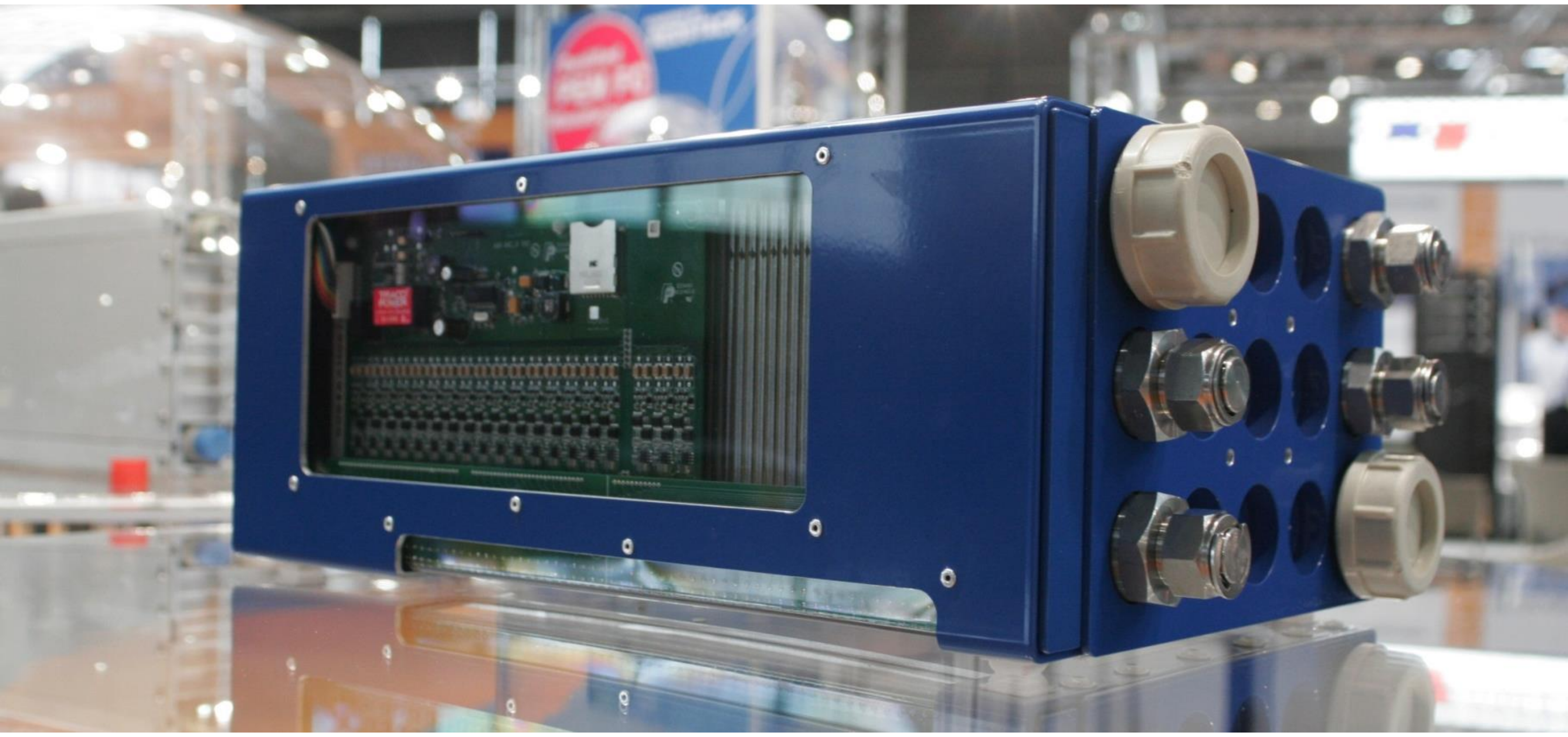
Autolab/

Electronic Load

Installation Description



Picture Courtesy of Nedstack Fuel Cell Technology BV

Metrohm
Autolab

Autolab/Electronic load combination

The Autolab range of instruments is limited in terms of maximum current or power that can be supplied to, or extracted from an electrochemical cell. When working with high power energy storage or energy conversion devices, the power requirements can often exceed those available with a normal Autolab PGSTAT, even when it is extended with a Booster 10 A or 20 A.

To meet these experimental requirements, the Autolab can be combined with a third-party programmable electronic load.

Modern electronic loads can reach over 100 A easily. This combination therefore extends the measurable range of the Autolab by decades of current or more.

When the Autolab is combined with an electronic load, the load will sink the current while the Autolab will measure the voltage across the electrochemical cell. The combination of the Autolab and the electronic load requires the dedicated DYNLOAD interface (Article code: LOAD.INT.S).

Note

It is also possible to combine the Autolab with a programmable power supply. In this case, the power supply will be used to source high currents to the cell and the Autolab is used to control the voltage across the cell. The use of a programmable power supply is not specifically covered in this manual. More information can be obtained by contacting Metrohm Autolab (autolab@metrohm.com).

Using the DYNLOAD interface, several types of measurements are possible:

- DC measurements at high current densities (up to the maximum current allowed by the load).

- Electrochemical impedance spectroscopy measurements at high current density (up to the maximum current allowed by the load).

Most electronic loads can be controlled in four operation modes:

- **Constant current (CC) mode**[1]: current is drawn from the cell until the specified current value is reached.
- **Constance voltage (CV) mode:** current is drawn from the cell until the cell voltage reaches a specified value.
- **Constant power (CP) mode:** current is drawn from the cell until the output power reaches a specified value.
- **Constant resistance (CR) mode:** current is drawn from the cell until the resistance to the current flow reaches the specified value.

The **constant current (CC)** mode is the most suitable for the combination with the Autolab, however the other modes are also available, but these modes are affected by ohmic losses and are therefore not accurate.

> ⚠ **Warning**
>
> When the Autolab is combined with an electronic load, the Autolab will only be used to control the load and measure the cell voltage. The specifications of the Autolab are therefore irrelevant for this application and only the specifications of the electronic load must be selected carefully (see Section 1). The Autolab AUT302N.FRA32M.S and AUT204,FRA32M.S are suitable for all the measurements described in this manual.

[1] This installation note only covers this operation mode. Please contact Metrohm Autolab for more information on the other modes (autolab@metrohm.com).

Table of Contents

1 – Choice of the electronic load 6
2 – Dynload interface part list 8
3 – Autolab PGSTAT part list 10
4 – Electronic load part list 11
5 – Polarity convention 12
6 – Connections to the Dynload interface 12
6.1 – Connections without a FRA module 13
6.2 – Connections with a FRA32M module 14
6.3 – Connections with a FRA2 module 16
8 – Connections to the cell 18
8.1 – Connections for cell voltages ≤ 10 V 19
8.2 – Connections for cell voltages > 10 V 20
8.2.1 – Voltage multiplier part list 20
8.2.2 – Connections to the instrument 21
9 – Electronic load settings 22
9.1 – Programming the load (Kikusui) 24
9.2 – Programming the load (GW Instek) 25
9.3 – Programming the load (TDI) - OBSOLETE INSTRUMENT 26
9.4 – Controlling the electronic load 27
9.4.1 – Examples of calculations of conversion factors 28
10 – NOVA hardware setup 29
10.1 – Analog input settings 30
10.2 – Analog output settings 31
11 – Manual control of the electronic load (DC only) 32
12 – Procedure control of the electronic load (DC only) 34
13 – Recording the output from the electronic load (DC only) 37
14 – Impedance spectroscopy measurements 39
14.1 – External settings 42
14.1.1 – Settings for ← V 42

14.1.2 – Settings for → X 43
14.1.3 – Settings for → Y 43
14.1.4 – Settings for Transfer function 44
14.2 – Frequency scan settings 45
14.3 – Sampler settings 46
14.4 – Plots settings 47
14.5 – Running a measurement 48
15 – Measurement examples 50
15.1 – i-V/Power curve 50
15.1.1 – Running the measurement 50
15.2 – Impedance spectroscopy measurement 51
Appendix 1 – Specifications of known electronic loads 54
Appendix 2 – Modification of the FRA2 module 56

1 – Choice of the electronic load

The electronic load is a critical component of this hardware setup, and it should be chosen carefully. Some electronic loads are more suitable for working with a low power energy storage device, while other electronic loads are adapted to very large power output systems.

Many commercially available electronic loads can be used in combination with the Autolab PGSTAT. However, to operate in combination with the PGSTAT, the electronic load must fulfil the following requirements:

- Analog external programming to control the setpoint (0-10 V range)
- Analog external current monitor for current readout (0-10 V range)

A list of compatible electronic loads can be found in Table 1.

Load	Application	Bandwidth
Kikusui PLZ164WA	Single cells	100 kHz
Kikusui PLZ664WA	Single cells, small stacks	100 kHz
Chroma 6300	Medium stacks	20 kHz
GW Instek PEL-3000/H	Single cells, small stacks	20 kHz
Previously tested loads:	(Obsolete)	
TDI RBL 488	Medium stacks	20 kHz
TDI WCL 488	Large stacks	1 kHz
Agilent 6060B	Single cells, small stacks	20 kHz
Agilent 3300	Single cells, small stacks	20 kHz

Table 1 – Overview of compatible electronic loads

For small energy storage devices, a low power electronic load is sufficient. For larger devices, more powerful electronic loads are required. Some electronic loads require active cooling for power dissipation.

As a practical rule, it is not possible to have the following specifications at the same time:

- Full current output even at 0 V cell voltage
- High bandwidth (> 1 kHz)
- High power

Small electronic loads like the Kikusui PLZ164WA have very high bandwidth ratings and can operate at maximum current even if the cell voltage is 0 V. The maximum power of these loads is however limited, which means that these instruments are suitable for small single cell systems. On the other hand, larger loads like the TDI RBL 488 have high maximum power and sufficient bandwidth, but they require a minimum cell voltage to operate at full power (for example, the TDI RBL 488 requires 3 V DC voltage to operate at 300 A, as shown in Figure 1). These systems are therefore more suitable for large stacked cells.

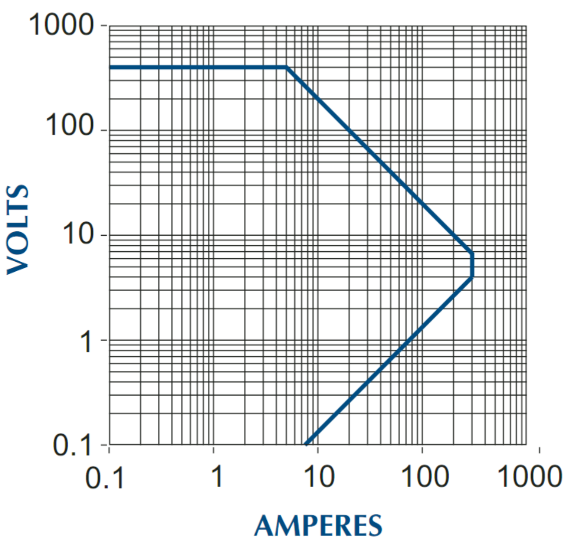


Figure 1 – Contour map of the TDI RBL 488

2 – Dynload interface part list

The Dynload interface kit (LOAD.INT.S) includes the following items:

1. The Dynload interface (see Figure 2).
2. 12 V power supply
3. A 2 m long BNC cable
4. A 50 Ω terminator plug
5. 6 BNC to SMB adaptor plugs
6. 3 SMB shielded cables (1 m)
7. A BNC splitter

Note

A special Dynload interface version (LOAD.INT.KIK.S) suitable for ribbon cable connections is available on request (see Figure 2).

Warning

This special Dynload interface version (LOAD.INT.KIK.S) is suitable only for some electronic loads such as the Kikusui PLZ-4W series or the GW Instek PEL-3000/H series. It is highly recommended to check in advance the connector type and the pin connections of the electronic load to make sure that it matches the connector of the Dynload interface.

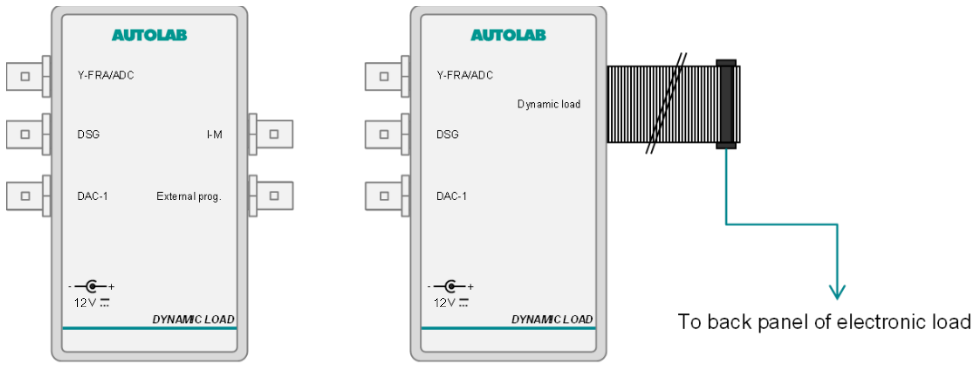


Figure 2 – Two versions of the Dynload interface:left – BNC compatible, for general purpose interface (LOAD.INT.S) and right – ribbon cable compatible (LOAD.INT.KIK.S), (e.g., for. Kikusui or GW Instek electronic loads)

The three SMB shielded cables can be fitted with SMB to BNC adaptor plugs. Depending on the type of FRA module used in combination with the LED Driver, these cables can be modified accordingly:

- For the FRA2 module, the cables must be fitted with SMB to BNC adaptors on both ends (see Figure 3).

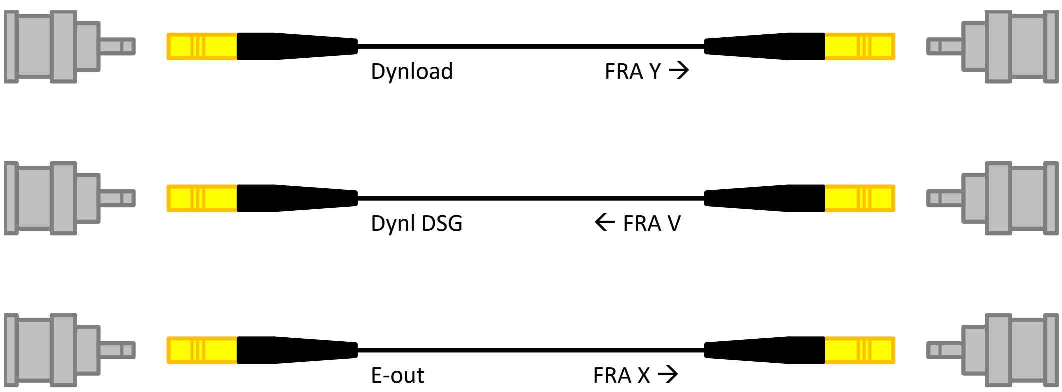


Figure 3 – Configuration of the SMB cables used in combination with the FRA2 module

- For the FRA32M module, the cables must be fitted with SMB to BNC adaptors on a single end (see Figure 4).

