

## Simultaneous Impedance measurements on each element of a running cell stack

### I- Introduction

Electrochemical generators such as primary and secondary batteries, fuel cells (FCs) and supercapacities are often made up of several elements connected in series. It is possible to connect dozens of these elements on FC stacks. The measure of the potential difference on each cell allows the user to detect if there is a dysfunction on a cell but does not give the reason why. On the other hand, impedance measurements on the different cells under a constant load, can be useful, for example, to determine the internal resistance value or if there is a problem with the gas distribution in the stack [1-6].

Theoretically, an impedancemeter alone is enough to proceed with the successive scans of each cell. However, given the number of elements to scan and the fact that one measure on a single cell can last over ten minutes, the system could derive in time. This might explain the fact that the impedance could be different from a cell to another. Also the use of a multiplexer between the different cells and the impedancemeter could be a source of artefacts.

The VMP3/Z multi-channel potentiostat and the EC-Lab Express module enable the user to make these measurements simultaneously. It reduces the experiment time significantly.

### 2 - Technical specificity of the stack applications

#### 2.1 – Materials and connection

This application requires a special set of cables to connect each channel to the elements of the stack. This set is provided upon request. The master channel is connected on the whole stack to control the current, measure the voltage and apply the AC stimulation. The slave channels are synchronized with the master one and measure the elements potential. The master channel can be coupled with a current booster 20 A/20 V to test the fuel cell stack and apply an AC signal of 10 A amplitude. Electronic loads are available too and can be connected to the master channel. These loads can receive up to 150 A and 20 V.

So these configuration can easily be used on

stacks of 20 elements of 100 cm<sup>2</sup> surface area.

#### 2.2 - Software

Ec-Lab Express software offers the user several specific techniques for fuel cell stack testing both in galvano and potention modes.

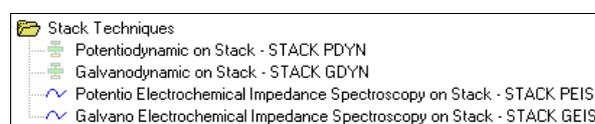


Figure 1 – Available stack techniques in EC-Lab Express software.

The GEIS stack technique (or another one) must be loaded on the master channel. When clicking on the Run button, the user will select the slave channel on which the EIS measurement will be done.

### 3 – Impedance measurement of an electrochemical generator

Two different protocols can be used to measure the impedance of the cells of a battery or of a stack. It can either be done with the galvanostatic impedance protocol (Fig. 2) or with a natural running protocol (Fig. 3). In the first case, the potentiostat delivers the discharge (or charge) current and the sine modulation of current. The impedance can then be directly measured on each cell. In the second case, the potentiostat only delivers the sine modulation, the impedance can only be measured on each cell if the charge impedance is high enough compared to the rest of the stack or if the value of the charge impedance is constant and has been already determined with an independent measurement.



Figure 2 – Galvanostatic impedance measurement on a cell stack

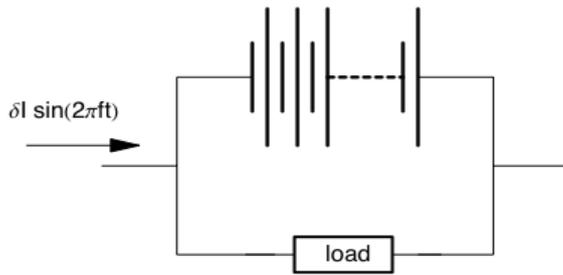


Figure 3 – Impedance measurement on a cell stack using a natural running protocol

#### 4 – Measurements on four batteries in series

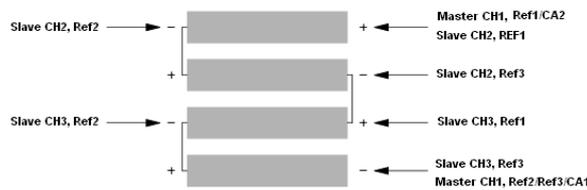


Figure 4 – Simultaneous impedance measurements on a 4-battery stack using only 3 channels of the VMP3/Z

These techniques have been tested on four alkaline batteries (type R6) connected in series. Only three channels of the VMP3/Z are needed to measure the impedance of the four batteries separately. The required connections of the cell cables with the four batteries in series are described on Fig. 4. These connections work with both protocols presented on Fig. 2 and Fig. 3. The first channel on which the parameters are loaded is the master channel. This channel will control the current and measure the potential of the whole stack. The two other channels will measure the 4 elements potential as slave channels synchronized with the master one.

