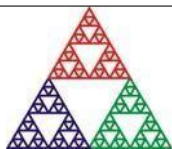


# I400

## Four Channel Digital Electrometer

### User Manual



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## Safety Information

This unit is designed for compliance with harmonized electrical safety standard EN61010-1:2000. It must be used in accordance with its specifications and operating instructions. Operators of the unit are expected to be qualified personnel who are aware of electrical safety issues. The customer's Responsible Body, as defined in the standard, must ensure that operators are provided with the appropriate equipment and training.

The unit is designed to make measurements in **Measurement Category I** as defined in the standard.



**CAUTION.** The I400 can generate high voltages as follows:

+ or – 400 V DC at 2mA maximum.

Present on the central conductor and inner guard screen of the triaxial signal connectors.

+ or – 1000 V DC at 1mA maximum.

Present on the central conductor of the SHV connector.

These voltages and currents are not classified as hazardous live under EN61010 but may nevertheless give a noticeable shock. The user must therefore exercise appropriate caution when using the device and when connecting cables. Power should be turned off before making any connections.

The maximum permissible voltage on an electrode connected to an I400 input is 400 V DC, and this voltage must be generated by the I400 input bias supply, not by an external voltage source. All four inputs of the I400 must be at the same voltage.

In applications where high energy charged particle beams can strike electrodes which are normally connected to the I400, voltages limited only by electrical breakdown can build up if the I400 is not connected to provide the earth return path. The user must ensure that a suitable earth return path is always present when the particle beam may be present.

The unit must not be operated unless correctly assembled in its case. Protection from high voltages generated by the device will be impaired if the unit is operated without its case. Only Service Personnel, as defined in EN61010-1, should attempt to work on the disassembled unit, and then only under specific instruction from Pyramid Technical Consultants, Inc.

The unit is designed to operate from +24VDC power, with a maximum current requirement of 500mA. A suitably rated power supply module is available as an option. Users who make their own power provision should ensure that the supply cannot source more than 1000mA.

A safety ground must be securely connected to the ground lug on the case.

Some of the following symbols may be displayed on the unit, and have the indicated meanings.



Direct current



Earth (ground) terminal



Protective conductor terminal



Frame or chassis terminal



Equipotentiality



Supply ON



Supply OFF



CAUTION – RISK OF ELECTRIC SHOCK



CAUTION – RISK OF DANGER – REFER TO MANUAL

## 2 Models

I400	Four channel gated integrator electrometer with 10pF and 1000pF feedback capacitors.
-P04	Add positive 0 to 400V bias for signal inputs
-N04	Add negative 0 to 400V bias for signal inputs
-XP10/5/2	Add positive 0 to 1000 V / 500 V / 200 V auxiliary bias output
-XN10/5/2	Add negative 0 to 1000V /500 V / 200 V auxiliary bias output
-TP	Add thermistor input and on-board atmospheric pressure sensor
-Cx/y	Change feedback capacitors to x pF and y pF (default is -C10/1000)

Example:

I400-N04-XP10-TP

I400 with 400V negative input bias, 1000V positive auxiliary bias output, thermistor input and pressure sensor.

### **3 Scope of Supply**

I400 model as specified in your order.

PSU24-40-1 24 VDC power supply.

USB memory stick containing:

- User manual

- PSI Diagnostic software guide

- PSI Diagnostic software installation files

Optional items as specified in your order.

## 4 Optional Items

### 4.1 Power supplies

PSU24-45-1 +24 VDC 45W PSU (universal voltage input, plug receptacle for standard IEC C14 three-pin socket) with output lead terminated in 2.1mm threaded jack.

### 4.2 Signal cables and cable accessories

PCB0T20PCB-80 Cable, triax plug to triax plug, 3-lug, 3 m.

PCB2T20P1A-80 Cable, triax plug 3-lug to BNC coax plug input cable, 3 m. Outer screen and signal core connected through, inner guard screen floated at BNC end.

ADBJ77-E2-PL20 Adaptor, triax 3-lug jack to BNC plug. Guard not connected through.

ADBJ20-E2-PL75 Adaptor, BNC jack to triax 3-lug plug. Guard not connected through.



RF175-1 Dust cap, 3-lug triax

SHV to SHV cable, 3m.

Remote temperature sensing thermistor cable assembly terminated in four pin Lemo type 0B plug (also available as part of I400 option –TP).

### 4.3 Data cables

AB450K-R RS-232 6 pin DIN male to 9 pin D sub female adaptor.



CAB-ST-P-5-ST (qty two) Fiber-optic cable pair, 5m plastic.

CBA-ST-HCS-5-ST (qty two) Fiber optic cable pair, 5m silica

#### **4.4 Fiber-optic loop**

A200 USB to fiber-optic adaptor.

A300 fiber-optic loop controller / Ethernet adaptor.

A500 intelligent cell controller with Ethernet interface.

## 5 Intended Use and Key Features

### 5.1 Intended Use

The I400 is intended for the measurement of small charges or corresponding currents (from pA to  $\mu\text{A}$ ) generated by devices such as ionization chambers, in-vacuum beam position monitors, proportional chambers and photodiodes. Four input channels make the I400 particularly well-suited to four-quadrant electrode systems used for beam centering. The I400 has design features which make it tolerant of electrically noisy environments, but the place of use is otherwise assumed to be clean and sheltered, for example a laboratory or light industrial environment. The unit may be used stand-alone, or networked with other devices and integrated into a larger system. Users are assumed to be experienced in the general use of precision electronic circuits for sensitive measurements, and to be aware of the dangers that can arise in high-voltage circuits.

### 5.2 Key Features

Highly sensitive charge and current measuring system.

Four fully-parallel gated integrator / ADC channels.

External gate input.

Multiple data acquisition modes

- continuous current measurement
- continuous charge integration
- no lost charge integration
- external gated charge integration
- externally-triggered

Dynamic range 0.1 pA to  $>80 \mu\text{A}$  with standard capacitors.

Built-in calibration check current sources feeding each channel.

RS-232 / RS-485 and fast fiber-optic serial interfaces built-in. Selectable baud rates.

Can be operated in a fiber-optic serial communication loop with up to thirteen other devices.

100BaseT Ethernet available through the A300 and A500 interfaces.

ASCII and binary serial data formats.

External thermistor temperature input and integrated atmospheric pressure input options.

Input bias option up to + or  $- 400 \text{ VDC}$

Auxiliary HV output option up to + or  $- 1000 \text{ VDC}$ .

## 6 Specification

Inputs	Four, independent parallel
Integration time	Adjustable, 100 $\mu$ s minimum, 65 s maximum.
Input noise current	< 100 fA rms + 1 fA rms per pF input load (0.1 second integration, 10 pF capacitor, 0 V bias)
Input background current	< 100 fA at 0 V bias, 25 C for 8 hours after nulling < 300 fA at 0 V bias, 35 C after for 8 hours after nulling (excluding external background current sources)
Stability	Output drift < 5 ppm / C / hour
Digitization	16 bit over +/- 10 V integrator output range, 250 kHz. Four ADC channels.
Linearity	Deviation from best fit line of individual readings < 0.1% of maximum current or charge reading for given feedback capacitor and integration time setting.
Drift	< 0.5% over 12 hours.
External accuracy	0.25% of full scale charge / current for the selected capacitor and integration time.
Signal input bias PSU (option)	0 to 400 V programmable 12 bit resolution, 1mA max. Noise and ripple <0.1% of full scale.
Auxiliary PSU (option)	0 to 1000 V programmable 12 bit resolution, 1mA max. Noise and ripple <0.1% of full scale.
External gate	0 / +5 V (TTL level), 2 kohm input impedance.
Power input	+24 VDC (+/-2 V), 350 mA.

Case	Stainless steel sheet.
Case protection rating	The case is designed to rating IP43 (protected against solid objects greater than 1mm in size, protected against spraying water).
Weight	1.2 kg (2.63 lb).
Operating environment	0 to 35 C (15 to 25 C recommended to reduce drift and offset) < 70% humidity, non-condensing

	vibration < 0.1g all axes (1 to 1000Hz)
Shipping and storage environment	-10 to 50C < 80% humidity, non-condensing vibration < 2 g all axes, 1 to 1000 Hz
Dimensions	(see figures 1 and 2).

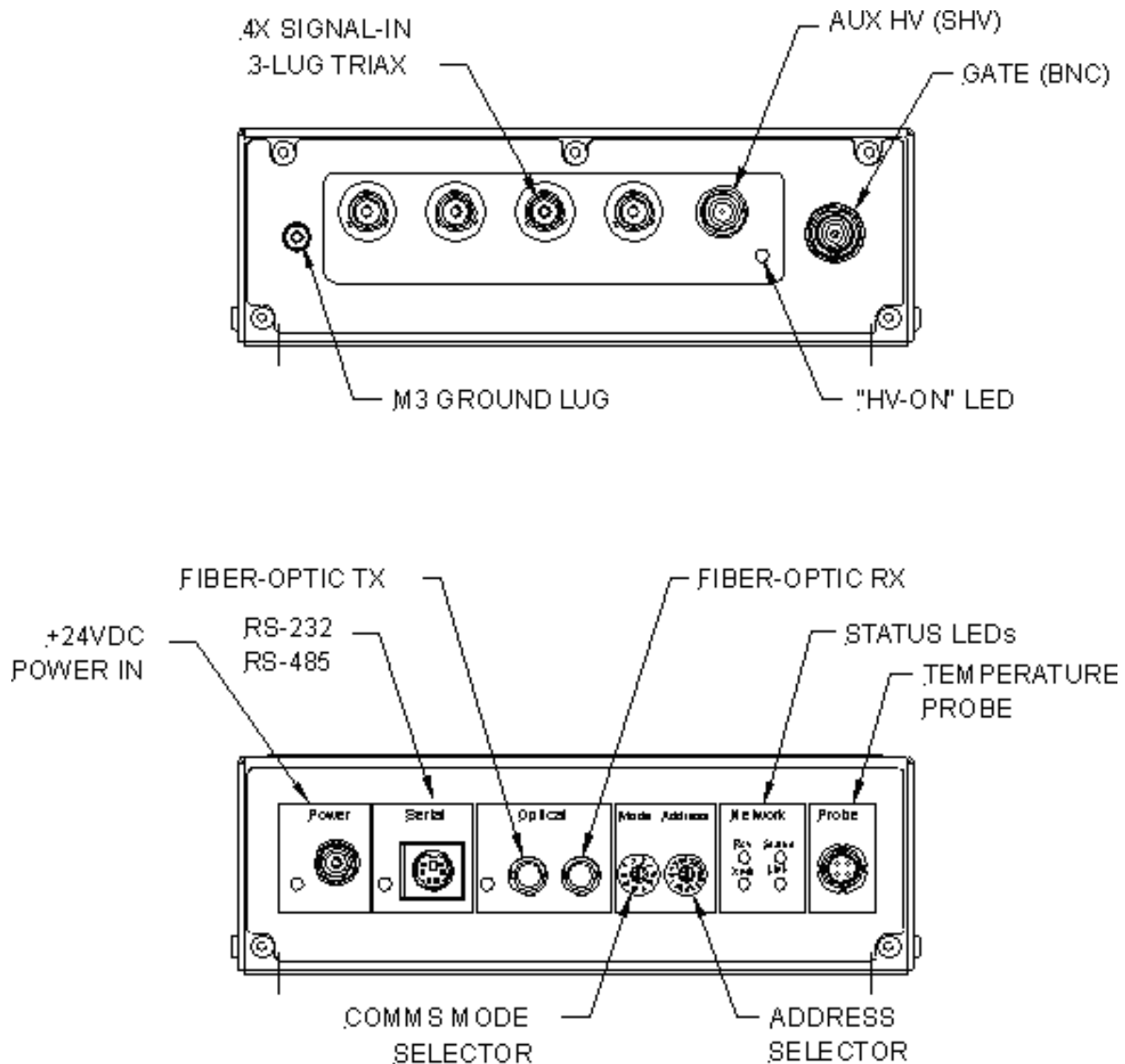


Figure 1. I400 chassis end panels.

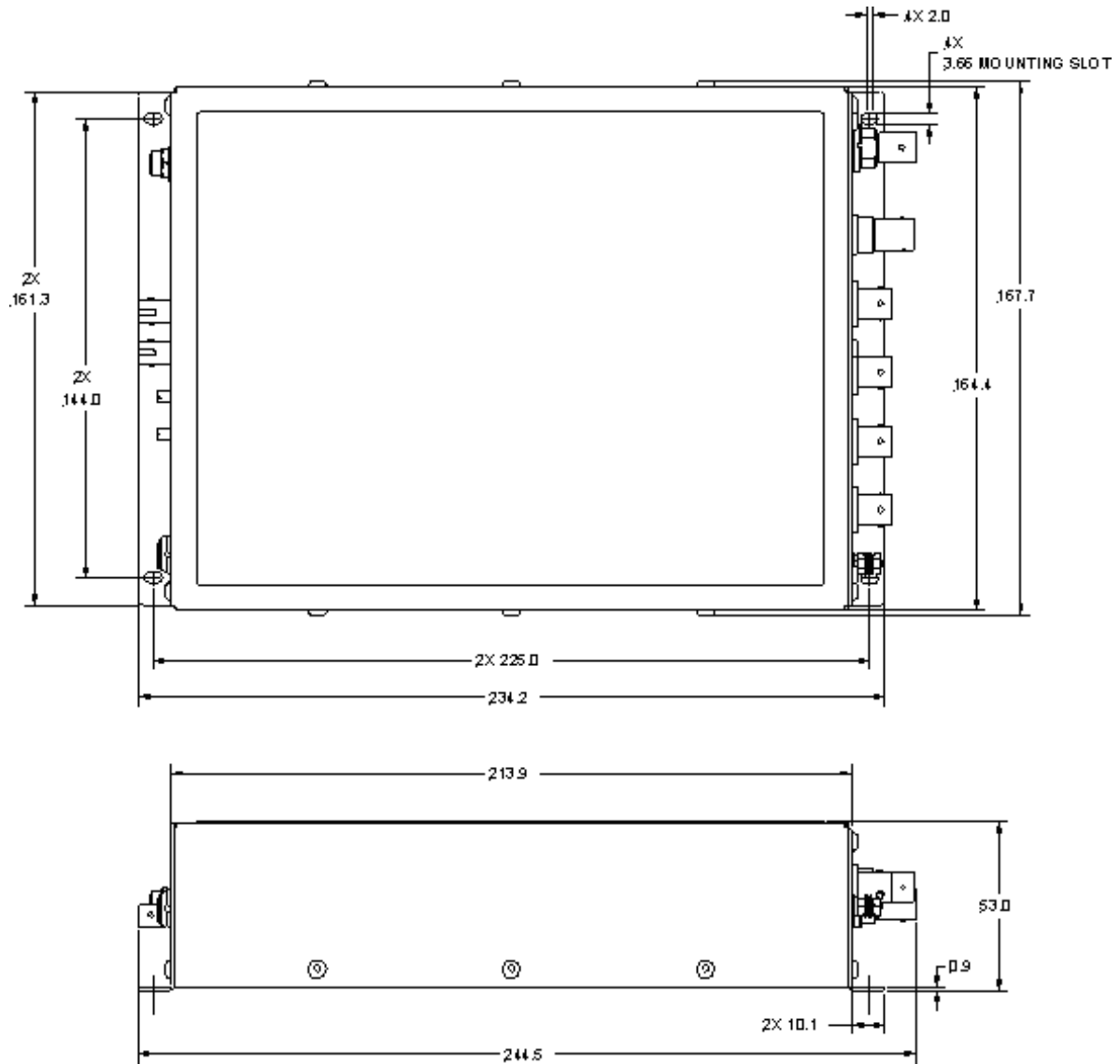


Figure 2. I400 case plan and side Dimensions mm.

## 7 How the I400 Works - an Overview

The I400 is a very flexible instrument which uses a charge measurement method that may be unfamiliar to you. This section gives you an overview of how incoming signal current is turned into readings, and the main features of the device. Full details are in the later sections of this manual.

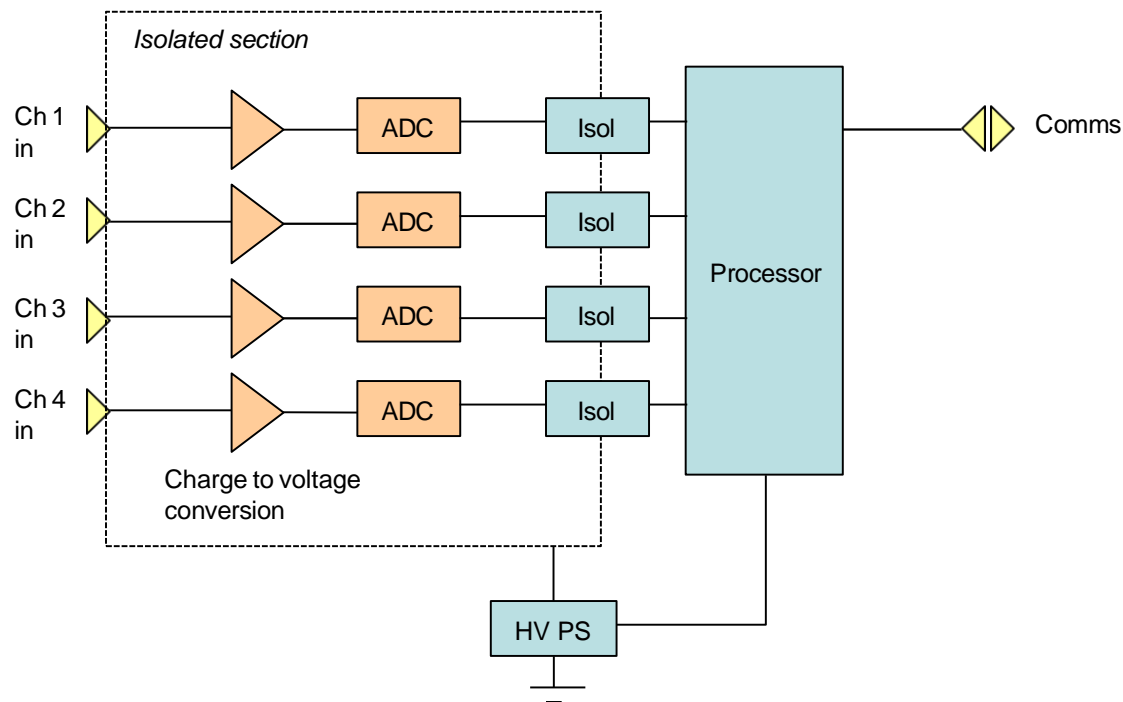


Figure 3. I400 block diagram.

The I400 has four parallel input channels floated at high voltage which convert very small currents to measurable voltages. The voltages are measured by ADCs (analog to digital converters), and the resulting digital data is transmitted over the high voltage isolation barrier. The resulting binary values are converted to current readings in amps by applying calibration factors. These currents can be requested over the communication link. Let's start by looking at the measurement process in a little more detail.

### 7.1 Current measurement process

Because all four channels are identical and work in synchronization, we can focus on a single channel. Imagine there is a small current that you wish to measure, which may be varying in time, as shown on the following graph.

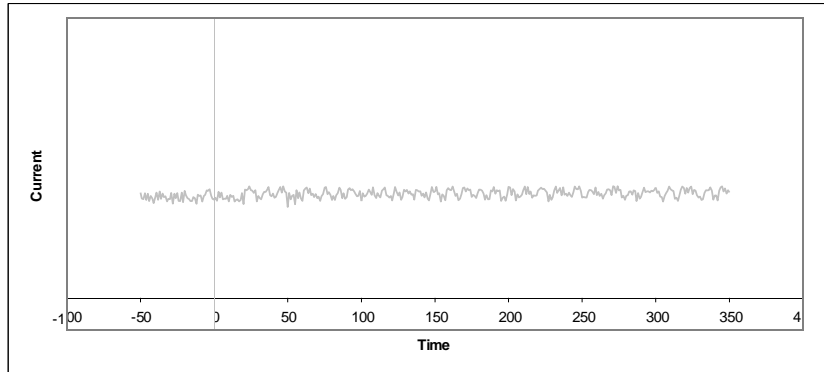


Figure 4. A current to be measured

A conventional current to voltage conversion method would convert this current into an equivalent voltage, and this voltage would be converted to a number by an ADC (analog to digital converter). However this method is less suitable for measuring very small currents because of signal to noise limitations. The I400 therefore uses a method called gated integration instead.

Imagine that at some point in time (zero on the graph), you start accumulating (integrating) this current on a capacitor. The capacitor will charge up, and an increasing voltage will therefore appear across the capacitor.

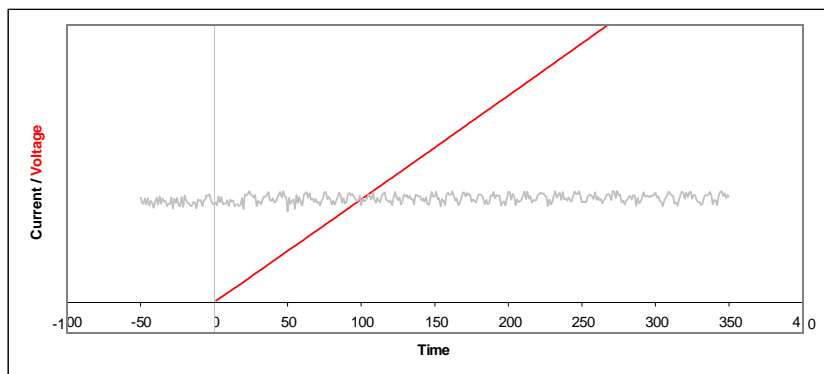


Figure 5. Voltage on a capacitor that is connected at time zero

If we measure this voltage with an ADC, we will know the charge on the capacitor at the time of the conversion. If we measure the voltage at two defined times, we will know the increase in charge over a known time interval.

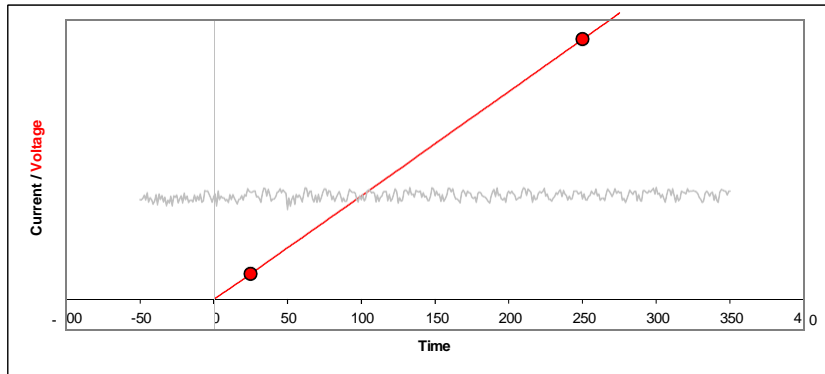


Figure 6. Capturing the voltage at two times

From this we know the average current during that time interval, because average current is simply charge divided by time. The time interval is called the integration period.

We cannot allow the voltage on the capacitor to simply increase for ever. The ADC has a specified input voltage range, and there is little point in exceeding it. Therefore we must discharge the capacitor periodically, and this takes some time, typically 20  $\mu\text{sec}$ . Then we can restart the cycle.

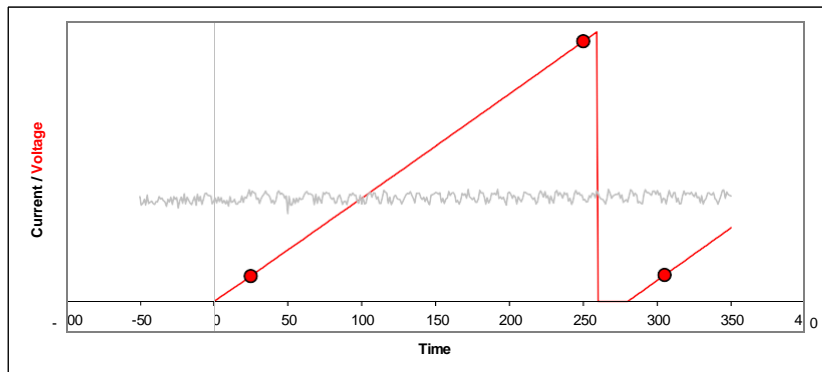


Figure 7. Discharging the integration capacitor and starting a new cycle.

The process of charging the capacitor and discharging to reset is called gated integration. The length of the integration can be controlled in the I400 in the range 100  $\mu\text{sec}$  up to 65 seconds, and typical working values are in the range 100  $\mu\text{sec}$  to 1 sec.

Notice that the first ADC conversion does not take place immediately when the integration starts. This is because the signal is unstable just after the reset, so we wait a time called the settle time before making the first conversion. This time is normally set to 25  $\mu\text{sec}$ . The settle time can be adjusted, but it is a detailed parameter that doesn't usually need to be worried about.

We can get a running measure of the current by simply repeating the integration cycle as many times as we want. Each time, we can divide the measurement of charge that is the difference between the ending and starting ADC values by the time interval between them to get the current

reading. In the figure, the blue bars indicate the readings; each is the final ADC value minus the starting ADC value for that integration.

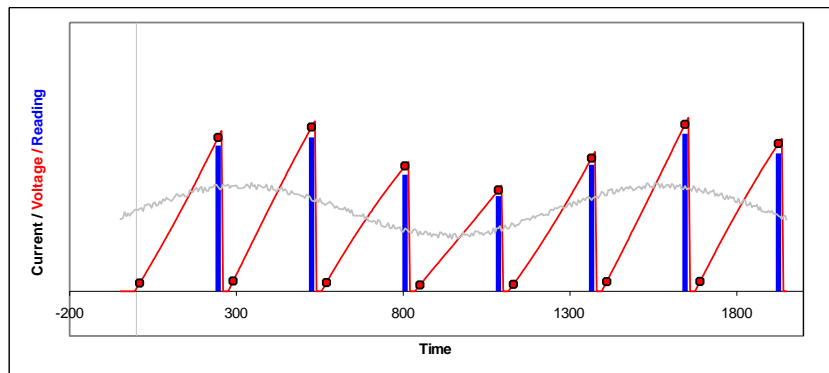


Figure 8 Repeated integrations to sample a continuous current signal.

There are some points to note. Firstly, notice that the readings are very clearly linked to the time of their integration. Because of the resets, there is no influence at all from earlier integrations. Next, notice also that we get no information about how the current may have varied within each integration - we see only the average. Finally, notice that we are not measuring at all during the resets. If you choose the shortest available integration times, the reset time might be a noticeable fraction of the overall time.

Why would you choose any particular integration time? The first consideration is the size of current you expect to measure. For a given charge integrating capacitor, the longer the integration, the smaller is the maximum current you can measure, and the more sensitive the I400 is to very small currents.

The next consideration is timing. If the current you are measuring is only present in a short pulse, there is little point in integrating longer than this, because you will simply be measuring extra noise. If the current is continuous but has variations that you wish to measure, then you must have integrations short enough to be sensitive to the variations, rather than smoothing them out.

The final consideration is filtering. A given integration time, used repeatedly to measure a continuous current, acts as rectangular low-pass filter. This has the property of completely suppressing frequencies in the signal which correspond to the integration period. If you are troubled by 60 Hz noise, for example, then using an integration period of 1/60 seconds will eliminate the problem. So will any integer multiple of that period. A good choice is 100 msec, as this is five times the 50 Hz period, and six times the 60 Hz period.

## 7.2 Triggering

In many cases you will need to coordinate the I400 measurements with external events. You can preset the I400 with all the measurement parameters such as integration time and capacitor

selection and so on, then initiate it ready to respond to a trigger signal. Measurements will start as soon as the trigger arrives.

### **7.3 Self-testing and calibration**

The I400 can calibrate itself on all channels fully automatically, and it stores the resulting factors so that it can provide results in physical units (amps or coulombs). You can also turn on the calibration current at any time and send it to any channel to check that the device is working correctly.

## 8 Installation

### 8.1 Mounting

The I400 may be mounted in any orientation, or may be simply placed on a level surface. A fixed mounting to a secure frame is recommended in a permanent installation for best low current performance, as this can be degraded by movement and vibration. Four clearance slots for M3 screws are provided in the base flange on a 225 mm by 144 mm rectangular pattern (see figure 2).

