

FRA-X

Interface for High Current Impedance

1 Introduction	4
1.1 Packing list.....	4
1.2 Requirements of the EXD	4
2 Hardware connection scheme.....	5
2.1 Current transducers: Dimensions	6
3 Setting up FRA-X.....	8
4 Define correlation parameters	9
4.1 Input signals	9
4.1.1 Current transducer	9
4.1.2 Voltage transducer	11
4.2 Output signal	13
4.3 Current and voltage limits	14
4.4 Saving setup.....	14
5 FRA-X with Regatron® Power Supplies	14
5.1 Mixed mode operation.....	15

1 Introduction

Zahner's ZENNIUM series potentiostats have limited voltage and current ranges (i.e., ZENNIUM X: Voltage range ± 15 V, Current range: ± 4 A). Even with an extension of Zahner's electronic load (EL1002), the maximum working voltage and current are ± 100 V and ± 680 A, respectively. In many applications, electrochemical impedance spectroscopy (EIS) is desired at even higher voltages and/or currents. For these applications, Zahner's ZENNIUM series potentiostat can be interfaced with an external device (EXD) via an FRA-X, allowing for high currents and voltages only limited by the specs of the external device.

The Thales software fully supports the FRA-X. It is possible to incorporate the FRA-X in a remote test stand and control the setup via Python or C++. The commands for remote control are provided in section 4.8 of the [Remote manual](#).

1.1 Packing list

Zahner products are carefully manufactured, calibrated and tested to ensure our high-quality standard. Packing is done with great care to avoid damage during transport. Upon receipt of the Zahner shipment, please check the device and accessories to ensure they are intact. If a product has been damaged during shipment, please immediately contact your Zahner's service partner.

- FRA-X
- Mains cable
- Connection cable "E" D-SUB9 to ODU
- Connection cable "I" D-SUB9 to ODU
- Voltage probe
- Connection cable "voltage probe" D-SUB9 to BNC-female
- USB power adapter (5 V) for voltage probe
- Current probe
- Connection cable "current probe" D-SUB9 to D-SUB9
- Regatron G5 control cable BNC-male to D-SUB25
- This manual

1.2 Requirements of the EXD

An FRA-X setup can be configured to control a third-party source, sink, or source/sink electronic device. The FRA-X acts as an interface and allows ZENNIUM potentiostat to control the output of an EXD. The ZENNIUM potentiostat can use its frequency generator to modulate the output signal of the EXD, so that sine-waves for measuring EIS can be generated, for example.

The EXD must be equipped with an analog control-input port for connecting with the FRA-X. The analog control input of the EXD should ideally be in the range of ± 10 V or slightly below.

The EXD must be able to operate in galvanostatic (constant current) and potentiostatic (constant voltage) modes to enable EIS measurements in either of these modes. For low-ohmic test objects or high-current measurements, the galvanostatic mode is mostly used and recommended.

When an EXD is interfaced with a ZENNIUM potentiostat via an FRA-X, the ZENNIUM potentiostat works as a controller and thus only the specifications of the EXD and the FRA-X are relevant for the overall system performance. For EIS, it is important to choose an EXD with a fast reaction time (i.e., short rise time).

2 Hardware connection scheme

The FRA-X is connected to a ZENNIUM potentiostat via I- and E-probe connection cables. The cables on one side are connected to I- and E-probe Lemos connections at the front panel of ZENNIUM potentiostat and on the other side to the back panel of the FRA-X. Moreover, the FRA-X needs to be powered using a mains cable.

The voltage and current measurements in many modern external sources or loads (EXDs) are often comparably slow, or not phase-coherent (especially in the case of digital signal processing paths, and especially for more elevated frequencies). This behaviour is not compatible with measuring EIS, while the EXDs may at the same time be able to follow an external signal with its current or voltage output with comparably fast dynamics (low rise times). Therefore, the FRA-X can be considered an upgrade to the EXD to access the EIS technique by enabling fast, dynamic and reliable voltage and current measurements. This is performed by external voltage- and current transducers, directly by the FRA-X (i.e., the Zahner device), separate from the EXD electronics (galvanically isolated).

Different EXDs have different types of analog input ports, hence the user is obliged to custom-build an adapter cable to connect FRA-X to the EXD. However, Zahner a suitable adapter cable for Regatron® power supplies is included.