##### 4.1 – In a relaxation regime (I=0)

The Nyquist representation of impedance diagrams measured simultaneously on four cells (relaxation regime) are presented on Fig. 5 (Galvanostatic impedance, I = 0).

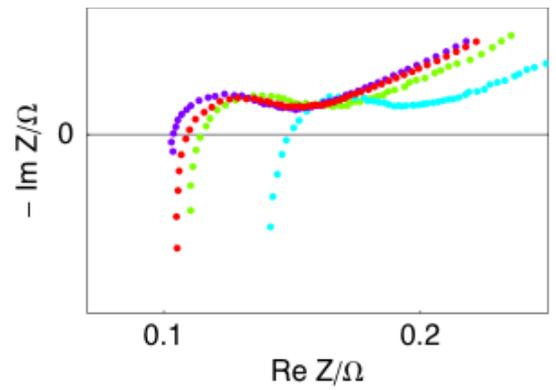


Figure 5 – Cell stack of four alkaline batteries (type R6). Impedance diagrams of simultaneous measurements on the four alkaline batteries. Galvanostatic mode (Fig. 1). I = 0,  $\delta I = 20 \text{ mA}$ ,  $f_{\min} = 0.1 \text{ Hz}$ ,  $f_{\max} = 50 \text{ kHz}$ .

##### 4.2 – In a charge regime

The Nyquist representation of impedance diagrams measured simultaneously on four cells in charge regime are presented on Fig. 6 (Galvanostatic impedance, I ≠ 0).

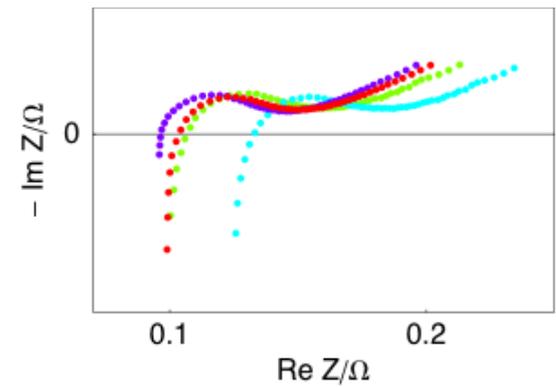


Figure 6 – Cell stack of four alkaline batteries (type R6). Impedance diagrams of simultaneous measurements on the four alkaline batteries. Galvanostatic mode (Fig. 1). I = 0.1 A,  $\delta I = 20 \text{ mA}$ ,  $f_{\min} = 0.1 \text{ Hz}$ ,  $f_{\max} = 50 \text{ kHz}$ .

##### 3.3 – In discharge regime

The Nyquist representations of pseudo-impedance diagrams measured simultaneously on four cells running on a 100 Ω resistor are presented on Fig. 7 (Galvanostatic impedance, I = 0).

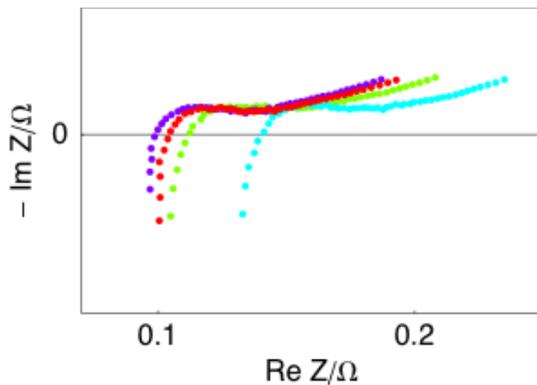


Figure 7 – Cell stack of four alkaline batteries (type R6). Impedance diagrams of simultaneous measurements on the four alkaline batteries running under a 100 Ω charge. Natural running mode (Fig. 2).  $\delta I = 20 \text{ mA}$ ,  $f_{\min} = 0.1 \text{ Hz}$ ,  $f_{\max} = 50 \text{ kHz}$ .

