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FX4

FX4 User Manual

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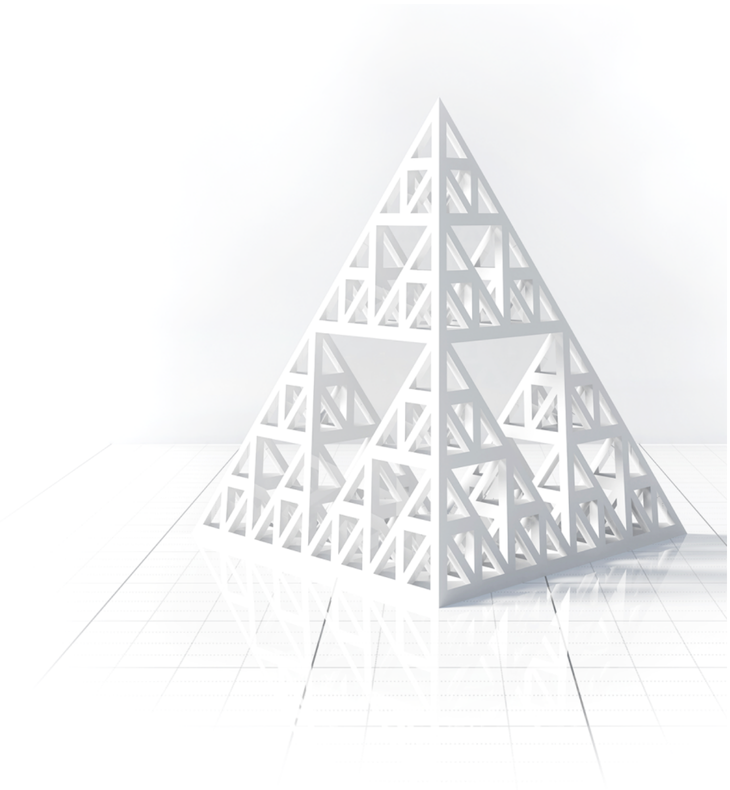
Version: v1



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1 Preamble

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1.1 Revisions

Version	Description	Saved by	Saved on	Status
v1	Initial release.	Matthew Nichols	Mar 6, 2025 10:32 PM	APPROVED

1.2 Document Approvals

This document has been reviewed and approved as follows.

Document Control Not Reviewed

Current document version: v.2

No reviewers assigned.

1.2.1 Signatures

for most recent document version

2 FX4 Introduction

Thank you for purchasing the FX4 four-channel precision electrometer. The FX4 enables fast and accurate current measurements, ranging from less than ten picoamperes to ten milliamperes, offering an impressive dynamic range of nine orders of magnitude. It supports high-voltage bias options for detector systems or Faraday cup suppression.

The FX4 includes a standard network connection for control and readback, facilitating easy integration into control systems. Its analog voltage outputs provide a means to monitor the measured current or a calculated combination of currents, which can be displayed using a meter, oscilloscope, or digitizer. Additionally, multiple digital inputs and outputs, including TTL, relays, and fiber optics, enable the FX4 to be used in process control applications such as dose delivery and beam interlocking. An I2C expansion interface allows the addition of peripherals such as environmental probes, additional high-voltage supplies, and process control interfaces.

Multiple FX4 units can be distributed across various locations to monitor currents, all of which communicate with a supervising computer system via Ethernet. The FX4 features a web page interface that allows you to view measurements and control acquisition via any standard web browser. It's also straightforward to integrate data collection into your own software, including Python, C++, JavaScript, HTTP, WebSockets, EPICS, and other programming environments and protocols.

This User Manual provides all the information you need to install and begin making measurements with the FX4.

2.1 Intended Use and Key Features

2.1.1 Intended Use

The FX4 is designed for low current measurements, spanning from picoamperes (pA) to milliamperes (mA), particularly in applications involving ionizing radiation or photon detectors within networked systems. The device is capable of monitoring currents at rates suitable for real-time observation and closed-loop control. Key applications include:

- Quadrant detector readout for beam centering
- Quadrant photodiode and diamond readout

- Dose delivery control
- Beam stabilization
- Any process control application involving the measurement of low currents

The FX4 features on-board interlock relays that can be controlled in real-time, providing an added layer of safety for the application.

2.1.2 Operating Environment

The FX4 is designed to be resilient in electrically noisy environments, though it is intended for use in clean, sheltered areas with a stable temperature range. The temperature of the FX4 should only vary by a few degrees to maintain optimal performance. The device is engineered for high precision, with minimal drift and aging. However, for the highest level of accuracy in critical applications, regular re-calibration is recommended. Please refer to the *FX4 Maintenance | Suggested Calibration Schedule*.

The Ethernet interface provides 1500 V isolation. For operations requiring higher electrical isolation, such as high-voltage terminals or other critical scenarios, a standard fiber optic Ethernet bridge can be used for enhanced protection.

2.1.3 Key Features

The FX4 offers a range of features designed for versatile use in measurement and control applications. These features are accessible through the web browser interface or via user software. More detailed information on each of the following features can be found in other sections of this manual.

- **Built-in Web Server**: Provides access to all FX4 features via a standard web browser interface.
- **User Software APIs**: Easy-to-use APIs available for user software integration through HTTP and EPICS.
- **High-Integrity QNX Operating System**: Ensures reliable and stable performance in critical applications.
- **Four Measurement Channels**: Capable of measuring currents from a few picoamperes (pA) up to 3 mA, or up to 10 mA by special order.
- **Adjustable Sample Rate**: Allows users to balance time resolution and signal-to-noise ratio according to the application's needs.
- **Choice of Analog Bandwidth**: On the two most sensitive measurement ranges, providing a faster sample rate when the capacitive load of the signal source and cables is low.
- **Four Analog Voltage Outputs**: These outputs can track the measured currents or custom-defined arithmetic functions of the currents.
- **Analog Outputs for Process Control**: Use the analog outputs to deliver user-selected or servo-controlled process control voltages to external devices.
- **Configurable Digital I/O**: For monitoring and controlling external devices.
- **Expansion Port Serial Interface**: For control of external devices.
- **Noise-Immune Fiber Optic Digital I/O**: Provides reliable control of external devices in electrically noisy environments.
- **Dual 24 V Relays**: Used for interlocks and external device control.
- **Data Capture to Internal Memory**: Capture data at the full sample rate and export it to a CSV file for further analysis.
- **Charge Measurement**: Digital accumulation of current measurements for precise charge measurement.
- **Beam Position Readout**: Compatible with quadrant detectors for beam position monitoring.
- **Dose Control**: Suitable for radiation therapy and other applications with one or multiple control points, using the sum of currents or custom-defined combinations.
- **Configurable Dosing Termination and Interlock Conditions**: For enhanced process control and safety.
- **Simple Software Updates**: Easily update the FX4 software to ensure optimal performance and features.

- **High Voltage Output**: Adjustable voltage range and polarity for biasing detectors.
- **High Voltage Loopback**: Used to confirm the bias of the detector.
- **Color LCD Display**: Provides real-time fault-finding information, including network status, high voltage output, sum of currents, and relay status.

2.2 Product Variants

2.2.1 Product Models

Device Model	Description
FX4	Base FX4 four-channel electrometer, no high voltage installed.
FX4-XP05 (+500V) FX4-XN05 (-500V) FX4-XP10 (+1000V) FX4-XN10 (-1000V) FX4-XP20 (+2000V) FX4-XN20 (-2000V)	Adds a 1-Watt unipolar high voltage supply. Maximum current depends on the selected voltage. This power supply is suitable for supplying bias for radiation detectors or providing modest power for an electron suppression ring.

Example: **FX4-XN05** FX4 electrometer with -500 V HV bias supply fitted.

2.2.2 Scope of Supply

The FX4 comes with the optional high voltage unit pre-installed inside the unit itself, it cannot be easily replaced by the user.

The FX4 does **not** come with a power supply, one must be ordered as separate line item. If you place the order on our website, you can easily specify a power supply as you are adding the FX4 to your cart or quote.

- PSU24-25-1[1] - A 24V 25W threaded 2.1 mm power supply suitable for a single unit.
- PD-8[2] - A 19” rack mount 8-port 24V power supply suitable for powering a set of devices.

The FX4 can be powered by and commercially available 24 VDC power supply that can deliver at least 25 Watts. However, for medical applications Pyramid highly recommends buying the Pyramid power supplies to ensure maximum performance.

OEM customers can create standardized purchase orders to receive only specific components relevant to their application and special components on request.

2.2.3 Optional Items and Related Products

Cables and Cable Accessories

- CAB-BNC - Doubly shielded low noise BNC cable suitable for low current measurements.
- CAB-SHV - Coaxial SHV cable for use with the FX4 high voltage bias power supply.
- CAB-D9 - Doubly shielded low noise D-sub DE-9 cable for use with the FX4 digital expansion port.

Mounting Accessories

- RCK-X3[3] - A 2U 19” rack mountable shelf designed to fit three FX4s side by side.
- DIN-X1 - A DIN rail mounting kit for a single FX4.

1 https://pyramid.tech/products/psu24
2 https://pyramid.tech/products/pd-8
3 https://pyramid.tech/products/rck-x3

Fiber Optic Accessories

- X22[4] - Bi-directional BNC TTL to Fiber Optic Converter
- TF1[5] - Self-powered BNC TTL to Fiber-Optic Converter

Pyramid Detectors

- BC-75[6] - Faraday Cup Beam Collector for Particle Therapy QA and Diagnostics
- QIC-6E[7] - Ultra-low WET Quadrant Transmission Ionization Chamber
- QIC-2S[8] - Mini Quadrant Ion Chamber

2.3 Safety Information

2.3.1 Safety Considerations for the Intended Application

The FX4 is designed to comply with the harmonized electrical safety standard **EN61010-1:2000**. It must be used in accordance with the specifications and operating instructions provided in this manual. Operators of the unit should be qualified personnel familiar with electrical safety protocols. The customer's **Responsible Body**, as defined in the standard, is responsible for ensuring that operators are equipped with the necessary safety equipment and receive the appropriate training.

The FX4 is designed for use in **Measurement Category I**, as defined in the EN61010-1:2000 standard, which pertains to equipment intended for measurement in circuits that are not directly connected to the mains power supply.

2.3.2 Power and Grounding

WARNING: The FX4 can deliver high voltage up to **2000 Volts** with a maximum continuous power of 1 W if fitted with the optional high voltage module. **Appropriate precautions** must be taken when handling the device. Always use only the **specified connectors and cables** and **never work on the unit or connected detector while high voltage is enabled**. The unit should not be operated outside its case unless you are specifically trained in FX4 service procedures.

Take extra care when installing, commissioning, or making measurements in systems where high voltages, high currents, high magnetic fields, or stored energy are present. Ensure that all safety protocols are followed to prevent injury or equipment damage.

The FX4 must not be operated unless it is correctly assembled within its case. **Only Service Personnel**, as defined in **EN61010-1**, are authorized to work on a disassembled unit, and then only under specific instruction from **Pyramid Technical Consultants, Inc.** or their authorized distributors.

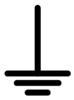
The FX4 unit is designed to operate from a **+24 VDC** power supply, with a maximum current requirement of **1 Amp**. A suitably rated power supply can be provided with an FX4.

When installed in a permanent location, the FX4 unit must be **properly grounded** by connecting it securely to the ground stud or by mounting it to a **grounded conducting surface** to ensure safety and proper and safe operation.

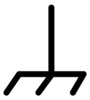
4 https://pyramid.tech/products/x22
5 https://pyramid.tech/products/tf1
6 https://pyramid.tech/products/bc-75
7 https://pyramid.tech/products/qic-6e
8 https://pyramid.tech/products/qic-2s

2.3.3 Standard Symbols


Direct current

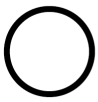

Earth (ground) terminal


Protective conductor terminal


Frame or chassis terminal


Equipotentiality

Supply ON


Supply OFF


CAUTION RISK OF ELECTRIC SHOCK


CAUTION RISK OF DANGER REFER TO MANUAL


CAUTION ENTRAPMENT HAZARD

2.4 Device Certification

The FX4 has been designed to comply with the following international standards:

- Manufactured and tested under **quality management systems** accredited to **ISO 9001** and **ISO 13485** (for medical applications).

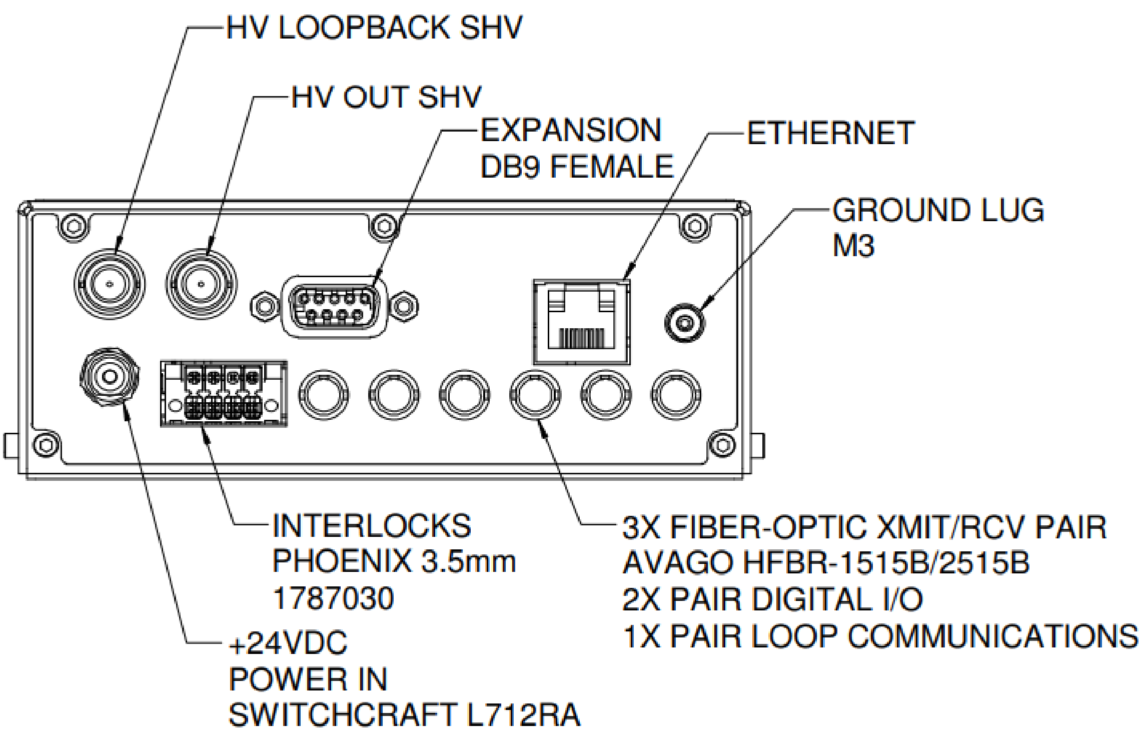
3 FX4 Getting Started

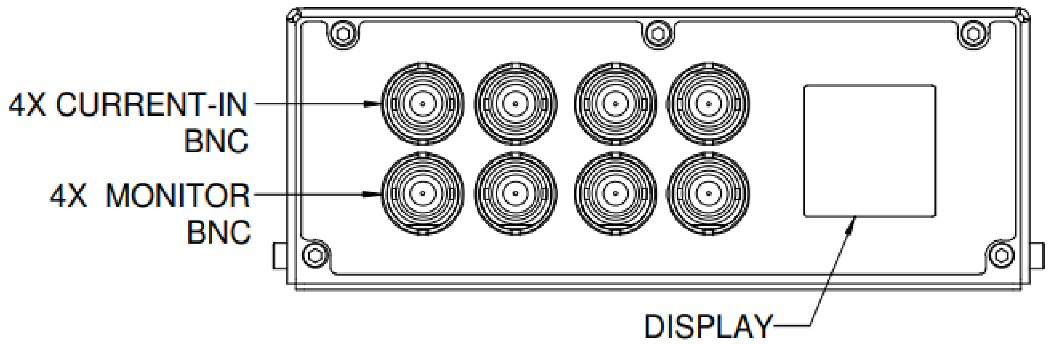
3.1 Mounting

The FX4 does not require special mounting and is typically placed flat on a tabletop or in a control chassis. The FX4 can be mounted in a 19" rack or DIN rail system using optional accessories sold by Pyramid.

3.2 Connectors and Cables

See the Features section of this manual for detailed information on connecting to the FX4.

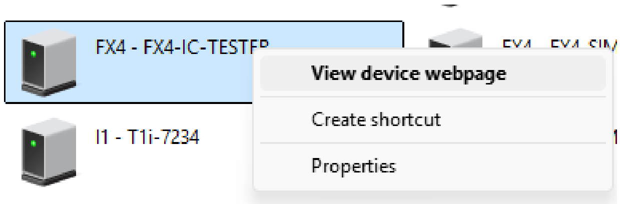




3.3 Network Connection

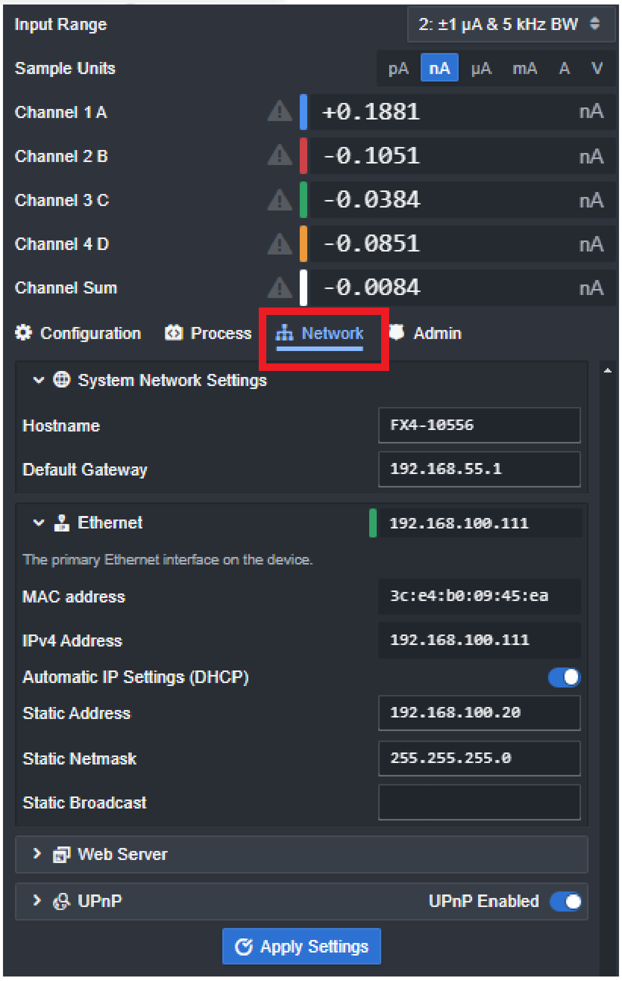
To establish a network connection, connect one end of an Ethernet cable to the device's Ethernet port and the other end to a network router or switch. Ensure the network is active and properly configured. The device should automatically obtain network settings via DHCP. If a static IP address is required, configure the network settings through the device interface. The device will default to a static IP address if there is no router on the network. The default static IP address is **192.168.100.20** with a netmask of **255.255.255.0**.

You can access the web interface by typing in the device's IP address in a supported web browser. On Windows, your device should also appear in the Network tab in your explorer. Right clicking on your device will provide an option to open to the device's web interface in your default browser.



You can give your device a unique name that will help you to identify it in a network. Enter the name in the Hostname field under the Network or Admin tab of the web interface. When you reboot the device, you will see the new name.

The Network tab gives access to the network settings of the device. For detailed instructions and advanced network configuration options, please refer to the IGX - User Manual.



1 Network Settings

3.4 Updating Instructions

Device updates for the FX4 are managed through the web interface. To check for and install updates, access the device's web interface using a compatible browser and navigate to the **System Firmware** section in the Admin tab. Updates can be downloaded from the **Pyramid website** and uploaded via the web interface. Follow the on-screen instructions to complete the update process.

For detailed instructions on updating, please refer to the **IGX User Manual**.

3.5 Rebooting

At times, it may be necessary to reboot your FX4 device. The device can be restarted in the following ways:

- **Power Cycle**: Turning the **24 V power** off and on will completely restart the device.
- **Hard Reset**: From the **Admin tab**, you can command a **hard reset**, which will drop all client connections, reboot the device, and reload the operating system along with the FX4 application.
- **Soft Reset**: A **soft reset** will only reset the web interface, while the operating system continues to run. For example, you can maintain an **SSH connection** to the operating system throughout the soft reset process.

4 FX4 Web GUI Overview

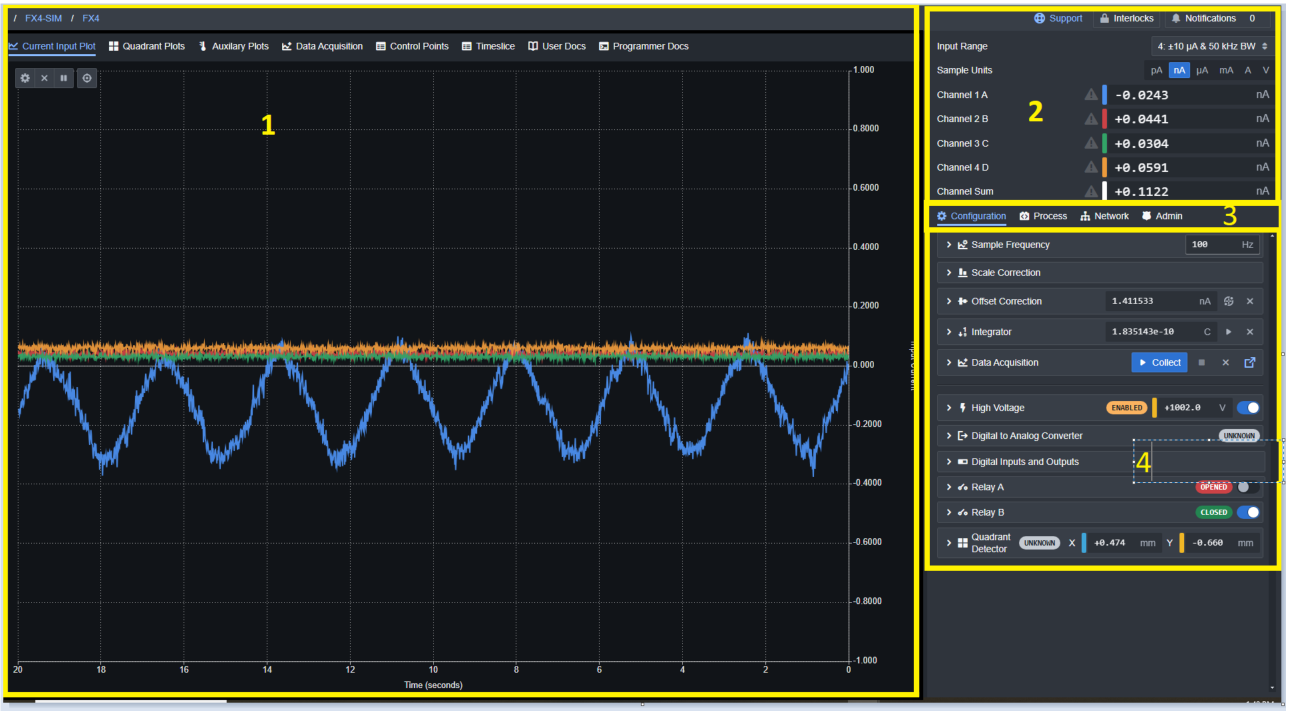
The web pages served by the FX4 allow access to all of the device's features, enabling measurements to be displayed, plotted, and adjusted as needed. The screens are generally self-explanatory, so this chapter provides an overview of these features.