The mounting position should allow sufficient access to connectors and cable bend radii. 100 mm minimum clearance is recommended at either end of the device.

Best performance will be achieved if the I400 is in a temperature-controlled environment. No forced-air cooling is required, but free convection should be allowed around the case.

### 8.2 Grounding and power supply

A secure connection should be made using a ring lug, from the M3 ground lug to local chassis potential. This is the return path for any high voltage discharge passing via the I400.

+24 VDC power should be provided from a suitably-rated power supply with the following minimum performance:

Output voltage	+24 +/- 0.5 VDC
Output current	500 mA minimum, 2000 mA maximum
Ripple and noise	< 100 mV pk-pk, 1 Hz to 1 MHz
Line regulation	< 240 mV

The I400 includes an internal automatically re-setting PTC fuse rated at 1.1 A. However the external supply should in no circumstances be rated higher than the I400 connector limit of 5 A, and a maximum of 2 A is recommended.

## 8.3 Connection to signal source

### 8.3.1 Typical setup

Figure 9 shows a typical installation in schematic form. Four quadrant readout electrodes in a signal source such as an ionization chamber are connected to the four inputs via individual triaxial cables. The electrodes are isolated from ground, and are biased by the I400 signal bias voltage. In this example, an additional electrode, perhaps a drift space-defining electrode, is biased by the auxiliary external HV output. A gate signal generated by a remote timing controller, for example, triggers the I400 to start measuring data. The data is transmitted to a host computer via one of the I400's communications interfaces. Software in the host computer can compute a position function from the signals if required, for example difference over sum, or log ratio.

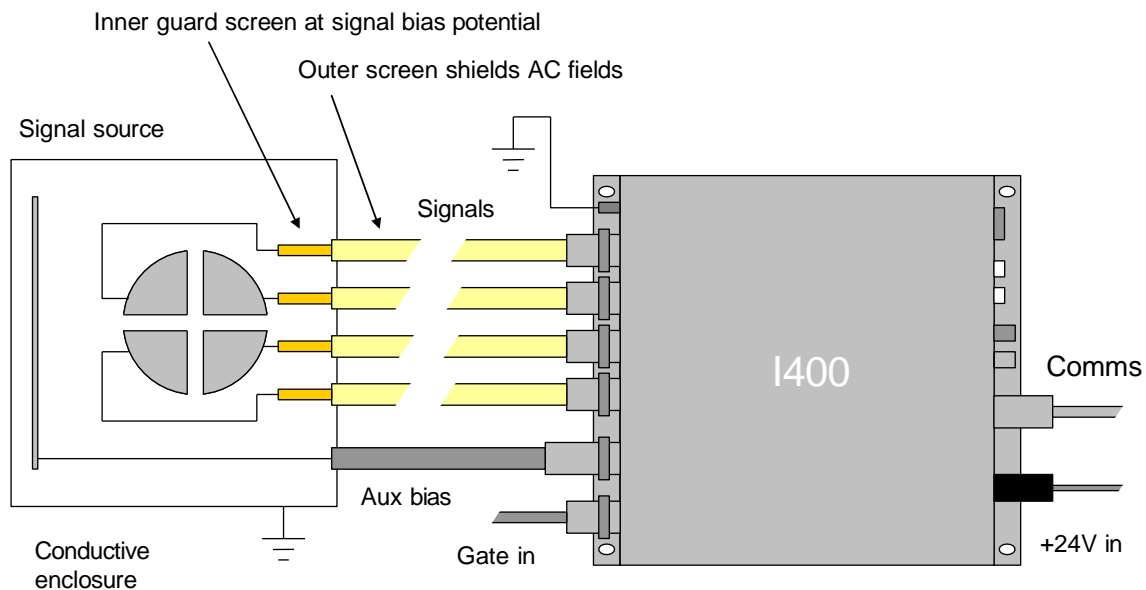


Figure 9. Schematic I400 installation

Refer to section 21 in this manual for general guidance on making low current measurements. The I400 should be located as close to the source of the signal as possible. Long signal cables increase the chances of seeing unwanted signals and noise. A maximum length of 3m is advised. Longer cables may be used, but the lowest detectable current will be increased, and the absolute accuracy of the measurement can be affected if the capacitive load is high (greater than around 750 pF).

### 8.3.2 Signal cables

Triaxial cable should be used, terminated in triaxial connectors at the I400 end. Three-lug triaxial connectors are standard on the I400. The signal core and the inner guard screen are at

bias potential, which can be up to 400V. The outer screen is at I400 chassis potential (ground). Do not attempt to mate a BNC connector to a triaxial connector!



Figure 10. Triaxial cable with 3-lug triaxial connector

The inner guard should be brought as close as possible to the point of connection to the signal source, but should not be connected to anything at that end. The outer screen should generally terminate on the grounded enclosure of the signal source.

If you have to use a coaxial cable, you will require a triax to coax adaptor. Put the transition from triax to coax as close to the signal source as possible. You should be aware that the coaxial cable length will represent an unguarded signal node, and a potential source of leakage current.

### 8.3.3 Signal current path

When making a current measurement, you must always think about how the signal current circuit is completed. Figure 11 illustrates the case where the I400 signal bias HV supply is the primary energy source. The voltage generated by the HV supply appears at the sensor, where it causes separation of charge that has been created by a physical interaction. An example is free charge created in the gas of an ionization chamber by incident radiation. The voltage thus causes a current to flow in the signal lead which is connected to an electrode in the sensor. Ultimately this current must return to its point of origin, via the HV supply. The measuring amplifier of the I400 is inserted into this loop.

The signal current flows in effect into the virtual earth of the amplifier, and is matched by current provided by the amplifier power supplies. The loop then continues via the HV supply then out to the case of the I400. If the supply is not enabled, then it appears as an impedance of approximately 300 kohm. The current then returns to the current source along the outer screen of the signal cable. If you need to break the continuity of the outer screen for noise suppression or other reasons, then you must ensure there is an alternative path between the I400 and the signal source, or you will see no current.

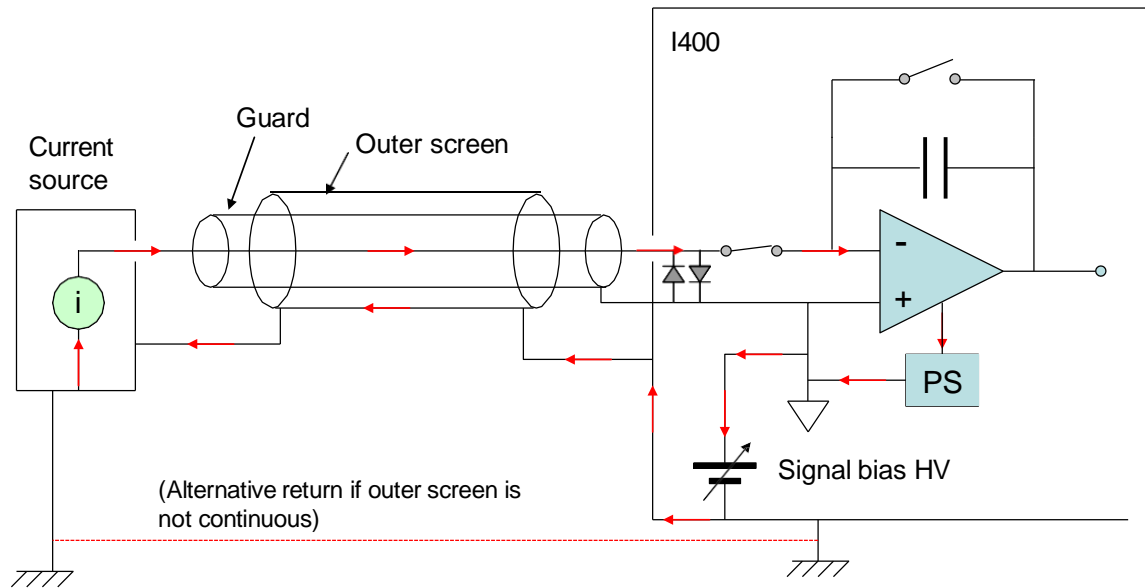


Figure 11. Path of measured current.

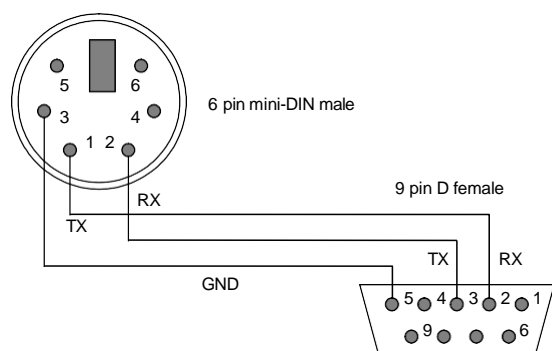
## 9 Getting Started Using ASCII Communication

Before installing the I400 in its final location, and if it is the first time you have used an I400, we recommend that you familiarize yourself with its operation on the bench. You can check the unit powers up correctly, establish communications, run the internal calibration procedure, and read the internal calibration current.



**CAUTION.** Do not touch the inner screen or pin triaxial signal input connectors while the unit is powered in case bias voltage up to 400V is present.

- 1) Inspect the unit carefully to ensure there is no evidence of shipping damage. If there appears to be damage, or you are in doubt, contact your supplier before proceeding.
- 2) Connect 24 V DC power but no other connections. The power LED should illuminate when the power is applied, and the status and link LEDs will cycle through green, orange and red (see section 18). The I400 should then have the “power”, “optical” and “status” LEDs illuminated.
- 3) Make a connection to a PC serial port. A three wire lead terminated in a six-pin mini-DIN male connector (PS/2 mouse type) and a nine-pin D female is required. When the connector is pushed home in the I400, the “optical” LED should extinguish and the “RS232” should illuminate. Connecting to this port forces the I400 to be a listening device.



*Figure 12. RS232 connection cable from the I400 to a PC serial port (DB9). Pins are shown looking at the face of the connectors.*

- 4) Set the address rotary switch to position “4” (address 4) and the mode rotary switch to position “3” (ASCII communication, 115 kbps). The address is arbitrarily chosen for this example.
- 5) Configure a Windows Hyperterminal session to use COM1 (or other available port on your PC) as shown in the following figures. A suitable Hyperterminal file is provided on the I400

software CD-ROM. Unfortunately Hyperterminal is not included with Windows Vista or Windows 7. You can copy the relevant files (hypertrm.dll and hypertrm.exe) from your old XP machine to your Vista or Windows 7 machine, or use one of many free terminal programs that are available, such as PuTTY or RealTerm.

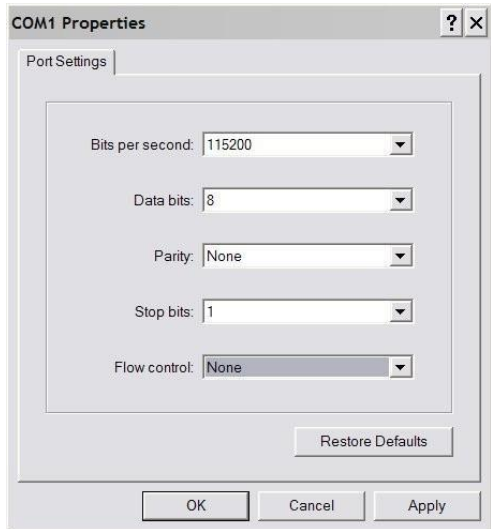


Figure 13. Hyperterminal COM port setup.

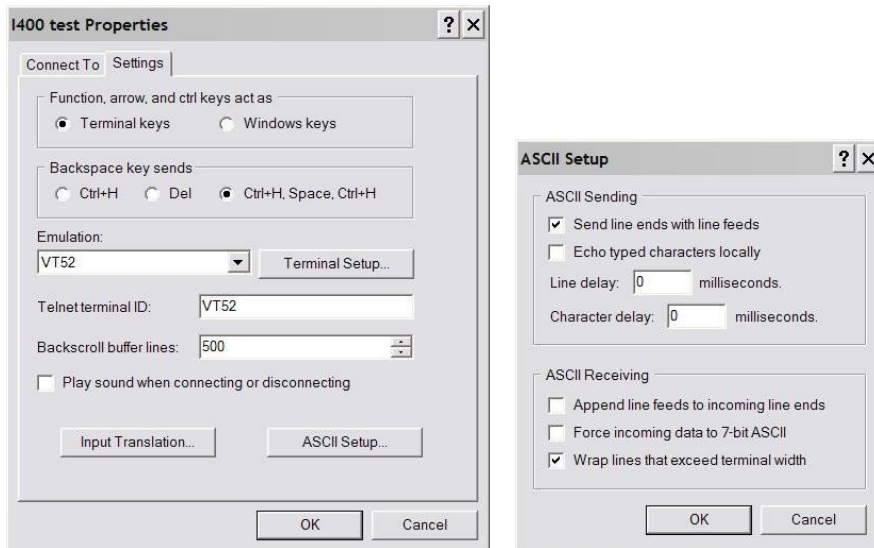


Figure 14. Hyperterminal terminal settings

6) Type “#?<CR>” to query the active listener. You should get the response “4”. You are communicating successfully with the I400. If you hear your computer’s bell sound when you send the string, the I400 did not understand it, probably because there was a typing error. If the I400 does not echo correctly, either the terminal settings or the I400 switch settings are likely to be wrong. Check them and retry until you see the characters echo correctly. If you make any errors while typing, use the backspace key and re-type from the error. While you are sending a

message you will see the Rcv LED illuminate, and when the I400 is sending its reply you will see the Xmit LED illuminate too.

- 7) Type “\*IDN?”. You should get a string back which includes the device type, serial number, and the application firmware and FPGA revision.
- 8) Type “calib:gain<CR>”. The characters can be upper or lower case. You should get an immediate “OK” response that indicates the I400 has received and recognized the command, The I400 will perform its internal calibration sequence.
- 8) Type “calib:gain?<CR>”. The I400 will return the gain factors for the four channels.
- 9) Type “read:curr?<CR>”. The I400 will do a measurement and return the integration period it used and the measured current values for each of the four channels. The current values should be close to background. The default integration period on power-up is the one that gives a one microamp full scale, for example 0.1 msec for a 10 pF feedback capacitor, 10 msec for a 1000 pF feedback capacitor and so on. If you repeat “read:curr?<CR>” a few times you should see the readings change due to background noise.
- 10) Type “calib:source 1<CR>”. This turns on the internal 500 nA calibration current to channel 1. Type read:curr?<CR>” to read this current. You should see a value very close to  $5.0e-7$  A for channel 1.
- 11) Type “syst:password 12345”. You are now in administrator mode and able to alter some important parameters. The I400 will leave administrator mode when it is reset or the power is cycled.
- 12) Type “conf:hivo:sig:max 100”. This establishes 100V as the maximum signal high voltage bias you can set. If your I400 has an external high voltage supply also, you can type “conf:hivo:ext:max 100” to do the same for the auxiliary HV supply. These values are retained indefinitely in EEPROM until you set new values. If you do not have the relevant high voltage options, then the I400 will return an error code “-241: hardware missing”.
- 13) Ensure nothing is connected to the signal inputs nor the external HV bias output. If your I400 has the external bias HV option, type “conf:hivo:ext:volt 25<CR>”. This will turn on the high voltage at 25 V and the “HV on” LED will illuminate. If your I400 has the signal bias HV option, type “conf:hivo:sig:volt 10<CR>”. This will turn on the high voltage at 10 V and the “HV on” LED will illuminate. Note that there is a slow start before the high voltage appears.
- 14) Type “\*rst<CR>” to reset the I400. Your unit is functioning correctly and is ready to be integrated into your system.

```

I400r4 mode3 - HyperTerminal
File Edit View Call Transfer Help
#?
4
*IDN?
PYRTECHCO,I400-REV4,0000001383,4.0B/1.5.6
calib:gain
OK
calib:gain?
15.1.1765e+00,1.1984e+00,1.1960e+00,1.2014e+00,1.1993e+00,1.1978e+00,1.1895e+00,
1.1731e+00
read:curr?
OK
1.0000e-04 S,-5.7448e-10 A,-3.2915e-10 A,-6.4967e-09 A,-3.2997e-10 A,0
read:curr?
OK
1.0000e-04 S,7.5401e-10 A,4.0229e-10 A,7.8836e-09 A,4.0330e-10 A,0
calib:source 1
OK
read:curr?
OK
1.0000e-04 S,4.9951e-07 A,-6.9486e-10 A,-4.4163e-09 A,0.0000e+00 A,0
syst:password 12345
OK
conf:hivo:sig:max 100
OK
conf:hivo:sig:volt 10
OK
*rst
OK
Connected 0:07:41 Auto detect 115200 8-N-1 SCROLL CAPS NUM Capture Print echo

```

Figure 15. Example Hyperterminal session

15) If you wish to explore the ASCII communication capabilities of the I400 more fully, refer to the commands list in section 19. You may also wish to try out the terminal mode, which provides feedback from the I400 to every message you send, not just query messages, and is therefore more user-friendly.

## 10 Getting Started using the PSI Diagnostic Host Program

### 10.1 Introduction to the PSI Diagnostic Program

The PSI Diagnostic is a non-application specific host program for Windows PCs that allows you to control and read back data from all compatible Pyramid Technical Consultants, Inc. devices. You will also find it described as the PTC Diagnostic, or the PSI Loop Diagnostic. They are all names for the same program. The Diagnostic also provides utilities to allow you to update firmware in the devices. It can handle a mixture of device types and communications channels simultaneously. You can find a general description of the program in the document PS455\_UM\_091204 which can be downloaded from [http://www.ptcusa.com/PTC\\_Downloads.html](http://www.ptcusa.com/PTC_Downloads.html).

### 10.2 Installing the PSI Diagnostic Program

The program runs under the Microsoft Windows operating system with the version 3.5 or higher .NET framework. This has to be installed before the PSI Diagnostic. New Windows PCs have .NET already installed. It can be downloaded from the Microsoft web site at no charge. The installer will alert you if the .NET framework needs to be installed.

Install the PSI Diagnostic by running the PTCDiagnosticSetup.msi installer, and following the screen prompts. Once the program has installed, you can run it at once. If you wish to view the files that have been installed, navigate to Program Files\Pyramid Technical Consultants, Inc.\PTCDiagnostic (or other folder if you did not accept the default during the installation). To do an update of the PSI Diagnostic, you will need to remove the old version using the Windows Remove Software utility, then simply run the new installer.

### 10.3 Connecting to the I400

Once the program has installed, you can run it at once. It will allow you to connect to the I400, and, depending upon your interface setup, multiple additional devices at the same time. The Diagnostic uses the concepts of ports and loops to organize the connected devices. A port is a communications channel from your PS, such as a COM port, a USB port or and Ethernet port. Each port can be a channel to one or more loops, and each loop may contain up to 15 devices.

Connect 24 V DC power but no other connections. The power LED should illuminate when the power is applied, and the status and link LEDs will cycle through green, orange and red (see section 18).

It is simplest to connect the I400 directly to the PC via its RS-232 port (figures 16). If you are using RS-232, set the mode switch to position 0 (115 kbps binary). The address switch can be set to anything between 1 and 15.

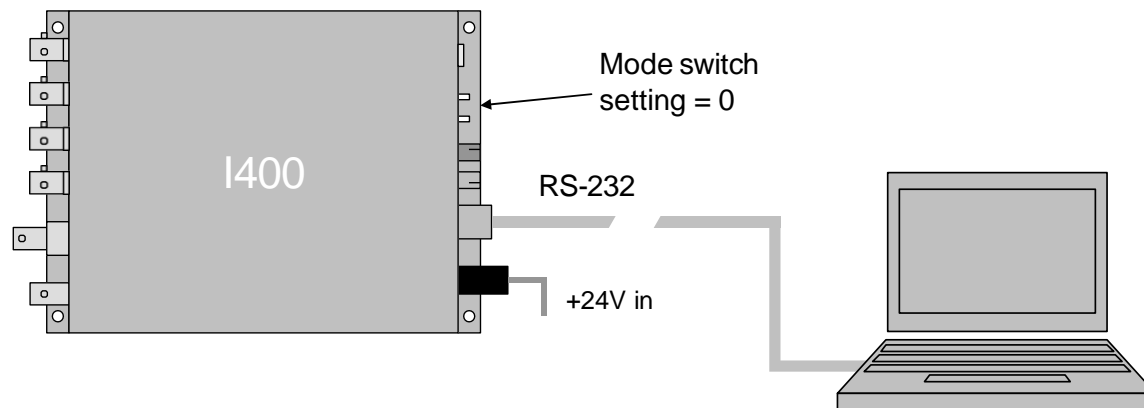


Figure 16. Direct RS-232 connection to the I400.

The Diagnostic will see this simple configuration as a loop with just a single device on it. Because the direct RS-232 connection does not allow other devices to be seen through that port, the I400 appears as both a loop and a device on that loop. Contrast this to the situation where you have a loop controller, such as the Pyramid Technical Consultants, Inc. A200, A300 or A500 devices, and the I400 is connected to the controller via a fiber-optic loop. In this case the loop controller is identified as the loop, and the I400 as a device on the loop.

Start the PSI Diagnostic. It will search the available ports and present a search a list. Figure 17 shows a case where the program found three serial ports, and a local area network adaptor for which various IP addresses have been defined previously. It will search for loops and devices on all the checked options.

If you wish to personalize your software, you can place your own graphic for the discovery window in png format into the \Images folder, with the name discoverbanner.png.

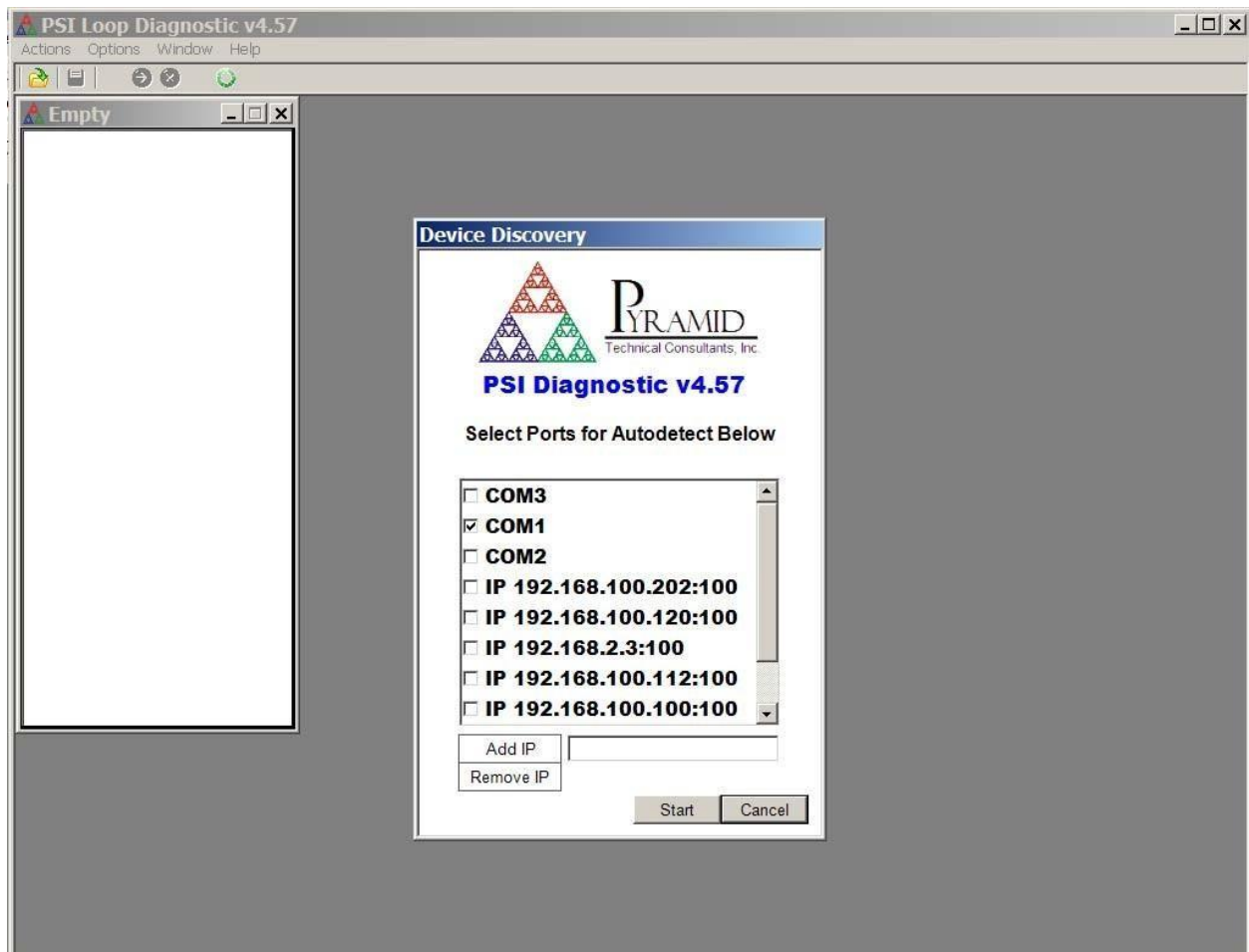


Figure 17. PSI Diagnostic Device Discovery Utility

#### 10.4 Data tab

A few seconds after you click the “Start” button, the program should find the I400 (plus any other devices). Clicking on the I400 entry in the explorer list in the System window will open the I400 window (figure 18). Explore the controls and readbacks on the Data tab to become familiar with the software and the I400.

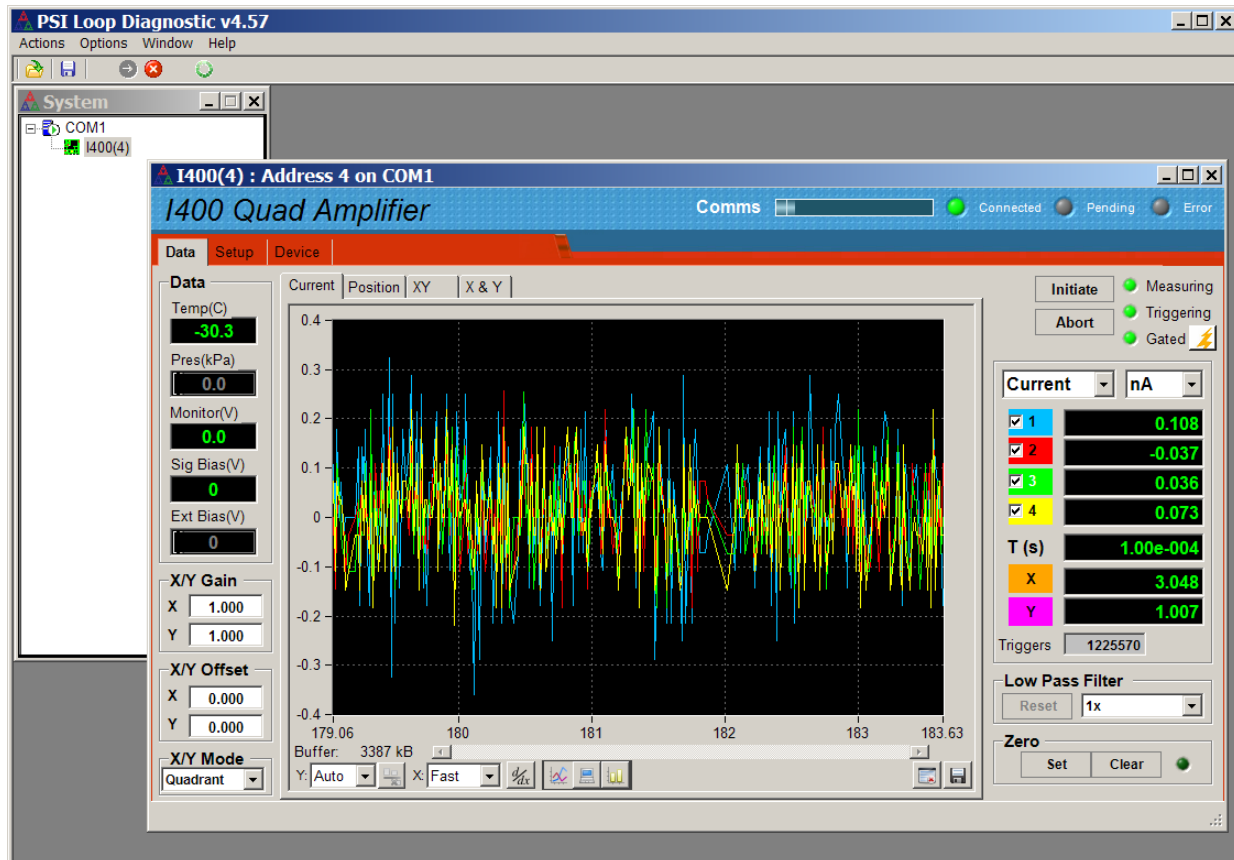
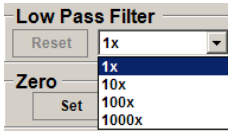
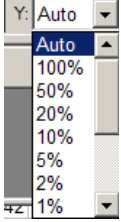
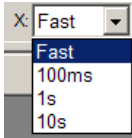









Figure 18. Data/current tab: I400 running with default settings, showing background noise.

