Reference 30k Booster™

Operator's Manual

Revision 1.8
March 19, 2025
988-00021

If You Have Problems

Please visit our service and support page at https://www.gamry.com/support-2/. This page contains information on installation, software updates, and training. It also contains links to the latest available documentation. If you are unable to locate the information you need from our website, you can contact us via email using the link provided on our website. Alternatively, you can contact us in one of the following ways:

Internet	https://www.gamry.com/support-2/
Phone	(215) 682-9330 9:00 AM−5:00 PM (US Eastern Standard Time) (877) 367-4267 (Toll-free US & Canada Only)

Please have your instrument model and serial numbers available, as well as any applicable software and firmware revisions.

If you have problems in installation or use of a system containing a Reference 30k Booster, please call from a phone next to your computer, where you can type and read the screen while talking to us.

We will be happy to provide a reasonable level of free support for registered users of the Reference 30k Booster. Reasonable support includes telephone assistance covering the normal installation, use and simple customization of a computerized system containing a Reference 30k Booster connected to a computer with Microsoft Windows® 10 or higher (64-bit version only).

A service contract that extends both the hardware warranty and software update period is available at an additional charge. Software updates *do not* include software enhancements offered to our customers at additional cost.

Enhancements to the Reference 30k Booster and Gamry's standard applications software that require significant engineering time on our part can be performed on a contract basis. Contact us with your requirements.

Limited Warranty

Gamry Instruments, Inc. warrants to the original user of this product that it shall be free of defects resulting from faulty manufacture of the product or its components for a period of two years from the original shipment date of your purchase.

Gamry Instruments, Inc. makes no warranties regarding either the satisfactory performance of the Reference 30k Booster including the software provided with this product or the fitness of the product for any particular purpose. The remedy for breach of this Limited Warranty shall be limited solely to repair or replacement, as determined by Gamry Instruments, Inc., and shall not include other damages.

Gamry Instruments, Inc. reserves the right to make revisions to the system at any time without incurring any obligation to install same on systems previously purchased. All system specifications are subject to change without notice.

There are no warranties which extend beyond the description herein. This warranty is in lieu of, and excludes any and all other warranties or representations, expressed, implied or statutory, including merchantability and fitness, as well as any and all other obligations or liabilities of Gamry Instruments, Inc., including but not limited to, special or consequential damages.

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No person, firm or corporation is authorized to assume for Gamry Instruments, Inc., any additional obligation or liability not expressly provided herein except in writing duly executed by an officer of Gamry Instruments, Inc.

Disclaimers

Gamry Instruments, Inc. cannot guarantee that the Reference 30k Booster will work with all computer systems, operating systems, and with older Reference 3000 potentiostat systems.

The information in this manual has been carefully checked and is believed to be accurate as of the time of printing. However, Gamry Instruments, Inc. assumes no responsibility for errors that might appear.

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Chapter 1: Safety Considerations

The Reference 30k Booster is a high-power electrical device used to test electrochemical cells—many of which can be dangerous when misused. The dangers can include fire, explosion, and emission of hazardous chemicals, and can be severe enough to cause personal injury or death. Gamry Instruments recommends a careful study of potential hazards before you start any experiments.

Your Reference 30k Booster has been supplied in a safe condition. The Reference 30k Booster includes safety features that can minimize some possible hazards encountered when testing high-power electrochemical devices.

This chapter of the Reference 30k Booster's Operator's Manual contains some information and warnings that you must follow to insure continued safe operation of the Reference 30k Booster. It starts with safety information generally applicable to AC powered electronics devices, and then discusses dangers specifically associated with testing energy storage devices.

Inspection

When you receive your Reference 30k Booster, inspect it for evidence of shipping damage. If any damage is noted, please notify Gamry Instruments, Inc. and the shipping carrier immediately. Save the shipping container for possible inspection by the carrier.

The protective grounding can be rendered ineffective if the Reference 30k Booster is damaged in shipment. Do not operate damaged apparatus until a qualified service technician has verified its safety. Tag a damaged Reference 30k Booster to indicate that it could be a safety hazard.

Protective Grounding and Product Safety

As defined in IEC Publication 348, Safety Requirements for Electronic Measuring Apparatus, the Reference 30k Booster is a Class I apparatus. Class I apparatus is only safe from electrical shock hazards if the case of the apparatus is connected to a protective earth-ground.

In the Reference 30k Booster this protective ground connection is made via the ground prong in the AC line cord. When you use the Reference 30k Booster with an approved line cord, the connection to the protective earth-ground is automatically made prior to making any power connections.

Do not negate the protection of the earth ground by any means. Do not use the Reference 30k Booster with a two-wire extension cord, with an adapter that does not provide for protective grounding, or with an electrical outlet that is not properly wired with a protective earth-ground. If the protective ground is not properly connected, it creates a safety hazard, which could result in personal injury or death.

The Reference 30k Booster is supplied with a high-current line cord suitable for use in the United States. In other countries, you may have to replace the line cord with one suitable for your electrical outlet type. Always use a line cord with a CEE 22 Standard V female connector on the instrument end of the cable.

Only use line cords rated to handle at least 1.5 kW power. Some 18 AWG cords provided with most computers in the USA are only rated for 10A (1150 W). The line cords supplied with personal computers are generally not rated for high-power applications.

If you replace the line cord, you must use a line cord with the same polarity and power rating as that supplied with the Reference 30k Booster. An improper line cord can create a safety hazard, which could result in personal injury or death.

The wiring polarity of a properly wired connector is shown in Table 1-1 for both US line cords and European line cords that follow the "harmonized" wiring convention.

Table 1-1. Line-cord Polarities and Colors

	Line	**Neutral**	**Earth Ground**
US	Black	White	Green
European	Brown	Light Blue	Green/Yellow

If you have any doubts about the line cord for use with your Reference 30k Booster, please contact qualified electricians or instrument-service technicians for assistance. They can perform a simple continuity check to verify the connection of the Reference 30k Booster chassis to earth, and check that the line cord is suitable for 1.5 kW power. Note that these checks only verify the safety of your Reference 30k Booster AC power connections — they do not verify safety of the system used for a specific application.

Line Voltage and Fuses

The Reference 30k Booster can be safely operated at two nominal line power (mains) voltages: 115 V_{AC} and 240 V_{AC}. Table 1-2 shows the allowed range of input voltage for each nominal line-voltage setting. AC power-line (mains) frequency must be between 47 and 65 Hz.

Table 1-2. AC Voltage Ranges for Each Nominal Line-voltage Setting

Nominal Setting	**Allowed Range**	**Fuse Rating**	**Schurter P/N**
115 V_{AC}	90 to 130 V_{AC}	12.5 A 250 V_{AC}	0034.3128
240 V_{AC}	215 to 264 V_{AC}	6.3 A 250 V_{AC}	0034.3125

The instrument automatically switches to use any power-line (mains) voltage in these ranges: however, safe, full power operation in each range requires different AC power-line fuses as noted above.

Gamry Instruments has attempted to ship your Reference 30k Booster configured for the power-line (mains) voltage in your area. The fuses installed in the Reference 30k Booster should be the correct values for the AC line (mains) voltage prevalent in your area. Spare fuses appropriate for your line voltage have also been included. If an error was made in the fuse selection, please contact Gamry Instruments or your local sales representative to get the correct fuses.

You can damage a Reference 30k Booster by attempting to operate it with incorrect power line fuses. It is dangerous to plug a unit fused for operation at 100 VAC or 120 VAC into a higher mains voltage such as 220 VAC. A power-supply fault under these conditions could create a fire or shock hazard.

Operating a Reference 30k Booster at high output current with incorrect power-line fuses can cause opening of a fuse. This problem is seen when operating the instrument with 115 VAC power and fuses appropriate for 240 VAC operation. Any open fuses must be replaced before the instrument will resume operation.

The Reference 30k Booster depends on fuses in the AC line (mains) input to prevent electrical shock and fire hazards in the unlikely case of a catastrophic failure of the power supplies. Two fuses are used, one for each side of the AC line. The Reference 30k Booster uses "European Style" 5 mm × 20 mm cylindrical fuses. Time-lag fuses that are designed to meet IEC Publication 60127-2 are required. We recommend Schurter FST series fuses as replacements.

If you are uncertain which fuses are installed in your Reference 30k Booster, check the fuse-rating printed on the fuses. See the next section for step-by-step instructions for checking or changing the AC line fuses in a Reference 30k Booster.

Replacing or Checking the AC Power Fuses

This section of the Reference 30k Booster manual gives step-by-step instructions for checking or changing the AC power fuses in your Reference 30k Booster. Please follow these instructions carefully. You need a small flat-bladed screwdriver to perform this procedure.

1) Unplug the AC power (mains) cord from the back of the Reference 30k Booster. The fuses cannot be changed with the AC line (mains) cord plugged into the Reference 30k Booster.

2) Locate the AC input module on the lower left-hand corner of the Reference 30k Booster rear panel. It can be identified by the power-cord connector built into it.

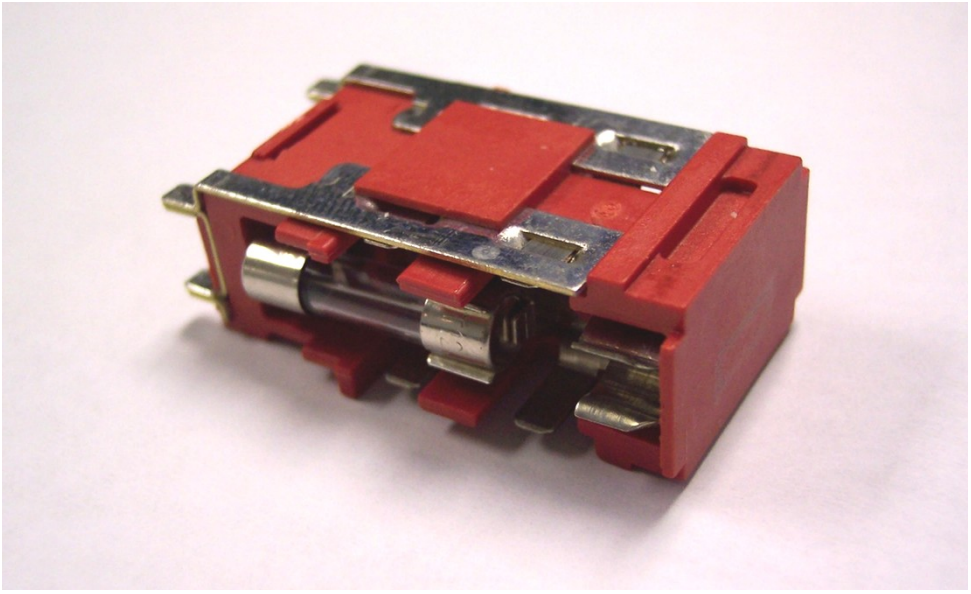
3) Find the small slot on the top of the AC input module. Use the blade of a small screwdriver to pry open the door on AC input module.

4) The fuses are contained inside a fuse holder. Use the blade of a small screwdriver to pry the fuse holder out of the AC input module.

5) Remove the old fuses by prying them out of the fuse holders. Replace them with the correct fuses, which pop into the fuse holders. The fuse holder allows for both US and European fuses. The European 5 × 20 mm fuses supplied with the instrument mount toward the interior end of the fuse holder. Note that only one end of the fuse clips into the fuse holder: see the photograph in Figure 1-1.

   The current-rating of the fuses is printed on the metal ends of the fuse. Make sure that your fuses are the appropriate value for your AC power-line voltage.

Figure 1-1
Photograph of Fuse Holder Removed from AC Input Module



   Replace the fuse(s) only with the correct value and type of fuse. See Table 0-2 and the text following it for fuse values and type descriptions.

6) Replace the fuse holder (with the correct fuses) in the AC input module. The end with four metal contacts goes into the AC-line connector first. Both orientations that fit work identically.

7) Close the cover of the AC input module. It should snap into place.

The AC power fuses are important components for safe operation of the Reference 30k Booster. Never replace the fuses with incorrect values or types, or in any way circumvent the fuse action. If your Reference 30k Booster routinely blows the AC-line fuses, it could indicate a serious problem with the Reference 30k Booster. Contact Gamry Instruments or your local sales representative for repair information.

Ventilation

Your Reference 30k Booster was designed to operate at ambient temperatures between 0°C and 40°C.

Be careful when operating the Reference 30k Booster in an enclosed space (such as an enclosed relay rack or NEMA enclosure).

The temperature within the enclosure must not exceed 40°C. You may need to provide ventilation holes or even forced air cooling for the enclosure if excessive temperature-rise occurs.

Defects and Abnormal Stresses

Treat your Reference 30k Booster as potentially hazardous if any of the following is true of the unit:

- It shows visible damage.
- It does not operate properly.
- It has been stored for an extended period of time under unfavorable conditions,
- It has been dropped or subjected to severe transport stress.
- It has been subjected to environmental stress (corrosive atmosphere, fire, etc.).

Do not use your Reference 30k Booster or any other apparatus if you think it could be hazardous. Have it checked by qualified service personnel.

Environmental Limits

There are environmental limit conditions on the storage, shipping, and operation of this equipment. The Reference 30k Booster is ***not*** designed for outdoor use.