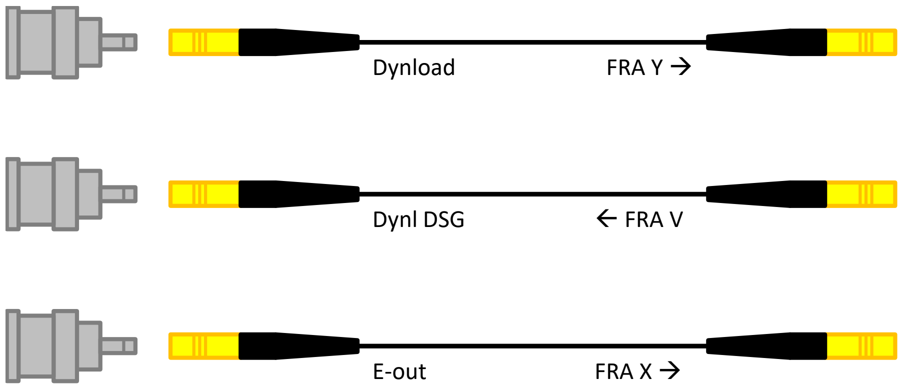


Figure 4 - Configuration of the SMB cables used in combination with the FRA32M module

3 – Autolab PGSTAT part list

The Autolab PGSTAT is used as a voltmeter in combination with the electronic load. This means that the WE and CE connectors provided by the Autolab **must not** be connected to the cell.

Warning

Never connect the WE/CE connectors of the Autolab to the electrochemical cell when working in combination with an electronic load. High currents can damage the Autolab!

The monitor cable is required for the combination with the electronic load, and it must be attached to the front panel of the PGSTAT (see Figure 5).

Note

The monitor cable for the PGSTAT204 is not supplied standard with the instrument and it must be ordered separately. Please contact autolab@metrohm.com for more information.

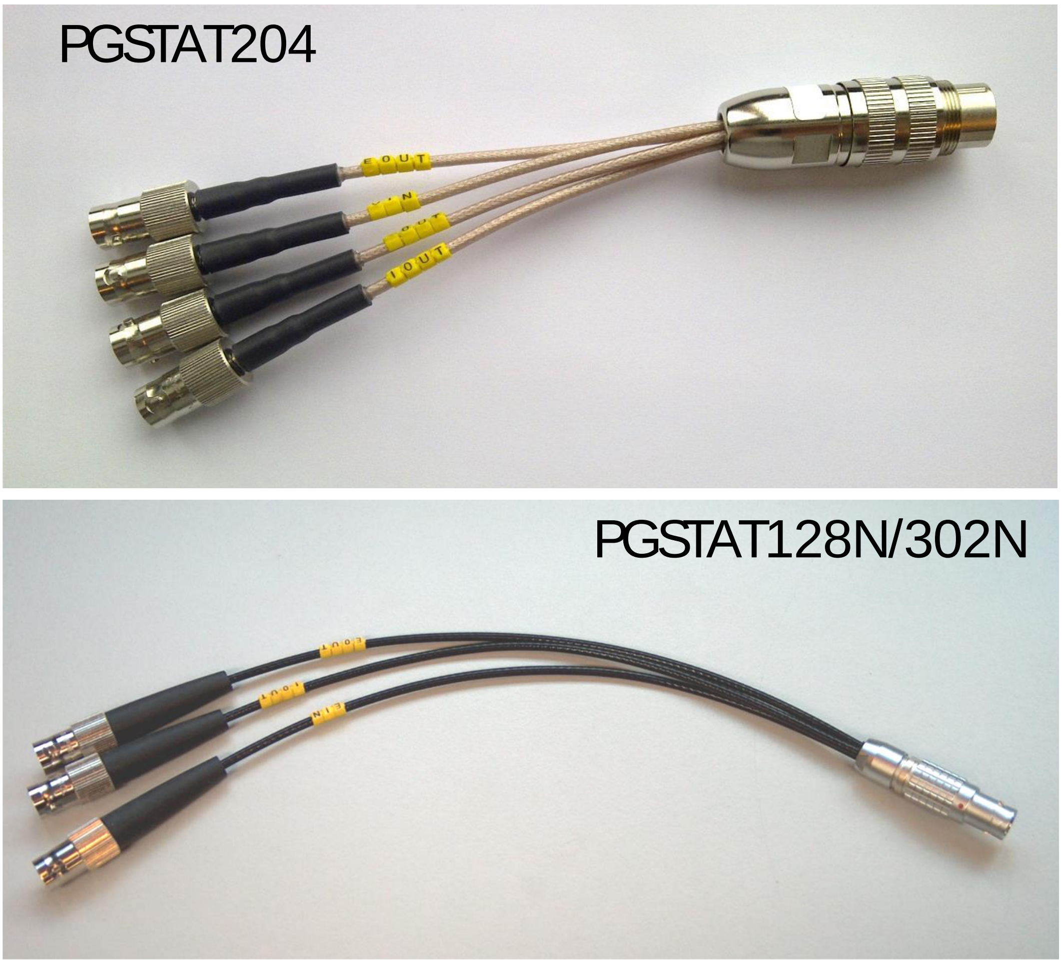


Figure 5 – Monitor cable for the PGSTAT204 (above) and the Series 8 PGSTAT128N/302N (below)

4 – Electronic load part list

The electronic load must be connected to the electrochemical cell using cell cables suitable for the expected power drawn from the cell. It is recommended to use thick cables with very low resistivity to avoid ohmic losses.

Additionally, the cables required to connect the Dynload interface to the programming port of the electronic load must be sourced by the end user. The type of cables required depends on the type of electronic load. The connections to the Dynload interface must be BNC.

Note

Please refer to the user manual of the electronic load for more information on the connection requirements or contact Metrohm Autolab (autolab@metrohm.com) for assistance.

5 – Polarity convention

The NOVA software, used to control the Autolab PGSTAT302N, the PGSTAT204 and the electronic load connected to it, uses the IUPAC convention for potential and current polarity. Charging (or anodic) currents are indicated with a positive sign. Discharging (or cathodic) currents are indicated with a negative sign.

For this application, working with an electronic load to discharge energy storage or conversion devices, the cell voltages will be positive and the discharge currents will be negative.

The software can be adjusted to account for this polarity convention.

Note

The current indicated on the front panel of the electronic load will be positive.

6 – Connections to the Dynload interface

This section describes the connections required to perform the measurements with the Autolab in combination with an electronic load. The connections depend on the instrument type and configuration. In the rest of this document, an N-series Autolab instrument is used; however, other NOVA controlled instrument configurations are also possible.

6.1 – Connections without a FRA module

If no FRA (i.e., EIS) module is present in the instrument (FRA2 or FRA32M), the connections between the Autolab and the Dynload interface should be as described in Figure 6.

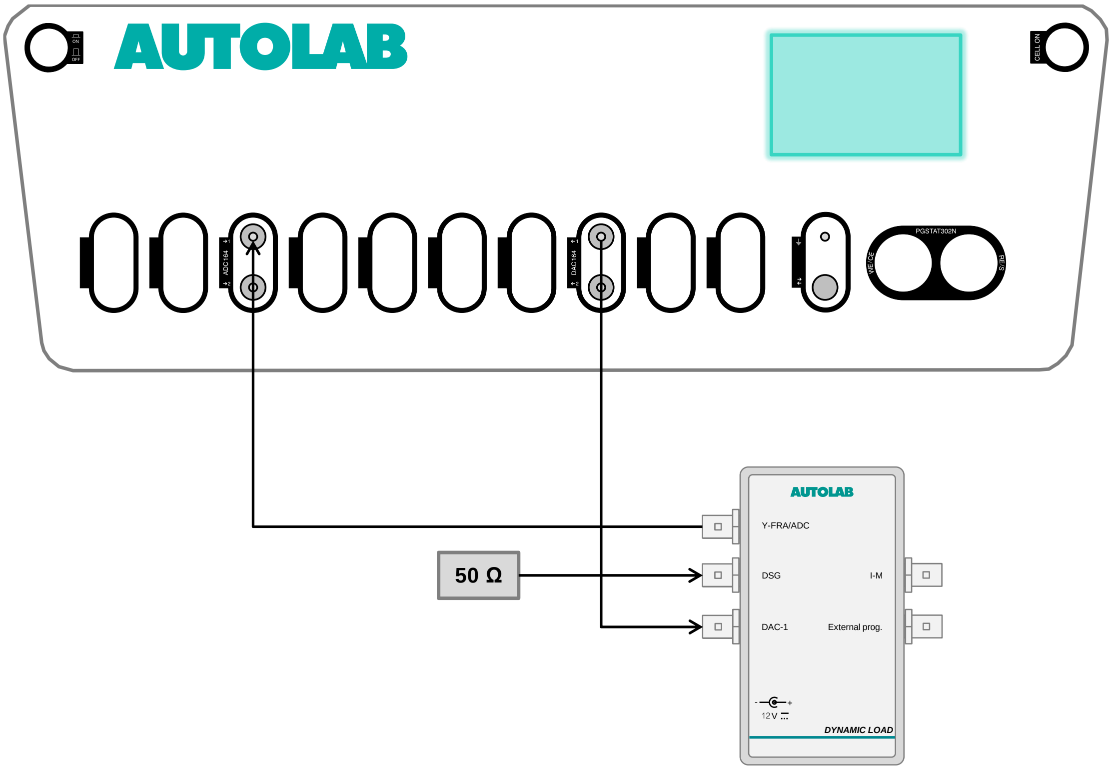


Figure 6 – Connections overview without FRA module

1. Connect the DAC164 output one on the front panel of the Autolab (DAC164 ←1) to the DAC-1 input of the Dynload interface.
2. Connect the Y-FRA/ADC output of the Dynload interface to the ADC164 input one on the front panel of the Autolab (ADC164 →1).
3. The DSG input of the Dynload interface **must be shorted** with the provided 50 Ω termination plug (see Figure 7).

Figure 7 – A 50 Ω terminator plug must be used to short the DSG input when this input is not used.

Note

Make sure that the 50 Ω plug is always connected to the DSG input!

Note

For the PGSTAT204, use the V_{out} and V_{in} provided by the monitor cable instead of DAC164 ←1 and ADC164 →1, respectively.

6.2 – Connections with a FRA32M module

If a FRA32M module is present in the instrument, the connections between the Autolab and the Dynload interface should be as described in Figure 8.

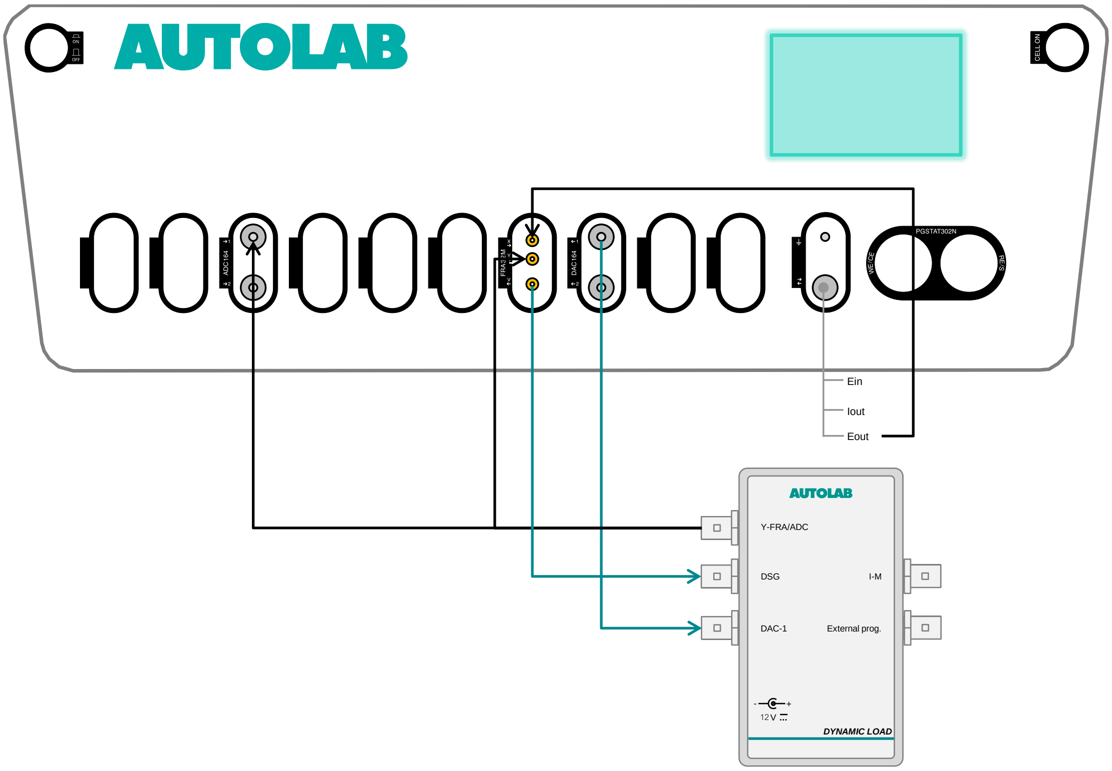


Figure 8 - Connections with the FRA32M module

1. Connect the DAC164 output one on the front panel of the Autolab (DAC164 ←1) to the DAC-1 input of the Dynload interface.
2. Connect the Y-FRA/ADC output of the Dynload interface to the ADC164 input one on the front panel of the Autolab (ADC164 →1) and using the provided BNC splitter, connect the same signal to the FRA32M →Y input.
3. Connect the E_{out} signal, provided by the monitor cable to the FRA32M →X input.
4. Connect the FRA32M V→ output to the DSG input on the Dynload interface.

Note

For the PGSTAT204, use the V_{out} and V_{in} provided by the monitor cable instead of DAC164 ←1 and ADC164 →1, respectively.

6.3 – Connections with a FRA2 module

If a FRA2 module is present in the instrument, the connections between the Autolab and the Dynload interface should be as described in Figure 9.

