# Simultaneous multi-point EIS using the peripheral port



# Introduction

A typical potentiostat measures EIS at the working electrode (WE). In 2-electrode measurement configuration, where WE+S and CE+RE are paired, the EIS result will be the total cell impedance. However, when measuring in the 3-electrode configuration, when a discrete reference point or electrode is used, the connections are WE+S, RE and CE. In this case the EIS will be measured between WE+S and RE, resulting in the impedance of the 'half-cell'.

There are various applications where it can be useful to measure EIS at multiple points in your cell, simultaneously. For example, if you wish to measure not only the impedance between WE+S and RE (the 'half-cell'), but also the impedance of the total cell (between WE and CE). Or even at multiple points in a cell or cell-stack.

For these applications Ivium offers the solution to use the peripheral port (analog input(s)) to measure additional impedances.

# Ivium peripheral port

Most Ivium potentiostats are equipped with a peripheral port, i.e. a connector that gives access to analog inputs, which can be used to measure additional impedances. An additional module may be required for this application. Some Ivium potentiostats without a peripheral port may have analog input 1 available on the cell connector through the WE2 pin. Your instrument specifications (see IviumSoft helpfile for specifications) will list if this option to connect to the analog input 1 is available.

#### Activating peripheral EIS

To allow correct measurement of EIS on the peripheral port, first **check the option** *Stackanalyser/PDA* in **the options>options window** accessed from the top menu bar of IviumSoft (see below). Here, PDA refers to any of PDA2, sPDA, PDA-T, Cell-PDA, OctoPDA, and OctoPDA-T.

Instrument Options:		×
Settings FRA Settings		
Environment 60 Hz Extended Range Edoubler / X100V eExtender 50V CompactStat.8V CompactStatPlus Type II IviumBoost	Data Display Mpy Instead Of mm/yr Automatic Charge Calc. 100A Booster High speed Gstat mode Stacked configuration Max 100A Booster current (CE abs) 105.0 A	Calibrate WE32 offsets Calibrate FastScan Fastscan Default
<ul> <li>Type II</li> <li></li></ul>	XP properties       Shutoff at         XP High Curr Connector       Emax         Remote EM0       Emin         Use Temp sensor       Tmax	Wait 20s to continue
		Close

# Cell-PDA

The Cell-PDA module connects between your Ivium potentiostat and the cell cable and gives access to the analog input 1.



The cell-PDA module creates 1 high impedance differential analog input signal. A terminal block allows connection of your leads of choice.

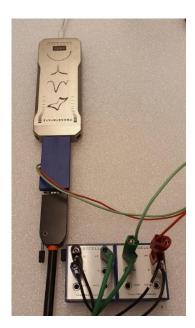
Using the Cell-PDA for a multi-point simultaneous EIS measurement will result in 2 impedance signals:

- 1 EIS signal from the cell cable
- 1 EIS signal from the Cell-PDA

#### Example 1: resistor measurement

#### <u>Setup</u>

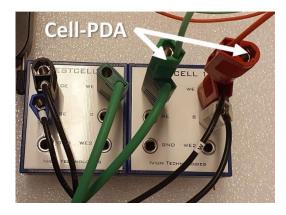
In this example a PocketSTAT2 potentiostat + Cell-PDA is connected to 2 x Testcell1 in series (each 1kOhm).



Note that the Cell-PDA is up-side down in the picture because of the orientation of cell connector of the pocketSTAT2.

The CE+RE of the cell cable are connected to the TestCell1 to the left, the WE+S of the cell cable are connected to the Testcell1 to the right.

The Cell-PDA is connected across the Testcell1 to the right.



This connection should result in 2 impedance signals of 2kOhm and 1kOhm respectively.

