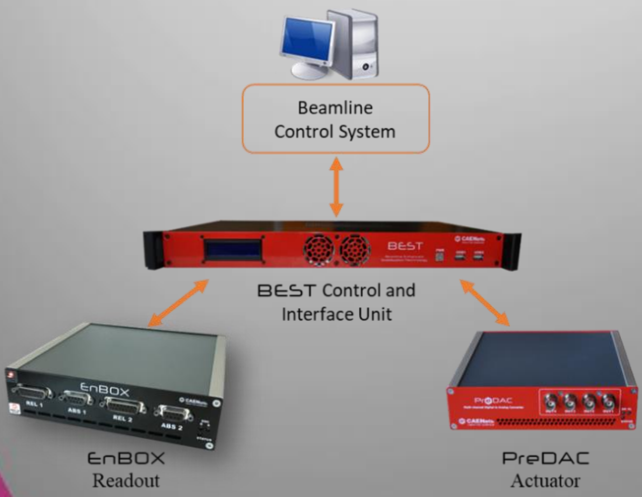
BEST-ENC

Beamline Enhanced Stabilization Technology ENCoders

S.RI. Tech

CAENels
Gear For Science

User's Manual



Rev. 3 –September2024

BEAMLINE ELECTRONIC INSTRUMENTATION

This product is CE & UKCA compliant.

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User Manual – Models – Options – Custom Models

This manual covers the following standard BEST-ENC models:

Model	Ordering code
BEST-ENC full system	WBESTENCXAAA
BEST Central Unit	COMP-BEI0004

The **WBESTENCXAAA** includes:

- 1 PreDAC - Standard version with 2 outputs;
- 1 EnBOX - Encoder Read BOX for BEST-ENC;
- 2 Optical Cables - OM2-50/125µm, Multimode Duplex DK-2533-10, length = 10 m;
- 4 SFP Fiber Optic Transceivers - 4.25Gbps 850nm 3 V ~ 3.6 V LC Duplex Pluggable - FTLF8524P2BNV

The **COMP-BEI0004** includes:

- 3 Optical Cables - OM2-50/125µm, Multimode Duplex DK-2533-10, length = 10 m;
- 6 SFP Fiber Optic Transceivers - 4.25Gbps 850nm 3 V ~ 3.6 V LC Duplex Pluggable - FTLF8524P2BNV

The **COMP-BEI0004** is more suitable when building up a custom system with two EnBOXes.

The BEST-ENC can be equipped with up to two EnBOX devices and one PreDAC device. See their respective User's Manuals for all ordering codes available.

Table Of Contents

Document Revision	Date	Comment
1.0	October 3rd, 2016	First release
2.0	January 9th, 2018	EPICS information added
2.1	December 11th, 2018	BEST Local GUI info updated
2.2	October 10th, 2019	Documentation updated
2.3	June 4th, 2020	Text review
2.4	February 17th, 2022	Major Text review
2.5	April 22th, 2022	Firmware Upgrade (1.2.20) and Text Update
2.6	June 21th, 2022	Text Update, S.RI. Tech text revision
2.7	August 29th, 2022	Text Revision
2.8	November 23rd, 2022	Added UKCA compliance logo
3	September 2nd, 2024	Updated address and revision numbering

Safety information - Warnings

CAEN ELS will repair or replace any product within the guarantee period if the Guarantor declares that the product is defective due to workmanship or materials and has not been caused by mishandling, negligence on behalf of the User, accident or any abnormal conditions or operations.

Please read carefully the manual before operating any part of the instrument

WARNING

Do NOT open the boxes

CAEN ELS s.r.l. declines all responsibility for damages or injuries caused by an improper use of the Modules due to negligence on behalf of the User. It is strongly recommended to read thoroughly this User's Manual before any kind of operation.

CAEN ELS s.r.l. reserves the right to change partially or entirely the contents of this Manual at any time and without giving any notice.

Disposal of the Product

The product must never be dumped in the Municipal Waste. Please check your local regulations for disposal of electronics products.

Read over the instruction manual carefully before using the instrument.
The following precautions should be strictly observed before using the BEST-ENC system:

WARNING

- Do not use this product in any manner not specified by the manufacturer. The protective features of this product may be impaired if it is used in a manner not specified in this manual.
- Do not use the device if it is damaged. Before you use the device, inspect the instrument for possible cracks or breaks before each use.
- Do not operate the device around explosives gas, vapor or dust.
- Always use the device with the cables provided.
- Turn off the device before establishing any connection.
- Do not operate the device with the cover removed or loosened.
- Do not install substitute parts or perform any unauthorized modification to the product.
- Return the product to the manufacturer for service and repair to ensure that safety features are maintained

CAUTION

- This instrument is designed for indoor use and in area with low condensation.