Description	**Specifications**
Storage	
Ambient Temperature	-20°C to +60°C
Relative Humidity	max. 90% non-condensing
Shipping	
Ambient Temperature	-20°C to +60°C
Relative Humidity	max. 90% non-condensing
Acceleration	max. 30 G
Operation	
Ambient Temperature	10°C to +40°C
Relative humidity	max. 90% non-condensing

Spill Hazard

Cooling of the Reference 30k Booster requires air-flow through the chassis. The cover of the instrument is perforated to allow this air-flow. The perforations add to the danger of accidental spills shorting the circuitry inside the chassis.

Take extra care when using chemicals near the Reference 30k Booster. Spills into the case can create hazardous conditions and could damage the instrument.

Take precautions to prevent spillage of liquids into the Reference 30k Booster's chassis. Spills could damage the instrument or create hazardous conditions. Turning the instrument off does not completely eliminate the hazard.

If you do spill anything into the Reference 30k Booster chassis, unplug it from AC power (mains) immediately. Refer cleaning the instrument to a qualified service person or contact Gamry Instruments. Do not replace the power until the instrument has been certified as safe.

Cleaning

Disconnect the Reference 30k Booster from all power sources prior to cleaning.

Clean the outside of the Reference 30k Booster enclosure with a rag dampened with either clean water or water containing a mild detergent.

Never use a wet rag or allow water to enter the Reference 30k Booster enclosure. Do not immerse the Reference 30k Booster in any type of cleaning fluid (including water). Do not use any abrasive cleaners.

Service

Your Reference 30k Booster has no user-serviceable parts inside. Refer all service to a qualified service technician.

Never operate the Reference 30k Booster with any cover or panel on the chassis open! Dangerous AC line voltages are present at several points within the Reference 30k Booster chassis, including PC board traces. Always remove the AC power cord before opening the Reference 30k Booster case.

RFI Warning

Your Reference 30k Booster generates, uses, and can radiate radio-frequency energy. The radiated levels are low enough that the Reference 30k Booster should present no interference problem in most industrial laboratory environments. The Reference 30k Booster could possibly cause radio-frequency interference if operated in a residential environment.

Electrical Transient Sensitivity

Your Reference 30k Booster was designed and has been tested to offer reasonable immunity from electrical transients. However, in severe cases, the Reference 30k Booster could malfunction or even suffer damage from electrical transients. If you are having problems in this regard, the following steps may help:

If the problem is static electricity (sparks are apparent when you touch the Reference 30k Booster):

- Placing your Reference 30k Booster on a static-control work surface may help. Static-control work surfaces are now generally available from computer supply houses and electronics tool suppliers. An antistatic floor mat may also help, particularly if a carpet is involved in generating the static electricity.
- Air ionizers or even simple air humidifiers can reduce the voltage available in static discharges.

If the problem is AC power line transients (often from large electrical motors near the Reference 30k Booster):

- Try plugging your Reference 30k Booster into a different AC power (mains) branch circuit.

- Plug your Reference 30k Booster into a power-line surge suppressor. Inexpensive surge suppressors are now generally available because of their use with computer equipment.

Contact Gamry Instruments, Inc. if these measures do not solve the problem.

CE Compliance

The European Community has instituted standards limiting radio-frequency interference from electronic devices and mandating several safety requirements.

Gamry Instruments, Inc. has modified its instruments, including the Reference 30k Booster, to comply with these standards.

The relevant CE regulations include EN55022 Class B and EN60950.

Cell Fuses

One of the safety features built into the Reference 30k Booster is fuses in the high-current cell leads. These fuses open if currents in excess of the booster's 30 A rating flow into or out of the cell. The time required to open the fuses depends on the severity of the current overload. Currents of 50 A of more will open the fuses quickly.

The cell fuses are not vital for electrical safety. They can prevent hazardous conditions within the cell attached to the Reference 30k Booster. They also prevent damage to the instrument when it is improperly grounded.

Both the Counter and Working electrode leads are protected by 30 A blade-type fuses, accessible from the front panel of the instrument.

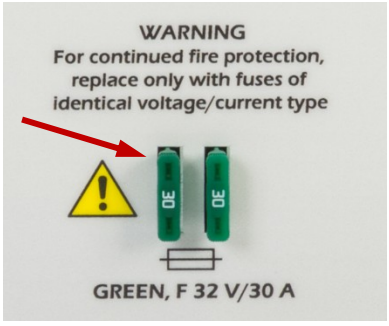
The cell lead fuses only prevent current flow into or out of the counter and working electrode terminals of the Reference 30k Booster. These fuses do not protect against excessive current that does not flow through the instrument. For example, they do not protect against short-circuits in the electrochemical cell or in the high-current cell leads.

The fuses protect the cell from excess current from two possible error conditions:

1) improper grounding
2) electronics failure in the booster

The grounding conditions that create the problem are discussed further in Appendix B.

The fuses used for this function are rated for 30 A and Fast Blow operation. One suitable replacement fuse is the Littelfuse 0257030.PXPV. The fuses are green. A portion of the plastic housing of each fuse can be seen near the middle of the Reference 30k Booster's front panel.



To replace the fuses:

1) Turn off the Reference 30k Booster power switch.
2) Disconnect the counter and working high-current cables from all electrochemical cells.
3) Grasp the portion of each fuse that protrudes through the Reference 30k Booster's front panel.
4) Pull the fuse out of the panel.
5) In many cases, visual examination of the fuse will show a discontinuity in the metal element, indicating an open fuse. However, this is not always the case. More accurately, the resistance of the fuses can be measured with an ohmmeter. Unblown fuse resistance should be less than 1 Ω. Blown fuses have very high resistance.
6) Good fuses are reinserted by simply pressing them into the original fuse location.
7) The plastic portion of correctly inserted fuses should extend 3 to 5 mm from the front panel.

The cell fuses are important components for safe operation of the Reference 30k Booster. Do not replace the fuses with incorrect values or types, or in any way circumvent the fuse action. If your Reference 30k Booster routinely blows the cell fuses you could have a grounding problem, or it could indicate a serious problem with the Reference 30k Booster. Consult Gamry Instruments or your local representative for assistance.

An open fuse may or may not create overload indications in the system, depending on the control mode being used in the test.

A Reference 30k Booster with one or both Front Panel cell fuses open can still allow current flow into or out of the cell in "pass-through" mode. A different set of fuses in the Reference 3000 Counter/Working cable prevent excessive current into the Reference 3000.

Fuses in Reference 3000 Counter/Working Cable

There are also 3.15 A fuses in the Reference 3000 Counter/Working cable. They are located on a small printed circuit board inside the hood on the Reference 3000 end of the cable.

These fuses should never blow (open circuit) during normal operation of the system. They are present to prevent damage to the Reference 3000 in two possible error conditions:

- The first error condition requires a booster malfunction. The malfunction must cause one of the two switches that enable pass-through to be set to the wrong state or must cause a switch failure. In this condition, the cell's Counter electrode lead is connected to the 30 A booster and the cell's Working lead is in pass-through mode. As a consequence, currents as high as 30 A could flow into the Reference 3000's Working lead. The fuses in the Reference 3000 Counter/Working cable prevent damage to the Reference 3000.
- The second error condition can occur when the system is improperly grounded. In this condition, the **System Ground** and earth ground are connected, and a cell with an earth ground connection is operated in pass-through mode. When this occurs, the cell is short-circuited through the Reference 3000. The fuses in the Reference 3000 Counter/Working cable prevent damage to Reference 3000 if the resulting currents exceed 3 A.

Contact Gamry Instruments technical support if the fuses in the Reference 3000 Counter/Working cable are open circuit. If you need additional fuses, their Gamry P/N is 630-00021. The manufacturer is Littelfuse and they are from their nano fuse series. The Littelfuse P/N is 04513.15MRL.

EMERGENCY SHUTDOWN Switch

Another safety feature built into the Reference 30k Booster is the **EMERGENCY SHUTDOWN** switch. This large red knob on the front panel of the Reference 30k Booster allows the user to immediately shut off all electrical

power flowing into or out of the cell from the Reference 30k Booster. Pressing on this obvious switch causes the switch to open. It remains open until reset by the user.

A red LED indicator on the front panel of the Reference 30k Booster glows when the **EMERGENCY SHUTDOWN** switch is in the tripped position. The system will not run experiments until the switch is reset and the indicator light is off.

The **EMERGENCY SHUTDOWN** switch is normally activated if you see a serious problem in your test cell, such as boiling of the cell electrolyte, gas evolution, swelling of a cell, or venting of a sealed cell.

The **EMERGENCY SHUTDOWN** switch only prevents current flow from the cell into or out of the Reference 30k Booster's high-current cell leads. It does not protect against dangerous cell conditions that do not involve current flow into the booster, such as short circuits within the cell.

Never use the **EMERGENCY SHUTDOWN** switch to shut down tests in non-emergency situations. Data collected prior to the shut-down could be lost.

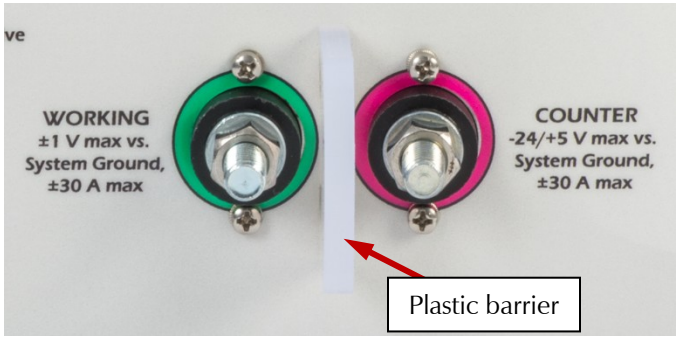
The Gamry Framework™ software does not recognize a Reference 3000/Reference 30k Booster system when the Booster is in its **EMERGENCY SHUTDOWN** state. The shut-down instrument cannot be operated because the Windows® Device Manager does not know it is connected.

Reset the **EMERGENCY SHUTDOWN** switch by turning the red knob clockwise. If the Gamry Framework is open, after a few seconds the Booster system reappears in the Framework window.

Shorting the Cell

By definition, batteries store energy. Fuel cells, supercapacitors, and electrolytic cells can also contain stored energy. A short-circuit across the cell terminals can cause large currents and hazardous conditions. The dangers can include fire, explosion, and emission of hazardous chemicals, and can be severe enough to cause personal injury or death. Operator error is a common and very dangerous source of short circuits.

Gamry has taken precautions against some forms of operator errors that can short the cell. For example, the high-current terminals on the front of the instrument have a plastic barrier between them. This barrier prevents a metal wrench (spanner) bridging between the terminals.



A user is responsible for his or her own safety. Gamry Instruments strongly recommends that you review all high-energy experiments with your organization's safety officer.

RoHS Compliance

The Reference 30k Booster has been built using lead-free components and lead-free solder. It is in compliance with the European RoHS initiative.

Chapter 2: Introduction

The Reference 30k Booster was developed to extend high-quality electrochemical measurements to high-current cells.

The Reference 30k Booster is always used in a system with a Gamry Instruments Reference 3000 Potentiostat/Galvanostat/ZRA. It cannot be used with other Gamry potentiostats or instruments from other manufacturers.

An electrochemical test system consisting of a Reference 30k Booster and a Reference 3000 Potentiostat offers these impressive characteristics:

- Currents up to 30 A
- Potentials up to 20 V
- Potentiostat, Galvanostat, and ZRA Operating Modes
- 2-, 3-, and 4-electrode modes
- A pass-through mode that allows current measurement with resolution as low as 1 μA without moving any cables

The system really shines when used for electrochemical impedance spectroscopy (EIS). It offers better frequency response than all competing systems. EIS performance includes:

- Accurate measurement at frequencies from 10 μHz to 300 kHz
- Measurement in three control modes: potentiostatic, galvanostatic, and a unique hybrid control mode
- Measurement of impedances from 10 μΩ to 10 kΩ without changing system connections

Applications for a system containing a Reference 30k Booster include research, quality control, and production in these areas:

- Precision plating
- Electrochemical synthesis
- Fuel cells
- Batteries
- Supercapacitors
- Solar cells

Systems built using a Reference 3000 with its Auxiliary Electrometer (AE) option allow DC and EIS measurements on series-connected stacks of energy-storage and -conversion devices. EIS characterization of individual fuel cells in a stack has never been easier.

Compatibility with Older Reference 3000 Potentiostats

The Reference 3000 may be incompatible with some older Reference 3000 potentiostats. If your Reference 30k Booster was purchased in a system with a Reference 3000 potentiostat, the two instruments are definitely compatible.

See Chapter 3 for more detailed Reference 3000 compatibility information.

Cable Connections from Reference 3000 to the Reference 30k Booster

Two cables connect the Reference 30k Booster to the Reference 3000.

Analog Cable

The first is an analog cable that connects the **Working/Counter** connector on the front panel of the Reference 3000 to the Reference 3000 **Working/Counter** connector on the front panel of the Reference 30k Booster. It is a 15-pin connector with a D-connector on each end. The connection **must** be made with a Gamry cable, P/N 985-00116.

Do **not** use any cable other than Gamry P/N 985-00116 to make this connection. This cable has special grounding and shielding required for operation of the system. Third-party 15-pin male-to-female cables may physically connect the instruments, but will not offer full performance, and could cause damage.

Digital Cable

The second cable is a digital control cable that connects the **Expansion Interface** connector on the rear panel of the Reference 3000 to the **REF3000 Expansion Interface** connector on the rear panel of the Reference 30k Booster. This is a 25-pin cable with a D-connector on each end. The connection **must** be made with a Gamry Cable, P/N 985-00120.