#### <u>IviumSoft</u>

LinearSweep     CyclicVoltammet     Transients     ElectroAnalysis     Impedance     Constant E     Constant E     DetrialSca     CurrentScan     E- Corrosion	'n		
	Value		Unit
Title	Cell-PDA		
+Redefine filename	Dff		
E start	0.0	0000	V
Equilibration time		0	s
Frequencies	24		
Current Range	100uA		
+Noise Reduction	Dff		
Filter	automatic		
Stability	automatic		
Connect to	Cell-4EL		
+AutoCR	Dff		
+Apply wrt OCP	Dff		
+Cell after meas	Dff		
Pretreatment	0		levels
Pretreat each freq	Dff Off		
Data Options			
+AUX	Dff		
+Anout2	Dff		
+Modules	Dff		
MeasConfig	standard		
ElSperipheral	1 channel	+	

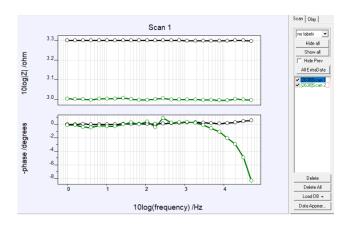
The measurement is done using the technique Impedance Constant E (50kHz to 1Hz, 50mV amplitude, 5 freq/decade):

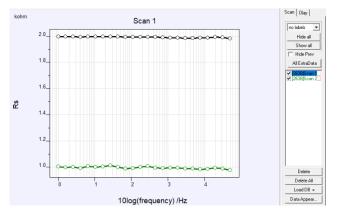
To activate the EIS measurement on the Cell-PDA (analog input) select the method parameter "EISperipheral" and choose "1 channel".

Ensure the option *Stackanalyser/PDA* is active in the options>options window (see page 1).

#### Measurement

Running the measurement will result in 2 EIS signals in the same graph. Each signal will be stored separately in its own scan in the Legend panel. Each scan can be analysed in the Sigview window and can be fitted in the Equivalent circuit evaluator.





Scan 1 (black) is the primary signal, i.e. the cell cable. Scan 2 (green) is Cell-PDA signal

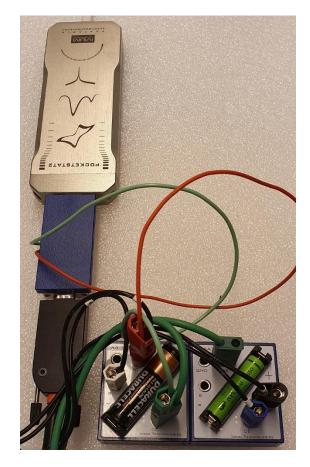
As can be seen, the measured signals correspond to the connections:

Scan 1: Cell cable - 2 x Testcell1 in series - 2kOhm Scan 2: Cell-PDA - Testcell1 to the right - 1kOhm

#### Example 2: measurement on 2 batteries

<u>Setup</u>

In this example a PocketSTAT2 + Cell-PDA is connected to 2 batteries in series, an AA-battery and an AAA-battery.



The WE+S are connected to the + of the battery to the left. The CE+RE are connected to the - of the battery to the right. The cell cable will thus measure the impedance of the total (= the two batteries in series).

The Cell-PDA is connected across the battery to the left. Cell-PDA +ve channel to AA battery +ve terminal and Cell-PDA -ve channel to AA battery -ve terminal.



# <u>IviumSoft</u>

The measurement is done using the technique Impedance Constant I (10kHz to 1Hz, 20mA amplitude, 5 freq/decade):

Direct Method		
		•
ElinearSweep     CyclicVoltammet     CyclicVoltammet     Transients     ElectroAnalysis     Impedance     Constant E     Constant I     OtentialSca     CurrentScan     E. Corrosion	'n	
	Value	Unit
Title	Cell-PDA	
+Redefine filename	🔲 Off	
l start	0.0	100 μA
Equilibration time		0 s
I_Frequencies	21	
Current Range	100uA	
+Noise Reduction	🔲 Off	
Filter	automatic	
Stability	automatic	
+Curr after meas	Dff Off	
IPretreatment	0	levels
Data Options		
+AUX	Off Off	
+Anout2	Dff Off	
+Modules	Dff Off	
MeasConfig	standard	
ElSperipheral	1 channel 🛛 🚽	
Report		

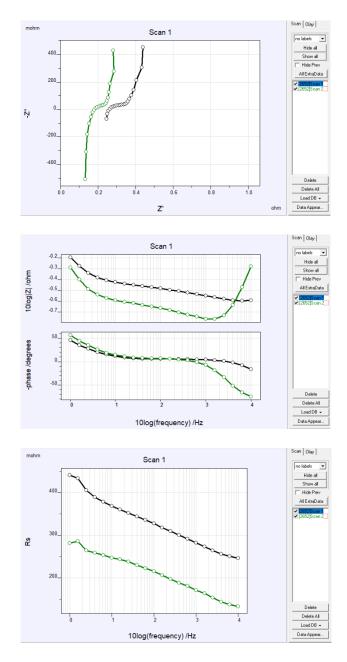
To activate the EIS measurement on the Cell-PDA (analog input1) select the method parameter "EISperipheral" and choose "1 channel". Now the analog input 1 is measured via the Cell-PDA.