The following table shows the general environmental requirements for a correct operation of the instrument:

Environmental Conditions	Requirements
Operating Temperature	0°C to 45°C
Operating Humidity	30% to 85% RH (non-condensing)
Storage Temperature	-10°C to 60°C
Storage Humidity	5% to 90% RH (non-condensing)

1. Introduction

The BEST-ENC (Beamline Enhanced Stabilization Technology – ENCoders) is a software and instrumentation suite, which was especially designed for real-time control and characterization of beam properties in X-ray beamlines by monitoring and using the output readout of relative and absolute encoders installed onto positioners of critical optical components.

The BEST-ENC suite is directly derived from the BEST system architecture (http://www.caenels.com/products/best/). The two systems share most of the hardware units, which are either freely swappable or can be reconfigured to switch them between the two systems. BEST and BEST-ENC differ mainly in the readout devices that they use: the BEST uses TetrAMM digital picoammeter units reading electric currents from phBPMs (photon Beam Position Monitor), while the BEST-ENC, with the ENBOX as readout device, reads digital signals from either incremental (quadrature) or absolute (*BiSS*©) optical encoders or from any instrument using the same communication protocols (e.g.: interferometers).

The BEST-ENC system follows the same modular architecture as the original BEST, allowing installation of all sensitive electronics building blocks as close as possible to the corresponding input or output device - e.g. encoders or a piezoelectric actuator driver/amplifier.

The building blocks of the BEST-ENC system are:

- the **readout** block – i.e. an EnBOX device;
- the **control and interface** block – i.e. a BEST-ENC Central Unit;
- the **actuator** block – i.e. a PreDAC device.

A simplified block diagram of the BEST-ENC architecture is shown in the following figure.

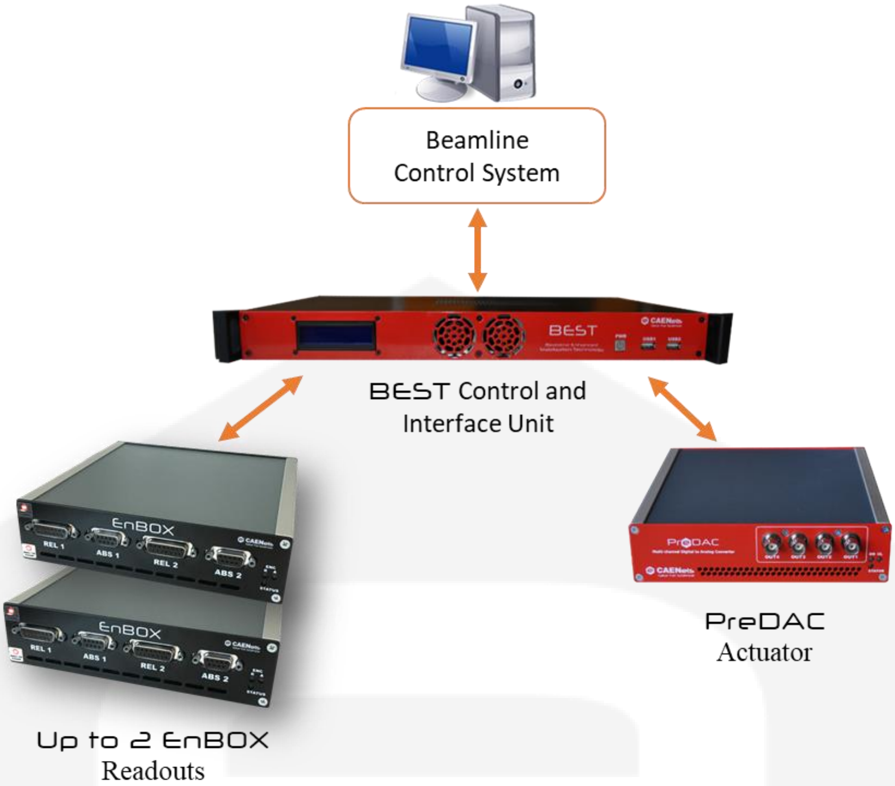


Figure 1: Simplified architecture of the BEST-ENC instrumentation suite.