Initiate	<p>This button starts an acquisition with the parameters set on the setup tab. If a starting trigger is present (for example if you are in internal trigger mode), then the acquisition will start at once. Otherwise the acquisition will start when the starting trigger is detected. The number of readings in the initiate in progress is displayed in the Triggers box.</p> <p>The LEDs indicate whether a measurement is in progress, whether triggers are being detected, and the state of the external gate input (whether or not this is being used to trigger measurements). The external gate will float high if not connected.</p>
Abort	This stops an acquisition in progress.
Current / charge	You can display the I400 reading in pA, nA, $\mu$ A or amps, or pC, nC, $\mu$ C or coulombs. The check boxes determine whether the data is displayed.
T	The integration time in use is displayed, in seconds.
X, Y	Position values calculated from the four signals.
Averaging	You can set up data filtering by the PSI Diagnostic, to make a fluctuating value easier to read. The filter type is a simple IIR (infinite impulse response) digital filter. The number in the drop down list is the parameter

	<p>A in the filter equation <math>Y_i = X_i/A + (1 - 1/A)Y_{i-1}</math>, where <math>Y_i</math> is the latest output of the filter, <math>Y_{i-1}</math> is the prior output of the filter and <math>X_i</math> is the latest reading from the I400.</p>  <p>Note that this filtering by the PSI Diagnostic is in addition to the data averaging done in the I400 itself. The Reset button clears past readings from the filter.</p> <p>The specified filtering is applied to the position values calculated by the PSI Diagnostic as well as the current or charge readings.</p> <p>The filtering affects the numeric display, the graphic display and any data that you capture. Note that this only applies for PSI Diagnostic versions 4.50 and later. In prior versions, only the numeric data was affected.</p>
Zero	<p>The PSI Diagnostic will capture the latest reading and subtract it from all subsequent readings if you click the Zero button. Pressing Clear stops this. Note that if you press zero when there is a real signal current, this current will then be hidden.</p> <p>The zeroing affects the numeric display, the graphic display and any data that you capture. Note that this only applies for PSI Diagnostic versions 4.50 and later. In prior versions, only the numeric data was affected.</p>
Data	<p>If you have the options for temperature probe, atmospheric pressure sensor, signal bias voltage or external bias voltage, the readback values are displayed here. If no temperature probe is connected, the displayed value will be meaningless and should be ignored.</p> <p>The probe connector also has a general purpose analog voltage input, and its value is also displayed.</p>
X/Y Gain	<p>These fields set the gain factors for position algorithms, to convert position readings into physical units.</p>
X/Y offset	<p>These fields allow you to set offsets in physical units for the position readback, in case the middle of your sensor is not at (0,0).</p>
X/Y mode	<p>Select split or quadrant to set the position algorithm that is used to calculate X and Y.</p>
Y-range	<p>This controls the vertical scaling of the data plot. It can be automatic or various fixed proportions of the full scale of the range in use.</p>

	
<p>X-time</p>	<p>This controls how fast new points are added to the data plot. This is generally limited by the speed of your PC.</p>  <p>If the integration or subsample time has been set to a large period, then this will override the update rate you set here, because new data is only available at the rate determined by the update rate.</p>
<p>Buffer</p>	<p>The PSI Diagnostic collects data coming from the I400 as fast as it can into a buffer. If the I400 rate, set by the integration time and the communications channel bandwidth, is relatively low, then every data point is logged. At high rates some readings will be lost, but you can see this because every reading gets a trigger count, and missing values are evident.</p> <p>Spooling data into the buffer can be halted with the slider .</p> <p>The plot can be cleared with the Clear Plot button .</p> <p>The data can be written to a nominated .csv file with the File button .</p> <p>The buffer is cleared by a new initiate command. The kB and Buffer indicator show how much data is currently in the buffer..</p>
<p>Couple</p>	<p>Selecting AC coupling removes any DC component from the graphic display only.</p>
<p>Mode</p>	<p>There are various ways to plot the data. There are:</p> <p>strip chart .</p> <p>or bar chart (histogram) . In histogram mode you can place a cursor on any channel by clicking on it. Click again to clear the cursor.</p> <p>Scope mode  is a variant of the strip chart. One full screen of data is displayed at a time, rather than the continuous scrolling of the strip chart.</p> <p>The derivative button  displays the difference between successive</p>

	<p>values, and is useful if you are looking for sudden changes in the signal. It only affects the graphic, not the numeric or logged data.</p> <p>The AC/DC toggle <input type="checkbox"/> DC / <input checked="" type="checkbox"/> AC is similar to zero subtraction, but only affects the graphic. When AC is selected, the average of all the display values for a channel is subtracted from the values before they are plotted. It is thus like a rolling offset removal or high-pass filter.</p>
Run	The Run control toggles whether data is accumulated into the buffer. It does not have any effect on the data being generated by the I400.

Notice that there are three subsidiary tabs under the Data tab. You have been looking at the default, labeled Current. The other subsidiary tabs display beam position monitor readout data. They are described in more detail in section 15.

### 10.5 Setup screen

Click on the “Setup” tab. Here you can adjust measurement parameters such as integration period, feedback capacitor, set the auxiliary high voltage, and use the built-in calibration facility.

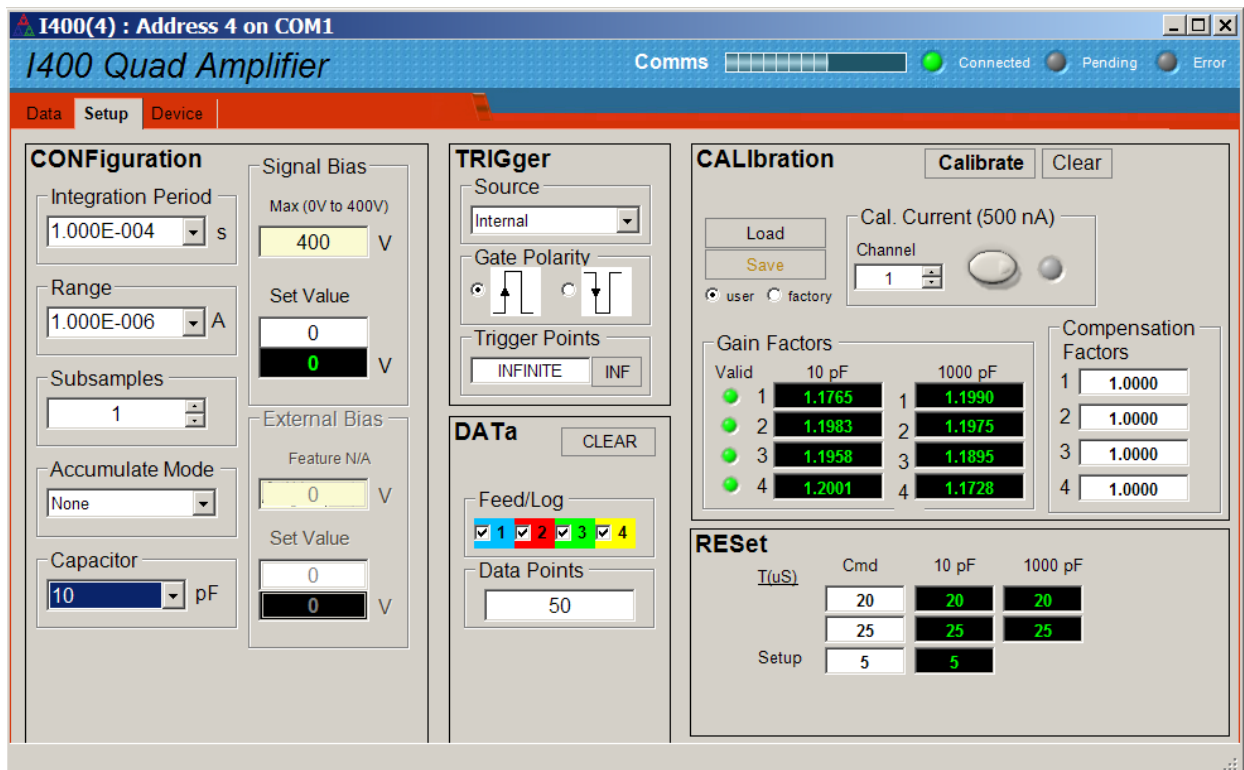


Figure 19. Setup tab: I400 running with default settings.

Become familiar with all the screen controls and displays:

Integration period Range Capacitor	These three controls together select the current range. Changes to the integration period result in the appropriate range being displayed for the selected feedback capacitor selection. Alternatively you can alter the range and the integration time will be altered to suit. Commonly used values can be selected from the dropdown. The smallest allowed integration time is 100 $\mu$ s. The range value is an approximate upper limit. See section 13 for more detail about the highest current you can reliably measure with a given selection of integration time and feedback capacitor.
Subsamples	This is the number of subsamples taken per integration. The default is one.
Accumulate mode	This control determines whether charge readings are accumulated over several integrations, and the method that is used to handle the deadtime when the integrator is being reset.
Signal Bias	<p>If your I400 has the signal bias high voltage option, you can set the output voltage with the Set Value box. The Max box allows you to constrain the settings to a particular maximum, for example to protect sensitive equipment that cannot sustain the maximum voltage of the supply. The parameter is administrator-level protected, so you will need to enter it twice if you are making the first edit since the I400 was last started up.</p> <p>The feedback value is not generally as accurate as the setpoint, but does allow you to see if the supply is being overloaded.</p> <p>Note that your setpoint entry must have the correct polarity (to set a -400 V supply to -250 V, you must enter “-250”.</p>
External Bias	<p>If your I400 has the auxiliary external high voltage option, you can set the output voltage with the Set Value box. If the option is not fitted, the fields will be grayed out. The Max box allows you to constrain the settings to a particular maximum, for example to protect sensitive equipment that cannot sustain the maximum voltage of the supply.</p> <p>The feedback value is not generally as accurate as the setpoint, but does allow you to see if the supply is being overloaded.</p> <p>Note that your setpoint entry must have the correct polarity (to set a -1000 V supply to -600 V, you must enter “-600”.</p>
Trigger	<p>You can set various trigger options. “Internal” setting allows the I400 to “free run” and take data without the need for incoming synchronization signals. Full details of trigger modes are given in section 13.</p> <p>You can set the logic sense (on = trigger or off = trigger) with the Gate Polarity selection.</p>
Trigger points	This parameter selects how many readings will be taken following initiate and triggering. “Infinite” setting allows the I400 to acquire data continuously, until you abort or alter settings.
Data	The I400 contains an internal data buffer. You can mask which channels

	are fed into the internal data buffer, and set the maximum size of the buffer.
Calibrate	<p>Clicking the calibrate button causes the I400 to execute its automatic self-calibration routine using the precision 500 nA internal current source. The gain values will be displayed upon completion. You can save the calibration to I400 EEPROM memory, load a previously stored calibration, or clear to the uncalibrated state. There are two calibration memories, labeled user and factory. The intent is that the factory calibration is retained as a safety fallback, whilst the user calibration can be updated at will. However you are free to use them in any other fashion.</p> <p>The green LEDs alongside the gain factors indicate that the calibration is within allowed tolerance bands.</p>
Cal Current	You can toggle the built-in 500 nA calibration source with this button, and control which channel it is directed to. This provides a useful diagnostic function.
Compensation Factors	These are user supplied values that allow you to tell the I400 about differences in sensitivity that may exist between the sensors in a position sensing array. The settings do not affect the currents and charges that are displayed, only the values that are fed to the position algorithms.
Reset	You can alter the reset, settle and setup times away from their default values. Refer to section 12 to learn about these parameters. In general, the values can be reduced to lower the deadtime proportion, at the expense of lower measurement accuracy.

As an exercise, do the following. Clear the calibration, then click the calibration button, and observe that the gain factors change. Store this new calibration in the user memory. Click the calibration current button to turn on the source, and select channel 2. Select 1e-4 s integration, 10 pF feedback capacitor, internal triggering and infinite trigger points. Now if you return to the data tab and initiate data acquisition, you should see the 500 nA calibration current on channel 3. Try displaying the data in histogram mode. Setting 100% vertical scale should show the calibration at half of full scale.

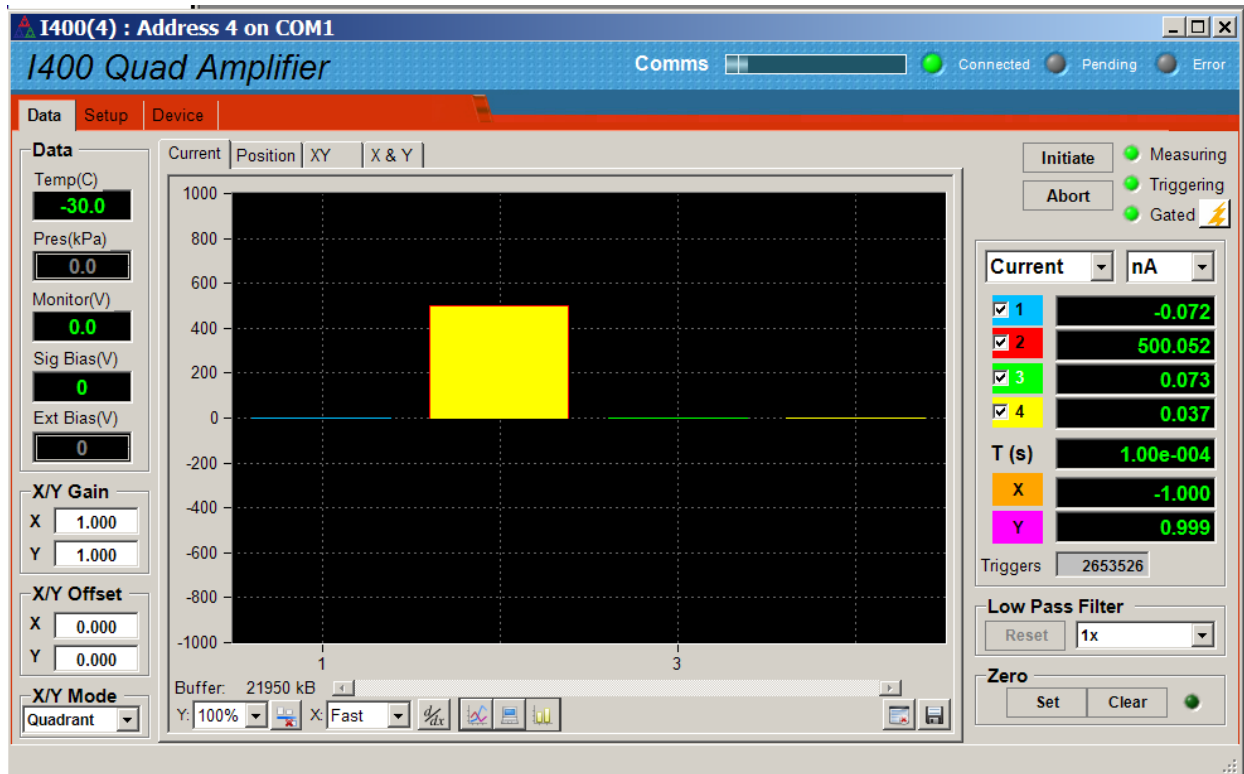


Figure 20. Internal calibration current routed to channel 2, histogram display format.

Try other channels, and investigate the effect of changing the integration time and the feedback capacitor, and of changing the display from current to charge. If the calibration current is overrange, the current reading is shown in red text.

## 10.6 Device screen

Click on the “Device” tab. You can check the communication link status and verify the versions of the hardware and firmware. On the right is the firmware update utility. You can use this to download firmware updates for both the microcontroller (.hex files) and the FPGA (.fhex files) downloaded from the Pyramid Technical Consultants, Inc. web site.

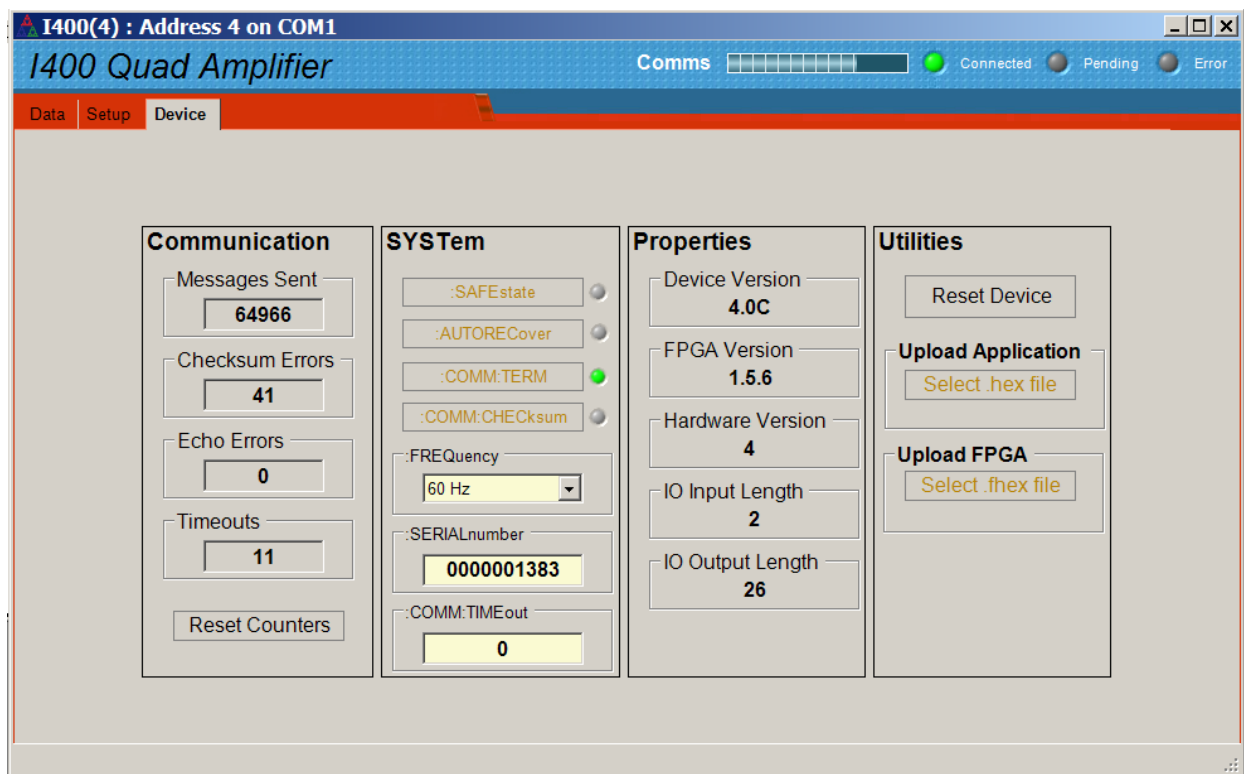


Figure 21. Device tab, showing firmware update utility controls.

Communication	The counters show details of the communications between the I400 and its host. You can click the Reset Counters button to reset the fields to zero.
SafeState	Enabling SafeState will cause the I400 to go to its defined safe state if there is a communications timeout. In particular the HV supply will be turned off.
Comm:Term, Comm:Checksum	These controls affect behavior of the I400 when in ASCII terminal mode. You can ignore them when using the PSI Diagnostic.
Frequency	This parameter sets the averaging period that will be used for calibration. You should set it to the dominant electronic noise frequency in your environment (normally the line frequency).
SerialNumber	This is the manufacturing serial number of your device, and should be left unchanged.
Comm:Timeout	This field can be used to control how the I400 behaves if the communication link to its host is lost. Entering any non-zero integer value sets the number of seconds that the I400 will continue what it is doing if communications are lost. After that it will go to its defined safe state.
Upload Application Select hex file	This button starts the I400 microcontroller firmware update process. It opens a file selection dialog. When you select a hex file it will start uploading to the I400 immediately. Upon completion the I400 will restart

	automatically, and you will see the new Device Version number displayed.
Upload FPGA Select fhex file	This button starts the I400 FPGA firmware update process. It opens a file selection dialog. When you select a fhex file it will start uploading to the I400 immediately. Upon completion you will need to power cycle the device to run the new code. You will see the new Device Version number displayed.
Reset Device	This button causes a full warm reset of the I400. Any acquisition in progress will be lost.

# 11 Principle of Operation

## 11.1 Gated Integrators

The I400 uses the gated integrator method. This is a particularly effective technique for measuring small amounts of electrical charge. The charge accumulates on a small low-leakage capacitor in the feedback loop of an operational amplifier, with the result that the voltage at the amplifier output is the integral of the current that flows into the input (figure 22).

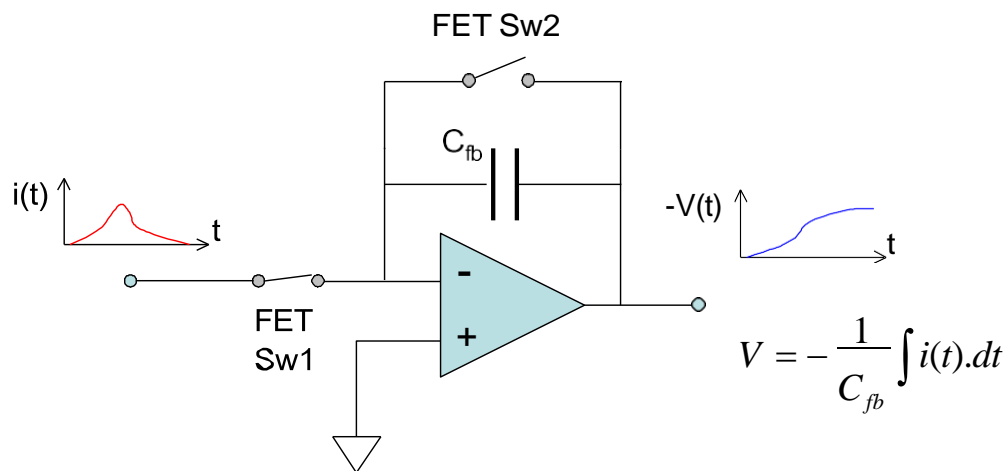


Figure 22. The basic gated integrator circuit.

Integration starts when FET switch Sw2 is opened. The current into the input can be negative or positive. The voltage at the output of the amplifier is sampled and digitized by an ADC. Calibration with a stable, accurately known test current allows variables such as the exact size of the feedback capacitor, buffer amplifier gain and ADC gain to be compensated in a single gain factor. At any time  $t$  after the start of the integration, the accumulated charge is thus given by

$$q_{meas} = k(ADC_t - ADC_{start})$$

where  $k$  is the gain factor. Note that the gain factor stored excludes large fixed components such as the ADC conversion gain, and is thus a number close to one. It primarily reflects the difference between the actual feedback capacitor value and the nominal value.

The data can also be presented as an average current in the time interval between the readings, because that interval is known accurately.

$$i_{meas} = \frac{k(ADC_t - ADC_{start})}{t}$$

As the integration proceeds, this measure of the average current achieves increasing signal to noise ratio, as more charge is accumulated and the low pass filtering roll-off due to the increasing integration time moves to lower frequency.

The inherent integration is very effective in reducing noise, being in effect a rectangular low-pass filter with -3dB response at  $0.44/t_n$  Hz and zero response at  $N/t$  Hz,  $N=1,2,3,\dots$ . Known dominant noise frequencies, for example line voltage interference at 50 Hz or 60 Hz, can be completely suppressed by choosing  $t_{per} = 1/50$  or  $1/60$  seconds, or integer multiples thereof.

Readings are available at times  $n \cdot t_{sub}$  during the integration, where  $n = 1 \dots N$  with  $N$  the number of sub-samples requested in the integration period,  $t_{per}$ , and  $t_{sub} = t_{per} / N$ . Figure 23 illustrates how a portion of the input waveform is integrated by the opening of Sw2. ADC readings are taken for the sub-samples, with  $ADC_{start}$  being subtracted from each subsequent sample to produce a charge reading.

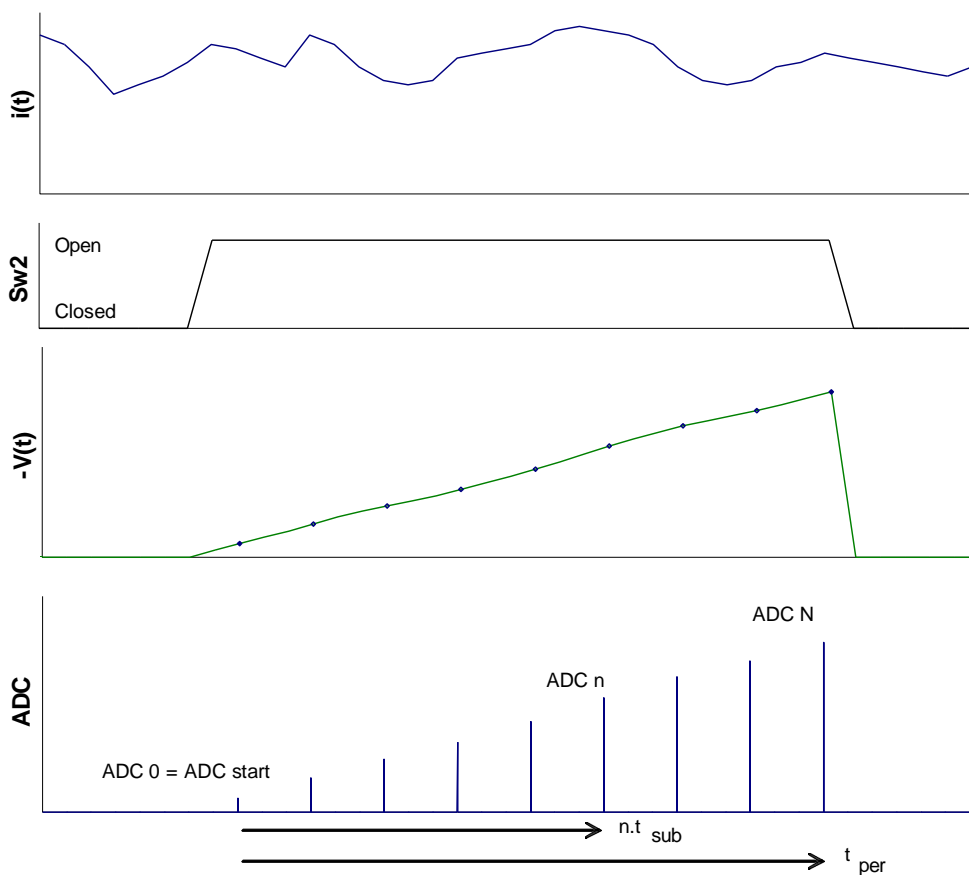


Figure 23. Data acquisition timing diagram. The plots are (from the top) illustrative input current waveform; integrator gate Sw2 state, integrator output with ADC sample points shown; ADC readings.

Integration cannot proceed indefinitely because the charge amplifier output voltage cannot exceed its voltage supply rails, and because the ADC input voltage range will be exceeded. It is

necessary to reset the integrator periodically, at a rate determined by the average input current and the size of the feedback capacitor. After the defined integration period,  $t_{per}$ , switch Sw2 closes to short the feedback capacitor and release the charge, so zeroing the integrator ready for the next cycle.