## 5 – Running a GEIS experiment on each element of a PEMFC Stack with EC-Lab® Express

The PEMFC stack used in this experiment is made with 16 elements of 25 cm<sup>2</sup> each. The “GEIS on stack” technique performs an impedance experiment in the galvanostatic mode simultaneously on different channels. The current is controlled and the sine modulation is imposed through the entire stack by the first channel called “master” channel. The connection is described in Fig. 4. the experiment was run on 13 elements of the stack, three of the potential measurement points were used by temperature probes.

To run an experiment with this technique, click on the “+” button in the experiment frame of EC-Lab® Express window and select “Stack GEIS”. The software’s main window is shown in Fig. 8.

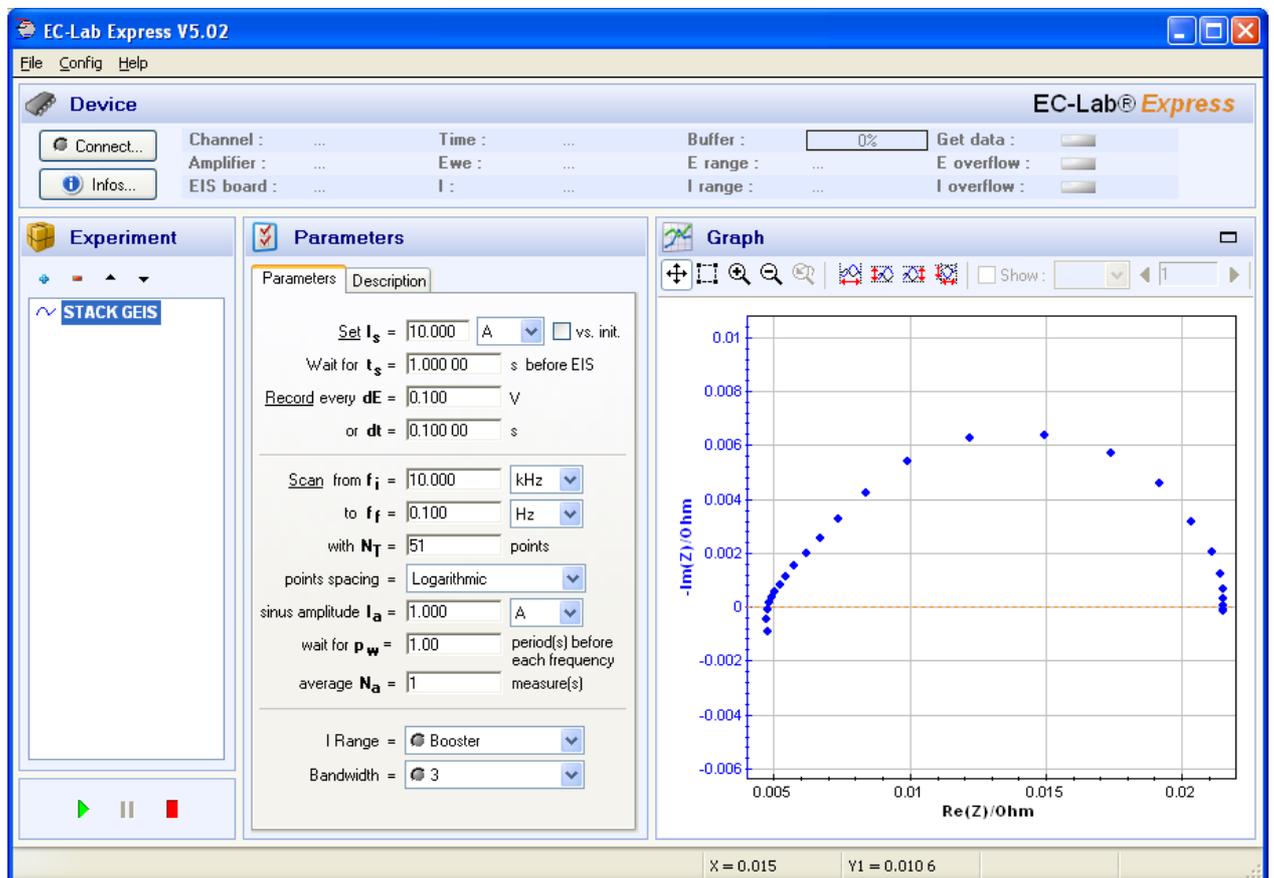


Figure 8 – Main window of ZStack protocol.

It is made of three parts:

- on the left: the experiment frame to add techniques at the experiment
- in the middle: the parameter setting frame

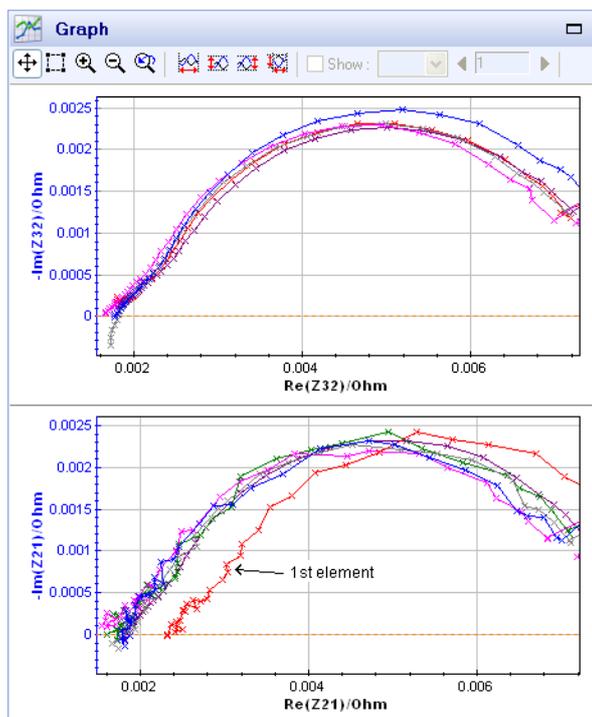
- on the right: the graphic display with the curve and the graphic tools.

The way to perform the experiment is as follows:

- 1 - Select the master channel in the device frame.

- 2 - Load the stack GEIS technique
- 3 - Choose the parameters
- 4 - Click on the "Run" button
- 5 - Select the slave channels
- 6- define a file name to store data

The data are displayed on separate graphs. The result of the stack GEIS experiment can be seen on figure 9 below.



**Figure 9 – Result of the simultaneous GEIS measurement on a PEM fuel cell Stack working at 50°C, 10 A.**

The general shape of the EIS curves present the classical main arc for fuel cells with a frequency on the top of the arc at 10 Hz.

All the curves present a similar shape with similar impedance. On the bottom graph, the red curve corresponding to the first element is shifted to the right. This is probably due to the different connexion on the extremity of the stack resulting in an higher contact resistance.

## Conclusion

- The simultaneous EIS measurements on 13 elements of a PEM fuel cell stack have been

demonstrated. EIS data can be fitted with electrical equivalent circuits in EC-Lab® Express software using ZFit too.

- Like the other products of our range, this option is is very modular and can be added on existing units (VMP2, VMP3 and VSP). EC-Lab® Express software is compatible with every unit cited above.

- Good measurements require a special set of instruments cables provided upon request.

- Depending on the size of the fuel cell stack, we can offer a range of current boosters from 2 A to 20 A / 20 V and a range of electronic loads also compatible with every unit cited above from 50 A / 20 V (500 W) to 150 A / 20 V (2 kW).

## References

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