

Power Potentiostats

**PP212/PP222/PP242
XPOT2**

(Operation Manual)

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1 Power Potentiostats

Zahner products are carefully manufactured, calibrated and tested to achieve high-quality standard. Packing of the power potentiostats and accessories is done with great care to avoid damage during transport. Upon reception of the Zahner's shipment, please check the potentiostat and accessories to make sure that they are intact. If a product is damaged during shipment, please immediately contact your Zahner's representative.

1.1 PP212/PP222/PP242 Packing List

- Power potentiostat (PP212 or PP222 or PP242)
- EPC42 cable
- USB cable
- Cell cable set:
 - Twisted sense cable (Lemosia plug to blue & green cables)
 - **For PP212/PP222:**
2 cables (red and black) with banana plugs (\varnothing 4mm), (Length: 1m)
- Rated for a maximum current of up to 32 A
2 alligator clips (red and black)
 - **For PP242:**
2 cables (red and black) with cable lugs, (Length: 1m)
- Recommended use for a maximum rated current of up to 40 A
- Power cord
- USB Stick:
 - Calibration report
 - Calibration data
 - This manual (pdf)
- Zahner Analysis license key
- This manual

1.2 XPOT2 Packing List

- XPOT2
- EPC42 cable
- USB cable
- Cell cable set:
 - 4 BNC/clips cables (0.1 m)
 - 4 BNC/banana cables (1 m)
 - 4 banana clips
- Power cord
- USB Stick:
 - Calibration report
 - Calibration data
 - This manual (pdf)
- Zahner Analysis license key
- This manual

2 Caution

Prevent the inputs of the potentiostat from electrostatic discharge (ESD)! ESD may damage the potentiostat. ESD related damages are not covered in warranty of the potentiostat. The user must discharge his-/herself from any electrical charge before touching the potentiostat (**TIP!**: use grounded ESD-matts).

Please read the [risk assessment document](#) before operating the potentiostat.

Zahner's potentiostats require a warm-up time of 30 minutes for optimum performance.

Do not connect active objects such as batteries or fuel cells to the power outputs of the potentiostat when the potentiostat is switched off! This may damage the potentiostat.

To drive more than 32 A with the PP242 the customer must use a cable, recommended for high current applications and fix it to the front terminal CE and WE with suitable cable lugs.

Properly connect (with screws) the EPC42 cable with the electronic load. An accidental unplugging of the EPC42 cable during operation may damage your device.

Don't touch the electrical connections during the operation.

The cables must be as short as possible and as thick as possible.

3 Introduction

Zahner's power potentiostats (PP2X2 or XPOT2) can be used as an extension to the Zennium series potentiostats or in a stand-alone configuration. In the following sections, both scenarios are discussed.

3.1 Modular Concept – Extension to Zennium Series Potentiostat

3.1.1 PP2X2 – Power Potentiostats

Dynamic measurements (e.g. impedance spectroscopy) on electrochemical objects is a topic of interest in the field of electrochemistry. Modern instruments can cover a broad frequency range from μHz to MHz and operate with huge impedance range from $\mu\Omega$ to G Ω . However, the maximum applied current is mostly limited to a few amperes. For many applications in the field of battery and fuel cell, high currents are needed. For Zennium series potentiostats, the current range can be extended via Zahner's power potentiostats (PP212/PP222/PP242).

With Zennium series potentiostat and power potentiostats, precise measurements can be carried out at high applied currents. The four-quadrant power potentiostats (PP212/PP222/PP242) provide up to ± 40 A (PP242) or up to ± 20 V (PP212) with a maximum power output of 200 W. To connect a power potentiostat with the Zennium potentiostat, an EPC42 interface card is used.

3.1.2 XPOT2

The XPOT2 is usually used as an external potentiostat for ring-disk electrode experiments and multi-cell experiments. The XPOT2 is fully integrated in to the Zennium series potentiostats and can perform all the experiments which are possible with the Zennium potentiostats. The XPOT2 provides electrical currents up to ± 500 mA and a voltage of up to ± 10 V (compliance voltage: ± 25 V). To connect a XPOT2 with the Zennium potentiostat, an EPC42 interface card is used.

3.1.3 EPC42 Controller Card

An EPC42 card has 4 connection ports and can connect up to 4 power potentiostats (PP2X2 and/or XPOT2). Up to four EPC42 cards can be installed in a Zennium series potentiostats. Therefore, with four EPC42 cards, a total of up to 16 external devices (PP2X2 and/or XPOT2) can be connected with a Zennium series potentiostat.

Each port in EPC42 card provides analogue and digital interfaces for the communication between the power potentiostat and the Zennium potentiostat. The analogue part of the port feeds the power potentiostat with a signal which dictates DC voltage and the AC amplitude at a resolution of 16 bit. Signals of measured

current and voltage by the power potentiostats are sent to the Zennium to be treated in the same way as signals from the internal cards are treated. The EPC42 card provides a bandwidth of 250 kHz.

A bi-directional serial communication line allows to digitally control the external potentiostat functions and measuring ranges.

The PP212, PP222, PP242 and XPOT2 require Thales version 5.8.0 or later.

Extended power potentiostats connected to the Zennium series potentiostats can only be operated sequentially. Simultaneously controlling multiple power potentiostats is not possible.

Never plug or unplug the D-SUB connector at the backside of the power potentiostat while the Zennium is switched on. Otherwise, the device and the object may be damaged. It is recommended to fix the D-SUB connector with the screws to prevent accidental unplugging.

3.2 Stand-Alone Mode

Zahner's power potentiostats (PP2X2 and XPOT2) can also be operated in stand-alone mode. To control the devices in stand-alone mode, Windows 10 or Linux computer is necessary. For software updates, Windows 10 is required and use of a virtual machine is not permitted. Use of a USB hub to connect to the power potentiostat is not recommended.

The power potentiostats are controlled in stand-alone mode by the Zahner-Lab. In stand-alone mode, DC measurements are possible (charging/discharging experiments, constant current/potential).

The PP2X2/XPOT2 potentiostat can also be controlled with other software (e.g., Python, and C++). This allows integration in already established experimental setups. The potentiostats provide serial interfaces via two USB COM ports which can be used to communicate with the potentiostat via SCPI protocol.

In future, the ethernet interface will be employed via a software update.

Zahner has prepared a GitHub library for controlling the PP2X2/XPOT2 power potentiostats with Python via SCPI:

https://github.com/Zahner-elektrik/zahner_potentiostat

And a GitHub repository with examples using the library:

<https://github.com/Zahner-elektrik/Zahner-Remote-Python>

The API documentation can be found at:

https://doc.zahner.de/zahner_potentiostat

3.3 Measuring Floating Objects

On the rear of the power potentiostats (PP2X2 and XPOT2), two connectors with a jumper are provided. If the jumper is set, the signal ground is connected to ground via a 100 Ω protective resistor. When examining grounded objects, the jumper on the back of the instrument must be removed. Otherwise, the device and the test object may get damaged.

4 Cell Connection Scheme

All Zahner’s potentiostats and power potentiostats follow the same cell connection scheme (4-electrodes connection scheme). The 4-electrode connection scheme includes connections for working electrode (WE), working electrode sense (WES), reference electrode (RE), and counter electrode (CE). These connections are specified by their color code, WE: black, WES: blue, RE: green, and CE: red. To minimize interference, stray- and mutual inductance, the red and black power cables (current carrying cables) must be twisted together, and the green and blue sense cables must be twisted together before the measurement. Twisting is not shown in the schematic below.

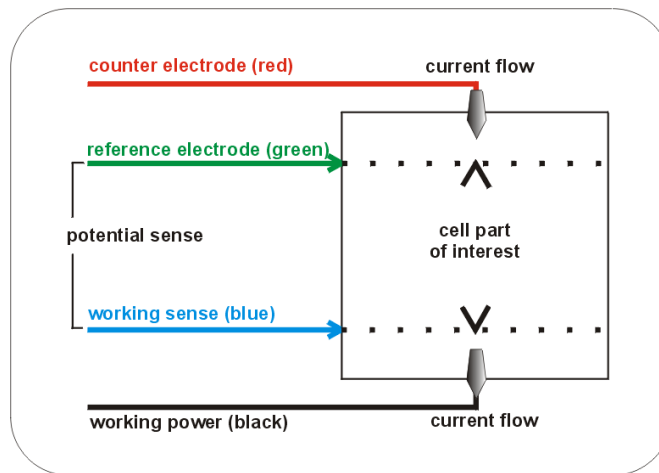


Fig. 1: 4-electrode connection scheme. The current is carried through the black (WE) and red (CE) wires. The voltage is measured between the green (RE) and blue (WES) wires.

For large current flow, especially with the PP2x2, the object must be connected with a four-electrode connection scheme in order to minimize the error margin in the measurement.

4.1 Contact Resistance

Fig. 2 shows a typical electrical wire used to connect the potentiostat with the test object. The resistance of the wire can be divided in to two parts (wire resistance and contact resistance).

