



*Defining High Performance Electrochemistry...*

# REFERENCE 600

- *Blazing Speed*
- *Wide Current Range*
- *Low Noise*
- *High Sensitivity*
- *Floating Operation*
- *Unsurpassed Versatility*
- *Connectivity*

**GAMRY**

# REFERENCE 600



at a **G**lance

## ■ **High Speed**

A CV scan rate of 3000 V/s with a 10 mV step. On-board Sub-Harmonic Sampling to perform EIS from 1 MHz to 10  $\mu$ Hz.

## ■ **Widest Range of Current Measurement**

11 current ranges from 600 mA to 60 pA. Enable the x100 gain for the equivalent of 13 current ranges, down to 600 fA full-scale.

## ■ **20 aA Current Resolution**

20 aA =  $20 \times 10^{-18}$  Amps! For demanding low-current experiments, the Reference 600 is simply your best choice.

## ■ **Noise and Ripple <10 $\mu$ V rms**

The Reference 600 has the lowest noise specification of any research potentiostat.

## ■ **Easy Operation with Grounded Electrodes**

The Reference 600 is fully isolated (electrically) from the host computer's chassis ground, allowing operation with earth-grounded cells.

## ■ **$10^{14} \Omega$ Input Impedance in Parallel with <0.2 pF and <5 pA Input Current**

Electrometer designed for low current measurements and high speed.

## ■ **Complete Software Library**

Software for the Reference 600 is available to run every major electrochemical technique.

## ■ **Current Interrupt and Positive Feedback iR Compensation**

The Reference 600 has both current interrupt and positive feedback modes of iR Compensation. It uses EIS to measure the uncompensated resistance prior to positive feedback iR compensation.

## ■ **Size Does Matter!**

Space is an important resource in your lab. You'll appreciate how little bench space it occupies. It weighs only 3 kg so it's easy to move.

## ■ **Portability**

The Reference 600 easily interfaces to a notebook computer through the USB Interface.

## ■ **Multiple Potentiostat Systems**

Up to 32 Reference 600's can be run by one computer.

## ■ **Easy Installation**

Load the Gamry software, connect the USB cable, and start your experiments.



## OVERVIEW OF THE REFERENCE 600™

The Reference 600™ is a high performance Potentiostat/Galvanostat/ZRA for demanding electrochemical applications. It is ideal for fundamental electrochemical studies in areas as diverse as physical electrochemistry, corrosion measurement, batteries, coatings, nanotechnology, and sensor development.

How do we define high performance? Blazing speed, wide current range, low noise, high sensitivity, and unsurpassed versatility combined with ease of connectivity.

The Reference 600 measures EIS between 10 Ohms and 100,000 Ohms at 1 MHz with less than 1% error. It has a rise time of < 250 ns. You can measure the potential, current, and auxiliary channels *simultaneously* at 3.3  $\mu$ s per data point! These impressive analog and digital specifications result in a cyclic voltammetric scan rate of 1200 V/s with a Step Height of 4 mV. Despite this speed, the intrinsic noise level in the Reference 600 is < 10  $\mu$ V rms. The noise in the measurement can be reduced even further by oversampling.

The Reference 600 has 11 electronic current ranges from 600 mA to 60 pA full-scale. Utilizing the built-in x10 and x100 gains gives you the equivalent of 13 current ranges and extends the sensitivity to 600 fA full-scale.

The Reference 600 has an applied potential range of  $\pm$  11 volts and a compliance voltage of  $\pm$  22 volts. A 22 volt compliance allows excellent performance in low-conductivity media such as high-purity water and concrete. This compliance voltage strikes a rational balance between performance, safety, and price.

### **Potentiostat and Galvanostat and Zero Resistance Ammeter**

The Reference 600, with its multiple control modes, can handle almost any laboratory electrochemical task. In addition to potentiostatic and galvanostatic modes, the Reference 600 also functions as a Zero Resistance Ammeter. A ZRA is required for galvanic corrosion measurements and is preferred for electrochemical noise measurements.

