T4U 4-CHANNEL ELECTROMETER OPERATORS MANUAL SI-401255

Rev	Date	Name	Description
A	2022	VF	Created
B	01JUNE2023	YF	Updated w/ Options
C	28MAY2024	YF	Pulsed Bias
D	24JULY2024	IM	Pulsed Bias EPICS and Minor Updates
E	16DEC2024	IM	EPICS Direct Instructions
F	05SEP2025	YF/IM	Pulsed Mode Additions

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Contents

1 INTRODUCTION

The T4U is a 4-channel electrometer capable of reading currents from tens of pA to mA across three gain ranges. It can act as a standalone product or in conjunction with one of Sydor's 4-channel diamond beam position monitors. This manual provides the basic instructions for installation and routine operation of the electrometer with a quadrant beam monitor.

Constant exposure to high intensity x-rays in the presence of atmosphere or contaminants will damage the diamond monitor used in conjunction with the T4U electrometer. Failure to use the appropriate UHP (research grade) inert gas or high vacuum may result in voiding the factory warranty.

Questions or Concerns

For any questions or concerns, please contact Sydor Technologies at:

Sydor Technologies
78 Schuyler Baldwin Dr.
Fairport NY, 14450

Phone: 585-278-1168
Email: info@sydortechnologies.com

Software and User Manual Download

All necessary files are available upon request.

2 CONFIGURATIONS

T4U is available in two configurations:

- Base Configuration
- T4U Advanced with PID

The base configuration is a software-only readout. Using a control computer, the position and currents can be viewed on screen, and also saved to disk for later analysis. The Advanced with PID option adds 6 additional electrical connections. There are 4 outputs with software selectable options and two inputs for trigger and inhibit functionality. One of the software options includes PID (Position-Integral-Derivative) which can drive a user-supplied feedback mechanism to keep the beam centered along X and Y axes.

A custom option allows for capturing pulsed x-ray signals, in tandem with a user-provided trigger. The final data report will include additional specific information on units equipped with pulsed-mode operation. This option is unrelated to pulsed-bias.

3 SPECIFICATIONS

Table 1: T4U Specifications; performance and characteristics.

SENSOR SPECIFICATIONS	
Material	IIa diamond substrate, platinum or aluminum contacts
Diamond Thickness	40 μm
Transmission	>90% above 6 keV
ELECTRONICS PERFORMANCE PARAMETERS	
Noise floor	<40 pA
Gain selection	range of selections available
Max current (pixel^{-1})	300 nA, 100 μA , 5 mA (high, medium, low gain)
Operation Modes	Continuous
Acquisition Speed	10.0 to 0.5 Ksps
Internal Bias Voltage Supply	+10 V, fixed
DATA PROCESSING	
Interface	T4U Viewer Graphical User Interface, EPICS IOC
Controller Outputs	Optional: Current measurement data, proportional output voltage, PID
Controller Outputs Type	Optional: 0 - 10 V
ENCLOSURE and CONNECTIONS	
Controller	19” rack mount
Data Cable	Ethernet or USB 3.0 Type B
Bias OUT	SMA
Monitor Inputs	4 SMA factory provides SMA cables, 2 m
User I/O	4 SMA Outputs (Optional)
	On request, the connections can be routed to the back
Rear Panel	2 SMA Inputs (Optional)

4 PRINCIPLES OF OPERATION

The T4U uses a transimpedance amplifier design (TIA) with 3 internal gain settings (shown below) to provide low noise current measurements from < 100 pA to 5 mA.

Setting	Electronic Gain (current/ADU)	Current Limit per Channel
Low	60.8 nA / ADU	5 mA maximum
Med	191 pA / ADU	100 uA maximum
Hi	572 fA / ADU	300 nA maximum

Data rates streaming from the T4U are up to 10 Ksps. Data is continuously broadcast out from the electrometer. For systems with PID, analog outputs provide a up to 100 Hz response rate to external control equipment.

Decimation Rate	Points per packet	Number of packets per chunk
500	50	1
4000	50	8
10000	50	20

The client application accumulates the streaming data into chunks. The size of the chunks is adapted to provide the UI with roughly a 10 Hz update rate. The X-Y plot on the Main Tab and the X,Y positions in the History Tabs are averages of each data chunk. The four channel plots on the bottom of the History Tab display the data chunks. For every 1000 points of data streamed into the client (assuming DR=10,000), there will be one point generated for X, Y and I_total. The T4U is connected to a control computer for control, viewing data, and saving data. The client, T4U Viewer, runs on Windows (Windows 10 or 11 recommended) or Linux (Ubuntu 22.04 or Debian 12.6 recommended), providing a direct user controlled interface. T4U Viewer can also be used as an intermediate layer to control and read from the electrometer using EPICS. EPICS controls are based on the standard EPICS QuadEM package. More information on installation and use is in Section 13.

5 DIAMOND SENSOR DETAILS AND CONNECTIONS

General

The 4-channel electrometer is ideally suited for Sydor's quadrant diamond position monitors. The quadrant monitor is consistent across most of the existing designs. It consists of a sensor with the following general specifications:

- 4.5 x 4.5 mm CVD Grade A electronics diamond, 25 - 50 micron thickness
- Pt or Al bias contact (side 1)
- Pt or Al quadrants covering a 3 x 3 mm area with 15 microns of separation (side 2)

Monitors can vary in packaging greatly from project to project depending on experiment requirements. Please see correspondence and documentation from Sydor for more detail on your specific model.

6 T4U DETAILS

The T4U is a 4-channel electrometer with 4 user outputs housed in a 19” rack mount case. There are 2 user inputs (optional) on the back panel. The drawing below highlights the main dimensions and connection locations for the electrometer. Please allow 2-3 inches away from the front panel for connections. The rear panel contains the main power switch and cable.

Figure 1: T4U front panel with dimensions in mm.

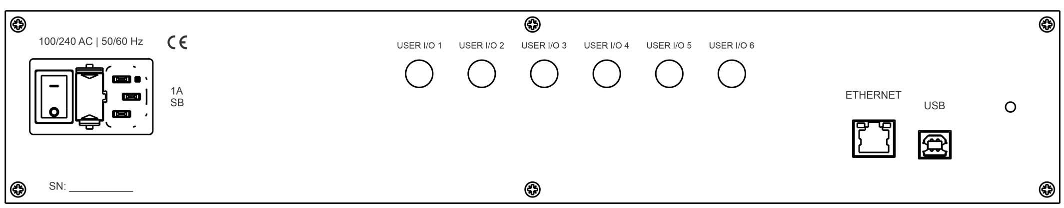

Figure 2: T4U rear panel.

7 FIRST TIME SETUP

7.1 System Components

The main components of the system provided are:

- quadrant diamond sensor
- bias/signal cables upon request
- T4U electrometer

Additionally, you will need:

- host computer running T4U Viewer software (Windows or Linux)
- research grade He (99.9999%) or high vacuum ($\leq 10^{-4}$)
- Ethernet (RJ-45 T100)
- diamond sensor cooling as needed for high flux applications

7.2 Electrometer Placement

The T4U controller can be positioned as a standard 19” rack mount unit in a rack, or stand alone. There should be approximately 3” of clearance at the front panel to allow for space to connect the signal/bias cables. Additional cable support or strain relief may be required. Standard factory provided cable length is 2 m. (Longer cables are available with an additional quote from Sydor, but low current reading performance will diminish with length.)

Each diamond monitor will likely have a unique experimental environment and therefore have variations from standard packaging. If it was not addressed with Sydor during the design phase, and there are any concerns, please get in touch to discuss any experiment specific setup. Here are some general considerations to follow when positioning this system component:

- Sydor recommends leaving the protective cover in place to guard the sensor and wire bonds from possible debris if the application allows.
- The SMA connectors are not recommended as the sole point of connection. Use a clamp or set screws to mount the diamond monitor housing.
- If the diamond carrier is not used in a flange mount design and the cables connect directly to the carrier board, mount the diamond monitor securely before connecting the cables.

7.3 Connections

The following connections are required for T4U operation with a Sydor diamond beam position monitor:

- Signal/bias cables to diamond sensor board (5x SMA or BNC, design dependant). Upon receipt they will be labeled 'signal [channel number]' and 'bias' for the factory recommended orientation on the diamond side.
- Main AC line cord to the rear panel of the controller.
- Ethernet data/control cable from the rear panel of the controller to the computer running the T4U Viewer software.
- **If your diamond monitor is a stand alone model, connect the required inert UHP gas (UHP grade gas, tubing, regulator, and fittings) or high vacuum tubing before beginning your experiment. Failure to do so may damage the diamond sensor and void the factory warranty.**

7.4 Power-On Sequence

Before taking images, the hardware must be connected appropriately and the computer used for control must be connected to the electrometer:

1. **Turn on inert gas flow or vacuum to the T4U diamond sensor. Allow the system to flush with inert gas for at least 20 minutes, or reach the 10^{-5} torr range before exposing the sensor to beam.**
2. Turn on liquid cooling to the appropriate temperature if required.
3. Power on the controller using the main rocker switch on the rear panel.
4. Open the T4U Viewer application on the host computer. If the controller is connected and on, it will start streaming data automatically.
   - If the device does not connect. Go to the menu option: Connection > Connect, and put in the IP Address assigned to the electronics. See 8.3 for more details.
5. Turn on bias to the sensor using the checkbox at the bottom right of the T4U Viewer window (more information on the software is in further sections).

8 T4U VIEWER

8.1 Installation

The T4U Viewer software will be provided as a single file. For Windows, Sydor will provide a zip file containing the program and its dependencies. The zip file can be extracted where desired. For Linux, Sydor will provide an AppImage file; set the executable bit and then run. Sydor will also provide a configuration file named "DBPM_Settings.ini"

For Windows, the configuration file must be placed in the same directory as the executable. For Linux, the configuration file must be placed in "∼/Sydor/DBPM" and named "DBPM_Settings.ini".