The four BNC inputs on the front panel of the ZENNIUM potentiostat **MUST** be disconnected when using FRA-X!

On the front panel of the FRA-X, three connectors are available for the current transducer, voltage transducer, and excitation signal output, respectively. The “excitation signal out” port will be connected to the analog control input port of the EXD.

The current and the voltage transducers are connected to the FRA-X via the defined current- and voltage transducer ports. Fig. 1 displays the connection scheme:

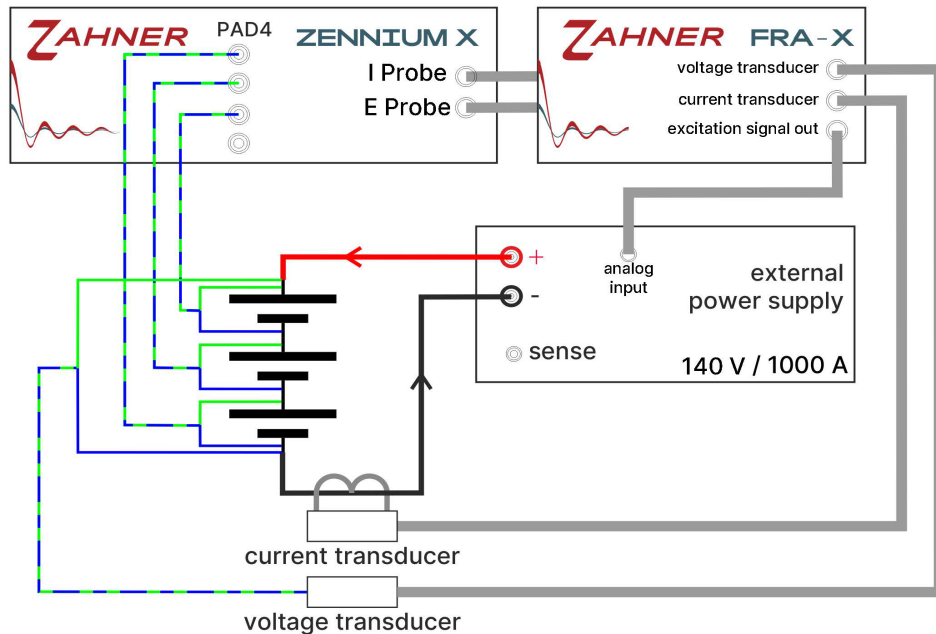


Fig. 1: Connection scheme of FRA-X setup

The PAD4 card is optional in the FRA-X setup shown in Fig. 1: Connection scheme of FRA-X setup.

The FRA-X is delivered with a voltage transducer from TESTEC which is powered up by USB connection, which must be used with a separate USB power supply. Powering the USB cables directly from a computer can lead to artefacts in the measurement.