The reset time needs to be sufficient to completely clear the accumulated charge through the FET on resistance, and thus depends upon the size of the feedback capacitor. There is also a short settle time allowed after opening Sw2 to start the integration before the start ADC reading is taken, to allow transients to die away. A further time associated with the reset, called the setup time, accounts for the fact that the ADC conversions are not generally exactly aligned with the end of the specified integration period.

## 11.2 I400 Circuit Overview

The whole of the front-end including the charge to voltage conversion amplifiers and the ADCs is floated at the signal bias voltage, up to 400 V relative to chassis ground. Low voltage power is delivered to the isolated section via isolation DC-DC converters. Parallel ADCs also floated at signal bias potential digitize the charge values from the conversion amplifiers, and the digital data is transmitted across the isolation barrier via high-speed digital couplers. The numeric values are managed by a microcontroller/FPGA combination which handles all measurement timing control, calibration, data conversion and communications to the user's host computer system.

Host communications can be via RS-232, RS-485 or fiber-optic using ASCII protocols based upon SCPI, or binary protocols. RS-232 and RS-485 are intended for direct connection to a host PC, with the RS-485 intended primarily for increasing the allowable serial cable length. The fiber-optic interface allows a full loop-based system, with multiple individually-addressed devices.

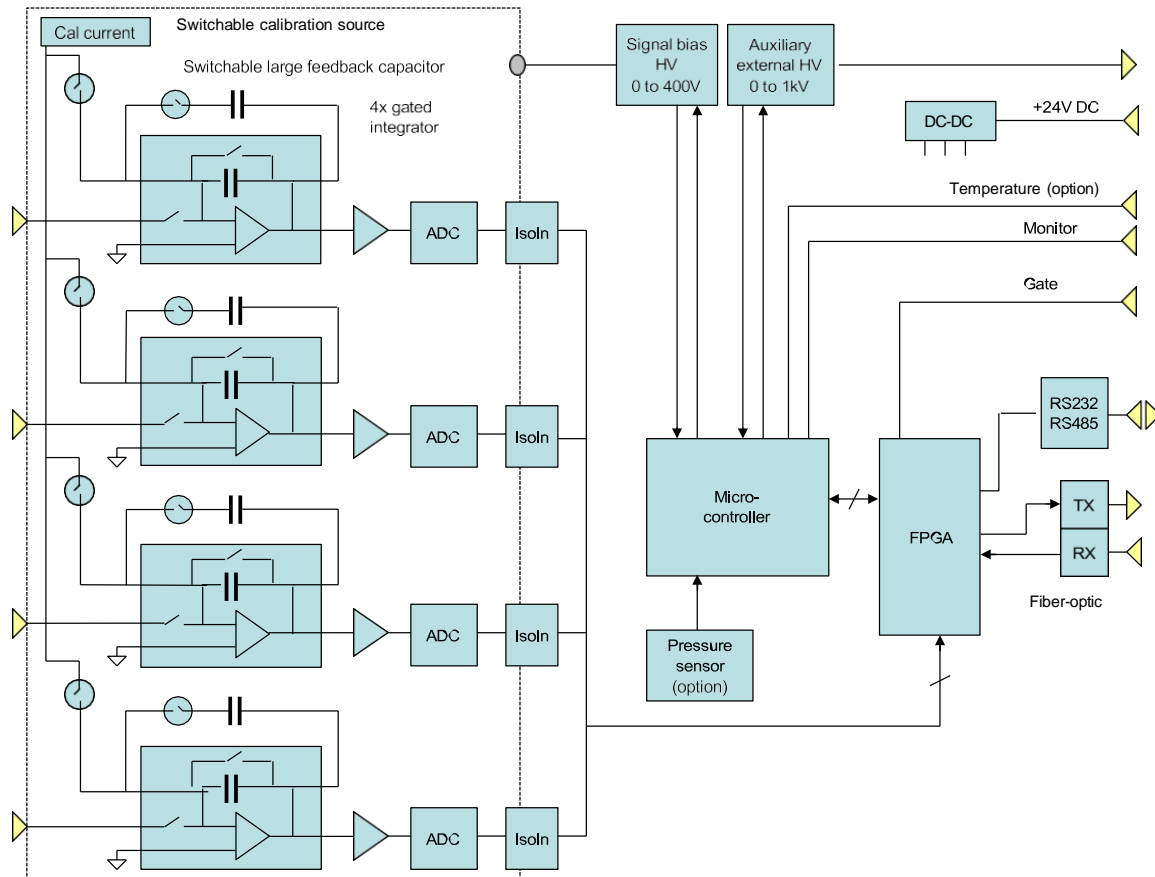


Figure 24. I400 block schematic.

The ADCs convert simultaneously as needed up to a maximum rate of 250kHz. Because the ADC conversion period can be considerably shorter than the integration period, the I400 can use sub-integration period sampling to track the charge build-up on the feedback capacitor between resets, as described in the previous section. This enables several useful measurement techniques and features in the I400: When the average current being measured is very low, so that a long integration period is needed to get a precise value, sub-integration sampling allows intermediate current values to be returned, rather than having to wait for the integration to end before getting a new reading. Time-resolved data is available from within the integration period. This allows, given adequate signal to noise ratio, reconstruction of the shape of a pulse that occurred within one integration period.

A precision calibration current source is built in to the I400. It can be switched into each channel under software control. The switching is controlled by the microcontroller during the automated calibration process. Confirmation of correct operation and gain calibration can be performed under remote control.

Each integrator circuit has a FET switch in series in its input, in addition to the reset switch in its feedback loop. Operation of this switch in combination with the reset switch allows an

integration mode where no charge is missed, even during resets. This is described in section 13.2 on charge accumulation measurements.

The on-board processor can monitor several additional parameters as well as the integrator outputs. The parameters available on individual I400s depend upon the options included.

- Signal bias HV output
- External auxiliary HV output
- Atmospheric pressure (built-in sensor)
- Temperature (external resistance thermometer probe)
- Monitor input (available for measuring any external parameter that can be presented as a 0 to 10 V signal)

These parameters are all digitized at 10 bit resolution.

### 11.3 Reset, Settle and Setup Times

The frequency at which new complete integration readings are generated is

$$F_{update} = \frac{1}{(t_{per} + t_{reset} + t_{settle} + t_{setup})}$$

where  $t_{reset}$  is the time that the integrator reset switch is kept closed,  $t_{settle}$  is the further time for transient effects to clear before the ADC captures the value corresponding to the start of the integration period, and  $t_{setup}$  is a time allowed to compensate the fact that ADC samples cannot occur precisely at the end of the integration period.

$t_{per}$  can be from 100 $\mu$ s up to 65 seconds, set according to the signal level. The live time proportion is given by

$$\frac{t_{per}}{(t_{per} + t_{reset} + t_{settle} + t_{setup})}$$

The integrators have the choice of two feedback capacitor values, under software control. All four channels are switched together. In combination with the choice of integration time, this allows a wide dynamic range of currents to be measured.

The default reset, settle and setup times for the standard capacitor choices are:

$C_{fb}$	$t_{reset}$	$t_{settle}$	$t_{setup}$
10 pF	25 $\mu$ sec	20 $\mu$ sec	5 $\mu$ sec
100 pF	25 $\mu$ sec	20 $\mu$ sec	5 $\mu$ sec
1000 pF	25 $\mu$ sec	20 $\mu$ sec	5 $\mu$ sec

## 12 Making Measurements

### 12.1 Maximum current

The maximum current that you can reliably measure with any combination of feedback capacitor and integration period must take account of settle time, component tolerance, threshold levels for the overrange flags and ultimate limitations of the charge integrating amplifiers. The range indications given in the PSI Diagnostic Setup screen are approximate upper values only. A more conservative value that can be guaranteed to be measureable without overrange is given by

$$i_{\max} = \frac{9.8 \cdot C_{fb}}{t_{per} + t_{settle}}$$

Using the values at the bottom of the capacitor tolerance bands in this expression gives further accuracy.

<i>Selected capacitor</i>	<i>Value recommended for conservative current range calculation</i>
10 pF	8 pF
1000 pF	908 pF

Thus the maximum you can guarantee to measure with the 10 pF capacitor, using the minimum integration time of 100  $\mu$ s and the default settle time of 25  $\mu$ s is 627 nA. The corresponding value for the 1000 pF capacitor is 71  $\mu$ A. In practice the capacitor values are much closer to nominal, and you will be able to measure somewhat higher currents before the overrange flags are set.

The I400 can be configured to measure currents of up to 200  $\mu$ A by suitable selection of feedback capacitors at time of purchase, which is the limit of the integrating amplifiers.

### 12.2 Continuous Current Measurement

The I400 can make a continuous reading of the current on its four inputs. In this mode it behaves like a sensitive current to voltage converter. The input current can be positive or negative. A positive reading represents conventional current flowing into the I400. A negative reading represents conventional current flowing out of the I400.

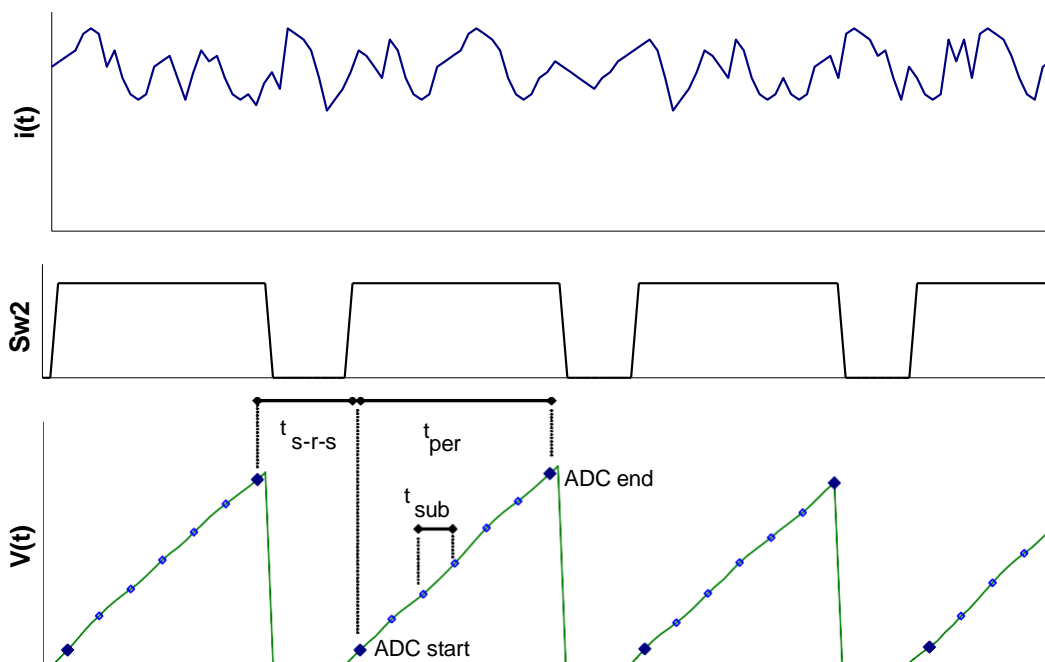


Figure 25. Timing diagram for continuous current monitoring. The deadtime for setup, reset and settle ( $t_{s-r-s}$ ) is shown relatively large.

Repeated integrations of the specified period are made. Each integration yields start and end ADC values, plus interim values from any sub-integration sampling that has been requested. The final measured current value for one integration is given by

$$i_{meas} = \frac{k(ADC_{end} - ADC_{start})}{t_{per}}$$

where  $k$  (coulomb  $\text{bit}^{-1}$ ) is the stored calibration factor for that channel with the feedback capacitor in use.

The interim current value for the  $N$ th sub-integration interval ( $N=1,2,\dots$ ) with ADC value  $ADC_N$  is

$$i_{measInterim} = \frac{k(ADC_N - ADC_{start})}{Nt_{sub}}$$

In current reading mode, the division by time to give current values is performed in the I400. Note however that values stored in the ring data buffer are always charge – see section 13.

The selection of feedback capacitor and integration period determines the maximum current that can be measured,

$$i_{max} = \frac{10C_{fb}}{t_{per}}$$

Commands to the I400 that return current readings also return the integration period in seconds and a bitwise overrange byte that flags any channels where the reading has gone overrange

(ADC value greater than 98% of full scale). The lower four bits indicate overrange positive, and the upper four bits indicate overrange negative.

LSB	Ch1 overrange +ve
	Ch2 overrange +ve
	Ch3 overrange +ve
	Ch4 overrange +ve
	Ch1 overrange -ve
	Ch2 overrange -ve
	Ch3 overrange -ve
MSB	Ch4 overrange -ve

The deadtime (composed of setup, reset and settle time components) while the integrators are being reset does not generally affect the integrity of the current measurement. The only exception would be a case where a significant frequency component of the signal happened to coincide closely with the integration cycle. This can be checked and avoided if necessary by altering the integration period.

### 12.3 Charge Accumulation

Applications such as radiation dosimetry often require the total charge to be accumulated, so that a process can be halted when a particular value is reached. When charge accumulation is turned on, a running total is kept of the total accumulated charge across all the integrations since the last initialize. All reported and buffered charge values show this accumulating value. If sub-samples have been specified, these are used as interim values to be added temporarily to the accumulating total. They are superseded by subsequent sub-samples in the same integration period up until the final sample which is logged permanently to the total.

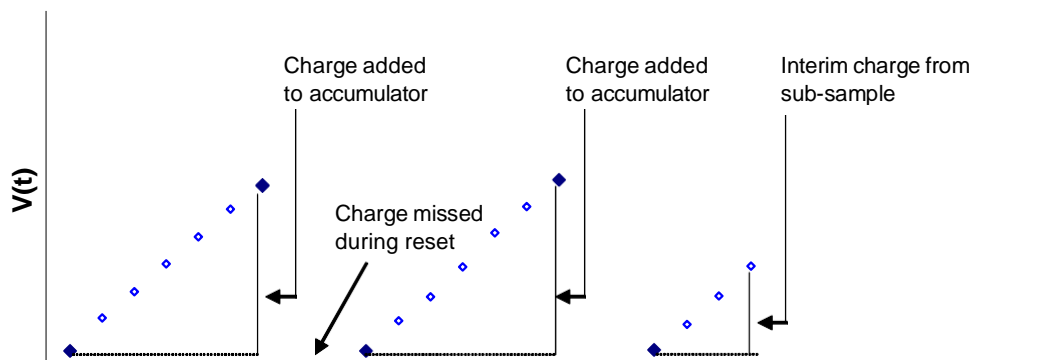


Figure 26. Illustration of integrator voltage at ADC sampling points during charge accumulation. The reset periods are shown relatively large.

There are three alternative means of dealing with the charge that is missed during the integrator resets. These are no correction, interpolation, and no-lost charge.

### 12.3.1 No reset time correction

Simply ignoring the loss during the deadtime can be appropriate when the deadtime is a very small fraction of the total time. For example, with one second integrations and a 10pF feedback capacitor, the percentage deadtime is about 0.003% of the total time, which is negligible.

### 12.3.2 Reset time interpolation

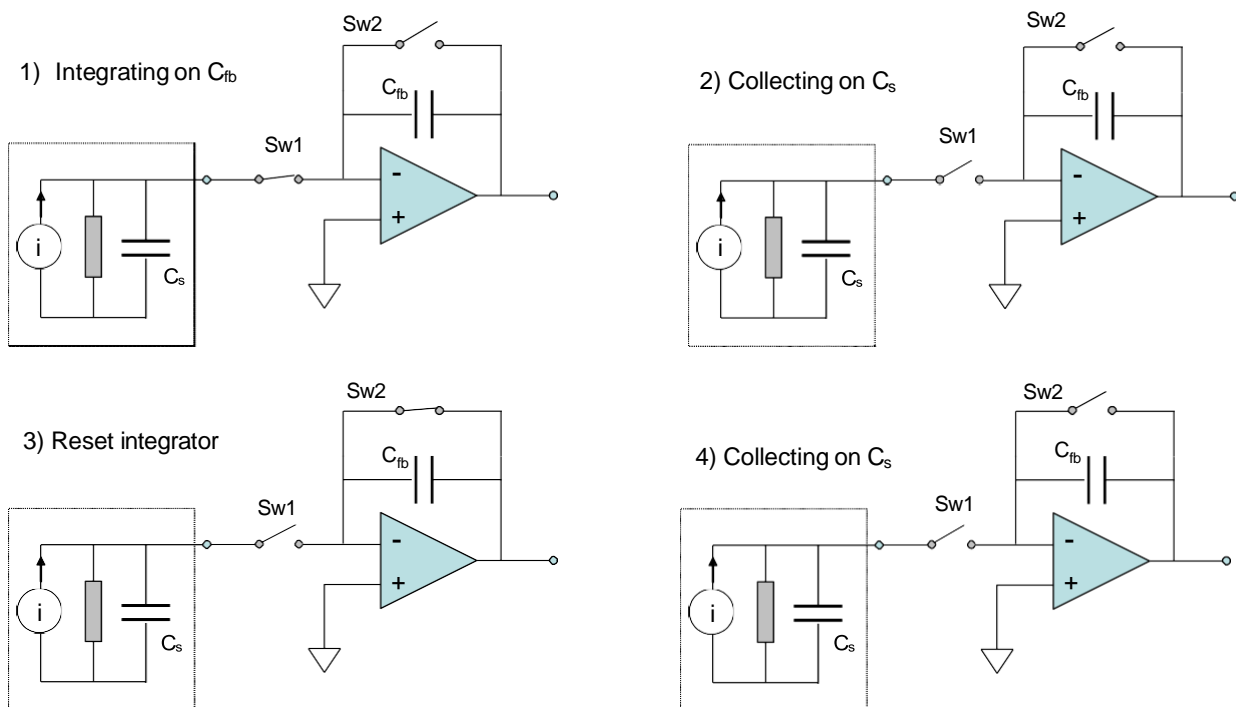
The I400 assumes that the measured charge in the last integration period may be pro-rata extended over the total cycle ( $t_{int} + t_{setup} + t_{reset} + t_{settle}$ ). The charge added to the accumulator for each integration cycle is thus

$$q = i_{meas} (t_{per} + t_{setup} + t_{reset} + t_{settle}) = \frac{k(ADC_{end} - ADC_{start})}{t_{per}} \cdot (t_{per} + t_{setup} + t_{reset} + t_{settle})$$

### 12.3.3 No-lost charge technique

In dosimetry applications it may be important to know the total accumulated charge over a period of time, without making any assumption about what happened during the integrator resets. The I400 can achieve this for signal sources that can be modeled as a capacitance in parallel with a very high resistance. This is a good model for ionization chambers, isolated electrodes that collect charged particles, and photodiodes.

The method is to use the inherent capacitance of the sensor,  $C_s$ , to capture the charge during the integrator reset cycle, then to transfer this charge onto the feedback capacitor at the start of the next integration. The switching sequence is illustrated in figure 27.



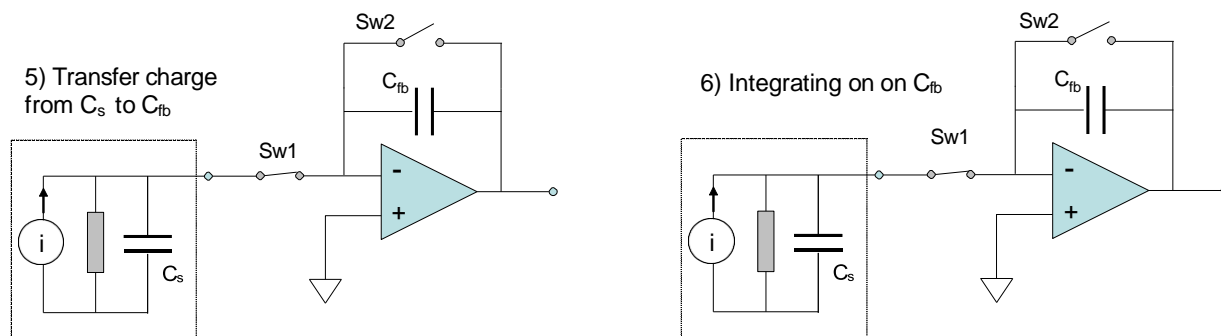


Figure 27. Switching sequence for the no-lost charge method.

Consider the integrator working normally, with charge accumulating on  $C_{fb}$ , and thus voltage increasing at the output (1). The mode 2 no charge loss reset cycle starts by opening the input switch Sw1 (2). If the load parallel resistance is high, the only place that the source current can now go is to build up charge on  $C_s$ . The integrator is now reset (3) by closing Sw1; charge continues to accumulate on  $C_s$  (4). When Sw1 closes again, the accumulated charge transfers quickly to  $C_{fb}$ . This is because the effective input capacitance of the integrator is much greater than  $C_s$  due to the amplifier action (5). The integrator output voltage jumps upward as a result of the transferred charge. Assuming lossless transfer, the net result is to extend the integration time over the complete reset cycle, so that all of the incoming charge is measured. The integration now proceeds normally again (6).

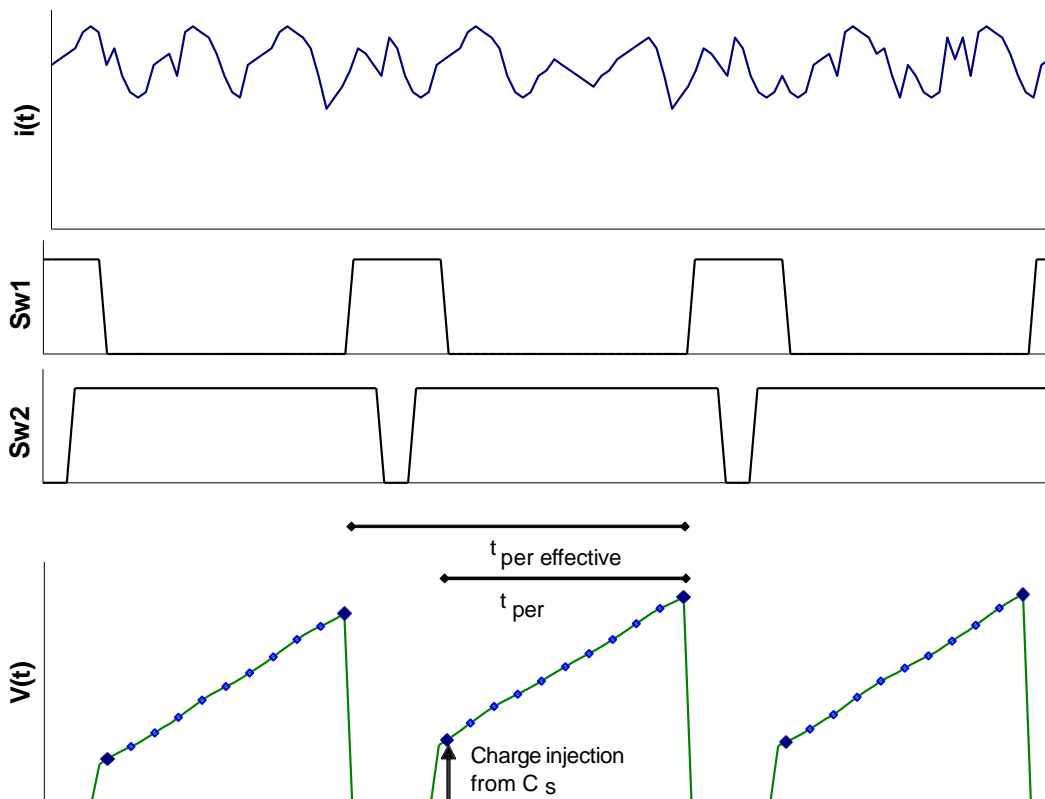


Figure 28. No lost charge timing diagram. The integration period  $t_{per}$  is effectively extended over the complete integration cycle.

## 12.4 Time Resolved Measurements

### 12.4.1 Standard Mode and FastMode

The I400 can operate in two data transfer modes according to the type of host system it is communicating with.

#### Standard mode

The I400 generates readings at the rate dictated by the integration time, subsample count and reset parameters. The host system collects these readings at the rate allowed by the host software and the communications link. Any readings which are not collected before the next reading overwrites them are lost.

Standard mode communications can be by ASCII or binary messages, with binary more efficient and thus faster. The readings are translated to coulombs by the I400 using the stored calibration.

#### FastMode

FastMode is only available in combination with the Pyramid Technical Consultants, Inc. A500 real-time controller. It is automatically selected with the first initiate command for all running modes *except* all accumulation modes, gated trigger mode, and message trigger mode. If you are

using the PSI Diagnostic host software, there is a LED display on the Data tab which shows that FastMode is in use. FastMode permits use of integration periods and subsample periods down to 100  $\mu$ sec.

FastMode communications are in the form of raw 16-bit data. The application of the calibration and translation to physical units is performed by the A500.

The I400 on-board memory can store up to 50 four channel readings. These are guaranteed to be contiguous, even at the shortest integration and subsample periods. Note that there will be deadtimes for each integrator reset, however. If you wish to capture a single shot event with no breaks in the data, then this is still possible by using multiple subsamples in a single integration which encompasses the event. Up to 256 subsamples can be used per integration. The full ADC resolution is effectively shared between the subsamples. You must also take care that the integrator does not overrange during the event.

In addition to the I400 on-board storage, the A500 can store over 500,000 readings. These will be contiguous if the communications between the I400 and the A500 can keep up with the data generation rate. This in turn depends upon the available bandwidth on the loop that services the I400.

## 12.5 Time resolution

There is an inevitable compromise between the ability to resolve time structure in a current waveform and signal to noise ratio. The I400 naturally averages and thus suppresses high frequency components in the signal. Where the signal to noise ratio is relatively large, however, data from sub-integration sampling allows the details of the rise of the output voltage as the charge pulse is integrated to be captured. The current pulse waveform may then be reconstructed by the host computer system as the differential of the measured integral curve.

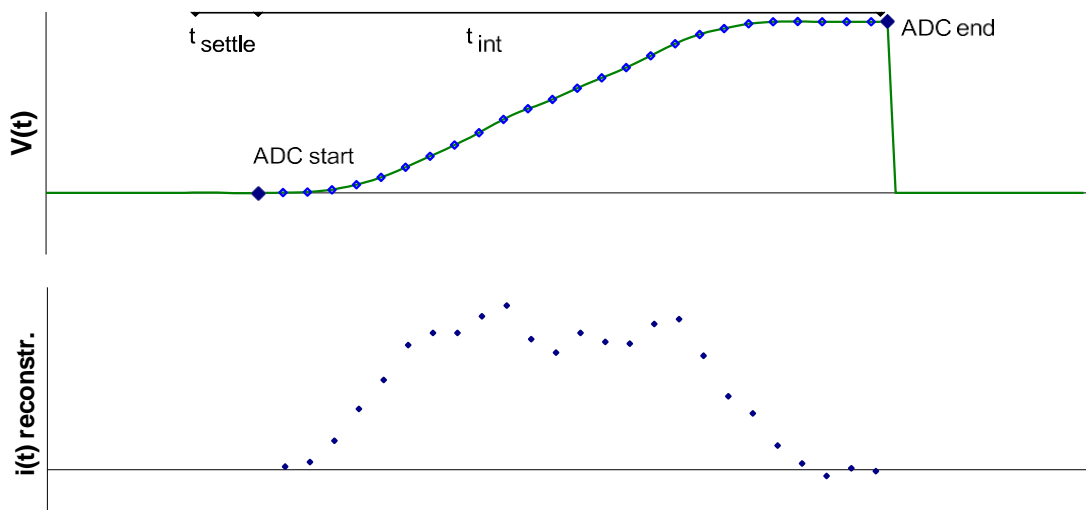


Figure 29. Reconstruction of a current pulse waveform from sub-samples.

## 12.6 Data Readout and Buffering

### 12.6.1 Dataflow

The dataflow in the I400 can best be understood by referring to figure 30. This shows the dataflow for a continuous current measurement, but the details are very similar for other modes. Host commands from the ASCII protocol are shown for reference. More details of these can be found in the section on communication protocols.