The configuration file contains calibrations for each of the four channels and is unique to your electrometer.

8.2 Overview

There are five main screens for using the T4U:

- The **Main** tab shows the immediate data. A graph shows the current beam position, a bar display shows the current values, and there are some basic controls.
- The **History** tab shows the recent total current and the position of the beam.
- The **History/200** tab shows a longer-term history. A new sample is added every 200 acquisitions.
- The **User I/O** tab controls the Proportional, Position, and PID options.
- The **Triggered Mode** tab controls acquisition options for triggered mode. It is only enabled if the firmware supports triggered mode.

The Debug tab shows a command log and provides some low-level communication details. It is displayed when Show Advanced Options is checked on the Main tab, but is not intended for general use.

8.3 Menus

There are several relevant entries in the menus.

- Connection
  - → *Connect*: This allows choosing the IP address of the T4U. Selecting this option will disconnect the current connection. There is also search option to discover the device on the network and attach if the IP address is unknown.
  - → *Disconnect*: Closes the connection
  - → *Reconnect*: Attempts to connect to the last set IP address. It bypasses the modal dialog.
- Data
  - → *Show Raw Counts*: This will cause the bar graphs on Main and the 4 channel plots in History to display in raw counts. Raw counts range from -524,288 to 524,288 which is (1<<19).
  - → *Scale to nAmps*: This will cause the bar graphs on Main and the 4 channel plots in History to display the the signal in Amps.
  - → *Save to Disk...*: Opens a dialog box to save the data.
  - → *Stop Saving*: Immediately closes the file and stops saving.
  - → *Reload Calibrations From Disc*: This will reload the calibrations from the disk. Use this option if the setting file has been modified to reload the new values.
  - → *Select External Attenuator*▷ : This changes the calibrations used for converting Raw counts to Current. By default, "None" will select no calibration, and "direct" will select the factory-supplied calibration values.
- Graphs
  - → *Rescale Total Current Graph*: This will rescale the Total Current Graph on the History tab; this has the same effect as double-clicking on the graph. The Total Current Graph on the History/200 tab is not affected.
  - → *Clear History Graphs*: This resets the graphs in the History and History/200 tabs; the graphs are cleared and the data discarded.

- → *AutoScale CH Graphs*: This affects the four channel plots in the History Tab. It toggles autoscale on the vertical axis.
- → *X-Y Plot Persistence*: Turn on or off a persistence on the X-Y plot. The persistence is 30 seconds and is useful for spotting transient events.

• About
- *About* → *About T4U*: Displays the T4U Viewer version number and the firmware of the hardware if connected.

8.4 Saving to Disk

Data can be saved to disk. Choose a file name and from the set of options: Raw Counts will save the values in analog digital units (ADU). Current will save the values in Amps. Average will compute standard deviations for each set of data. Data is streamed from the device to the client. Depending on the decimation ratio (sampling frequency) the data is accumulated into chunks that range from 50 points (DR=500) to 1000 points (DR=10,000). The standard deviations are calculated for each chunk of data. When averaging is selected, the standard deviations become automatically selected for the Raw Counts and Current options. Stop after M reads. Check this box and enter a value. The save operation will close out automatically when M reads have been acquired.

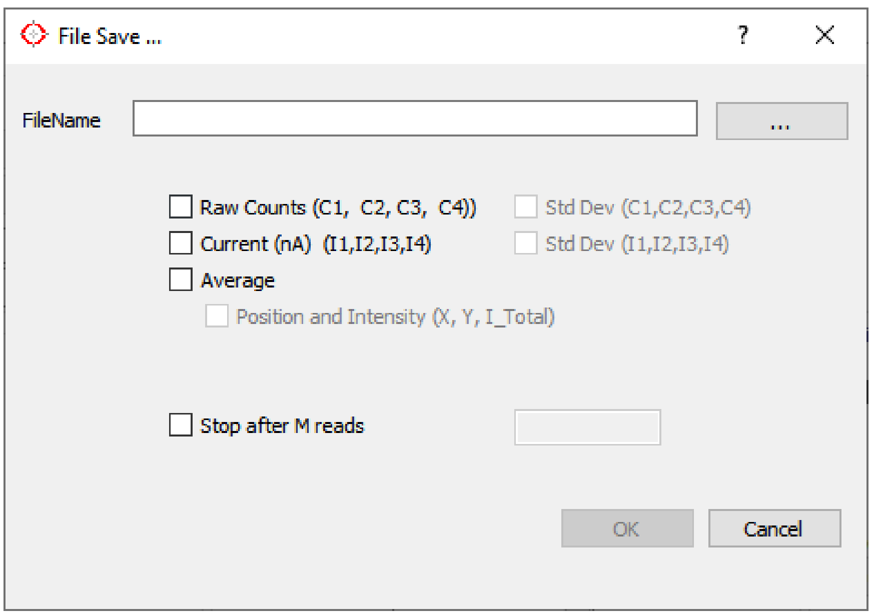

Figure 3: The File Save dialog

8.5 Connect to device

Select → *Connect...* from the Main menu. Enter the IP address of the device, or press Search to locate the device.

The search will bring up another dialog where you can see other devices on the network. Select the one to connect and press Connect. The device can also be configured for fixed IP or DHCP. If fixed IP is selected, enter the desired IP address, gateway, and netmask, then press the Update button. Any changes to the network configuration require a power cycle on the device.

8.6 Main Tab

Refer to Figure 6 for details.

Position shows the position of the beam. The position is normalized to ranges of [-1,1] for X and Y.