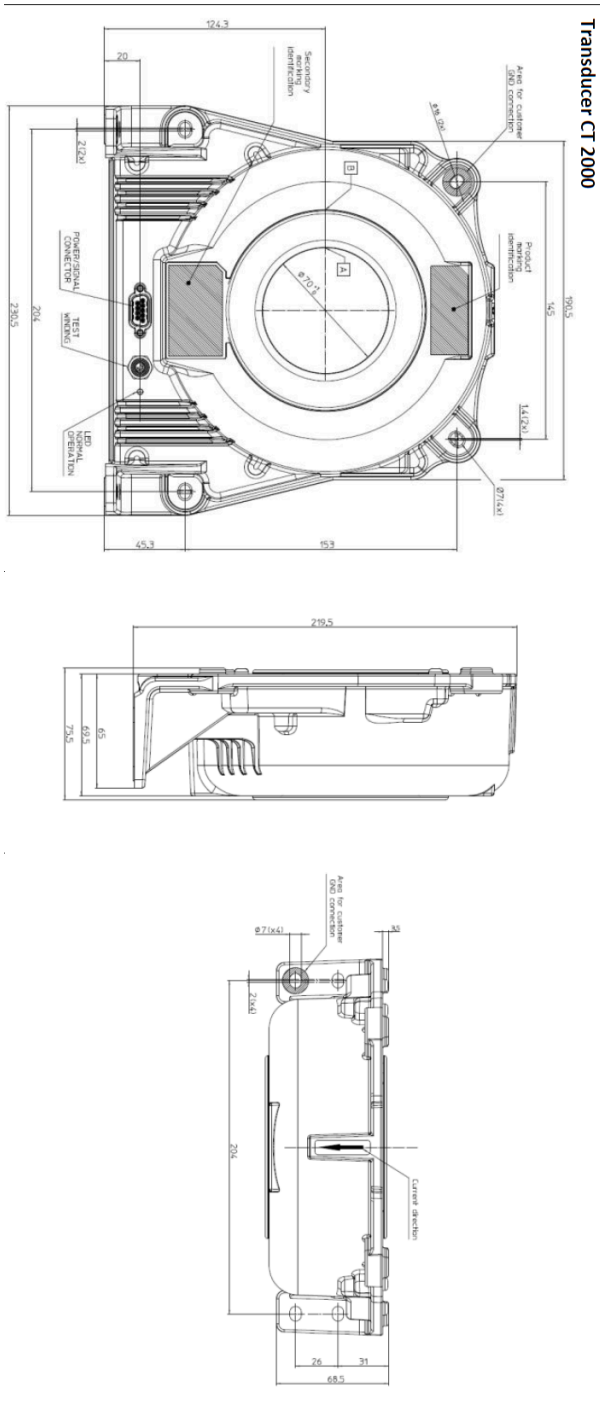
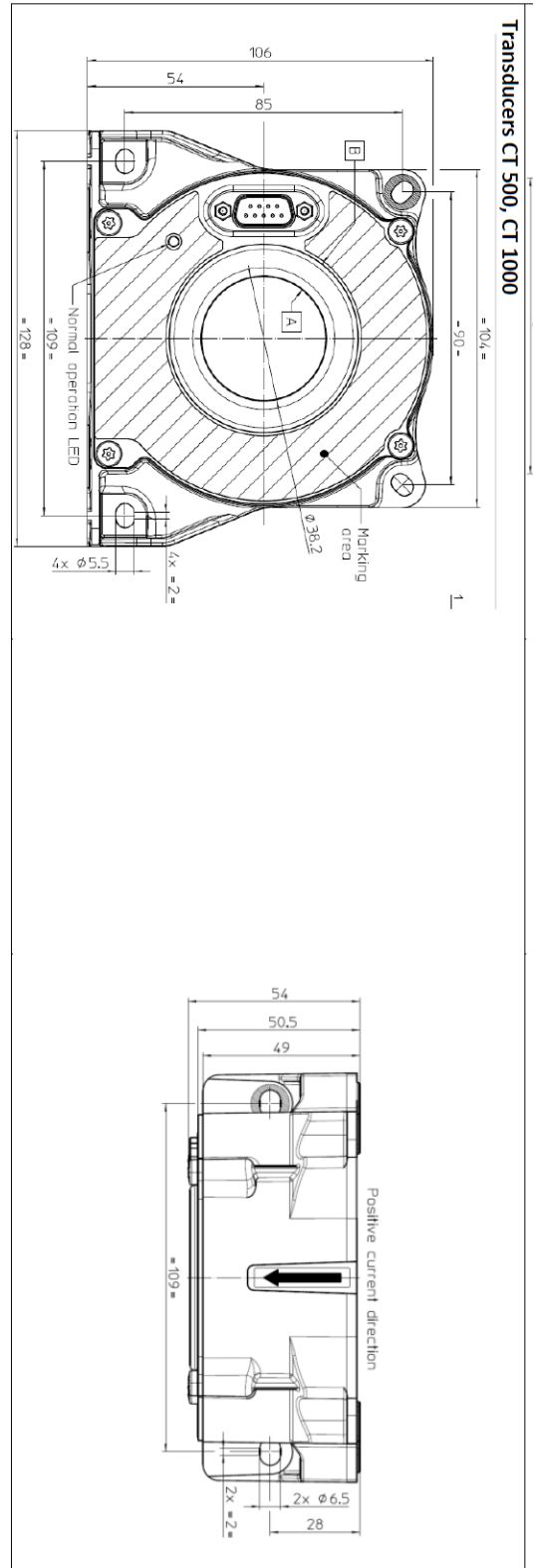
The current-transporting cables from the EXD to the DUT should be twisted around each other to mitigate the induction effect. For simplicity, this is not shown in Fig. 1: Connection scheme of FRA-X setup.

2.1 Current transducers: Dimensions

For measurement of current in the DUT, the current carrying cable must be routed to go through the current transducer.