The BEST-ENC full-configuration is composed by up to:

- The "EYE" – inputs readout. One or two encoders readout/supply blocks (EnBOX, each of them allows reading and powering up either two absolute or two relative encoders);
- The "ARM" – outputting driving signals. One actuator block (PreDAC, with up to 4 low-voltage output channels, thus allowing running up to 4 different PID control loops on 4 different piezoelectric actuators);
- The "BRAIN" – executing the required calculations and interfacing with the external world. One BEST-ENC Central Unit with all the necessary programming and calculating power, which can be controlled either locally or remotely.

A typical setup for an operational BEST-ENC system is presented below; the feedback regulation is performed based on up to 4 different sensors (encoders) inputs and corrections to beam properties are carried out by up to 4 separated piezoelectric actuators acting on four mechanical systems:

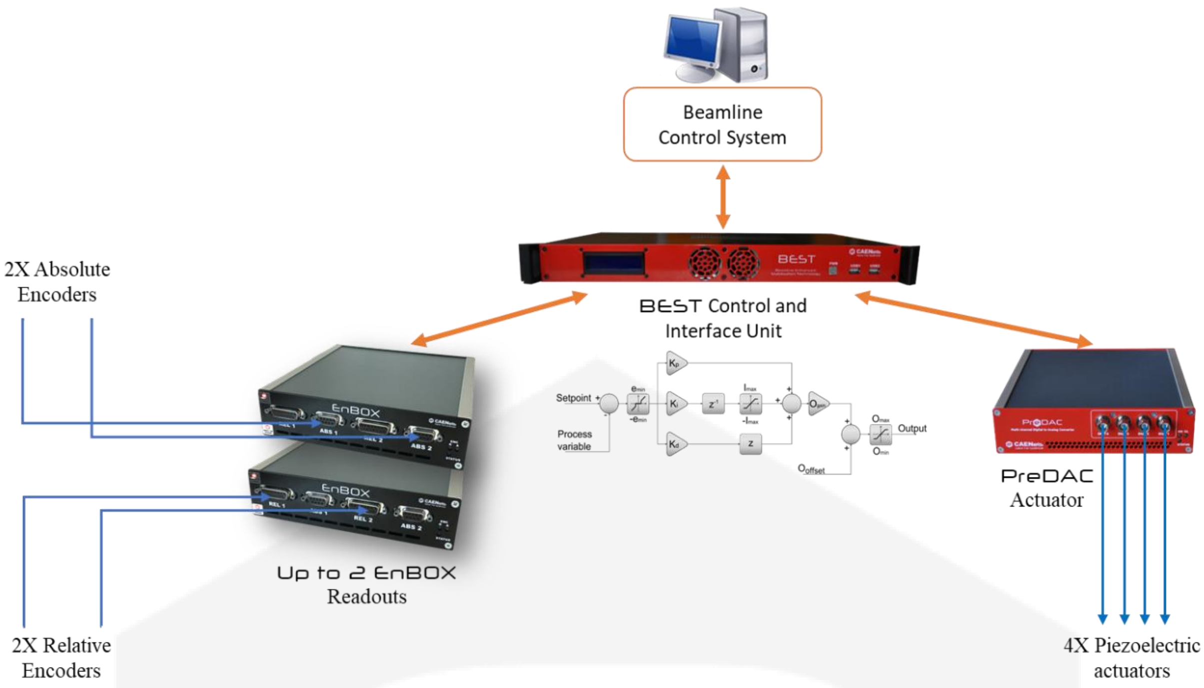


Figure 2: BEST-ENC application example.

A detailed description of each building block of the BEST-ENC system is provided in the next sections of this manual.

1.1 EnBOX (Encoder BOX)

The BEST-ENC system can read at high frequency position/angle data provided by encoders using two different protocols, which are routinely used in synchrotron radiation and XFEL laboratories: incremental (quadrature) or absolute (*BiSS©*). These two protocols are used, for example, by Renishaw in-air or UHV encoders: both TONiC™ relative encoders and RESOLUTE™ absolute units are supported and can be easily and directly integrated in the BEST-ENC system. Please note that also other devices can be integrated, provided that they follow the same protocols for their outputs. Please contact either CAEN ELS s.r.l. or S.RI. Tech for technical clarifications, should any need for different inputs arise.

Interfacing, as well as supplying power to the encoders is performed directly by the EnBOX unit which is able to provide the TONiC™ and also the RESOLUTE™ encoders with the necessary stable and clean 5V@250mA input.