### **2, 3, or 4 terminal measurement**

The working electrode current is measured by the Working lead and the working electrode voltage is measured by a separate Working Sense lead. This allows easy four-terminal electrochemical measurements on membranes or films.

### **Electrical isolation for grounded samples**

The Reference 600 is designed with full electrical isolation from earth ground, so it operates easily with grounded cells. If you're tasked with making measurements in autoclaves, on strain rate testers, or on pipelines, the Reference 600 will do the job properly with no modification or extra-cost options.

Isolation is accomplished by transformer-coupling a dedicated USB processor and a PowerPC processor. The USB processor is at earth ground, while the PowerPC and all of the Reference 600's analog circuitry are electrically floating.

Additionally, the power supply in the Reference 600 is carefully designed to fully isolate the output from ground. Isolated DC-to-DC converters within the Reference 600 condition and isolate the internal voltage supplies.

### **Connectivity and portability**

The USB Interface allows easy connection to desktop and notebook computers. Because the Reference 600 is about the same size as a textbook, it makes a very convenient portable



At a glance

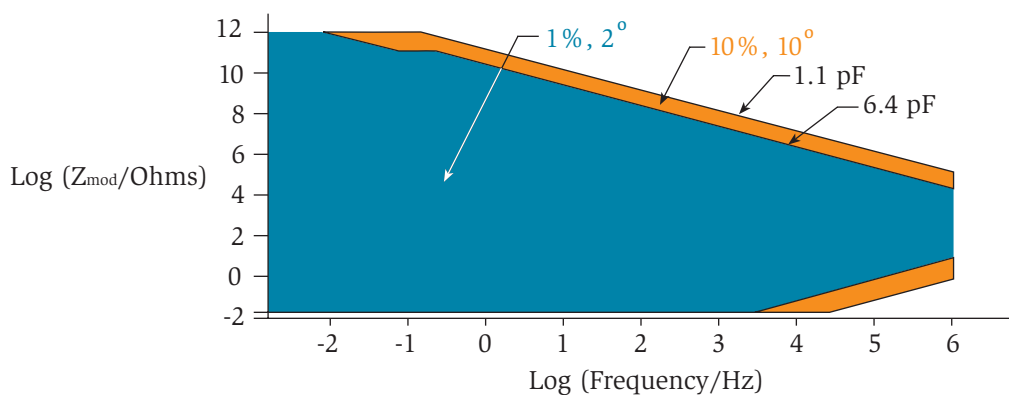




electrochemistry system. But even for laboratory measurements, it's liberating to be able to quickly and easily move the entire system from one location to another.

### ***EIS that's designed in, not added on***

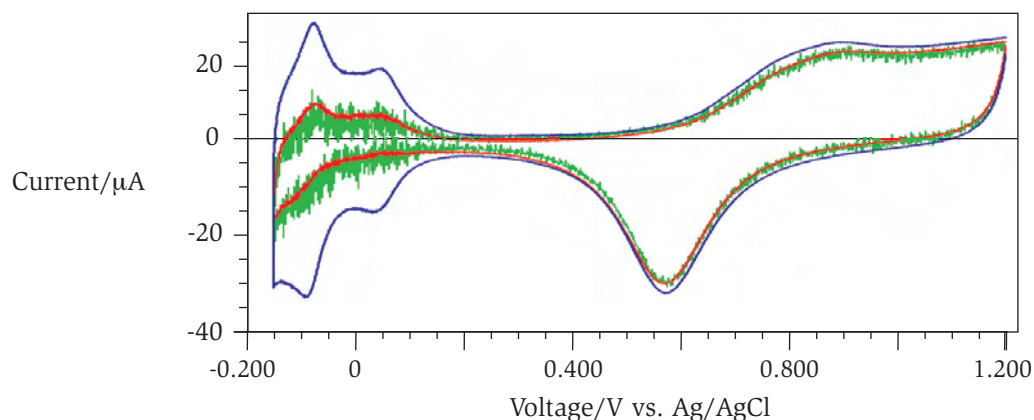
Every Reference 600 is equipped to perform EIS. The built-in Direct Digital Synthesis circuitry generates a pure sine wave that is ideal for electrochemical applications. Use the EIS300 Electrochemical Impedance Spectroscopy Software to enable Gamry's Sub-Harmonic Sampling technique to run EIS from 1 MHz to 10  $\mu$ Hz. Thanks to the wide range of currents that can be measured, the Reference 600 can accurately measure impedances from  $10^{12}$  ohms to less than 1 milli-ohms. Finally, one instrument that can address the challenges of corrosion, coatings, and sensors! The Accuracy Contour Plot of the Reference 600 is shown in the figure.