Do **not** use any cable other than Gamry P/N 985-00120 to make this connection. This cable has special grounding and shielding required for operation of the system. Third-party 25-pin male-to-female cables may physically connect the instruments, but will not offer full performance, and could cause damage.

Theory of Operation

Perhaps the easiest way to think of the Reference 30k Booster is as a part that adds one additional current range to the Reference 3000. The highest measurable current on the Reference 3000 is 3 A full-scale. When the system is boosted with a Reference 30k, the largest measurable current increases to 30 A. Transparent to the user, the ±30 A cell current is measured by the electronics in the Reference 30k Booster, converted to ±3 mA, and then sent to the Reference 3000's current-measurement circuit.

Of course, adding an additional measurement range is useless if the system cannot control cell voltage or current. The Reference 30k Booster also contains a power amplifier that increases the output current of the system to 30 amperes. This power amplifier has an asymmetrical output-voltage swing: it can control cell voltages as high as +20 V, but only as low as –2.5 V. The output current is symmetrical at ± 30 A.

Unlike many other boosted electrochemistry systems, the Reference 3000 and Reference 30k Booster can operate using the lower-current instrument's current ranges without disconnecting or moving any cables. Switches in the Reference 30k Booster allow connection of the cell's counter and working electrodes to either:

- The high current (30 A) control amplifier and 30 A I/E converter in the Booster, or
- The 3 A control amplifier and 3 A-to-30 mA current range I/E converter in the Reference 3000, which is called "pass-through" mode.

Figure 2-1 shows a simplified schematic of the Reference 30k Booster connected to a Reference 3000 Potentiostat. The diagram shows the connections for potentiostatic operation using half-cell connections to a three-electrode cell.

The electrochemical cell under test is depicted on the right side of the diagram. The cell has connections to both the Reference 30k Booster and the Reference 3000 potentiostat as follows:

- The Reference 3000's Reference lead and Working Sense lead connect directly to the cell. These leads sense the voltage-difference between two points in the cell. In three-electrode cells, this is usually the

voltage between the working electrode and a reference electrode. In two-electrode cells, this is the voltage across the two available cell terminals

- The Counter and Working Electrode connections can carry very high currents. The high-current terminals on the Reference 30k Booster are usually connected to the cell using a heavy, large diameter cable.

Whenever possible, use the Reference 30K Booster with the high-current cell cable shipped with the unit. This cable has been specially designed for low inductance. Use with other cables could result in control-loop oscillation.

In Figure 2-1, note that the Working and Counter connections are switched within the Reference 30k Booster.

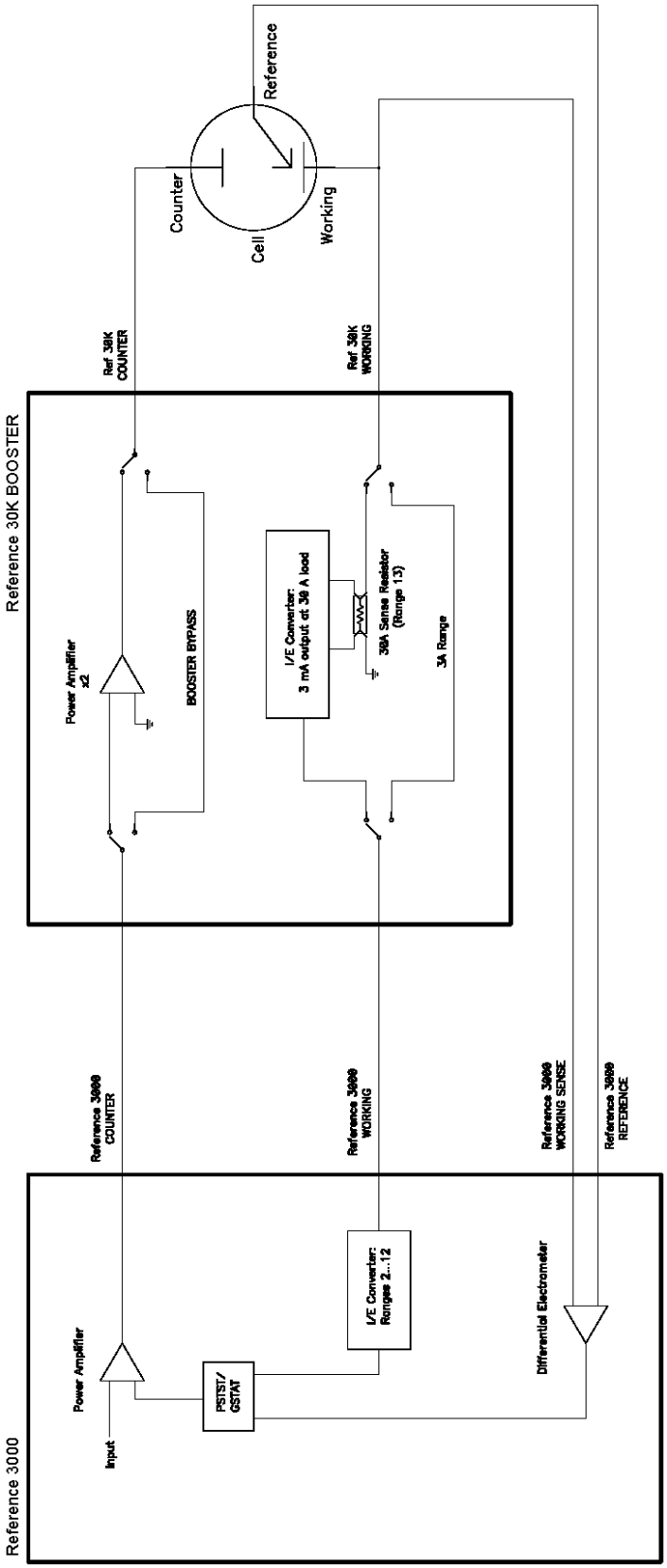
When the system is on the 30 A current range, a switch connects the Counter electrode to the output of the Reference 30k Booster's 30 A power amplifier. The input voltage for this high-current amplifier comes from the voltage on the Reference 3000's Counter electrode lead. A second switch connects the working electrode to the 30 A current-measurement circuit. The output of this current-measurement circuit is converted into a ±3 mA current and connected to the Reference 3000's Working Lead.

On all other current ranges, the system operates in its pass-through mode. The switches described above connect the high-current Working and Counter Electrode terminals to the lower current Reference 3000 cell leads.

While the system does treat the Reference 30k Booster as an additional current range, Gamry's software does not allow auto-ranging between the 30 A range and the lower ranges. The transition between the boosted and non-boosted ranges can only be made when the cell is turned off.

The high-current cable connecting the cell to the Reference 30k Booster is not shielded. This cable is optimized for low inductance, not low capacitance. The lack of shielding generally allows significant noise pick-up in the system, especially at the power-line (mains) frequency of 50 or 60 Hz. This noise is usually large enough to preclude use of sensitive current ranges in pass-through mode. Gamry's software currently does not allow pass-through mode to use ranges more sensitive than 30 mA full-scale.

Figure 2-1
Simplified Range-switching Reference 30k Booster



Grounding (Earthing)

A Reference 30k Booster system can be operated floating (isolated) from earth ground. This allows control current or voltage on electrochemical systems where one electrode or the system plumbing is earth-grounded.

System grounding is discussed more fully in Appendix B. See this chapter if you need to float your cell.

Operating Modes

As described above, the Reference 30k Booster can be thought of as an additional current range added to the Reference 3000 instrument. This additional range is available in all three common Reference 3000 control modes: potentiostatic, galvanostatic and ZRA.

Potentiostatic: In this mode, the system controls the potential between two voltage-sensing points. Some of Gamry's control software allows variation in potentiostat mode, including 2-electrode and 3-electrode operation, and connection of a high-voltage electrometer.

Voltage-sensing is always done using the leads in the Reference 3000's sense cable. In the standard or "low-voltage" mode, the voltage is always measured between the Reference (white) lead and the Working Sense (blue) lead. In high-voltage mode, the sensing is done between the Counter Sense (orange) lead and the Working Sense (blue) lead.

Galvanostatic: In this mode, the system controls the current flow through the cell. The current can be measured directly by one of the Reference 3000's current ranges or can be measured on the Reference 30k Booster's 30A range. In either case, the current flows between the high-current terminals on the front panel of the Reference 30k Booster.

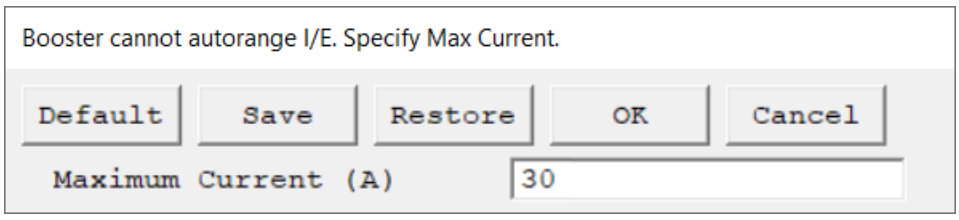
ZRA: In this mode, the cell is kept with zero volts between the counter sense (orange) lead and the working sense (blue) leads.

Operation with Gamry Instruments Software

Gamry's Framework software was written to allow device-independent potentiostat operation. Most tests can run using any Gamry Instruments potentiostat. There is one obvious limitation: tests cannot exceed the specifications of the potentiostat in the system.

Some Potentiostatic mode scripts in Framework software normally only allow current-range auto-ranging; they do not allow user-selection of a current range. All Gamry DC Corrosion Scripts operate in this way. A special provision in the Reference 30k Booster driver allows limited operation of these scripts. Whenever the scripts attempt to set up current-range auto-ranging, a dialog box appears that allows you to enter a maximum expected current. A typical dialog box is shown in Figure 2-2.

Figure 2-2
Simplified Range Switching Reference 30k Booster



After you click the **OK** button, the entered current is used to set a current range in either boosted or pass-through mode. The range is **not** changed during curve acquisition.

One place that auto-ranging is allowed is during acquisition of an EIS spectrum. The system turns off the cell, changes the current range, and then turns the cell back on when EIS needs a change in the current range.

Similar limitations apply when the Reference 30k Booster is used with other Gamry Instruments software or with user-written software that uses the Gamry Instruments Toolkit for experiment control and data acquisition.

Limitations

A system with a Reference 3000 Potentiostat and a Reference 30k Booster does have limitations compared to the non-boosted system. These limitations include:

- The maximum allowed frequency for EIS measurement is 300 kHz. The new limit applies in both 30 A and pass-through modes.
- Current-range auto-ranging is not allowed.
- The system does not operate on ranges more sensitive than 30 mA full-scale.

All of these limitations can be overcome if cell current will not exceed 3 A. In this case, you can disassemble the system and connect the cell directly to the Reference 3000 Cell Cables. Make sure to disconnect the Expansion cable connecting the rear panels of the Reference 3000 and the Reference 30k Booster.

Reference 30k Booster Test and Cal Cell

Every Reference 30k Booster is shipped with a Reference 30k Test and Cal cell, Gamry P/N 990-00284. This fixture is a small printed-circuit board designed specifically for use with the Booster. It has a **Test** side that is a 3 mΩ 6 W resistor, and a **Cal** side that is a 200 mΩ 1 W resistor. The nominal tolerance of the resistors is ±1%.

The **Test** side of the fixture can handle the full 30 A output of the Reference 30k Booster. While it was wired for minimum inductance, resistances this low always suffer from errors caused by stray inductance. EIS on the test side of the fixture shows an inductive impedance spectrum above 10 kHz.

The **Cal** side of the fixture can only handle 2 A. Higher currents will blow (open circuit) a 2 A fuse on this side of the fixture. This fuse prevents damage to the fixture when higher currents are applied. Spare fuses are provided with the fixture. If you need additional fuses, their Gamry P/N is 630-00027. The manufacturer is Littelfuse and they are from their Nanofuse series. The Littelfuse P/N is 451002MRL.

Chapter 3: Installation

This chapter covers normal installation of the Reference 30k Booster in a system with a Reference 3000 potentiostat.

Initial Visual Inspection

After you remove your Reference 30k Booster from its shipping carton, check it for any signs of shipping damage. If any damage is noted, please notify Gamry Instruments, Inc., and the shipping carrier immediately. Save the shipping container for possible inspection by the carrier.

The protective grounding can be rendered ineffective if the Reference 30k Booster is damaged in shipment. Do not operate damaged apparatus until a qualified service technician has verified its safety. Tag a damaged Reference 30k Booster to indicate that it could be a safety hazard.