Following setup of the acquisition mode, trigger mode, integration period and other parameters as required, the I400 is primed to acquire data by an initialize command. The acquisition occurs when an internally-generated trigger is received. The figure shows schematically the input of four (end – start) ADC differences  $a_1$ ,  $a_2$ ,  $a_3$ ,  $a_4$ , acquired in an integration period  $t$  as a result of a trigger event. These are converted to four floating point charge values  $c_1$  ..  $c_4$  by multiplying by the respective gain factors  $g_1$  ..  $g_4$ , and the results are held in a temporary buffer, together with the integration time and the flag representing the overrange states of the channels.

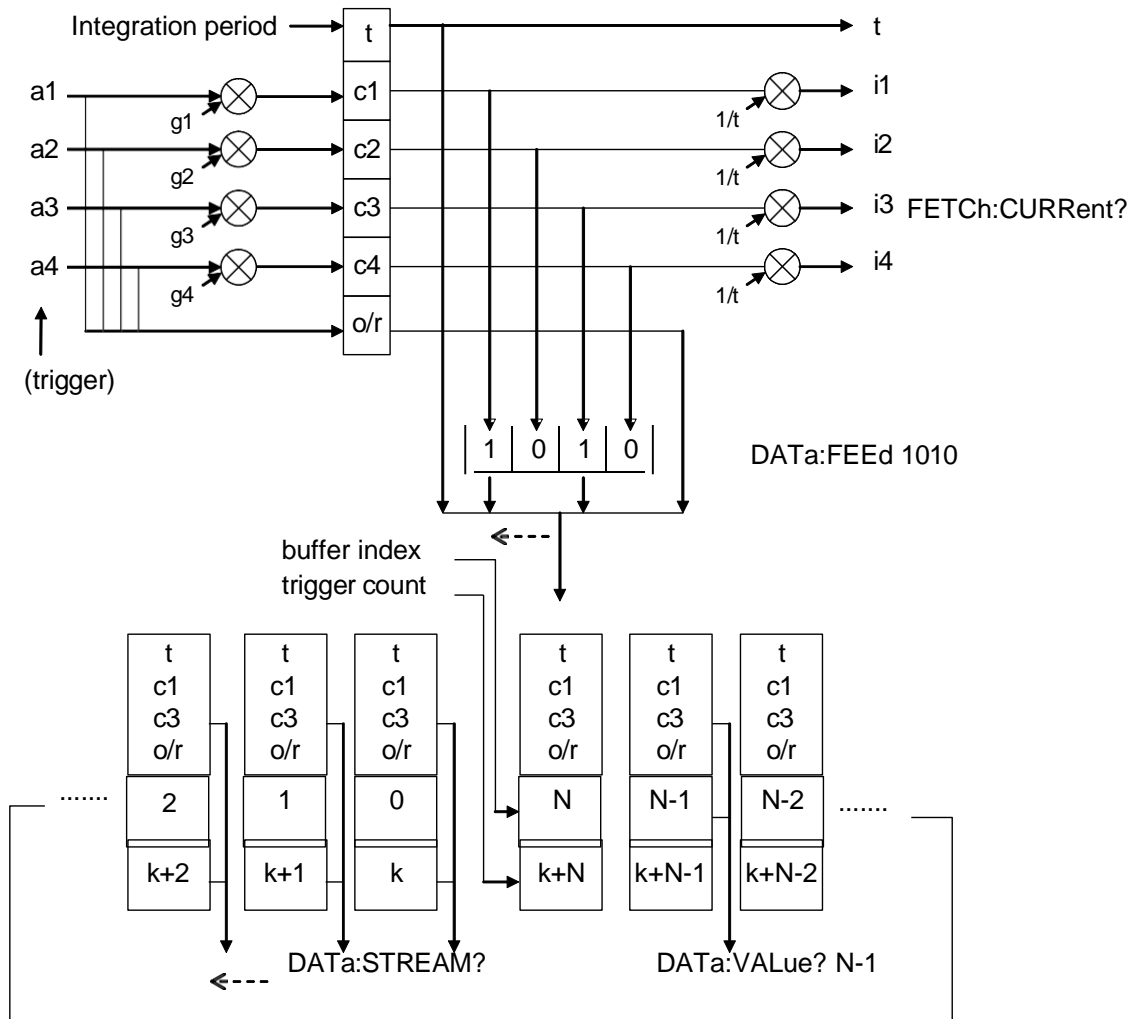


Figure 30. I400 data flow. The feed mask is set to pass data from channels 1 and 3.

The contents of the temporary buffer can be read out at any time by FETCh commands. If the fetch is for current, as illustrated, then the charge values are divided by the time to give four currents  $i_1 \dots i_4$ . If the fetch is for charge, no division is performed. The alternative READ command causes an initialize (canceling any acquisition in progress), then does a fetch when the acquisition has triggered and is complete.

### 12.6.2 Data buffer and data feed mask

A ring data buffer in the I400 allows data to be stored in the unit, so that the host does not need continuously to keep pace with the data rate. The values passed into the buffer include a trigger count, the integration period, the measured charges and the over range flags byte. If you want to present the data as current samples, then it is a simple matter to divide the charge values by the integration periods.

The channels that are buffered are selected according to a data feed mask. The fixed maximum amount of buffer memory is 200 charge values. This can hold more measurement points if fewer

channels are selected in the mask. Setting the data points parameter to zero makes the I400 use the whole available buffer memory. The number of data points that this represents (N+1 in figure 30), given the data feed mask setting in force, can be queried, for example with the “DATA:POINTS?” command in the ASCII communications protocol.

The trigger count is a number that increments with each measurement trigger. It is reset to zero by the initialize command. It allows the data points recovered from the buffer to be correctly ordered, and any missing data to be identified.

When the buffer fills, then data buffering is halted. It will also halt if the trigger point limit is reached. Individual values may be read from the buffer by the buffer index (from 0 to buffer points – 1). If wrap is on, incoming values continually overwrite the oldest value in the buffer. The best way for a host computer to recover the measurements is with the data stream command. This gets values starting with the oldest in the buffer and moving forwards each time it is called. So long as the average rate of calling data stream is not lower than the incoming data rate, no data points will be lost.

## 12.7 Triggering and externally-triggered acquisitions

### 12.7.1 Triggering, trigger points and measurement timing

Every measurement sequence recorded by the I400 is a result of a sequence of triggers. The sequence is started either internally, or as the result of an external event. You preset all the relevant parameters such as feedback capacitor, integration period, number of sub-samples, and type and number of triggers. Then initiate the measurement. The measurements only starts however when a trigger is detected.

As an example, say that you have requested ten trigger points, four sub-samples per integration, and “ExternalStart” trigger mode, looking for a high logic level on the BNC input. The initiate command primes the I400, but it will then wait until the trigger start event is detected. The status LED will be orange in this waiting state. When the gate input goes high, the measurement sequence will start. The status LED goes to green. Four trigger points occur in the first integration period from the four sub-samples, four in the second integration, and then the requested total of ten is reached halfway through the third integration. Measurements stop being recorded, and the status LED turns off. Note that the analog integrators continue to run even after the measurement has been completed, until you send the abort or initiate commands, or new parameters are sent. If you set the number of trigger points to infinite, measurements will continue indefinitely following the start event.

If you are in internal triggering mode, the start event is generated internally. The sequence therefore starts immediately after you send the initiate command.

The I400 keeps count of the number of trigger points,  $n$ , following the start event, and this number is used to determine the time of any measurement relative to the start of the sequence:

$$t_n = t_{settle} + n \left\lfloor \frac{t_{int}}{N_{sub}} \right\rfloor + INT \left( \frac{n}{N_{sub}} - 0.1 \right) (t_{settle} + t_{reset} + t_{setup})$$

where  $N_{sub}$  is the number of subsamples per integration. The formula simply reflects the fact that you always start with a settle time, followed by an integration with a number of subsamples, then followed by the reset sequence.

### 12.7.2 Trigger sources

There are several potential trigger sources and modes. The gate polarity (ie whether rising or falling edges cause the stated responses) depends on the gate polarity parameter.

Internal	Auto-run. The start event is generated internally by the I400 once the “initiate” message is received. Readings continue until the defined number of trigger points is reached, or the “abort” message is received.
External Start	A rising (falling) edge on the gate input starts a predefined acquisition sequence. Readings continue until the defined number of trigger points is reached, or the “abort” message is received.
External Start-Stop	A rising (falling) edge on the gate input starts a predefined acquisition sequence. Readings continue until either the programmed number of integrations is complete, or the gate input falls (rises) again, in which case the sequence terminates after the sub-sample in progress. Readings continue until the defined number of triggers is reached, or the “abort” message is received.
External Gated	The gate input drives the integrators directly. A rising (falling) edge on the gate input causes the S2 switches to close. The ADC converts at maximum rate. When the gate input falls (rises) again, the latest ADC reading is used together with the first to obtain the measured charge, and the integration time is recorded. The maximum integration time allowed is 64 msec. If you use a longer time the internal time counter will overflow and data will be incorrect.
Message	A special one-byte message on the communication link triggers the predefined acquisition sequence. Readings continue until the defined number of triggers is reached, or the “abort” message is received. This trigger mode is only supported via the RS-232 / RS-485 ports, or via the A200 loop controller. It is not supported through the A500 or A300 loop controllers.

In all cases you can select infinite triggers and the acquisitions will continue indefinitely until you send the abort command or reset the I400.

The external and gated modes require a physical signal via the gate input BNC. They are the most appropriate modes to use when you require the minimum (sub-microsecond), and most

consistent, delay between the trigger and the start of integration. The sense of the logic is a software configurable parameter.

The gate input requires a TTL level, and presents a TTL gate impedance. To avoid spurious signals due to noise, we recommend that you fit a 50 ohm terminator to this input if you are not using it. If your trigger source is able to drive a 50 ohm load, we also recommend this termination if you are using the input.

Message triggering provides similar performance to the external modes, but with slightly greater delay. In looped systems, the loop controller knows the position of each device in the loop, and arranges for each device on the loop responding to the trigger to delay its response according to its position in the loop, so that all devices start their acquisitions at the same time.

### 12.7.3 Illustrations of external triggers

Figure 31 is a schematic example showing an external start trigger of a sequence of seven integrations. Each integration includes three sub-samples, for a total trigger point count of 21. Data is of course gathered on each of the two channels. A similar sequence could be started by a message trigger.

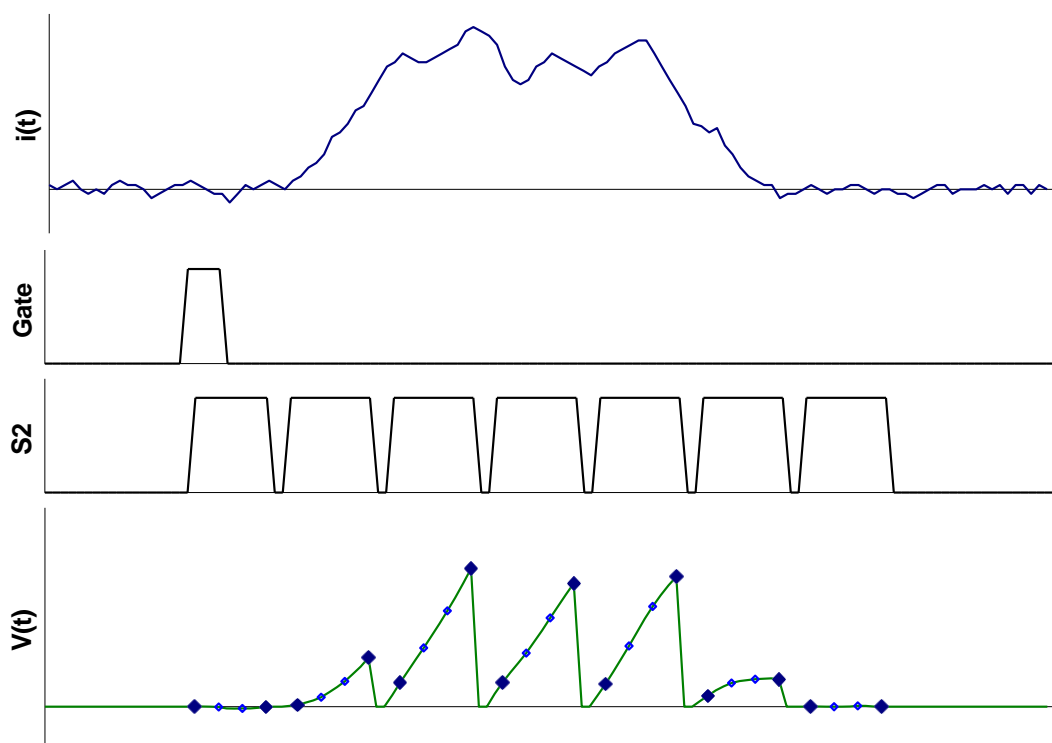


Figure 31. Example of an “external start” triggered measurement sequence started by a rising edge

Figure 32 shows an External StartStop trigger example. The sequence starts on the rising edge as in the previous example. However in this case the I400 is now also sensitive to the falling edge. When the gate line falls again, the sequence terminates after the acquisition in progress.

The external signal that starts the measurement sequence can be also be sent over the communications channel, as an alternative to making a hardware connection to the gate input connector.

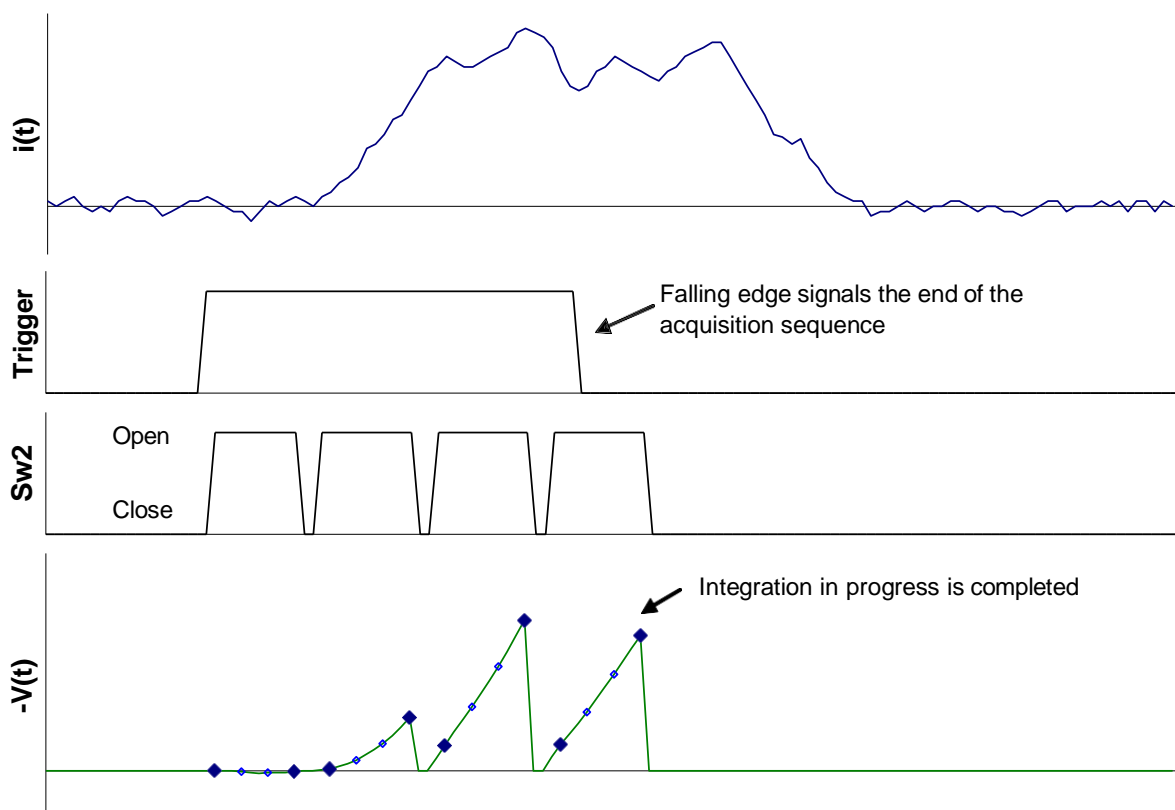


Figure 32. Example of an “external start/stop” triggered measurement sequence started by a rising edge and ended by a falling edge.

These acquisition modes would be useful where short pulse of charge, for example the macropulse in a pulsed accelerator system, needs to be sampled at relatively high rate.

Figure 33 shows an External Gated example. The integration timing in the I400 is controlled directly by the signal applied to the external gate input in gate trigger mode. You can consider that the incoming gate signal is connected directly to the feedback capacitor switches (Sw2). The switches open on the specified edge, remain open while the signal is maintained, and close again when the signal returns to its original state. Settle time is allowed as usual after the gates open before the start ADC reading is taken. Sub-sampling is not possible for gated acquisitions.

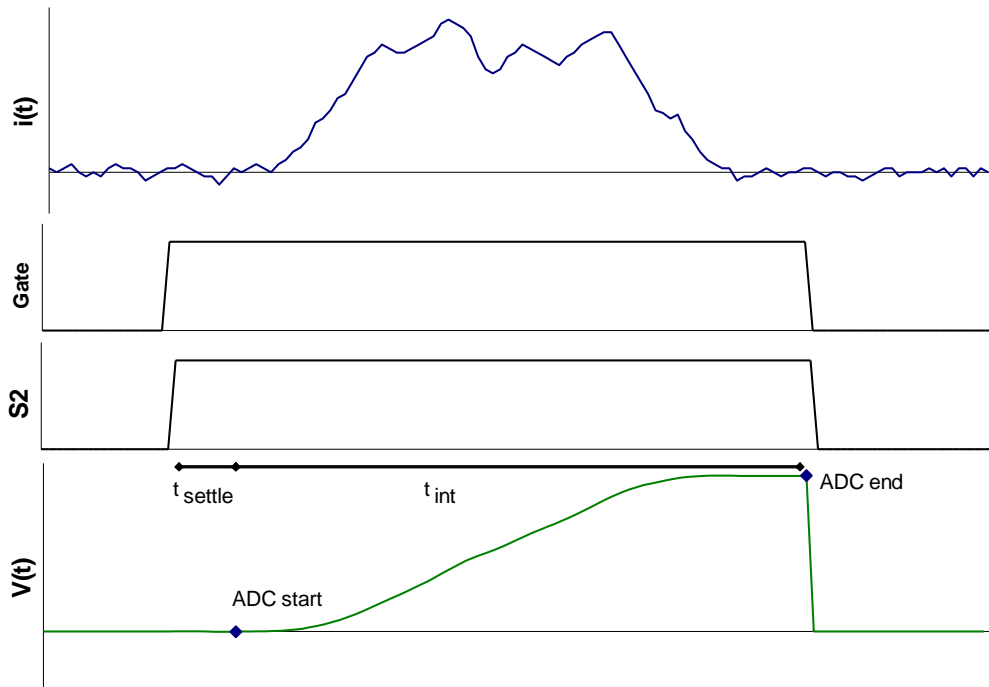


Figure 33. Illustration of a gated measurement.

## 13 Calibration and background offset current correction

Taking accurate current or charge measurements with the I400 require accurate gain factors,  $k$ , for each channel and consideration of the background offset current.

### 13.1 Background offsets

Consider an integration cycle as shown in figure 34. The voltage presented to the (ideal) ADC comprises the integrated signal,  $V_{\text{signal\_voltage}}$ , the integral of any net background offset current,  $V_{\text{bdg\_current}}$ , and a voltage pedestal,  $V_{\text{offset}}$ , due to amplifier offsets and the offset of the ADC itself. In practice these unwanted offsets will be much smaller than the signal, and may be negative or positive relative to the signal, but they must nevertheless be managed correctly to get maximum accuracy at the lowest currents and charges.

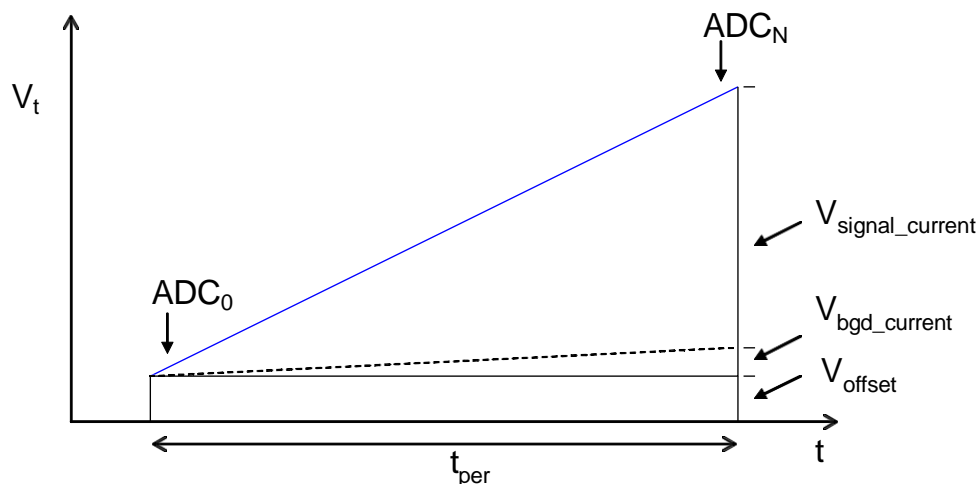


Figure 34. An integration showing signal and noise contributions to the final output.

$V_{\text{offset}}$  is eliminated automatically by the operation of the I400, because the charge is measured as  $k(ADC_N - ADC_0)$ , so the offset cancels.

Background current is not eliminated automatically, because it is indistinguishable from signal current at any moment in time. The I400 internal background current is small (pA level) and stable. The background from the external circuit will generally be higher, but depends greatly on the particular sensor or transducer.

Depending upon your measurement needs, it may be appropriate to subtract the total background current if it is significant relative to the signal, and relatively stable. The PSI Diagnostic software has this function. You should be careful of changes to the background which would render any such correction invalid, however. This could be due to changes in temperature or electrical noise.

You can include background nulling can be automated your own host software. To get the best results, the background should be measured with a long integration period, sufficient to get an accurate value, and with no true signal present, only the background current. The resulting

background current values,  $i_{bgd}$ , for each channel can be subtracted from subsequent current readings, either manually or in host software. In charge measurement modes, subtract ( $i_{bdg} \times t_{per}$ ).

### 13.2 Gain calibration

The calibration gain factors convert charge into ADC output, and thus are the composite of the feedback capacitor size, buffer amplifier gain and ADC gain. The I400 calibrates itself automatically on all channels by switching on the internal 500.00 nA current sources and making measurements with known integration period.

**IMPORTANT:** There must be no signal current flowing into the inputs when the calibration is taking place, because it will add to the calibration current and give an incorrect result. This incorrect calibration would not be detectable by checking the internal calibration source readback, but only by measuring a known independent current source. If you invoke the calibration from the PSI Diagnostic software, you will be prompted to confirm your selection, and this is your opportunity to check that the I400 is ready to be calibrated.

Because background offset current can affect the gain calibration process itself, the I400 also makes a background measurement as part of the calibration cycle. The measured background ADC difference is subtracted from the ADC difference measured with the calibration source on to get the net value that is equated to 500 nA.

The calibration factors are stored in the I400 in EEPROM when a save calibration command is issued. They are then loaded automatically on power-up. If there is no calibration available, the I400 will use a nominal calibration and the measurements will be of limited accuracy.

## 14 Beam position monitor readout

A common application for the I400 is readout of beam position monitors. These can take the form of dual sensors for one-axis position readout, or quadrant sensors for simultaneous two-axis readout at a single plane transverse to the beam direction. The sensors may intercept the beam directly, for example biased blades that emit electrons when struck by a high energy photon beam, or the interaction may be indirect, for example electrodes in an ionization chamber, or the readouts of photodiodes.

The PSI Diagnostic software provides position calculation and display options. The algorithms are the standard “difference over sum” calculations, and there are two options, depending on whether you consider the four I400 inputs as two pairs of split sensors (split mode), or a set of four sensors in a quadrant pattern. Note that in split mode, the X and Y axes are completely independent. They do not even have to be orthogonal. In quadrant mode the sensors should be coplanar, and laid out in the pattern shown in the figure. If in doubt, it is safer to use split mode.

The basic algorithms return position values  $-1 \leq X, Y \leq +1$ . Gain factors  $G_x$  and  $G_y$  can be entered in the PSI Diagnostic to convert to physical units, and offsets  $X_{off}$  and  $Y_{off}$  can be added in case your sensor is not centered on (0,0).

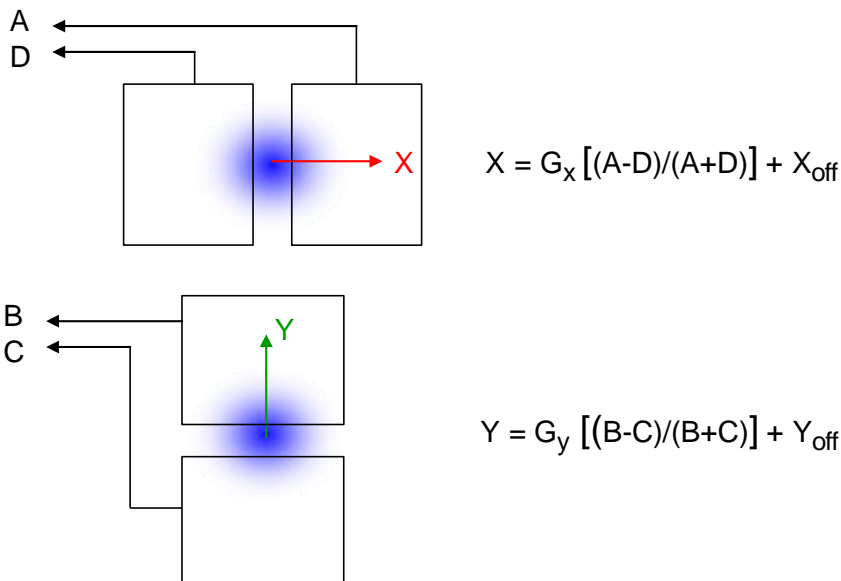


Figure 35. Split mode calculation. Signals A to D correspond to I400 channels 1 to 4.

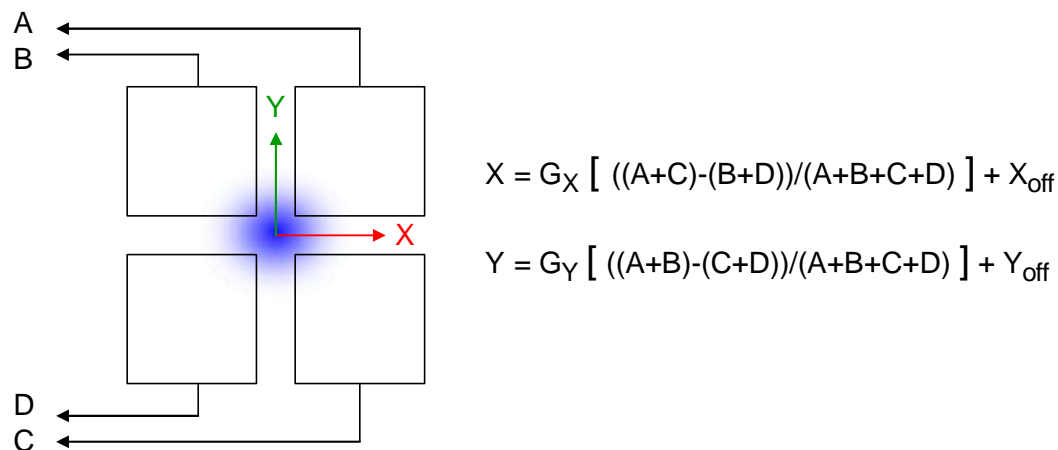


Figure 36. Two axis readout from a quadrant sensor

The algorithms assume that the measured signals are all of the same polarity. Provided that the beam dimensions are not small or large relative to the sensor dimensions, then the position functions will be linear with actual beam position over a reasonable range. The position functions shown in the figures have the ranges  $-1 \leq X, Y, \leq +1$ . In order to convert to physical units, you can multiply the result by a gain factor.