The **Web GUI** layout consists of two main sections:

- **Graphic Representation of Measurements** (Left, 1 in the figure below): This section visually represents the measurements in real-time.
- **Numeric Values, Settings, and Additional Information** (Right, 2 in the figure below): Displays the four measured currents, the measurement scale selection, and the current display units. These elements are always visible at the upper right of the screen.

Below the numeric display are several **control groups** (3). These can be expanded by clicking the **expand arrow**. A slider is available to reveal more of the control list if it extends beyond the screen.

The screen also contains **rows of tabs** (4 and 5) that allow users to navigate between different sections of the display.

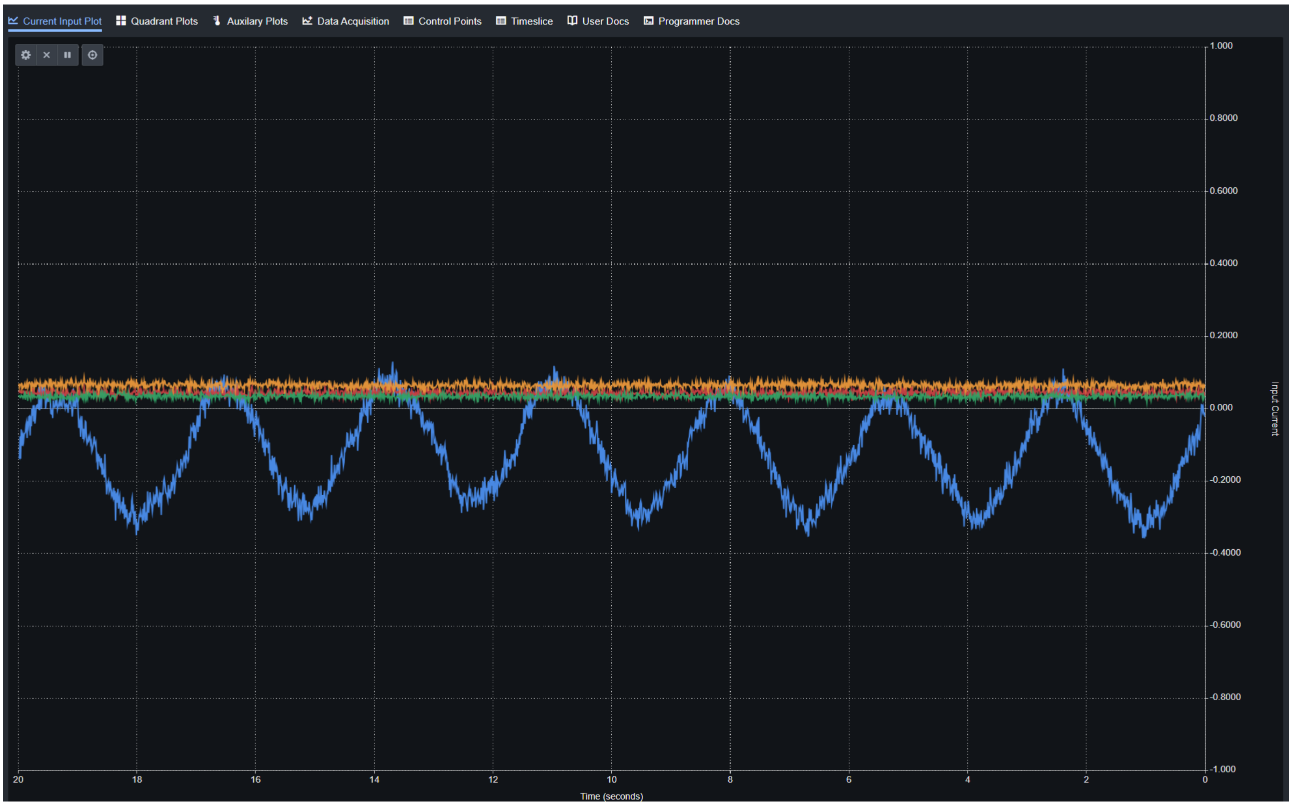


The FX4 always starts up with the same system state as before it was shut down. The state includes range selection, sampling settings and high voltage setting. However, any browser display settings such as graph scaling, or tab selections start in the default arrangement when the page is first opened in a browser.

4.1 Data Plotting (1)

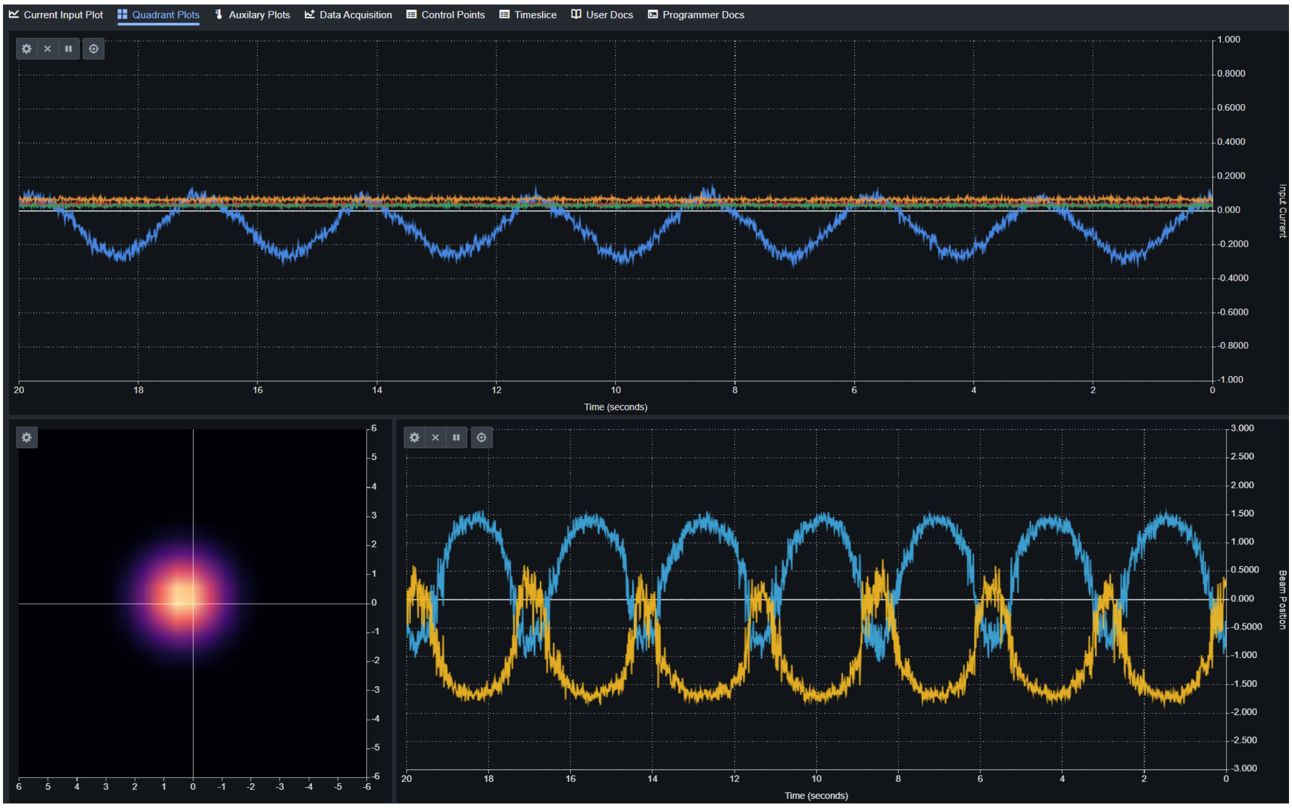
4.1.1 Current Input Plot

The default graphic displays the four measured currents as a function of time. You can customize the plot by selecting which channels to display, adjusting the graph axes, clearing the data buffer, pausing the data accumulation, and placing a cursor on the plot. These controls are located in the upper left corner of the plot, providing flexibility for how you view and interact with the current measurements.



4.1.2 Quadrant Plots

Selecting the **Quadrant Plots** option presents the incoming data in a format suited for situations where the four currents are derived from sensing elements arranged in a symmetric quadrant pattern. For more information, refer to the section of this manual on **quadrant sensor readout**.

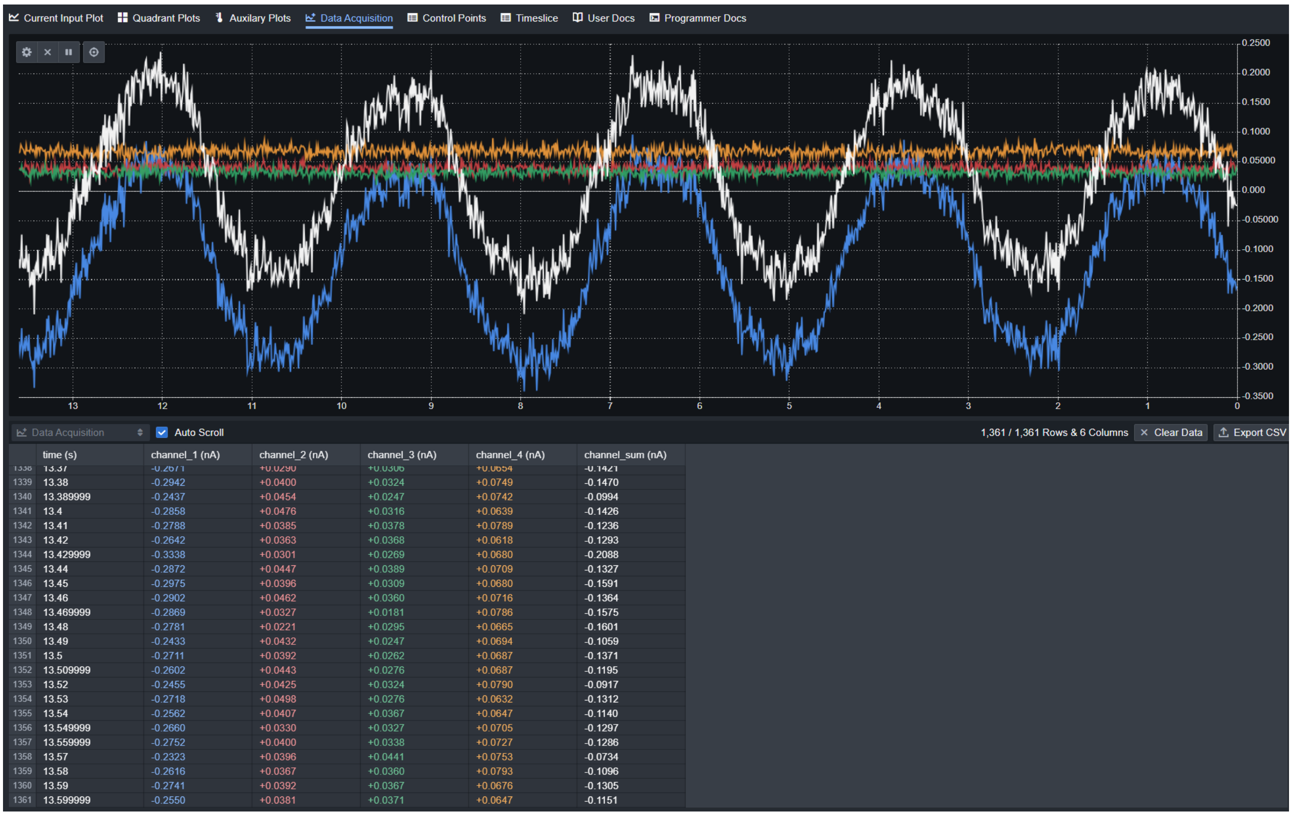


4.1.3 Auxiliary Plots

The auxiliary plots provide tracking of additional parameters of the FX4. The top plot is a smaller version of the four signal inputs. The central plot displays the internal high voltage monitor alongside the external high voltage loopback measurements. The bottom three plots show environmental sensor readbacks, including temperature, pressure, and humidity. To use these features, a compatible environmental sensor, such as the Pyramid **QIC-6E quadrant detector**, must be connected.

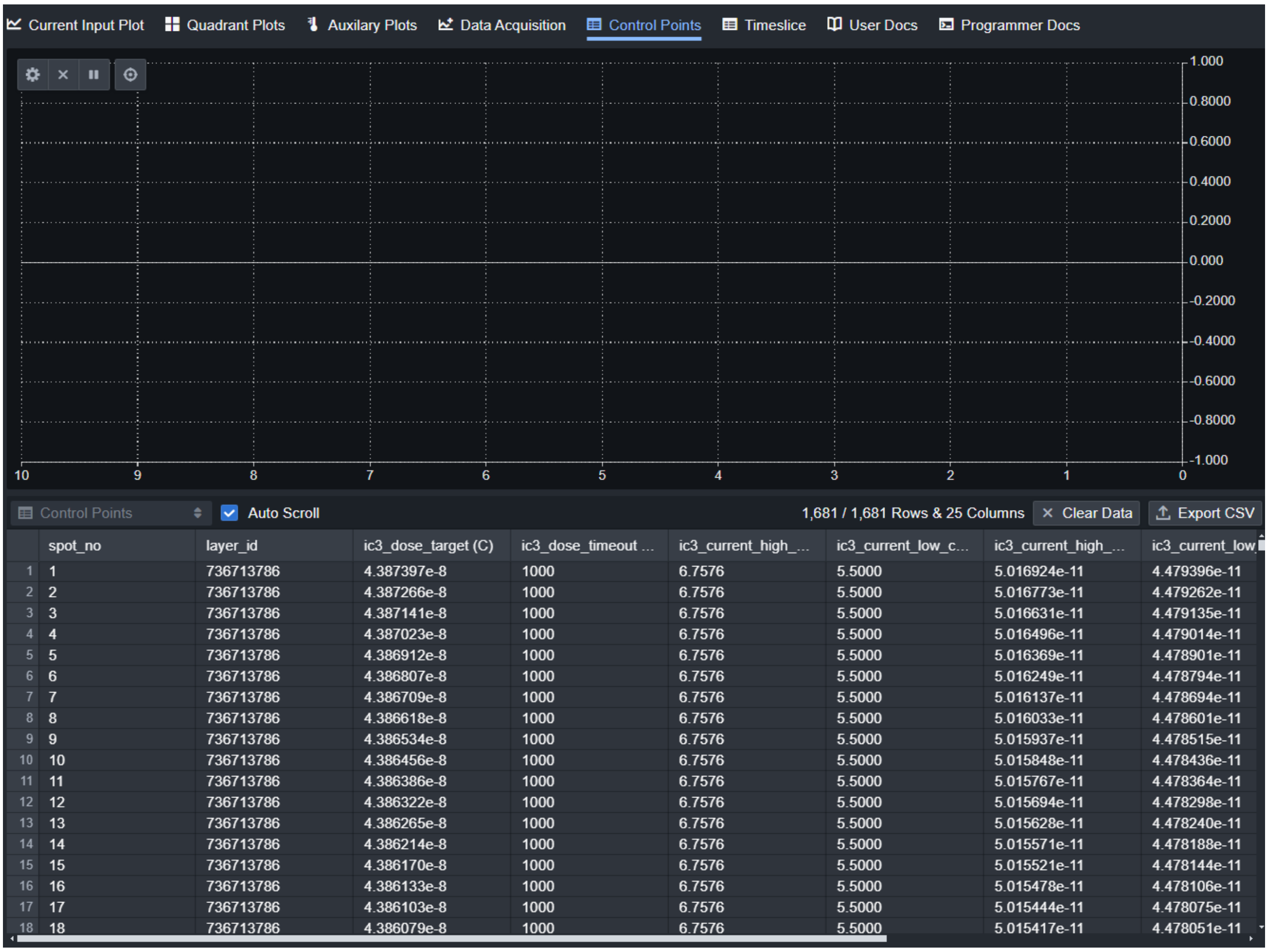
4.1.4 Data Acquisition

The **Data Acquisition** screen works in conjunction with the Data Acquisition feature of the FX4 (see below for detailed instructions on its use). The screen displays a plot of the inputs along with a listing of the acquired data below. This includes the sample acquisition time, the four input currents, and the sum of the four inputs.



4.1.5 Control Points

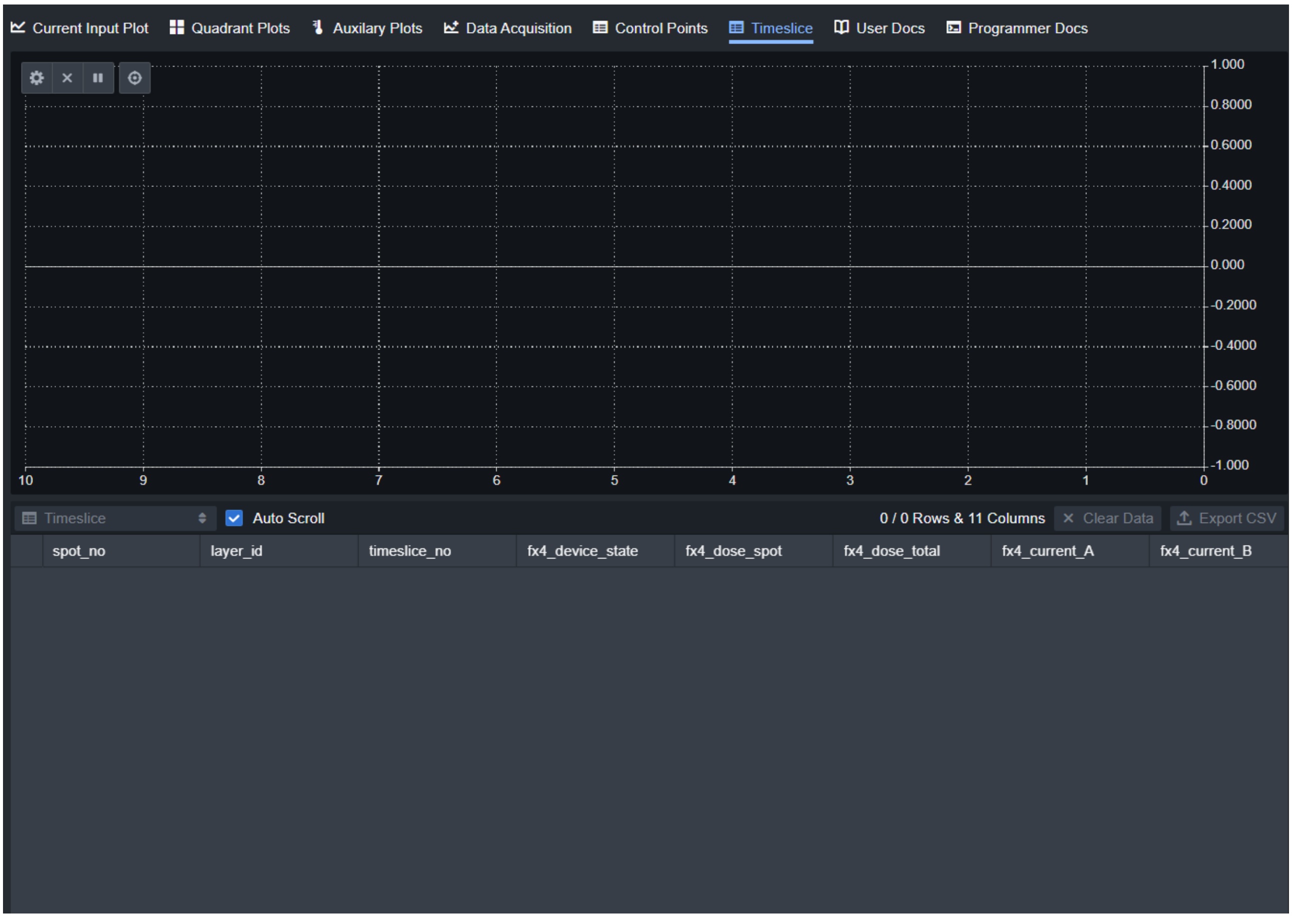
The **Control Points** plot is used when programming the FX4 for multi-spot dosimetry. After loading a map, each control point is displayed in the table below the plot. Measured values will be added once the map is run. The values for each column can be viewed in the plot and can be enabled or disabled individually through the standard plotting options.



	spot_no	layer_id	ic3_dose_target (C)	ic3_dose_timeout ...	ic3_current_high_...	ic3_current_low_c...	ic3_current_high_...	ic3_current_low
1	1	736713786	4.387397e-8	1000	6.7576	5.5000	5.016924e-11	4.479396e-11
2	2	736713786	4.387266e-8	1000	6.7576	5.5000	5.016773e-11	4.479262e-11
3	3	736713786	4.387141e-8	1000	6.7576	5.5000	5.016631e-11	4.479135e-11
4	4	736713786	4.387023e-8	1000	6.7576	5.5000	5.016496e-11	4.479014e-11
5	5	736713786	4.386912e-8	1000	6.7576	5.5000	5.016369e-11	4.478901e-11
6	6	736713786	4.386807e-8	1000	6.7576	5.5000	5.016249e-11	4.478794e-11
7	7	736713786	4.386709e-8	1000	6.7576	5.5000	5.016137e-11	4.478694e-11
8	8	736713786	4.386618e-8	1000	6.7576	5.5000	5.016033e-11	4.478601e-11
9	9	736713786	4.386534e-8	1000	6.7576	5.5000	5.015937e-11	4.478515e-11
10	10	736713786	4.386456e-8	1000	6.7576	5.5000	5.015848e-11	4.478436e-11
11	11	736713786	4.386386e-8	1000	6.7576	5.5000	5.015767e-11	4.478364e-11
12	12	736713786	4.386322e-8	1000	6.7576	5.5000	5.015694e-11	4.478298e-11
13	13	736713786	4.386265e-8	1000	6.7576	5.5000	5.015628e-11	4.478240e-11
14	14	736713786	4.386214e-8	1000	6.7576	5.5000	5.015571e-11	4.478188e-11
15	15	736713786	4.386170e-8	1000	6.7576	5.5000	5.015521e-11	4.478144e-11
16	16	736713786	4.386133e-8	1000	6.7576	5.5000	5.015478e-11	4.478106e-11
17	17	736713786	4.386103e-8	1000	6.7576	5.5000	5.015444e-11	4.478075e-11
18	18	736713786	4.386079e-8	1000	6.7576	5.5000	5.015417e-11	4.478051e-11