Included Parts

The following items are included with a Reference 30k Booster:

Item	Gamry P/N	Description	Notes
1	990-00275	Reference 30k Booster Chassis	The Booster Box
2	985-00122	Cable, Ref 30k Counter Working	High-current cable to the cell, 90 cm
3	988-00021	Manual, Reference 30k Booster	This document
4	990-00284	Reference 30k Test and Cal cell	3 mΩ and 200 mΩ
5	985-00116	Cable, Ref3000 to Ref30k Working Counter	15-pin D Male to Female
6	985-00120	Cable, Ref3000 to Ref30k Expansion Interface	25-pin D Male to Female
7	630-00023	Fuse, Blade, 30 A, Green	Qty 2, Spare fuses for Working and Counter
8	630-00027	Fuse, Nano 2 A	Qty 3, Spare fuses for Test and Cal cell
9	821-00001	Nut Driver, 9/16″	Red Nut Driver for Front-Panel Working and Counter-Mounting Studs
10	821-00002	Nut Driver, 13 mm	Black Nut Driver for Test and Cal cell

In addition, shipments to locations known to have 115 VAC power should include:

Item	Gamry P/N	Description	Notes
11	630-00024	Fuse, 5 × 20 mm, 12.5 A time delay	Qty 2, Spare AC line fuse
12	630-00026	Fuse, 5 × 20 mm, 6.3 A time delay	Qty 2, Spare mains fuse

Shipments to locations known to have 240 VAC mains should include:

Item	Gamry P/N	Description	Notes
13	630-00026	Fuse, 5 × 20 mm, 6.3 A time delay	Qty 2, Spare mains fuse

Reference 3000 Compatibility

The Reference 30k Booster is compatible with all Reference 3000 potentiostats shipped after December 28, 2010. Reference 3000 potentiostats manufactured earlier than that date are only compatible with the Reference 30k Booster after an upgrade.

Incompatible Reference 3000 Potentiostats can be upgraded by replacing their potentiostat card. This can only be done at Gamry's USA facilities. This upgrade will be covered under Gamry's two-year warranty, if applicable. Owners of out-of-warranty systems will be charged for the upgrade. Gamry will only provide an in-warranty upgrade with the purchase of a Reference 30k Booster.

If you are adding a Reference 30k Booster to an older existing Reference 3000 system, note the serial number of the Reference 3000 and contact your local Gamry representative or email techsupport@gamry.com to get information on Booster compatibility of that specific Reference 3000 potentiostat.

Physical Location

You can place your Reference 30k Booster on a normal workbench surface. You need access to the rear of the instrument because some cable connections are made from the rear.

The Reference 30k Booster is generally restricted to operation in a horizontal position with the instrument sitting on a flat surface. Operation in other positions can result in restricted airflow and overheating of the circuitry. We do not recommend placing solid objects near the Reference 30k.

The Reference 30k Booster requires unrestricted airflow entering the perforations in the instrument's chassis and exiting from the rear of the chassis. We recommend at least 10 cm clearance between the sides, top, and bottom of the Reference 30k Booster and any object that would restrict this airflow.

The Reference 30k Booster is only useful when connected in a system with a Reference 3000 potentiostat. The Reference 3000 can be placed on either side of the Reference 30k or can be located on top of the Reference 30k chassis. The 10 cm recommended clearance may be relaxed when the Reference 3000 is on top of the Reference 30k.

If the Reference 3000 potentiostat and/or Reference 30k Booster are located within an enclosure, you must keep the enclosure temperature below the 40°C ambient-temperature limit of the Reference 30k Booster. This may be difficult when the enclosure includes an inert atmosphere, such as a glove box. Consult an experienced engineer for heat-exchanger solutions if you must operate the Reference 30k Booster in an enclosed space.

Software Installation

Similar to most Plug-and-Play Windows-compatible devices, install the software before you plug the potentiostat's USB cable into the computer.

The latest Gamry software is not provided on a DVD anymore but is now available for download as `*.exe` or `*.iso` file on Gamry Instruments' Client Portal after creating an account and registering your instrument:

https://www.gamry.com/client-portal/my-account/

An internet download of Gamry Instruments' software will download a self-extracting file. Running this file will extract the software and begin the installation.

Normal Reference 3000 Installation

Install the Reference 3000 potentiostat as a stand-alone instrument **before** connecting the Reference 30k Booster. After the Reference 3000 installation is complete, test the Reference 3000 system for nominal operation using a UDC dummy cell and the standard Reference 3000 cell cables. Use the *Reference 3000 Quick-start Guide* to aid in the system installation.

Calibrate the Reference 3000-based system. Gamry Instruments also recommends that you run a standard test from your favorite application software using the UDC's 2 kΩ calibration cell. Potentiostatic EIS and cyclic voltammetry are popular choices.

This calibration step is important. If the system with both the Reference 3000 and the Reference 30k Booster malfunctions, Gamry's support engineer will generally ask you to test the less-complicated Reference 3000 system. If it works properly, any malfunctions are localized to the Reference 30k Booster and the cables.

Power Cord and Line-Voltage Selection

The Reference 30k Booster is a high-power device that draws significant currents from the AC line (mains). The Reference 30k Booster can be safely operated at two nominal line power (mains) voltages: 115 V_{AC} and 240 V_{AC}. Table 1-2 shows the allowed range of input voltage for each nominal line voltage (mains) setting. AC power-line (mains) frequency must be between 47 and 65 Hz.

The instrument automatically switches to use any power-line (mains) voltage in these ranges: however, safe, full power operation in each range requires different AC power line fuses as noted in Table 1-2.

Chapter 1 discusses important safety information regarding choice of fuses, how to change the fuses, and use of a power cord to the electrical outlet.

Connections between Reference 3000 and Reference 30k Booster

1) When your stand-alone Reference 3000 system is functional, turn off the power switches on the Reference 3000 and the Reference 30k Booster.
2) Disconnect the Reference 3000's Working/Counter cable.
3) Replace it with a Reference 3000 to Reference 30k Working/Counter cable. This cable, Gamry P/N 985-00116 has a 15-pin D connector on either end.
4) Connect the other end of this cable to the Reference 30k Booster's front panel **Counter/Working** input.

Do **not** use any cable other than Gamry P/N 985-00116 to make this connection. This cable has special grounding and shielding required for operation of the system. Third-party 15-pin male-to-female cables may physically connect the instruments, but will not offer full performance, and could cause damage.

5) Locate a cable with a 25-pin D-connector on both ends. This is a digital control cable that connects the **Expansion Interface** connector on the rear panel of the Reference 3000 to the Reference 3000 **Expansion Interface** connector on the rear panel of the Reference 30k Booster.

Do **not** use any cable other than Gamry P/N 985-00120 to make this connection. This cable has special grounding and shielding required for operation of the system. Third-party 25-pin male-to-female cables may physically connect the instruments, but will not offer full performance, and could cause damage.

Installation of the Working/Counter Cable on the Booster

The Reference 30k Working/Counter cable is a heavy-duty cable with ring terminals on each end. The Gamry P/N for this cable is 985-00122.

This Working/Counter cable contains an EMI filter, which forms a visible lump in the cable. Always keep the end with this EMI filter nearest the booster.

1) Loosen the nuts on the **Counter** and **Working** terminals on the Reference 30k Booster's front panel. The red 9/16" nut-driver provided with your system fits these nuts.
2) Remove the nuts.
3) Place the **Working** ring terminal (the one with the green wires) on the bolt on the green terminal.
4) Place the **Counter** ring terminal (the one with the red wires) on the bolt on the red terminal.
5) Replace the nuts and tighten the connections with the nut driver.

Do **not** over-tighten the connections. We do **not** recommend tightening the connections with a high-torque wrench such as a socket wrench. The supplied nut-driver minimizes the probability of shorts and prevents over-tightening the terminals.

6) Double check the colors: green wires on green terminal, and red wires on red terminal.

Cal Cell Connections

Connect the other end of the Working/Counter cable to the **Cal** (Calibration) side of a Reference 30k Booster Test & Cal cell. This Test & Cal cell is a small printed circuit board.

The **Cal** Side of the Test & Cal cell is a 200 mΩ, ±1% tolerance resistor wired in a 4-terminal manner. The resistor is only rated for 1 W of power dissipation. This side of the fixture includes a 2 A fuse that keeps the resistor safe from over-current damage. Operator error can easily open this fuse. If the system does not operate as described below when it is run using the **Cal** Cell, have a service technician check that the fuse is intact.

1) Loosen the nuts on the Counter and Working terminals on the **Cal** side of the Test & Cal cell. The black 13 mm nut-driver provided with your system fits these nuts.
2) Remove the nut and one of the two copper washers on each bolt.
3) Place the Working ring terminal (the one with the green wires) on the **Working** electrode bolt, labeled **Green**. Replace the washer and nut. The ring terminal ends up sandwiched between two copper washers.

4) Place the Counter ring terminal (the one with the red wires) on the **Counter** electrode bolt, labeled **Red**. Replace the washer and nut. The ring terminal ends up sandwiched between two copper washers.

5) Tighten the connections with the 13 mm nut driver.

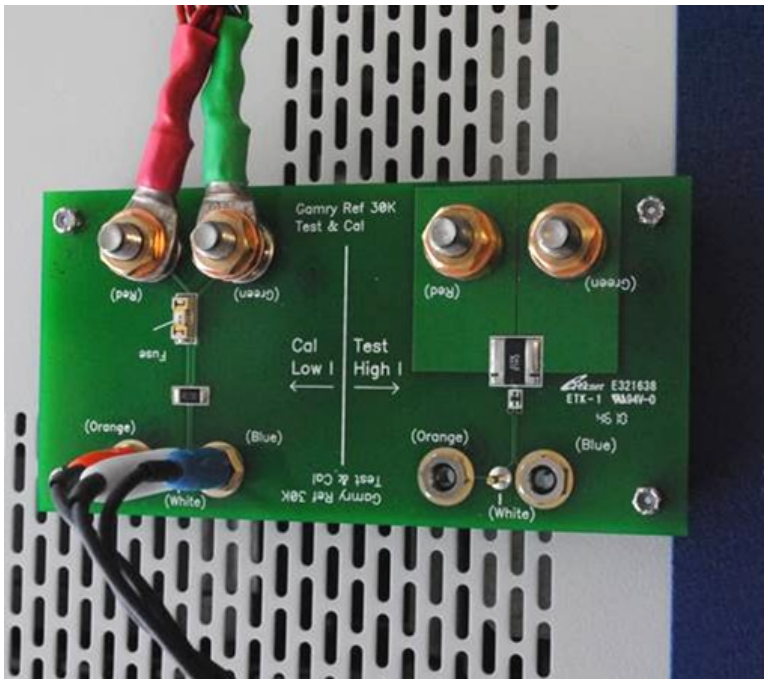
Do **not** over-tighten the connections. We do **not** recommend tightening the connections with a high-torque wrench such as a socket wrench. The supplied nut-driver prevents over-tightening the terminals.

6) Double check the colors: green wires on terminal labeled **Green**, and red wires on the terminal labeled **Red**. Make sure your connections are to the **Cal** side of the fixture.

The other three connections to the test cell come from the Reference 3000 Sense Cable. They are the white Reference, blue Working Sense and orange Counter Sense leads. They plug into the Test & Cal cell, in the jacks labeled by color.

The correct connections are shown in Figure 3-1.

Figure 3-1
Connections to the Cal Side of the Test & Cal Cell



Power-Up Test

The power switches on the Reference 3000 potentiostat and the Reference 30k Booster can be turned on in any order.

When power is applied, the blue **Power** LED indicators on both the Reference 3000 and the Reference 30k should illuminate. If your computer is powered and connected to the Reference 3000's USB, the **USB** LED on the Reference 3000 should glow green.

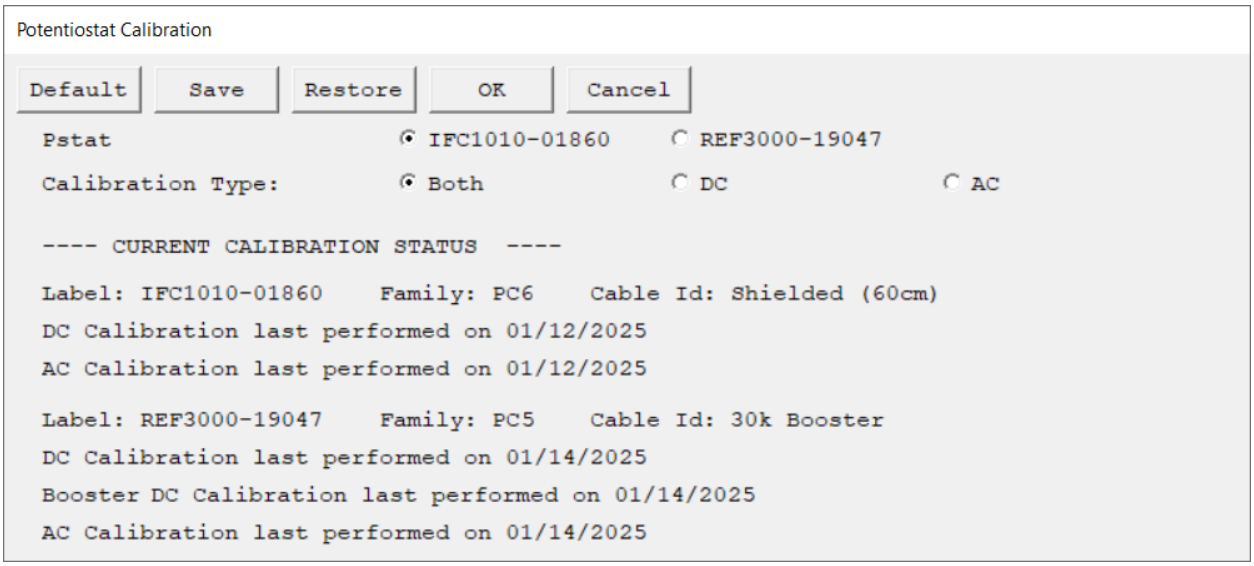
No other LEDs should be illuminated. If either instrument has its red **Overload** LED lighted, turn off the power and recheck all the connections. An open fuse in the **Cal** Cell could cause an **Overload** condition.