If multiple cables are run between the EXD and the DUT or if the cable is too thick to fit into the current transducer ring, the user must custom-build a solution (i.e., a copper assembly) so that the current transducer can properly measure the current.

The dimensions of the SIGNALTEC current transducers are provided below. The CT 500 and CT1000 both have an inner diameter of 38 mm. The CT2000 has an inner diameter of 70 mm.



3 Setting up FRA-X

The output of the ZENNIUM potentiostat is correlated with the output of the EXD by the FRA-X setup. For this, the voltage and current parameters (gains, offsets, ranges) between the ZENNIUM potentiostat and the EXD must be set properly. Similarly, the parameters (gains, offsets, and ranges) for the inputs from the transducers must also be defined before starting measurements with the FRA-X.

Before setting up the parameters, the EXD must be turned off or at least the output from the EXD must be turned off. Thereby, you disconnect the DUT from the FRA-X and avoid possible damage to the connected DUT.

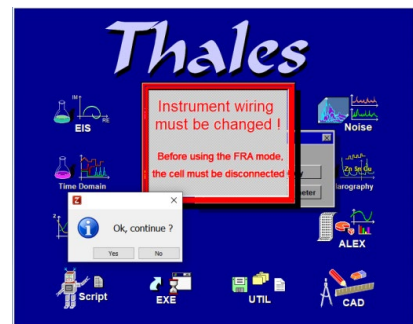
After setting up the hardware (as described in Section 2), start the Thales software in classic mode and proceed as follows:

1. Click on the *FRA* icon in the Thales software and then click on the *EIS: Spectra vs. Frequency*.
 - a. The Thales software displays a warning that you must disconnect your DUT. Disconnect the DUT or turn off your EXD now before proceeding further.

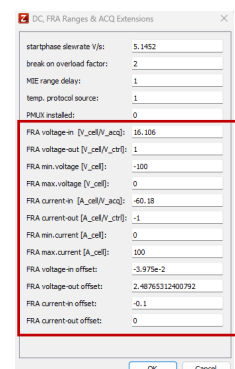
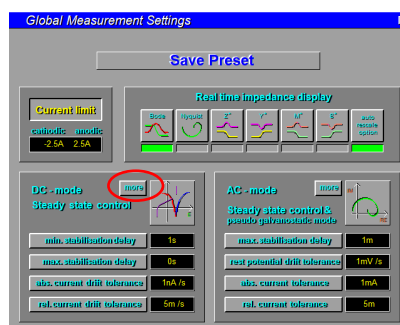
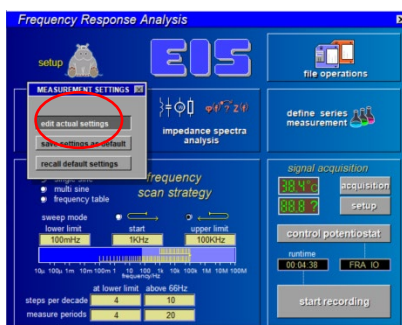


- a. Make sure nothing is connected to the four BNCs at the front panel of the ZENNIUM potentiostat.
 - b. Click Yes to continue.

NOTE: After clicking Yes, the ZENNIUM potentiostat is always ON. This is indicated by the orange "POT" LED above the BNC and Lemosa connectors on the front panel of the ZENNIUM potentiostat.



2. In the *FRA* menu, click on the "Hippo-pictogram" and then click on *edit actual settings* to enter the *Global Measurement Settings* window. Alternatively, you may also access the *Global Measurement Settings* by clicking on "Hippo-pictogram" in the *FRA TESTSAMPLING* window.



3. In the “DC-mode” sub-section, click on *more* to access the FRA settings.
4. Define the FRA-related parameters described in Section **Fehler! Verweisquelle konnte nicht gefunden werden.** (highlighted in a red box in the image).
5. Click OK.
6. Turn on the EXD or EXD device output for measurement.

4 Define correlation parameters

The following subsections explain the procedures for setting up the gains, offsets and limits for the input and output signals.

4.1 Input signals

4.1.1 Current transducer

Zahner offers multiple current ranges for the transducers. For a certain type of transducer, a suitable current-in gain [A_cell/V_acq] must be set in the *Global Measurement Settings* window. The default current-in gain values for different current transducers are displayed in Table 1.