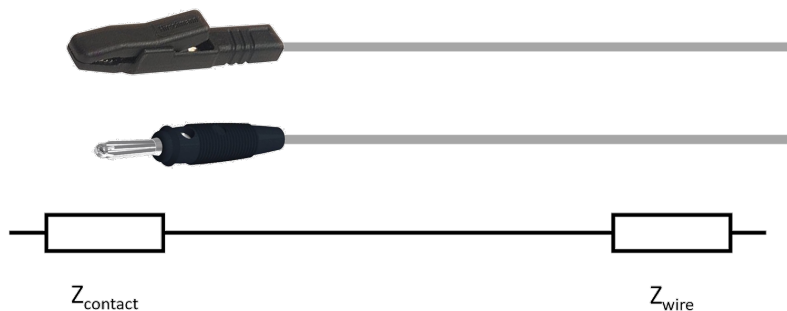


Fig. 2: Typical electrical wire used to contact potentiostat with the test object. Resistance of the electrical wire is divided in to two different parts. 1) contact resistance and 2) wire resistance.

4.2 Four-Electrode Cell Connection Scheme

The advantage of a 4-electrode connection scheme can be illustrated with Fig. 3. In Fig. 3, a pouch cell is connected with the Zennium potentiostat via a 4-electrode connection scheme. With the WES and RE being directly connected to the pouch-cell, the contact resistance for the WE and CE can be ignored as they don't affect the voltage value (not possible with 2-electrode connection scheme).

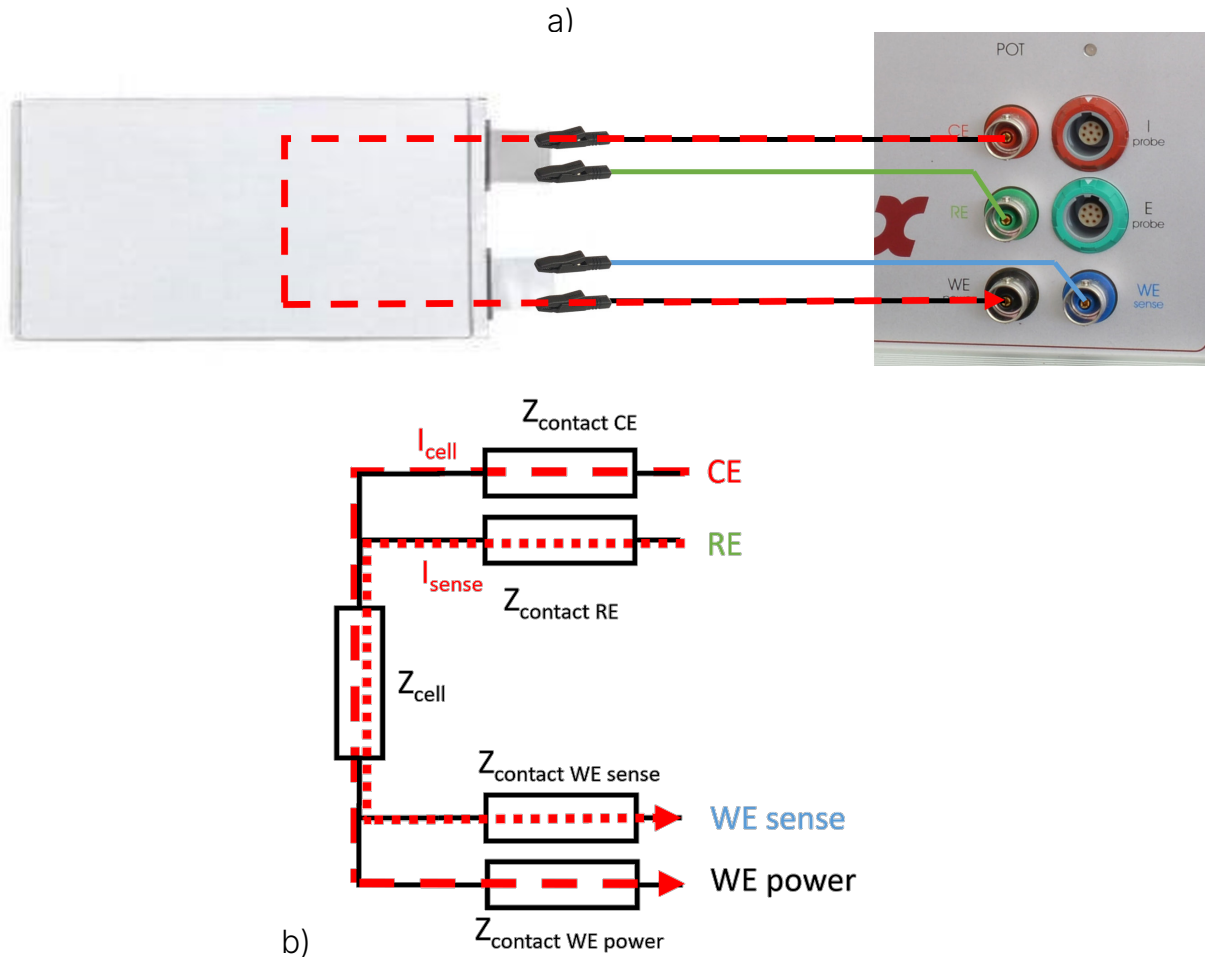


Fig. 3: (a) Four-electrode connection scheme for a 2-electrode pouch cell. For optimum measurement results, the WE and CE as well as the RE and WES cables must be twisted together (not shown in the image). (b) Equivalent circuit diagram of (a).

The voltage across the pouch-cell can be calculated with the following equation. Neglecting the cell voltage for this consideration.

$$U_{Ref} = Z_{cell} * (I_{cell} + I_{sense}) + Z_{contact-RE} * I_{sense} + Z_{contact-WES} * I_{sense} \quad (1)$$

Due to the high input-impedance of the potentiostat (many orders higher than Z_{cell}), the input current I_{sense} to the sense inputs is close to zero.

$$I_{sense} \sim \frac{1}{R_{IN}} \approx \frac{1}{\infty} \approx 0 \quad (2)$$

With $I_{sense}=0$, the eq. 1 can be simplified to the following

$$U_{Ref} = Z_{cell} * I_{cell} \quad (3)$$

$$Z_{cell} = \frac{U_{Ref}}{I_{cell}} \quad (4)$$

With the 4-electrode connection scheme, the contact resistances are in most cases not significant in the measured cell impedance. This is only true if the cell resistance of the test object is much smaller than the input resistance of the potentiostat. The input impedance of the power potentiostat is provided in the PP2X2 specification in chapter 8. Test objects with a resistance higher than 1 kΩ will have a marginal error in the measured voltage value.

4.3 Two-Electrode Cell Connection Scheme

Fig. 4 shows a 2-electrode cell connection scheme for measurements on a pouch cell. The WE and WES cables are joined together to make one electrode connection and RE and CE cables are joined together to make the second electrode connection.

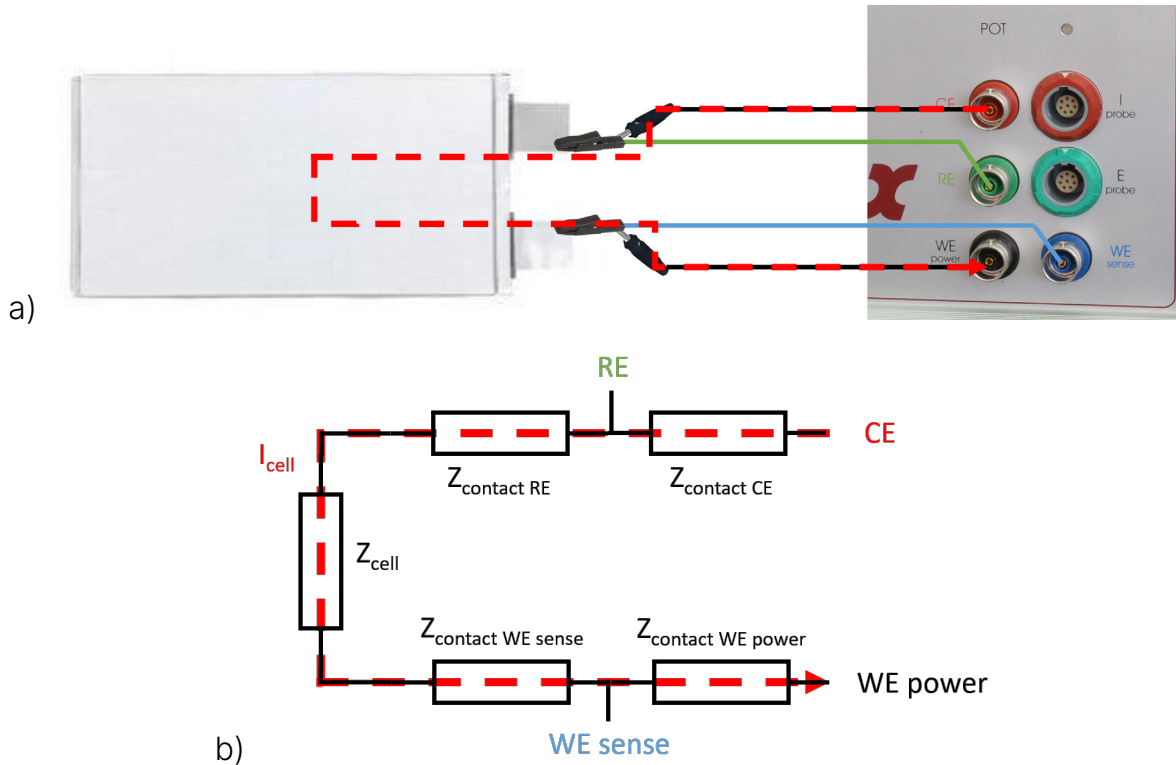


Fig. 4: a) Illustration of a 2-electrode connection scheme for a 2-electrode pouch cell. (b) Equivalent circuit diagram of (a).