The *BiSS©* protocol is used in order to read encoder data (including error bits, CRC, etc.) when using the RESOLUTE™ type, and a different readout logic is implemented for the TONiC™ type. Since the user selects which protocol to use, the four inputs of each EnBOX unit allow reading either two TONIC™ encoders <u>or</u> two RESOLUTE™ ones.

<u>Please note that a single EnBOX unit must be dedicated to readout of encoders of the same type: it is not possible to mix relative and absolute input protocols one the same EnBOX</u>.

Up to two EnBOX units can be connected in a single BEST-ENC system – i.e. four encoders can be integrated in the system.

<u>Please note that two can be absolute and two relative: it is not required that all four encoders are of the same type, provided that each EnBOX reads two identical input protocols</u>.

Two Sub D 9-pin and two Sub D 15-pin connectors are installed on the device front panel in order to get interface/power to and from the RESOLUTE™ and TONiC™ encoders respectively.

Figure 3: Front view of an EnBOX unit.

As stated earlier, different measuring/monitoring devices can also be easily integrated, provided that they follow the same protocols for their outputs as the RENISHAW encoders previously mentioned. Please contact either CAEN ELS s.r.l. or S.RI. Tech for technical clarifications, should any need for different inputs or pin-outs arise.

The EnBOX converts the input raw digital encoder data into output position measurements that are shared with the BEST-ENC central unit via a fast SFP link running a proprietary protocol.

Each EnBOX unit can be controlled independently via its 10/100/1000 Mbps Ethernet TCP/IP connection. Data generated by the unit and the associated encoders are integrated into the EPICS driver that each system runs on its central unit and are also accessible from the system Web Interface.

Detailed information on the EnBOX operation is available in a specific EnBOX User's Manual.

1.2 PreDAC (Precision Digital-to-Analog Converter)

The PreDAC is a (up to) 4-channel, 21-bit resolution, wide-bandwidth Digital to Analog Converter (DAC) which is especially designed for seamless integration and operation within the BEST systems. At the core of the PreDAC system there is a high-speed 16-bit digital to analog converter that uses dithering technique and active low-pass filtering to obtain a stable high accuracy (21-bit) output signal.

This device is capable of outputing up to ±12 V bipolar voltage with an ultimate resolution of 12 µV – i.e. 21 bits on the bipolar full output range. Output voltage noise is suppressed using a 4th order active low-pass filter with cut-off frequency (-3 dB) of 10 kHz. Its minimized temperature-induced drifts, good linearity and very low noise levels enable users to perform high-precision voltage signal generation to be fed into a piezoelectric actuator.

The standard PreDAC has two voltage output channels but can be optionally upgraded to have three or even four output channels on a single unit. It is housed in a light, robust and extremely compact metallic box that can be placed as close as possible to the piezoelectric actuator power driver/amplifier in order to reduce cable lengths and consequently minimize possible noise pick-up on the analog signal path. It is specially suited for applications where multi-channel simultaneous actuations are required, a typical application being control of position (X, Y) and intensity (I_0) of the photon beam in synchrotron radiation or XFEL X-ray beamlines.

The PreDAC communication to a host PC when used as a standalone unit is guaranteed by a standard 10/100/1000 Mbps Ethernet TCP/IP protocol while its integration in the BEST (Beamline Enhanced Stabilization Technology) system is performed via the SFP link available on the rear panel.

The PreDAC unit and its I/O connections can be easily seen in **Figure 4** (front) and in **Figure 5** (rear).

