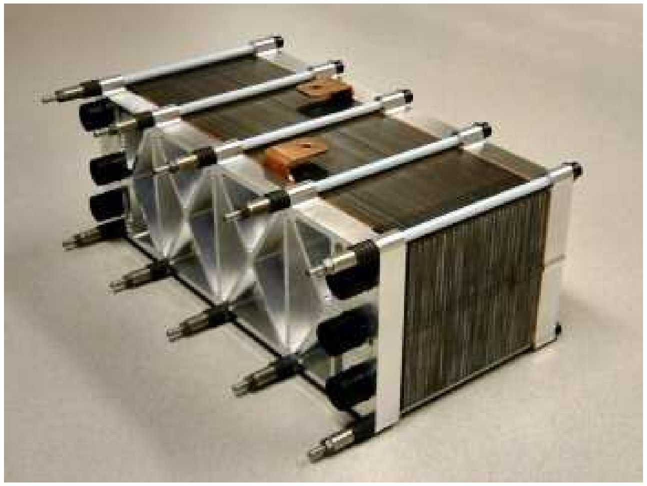


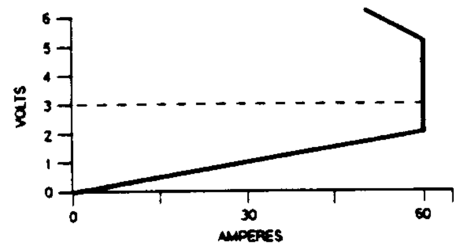
Impedance Measurements on Fuel Cells at high currents: Autolab in combination with an electronic load.

The use of impedance measurements on fuel cells under load, makes it possible to study the influence of the different fuel cell elements on the behaviour and (if present) the degradation of the fuel cell. However, most fuel cells operate at currents far higher than 1 A, while most potentiostat/FRA combinations are limited to 1 A. The maximum current of the PGSTAT30 with FRA2 module can be extended to 20A by use of the Booster20A, but even 20A is not enough to study a Polymer Fuel Cell of reasonable size (50 cm^2 for example). It is therefore desirable to be able to combine the PGSTAT30 with FRA2 module with an electronic load. The load is then capable of drawing the current from the fuel cell, whilst the Autolab is used to do the impedance measurements.

Choice of electronic load

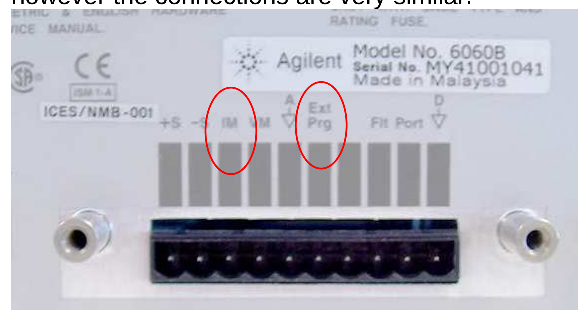
For the experiments presented in this application note we have used the Agilent 6060B load. The experiments described below also can be performed in combination with many other commercially available loads as well.
There are however some important requirements for the load:

1. The load needs to have the possibility for an external input. This is needed to take the frequency signal from the FRA module into the load.
2. Output of current as well as potential needs to be present. These are in turn connected to the external inputs of the FRA2 module.
3. The bandwidth of the electronic load is the limiting factor in the frequency range that can be used. The Agilent 6060B has a bandwidth of 10 kHz, limiting the frequency range that can be used to 2 kHz. Other loads are available with higher bandwidths.
4. The voltage range of the load should preferably start at 0 Volt, especially if measurements are done at single cells. Although the Agilent load is capable of measuring voltages below 3 Volt, the maximum current in that case is no longer 60A, but decreases rapidly with the voltage (see graph below).



Connections between Autolab and Load

The connections described below are specific for the Agilent 6060B load. For most other loads however the connections are very similar.