Here the voltage can be calculated with the equation provided below, neglecting the cell voltage for this consideration:

$$U_{Ref} = (Z_{cell} + Z_{contact-RE} + Z_{contact-WES}) * (I_{cell} + I_{sense}) \quad (5)$$

The currents (I_{cell} and I_{sense}) are flowing through the pouch cell and the WES- and the RE contacts. Neglecting the small sense current (I_{sense}) to the input of the potentiostat, the eq. 5 can be simplified in to the eq. 6.

$$U_{Ref} = Z_{cell} * I_{cell} + Z_{contact-RE} * I_{cell} + Z_{contact-WES} * I_{cell} \quad (6)$$

Eq. 6 shows that the calculated voltage of the pouch cell includes the voltage drop at the RE and WES contacts.

5 Thales Software

The PP212, PP222, PP242 and XPOT2 require Thales version 5.8.0 or later.

All external potentiostats are directly controlled by the Thales software. Each device has a unique device number which is identical to the EPC42 port number with which the external potentiostat is connected, if no RMUX card is installed. For example, if a device is connected to EPC port 3 then in Thales, the device is addressed as “device number 3”. Device number 0 is reserved for the internal main potentiostat of the Zennium series potentiostat.

If a RMUX (relay multiplexer) card is installed in a Zennium series potentiostat then the 16 device numbers (per RMUX card) are assigned to the RMUX channels. Hence, if one RMUX card is installed then the device numbers, 1-16, are assigned to the RMUX channels. Similarly, if 2 RMUX cards are installed in Zennium series potentiostat then 1-32 device numbers are assigned to the RMUX channels.

To select a potentiostat in the Thales software, follow the steps provided below

1. Start Thales software (classic mode)
2. Click on “EIS” icon
3. Click on “Control potentiostat”
4. Click on “DEVICE” button in “Test sampling & control potentiostat” window.

By clicking on the “DEVICE” button, an input box will appear where the user can provide the device number. After inserting the correct device number, the device shows the type of active external potentiostat.



Fig. 5: Selecting an external potentiostat in test sampling window. DEVICE 1: XPOT2 indicates that the XPOT2 is connected to the port 1 of the EPC42 card.

When the mouse cursor hovers above a button and the button is highlighted in yellow, the current and voltage displays are not updated.

If no device has been connected to the addressed EPC42 port an error message is displayed and the Thales software automatically selects the internal potentiostat.

If the selected device is present then upon selection of the external device, the Thales software automatically starts the start-up calibration routine of the external potentiostats.

When changing the device number, the now non-selected external potentiostat will hold its DC conditions such as DC potential or current and on/off status.

Voltage and current outputs of the non-selected external potentiostat are not measured and are not monitored for defined voltage/current limits.

Only the selected external potentiostat is internally connected to the FRA of the ZENNIUM series potentiostat. Therefore, only the active external potentiostat is able to output an AC signal.

6 XPOT2

The XPOT2 is an external low power four-quadrant potentiostat and is able to sink and source current up to ± 0.5 A.

The XPOT2 potentiostat can be operated in both potentiostatic and galvanostatic modes. The output as well as the input is electrically isolated up to a maximum difference potential against ground of ± 12 V.

The shields of the BNC connectors are connected to the test electrode (virtual ground) via a 2.2 k Ω resistor.

7 PP212/PP222/PP242

The PP2X2 are external four-quadrant potentiostats and are able to sink and source current up to $\pm 10/\pm 20/\pm 40$ A, depending upon the power potentiostat model.

The PP2x2 as power potentiostats to the Zennium series potentiostats can be used to carry out DC measurements (charging/discharging measurements) as well as AC measurements (electrochemical impedance spectroscopy). The power potentiostats can be operated in both potentiostatic and galvanostatic modes. The output as well as the input is electrically isolated up to a maximum potential difference of ± 12 V (for PP222 and PP242) and of ± 24 V (for PP212) against ground potential.

In the following sections, different experimental scenarios are described in which the PP2X2 power potentiostats (with Zennium series potentiostats) can be used to characterize the cell (fuel cell, electrolysers or battery) in

1. Full cell configuration,
2. Half-cell configuration (anodic or cathodic part), and
3. Partial cell configuration.

7.1 Full Cell Configuration (Standard Kelvin Scheme)

This configuration is used if a complete cell is to be investigated.

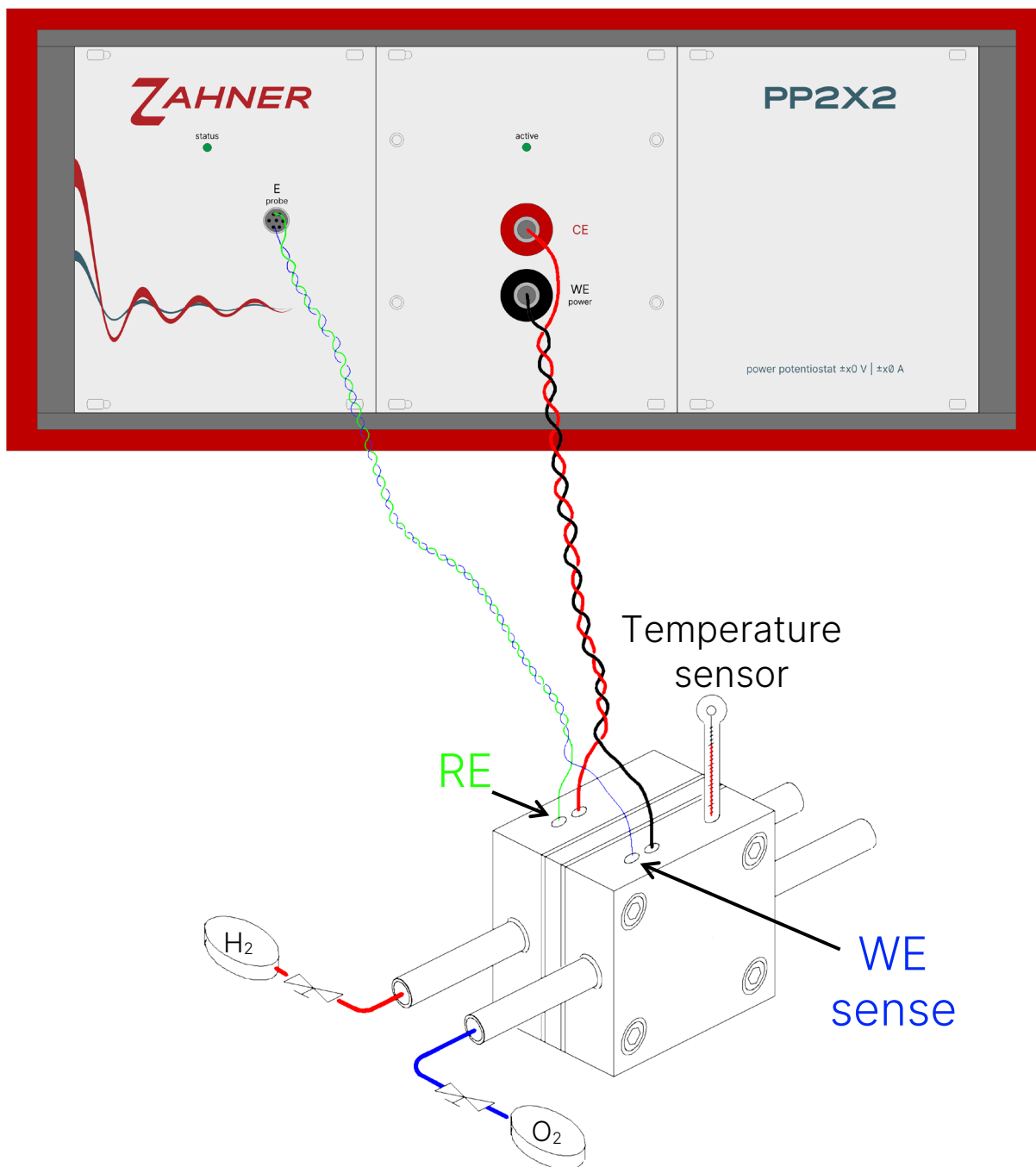


Fig. 6: Cable connection schematic for full cell characterization. WE and WES connections are connected to the one electrode of the cell and RE and CE connections are connected to the other electrode. Current carrying cables (WE and CE cables) and sense cables (WES and RE cables) are twisted together to minimize the artefacts. The main Zennium series potentiostat is not shown in the schematic.

7.2 Half Cell Configuration – Anode

This configuration is used if the anodic part of the cell is to be investigated. Here the voltage is measured between anode and a reference electrode.

