FCI4 Fuel Cell Interface

Operator's Manual

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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 date of shipment.

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If You Have Problems

Contact us at your earliest convenience. We can be contacted via:

Telephone	(215) 682-9330 8:30 AM - 6:30 PM US Eastern Standard Time
Fax	(215) 682-9331
Email	techsupport@gamry.com
Mail	Gamry Instruments, Inc. 734 Louis Drive Warminster, PA 18974 USA

If you write to us about a problem, provide as much information as possible.

If you are having problems with installation or use of your FCI4 Fuel Cell Interface, it would be helpful if you called from a phone near to your computer, where you can type and read the screen while talking to us.

We are happy to provide a reasonable level of free support for registered users of our products. Reasonable support includes telephone assistance covering the normal installation and use of the FCI4 in standard computer hardware.

We provide a two-year warranty covering both parts and labor. A service contract that extends the warranty is available at an additional charge.

Enhancements to the FCI4 that require significant engineering time on our part may be available on a contract basis. Contact us with your requirements.

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Chapter 1 -- Introduction

About This Manual

This manual covers the installation and use of the FCI4 Fuel Cell Interface.

This manual describes use of a FCI4 with Revision 5.1 (and later revisions) of the Gamry Framework software and the FC350 Fuel Cell Monitor.

The bulk of Chapter 1 is an overview of the FCI4's design and functions and a discussion of fuel cell and battery EIS. Chapter 2 contains PCI4 installation instructions.

You will find dry technical material such as specifications and connector pin- outs in the Appendices.

This manual does not discuss software installation or operation. Software support for the FCI4 is described in the ***Getting Started Guide*** for Gamry's Windows based software. All the Gamry Instruments' applications that which run under the Gamry Framework control the FCI4 via a PSTAT object. See the Framework's On-line Help for programming information.

CE Compliance Required for Sale in Europe

The European Community has instituted standards limiting radio frequency interference from electronic devices and mandating several safety requirements. Gamry Instruments has modified its instruments to comply with these standards.   We are shipping CE compliant instruments to all destinations.

The relevant CE regulation is EN 61326.

About the FCI4

The FCI4 is a pair of printed circuit cards that are installed into an AT compatible personal computer.   They interface to an electronic load or bi-polar power supply, which in turn connects to a fuel cell, super capacitor, or battery (device-under-test).   The Gamry Instrument FC350 software then uses this combined device to apply both AC and DC currents to the device-under-test and measure the device's voltage response.   The AC voltage measured by the FC4 divided by the measured AC current is used to calculate the complex impedance of the device-under-test.

The FCI4 is a member of Gamry Instruments' PCI4 Potentiostat family. It shares a number of characteristics with the other members of this family, especially in the areas of signal generation and signal preconditioning prior to A/D conversion.

FCI4 features include:

- A differential voltage measurement circuit that can accept inputs up to 50 volts

- Differential inputs for a signal proportional to cell current

- Electrical isolation from earth ground,

- Extensive filtering.

- Offset and gain circuitry that allows measurement of a 10 mV AC signal that is 50 V above ground

- A sine wave generator that can apply low distortion sine waves at up to 100 kHz

Both FC4 printed circuit cards install directly into a computer. Each card requires one expansion slot, although only one PCI connection is required. A ribbon cable interconnects the FC4 cards. Depending on the number of available slots, up to four FCI4 interfaces can be installed in one computer.

The first printed circuit card will be referred to as the Controller Card. It contains a PCI bus interface, opto⁻coupled serial transfer logic, an isolated power supply, an AC and DC signal generator, and a high performance measurement system. This manual describes systems based on both the PCI4 and Series G controller cards. These cards are also used to control PCI4 and Series G potentiostats in other systems.

> NOTE: The controller card in your system has been customized for use in an FCI4 system. You cannot use it to operate a Gamry potentiostat.

The second card is called the Interface Card. It contains analog conditioning circuitry. This card is not directly connected to the computer's PCI bus. It communicates with the computer over serial lines isolated by opto-couplers on the other card.

- The PCI bus interface communicates with the rest of the FCI4 over opto-coupled serial lines. There is no ground connection between the PCI bus circuitry and the analog circuits in the FCI4.

- The controller card contains an isolated DC/DC converter. This power supply converts the computer's 12 volt supply into the voltages needed to power its own analog circuitry. The interface card gets its power supplies from the Controller Card.

- The standard "DC" signal generator on the Controller Card uses two 16-bit D/A converters. A DDS sine wave generator is packaged on a small "piggyback card" that plugs into the Controller card.

- The Controller Card measurement circuitry includes signal filtering, offset, and decade gains of 0.1x, 1x, 10x, and 100x on two independent measurement channels. The output of these channels is measured using a 16-bit A/D converter.

Fuel Cell Testing Using EIS

Electrochemical Impedance Spectroscopy has become a well-accepted technique in many areas of electrochemistry. A skilled EIS analyst can use the technique to model an electrochemical cell into equivalent circuit elements, each of which correspond to a specific physical or chemical process in the cell. The analysis can be confirmed by looking at changes in the equivalent circuit elements as the experimental conditions are changed.

Fuel Cells are of great scientific and engineering interest as replacements for batteries and internal combustion engines. Both fundamental studies of new Fuel Cell approaches and attempts to optimize Fuel Cell performance can benefit from EIS testing and modeling. EIS is useful in both research and QC applications.

Electrochemical impedance spectroscopy (EIS) can identify problems that limit a Fuel Cell's efficiency, it can help optimize a cell, and it can determine anodic and cathodic process mechanisms.

Clever placement of reference electrodes in a cell may allow an analyst to test subsections of the cell, such as the anode, the cathode, and the electrolyte separately.

FC350 System Description

The FC350 Fuel Cell EIS Test System provides a comprehensive set of tools for Electrochemical Impedance Spectroscopy.   The FC350 uses an electronic load to control the flow of both DC and AC current through the cell.   EIS Spectra can be recorded while a DC current of ten or even hundreds of amps flow. In a typical test, an AC current of 8 amps is superimposed on a DC current of 120 amps.

As in all modern EIS systems, the FC350 uses a computer to automate EIS data acquisition and assist in data analysis. The FC350 software operates under the Gamry Framework™, which in turn operates in the Microsoft Windows® environment.

The FC350 can measure impedance over a frequency range of 10 µHz to 10 kHz. The impedance range that can be measured depends on the load used in the system.

The FC350 is available as a complete turnkey system built around a desktop or a portable computer and a TDI Dynaload. It is also available as a board set and software kit that you can install in your existing AT compatible computer using a 3rd party load or power supply.

While the FC350 was specifically designed for use in fuel cell testing, it can also be used for impedance testing of other power devices, including batteries and "super" capacitors used for energy storage. Operation in both charge and discharge modes is possible when a bipolar power supply is used instead of an electronic-load.

Standard System Hardware

The FCI4 is normally part of an FC350 system that includes:

- A Windows based computer with at least one PCI slot and one additional I/O card slot (PCI, shared, or ISA slots are all Ok).

- A PCI4 or Series G Controller Board customized for use in an FCI4 system. This card uses the PCI slot mentioned just above.

- An FCI4 Interface Board (which uses the other I/O slot)

- A 26 pin 30 cm long ribbon cable

- An electronic load or programmable power supply (TDI Dynaload, RBL series preferred)

- A cable to connect the FC350 Interface to the load and to the Fuel Cell

A turnkey FC350 system contains all of these pieces pre-configured for immediate use.

Use with Other Loads

The FC350 has been developed for and tested with the TDI Dynaload RBL series of electronic loads. Gamry therefore recommends these loads.

Other loads and power supplies may be usable with the system. However, cabling and script changes may be required - either to obtain basic functionality or to improve the user friendliness of the system.

Contact Gamry Instruments in the USA or your local sales representative if you need help modifying the FC350 for use with a different load or power supply.

Test Protocols

The standard scripts supplied with the FC350 perform two types of experiments. The two experiments are:

Galvanostatic EIS
In this experiment, a user specified DC current is applied to the load. A user specified AC current is then superimposed on the DC current.

The AC load current and the AC voltage between two voltage sensing points are measured and their relative magnitude and phase are computed. This process is repeated at a number of AC frequencies to develop an impedance spectrum.

Hybrid EIS
In this experiment, a user specified DC current is applied to the load. An initial AC current is then superimposed on the DC current.

The AC load current and the AC voltage between two voltage-sensing points are measured. The AC voltage between the voltage sensing points is compared with a user specified value. The AC current value is changed to a value that the system predicts will generate the correct value for the AC voltage. If the magnitude of the AC voltage is close to the desired value, the relative magnitude and phase of the voltage and current are computed.

This process is repeated at a number of AC frequencies to develop an impedance spectrum.

The galvanostatic experiment is the more straightforward of the two protocols.   The hybrid experiment is preferred when the impedance of the Fuel Cell changes drastically as a function of time or AC frequency.

The FC350 is built on the Gamry Instruments' EIS300 Electrochemical Impedance System, which in turn operates under the Gamry Framework Software. Both the Framework and EIS300 are required for operation of the FC350 software.

Notational Conventions

In order to make this manual more readable we have adopted some notational conventions. These are used throughout this manual and all other Gamry Instruments manuals.

- Numbered lists. A numbered list is reserved for step-by-step procedures, with the steps always performed sequentially.

- Bulleted List. The items in a bulleted list, such as this one, are grouped together because they represent similar items. The order of items in the list is not critical.

- Hexadecimal numbers. Hexadecimal numbers are used for hardware related items such as I/O addresses. The Gamry Framework and this manual use the C programming language convention: all hexadecimal numbers have a prefix of 0x. For example, the default I/O addresses used by a PC4 Potentiostat are 0x120 through 0x13F.

- File names and directories. Inside paragraphs, references to computer files and directories will be in quotes, for example: "WIN.INI" and "\FRAMEWORK\FRAMEWORK.EXE".

Chapter 2 – Hardware Installation into a Computer

A FC350 system is only useful after its FCI4 Fuel Cell Interface has been installed in an AT compatible computer.

If you purchase a complete FC350 system, Gamry Instruments, Inc. will install the FCI4 (and the system software) to produce a "turnkey" system. You can skip reading this chapter if you have purchased a turnkey system.

If you buy your own computer or need to move the FCI4 to a new computer, you need to know how to install the hardware into a computer. Read on.

Software installation is discussed in the next chapter.

Computer Requirements

Before you install the FCI4 hardware into your own computer you must make sure that your computer meets these simple requirements.

- A computer based on one of the Pentium™ family of Intel microprocessors or a 100% compatible processor from another vendor.

- One unobstructed, full height (11 cm) PCI expansion slots for each PCI4 in the system. Each slot must be capable of accepting a 26 cm long (10 inch) card.

- A second slot, which holds the FCI4 Interface card. This card does not plug into the computer's motherboard.

   This slot does not need to be PCI compatible, full length or full height.

- Up to 20 watts of power supply capacity for each FCI4. This is in addition to the power normally drawn by your computer and its standard peripherals.