Table 1: Default values for current-in gains for different transducers

Current range (A)	Default current-in gain
± 100 *)	20
± 500	120
± 1000	240
± 2000	320

*) The device is internally configured for the 100A range. Other current ranges require a change to the internal amplifier configuration. This must be agreed with the manufacturer.

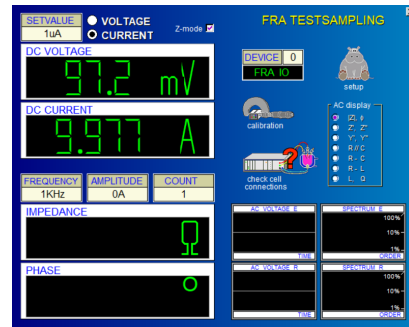
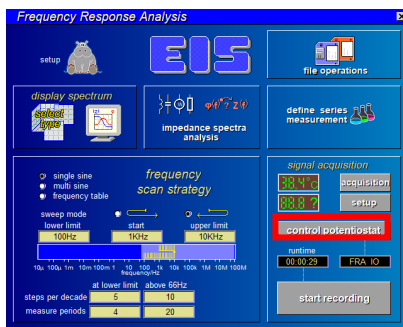
The current transducers have their current accuracy within a certain range, and therefore the current-in gain and the current-in offset have to be fine-tuned in the *Global Measurement Settings* window to compensate for the accuracy margin of the current transducer. For reproducible EIS measurements, an adequate current-in offset must be set besides the current-in gain. For finding the correct gain and offset values, follow the instructions provided below.

1. Connect the current transducer with the FRA-X.

2. Connect the output from a power supply with a suitable test object, if possible a passive test object such as a known resistor.
3. Pass one current-carrying cable from the power supply to the DUT through the current transducer.

In the case of small currents, multiple turns of a cable can be run through the current transducer to improve the accuracy of the current measurement. In this case, the default current-in gain must be divided by the number of cable turns.

4. Set the respective default current-in gain value in the *Global Measurement Settings* window.
5. Using the trial-and-error method, adjust the “Current-in offset” in a way that the DC CURRENT in *FRA TESTSAMPLING* reads zero.
6. Set an output current on the power supply (i.e., 10 A), operating the power supply in CC mode.
7. The *FRA TESTSAMPLING* window will show a DC CURRENT value close to the applied current (i.e., 9.97 A)., Modify the current-in gain value in a way that the *FRA TESTSAMPLING* window reads the correct value of the applied current (i.e., 10 A).



The *FRA TESTSAMPLING* window can be accessed by clicking on *control potentiostat* in the FRA menu.

8. To further fine-tune the current-in offset, turn off the power output of the power supply. The *FRA TESTSAMPLING* window should now display a DC CURRENT of 0 A. If it significantly deviates from 0 A, adjust the value for the “current-in offset” in the *Global Measurement Settings* window accordingly.
9. Turn on the output of the power supply and set again a DC current value in Thales (e.g., 10 A) and check if the displayed DC CURRENT in the *FRA TESTSAMPLING* window matches the setpoint value. If needed, fine-tune the current-in gain value.
10. Increase the current output from the power supply to another current value (i.e., 20 A) and check if the *FRA TESTSAMPLING* reads the correct

DC CURRENT value. If needed, fine-tune using the current-in gain and offset values.

Repeat steps 5 to 10 until the current output from the power supply and the Thales software match across a broad current range, ideally most accurately in the region of the most commonly used current values.

4.1.2 Voltage transducer

Zahner offers multiple voltage ranges for the FRA-X voltage transducers. For different voltage ranges suitable voltage-in gains [V_{cell}/V_{acq}] must be set in the *Global Measurement Settings* window. The gains for each voltage range are provided in

Table 2: Default values for voltage-in gains for different voltage ranges

Voltage range (V)	Default voltage-in gain
±5	0.4
±70	8
±140	16
±700	80
±1400	160

For the voltage range of ±5 V, the voltage is measured directly by the ZENNIUM series potentiostat. In this case, a LoZ probe cable is recommended to be used to contact the E-probe on the front panel of the ZENNIUM potentiostat to the DUT. For other voltage ranges, a TESTEC voltage transducer is used. Since these devices have a DC accuracy tolerance of up to ±2%, it is recommended to fine-tune the default voltage-in gain value to compensate for the offset. Therefore, the voltage-in gain value may deviate by up to ±2% from the default value.