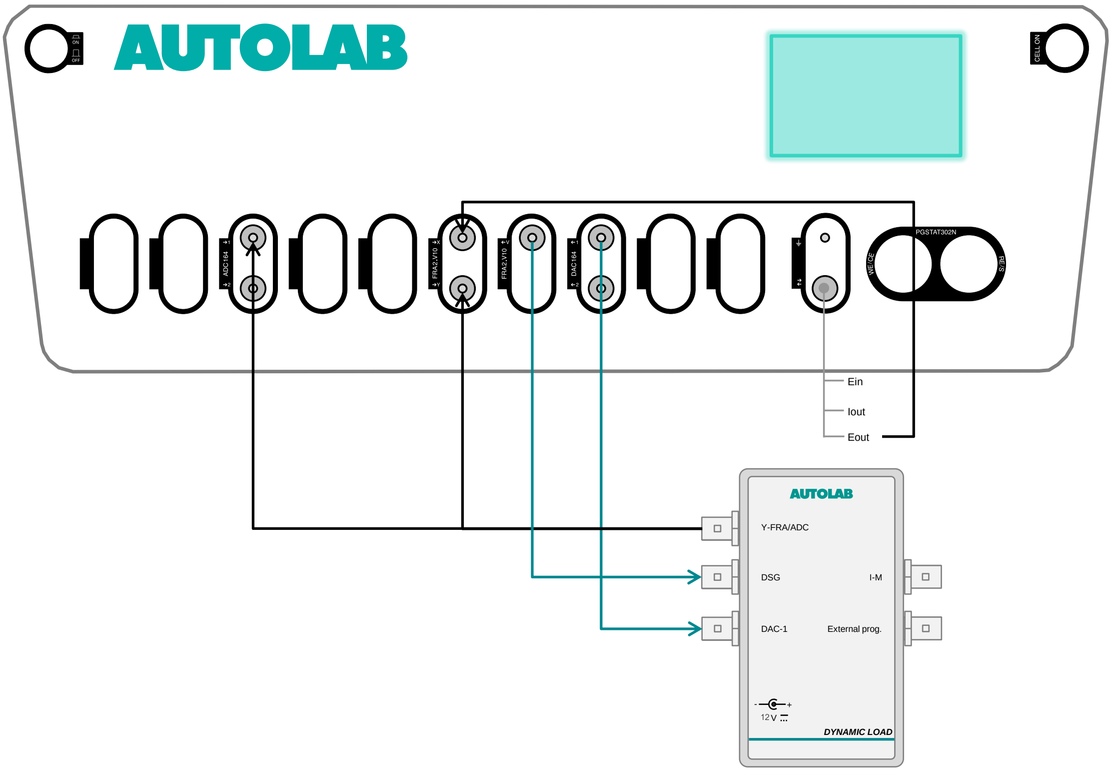


Figure 9 – Connections with the FRA2 module

1. Connect the DAC164 output one on the front panel of the Autolab (DAC164 ←1) to the DAC-1 input of the Dynload interface.
2. Connect the Y-FRA/ADC output of the Dynload interface to the ADC164 input one on the front panel of the Autolab (ADC164 →1) and using the provided BNC splitter, connect the same signal to the FRA2 →Y input.
3. Connect the E_{out} signal, provided by the monitor cable to the FRA2 →X input.
4. Connect the FRA2 V→ output to the DSG input on the Dynload interface.

Warning

Analog programming of the electronic load requires a modification of the FRA2 module to accept an analog signal up to 10 V. A hardware and software modification may be required. More information is provided in the Appendix 2.

Please contact Metrohm Autolab (autolab@metrohm.com) or your local distributor in case of any doubts.

7 – Connections to the Electronic load

The Dynamic load interface must be connected to the electronic load. This connection can be done in two different ways according to the type of connection supported by the electronic load. In most of the cases, this connection is done through **BNC connectors**. Present on the dynamic load interface (LOAD.INT.S) are two BNC female ports, one for the current monitoring (I-M) and one for the voltage output (External prog.) which must be connected to the corresponding BNC connections on the electronic load (see electronic load user manual to ensure a proper connection).

Some electronic loads might not support the BNC connection and therefore need to be connected differently. A common alternative connection is represented by the **ribbon cable connection** (adopted by both Kikusui and GW Instek). For this kind of connection, the Dynamic load interface ribbon cable compatible (LOAD.INT.KIK.S) has to be used (see Figure 2).

Warning

The Dynamic load interface ribbon cable compatible has a three pin connection and this is specifically built for **Kikusui PLZ164WA.** While working for compatible instruments, such as the **GW Instek PEL-3000 series**, on other instruments having the same type of connection, might not be supported. For example, the **Kikusui 5W-series** are not supported despite having the same type of connection, due to a different pin position within the connector.

It is therefore recommended to always check the manual of the electronic load to ensure the compatibility of the dynamic load interface. Contact Metrohm Autolab for connection guidelines (autolab@metrohm.com).

8 – Connections to the cell

The electronic load (+) is connected to the (+), or cathode, of the cell, and the electronic load (-) is connected to the (-), or anode, of the cell.

Warning

The cables connecting the electronic load to the cell must have the lowest possible resistance and should be able to withstand high current densities. Keep in mind that ohmic losses cannot completely be avoided. Most electronic loads have a **voltage reversal detection** circuit that monitors the cell voltage and shuts down the load when this value becomes negative or lower than a threshold. For electronic loads that are unable to operate at low cell voltages, the maximum current that can be drawn from the cell may be affected by ohmic losses.

Because of ohmic losses, the apparent voltage measured by the load, ΔE_{LOAD} is always smaller than the voltage measured by the Autolab (ΔE_{AUT}) by a value equal to the product of i and R, where R is the total resistance of the cables:

$$\Delta E_{LOAD} = \Delta E_{AUT} - iR$$

e.g., passing 80 A through 10 mΩ cables, leads to 800 mV ohmic drop.

8.1 – Connections for cell voltages ≤ 10 V

The S and RE cables of the Autolab differential amplifier are connected to the cell under study. The S is connected to the (+) and the RE connected to the (-). The CE and WE connections of the PGSTAT are not used.

Warning

Never connect the CE and WE from the Autolab PGSTAT to the cell!

Note

It is recommended to connect the RE and S leads from the PGSTAT as close as possible to the cell.

8.2 – Connections for cell voltages > 10 V

The input range of the Autolab differential amplifier is limited to 10 V. When the cell voltage is larger than 10 V, for example when measuring on large cell stacks, the input voltage of the Autolab can be extended to 30 V by using the **Voltage multiplier** (Item code: VOLT.MULT.S).

Important restriction

The Voltage Multiplier reduces the **input impedance** of the PGSTAT electrometer to ~ 100 kΩ. Only use the Voltage Multiplier when the total impedance of the DUT is very low with respect to the input impedance (typically, 100 Ω or less).

8.2.1 – Voltage multiplier part list

The Voltage Multiplier (VOLT.MULT.S) kit includes the following items:

1. The Voltage Multiplier box (see Figure 10)
2. A red 30 cm long male banana to banana cable
3. A blue 30 cm long male banana to banana cable

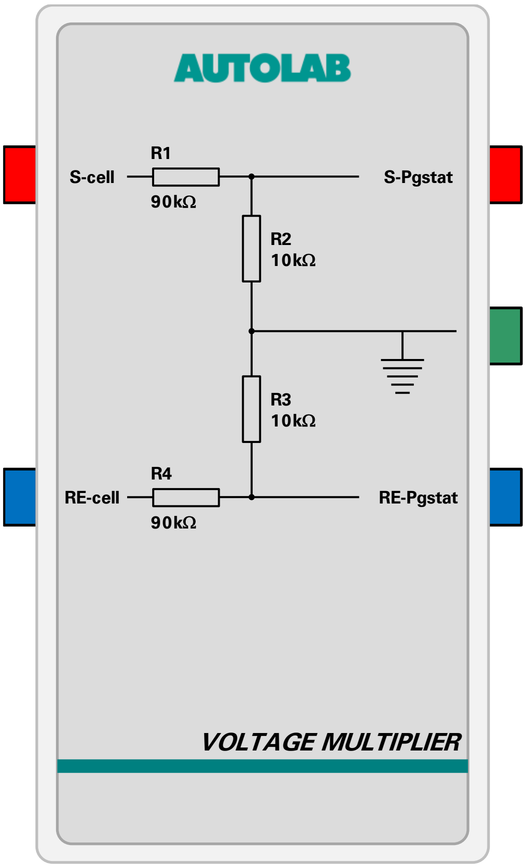


Figure 10 – The Voltage Multiplier

8.2.2 – Connections to the instrument

Connect the voltage multiplier to the differential amplifier. Connect the Sense (S) lead to the S-Pgstat connector and the Reference lead (RE) to the RE-Pgstat connector on the voltage multiplier.

The voltage multiplier provides two connections to the DUT. Connect the S-Cell connector to the WE banana connector of the PGSTAT and the positive pole of the DUT using the provided additional red cable. Connect the RE-Cell connector to the CE banana connector of the PGSTAT and the negative pole of the DUT using the provided additional blue cable (see Figure 11).

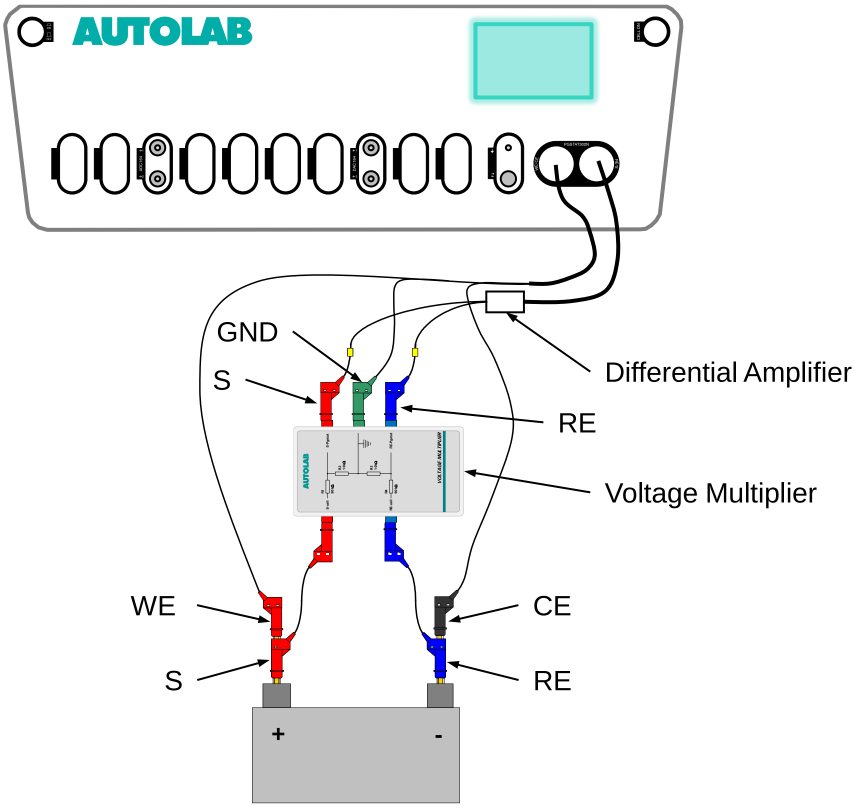


Figure 11 – Wiring diagram of the voltage multiplier between the DUT and the PGSTAT

Warning

Connect the green ground cable from the PGSTAT to the GND connector on the voltage multiplier! The ground cable must be always connected to the voltage multiplier.

9 – Electronic load settings

Before the measurements can be performed, it is mandatory to program the electronic load. Please refer to the user manual provided with the electronic load for more information or contact Metrohm Autolab for setup guidelines (autolab@metrohm.com).

Most electronic loads have several common settings that must be considered:

- **External control (ON/OFF):** all electronic loads have a switch that activates or deactivates the external programming capability. This switch must be set to ON.
- **Bandwidth, Slew rate:** on some devices, the bandwidth or the slew rate can be set manually. If this is the case, the highest possible value should be used.
- **Mode (CC, CV, CP, CR):** all electronic loads have four operation modes: constant current (CC), constant voltage (CV), constant power (CP) and constant resistance (CR). For this application, the constant current mode (CC) is required for this application.
- **Voltage and current range:** some electronic loads provide different voltage and current ranges, which must be set according to the experimental conditions.
- **Cell switch:** all electronic loads have a manual cell switch that must be set ON before the measurement starts.

9.1 – Programming the load (Kikusui)

Figure 12 shows the overview of the front panel of the Kikusui PLZ164WA.

Figure 12 – Front panel of the Kikusui PLZ164WA

Follow these steps to ensure that the load is setup correctly for this application:

1. Switch on the Kikusui load.
2. Press **SHIFT** key and **SET/VSET** key on the front panel.
3. Using the rotating knob, highlight the Configuration menu item and press the **ENTER** key.
4. Using the rotating knob, highlight the External menu item and press the **ENTER** key.
5. Using the rotating knob, set change the Control menu item to **V** and the *LoadOn In* item to **HIGH.**
6. Press the **SHIFT** and **SET/VSET** keys to return to the main menu.
7. Press the **RANGE** key to cycle through the different current ranges and set the active range to the highest available (33 A for the PLZ164WA).

8. Press the **MODE** key to cycle through the different operation modes and make sure that the constant current mode (CC) is selected.
9. Press the **SLEW RATE** key and adjust the slew rate to the highest possible value, using the rotating knob.
10. Switch the load off and then on again to confirm the changes.

9.2 – Programming the load (GW Instek)

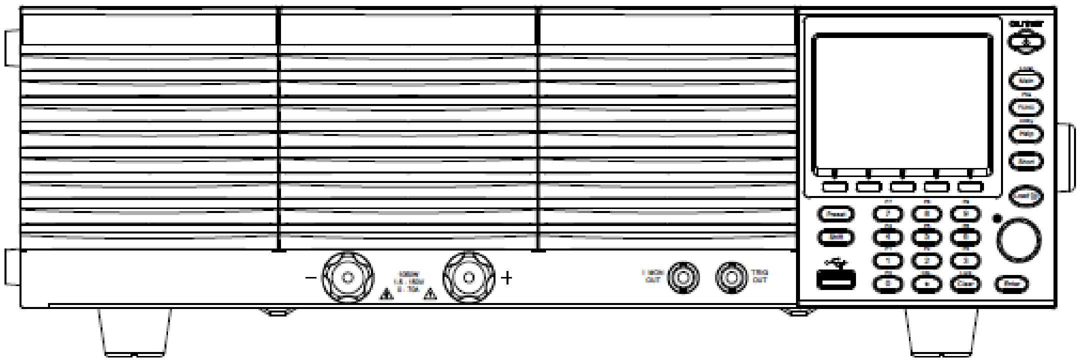


Figure 13 – drawing of the front panel of GW Instek PEL-3000 series.

1. Turn the power on the **PEL-3000**(H).
2. Make sure the instrument is in CC operating mode:
    a) Make sure the **load** is **off**.
    b) Press **Main** button.
    c) Select Constant current mode with the **Mode** soft key.
    d) Select the desired current range with the **I Range** soft key.
    e) Select the desired voltage range with the **V Range** soft key.
3. Activate the **External Control** by pressing on **Main**, then select **Configure**, then **Next Menu** and finally press **External**.
4. Set the **Control parameter** to **V** by rotating the knob and press **Enter** to confirm the selection.
5. The J1 connector is now ready for external voltage control.

9.3 – Programming the load (TDI) - OBSOLETE INSTRUMENT

Figure 14 shows the overview of the front panel of the TDI RBL 488 series.

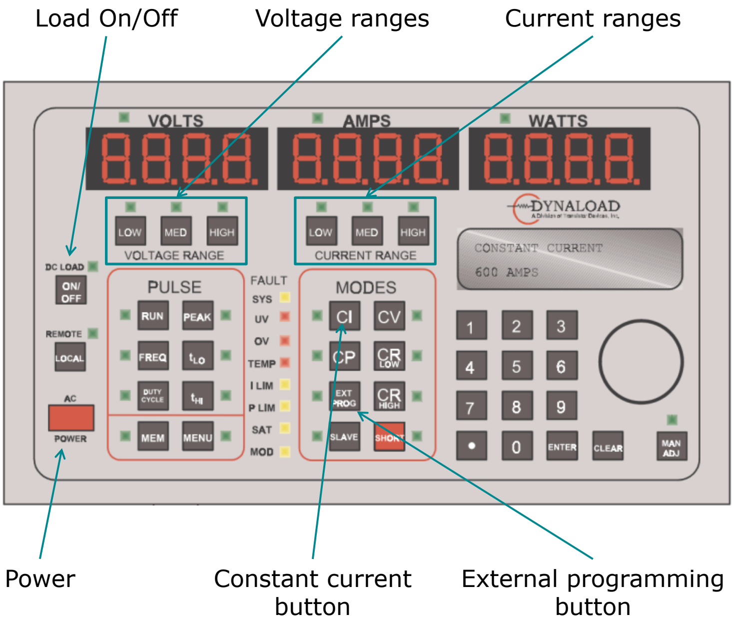


Figure 14 – Front panel of the TDI RBL 488 series

Follow these steps to ensure that the load is setup correctly for this application:

1. Switch on the **TDI load**.
2. Set the instrument to constant current mode by pressing the **CI** button.
3. Select the **voltage range** and the **current range** of the instrument by pressing the corresponding buttons. Set the active current range to the highest available (300 A for the RBL 488 100 – 300 – 2000).
4. Activate the external programming of the load by pressing the **EXT PROG** button.