- One unused disk drive power connector. This connector is used to power the Controller Card that is an essential component in the FCI4 system.

Most of the power is drawn from the computer's +12 volt and +5 volt supplies. In addition, a small amount of current (< 100 mA) is drawn form the -12 volt supply, so this supply must be present for FCI4 operation.

Board Identification

The FCI4 hardware consists of two printed circuit boards.

The larger board has changed over time. It was originally a modified component from Gamry's PCI4 Potentiostat. It has since been changed to a modified component from Gamry's Series G potentiostat.

This larger board functions as a versatile D/A and A/D interface, as a digital control interface and as a Frequency Response Analyzer. This board will be referred to as the FCI4 Controller Board.

The smaller board interfaces the Controller board to a load. This board will be referred to as the FCI4 Interface Board.

Positional Conventions

This manual will occasionally need to reference positions on the FCI4 Controller Card. In order to avoid confusion, we will define some conventions that describe positions on this board.

Assume:

- • The board in question is lying on a table in front of you.
- • The component side of the board is up.
- • The metal bracket on one side of the board is on your left.

Under these assumptions, Figure 2-1 illustrates our positional convention.

Figure 2-1
FC350 Boards Positional Conventions

Top

Left   Right

Bottom
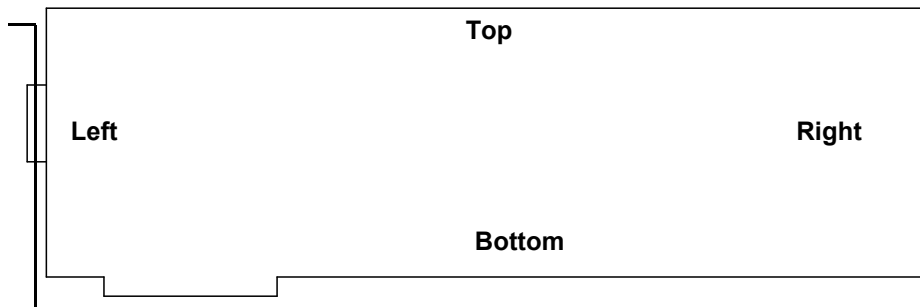
Handling the Boards

The FCI4 boards, like most electronic components, are susceptible to damage from static discharges and connection to live circuits. Some elementary precautions should be taken when handling and installing these boards.

- The boards are shipped in anti-static bags. Leave them in these bags until you need to install or reconfigure them.

- Always turn off your computer before plugging in any board.

- If you need to leave a board out of its anti-static bag, such as when you change a configuration DIP-switch, lay the anti-static bag on a flat surface, then lay the board on top of the bag.

- Prior to handling the boards, you should momentarily ground yourself to eliminate any static charges on your body. A good way to accomplish this is to turn off your computer, then lightly touch your finger to an unpainted portion of the computer's metal chassis.

- Save the anti-static bags. You must use them if the boards are shipped while not installed in a computer. This includes occasions when the boards must be returned to Gamry Instruments, Inc. for repair.

Plug & Play System Configuration

The FCI4 Controller Card is completely compatible with the Windows Plug & Play configuration system. Unlike Gamry's older hardware, you don't need DIP-switches to configure the card. Like most Plug & Play hardware, it is best if you install the software for the FCI4 <u>before</u> you install the potentiostat hardware.

A Setup program will normally startup automatically when you place the Gamry Instrument's Software CD into the CD drive on your computer. Consult Gamry's software installation manual if you need assistance accessing the Setup program or choosing options in its menus.

Installing the Boards in Your Computer

NOTE: Please review the discussion on **Handling the Boards** earlier in this chapter prior to proceeding.

The following procedure is used to install the FCI4 boards in your computer.

1. Turn off your computer.

2. Following your computer manufacturer's instructions open up the computer to expose its expansion board slots.

3. Locate an empty full-length expansion slot that has a PCI interface. If necessary, remove the retaining screw and slot cover (the 'L' shaped metal bracket). Save the screw for use later.

4. Locate a second empty slot that is within 10 cm of the first. This slot does not need a PCI interface. You may have to move some of your existing boards to get two suitable slots. Again, remove the retaining screw and slot cover, saving the screw for use later.

5. Remove the larger (FCI4 Controller) board from its anti-static bag.

6. Plug this board into the slot with the PCI interface. Make sure the board seats securely in the edge board connector on the motherboard. Secure the board's metal mounting bracket using the screw from Step 3.

    NOTE: All the gold fingers on the lower edge on this board <u>must</u> be in a motherboard edge connector.

7. Remove the smaller (FCI4 Interface) board from its anti-static bag.

8. Mount this card into the computer using its mounting bracket. Unlike the Controller Board, this board does not plug into any connectors on the computer's motherboard. Secure the mounting bracket using the screw from Step 4.

9. <u>Do not</u> close up the computer yet.

Installing the Internal Cables

1. Locate the 26-pin headers on both the PCI4 Controller and the PCI4 Interface boards. Each header contains 26 pins enclosed within a black rectangle.   The headers are located on the upper middle section of the Controller Board and on the top of the Interface Board.

2. Examine the ribbon cable that came with the FC350 system (Part Number 985-00068). Each end of this cable has a 26-pin connector on it.   The two ends of the cable are identical and therefore interchangeable.

3. Plug one end of this ribbon cable into the 26-pin header on the Controller board.   The colored stripe on one side of the cable <u>must</u> go on the left side of the board (the side of the connector nearest to the metal bracket). The cable is keyed to prevent improper installation.

4. Plug the other end of the cable into the 26-pin header on the Interface board.   The colored stripe on one side of the cable <u>must</u> go on the left side of the connector (nearest the metal bracket). The cable is keyed to prevent improper installation.

5. Locate the power input connector on the upper left side on the FCI4 Controller card.   On older systems it is a larger "hard drive" style connector, on newer systems it is a much smaller "floppy drive" style connector. In either case, Gamry provides a adapter power cable to convert the computer's drive power to the appropriate power input.

   Note that the computer power cables can only mate in one direction. If any power cable will not plug into a connector, rotate the cable 180°.

6. Carefully double-check your work.

7. Once this step is completed you may close up the computer.

1st Time Device Installation in Windows

When a FCI350 is first connected to a computer running Windows, the Windows Plug and Play Manager will see the new device, but will be uncertain what device it is. The message that will appear is something like "New device found" or "Unknown PCI Bridge device Detected".   When this occurs after you've plugged in a FCI350 instrument, tell Windows that you would like to install the new device.

Regardless of the age of the FCI4 hardware, our aim during installation is to identify the FCI4 interface as a "PCI4 family" device and load the appropriate device drivers into the computer.

Windows 7 Users: The following windows will not be displayed. Please skip to page 2-8 to continue the installation process.

All other users should see a screen that looks something like this:

Figure 2 - 2
Welcome to the Found New Hardware Wizard

As shown in this Figure, do <u>not</u> choose to let Windows Update find the device driver that you need. The Windows Update web site has no knowledge of the Gamry Instruments PCI4 family of devices.

Make sure you select **No, not this time**.   After you select, **<u>Next</u>**, you should see a screen that looks like this:

Figure 2-3
Install the Software Automatically
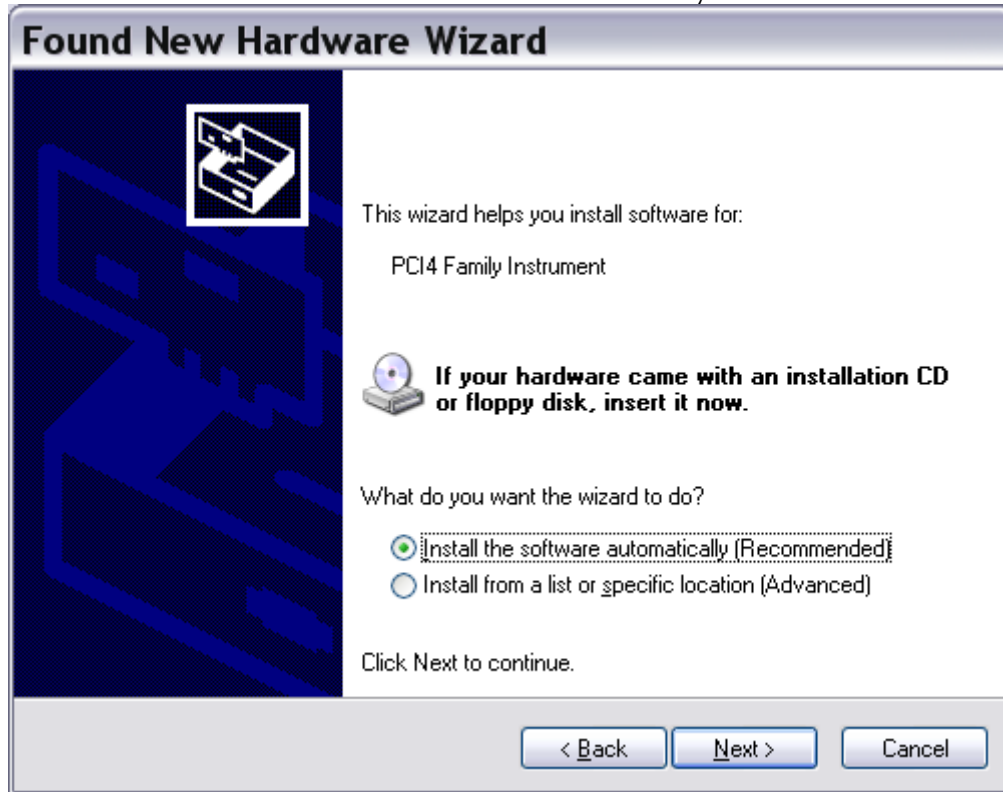
All Gamry device drivers are pre-installed to your machine during the software installation process. Select **Install the software automatically**, then select **Next**.

These messages will also be seen when a FCI4 instrument is moved to a new PCI slot. In this case, you can select **Install the software automatically** even if you do not have the Gamry Instruments CD. The driver that was previously installed on your computer's disk drive will be used.

The Windows Device Manger will locate and install the required files, which are already on your system.

Your Gamry Software CD is not required at this point. However, if you do not have your Gamry Software CD or lose the CD at any point, contact Gamry Instruments, or your local Gamry Sales representative for assistance.

