Operation Manual

Impedance Spectroscope

Model: EISmeter 2-20-4
Serial No.: 2015000108

ATTENTION!

Before proceeding to the installation and commissioning, read these instructions carefully and in full and strictly observe all safety instructions.
Use the unit only in a perfect technical state in accordance with the intended purpose and subject to the operating instructions and be aware of contingent hazards and risks. Immediately eliminate any faults that might affect the safety.

Appendix:

- Graphical Display of EIS Data in BTS-600

EIS-METER – Impedance Spectroscope

Operation Manual

Table of Contents

1 Safety Instructions

Temperature

The power section of the EIS-METER (EIS = electrochemical impedance spectroscopy) produces – depending on actual voltage of connected battery as well as measurement parameters – sometimes a significant amount of waste heat. To ensure its conduction, ventilation slots on the top and bottom must remain free all the time.

The power operational amplifiers on the cards have an emergency shutdown function when a critical temperature limit is reached. Running measurements are then terminated with error and must eventually be repeated.
After an automatic shutdown like this and before switching the unit on again the reason for the shutdown should be analyzed. If the shutdown is e.g. not a result of covered ventilation slots or something similar, it should be investigated if a fan on one of the cards is defective.
If for no visible reason an error occurs several times due to high temperatures, the user should contact Digatron.

Static Electricity

The input section of the EIS-METER is very sensitive due to measurement accuracy. Discharging static electricity on the terminals to the test objects have to be avoided by any means. In a worst case scenario they could lead to permanent hardware damages.

Liquids, Acids

EIS-METER is not durable against any kind of liquids. Contact with or dashing liquids like water or acids over the rack must strictly be avoided. Acid splashes can damage or discolor the material of the front plates and should therefore be wiped off immediately.
Enclosed measuring leads are durable against e.g. sulphuric acid, but for self-protection acid splashes should be removed as quickly as possible.

Input Voltage Range

Potential difference of EIS-METER's current output clamps must not exceed (depending on preset measurement range, connected battery, battery voltage defined in control software and technical data of the unit) 12V or 24V and not go below -4V.
The allowed input voltage of measurement inputs is also limited. The individual maximum values are defined in the technical specification of each unit. A valid measurement is only possible within a defined voltage range because otherwise the input module might reach its saturation.

Input Voltage Power Unit

The power supply units of the rack contain (inside the casing) a switch between 120V and 230V mains voltage.. Switching must be done for each power supply unit individually as each channel has its own power supply unit.
The preset mains voltage must not be exceeded or fallen short of.[1]

[1] 10% deviation is specified.

2 Unit

The basic idea behind (electrochemical) impedance spectroscopy is that the system to be measured is stimulated with a sinusoidal alternating current of a defined frequency and amplitude. The resulting voltage answer is measured. With voltage and current known the system's impedance can be easily calculated for the specific frequency.

2.1 Technical Data

Resistance range	0.3 – 3000 mΩ
Output current AC	2 A (max. peak)
Resolution AC current	< 100 µA
Frequency range AC current	10 mHz – 6.5 kHz
Accuracy frequency	0.005 % from displayed value
Voltage range measurement	0 V – 20 V
Input impedance (typical)	10 GΩ
Resolution voltage channel	5 µV
Meas. accuracy abs{Z}	< 1 %
Meas. accuracy arg(Z)	< 1 °
Power consumption	65 W per channel / EIS card (typical)
Power supply	230 V / 50 Hz, 0.6 A for 2 EIS cards
Casing (W x D x H)	500 x 500 x 150 mm
Weight	4,43 kg + 2.47 kg per channel
Environment temperature	0 °C – 40 °C

2.2 System design

EIS-METER is typically used in a configuration like in figure 1.

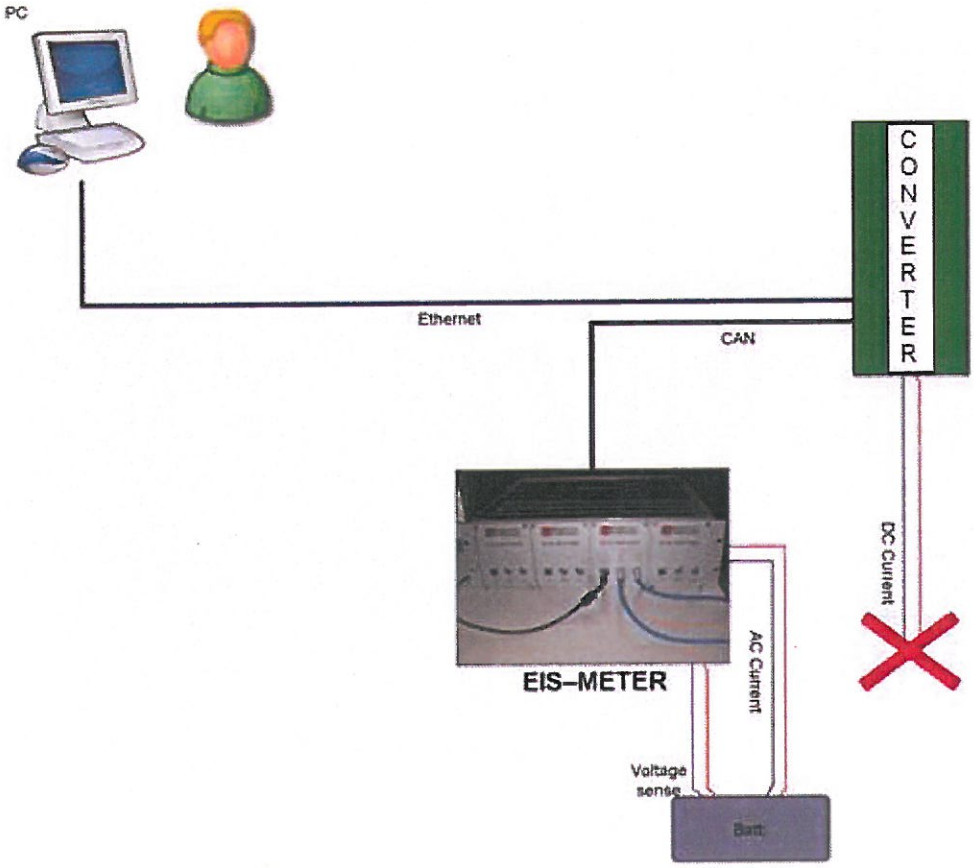


Figure 1: Typical system configuration: EIS-METER with 4 channels, operating together with one power circuit on a battery

EIS-METER is connected to the converter via CAN.

During spectrum measurements the connection between battery and power circuits should be opened.

2.3 Structure, Perspective, Variations

One rack can contain up to four EIS channels. Every number between one and four is possible. Each channel consists of an EIS card and a power supply unit.
By using a separate power supply unit for each channel the electrical isolation of channels is assured.

Each channel provides an output for the current supplied by the card and an entry for measurement of the voltage answer from the battery (input left, output right).
Additionally there is an (electrically isolated) USB-B socket for calibration/maintenance purposes.

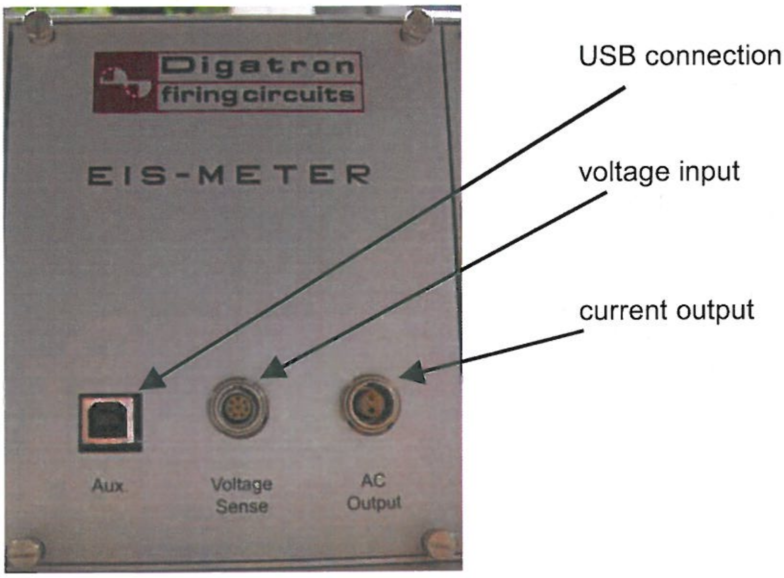


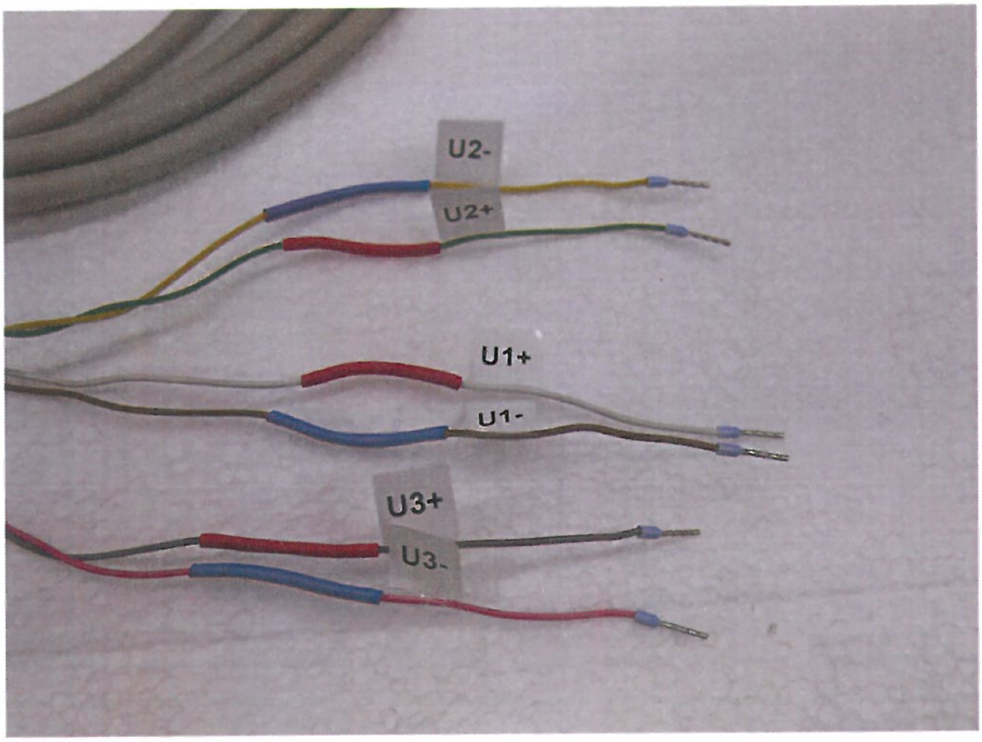
Figure 2: Connections at the front plate of an EIS-METER

2.4 Connector Pin Assignment

2.4.1

For the measurement input (voltage input, fig. 2) a plug of type *LEMO FGG.1B.308.CLAD72Z* is required.