For reliable EIS measurements, suitable values for the voltage-in offset as well as the voltage-in gain need to be found. For this, follow the instructions provided below.

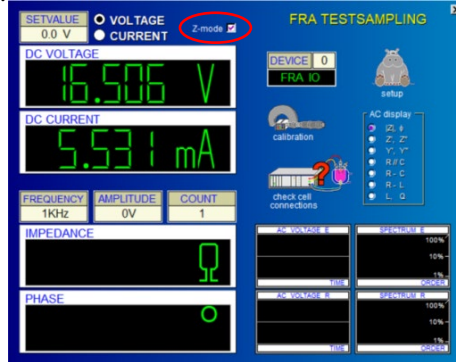
1. Connect the voltage transducer with the FRA-X.
2. Power up the transducer using the USB plug and select the suitable voltage range from the transducer.
3. Leave the outputs of the power supply open-ended.
4. Connect the cables from the voltage transducer to the outputs of the power supply.

5. Set the default voltage-in gain value in the *Global Measurement Settings* window.

For defining the correct gain and offset for the voltage transducer, the user may also use a passive test object and read the voltage drop across the passive object with the voltage transducer while operating the external power supply in galvanostatic mode: the same operation mode used for current transducers. In this way, the user can set the gains and offsets of the current transducer and the voltage transducer in the same setup.

6. Using the trial-and-error method, adjust the "Voltage-in offset" so that the DC VOLTAGE in *FRA TESTSAMPLING* reads zero.
7. Set an output voltage on the power supply (i.e., 10 V), operating the power supply in CV mode.
8. Due to the $\pm 2\%$ accuracy margin, the *FRA TESTSAMPLING* window will show a DC VOLTAGE value close to the applied voltage (i.e., 9.85 V instead of set 10 V). Using the trial-and-error method, modify the voltage-in gain value in a way that the Thales software reads the correct set voltage (i.e., 10 V).
9. Now turn off the output of the power supply. The DC VOLTAGE in the *FRA TESTSAMPLING* window should read 0 V. If this is not the case, use the trial-and-error method and set a value for the "voltage-in offset" in the *Global Measurement Settings* window that the DC VOLTAGE in the *FRA TESTSAMPLING* reads 0 V.
10. Turn on the output of the power supply again to the previously applied voltage value. If needed, fine-tune the voltage-in gain so that the software shows the correct voltage value.
11. Increase the voltage output from the power supply to another voltage value (i.e., 20 V) and check if the Thales software shows the correct voltage. If needed, fine-tune the voltage-in gain and the offset values.
12. Repeat steps 6 to 11 until the voltage output from the power supply and the Thales software match across a broad voltage range, ideally most accurately in the region of the most commonly used voltage values.

Important: The user must activate the Z-mode to see the correct current/voltage values in the FRA-X mode.



4.2 Output signal

For controlling an EXD via FRA-X, the voltage- and/or current-out gains ($[V_{cell}/V_{ctrl}]$ and $[A_{cell}/V_{ctrl}]$, respectively) as well as their offset values need to be adjusted.

The voltage- and current-out gains can be calculated from the equation below.

$$Out\ gain = \frac{Upper\ parameter\ limit}{Analog\ input\ value}$$

Example: In the case of a power supply with a voltage range of ± 200 V, a current range of ± 1000 A, and an analog input of ± 10 V. The gains will be

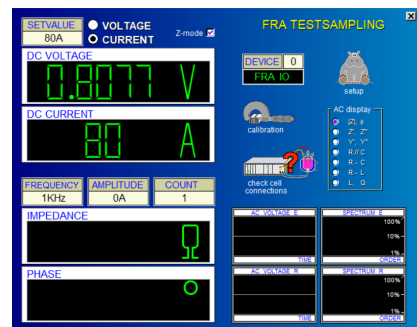
$$Voltage\ out\ gain = \frac{200}{10} = 20$$

$$Current\ out\ gain = \frac{1000}{10} = 100$$

If an EXD has non-symmetrical parameters (i.e., voltage range: -50 V to $+200$ V), the higher absolute value (here 200) will be used for the calculation. The same also applies to the current-out gain.

The user also needs to adjust the voltage- and current-out offsets so that the EXD shows the correct voltage or current value as defined in the SET VALUE in the FRA TESTSAMPLING window.