Once the drivers and associated support files have been installed, you should see another screen that looks like this:

Figure 2-4
Install the Software Automatically
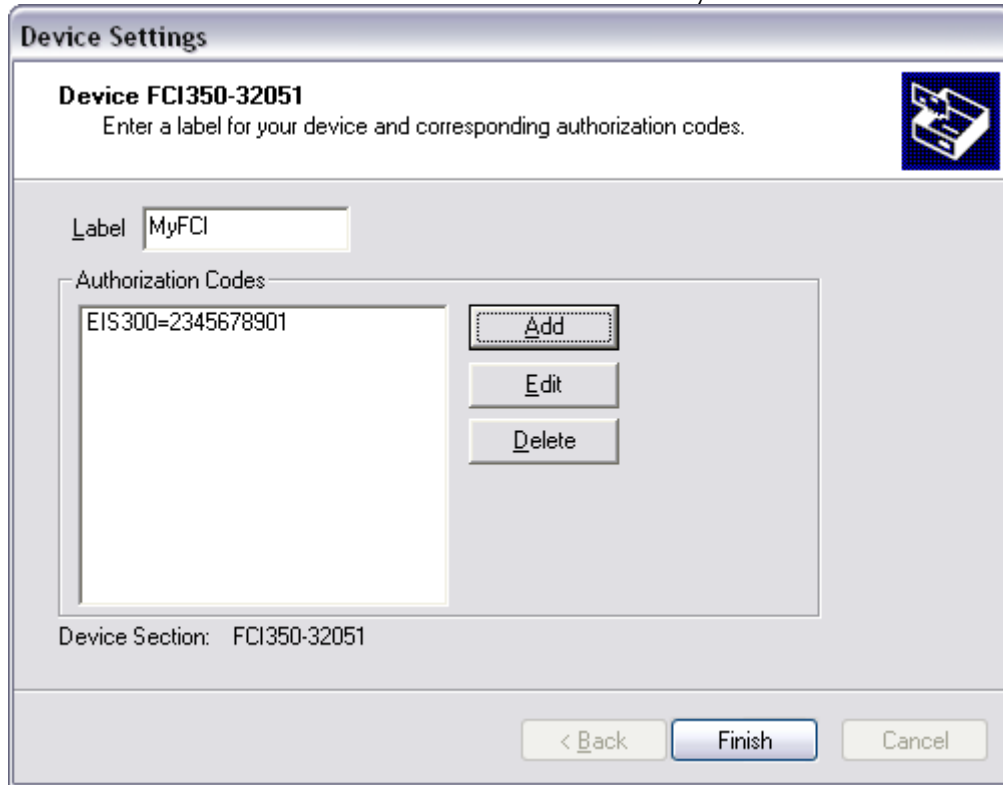
As displayed in Figure 2-4, you enter a friendly name for your FCI350, as well as any authorization codes you received with your instrumentation. The authorization codes are 10 digit codes that allow different Gamry application software to be used with your FCI350. If you cannot locate your authorization codes, please contact Gamry Instruments or your local Gamry Sales representative for assistance.

To enter an authorization code, simply click on the **Add** button. A dialog box will appear as shown in Figure 2-5. You enter the package name, like "EIS300", followed by the 10 digit authorization code.

Figure 2-5
Enter an Authorization Code
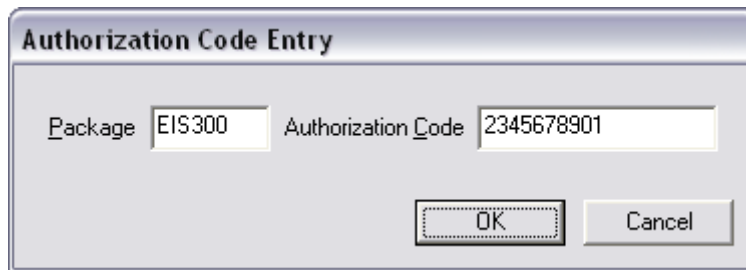
Press **OK** when you are finished.

Multiple Potentiostat Systems

Gamry's current Framework software (Revision 5.0) allows a computer to operate up to 16 Gamry Instruments devices simultaneously. The 16 potentiostats can include both PCI4 family devices and the newer PC5 family devices.

Contact our home office or your local Gamry Instruments representative if you need assistance configuring a system containing both FCI350 and Reference 600 hardware.

Device Manager

If you wish to make changes to the configuration of your FCI350 after it has already been installed, you must use the Windows Device Manager. Steps for getting to the Device Manager can vary by operating system, so check your operating system's online help for more specific information on how to get to the Windows Device Manager.

Under Windows XP, right clicking on the **My Computer** icon and selecting **Properties** brings up the **System Properties** dialog box. Select the **Hardware** Tab and then click on the **Device Manager** button. This should bring up the Device Manager screen. Clicking on the + sign next to Gamry Instruments, should expand the tree view to give you a screen that looks similar to the following figure:

Figure 2-6
Device Manager Window
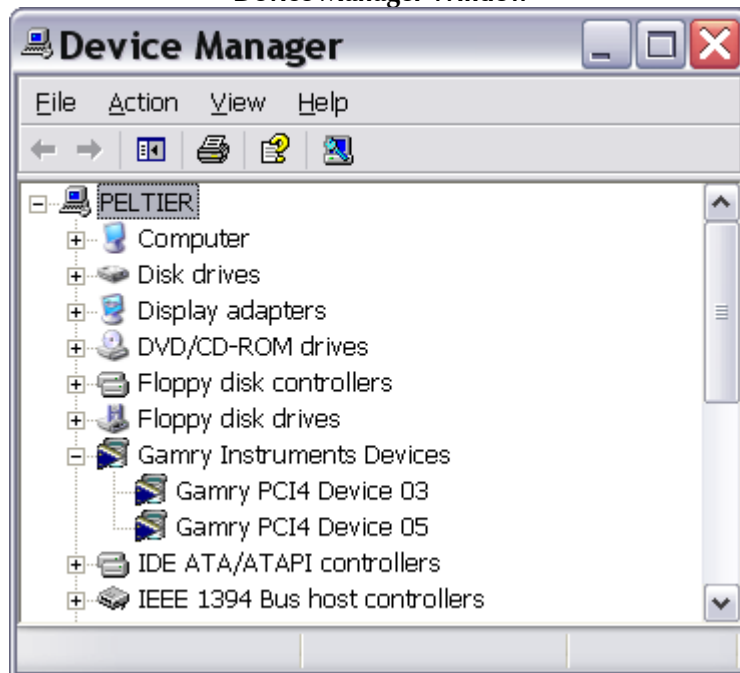
You can now right click on any of the Devices listed under Gamry Instruments and select **Properties** to look at or change its configuration.

Authorization Codes and Label

If you purchase additional Gamry application software, did not enter your authorization codes upon initial device installation, or simply need to make a correction to your authorization codes, you can do so using the Windows Device Manager. You can also change the Label you use for your device.

The Gamry Framework Application Software must first be closed before you can use the Device Manager to make changes. Next, you must select the appropriate device, as discussed in the Device Manager section. Once you have selected the appropriate device, right click and select **Properties**. Next, select **Device Settings** and you will see a screen that looks like Figure 2-7:

Figure 2-7
Device Settings Tab
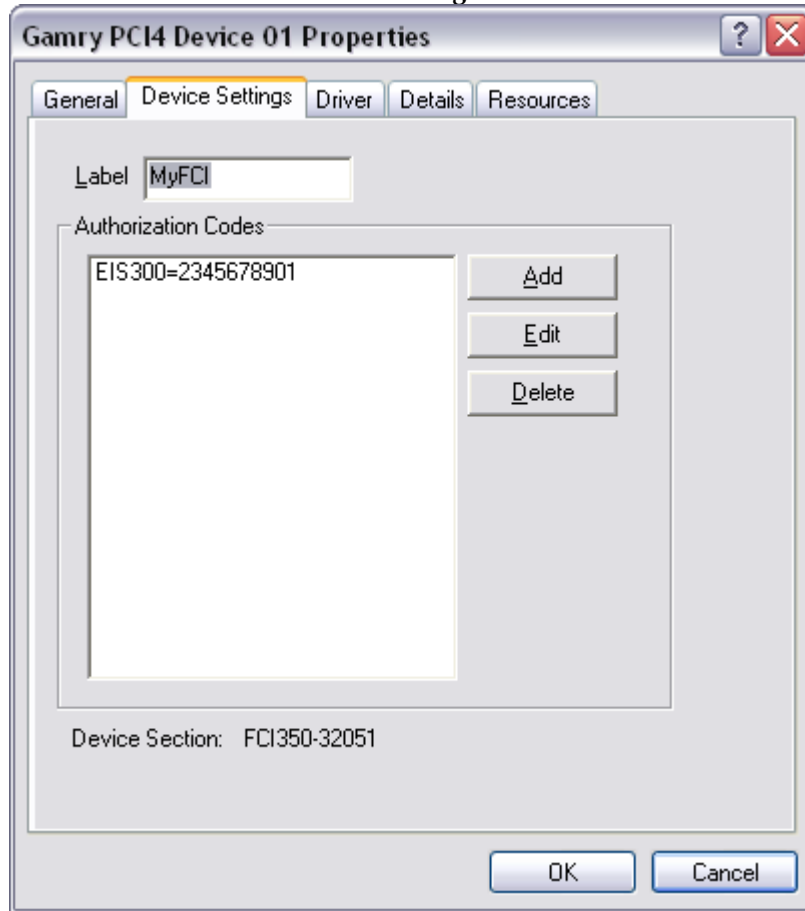
You can enter or edit any of the authorization codes or Label for the device by clicking on the appropriate edit box and entering the information. When you are finished making changes press **OK** to store the changes.

Chapter 3 - Framework Installation

The FC350 in turn operates under Gamry's Framework software. Framework Revision 5.0 (or greater) is required for operation of the FCI4 as described in this manual. The Gamry Framework Setup program takes care of all the details of FC350 software installation.

Full installation instructions for the Gamry Framework can be found in the ***Getting Started Guide*** that was included in your FC350 shipment. Follow those instructions to set-up the Gamry Framework.

Two things to remember during the Framework and driver setup process:

1. You will see a dialog box that selects Applications software packages. In this dialog box, select the FC350.

2. The driver installation will ask you to enter Authorization Codes for the FCI4 (calling it a PCI4 family potentiostat). The Authorization Code is a 10-digit number that you can find printed on the packing slip for your FC350 system purchase.

   The FC350 shares authorization codes with the EIS300 EIS system. Enter the FC350 code in the EIS300 Authorization Code field.

Echem Analyst Installation

Full installation instructions for the Echem Analyst can be found in the ***Getting Started Guide*** that was included in your FC350 shipment. Follow the instructions in this guide to set-up the Echem Analyst. This manual will not duplicate the information in this guide.

The only portion of the Echem Analyst that must be loaded is the EIS300 application.

Load Configuration

The FC350 was designed to be a general-purpose analyzer capable of operation with many different loads and programmable power supplies. It was tested with the TDI Dynaload series of loads, so Gamry is confident it will interface with these loads. We attempted to anticipate unique characteristics of other loads and power supplies.

You use a special Load Setup script to enter the characteristics of the load or power supply used with the system. These characteristics are then used in the FC350 control and measurement algorithms.

> **NOTE:** The Load Setup script MUST be run prior to any use of your FC350 System, even if you are using a TDI Dynaload in your system.

Even TDI Dynaloads come in a wide variety of models with a wide range of specifications, so even they require characterization before they can be used.

The Load Setup script can be run by selecting **E̲xperiment, Fuel Cell Monitor, Load Setup** on the Gamry Framework's menu bar.

The Load Setup script will output a series of three dialog boxes. The first asks for the device that you wish to setup. See Figure 3-1,   In a simple system, there is only one device, as seen in this figure. In a system with two (or more) instruments, you use this dialog box to select the instrument to be characterized.

