



Redefining Electrochemical Measurement

## EIS300™ Electrochemical Impedance Spectroscopy Software

Electrochemical impedance spectroscopy (EIS) is a powerful electrochemical technique that has enjoyed wide acceptance in the modern electrochemical laboratory. EIS is routinely employed in battery development, sensor evaluation, fuel cell characterization, corrosion science, paint testing, and physical electrochemistry.

The EIS300™ Electrochemical Impedance Spectroscopy Software from Gamry is an exceptional value in EIS with unsurpassed performance and versatility. Use the EIS300 to measure the impedance between 10  $\mu$ Hz and 300 kHz. With three research potentiostats and three modes of EIS measurement, a Gamry EIS system can reliably measure impedances as low as 1 m $\Omega$  or as high as 10<sup>13</sup>  $\Omega$ !

The EIS experiment places some critical demands upon potentiostat performance. Gamry understands sometimes-subtle potentiostat behavior and how it is affected by the sample. More than anyone, Gamry designs potentiostats for EIS — every Gamry Potentiostat leaves the factory ready to perform EIS!

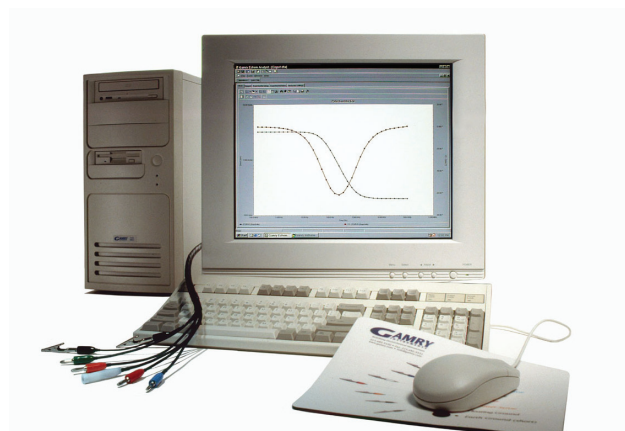
In 1995, Gamry pioneered a novel single-sine EIS technique called Sub-Harmonic Sampling. Every Gamry Potentiostat includes the electronics for Sub-Harmonic Sampling, so there's no need to purchase any additional instrumentation. When the EIS300 software is installed, the Potentiostat is ready to record impedance spectra.

A Gamry EIS System with Sub-Harmonic Sampling has several benefits:

- Accuracy and precision are equal to or better than other EIS techniques.
- The instrumental footprint is small, saving bench space.
- The instrumental configuration is simplified -- no tangled web of BNC cables connecting several instruments.
- Your ability to tailor the Gamry EIS System to your specific sample is not compromised.
- Lower cost than alternative techniques.

If a special application arises, Gamry's **Open Source Scripting** allows you to make software changes to perform

your custom experiment -- either in the data acquisition or the data analysis! If you like, Gamry can modify the software under your direction.



*The EIS300 Electrochemical Impedance Spectroscopy System packs a powerful punch in a pristine package! The clean, space-saving design liberates bench space in your lab.*

Like most Gamry software, the EIS300 and a Gamry Potentiostat use the Gamry Framework™ for data acquisition and the Echem Analyst™ for data analysis. The general features of the Gamry Framework and the Gamry Echem Analyst are described in a separate brochure entitled "An Overview of Gamry Software".

Gamry has an instrument for virtually every technique in the electrochemical laboratory. Other Gamry software includes DC Corrosion Techniques, Cyclic Voltammetry, Pulse Voltammetry, Electrochemical Frequency Modulation, Electrochemical Noise, and Critical Pitting Temperature. Measure the impedance of a fuel cell with the FC350 Fuel Cell Monitor. You can be confident that your Gamry system can adapt as your electrochemical needs expand.

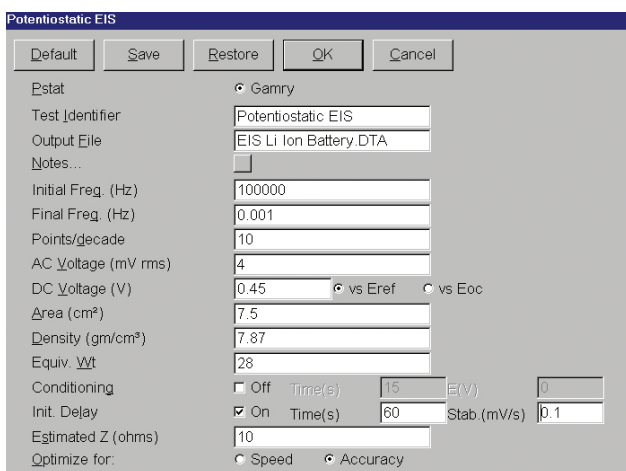
A Gamry EIS System can be configured in a desktop or in a portable computer for experiments in the field or for convenient transport to other locations. All Gamry Potentiostats are electrically floating, so you can perform experiments on grounded samples.