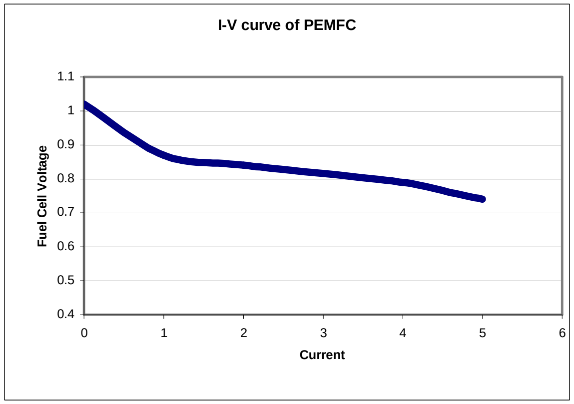
1. The FRA2 DSG output on the front of the FRA2 module is connected to the pin called “Ext Prg” on the back of the load as shown in the picture above.
2. The pin called IM (Current monitor) on the back of the load is connected to “Y” on the front of the FRA2 module.
3. The Eout (monitor cable of the PGSTAT30) is connected to the “X” on the front of the FRA2 module.

By using the connections described above, the current of the fuel cell is modulated by the frequency signal from the FRA2 module, and the impedance is calculated based on that current and the measured potential response from the differential amplifier.

Experimental conditions

The load used in these experiments has a maximum current of 60A, and a voltage range of 3-60 Volt.
Measurements were performed on a PEMFC fuel cell (7 cm^2) with Pt catalyst on both anode and cathode side. The fuel cell was operated on humidified H_2/O_2 at 65 ºC. For the impedance measurements an Autolab PGSTAT30 with FRA2 module was used, in combination with the FRA 4.9.005 software.
The load was only used to measure the current. The voltage of the cell was measured by using the differential amplifier of the PGSTAT30, as we found that this results in less noisy measurements.
The load was operated in galvanostatic mode, whereas the PGSTAT30 was operated in potentiostatic mode. The current range in the FRA software was fixed to 1 A. Since the current input (Ext Prg) and the current output (IM) of the load both have a range of 60A/10V, some multiplication factors need to be set in order to obtain the correct impedance values. For the load input (60A≡10V) the DSG signal of the Autolab is multiplied by 6 (and an additional factor of 10 of the DSG, see the installation note), so that 10 mV amplitude in the FRA software, results in a 600 mA perturbation on the fuel cell. For the load output the IM signal (60A≡10V) needs to be divided by 6, in order to obtain a 1A/V signal. These factors can be set in the dynload.ini file in the Autolab software.

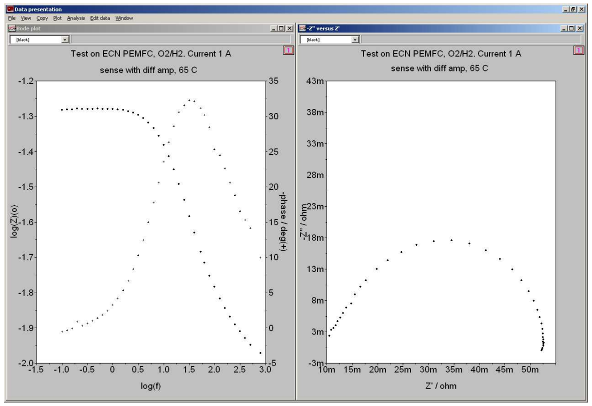
In the FRA software, in the FRA manual control window, the option 'use external inputs' needs to be selected.