The used voltage channels for this plug are : pin 5 (U1+), pin 6 (U1-)
pin 7 (U2+), pin 1 (U2-)
pin 2 (U3+), pin 3 (U3-).



2.4.2

The opposite for the current output (fig. 2) is a plug of type *LEMO FGG.1B.302.CLAD72Z*.
For this plug "+" is pin 1 (above) and "–" (internal => analog ground) is on pin 2.

2.4.3

The USB connection is intended for maintenance and diagnose purposes and typically not required by the customer.

2.5 Accessories

Measuring lead (optional)	1x per channel (standard length 3m), 6 wires twisted together, plug like described under 2.4.1
Connecting cable current (optional)	1x per channel (standard length 3m), 2 wires twisted together, plug like described under 2.4.2, ohmic resistance <= 0.039 Ω/m, cross section 0.5mm²
Power supply cable	standard cable for non-heating apparatus

The maximum length of the connecting cable for the current is limited by the voltage drop on the cable (depending on cross section and ohmic resistance). For the recommended current connecting cable *LAPP cable Ölflex Classic 400 P* a maximum length of 5.5 meters is allowed (under ideal conditions).

The current cable enclosed with delivery of the unit must be used for calibration.

3 Maintenance

Generally there is no special maintenance procedure for the unit under normal laboratory conditions.
If the environment is exceptionally dusty a cleaning of fans and other cooling elements can be required to maintain a good heat dissipation.

One EIS-METER rack contains up to five fuses. One is placed at the back of the casing inside the mounting of the power switch (250V, 10A slow (20x5mm)). Additionally there is a fuse per power supply unit (250V, 2A slow (20x5mm)).
If the whole unit or a channel shows no function while the unit is switched on, please check the fuses (unplug power plug!).
If a fuse blasts several times without significant mistakes by the operator, it indicated a problem or a defect. Please contact Digatron's service department.

Calibration of EIS-METER has to be conducted according to the date on the sticker at the back of the unit. A calibration is also necessary when conditions change drastically at the usage site (temperature etc.).
If measurement values seem to be implausible, a calibration or at least a reference measurement with a low-inductive shunt should be taken into consideration to estimate if a new calibration is necessary.

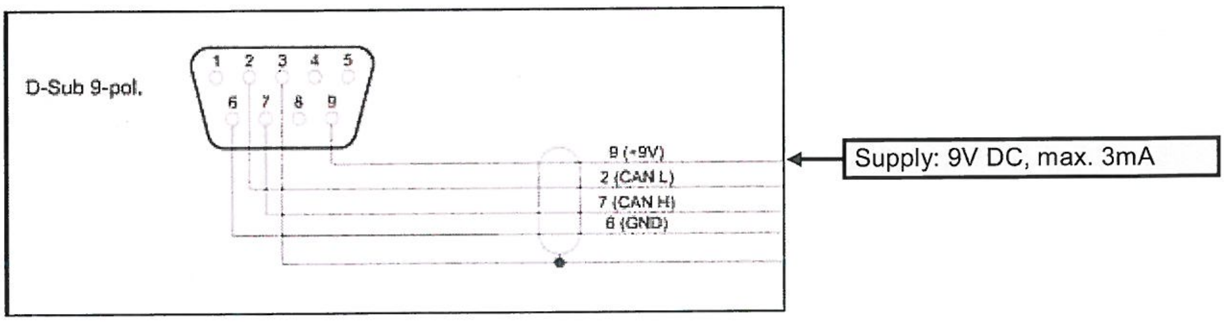
Please contact Digatron when thinking about a calibration.

Note: When exchanging an EIS card the new card must use the same CAN address as the old one.

4 Communication

The communication between EIS-METER channels and the controlling unit (RailPC in Digatron cabinet) is done via CAN bus. Each channel (EIS card) has its own address.
CAN interfaces on the cards are electrically isolated from the rest of the circuitry. The power supply of the isolated side is achieved via the CAN line.

<u>Pin assignment CAN bus</u>:



Maximum cable length: 20 m with baud rate 250 kbit/s

5 Electrochemical Impedance Spectroscopy

The basic idea behind (electrochemical) impedance spectroscopy is that the system to be measured is stimulated with a sinusoidal alternating current of a defined frequency and amplitude. The resulting voltage answer is measured. With voltage and current known the system's impedance can be easily calculated for the specific frequency.

A general definition of the term "Impedance Spectroscopy" is given by J. R. MacDonald in [1]. It states that "impedance spectroscopy" is a term that defines the combination of small-signal measurement of the linear electric answer of a material and the analysis of the answer to gain useful information about the physical characteristics of the material.

In many cases – like with EIS-METER – measurements are made in time range and later transformed into frequency range.

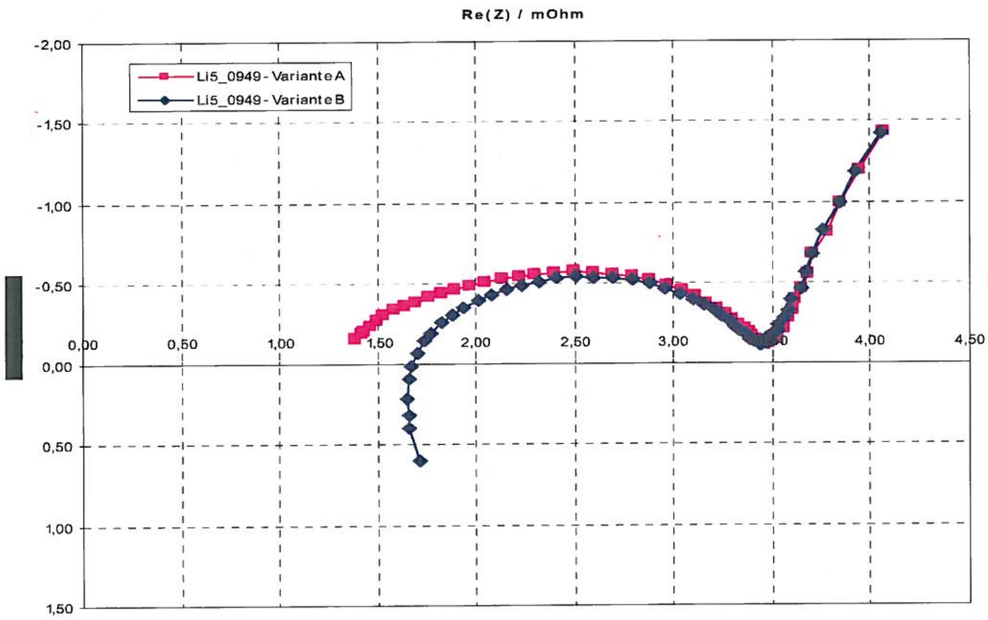


Figure 3: Presentation of an impedance spectrum as Nyquist plot

The term *Electrochemical Impedance Spectroscopy (EIS)* describes a special case of impedance spectroscopy where materials are analyzed whose electric charge is mainly effected by ions instead of electrons (ionic conduction). Examples for ionic conductors are ionizes gases.

Changing the frequency of the excitation current over a defined range results in a spectrum of the complex impedance that can be presented e.g. as Bode diagram or Nyquist plot (see figure 3).

Possible applications for electrochemical impedance spectroscopy can be found in characterizing batteries or fuel cells.

Measuring the complex impedance of a battery over a frequency range (impedance spectrum) classifies defined parameters of the device under test. By this means models (with limited significance) can be developed for the investigated system, e.g. for simulation purposes.