The EIS300 performs the following electrochemical impedance spectroscopy techniques:

- Potentiostatic EIS
- Multiplexed Potentiostatic EIS
- Galvanostatic EIS
- Hybrid EIS
- Single Frequency EIS
- Mott Schottky

## Potentiostatic EIS

Potentiostatic EIS measures the impedance by applying a sinusoidal voltage to the sample and measuring the current. A DC voltage of  $\pm 8$  volts and an AC voltage of 1.8 V rms may be applied to the sample. Measure up to 1000 points/decade and collect up to 65,535 data points! Potentiostatic EIS is the most popular EIS technique and is favored by corrosion scientists and sensor developers.



*Setup Window for Potentiostatic EIS. Every parameter required to make the EIS measurement is available on the single Setup Window.*

## Multiplexed Potentiostatic EIS

Multiplexed Potentiostat EIS is used with the ECM8 Multiplexer to automate the measurement on as many as eight samples. The ECM8 is an excellent tool to move more samples through your laboratory and is often used in paint testing and corrosion inhibitor testing programs.

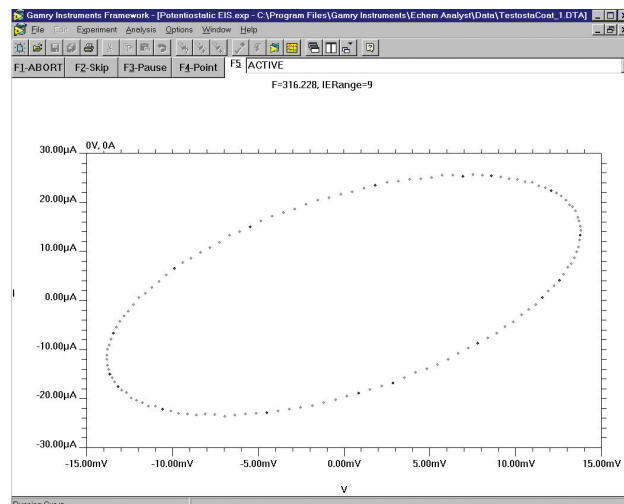
## Galvanostatic EIS

Galvanostatic EIS involves the application of an AC current and measurement of the potential. Galvanostatic EIS is commonly used in battery and fuel cell studies. It is also often recommended for corrosion samples with an unstable open-circuit potential.

## Hybrid EIS

Galvanostatic EIS is a perfectly valid technique for EIS, but it must be used carefully to obtain valid results. It is possible for the sample to encounter voltage levels during Galvanostatic EIS that threaten the integrity of the experiment. For example, a sample impedance of 1  $\Omega$  at

100 kHz will result in a voltage of 10 mV with a 10 mA excitation. If the impedance increases to 100  $\Omega$  at 100 Hz, however, the 10 mA excitation will produce a voltage of 1000 mV, almost certainly outside the linear range and possibly even damaging to the sample.



*A Lissajous Figure Displayed During Data Acquisition provides a snapshot of the data quality and potentiostat performance.*

Hybrid EIS<sup>1</sup> overcomes this problem by continually adjusting the applied current during the experiment. The EIS measurement at the Initial Frequency is made in Potentiostatic mode using the user-specified "Initial Potential". The impedance at all other frequencies is performed in galvanostatic mode by first using the current measured at the Initial Frequency, and then adjusting the current value throughout the frequency range as the impedance of the sample changes. In this manner, the amplitude of the AC current is continually regulated so that the AC voltage does not extend beyond the linear, non-destructive range.

<sup>1</sup> Orazem *et al*, Electrochimica Acta, **41**, 977 (1996).

## Single Frequency EIS

Single Frequency EIS measures the impedance at a fixed frequency versus time. The user controls the experiment with a Repeat Time and a Total Time. Single Frequency EIS can be used for sensor evaluation, process monitoring, or to evaluate slow time-dependent changes in a sample.

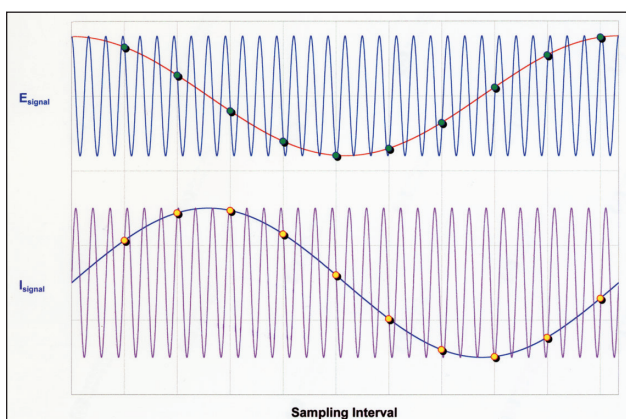
## Mott Schottky EIS

In Mott Schottky EIS, the impedance is measured at a fixed frequency as a function of applied DC potential. It is used most often in the studies of semiconductor interfaces or space charge regions.