**Accuracy Contour Plot of a Reference 600** Standard 0.6 m cell cable. Potentiostatic mode. 10 mV rms AC amplitude. Faraday Cage.

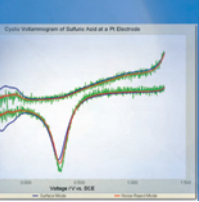
### ***Low noise...and lower noise!***

The Reference 600 enjoys an intrinsic noise level of  $< 10 \mu$ V rms, thanks to a well-designed electronic layout, components selected to balance speed and noise, and intelligent analog filtering and shielding. In addition, the Reference 600 employs a clever electronic scheme to reduce the noise levels in the measurement of the current, voltage, and auxiliary input signal. The Reference 600 can oversample and average to smooth a noisy signal. When oversampling, the Reference 600 samples at 60 kHz (16.6  $\mu$ s/point). Oversampling reduces the measured noise by the square root of the number of samples.



### ***CV of 1 M Sulfuric Acid at a Platinum Electrode***

- Fast Acquisition Mode: sample current at end of step.
- Noise Reject Acquisition Mode: sample and average current last 20% of step.
- Surface Acquisition Mode: sample and average during entire step. This mode enhances the response of surface-bound reactants. Note the hydrogen adsorption fine structure.



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### **High resolution ...and higher resolution!**

All of the data converters in the Reference 600, both D/A and A/D, are 16-bit devices and operate at up to 300 kHz for fast waveform generation and data sampling and processing. Signals in electrochemistry can be vanishingly small. To measure these low signal levels, the offset and gains in the Reference 600 can amplify the signal. Programmable internal offset and gain circuitry allows the equivalent of 22-bit resolution on current and voltage measurements! That's important when you are looking for small changes in your signal, especially in EIS.

### **Smart Cell Cables...engineering extended all the way to your cell**

Even the cell cables for the Reference 600 are engineered for high performance. The cell cables have been optimized for low stray capacitance and high resistance isolation between the internal conductors and the driven shields. You get better EIS results for high impedance samples and truer signals for high speed experiments.

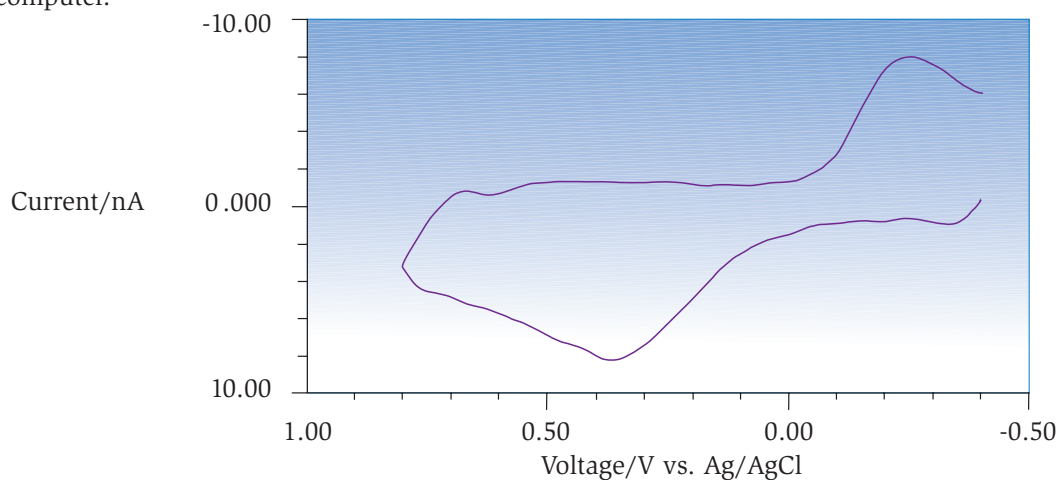
An optional low-impedance cable uses twisted-pair wiring to reduce apparent stray inductance by a factor of 100 or more – great for EIS on batteries and fuel cells, or other experiments where currents are high. Extra length cables are also available.