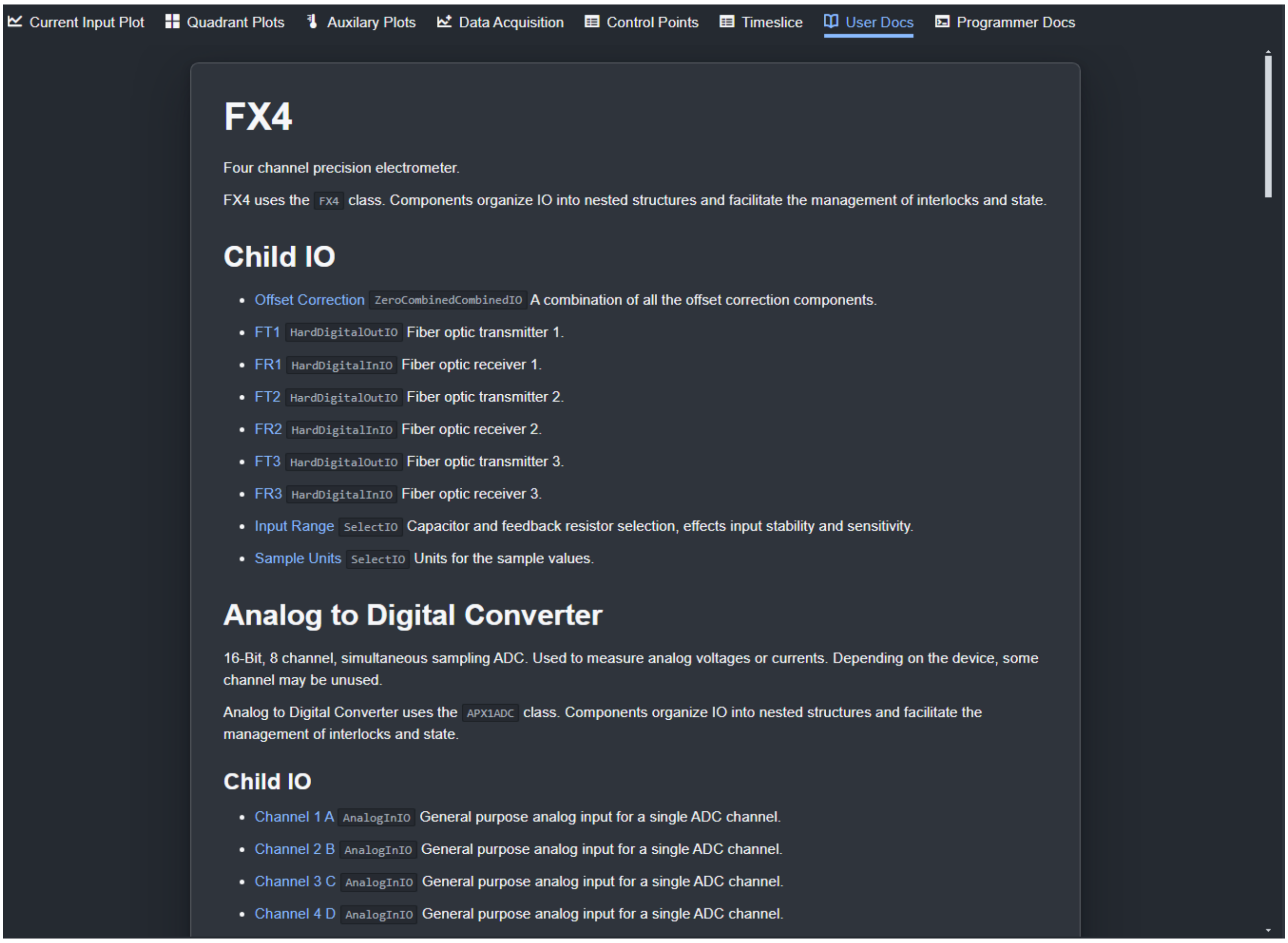
4.1.6 Time Slice

The **Time Slice** plot displays the data accumulated from running the map, with each slice representing a **1 ms** interval.



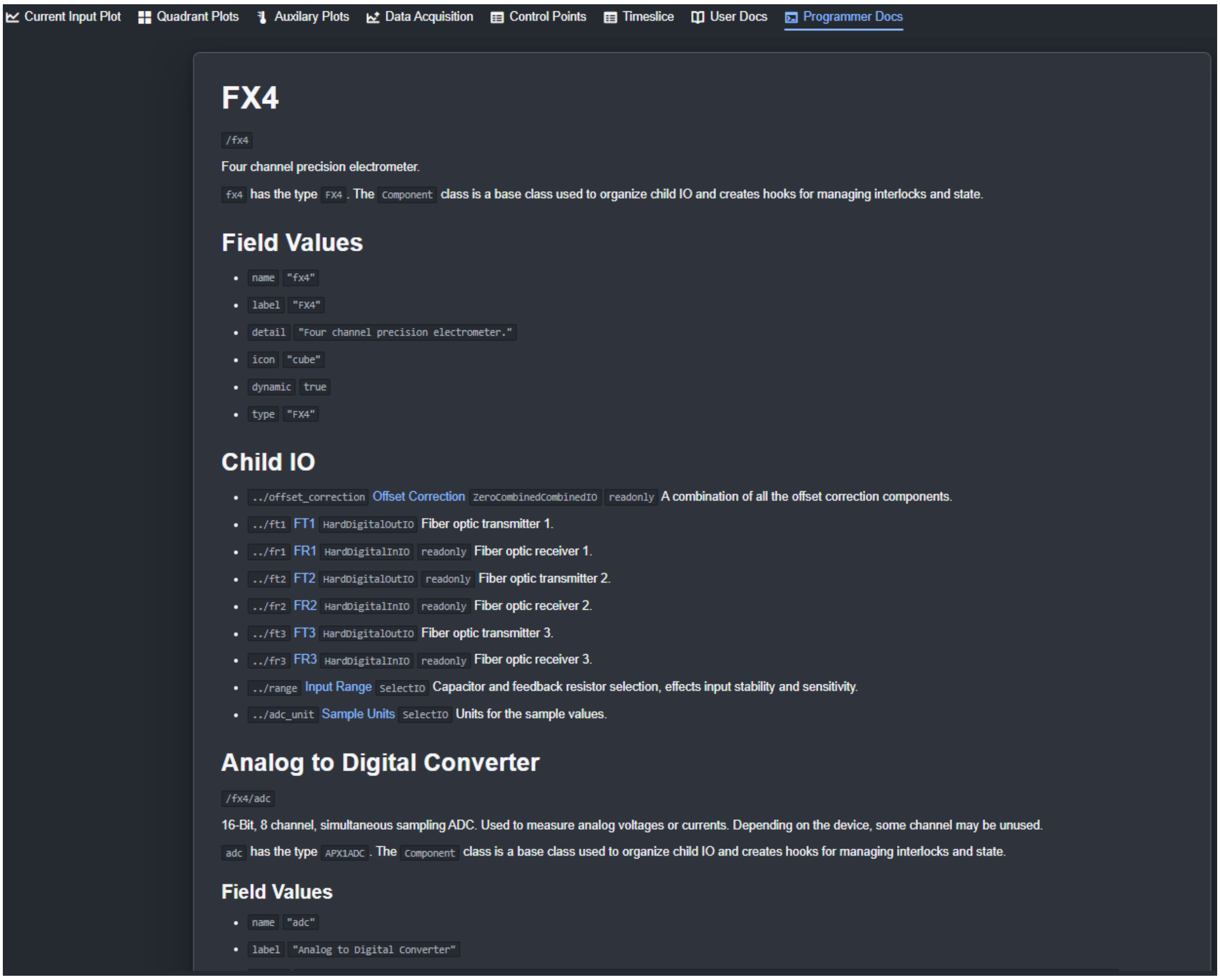
4.1.7 User Docs

The **User Docs** page provides users with detailed information about the FX4. It typically includes a descriptive listing of all relevant I/O for the device.



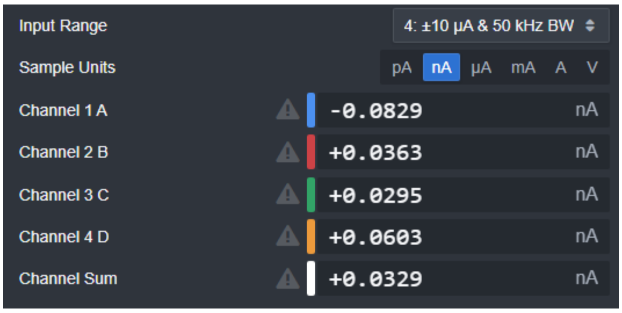
4.1.8 Programmer Docs

The **Programmer Docs** page provides information for developers working with the FX4. It typically includes a listing of all relevant I/O names for the device.



4.2 Data Display (2)

The **Data Display** section shows the numeric values for each of the four current inputs, as well as their sum. The selected range is displayed in the upper right corner.

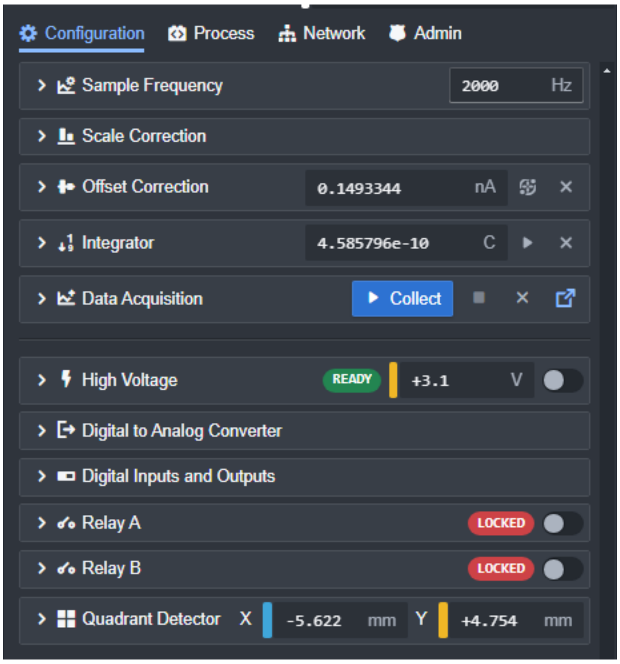


4.3 Function Selection (3)

This tab control allows for the selection of one of four functions.

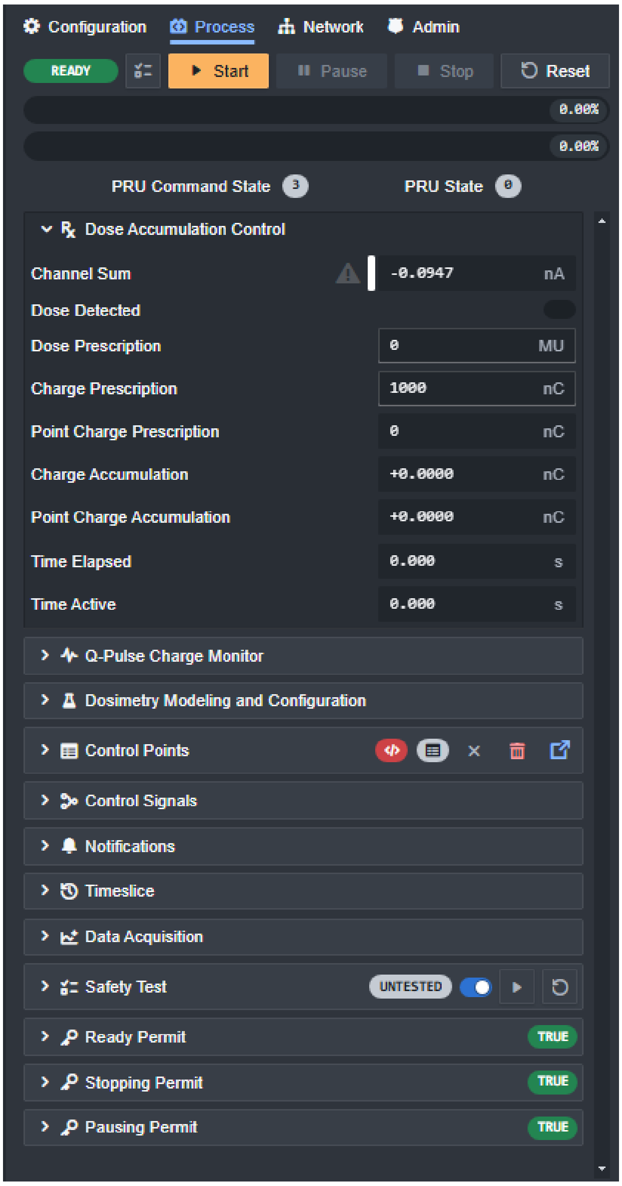
4.3.1 Configuration

The Configuration section is used to set all features on the device, as well as control the data acquisition and output. See the *Features* section of this manual for full details.



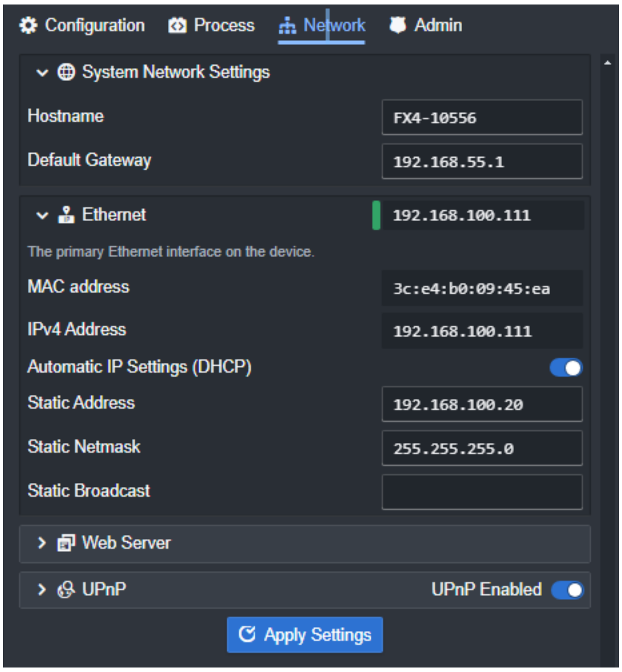
4.3.2 Process

The Process section is used to configure and operate the Dosimetry process feature. The Pyramid Nozzle software uses this feature to implement the scan/dose product. For full information on this feature see the *IGX User Manual*.



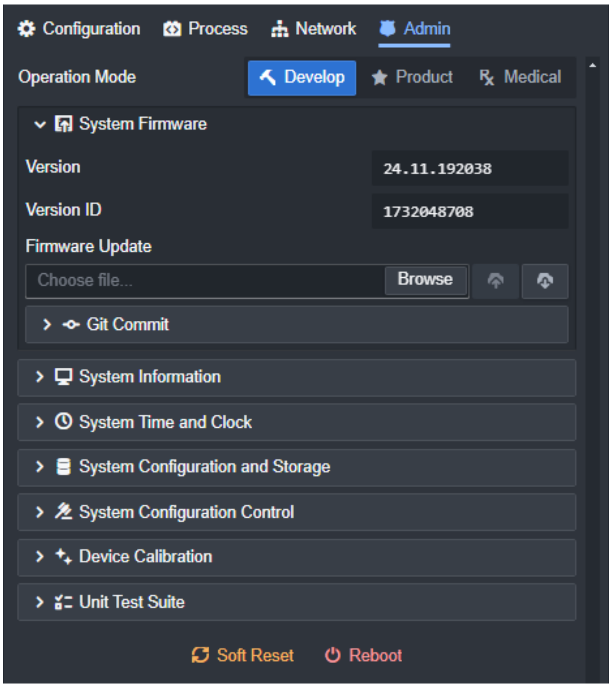
4.3.3 Network

The network section is used to configure the Ethernet network options for the FX4. For full information on this feature see the *IGX User Manual*.



4.3.4 Admin

The Admin section is used for administrative tasks, such as reporting the version, updating firmware, and other tasks. For full information on this feature see the *IGX User Manual*.



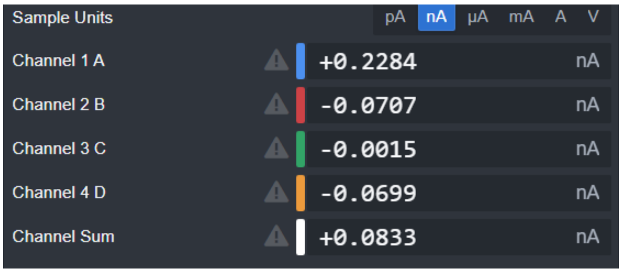
5 FX4 Features

5.1 FX4 Current Inputs

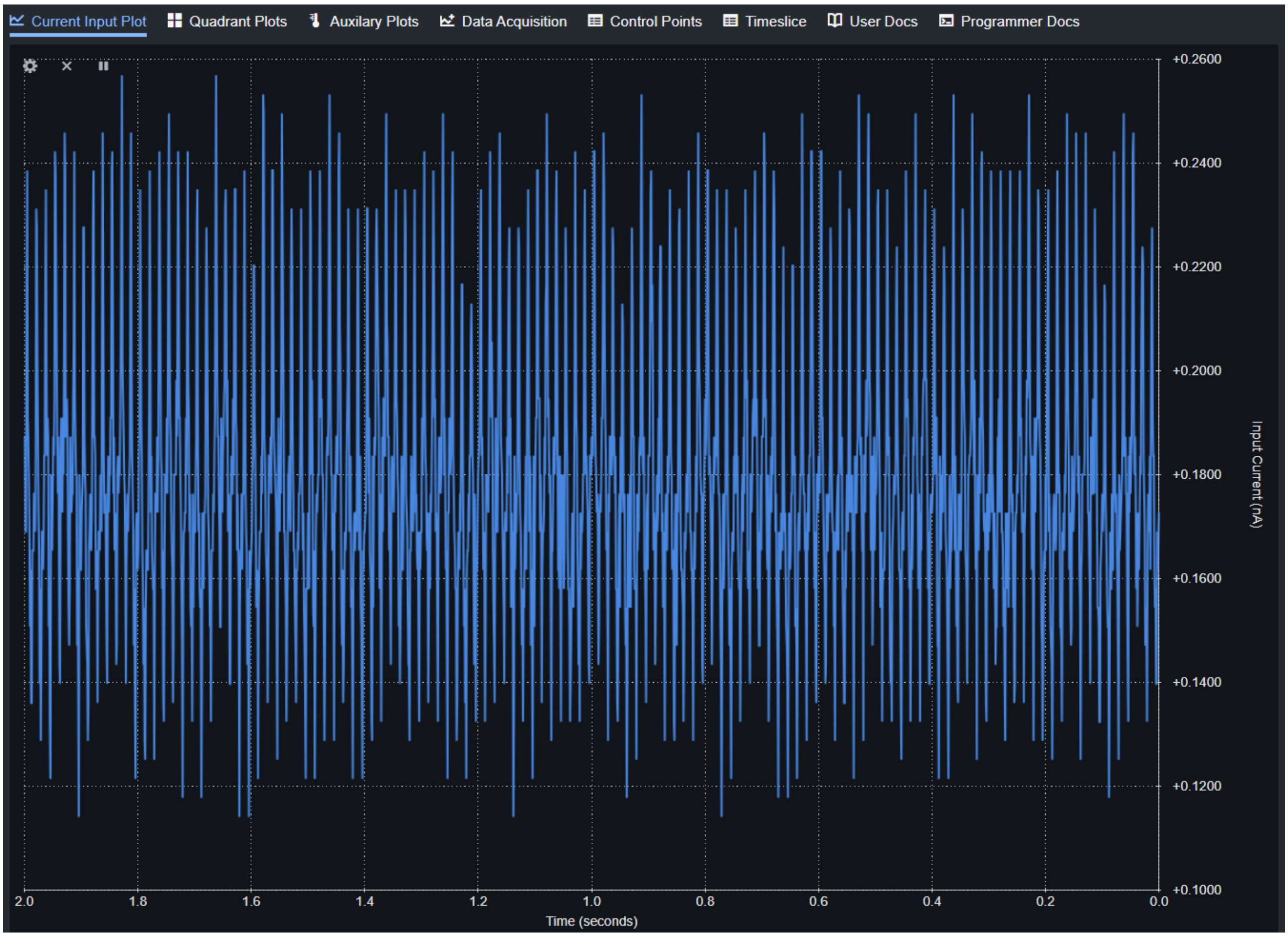
The primary function of the FX4 is to make current measurements. To facilitate this, the unit is equipped with four separate inputs. For detailed instructions on how to make measurements using these inputs, please refer to the section on *Making Measurements* in this manual.

A real-time display of the current inputs is shown in the upper right portion of the screen. The units of measurement can be selected from the upper right corner.

The data is plotted in real time, as described in the *Operating Instructions* section of this manual.



2 FX4 Current Display



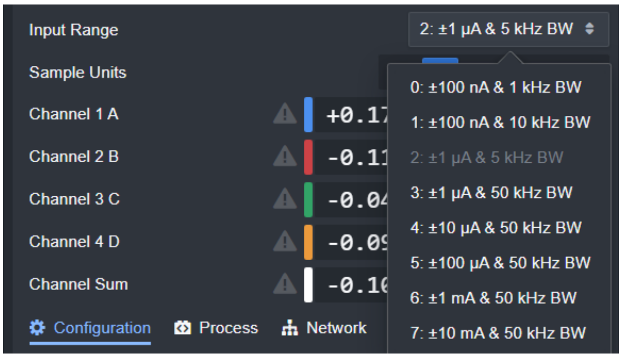
3 FX4 Realtime Data Plot

5.1.1 Current Measurement Configuration

Input Range

The FX4 offers eight input ranges, each of which specifies the full-scale range and the analog bandwidth of the circuit. The selected range applies to all four input channels.

The FX4 operates as a Transimpedance Amplifier (TIA), where each input range is configured with a different resistor and feedback capacitor. These components adjust the sensitivity and bandwidth of the circuit, optimizing it for different current levels. This design ensures that the unit provides accurate measurements across a wide range of input signals.