Figure 3-1
Load Setup Device Selection
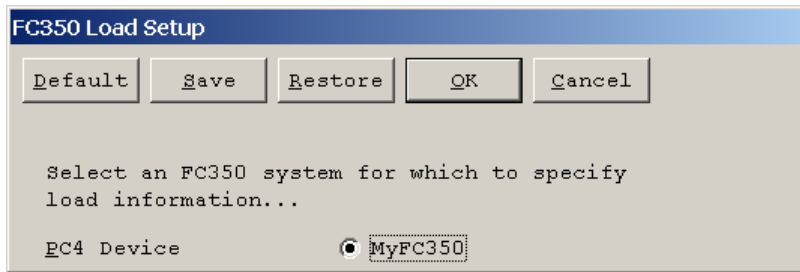
The next dialog box, a sample of which is seen in Figure 3-2, is used to select the number of current ranges in the load or power supply. TDI Dynaloads have three current ranges. These ranges are used both in setting and measuring the cell current.

Most other loads and power supplies have only one range.

Figure 3-2
Load Setup – Selecting the Number of Current Ranges
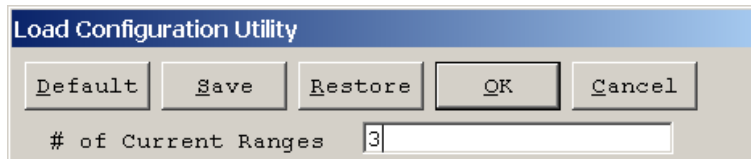
Once Load Setup knows the number of current ranges, the rest of the load information can be entered into a dialog box similar to that in Figure 3-3. Note that this dialog box is output after the previous dialog box has specified a load with three current ranges. A simpler dialog box is seen if only current range is specified.

Figure 3-3

Main Load Setup Dialog Box

Current Range Information	
Default Save Restore OK Cancel	
Label Range 1	LOW
I Range 1 (A)	2
Label Range 2	MED
I Range 2 (A)	20
Label Range 3	HIGH
I Range 3 (A)	120
V Range 1 (V)	10
V Range 2 (V)	50
Full Scale Output	10
Full Scale Input	10

The Range labels are arbitrary and can be changed. We suggest that you use the range labels on the front panel of the Dynaload (Low, Med, and High). Another good choice for ranges labels might be the actual current range (replace "Low" with "20A").

The values following the range labels are the full scale current in amps for each range.

> **Note**: The Range numbers entered into this table <u>must</u> be correct! If they are wrong, both the applied currents and the measured impedances will be wrong. If you are using a TDI Dynaload, please consult the Dynaload documentation and find the full scale current on each of its ranges. Be careful, different Dynaload models have different ranges!

The FC350 Interface has two input voltage ranges. By default they are 10 V full scale and 50 volts full scale. They are identified in the Load Setup as V Range 1 and V Range 2. In most cases, the numbers in Figure 3-3 should be entered as shown.

If you need to operate at voltages in excess of 50 volts, you can put a voltage divider in front of <u>both</u> voltage input leads. If 10 to 1 dividers are used, the effective input range becomes 100 volts. A 20 to 1 divider allows operation at 200 volts. If you do this, you can enter 200 for the full-scale voltage V Range 1.

> **Note**: Load Setup MUST be run whenever the divider radio is changed!

> **Warning**: Operation at voltages beyond 50 volts can create a significant safety hazard and can be dangerous to the instrument. We recommend that you contact Gamry for advice before attempting high voltage operation.

The final two entries in the Current Range information dialog box are only applicable to systems with "3rd party" loads. A TDI Dynaload always applies full-scale current when +10 volts is applied to its remote programming input. It always outputs +10 volts when the cell current is at full-scale.

Other loads or power supplies may use other scale factors or even opposite signs. The Full Sale Input and Full Scale Output field are used to allow use of these devices. Consult Gamry if you need to modify these values.

The load configuration data is stored in the system "GAMRY5.INI" file, in a section labeled [PstatX] (where X is generally 1, 2, 3 or 4). This data can be edited directly.

The load configuration data is read upon starting up the Gamry Framework. After running Load Setup, you must leave and then restart the Framework before the new values take effect.

CAUTION: **Failure to restart the Framework after running Load Setup can cause unusual system operation and incorrect results.**

Software Calibration of Your FCI4 Hardware

After you have installed your new Gamry Software and Setup your load, you should run the calibration routine for the FCI350 Hardware.

The calibration procedure uses a special FC350 Calibration Fixture that is provided with your system. This fixture looks like a D connector hood with a switch mounded on it. During calibration this fixture replaces the cable used to connect the FC350 Interface board to the load.

> **Caution:**
> 9-pin D connectors are used for several computer functions other than the FC350 connection. Make sure that you plug the fixture into the correct connector.

Carefully follow the connection and switch connection instructions displayed during calibration.

The procedure to calibrate the FC350 Hardware is:

1. Run the Framework.

2. From the Framework bar, select **File, Calibrate…**. A Setup dialog box will be displayed.

3. Connect the Calibration Fixture to the FC350 Interface card. Make sure the switch on the fixture is in the Zero position.

4. When you are prompted, change the switch to the Signal position (away from the Zero position).

5. Once calibration is complete, replace the cable connecting the FC350 Interface card to the load.

Hardware calibration is required infrequently. You should recalibrate under the following circumstances:

- You are installing the hardware into a new computer.

- It has been about one year since your last calibration.

- Your hardware has been repaired.

- You notice breaks or discontinuities in the data curves recorded with your system.

- You have replaced your "GAMRY5.INI" file.

Chapter 4 -- External Cabling

This chapter describes the cables used to interconnect the FCI4 Hardware, a Fuel Cell, and a load. The first section of this chapter describes the connections assuming a TDI RBL Series DYNALOAD is used in the system. A second section describes FCI4 connection in more general terms.

Dynaload Connections

Many of the Dynaload connections are made on a nine position terminal block on the rear of the Dynaload chassis. The terminals on this block are labeled on the rear panel. For ease in description, this terminal block will be referred to as the "Dynaload Terminals".

Dynaload Current Path Cabling

The load has two high current connectors labeled E+ and E-. These are large diameter threaded studs equipped with Hex nuts. Dynaloads are normally shipped with thick, high current cables designed for connection to these terminals.

The terminal labeled E+ is connected to the positive terminal of the Fuel Cell. The terminal labeled E- is connected to the negative terminal of the Fuel Cell.

Do not connect the "low current" E+ and E- screws on the Dynaload terminal block to the Fuel Cell! Only the high current studs should be connected to the cell.

Remote Sense on the Dynaload

The Dynaload is typically shipped with a jumper between the E+ and S+ terminals and between the E- and S- terminals. This configures the load for local voltage sensing. We recommend you leave the Dynaload configured in this manner.

FC350 to Dynaload Interface Cable

FC350 systems that we know will be used with a Dynaload are shipped with a complex cable that makes the remaining system connections.

The part number of this cable is 985-00069. It is called the FC350 to Dynaload Interface Cable.

One end of this cable plugs into the 9-pin D connector on the FC350 Interface board. This connector is located on the mounting bracket that holds this card in place.

> **Caution:**
> 9-pin D connectors are used for several computer functions other than the FC350 connection. Make sure that you plug the cable into the correct connector.

Please use the thumbscrews on the 9-pin end of the cable to securely hold the cable in place.

The other end of the cable includes two types of connections. The first is spade lugs that connect with the Dynaload terminals. The second type includes two banana plugs.   These banana plugs connect directly to the Fuel Cell.

See the diagram in Figure 4-1 for an overview of the connections.

Figure 4-1
FC350 Connections to Dynaload
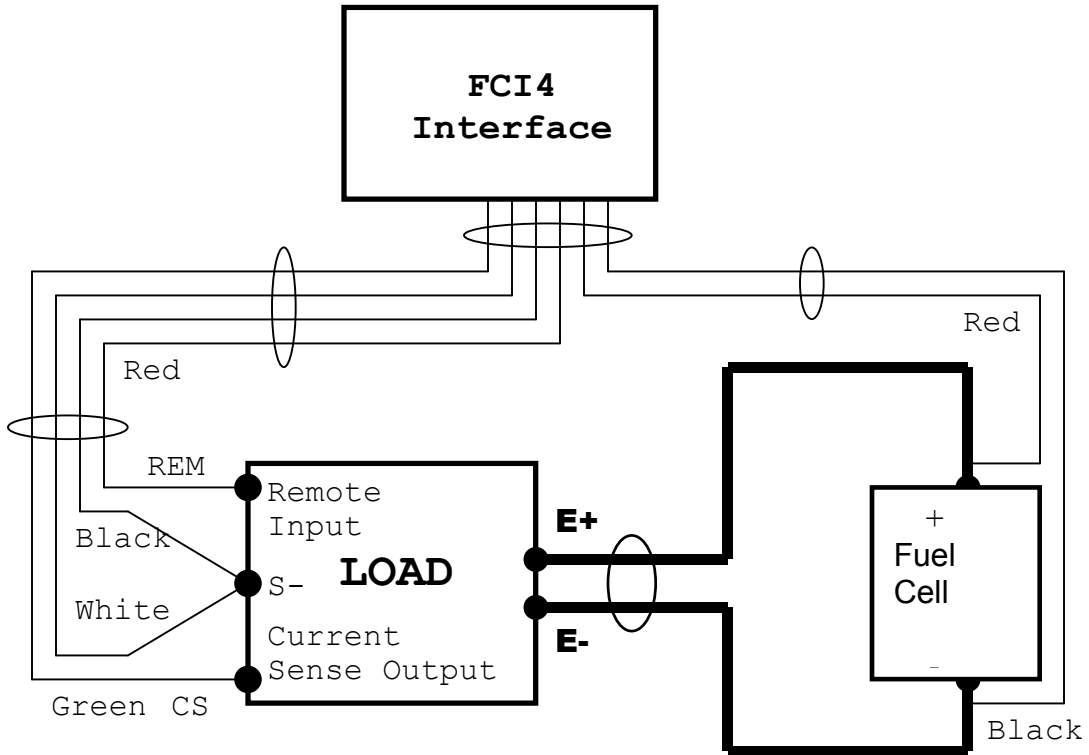
Connecting the FCI4 Interface to the Dynaload Terminals
The FC350 to Dynaload Interface Cable includes three spade terminals. These are identified by the color of the wire connected to the terminal. They are used to connect to the Dynaload terminals as follows:

Table 4-1
FC350 to Dynaload Connections

Wire Color	Function	Dynaload Terminal
Green	Current Sense +	CS
Red	Remote Signal	REM
Black*	Ground	S-
White*	Current Sense -	S-

* Note that the White and Black wires are twisted together and connect to a single spade lug on the FC350 to Dynaload Interface Cable.

Some Dynaload models use a small terminal block that does not accommodate the spade lugs on the supplied cable. In this case, the lugs must be removed, the wire ends stripped, and the wire poked directly into the Dynaload terminal strip and tightened into place.