Ensure the option *Stackanalyser/PDA* is active in the options>options window (see page 1).

#### Measurement

Running the measurement will result in 2 EIS signals in the same graph. Each signal will be stored separately in its own scan in the Legend panel. Each scan can be analysed in the Sigview window and can be fitted in the Equivalent circuit evaluator.

In the result graphs below the Nyquist plot, Bode plot and Rp results are shown.



In the measurement results, the different impedances can clearly be distinguished between the total (black line, scan1) and the AA-battery to the left (green line, scan2).

# sPDA

Most Ivium potentiostats that are equipped with a peripheral port have a 15pin subD connector to interface with this port. The sPDA is a module that connects to the 15pin peripheral port.



It creates 2 high impedance differential analog input signals (Ch1 and Ch2) that can be connected directly to the cell using 4mm bananas.

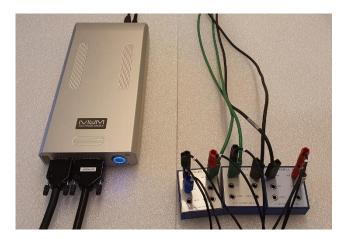
Using the sPDA for a multi-point simultaneous EIS measurement will result in up to 3 impedance signals:

1 EIS signal from the cell cable up to 2 EIS signals from the sPDA

Example 3: resistor measurement

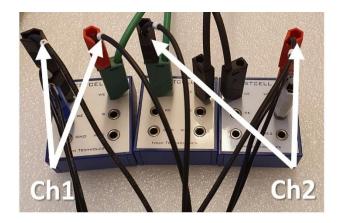
#### <u>Setup</u>

In this example a Vertex.1A.EIS potentiostat + sPDA is connected to 3 x Testcell1 in series (each 1kOhm).



The CE+RE of the cell cable are connected to the TestCell1 to the left, the WE+S of the cell cable are connected to the Testcell1 to the right.

On the sPDA, Ch1 is connected across Testcell1 to the left, Ch2 is connected across the 2 x Testcell1 to the right.



This connection should result in 3 impedance signals of 3kOhm, 1kOhm and 2kOhm respectively.

The measurement is done using the technique Impedance Constant I (10kHz to 10Hz, 1mA amplitude, 5 freq/decade):