Figure 4: front view of a PreDAC unit

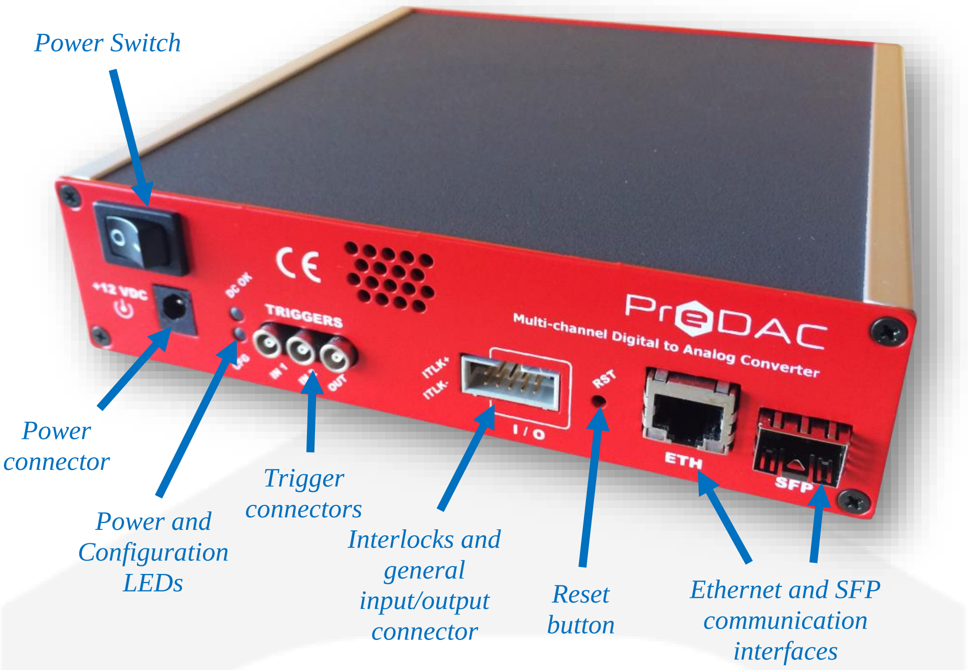


Figure 5: rear view of a PreDAC unit

It is of uttermost importance to suitably limit, when required, the PreDAC voltage outputs in order to prevent any possible damage to the connected units (for example the piezoelectric actuators).

To perform this task, please refer to the "MIN" and "MAX" Commands of the PreDAC User's manual.

1.3 BEST-ENC Central Unit

The BEST-ENC Central Unit is the "core" of the entire system: it acts as data collector for all connected devices and provides all the necessary computing power to (i) run the parallel, real-time feedback loops (up to 4) and to (ii) establish communication with the beamline control system scripts and with beamline operators. It is based on a specially designed architecture where the control loops are performed on an FPGA PCI-e board that receives and sends data via the fast and low delay SFP links. Remote control of the central unit is possible using a Web Interface or the dedicated EPICS driver using a standard 10/100/1000 Ethernet link. This provides the possibility to directly connect the BEST-ENC Control and Interface Unit to the beamline control system.

The BEST-ENC Central Unit and its I/O connections can be easily seen in the following pictures.

Figure 6: Front view of a BEST-ENC Central Unit.

Figure 7: Rear view of a BEST-ENC Central Unit.

Detailed information on the BEST-ENC Central Unit installation and operation is available in the BEST User's Manual. The BEST and the BEST-ENC use the same Central Unit hardware.

2. BEST-ENC Local GUI

This chapter describes the main features of the BEST-ENC Local GUI (Graphical User Interface) which can be simply accessed after switching on the BEST-ENC Central Unit. The BEST-ENC Local GUI is already installed on the Linux OS. To run the program simply click on the "BEST-ENC Local GUI" icon on the Linux desktop.

The default Linux OS user and password are (case-sensitive):

- User: *best*
- Password: *WeAreTheBest*

2.1 Main Window

The main screen of the BEST-ENC Local GUI is shown in **Figure 8**.

The main graph is located in the upper section and shows the current beam "position" in the XY (typically, horizontal & vertical) plane. This is a 2D representation of the calculated "positions" directly derived from the two X and Y encoder readings.

Various possible plots can be selected in the bottom section of the GUI in order to better monitor and/or analyze X-ray beam properties or perform sanity checks on the feedback system itself. The quantities shown are real-time plots and the time window can be adjusted by the user.

A *feedback control* panel located in the top-right part of the GUI allows users to activate, pause or reset the feedback controller, change the controller input/output configuration and set the desired setpoints (see section 2.1.2).

The *PID configuration* panel is located in the bottom-right part of the GUI and gives to users the possibility to: (i) fully configure the system in the *Feedback Tab* and (ii) set and tune all three PID parameters according to the required system dynamics in the *PID Params Tab*. Some statistical parameters of relevance for diagnostics and evaluation of system performance are reported and continuously updated in the *Stats Tab.*

<u>IMPORTANT: some specific settings must properly initialized according to the beamline configuration and to the encoders performance prior to starting the feedback system. What these setting are and where to find them will be clarified in the following sections.</u>