The CS terminal on the Dynaload is a 10 V full-scale signal proportional to the cell current. The amount of current that correspond to full scale varies with the Dynaload current range. On a 200 amp range, 10 V on the CS terminal corresponds to 200 A, 5 V correspond to 100 amps, etc. The reference signal for the CS signal is the Dynaload S- terminal.

The FC350 receives the CS input differentially. The voltage difference between the green and white wires is measured. This voltage should not exceed 11 volts.

The REM terminal on the Dynaload is the remote programming signal. The FC350 always operates the Dynaload in its constant current (CI) mode. In this mode, 10 V applied to the REM terminal will give you full-scale load current. The amount of current that corresponds to full scale varies with the Dynaload current range. On a 200 amp range, 10 V on the CS terminal corresponds to 200 A, 5 V correspond to 100 amps, etc. The reference signal for the REM input is the Dynaload S- terminal.

The FC350 outputs a signal generator voltage on the red wire. Both a DC voltage corresponding to the DC current to be applied and an AC voltage corresponding to the desired AC current are output by this signal generator. The reference voltage for the signal generator is the black wire. The wire is internally connected to a floating ground reference on the FC350 Hardware.

The black wire is normally connected to the Dynaload's S- terminal. In effect, this connects the grounds of the two instruments together. Note that neither the black wire nor the S- terminal is connected to an earth ground, so the system is doubly protected from ground loops.

Connections to the Dynaload should be made with the Dynaload and computer power supplies switched OFF. Make sure that all the connections are correct and screwed in tightly before you power the load and the computer.

Do not switch the Dynaload Current On until you have started an FC350 script and it has told you to turn on the load.

Voltage Sense Terminals in a Dynaload System
The FC350 makes an impedance measurement taking the ratio of an AC voltage measurement and an AC current measurement. The AC current measurement is made by the system's electronic load.

The AC voltage measurement is made using the red and black banana plugs on the FC350 to Dynaload Interface cable. The red probe should be connected to a more positive potential than the black probe. If this relationship is not observed, the phase of the measured impedance will be incorrect (shifted by 180°).

The banana plugs can be covered with alligator clips. These easily slip on and off the banana plugs.

The voltage measurement can be made several places in the Fuel Cell. If you place the voltage sensing probes across an entire Fuel Cell stack, the impedance of that entire stack is measured. If you place the probes between the anode and cathode contacts of a single cell, the impedance of that one cell is measured. If you place a reference electrode in the "electrolyte" of a cell and then connect the probes to this reference and the cell's anode current collector, you measure the impedance of that anode separately.

The placement of the probes is critical. Ideally the probes should be connected as close as possible to the point in the cell that will be measured. Remember that wire has both resistance and inductance and that these create significant voltage in a wire passing 10's or even 100's of amps of current.

The voltage sense terminals are shielded with the computer's earth ground potential. Excessive input resistance can create a phase shift. The input resistance and the cable capacitance create an RC filter, which creates the phase shift. If you use a reference electrode to look at points within a Fuel Cell, we recommend that the reference electrode impedance not exceed 200 Ohms.

3rd Party Connections

Table 4-2 shows the pin-out of the Load connector on the FC350 Interface Board. This connector is a standard male, 9 pin, D type connector.

Table 4-2
FC350 Interface Board Load Connector

Pin Number	Signal Name	Function
1	E -	Negative Input to a Differential Electrometer
2	E +	Positive Input to a Differential Electrometer
3	Floating Ground	Ground Reference for the FC350
4	I -	Negative Input to current monitor circuit
5	I +	Positive Input to current monitor circuit
6	Floating Ground	Ground Reference for the FC350
7	Spare Digital	Reserved for Future Use
8	Signal Output	AC and DC voltage proportional to desired current
9	Floating Ground	Ground Reference for the FC350

Typical System Connections
Figure 4-3 shows the schematic of the FC350 used with a load.

Figure 4-3
FC350 Connections to a Generic Load
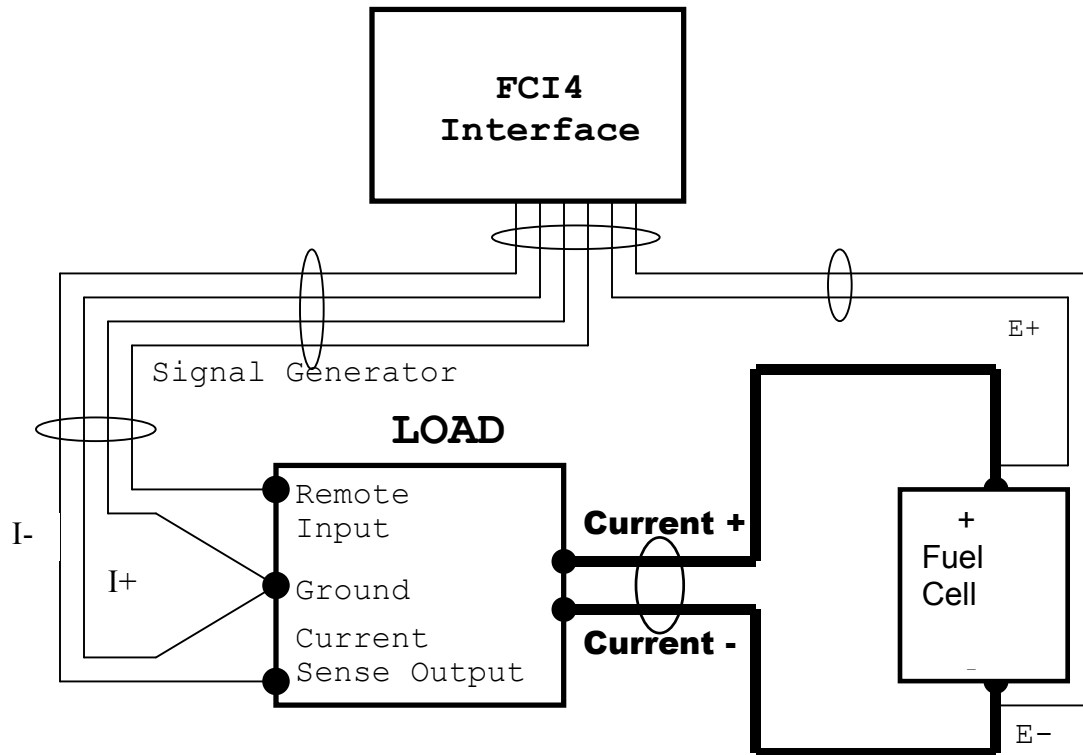
Reading Cell Current
Any load used with the FC350 must provide an output voltage that is proportional to the load current. This signal will be referred to as the current monitor signal.

By default 10 volts at the current monitor signal is assumed to correspond to full-scale current.

In cases where this default value doesn't work, the current that corresponds to full scale, the full-scale voltage and the polarity of the current monitor signal can be changed using the Load Setup script.

The FC350 receives the current monitor signal differentially. The voltage difference between pins 4 and 5 is measured. This voltage between these pins should not exceed +/- 11 volts.

> **Note**: To insure compatibility with the first prototype FC350 instruments, the current monitor signal is inverted as it is read. The signal is connected to the minus input of the FC350's current monitor and the signal's reference is connected to the positive input

Controlling the Cell Current
Any load or power supply used with the FC350 must be in a constant current mode. The load or power supply must provide an input terminal used to control the current level. The load current must be proportional to the voltage on this input. This input signal will be referred to as the remote input signal.

By default, the FC350 system assumes that 10 V applied to the remote input terminal will give you full-scale load current.

In cases where this default value doesn't work, the current that corresponds to full scale, the full-scale input voltage and the polarity of the input signal can be changed using the Load Setup script.

The FC350 outputs a signal generator voltage on pin 8 of it's Interface board connector. Both a DC voltage corresponding to the DC current to be applied and an AC voltage corresponding to the desired AC current are output. The reference voltage for the signal generator is Floating Ground, pin 3, 6 and 9 of the connector.

Floating ground is normally connected to the load's ground, where it functions as the reference signal for the remote input signal.

Voltage Sense Terminals
The FC350 makes an impedance measurement by taking the ratio of an AC voltage measurement and an AC current measurement. The AC current measurement is made by the system's electronic load.

The AC voltage measurement is made between pins 1 and 2 of the FC350 Interface connector. Pin 1 should be connected to a more positive potential than pin 2. If this relationship is not observed, the phase of the measured impedance will be incorrect (shifted by 180°).

The voltage measurement can be made several places in the Fuel Cell.

If you place voltage-sensing probes across an entire Fuel Cell stack, the impedance of that entire stack is measured. If you place the probes between the anode and cathode contacts of a single cell, the impedance of that one cell is measured. If you place a reference electrode in the "electrolyte" of a cell and then connect the probes to this reference and the cell's anode current collector, you measure the impedance of that anode separately.

The placement of the probes is critical. Ideally the probes should be connected as close as possible to the point in the cell that will be measured. Remember that wire has both resistance and inductance and that these create significant voltage in a wire passing 10's or even 100's of amps of current.

Any cables provided by Gamry are built with voltage sense coax leads shielded with the computer's earth ground potential. Excessive input resistance can create a phase shift. The input resistance and the cable capacitance create an RC filter, which gives you the phase shift. If you use a reference electrode to look at points within a Fuel Cell, we recommend that the reference electrode impedance not exceed 200 Ohms.

Chapter 5 – Cables and Mutual Inductance

The type of cables used in an FC350 system and the placement of those cables can have a major effect on system performance. A phenomenon known as mutual inductance limits the ability of an FC350 system to make accurate measurements at low impedances and high frequencies.

This chapter describes mutual inductance and its effect on EIS measurements and offers practical suggestions for its minimization.

FC350 Lead Pairs

Four leads connect to the cell in a typical FC350 system.   Their function naturally groups them into two pairs.

One pair of heavy-duty leads conducts the current between the cell and the load or power supply in the system. These leads will be called the current carrying leads or primary leads.

A pair of lighter duty leads measures the voltage across two points in the cell.   These points can be at the two ends of a cell stack, across one cell, or even between a reference electrode and one electrode in a cell. These leads will be called the sense leads or the secondary leads.

Mutual Inductance and Its Minimization

A *mutual inductive effect* limits the ability of an FC350 system to measure small impedance at higher frequencies. The term mutual inductance describes the influence of the magnetic field generated by the current carrying leads on the sense leads.

In essence, the current carrying leads are the primary of a transformer and the sense leads are the secondary.   The AC current in the primary creates a magnetic field that then couples to the secondary, where it creates an AC voltage.

This unwanted effect can be minimized in a number of ways:

- Avoid Higher Frequencies
- Minimize the net field generated by the current carrying leads.
- Separate the current carrying leads from the sense leads.
- Minimize pickup of the field in the sense leads.

Avoid High Frequency
Mutual inductance is an inductive effect. The voltage error is given by:

$$Vs = M \, di/dt$$

-- Vs is the induced voltage on the secondary, M is the coupling constant (with units of Henries), and di/dt is the rate of change in the <u>primary</u> current.   M depends on the degree of coupling and can range from zero up to the value of the primary inductance.