Image: Constant Point Scan         Constant Scan         Stability         Stability         IntA         Stability         automatic         Stability         automatic         Inta Options         Inta Options         Autox         Off         Autox         Off         Autox         Off         Autox         Off         Autox         Off         Autox         Off	Direct Method		
• CyclicVoltammetry         • Transients         • ElectroAnalysis         • ElectroAnalysis         • Constant E         • PotentialScan         • Constant E         • PotentialScan         • PotentialScan         • PotentialScan         • PotentialScan         • Constant E         • PotentialScan         • Constant E         • Off         • I Stability         • I Confi         • I Confi         • CurrentRange         • I Confi			•
Title         sPDA           +Redefine filename         Off           I start         0.000           Equilibration time         0           I_Frequencies         16           I_Frequencies         16           Current Range         ImA           +Noise Reduction         Off           Filter         automatic           Stability         automatic           Perturafter meas         Off           IPretreatment         0           Data Options         Off           +AUX         Off           +Modules         Off           EISperipheral         2 channels	CyclicVoltammet     Transients     ElectroAnalysis     Impedance     Constant E     Constant I     PotentialSca     CurrentScan	n	
+Redefine filename         Off         mA           I start         0.000         mA           Equilibration time         0.000         s           I_Frequencies         16         s           L_Frequencies         1mA         s           +Noise Reduction         0ff         s           Filter         automatic         s           stability         automatic         s           +Curr after meas         0ff         s           IPretreatment         0         s           Data Options         0ff         s           +AlUX         0ff         s           +Modules         0ff         s           IPretreatment         0ff         s           +AlDX         0ff         s           +Alout2         0ff         s           IPretreatment         0ff         s           +Anout2         0ff         s           IPretreatment         0ff         s           +Anout2         0ff         s           IPretreatment         0ff         s           IPretreatment         0ff         s           +Anout2         0ff         s <t< td=""><td></td><td>Value</td><td>Unit</td></t<>		Value	Unit
I start     0.000     mA       Equilibration time     0.000     s       I_Frequencies     16     s       L_Frequencies     16     s       Current Range     1mA     s       +Noise Reduction     0ff     s       Filter     automatic     s       stability     automatic     s       +Curr after meas     0ff     levels       Data Options     0ff     s       +AUX     0ff     s       +Modules     0ff     s       ISperipheral     2 channels     s	Title	sPDA	
Equilibration time       Image       s         I_Frequencies       16       Image         Current Range       1mA       Image         +Noise Reduction       0ff       Image         Filter       automatic       Image         Stability       automatic       Image         +Curr after meas       0ff       Image         IPretreatment       0       Image         AUX       0ff       Image         +Anout2       0ff       Image         +Modules       0ff       Image         IEISperipheral       2 channels       Image	+Redefine filename	Dff Off	
I_Frequencies       16       1         Current Range       1mA       1         +Noise Reduction       0ff       1         Filter       automatic       1         Stability       automatic       1         +Curr after meas       0ff       1         IPretreatment       0       1         Data Options       0ff       1         +AUX       0ff       1         +Modules       0ff       1         MeasConfig       standard       1         EISperipheral       2 channels       1	l start	0.000	mΑ
Current Range     ImA       +Noise Reduction     Off       Filter     automatic       Stability     automatic       +Curr after meas     Off       IPretreatment     O       Data Options     Image       +AUX     Off       +Anout2     Off       +Modules     Off       EISperipheral     2 channels	Equilibration time	0	s
+Noise Reduction     Off       Filter     automatic       Stability     automatic       +Curr after meas     Off       Pretreatment     Off       Data Options     Image: Config       +AUX     Off       +Anout2     Off       +Modules     Off       EISperipheral     2 channels	I_Frequencies	16	
Filter     automatic       Stability     automatic       +Curr after meas     Off       IPretreatment     0       Data Options     Image: Config C	Current Range	1mA	
Stability     automatic       +Curr after meas     Off       IPretreatment     0       Data Options     Ievels       +AUX     Off       +Anout2     Off       +Modules     Off       IPseripheral     2 channels	+Noise Reduction	Díf Off	
+Curr after meas Off levels IPretreatment O levels Data Options Off +AUX Off +Anout2 Off +Modules Off 4 +Modules Off 4 IPretreatment O levels Off 4 IPr	Filter	automatic	
IPretreatment     0     levels       Data Options	Stability	automatic	
Data Options	+Curr after meas	Díf Off	
+AUX 0ff +Anout2 0ff +Modules 0ff MeasConfig standard 2 EISperipheral 2 channels	IPretreatment	0	levels
+Anout2 Off +Modules Off MeasConfig standard EISperipheral 2 channels	Data Options		
+Modules Diff MeasConfig standard EISperipheral 2 channels	+AUX	Dff Off	
MeasConfig     standard       EISperipheral     2 channels	+Anout2	Dff Off	
EISperipheral 2 channels	+Modules	Dff Off	
	MeasConfig	standard	
Report	ElSperipheral	2 channels 🛛 🔶	
	Report		

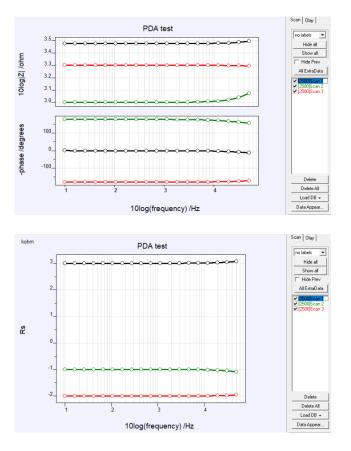
To activate the EIS measurement on the sPDA (analog inputs) select the method parameter "EISperipheral" and choose "1 channel" or "2 channels". Now both Ch1, or both Ch1 and Ch2 of the sPDA will be used.