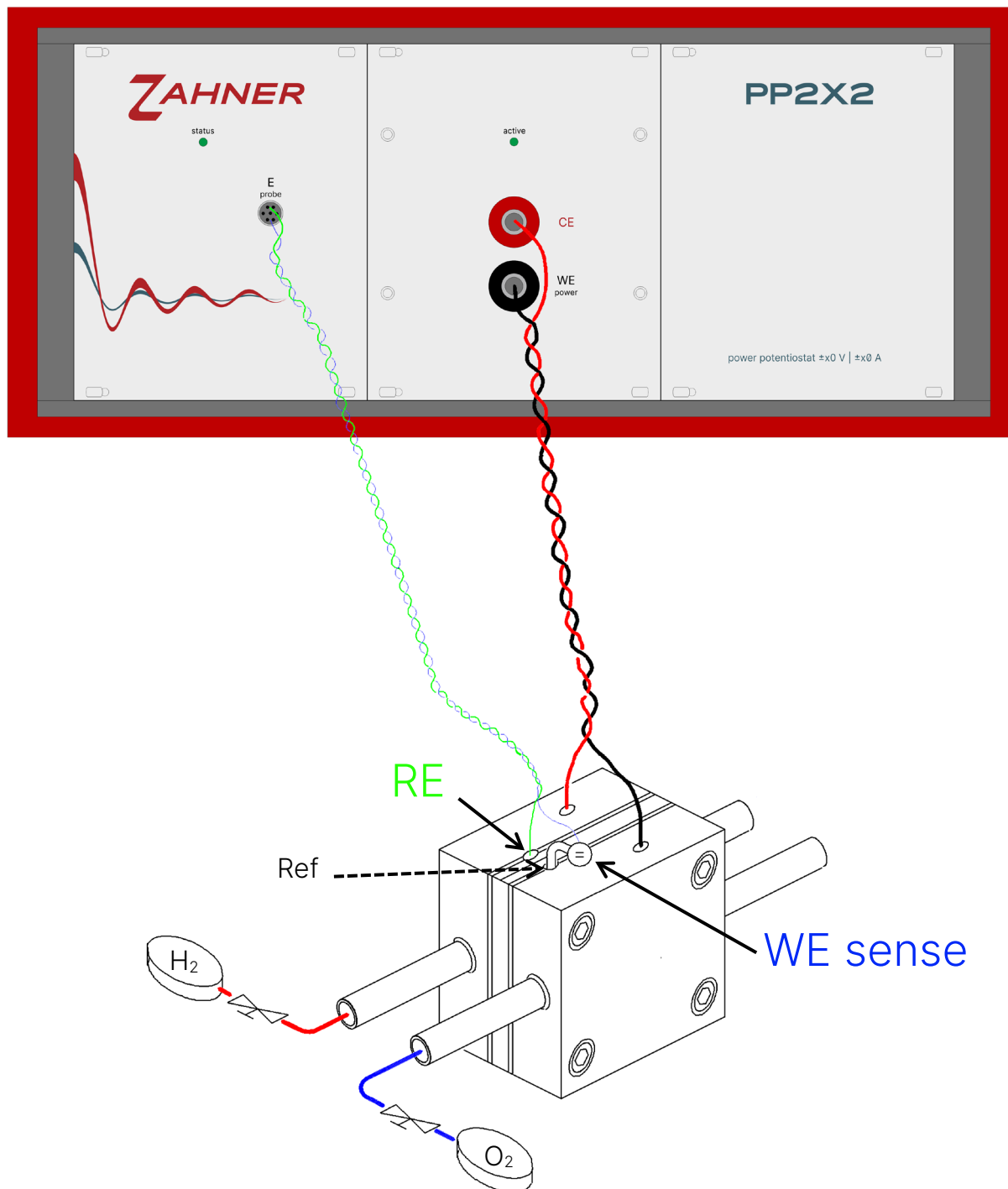


Fig. 7: Cable connection schematic for characterizing the anode of the cell. Current is applied/measured between the anode and cathode whereas voltage is measured between the anode and a reference electrode (Ref). Current carrying cables (WE and CE cables) and sense cables (WES and RE cables) are twisted together to minimize the artefacts. The main Zennium series potentiostat is not shown in the schematic.

7.3 Half Cell Configuration – Cathode

This configuration is used if the cathodic part of the cell is to be investigated. Here the voltage is measured between cathode and a reference electrode.

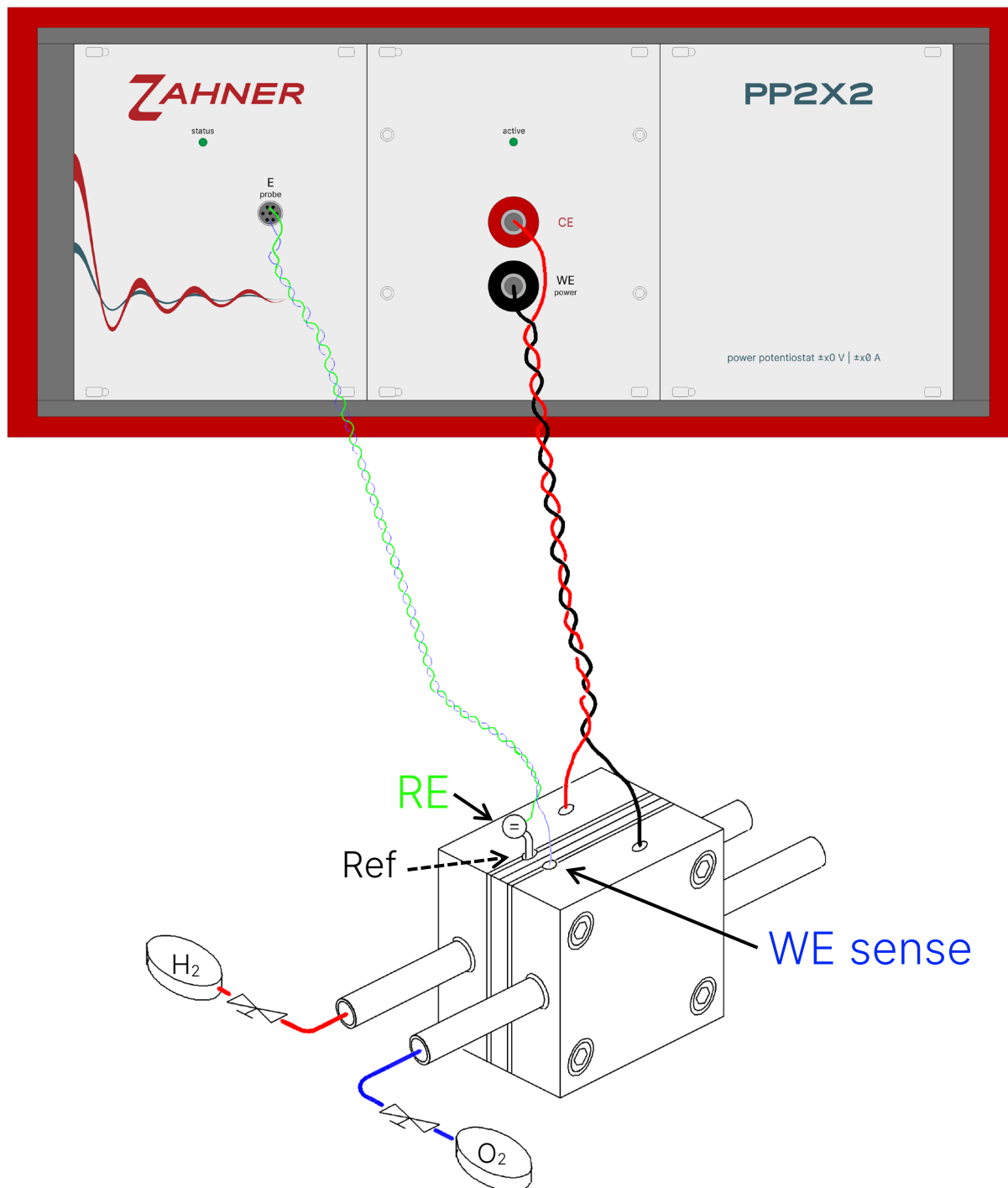


Fig. 8: Cable connection schematic for characterizing the cathodic part of the cell. Current is applied/measured between the anode and cathode whereas voltage is measured between the cathode and a reference electrode (Ref). Current carrying cables (WE and CE cables) and sense cables (WES and RE cables) are twisted together to minimize the artefacts. The main Zennium series potentiostat is not shown in the schematic.

7.4 Partial Cell Configuration

This configuration may be used, if a certain part of a battery or fuel cell stack has to be investigated.