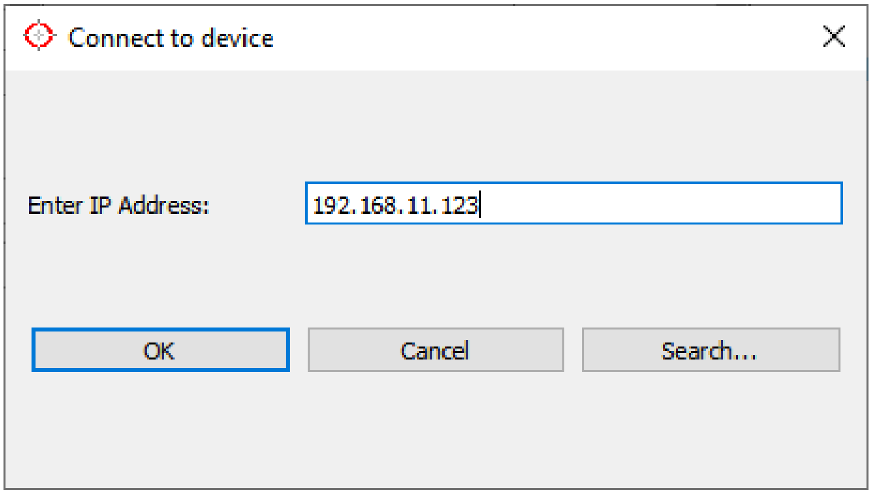

Figure 4: The Connect dialog

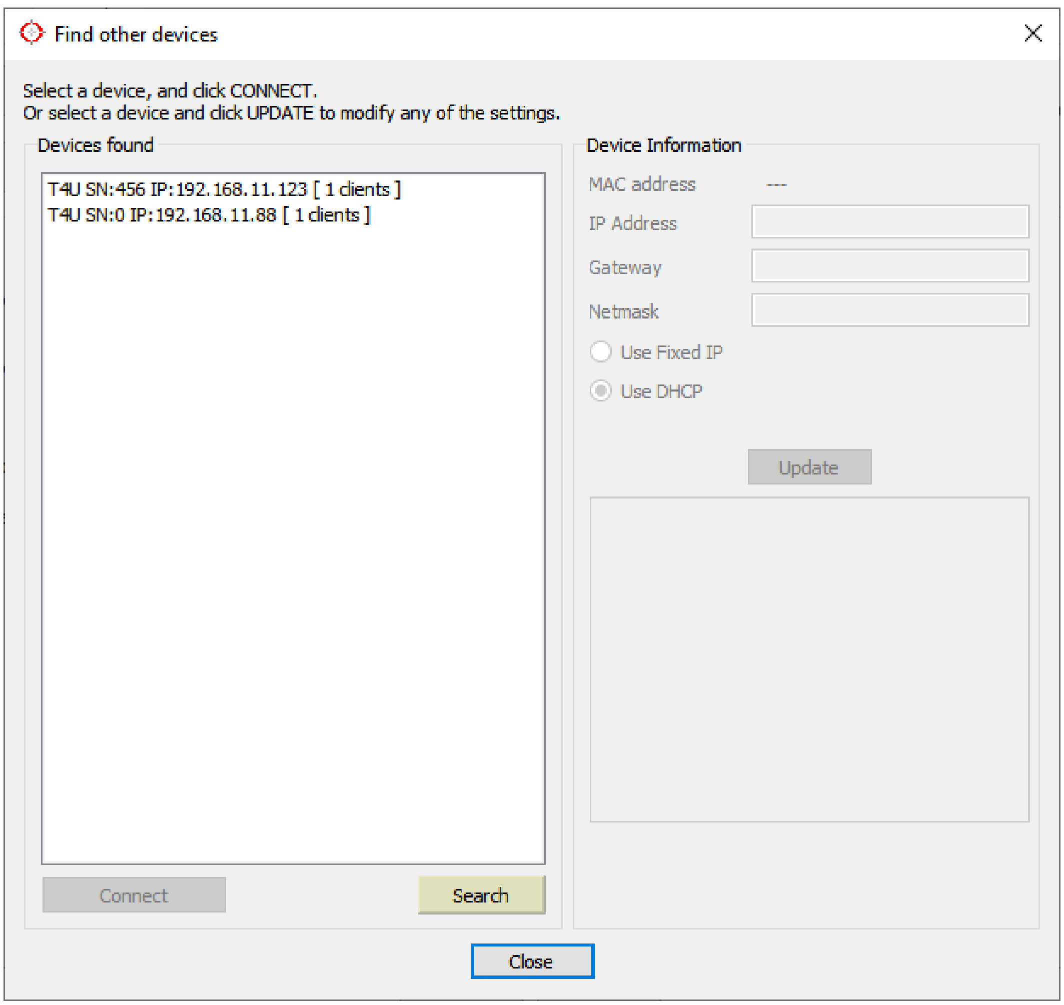

Figure 5: The Find other devices dialog

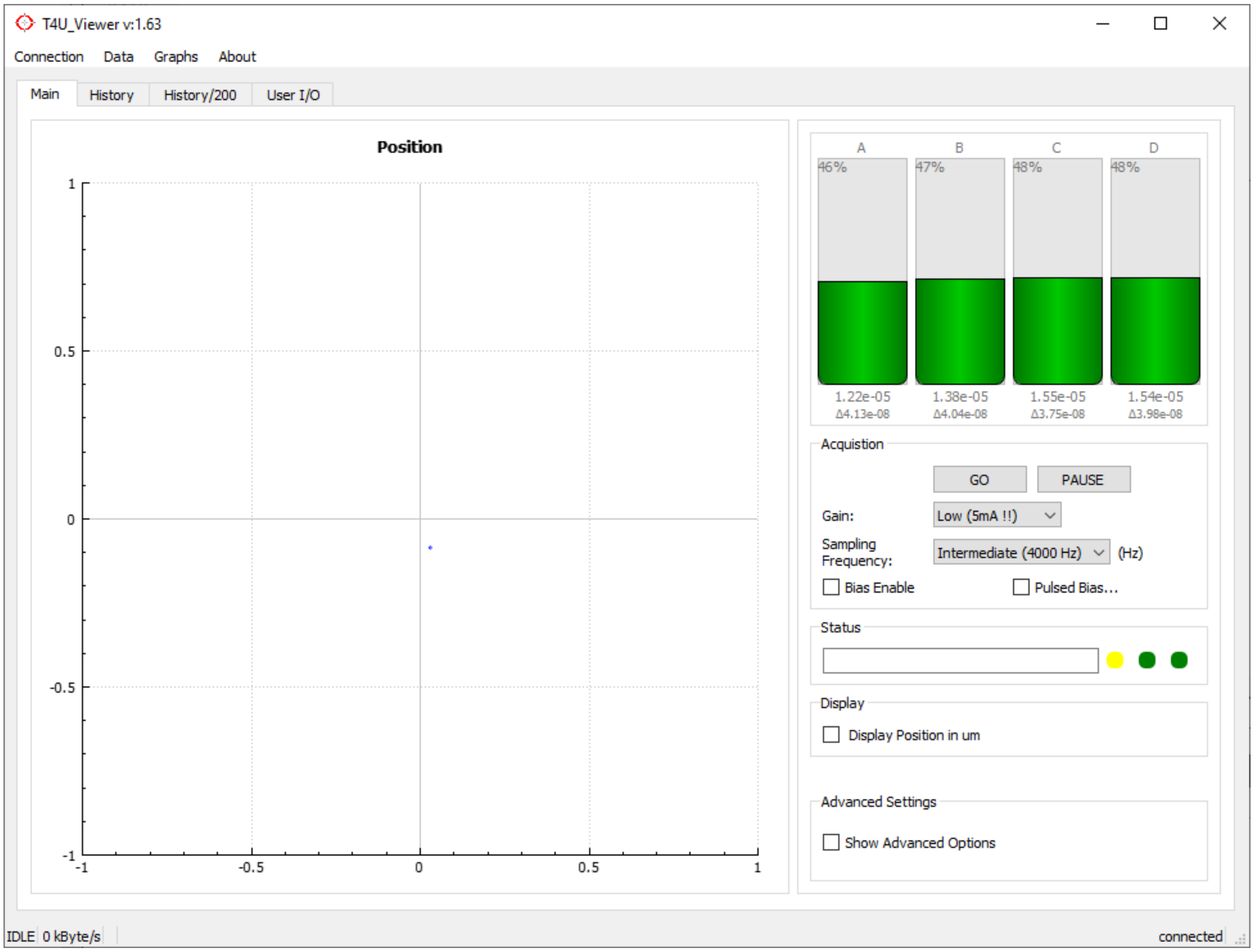

Figure 6: T4U Viewer Main Tab

The bar graph section shows the channel currents and their standard deviations. The bar graphs themselves show a logarithmic representation of the measured current versus the full scale value.

Acquire controls input parameters. Acquisition may be started and stopped with the "Go" and "Pause" buttons. The range of currents is controlled through "Gain", which shows the allowable current at each range. The Sampling Frequency is displayed. Note that the sampling frequency can slightly change the calibration. The factory-supplied calibration was calculated at 4000 Hz. On a technical note, the underlying technology uses a high rep rate sampling frequency and it is decimated down to the requested speed. Decimation is the process of averaging multiple reads and averaging them (in hardware). At a lower decimation frequency the noise (the component that is true random noise) will go down due to the higher averaging.

Display will display "EPICS Connected" when the EPICS IOC has connected to the Viewer; details are under the section on EPICS. "Display position in um" converts the normalized (x,y) position to match the physical diamond. x and y have a scale and offset applied; the coefficients are in `DBPM_Settings.ini`. This setting only applies to the position graph in this tab.

Below *Display* is the bias enable checkbox. This turns the bias on or off. For systems enabled with Pulsed Bias, the Pulsed Bias checkbox can be used on setups that generate high currents, and sets a duty cycle for the bias ON time. See the section 11 for more details on setting up and using Pulsed Bias.

The *Status* section shows the connection health of the system and displays errors. The three indicators are green when there are no errors. The first indicator is a connection status indicator. It will be green if data is being received properly and there have been no communication errors. A yellow may indicate either a current error or a past error that has latched. Clicking on the yellow indicator will clear the error counters and clear any latched errors. The second indicator is for the internal Analog Converter. It can detect errors, one of which is if the signal is too high it will generate Saturation errors. If this occurs the second indicator will be yellow only while this error is active. Reducing the signal or switching to a lower gain will resolve this. The third indicator is an internal ADC error called Over/Under error. This is similar to the Saturation error and often occurs in tandem, but this error flag is latched by the hardware and will stay asserted even if the signal is no longer too high. It can only by reset by selecting a new sampling frequency, and then re-selecting the original sample frequency. Data is paused for several seconds during the change.

Advanced Settings enables Advanced Mode. Selecting this shows a new Debug tab which has additional low level information, and can also be used to send direct commands to the hardware.

8.7 History Tab

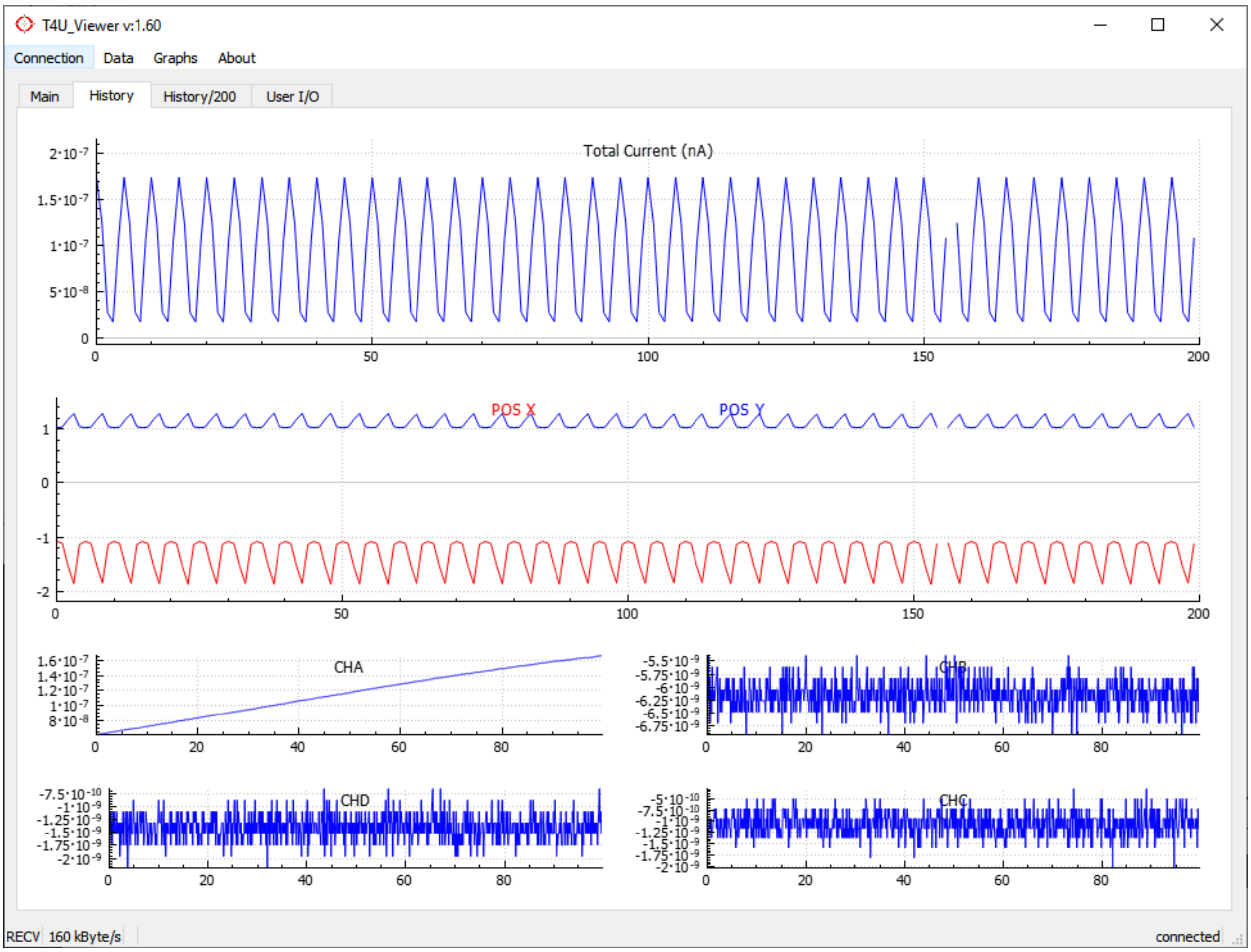

Figure 7: T4U Viewer History Tab

Refer to Figure 7. This page has two main graphs and four smaller graphs. The upper graph shows the most recent 200 total current readings. Double-clicking on either graph will zoom in to the data. The lower graph shows the most recent 200 calculated positions. The four lower graphs are the signal from each of the four inputs. The x axis is in time, in units of ms. The application displays about 100 ms of time regardless of the decimation rate used, and adjusts the update rate accordingly.