The user can set output gain values for voltage as well as current, depending on the operation mode. In many scenarios, the FRA-X will permanently be used in either galvanostatic or potentiostatic mode. If this is the case, only the relevant parameter needs to be set while the respective other one can be ignored.



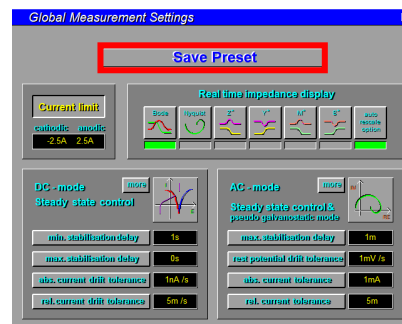
4.3 Current and voltage limits

In the *DC-mode* menu, the user must set the current and voltage limits. If the EXD or the transducers have different current and/or voltage limits, apply the lower limit value, respectively.

If the user does not want to make use of the full current or voltage range, lower limits may as well be applied. Since the Thales software handles the limits very strictly and measurements will be stopped as soon as a voltage or current limit is reached, the user should provide some headroom to avoid interruption of experiments.

4.4 Saving setup

The user only needs to set up the gains, offsets and ranges for the FRA-X setup once. The settings can then be saved in the *Global Measurement Settings* by clicking on *Save Preset*.



If the user does not save the parameter settings and turns off the Thales software, the defined settings parameters will be reset to default upon switching off the device or the Thales software.

5 FRA-X with Regatron® Power Supplies

Depending on the power range, a Regatron® power supply may need a 3-phase main power connection. The user may have to custom-build a mains cable according to the instructions provided by Regatron®.

The cable connections between ZENNIUM, FRA-X, Regatron power supply and the DUT are to be realized according to the schematic shown in Fig. 1. The Regatron® power supply may consist of several units in parallel connection, where each unit has a current output and the applied current is distributed across all units. In this case, the user needs to custom-build a solution (i.e., a copper assembly) for the placement of the current transducer that allows for measuring the total current.

To operate the setup, turn on the Zahner ZENNIUM, Zahner FRA-X and Regatron® power supply. The user must connect the Regatron® power supply and ZENNIUM potentiostat by USB to the computer with the control software. Start Zahner's Thales software as well as the G5.Control software from Regatron®. Find and adjust the

parameters for the FRA-X operation as defined in this manual. In the G5.Control software, the user needs to connect the device, and activate the I/O option so that the FRA-X can control the power supply.

In the G5.Control software, clicking on “Device → Connect” will open the *Connection Manager*, where a list of all connected Regatron devices is displayed. If no device is visible, click on *Refresh*. Select the correct device from the list and click on “Connect”. When the connection is established, the user will see the current and voltage values from the device. Now the user may define the current/voltage limits directly in the G5.Control software.

In the G5.Control software, the user can activate the analog control by clicking on “View → I/O Configuration”. In the *I/O Configuration* sub-window, set the “Input 1” to “Output Current Reference Value”. With this, the *Reference value* (i.e., output current in CC mode) will show the I/O sign. Now, provided that the correct output gain and offset are set in the Thales menu, the output parameter defined in the Thales software will be taken as the output parameter by the Regatron® power supply.



Now the user may turn on the Regatron® power supply and control the setup using the Thales software for EIS measurements.

5.1 Mixed mode operation

Regatron® power supply also allows a mixed control mode where the DC offset for the measurement is applied directly by the Regatron® power supply and the FRA-X controls the AC modulation.

This mixed-mode can lead to better resolution of the output current signal in case of a large DC bias. In such a scenario, the 10 V range of the analog control will correlate to the maximum defined AC amplitude. The user may activate the mixed mode by clicking on “View → I/O Configuration”. In the *I/O Configuration* sub-window, set the “Input 1” to “Current Modulation Mode”. With the Current Modulation Mode selected, a current input box will appear where the maximum AC amplitude is to be defined.

For the mixed mode, the user must set the current out-gain properly.

$$FRA \text{ current} - \text{out gain} = \frac{\text{Max. AC amplitude}}{\text{Analog input value}}$$

In most cases, the analog channel has a 10 V range so the formula can be simplified to

$$FRA \text{ current} - \text{out gain} = \frac{\text{Max. AC amplitude}}{10}$$