How Cabling and Signal Amplitudes Affect EIS Results

Accurate EIS

Gamry Instruments prides itself on performing accurate EIS. We publish an Accuracy Contour Plot (ACP) for every instrument we sell. ACPs describe a region of accuracy over a given range of impedances and frequencies under a defined set of conditions.

Why Generate ACPs?

Why do we do this? Two main reasons:

1. So that you understand the ranges and limitations of our instruments when performing EIS under typical conditions
2. ACPs can change depending on cable length and signal amplitude

Generating an ACP typically starts with examining the open lead curve and the shorted lead curve. The open lead curve is meant to describe the absolute capacitive limits of the entire potentiostat and cable under a stated amplitude. Any result that you get from an EIS experiment that is at or above open lead curve should be thrown out no matter how nice the data appear. You are measuring the capacitance of your measurement system and not your sample. Extremely well insulating coatings can be one example.

Potentiostatic experiments are typically performed at 10 mV rms or smaller in order to maintain a linear response. Remember that in order for EIS results to be valid, your system needs to be linear, stable, and casual. Linearity, stability, and causality can assessed using Gamry's built-in Kramers-Kronig function found in our analysis software. Galvanostatic experiments are a little bit different in that the current amplitudes can get larger as long as the voltage response maintains linearity – i.e. passes the Kramers-Kronig test.

ACPs of the Interface 1000

ACPs are only valid under the applied conditions. For example, the ACP for the Interface 1000 as seen below shows that you can measure impedances from 3 GΩ down to less than 1 mΩ at greater than 99% accuracy. The lower impedance limit is useful to know when examining energy storage and conversion devices while the upper impedance limit is useful for corrosion-resistant materials and well-coated samples. It is also helpful to know the capacitive limit, seen as an increasing line as frequency decreases, for well-coated samples. If you were to use a longer cable you would expect a decrease in bandwidth due to the added R and C.

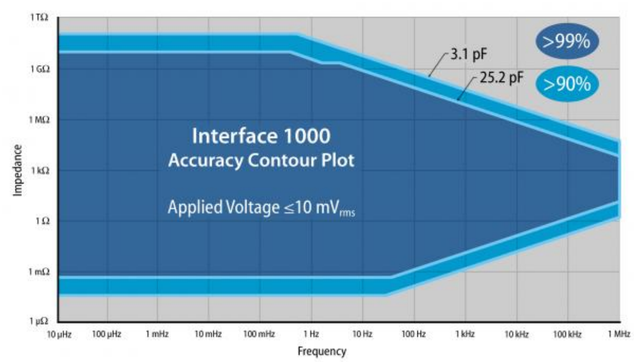

Figure 1. Accuracy Contour Plot for an Interface 1000 with a 60 cm cell cable and ≤ 10 mV rms signal amplitude.

Gamry's standard cell cable is 60 cm but we also have 1.5, 3, and 10 m cables available as options. Since the open lead curve is the measure of the instruments capacitive limit for a measurement, we measured the open lead curve for the 3 and 10 m cables also. Additionally, we measured the open lead curve without a cable. As shown in **Figure 2**, the maximum applied frequency decreases as a function of cable length. The capacitive region of the ACP decreases slightly as the cable length is increased. The No Cable line falls in the middle due to the unshielded shunts we used to short the pins on our cell cable connector. Notice too that the maximum impedance limit decreases as a function of cable length due to the increased R of the cable.

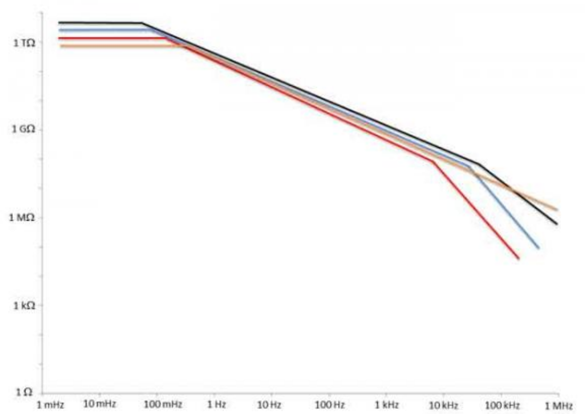

Figure 2. Open Lead Curve for an Interface 1000 with a 10mV rms amplitude and different cable lengths. Orange curve – no cable; Black curve – 60 cm; blue curve – 3 m; Red curve – 10 m.

Changing the signal amplitude also has an effect on the ACP. An increase in amplitude increases signal to noise, pushing the capacitive limit higher as shown in Figure 3. Signal amplitudes of 1, 10, 100, and 707 mV rms were used to generate the four open lead curves. A 60 cm cell cable was used. Though it seems logical to use larger amplitudes, in reality, the larger amplitude likely invalidates the linearity criterion of EIS.