## Sub-Harmonic Sampling

The AC waveform for EIS is generated using Direct Digital Synthesis (DDS). The DDS electronic circuitry is built into every Gamry Potentiostat. DDS employs digital signal processing techniques to generate a low-distortion, true sine wave excitation at the desired frequency (300 kHz – 1 Hz). Gamry's unique circuit design insures that the excitation waveform from the DDS is precisely synchronized with the Potentiostat's data acquisition.

Sub-Harmonic Sampling transforms high frequency AC waveforms to lower frequency waveforms. Above a frequency of 8 Hz, the Potentiostat's Analog/Digital Converter samples the excitation and response (voltage and current) waveforms at many points on different cycles of the waveform. The exact sampling position on the waveform is precisely controlled because the data acquisition frequency is an exact sub-harmonic (fractional harmonic) of the excitation waveform.



*Sub-Harmonic Sampling transforms the high-frequency voltage and current signals to a lower frequency while maintaining the amplitude and the phase relationship.*

The result is a sine wave of lower frequency but with the same amplitude as the original current or voltage waveform. The relative phase shift between voltage and current is also preserved in these lower frequency curves because current and voltage are synchronously sampled.

After the current and voltage curves have been sampled, they are each transformed into the frequency domain using a discrete Fourier Transform. The impedance is calculated from the voltage and current signals.

## Other Technical Details

The precision of a dynamic electrochemical measurement such as EIS is an important issue. Unlike other instruments where the user can only control the number of cycles, the Gamry EIS300 performs a statistical analysis of the data at each frequency during acquisition. The data is accepted only after the precision criteria are met. The precision criteria can be adjusted by the user.

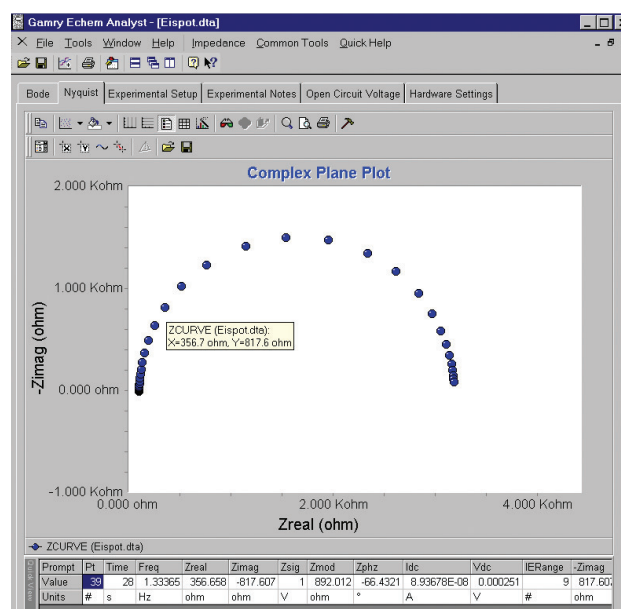
An electrochemical system is a dynamic sample and it can be important to make the measurement quickly. The EIS300 user has a choice of optimizing Speed or Accuracy during acquisition. When Speed is selected, the precision criteria are relaxed and a minimum amount of information is displayed during the experiment. The measurement time for a Potentiostatic EIS measurement on the Gamry Universal Dummy Cell from 100 kHz to 0.1 Hz with 6 points per decade is only 48 seconds in High Speed mode. The EIS scan is completed in 156 seconds in High Accuracy mode.

The accuracy of the EIS measurement is dependent upon the potentiostat, the impedance of the sample, and frequency. Every potentiostat is less accurate at high frequencies than at low frequencies, particularly at the extremes of impedance. The Accuracy Contour Plot details the accuracy of a potentiostat as a function of impedance and frequency and is available for all Gamry Potentiostats (see [www.gamry.com](http://www.gamry.com)).

EIS may be measured under conditions where the DC values are zero, e.g., open-circuit, or under conditions of high background levels of voltage and/or current for batteries, fuel cells, and physical electrochemistry. In these cases, the EIS300 System offsets these DC levels to zero so that the AC values can be measured at a high gain for maximum accuracy.