8.8 History/200 Tab

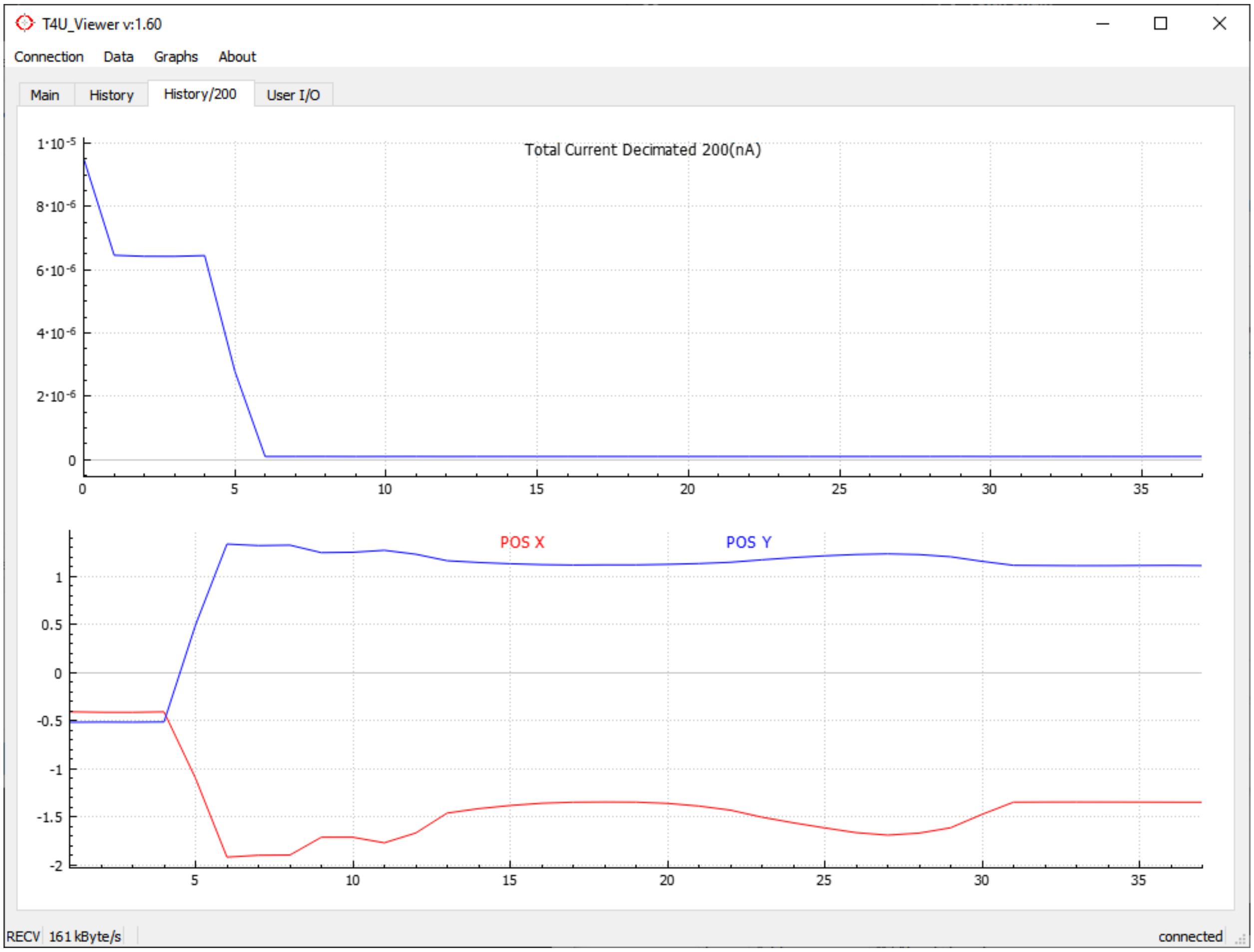

Figure 8: T4U Viewer History/200 Tab

Refer to Figure 8. This page has two graphs. A new data point is added every 200 regular samples. Each new data point is the average of the previous 200 samples. The graphs scroll to the left after a maximum of 1000 points. The oldest points will drop off on the left side as each new point is added to the right side.

8.9 User I/O

NOTE: User I/O is only available with the T4U Advanced with PID option.

Inputs "IN1" and "IN2" refer to the two inputs on the rear panel. Outputs O1 through O4 refer to the four User I/O connections.

This page controls the I/O ports on the hardware. There are several modes available, described below. Some controls are applicable to all modes; these are described first. There are a number of parameters common to multiple modes, described in their own section. The common controls can be found in Figure 9.

Select Configuration allows selecting different modes and provides some information on them. "Config" allows selecting I/O modes among "None", "I1 I2 I3 I4", "X Y I_Tot", and "PID, I_Tot, Active". The textbox next to "Config" describes the selected mode and I/O port details. The "IO #" widgets show which I/O ports are active in a given mode.

The "Refresh" and "SEND" widgets are used to synchronize the GUI and the T4U hardware. "SEND" transfers the settings in the GUI to the T4U hardware; some of the changes made in the GUI *are not* reflected in the hardware until

"SEND" is clicked. "Refresh" queries the hardware for the configuration and adjusts the GUI accordingly; this may be most useful if EPICS is used.

In all four modes, IN2 can be set to pause acquire when high. Setting this option allows an external gate signal such as from a shutter to pause and start the acquisition. Data stops streaming when paused.

Pulse-Mode equipped hardware only:
IN2 may also be set to acquire data on a trigger. The T4U in Trigger mode requires a pre-trigger where data are sampled on the rising edge of the pre-trigger. The results are read into the T4U software on the falling edge of the pre-trigger, the data having been cached on acquisition.

8.9.1 None

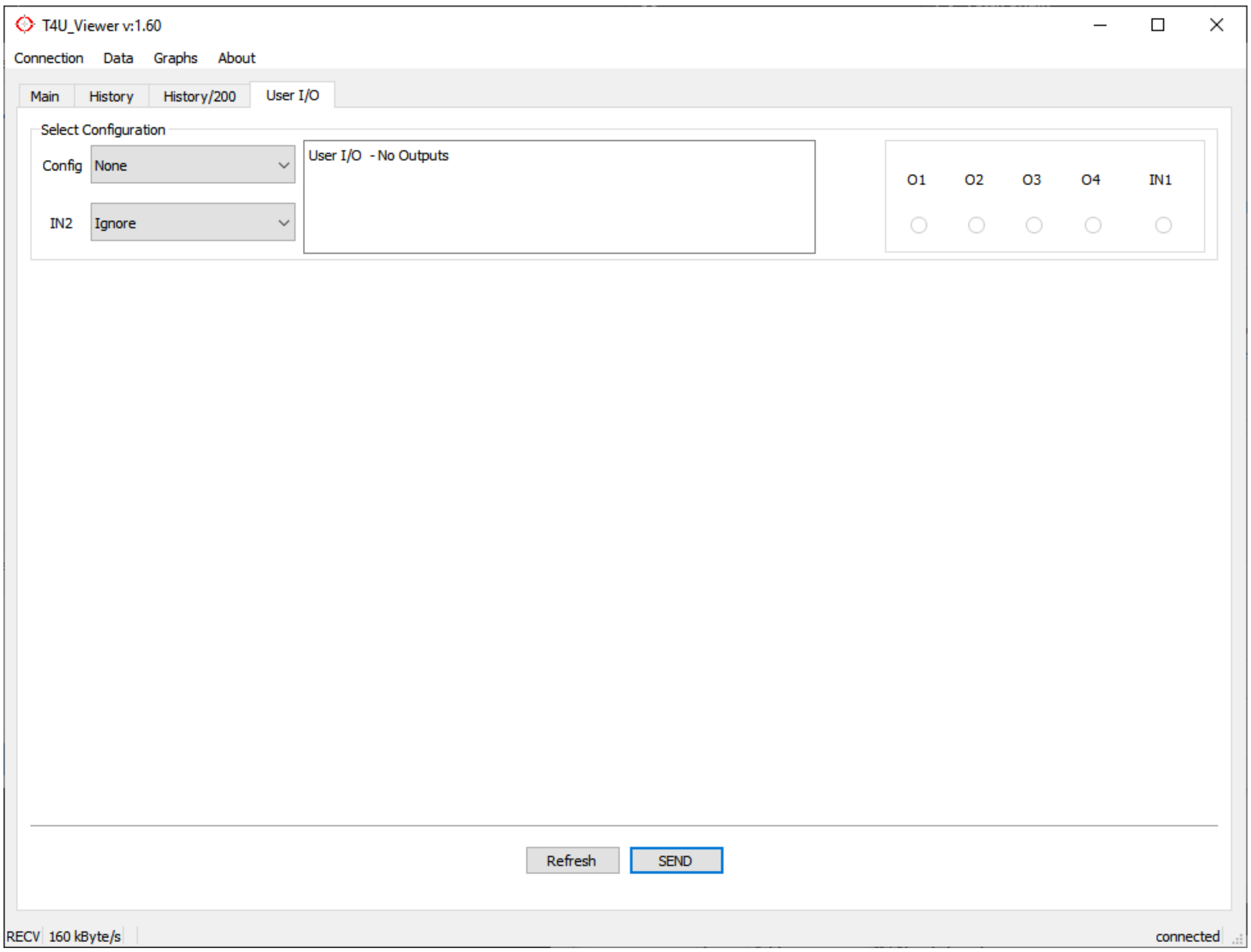

Figure 9: T4U User I/O Tab - None Mode

Refer to Figure 9. In this mode, there are no outputs.