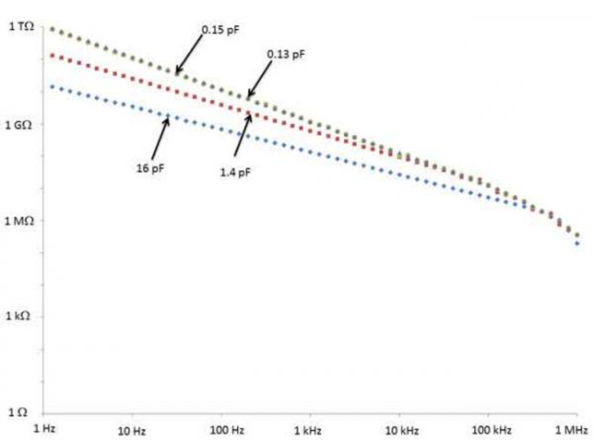

Figure 3. Open Lead Curve for an Interface 1000 using a 60 cm cell cable with different signal amplitudes. Blue diamonds – 1 mV rms; Red squares – 10 mV rms; Green dots – 100 mV rms; Purple triangles – 707 mV rms.

Consider the potentiodynamic scan shown in **Figure 4**. The response is linear around the open circuit potential but moving away from open circuit creates a non-linear response.

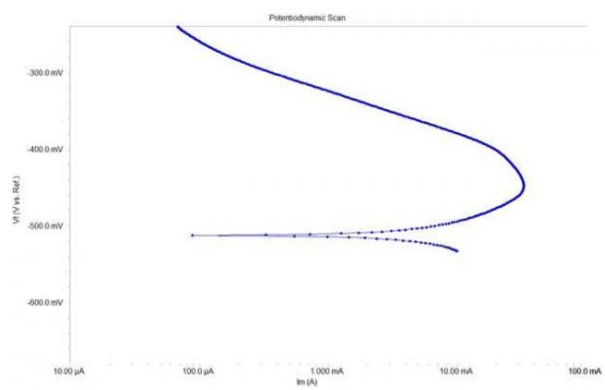

Figure 4. Potentiodynamic scan on 430 SS in 1 M H_2SO_4. 0.167 mV/s.

Hence, in an EIS experiment, you need to use small amplitudes such as 10 mV. As can be seen in the ACPs shown in **Figure 3**, the capacitive limit increases when you use larger signals but as was just mentioned you cannot use larger signals without risk of damaging the sample. These are the changes that affect the capacitive region of the ACPs. The second important region is the lower impedance limits and bandwidth.

The lower impedance limits are typically determined by the maximum current of the instrument along with instrument design. Separation of the current carrying leads from the sense leads increases the bandwidth for the inductive region. Note that the 1.5 m Low Z cable has separated current carrying and sense leads thereby increasing the bandwidth as shown in the plot below. The plots shown here are for an uncalibrated 0.500 mΩ shunt whose actual bandwidth is unknown. The illustration of the plot is to show the effect of increased cable length on bandwidth.

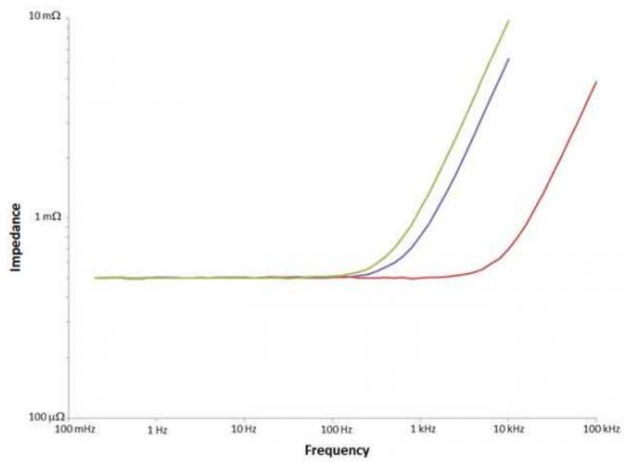

Figure 5. ACP showing lower impedance limits for three different cable on an Interface 1000 using a signal amplitude of 100 mA rms. Blue - 60 cm, green - 1.5 m, purple - Low Z cable.

What is the point of all this?

Lots of instrument manufacturers don't publish ACPs and of those that do they don't provide you with realistic or even any conditions related to how those ACPs were generated. Be sure you understand the limits of any instrument before making your purchase.

The purpose of this technical note is to describe the effect of signal amplitudes and cable lengths on accuracy contour plots. Gamry prides itself on providing accurate ACPs generated using real-world signal amplitudes and actual cell cables.

C3 Prozess- und Analysentechnik GmbH
Peter-Henlein-Str. 20
85540 Haar b. München

Tel: 089/45600670
FAX: 089/45600680

info@c3-analysentechnik.de
www.c3-analysentechnik.de

www.gamry.com