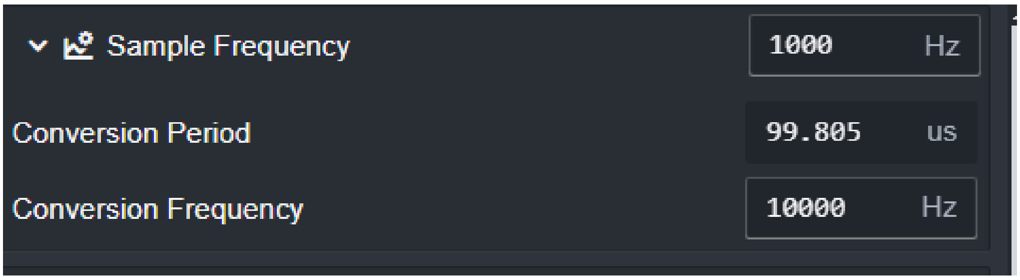
4 FX4 Selectable Range

Sample Frequency

There are two frequencies to consider in the measurement process:

- **Conversion Frequency**: This is the rate at which the analog-to-digital converter (ADC) performs conversions. For typical measurements, the default conversion frequency of 1e5 Hz (100,000 conversions per second) is sufficient.
- **Sample Frequency**: This defines the rate at which data is produced, and it is determined by averaging multiple ADC conversions. For example, with a conversion frequency of 1e5 Hz and a sample frequency of 50 Hz, each reading represents the average of 2000 ADC conversions.

The sample frequency allows you to strike a balance between signal-to-noise ratio and time resolution. A lower sample frequency helps reduce noise by averaging more conversions, while a higher sample frequency gives better time resolution but may allow more noise. You can adjust the sample frequency to meet the specific needs of your measurement, ensuring the best compromise between the two factors.

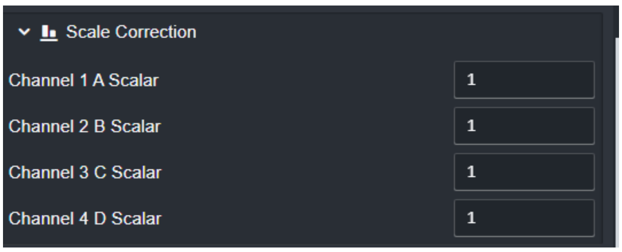


5 The FX4 GUI to Adjust Sample and Conversion Frequency

Scale Correction

The scalar is applied to each channel at the full data rate, immediately following the conversion process. All FX4 software, including the Dose Controller feature, respects this scalar.

A typical application of scaling is to “flat field” a sensor, where the four individual sensor elements may have slightly different responses. By applying the appropriate scaling factor, you can equalize their output.



6 FX4 Scale Correction GUI

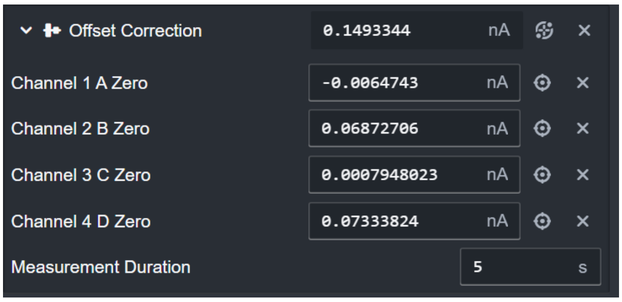
The scaling factor can be used to effectively "turn off" an unused channel by setting its value to 0.

The scalar is retained even after a reboot, so it will persist across restarts.

> It is important to ensure that the scale factors are set to 1 when they are no longer needed for a specific measurement. Leaving them set to any value other than 1 may result in incorrect data being recorded at a later time.

Offset Correction

In addition to small electronic inaccuracies, offsets can also arise from the cabling and connected devices, potentially distorting the readings. It is recommended to compute these offsets before taking measurements. There is an offset for each input channel.



7 FX4 Offset Correction GUI

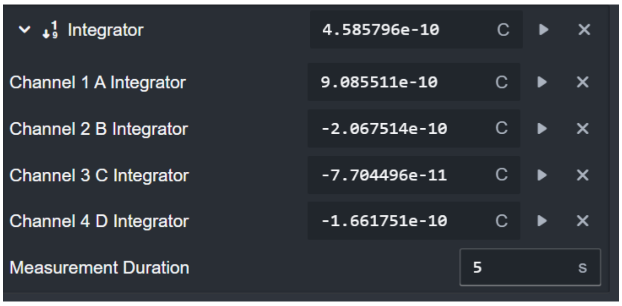
To compute the offsets, connect your equipment and turn off the current source. Select the duration of the measurement to average out any low-frequency noise. Press the target button for a specific channel, or the button at the top to apply the calculation to all channels. This will trigger the automatic computation of the offsets, which will then be stored in the FX4's non-volatile memory.

Much like the scalar, the offset is also honored by all FX4 software features, ensuring consistent correction across all functionalities.

Charge Integrator

The Integrator allows you to configure one or all channels to integrate the current. The integration time, in seconds, is entered into the Measurement Duration field.

Pressing the arrow key  next to each channel will start the integration for that specific channel. The arrow key at the top will initiate the integration for all channels simultaneously. The sum of all four integrations is displayed at the top of the screen.



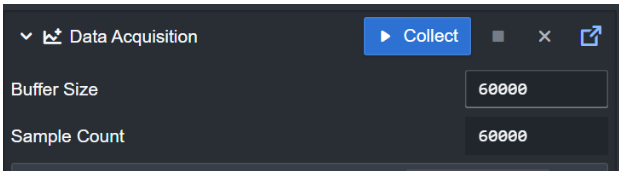
8 FX4 Integrator GUI

The Integrator is helpful when you want to integrate incoming charge but find that the full Dose Controller feature is too complicated for the task. It provides a simple way to integrate current without the need for the more advanced functionality of the Dose Controller.

Data Acquisition

Data Acquisition is a feature that allows the FX4 to capture a window of data at the sample frequency, with a guarantee of no lost samples. The device buffers the data locally in a table and can either download the data via the web GUI once the acquisition is complete or stream it to the GUI while the acquisition is still ongoing.

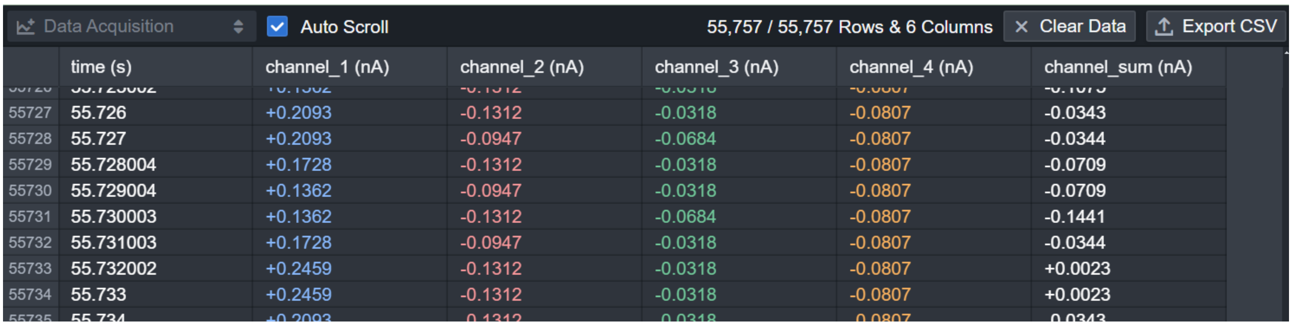
To acquire data in this mode, select the desired buffer size, up to a maximum of 1 million samples, and press the blue Collect button. The Sample Count field will increment as samples are acquired. You may press the stop button at any time to halt the acquisition before all samples are collected. Pressing the clear button will clear the table of any data.



9 Data Acquisition Configuration GUI

You can view the data table and a plot of the columns by switching to the Data Acquisition tab.

Pressing the Link button will open the data in a new browser tab, displaying only the table data.



Data Acquisition | Auto Scroll | 55,757 / 55,757 Rows & 6 Columns | Clear Data | Export CSV

	time (s)	channel_1 (nA)	channel_2 (nA)	channel_3 (nA)	channel_4 (nA)	channel_sum (nA)
55727	55.726	+0.2093	-0.1312	-0.0318	-0.0807	-0.0343
55728	55.727	+0.2093	-0.0947	-0.0684	-0.0807	-0.0344
55729	55.728004	+0.1728	-0.1312	-0.0318	-0.0807	-0.0709
55730	55.729004	+0.1362	-0.0947	-0.0318	-0.0807	-0.0709
55731	55.730003	+0.1362	-0.1312	-0.0684	-0.0807	-0.1441
55732	55.731003	+0.1728	-0.0947	-0.0318	-0.0807	-0.0344
55733	55.732002	+0.2459	-0.1312	-0.0318	-0.0807	+0.0023
55734	55.733	+0.2459	-0.1312	-0.0318	-0.0807	+0.0023

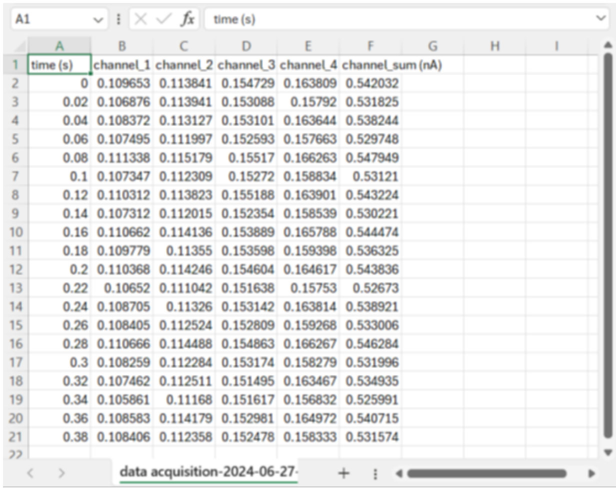
10 FX4 Data Acquisition Table View

To export the data, press the Export CSV button located in the upper right corner of the table view. This will download the data in a CSV-compatible file to your local file system.

By default, IGX will name the file based on the device type, along with the date and time of the acquisition.

The time column is measured in seconds, starting from the first sample.

The units in each channel column will be the same as the user-selected units from the GUI.



	A	B	C	D	E	F
1	time (s)	channel_1	channel_2	channel_3	channel_4	channel_sum (nA)
2	0	0.109653	0.113841	0.154729	0.163809	0.542032
3	0.02	0.106876	0.113941	0.153088	0.15792	0.531825
4	0.04	0.108372	0.113127	0.153101	0.163644	0.538244
5	0.06	0.107495	0.111997	0.152593	0.157663	0.529748
6	0.08	0.111338	0.115179	0.15517	0.166263	0.547949
7	0.1	0.107347	0.112309	0.15272	0.158834	0.53121
8	0.12	0.110312	0.113823	0.155188	0.163901	0.543224
9	0.14	0.107312	0.112015	0.152354	0.158539	0.530221
10	0.16	0.110662	0.114136	0.153889	0.165788	0.544474
11	0.18	0.109779	0.11355	0.153598	0.159398	0.536325
12	0.2	0.110368	0.114246	0.154604	0.164617	0.543836
13	0.22	0.10652	0.111042	0.151638	0.15753	0.52673
14	0.24	0.108705	0.11326	0.153142	0.163814	0.538921
15	0.26	0.108405	0.112524	0.152809	0.159268	0.533006
16	0.28	0.110666	0.114488	0.154863	0.166267	0.546284
17	0.3	0.108259	0.112284	0.153174	0.158279	0.531996
18	0.32	0.107462	0.112511	0.151495	0.163467	0.534935
19	0.34	0.105861	0.11168	0.151617	0.156832	0.525991
20	0.36	0.108583	0.114179	0.152981	0.164972	0.540715
21	0.38	0.108406	0.112358	0.152478	0.158333	0.531574

data acquisition-2024-06-27-

11 Example CSV File

Start Trigger

A start trigger precondition allows you to specify that the data collection will only start once a specific condition is met. This ensures that data is captured only when the system reaches the desired state, allowing you to reject noise or capture a fast-moving signal. The feature allows you to set a condition that must be true before data acquisition begins, after the Collect button is pressed.

12 Start Trigger Configuration

The following conditions can be configured:

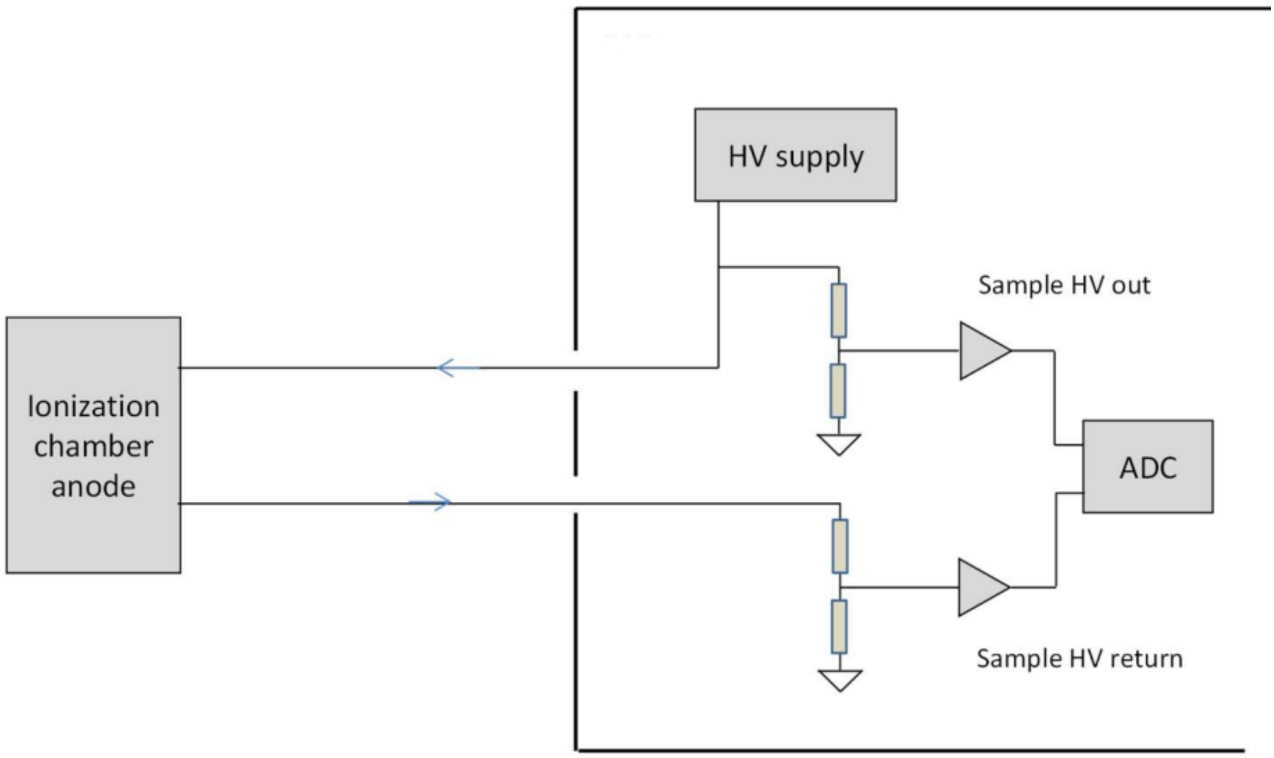
- **Trigger Enable**: The enable switch activates or deactivates the trigger feature. When enabled, the system will wait for the specified condition to be met before starting the data acquisition process.
- **Trigger Source**: This specifies the channel to use for triggering the acquisition. You can select an individual channel or choose the sum of all channels as the trigger source, depending on which data point you wish to monitor for the trigger.
- **Trigger Threshold**: This is the current value that must be observed for the acquisition to be triggered. It defines the minimum or maximum value that must be reached before the system starts collecting data.
- **Trigger Mode**:
  - **Rising Edge**: The data collection will begin when the current rises from below the Trigger Threshold to above it, indicating an upward transition across the threshold.
  - **Falling Edge**: The data collection will begin when the current falls from above the Trigger Threshold to below it, indicating a downward transition across the threshold.

5.2 FX4 High Voltage

Many radiation detectors, including ionization chambers, require a bias voltage, and it is often convenient to integrate the voltage source with the signal readout. The FX4 allows you to specify high voltage modules of either polarity, with output voltages up to 2,000 Volts with 1 Watt of power.

For critical dose measurement applications, it is essential to verify that the bias voltage is reaching the ionization chamber. The FX4 includes a loopback facility, providing clear confirmation that the voltage is being delivered correctly. To ensure accurate monitoring, your high-voltage electrode should have two discrete connection points, one for applying the voltage and another for sampling it. The FX4 measures the sampled voltage, and if it matches the expected level, you can be confident that the bias voltage is being properly delivered. This loopback connection is completely optional and is not required for proper high voltage output.

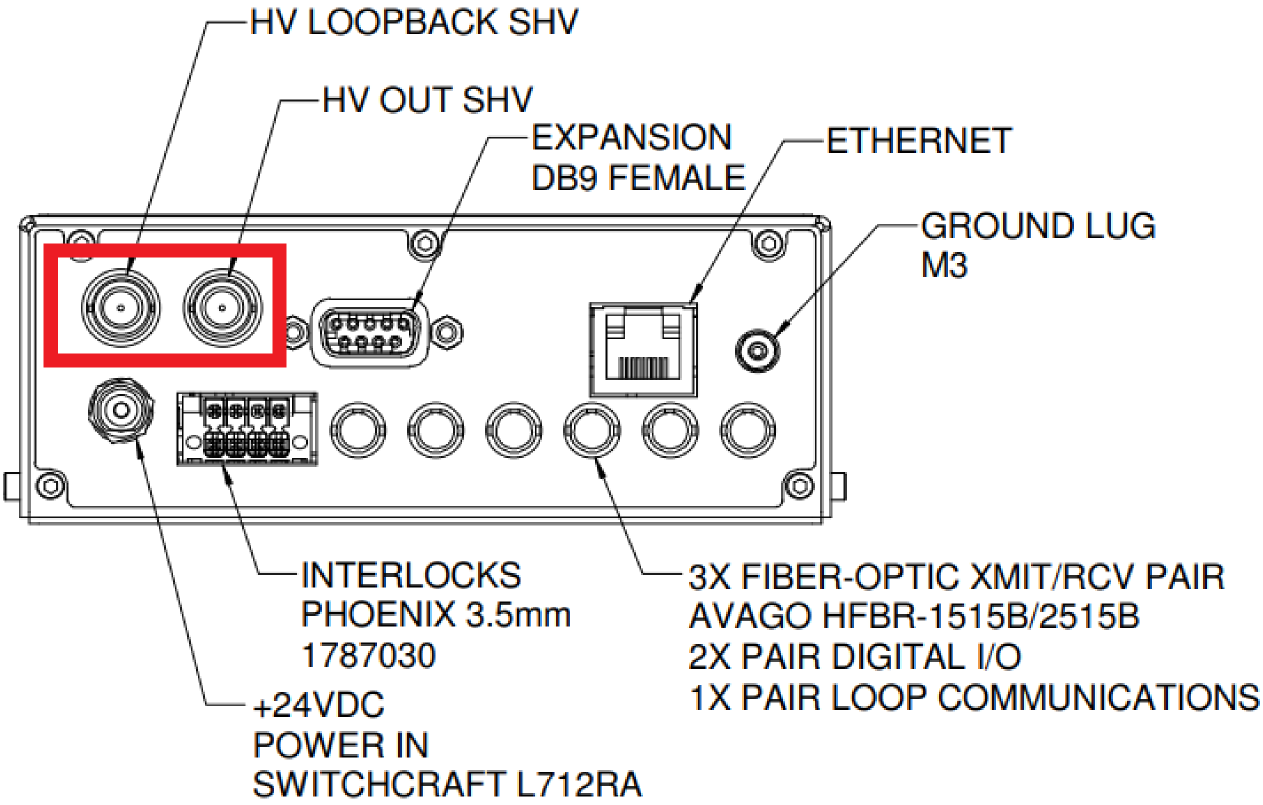
The FX4 high voltage can also be used to power an electron suppression ring. The power supply offers a fast response and sufficient current to effectively suppress modest incoming electrons.



13 High Voltage Loopback Arrangement

5.2.1 Connections

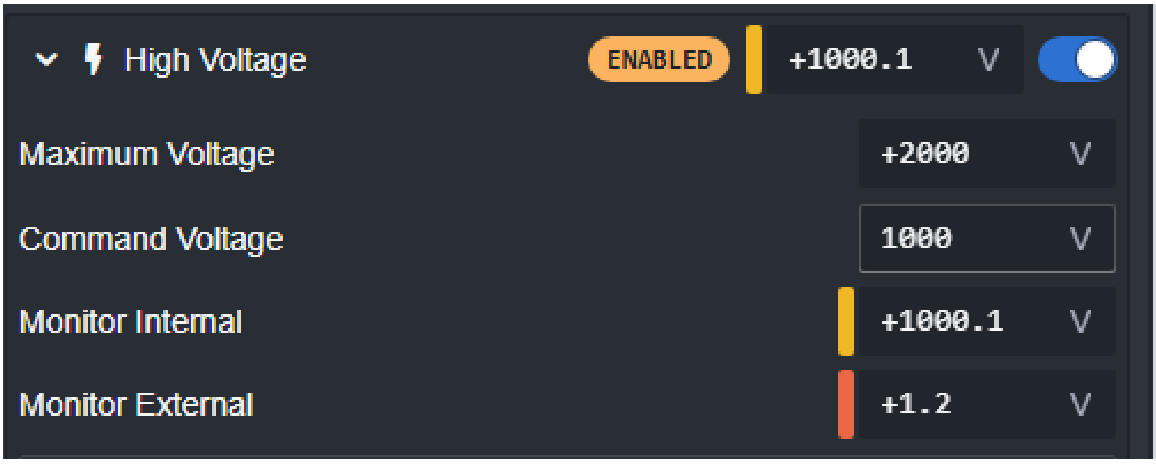
Two **SHV** connectors interface with the high voltage **output** and **loopback** signals.



14 High Voltage Connectors on Rear Panel

5.2.2 High Voltage Configuration

The High Voltage configuration section allows you to set the command voltage up to the maximum allowed voltage for the device. It also displays the values of both the **internal** and **external (looped back)** high voltage monitors. The switch in this section enables or disables the **HV output**.