8.9.2 I1 I2 I3 I4

Refer to Figure 10. In this mode, the four outputs provide a voltage proportional to the current on the corresponding input channel. The output is scale-able through the "Current to Voltage Scale Factor" option; details are elsewhere. The Offset is in units of volts and may need to be set if measuring negative signals.

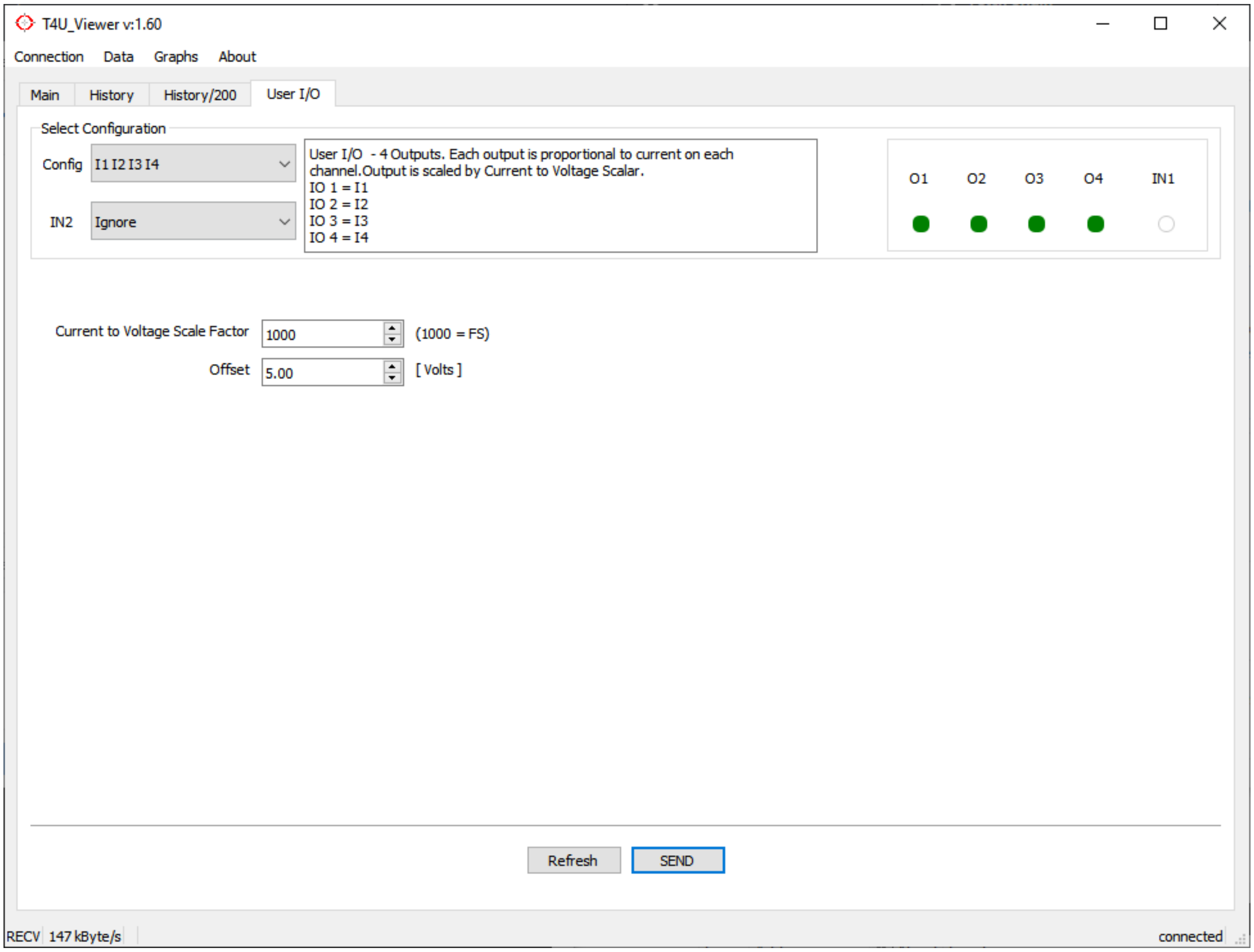

Figure 10: T4U User I/O Tab - Quadrant Mode

8.9.3 X Y I_Tot

Refer to Figure 11. In this mode, two outputs represent the position of the beam and a third is proportional to total current. Scale and Offset values can be set independently for X and Y. The I_Tot output scale and offset are configurable.

8.9.4 PID, I_Tot, Active

Refer to Figure 12. In this mode, two outputs provide PID control based on beam position, one output provides a voltage proportional to total current, and a fourth indicates if PID is presently active.

Feedback Outputs provides Enable and Disable controls for the PID signal. “Enable” will enable or disable PID. “Cut out at” specifies the current below which the PID will be disabled. “Auto re-enable” is the hysteresis value to re-enable PID after having cut out from the current being too low. “Use Current position” copies the measured X,Y position into the Target X and Target Y positions respectively.

The “Enable” checkbox is not automatically updated if the PID goes below the cutout threshold. If “SEND” is clicked after cutout, but while the current is between the Cutout and Re-enable levels, the PID will be re-enabled. This may be avoided, if desired, by clicking “Refresh” first to update the “Enable” checkbox before clicking “SEND”.

X position feedback and *Y position feedback* control the PID parameters. The position setpoints are normalized to the range [-1,1]. The PID P, I, and D coefficients are limited to P: 0 to 100, I: 0 to 100, and D:-1 to +1. They may be set independently for X and Y. The Scale Factor and Offset parameters are described below. The “Current to Voltage

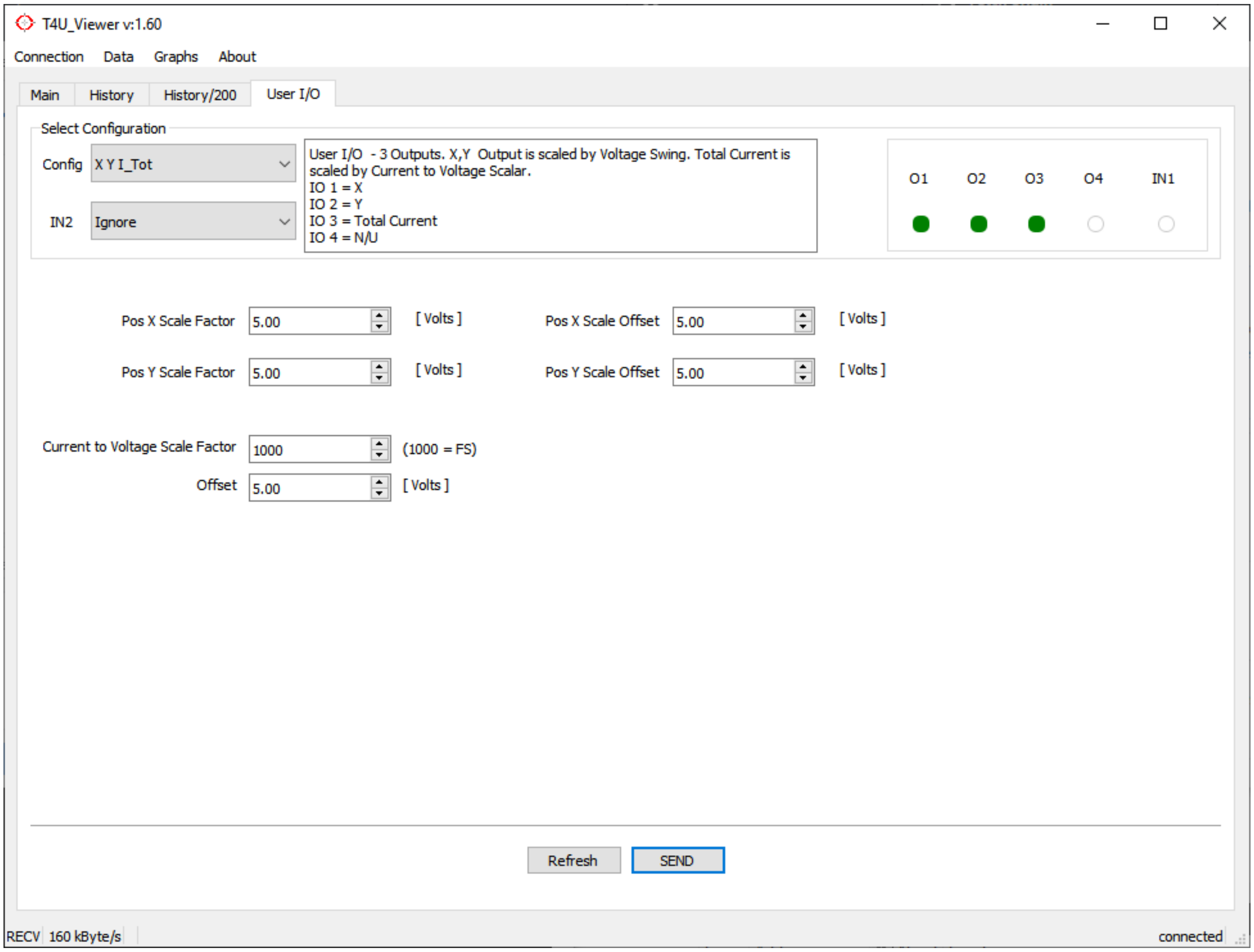

Figure 11: T4U User I/O Tab - Position Mode

Scale Factor" scales the total current to an output voltage. Details are below.