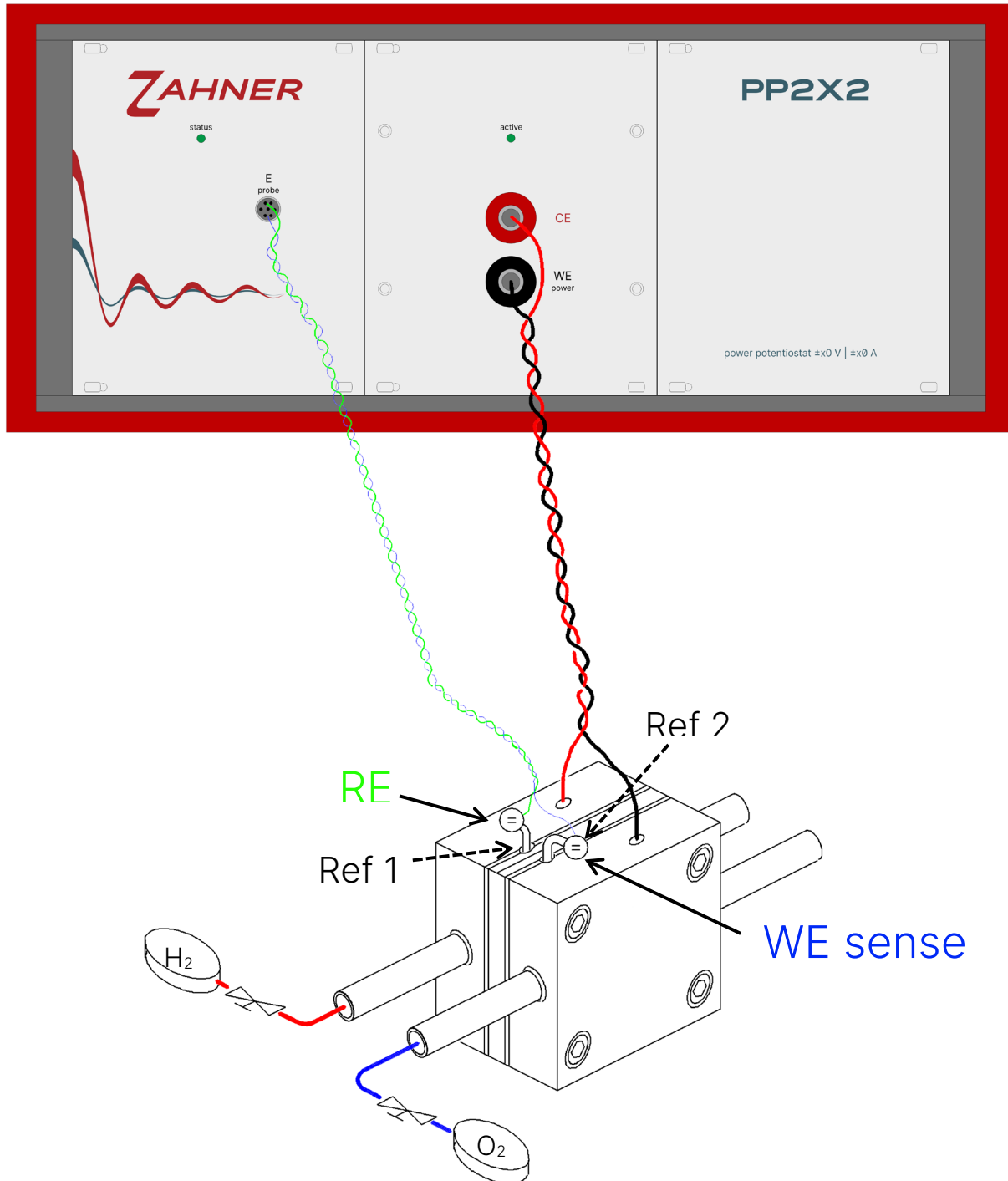


Fig. 9: Cable connection schematic for characterizing a part of the cell. Current is applied/measured between the anode and cathode whereas voltage is measured between two reference electrodes (Ref1 and Ref2). Current carrying cables (WE and CE cables) and sense cables (WES and RE cables) are twisted together to minimize the artefacts. The main Zennium series potentiostat is not shown in the schematic.

7.5 Battery Configuration

In this configuration, the battery is connected in such a way that a positive open circuit potential can be read in the Thales software.

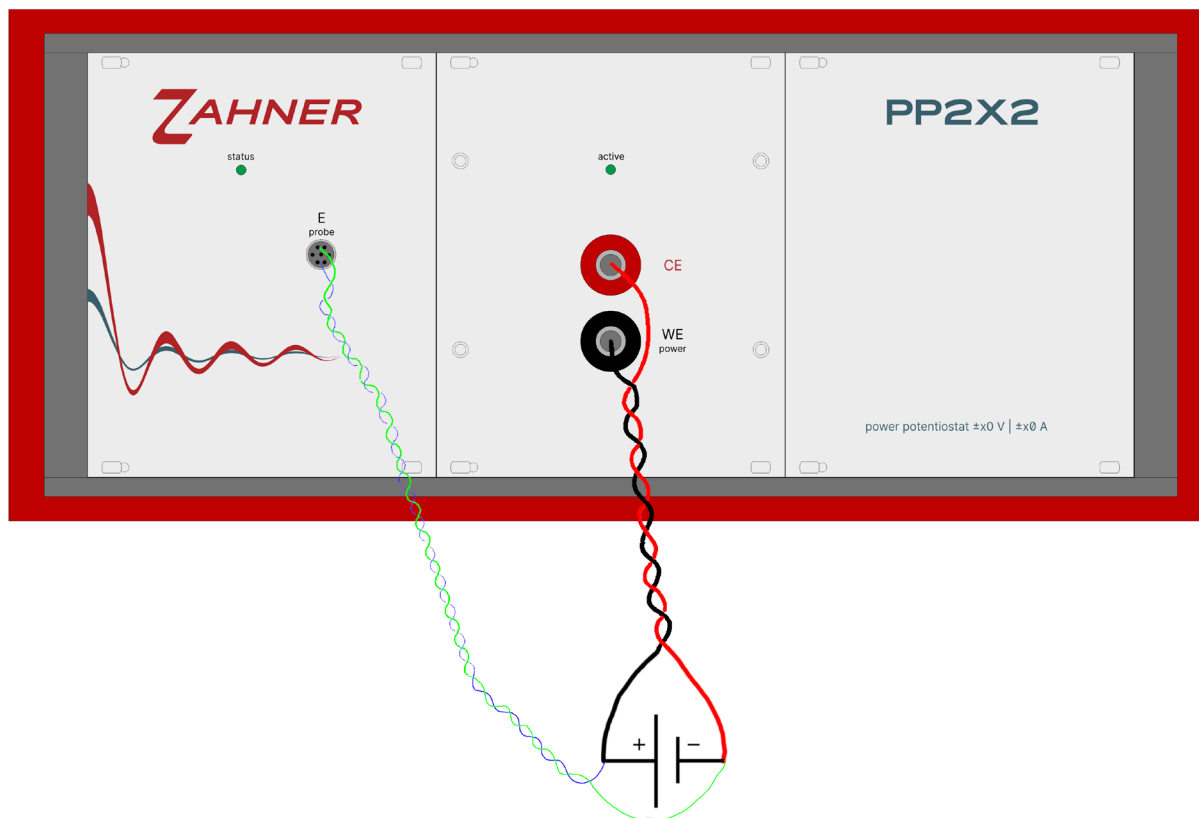


Fig. 10: Cable connection schematic for full cell characterization. WE and WES connections are connected to the one electrode of the cell and RE and CE connections are connected to the other electrode. Current carrying cables (WE and CE cables) and sense cables (WES and RE cables) are twisted together to minimize the artefacts. The main Zennium series potentiostat is not shown in the schematic.

Switching power potentiostat in the Thales software:

When changing the device number, the now non-selected external potentiostat will hold its DC conditions such as DC potential or current and on/off status.

Voltage and current outputs of the non-selected external potentiostat are not measured and are not monitored for defined voltage/current limits.

Only the selected external potentiostat is internally connected to the FRA of the Zennium series potentiostat. Therefore, only the active external potentiostat is able to output an AC signal.

8 Specifications

In the following subsections, current and voltage ranges for different power potentiostats are provided for use with Zennium series measurement (Range Thales) and for stand-alone mode. The PP2X2 power potentiostats have 4 shunts and XPOT2 has 8 shunt resistances.

8.1 Ranges and tolerances

8.1.1 PP212

Voltage Ranges						
Voltage Range		Range Standalone [V]		Range Thales [V]		Tolerance
Index	Factor	min	max	min	max	
0	1	-10	10	-8	8	$\pm 1000 \mu\text{V} \pm 0.1\%$ of reading
1	0,4	-20	20	-20	20	$\pm 2500 \mu\text{V} \pm 0.1\%$ of reading
Current Ranges						
Shunt		Range Standalone [A]		Range Thales [A]		Tolerance
Index	Resistance	min	max	min	max	
0	10m	-10	10	-10	10	$\pm 400 \text{ mA} \pm 0.2\%$ of reading
1	100m	-10	10	-10	10	$\pm 40 \text{ mA} \pm 0.2\%$ of reading
2	1	-2	2	-2	2	$\pm 4 \text{ mA} \pm 0.2\%$ of reading
3	10	-400m	400m	-400m	400m	$\pm 400 \mu\text{A} \pm 0.2\%$ of reading

Table 1: PP212 Ranges and tolerances

8.1.2 PP222

Voltage Ranges						
Voltage Range		Range Standalone [V]		Range Thales [V]		Tolerance
Index	Factor	min	max	min	max	
0	1	-5	5	-4	4	$\pm 500 \mu\text{V} \pm 0.1\%$ of reading
1	0,4	-10	10	-10	10	$\pm 1250 \mu\text{V} \pm 0.1\%$ of reading
Current Ranges						
Shunt		Range Standalone [A]		Range Thales [A]		Tolerance
Index	Resistance	min	max	min	max	
0	10m	-20	20	-20	20	$\pm 400 \text{ mA} \pm 0.2\%$ of reading
1	100m	-20	20	-20	20	$\pm 40 \text{ mA} \pm 0.2\%$ of reading
2	1	-2	2	-2	2	$\pm 4 \text{ mA} \pm 0.2\%$ of reading
3	10	-400m	400m	-400m	400m	$\pm 400 \mu\text{A} \pm 0.2\%$ of reading