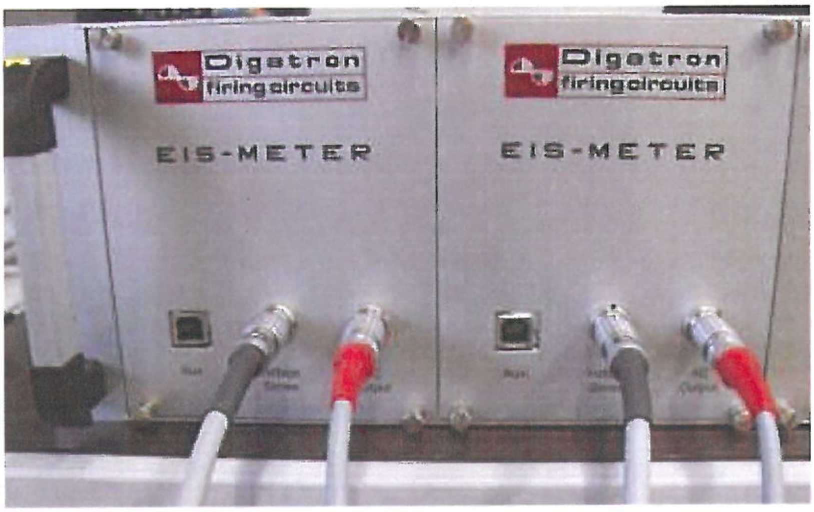
For batteries, values from impedance measurement are only valid for the current battery state. The result depends among others from the state of charge (SOC), the temperature, the aging state as well as a possible charge/discharge of the battery during measurement (overlaid DC) with a future version of EIS-METER. The last aspect results from a strong non-linear behavior of the current-voltage-characteristic of a battery.
For complete characterization of a battery it is necessary to investigate several operating points (see also [2], [3] and chapter 7.7).

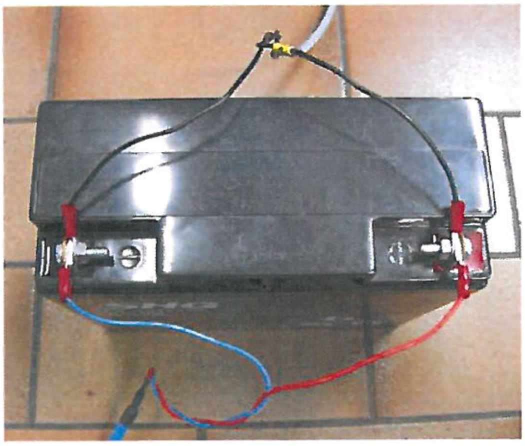
6 Measurement

Because amplitudes of voltage responses are usually very small for this type of impedance spectroscopy, the measurement setup requires special carefulness. See notes concerning measurement setup in chapter 8.

This chapter describes required steps to prepare and start a measurement.

6.1 Connecting a Battery (Principal)





Connect the battery to EIS-METER like in the above photograph.
Connect EIS-METER with a Rail-PC via the CAN interfaces on EIS-METER's backside. Connect Rail-PC with your BTS-600 PC via Ethernet.

Start BTS-600 on the PC and write a program using operator EIS described in the next chapter.

Figure 4: Connecting a battery

Connect EIS-METER via CAN interface on the back with a converter. The converter is connected with a PC by Ethernet.

7 Impedance Measurement with Batteries

This chapter was created in cooperation with the battery group from Institute for Converter Technique and Electric Drives (ISEA) from RWTH Aachen.

7.1 Contacting of Cells

Important for measurement setups with batteries is the contacting of batteries or single cells. This is not only valid for impedance measurements but also for other measurements like capacity and cycle tests. Incorrect contacting can lead to inaccurate results and aggravate test evaluation.

7.2 Four-Wire-Configuration

The principal of four-wire-configuration (also known as Kelvin measurement) is based on the fact that contacting test elements is realized with two separate pairs of cables for power supply and voltage measurement.

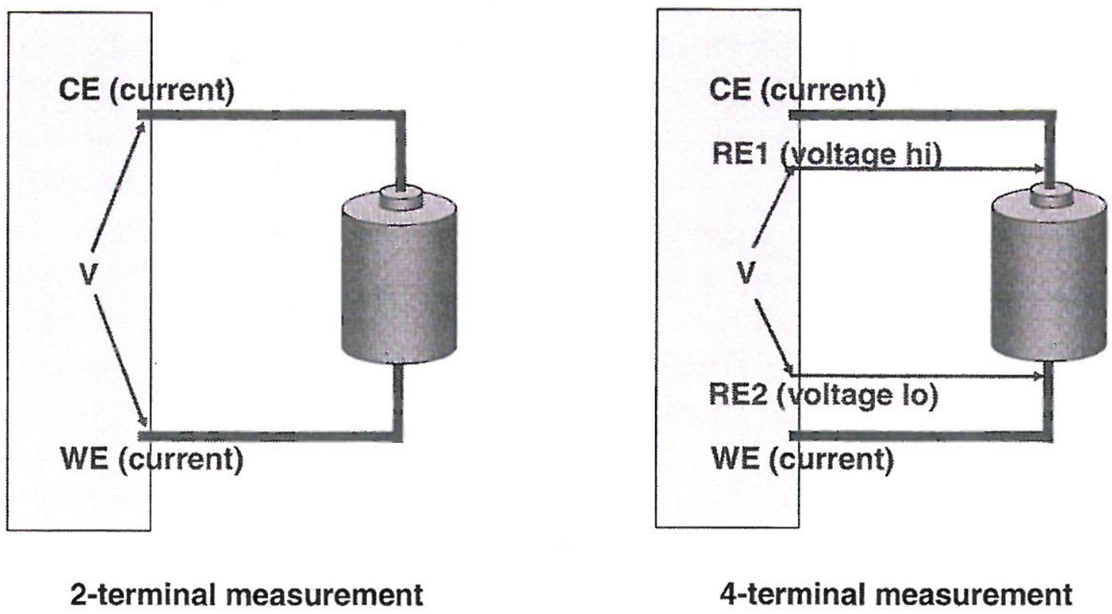


Figure 5: Comparison of 2- and 4-terminal measurement. *Source: [1]*

Figure 5 shows a comparison between 2- and 4-terminal measurements. With the 2-terminal measurement in the left part the measuring instrument does not only measure the voltage of the test object, but also the voltage decrease over the current-carrying cables.
Because they have a small but finite resistance the current flow results in a measured voltage error that depends on the resistance of the current cable. The 4-terminal measurement in the right part of figure 5 does not have this disadvantage.

When contacting cells with 4-terminal measurement it has to be taken into account that the plugs used have an ohmic resistance that is not negligible.

Negative Example

Figure 6 shows the construction of a pulse measurement on a bigger lead-acid battery.

A measurement was conducted using rectangular current (70 Hz) with the voltage response of the battery recorded.
It was denied to use separate pole shoe contactors for current and voltage cables. Instead, current-carrying cables where plugged directly on voltage measuring cables.

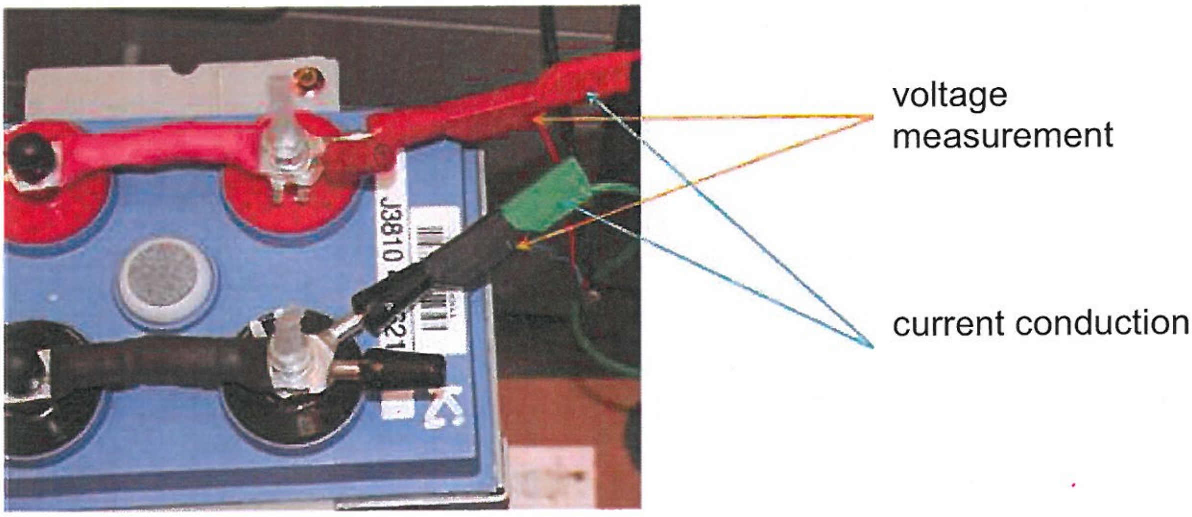


Figure 6: Faulty measurement setup, no true 4-terminal measurement

With the following measurement using a 70 Hz rectangular discharge current (amplitude 6A) there was a voltage decrease of 10 mV over the voltage measurement cables that can be seen in figure 7.

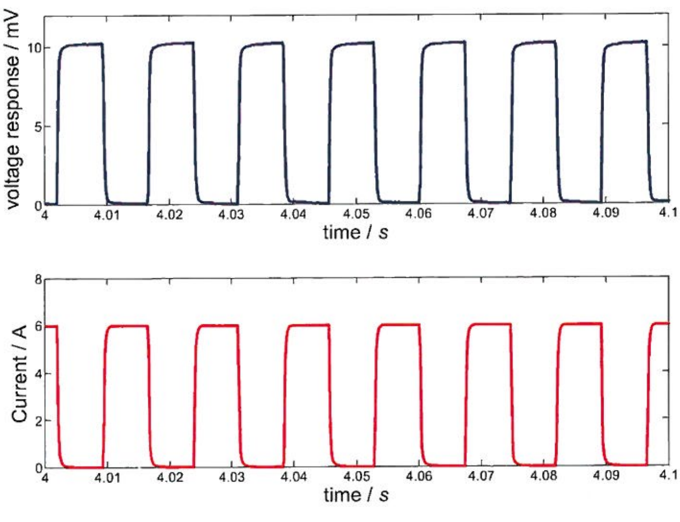


Figure 7: Result of measurement with setup leading to incorrect 4-terminal measurement

How It's Done

Now this experiment was soon repeated with proper cabling of the 4-terminal measurement which means that for current carrying cables as well as voltage measurements separate contacts were used on the battery poles (see figure 8).