## Data Presentation and Analysis

Presentation and analysis of your EIS300 data is done in the Echem Analyst. Bode and Nyquist Plots are standard and other plotting formats are available through the Curve Selector, including Admittance, Capacitance,  $-\omega Z_{\text{imag}}$ ,  $V_{\text{dc}}$ ,  $i_{\text{dc}}$ , and time. Multiple EIS curves can be easily overlaid. Place the cursor over a data point and detailed information (frequency, Zreal, Zimag, etc.) is displayed, particularly useful for Nyquist Plots.



*A Nyquist Plot in the Echem Analyst. Notice the detailed information on the selected data point.*

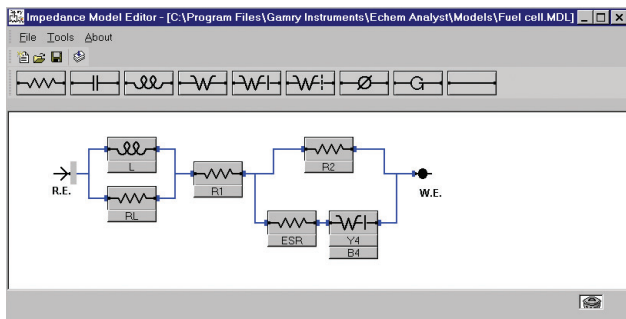
Convenient tabs are available to quickly display the Experimental Setup and Experimental Notes. Notes can be entered during setup for a detailed description of your sample. The data for Open Circuit Voltage vs. Time, measured prior to the EIS curve, is always saved and is available from a tab. The Hardware Settings tab contains detailed information on the Potentiostat during the EIS experiment.

## Modeling the EIS Results

The EIS300 includes a complete modeling package for interpretation of the results. Use the six pre-configured models or build and save your own model using the graphical Model Editor. The following elements are included in the EIS300:

Resistor	Capacitor
Constant Phase Element	Inductor
Infinite Warburg	Bounded Warburg
Porous Bounded Warburg	Gerischer

The equivalent circuit is fit to the data using either the Marquardt-Levenberg or the Simplex algorithm. The EIS300 overlays the fit onto the data and generates a goodness-of-fit coefficient that approximates the relative error. If you wish, you can model a portion of the EIS curve and undesirable data points can be excluded from the fit. The data with the fit can be saved in the Echem Analyst.

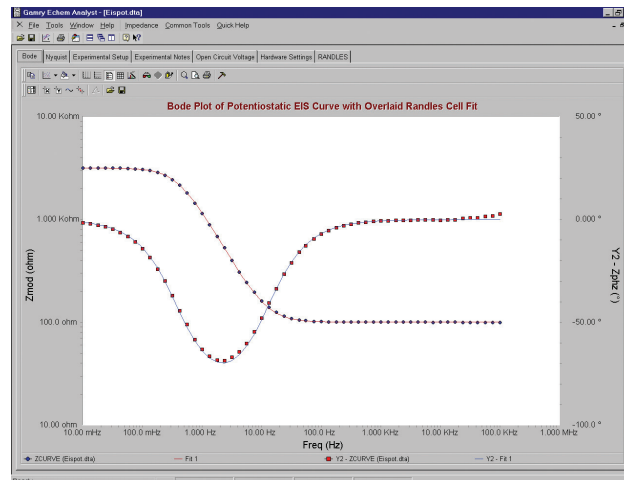


*The EIS300 Model Editor employs an easy-to-use click-and-drag mechanism to build an equivalent circuit. Build it once and save it.*

If you prefer, you can use other EIS modeling programs. The data format of the EIS300 is tab-delimited ASCII text, so it can be easily imported into other EIS data analysis software such as Equivalent Circuit, Zview 2, or ZsimpWin.

## Applications Assistance

If you're new to EIS, we can provide some suggestions. Pay a visit to [www.gamry.com](http://www.gamry.com), go to the App Note section, and take a look at "The EIS Primer". There's an excellent list of references at the end of the Application Note. For specific questions, call us at our factory or your local Gamry distributor.



*A Bode Plot of a Randles Cell with the fit overlaid on the data. Click the "Randles" tab to view the values of the elements in the equivalent circuit and the Goodness of Fit coefficient.*

## System Information

The EIS300 Electrochemical Impedance Spectroscopy Software requires a Gamry Potentiostat to conduct experiments. Gamry Potentiostats are described in a separate brochure. Microsoft® Windows® 98, Me, 2000, or XP is required for operation of the EIS300.

Gamry Instruments can supply complete systems installed in a desktop or portable computer. Custom computer configurations, software, training, and installation are available by special order. Contact the factory or your local Gamry Distributor for further details on these systems.

## Specifications

Frequency Range: 10  $\mu$ Hz-300 kHz  
AC Amplitude: 27.6  $\mu$ V - 1.81 V rms

See Potentiostat specifications for additional information

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All specifications subject to change without notice.