Calibration

Run the Gamry Framework software. In an earlier installation step, you already had the Reference 3000 running, so it should already be installed as a Gamry Device. If you get an error message when the Framework software runs, contact Gamry Technical Support.

Assuming that the Framework software is running, select **Experiment > Utilities > Calibration** on the Framework menu. A dialog box like the one shown in Figure 3-2 should appear:

Figure 3-2
Calibration Dialog Box



Select the device you want to calibrate. In the dialog box above, the Boosted system was labeled with a radio button **REF3000-19047**, so we select that device. Select the **Both** radio button to tell the system you want to run both a DC calibration and an AC calibration. When you click the **OK** button, the Framework software opens a runner window, and records current- and voltage-versus-time curves under a number of conditions.

If the calibration fails, you will see an Error window appear. If you see a failure, always suspect incorrect cable connections first. An open fuse in the Calibration Cell causes calibration failures.

A service technician can use an ohmmeter to test for an open fuse in the Test & Cal cell. An open fuse in the Cal side of the Test & Cal cell always causes AC Calibration failures.

Optional 30 A Test

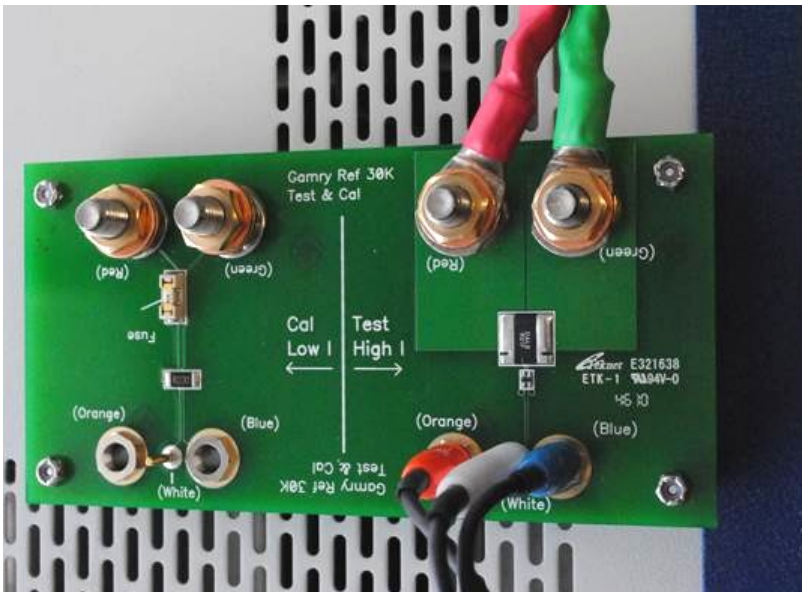
If you wish to further test your system, you can switch the cell cabling to the **Test** side of the Test & Cal cell. This side is a 3 mΩ 6 W resistor that will develop 90 mV at 30 A of applied current.

The connections are similar to the **Cal** side connections described above but made on the **Test** side of the fixture. Remember to move both the Counter and Working connections and the three Sense cable connections.

Do **not** run the 30 A test on the **Cal** side of the of the Test & Cal cell. You will blow (open-circuit) the fuse.

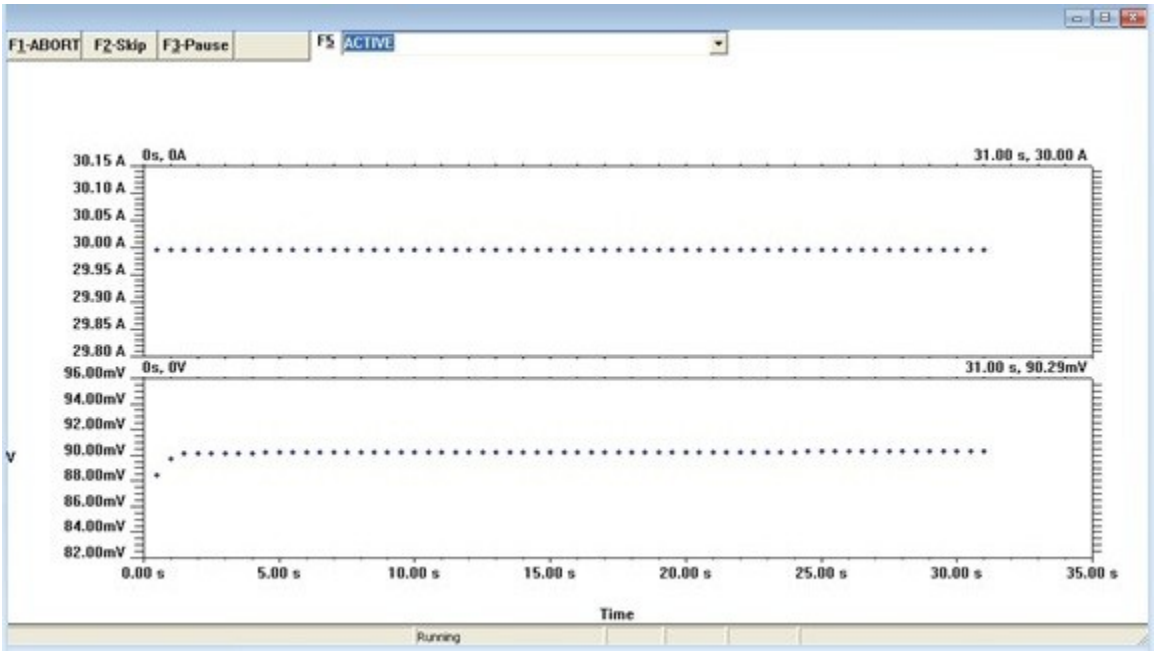
Figure 3-3 shows the connections on the **Test** side of the Test & Cal cell.

Figure 3-3
Connections to the Test Side of the Test & Cal Cell



Apply currents by selecting **Experiment > Utilities > Set a Current** on the Framework menu. In the window that appears, enter a current density of 3.0E4 mA/cm^2 and an area of 1.0 cm^2. After you click the **OK** button, a runner window displays a current and voltage versus time curve that looks similar to Figure 3-4.

Figure 3-4
Current-versus-Time Curve for 30 A Applied to the Test Cell



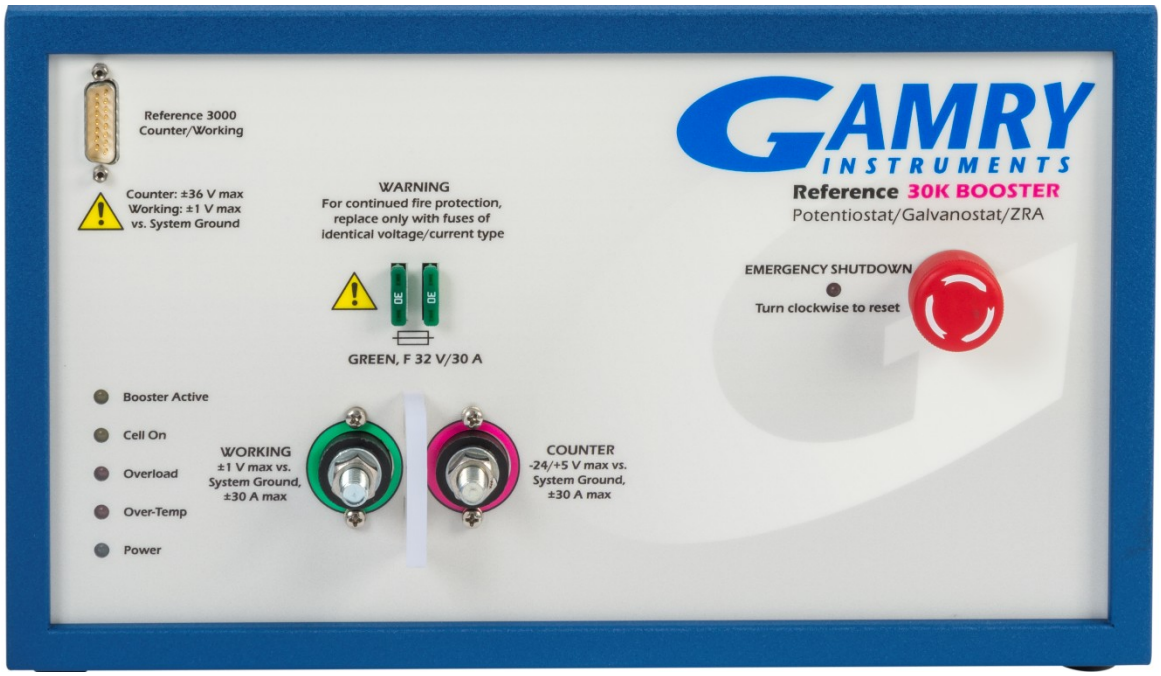
The voltage on the plot should be between 88 and 92 mV. The current should be between 29 and 31 A.

As a further check, you can repeat this test applying -30 A. The nominal voltage and current values will be -90 mV and -30 A.

Chapter 4: Panel Indicators, Controls and Connectors

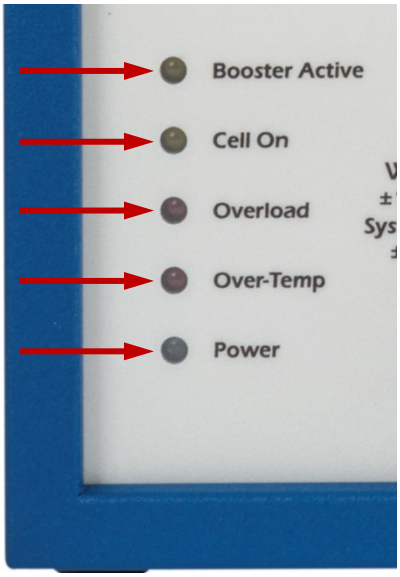
Figure 4-1 shows the front panel of the Reference 30k Booster. Its indicator lights, controls, fuses, and connectors are discussed in detail in this chapter.

Figure 4-1
Front Panel of the Reference 30k Booster



Front-panel Indicators

There are six indicator LEDs on the Reference 30k Booster's front panel.



Booster Active LED

This is a yellow LED, which lights when the system's software requests Booster operation on the 30 A current range. It is off when the software is operating on a lower current range.

Cell On LED

This is a yellow LED, which lights when the system's software turns on the Booster's Cell Switch. When this indicator is off, cell current will not flow through the Counter lead in the Booster's cell cable.

Overload LED

This is a red LED, which lights when the Booster encounters an **Overload** condition. There are three possible overload conditions:

- The control amplifier output current has exceeded its compliance limit of ±30 A. In this condition, the cell remains ON, and the output current is slightly higher than the limit. The desired control variable (current or voltage) is not being reached.
- The control amplifier output voltage has exceeded its compliance limits of –2.5 V or +20 V. In this condition, the cell remains ON, and the Counter lead generates a voltage slightly greater than the compliance limit. The desired control variable (current or voltage) is not being reached.
- The current measurement circuit is measuring a current in excess of ±30 A.

This indicator may light momentarily during AC experiments and when voltage steps are applied to capacitive cells. Momentary **Overload** indications generally do not imply a dangerous condition.

If the **Overload** indicator light goes on and stays on, this **can** indicate a dangerous condition, especially when the cell cannot handle high power.

Over-Temp LED

This is a red LED, which lights when the Booster heat-sink exceeds a temperature threshold. There are two temperature limits for the system:

- At the first, lower temperature threshold, the **Over-Temp** light goes on. The system does not shut down.
- At the second, if the temperature reaches the higher limit, the system shuts down. In this state the cell is turned off and power is removed from the system's control amplifier.

The **Over-Temp** indicator should never light during normal operation of the system. Possible causes for an **Over-Temp** condition include:

- Restricted airflow. The Booster needs 10 cm of airspace on all sides.
- An external environment above 40°C, such as in a glove-box with inadequate cooling.
- A system failure, such as an inoperative cooling fan, a shorted transistor, or a damaged temperature sensor.

Power LED

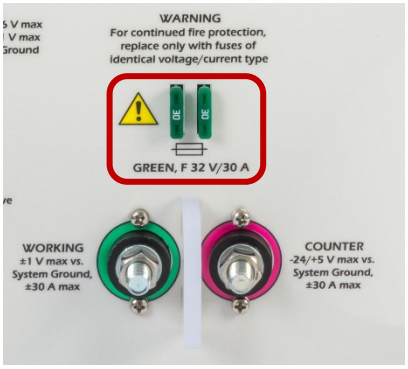
This is a Blue LED, which lights when the Booster has AC power (mains) connected and the rear panel power switch is turned on. Experiments at currents less than 3 A can still be run when the Booster is properly connected to a Reference 3000 potentiostat, even when it is not powered.

EMERGENCY SHUTDOWN LED

This is a red LED located near the **EMERGENCY SHUTDOWN** switch. It is off during normal system operation. It lights when the **EMERGENCY SHUTDOWN** switch has been activated. It remains on until the switch is reset.

Front-panel Fuses

The cell cable fuses are located on the Reference 30k Booster's front panel just above the Working and Counter terminals. Details concerning these fuses and instructions for replacing them are in Chapter 1.



EMERGENCY SHUTDOWN

The emergency shutdown control is a big red button on the right side of the Reference 30k Booster's front panel. It gives you an easy method to turn off an experiment.