For this setup, first voltage measurement lines and then current lines were screwed on the battery poles.

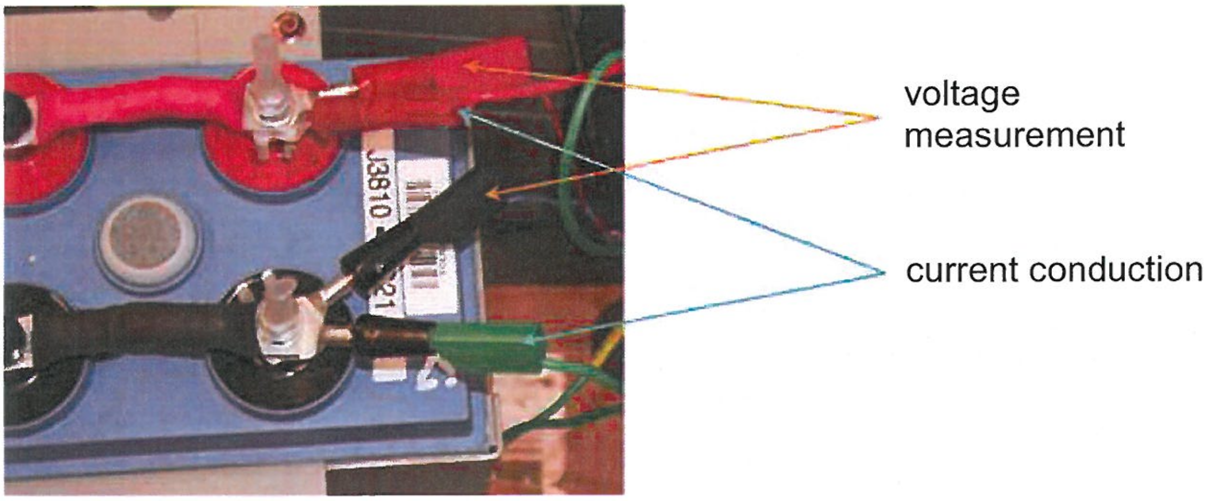


Figure 8: Setup with correct 4-terminal measurement

Figure 9 shows that the voltage response from a battery with 6 A excitation current is smaller by far.

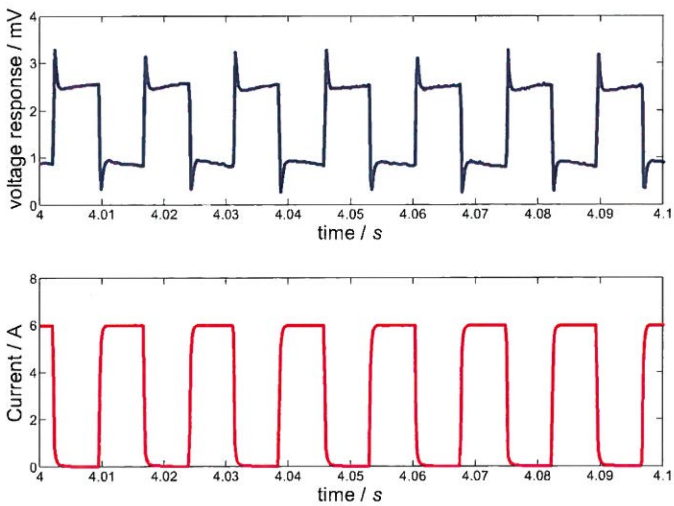


Figure 9: Results of correct 4-terminal measurement

Contrary to the previous measurement the voltage response is lower by factor 5.5. This indicates that the plug's impedance is not only in the range of the measured impedance of the battery but even larger.
This is the reason why the real part of the measurement is not only strongly falsified, but like figure 9 shows also other (inductive) parts of the voltage response are hidden by the voltage decrease on the plugs.

⚠ **With a setup for impedance measurement on batteries a correct 4-terminal (Kelvin) measurement has to be taken care of!**

7.3 Voltage Measurement at Zero Current

Negative Example

Following the consideration of plug resistances this chapter will look at the contacting a cell during 4-terminal measurements. As already mentioned, the influence of connectors when contacting cells can not be ignored.

Figure 10: Round cell with two contacts for current and voltage measurement (no isolation)

For that reason when using shunts, voltage measurement circuits are often contacted directly on the resistance stretch while current connections are installed "outside". Figure 10 shows this kind of contacting for a lithium round cell.

This type of contacting assures effective results but not ideal for tiny impedances that can be expected. This setup does not guarantee that the contacting between voltage measurement and cell remains good if connections are moved for some reason (by a downfall e.g.). If the screwing on the cell has to be loosened for another experiment it can not be assured that the contacting has the exact same quality when put together again.

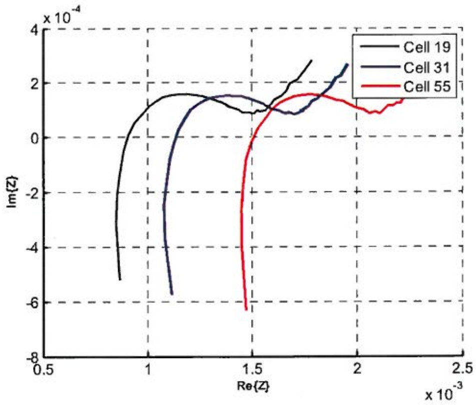


Figure 11: Impedance spectrums from 3 different cells, all contacted like in Figure **10**

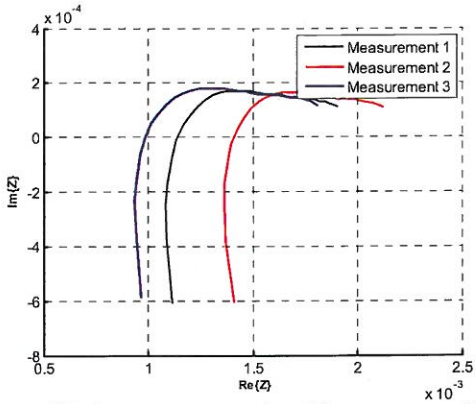
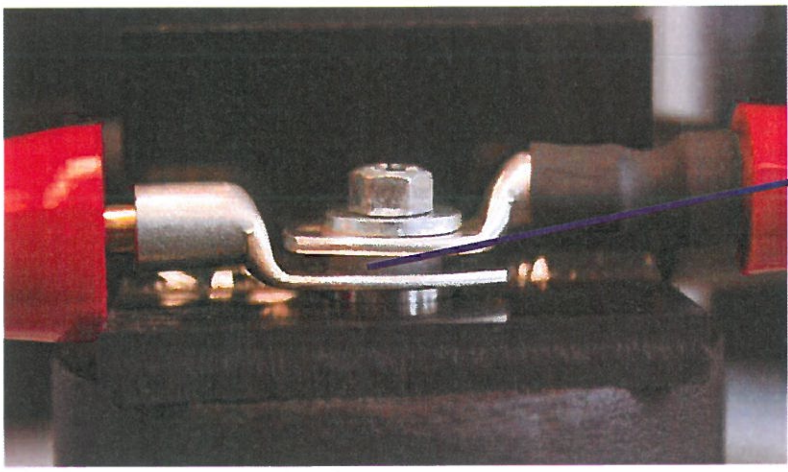


Figure 12: 3 measurements of the same cell (cell 55, see figure 11) after loosening once and fastening cell contacts again

The dimension of errors is indicated by Figure 11 and Figure 12. Figure 11 shows 3 cells of the same type with the same capacity and from the same manufacturer measured with an impedance spectrum.

How It's Done

As you can see all cells show a different behavior for the real part of the resistance (approx. factor 2) although impedance show a similar progress. For this measurement all 3 cells were measured with contacting like in
Figure 10 with all screws were mounted with the same moment of force.
Figure 12 shows a comparative measurement on a cell where the screwing was loosened three times and mounted again with the same moment of force. The movement of the real part with otherwise similar progress of the spectrums indicates that contacting still shows a significant influence on the measurement. Especially when the contacting can not remain in the same position and not only is there a comparative measurement for one cell but for several cells, a better contacting is absolutely essential.



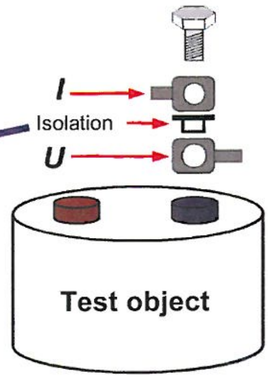


Figure 13: Contacting cell for voltage measurement at zero current (real assembly)

Figure 14: Principal of cabling for voltage measurement at zero current

To eliminate influence of voltage sense contacts completely, a voltage measurement at zero current is necessary.

Figure Figure 14 indicates the principal. The contact for voltage measurement is directly on the cell and contacted with a screw that has been mounted on the cell's pole shoe with a defined moment of force. The cable shoe for the current path is mounted on top of the cable shoe for the voltage contact using a plastic disc to isolate from voltage sense. The current goes to the cell through the screw without causing a voltage loss on the sense.
Figure 15 and Figure 16 show the positive consequences of this contact type. Spectrums in figure 15 are almost the same as is expected for cells of the same type, age, state and manufacturer.