15 High Voltage Configuration GUI

The following inputs and outputs are available:

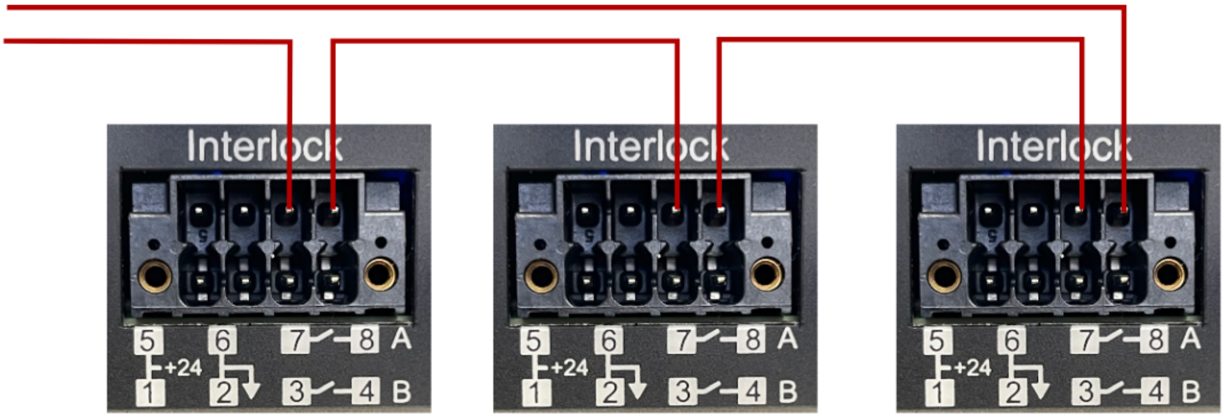
- **State**: The high voltage state is displayed at the center top. It can be **READY** if the supply is prepared but disabled or **ENABLED** if the supply is active and delivering high voltage.
- **Enable Switch**: This slider button enables or disables the high voltage supply.

- **Maximum Voltage**: The maximum voltage supported by the device.
- **Command Voltage**: The desired voltage, which must be less than or equal to the **Maximum Voltage**.
- **Monitor Internal (Output)**: The voltage measured at the output of the device.
- **Monitor External (Input)**: The voltage measured at the input of the device. Typically, the high voltage is looped through the device to be powered (e.g., an ionization chamber) and then looped back into the device for verification.

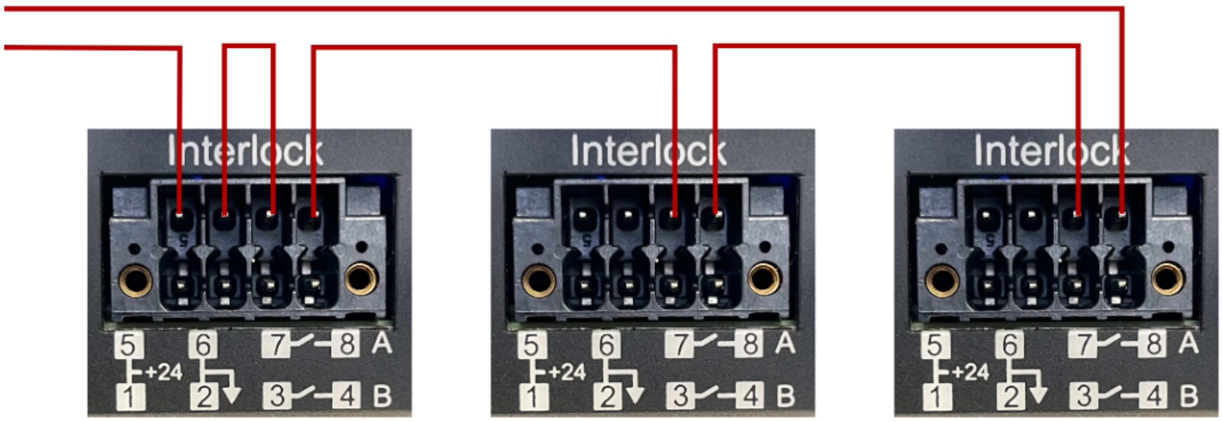
5.3 FX4 Solid State Relays

The FX4 includes a suite of interlock features that allow it to integrate into a dosimetry system where irradiation must stop if a failure or out-of-tolerance condition occurs. While the FX4 itself is not intended to implement a complete safety system, it can be a key component in such a system, specifically for tracking delivered dose, provided that a risk analysis is conducted and approval is obtained from the appropriate regulatory bodies.

The relays on the FX4 can be configured to operate in current loops or as 24V logic. A +24 VDC supply is provided and fused at 300 mA. In either configuration, it is straightforward to connect multiple devices in a series interlock loop, where any single device can interrupt the line, providing redundant interlocking and enhancing system reliability.

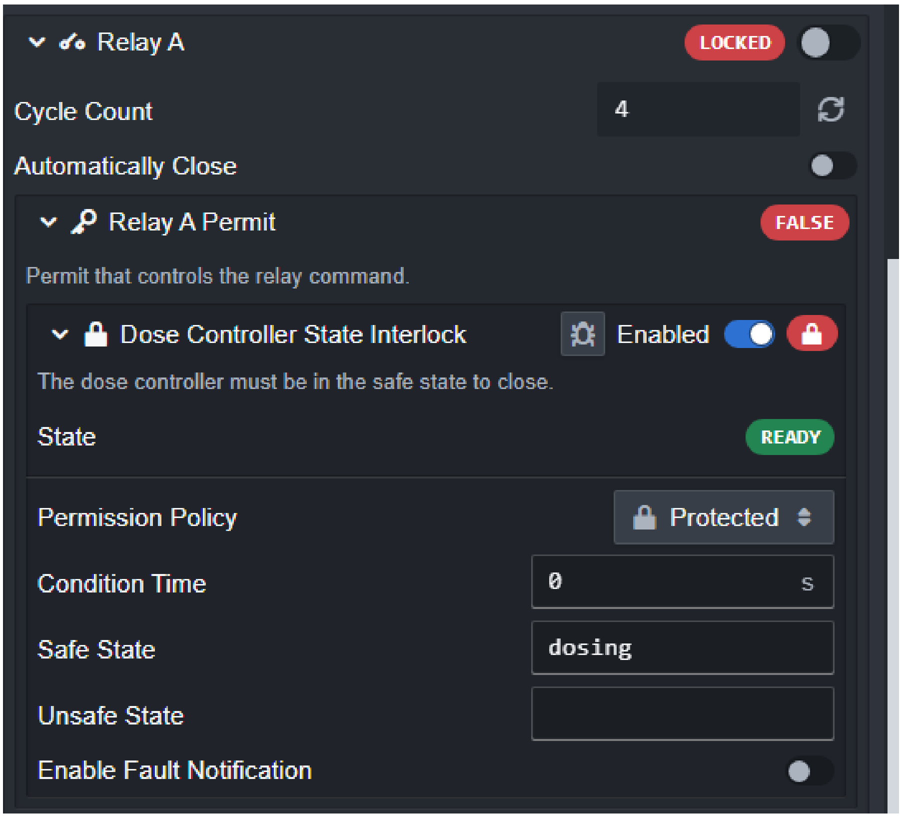


16 Interlock relays in series on multiple devices wired for current loop



17 Interlock relays in series on multiple devices wired for 24V logic

5.3.1 Configuration



- **Relay State**: Displays the current state of the relay. It will show CLOSED if the relay is closed, OPENED if the relay is open, or LOCKED is the relay is open and cannot be closed due to an interlock.
- **Relay Close**: A switch to manually open or close the relay, provided the relay is not in LOCKED state.
- **Cycle Count**: A readback that counts the number of times the relay has been closed.
- **Automatically Close**: When enabled, the relay will always close as soon as all enabled interlocks are ok. Relays always automatically open when an enabled interlock faults.

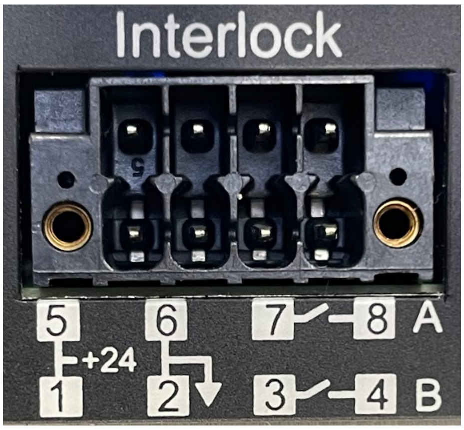
See the IGX User Manual for more information on how the IGX interlock and permit system works and how to configure induvial interlocks.

5.3.2 Connectors

The relay outputs are available on a single **Phoenix Combicon DMC8 pin header** (part number **1787030**, 3.5 mm pitch).

The pinouts are shown in the table below.

24 VDC power is provided through this connector for user convenience. However, it is not required to operate the relay contacts correctly.

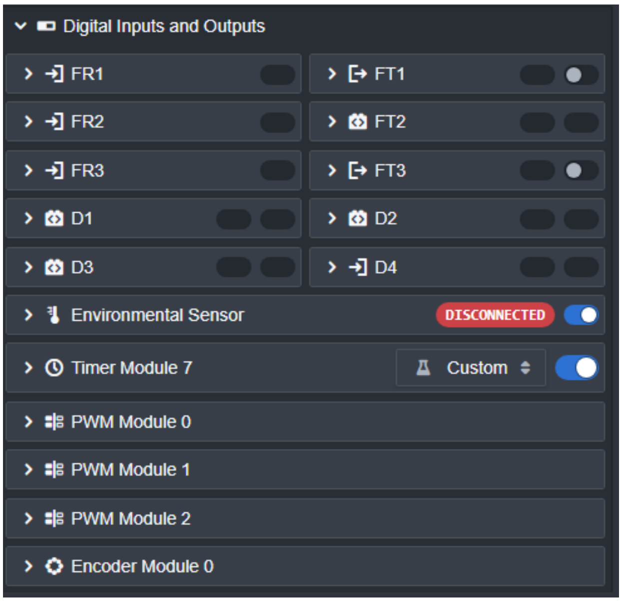


1	24 VDC Output (300 mA Fuse)	5	24 VDC Output (300 mA Fuse)

2	24 VDC Ground Return	6	24 VDC Ground Return
3	Relay B Contact 1	7	Relay A Contact 1
4	Relay B Contact 2	8	Relay A Contact 2

5.4 FX4 Digital Inputs and Outputs

The FX4 features a variety of digital inputs and outputs, including fiber optic I/O, digital I/O, and support for environmental sensors. The digital I/O is highly flexible and can perform a range of functions, including general-purpose I/O, encoder readout, pulse width modulation (PWM), UART communications, and process variables for dosimetry and other applications.



18 FX4 Digital IO GUI

Each digital may be assigned one of the following I/O Modes, depending on which digital:

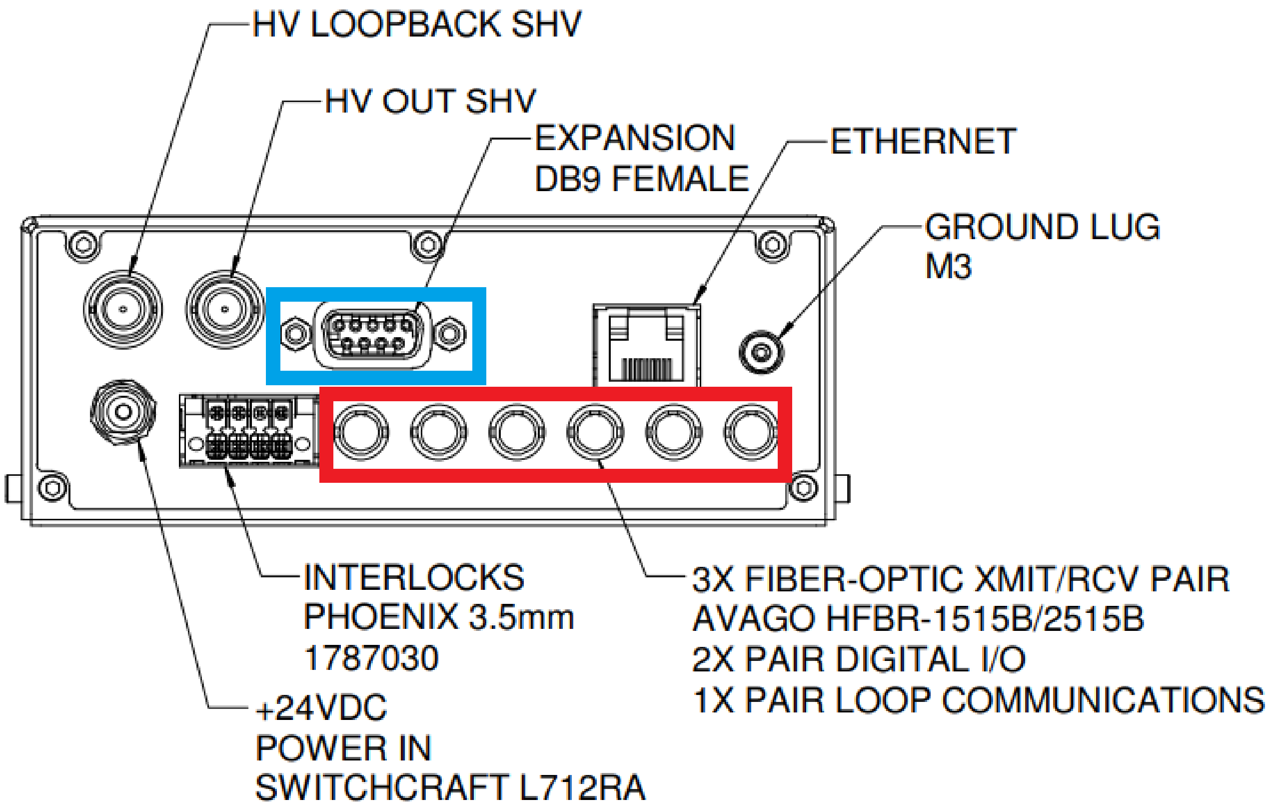
- **GP Input:** A general-purpose input.
- **GP Output:** A general-purpose output.
- **PWM 2 A/B Output:** An output that emits a PWN signal.
- **Encoder 0 A/B input:** One of the two encoder inputs when using the digital as an encoder.
- **Encode 0 Index Input:** Encoder index input when using the digital as an encoder.
- **Timer 7 I/O:** When the digital is used with timer 7 (D3 only)
- **UART Receiver:** Tx line when used as a UART.
- **UART Transmitter:** the Rx line when used as a UART.
- **Process Input:** Used for process (dosimetry) control as an input.
- **Process Output:** Used for process (dosimetry) control as an output.

Each digital may have one of the following options:

- **De-bounce:** Refers to the debounce of input signals. This is a setting within the electronics that will either report the instantaneous value of the input or a the value read after ~1 microsecond of delay.
- **Pull Mode:** Refers to the value of a digital input when the input is disconnected. Pull Down will cause the signal to read low (0), Pull Up high (1), and Disable will leave the input floating.
- **Output Slew Control:** refers to the rise rate of a digital output. This is ~5us when disabled, or 20us when enabled.

Some of the digitals may be used as a process signal, where the digital can be assigned to a process variable that can be used, for example, to start a process such as use with the Dose Controller.

5.4.1 Physical Connections



19 FX4 Rear Pannel Connectors

Fiber Optics

In the red section, there are three fiber optic transmitters with ST bayonet connectors (light grey, HFBR-1515) and three fiber optic receivers with ST bayonet connectors (dark grey, HFBR-2515).

Digitals and Environmental Sensors

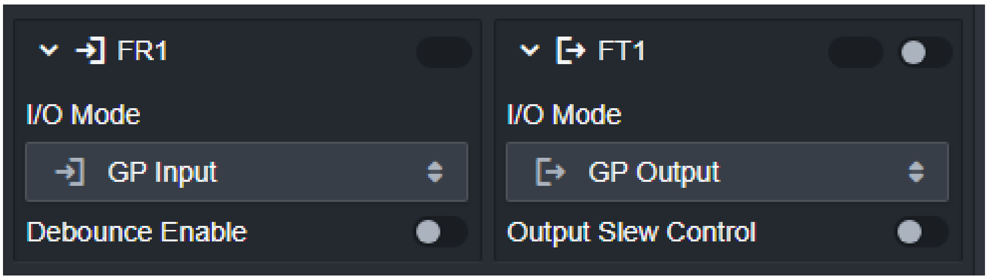
In the blue section, the digitals (D1-D4) and the environmental sensor are located on the D-sub 9 (female) expansion port.

1	D1 3.3V GPIO	6	I^2C SCL
2	D2 3.3V GPIO	7	I^2C SDA
3	D3 3.3V GPIO	8	3.3 VDC Output (300 mA max)
4	D4 3.3V GPIO	9	Ground
5	5.0 VDC Output (300 mA max)	SH	Ground

5.4.2 Digital Configuration

Fiber Optic Transmitters and Receivers

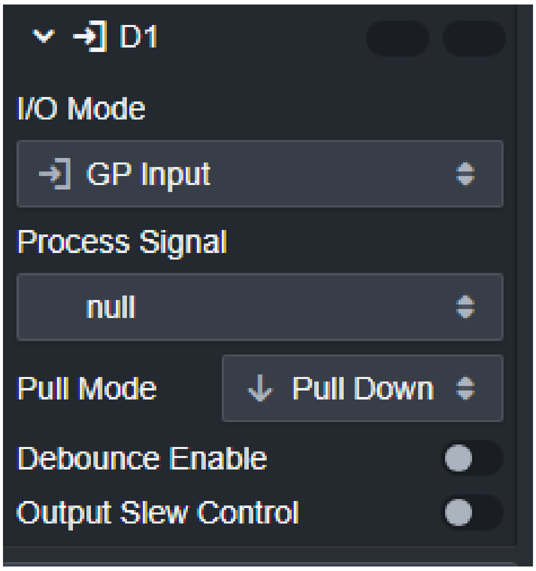
The FX4 is equipped with three fiber optic transmitter/receiver pairs, all of which can be used for general-purpose I/O. However, the first pair has a special function that allows it to be used for remote communication. The inputs can be de-bounced to eliminate noise, and the outputs can be slewed to smooth transitions.



3.3V Logic Digital I/O

Digital I/O is typically available through the D9 expansion connector, with individual pins referred to as D1, D2, D3, and D4. These digital I/O pins can be independently configured as either inputs or outputs.

For inputs, you can configure the de-bounce behavior and set pull-up or pull-down resistors. For outputs, the slew rate can be adjusted to control the signal transition.

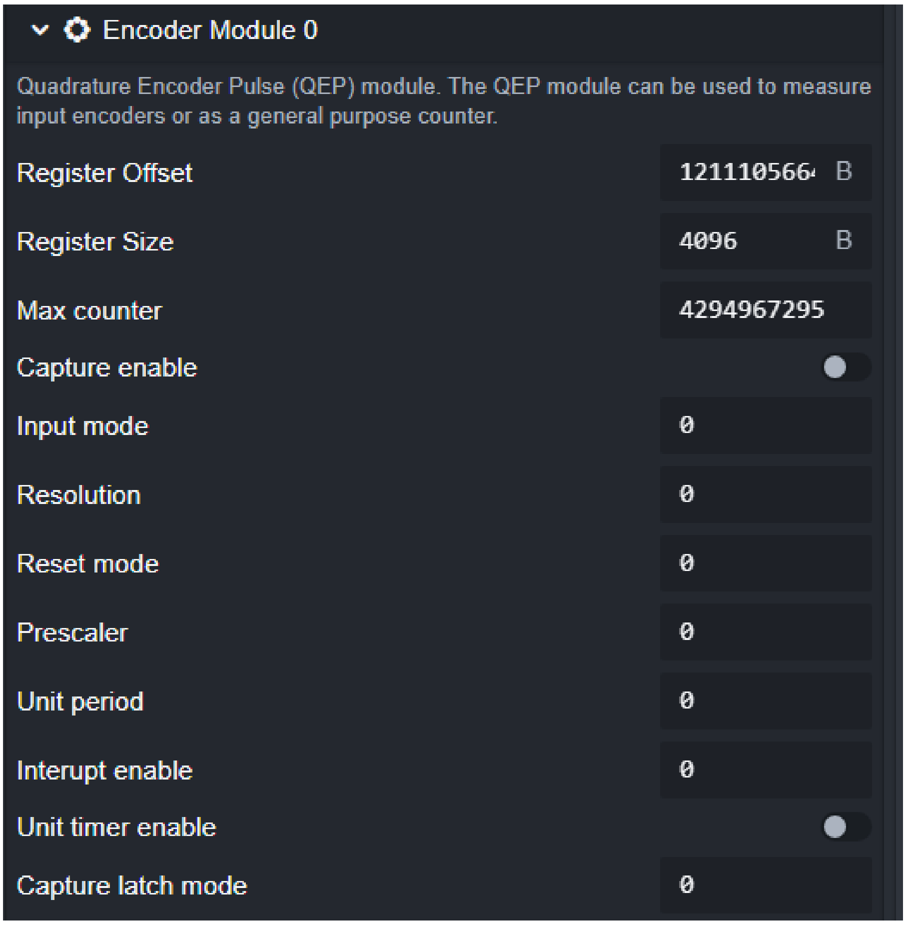


5.4.3 Digital Control Modules

Special control modules can be attached to these digitals as follows.

Encode Module 0

Encoder module 0 establishes a Quadrature Encoder Pulse (QEP) module. The QEP module can be used to measure input encoders or as a general purpose counter.



The encoder typically has three inputs, two to receive the encoder pulses, and one for the encoder index. These dedicated inputs must be programmed to enable the encode feature.

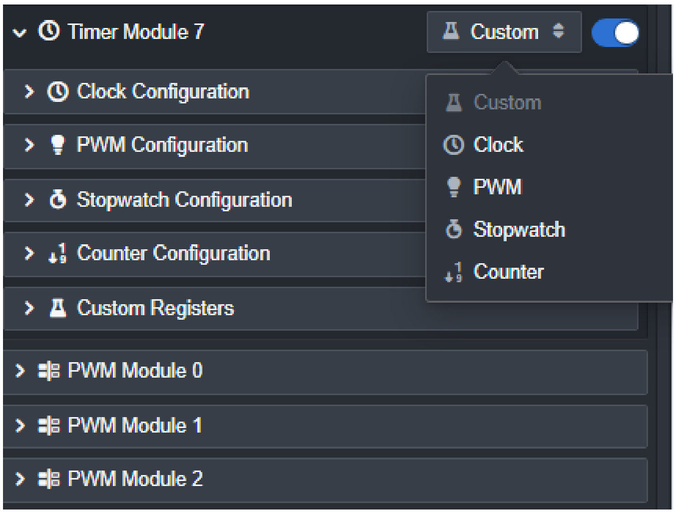
The following setups and readbacks are available:

- **Register Offset:**
- **Register Size:**
- **Max Count:** Contains the maximum position counter value (QPOSMAX).
- **Capture Enable:** Enables or disables the encoder input function.
- **Input Mode:** Quadrature count mode
- **Resolution:**
- **Reset mode:**
- **Prescaler:**
- **Unit Period:** Sets the unit period (QUPRD) that sets the periodic count of the system clock (SYSCLKOUT) that will cause an interrupt.
- **Interrupt Enable:** Enables unit interrupts.
- **Unit Timer Enable:** Enables or disables the unit timer (UTE).
- **Capture Latch mode**: Sets the capture mode (QEPCTL).