### **Dual iR compensation modes**

The Reference 600 offers both current interrupt and positive feedback iR compensation for operation in high resistance electrolytes. To set the degree of positive feedback, the on-board EIS capability is used to measure the uncompensated resistance. Positive feedback that really works!

### **Impressive processor power for impressive electrochemistry**

The Reference 600 is designed around a 350 MHz PowerPC® microprocessor that controls waveform generation, data acquisition, and experiment control. The PowerPC also performs digital signal processing. It incorporates 256 MB of RAM for buffering data to insure reliable high-speed data transfer between the Reference 600 and the host computer.



**CV of 200  $\mu$ M Catechol in Phosphate Buffer.** 1200 V/s with 4 mV potential step. 5  $\mu$ m carbon electrode. Background subtracted. Data smoothing applied. Faraday Cage.

### **Multiple potentiostat systems for high sample throughput**

You can configure a MultEchem™ Electrochemistry System based on the Reference 600. Connect up to 32 Reference 600's to one computer and operate them simultaneously while conducting completely different experiments. Don't forget that, because of special software pricing, a MultEchem offers Gamry's lowest available price-per-potentiostat.

### **We build it small because we can**

Despite these impressive specifications, the Reference 600 is surprisingly compact and lightweight. Over 2400

components in each Reference 600 are built into an instrument that measures 9 cm W x 19 cm H x 27 cm D and weighs about 3 kilograms. Gamry Engineers worked long and hard to build the smallest possible instrument without sacrificing functionality or reliability. As a result, the Reference 600 is a world-class research potentiostat that occupies minimum bench space, is easily portable, and can reside inside your Glove Box!

### ***The Gamry Difference is in the details***

Finally, you'll find it's the little things that make a big difference. For example, when you perform a potentiostatic experiment with the Reference 600, or any Gamry Potentiostat, the potential that is plotted is measured at the electrometer – it's not the voltage that was input into the Control Amp as with other potentiostats. You see exactly what is happening in your electrochemical cell. Result? A measurement you can trust.

### ***It's not easy being green***

The environmentally-friendly Reference 600 is lead-free and conforms to RoHS requirements. It has been tested and approved for CE Certification, insuring low electronic emissions and operator safety.

## **ELECTROCHEMICAL SOFTWARE FOR THE REFERENCE 600**

Gamry offers a complete library of electrochemical application software for the Reference 600. Electrochemical experiments are performed in the Gamry Framework™ and the data are analyzed in the Gamry Echem Analyst™.

### ***PHE200™ Physical Electrochemistry Software***

The PHE200 provides a complete library of electrochemical techniques, such as cyclic voltammetry, for characterizing electrochemical reaction mechanisms and studying the electrode interface.

### ***PV220™ Pulse Voltammetry Software***

The PV220 Software is a companion to the PHE200. The extraordinary sensitivity of the pulse techniques allows electrochemical measurements to be made at very low concentrations. The PV220 includes square wave voltammetry and differential pulse voltammetry.

### ***EIS300™ Electrochemical Impedance Spectroscopy***

EIS is a powerful tool for a variety of applications. Using our unique Sub-Harmonic Sampling, Gamry has civilized EIS – it's easy to use, it's compact, and it's very affordable. Gamry offers the widest range of EIS techniques, including potentiostatic, galvanostatic, and hybrid (great for batteries and fuel cells).

### ***DC105™ Corrosion Techniques Software***

The DC105 software includes 14 electrochemical techniques for the study of corrosion. Corrosion rates can be measured using Polarization Resistance or Tafel Plots. Potentiodynamic Plots, Cyclic Polarization, and Critical Pitting Potential are available to evaluate passivity and pitting.