EMERGENCY SHUTDOWN is intended for use only when a test has gone out of control. Pressing the button:

- Turns off the cell
- Removes power from the control-amplifier power transistors
- Shuts down the Reference 3000 USB, removing the system from the Windows Device Manager
- Turns on the **EMERGENCY SHUTDOWN** LED

Gamry Instruments does not recommend using the **EMERGENCY SHUTDOWN** in non-emergency situations. Any data already collected in an experiment can be lost.

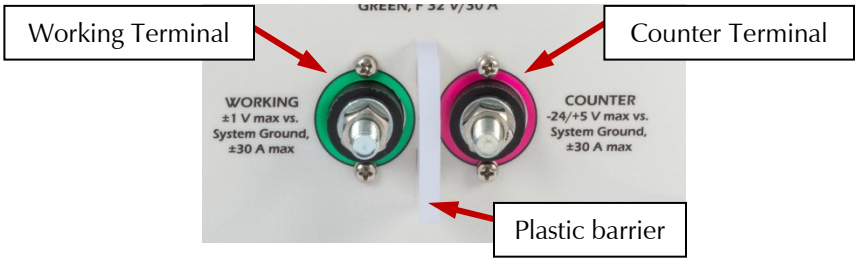
The button has a mechanical reset. It only resets when you turn it one-half turn clockwise. Reset will not turn the cell switch back on. It will turn off the **EMERGENCY SHUTDOWN** LED and repower the control amplifier.

The **EMERGENCY SHUTDOWN** switch only prevents current flow from the cell into or out of the Reference 30k Booster's high-current cell leads. It does not protect against dangerous cell conditions that do not involve current flow into the booster, such as short circuits within the cell. For this reason, it does not replace safety precautions against explosion, fire, or chemical spills in the cell.

A Reference 3000/Reference 30k Booster system in **EMERGENCY SHUTDOWN** mode disappears from the Windows Device Manger. It therefore will not appear as a device in Gamry's Framework software. When you reset the **EMERGENCY SHUTDOWN** control, the device should reappear in Windows after a few seconds.

Front-panel Connectors

There are three connectors on the front panel of the Reference 30k Booster.



Working Terminal

The **Working** terminal is a high-current connector that normally connects to the working electrode of an electrochemical cell. It can handle currents up to 30 A.

This terminal is a USA 3/8″ × #16 bolt. It is normally connected to the cell with a heavy-gauge, low-inductance cable. The standard length cable is 90 cm long. Its Gamry P/N is 985-00122.

Gamry has provided a nut-driver for easy connection to this terminal. It prevents over-tightening the terminal and minimizes the probability of short-circuiting the cell.

The plastic partition between the two high-current terminals on the front panel of the Reference 30k Booster is a vital safety feature. It prevents metal wrenches or other metal tools bridging between the terminals and short-circuiting the cell.

Counter Terminal

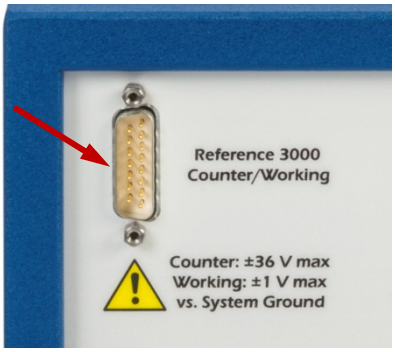
The **Counter** terminal is a high-current connector that normally connects to the working electrode of an electrochemical cell. It can handle current up to 30 A.

This terminal is a USA 3/8" × #16 bolt. It is normally connected to the cell with a heavy-gauge, low-inductance cable. The standard length cable is 90 cm long. Its Gamry P/N is 985-00122.

Gamry has provided a nut-driver for easy connection to this terminal. It prevents over-tightening the terminal and minimizes the probability of short-circuiting the cell.

Reference 3000 Counter/Working Connector

The **Reference 3000 Counter/Working** connector on the front panel of the Reference 30k Booster connects two analog signals between the booster and the Reference 3000. The signals are the Reference 3000's **Working** electrode (a current input) and the **Counter** electrode (a voltage output).



The cable normally used for this interconnect is Gamry P/N 985-00116. It has a 15-pin D-connector on each end.

Do not use any cable other than Gamry P/N 985-00116 to make this connection. This cable has special grounding and shielding required for operation of the system. Third-party 15-pin male-to-female cables may physically connect the instruments, but will not offer full performance, and could cause damage.

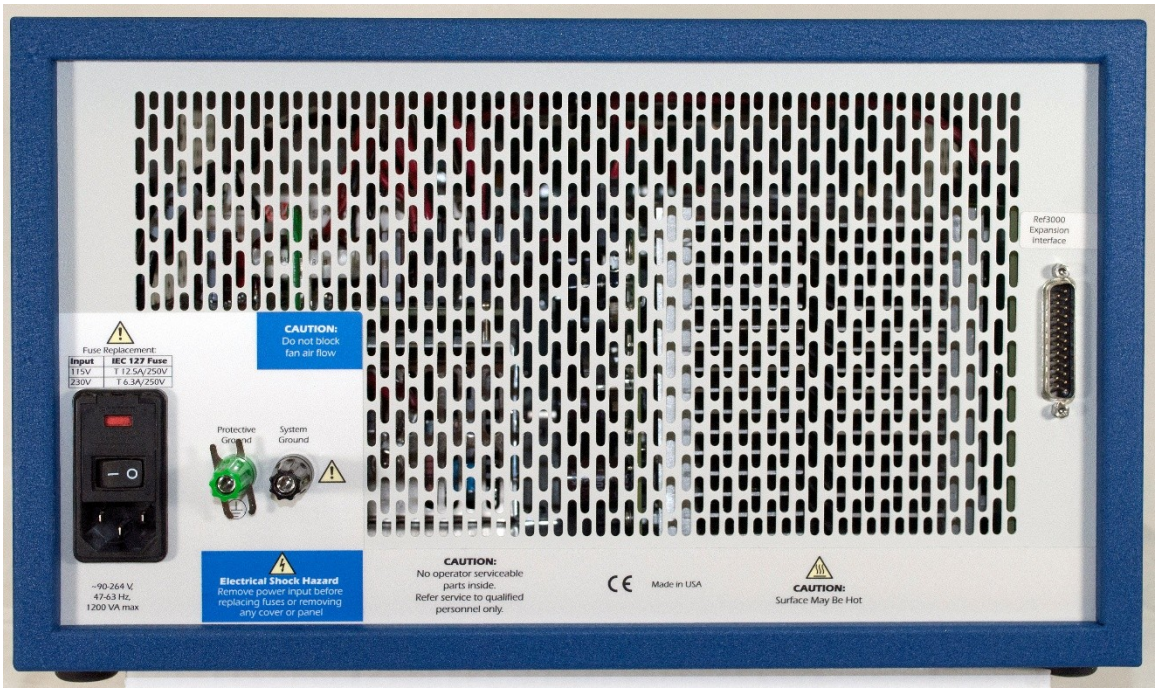
In pass-through mode, the Reference 3000 **Counter** and **Working** signals are routed to the high-current terminals on the Reference 30k Booster.

In the boosted mode, the Reference 3000 Counter signal is used as the input signal to the high-output-current control amplifier in the Reference 30k Booster. In this mode, a 30 A-to-3 mA current converter is used to provide a current to the Reference 3000's Working Signal.

Rear-panel Connectors

Figure 4-2 shows the rear panel of the Reference 30k Booster. Its connectors are discussed in detail below.

Figure 4-2
Rear Panel of the Reference 30k Booster



Power Input Connector

The power input connector is a three-function module. It contains a line-cord connector, a fuse block, and the power switch.

The fuses and fuse selection are described in Chapter 1. You must use fuses appropriate for the AC line voltage (mains) in your area.

You must use AC line fuses appropriate for the line voltage (mains) in your working area. Incorrect line fuses can limit system performance and create hazardous conditions.

Line cord selection is also described in Chapter 1. You must use a line cord rated for a minimum of 1500 W.

The power switch is used to turn on the electronics in the Reference 30k Booster. It controls AC power (mains) into three AC-DC converters (power supplies) inside the Reference 30k Chassis. The instrument can operate in pass-through mode even with the power switch off.

Protective Ground and System Ground Binding Posts

Grounding is discussed in detail in Appendix B.

The **Protective Ground** binding post is a convenient access point to the protective (earth) ground in the Reference 30k Booster. It is connected to the third wire in the AC power cord and to the Reference 30k Booster's metal chassis.

This binding post can be connected to an additional earth ground to form a redundant protective ground.

The **System Ground** is the common voltage reference point for the Reference 30k Booster's circuitry. It floats with respect to the **Protective Ground**.

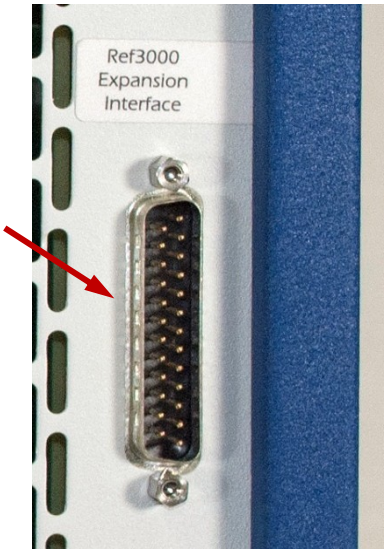
A strap is provided to connect the **Protective Ground** and **System Ground**. Tests on electrochemical cells isolated from earth ground may see lower noise when the grounds are connected.

Do **not** connect **Protective Ground** and **System Ground** if the electrochemical system you are testing is earth-grounded. Two earth-ground connections in a high-energy electrochemical system can create hazardous conditions.

The ground strap is normally left on one of the binding posts when it is not being used. Pictures in this chapter show the strap rotated to a safe position. A photograph in Appendix B shows the strap in use.

Ref3000 Expansion Interface

The **Ref3000 Expansion Interface** contains control and status digital signals needed for Reference 30k Booster operation. Gamry does not support connection of this interface to any instrument other than a Reference 3000 potentiostat.



In the Reference 3000/Reference 30k Booster system, make this connection with a 25-pin D-sub to 25-pin D-sub cable, Gamry P/N 985-00120.

The Gamry 985-00120 cable contains special shielding and grounding. Do not substitute third-party 25-pin D-sub to 25-pin D-sub cables for the Gamry cable.

Chapter 5: Suggestions for Cell Connection

This chapter contains suggestions for making connections to an electrochemical cell. We assume a Reference 3000/Reference 30k Booster system using the standard cables unless otherwise noted.

Avoid Short Circuits in Cell Connections

When you are testing a battery or other energy-storage device, you must avoid short circuits across the cell terminals. Short circuits are likely to destroy the device under test and can create dangerous conditions.

Short-circuits across an electrochemical cell can create hazardous conditions, including fire, explosion, and chemical discharge.

Always be very careful when designing your experiment: make sure you cannot short-circuit the cell under all conditions. Don't forget the possibility of short-circuits when you are connecting or disconnecting the device.

Voltage Errors Caused by Wire and Contact Resistance

In electronics, the resistance of a wire is often assumed to be zero. This is usually okay, because voltage error (*iR*-drop) caused by current flow through the wire resistance is small compared to the voltages in the system.

For example, 1 mA of current flow through 1 meter of 20 AWG (0.8 mm diameter) solid copper wire creates an *iR* voltage drop of: 1 mA × 33 mΩ/m = 33 μV. This voltage can safely be ignored in most electrochemical tests.

But if the current is much higher, for example 5 A, the voltage drop through 1 meter of 20 AWG wire is 165 mV. This is a significant error in any electrochemical test.

This problem becomes very significant in EIS testing of energy-storage and -conversion devices. Large high-rate batteries often have cell impedance less than 1 mΩ. Test set-ups for these devices require contact and lead resistances less than 10 μΩ. Fortunately, you can often employ a technique called 4-terminal measurements to minimize errors due to contact resistance.

4-Terminal Cell Connections

Accurate measurements of the current-voltage characteristics of high current electrochemical cells require 4-terminal (also known as Kelvin-type) connections. In a 4-terminal connection, the four leads that connect to the cell under test are grouped into two pairs.

- One pair of leads conducts the current between the cell and Reference 30k Booster. These leads are the "current-carrying leads".
- A second pair of leads measures the voltage across two points in the cell. These leads will be called the "sense leads".

In all Reference 3000 or Reference 30k Boosted systems, the Counter (Red) and Working (Green) high-current cell connections are the current-carrying leads.

In low-voltage systems, the sense leads are the Reference (White) and Working Sense (Blue) leads. The voltage sensed by these leads is generally assumed to be a cell voltage, although other voltages (such as a half-cell or multiple-cell voltage) can also be sensed. The maximum voltage on either lead is limited to ±10 volts. All standard Gamry application scripts, except those in the Electrochemical Energy software, assume low-voltage potential sensing.

In the Gamry Electrochemical Energy software, the Counter Sense (Orange) and Working Sense (Blue) leads can act as high-voltage sensing leads.

- The software opens a message box telling you how the connections should be made based upon your expected maximum voltage.

The allowed voltage on the Counter Sense (Orange) lead is ±30 volts. DC accuracy of the voltage measurement is reduced in high-voltage mode.