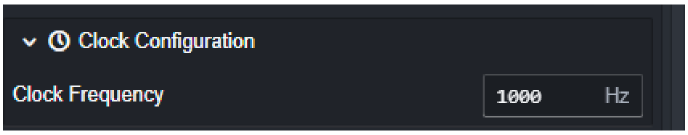
For more information on the encoder feature see the *Sitara AM335x Programmer Manual.*

Timer Module 7

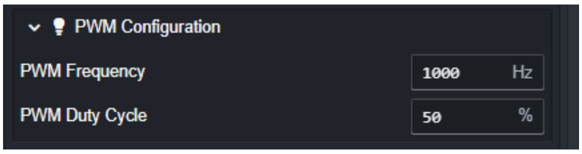
Timer Module 7 is used in conjunction with a digital when the digital type is selected as Timer 7 I/O. This option is used to enable several output and input options on the digital. An enable switch enables or disables the timer functionality.



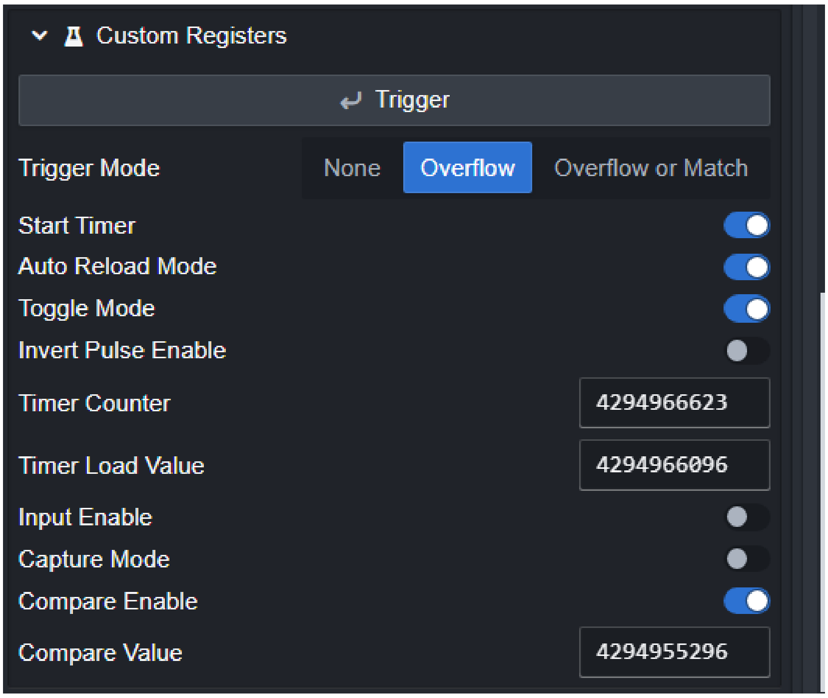
- **Clock Configuration:** When the timer module is set to “Clock”, the digital is programmed to output a standard clock signal. The clock frequency is configurable.



- **PWM Configuration:** When the timer module is set to “PWM”, then the digital can be programmed to output a Pulse Width Modulation (PWM) signal. The frequency and duty cycle of the PWM is specified from the GUI.



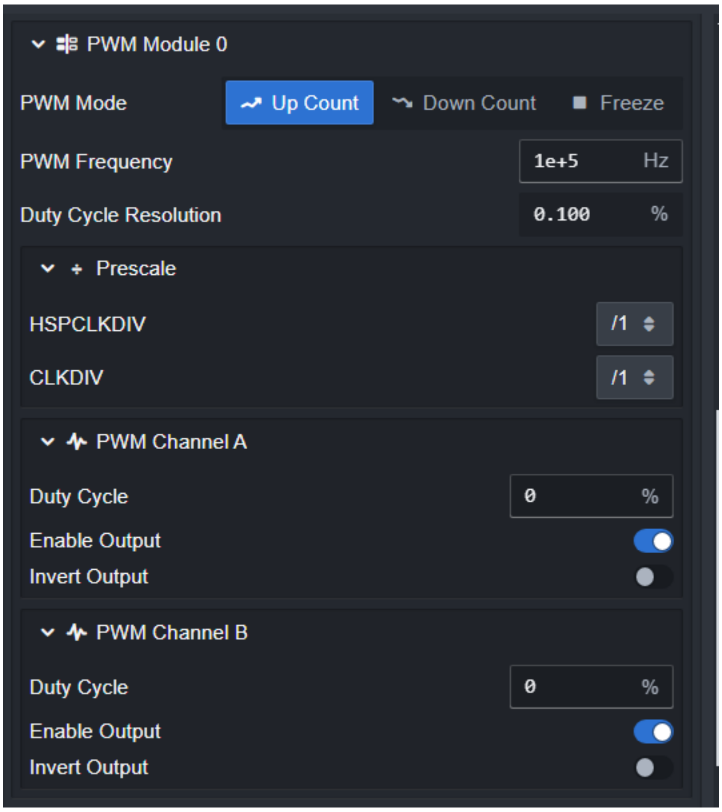
- **Stopwatch Configuration:** reserved for future use.
- **Counter Configuration:** reserved for future use.
- **Custom Registers:** this panel refers to the low level configuration of the timer module. Selecting any of the above options configures these registers as needed to achieve the Clock or PWM functionality. Custom programming of these registers is possible.



For more information on the Timer 7 feature see the *Sitara AM335x Programmer Manual.*

PWM Module 0, 1, and 2

PWM modules can control up to two digital outputs for pulse width modulation output. The digitals will be specific to the device, which will need to be programmed for PWM functionality.



The following setups and readbacks are available:

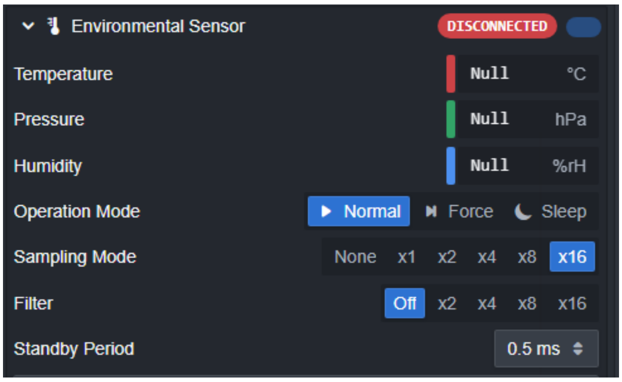
- **PWM Mode:** Sets the PWM mode to

  - up-count: the time based counter starts from zero and increments until it reaches the value in the period register.
  - down-count: the time based counter starts from the period register and decrements when it reaches zero.
  - freeze: the time-base counter starts from zero and increments until the period value is reached. When the period value is reached, the time base counter then decrements until it reaches zero. At this point the counter repeats the pattern and begins to increment.
- **PWM Frequency:** Base timer counter frequency which is used to determine the PWM period (see modes above).
- **Duty Cycle Resolution:** a readback that displays the resolution of the PWM, which is a function of the programmed frequency and the 16 bit counter.
- **Prescale:** scales the time base clock (TBCLK) of the PWM to the system clock according to the relationship TBCLK = SYSCLKOUT / (HPSCLKDIV * CLKDIV).
- **PWM A and B:**
  - Duty Cycle - the duty cycle of the PWM output
  - Enable Output - enables the output channel
  - Invert Output - inverts the output sense

Environmental Sensors

Several Pyramid ionization chambers are equipped with environmental sensors that measure temperature, pressure, and humidity within the chamber. These sensors report their readings via an I2C interface. Currently, the QIC-3E and IC128-25-LC models support this interface.

The GUI will display the connection status of the sensor, along with the value of each measured parameter.



20 Environmental Sensor GUI

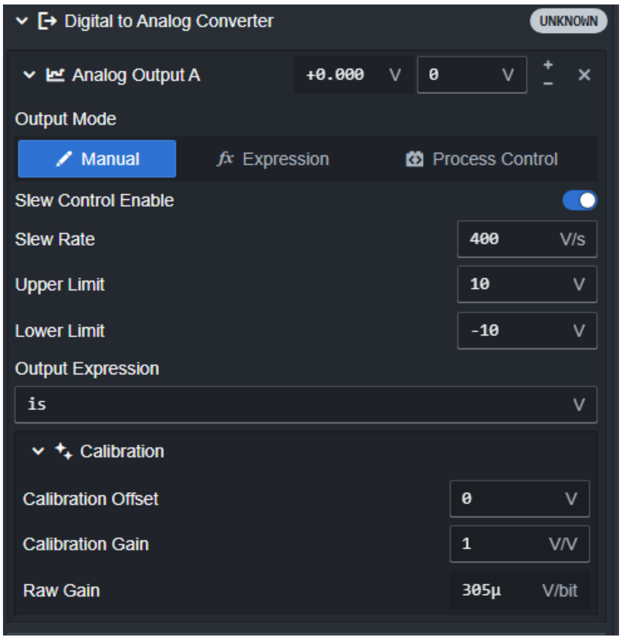
The following setups and readbacks are available:

- **Operation Mode**: When set to **Normal**, samples are continuously displayed. Toggling between **Force** and **Sleep** modes acquires single samples, useful for debugging purposes.
- **Sampling Mode**: Defines the number of samples to average for each reading, with a range from 1 to 16 (block average).
- **Filter**: Determines how incoming data is filtered using a low-pass filter to reduce noise.
- **Standby**: Sets the sample time interval between individual samples.

5.5 FX4 Digital to Analog Converter

The FX4 features four general-purpose analog outputs, each providing ±10 V with a maximum update rate of 1,000 Hz.

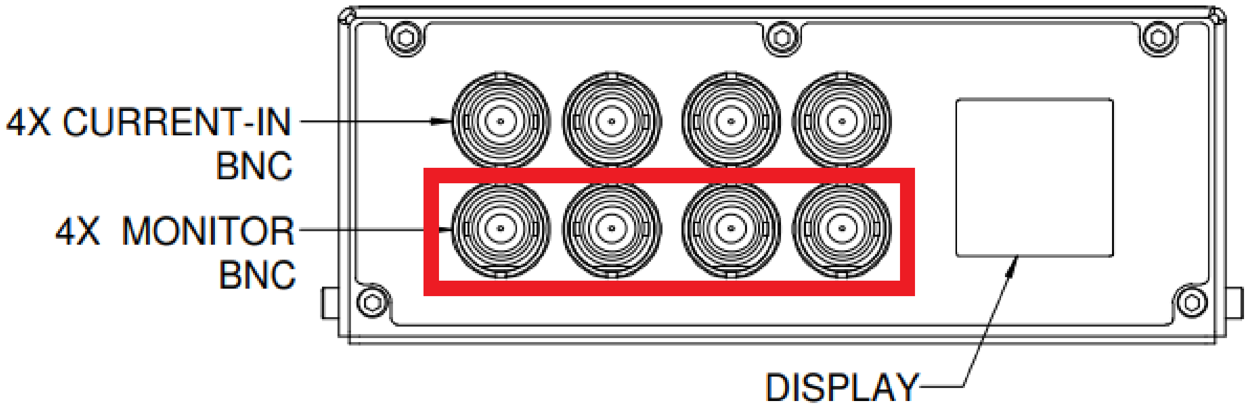
These outputs can be configured for manual operation or linked to various inputs and logic, allowing for flexible control and integration with other systems.



21 FX4 Digital to Analog Converter GUI

5.5.1 Analog Output Connections

The analog outputs are accessed via four BNC connectors as show in the diagram below.



22 The FX4 Analog Output Connectors

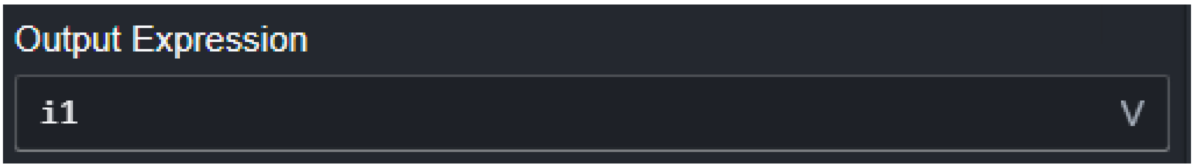
5.5.2 Analog Output Configuration

Output Mode

There are three output modes that determine what signals are sent to the outputs. The mode is selected by pressing one of the Output Mode buttons.

Manual mode allows the output voltage is manually specified. This can be done using the Web GUI or over the HTTP interface. On the GUI simply type in the desired voltage or use the increment keys.

Expression mode can be used to direct various inputs to the analog outputs, or a mathematical expression thereof. Consult the *IGX Programmer Manual* for details on expressions. The expressions can be used to simply reflect other values, such as the measured currents or the quadrant position, or to implement more complex expressions as needed.



Some common expressions are shown in the table below.

Expression	Description
i1, i2, i3, i4	Input current for channels 1to 4. Note that the units will correspond to the units currently selected - for example, if nA is selected, then the output will be 1 V/nA. The value could be multiplied by a factor to get a full scale. 1 * i1 would then set the scale to 10 nA/V. A function will be added in a future release to convert the value to A so that the sale would be independent of the set units.
is	Input current channel 1-4 sum
px, py	X and Y positions from the quadrant detector

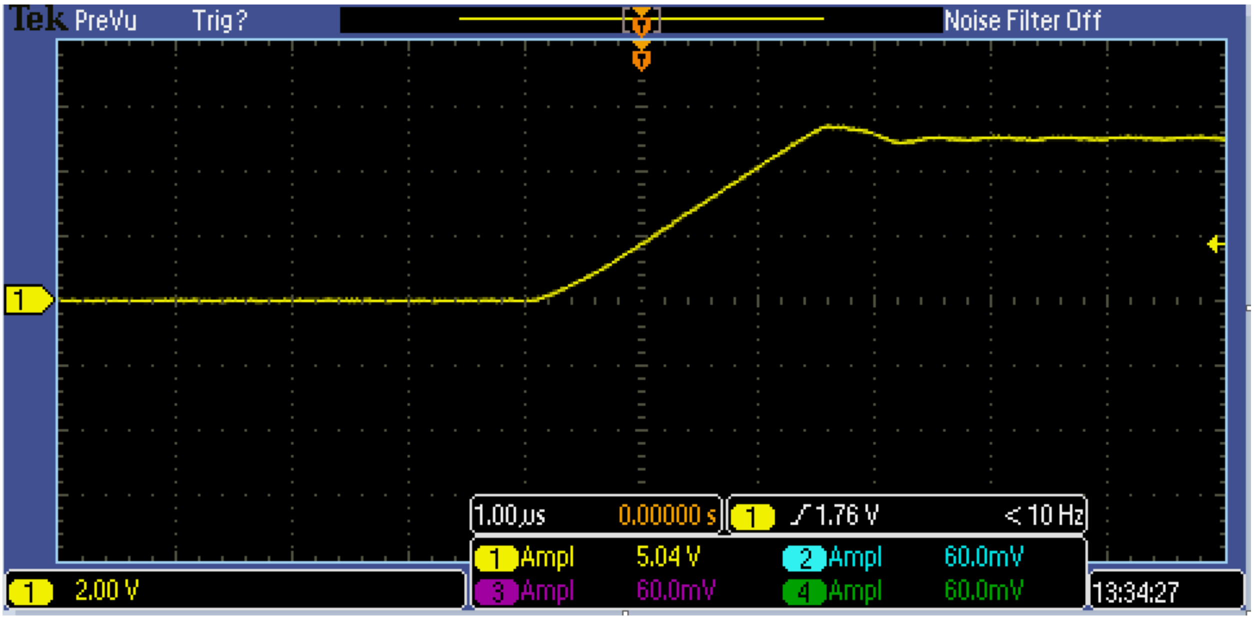
Process mode is reserved for process related functions, such as employed by the Pyramid Nozzle software. This feature is not otherwise available to the user.

Slew Rate

It may not always be appropriate to make large steps in the FX4 analog outputs. For instance, if the FX4 is controlling a power supply driving an inductive load, a sudden demand for a current step may cause the power supply to hit its voltage compliance limit and possibly lose regulation. One way to manage this is by commanding the FX4 to make a series of small steps, effectively simulating a smooth ramp. However, implementing this through a sequence of commands may impose an unacceptable load on the communications.

The slew rate is set in volts per second, with the ramp waveform generated internally by the FX4. The host software only needs to specify the target voltage, and the FX4 will compute and execute the ramp. The ramp rate value is available in the Web GUI or can be programmed via the HTTP interface.

If the ramp rate is set to zero, the feature is disabled, and the output will change as fast as the FX4 internal amplifiers allow. The figure below illustrates a 5V step without rate limiting, with the main linear portion of the change occurring at 1.9e6 V/s.

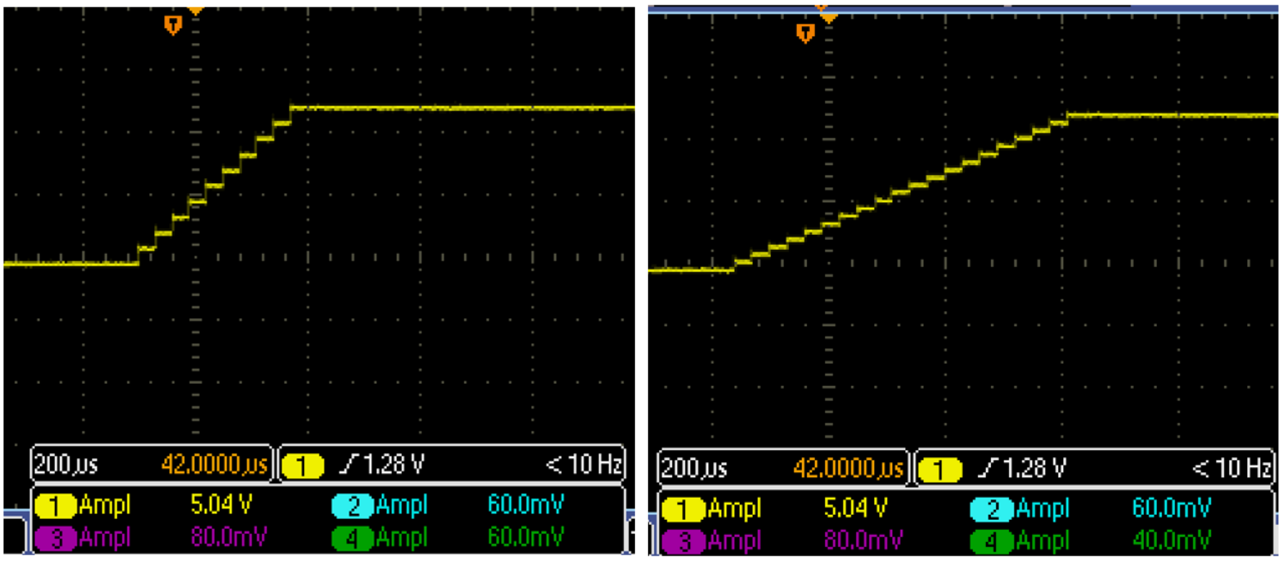


23 Analog Output Ramp Rate with No Slew

Setting a non-zero value for the ramp rate defines the rate in V/sec. The FX4 will then execute a staircase of small, short steps to closely approximate a smooth slope at the requested rate. The fine detail of this staircase is constrained by the minimum time between steps (25 microseconds) and the smallest possible voltage step (one bit = 0.3 mV).

The slew rate is set in the GUI in V/s.

The plots below show slewing at various rates:



24 Slewing output at 50,000 V/s (left) and 20,000 V/s (right5

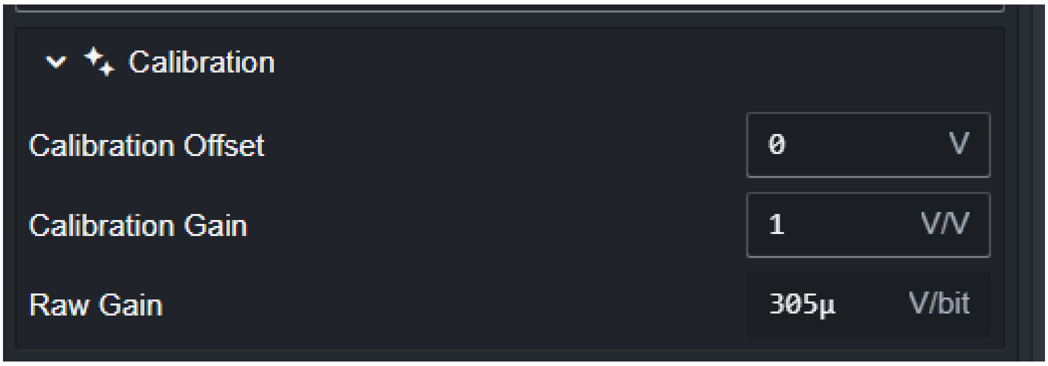
Output Voltage Limits

Limits can be imposed on the analog outputs by entering the appropriate values in the Upper Limit and Lower Limit fields. This ensures that the outputs will never exceed these specified values. For example, the output signal can be constrained to a range of 0-5 V by setting the corresponding limits. These limits are of particular importance when using the expression mode.

Output Voltage Calibration

Ideally, the FX4 would output and input perfectly accurate analog voltages. In practice, small circuit offsets and gain errors introduce minor inaccuracies. To compensate for these, the FX4 stores calibration factors that improve the absolute accuracy of the device by an order of magnitude. Each analog output has its own gain and offset factor.

These values can be viewed in the GUI as shown below. Please note that these values are modifiable only in Develop mode.



The calibration factors are determined using high-precision test equipment and stored in the FX4's internal memory as part of the manufacturing process, or when the unit is returned for recalibration. These parameters are reloaded each time the FX4 is powered up.

The calibration factors are applied as follows:

```
Vout = Gain * (Vraw - Offset)
```

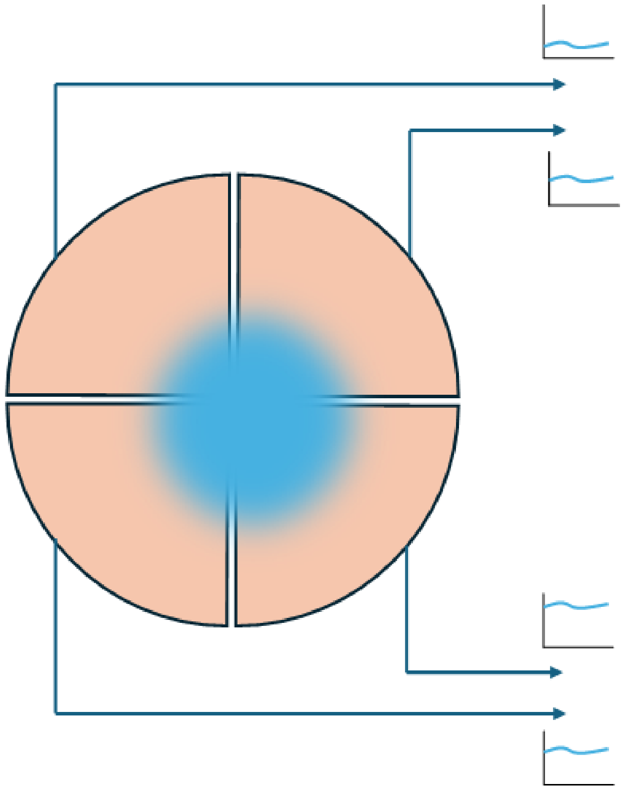
Where Vout is the voltage sent out by the FX4, and Vraw is the voltage that would be sent out if no calibration were applied.