### ***CPT110™ Critical Pitting Temperature Software***

The Critical Pitting Temperature test is specified in ASTM G 150. The CPT110 software choreographs the potentiostat, the Flexcell, and the temperature controller to perform a completely automated measurement!

### ***VFP600™ Virtual Front Panel\****

The low-cost VFP600 Virtual Front Panel simulates an old-fashioned analog potentiostat. You can easily run electrochemical experiments such as long-term potentiostatic or galvanostatic tests, simple CV, or pulse plating.

### ***ESA400™ Electrochemical Signal Analyzer\****

The ESA400 brings a high degree of sophistication to both data acquisition and analysis for electrochemical noise measurements. Data can be acquired in a continuous stream so no transient events are missed. Analysis algorithms include Power Spectral Density, Joint Time-Frequency Analysis, and Cross Correlation.





## Custom Scripting

The Reference 600 enjoys the benefits of Open Source Scripting. For non-standard electrochemical experiments, Gamry software can be customized with Open Source Scripting. Call us to discuss your application.

## eChemBasic, eChemDC, and eChemAC Toolkit Software

eChemDC and eChemAC are powerful software applications to control your Gamry Potentiostat using the programming language of your choice, e.g., LabVIEW. eChemBasic is an entry-level product for less demanding applications.

## FRONT PANEL

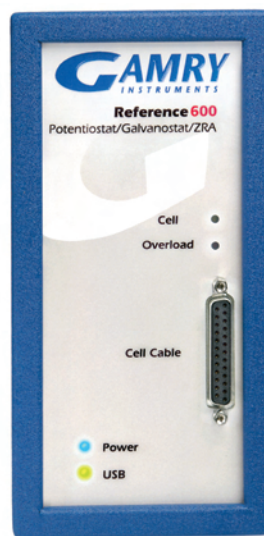
The Reference 600 front panel houses four indicator LEDs:

**Cell:** Yellow LED indicates that the cell is ON.

**Overload:** Red LED indicates an out-of-range condition, such as an excessive reference voltage, compliance voltage limit, or compliance current limit.

**Power:** Blue LED indicates that the power is ON.

**USB:** Indicator of activity on the USB bus. Green indicates the connection is established, yellow indicates that a data transfer is in process.



## BACK PANEL

The Reference 600 allows you to control additional equipment or monitor cell activity from the back panel.

**E Monitor:** Voltage output that is identical to cell voltage,  $\pm 11$  V.

**I Monitor:** Voltage output that is proportional to cell current,  $\pm 3$  V full-scale.

**External Signal Input:** Input from an external Function Generator is summed with applied cell signal.

**Auxiliary A/D Input:** Voltage input at this connector will be saved with the data file,  $\pm 3$  V DC full-scale.

**Signal Generator Output:** An output monitor that indicates the voltage that is applied to the input of the Reference 600 control amplifier.

**Miscellaneous I/O Connector:** This 15-pin connector provides a number of inputs and outputs to customize an electrochemical experiment, including a software-controlled analog output voltage (e.g., to drive a Rotator), two fixed triggers, 4 software-readable inputs, and 4 software-controlled outputs.

**Type K Thermocouple Input:** Input for a thermocouple. The Reference 600 converts the thermocouple voltage to temperature.

**Chassis Ground Pin:** A binding post used to ground the (normally floating) Reference 600 chassis, connect a Faraday Cage, etc.

**USB:** USB cable connects to the host computer or hub. The Reference 600 is USB 2.0 compatible.

**Power In:** Power from the Power Module is supplied at this point.

**Power:** Manual power ON/OFF control.



## SYSTEM INFORMATION

The Reference 600 requires electrochemical software for specific electrochemical applications. The Reference 600 is shipped with the Gamry Framework™ Software, Gamry Echem Analyst™ Software, the Quick-Start Guide, a Hardware Operator's Manual (CD), a Software Operator's Manual (CD), a Universal Dummy Cell 3, one 0.6 m Standard Cell Cable, a Calibration Shield, and a Gamry Mouse Pad.