Three graphical displays of the position data are available: a strip chart ( $X, Y(t)$ ), an XY plot, and X and Y independent linear plots. Note that you don't have to select a particular position algorithm to view the data a particular way. However the XY display will only be physically sensible if the sensor axes are orthogonal.

### 14.1 Compensation factors

Notice that the position algorithms described above assume that your sensor has a uniform response. A uniform irradiation should give  $X = Y = 0$ , if you have not set up offsets. However in practice the responses of the individual sensor elements might differ somewhat. The compensation factors on the Setup screen allow you to compensate for such differences. You can set these factors either by adjusting them under uniform sensor irradiation until you read a centered response, or by delivering a stable beam that you know is at exactly centered, and adjusting the factors until the I400 reads the correct position.

The current or charge readings that are used in the algorithms are first multiplied by the factors. The basic current readings that the I400 returns are not changed, but you can see the signals multiplied by the compensation factors on the XY and Y & Y graphics.

### 14.2 Position strip chart data screen

The Position sub-tab shows you a plot of the computed positions as a function of time. The controls for vertical and horizontal scaling are the same as for the Current sub-tab. Low pass

filtering can be applied to the position readings. If you change the X/Y gain, X/Y offset or X/Y calculation mode, the results are shown immediately in the display.

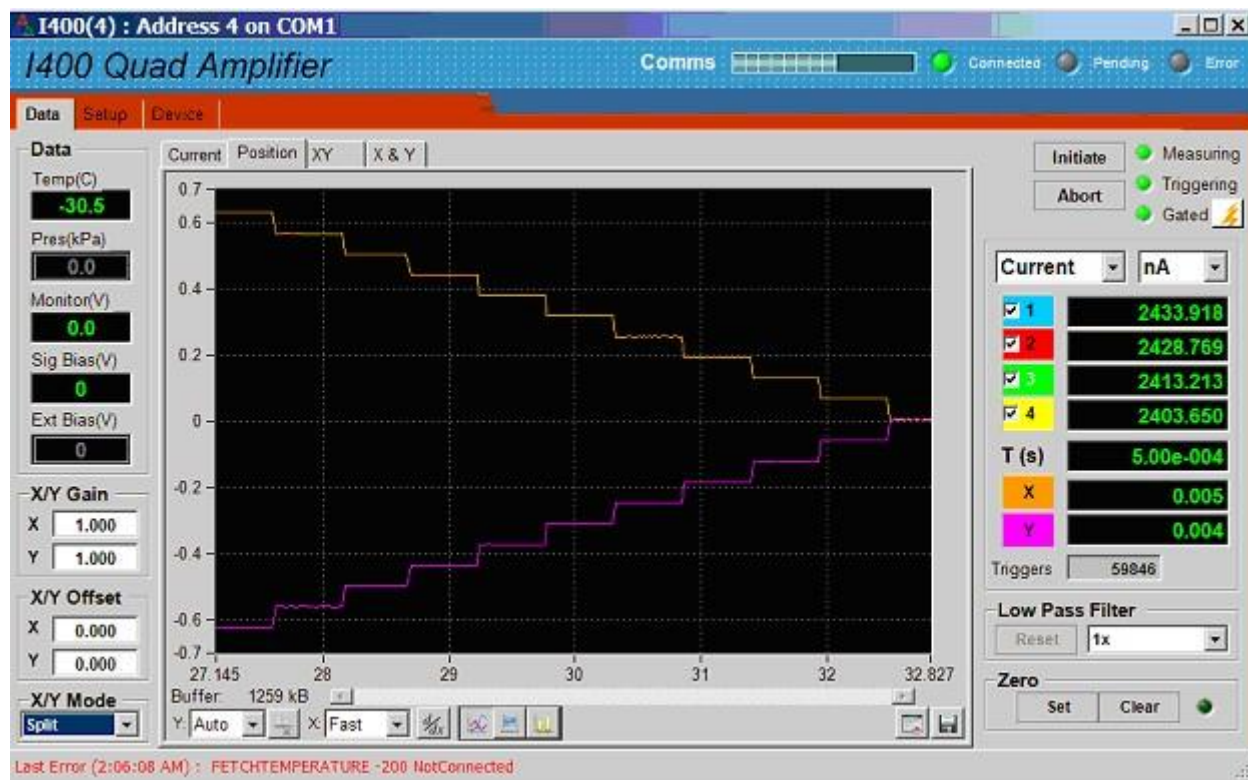


Figure 37. Strip chart position readout

Note that setting the graph to display positive values only may not be appropriate for position signals, which are typically bipolar even though the measured currents are all unipolar.

### 14.3 XY data screen

The XY screen plots X against Y as a moving crosshair. The readings shown on the graphic are the signals from the I400 multiplied by the compensation factors that you have entered on the Setup tab.

If you have set quadrant calculation mode, then the channel indicators and readings are arranged around the graphic in the pattern that is assumed by that calculation.

If you have selected split mode, then this graphic may not be physically meaningful, depending on the actual arrangement of your sensors. The channel indicators and readings are moved on the graphic to indicate that the quadrant layout may not apply.

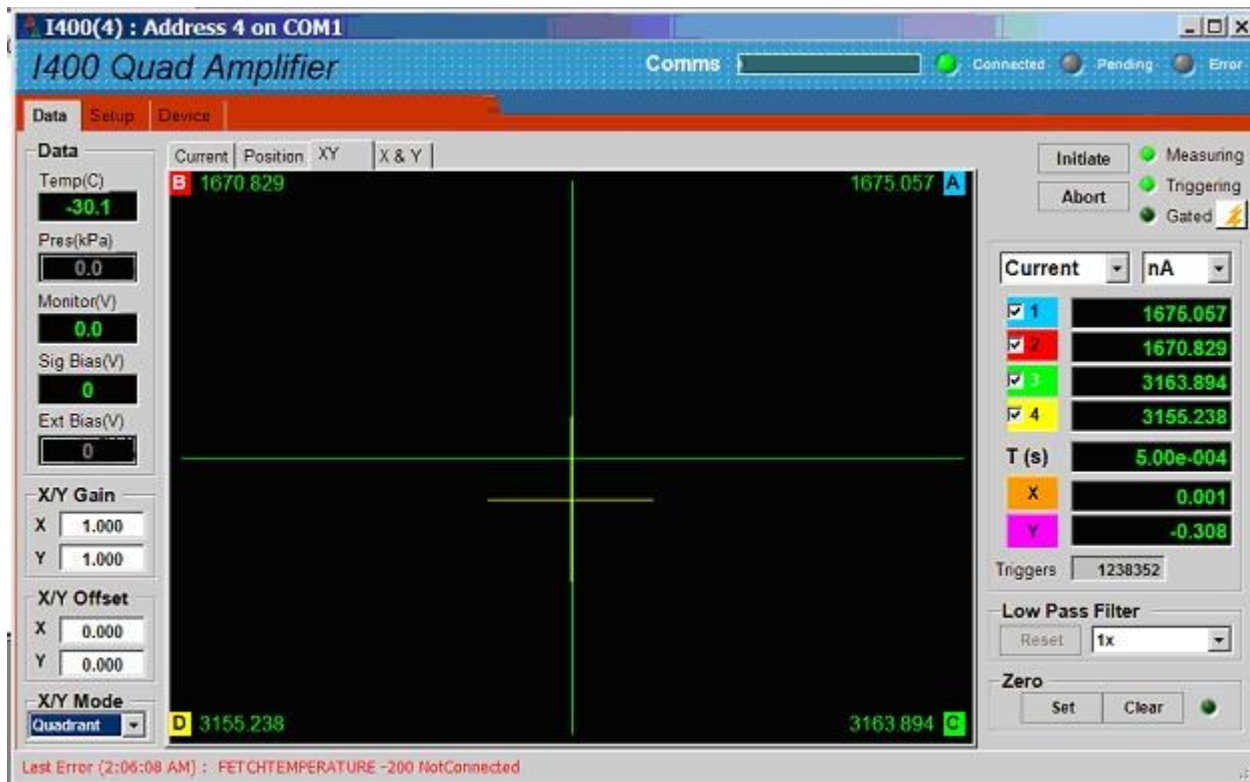


Figure 38. XY position data tab - quadrant calculation mode

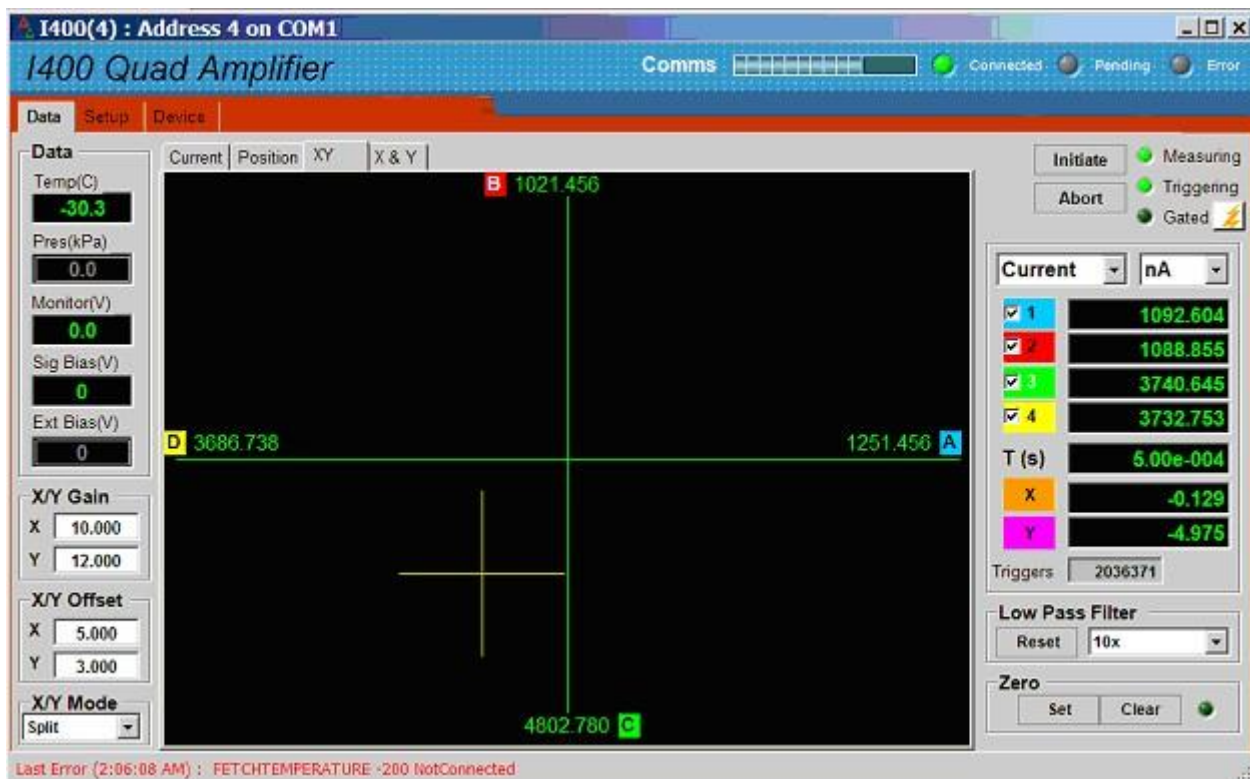


Figure 39. XY position data tab - split mode calculation

## 14.4 X & Y data screen

The X & Y screen presents the positions as two independent markers that move along the span of the position range. This display would be most appropriate if you have two independent sensor pairs, each pair encoding an individual axis. There is no requirement that the sensing axes be orthogonal, or coupled.



Figure 40. Independent X and Y position data tab, compensation factors, X/Y gains and offsets applied.

## 15 Setting the High Voltage

The I400 is normally supplied with a signal bias high voltage module that permits the input circuitry within the I400, plus any external components connected to the signal inputs or the guard screens to be biased up to 400 V away from chassis ground. The HV module is nominally rated to 500 V, 1 watt, but is limited to 400 V in the I400 due to the rating of the triaxial connectors.

As an option on the I400, you can also add a auxiliary external HV module which delivers ground-referenced HV to the SHV connector. The maximum available voltage rating is 1000 V. This can be used for any purpose, for example to put potential on a focus lens or screen grid.

The range and polarity of the high voltage supplies is fixed and must be specified at time of purchase. Units may be returned to the factory to alter the high voltage modules if necessary. If your I400 has both signal bias and external HV supplies, these are fully independent. The set values can be adjusted at any time, independent of what measurements are in progress.

Any valid setpoint above zero volts enables the relevant supply. The HV on LED illuminates when either or both supplies are enabled. There is a soft start delay before the HV comes on. The signal bias circuit includes a series relay that opens when the HV module is enabled, to prevent turn-on voltage surges. Note that this relay is open if the I400 is unpowered, and thus there is no return path for any externally imposed voltages in this state.

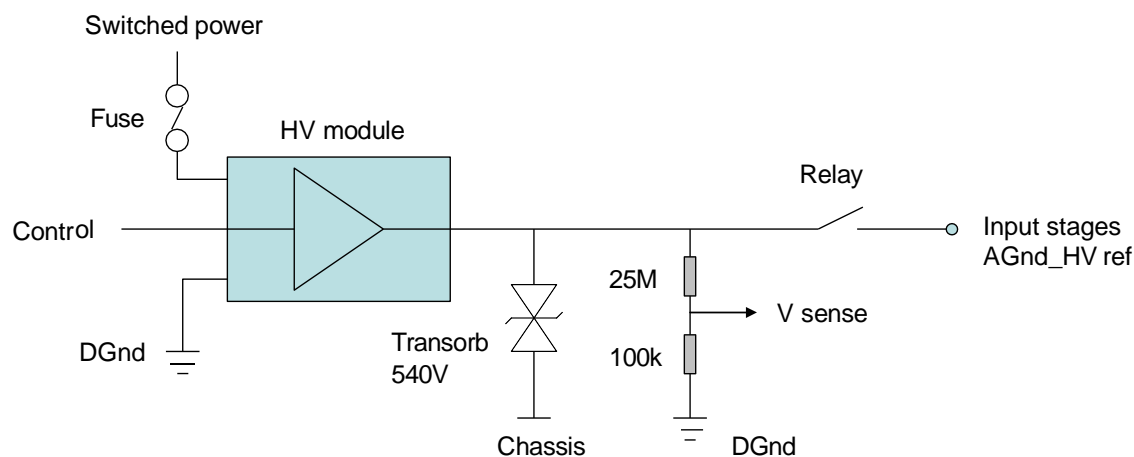


Figure 41. HV supply schematic for signal bias.

The I400 is not optimised to work at zero bias voltage. If you do need to use the I400 at zero bias, we recommend that you ask your supplier to fit a short in place of the HV module. The Pyramid Technical Consultants, Inc. I404 product is intended for use in applications where signal bias is not required.

The readback value of the high voltage is sampled from the HV output. It is not as accurate as the set value, but does provide a useful diagnostic if the high voltage is being shorted or overloaded.

Each HV supply is limited by a software high voltage limit, which is password protected and stored in EEPROM in the I400. The I400 will reject any attempts to set the voltage higher than the limit. This allows sensitive detector systems, or experiments which may be damaged by excessive voltage, to be protected.

Positive supplies source conventional current, and negative supplies sink conventional current. A bleed resistor fixed load is connected to each high voltage supply output which drains 40  $\mu$ A at maximum voltage. Transorb protection devices prevent the absolute value voltage at the output going more than 140 V (signal bias) or 80 V (external high voltage) above the maximum rating. However these devices are not designed to pass large currents indefinitely, so you should be careful not to overdrive the outputs with other power supplies or with charged particle beam strike currents.



**CAUTION**

Do not connect external power supplies to the I400 signal inputs or external high voltage output that will drive the built-in supplies away from the voltages they are trying to regulate, or you may cause damage to the I400.



**CAUTION**

Do not connect the I400 signal inputs, or the external high voltage output, to electrodes in a system that will be subject to direct strike by high energy, high current charged particle beams that will drive the built-in supplies above the voltages they are trying to regulate, or you may cause damage to the I400.

## 16 Using the Monitor Port

### 16.1 Temperature and Pressure Compensation

The I400 is designed to make additional measurements to increase its accuracy as a dosimeter for ionization chamber measurements. Many ionization chambers operate using the atmosphere as the ionizing medium. The number of charged particle pairs created in air depends upon the density of the gas, and thus on the temperature and pressure of the atmosphere, if the chamber is operated in equilibrium with the atmosphere.

If you select the -TP option with your I400, the unit is supplied with a B57703 thermistor probe, which you should attach securely to the ionization chamber, and an internal barometer that monitors the atmospheric pressure in the range 600 to 1100 mbar. The values from these sensors are converted to degrees centigrade and mbar by the I400 and can be logged together with the current readings by the host software. Note that if you are using the I400 to make position measurements, then correction for temperature and pressure is not necessary, because the position algorithms normalize the readings.

The monitor port also provides an uncommitted 0 to +5 VDC analog input that is read with 10 bit resolution, and which you may use for any monitoring purpose.

### 16.2 Dose Monitor Unit Output

Radiation therapy applications typically express dose as delivered to the patient in terms of Monitor Units. Dose measuring equipment is calibrated so that there is a known conversion between measured charge using a particular sensor and dose that would be delivered to a patient, as determined by measurements in reference phantom targets or other means. If you have an I400 with the -MU option, then you can upload this relationship and the I400 will calculate monitor units when you use one of the accumulation modes. Each time the number of monitor units increments, a TTL pulse is put out on pin four of the monitor port connector.

## 17 Connectors



Figure 42. Front panel showing signal inputs, auxiliary HV output, gate input.

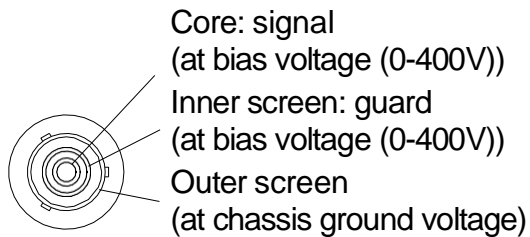


Figure 43. Rear panel power input, communications interfaces, temperature probe connector.

### 17.1 Front panel connectors

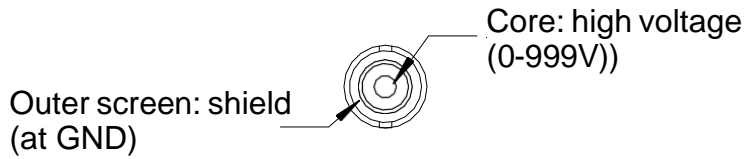
#### 17.1.1 Signal inputs

Triaxial female. To mate with three-lug standard triaxial connector such as Trompeter PL75-7.



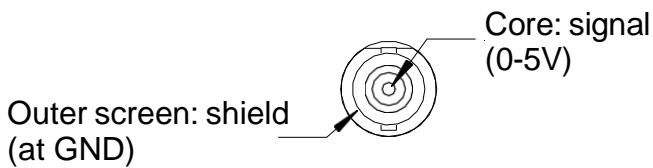
### 17.1.2 Auxiliary HV out (option)

SHV male. To mate with standard SHV connector such as Radiall R317 005.



### 17.1.3 Gate input

BNC socket (female), shield at circuit DGnd, isolated from case. To mate with standard signal BNC.



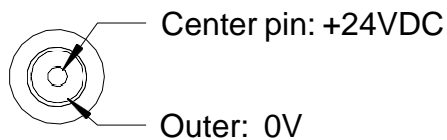
### 17.1.4 Ground lug

M3 threaded stud. To mate with M3 ring lug.

## 17.2 Rear panel connectors

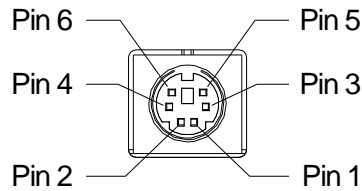
### 17.2.1 Power input

2.1 mm threaded jack. To mate with Switchcraft S761K or equivalent



### 17.2.2 RS-232 / RS-485 communications

Six pin mini-DIN socket (PS/2 mouse/keyboard type).



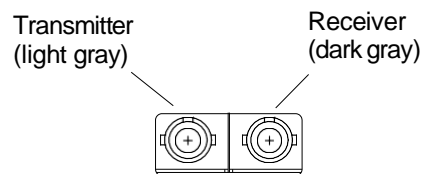
(External view on connector / solder side of mating plug)

1	RS-232 Tx / RS-485 Tx-	4	n/c
2	RS-232 Rx / RS-485 Rx+	5	RS-485 Tx+
3	Gnd	6	RS-485 Rx-

The socket incorporates a sensor switch that allows the I400 to detect that a plug has been connected. When a connection is made, the RS-232 / RS-485 transceiver is active, and the communication mode is set by the mode switch. When there is no connection, the fiber-optic communications are active.

### 17.2.3 Fiber-optic communications

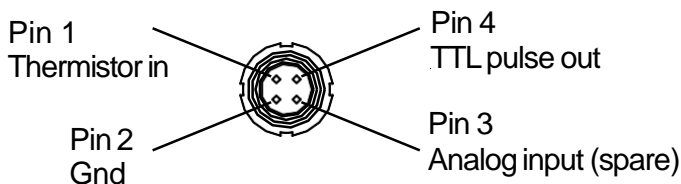
ST bayonet. To mate with ST male terminated fibre optic cable.



Take appropriate care when making ST connectors. If there is a key on the central body of the ST plug must align with the keyway on the top of the socket on the I400 before the plug can be pushed home. The outer shell of the plug can then be rotated while pushing against the spring pressure to engage the bayonet.

### 17.2.4 Monitor (remote thermistor connection, monitor pulse out)

Type 0B Lemo four pin female. To mate with Lemo FGG.0B.304 or equivalent.



(External view on connector / solder side of mating plug)

## 18 Controls and Indicators

### 18.1 Front panel controls

None.

### 18.2 Rear panel controls

#### 18.2.1 Mode switch

10 position rotary switch setting communications mode. The switch setting becomes active when a connection is made to the serial connector. Binary protocols are used for highest data rates by the PSI Diagnostic host system. The fiber optic link can run up to 10Mbps, the RS-485 and the RS-232 up to 115.2 kbps. The ASCII protocol is provided for ease of connection to existing systems and simple terminal programs.

<i>Setting</i>	<i>Function</i>
0	8 bit binary, 115.2 kbps, RS-232 levels
1	8 bit binary, 57.6 kbps, RS-232 levels
2	8 bit binary, 19.2 kbps, RS-232 levels
3	8 bit ASCII, 115.2 kbps, RS-232 levels
4	8 bit ASCII, 57.6 kbps, RS-232 levels
5	8 bit ASCII, 19.2 kbps, RS-232 levels
6	8 bit binary, 115.2 kbps, RS-485 levels
7	8 bit binary, 57.6 kbps, RS-485 levels
8	8 bit ASCII, 115.2 kbps, RS-485 levels
9	8 bit ASCII, 57.6 kbps, RS-485 levels

### 18.2.2 Address switch

16 position rotary switch setting device address. Choice of address is arbitrary, but each device in a fiber-optic loop system must have a unique address.

<i>Setting</i>	<i>Function</i>
0	(Reserved to loop controller)
1-15	Available address settings.

## 18.3 Front panel indicators

### 18.3.1 HV on

Red LED. Either or both of the HV supplies (signal bias or auxiliary external) are enabled.

## 18.4 Rear panel indicators

### 18.4.1 +24V

Green LED. +24VDC power is present, internal 5V DC-DC converter is running.

### 18.4.2 Serial

Green LED. Serial communication port is active.

### 18.4.3 Optical

Green LED. Fiber-optic communication is active.

### 18.4.4 Xmit


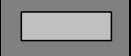




Green LED. Data being transmitted from the unit.

### 18.4.5 Rcv

Green LED. Data being received by the unit.








### 18.4.6 Status

Red/Green LED. This LED indicates a variety of internal states, as follows:

	Alternating red/orange/green/off	Unit powering up
	Off	Unit idle (not measuring)
	Orange	Waiting for trigger; or resetting integrators
	Green	Integrating
	Red	Error
	Alternating green/orange	Downloading program from host

### 18.4.7 Link

Red/Green LED. This LED indicates a variety of communication states, as follows:

	Alternating red/orange/green/off	Unit powering up
	Off	No connection since last power-up.
	Alternating green/off	Unconnected
	Alternating orange/off	Unconnected; unit has gone to the safe state.
	Green	Connected
	Red	Fatal communications error
	Fast alternating green/orange	Boot state (waiting start command or code download)

### 18.5 Internal switches and jumpers

There are no user-serviceable parts inside the I400. We do not recommend that you open the case because of the risk of damaging the components or contaminating the highly-sensitive current measurement circuits. There are internal switches and jumpers that are configured at the time of manufacture to reflect the configuration of the particular unit. Please contact your supplier or Pyramid Technical Consultants, Inc. before attempting any work inside the unit.

The settings of internal switches and jumpers is given here for reference only. The locations are shown in figure 44, together with the programming connectors for the PIC microcontroller and FPGA. The programming connectors are only used during manufacture. Firmware upgrades in the field are performed by upload from the host computer over the normal communication interfaces.

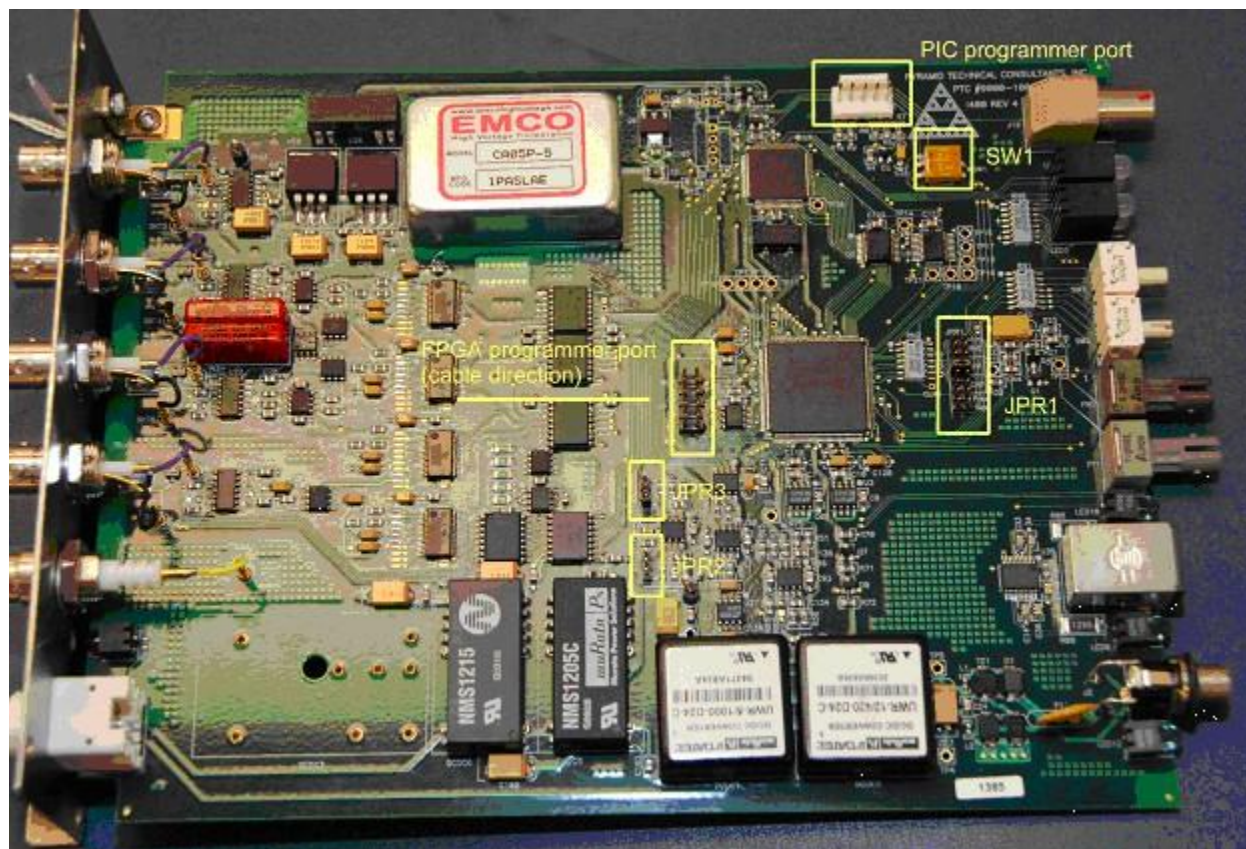


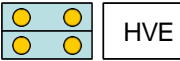

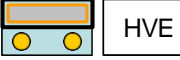




























Figure 44. Internal switch and jumper locations.

