices and systems according to IEC 61508 or IEC 61511 which are considered as “operationally well-tried”, are excluded from the scope of IEC 61326-3-1.

Fire-alarm and safety-alarm systems, intended for the protection of buildings, are excluded from the scope of IEC 61326-3-1.

12. Documentation version history

Version	Date	Notes
V26-3	2026-10-15	First initial version