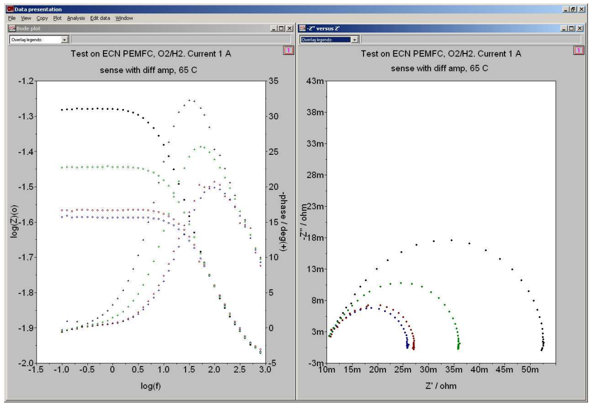
Experimental Results

The initial part of a full I-V curve of the fuel cell is shown in the graph below
Impedance measurements were done on several points along this I-V curve in a frequency range from 1 kHz to 100 mHz, with an amplitude of 40 mV in the Autolab software, or 400 mA in fuel cell current, which resulted in a voltage fluctuation of maximum 10 mV.

The graph below shows the results of a measurement at a DC current of 4.6A, or a fuel cell voltage of 0.76 Volt.



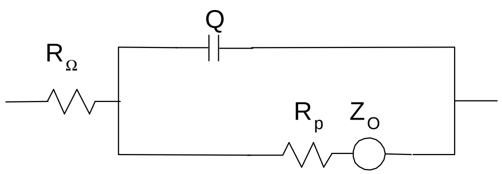
A comparison of impedance measurements at different fuel cell currents is shown below. (Black = 1A, Green = 2 A, Red = 4 A, Blue = 4.6 A)



Data Analysis

Choice of equivalent circuit

All data are analyzed using the fit and simulation program in the FRA software. The following circuit has been used to fit the data:



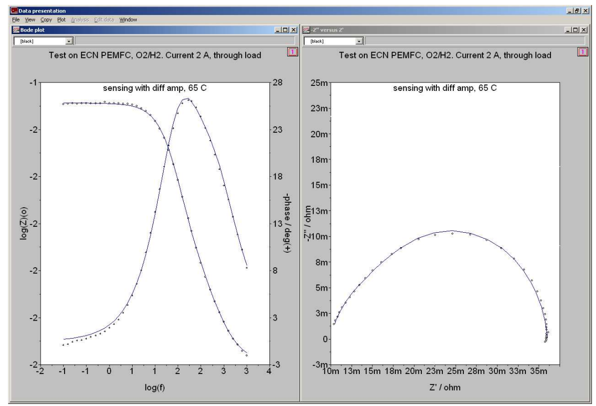
In which Q represents a so-called constant phase element, O is the cotangent hyperbolic diffusion element. This latter element is used in cases where finite diffusion plays a role. This is the case for example when a RDE is used, or in cases where diffusion takes place through a thin film or a coating. The idea is that the concentration of the species involved is constant in the bulk, but is determined by diffusion in the thin film close to the electrode.
The impedance of O is defined by:

$$\vec{Z}(\omega)=\left\{\frac{1}{Y_0\sqrt{j\omega}}\right\}\coth\left[B\sqrt{j\omega}\right]$$

Which upon fitting will result in two values, for Y_0 and B. The value for B depends on the diffusion layer thickness and the diffusion coefficient.

Fitting of the Data

In the graph below the impedance data taken at 2 A fuel cell current are shown, together with the fitted curve done with the before mentioned equivalent circuit.



The values for the different elements are given in the fit window on the right hand side.

The table below shows the values for the different elements at different currents.

	1 A	2 A	4 A	4.6 A
R_Ω	10.5 mΩ	10.1 mΩ	10.1 mΩ	10.2 mΩ
Rp	14.4 mΩ	10.1 mΩ	8.4 mΩ	8.8 mΩ
Q(Y0)	0.247	0.185	0.113	0.156
Q(n)	0.890	0.911	1.000	0.943
O(Y0)	4.33	6.37	11.39	11.86
O(B)	0.12	0.10	0.097	0.082

It is clearly visible from the table that upon change in current, especially the values for O (or the diffusion behavior) change.