Input Options has a checkbox to control PID using input IN1. Unlike the signal on IN2, this setting will not pause streaming, but only prohibits PID from operating. The X and Y outputs will be frozen until the signal de-asserts.

Position Tracking can be enabled by checking the box. Select a radius and an output polarity. The output on O3, instead of outputting total current, becomes a digital signal. It asserts when the position is within the radius specified.

8.9.5 Scaling and Offset Parameters

There are several scaling and offset factors in the User I/O options.

- *Current to Voltage Scale Factor*: Ranges from -999999 to 999999. If the value is 1000, the maximum signal will give a 10 V output.
- *Offset*: Ranges from 0 to 10.00V.
- *X and Y Scale*: Ranges from -5.00 to 5.00V. Use negative scaling with negative signals to invert the output.
- *X and Y Offset*: Ranges from 0 to 5.00V.

8.10 Triggered Mode Tab

The Triggered Tab will only appear on hardware that supports the trigger-mode option.
This tab controls the acquisition parameters needed when in triggered mode, and is shown in Figure 13.

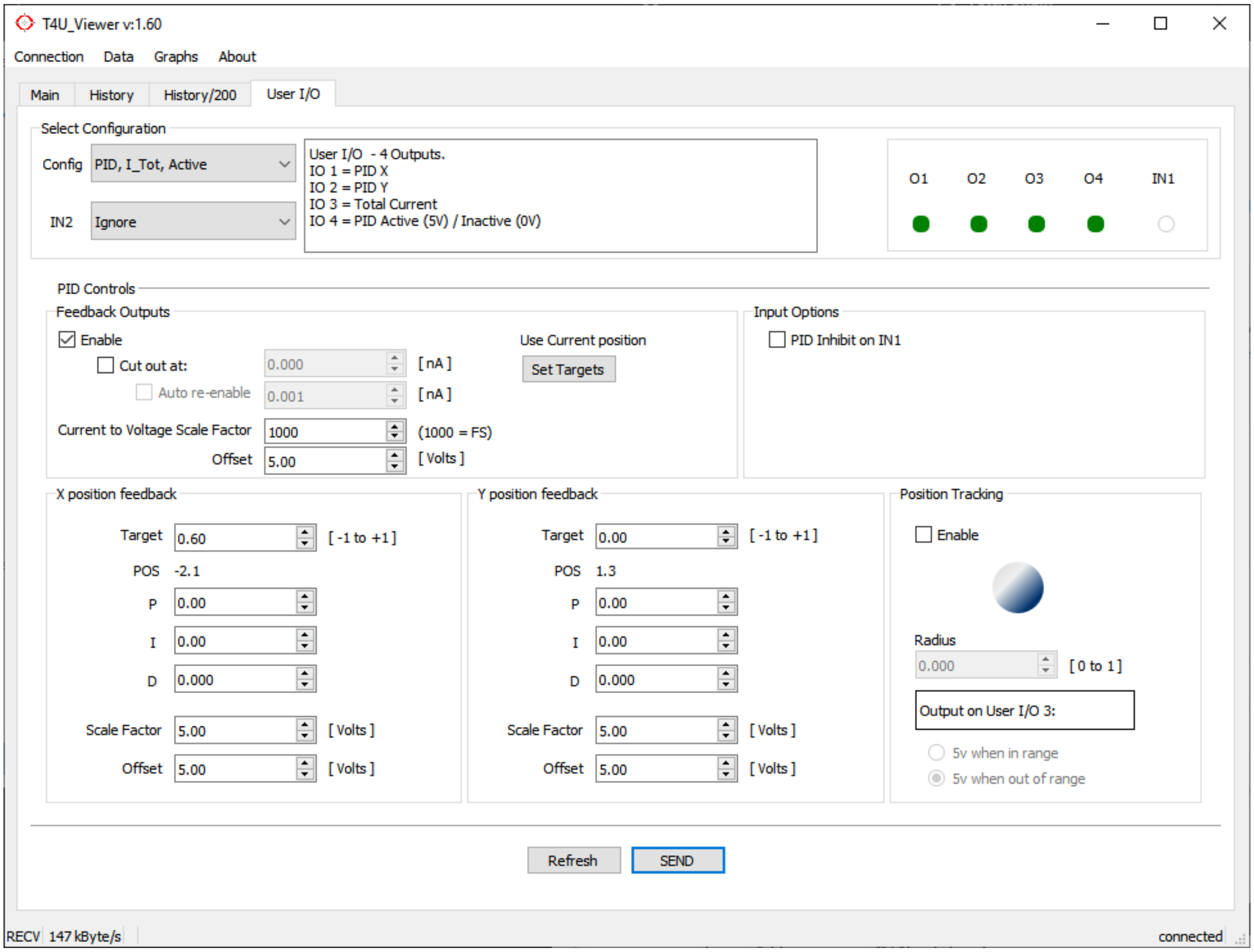

Figure 12: T4U User I/O Tab - PID Mode

Triggered Mode enables or disables changing the acquisition parameters in triggered mode. This box should be checked after changing *IN2* to **Triggered Mode**, and before changing it from **Triggered Mode** to some other mode.

One Shot forces the *Reads per Packet* and *Packets per Update* to 1, ensuring an update on each shot.

Sample Frequency, *Reads per Packet*, and *Packets per Update* are used to set the acquisition parameters for a suitable GUI update rate. *Sample Frequency* is set to the frequency of the trigger. *Reads per Packet* may assume values from 1 to 50; 50 is the default value. *Packets per Update* may vary from 1 to 20, and is set accordingly. These values are used for the calculation Calculated Rate = Sample Frequency / Reads per Packet / Packets per Update. This result is displayed in *Calculated Rates*. To be applied, the result must be 10 Hz or lower. When the rate is suitable, the *Update Hardware* button is enabled, configuring hardware and software for the new update rate. Note that the Decimation Rate must be sufficiently high for the hardware to sample at the selected Sample Frequency; the timings are discussed in Section 9.

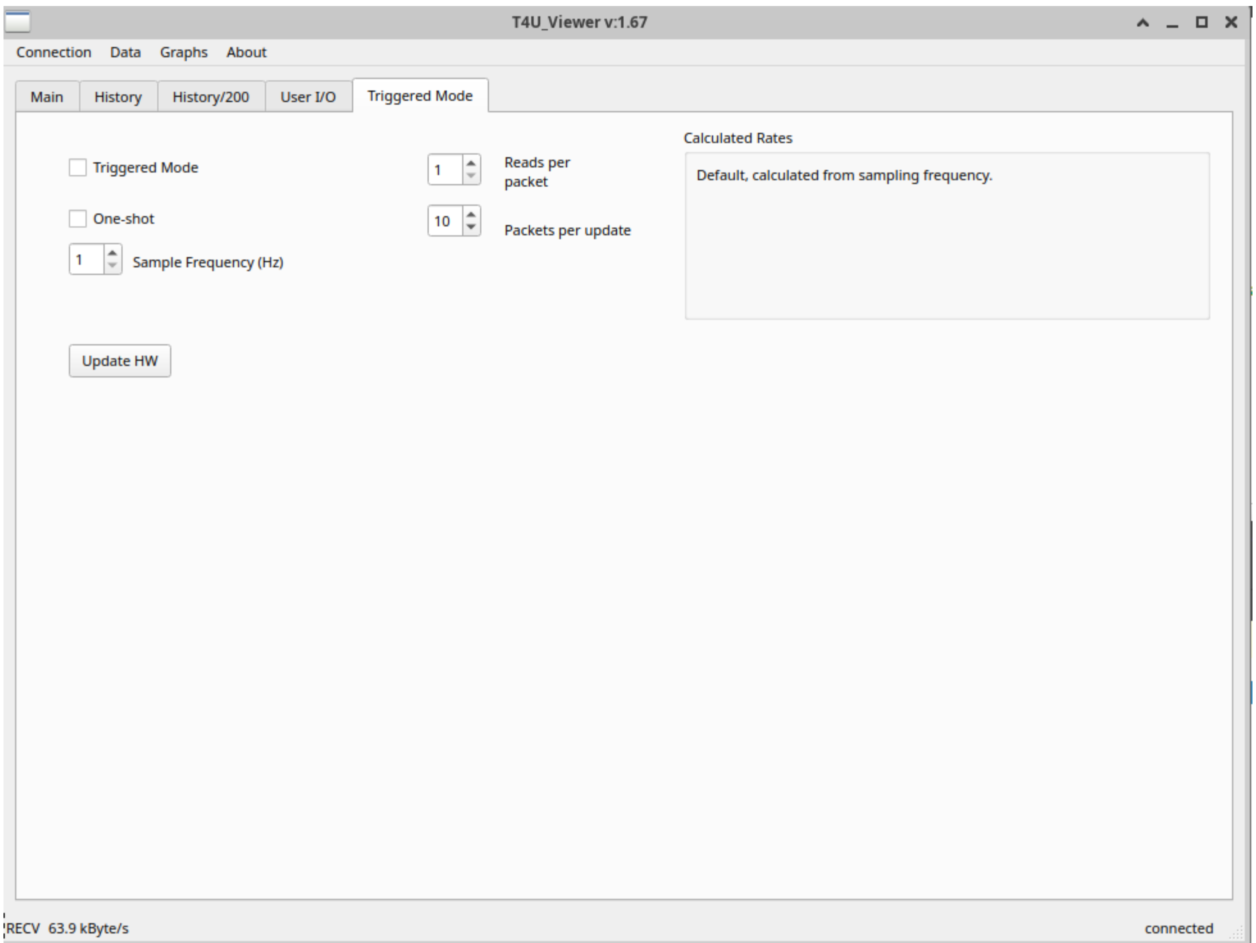

Figure 13: T4U Triggered Mode Tab

9 Trigger Mode Timing

This section pertains only to systems that support the trigger-mode option.