When you are making 4-terminal measurements on a two-terminal device, one current-carrying and one sense lead connects to each terminal on the device. Ideally, the sense lead contacts the terminal independently of the current-carrying contact.

The sense lead should be connected as close to the device as possible.

Figure 5-1 shows a half of a reasonably good 4-terminal connection with two alligator clips to a battery terminal. Each clip contacts the terminal independently and the sense clip is closest to the battery. The sense lead "sees" voltage drop caused by current through the battery terminal. The copper terminal's resistance is quite low, so voltage errors are small.

The resistance of this "good 4-terminal" battery contact was measured using a Gamry EIS system. The measured resistance was 0.3 mΩ.

Figure 5-1
Good 4-Terminal Clip Placement on a Battery Terminal

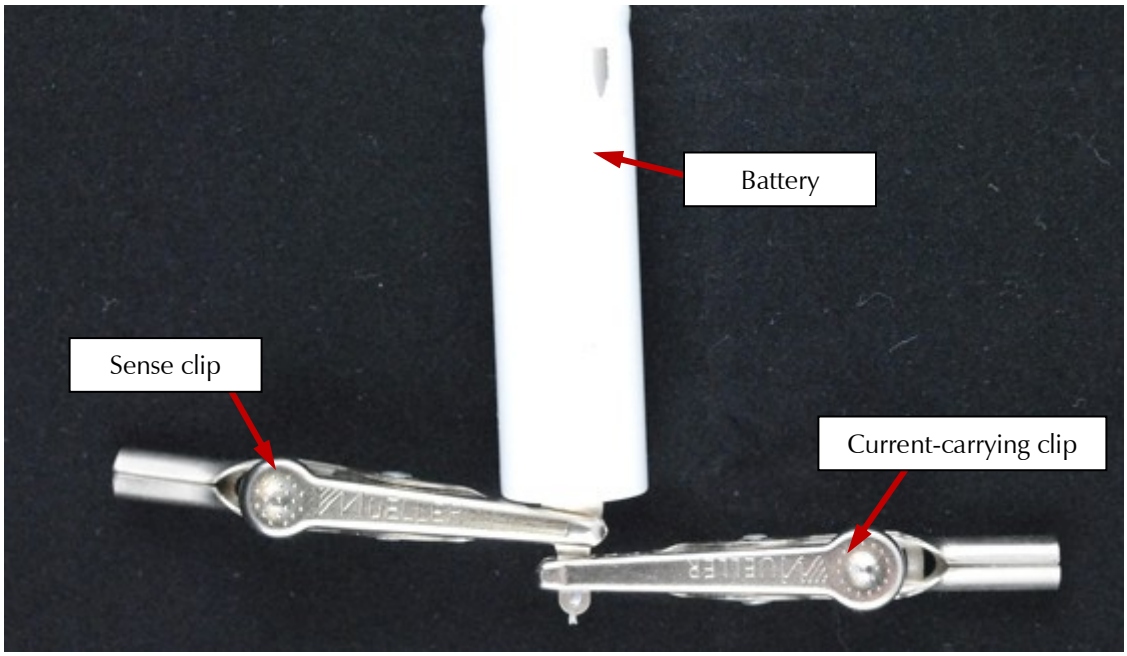
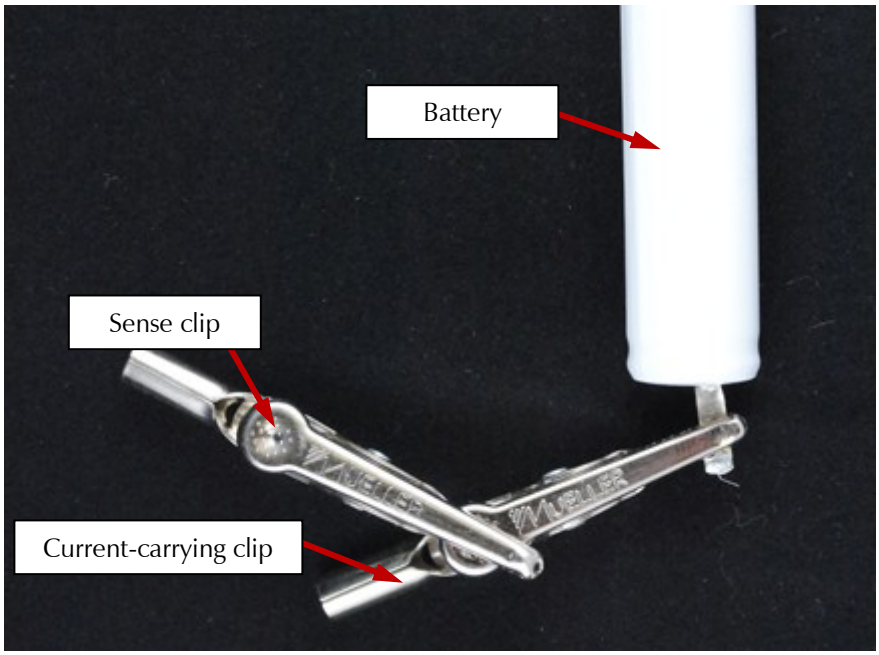


Figure 5-2 shows half of a very poor 4-terminal connection with two alligator clips to the same battery terminal. The sense lead "sees" voltage drop caused by the resistance both in the current-carrying clip, and the resistance of the clip-to-terminal contact.

Figure 5-2
Bad 4-Terminal Clip Placement on a Battery Terminal



Resistance was also measured for this "poor" connection. The measured resistance was 3.4 mΩ, more than 3 mΩ higher than the better connection.

Kelvin (4-terminal) Clips

Commercial Kelvin clips that resemble an alligator clip with two isolated jaws are available. One example is the Mueller Model BU-75k. Unfortunately, it is limited to currents of 10 A and below.

A higher current alternative is the Mueller Model BU-102BK which is a large 400 A Kelvin clip. You must do some modification to the clip to get convenient access to the sense side of the clips.

General Suggestions for High-current Connections

Even with 4-terminal connections, you should not ignore the quality of the current-carrying connections.

High-current connections to commercial batteries and supercapacitors are generally made using large-diameter bolts, like those found on the Reference 30k front panel. This can lead to very-low-resistance contacts. Remember that copper is an excellent conductor, so copper washers, bolts, and nuts are preferred. Steel's bulk resistivity is more than six times higher than that of copper.

Contact area is also important. Flat surfaces make better contact than uneven surfaces. Copper has a second advantage over steel in this regard: copper is softer than steel so it can deform to contact a larger surface area.

Do not over-tighten the terminal bolts on commercial batteries. Over-tightening can lead to cell damage and hazardous conditions. Cell manufacturers specify maximum allowed torque allowed on the terminal bolts.

Small alligator clips are a poor choice for high-current contacts. Standard alligator clips are typically rated for a maximum current of 5 A. The surface area of the contact between the alligator teeth and the cell terminal is generally very small.

A non-conductive washer between two ring terminals on a bolt can form a very good 4-terminal connection.

Large-diameter Threaded Connections

The diameter of the ring terminals on the Reference 30k Booster's Counter/Working cable (985-00122) is 10.5 mm (0.42″). The maximum bolt diameters that it can work with are 10 mm (metric) and 3/8″ (imperial).

Some batteries may have terminals with a larger diameter. If you need to make contact with a larger-diameter terminal, you can:

- Remove the ring terminal of the 985-00122 cable and replace it with a larger-diameter terminal. This may require the services of a professional electrician.
- Make a small cut in the ring terminal on the cell end of a 985-00122 cable and widen the hole.
- Construct an adapter from copper or some other high-conductance metal.
- Contact Gamry Instruments for a special cable with a larger-diameter terminal.

If you need to modify the Reference 30k Booster Counter/Working cable, Gamry Instruments recommends that you do so starting with a spare cable. Replacement cables are available; contact sales@gamry.com and ask for part number 985-00122.

Appendix A: Reference 30k Booster Specifications

All specifications are at an ambient temperature of 25°C, 115 V_{AC} power, and the Reference 30k Booster operated with a Reference 3000 potentiostat unless otherwise noted.

All specifications are subject to change without notice.

Control Amplifier

Compliance Voltage	+20 to –2.5	V
Compliance Current	±30	A
Voltage Gain	2	
Unity-gain Bandwidth	500	kHz
Slew Rate	>20	V/μs

30 A Current Range

Full-scale Current	±30	A
Accuracy	±0.3	% of range

System (all with a Reference 3000 potentiostat)

Control Modes	Potentiostatic, Galvanostatic, ZRA	
Allowed Current Ranges	30, 3, 0.3, 0.03	A

Mechanical

Dimensions (w x h x d)	37 x 23 x 44 14.5 x 9 x 17.5	cm inch
Weight	16 35	kg lbs

Power

Input Voltage	90 to 263	V_{AC}
Power (max.)	1200	W

A potentiostat system with a Reference 30k Booster connected to a Reference 3000 Potentiostat will not oscillate with any capacitive load as long as the Reference electrode impedance is less than 10 kΩ and the control amplifier bandwidth is Normal or slower.

A galvanostat system with a Reference 30k Booster connected to a Reference 3000 Potentiostat will not oscillate with any resistive load less than 100 Ω as long as the control amplifier bandwidth is Normal or slower. This is only guaranteed when the cell is connected using Gamry's P/N 985-00122 cable. Stability with inductive loads is not guaranteed.

Appendix B: Grounds and Floating Operations

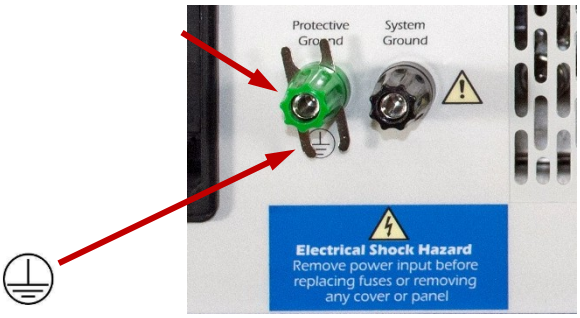
Ground Definitions

Ground is an electronics term that is often misunderstood. In non-technical English, one meaning of the word *ground* is the surface of the planet Earth on which we all live. In technical English, the definition of ground usually involves a point with an electrical connection to Earth. In this section, we will call this type of ground *earth ground*, or *earth*.

Knowledgeable electronics engineers use a somewhat different definition for the term *ground*. *Ground* is a common point in a circuit. Some English-speaking countries use the term *earth* instead of ground. Voltages are referred to this ground point as though they were at zero volts. A ground that functions as a reference point in a circuit, but is not connected to Earth, can be called a *floating ground*.

Grounding in the Reference 30k Booster

The metal case of the Reference 30k Booster is connected to earth ground via the ground pin in the AC power (mains) cord. This connection is essential to the electrical safety of this instrument. As defined in IEC Publication 348, *Safety Requirements for Electronic Measuring Apparatus*, the Reference 30k Booster is a Class I apparatus. Class I apparatus is only safe from electrical-shock hazards if the case of the apparatus is connected to a protective earth ground. In the Reference 30k Booster, the **Protective Ground** is available on a binding post on the rear of the Reference 30k Booster. This binding post is green and identified with the standard symbol for protective earth ground:



The green binding post is only provided as a convenient access point for the protective earth ground. This binding post is connected to the instrument chassis, which, in turn, is connected to the third wire in the power cord for the Booster. The instrument is electrically safe with no connection to this point.

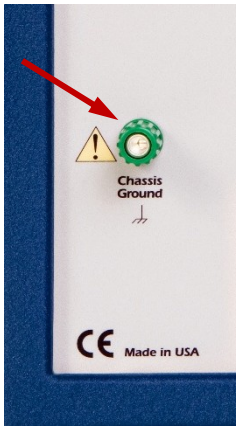
The internal circuitry of the Reference 30k Booster is not referenced to this **Protective Ground**. Instead, voltages within the Reference 30k Booster's chassis are measured with respect to a Floating ground, labeled **System Ground**. System Ground is used as the zero-volt reference point for the Reference 30k's power supplies and other circuitry. A black binding post on the Reference 30k Booster's rear panel allows easy access to this (floating) **System Ground**.

Grounding in the Reference 3000 Potentiostat

Unlike the Reference 30k Booster, the circuitry and the metal case of the Reference 3000 potentiostat are **not** connected to earth ground. The Reference 3000 is an IEC Publication 1010 Class II apparatus, in which contact with all hazardous voltages are prevented by means of "reinforced insulation".

Like operation of the Reference 30k Booster, voltages within the Reference 3000 chassis are measured with respect to a floating ground, which is the zero-volt reference point for its power supplies and other circuitry. Unlike the Booster, the Reference 3000 chassis is connected to the floating ground.

A green **Chassis Ground** binding post on the rear panel of the Reference 3000 allows easy access to the chassis and hence to floating ground.



The Reference 3000 **Chassis Ground** binding post is only provided as a convenient access point for the floating system. This binding post is connected to the instrument chassis but is not connected to earth ground. The instrument is electrically safe with no connection to this point.

USB Ground

The USB bus connector includes a ground connection that is directly or indirectly connected to the computer controlling a Reference 3000/Reference 30k Booster system. If the computer is earth-grounded (which should be true for all desktop computers), the USB ground will be an earth ground. In most laptop computers, even with a charger plugged in, the USB is not earth-grounded.