9.4 – Controlling the electronic load

The control of the electronic load is achieved by providing an analog (0-10 V) signal from the Dynload interface to the external programming connection of the load.

The output of the Dynload interface in turn is controlled by the output of the DAC164 →1 of the Autolab and the FRA2/FRA32M V→ output, if applicable.

To have the PGSTAT to control the load, it is necessary to set up the proper **conversion factors** (C_f), in NOVA expressed as conversion slopes in the hardware setup (Table 2). Conversion factors are specific for each instrument and are calculated as follows:

With the load in constant current (CC) mode the whole current rage of the instrument will correspond to the analog voltage signal from the PGSTAT, in our case from 0 V to 10V. In other words, when a 0 V analog signal is sent from the PGSTAT, the load will operate at 0 A and when a 10 V analog signal is sent from the PGSTAT, the load will operate at the maximum current allowed in the selected current rage.

$$C_f = \frac{Analog\ signal\ (V)}{Max\ current\ \ (A)}$$

The same but inverted conversion is used for the current readout. The electronic load has an analog output corresponding to the measured current. The range of the current monitor analog signal is 0-10 V, which corresponds to the range of 0 A to maximum current depending on the selected current range of the electronic load.

$$C_f = -\frac{Max\ current\ \ (A)}{Analog\ signal\ (V)}$$

With 0 V output voltage measured on the current monitor, the current drained by the electronic load is 0 A. When 10 V output voltage is measured, the current drained by the electronic load it the maximum value of the selected current range.

9.4.1 – Examples of calculations of conversion factors

The **TDI RBL 488** (100 V, 300 A, 2000 W) is an electronic load with a maximum voltage of 100 V and a maximum current of 300 A. Operating in the 300 A current range, the conversion factor will be:

$$C_f = \frac{10\ V}{300\ A} = 0.03333\ V/A$$

And for the current monitor the conversion factor would be:

$$C_f = -\frac{300\ A}{10\ V} = -30\ A/V$$

The **Kikusui PLZ164WA** (150 V, 33 A, 165 W) is an electronic load with a maximum voltage of 150 V and a maximum current of 33 A. The maximum power is 165 W.

If the load is in constant current (CC) mode, with the 33 A current range selected, the conversion will be:

$$C_f = \frac{10\ V}{33\ A} = 0.30303\ V/A$$

And for the current monitor the conversion factor would be:

$$C_f = -\frac{33\ A}{10\ V} = -3.3\ A/V$$

The **GW Instek PEL-3111** (150 V, 210 A, 1050 W) is an electronic load with a maximum voltage of 150 V and a maximum current of 210 A. The maximum power is 1050 W.

If the load is in constant current (CC) mode, with the 210 A current range selected, the conversion will be:

$$C_f = \frac{10\ V}{210\ A} = 0.04762\ V/A$$

And for the current monitor the conversion factor would be:

$$C_f = -\frac{210\ A}{10\ V} = -21\ A/V$$

Note

A list of already calculated conversion factors for all the tested instruments is available at Appendix 1 – Specifications of known electronic loads.

10 – NOVA hardware setup

The hardware setup must be specified before the electronic load can be controlled. From the Tools menu, open the hardware setup and specify the configuration of the instrument.

Select the *External* additional module (see Figure 15).

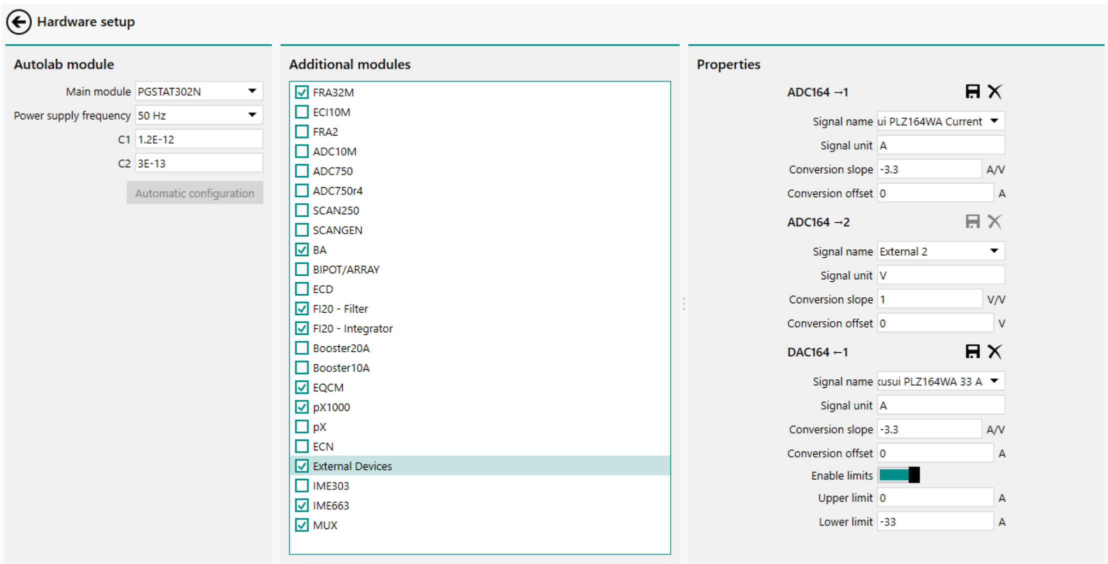


Figure 15 – Specifying the hardware setup.

With the *External* module selected, an additional configuration panel is shown in the frame on the right-hand side of the Hardware setup. This panel can be used to specify the conversion settings required to control the electronic load.

When finished editing the Hardware setup, click the button to close the window.

10.1 – Analog input settings

In the ADC164 → 1 section, the conversion settings required to measure the current from the external output of the electronic load can be defined and saved for future use. The settings depend on the type of load. Please refer to the electronic load user manual for more information.

For the Kikusui PLZ164WA load, used in the examples in Section 9.4.1 of this manual, the settings required to convert the analog signal from the load into the correct current value are shown in Figure 16.

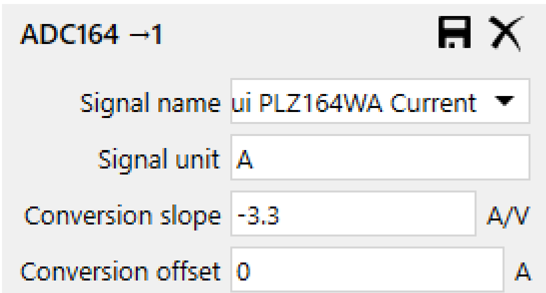


Figure 16 – The conversion settings for the Kikusui PLZ164WA electronic load

These settings indicate that the analog signal provided by the Kikusui electronic load, in V, need to be multiplied by -3.3 to be converted into current, with the correct polarity.

Note

It is possible to save these settings in the Hardware setup for future use by clicking the button on the right-hand side of this panel.

Note

The parameters for other electronic loads are reported in the Appendix of this document.

10.2 – Analog output settings

In the DAC164 → 1 section, the conversion settings control the current setpoint of the electronic load can be defined and saved for future use. The settings depend on the type of load. Please refer to the electronic load user manual for more information.

For the Kikusui PLZ164WA load, used in the examples in Section 9.4.1 of this manual, the settings required to convert the analog signal from the load into the correct current value are shown in Figure 17.

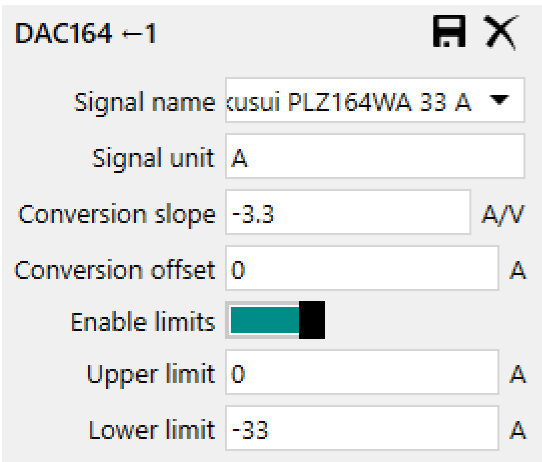


Figure 17 – The conversion settings for control of the Kikusui PLZ164WA electronic load

These settings indicate that to control the setpoint of the electronic load, the specified current needs to be divided by -3.3 to be converted to the analog signal with the correct polarity. Upper and lower limits can be specified, these are defined by the electronic load.

> **Note**
>
> It is possible to save these settings in the Hardware setup for future use by clicking the button on the right-hand side of this panel.

> **Note**
>
> The parameters for other electronic loads are reported in the Appendix of this document.

11 – Manual control of the electronic load (DC only)

Manual control of the electronic load is possible in NOVA provided that the settings are specified correctly (see Section 10).

To open the manual control of the electronic load, select the *Manual control* option from the View menu (see Figure 18).

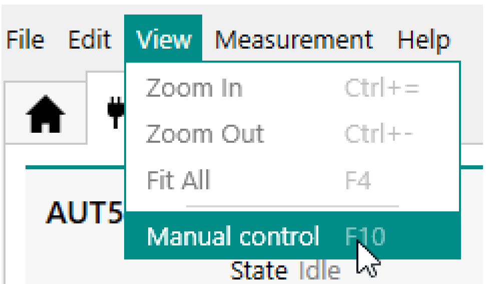


Figure 18 – Select the *Manual control* option to open the manual control of the electronic load.

The Autolab display will be shown, with an additional panel below it (see Figure 19).

Note

The Current value shown in the Autolab control window corresponds to the current measured by Autolab. Since the Autolab is not connected to the cell, this value will be 0 and needs to be always ignored. All the manual settings available in the Autolab display (iR compensation, current range…) are also irrelevant for this application.

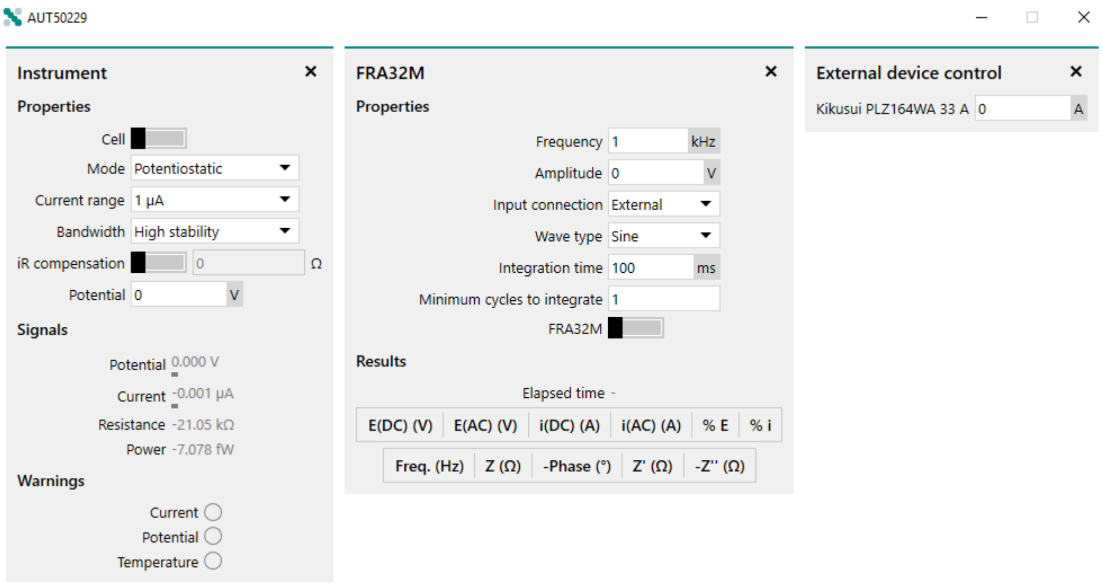


Figure 19 – The Autolab display window with the External device control panel.

Note

The name shown in the External device control panel (*Kikusui PLZ164WA 33 A*) depends on the settings specified in the Hardware setup window.

To specify the discharge current of the electronic load, click the label in the *External device control* panel and edit the value as shown in Figure 20. Press the Enter key to validate the value.

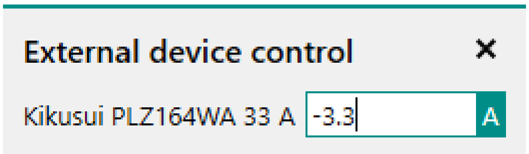


Figure 20 – Specifying the discharge current manually.

Note

Remember to switch on the load to allow the current to be drawn from the cell.

12 – Procedure control of the electronic load (DC only)

The discharge current of the electronic load can be adjusted in a NOVA procedure as well using the *Autolab Control* command. This is possible provided that the settings are specified correctly (see Section 10).

To define the discharge current setpoint of the electronic load at any time in a NOVA procedure, the *Autolab Control* command can be used. To edit the settings, click the More button next to this command in the properties section (see Figure 21).

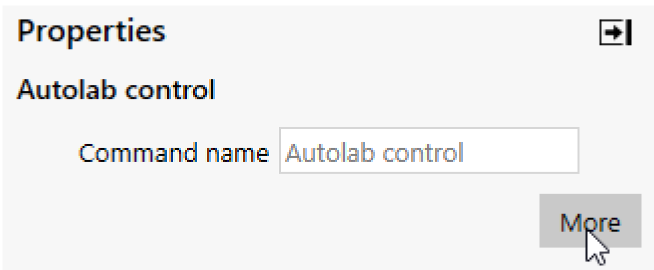


Figure 21 – Using the Autolab control command to edit the current setpoint of the electronic load.

The properties of the *Autolab Control* command will be displayed (see Figure 22).