Assuming a constant amplitude waveform in the primary, di/dt is proportional to frequency.   There is always a frequency below which the effect of mutual inductance errors is unimportant. Unfortunately, many electrochemical systems need information at frequencies above this limit.

Minimize the Net Magnetic Field
A current passing through a wire creates a magnetic field.   The field strength is proportional to the current. Fortunately, passing the same current in opposite directions through adjacent wires tends to cancel the external field.   This also minimizes the net inductance in the wires.   The paired high current connections in an FC350 system allow for this type of cancellation.

From your college physics course, the E ⊗ B cross-product relationship for current through a wire obeys the Right-Hand-Rule. Because the current in the two wires is flowing in opposite directions, your thumb points in opposite directions for each lead, causing cancellation. Since the wires are not in identically the same location, the cancellation is imperfect, and some net magnetic field is still present.

Two different wire arrangements are commonly used to minimize inductance and magnetic fields. The first is a coaxial cable.   A central conductor is used to carry the current in one direction. A second conductor surrounding the first carries the current in the opposite direction.   Light to medium duty coaxial cable is commercially available, because of its extensive use in RF systems. Unfortunately, heavy-duty coaxial cable (capable of passing 100's of amps) tends to be very expensive and inflexible.

TDI loads are generally equipped with a custom current-carrying coaxial cable built using a braided wire shield over a heavy gauge insulated wire.

The second common arrangement for inductance and field minimization is the twisted pair. Two insulated wires are simply twisted together. The twisted pair offers good field cancellation in a very simple and inexpensive cable. Unfortunately, a twisted pair is often impractical for the current carrying leads since heavy gauge wire capable of passing hundreds of amps is quite rigid.

Separate the pairs
If you place a magnetic field probe near a wire passing current, you will measure a field inversely proportional to the square of the distance between the probe and the wire.

In the FC350, the probe is our sense wiring. Separating the sense wires from the current carrying wires can dramatically reduce the magnetic coupling, reducing errors in the EIS measurement.

Twist the Sense Wires
The concept of a magnetic loop probe is useful in understanding why twisted wire minimizes magnetic pickup. A loop of wire in a changing magnetic field will see a loop voltage proportional to the area of the loop.

Twisting the sense wires together helps in two ways – even though twisting the wire forms loops. First, the twisted wires are forced to lie close to each other, minimizing the loop areas.   Secondly, adjacent loops pickup opposite polarity voltages which results in cancellation.

A Practical Example

A FC350 system based on a bi-polar power supply was used to measure the "EIS spectrum" of a high current shunt. This shunt is a high current, four-terminal resistor, of a type commonly used in high power electronics.

The shunt we used has a resistance of 2.5 mΩ. Calculations based on the geometry of the conductors in the shunt indicate that it should be resistive (no appreciable inductive behavior) at frequencies below 10 kHz.   The current carrying wires connected to the shunts were PVC insulated 18-AWG hook-up wire.

The small diameter coax sense wires provided with the FC350 cable were used for the remaining connection to the shunt. Each sense wire is individually shielded with a ground from the computer's chassis.

The Bode plot labeled "FC350EIS-K3.DTA" in Figure 5-1 shows the impedance recorded on this system before we twisted the wires. The wires were left in arbitrary positions on our lab bench.   Both the magnitude and phase data shows significant inductive behavior, with the phase showing deviations from zero degrees at frequencies below 200 Hz.   Below this frequency the impedance is resistive (independent of frequency and 0° phase shift).

This data was fit to a series RL model, resulting in an L value of 25 nH.

Figure 5-1
Bode Plot of a Shunt with and without Twisted Pair Leads
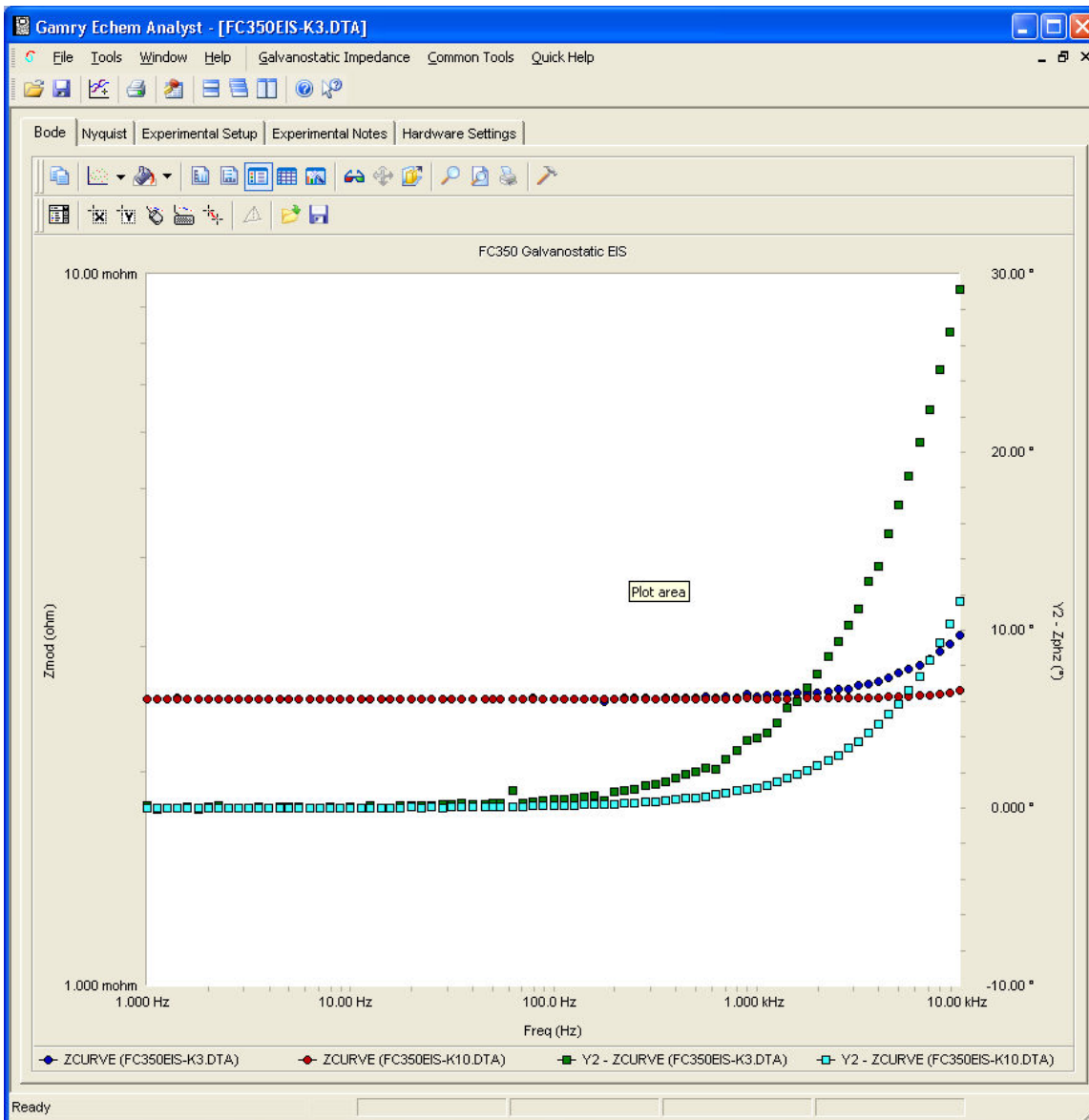
Superimposed on this plot is the spectrum of data file FC350EIS-K10. This was recorded after twisting the current carrying pair, twisting the sense pair, and separating them. One pair approached the shunt from one direction, the other pair approached from the other direction.

The data is clearly resistive at frequencies where the previous data was inductive. This time, a fit of this data to a series RL model resulted in an L value of 8 nH.

This remaining inductive behavior could be the result of uncorrected mutual inductance. However, it could also be caused by the limited bandwidth of the power supplies' current measurement circuitry or phase shift in the FCI4 Interface.

Conclusions

If your experiments are in the region where mutual inductance may limit performance, loop area within the sense leads and and the current-carrying leads must be minimized. We recommend either a tightly braided twist or coaxial cable for the current carrying wires. We recommend twisted coax (using the standard FC350 cable) for the sense wires. This minimizes both broadcast and pickup of the magnetic field.

Also, the distance between the pairs should be maximized. Arrange each pair so that they approach the cell from opposite directions as shown in Figure 5-2.

Figure 5-2
Diagram of Recommended Lead Placement
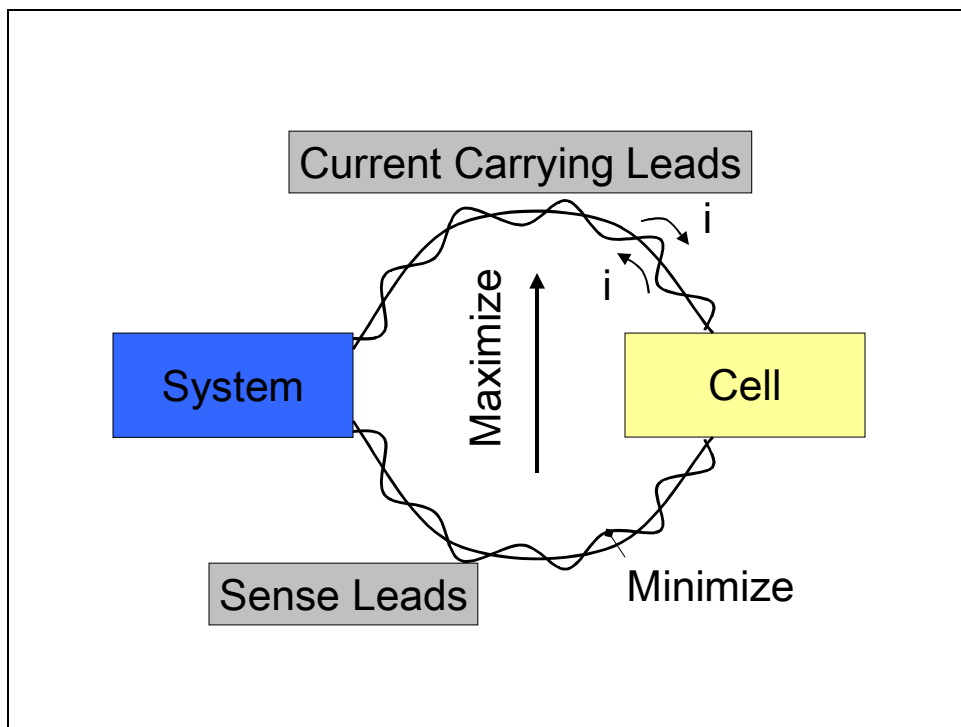
Appendix A -- Specifications

The specifications of an FC350 system are largely controlled by the characteristics of the load or power supply that controls the fuel cell current.

No attempt will be made to give system specification here. Only specifications that are controlled by the FCI4 cards, and the FC350 system software are here.