The maximum allowable sample frequency in Trigger Mode timing depends on the Decimation Rate and its reciprocal, denoted the *Decimation Period*. The Decimation Rate determines some of the timing parameters of the pre-trigger.

The pre-trigger must be high for at least one Decimation Period plus a margin; factory-tested values used a margin of $50\mu s$ at Decimation Rates of 10 kHz and 4 kHz, and $100\mu s$ at the 500 Hz Decimation Rate. The pre-trigger must then be low for at least two Decimation Periods. The theoretical maximum Sample Frequency is

$$f_{\text{max}} = \frac{1}{\text{Pre-Trigger High Time} + 2 \times \text{Decimation Period}}$$

The T4U was tested in triggered mode at various decimation rates to verify near-theoretical maximum sample frequencies were viable.

Decimation Rate	Minimum Pre-Trigger High Time (μs)	Maximum Sample Rate
10 kHz	150	2.8 kHz
4 kHz	300	1.2 kHz
500 Hz	2100	160 Hz

10 Calibration Procedure and File Format

Each input channel is calibrated at the factory at each gain range. The factory calibration results are in the test report unique to your unit and in the corresponding DBPM_Settings.ini file.

The T4U can be re-calibrated by the end user. Calibrations should be done at each current range for all four channels.

10.1 Calibration Procedure

The standard procedure for calibration is first to set the external attenuator to "None" to disable the current calibration coefficients. Next is to input a known current into a channel and record the reported current from either T4U Viewer or EPICS. Repeat for several currents. Perform a linear regression on the data and enter Slope and Offset into the calibration file. Repeat for all channels and all ranges.

10.2 Calibration File Format

The calibration details are stored in "DBPM_Settings.ini". The file format differs slightly between T4U Viewer and EPICS Direct.

In T4U Viewer, the format for the corrections values is to have sections named in the form `[<name>_range<n>]` where "name" is the correction name, and n ranges from 0 (high gain) to 2 (low gain). The keys for each section take the form `Channel<l>="<slope>, <offset>"`. The "l" assumes the values from "A" to "D".

For EPICS Direct, the corrections value sections take the same format as for T4U Viewer. There must be a new section with title `[config]`. The first key in this section is "selected", whose value must be the <name> of the correction name for use in regular operation. If you are using a T4U with pulsed mode support, there must be a second key "pulsed", with value of the <name> of the correction for pulsed operation.

11 Pulsed Bias Operation

On setups that generate currents above 5 mA of induced current, Pulsed Bias operation can be used to lower the average current, and hence lower the average induced Joule heating in the detector. The correct duty cycle factor involves many parameters, and it is advised to consult with Sydor for the correct parameters before using the system in this mode.

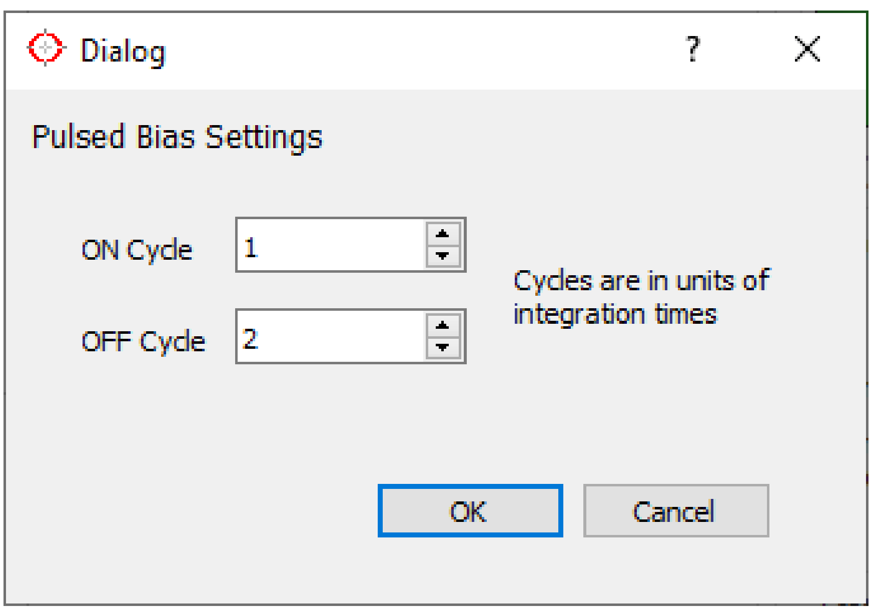

Figure 14: The Pulsed Bias settings window.

This mode works by turning the Bias Voltage on for a short duration, and back off at a regular rate. The software will only poll the hardware and take a reading once - at the end of the ON time, to allow for voltages to settle and get a stable reading. The ratio of ON time to OFF time determines the duty cycle, and should be chosen to prevent Joule heating in the detector and/or wirebonds from exceeding the design limits. The ON time must be chosen to be long enough to get an accurate reading. There is a capacitive coupling between the Bias and the Outputs, that can cause an inaccurate reading if the detector is read-out too soon.

For example, to get a 1% duty cycle, use:

ON Cycle = x
OFF Cycle = 99x

The data rate will slow down correspondingly. The detector will update the history graphs at a reduced rate, with one new data point generated for every completed sequence of ON cycles + OFF cycles. If the ON + OFF cycles adds to 100 cycles, for example, the data rate will be reduced by 100 as well. This will affect the rate at which outputs are updated, and the rate of PID as well.

The time units used are in units of sampling frequency, where

Fast (10,000 Hz) $\longrightarrow$ 100 μs
Intermediate (4000 Hz) $\longrightarrow$ 250 μs
Hi Precision (500 Hz) $\longrightarrow$ 2 ms

The minimum ON cycle will depend on the sampling frequency, and the geometry of the diamond detector. These values were gathered empirically for a $\sim$ 50 μm thick, 5 mm x 5 mm diamond.

Sampling Frequency	**Min ON Cycle**
10 kHz	7
4 kHz	6
500 Hz	4

Table 2: Suggested minimum ON cycle times for accurate readings.

12 EPICS Direct

12.1 Introduction

There are two EPICS IOCs available for the T4U. Both are derived from the standard EPICS QuadEM. The preferred IOC communicates directly with the T4U; this is called EPICS Direct. The deprecated IOC uses T4U Viewer as an intermediate layer, and is denoted EPICS Indirect. This approach is discussed in section 13.

12.2 Installation

The T4U IOC is built as part of a modified synApps installation. The general approach for the IOC proper is to retrieve synApps in a standard manner, download the Sydor-modified quadEM package, and then configure the synApps build to use the new quadEM.

12.3 synApps Installation

The IOC is tested with EPICS Base 7. Installation of EPICS Base is beyond the scope of this manual.

Refer to `https://github.com/EPICS-synApps/support` for more details on the retrieval.

1. Retrieve the assembly script: wget https://raw.githubusercontent.com/EPICS-synApps/support/master/assemble_synApps.sh
2. Edit `assemble_synApps.sh` to have **EPICS_BASE** point to the base directory of the EPICS 7 installation.
3. Set the executable bit on `assemble_synApps.sh` and run `assemble_synApps.sh full`
4. `cd` to the quadEM directory that was downloaded
5. `git checkout master`
6. `cd ..`
7. Edit `configure/RELEASE` as follows:
   7.1 Change **QUADEM** to `$(SUPPORT)/quadEM`
   7.2 Comment out **CAMAC**, **MOTOR**, **DXP**, **DXPSITORO**, **GALIL**, **SOFTGLUE**, **SOFTGLUEZYNQ**, **XSPRESS3**, and **OPCUA**
8. Edit `<asyn dir>/configure/CONFIG_SITE` and uncomment `TIRPC=YES`
9. From the synApps/support directory: `make release`
10. From the synApps/support directory: `make`

12.4 Configuration

1. `cd <synApps support dir>`
2. `cd quadEM/iocBoot/iocT4UDirect_EM`
3. Edit `st.cmd` to invoke the IOC. The first line must point to the quadEM IOC, and will probably be "`#!<support directory>/quadEM/bin/linux-x86_64/quadEMTestApp`", without quotation marks.
4. Edit `T4UDirect_EM.cmd` as follows:
   4.1 Set **PREFIX** to the preferred string for the PV names.
   4.2 Set **RECORD** to the preferred string for the PV names.
   4.3 Set **T4U_ADDR** to the IP address of the T4U. The Search function of T4U Viewer may be useful to discover the IP address.
   4.4 **DATA_PORT** may be left as is.

4.5 Set **CALFILE** to the calibration file for EPICS.

12.5 EPICS Usage

The IOC must first be started:

1. `cd <synApps support dir>/quadEM/iocBoot/iocT4UDirect_EM`
2. `./st.cmd`

The IOC uses the standard QuadEM PVs, and may be used with the OPIs provided as part of the standard QuadEM package. `quadEM.opi` will allow control and readback of the data. The PVs themselves are described in 14

Note: If pulsed bias is used, then the averaging time must change to reflect the reduced data rate of measurements. Compute the new rate data rate and adjust the averaging time for the desired number of samples averaged. Refer to Section 11 for more details.

Further, if using pulsed bias, set the timing parameters first, then enable bias, then enable pulsed bias.

13 EPICS Indirect – Deprecated

13.1 Introduction

There is an EPICS IOC available for the T4U. The IOC is based off of the standard EPICS QuadEM. The IOC uses T4U Viewer as an intermediate layer. When EPICS is connected to the T4U Viewer, an indicator will appear in the Main tab.