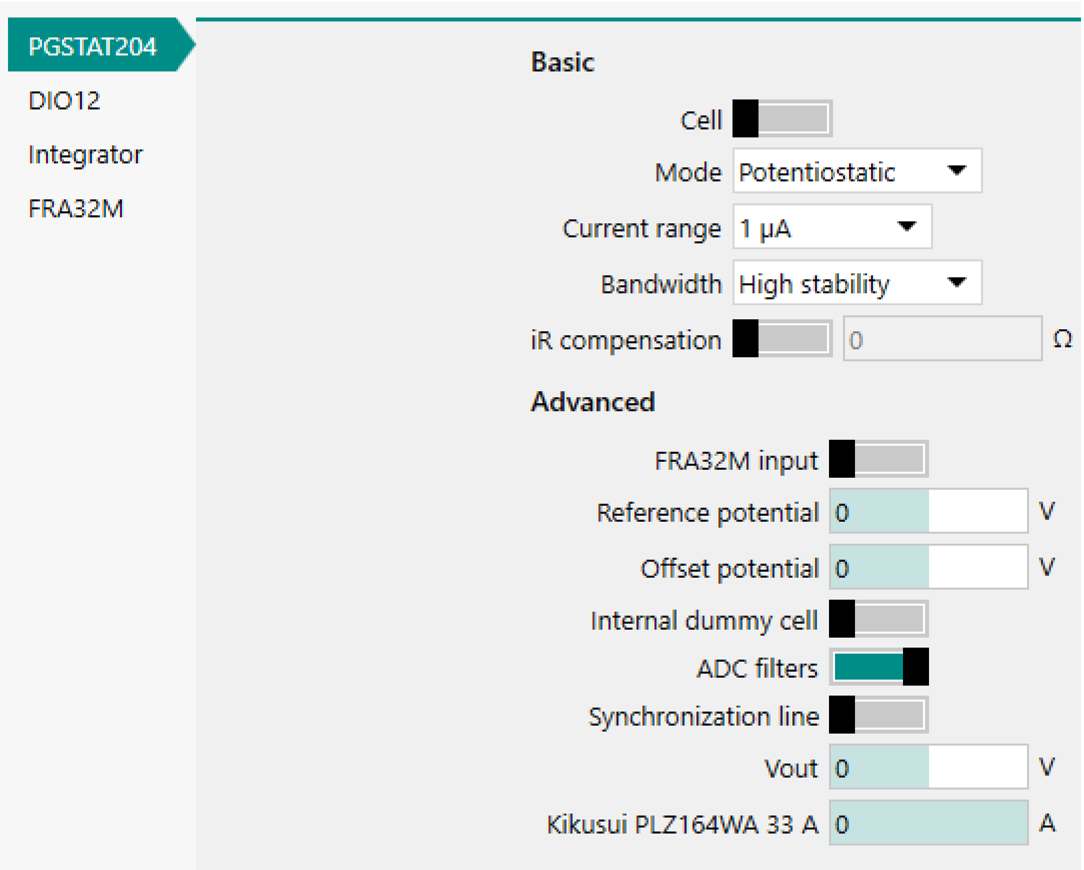


Figure 22 – The Autolab control window

The control of the electronic load is available on the **Advanced** part (see Figure 23).

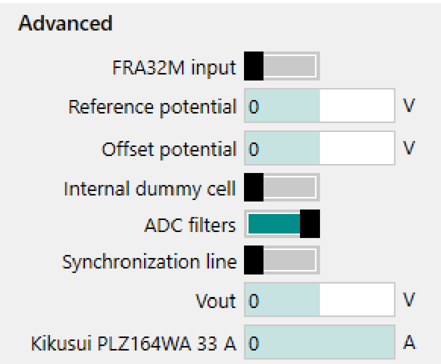


Figure 23 – The control of the electronic load is provided on the Advanced part.

To specify the current setpoint of the electronic load, the value can be typed into the required field of the Autolab control window. It can also be specified by sliding the provided slider in the same editor (see Figure 24).

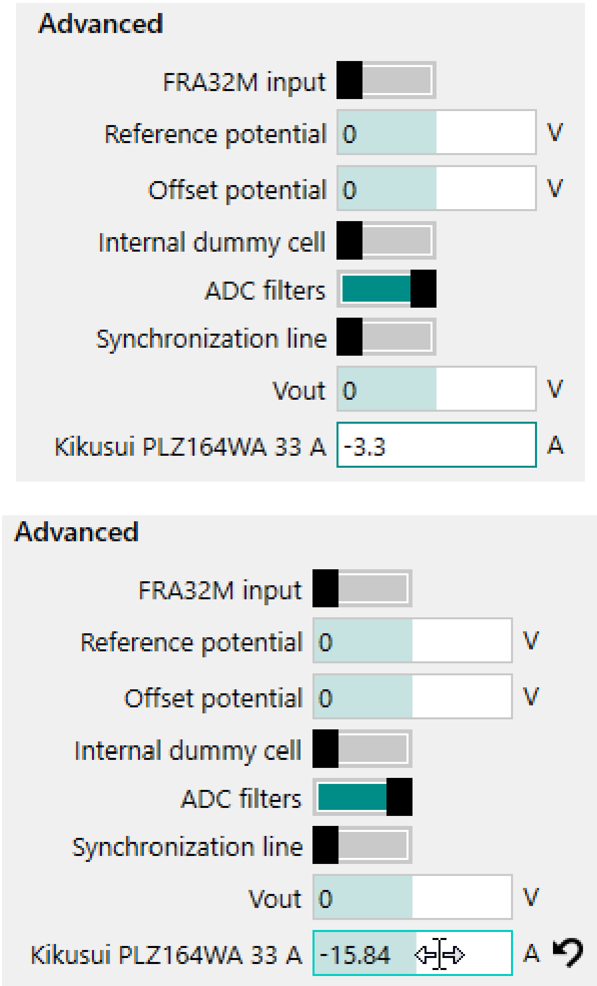


Figure 24 – Setting the electronic load setpoint (top: manually; bottom: using the slider)

Click the  button to close the window. The procedure will be updated displaying the value specified in the Properties section of the *Autolab control* command (see Figure 25).

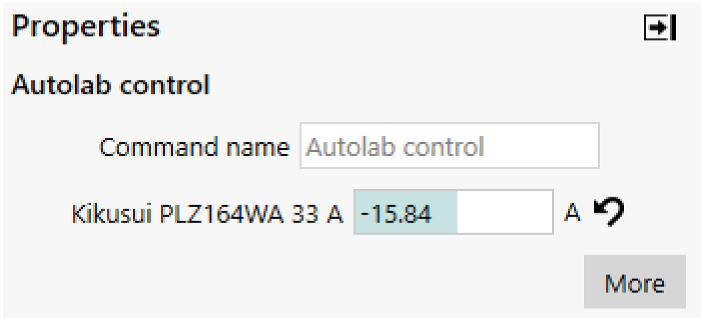


Figure 25 – The updated procedure editor

The parameter provided by the *Control external device* command can be linked to other commands, like an *Input box* command or a *Repeat for each value* command, as show in Figure 26.

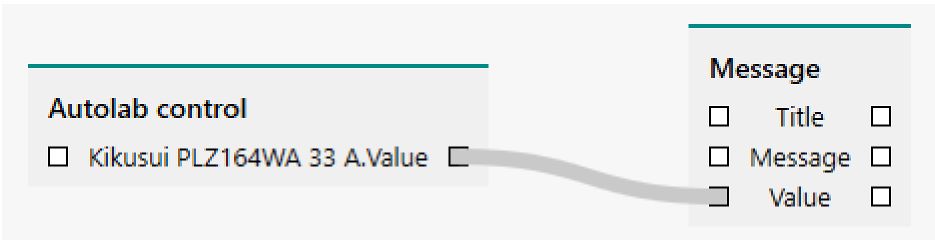


Figure 26 – Linking the electronic load setpoint to an *Input box* command.

13 – Recording the output from the electronic load (DC only)

The output of the electronic load is fed back to one of the external inputs of the Autolab. If the conversion settings are specified properly, as indicated in Section 10, the output from the load can be converted directly and recorded by the NOVA software.

To sample the output of the electronic load, the corresponding signal can be added to the Signal sampler, as shown in Figure 27.

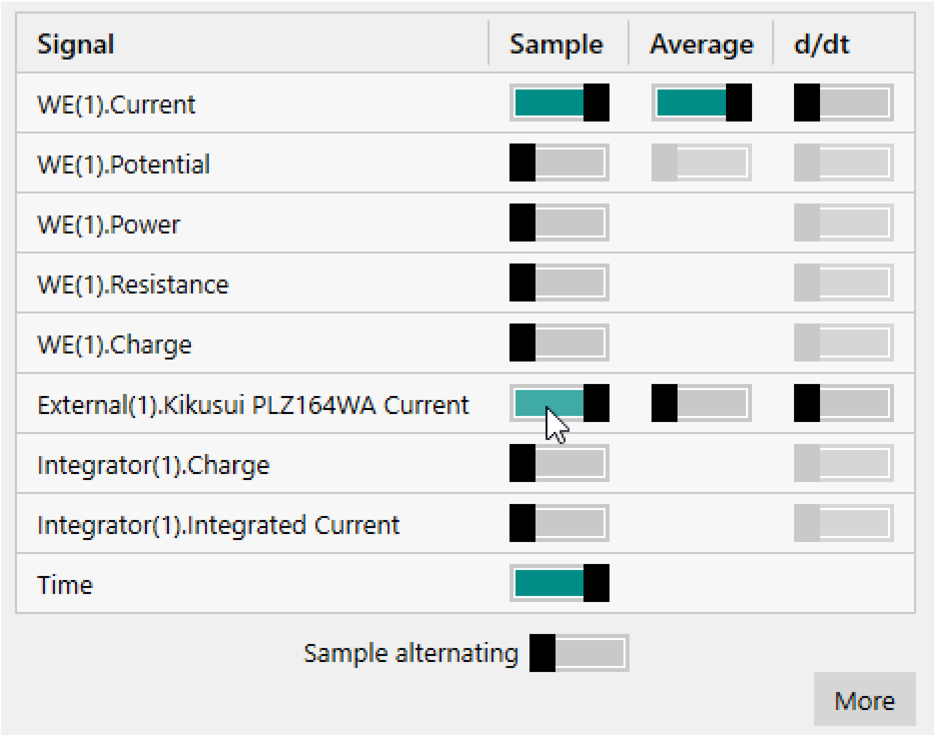


Figure 27 – Specifying the output signal from the electronic load in the Signal sampler.

Note

The output signal of the electronic load can be sampled by any measurement command that uses the Signal sampler.

Warning

The WE(1).Current, WE(1).Power, WE(1).Resistance and WE(1).Charge signals cannot be sampled since the WE is not connected to the cell in the application.

The measured values will be displayed in the Autolab display window (see Figure 28).

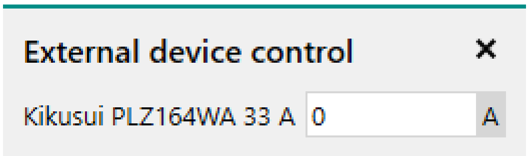


Figure 28 – The output of the electronic load displayed in the Autolab display window.

Note

The value shown in the Autolab display is only visible during a measurement.

Since the measurements are performed without switching ON the cell switch of the Autolab, a warning will be shown during validation (see Figure 29).

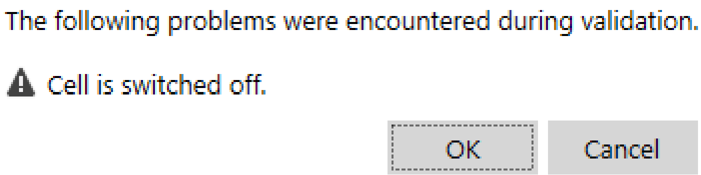


Figure 29 – Measurements with an external electronic load trigger a warning during validation.

It is possible to click OK to the message, to continue with the measurement (see Figure 29).

14 – Impedance spectroscopy measurements

Impedance spectroscopy measurements are possible using similar settings as those defined in the Hardware setup of NOVA. The *FRA measurement* command in the Measurement – Impedance group of commands.

Note

Impedance spectroscopy measurements require the definition of a DC setpoint on the electronic load. This can be done by using the methods indicated in Sections 11 and 12.

To perform a frequency scan using the external electronic load, select the *external* input connection, in the properties of the *FRA measurement* command (see Figure 30).

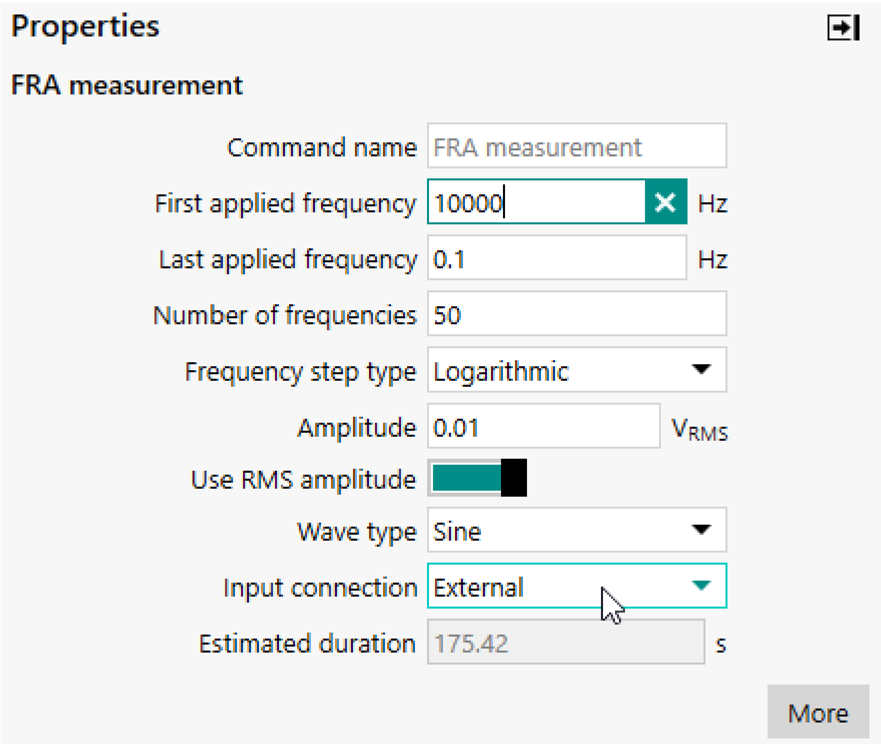


Figure 30 – Selecting the External input connection in the *FRA measurement* command.

To edit the settings of the *FRA measurement external* command, click the button next to the command in the procedure editor (see Figure 30).

A new window will be displayed (see Figure 31).