Voltage Inputs

Ranges	±10 volts and ±50 volts full scale	
Maximum voltage	±60 volts	(either range, no damage)
Voltage Offset	< 0.5 mV	
Gain Error	< 0.5%	measured at DC
Bandwidth	> 200 kHz	-3 dB, 10 Vpp
CMRR	> 60 dB	DC to 50 kHz
Input Impedance	25 kΩ	50 volt range
	> 10 GΩ	10 volt range

Current Input

Range	±10 volts	
Maximum voltage	±15 volts	no damage
Voltage Offset	< 0.5 mV	
Gain Error	< 0.5%	measured at DC
Bandwidth	> 200 kHz	-3 dB, 1 Vpp
CMRR	> 40 dB	DC to 20 kHz
Input Impedance	> 1 GΩ	

Signal Generator

DC Output	±10 volts	minimum
AC Amplitude	10.24 Vpp	DC to 100 kHz
AC Resolution	1.25 mVpp	
Output Range	± 12 V	
Voltage Offset	< 0.5 mV	after software calibration
Gain Error	< 0.5%	
Bandwidth	> 100 kHz	-3 dB, 10 Vpp

System

Power	< 20 W

Appendix B – Extra I/O Connections for the FCI4

The FCI4 Fuel Cell Interface has a number of connectors that allow it to communicate electronically with the world outside of the computer. This appendix describes these connectors and the signals available on their pins.

CE Compliance, EMI and Cable Shielding

The European Community has instituted standards limiting radio frequency interference (EMI) from electronic devices. Compliance with these standards requires that special shielded cell cable connections are used in all CE compliant systems.

The FCI4 is electrically floating. Its connections to the electrochemical cell under test are not connected in any way to earth ground. While this is advantageous for testing many types of electrochemical systems, it can result in significant radio frequency (RF) interference.

The interior of a personal computer is filled with RF energy.   The computer's earth grounded enclosure prevents the escape of this energy.

Now consider the case of the FCI4. Its circuitry is built on boards that mount inside the computer. The floating circuits inside the computer act as an antenna, picking up RF energy. The FCI4's cables can then radiate this energy outside of the enclosure, generating RF emissions.

The cables supplied with your FCI4 have an overall shield that is connected to the computer's chassis ground.   This shield acts as an extension of the computer's chassis, keeping the RF emission level lower than the limits in the regulations.   Note that use of cables not designed and sold by Gamry Instruments can result in excessive RF radiation.

Aux A/D Input

This input allows you to measure an externally generated voltage signal.

PCI4 Based Controller Card
The Aux A/D input is the top SMC connector on the **FCI4** Controller Card's mini-panel.   See Figure B-1 for the identity of all the SMC connectors on this mini-panel.

Series G Based Controller Card
The Aux A/D input is the bottom BNC connector on the **FCI4** Controller Card's mini-panel. See Figure B-2 for the identity of all the SMC connectors on this mini-panel.

Uses of this input include the measurement of temperature, strain, or other non-electrochemical parameters. This input is fully differential, with about 80 dB of common mode rejection. Be careful though, the allowed common mode voltage range is only ± 11 volts with respect to the floating ground. Voltages outside this range should not damage the instrument but they cannot be measured.

The scaling on this signal is ± 3 volts full scale, resulting in ± 30,000 counts on the A/D converter.

The signal conditioning circuitry on this input includes jumpers to select both input impedance and bandwidth. See Appendix C for a description of these jumpers.

Control Signal Input

The Control Signal Input allows you to inject a signal into the FCI4's potential or current control circuits. One use for this input is modulation of the applied voltage or current.

PCI4 Based Controller Card
This input is the upper-middle SMC connector on the Controller Card mini-panel. See Figure B-1 for the identity of all the SMC connectors on this mini-panel.
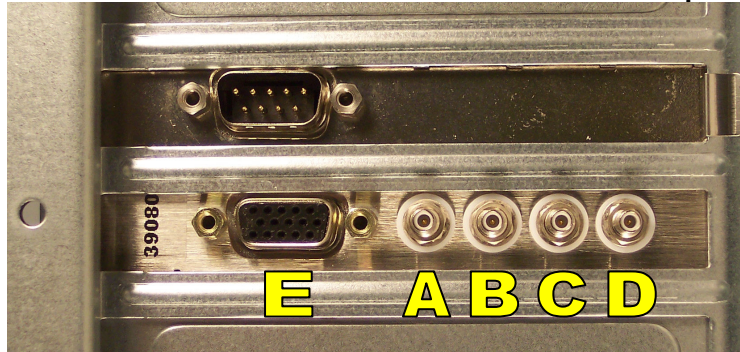
Series G Based Controller Card
This input is the upper BNC connector on the **FCI4** Controller Card's mini-panel.   See Figure B-2 for the identity of all the SMC connectors on this mini-panel.

Note that the shell of this connector is connected to the FCI4's floating ground. Connecting an earth ground referenced signal source to this input will cause problems if you are need the FCI4 circuitry to float relative to earth ground.
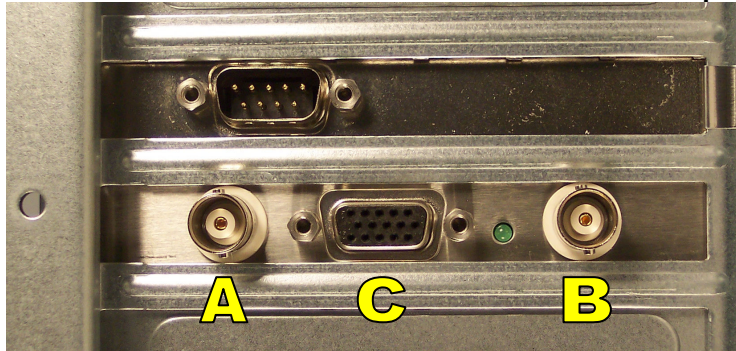
The voltage at this input that will cause a full scale current depends on the Load Setup.

Figure B-1
SMC Connectors on the PCI4 Based Controller Card Mini-panel

A – Aux A/D Input
B – Control Signal Input
C – I Channel Output
D – E Channel Output
E – Miscellaneous I/O connector

Figure B-2
BNC Connectors on the Series G Based Controller Card Mini-panel

A – Aux A/D Input
B – Control Signal Input
C – Miscellaneous I/O connector

I Channel Output (PCI Controller Only)

This output reflects the cell current signal as seen by the FCI4 A/D converter. The I Channel output is the lower-middle SMC connector on the FCI4 Controller Card's mini-panel. See Figure B-1 for the identity of all the SMC connectors on this mini-panel.

The signal on this connector has been through a long and complex analog signal processing chain. It may have been filtered, offset by a DC voltage, and gained. All of these functions are under computer control. The meaning of the signal on this connector is therefore highly dependent on the program controlling the PCI4 and cannot be described simply here.

Note that the shell of this SMC connector is connected to the FCI4's floating ground. Connecting an earth ground referenced measurement device to this output can cause problems if you are using the FCI4 with a cell that has an earth grounded electrode.

V Channel Output (PCI Controller Only)

This output reflects the cell voltage signal as seen by the FCI4 A/D converter. The V Channel output is the bottom SMC connector on the FCI4 Controller Card's mini-panel. See Figure B-1 for the identity of all the SMC connectors on this mini-panel.

The signal on this connector has been through a long and complex analog signal processing chain. It may have been filtered, offset by a DC voltage, and gained. All of these functions are under computer control. The meaning of the signal on this connector is therefore highly dependent on the program controlling the FCI4 and cannot be described simply here.

Note that the shell of this SMC connector is connected to the FCI4's floating ground. Connecting an earth ground referenced measurement device to this output can cause problems if you are using the FCI4 with a cell that has an earth grounded electrode.

Miscellaneous I/O Connector

This connector contains a number of chassis ground related signals. It is the miniature 15 pin female D shaped connector on the FCI4 Controller Card.   The pin-out is identical on both the PCI4 and Series G Controller Cards.

Be careful, the ground on this connector is <u>not</u> the FCI4 floating ground. Connecting the two grounds may lead to problems if you are using the FCI4 in a floating mode.

The auxiliary analog output, derived from a D/A converter, is on this connector. The scaling is normally 2.5 mV per bit, for a $\pm$ 5 volt full scale range. These ranges can be altered via the AUXDACRES field in the "GAMRY5.INI" file.

The pin out of this connector is shown in Table B-1.

Table B-1
Miscellaneous I/O Connector

Pin	Name	Use
1	Analog Output Low	The auxiliary output ground connection.
2	Analog Output High	The auxiliary output signal.
3	Sync In	Used in slave mode – starts data acquisition
		2.2 kΩ input impedance
4	Sync Out	A 125 nsec TTL pulse output before the start of a data point
		330 Ω output impedance
5	NC	No connection
6	Ground	Digital ground
7	Digital Out 0	A TTL digital output- 330 Ω output impedance
8	Digital Out 1	A TTL digital output- 330Ω output impedance
9	Digital Out 2	A TTL digital output- 330Ω output impedance
10	Digital Out 3	A TTL digital output- 330Ω output impedance
11	Digital In 0	A TTL digital input- 2.2 kΩ input impedance
12	Digital In 1	A TTL digital input- 2.2 kΩ input impedance
13	Digital In 2	A TTL digital input- 2.2 kΩ input impedance
14	Digital In 3	A TTL digital input- 2.2 kΩ input impedance
15	+5 Volts	Power- 100 mA maximum current

# Appendix C – Auxiliary A/D Input Characteristics

Overview

The Controller Card used in the Gamry Instruments FCI4 Interface has jumpers that configure the input circuitry used for the Aux A/D function.

Jumper Identification

The three jumpers that configure the Aux A/D input are in a cluster located at the right side of the Controller Card.   The four coax cables that route analog I/O to the card enter the card just above these jumpers. See the figure to the right for jumper locations.