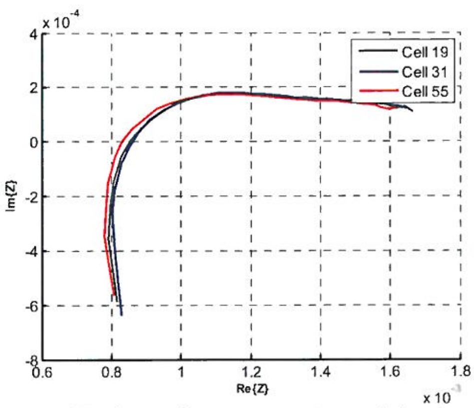


Figure 15: Impedance spectrum (shortened) for the same cells as in figure 11, this time with voltage measurement at zero current

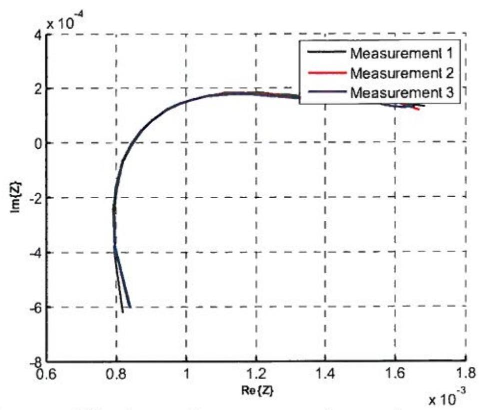


Figure 16: impedance spectrum for a cell with voltage measurement at zero current after loosening and mounting cell contacts several times

Figure 16 shows that this contacting leads to the same results after loosening and mounting several times.

For new experiments with isolated screwings all screws were mounted with a defined moment of force. This indicates that the firmness of connection between pole shoe and cell has been the same every time.

⚠ **Besides 4-terminal measurement, when contacting cells, voltage measurement at zero current has to be assured. Contacting of voltage and current should be as constant as possible. Screwings must therefore always be mounted with a defined moment of force (torque spanner).**

7.4 Wiring and Cabling

For impedance measurements with batteries wiring and cabling of current-carrying as well as sense cables is of primary importance.
This is especially true when impedance measurements are carried out with higher frequencies.

Decisive for unbiased impedance measurements concerning the wiring and cabling is the minimum interconnection between current-carrying and as sense cables.
The following test setups show the set of difficulties:

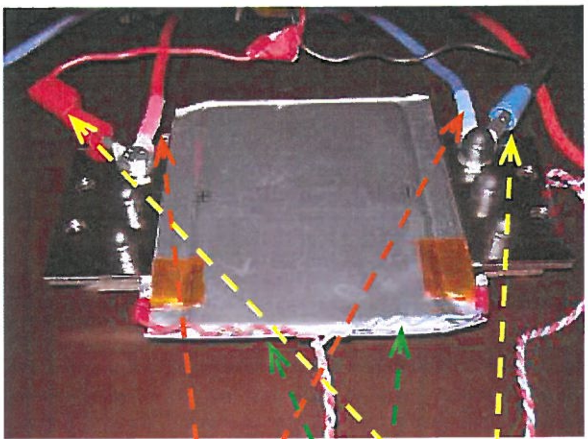


Figure 17: Wiring and cabling on a flat lithium cell (variation A)

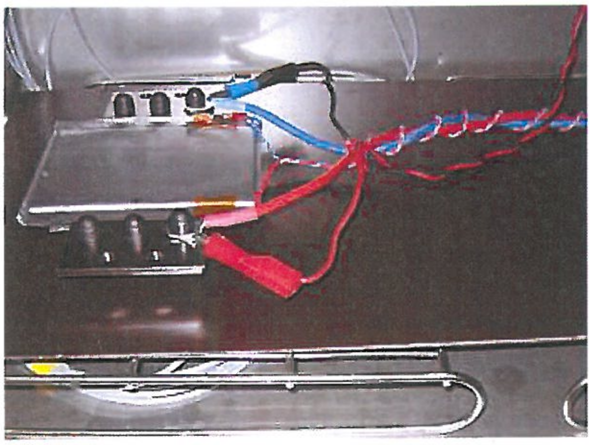


Figure 18: Wiring and cabling on the same flat lithium cell (variation B)

current power element

sense EIS-METER

current EIS-METER

The same flat lithium cell (3.6 V, 10 Ah) was tested twice. For the first test, the current-carrying cables were positioned with a large distance to the sense cables (variation A in figure 17). in the second test sense and current-carrying cables were connected with the cell coming from the same side and being twisted together (variation B in figure 18).

In both cases is was taken care that sense and current-carrying cables were twisted themselves to keep them as low-inductive as possible. The state of charge for the cell as well as the temperature were not changed between measurements.

Figure 19 shows measurement results in two impedance spectrums.

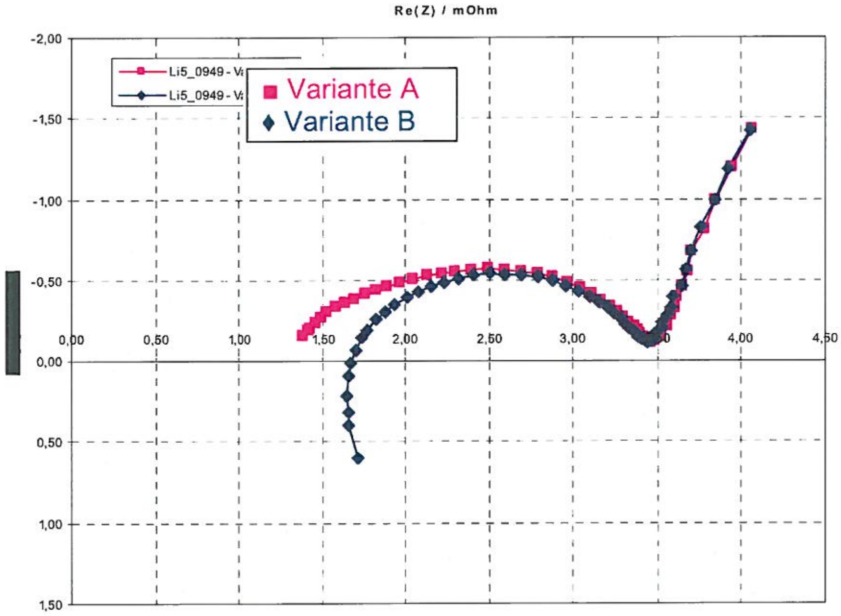


Figure 19: Comparison of two impedance spectrums after wiring with variations A and B.

Measurements with wiring following variation B show a clear inductive part for high frequencies. With variation A even for the highest measuring frequency there is no positive imaginary part and therefore no inductive part.
This effect can be explained with the interconnection between current-carrying and sense cables. In variation B there is a big interlinking between the two bifilar lines which results in a bigger measured inductivity. This effect is basically an electrically isolated counterpart to the one with the voltage measurement at zero current from chapter 7.3.
For high frequencies the influence by inductive interference between current and voltage lines increases which leads to a false measurement.
For that reason it is important to keep voltage and current-carrying cables as far apart from each other as possible and make sure that no inductive interference is possible.
Additionally for current-carrying cables as well as voltage measurement lines it should be taken care that the spanning area between the wires is as small as possible. By this means the "antenna effect" of the cables is minimized.

⚠ **For wiring and cabling with impedance measurements it has to be assured that now inductive interference develops between and current-carrying and voltage sense cables. Each cable should be twisted as well as possible.**

7.5 Requirements for Impedance Measuring Instruments

This chapter deals with requirements for impedance spectroscopes when measuring batteries and other electrochemical sources of energy. This includes conditions the experimenter has no influence on because they are strictly characteristics of the measuring equipment. It might nevertheless be important to know how missing function of a impedance spectroscope affect the measured results.

First of all this chapter deals with correction of voltage drift and maintaining the quasi-linear operating point.

For post-processing spectrums and checking plausibility literature often mentions the "Kramers Kronig“ transformation. An applicable form of this method exists in the so-called "Z-Hit Algorithm", which is described e.g. in [4].

Further reading can be found in [5], [6], [7] and [8].

7.6 Drift Adjustment

To characterize batteries using impedance spectroscopy it is necessary besides the sinusoidal stimulation current to add a DC for charging and discharging the battery. Only by this means impedance-based models for characterizing non-linear behavior can be developed. [9].

Changing the cell voltage with the respective charge state cannot be neglected for impedance spectroscopy as will be shown in the following.
We first assume that compared to the measuring frequency the cell voltage drift by the charge current is linear.

Figure 20 shows a comparison between a sinus signal with and without an overlaid linear voltage increase. Besides the time dependent course the signal's frequency range is also shown.

It is clearly visible that the frequency spectrum is different for the sinusoidal oscillation with overlaid linear voltage increase. The precondition that time function is periodic is not fulfilled with an overlaid linear voltage increase.