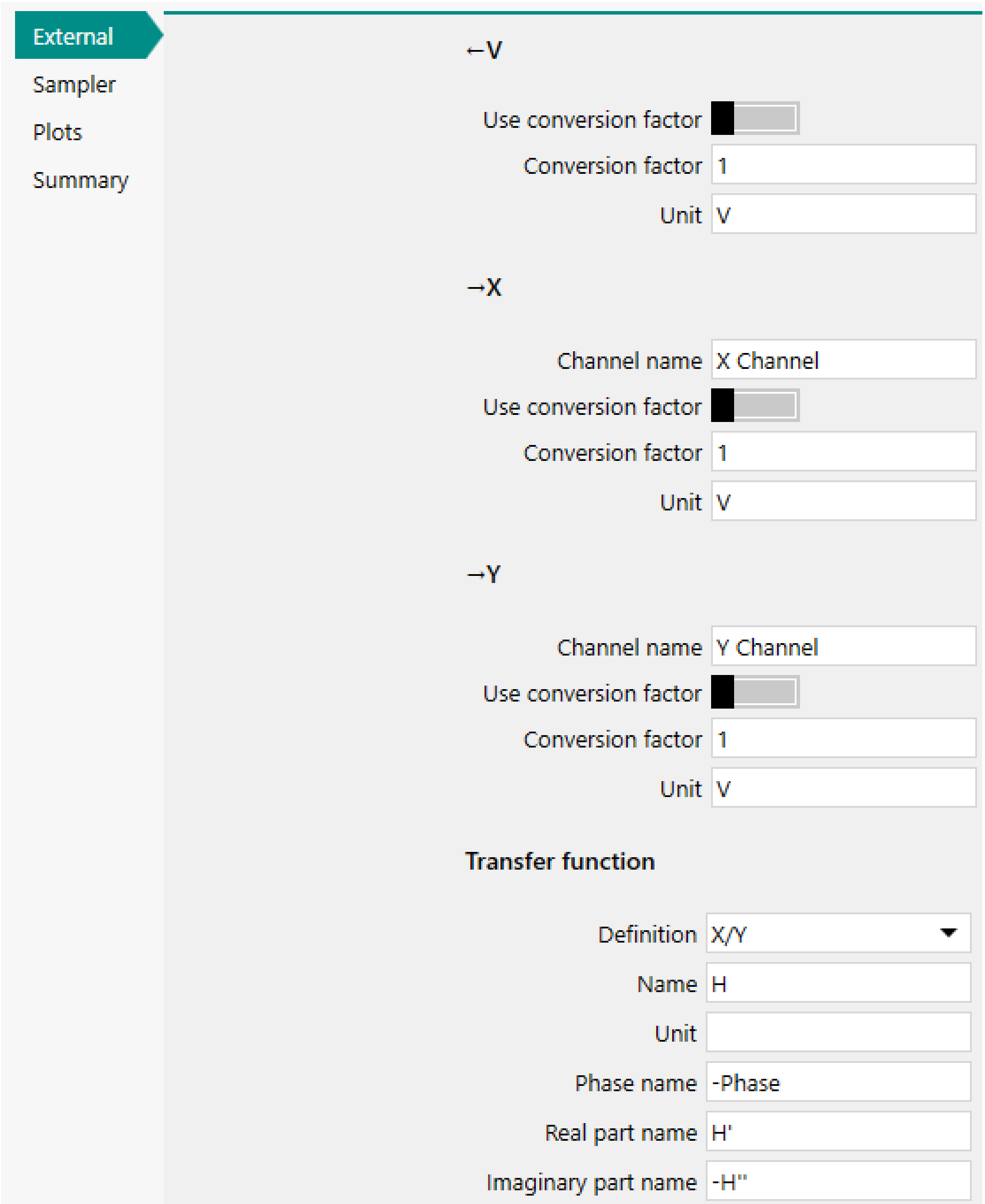


Figure 31 – The FRA editor window

This window can be used to specify all the settings required to perform an impedance measurement using the external electronic load.

14.1 – External settings

The parameters on the **External** section of the FRA editor window are related to the conversion parameters for setting and measuring the setpoint of the electronic load as well as the definition of the transfer function.

14.1.1 – Settings for ← V

The parameters for the ← V signal define the conversion factor between the output of the FRA2/FRA32M module and the input of the electronic load.

For this application, set the *Unit* parameter to A and specify a multiplier (see Figure 32).

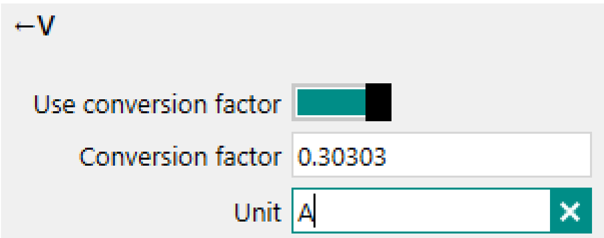


Figure 32 – Setting the parameters for the ← V output.

The value of the multiplier depends on the type of electronic load and the settings for the Kikusui PLZ164WA in 33 A current range will be used in this section. For this load, the multiplier is 0.30303 (10 V / 33 A).

Note

The parameters for other electronic loads are reported in the Appendix of this document.

14.1.2 – Settings for → X

The parameters for the → X signal define the conversion factor between the analog output of the Autolab differential amplifier and the X input channel of the FRA2/FRA32M.

For this application, set the name to Potential, set the *Unit* parameter to V and specify a multiplier of -1 (see Figure 33).

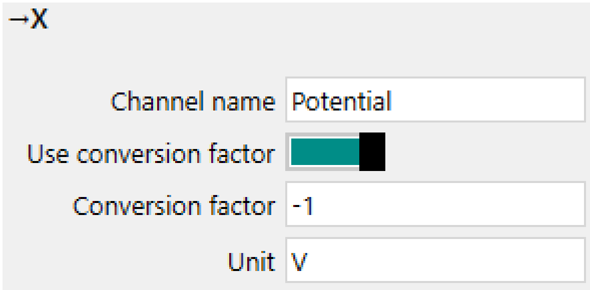


Figure 33 – Setting the parameters for the → X input.

14.1.3 – Settings for → Y

The parameters for the → Y signal define the conversion factor between the analog output of the electronic load and the Y input channel of the FRA2/FRA32M.

For this application, set the name to Current, set the *Unit* parameter to A and specify a multiplier (see Figure 33).

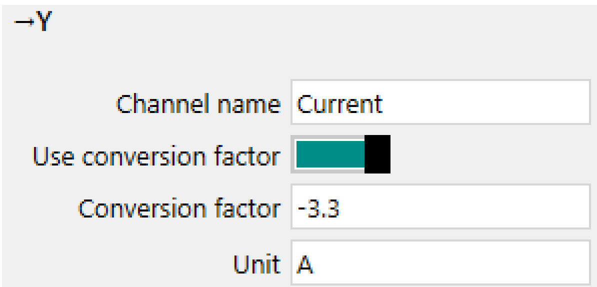


Figure 34 – Setting the parameters for the → Y input.

The value of the multiplier depends on the type of electronic load and the settings for the Kikusui PLZ164WA in 33 A current range will be used in this section. For this load, the multiplier is -3.3 (33 A / 10 V)[2].

Note

The parameters for other electronic loads are reported in the Appendix of this document.

14.1.4 – Settings for Transfer function

The parameters for the Transfer function define the way the transfer function is calculated and identified during a measurement. For convenience's sake, the name and unit of the transfer function can be adjusted here, as shown in Figure 35.

Note

The default transfer function is identified as H.

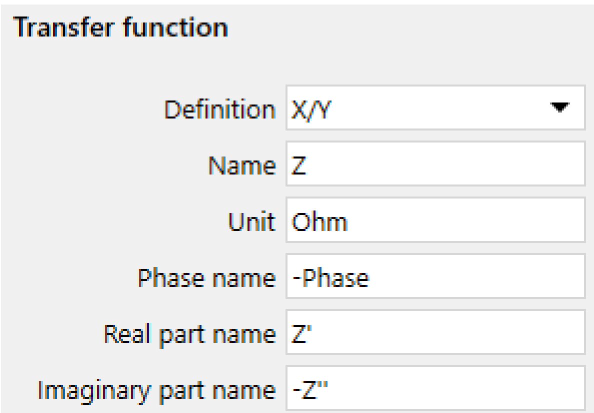


Figure 35 – Specifying the name and units for the transfer function.

[2] The – sign is used to correct the output of the load for the polarity convention as indicated in Section 5.

14.2 – Frequency scan settings

The parameters on the **Properties** of the *FRA measurement* command are related to the frequency scan itself.

> **Note**
>
> Make sure that the settings defined on the **External** section of the FRA editor are adjusted properly before editing the **Properties** on the *FRA measurement* command.

This section can be used to specify the parameters for the frequency scan (see Figure 36).

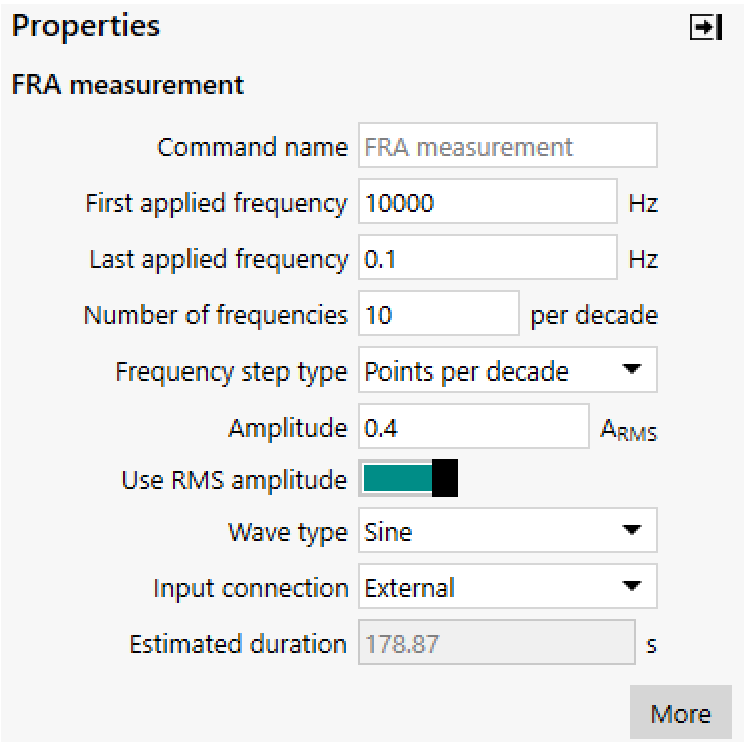


Figure 36 – Defining the settings for the frequency scan.

Note

The amplitude value is specified in **absolute values**.

14.3 – Sampler settings

The parameters on the **Sampler** section of the *FRA measurement* command are related to the signals to sample during the impedance spectroscopy measurement and the acquisition parameters (see Figure 37).

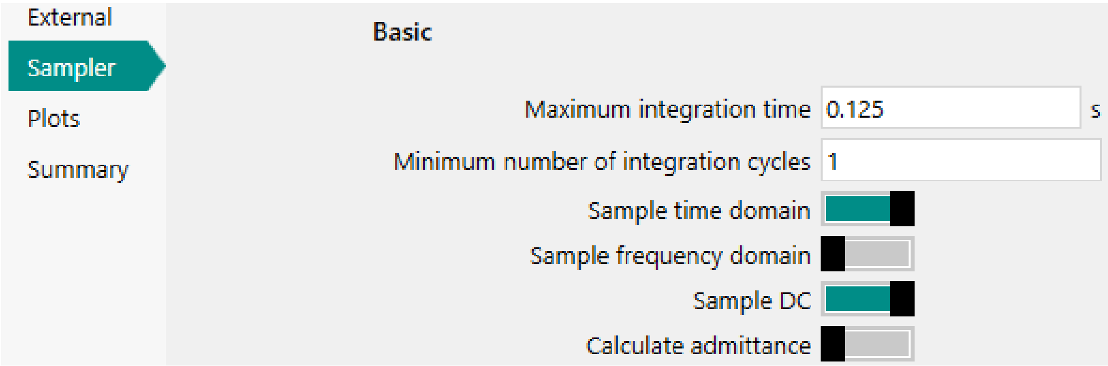


Figure 37 – The acquisition parameters are defined on the Sampler section of the *FRA measurement* command.

The acquisition parameters are predefined for a normal impedance measurement, and it is recommended to use the default settings. Additional signals to be measured can be specified in the section:

- **Sample time domain:** if this option is active, the time domain information will be sampled and stored for both input signals. The time domain information consists of the raw X and Y sine waves. This information can be used evaluate the signal to noise ratio and to evaluate the linearity of the cell response.

- **Sample frequency domain:** if this option is active, the frequency domain information will be sampled and stored for both input signals. The frequency domain information consists of the calculated FFT results obtained from the measured time domain. The frequency domain information can be used to evaluate the measured frequency contributions.
- **Sample DC** (active by default): if this option is active, the DC component for both input signals will be sampled and stored.
- **Calculate admittance:** if this option is active, the admittance will be calculated based on the measured impedance data.

Note

For this application, it is highly recommended to activate the **Sample time domain** option to verify that the sinewaves from the Autolab and electronic load are recorded properly. Once the correct signals are ensured, the Sample Time Domain functionality can be turned Off.

14.4 – Plots settings

The parameters on the **Plots** section of the FRA editor window are related to the plotting of the data measured during the impedance spectroscopy measurement and the acquisition parameters (see Figure 38).

Note

The available plots on the **Plots** section depend on the signals specified in the **Sampler** section of the FRA editor.

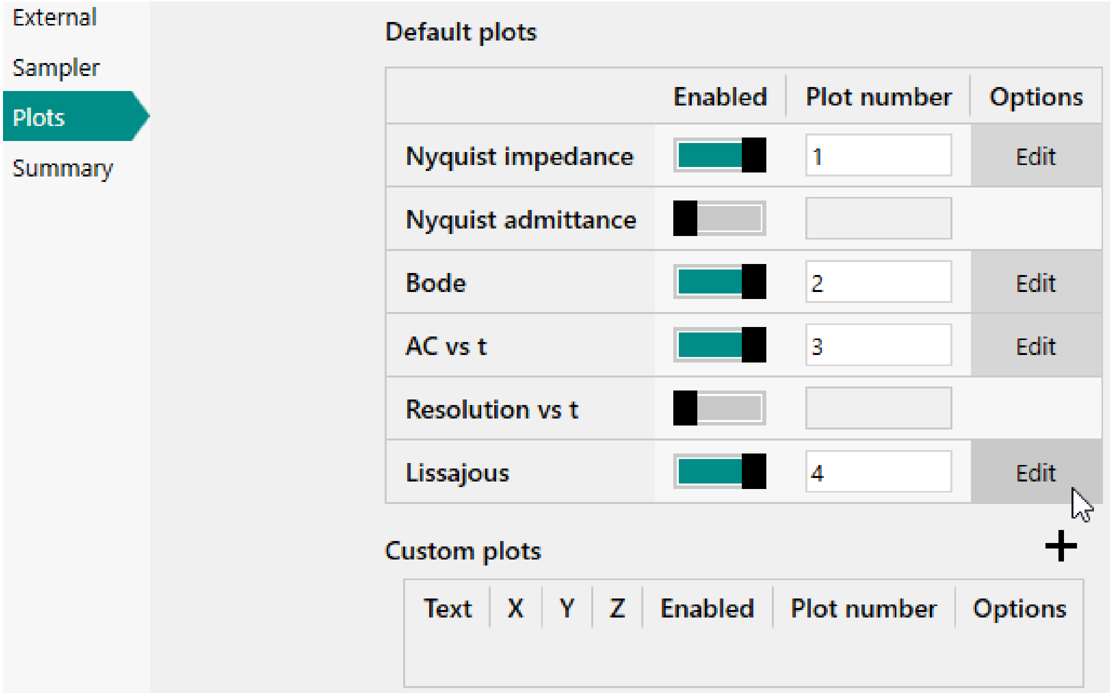


Figure 38 – The plot settings are defined on the Plots section of the FRA editor.

More information is provided in the Impedance tutorial, provided in the Help menu of Nova.

When all the parameters and settings are specified, click the button to close the FRA editor. The procedure editor will be updated.

14.5 – Running a measurement

Using the recommended settings specified in this document, impedance measurement can be carried out and displayed as shown in Figure 39.