### 18.5.1 HV option selection

The installed external (auxiliary) HV option is defined by the setting of SW1/1, the HVE section of JPR1 and the setting of JPR2. The signal bias (internal) HV option is defined by the setting of SW1/2, the HVI section of JPR1 and setting of JPR3. The settings are summarized in the following tables. SW1 sets the polarity. JPR1 sets the range and HV module type. JPR2 and JPR3 also set the polarity, for the voltage monitor readback.

The HV modules are socket mounted, and can be exchanged in the field by suitably-trained technicians.

### External HV options

Installed option	SW1/1	JPR1	JPR2
No external HV	(don't care)	 HVE	(don't care)
-1000 V (CA10N module)		 HVE	POS  INT HV  NEG 
+1000 V (CA10P module)		 HVE	POS  INT HV  NEG 
-500 V (CA05N module)		 HVE	POS  INT HV  NEG 
+500 V (CA05P module)		 HVE	POS  INT HV  NEG 
-200 V (CA02N module)		 HVE	POS  INT HV  NEG 
+200 V (CA02P module)		 HVE	POS  INT HV  NEG 

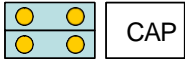
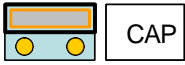


### 18.5.1.1 Signal bias HV options

Installed option	SW1/2	JPR1	JPR3
No signal bias HV §	(don't care)		(don't care)
-400 V (CA10N module)			NEG INT HV POS
+400 V (CA10P module)			NEG INT HV POS
-400 V (CA05N module)			NEG INT HV POS
+400 V (CA05P module)			NEG INT HV POS
-200 V (CA02N module)			NEG INT HV POS
+200 V (CA02P module)			NEG INT HV POS



§ If no signal bias HV module is fitted, then a shorting link should be installed between the PCB sockets corresponding to the HV output pins of the module. This ensures that the isolated signal input section is connected to chassis ground potential.

### 18.5.1.2 Feedback capacitor options

Changing the feedback capacitors requires specialized soldering techniques and can only be done in the factory. The following information is for reference only.

Installed option	JPR1
Lo = 10 pF Hi = 1000 pF	 CAP
Lo = 100 pF Hi = 1000 pF	 CAP
Lo = 10 pF Hi = 10000 pF	 CAP
Lo = 100 pF Hi = 10000 pF	 CAP

### 18.5.1.3 Pressure and temperature sense options

Installed option	JPR1
No pressure or temperature options installed	 Pres Res
Atmospheric pressure sensor installed	 Pres Res

Note: the resistance thermometer input is read and displayed by the PSI Diagnostic host software even if no probe is connected. The pressure sensor input is only read and displayed if the option is fitted and enabled with JPR1.

The final position on JPR1 (Res) is reserved for future use.

## 19 Communications Interfaces

The I400 is a member of the PSI range of devices. More details of PSI device interfacing options can be found in document Pyramid Technical Consultants document PSI\_OV\_090127.

The unit is provided with three hardware interfaces, RS-232, RS-485 and fiber-optic. The RS-232 interface is intended for simple direct connection to PCs, with no other equipment necessary. The RS-485 interface is used primarily as an RS-232 extender. Because it uses differential lines, you can transmit data reliably over hundreds of meters using the RS-485 interface, rather than a few metres with RS-232. RS-485 is not generally provided on PC motherboards, but RS-232 to RS-485 adaptors are widely available and cost-effective.

The fiber-optic interface provides greater speed, excellent noise immunity, and allows multiple devices to be connected in a looped topology. It requires a fiber-optic adaptor or loop controller device to connect to the host computer. The fiber-optic interface is well-suited to large systems.

Only one interface is in use at any time. Selection of the active interface is according to the cables that are connected and the mode switch setting.

### 19.1 RS-485 connection example

Figure 45 shows a typical configuration where RS-485 is used to extend a 115 kbps ASCII RS-232 connection over a long distance. An RS-232 to RS-485 converter is used at the host PC end. The built-in RS-485 of the I400 allows a direct connection at its end.

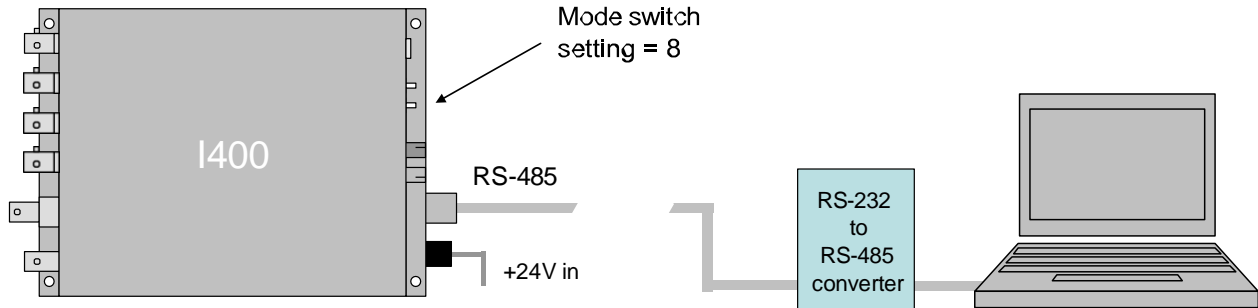


Figure 45. Using RS-485 as an RS-232 extender

A commonly-used converter for the beam position monitor application is the MOXA TC100. The Moxa TCC-80 is a low-cost alternative for less critical applications. The converter should be configured for four wire (full duplex) RS-485 operation. The I400 provides parallel termination for transmit and receive. It is therefore optional whether you also terminate at the TC100 end, but there is no harm if you do. The recommended Dip switch setting for the TC100 is:

Sw1	Sw2	Sw3
OFF	ON	ON

The recommended Dip switch setting for the TCC-80 is:

Sw1	Sw2	Sw3
ON	OFF	ON

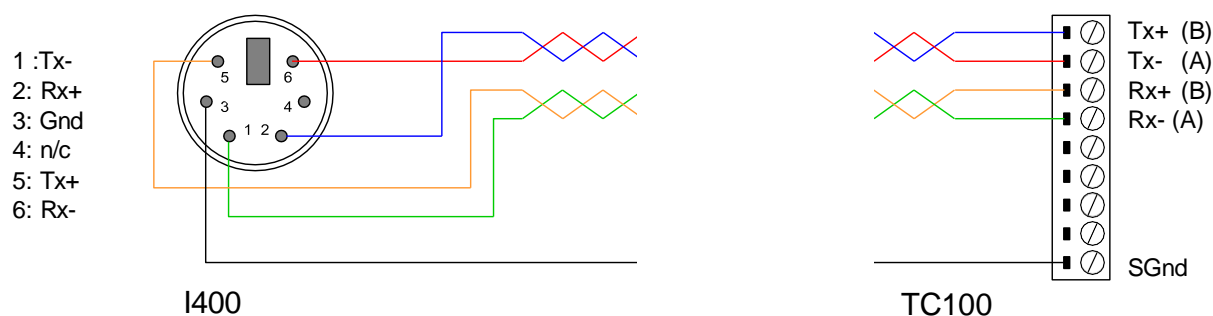


Figure 46. RS-485 cable I400 to TC100.

In order to enable the RS-485 interface on the I400, you must have a physical connection to the serial port, and you must select one of the relevant modes (modes 6 through 9). If you have trouble getting the RS-485 connection to work, check carefully to ensure that you have all the transmit and receive lines connected as shown.

## 19.2 Protocols

The I400 supports three types of communication protocol, selected according to the setting of the mode switch and whether the serial port is in use:

- An eight bit ASCII protocol, messages compliant with SCPI. The low seven bits are used to encode the ASCII character. The eighth bit is only set for synchronization when the <ACK>, <BELL>, <CR>, <LF>, and <ESC> characters are transmitted.
- An eight bit binary protocol. The first and last bytes of the entire command or reply have the eighth bit set and contain the address. All other bytes in the messages are broken into two bytes, encoded into the low nibble (4 bits), thus never having the top bit set.
- A nine bit binary protocol. Synchronization is done with the ninth bit. The first and last byte of each message have the ninth bit set and contain the address, and all other bytes are unmodified binary (with the ninth bit clear).

ASCII messaging is provided for users who wish to use existing host software systems that provide convenient support for ASCII communications. All the capabilities of the I400 are available through a familiar virtual instrument model and message structure. A simple terminal program such as Windows Hyperterminal is sufficient to establish communication with the device. It is possible to communicate with multiple devices at different addresses on the same channel by selecting a particular address to be the listener device at any time.

The binary messaging is more efficient in its use of communications bandwidth. It is fully deterministic with embedded addressing in the messages and immediate responses, including error reports, from the devices. Pyramid provides software drivers and diagnostic host programs for users who wish to use binary communication protocols. Eight bit binary is primarily intended for direct host to device communication, for example via RS-232 or RS-485 links. Nine bit binary is reserved for the 10 Mbit/s fiber-optic channel, and is highly recommended for larger systems with multiple addressable devices in a loop.

### 19.3 ASCII Protocol - SCPI

Standard Commands for Programmable Instruments (SCPI) is an extension of the IEEE 488.2 standard. This was originally developed by Hewlett-Packard for the HP-IB (later GP-IB) interface before being adopted by the IEEE, and is widely used by manufacturers of measurement equipment. The I400 implements the 1999.0 revision of SCPI (© 1999 SCPI Consortium).

#### 19.3.1 Messages

The first bit of every eight bit group in a message is the start bit, followed by seven bits encoding a character from the ASCII character set.

A full command from the host to the I400 comprises as many ASCII characters as needed to form the message, terminated by the LF (0x0A) character. The I400 will not start to process a command until the 0x0A character is received. The list of valid commands is listed in the next section. If the communications is being handled in a terminal session, the terminal program should send CR (0x0d) before the LF to get a legible display. The CR is ignored by the command interpreter in the I400.

The I400 generates a reply to every message from the host when it is the listener. The first byte of its reply will always be a single non-printing character. The first character is ACK (0x06) when the command has been successfully executed with no errors. Responses to host commands with a '?' will then have the required data, terminated with the CR,LF sequence. If the host is not requesting data (no "?"), no other bytes will be transmitted after the ACK. If the I400 generates an error when executing the host command, it will transmit a single BELL (0x07) as its response. A computer running a terminal program will therefore "beep" when the I400 cannot execute a command, for example due to incorrect syntax. A more interactive "terminal mode" can be selected which modifies this behavior to make the I400 more user-friendly when it is being driven from a terminal program.

Device addressing is performed using the special command '#'. Addressing is only necessary for devices linked by a fiber-optic loop, but a device is made the "listener" when the host sends #ADDRESS. For example, #4 will make the device with address 4 the listener. You must ensure that all devices on the same communications channel have unique addresses. All subsequent commands sent (without address) will be listened and responded to by device 4 only. The host message #? asks who the listener is. The # command can be sent as a compound message, such as #3;\*IDN?.

### 19.3.2 Status registers

The I400 implements the IEEE 488.2 status register method. Each of the registers is masked by a corresponding enable register. It is recommended that you set all the enable registers to all 1's. The host software should use the \*STB? command to watch for changes to the status of the I400, and then \*ESR?, :STATus:OPERation:CONDition? or :STATus:QUESTionable:CONDition? as appropriate to recover the details from the relevant register.

# Status Structure

I400

:STATus

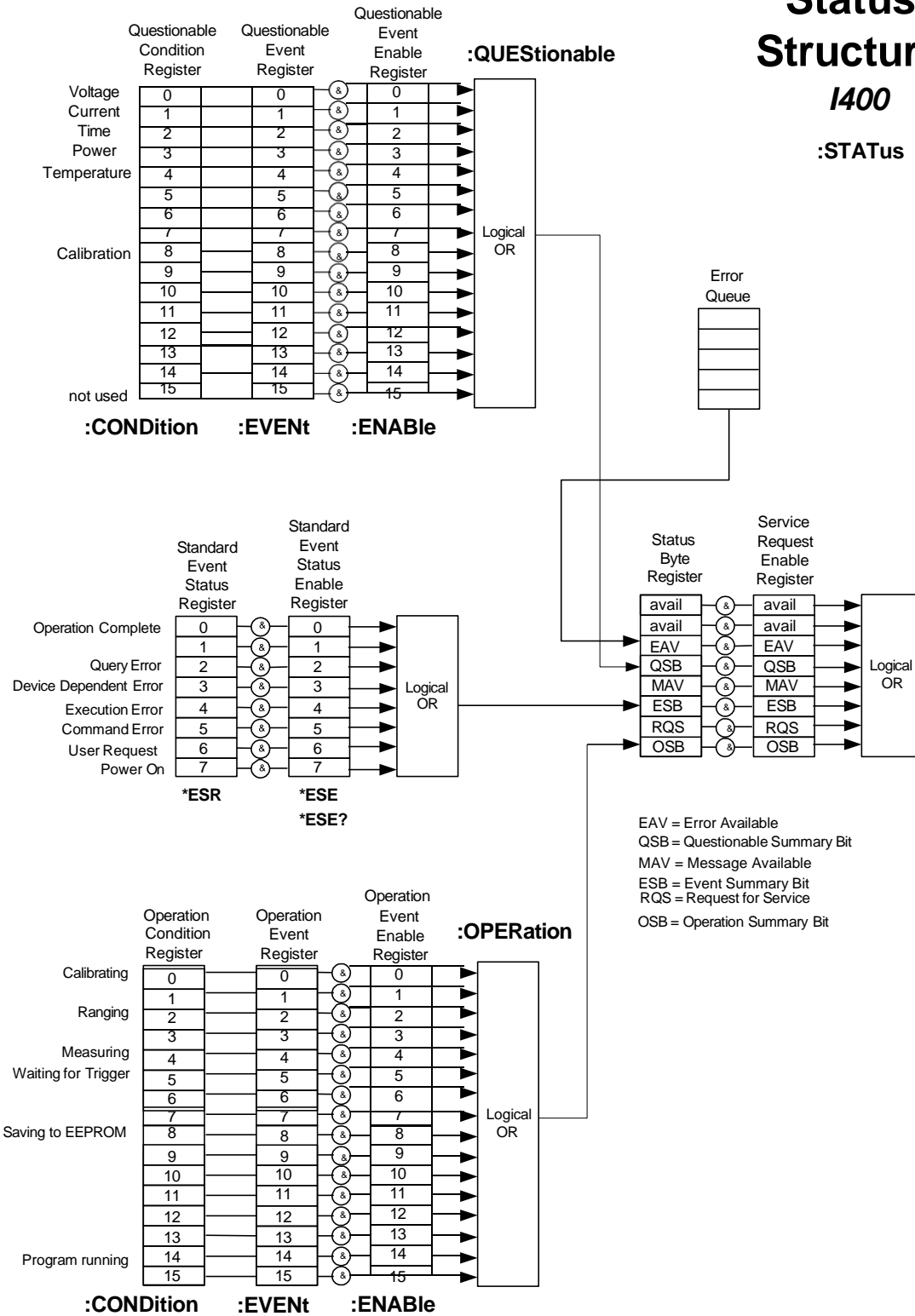


Figure 47. SCPI Status registers structure

### 19.3.3 Host Commands

The I400 responds to the mandatory commands prescribed by SCPI and IEEE 488.2, plus specific commands as required by the operation of the device. The commands are grouped with a hierarchical structure, with the levels separated by the colon character. For example:

```
CONFigure:GATe:INTernal:PERiod 1e-2 5
```

This command configures the internal integration gate to have a length of 10 milliseconds with five sub-samples of the integrator output, after 2, 4, 6, 8, and 10 milliseconds.

SCPI provides for a long and short form for each command. The short forms are indicated by the capitalized part of the command. { } denotes a required argument, [ ] denotes an optional argument.

Some commonly-used commands are available from the root of the hierarchy, as a shortcut, as well as in their logical position in the structure. For example:

```
CAPacitor 1  
and
```

```
CONFigure:CAPacitor 1
```

are equivalent ways to switch in the large feedback capacitors on the four channels.

A number of commands are password protected to reduce the chance of changing them accidentally. The commands only effective after the device has been rebooted if they have been enabled by first sending

```
SYSTem::PASSword 12345
```

Sending any other number as the argument of this command disables the protected commands again.

#### 19.3.3.1 ADDRESSING DEVICES

SCPI does not provide specific commands for addressing multiple devices, because this was handled by hardware in the original IEEE 488.1 specification. The I400 provides a simple mechanism for making any device on the loop the listener. The device will remain the listener until another device is selected.

```
# {address} // Make device address (1 to 14) the listener
```

```
#? // Query which device is listener.
```

**19.3.3.2 IEEE 488.2 MANDATORY COMMANDS**

\*CLS // Clear Status Command. Clear all event registers and the error queue.

\*ESE // Standard Event Status Enable Command. Program the Standard Event Enable  
// register (8 bits).

\*ESE?  
Enable // Standard Event Status Enable Query. Query the state of the Event Status  
  
// register. I400 returns decimal value.

\*ESR? // Standard Event Status Register Query. Query the state of the Event Status  
// register. I400 returns decimal value.

\*IDN? // Identification Query. Query the device identification. I400 returns  
// manufacturer, model number, serial number, firmware version.

\*OPC // Operation Complete Command. Set the Operation Complete bit in the Standard  
// Event Status Register after all pending commands have been executed.  
// Not currently supported.

\*OPC? // Operation Complete Query.

\*RST // Reset Command. Return the device to the \*RST default conditions.

\*SRE // Service Request Enable Command. Program the Service Request Enable  
// Register <8 bit value>  
// Not currently supported.

\*SRE? //Service Request Enable Query. Query the Service Request Enable Register.  
// I400 returns decimal value.  
// Not currently supported.

\*STB? // Read Status Byte Query. Query the Status Byte Register.  
// I400 returns decimal value.

\*TST? // Self-Test Query. Perform a checksum test on ROM and return the result.  
//I400 returns <1>.

\*WAI // Wait-to-Continue Command. Wait until all previous commands are executed.  
 // Not currently supported.

### 19.3.3.3 IEEE 488.2 OPTIONAL COMMANDS

\*RCL // Recall instrument state from EEPROM.  
 \*SAV // Save present instrument state to EEPROM.

The settings covered by \*RCL and \*SAV are:

SOURce  
 CONFig:ACCumulation  
 CAPacitor  
 PERiod  
 CONFig:GATe:EXTernal:POLarity  
 TRIGGER:SOURce  
 TRIGger:POInts  
 DATA:FEEd  
 DATA:POINts  
 DATA:WRap

Note that the high voltage settings (CONFigure:HIVoltage) are NOT included.

### 19.3.3.4 I400 COMMANDS

ABORt //Abort measurement.  
 CALIBration //  
   :GAIIn [{CLEar}] // Calibrate gain for each channel or reset stored gains to nominal  
   :GAIIn? // Query gains for each channel  
   :SOURce {0|1} // Turn on internal calibration source, 0 = off, 1 = on  
   :SOURce? // Query internal calibration source state

```

:RCL // Recall the gains and zero offset currents from EEPROM
:SAV // Store the gains and zero offset currents to EEPROM
CAPacitor {0|1} // Set feedback capacitor for all channels; 0 = small value, 1 = large value
CAPacitor? // Query feedback capacitor setting
CONFigure
:ACCUMulation {0|1|2|3} // Accumulate charge across gate resets, 0 = do not accumulate, 1 = accumulate by
// interpolation, 2 = accumulate by no-lost charge method, 3 = accumulate without
// correction for deadtime during resets
:ACCUMulation? // Query accumulation setting
:CAPacitor {0|1} // Set feedback capacitor (all inputs), 0 = small value, 1 = large value
:CAPacitor? // Query feedback capacitor setting and value in F
:GATe // Configure integration gate
:EXTernal // Configure external integration gating
:POLarity {0|1} // Set external gate polarity (external trigger only), 0 = high active, 1 = low active
:POLarity? // Query external gate setting
:INTernal // Configure internal integration gating
:PERiod {<total>|AUTOScale} [{subsamp}] // Set integration period in seconds or enable autoscaling, <subsamp> subsamples
// per period (default 1)
:PERiod? // Query integration period and subsamples
:RANGe {<amps>} [{subsamp}] // Set a full scale current range by adjusting integration period for the selected
// capacitor, <subsamp> subsamples per period (default 1)
:RANGe? // Query the full scale current range setting
:RESET {<reset>} {<settle>} {<setup>} // Set the reset, settle and setup times (password protected)
:RESET? // Query the reset, settle and setup times
:HIVoltage // High voltage configuration
:EXTernal // External (auxiliary) high voltage
:MAXvalue {<volts>} // Set maximum allowable external high voltage setting (password protected)
:MAXvalue? // Query maximum allowable external high voltage setting~
:VOLTs {<volts>} // Set the external high voltage
:VOLTs? // Query the external high voltage

```

```

:SIGnal // Signal input bias high voltage
:MAXvalue {<volts>} // Set maximum allowable signal high voltage setting (password protected)
:MAXvalue? // Query maximum allowable signal high voltage setting~
:VOLTs {<volts>} // Set the signal high voltage
:VOLTs? // Query the signal high voltage
CONFigure? // Query the last CONFIGURE or MEASURE command.
DATA // Charge data
:CLEar // Clear all data from I400
:FEEd {<source>} // Feed data according to source mask, "1111" = data from channels 1, 2, 3, 4
:FEEd? // Query data feed mask
:POINts {<points>} // Set the data buffer size (limited to available data memory)
:POINts? // Query the data buffer size
:VALue? <source> {<index>} // Read data from buffer at index. Returns <integration period, charge1, charge2,
// charge3, charge4, over range byte>
:STREAM? // Stream data buffer contents to host (get oldest buffer entry and clear from
// buffer). Response is <integration period, [charge1], [charge2], [charge3],
// [charge4], over range byte, trigger count> where charge values are returned
// according to DATA:FEEd setting

FETCh // Fetch data
:CHArge? // Fetch charge data <integration period, charge1, charge2, charge3, charge4,
// over range byte>
:CURRent? // Fetch current data <integration period, charge1, charge2, charge3, charge4,
// over range byte>
:DIGital? // Read digitals (bit0-2 = reserved, bit3 = HV enabled, bit4 = external gate
present)
:MONitor? // Fetch monitor voltage input value
:PRESSure? // Fetch pressure input value in pascals
:TEMPerature? // Fetch temperature input value in C
FETCh? // Do same FETCh as last (defaults to fetch charge if no defined last FETCh)
INITiate // Initiate taking readings as soon as triggered

```

```

PERiod {<period>} [{sub}]           // Set integration period in seconds, minimum 1e-4 s, maximum 6.5e+1 s,
                                     // <sub> subsamples per period (default 1) (shortcut)
PERiod?                               // Query integration period (shortcut)
READ                                   // Initiate single acquisition and fetch data when complete
  :CHArge?                             // Read charge data <integration period, charge1, charge2, charge3, charge4,
                                     // over range flags>
  :CURRent?                             // Read current data <integration period, current1, current2, current3, current4,
                                     // over range flags>
  :DIGital?                             // Read digitals (bit0-2 = reserved, bit3 = HV enabled, bit4 = external gate
present)
  :MONitor?                             // Read monitor voltage input ADC
  :PRESsure?                             // Read pressure input ADC
  :TEMPerature?                         // Read temperature input ADC
READ?                                  // Do same READ as last (defaults to charge if no defined last READ)
STATus                                 // Status registers
  :OPERation                             // Operation register
    :CONDition?                         //
    :ENABle                              //
    :ENABle?                             //
    :EVENt?                              //
  :QUESTionable                         // Questionable register
    :CONDition?                         //
    :ENABle                              //
    :ENABle?                             //
    :EVENt?                              //
  :PRESet                               // (Not used)
SYSTem                                 // System commands
  :COMMunication                         // Communication settings
    :CHECKsum {0|1}                     // Append checksum to all replies (password protected); 0 = off, 1 = on
    :TERMinal {0|1}                     // Enter terminal mode (password protected), 0 = off, 1 = on
                                     // In terminal mode, ACK and NACK are not sent, and "OK" or error response is
                                     // sent for all valid commands that do not otherwise generate a response.

```

```

:TERMinal? // Query terminal mode setting
:TIMEout {<timeout>} // Set timeout in seconds (password protected); 0 = timeout disabled. I400 will go
// to unconnected state if no valid message is received in the timeout period.
:TIMEout? // Query timeout setting
:ERRor? // Return next error in the error event queue
:FREQuency {<frequency>} // Set dominant noise frequency (generally line frequency, 50 or 60 Hz)
:PASSword {<password>} // Enter the device password to allow access to protected functions
:PASSword? // Query the password
:SAFEstate // Enable going to the safe state when unconnected (0 = do not go to safe state
// when unconnected, 1 = go to safe state when unconnected)
:SAFEstate? // Query the safe state
:SERIALnumber {<string>} // Set the device serial number (max ten alphanumeric) (password protected)
:SERIALnumber? // Query the serial number
:VERSion? // Return the SCPI standard version

TRIGger // Establish trigger conditions
:COUNT? // Query the trigger count since the last INITiate
:DELAY {<delay>} // Set trigger delay for message trigger mode
:DELAY? // Query trigger delay
:POINts {<number>|INFinite} // Set the number of trigger points after an INITiate before acquisition stops
:POINts? // Query the number of trigger points
:SOURce {INTernal|EXTERNAL_START|EXTERNAL_START_STOP|MESSage} // Set the acquisition trigger source
:SOURce? // Query the trigger source

```

## 19.4 ASCII Protocol – Terminal Mode

SCPI is not ideal for a user trying to control the I400 from a terminal program. A more interactive terminal mode can be turned on by sending the command

```
SYSTem:COMMunication:TERMinal 1
```

After this command is executed, the I400 will provide a response to every command. Valid query commands will get their normal reply. Other commands will generate an <OK> response if they were interpreted without errors, or an error message if they could not be interpreted. The non-printing ACK and BEL characters are not sent.

Terminal mode is the startup default for the I400.

## 19.5 Binary protocol

The binary protocol is optimized for deterministic loop operation, and is primarily intended for use with Pyramid Technical Consultants host software and software device drivers. Users who wish to develop their own host software using binary communications are advised to use the supplied device drivers. For further details refer to the I400 Software Documentation. The device model for the binary communications is essentially the same as for ASCII, and particularly the terminal mode. All host messages get an immediate response from the I400. There are a range of summary level commands that are unavailable under SCPI. For example the complete contents of the data buffer can be returned with a single command.

## 20 Software updates

The I400 has three embedded firmware releases.

Firmware	Function
FPGA (.fhex file or .pof file)	General logic, loop message passthrough, timing control, ADC reading.
PIC Boot (.hex file)	Boot up, code upload
PIC Application (.hex file)	Main application; calibration, conversion to floating point values, range control, HV PSU control, I/O readback, host communications, SCPI instrument model.

The PIC microcontroller boot code should not require updating. It requires access to the circuit board and dedicated programming tools to load new code. If the boot code ever needs to be updated, your supplier will contact you and make arrangements either to return the unit for upgrade, or to have an engineer call. The same applies if you ever have a problem during a firmware upload such as loss of power or broken communication link, and your I400 becomes unusable as a result.

The PIC microcontroller and/or the FPGA code may be updated periodically to add new operating features. New code releases will be provided by your supplier, or can be downloaded from the Pyramid Technical Consultants, Inc. website. The hex and the fhex file can be loaded using the PSI Diagnostic host without any need to access the unit. The upload can be performed directly from the PC host via RS-232, RS-485 or fiber-optic, or routed via an A200, A300 or A500 controller. The FPGA .pof file is the same code as the fhex, but formatted for upload from an FPGA programming adaptor. For normal updates from a host computer, you only need to use the fhex file.