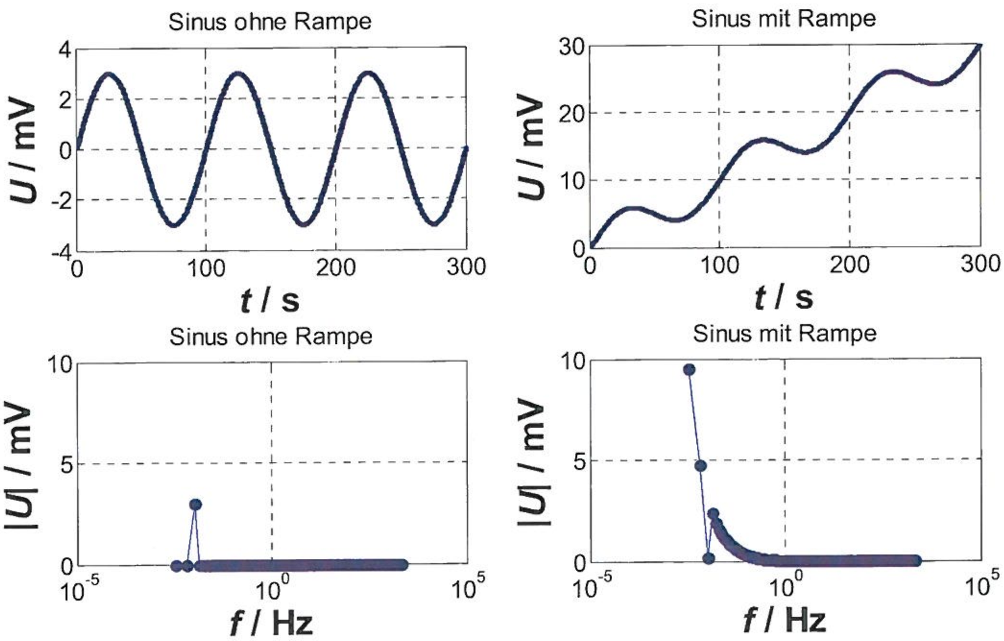


Figure 20: Comparison of sinusoidal signal without and with overlaid linear voltage increase.

For this reason before evaluating the measured signal by means of Fourier Transformation, the linear increased component must be eliminated. This correction (called drift correction or drift compensation) is done before evaluating the voltage response and assumes a linear rise or fall of the battery voltage during impedance measurement. By this means batteries that have a certain load or discharge current added can also be measured.

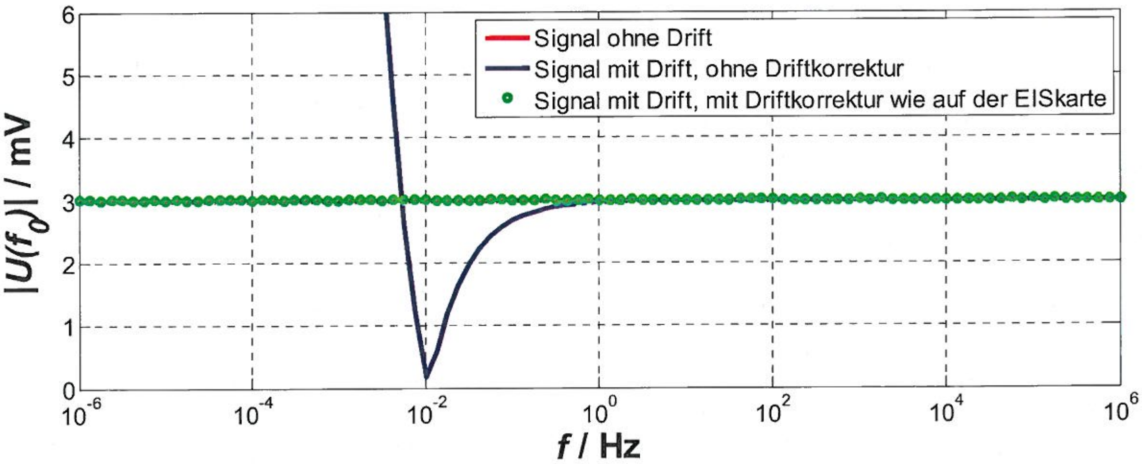


Figure 21: Amplitude of fundamental for frequency sweep of 1 MHz to 1 mHz and an overlaid linear voltage increase of 100µV/s. Displayed are voltage response without linear voltage increase (red), with linear voltage increase (blue) and with voltage drift correction.

Figure 21 shows for example a comparison for a simulated impedance spectrum. By this the fundamental of a sinusoidal signal has been analyzed and the frequency of the signal was varied from 1 mHz to 1 MHz. The signal's amplitude was always 3 mV. Three different cases are shown. The red curve in Figure 21 shows the fundamental without overlay; with the blue curve a linear voltage increase of 100 µV / s was overlaid.

The green curve finally shows the signal with overlaid linear voltage increase of 100 µV / s and drift compensation before analyzing the voltage response with Fourier Transformation.

7.7 Quasi-Linearity

Batteries are more or less non-linear concerning their current/voltage characteristic. This requires special efforts for impedance spectroscopy. In [9] you can read that for a complete battery characterization several operating points must be approached and measured.

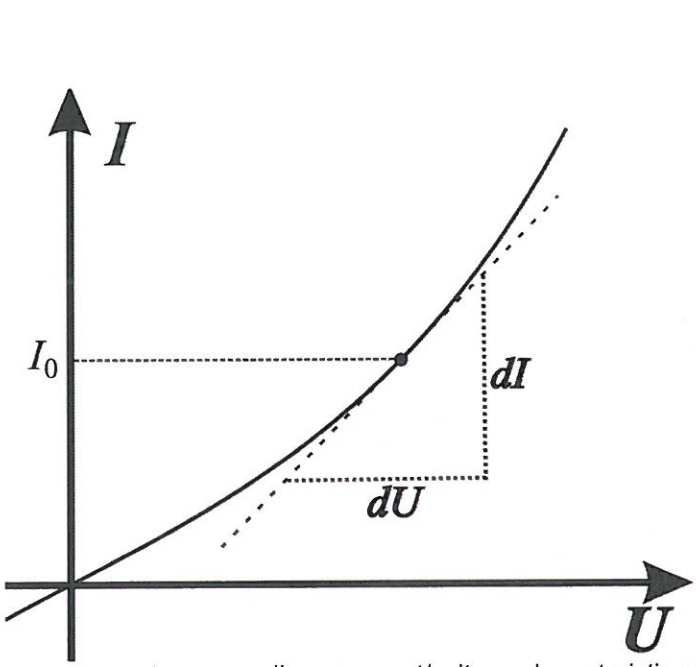


Figure 22: Impedance measurement on a non-linear current/voltage characteristic curve. Small signal behavior dU/dI is analyzed for a given operating point I.

Figure 22 shows this. For a given operating point I_0 impedance is measured as small signal response dU/dI. The result changes depending on the operating point.
The graph also indicates that dU or dI has to be chosen in a way that the small signal response can be seen as a tangent on the curve. If dI or dU is chosen too big, this results in impedance measurement errors ([7], [8]). With growing excitation amplitude the measured impedance decreases.
Especially low measuring frequencies are affected by this.

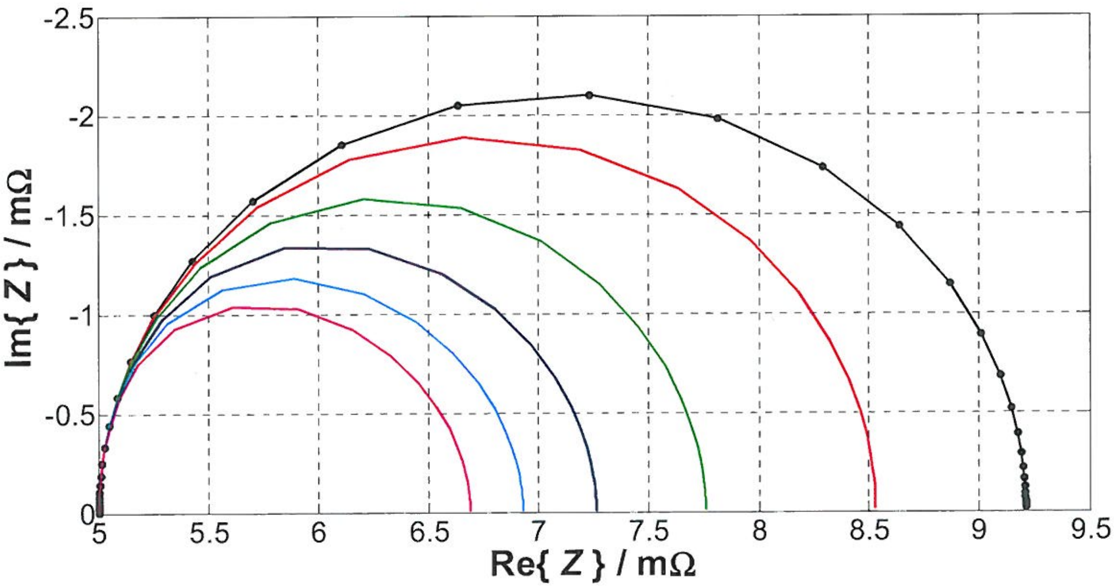


Figure 23: Simulated impedance measurement using a simplified Randles equivalent circuit diagram with non-linear charge transfer resistance. Simulated impedance spectrum with constant signal amplitude that was varied for each spectrum. As can be seen errors occur regarding the linear model (black curve) when excitation current is too big.

For this reason it's important during measurement that quasi-linearity is held. Literature [1] suggests not to exceed a voltage amplitude of 10 mV per cell during measurements. An alternative method is advocated in [8] by analyzing non-linearities of harmonic oscillations to guarantee quasi-linearity.

With EIS-METER this happens by setting parameter mVideal. It defines on which voltage response EIS-METER regulates the excitation current.