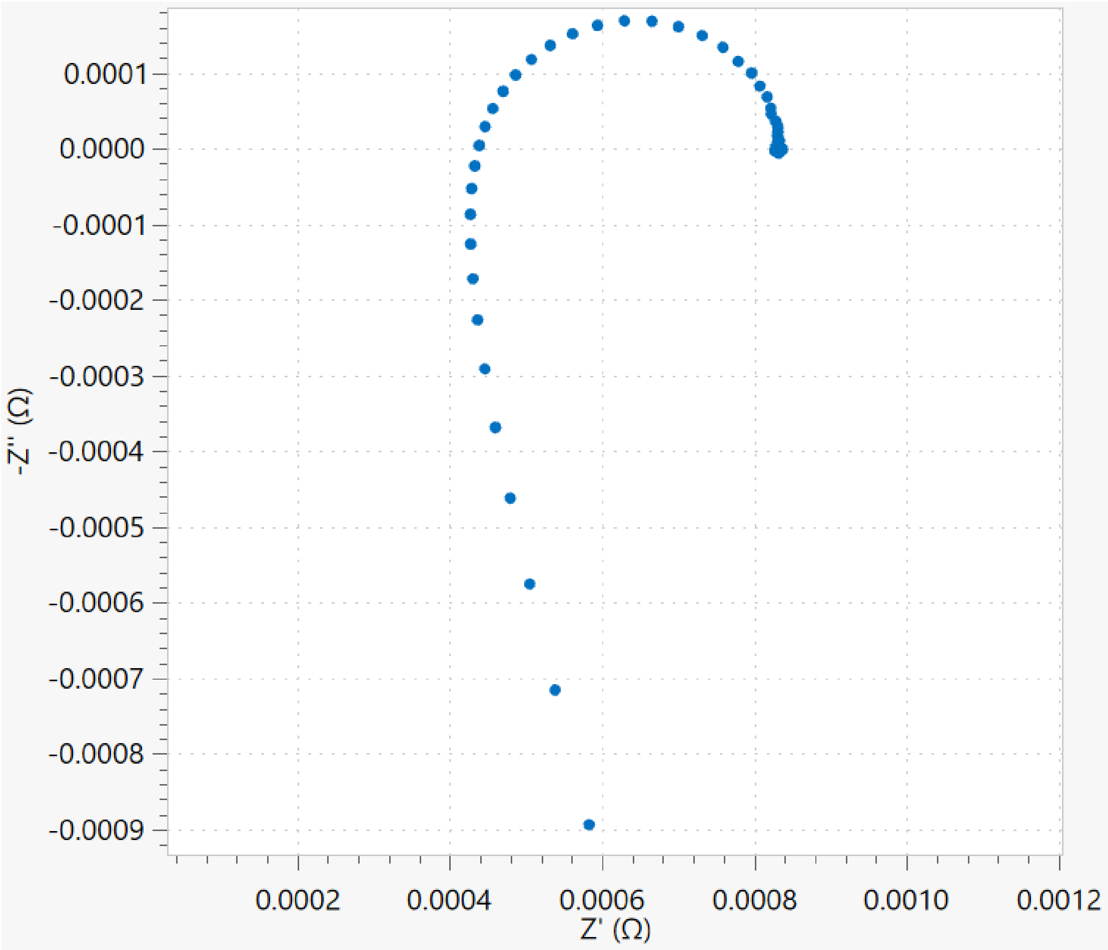


Figure 39 – Example of a typical impedance measurement using an external electronic load.

Note

Metrohm Autolab can assist in setting up the experimental conditions and the procedure used to perform the measurements. Contact autolab@metrohm.com or your local distributor for more information.

15 – Measurement examples

This section provides a few examples of procedures designed for the combination of the Autolab PGSTAT and an electronic load.

15.1 – i-V/Power curve

The combination of the *Autolab control* command and the *Repeat for multiple values* command provides the backbone for a complete i/V and power curve measurement, as shown in Figure 40.

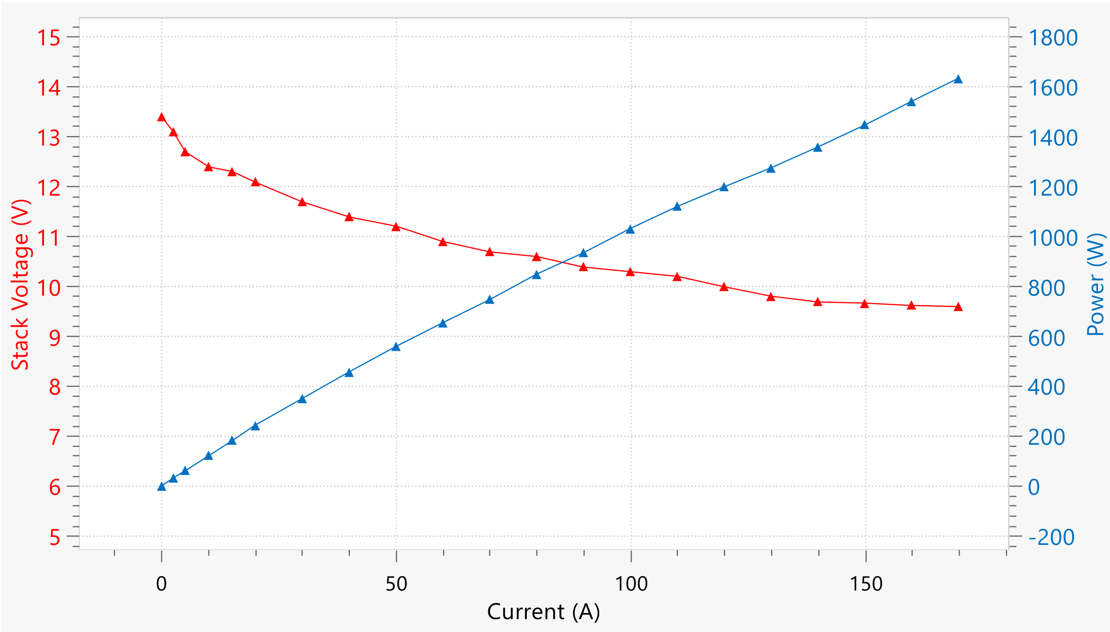


Figure 40 – Typical i/V curve of a fuel cell stack

15.1.1 – Running the measurement

Using the *Autolab control* and the *Record signals (>1 ms)* commands, it is possible to construct a complete procedure to perform an i/V measurement using the electronic load.

Figure 41 shows an example of a suitable procedure for this type of measurement.

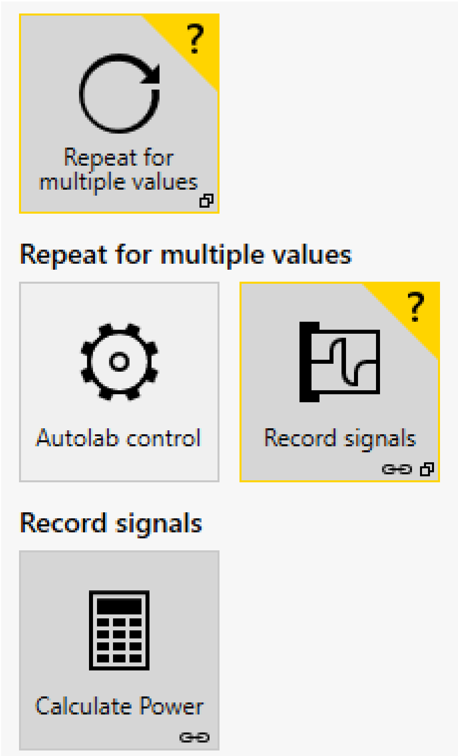


Figure 41 – Example of a complete procedure used to perform an i/V measurement using an electronic load in combination with the Autolab.

These commands are embedded into a *Repeat for multiple values* command used to walk through different current values.

The *Calculate signal* command is used to calculate the power so that it can be plotted against the discharge current.

For more information, please refer to the NOVA user manual.

15.2 – Impedance spectroscopy measurement

The combination of the *Autolab control* command and the *FRA measurement* command provides the backbone for a complete impedance spectroscopy measurement, as shown in Figure 42.

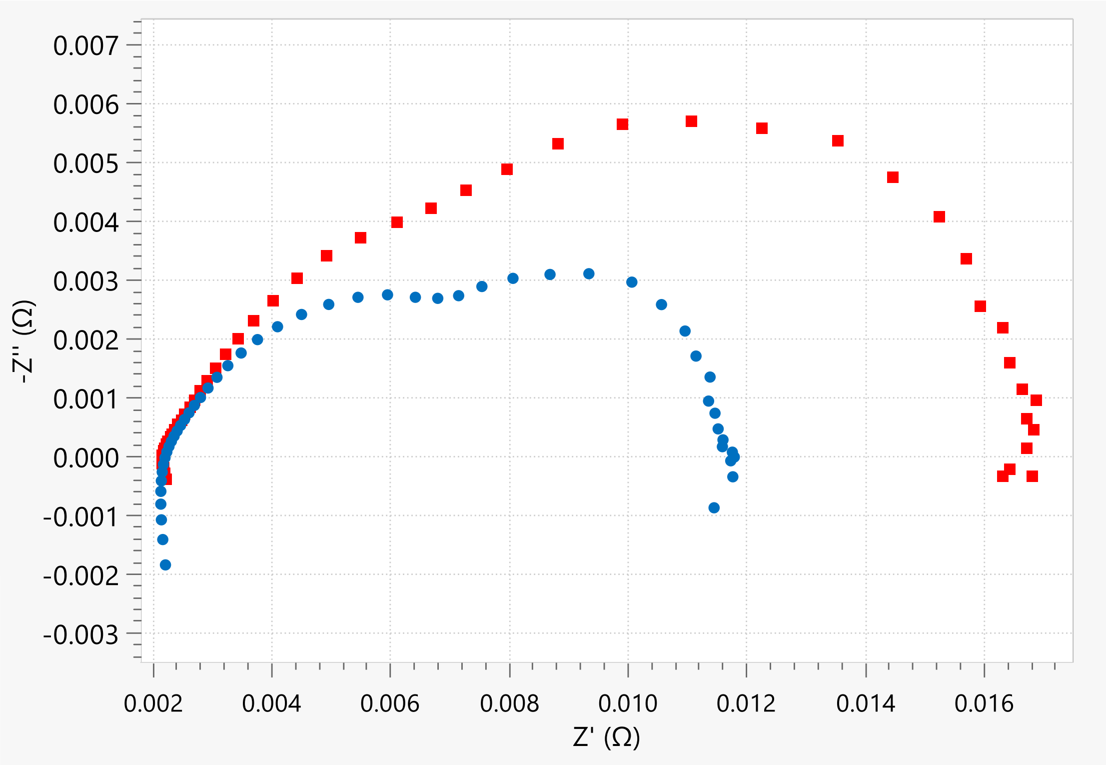


Figure 42 – Typical Nyquist plots obtained on a fuel cell at 120 A and 200 A DC current, 9 A AC amplitude

Figure 42 shows a typical Nyquist plot that can be obtained with an electronic load. The measurements were obtained at 120 A and 200 A DC current, with a 9 A AC amplitude. The TDI RBL 488 was used for these measurements.

Figure 41 shows an example of a suitable procedure for this type of measurement.

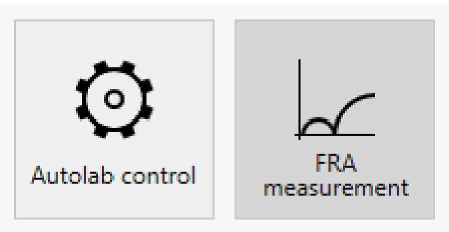


Figure 43 – Example of a complete procedure used to perform an impedance spectroscopy measurement using an electronic load in combination with the Autolab.

Note

Metrohm Autolab can assist in setting up the experimental conditions and the procedure used to perform the measurements. Contact autolab@metrohm.com or your local distributor for more information.

Appendix 1 – Specifications of known electronic loads

The DC and AC conversion settings are specified in Table 2 and Table 3, respectively.

Load	Current range (A)	ADC164 → 1 Conversion slope	ADC164 → 2 Conversion slope	DAC164 ← 1 Conversion slope
Kikusui PLZ164WA	33	-3.3	1	-3.3
Kikusui PLZ664WA	132	-13.2	1	-13.2
TDI RBL 488	300	-30	1	-30
TDI WCL 488	1000	-100	1	-100
Agilent 6060B	60	-6	1	-6
Agilent 3300	60	-6	1	-6
Chroma 6300	60	-6	1	-6
GW Instek PEL-3000/H	210	-21	1	-21

Table 2 – Overview of the DC settings (to be specified in the Hardware setup) for known electronic loads.

Load	Current range (A)	← V Settings	→X Settings	→Y Settings
Kikusui PLZ164WA	33	0.303	-1	-3.3
Kikusui PLZ664WA	132	0.0757	-1	-13.2

TDI RBL 488	300	0.0333	-1	-30
TDI WCL 488	1000	0.0100	-1	-100
Agilent 6060B	60	0.166	-1	-6
Agilent 3300	60	0.166	-1	-6
Chroma 6300	60	0.166	-1	-6
GW Instek PEL-3000/H	210	0.0476	-1	-21

Table 3 –Overview of the AC settings (to be specified in the *FRA measurement external* command) for known electronic loads.

Note

For information on electronic loads not listed in the Appendix please contact Metrohm Autolab (autolab@metrohm.com).

Appendix 2 – Modification of the FRA2 module

By default, the external inputs of the **FRA2 modules shipped before July 2009 (revision number 8.0 and lower)** can be used to record analog signals in the ± 5 V range. For some applications, analog signals in the ± 10 V range are required. In order to be able to record voltages between 5 and 10 V, the FRA2 modules with revision numbers lower than 8.1 need to have the extended range offset DACs activated. This requires a simple hardware modification described in this document. Please contact Metrohm Autolab (autolab@metrohm.com) or your local distributor in case of any doubts.

The modification described in this document requires the following items:

1. ESD safety kit (see Figure 44)
2. Soldering iron and solder

The modification requires soldering **JP2** and **JP3** of the analog board of the FRA2 module. Figure 44 shows a picture of the Analog board. The two jumpers are highlighted.

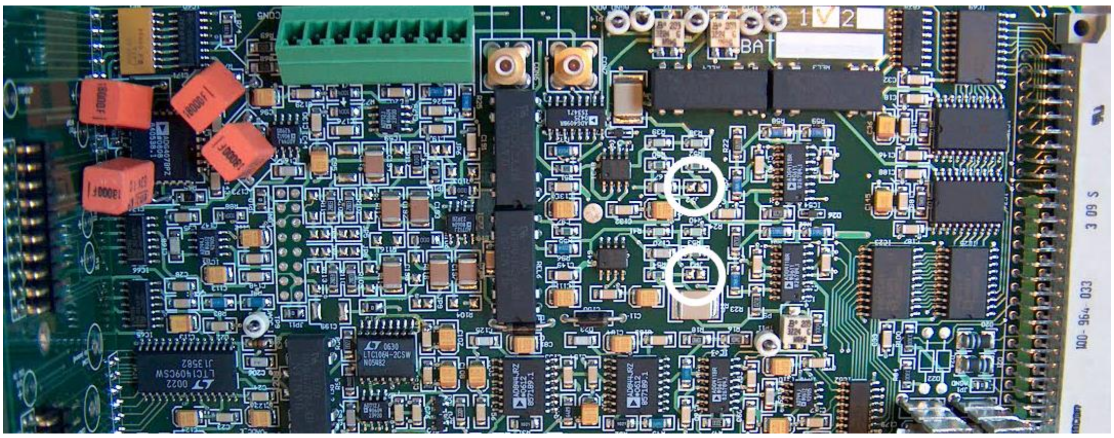


Figure 44 – The FRA2 Analog board (JP2 and JP3 are highlighted)

The two jumpers need to be soldered together.