13.2 Installation

The T4U IOC is built as a part of a modified synApps installation. The general approach for the IOC proper is to retrieve synApps in a standard manner, download the Sydor-modified quadEM package, then configure the synApps build to use the new quadEM.

13.2.1 Prerequisites

The T4U software is tested with EPICS Base 7. The build process will require several development tools. You will need `gcc`, `g++`, and `make` at a very minimum. The relevant Ubuntu packages include, but are not limited to: `libreadline-dev libperl-dev re2c libusb-1.0.0-dev libusb-dev zlib1g-dev libx11-dev libxext-dev libcurl4-openssl-dev libcfitsio3-dev git ant antlr`. You must install the equivalents for your distribution. For Fedora, the packages installed were `perl-FindBin perl-core re2c rpcgen rpc2-devel grpc-devel libtirpc-devel libusb-devel libusb1-devel xorg-x11-server-devel libX11-devel libXext-devel`. These packages are for the IOC, not CSS. CSS was tested with the NSLS-II release of version 4.5.1-SNAPSHOT.

13.2.2 synApps Installation

Refer to `https://github.com/EPICS-synApps/support` for more details on the retrieval.

1. Retrieve the assembly script: wget https://raw.githubusercontent.com/EPICS-synApps/support/master/assemble_synApps.sh
2. Edit `assemble_synApps.sh` to have **EPICS_BASE** point to the base directory of the EPICS 7 installation.
3. Set the executable bit on `assemble_synApps.sh` and run it.
4. `cd synApps/support`
5. `git clone https://github.com/iainmarcuson/sydor-t4uepics`
6. `mv sydor-t4uepics quadEM`
7. `cd quadEM`

8. `git checkout -t origin/add_t4u`
9. `cd quadEMApp/src`
10. `python3 t4u_gen_code.py T4U_param_list.txt`
11. `cp gc_t4u.db ../Db`
12. `cd ../../..`
13. Edit `configure/RELEASE` as follows:
    13.1 Change **QUADEM** to `$(SUPPORT)/quadEM`
    13.2 Comment out **CAMAC**, **MOTOR**, **DXP**, **DXPSITORO**, **GALIL**, **SOFTGLUE**, **SOFTGLUEZYNQ**, **XSPRESS3**, and **OPCUA**
14. Edit `<asyn dir>/configure/CONFIG_SITE` and uncomment `TIRPC=YES`
15. From the synApps/support directory: `make release`
16. From the synApps/support directory: `make`

13.3 Configuration

With the IOC installed above, it will need to be configured for running.

1. `cd <synApps support dir>`
2. `cd quadEM/iocBoot/iocT4U_EM`
3. Edit `st.cmd` to invoke the IOC. The first line must point to the quadEM IOC, and will probably be "`#!<support directory>/quadEM/bin/linux-x86_64/quadEMTestApp`", without quotation marks.
4. Edit `T4U_EM.cmd` as follows:
    4.1 Set **PREFIX** to the preferred string for the PV names.
    4.2 Set **RECORD** to the preferred string for the PV names.
    4.3 Set **QTHOST** to the IP address of the computer running T4U Viewer.
    4.4 Set **QTBASEPORT** to the base port number of the T4U Viewer to connect to. The default is 15001.

13.4 EPICS Usage

The IOC must first be started:

1. `cd <synApps support dir>/quadEM/iocBoot/iocT4U_EM`
2. `./st.cmd`

The IOC uses the standard QuadEM PVs, and may be used with the OPIs provided as part of the standard QuadEM package. `quadEM.opi` will allow control and readback of the data.

14 EPICS PVs

The T4U IOC is built off of the standard QuadEM PVs. There are new PVs for User I/O and PID controls, and some of the PVs have been repurposed for the specifics of the T4U. Many of the PVs come in setter/getter pairs, with the getter PV name having the suffix `_RBV`.

14.1 EPICS Indirect Considerations

The T4U must be in Broadcast mode for proper communications.

Communication between EPICS and T4U Viewer is bi-directional, but a manual refresh is generally needed to do the transfer. To refresh the *QuadEM Control PVs* or the **Main** tab, switch to the **Main** tab, switching away if already on that tab. To refresh the *User I/O and PID PVs* or the **User I/O** tab, either switch to the **User I/O** tab or click the **Refresh** button if already on that tab. Sending a command from EPICS to T4U Viewer will refresh all registers, but a tab change may be needed for the results to show in T4U Viewer.

14.2 QuadEM Control PVs

(P)(R)BiasPEn, (P)(R)BiasPEn_RBV
Bias enable. Set to 1 to enable, 0 to disable. (Only BiasP is available on T4U.)

(P)(R)BiasPVoltage, (P)(R)BiasPVoltage_RBV
Positive bias voltage. Not supported.

(P)(R)BiasNEn, (P)(R)BiasNEn_RBV
Negative bias enable. Not enabled; see BiasPEn above.

(P)(R)BiasNVoltage, (P)(R)BiasNVoltage_RBV
Negative bias voltage. Not supported.

(P)(R)Range, (P)(R)Range_RBV
Repurposed to control ADC gain and thus range.

- **0** Low gain. Range 5 mA, but see manual about full scale.
- **1** Medium gain. Range 100 μA.
- **2** High gain. Range 300 nA.

(P)(R)SampleFreq, (P)(R)SampleFreq_RBV
Decimation frequency in Hz. Allows any value, but three are standard for T4U Viewer: 10000, 4000, 500.

(P)(R)PulseBiasOnCnt, (P)(R)PulseBiasOnCnt_RBV
The number of On cycles for pulsed bias. See Section 11 for more details.

(P)(R)PulseBiasOffCnt, (P)(R)PulseBiasOffCnt_RBV
The number of Off cycles for pulsed bias. See Section 11 for more details.

(P)(R)PulseBiasEn, (P)(R)PulseBiasEn_RBV
Enables or disables pulsed bias. **Ensure that On and Off count, above, have already been set.**

(P)(R)WaitStateMode, (P)(R)WaitStateMode_RBV
Used to select the wait state mode and behavior of **IN 2**.

- **0** Ordinary operation.
- **1** Inhibit Mode.
- **2** Triggered (Pulsed) Mode. Not supported on all units.

14.3 User I/O and PID PVs

(P)(R)DACMode, (P)(R)DACMode_RBV
Controls the User I/O mode. These modes are documented under User I/O above.

- **0** None.
- **1** Quadrant i.e. I1 I2 I3 I4

2 XY i.e. X Y I_Tot

3 PID i.e. PID, I_Tot, Active

(P)(R)PIDEn, (P)(R)PIDEn_RBV
PID enable. Set to 1 to enable, 0 to disable. This variable affects both X and Y PID enables.

(P)(R)PIDX_Sp, (P)(R)PIDX_Sp_RBV
PID X setpoint. Ranges from [-1.0, 1.0].

(P)(R)PIDX_Kp, (P)(R)PIDX_Kp_RBV
PID X P term.

(P)(R)PIDX_Ki, (P)(R)PIDX_Ki_RBV
PID X I term.

(P)(R)PIDX_Kd, (P)(R)PIDX_Kd_RBV
PID X D term.

(P)(R)PIDX_Scale, (P)(R)PIDX_Scale_RBV
PID X scale factor. Not used.

(P)(R)PIDX_VScale, (P)(R)PIDX_VScale_RBV
PID X output voltage scale factor. Ranges from [-5, 5].

(P)(R)PIDX_VOffset, (P)(R)PIDX_VOffset_RBV
PID X output voltage offset. Ranges from [0,10].

(P)(R)PIDY_Sp, (P)(R)PIDY_Sp_RBV
PID Y setpoint. Ranges from [-1.0, 1.0].

(P)(R)PIDY_Kp, (P)(R)PIDY_Kp_RBV
PID Y P term.

(P)(R)PIDY_Ki, (P)(R)PIDY_Ki_RBV
PID Y I term.

(P)(R)PIDY_Kd, (P)(R)PIDY_Kd_RBV
PID Y D term.

(P)(R)PIDY_Scale, (P)(R)PIDY_Scale_RBV
PID Y scale factor. Not used.

(P)(R)PIDY_VScale, (P)(R)PIDY_VScale_RBV
PID Y output voltage scale factor. Ranges from [-5, 5].

(P)(R)PIDY_VOffset, (P)(R)PIDY_VOffset_RBV
PID Y output voltage offset. Ranges from [0,10].

(P)(R)PIDCuEn, (P)(R)PIDCuEn_RBV
Boolean to enable automatic cutout. Set to 1 to enable, 0 to disable.

(P)(R)PIDHystEn, (P)(R)PIDHystEn_RBV
Boolean to enable automatic re-enable. Set to 1 to enable, 0 to disable.

(P)(R)PID_Cutout, (P)(R)PID_Cutout_RBV
PID cutout current in nA.

(P)(R)PID_Hyst, (P)(R)PID_Hyst_RBV
PID re-enable hysteresis current in nA.

(P)(R)PIDCtrlPol, (P)(R)PIDCtrlPol_RBV
PID Control Polarity.

0 Active High

1 Active Low

(P)(R)PIDCtrlEx, (P)(R)PIDCtrlEx_RBV
PID External Control.

0 No External Control

1 GPI1

(P)(R)DACItoV, (P)(R)DACItoV_RBV
User I/O current to voltage scale.

(P)(R)DACItoVOffset, (P)(R)DACItoVOffset_RBV
User I/O current to voltage offset.

(P)(R)PosTrackMode, (P)(R)PosTrackMode_RBV
Position tracking mode.

0 None.

1 Active High

2 Active Low

3 Reserved

(P)(R)PosTrackRad, (P)(R)PosTrackRad_RBV
Position tracking radius.

14.4 Data PVs

The current measurements and calculations based on them are the standard data PVs for the QuadEMs. The quadEM OPI provides access to these PVs and the associated controls, either for direct display or to get the names of the PVs.