Ensure the option *Stackanalyser/PDA* is active in the options>options window (see page 1).

#### <u>Measurement</u>

Running the measurement with 2 channels will result in 3 EIS signals in the same graph. Each signal will be stored separately in its own scan in the Legend panel. Each scan can be analysed in the Sigview window and can be fitted in the Equivalent circuit evaluator.

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Scan 1 (black) is the primary signal, i.e. cell cable. Scan 2 (green) is Ch1 of the sPDA

Scan 3 (red) is Ch2 of the sPDA.

As can be seen, the measured signals correspond to the connections:

Scan 1: 3xTestcell1 - 3kOhm

- Scan 2: Testcell1 to the left 1kOhm
- Scan 3: 2xTestcell1 to the right 2kOhm

#### Example 4: measurement on 2 batteries

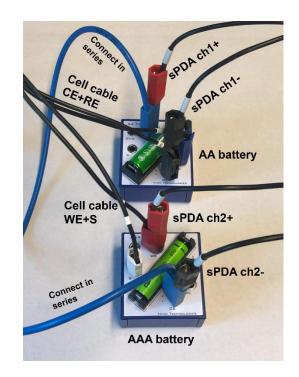
#### <u>Setup</u>

In this example a Vertex.1A.EIS + sPDA is connected to 2 batteries in series, an AA battery and an AAA battery.

The CE+RE are connected to the - of the AA battery (top). The WE+S are connected to the + of the AAA battery (bottom). The cell cable will thus measure the impedance of the total (= the two batteries in series).

The sPDA is connected with Ch1+ to the + of the AA battery (top) and Ch1- to the - of the AA battery (top).

The sPDA is connected with Ch2 + to the + of the AAA battery (bottom) and Ch2 - to the - of the AAA battery (bottom).



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The measurement is done using the technique Impedance Constant I (10kHz to 10Hz, 50mA amplitude, 5 freq/decade):

	n		
	Value		Unit
Title	sPDA		
+Redefine filename	Off		
l start	0.00	00	mΑ
Equilibration time		0	s
I_Frequencies	16		
Current Range	100mA		
+Noise Reduction	Off Off		
Filter	automatic		
Stability	automatic		
+Curr after meas	Dff Off		
IPretreatment	0	1	levels
Data Options			
+AUX	Dff		
+Anout2	Dff		
+Modules	Dff Off		
MeasConfig	standard		
ElSperipheral	2 channels	4	
Report		1	

To activate the EIS measurement on the sPDA (analog inputs) select the method parameter

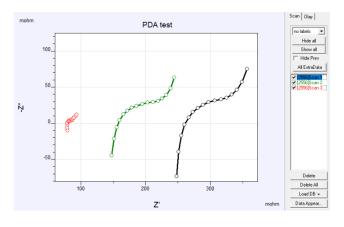
"EISperipheral" and choose "2 channels". Now both Ch1 and Ch2 of the sPDA will be used.

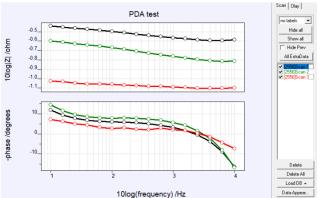
Ensure the option *Stackanalyser/PDA* is active in the options>options window (see page 1).

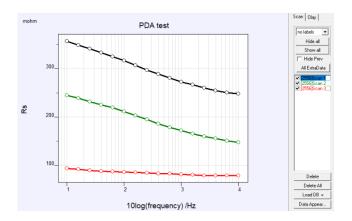
#### <u>Measurement</u>

Running the measurement will result in 3 EIS signals in the same graph. Each signal will be stored separately in its own scan in the Legend panel. Each scan can be analysed in the Sigview window and can be fitted in the Equivalent circuit evaluator.

In the result graphs below the Nyquist plot, Bode plot and Rp results are shown.







In the measurement results, the different impedances can clearly be distinguished of the total (black line, scan1), battery1 (green line, scan2) and battery2 (red line, scan 3).

#### StackAnalyser

The StackAnalyser is a module that can be connected to the 15pin peripheral port of an Ivium potentiostat.