⚠ **For each impedance measurement with EIS-METER parameter mVideal must be set accordingly to guarantee a quasi-linear measurement.**

8 Bibliography

[1] J. Ross Macdonald, “IMPEDANCE SPECTROSCOPY”, Encyclopedia of Physical Science and Technology, 1991 Yearbook, p. 279-291

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[3] J. Kowal, D. Hente, D.U. Sauer, "Model Parameterization of Nonlinear Devices Using Impedance Spectroscopy“, Instrumentation and Measurement, Volume 58, Issue 7, July 2009 Page(s):2343 – 2350

[4] W.Ehm, H. Göhr, R. Kaus, B. Röseler, C.A. Schiller, Acta Chim. Hung. 137 (2000) 145

[5] C.A. Schiller, W. Strunz, "Impedanzmessungen – Sein oder Schein“, Technische Mitteilungen, HDT Essen, ISSN 0040-1439,S. 12 – 13

[6] C.A. Schiller, W.Strunz, "Impedanzmessungen an Systemen mit merklicher zeitlicher Drift“, Technische Mitteilungen, HDT Essen, ISSN 0040-1439, S. 12 – 13

[7] K. Darowicki, “The Amplitude Analysis of Impedance Spectra”, Electrochimica ACTA. Vol. 40, No 4. pp. 439 445. 1995

[8] M. Kiel, O. Bohlen, D.U. Sauer, "Harmonic Analysis for Identification of Nonlinearities in Impedance Spectroscopy“, Electrochim. Acta (2008), doi:10.1016/j.electacta.2008.01.089

[9] J. Kowal, D. Hente, D.U. Sauer, "Model Parameterization of Nonlinear Devices Using Impedance Spectroscopy“, Instrumentation and Measurement, Volume 58, Issue 7, July 2009 Page(s):2343 - 2350

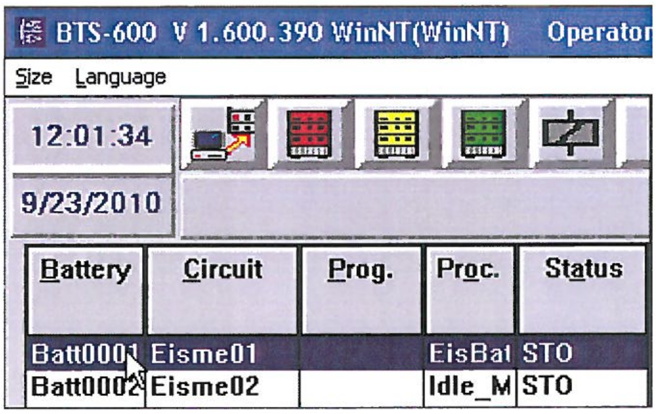
Graphical Display of EIS Data in BTS-600

To get a graphical presentation of measured data from EIS-METER, proceed as follows in BTS-600.

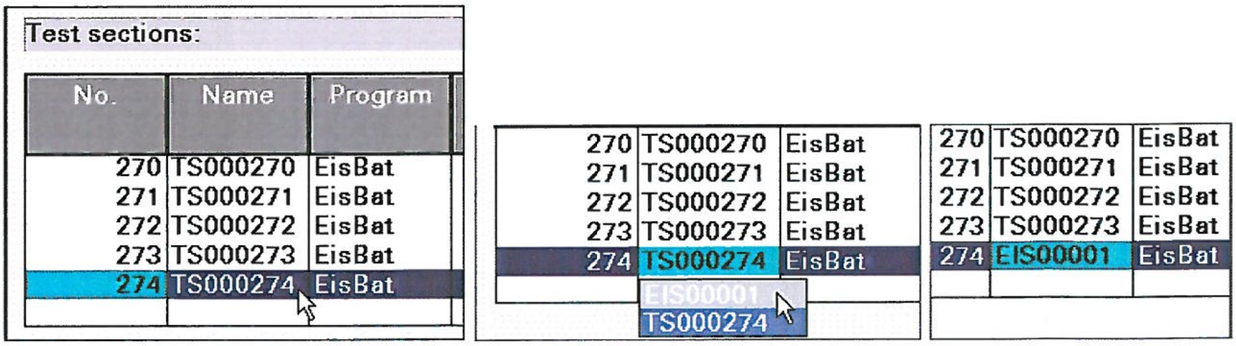
When an EIS measurement is running, this is indicated in the BTS-600 main screen with state EIS.

If a measurement is terminated, state STOP is displayed.

You can look at past measurements by double-clicking the respective battery in the main screen.



In the appearing list of test sections you go to the requested section and double-click its name. For each EIS step in a BTS-600 program a test section EIS0000x must exist.

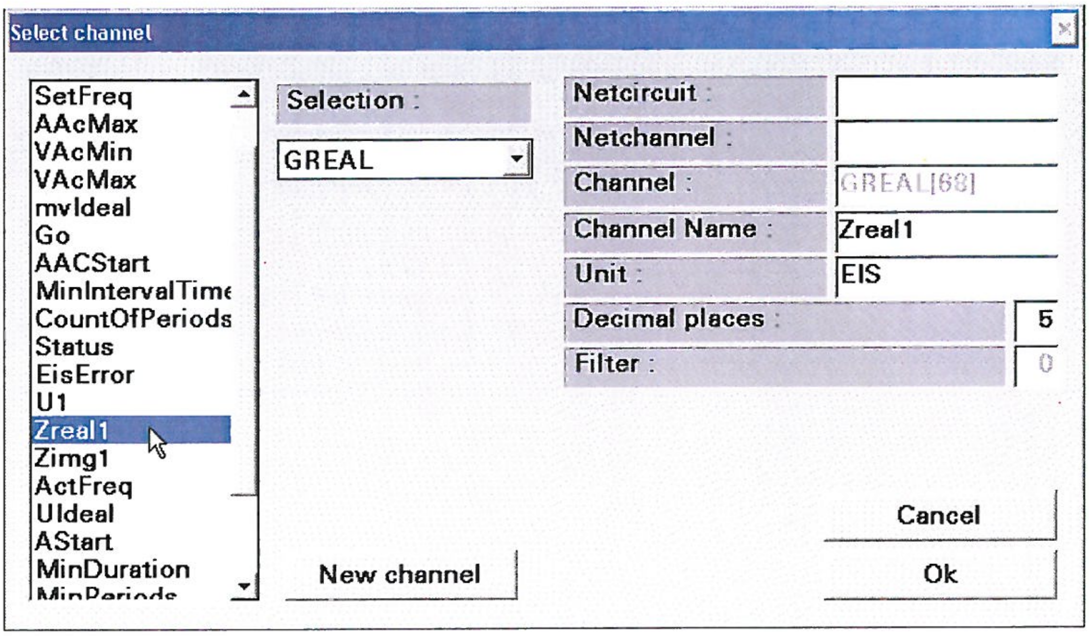


Now click button **Graphic display** in the top right of the window. As an alternative you can also click button **Numeric display** to see a numeric list of data. You can also use button **Export** to export data into a file.

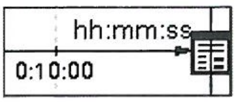
After clicking button **Graphical display** a new window appears where you can determine graphic borders automatically or manually. **Automatic** is the default setting.

For the appearing graphical display you now have to define the axes. Click the button at the bottom left to choose the channel to be displayed.

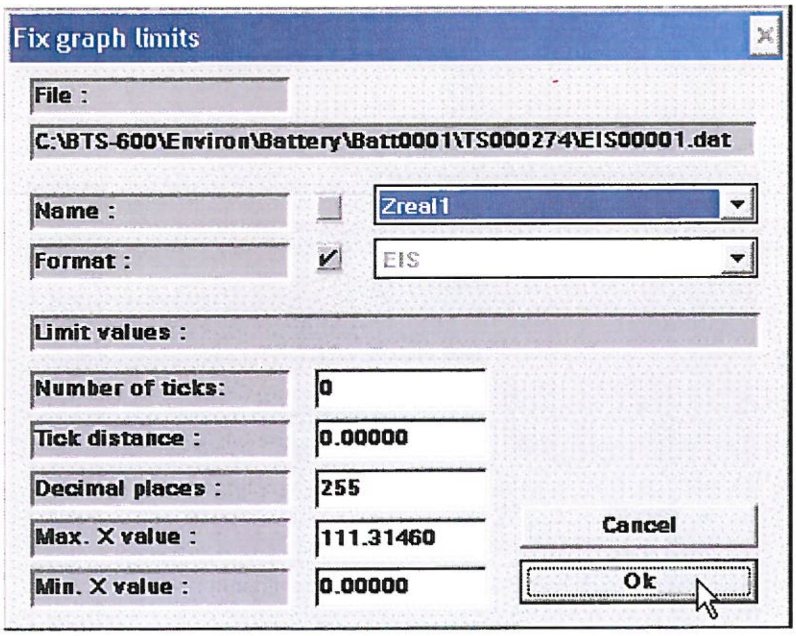
From the appearing window select **Zreal1** for the real part or **Zimg1** for displaying the imaginary part. Use option **Selection: GREAL** to display only EIS-relevant channels leading to better readability.



To create a Nyquist diagram proceed as follows: in the dialog above select **Zimg1** and confirm with **Ok**. Move the mouse cursor to the very right edge of the horizontal axis until the mouse pointer changes its look.