Warning

Take all the necessary steps to avoid ESD damage to the module by grounding yourself during the handling of the module and the soldering of the jumpers. The use of an ESD safety kit is highly recommended.

Remove the FRA2 module from the Autolab frame. To remove the FRA2 module follow the instructions reported the following documents:

The modification described in this document requires the following items:

1. For the PGSTAT128N, PGSTAT302N, PGSTAT302F and PGSTAT100N: *All modules – Insert new module in 8-series cabinet.pdf*
2. for the PGSTAT12, PGSTAT30, PGSTAT302 and PGSTAT100 *All modules – Insert new module in 7-series cabinet.pdf*

The FRA2 module consists of 2 PCBs (see Figure 45). One PCB is the digital signal generator (DSG) PCB and the second one is the Analog PCB.

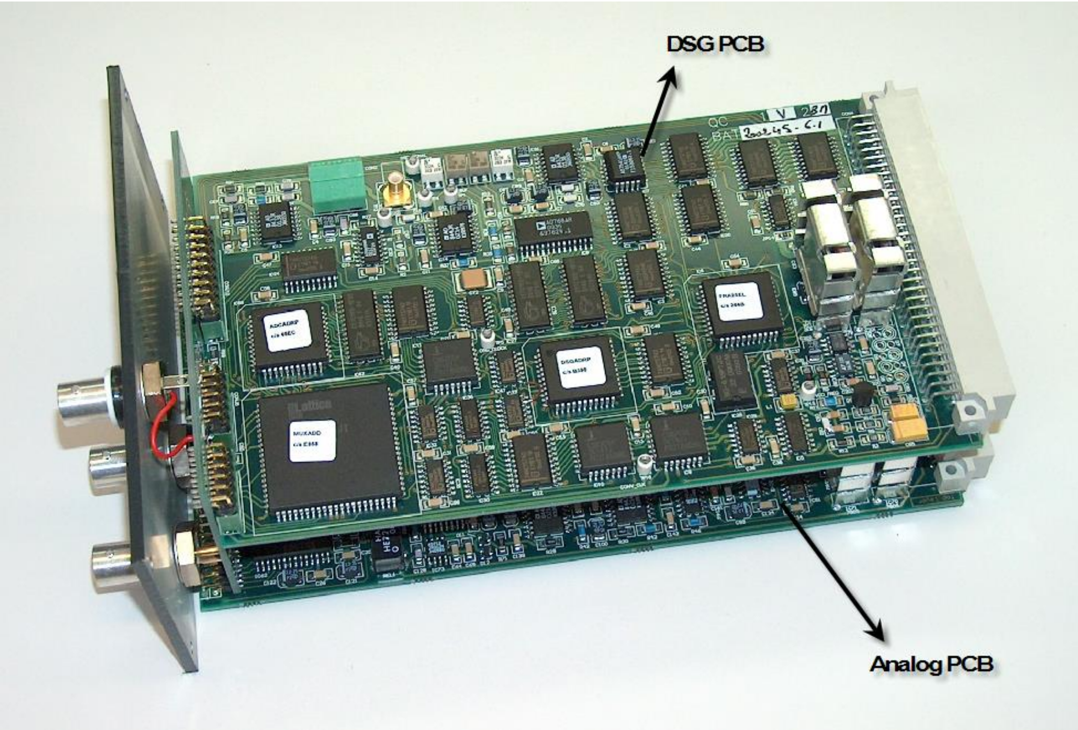


Figure 45 – The FRA2 consists of two PCBs (the DSG on top, and the Analog below)

To access the Analog PCB, the DSG PCB must be detached. To do this, gently push on both sides of the board as shown in Figure 46 and Figure 47.

Note

It is recommended to store the DSG PCB in an ESD safe bag during the modification.

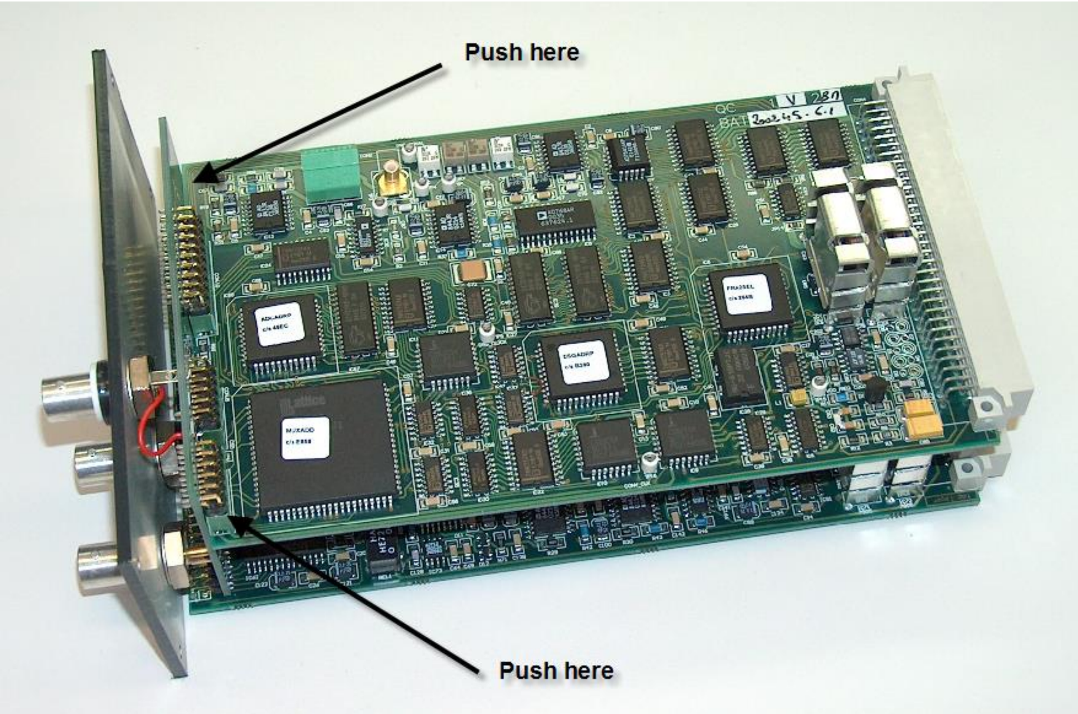


Figure 46 – Pressure points on the DSG PCB

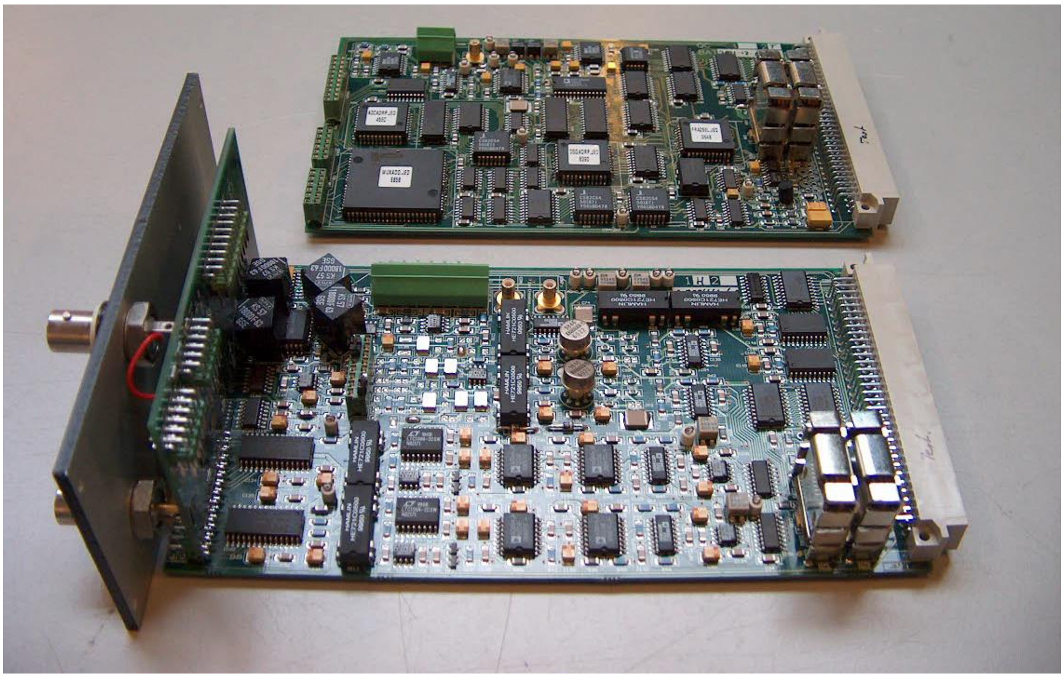


Figure 47 – The removed DSG PCB and the Analog PCB of the FRA2 module

Figure 47 shows the FRA2 module, with the removed DSG PSB. Locate JP2 and JP3 on the Analog PCB and close both jumpers by applying a bit a solder.

To reassemble the 2 boards, all the holes in the 3 green connectors of the DSG PCB have to be aligned with the matching pins on the FRA2 module assembly (see Figure 48).

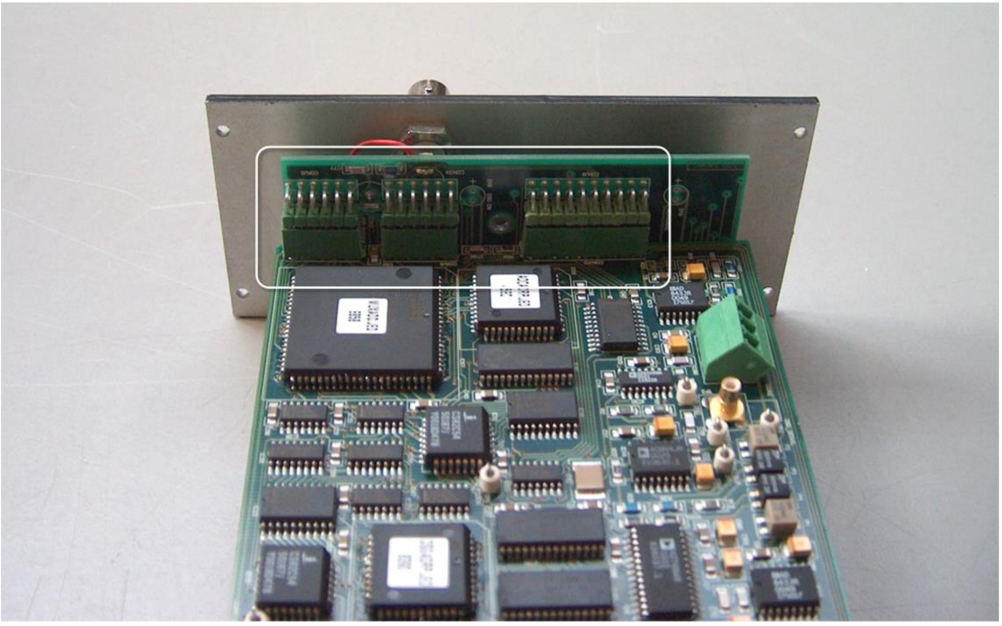


Figure 48 – Reassembling the FRA2 module

Note

The factory FRA2CAL.INI file can still be used. No recalibration is required.

Reinstall the module in the Autolab following the instructions provided in the installation guides mentioned at the beginning of this section.

After modification of the FRA2 module has been modified, the software needs to be adjusted.

The FRA2 input range is directly specified in the Hardware setup. Start NOVA and open the Hardware setup. Locate the FRA offset DAC range toggle at the bottom of the Hardware setup window (see Figure 49).

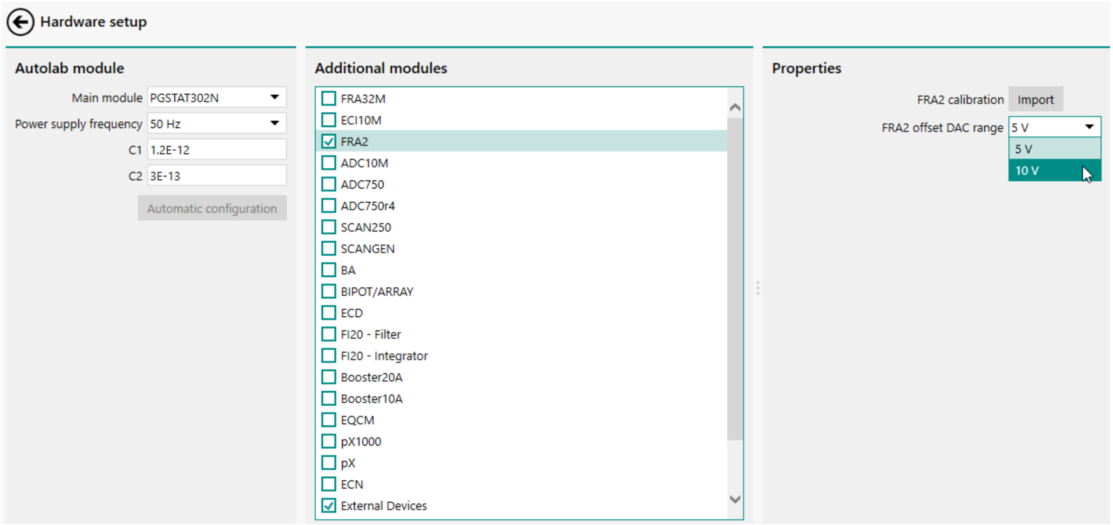


Figure 49 – The 10 V input range can be specified in the Hardware setup directly

Set this toggle to 10 V as shown in Figure 49. Click OK to close the Hardware setup and save the modifications when prompted.

This modification is permanent.

If necessary, new labels (article codes: CAB.LABEL.FRA2.V10.V and CAB.LABEL.FRA2.V10.XY) can be ordered for the modified FRA2 module (see Figure 50).

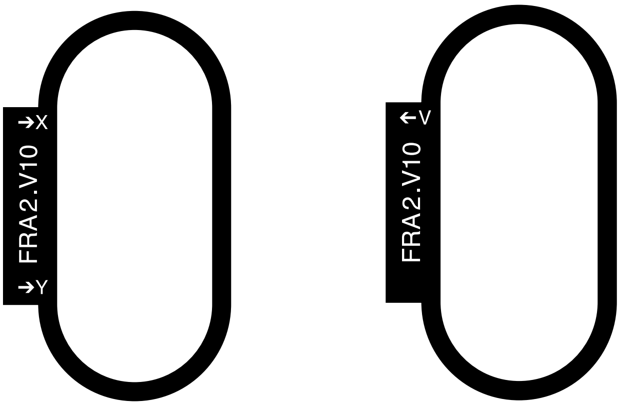


Figure 50 – FRA2 10 V input range labels

05/2025

Woudwetering 3-5
3543 AV Utrecht
The Netherlands