The Reference 600™ is protected by a 2-year factory service warranty.

### Available cell cables

985-71	Standard Cell Cable, 0.6 m
985-91	1.5 m Cell Cable
990-239	Low Impedance Cable (1 m) Kit
985-78	3 m Extended Cell Cable
985-79	10 m Extended Cell Cable
985-80	ECM8 Multiplexer Interface Cable

## SPECIFICATIONS

Potentiostat	Yes
Galvanostat	Yes
Zero Resistance Ammeter	Yes
Cell Connections	2, 3, or 4
Isolated from earth	Yes

### System

Max. Current	±600 mA
Current Ranges	11 (60pA-600mA)
Current Ranges (inc. internal gain)	13(600 fA-600mA)
Min. Voltage Resolution	1 µV
Min. Current Resolution	20 aA
Max. Applied Potential	±11 V
Rise Time	< 250 ns
Noise and Ripple	< 10 µV rms
<i>*Noise and Ripple (typical)</i>	<i>&lt; 2 µV rms</i>
Min. Time Base	3.333 µs
Max. Time Base	715 s
Min. Potential Step	12.5 µV
Analog/Digital Converters	16 bit
Max. Data Points Per Experiment	262,143

### EIS Measurement

Frequency Range	10 µHz – 1 MHz
Impedance Accuracy	See Accuracy Contour Plot
Max AC Amplitude	2110 mV rms
Min AC Amplitude	4.03 µV rms

### Control Amp

Compliance Voltage	> ±22 V
Output Current	> ±600 mA
Speed Settings	5
Unity Gain Bandwidth (typical)	980, 260, 40, 4, 0.4 kHz

### Electrometer

Input Impedance	> 10 <sup>14</sup> Ω
Input Current	< 5 pA
<i>*Input Current (typical)</i>	<i>&lt; 2 pA</i>
Bandwidth (-3dB) (typical)	> 15 MHz
Common Mode Rejection	> 80 dB (3 Hz)
Ratio	> 60 dB (1 MHz)

### Applied Potential

Accuracy	±1 mV ± 0.2% of setting
<i>*Accuracy (typical)</i>	<i>±375µV ± 0.04% of setting</i>
Resolution	12.5 µV, 50 µV, 200 µV/bit
Drift	< 20 µV/°C
Potential Scan Range	±0.4 V, ±1.6 V, ±6.4 V



### Measured Potential

Accuracy	±1 mV ± 0.3% of reading
<i>*Accuracy (typical)</i>	<i>±250 µV ± 0.5% of reading</i>
Full-Scale Ranges	12 V, 3 V, 300 mV, 30 mV
Resolution	400 µV, 100 µV, 10 µV, 1 µV/bit
Offset Range	±10 V

### Applied Current

Accuracy	±10 pA ± 0.3% of range
<i>*Accuracy (typical)</i>	<i>±3 pA ± 0.08% of range</i>
Resolution	0.0033% full-scale/bit

### Measured Current

Accuracy	±10 pA ± 0.3% range
<i>*Accuracy (typical)</i>	<i>±3 pA ± 0.12% range</i>
Resolution	0.0033% full-scale/bit
Bandwidth (-3dB)	> 10 MHz(600 mA-600 µA)
<b>Note: Bandwidth is current range dependent</b>	> 1.5 MHz (60 µA) > 0.15 MHz (6 µA)

Stability Settings	4
Post Offset Gain	1, 10, 100
Offset Range	±1X full-scale

### iR Compensation

Mode	Current interrupt and positive feedback
Minimum interrupt time	33 µs
Maximum interrupt time	715 s

### Auxiliary A/D Input

Range	±3 V
Resolution	0.1 mV
Input Impedance	100 kΩ or > 10 GΩ

### Auxiliary D/A Output

Range	0-4 V
Resolution	1 mV

### Physical Dimensions

Weight	3 kg
Size	9 (W) x 19 (H) x 27 (D)cm

*\*Typical specifications are representative of the actual performance of the Potentiostat, but are not guaranteed. Specifications are for electrically isolated cells and are subject to change*



Redefining Electrochemical Measurement

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