Table 2: PP222 Ranges and tolerances

8.1.3 PP242

Voltage Ranges						
Voltage Range		Range Standalone [V]		Range Thales [V]		Tolerance
Index	Factor	min	max	min	max	
0	1	-5	5	-4	4	$\pm 500 \mu\text{V} \pm 0.1\%$ of reading
1	0,4	-5	5	-5	5	$\pm 1250 \mu\text{V} \pm 0.1\%$ of reading
Current Ranges						
Shunt		Range Standalone [A]		Range Thales [A]		Tolerance
Index	Resistance	min	max	min	max	
0	10m	-40	40	-40	40	$\pm 400 \text{ mA} \pm 0.2\%$ of reading
1	100m	-40	40	-40	40	$\pm 40 \text{ mA} \pm 0.2\%$ of reading
2	1	-2	2	-2	2	$\pm 4 \text{ mA} \pm 0.2\%$ of reading
3	10	-400m	400m	-400m	400m	$\pm 400 \mu\text{A} \pm 0.2\%$ of reading

Table 3: PP242 Ranges and tolerances

8.1.4 XPOT2

Voltage Ranges					
Voltage Range Index	Range Stand-Alone [V]		Range Thales [V]		Tolerance
	min	max	min	max	
0	-5.0	5.0	-4.0	4.0	$\pm 0.5 \text{ mV} \pm 0.1\%$ of reading
1	-12.5	12.5	-10.0	10.0	$\pm 1.25 \text{ mV} \pm 0.1\%$ of reading
Current Ranges					
Shunt Index	Range Stand-Alone [A]		Range Thales [A]		Tolerance
	min	max	min	max	
0	-500m	500m	-500m	500m	$\pm 250 \mu\text{A} \pm 0.1\%$ of reading
1	-160m	160m	-160m	160m	$\pm 85 \mu\text{A} \pm 0.1\%$ of reading
2	-40m	40m	-40m	40m	$\pm 20 \mu\text{A} \pm 0.1\%$ of reading
3	-4m	4m	-4m	4m	$\pm 2.5 \mu\text{A} \pm 0.1\%$ of reading
4	-400 μ	400 μ	-400 μ	400 μ	$\pm 250 \text{ nA} \pm 0.1\%$ of reading
5	-40 μ	40 μ	-40 μ	40 μ	$\pm 25 \text{ nA} \pm 0.1\%$ of reading
6	-4 μ	4 μ	-4 μ	4 μ	$\pm 2.5 \text{ nA} \pm 0.1\%$ of reading
7	-400n	400n	-400n	400n	$\pm 250 \text{ pA} \pm 0.1\%$ of reading

Table 4: XPOT2 Ranges and tolerances

8.2 General specifications

	PP212	PP222	PP242	XPOT2
Potentiostatic Modes	Potentiostatic, Galvanostatic, Pseudo-Galvanostatic, Off			
Cell Connection	2-, 3-, 4-Terminal Sensing			
Ground Reference	Grounded, Floating			
Compliance Voltage	±20 V	±10 V	±5 V	±25 V
Maximum Current	±10 A	±20 A	±40 A	±0.5 A
Output Power	200 W			12 W
Power Dissipation	250 W			
Input Impedance	2 MΩ	100 MΩ		1 TΩ
Equivalent Input Noise	< 10 μV rms			
Memory	64 GB			
Interface	USB, Ethernet ²			
Additional IOs	5 ²			
Additional Analog Outputs	1 ²			
Additional Analog Inputs	4 ²			
Temperatur Sensor Interface	Type K ²			
Ambient Temperature	10 °C - 30 °C			10 °C - 25 °C
Maximum Humidity	60 %			
Dimensions (H x W x D) in mm	160 x 364 x 378			160 x 185 x 327
Weight	10.2 kg			4.6 kg
Zahner-Lab / SCPI				
ADC Resolution	24 bits			
Voltage Input Resolution	1.192 μV	0.596 μV		
Current Input Resolution	5.96 nA			59.6 fA
DAC Resolution	18 bits			
Voltage Output Resolution	76.3 μV	38.14 μV		
Current Output Resolution	3.81 μA			3.81 pA
Thales XT				
ADC Resolution	24 bits			
Voltage Input Resolution	1.192 μV	0.596 μV		
Current Input Resolution	5.96 nA			59.6 fA
DAC Resolution	16 bits			
Voltage Output Resolution	250 μV	125 μV		
Current Output Resolution	12.5 μA			12.5 pA
Impedance Frequency Range	10 μHz - 200 kHz			
Impedance Range	1 μΩ - 1 kΩ ¹			100 mΩ - 1 GΩ

¹Impedances below 1 mΩ must be measured galvanostatically.

²Hardware feature will be unlocked in future with a free software update.

Table 5: General specifications of power potentiostats (PP2X2 and XPOT2)

9 Safe operating conditions

In this section, the safe operating ranges for the power potentiostats (PP2X2 and XPOT2) are provided. In the tables, the “power loss” is taken as an indicator of safe operating conditions. The PP2X2 potentiostats can accommodate a maximum power loss of up to 250 W. The XPOT2 potentiostat can accommodate a maximum power loss of up to 12 W. A higher power loss will trigger the safety precautions setup of the potentiostats and the output will be limited.

Please note that the “power loss” in the potentiostat is not the same as “power output” (=Current x Voltage).

9.1 PP212

Power loss [W]	Output current [A]																																								
	Sink															OCP	Source																								
	10	9.5	9	8.5	8	7.5	7	6.5	6	5.5	5	4.5	4	3.5	3	2.5	2	1.5	1	0.5	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10
20	429	408	387	366	345	324	302	281	260	239	217	196	174	153	131	109	88	66	44	22	0	2	4	6	8	9	11	13	14	16	17	19	20	21	22	24	25	26	27	28	29
18	409	389	369	349	329	309	288	268	248	228	207	187	166	146	125	104	84	63	42	21	0	3	6	9	12	14	17	20	22	25	27	30	32	34	36	39	41	43	45	47	49
16	389	370	351	332	313	294	274	255	236	217	197	178	158	139	119	99	80	60	40	20	0	4	8	12	16	19	23	27	30	34	37	41	44	47	50	54	57	60	63	66	69
14	369	351	333	315	297	279	260	242	224	206	187	169	150	132	113	94	76	57	38	19	0	5	10	15	20	24	29	34	38	43	47	52	56	60	64	69	73	77	81	85	89
12	349	332	315	298	281	264	246	229	212	195	177	160	142	125	107	89	72	54	36	18	0	6	12	18	24	29	35	41	46	52	57	63	68	73	78	84	89	94	99	104	109
10	329	313	297	281	265	249	232	216	200	184	167	151	134	118	101	84	68	51	34	17	0	7	14	21	28	34	41	48	54	61	67	74	80	86	92	99	105	111	117	123	129
8	309	294	279	264	249	234	218	203	188	173	157	142	126	111	95	79	64	48	32	16	0	8	16	24	32	39	47	55	62	70	77	85	92	99	106	114	121	128	135	142	149
6	289	275	261	247	233	219	204	190	176	162	147	133	118	104	89	74	60	45	30	15	0	9	18	27	36	44	53	62	70	79	87	96	104	112	120	129	137	145	153	161	169
4	269	256	243	230	217	204	190	177	164	151	137	124	110	97	83	69	56	42	28	14	0	10	20	30	40	49	59	69	78	88	97	107	116	125	134	144	153	162	171	180	189
2	249	237	225	213	201	189	176	164	152	140	127	115	102	90	77	64	52	39	26	13	0	11	22	33	44	54	65	76	86	97	107	118	128	138	148	159	169	179	189	199	209
0	229	218	207	196	185	174	162	151	140	129	117	106	94	83	71	59	48	36	24	12	0	12	24	36	48	59	71	83	94	106	117	129	140	151	162	174	185	196	207	218	229
-2	249	237	225	213	201	189	176	164	152	140	127	115	102	90	77	64	52	39	26	13	0	11	22	33	44	54	65	76	86	97	107	118	128	138	148	159	169	179	189	199	209
-4	269	256	243	230	217	204	190	177	164	151	137	124	110	97	83	69	56	42	28	14	0	10	20	30	40	49	59	69	78	88	97	107	116	125	134	144	153	162	171	180	189
-6	289	275	261	247	233	219	204	190	176	162	147	133	118	104	89	74	60	45	30	15	0	9	18	27	36	44	53	62	70	79	87	96	104	112	120	129	137	145	153	161	169
-8	309	294	279	264	249	234	218	203	188	173	157	142	126	111	95	79	64	48	32	16	0	8	16	24	32	39	47	55	62	70	77	85	92	99	106	114	121	128	135	142	149
-10	329	313	297	281	265	249	232	216	200	184	167	151	134	118	101	84	68	51	34	17	0	7	14	21	28	34	41	48	54	61	67	74	80	86	92	99	105	111	117	123	129
-12	349	332	315	298	281	264	246	229	212	195	177	160	142	125	107	89	72	54	36	18	0	6	12	18	24	29	35	41	46	52	57	63	68	73	78	84	89	94	99	104	109
-14	369	351	333	315	297	279	260	242	224	206	187	169	150	132	113	94	76	57	38	19	0	5	10	15	20	24	29	34	38	43	47	52	56	60	64	69	73	77	81	85	89
-16	389	370	351	332	313	294	274	255	236	217	197	178	158	139	119	99	80	60	40	20	0	4	8	12	16	19	23	27	30	34	37	41	44	47	50	54	57	60	63	66	69
-18	409	389	369	349	329	309	288	268	248	228	207	187	166	146	125	104	84	63	42	21	0	3	6	9	12	14	17	20	22	25	27	30	32	34	36	39	41	43	45	47	49
-20	429	408	387	366	345	324	302	281	260	239	217	196	174	153	131	109	88	66	44	22	0	2	4	6	8	9	11	13	14	16	17	19	20	21	22	24	25	26	27	28	29