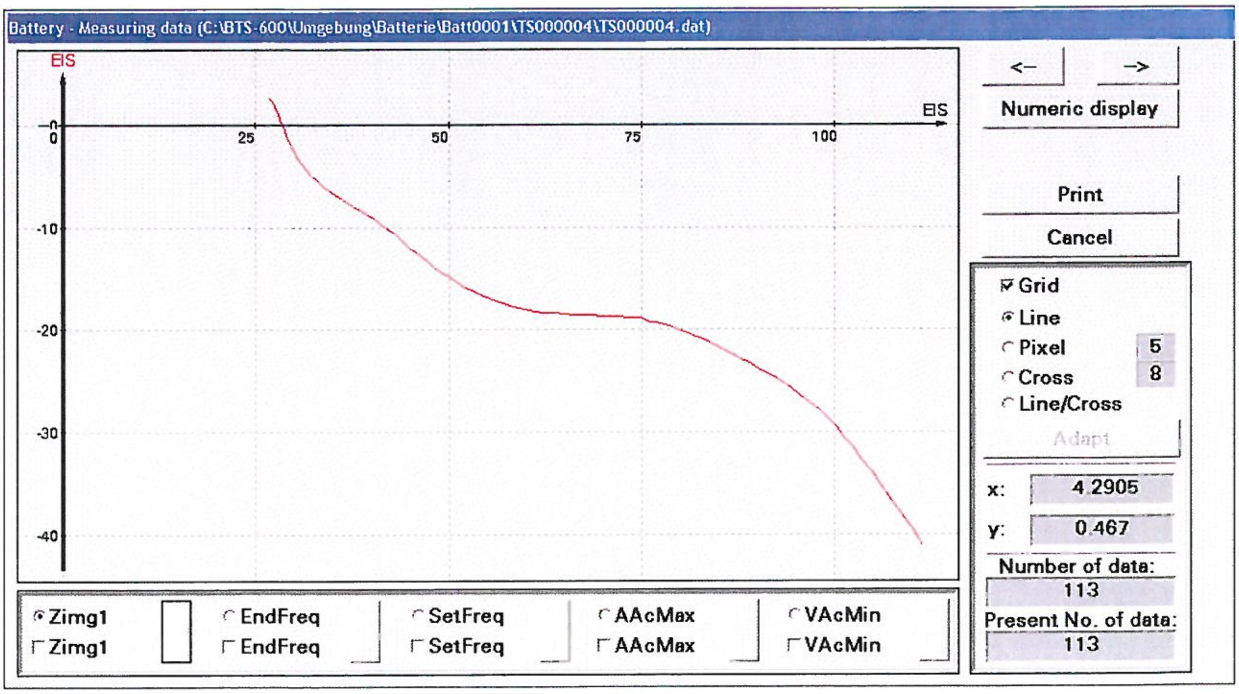


Click with the mouse while the mouse pointer shows this new look. A new window appears.



Now select entry **Zreal1** from the selection above.

After clicking **Ok** the Nyquist diagram is shown.



Appendix

1. EIS-METER attribution circuit / channel

For detailed information on attribution circuit / channel please see **appendix A** of BTS-600 manual (as PDF file on BTS-600 CD).
These EIS channels have to be added to the attribution circuit / channel:

Netcircuit	Circuit address	Net channel	Channel	Channel Name	Unit	Decimal places
			GREAL[47]	StartFreq	EIS	2
			GREAL[48]	EndFreq	EIS	0
			GREAL[49]	SetFreq	EIS	3
			GREAL[50]	AAcMax	EIS	0
			GREAL[51]	VAcMin	EIS	0
			GREAL[52]	VAcMax	EIS	0
			GREAL[53]	mVideal	EIS	0
			GREAL[54]	Go	EIS	0
			GREAL[55]	AACStart	EIS	2
			GREAL[56]	EIStime	EIS	2
			GREAL[57]	EISperi	EIS	0
			GREAL[62]	Status	EIS	0
			GREAL[63]	EisError	EIS	0
			GREAL[64]	U1	EIS	5
			GREAL[65]	U2	EIS	5
			GREAL[66]	U3	EIS	5
			GREAL[68]	Zreal1	EIS	5
			GREAL[69]	Zreal2	EIS	5
			GREAL[70]	Zreal3	EIS	5
			GREAL[72]	Zimg1	EIS	5
			GREAL[73]	Zimg2	EIS	5
			GREAL[74]	Zimg3	EIS	5
			GREAL[76]	ActFreq	EIS	3
			GREAL[91]	VRelativ	EIS	0
			GREAL[92]	AAmplitude	EIS	2
			GREAL[93]	NomVal1	EIS	5
			GREAL[94]	Phase1	EIS	5
			GREAL[95]	NomVal2	EIS	5
			GREAL[96]	Phase2	EIS	5
			GREAL[97]	NomVal3	EIS	5
			GREAL[98]	Phase3	EIS	5

If you want to delete a channel, simply delete entry **EIS** in column **Unit** of the respective line.

Meaning of Channels

Channels that are set by the program.

At program start:

GREAL[47] StartFreq
The larger of the frequencies defined in the program (e.g. 10 kHz).

GREAL[48] EndFreq
The smaller of the frequencies defined in the program (e.g. 10 mHz).

GREAL[50] AAcMax
Maximum amplitude of the sinusoidal current (A).

GREAL[51] VAcMin
Minimum voltage on sense lines (V).

GREAL[52] VAcMax
Maximum voltage on sense lines (V).

GREAL[53] mVideal
Maximum amplitude of the sinusoidal current voltage (mV).

GREAL[55] AACStart
Amplitude of the sinusoidal current that is used to try to reach voltage value mVideal (A).

GREAL[56] ElStime
Minimum time for a frequency measurement.

GREAL[57] ElSperi
Number of periods per frequency measurement.

During the program (per measurement):

GREAL[49] SetFreq
Actual frequency with which EIS-METER shall execute the current measurement.

GREAL[54] Go
Counter for measured frequencies, starting with 1.

Channels that are read by the program.

During program (measurements):

GREAL[64] U1
Voltage on sense line (Volt).

GREAL[65] U2
Voltage on sense line (Volt).

GREAL[66] U3
Voltage on sense line (Volt).

During program (at the end of a measurement):

GREAL[62] Status
Number of EIS-METER-task state on RailPC.

GREAL[63] EisError
Error number that EIS-METER or EISmeterTask report.

GREAL[68] Zreal1
Measured reale resistance (mOhm).

GREAL[69] Zreal2
Measured reale resistance (mOhm).

GREAL[70] Zreal3
Measured reale resistance (mOhm).

GREAL[72] Zimg1
Measured imaginary resistance (mOhm).

GREAL[73] Zimg2
Measured imaginary resistance (mOhm).

GREAL[74] Zimg3
Measured imaginary resistance (mOhm).

GREAL[76] ActFreq
Frequency that EIS-METER conducted measurement with (Hz).

GREAL[91] VRelativ
Percentage value of maximum amplitude of sinusoidal voltage that is determined by mVideal (%).

GREAL[92] AAmplitude
Amplitude of sinusoidal current that EIS-METER conducts measurement with (A).

GREAL[93] NomVal1
Calculated absolute value (mOhm).

GREAL[94] Phase1
Calculated phase (degrees).

GREAL[95] NomVal2
Calculated absolute value for U-Channel2 (mOhm).

GREAL[96] Phase2
Calculated phase for U-Channel2 (degrees).

GREAL[97] NomVal3
Calculated absolute value for U-Channel3 (mOhm).

GREAL[98] Phase3
Calculated phase for U-Channel3 (degrees).

2. Program

Use operator **EIS** to realize an EIS step in BTS-600.

Step	Label	Procedure	Nominal Value	Limit	Action	Registration
1		SET				EisReg
2		PAU		5 sec		
3		EIS	25.0 ADC 4.2 VDC 10 mHz 6.0 kHz 2.0 AAcMax 4.2 VAcMax 3.0 VAcMin	30 min		
2		STO				

Possible nominal values for EIS-METER:

ADC (as of BTS-600 V395 SP15) — **Nominal value optional** – load current in Ampere by the circuit like in a normal charge step with operator CHA.

ADC > 0	=>	charge step
ADC < 0	=>	discharge step
ADC not defined	=>	pause step
ADC = 0	=>	pause step

VDC (as of BTS-600 V395 SP15) — **Nominal value optional** – voltage limit like in a normal charge step. Defining VDC is only possible if current ADC is also defined; otherwise an error occurs.

mHz, Hz, kHz Defines frequency for each measurement.
If two values are defined, a spectrum is measured with the smaller value being the start frequency and the larger value being the end frequency. 8 measurements per decade will be made.
If only one value is defined, measurement is only conducted at this frequency.

AAcMax **Optional** – Maximum AC measuring current allowed. If this value is not defined, it will be set to 2 A.

VAcMax **Optional** – Maximum voltage. When exceeded, EIS-METER indicates error. If this value is not defined, it will be set to 20 V.

VAcMin **Optional** – Minimum voltage. When below, EIS-METER indicates error. If this value is not defined, it will be set to -2 V.

mVideal **Optional** - Amplitude of the voltage response coming from the battery.
For linearity reasons it should range between 3 and 10 mV / cell. EIS-METER measures a frequency and adjusts the stimulatory current amplitude in a way that mVideal is met as well as possible.
3 mV / cell is a good choice. If this value is not defined, it will be set to 10 mV.

mVideal

EIStime **Optional** – Minimum time for measurement per frequency.
A frequency is measured for the time given with EIS time, but at least for 3 periods. With e.g. 1 Hz a measurement takes 3 seconds even when EIStime is defined as 1 s. If this value is not defined, it will be set to 10 s.

EISperi **Optional** – defines the number of periods per frequency. If not defined, value is internally set to 3.

AACstart **Optional** – Current amplitude to start a spectrum.
For safety reasons this parameter should initially be chosen small (e.g. 20 mA). However EIS-METER might measure the frequency again with a larger amplitude due to a small voltage response. If you know your test object and you know what kind of impedance to expect at the beginning of the spectrum, you can choose a larger amplitude (e.g. 1 A). You thereby save the effort of a second measurement for the first frequency. If this value is not defined, it will be set to 20 mA.

Limit for EIS-METER:

n min Defines a time limit. The user **must** set this time e.g. to protect the connected test object. The limit must be greater than the duration of the measurement.

Define registration format:

In column **Registration** of BTS-600 program editor you can define a registration format of your choice. When a new registration format is entered, confirming with ENTER opens a new window. Click button **New** in this window to define a new registration format. A new dialog then shows registration format **EIS** that includes all required channels for EIS measurement. Move **EIS** to the right and confirm with **Ok**.