The Raw Gain represents the resolution of the output, or the number of microvolts per bit.

5.6 FX4 Quadrant Sensor Readout

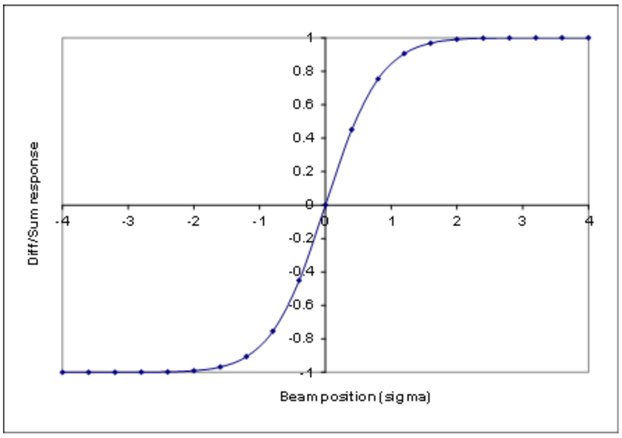
If the FX4 is connected to a symmetric quadrant sensor arrangement, the centering of a charge distribution can be determined from the four signals.

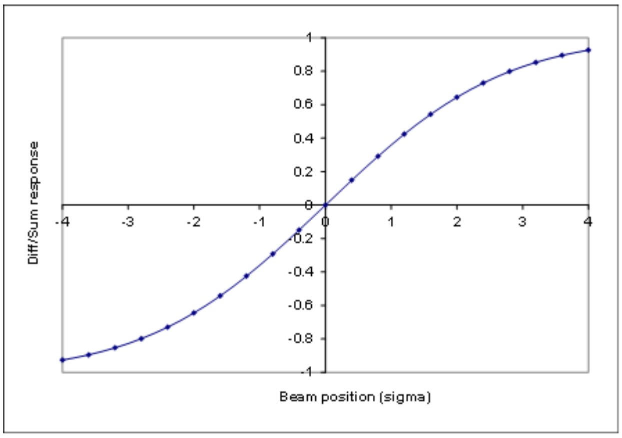
The labeling of the four quadrants, the orientation of the sensor, and the required **XY** coordinate system must all be carefully considered when mapping the sensor outputs to the FX4 inputs. For example, the Pyramid QIC-6E[9] quadrant ionization chamber labels the quadrants in an anticlockwise direction, starting at the lower right. To align with a conventional coordinate system where positive **X** and **Y** indicate a position in the upper right quadrant, the connections must be made as shown in the diagram.



25 Example Quadrant Detector Signals

If the distribution of current density is fairly well centered on the four sensors, such that the currents are similar, the position response function is reasonably linear around the centered position. The slope of this function depends on the width of the current distribution. As less of the current falls on one half of the quadrant pattern, the sensitivity gradually decreases, eventually reaching zero. The plots below show the shape of the response function along one axis for a narrow **Gaussian** current distribution with a **sigma of 1.0** in the position axis units and a broader distribution with a **sigma of 2.5**.





If the current distribution is nominally centered and flat between some limits, then the response function can be interpreted as a measure of flatness or symmetry rather than position. A typical application would be a particle beam that is scattered laterally then collimated with an aperture.

9 https://pyramid.tech/products/qic-6e

> The whole of the current distribution must be collected by the quadrant pattern in order to get the correct response function.

5.6.1 Quadrant Position Calculation

The FX4 employs an algorithm to calculate the beam position, based on a standard method used for beam position calculations. The basic algorithm assumes a **Gaussian beam** and is as follows:

- **X** = **F** * (((**A** + **D**) - (**B** + **C**)) / (**A** + **B** + **C** + **D**))
- **Y** = **F** * (((**A** + **B**) - (**C** + **D**)) / (**A** + **B** + **C** + **D**))

In this formula, **A**, **B**, **C**, and **D** represent the measurements from the four detector elements, and **F** is a scaling factor.

While this basic algorithm provides a starting point, modifications are often necessary to handle real-world data effectively. These adjustments ensure that the calculated beam positions are stable and suitable for use in feedback systems, where accurate and reliable positioning is critical.

The exact C++ code used to calculate the beam position is provided below for reference.

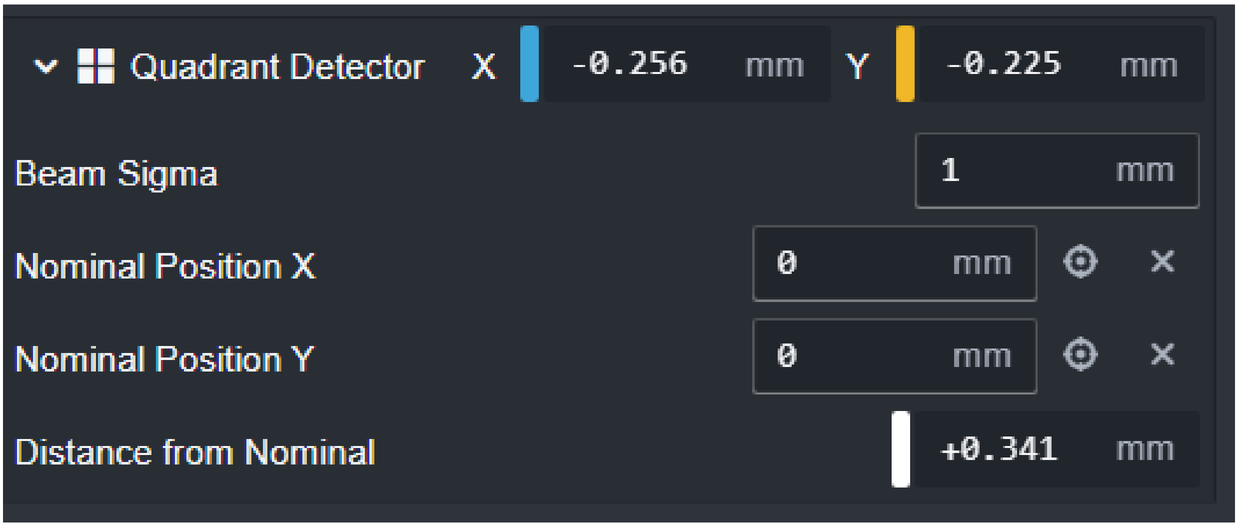
```
const double a   = quadrant_a.get();
const double b   = quadrant_b.get();
const double c   = quadrant_c.get();
const double d   = quadrant_d.get();

// Calculate the absolute sum.
const double sum = std::abs(a) + std::abs(b) + std::abs(c) + std::abs(d);

const double cos45 = 0.70710678118; // cos(45 degrees)
const double sin45 = 0.70710678118; // sin(45 degrees)

// Calculate beam position from -1 to 1 where 0 is centered.
// Normalize by the absolute sum
double x = ((a * -cos45) + (b * cos45) + (c * cos45) + (d * -cos45)) / sum;
double y = ((a * sin45) + (b * sin45) + (c * -sin45) + (d * -sin45)) / sum;

// Get 3 sigma as a close approximation of beam size
const double sigma3 = beam_sigma.get() * 3.0;

// Multiply the normalized beam position by 3 sigma in order to get
// the new beam position in millimeters.
position_x.set(x * sigma3);
position_y.set(y * sigma3);
```

At the very end of the algorithm, the normalized values are multiplied by beam sigma to get the position in millimeters. This is a rough approximate and should not be used for precise beam alignment except for centering.

> If you want the position function to vary between -1.0 and +1.0, set the beam sigma value to **0.42** mm which sets the multiplying gain factor F to 1.

5.6.2 Quadrant Configuration

The Quadrant Detector GUI provides the user interface for managing and interacting with the quadrant feature of the FX4. This interface allows users to monitor and configure the parameters related to beam positioning, making it easier to align and optimize the beam for various applications.



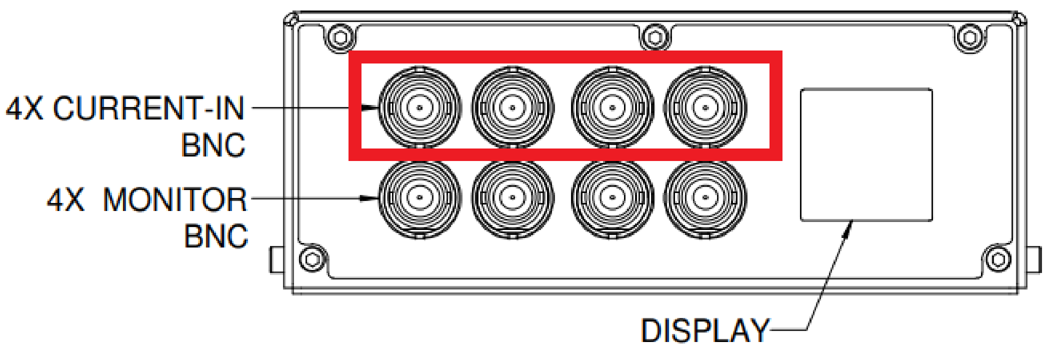
26 Quadrant Detector Configuration GUI

The following setups and readbacks are available:

- **Beam Position**: The calculated **XY** beam position is displayed in the upper portion of the GUI, in millimeters (mm). This value is derived from the signals provided by the quadrant detector and is influenced by the **Beam Sigma**, as described in the overview section.
- **Beam Sigma**: This is a scale factor used to specify the **beam sigma**, which is a parameter that describes the beam's width or spread. The beam sigma is used in the calculation of the beam position in millimeters (mm), helping to adjust the sensitivity of the system to changes in the beam's spatial distribution.
- **Nominal X Y Position**: This represents the expected or target location of the beam in **X** and **Y** coordinates, displayed in millimeters. It provides a reference for where the beam should ideally be positioned. This factor is used to correct for any misalignment of the beam in the detector.
- **Distance from Nominal**: This value shows the **distance** the beam is from the nominal position, in millimeters. It helps the user understand the current alignment of the beam relative to the expected or ideal position. This readout is used for interlocking on beam position because it provides an unbiased magnitude that treats all offsets within the radius equally.

5.6.3 Connections

The quadrant detector algorithm utilizes the four current inputs from the quadrant detector, which are accessed via BNC connectors, as shown in the diagram below. Each of these inputs corresponds to a different sensor element in the quadrant detector, allowing the system to calculate the position of the beam by comparing the relative currents detected by each sensor.

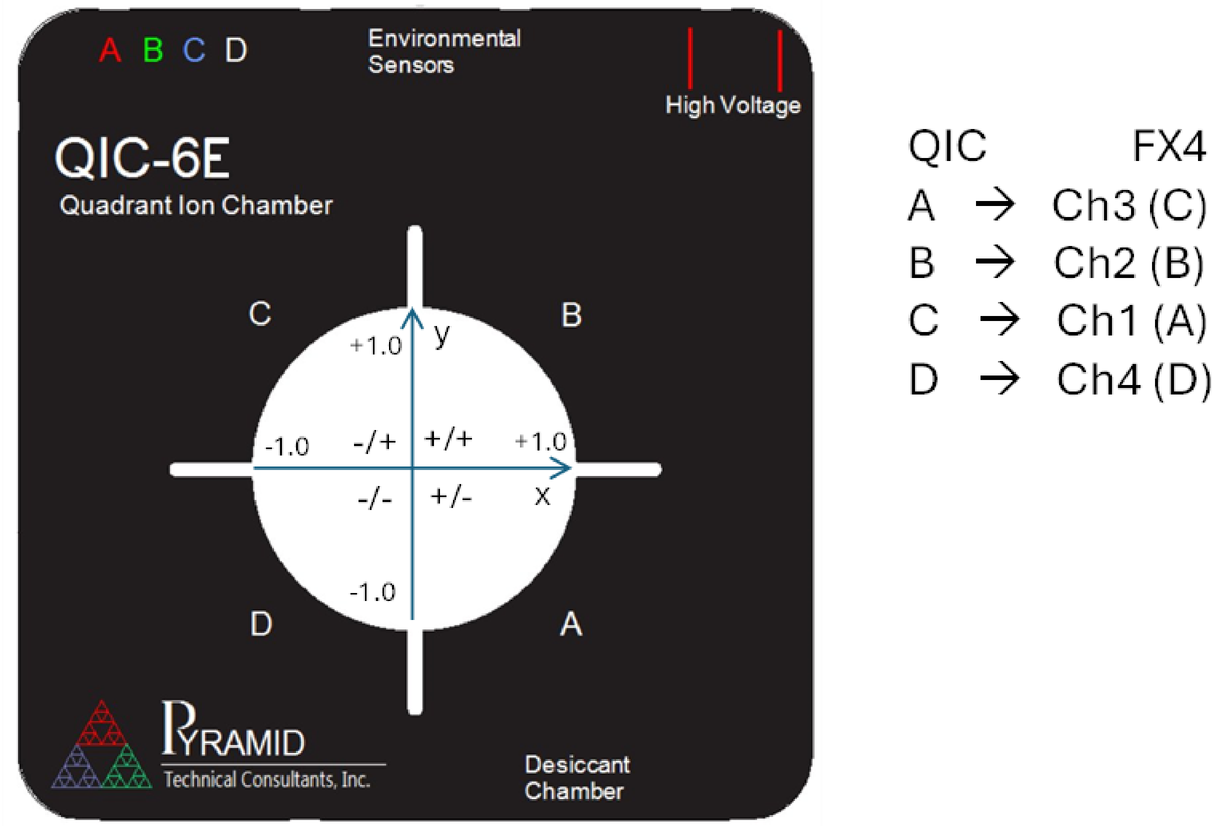


27 Connecting the Quadrant Detector

The labeling of the four quadrants, the orientation of the sensor, and the required XY coordinate system must all be carefully considered when mapping the sensor outputs to the FX4 inputs. These factors ensure that the calculated beam position aligns with the expected coordinate system for accurate feedback and measurement.

As an example, the Pyramid QIC-6E quadrant ionization chamber labels the quadrants in an anti-clockwise direction, starting from the lower right. To achieve a response that corresponds to a conventional XY coordinate system, where positive X and Y indicate positions in the upper right quadrant, the connections must be made in the specific configuration shown in the diagram below.

By correctly mapping the sensor outputs to the FX4 inputs, you can ensure that the beam position calculation accurately reflects the correct X and Y coordinates, as required for your system.



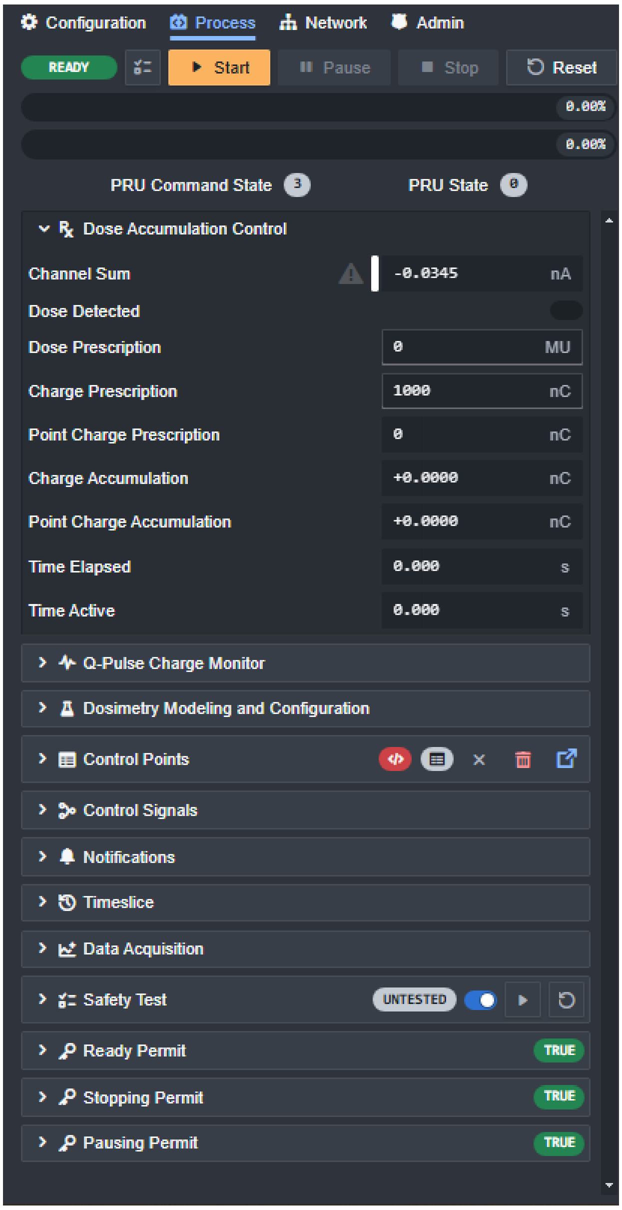
28 The QIC-6E Quadrant Detector

5.7 FX4 Dose Controller

The FX4 Dose Controller software allows a target dose to be delivered by controlling the total charge, which is measured as the integrated sum of the channel currents. Once the target charge is reached, the FX4 will alter the state of one or more of the digital outputs, fiber optic outputs, and relay states.

The Web GUI for controlling and monitoring the dose delivery can be accessed from the Process tab.

A typical application of this functionality is the delivery of a dose to a target using a radiation beam, which may be used in investigations, therapy, or material modification. The dose can be delivered in a single irradiation event or as a sequence of shorter irradiations at designated control points, often referred to as "spots." At each control point, parameters such as the delivered charge, beam position, size, and energy can be varied. These control parameters are typically specified in a map file.



29 FX4 Dose Controller GUI

In operation, the FX4 enables the radiation beam by setting the requisite outputs, but only after confirming that all necessary preconditions and safety checks are met. If the beam stays within the defined tolerances and all other safety conditions are satisfied, the target dose is delivered. Once this is completed, the beam is turned off through one or more of the FX4 outputs. Additionally, in the case of an error or fault condition, the beam will be immediately turned off to ensure safety.

The FX4 can be configured to either stop or not even start the beam in various interlock conditions. These interlock conditions have configurable parameters that determine the sensitivity and speed of the shutoff response, providing flexibility to meet different safety and operational requirements.

For a complete description of the *Dose Controller* functionality, please refer to the *IGX User Manual | Dose Controller.*

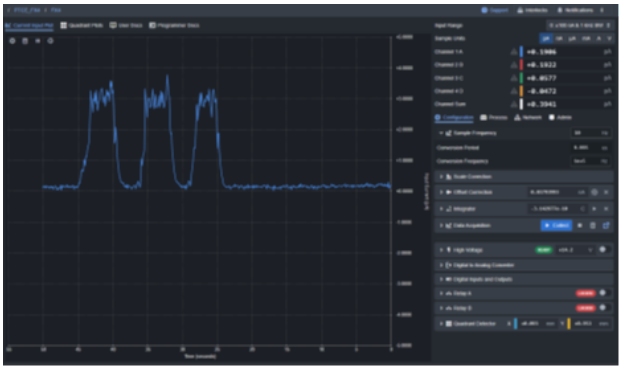
The Dose Controller feature can be quite complex and intimidating to use, especially for new users. Please do not hesitate to reach out to Pyramid for any assistance during this process. Many of our Dose Controller users seek help at various stages, and we are more than happy to guide you through the setup and operation to ensure that everything runs smoothly and safely.

6 FX4 Making Measurements

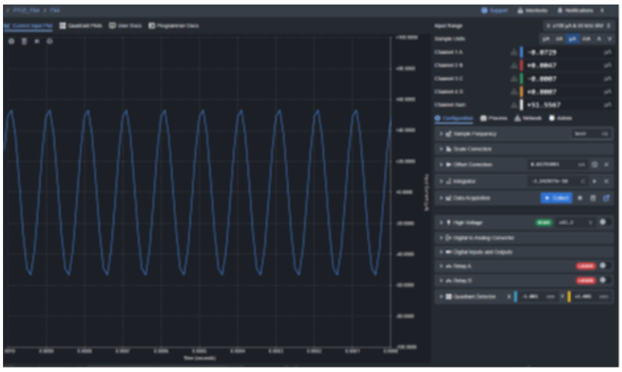
The FX4 can measure currents ranging from a few picoamperes (pA) to several milliamperes (mA), offering a dynamic range of nine orders of magnitude. This range can be extended to ten orders of magnitude when the full 10 mA range is enabled. High-precision components in the input stage ensure excellent stability and accuracy across this broad range.

To fully exploit the FX4's performance, careful attention must be given to the settings, including the tradeoff between speed of response and signal-to-noise ratio. It's essential to consider sources of noise and the overall measurement setup to achieve optimal results.

The signals shown below illustrate the FX4's capability: On one end of the spectrum, it can resolve a three pA current from an ionization chamber using the most sensitive range with slow sampling. On the other end, it can accurately measure a 10 kHz sine wave on the 100 µA range with fast sampling.



30 Extremely Small Pulses of Current



31 Fast Sin Wave of Current

6.1 Signal Cable Length and Type

For optimal performance, it's important to use high-quality, fully shielded coaxial cables. While RG-58 and RG-59 are cheap and common choices, they provide poor shielding and poor triboelectric performance, making them more susceptible to electromagnetic interference (EMI) and signal degradation. These cables are typically used in general applications but are not ideal when accuracy and signal integrity are critical.

A much better option is the Times Microwave LMR®-240-UF, which offers superior shielding and excellent triboelectric performance. This cable is doubly shielded and designed to minimize noise, ensuring precise measurements. While it is more expensive than typical cables, it is highly recommended for applications that require high performance. Pyramid offers this cable for sale upon request.

Additionally, the length of the cable is important. Longer cables add capacitance to the Transimpedance Amplifier (TIA) input, which can increase the intrinsic noise of the TIA and degrade signal quality. Extra cable length also exposes the system to more EMI through increase surface area. To minimize these effects, it is best to keep cable lengths short. A typical length of up to **1 to 10 meters** is recommended, but lengths of up to **50 meters** can be used for measuring nanoamp currents if necessary. One such case could be when keeping the FX4 outside a controlled area like a radiotherapy patient treatment room.