The module is powered from a 5V DC power supply and connects to the 15pin subD connector of the peripheral port. At the front the StackAnalyser has 8 channels, each with 2 BNC connectors for the Chand Ch+ respectively. In this case, each of the 16 BNCs has its own BNC to 4mm banana cable.

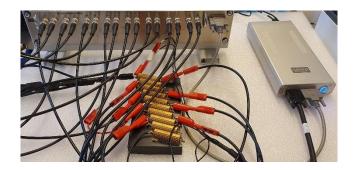
The Ch- and Ch+ connections of each of the 8 channels can be connected to any point of the cell or cell-stack.

When the StackAnalyser is connected, the user can make a choice to measure 1, 2, 4 or all 8 channels. Together with the primary cell cable, this results in a maximum of 9 EIS signals.

#### Example 5: resistor measurement

#### <u>Setup</u>

In this example a Vertex.1A.EIS potentiostat + StackAnalyser is connected to  $10 \times 10$  hm resistors in series.



The WE+S of the cell cable are connected to the resistor to the left, the CE+RE of the cell cable are connected to the resistor to the right.

On the StackAnalyser, The Ch- of each of the 8 channels are connected to the resistor to the left; the Ch+ of each channel is connected across each following resistor (i.e. Ch1+ across the resistor to the left, Ch2+ across the next resistor from the left, Ch3+ to the third resistor in line, etc.).



This connection should result in 9 impedance signals of 10 Ohm and 1 Ohm – 8 Ohm respectively.

#### <u>IviumSoft</u>

Subsequently, the measurement is done using the technique Impedance Constant E (50kHz to 1Hz, 50mV amplitude, 5 freq/decade):

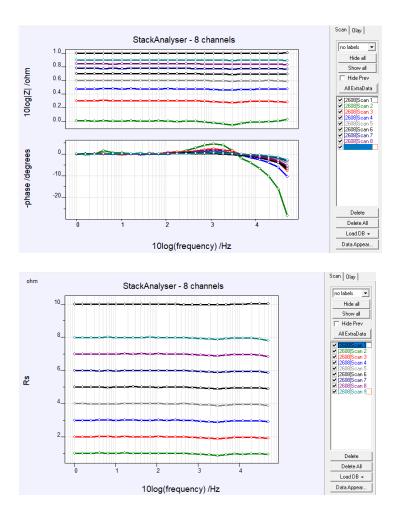
At the method parameter "EISperipheral" the number of channels needs to be selected (8 channels in this example). Now all 8 channels of the StackAnalyser will be measured.

Ensure the option *Stackanalyser/PDA* is active in the options>options window (see page 1).

			•
<ul> <li>DinearSweep</li> <li>CyclicVoltammet</li> <li>Transients</li> <li>ElectroAnalysis</li> <li>Impedance</li> <li>Constant E</li> <li>Constant IS</li> <li>PotentialSca</li> <li>CurrentScar</li> <li>Corrosion</li> </ul>	an		
	Value	_	Unit
Title	FRA	111	
+Redefine filename	Dff		
E start	0.00	000	V
Equilibration time		0	s
Frequencies	24		
Current Range	10mA		
+Noise Reduction	Dff Off		
Filter	automatic		
Stability	automatic		
Connect to	Cell-4EL		
+AutoCR	C Off		
+Apply wrt OCP	C Off		
+Cell after meas	C Off		
Pretreatment	0		levels
Pretreat each freq	C Off		
Data Options			
+AUX	C Off		
+Anout2	C Off		
+Modules	C Off		
MeasConfig	standard		
ElSperipheral	8 channels	4	
Report		1	

#### <u>Measurement</u>

Running the measurement with 8 channels will result in 9 EIS signals in the same graph. Each signal will be stored separately in its own scan in the Legend panel. Each scan can be analysed in the Sigview window and can be fitted in the Equivalent circuit evaluator.



Scan 1 is the primary signal, i.e. the cell cable. Scan 2 is Ch1 of the StackAnalyser Scan 3 is Ch2 of the StackAnalyser etc.

As can be seen, the measured signals correspond to the connections: Scan 1: cell cable – 10 Ohm Scan 2: resistor to the left – 1 Ohm Scan 3: 2nd resistor from the left – 2 Ohm etc.

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