A USB processor within the Reference 3000 operates using this USB ground as its ground reference voltage. This USB processor receives and sends messages from the USB bus and relays them to the main processor in the Reference 3000. All inter-processor communications are via a serial bus isolated using transformer-coupled digital isolators. These isolators eliminate the USB as a contributor to ground issues.

System Ground

The Expansion Interface cable between the Reference 3000 and Reference 30k Booster connects the **System Ground**s of the two instruments. All control signals passing between the instruments are referenced to this shared ground. With this cable connected, the system ground becomes one signal: a connection made to the ground of one instrument affects both instruments.

The cable connections between the instruments do not connect the system to earth ground.

Connecting Earth and System Ground

If the system you are testing is isolated from earth ground, you can connect earth and **System Ground**s using the ground jumper provided with the system. This connection may reduce noise in the system. This jumper goes between the **Protective Ground** and **System Ground** binding posts on the rear panel of the Reference 30k Booster.

Connection of an earth-grounded cell to an earth-grounded Reference 30k Booster can short the cell. This can create excessive current and hazardous conditions. The 30 A **Counter** and **Working** fuses provide only limited protection.

If the **Counter** and **Working** fuses open when you hook up your cell, you probably have an earth ground in your cell system and an earth-grounded test system. Disconnecting the jumper between **System Ground** and **Protective Ground** is likely to remedy this problem.

If the problem reoccurs with the ground jumper disconnected, make sure you do not have additional test equipment connected to the system. If it still occurs with all additional equipment disconnected, contact Gamry Instruments' technical support staff.

Figure 5-3 shows the ground jumper in place.

Figure 5-3
Jumper Connection between Protective Ground and System Ground

When earth-grounding the System Ground is not desired, rotate the ground jumper out of the way but left attached to one of the binding posts (Fig. 7-2). This will prevent it being lost. If the jumper has been misplaced, you can run a wire between the binding posts to earth-ground the system.

Figure B-4
Storing Ground Jumper When Disconnected

Grounds and Additional Test Equipment

Most electronic test equipment, including oscilloscopes, signal generators, and data loggers, have an earth ground on their inputs and outputs. Connection of an instrument of this type in your system will earth-ground the system. For example, connection of a bench oscilloscope to the Reference 3000's **Isig monitor** BNC connector earth-grounds the system.

Do not use additional electronic test equipment connected to your Reference 3000 or Reference 30k Booster unless absolutely necessary. If you must use additional equipment, make sure that your cell is isolated from earth ground.

Reference 30k Booster Use in Systems Isolated from Earth Ground

Most laboratory electrochemical cells are isolated from earth ground. A glass cell on a bench top is an obvious example. Commercial packaged batteries and supercapacitors are usually tested with the device isolated from earth ground.

Be careful: earth connections on a high-powered system may not be obvious. Water-cooled cells and systems containing large AC-power pumps may have earth connections. Earth connections can also occur in a fault condition, such as a water leak or dielectric failure.

In most cases, you can leave the **System Ground** isolated from earth ground.

If you are testing a cell that is isolated from earth ground, earth-grounding your instrument system can reduce noise. The pair of ground terminals on the rear panel of the Reference 30k Booster was provided so a user can easily connect **System Ground** to **Protective Ground**. A shorting bar suitable for making this connection was provided with the system.

Two connections to earth ground in an electrochemical system can create a hazardous condition. If your cell has an earth-ground connection, you must not connect the system ground to earth. One symptom of multiple earth connections is opening of the Reference 30k Booster's front-panel fuses which protect the **Counter** and **Working** leads.

If the **System Ground** is connected to the **Protective Ground**, it compromises a boosted system's ability to make measurements in electrochemical cells that contain earth-grounded metal. One prominent example is electrochemical cells in autoclaves, where the autoclave's earth-grounded wall is generally used as the counter electrode of the cell.

Use in Systems Connected to Earth Ground

The Reference 30k Booster can be used to make measurements on systems with one electrode connected to earth ground. High-temperature cells in an autoclave, water-cooled cells, and systems with AC-powered pumps may have earthed metal in the cell's electrolyte.

The **System Ground** must be isolated from earth ground when you test earth-grounded systems. Disconnect the ground jumper as described above.

Two connections to earth ground in an electrochemical system can create a hazardous condition. If your cell has an earth-ground connection, you must not connect the system ground to earth. One symptom of multiple earth connections is opening of the Reference 30k Booster's front-panel fuses which protect the **Counter** and **Working** leads.

When you use a Reference 30k Booster in a system with an earth-grounded electrode, the **System Ground** will develop a voltage versus earth ground. The magnitude of the voltage depends on which electrode is earthed and the cell voltage. In all cases, the voltage will be less than 24 volts.

Limits on Ground Voltage

The Reference 3000 contains TVS surge suppressors that limit the voltage difference between the Reference 3000's chassis ground and the USB ground to about 40 volts. These surge suppressors are not part of the safety mechanisms in the Reference 3000. Instead, they are present to limit the possibility of improper instrument operation or instrument damage from electrostatic discharge (static electricity) and other surge events such as lightning.

Appendix C: Certifications

GAMRY INSTRUMENTS

Redefining Electrochemical Measurement

Declaration of Conformity: No. DOC-2011-CE-REF30KBOOSTER

According to ISO/IEC Guide 22 and CEN/CENELEC EN 45014

Manufacturer's Name and Location:
Gamry Instruments
734 Louis Drive
Warminster, PA 18974
USA

This declaration is for the Gamry Instruments product model: Reference 30k Booster
The declaration is based upon compliance with the following directives:

- EMC Directive 89/336/EEC as amended by 92/31/EEC and 93/68/EEC
- Low Voltage Safety Directive 73/23/EEC as amended by 93/68/EEC

The declaration is based upon product compliance with the following standards as defined in report number R0540-000 from Ergonomics, Inc. for safety analysis and report number R-1571P from Radiation Sciences, Inc. for EMC test and analysis.

EMC Standards	Title	Class/ Criteria
EN 61000-4-2	EMC – Electrostatic discharge, Immunity	B
EN 61326:2002-2	EMC – Radiated Emissions	A

Low Voltage Directive Safety Standards	Title
EN 61010-1:2001	Safety requirements for electrical equipment for measurement, control and laboratory use, Part 1: General requirements.
EN 61010-2-081: 6/2003	Safety requirements for electrical equipment for measurement, control and laboratory use, Part 2 Particular requirements for automatic and semiautomatic laboratory equipment for analysis and other purposes

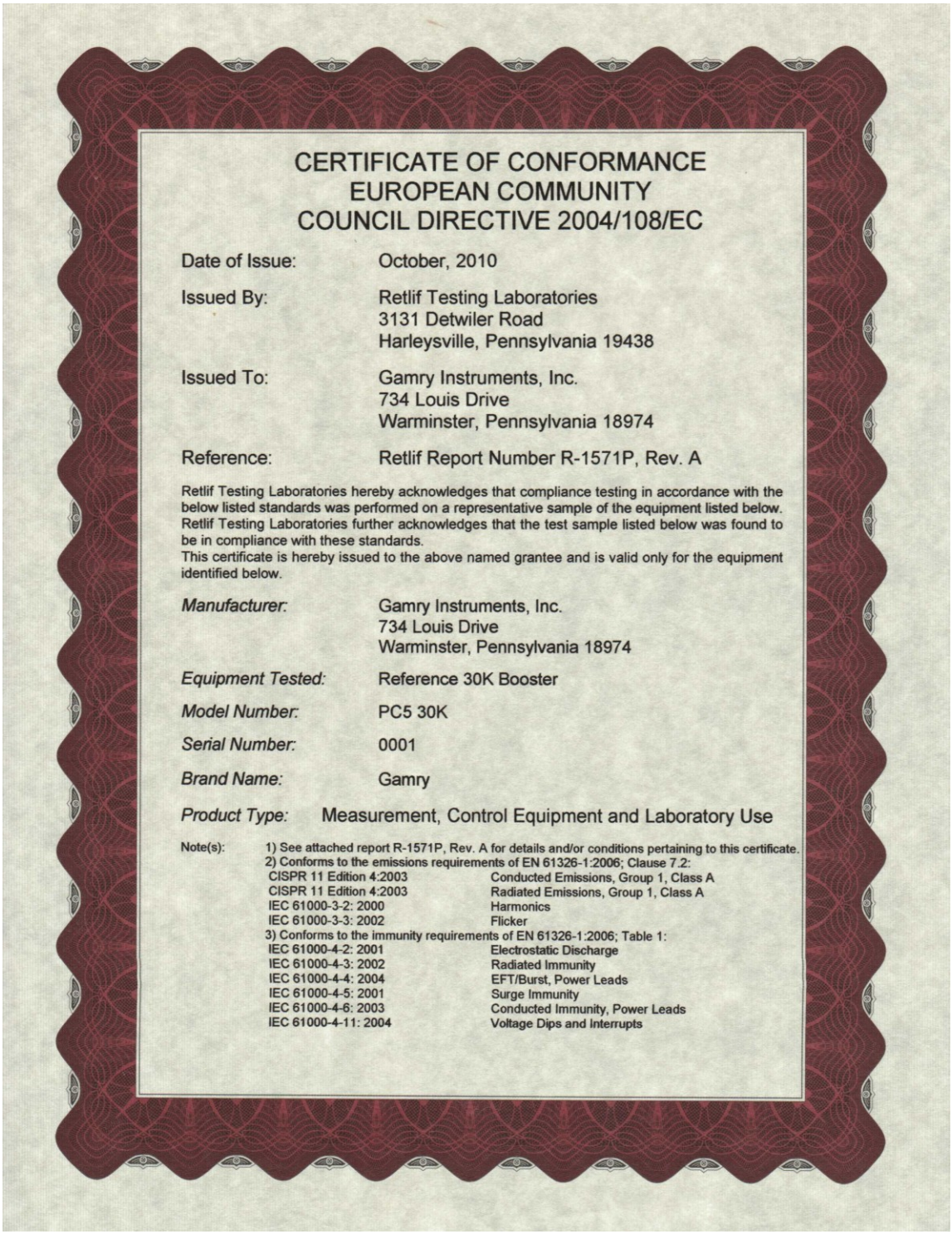
Signature

May 11, 2011
Date

Dr. Gregory A. Martinchek, PhD
Title: President

Formal signed declaration is on file at Gamry, Inc.

Certificate of Conformance



CERTIFICATE OF CONFORMANCE
EUROPEAN COMMUNITY
COUNCIL DIRECTIVE 2004/108/EC

Date of Issue: October, 2010

Issued By: Retlif Testing Laboratories
3131 Detwiler Road
Harleysville, Pennsylvania 19438

Issued To: Gamry Instruments, Inc.
734 Louis Drive
Warminster, Pennsylvania 18974

Reference: Retlif Report Number R-1571P, Rev. A

Retlif Testing Laboratories hereby acknowledges that compliance testing in accordance with the below listed standards was performed on a representative sample of the equipment listed below. Retlif Testing Laboratories further acknowledges that the test sample listed below was found to be in compliance with these standards.
This certificate is hereby issued to the above named grantee and is valid only for the equipment identified below.

Manufacturer: Gamry Instruments, Inc.
734 Louis Drive
Warminster, Pennsylvania 18974

Equipment Tested: Reference 30K Booster

Model Number: PC5 30K

Serial Number: 0001

Brand Name: Gamry

Product Type: Measurement, Control Equipment and Laboratory Use

Note(s):
1) See attached report R-1571P, Rev. A for details and/or conditions pertaining to this certificate.
2) Conforms to the emissions requirements of EN 61326-1:2006; Clause 7.2:

CISPR 11 Edition 4:2003	Conducted Emissions, Group 1, Class A
CISPR 11 Edition 4:2003	Radiated Emissions, Group 1, Class A
IEC 61000-3-2: 2000	Harmonics
IEC 61000-3-3: 2002	Flicker

3) Conforms to the immunity requirements of EN 61326-1:2006; Table 1:

IEC 61000-4-2: 2001	Electrostatic Discharge
IEC 61000-4-3: 2002	Radiated Immunity
IEC 61000-4-4: 2004	EFT/Burst, Power Leads
IEC 61000-4-5: 2001	Surge Immunity
IEC 61000-4-6: 2003	Conducted Immunity, Power Leads
IEC 61000-4-11: 2004	Voltage Dips and Interrupts

GAMRY INSTRUMENTS

Redefining Electrochemical Measurement

Declaration of Conformity: No. DOC-2021-UKCA-REF30KBOOSTER

According to ISO/IEC 17050-1:2004 and CEN/CENELEC EN 45014

Manufacturer's Name and Location:
Gamry Instruments
734 Louis Drive
Warminster, PA 18974
USA

This declaration is for the Gamry Instruments product model: Reference 3000 Potentiostat/Galvanostat/ZRA
The declaration is based upon compliance with the following directives:

- Electromagnetic Compatibility Regulations 2016
- Electrical Equipment (Safety) Regulations 2016

EMC Regulations	Title	Class/ Criteria
EN 61326-1:2013	EMC – Electrostatic discharge, Immunity	B
EN 61326-1:2013	EMC – Radiated Emissions	A

Electrical Equipment (Safety) Regulations	Title
EN 61010-1:2010	Safety requirements for electrical equipment for measurement, control and laboratory use, Part 1: General requirements.

Signature

August 24, 2021
Date

Dr. Gregory A. Martinchek, PhD
Title: President

Formal signed declaration is on file at Gamry, Inc.

Appendix D: Index