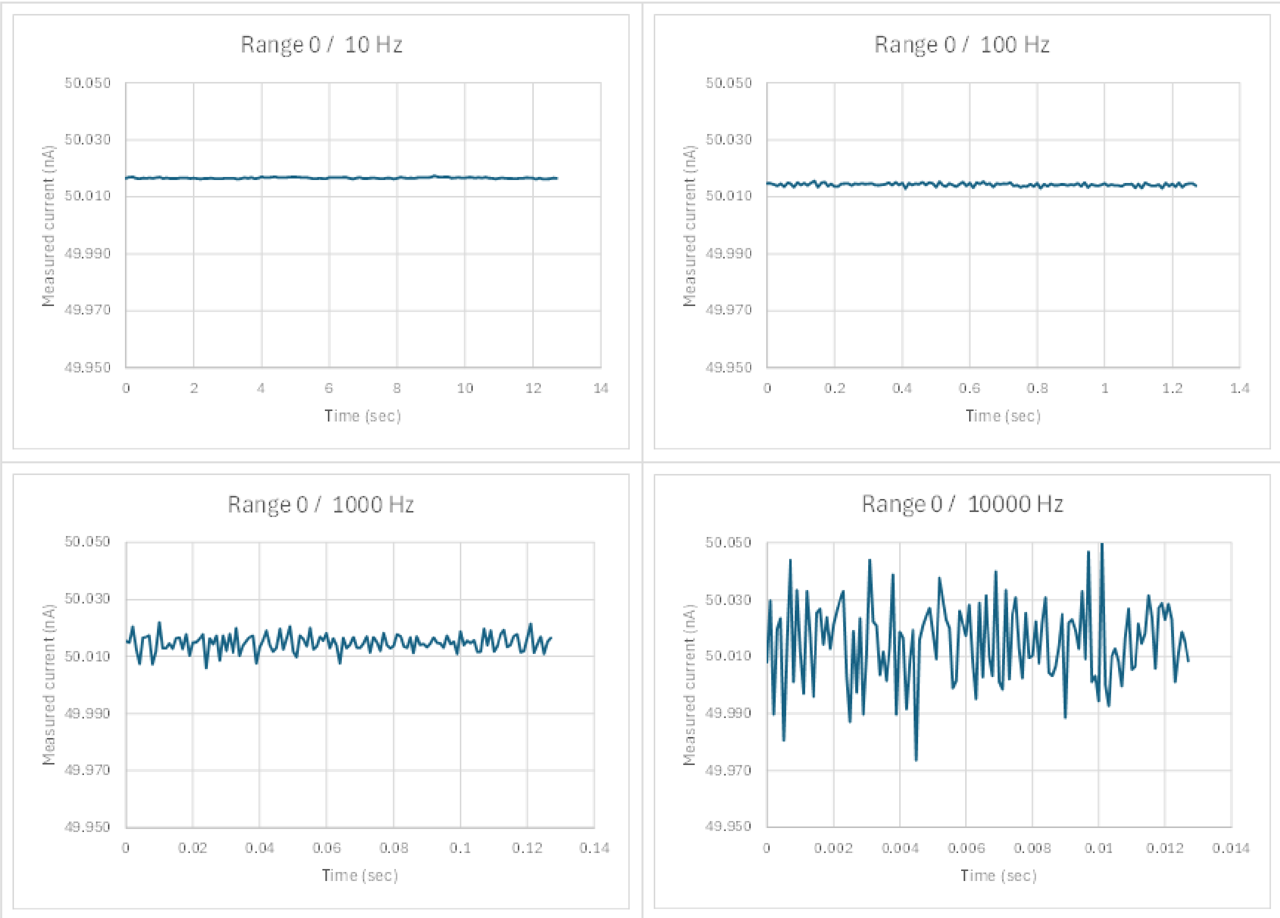
For permanent installations, it is important to consider the FX4's location, cable routing, cable quality, termination, and overall ground continuity between the signal source and the electronics to achieve the best possible performance.

6.2 Sampling Rate and Measurement Range

When investigating an unknown signal, especially for small current measurements, it's a good practice to start by testing different sampling rates. This allows you to find the best balance between time resolution and signal-to-noise ratio. It can also help identify AC interference at specific frequencies, such as the common 50 or 60 Hz line voltage interference.

The FX4 averages multiple analog-to-digital converter (ADC) readings to produce each sample. For example, if the ADC rate is set to 1e5 Hz (100,000 samples per second) and the sample rate is set to 10 Hz, then 10,000 conversions are averaged to provide each reading. This averaging process significantly enhances the sensitivity of the measurement by filtering out higher frequency random noise.

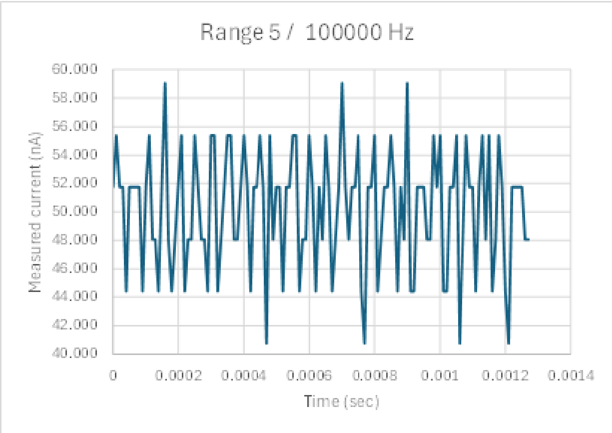
The illustrative data plotted below shows 128 consecutive samples of a 50.015 nA signal measured on range 0 (100 nA full scale), at various FX4 sample rates. Note the difference in timescales: at a 10 Hz sample rate, the plot covers a total of 12.8 seconds of data, whereas at a 10,000 Hz sample rate, the plot shows only 12.8 milliseconds of data.

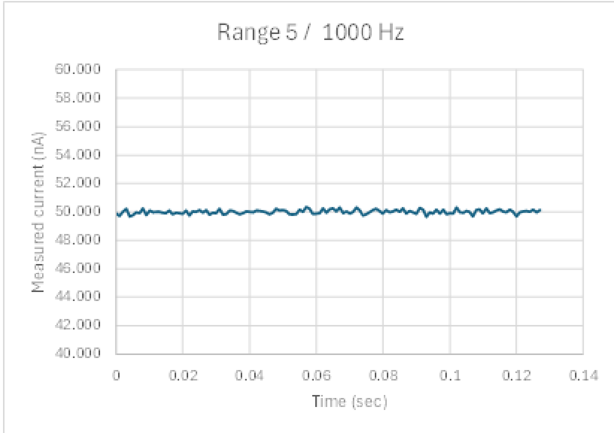


Whenever possible, it is best to use the most sensitive range that will cover your anticipated maximum currents. This ensures the best resolution and signal-to-noise ratio. However, if you're concerned about potential overranges, the next higher range may still provide acceptable performance while ensuring you stay within the measurement limits.

The current change corresponding to one ADC bit varies with the selected range, which determines the ultimate resolution of the measurement. For example, on the 100 nA scale, the resolution is around 3 pA per bit, while on the 10 mA scale, it is around 300 nA per bit. The effect of averaging also improves the effective resolution, especially in real-world scenarios where some noise is typically present.

However, if averaging is reduced by using a fast sample rate on a very low-noise signal, or on a signal that is close to the bottom of the selected range, digitization effects can become apparent. The example below shows the limited number of values that can be returned when a relatively stable 50 nA signal is sampled at 1e5 Hz (no averaging) on the 100 µA range. This situation can be easily avoided by correctly selecting the measurement range and sampling rate. For instance, reducing the sample rate to 1000 Hz provides useful data even when measuring a signal that is just 0.05% of full scale.

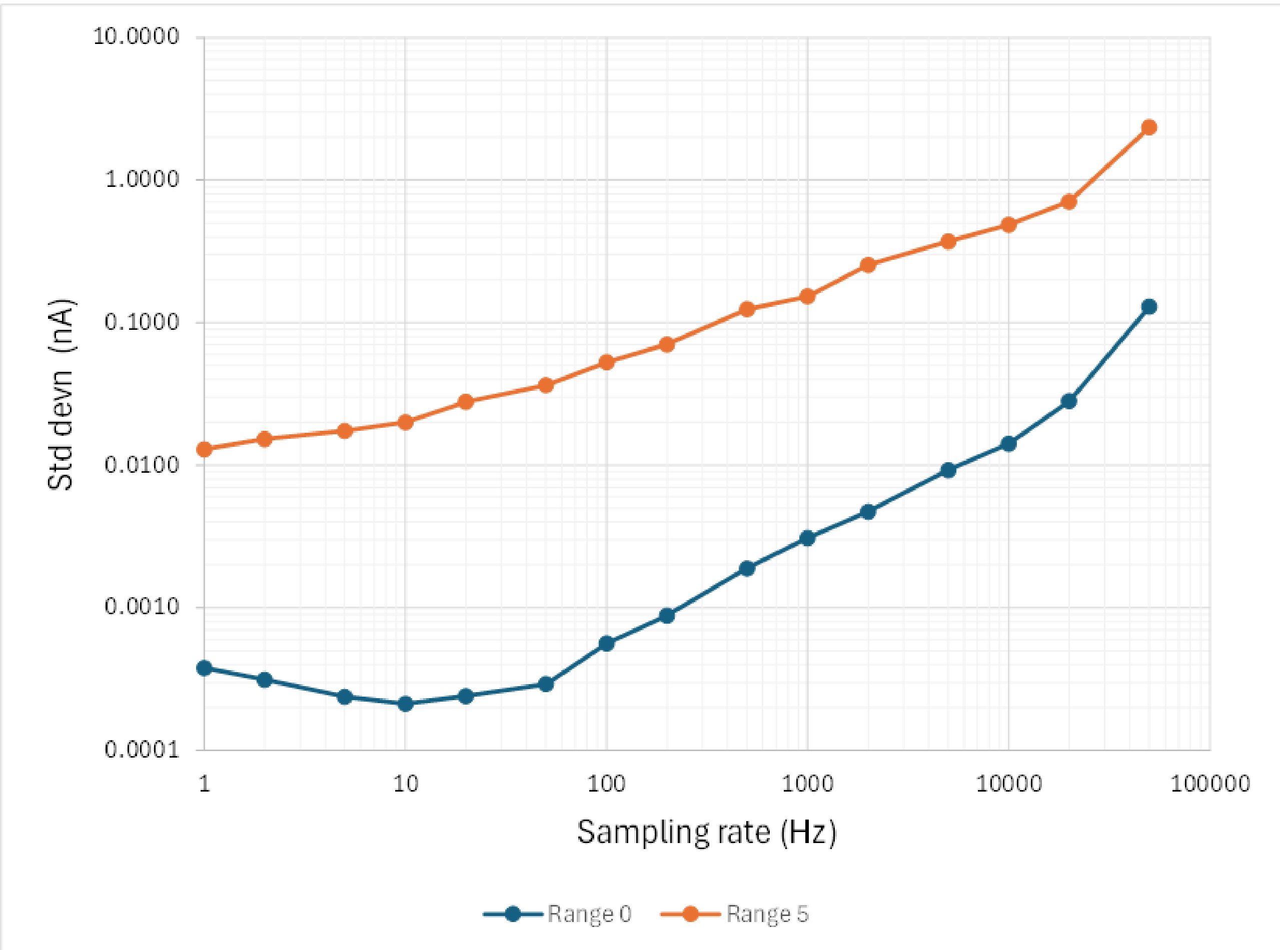




To avoid digitization effects in your data, use a more **sensitive range** whenever possible and consider selecting a **lower sampling rate**.

A quantitative way to evaluate the effect of averaging at different sampling rates is to examine the standard deviation of repeat readings. The log-log plot below demonstrates how this measure changes with the sampling rate when measuring a 50 nA signal on ranges 0 (100 nA) and 5 (100 µA).

Notice that a sampling rate of 10 Hz (a 100 millisecond period) provides the best performance on the most sensitive range. Setting the sample rate below this value begins to expose the repeatability of the measurements to small, slow drifts in the data. This rate is particularly useful for measurements of very small currents, as it completely eliminates interference from 50 Hz or 60 Hz power line noise.



6.3 Higher Bandwidth 100 nA and 1 µA Ranges

The FX4's response to higher frequencies is influenced by both the analog bandwidth of the input circuits and the sampling frequency as discussed earlier. The most sensitive ranges require higher conversion gain to convert current into voltage, but high gain can make the circuit less stable. This instability is managed by filtering out higher frequencies using analog components.

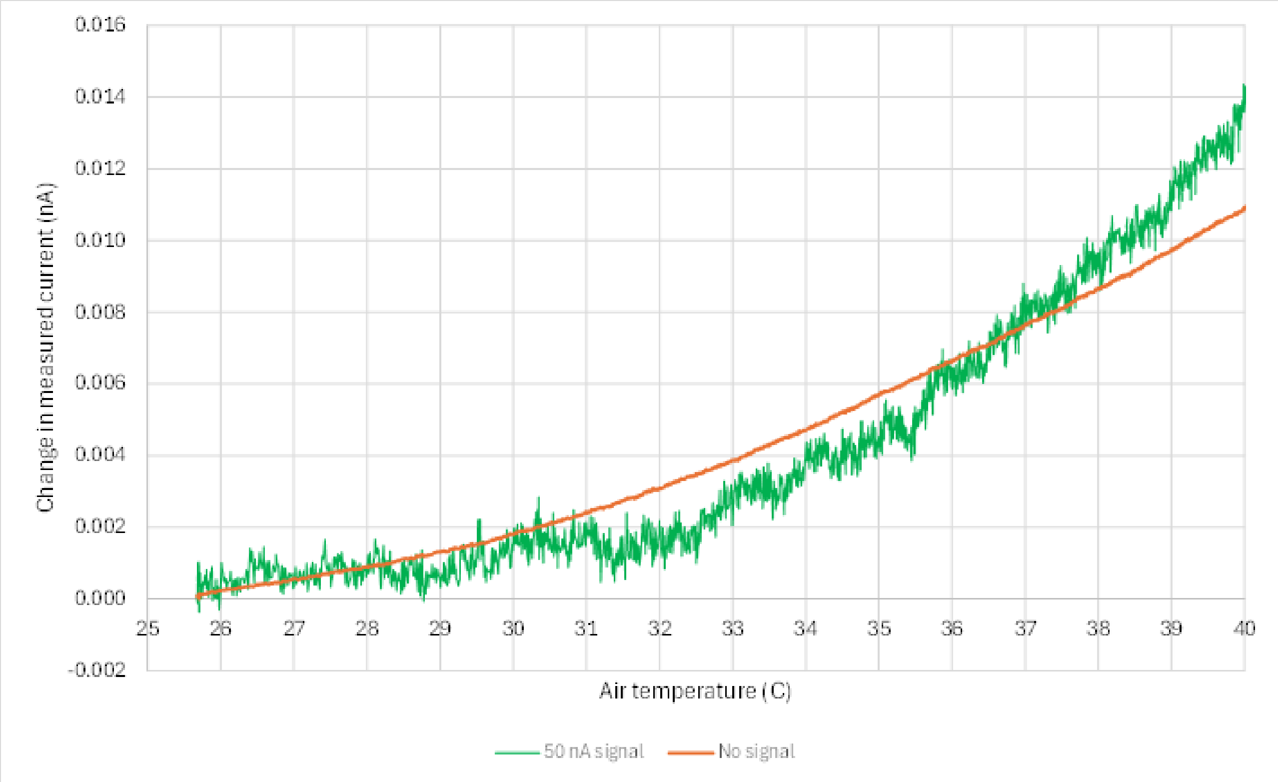
As a result, the two most sensitive ranges, 0 (100 nA) and 2 (1 µA), have reduced bandwidth. However, if the capacitive load on the input of the FX4 is kept low, the circuit can still remain stable. To offer greater time resolution, the FX4 provides higher bandwidth versions of these two ranges, 1 (100 nA) and 3 (1 µA). These higher bandwidth ranges allow for better time resolution but at the expense of increased noise, especially if the load is below about **1000 pF**.

The figures below illustrate the effects of these bandwidth changes. A 100 Hz current sine wave is displayed identically on both ranges 0 and 1. However, a 2 kHz sine wave is strongly attenuated on range 0, while range 1 accurately shows the amplitude of the signal.

6.4 Environmental Temperature

All electronics are sensitive to temperature variations, and as temperature increases, both noise and offsets tend to rise. Additionally, the conversion gain of the input circuits can change with temperature. To ensure the best stability and performance from the FX4, it should ideally be operated in a moderate, relatively stable environmental temperature range. The recommended operating temperature range is between **15°C and 25°C**.

However, good performance can still be achieved if the unit must be used at higher temperatures. The graph below shows the measured change in the readings as the surrounding air temperature increased from 25°C to 40°C, while measuring a 50 nA current on range 0. The change in reading was less than 0.03% over the temperature range, and this was primarily attributable to changes in the offset current, rather than a change in gain.



32 Offset of 50nA Signal Over Air Temperature

For optimal accuracy, it is recommended to use the **offset correction** feature to remove any residual offset before taking measurements.

7 FX4 Troubleshooting Guide

The following guide is organized by symptom. First, identify the symptom you're experiencing, then review the possible causes. Use the confirmation steps to determine if they apply to your situation. If they do, apply the recommended solution. If you require further assistance, please refer to the section at: FX4 Support & Returns Procedure (see page 58)

7.1 Incorrect Current Readings

Possible Cause	Confirmation	Solution
Bade scalars	Check scale correction values	Set scalar to 1.00
Zero offset incorrect	Clear zero offsets	Set offsets with no signal
Calibration issue	Check known current source	Contact Pyramid for recalibration

7.2 Unstable Current Reading

Possible Cause	Confirmation	Solution
Calibration issue	Check known current source	Contact Pyramid for recalibration
Cable capacitance	Try with very short cable	Reduce cable length
Voltage offset on input	Measure input with meter	Find and remove voltage source

7.3 Not Seeing AC Component

Possible Cause	Confirmation	Solution
Sampling rate too low	Increase sampling rate	Use at least 4x AC frequency

7.4 High Noise Levels

Possible Cause	Confirmation	Solution
Sampling rate too high	Noise reduces with rate	Adjust to appropriate rate
Line voltage interference	Interference disappears if sampling frequency set to line frequency	Use 50 or 60 Hz, or multiples like 10 Hz sample frequency or improve shielding from EMI.

7.5 Network Communication Issues

Possible Cause	Confirmation	Solution
Duplicate IP address	Unplug device from network and ping the known IP address.	Change IP or use DHCP
Incorrect IP in browser	Check FX4 IP on LCD	Use correct IP in browser
Wrong net mask	Check computer and FX4 netmask	Use the FX4 netmask or modify

Possible Cause	Confirmation	Solution
Bad Ethernet cable	Try a CAT 5e or better cable	Replace defective cable
Software failure	Contact Pyramid	Contact Pyramid

7.6 Communication Interruptions

Possible Cause	Confirmation	Solution
Network traffic too high	Test direct connection	Use low traffic closed network
Client PC overloading CPU	Close unnecessary apps	Use dedicated PC for data collection
Excessive web clients	Close extra clients	Use dedicated PC for data collection

7.7 Random Settings Changes

Possible Cause	Confirmation	Solution
Another client connected	Check for other clients	Use direct connection
VPN access	Disable VPN	Use direct connection

8 FX4 Maintenance

8.1 Preventative Maintenance

The **FX4** does not *require* routine maintenance, and there are no user-serviceable parts inside the case. See the IGX User Manual for import maintenance information related to the software itself.

8.1.1 Suggested Calibration Schedule

The calibration of the FX4 is stable over reasonable time periods. However, if re-calibration is required and needs to be traceable to a reference standard, please contact **Pyramid Technical Consultants** to arrange a return. Calibration services can also be provided by certified calibration laboratories.

For maximum accuracy in critical applications, it is recommended that the FX4 be re-calibrated every **1-2 years** against a traceable reference.

The FX4 is equipped 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 activates due to overcurrent; the fuse will automatically reset when the overcurrent condition ends.

8.1.2 Dust Management

The FX4 is a highly sensitive electrometer, and even small amounts of dust or debris can introduce measurable noise or offsets in measurements. To maintain accuracy, ensure that the FX4 is placed in a well-ventilated and clean environment. Periodically check the device to ensure it remains free from dust and debris. It is also recommended that unused BNC ports have dust covers to prevent debris buildup.

If you clean the FX4 using compressed air, ensure the device is fully powered off before blowing away any debris. Leaving the device powered on could allow debris to cause arcing or shorts inside, potentially damaging the unit.

8.2 Software Maintenance

To ensure optimal performance and the best user experience, it is recommended to keep your FX4 software updated to the most recent version. Instructions on how to update the software via the web interface are provided in the IGX User Manual.

If the FX4 is being used in a medical application, Pyramid is equipped to assist you in tracking and managing software versions that are appropriate for your application. Additionally, Pyramid can provide guidance on recommended update schedules and strategies to ensure compliance and optimal performance.

9 FX4 Support & Returns Procedure

9.1 Support

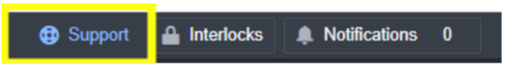
For assistance, you can access our Pyramid Help Center at https://ptcusa.com/support to submit a support ticket. We offer help with a variety of inquiries, including:

- **Technical Support** – Assistance with setup, troubleshooting, and general usage.
- **Documentation Improvement –** Suggestions for updates or clarifications in manuals and guides.
- **Feature Request** – Requests for new features or enhancements.
- **Software Bug Report** – Reporting software issues or unexpected behavior.
- **Hardware Failure** – Support for diagnosing or servicing a faulty unit.
- **Other Questions** – Any additional inquiries not covered above.

Alternatively, technical support is available by email at **support@ptcusa.com**[10]. When submitting a request, please have ready your **device type**, **serial number**, and a clear description of your issue to help us assist you efficiently.

9.1.1 Accessing Support Via the Web Interface

A link to our support ticket can be found via the web interface by clicking the "Support" button on the top of the screen.



9.2 Returns Procedure

To return a damaged or faulty unit, you must first obtain a Return Material Authorization (RMA) number from Pyramid Technical Consultants, Inc. Returns without an RMA cannot be accepted.

To request an RMA, please contact Pyramid Technical Consultants at **support@ptcusa.com**[11] with the following details:

- **Model number**
- **Serial number**
- **Description of the issue**

Once your request is processed, we will provide you with an RMA number and instructions on where to send the unit for service.

10 mailto:support@ptcusa.com
11 mailto:support@ptcusa.com

10 FX4 Disposal

We hope your FX4 device provides long and reliable service. It is manufactured in compliance with the European Union **RoHS Directive 2002/95/EC**, ensuring that it is free from hazardous substances and meets the environmental standards set forth for electronic equipment. However, when the device reaches the end of its operational life, it is essential to dispose of it in accordance with local environmental regulations.

For users within the **European Union**, disposal must comply with the **Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC**, which aims to reduce waste from electrical and electronic equipment and promote the recycling and reuse of materials.

To ensure that your device is disposed of properly and responsibly, please contact Pyramid for guidance on the correct disposal procedure. In many cases, we are happy to assist with recycling your device to minimize its environmental impact and ensure compliance with all applicable waste disposal regulations.