Table 6: Safe operating range for power potentiostat PP212

9.2 PP222

Power loss [W]		Output current [A]																																								
		Sink																				OCP	Source																			
		20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Output voltage [V]	10	417	397	377	357	337	317	297	276	256	235	214	193	172	151	130	109	87	65	44	22	0	2	4	5	7	9	10	11	12	13	14	15	16	16	17	17	17	17	17	17	
	9	397	378	359	340	321	302	283	263	244	224	204	184	164	144	124	104	83	62	42	21	0	3	6	8	11	14	16	18	20	22	24	26	28	29	31	32	33	34	35	36	37
	8	377	359	341	323	305	287	269	250	232	213	194	175	156	137	118	99	79	59	40	20	0	4	8	11	15	19	22	25	28	31	34	37	40	42	45	47	49	51	53	55	57
	7	357	340	323	306	289	272	255	237	220	202	184	166	148	130	112	94	75	56	38	19	0	5	10	14	19	24	28	32	36	40	44	48	52	55	59	62	65	68	71	74	77
	6	337	321	305	289	273	257	241	224	208	191	174	157	140	123	106	89	71	53	36	18	0	6	12	17	23	29	34	39	44	49	54	59	64	68	73	77	81	85	89	93	97
	5	317	302	287	272	257	242	227	211	196	180	164	148	132	116	100	84	67	50	34	17	0	7	14	20	27	34	40	46	52	58	64	70	76	81	87	92	97	102	107	112	117
	4	297	283	269	255	241	227	213	198	184	169	154	139	124	109	94	79	63	47	32	16	0	8	16	23	31	39	46	53	60	67	74	81	88	94	101	107	113	119	125	131	137
	3	277	264	251	238	225	212	199	185	172	158	144	130	116	102	88	74	59	44	30	15	0	9	18	26	35	44	52	60	68	76	84	92	100	107	115	122	129	136	143	150	157
	2	257	245	233	221	209	197	185	172	160	147	134	121	108	95	82	69	55	41	28	14	0	10	20	29	39	49	58	67	76	85	94	103	112	120	129	137	145	153	161	169	177
	1	237	226	215	204	193	182	171	159	148	136	124	112	100	88	76	64	51	38	26	13	0	11	22	32	43	54	64	74	84	94	104	114	124	133	143	152	161	170	179	188	197
	0	217	207	197	187	177	167	157	146	136	125	114	103	92	81	70	59	47	35	24	12	0	12	24	35	47	59	70	81	92	103	114	125	136	146	157	167	177	187	197	207	217
	-1	237	226	215	204	193	182	171	159	148	136	124	112	100	88	76	64	51	38	26	13	0	11	22	32	43	54	64	74	84	94	104	114	124	133	143	152	161	170	179	188	197
	-2	257	245	233	221	209	197	185	172	160	147	134	121	108	95	82	69	55	41	28	14	0	10	20	29	39	49	58	67	76	85	94	103	112	120	129	137	145	153	161	169	177
	-3	277	264	251	238	225	212	199	185	172	158	144	130	116	102	88	74	59	44	30	15	0	9	18	26	35	44	52	60	68	76	84	92	100	107	115	122	129	136	143	150	157
-4	297	283	269	255	241	227	213	198	184	169	154	139	124	109	94	79	63	47	32	16	0	8	16	23	31	39	46	53	60	67	74	81	88	94	101	107	113	119	125	131	137	
-5	317	302	287	272	257	242	227	211	196	180	164	148	132	116	100	84	67	50	34	17	0	7	14	20	27	34	40	46	52	58	64	70	76	81	87	92	97	102	107	112	117	
-6	337	321	305	289	273	257	241	224	208	191	174	157	140	123	106	89	71	53	36	18	0	6	12	17	23	29	34	39	44	49	54	59	64	68	73	77	81	85	89	93	97	
-7	357	340	323	306	289	272	255	237	220	202	184	166	148	130	112	94	75	56	38	19	0	5	10	14	19	24	28	32	36	40	44	48	52	55	59	62	65	68	71	74	77	
-8	377	359	341	323	305	287	269	250	232	213	194	175	156	137	118	99	79	59	40	20	0	4	8	11	15	19	22	25	28	31	34	37	40	42	45	47	49	51	53	55	57	
-9	397	378	359	340	321	302	283	263	244	224	204	184	164	144	124	104	83	62	42	21	0	3	6	8	11	14	16	18	20	22	24	26	28	29	31	32	33	34	35	36	37	
-10	417	397	377	357	337	317	297	276	256	235	214	193	172	151	130	109	87	65	44	22	0	2	4	5	7	9	10	11	12	13	14	15	16	16	17	17	17	17	17	17	17	

Table 7: Safe operating range for power potentiostat PP222

9.3 PP242

Power loss [W]		Output current [A]																																								
		Sink																		OCP	Source																					
		40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10	8	6	4	2	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Output voltage [V]	5	458	437	416	394	373	351	329	307	285	262	239	216	193	170	146	122	98	74	50	25	0	5	10	14	18	22	26	30	33	36	39	42	45	47	49	51	53	54	56	57	58
	4.5	438	418	398	377	357	336	315	294	273	251	229	207	185	163	140	117	94	71	48	24	0	6	12	17	22	27	32	37	41	45	49	53	57	60	63	66	69	71	74	76	78
	4	418	399	380	360	341	321	301	281	261	240	219	198	177	156	134	112	90	68	46	23	0	7	14	20	26	32	38	44	49	54	59	64	69	73	77	81	85	88	92	95	98
	3.5	398	380	362	343	325	306	287	268	249	229	209	189	169	149	128	107	86	65	44	22	0	8	16	23	30	37	44	51	57	63	69	75	81	86	91	96	101	105	110	114	118
	3	378	361	344	326	309	291	273	255	237	218	199	180	161	142	122	102	82	62	42	21	0	9	18	26	34	42	50	58	65	72	79	86	93	99	105	111	117	122	128	133	138
	2.5	358	342	326	309	293	276	259	242	225	207	189	171	153	135	116	97	78	59	40	20	0	10	20	29	38	47	56	65	73	81	89	97	105	112	119	126	133	139	146	152	158
	2	338	323	308	292	277	261	245	229	213	196	179	162	145	128	110	92	74	56	38	19	0	11	22	32	42	52	62	72	81	90	99	108	117	125	133	141	149	156	164	171	178
	1.5	318	304	290	275	261	246	231	216	201	185	169	153	137	121	104	87	70	53	36	18	0	12	24	35	46	57	68	79	89	99	109	119	129	138	147	156	165	173	182	190	198
	1	298	285	272	258	245	231	217	203	189	174	159	144	129	114	98	82	66	50	34	17	0	13	26	38	50	62	74	86	97	108	119	130	141	151	161	171	181	190	200	209	218
	0.5	278	266	254	241	229	216	203	190	177	163	149	135	121	107	92	77	62	47	32	16	0	14	28	41	54	67	80	93	105	117	129	141	153	164	175	186	197	207	218	228	238
	0	258	247	236	224	213	201	189	177	165	152	139	126	113	100	86	72	58	44	30	15	0	15	30	44	58	72	86	100	113	126	139	152	165	177	189	201	213	224	236	247	258
	-0.5	278	266	254	241	229	216	203	190	177	163	149	135	121	107	92	77	62	47	32	16	0	14	28	41	54	67	80	93	105	117	129	141	153	164	175	186	197	207	218	228	238
	-1	298	285	272	258	245	231	217	203	189	174	159	144	129	114	98	82	66	50	34	17	0	13	26	38	50	62	74	86	97	108	119	130	141	151	161	171	181	190	200	209	218
	-1.5	318	304	290	275	261	246	231	216	201	185	169	153	137	121	104	87	70	53	36	18	0	12	24	35	46	57	68	79	89	99	109	119	129	138	147	156	165	173	182	190	198
	-2	338	323	308	292	277	261	245	229	213	196	179	162	145	128	110	92	74	56	38	19	0	11	22	32	42	52	62	72	81	90	99	108	117	125	133	141	149	156	164	171	178
	-2.5	358	342	326	309	293	276	259	242	225	207	189	171	153	135	116	97	78	59	40	20	0	10	20	29	38	47	56	65	73	81	89	97	105	112	119	126	133	139	146	152	158
-3	378	361	344	326	309	291	273	255	237	218	199	180	161	142	122	102	82	62	42	21	0	9	18	26	34	42	50	58	65	72	79	86	93	99	105	111	117	122	128	133	138	
-3.5	398	380	362	343	325	306	287	268	249	229	209	189	169	149	128	107	86	65	44	22	0	8	16	23	30	37	44	51	57	63	69	75	81	86	91	96	101	105	110	114	118	
-4	418	399	380	360	341	321	301	281	261	240	219	198	177	156	134	112	90	68	46	23	0	7	14	20	26	32	38	44	49	54	59	64	69	73	77	81	85	88	92	95	98	
-4.5	438	418	398	377	357	336	315	294	273	251	229	207	185	163	140	117	94	71	48	24	0	6	12	17	22	27	32	37	41	45	49	53	57	60	63	66	69	71	74	76	78	
-5	458	437	416	394	373	351	329	307	285	262	239	216	193	170	146	122	98	74	50	25	0	5	10	14	18	22	26	30	33	36	39	42	45	47	49	51	53	54	56	57	58	