Figure C-1
Auxiliary A/D Input Configuration Jumpers
View of FCI4 Controller Card
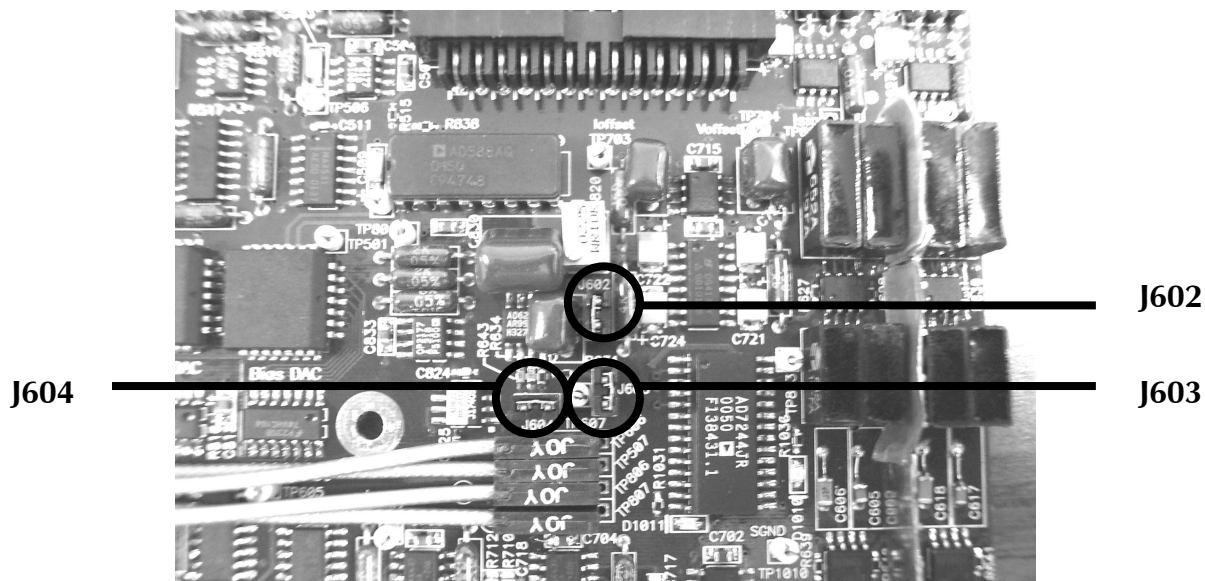
Input Impedance Selection

Two jumpers are associated with the input impedance – J603 and J604. With J603 and J604 installed, the Aux A/D inputs have a 100 kΩ input impedance. This is the default setting.   With the jumpers installed, the potentiostat can be calibrated without a cable on the input SMC connector.

With both J603 and J604 removed, the Aux A/D input impedance is 10 GΩ (typically).   This setting is suitable for use with a high impedance source such as a reference electrode. If you have removed these jumpers, <u>do</u> <u>not</u> calibrate the potentiostat unless you have a cable connecting both Aux A/D inputs to floating ground.

Filter Selection

J602 controls filtering of the Aux A/D input. With J602 removed, there is no filtering on this input. With J602 in place (the default setting), a single pole RC filter is used to limit noise into the A/D. The nominal cutoff frequency of this filter is 20 Hz.

Note that source impedances greater than 1 kΩ will appreciably lower this cutoff frequency. When the Aux A/D input is driven by a source with an output impedance of 1 MΩ, the frequency cutoff will be less than 0.25 Hz.

Aux A/D Specifications

These specifications apply:

Range	±3.276 volts	
Input Impedance	100 kΩ (approx)	J603 & J604 installed
	or	
	10 GΩ (typical)	J603 & J604 removed
Input Bias Current	< 10 nA	J603 & J604 removed
Filter Cutoff	20 Hz ± 20%	J602 in place with Zsource < 1 kΩ

Appendix D -- Changing The Default FCI4 Settings

Overview

Your FCI4 Fuel Cell Interface is fully compliant with the Windows Plug & Play system. FCI4 resources (interrupt settings, register addresses) are not assigned hardware switches or jumpers. Instead, the Windows Device Manager chooses resource assignments. You can review the settings chosen by the Device Manager by selecting **Windows Control Panel, Device Manager** from the Windows Start Menu.

The Gamry Framework still requires a "GAMRY5.INI" file. This file is used to name the Fuel Cell Interfaces and potentiostats in the system.

Turnkey systems are configured appropriately for the items you have purchased with that system. User installed systems should be configured using the Setup programs that come with Gamry Instruments' Windows based application software.

This appendix is used when manual configuration is convenient or required. It includes:

- A description of the "GAMRY5.INI file
- Instructions for changing the Auxiliary D/A ranges.
- Instructions for changing settings for the Auxiliary A/D input

About the "GAMRY5.INI" File

The "GAMRY5.INI" file contain system configuration information. This file is used to:

- Store hardware names.
- Store auxiliary equipment configurations (multiplexers and temperature controllers).
- Authorize use of a specific potentiostat or Fuel Cell Interface by specific software packages.
- Store calibration data for each potentiostat or Fuel Cell Interface.
- Store scaling factors for system D/A and A/D converters.
- Store software configuration information.

The "GAMRY5.INI" file is an ASCII file that is divided into sections identified by a section name in square brackets (e.g. [FC350]). Each section contains setting for a specific aspect of the system.

You can modify the file using an ASCII editor or a word processor in a non-document mode (a mode with no formatting codes in the text). The Windows Notepad accessory is a convenient ASCII editor.

The copy of "GAMRY5.INI" actually used by the software must be located in the Windows directory (normally C:\WINDOWS). The Setup programs provided with Gamry Instruments' software either installs "GAMRY5.INI" in the correct directory or modifies modify an existing file in this location.

A portion of a typical "GAMRY5.INI" file is shown in Figure D-1. Only some of the information required for FCI4 configuration is shown. A complete "GAMRY5.INI" file is longer than this example.

In Figure D-1, the 1st line is called a section identifier. The name of the section is enclosed in square brackets, e.g. [Framework5]. The [Framework5] section extends to the next section identifier [FCI350-32051]. The [Framework5] section contains configuration information for the Gamry Framework program. This section is required in all "GAMRY5.INI" files that configure a Gamry Framework System.

"GAMRY5.INI" normally contains potentiostat calibration information (not shown). Each potentiostat's data is in its section. You do not normally have to edit the calibration data which is automatically created and updated by the calibration routine built into the software.

The [FCI350-32051] section also contains the AUXDACRES field which you may need to change. See below for details. The 32051 number is a sample serial number, and your number will reflect the serial number of your FCI350 system.

Figure D-1
Portion of a Typical "GAMRY5.INI" File

```
[Framework5]
Version=5.0
SystemDir=C:\Program Files\Gamry Instruments\Framework 5\
ScriptDir=C:\Program Files\Gamry Instruments\Framework 5\Scripts\
PACKAGE0=FC350

[FCI350-32051]
Label=My FCI4
CMSDriver=PCI4.DLL
LABVIEWDriver=PCI4LV.DLL
BaseAddress=
PstatClass=PCI4
FraCurveClass=FRACURVE4
BoardNo=1
SerialNo=12345
AuthEIS300=1234567890
AUXDACRES=2.5E-3,0
…

[FC350]
NAME=Fuel Cell Monitor
…
```

Using Notepad to alter "GAMRY5.INI"
It is often convenient to use an ASCII editor to make small changes in the "GAMRY5.INI" file. The Notepad accessory included with Windows is a useful ASCII editor. Please read the Microsoft documentation for full instructions about using it Notepad.

Removing a Fuel Cell Interface from an Existing System

To remove a Fuel Cell Interface from a system you simply need to remove the card set from the computer. No changes to the "GAMRY5.INI" file are required.

Interrupt Level Setting

Most peripheral devices in an AT compatible computer coordinate I/O (input/output) operations with the microprocessor by means of hardware interrupts. An interrupt is a request by a device that the computer suspend the program it's currently running, and perform an I/O operation. The FCI4 Fuel Cell Interface generates an interrupt at the end of each data point.

All PCI devices in a computer generally share one interrupt level.

Register Address

The FCI4 Fuel Cell Interface card set, like virtually all IBM compatible expansion cards, has hardware registers that the computer must be able to access. These registers are located at a specific address in the memory address space of the computer's microprocessor. Addresses are expressed in the hexadecimal numbering system where the digits are 1,2,3,4...8,9,A,B,C,D,E,F. We will always precede a hexadecimal number with the prefix 0x, e.g. 0x22F.

The FCI4 requires a 64 byte memory space for it's hardware control registers.

Changing the Auxiliary Analog Output Scaling

A setting in the "GAMRY5.INI" file allows you to change the scaling of the D/A converter used to generate the auxiliary analog output.

The default setting configures this D/A converter for a bipolar output of ± 5 volts with a bit resolution of 2.5 mV/bit. You can switch to a unipolar output of 0 to 10 volts, still with a bit resolution of 2.5 mV/bit.

The D/A scaling is controlled by a field in the [FCI350-xxxx] section of the "GAMRY5.INI" file. This field has the form:

        AUXDACRES=2.5E-3,0

The final 0 indicates that the scaling is bipolar. If this digit was a 1, the scaling would be unipolar.

Appendix E – CE Certificate

Certificate of Compliance

NTS

89/336/EEC
EMC Directive Compliance Report
For
Gamry Instruments, FC350
Fuel Cell Impedance Test System
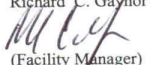
Date	:	4/18/02
MJO #	:	40280-03
File	:	40280-03.GAM
Revision #	:	None
Product	:	Fuel Cell Impedance Test System
Manufacturer	:	Gamry Instruments
P.O. #	:	2002-0081

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NTS

Product	:	Fuel Cell Impedance Test System
Model	:	FC350
Serial Number	:	See Equipment List
Manufacturer	:	Gamry Instruments
Address	:	734 Louis Drive Warminster, PA 18974 USA
Phone	:	215 682 9330
Fax	:	215 682 9331
Date Received	:	2/15/02
Contact	:	Greg Martinchek
Test Laboratory	:	National Technical Systems 36 Gilbert Street South Tinton Falls, NJ 07724 USA Phone: 732 936 0800 Fax: 732 936 0700 E-mail: nts-nj@ntscorp.com

Prepared By : Mark S. Betts   Date: 4/30/02
(Senior EMC Test Engineer)

Reviewed By : Mark Betts   Date: 4/30/02
(Program Manager)

Approved By : Richard C. Gaynor   Date: 4/30/02
(Facility Manager)

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NTS

1. **General Description:**

   The FC350, Fuel Cell Impedance Test System is an electrochemical instrument that measures the impedance of an operating fuel cell. This system can measure impedance on single cells or cell stacks passing hundreds or even thousands of amps.

2. **Classification and Environment:**

   Electrical Equipment for Measurement, Control and Laboratory Use, Emissions and Immunity standards are applied to the FC350 Fuel Cell Impedance Test System.

   Emissions: EN 61326: 1998

   Immunity: EN 61326: 1998

3. **Test and Results Summary:**

Tests	Standards	Results
Emissions, EN 61326: 1998		
Radiated Emissions	EN 55011: 1998, Class A	Pass
Conducted Emissions	EN 55011: 1998, Class A	Pass
Immunity, EN 61326: 1998		
Radiated Immunity	EN 61000-4-3: 1996	Pass
Conducted Immunity	EN 61000-4-6: 1996	Pass
Electrical Fast Transients	EN 61000-4-4: 1995	Pass
Electrostatic Discharge	EN 61000-4-2: 1995	Pass
Voltage Interruptions	EN 61000-4-11: 1995	Pass
Surge Immunity	EN 61000-4-5: 1995	Pass
Magnetic Field Immunity	EN 61000-4-8: 1995	Pass
Other Standards		
Harmonic Emissions	EN 61000-3-2: 1995	Pass
Voltage Fluctuations and Flicker	EN 61000-3-3: 1995	Pass

4. **Test Report Summary:**

   The FC350 Fuel Cell Impedance Test System was tested to the specified standards and was found to comply with all of the criteria.

   4.1. **Test Sample Description:**

   See sections 4.1 and 4.2.