### 20.1 Updating Application Firmware

On the Device tab, click the “Select .hex file” button and navigate to the relevant file. The code will then load. The process takes about 10 to 30 seconds depending on the type of communications you are using, and the I400 will start running the new code immediately.

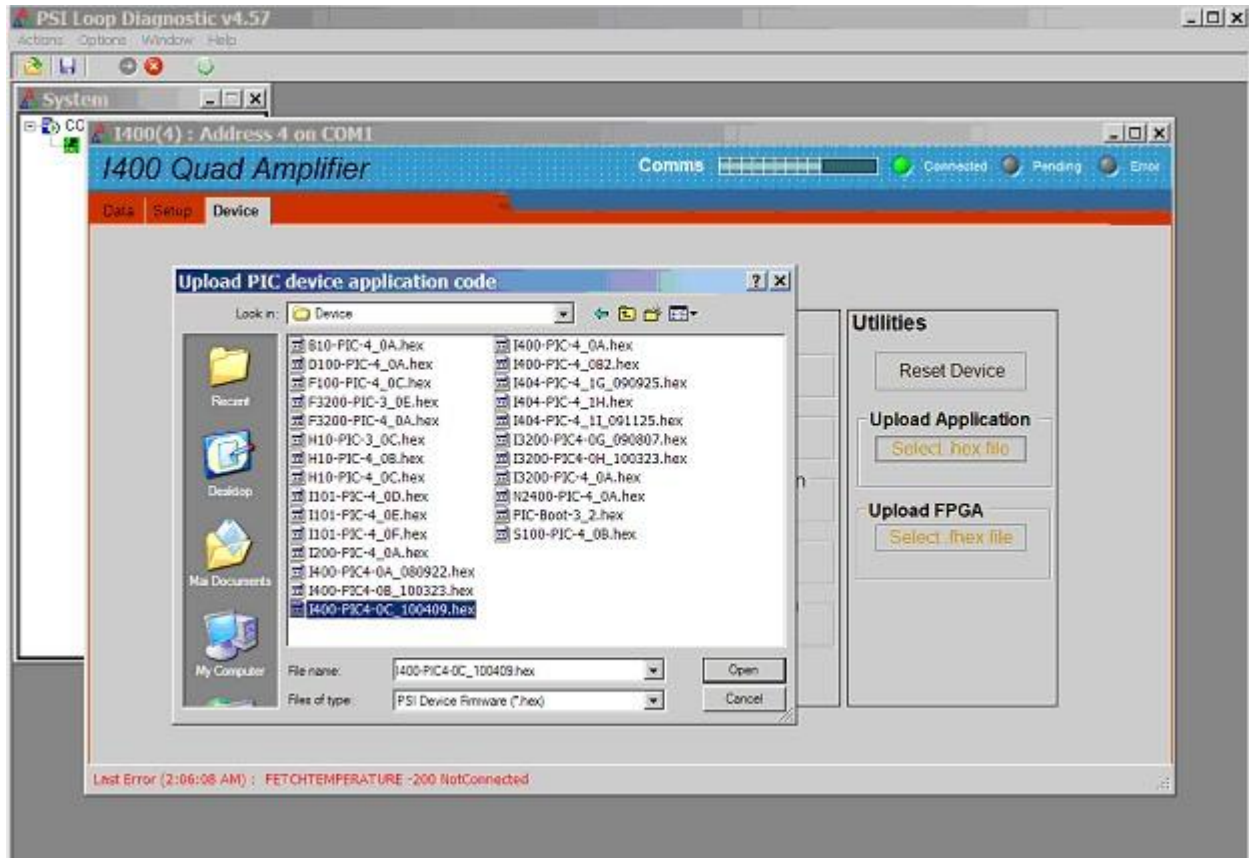


Figure 48. Selecting the hex file to load.

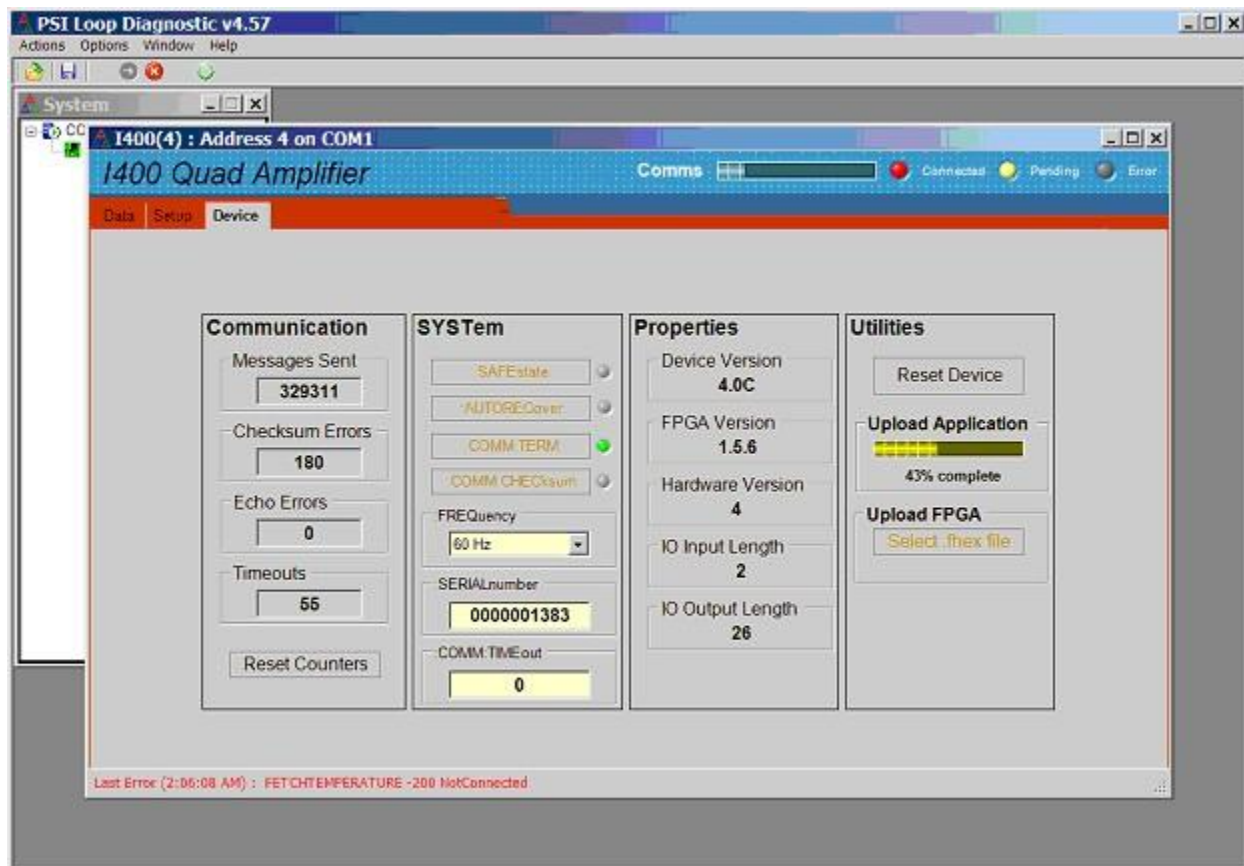


Figure 49. Microcontroller application upload in progress.

## 20.2 Updating FPGA Firmware

On the Device tab, click the “Select .fhex file” button and navigate to the relevant file. The code will then load. The process takes one to two minutes depending on the type of communications you are using. After the update you will be prompted to power cycle the I400 to start the new code.



Figure 50. FPGA upload in progress.

## 21 Techniques for Making Low Current Measurements

Measurements of currents of around 10 nA and below require some care to prevent unwanted interference that can distort the results. In particular, the conductor that carries the current to the I400 input (the sensitive node) must be carefully isolated and guarded to ensure unwanted currents cannot flow into it.

When an unexpectedly high background offset current is seen, the first thing to do is to check again with the signal input(s) disconnected from the I400. This will isolate the problem to the external measurement circuit, or within the I400 itself.

### 21.1 Guarding and screening

If the sensitive node is separated from a voltage source (such as a power rail) by an insulating layer, then a small current will flow through the finite impedance of the insulator.

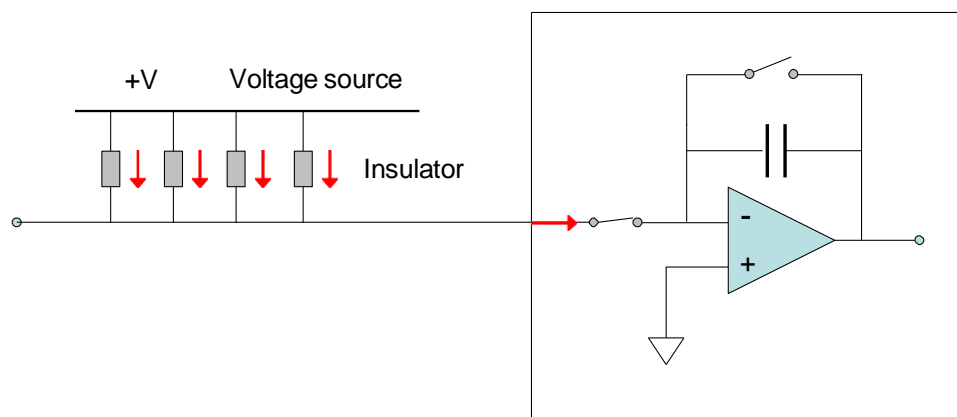


Figure 51. Offset current to unguarded input

For example, a 10 V conductor separated from the sensitive node by 1 Gohm of total resistance would drive in 10 pA of background current. The maximum bias voltage of the I400 could drive in 0.4 nA in similar circumstances. If the insulation is compromised by contamination, then the problem is magnified. The solution is to provide a guard shield around the sensitive node, at the same electrical potential. Leakage currents across insulators now flow to the guard, where they do not affect the reading

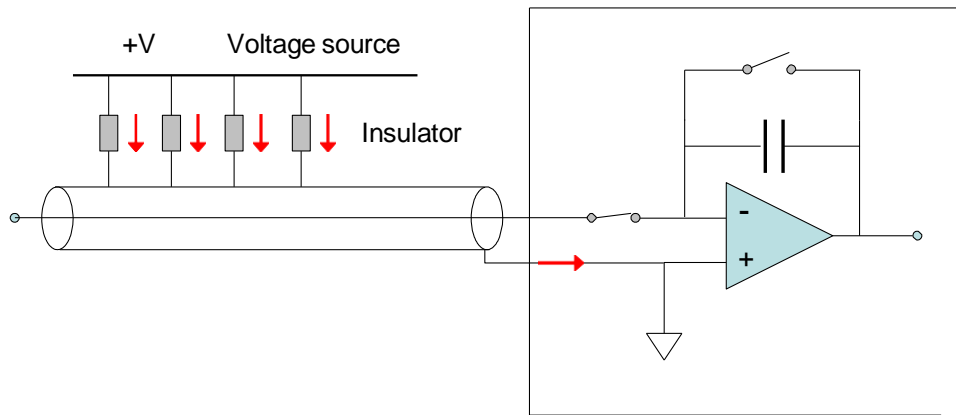


Figure 52. Guarded input

AC fields in the environment can induce AC currents in the sensitive node. Depending upon the frequencies and the integration time in use, these may appear as noise fluctuation in the signal. An outer cable screen is used to shield the sensitive node from external fields. In combination with the need to guard the sensitive node, the result is that the use of triaxial cable is necessary. The core and inner guard screen are at bias voltage, and the outer screen is at the chassis ground potential of the I400.

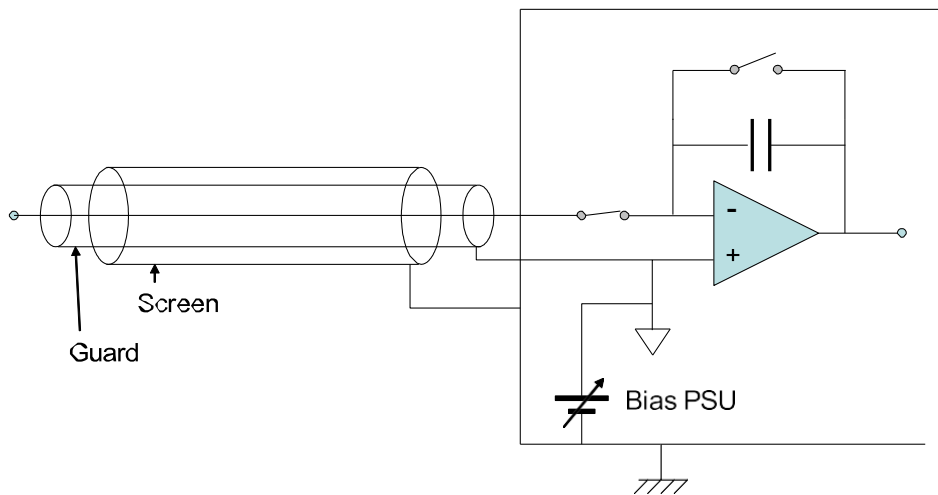


Figure 53. Guarded and screened input

## 21.2 Temperature

Offset factors are generally exacerbated by increased temperatures. Temperature fluctuation can appear as variation in the reading. When very small currents need to be measured, the experimental arrangement should be temperature stabilized as far as possible.

### 21.3 Triboelectric effects

When there is relative movement of insulators and conductors in signal cabling, free charge is released. This is particularly the case for the screen of coaxial cable. The resulting potential difference can drive small currents to the signal conductor across the high impedance of the insulator. Additionally, charge may leak in directly if there are any breaks in the insulator.

Special low-noise cable is available with graphite lubrication bonded to the insulator, to reduce charge generation, and to conduct any released charge away harmlessly. Other mitigations include keeping the signal cables short and motionless.

### 21.4 Battery Effects

Ionic contamination, such as salt from fingerprints, which connects to the sensitive node, can give battery effects, particularly in the presence of moisture, which can drive unwanted currents. Any insulating surfaces in contact with the sensitive node must be clean. Humidity levels should be such that there is no moisture condensation. Wherever possible the sensitive node should be insulated by vacuum or air.

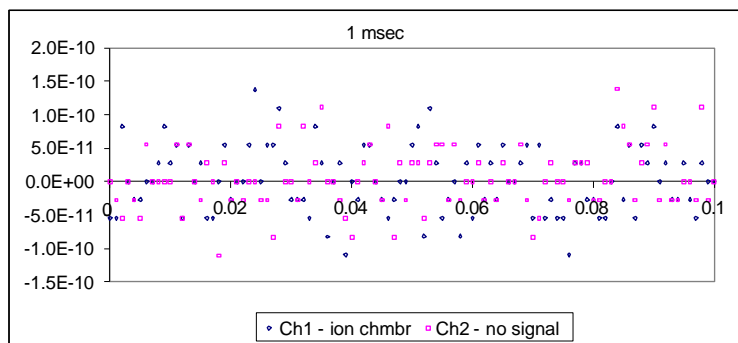
### 21.5 Piezoelectric Effects

Ceramic and plastic insulators can release charge when under mechanical stress, which may be collected on the sensitive node. The effect is generally small (less than 10 pA), and can be avoided by eliminating stresses in cables and connections.

### 21.6 Integration Period and Synchronization

The I400 provides considerable flexibility in setting the integration time interval, and synchronizing the integration to external events. The integration method is inherently good at averaging noise. Very low current currents generally require the smallest available feedback capacitor and the longest practicable integration time to build up a readily measurable voltage. For example, a 1 pA current integration on a 10 pF feedback capacitor requires 10 seconds to develop 1 V. Background offset noise is also integrated, of course, and cannot be distinguished from the signal. This sets the ultimate detection limit.

The plots in figure 54 illustrate how a 5 pA signal from a small ionization chamber becomes clearly distinguishable from a reference background signal, and the noise reduces, as the integration period is increased from 1 msec to 100 msec to 10,000 msec.



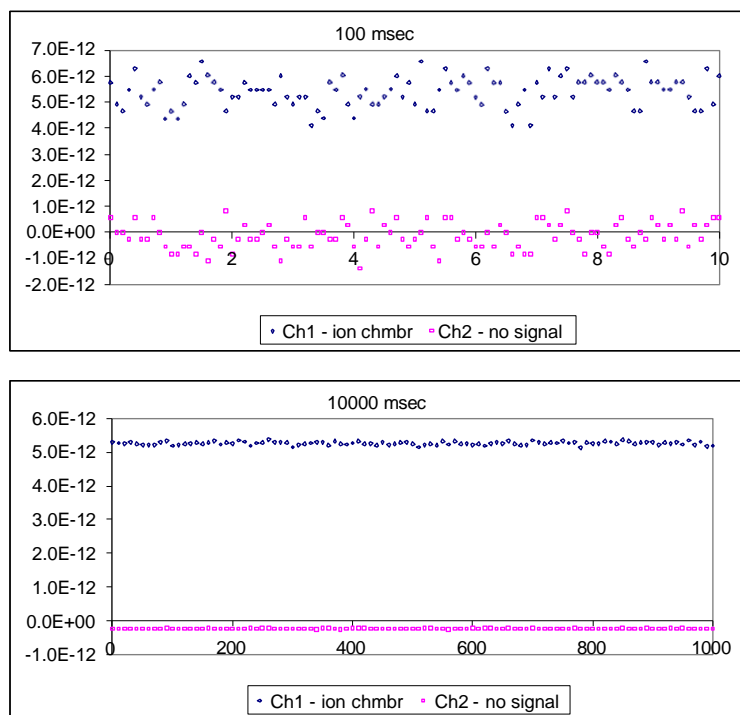


Figure 54. Separation of a 5 pA signal from background

Where there are known dominant noise frequencies in current measurements, for example line voltage interference, these can be suppressed by choosing an integration periods that is an integer multiple of the noise period. For example, 50 Hz or 60 Hz noise from the power line is present in most environments. This can be completely removed in the I400 by selecting the integration period as follows:

Noise frequency	Integration period choices to eliminate noise
50 Hz	20.00, 40.00, 60.00, 80.00, 100.00 .... K x 20.00 msec
60 Hz	16.67, 33.33, 50.00, 66.67, 83.33, 100.00, .... K x 16.67 msec

Very small charge package measurements should be optimized by synchronizing the integration carefully around the arrival of the charge. This minimizes the amount of background offset current that is included in the reading. Often the arrival of the charge is associated with an event in the system which can be used to drive the external gate input of the I400 to obtain the required synchronization.

### 21.7 Summary

Factor	Typical noise offset current	Mitigation	Typical noise after mitigation
Triboelectric effects in cable	$10^{-8}$ A	Reduce cable lengths.	$10^{-12}$ A

		Keep cable from moving. Use low-noise cable.	
Current across insulators from voltage sources	$10^{-7}$ to $10^{-10}$ A	Guard the sensitive node Use triaxial cable	$10^{-12}$ A
AC interference	$10^{-6}$ to $10^{-10}$ A (AC)	Used screened (triaxial) cable	$10^{-12}$ A
AC interference	$10^{-6}$ to $10^{-10}$ A (AC)	Use integration periods that are an integer multiple of the dominant noise frequency.	$10^{-12}$ A
Contaminated insulators	$10^{-8}$ A	Clean insulating surfaces with solvent  Use air insulation where possible  Keep humidity low	$10^{-13}$ A
Piezoelectric effects	$10^{-12}$ to $10^{-13}$ A	Avoid mechanical stresses and vibration, in the sensor and cable.	Negligible
Resistor Johnson noise	$< 10^{-14}$ A	None – fundamental limit set by signal source resistance	
Temperature fluctuation	$10^{-9}$ to $10^{-12}$ A fluctuation	Temperature stabilize the whole measurement apparatus	$10^{-10}$ to $10^{-14}$ A fluctuation
Elevated temperature	$10^{-13}$ to $10^{-11}$ A	Reduce temperature of the whole measurement apparatus	$10^{-13}$ A

## 22 Fault-finding

<i>Symptom</i>	<i>Possible Cause</i>	<i>Confirmation</i>	<i>Solution</i>
High background current	Resistive path to signal input due to missing or broken guard.	Disconnect input – background should reduce to specification levels	Ensure good guard integrity all the way to the signal source.
	High humidity	Problem varies with relative humidity.	Ensure there are no water-absorbent insulators. Reduce the humidity levels.
	Internal contamination.	Background current remains high with inputs disconnected.	Contact your I400 supplier for advice or to organize a return for cleaning.
High noise levels	Integration time too short for signal being measured	Noise level reduces with integration period	Use an appropriate integration time for the signal level.
	RF pickup	Noise varies with cable position, status of neighboring equipment.	Check integrity of outer screens of signal cables.
	Line voltage pickup	Noise level drops sharply if integration period is 16.7 msec (60 Hz) or 20 msec (50 Hz)	Keep I400 and signal cables clear of unscreened high current mains voltage. Use integration periods (N/line frequency).

No signal	Small signal lost in noise		Use longer integration time.
Signal does not vary as expected	Integrators are overrange.	Ovrange flags are set, signal recovers if integration period is reduced.	Reduce the integration period or use the larger feedback capacitor.
Measured currents or charges are inaccurate by up to 15%	Unit not calibrated.		Calibrate.
	Calibration was carried out while a signal current was present.	Internal calibration source does not measure as 500nA with all inputs disconnected.	Repeat calibration with no external signal present.
High background offset current	Various causes		Refer to section 21.
500 nA background on one channel.	Internal calibration source has been turned on.		Turn off calibration source.
I400 stops measuring	Trigger points limit reached.	Measurement starts again if I400 is reinitialized.	Adjust trigger points as required.
	Data buffer full.	Measurement starts again if I400 is reinitialized.	Adjust data points as required and/or turn on data buffer wrap.
	Communication link timeout		Investigate and fix communications issue. Use a longer timeout setting.
No or incorrect response to external trigger or gate	Incorrect gate polarity selected.		Use correct polarity.
	I400 not configured to respond		Use correct setup.

	to external gate.		
No high voltage	Shorted to ground in external circuit	Monitor HV reading zero or very low relative to setpoint. Monitor value recovers if I400 disconnected from the external circuit.	Eliminate shorts to ground.
Cannot set high voltage	Trying to set above the maximum allowed value soft limit.	Sets OK if a lower value is chosen.	If allowed, increase the maximum allowed value.
Unable to communicate with I400	Wrong mode switch or address setting	Check mode switch setting against table in section 18 and address against expected address in host software.	Use correct switch settings. Switches can be changed while the unit is operating.
Unable to connect on fiber loop	Connector still fitted to serial port		Remove connector from serial port.
Communications interruptions	Other processes on PC host interfering with comms ports.		Use a dedicated PC with simple configuration and minimum number of processes running.
Unable to connect on RS485	Host computer does not have RS-485 interface	Check hardware	Use RS-232 to RS-485 adaptor as needed.
	Incorrect duplex or mode settings on adaptor	Check settings (see section 18)	Correct settings.

Unable to connect on RS232	Another program is using the COM port.	Try to access the required port with Windows Hyperterminal.	Choose another port or close down the other program.
	Incorrect port settings.	Try to connect with the .htm file supplied with the unit.	Correct the settings.
	Incorrect cable.		Make up a suitable cable. See sections 10 and 18.

## 23 Maintenance

The I400 does not require routine maintenance. There is risk of contamination which may degrade performance if the case is opened. There are no user-serviceable parts inside.



**CAUTION.** High voltages are present inside the case. Do not open the case when power is applied.

The I400 is fitted with a 1.1 A automatically resetting positive temperature coefficient (PTC) fuse in the 24 VDC input. No user intervention is required if the fuse operates due to overcurrent. The fuse will reset when the overcurrent condition ends.

## 24 Returns procedure

Damaged or faulty units cannot be returned unless a Returns Material Authorization (RMA) number has been issued by Pyramid Technical Consultants, Inc. If you need to return a unit, contact Pyramid Technical Consultants at [support@ptcusa.com](mailto:support@ptcusa.com), stating

- model
- serial number
- nature of fault

An RMA will be issued, including details of which service center to return the unit to.

## 25 Support

Manual and software driver updates are available for download from the Pyramid Technical Consultants website at [www.ptcusa.com](http://www.ptcusa.com). Technical support is available by email from [support@ptcusa.com](mailto:support@ptcusa.com). Please provide the model number and serial number of your unit, plus relevant details of your application.

## 26 Disposal

We hope that the I400 gives you long and reliable service. The I400 is manufactured to be compliance with the European Union RoHS Directive 2002/95/EC, and as such should not present any health hazard. Nevertheless, when your I400 has reached the end of its working life, you must dispose of it in accordance with local regulations in force. If you are disposing of the product in the European Union, this includes compliance with the Waste Electrical and Electronic Equipment Directive (WEEE) 2002/96/EC. Please contact Pyramid Technical Consultants, Inc. for instructions when you wish to dispose of the device.

## 27 Declaration of Conformity

### Declaration of Conformity

Issued by: Pyramid Technical Consultants, Inc.  
259 Bishops Forest Drive, Waltham, MA 02452, USA

The undersigned hereby declares, on behalf of Pyramid Technical Consultants, Inc. that the referenced product conforms to the provisions as listed:

Product: I400 Four Channel Digital Electrometer

Year of initial manufacture: 2006

Applicable Directives: 73/23/EEC Low Voltage Directive:  
Laws for electrical equipment within certain voltage limits

89/336/EEC- EMC Directive:  
Laws relating to electromagnetic compatibility

Applicable Standards: IEC 610101: 2002 (2nd Edition)  
UL 61010-1: 2004  
EN 61326: 1997+A1:1998+A2:2001  
EN 55011:1998, A2:2002  
EN 61000-6-2:2001 - Electromagnetic Compatibility  
Generic Standard, Immunity for Industrial Environments

Issuing Agencies: Safety: TUV Rheinland North America,  
12 Commerce Rd, Newton, CT 06470 USA

EMC: TUV Rheinland North America,  
12 Commerce Rd, Newton, CT 06470 USA

Applicable Markings: TUV, FCC, CE

Authorized by: *R. P. Basseau*  
President, Pyramid Technical Consultants, Inc.

Date: *August 1 2006*

The Technical Construction File required by these Directives are maintained at the offices of Pyramid Technical Consultants, Inc, 259 Bishops Forest Drive, Waltham, MA., USA  
A copy of this file is available within the EU at the offices of Pyramid Technical Consultants Europe, Ltd, 2 Chanctonbury View, Henfield BN5 9TW, United Kingdom.

## 28 Hardware Versions

This user manual refers specifically to the I400 at hardware revision 4. Revision 2 and 3 units were also supplied to customers. Major differences between versions that are, or have been in regular production are summarized below. Revisions 2 and 3 are covered by a separate user manual I400\_UM\_yymmdd.

<i>Revision</i>	<i>Changes</i>
Rev 2	First production version
Rev 3	Signal connectors 3-lug triax as standard (previously 2-lug as standard) Screen cover introduced over high voltage circuitry HV modules made demountable Fiber-optic connectors ST type (previously Versatile Link push-fit)
Rev 4	Stainless steel case design Relay isolation of HV for startup moved from external bias to signal bias. USB interface removed, RS-485 interface added. Temperature probe connector moved to rear panel.

## 29 Firmware compatibility

The following combinations are compatible, with the highlighted combinations the recommended ones that take most advantage of software improvements. The configurations of compatible loop controllers are also given.

<i>I400 revision 4</i>			
<i>Hardware revision</i>	<i>I400 device code</i>	<i>I400 FPGA code</i>	<i>PTC Diagnostic version</i>
<b>Rev 4</b>	<b>4.0C</b>	<b>1.5.6</b>	<b>4.58</b>

## 30 User Manual Revision History

The release date of a Pyramid Technical Consultants, Inc. user manual can be determined from the document file name, where it is encoded yymmdd. For example, M10\_UM\_080105 would be a M10 manual released on 5 January 2008.

<i>Version</i>	<i>Changes</i>
I400r4_UM_100415	First general release for I400 hardware revision 4
I400r4_UM_100505	Corrected error in RS-485 pinouts.
I400r4_UM_250805	Updated address and removed outdated references.