Table 8: Safe operating range for power potentiostat PP242

9.4 XPOT2

Power loss [W]		Output current [A]																																								
		Sink																			OCP	Source																				
		0.5	0.48	0.45	0.43	0.4	0.38	0.35	0.33	0.3	0.28	0.25	0.23	0.2	0.18	0.15	0.13	0.1	0.08	0.05	0.03	0	0.03	0.05	0.08	0.1	0.13	0.15	0.18	0.2	0.23	0.25	0.28	0.3	0.33	0.35	0.38	0.4	0.43	0.45	0.48	0.5
Output voltage [V]	12.5	18.5	17.6	16.7	15.8	14.8	13.9	13.0	12.1	11.2	10.2	9.3	8.4	7.5	6.5	5.6	4.7	3.7	2.8	1.9	0.9	0	0.3	0.6	0.9	1.2	1.5	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3	4.5	4.8	5.1	5.4	5.7	6.0
	11.25	17.9	17.0	16.1	15.2	14.3	13.5	12.6	11.7	10.8	9.9	9.0	8.1	7.2	6.3	5.4	4.5	3.6	2.7	1.8	0.9	0	0.3	0.7	1.0	1.4	1.7	2.0	2.4	2.7	3.0	3.4	3.7	4.0	4.4	4.7	5.0	5.3	5.7	6.0	6.3	6.6
	10	17.3	16.4	15.5	14.7	13.8	13.0	12.1	11.3	10.4	9.5	8.7	7.8	7.0	6.1	5.2	4.4	3.5	2.6	1.7	0.9	0	0.4	0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.3	3.7	4.0	4.4	4.8	5.1	5.5	5.8	6.2	6.5	6.9	7.3
	8.75	16.6	15.8	15.0	14.2	13.3	12.5	11.7	10.9	10.0	9.2	8.4	7.5	6.7	5.9	5.0	4.2	3.4	2.5	1.7	0.8	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.6	6.0	6.3	6.7	7.1	7.5	7.9
	7.5	16.0	15.2	14.4	13.6	12.8	12.0	11.3	10.5	9.7	8.9	8.1	7.3	6.5	5.7	4.9	4.0	3.2	2.4	1.6	0.8	0	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.5	3.9	4.3	4.7	5.2	5.6	6.0	6.4	6.8	7.3	7.7	8.1	8.5
	6.25	15.4	14.6	13.9	13.1	12.3	11.6	10.8	10.1	9.3	8.5	7.8	7.0	6.2	5.4	4.7	3.9	3.1	2.3	1.6	0.8	0	0.5	0.9	1.4	1.9	2.3	2.8	3.3	3.7	4.2	4.6	5.1	5.5	6.0	6.4	6.9	7.3	7.8	8.2	8.7	9.1
	5	14.8	14.0	13.3	12.6	11.8	11.1	10.4	9.6	8.9	8.2	7.4	6.7	6.0	5.2	4.5	3.7	3.0	2.2	1.5	0.7	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.4	4.9	5.4	5.9	6.4	6.9	7.4	7.8	8.3	8.8	9.3	9.8
	3.75	14.1	13.4	12.7	12.0	11.3	10.6	9.9	9.2	8.5	7.8	7.1	6.4	5.7	5.0	4.3	3.6	2.9	2.2	1.4	0.7	0	0.5	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7	5.3	5.8	6.3	6.8	7.3	7.8	8.3	8.9	9.4	9.9	10.4
	2.5	13.5	12.8	12.2	11.5	10.8	10.2	9.5	8.8	8.2	7.5	6.8	6.1	5.5	4.8	4.1	3.4	2.7	2.1	1.4	0.7	0	0.6	1.1	1.7	2.2	2.8	3.4	3.9	4.5	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.8	9.4	9.9	10.5	11.0
	1.25	12.9	12.2	11.6	11.0	10.3	9.7	9.1	8.4	7.8	7.1	6.5	5.9	5.2	4.6	3.9	3.3	2.6	2.0	1.3	0.7	0	0.6	1.2	1.8	2.4	3.0	3.5	4.1	4.7	5.3	5.9	6.5	7.0	7.6	8.2	8.8	9.3	9.9	10.5	11.1	11.6
	0	12.3	11.6	11.0	10.4	9.8	9.2	8.6	8.0	7.4	6.8	6.2	5.6	5.0	4.3	3.7	3.1	2.5	1.9	1.2	0.6	0	0.6	1.2	1.9	2.5	3.1	3.7	4.3	5.0	5.6	6.2	6.8	7.4	8.0	8.6	9.2	9.8	10.4	11.0	11.6	12.3
	-1.25	12.9	12.2	11.6	11.0	10.3	9.7	9.1	8.4	7.8	7.1	6.5	5.9	5.2	4.6	3.9	3.3	2.6	2.0	1.3	0.7	0	0.6	1.2	1.8	2.4	3.0	3.5	4.1	4.7	5.3	5.9	6.5	7.0	7.6	8.2	8.8	9.3	9.9	10.5	11.1	11.6
	-2.5	13.5	12.8	12.2	11.5	10.8	10.2	9.5	8.8	8.2	7.5	6.8	6.1	5.5	4.8	4.1	3.4	2.7	2.1	1.4	0.7	0	0.6	1.1	1.7	2.2	2.8	3.4	3.9	4.5	5.0	5.6	6.1	6.7	7.2	7.8	8.3	8.8	9.4	9.9	10.5	11.0
	-3.75	14.1	13.4	12.7	12.0	11.3	10.6	9.9	9.2	8.5	7.8	7.1	6.4	5.7	5.0	4.3	3.6	2.9	2.2	1.4	0.7	0	0.5	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7	5.3	5.8	6.3	6.8	7.3	7.8	8.3	8.9	9.4	9.9	10.4
	-5	14.8	14.0	13.3	12.6	11.8	11.1	10.4	9.6	8.9	8.2	7.4	6.7	6.0	5.2	4.5	3.7	3.0	2.2	1.5	0.7	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.4	4.9	5.4	5.9	6.4	6.9	7.4	7.8	8.3	8.8	9.3	9.8
-6.25	15.4	14.6	13.9	13.1	12.3	11.6	10.8	10.1	9.3	8.5	7.8	7.0	6.2	5.4	4.7	3.9	3.1	2.3	1.6	0.8	0	0.5	0.9	1.4	1.9	2.3	2.8	3.3	3.7	4.2	4.6	5.1	5.5	6.0	6.4	6.9	7.3	7.8	8.2	8.7	9.1	
-7.5	16.0	15.2	14.4	13.6	12.8	12.0	11.3	10.5	9.7	8.9	8.1	7.3	6.5	5.7	4.9	4.0	3.2	2.4	1.6	0.8	0	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.5	3.9	4.3	4.7	5.2	5.6	6.0	6.4	6.8	7.3	7.7	8.1	8.5	
-8.75	16.6	15.8	15.0	14.2	13.3	12.5	11.7	10.9	10.0	9.2	8.4	7.5	6.7	5.9	5.0	4.2	3.4	2.5	1.7	0.8	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.6	6.0	6.3	6.7	7.1	7.5	7.9	
-10	17.3	16.4	15.5	14.7	13.8	13.0	12.1	11.3	10.4	9.5	8.7	7.8	7.0	6.1	5.2	4.4	3.5	2.6	1.7	0.9	0	0.4	0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.3	3.7	4.0	4.4	4.8	5.1	5.5	5.8	6.2	6.5	6.9	7.3	
-11.25	17.9	17.0	16.1	15.2	14.3	13.5	12.6	11.7	10.8	9.9	9.0	8.1	7.2	6.3	5.4	4.5	3.6	2.7	1.8	0.9	0	0.3	0.7	1.0	1.4	1.7	2.0	2.4	2.7	3.0	3.4	3.7	4.0	4.4	4.7	5.0	5.3	5.7	6.0	6.3	6.6	
-12.5	18.5	17.6	16.7	15.8	14.8	13.9	13.0	12.1	11.2	10.2	9.3	8.4	7.5	6.5	5.6	4.7	3.7	2.8	1.9	0.9	0	0.3	0.6	0.9	1.2	1.5	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3	4.5	4.8	5.1	5.4	5.7	6.0	

Table 9: Safe operating range for power potentiostat XPOT2