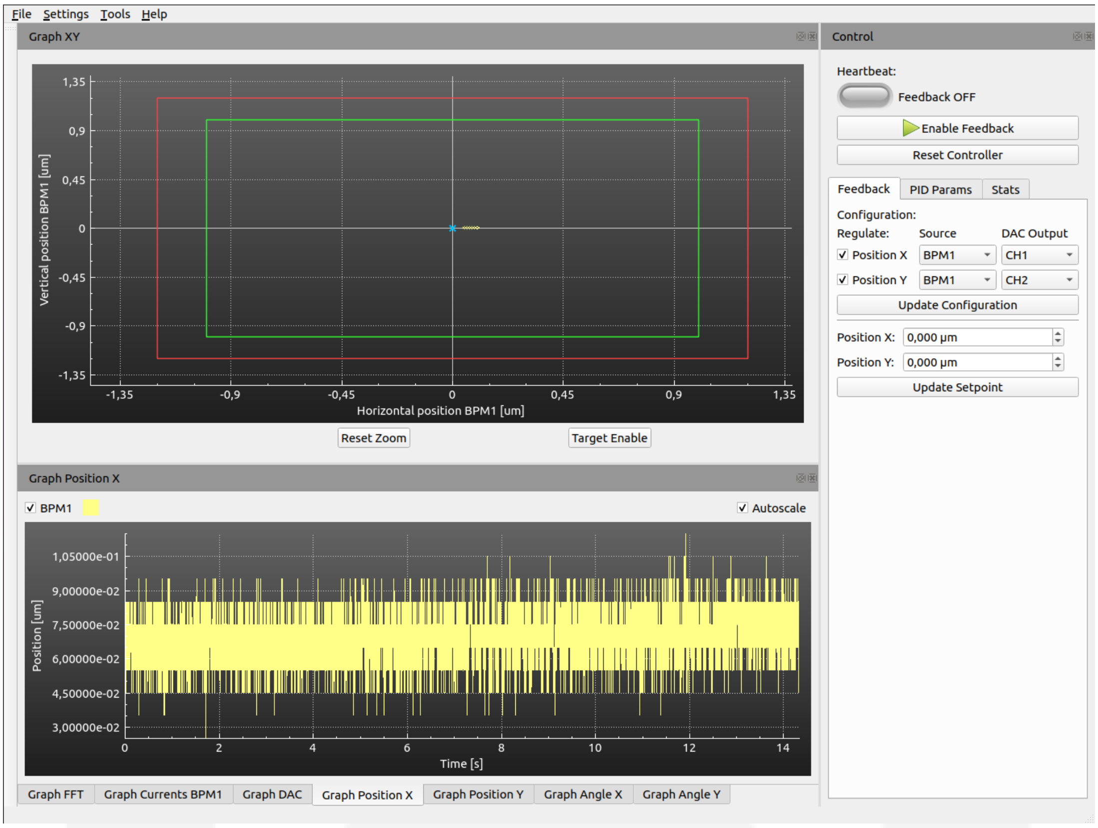


Figure 8: BEST-ENC Local GUI main window

2.1.1 Graph XY

The Graph XY window in the upper section of the GUI shows the X-ray beam "position" in XY plane (**Figure 9**) as calculated from the X and Y encoders readout. Please note that as X and Y may not necessarily be related to readout of angles of optical elements deflecting in the horizontal and vertical plane, in such case there is no direct correlation between the graph and physical X-ray beam position.

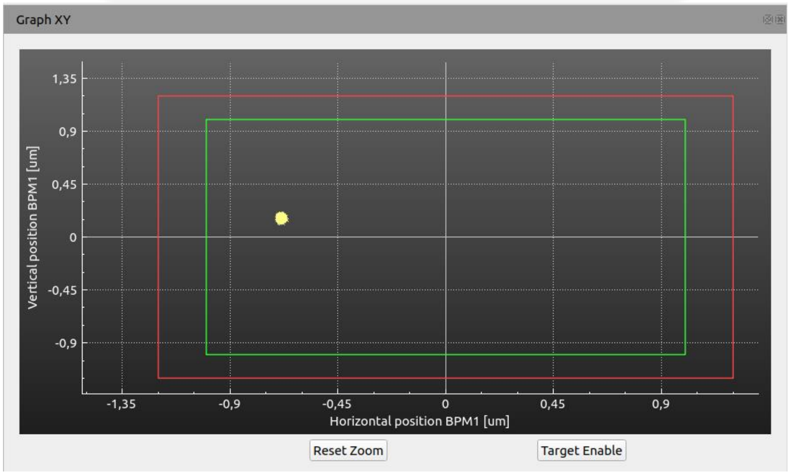


Figure 9: Graph XY

The graph is updated in real-time with a fixed time window of one second, thus the user can get a precise view of the beam "position" distribution in the last second.

As described before, the PID control of beam position can be performed in different configurations. For example it is possible to control the beam in a single dimension (i.e. Y - dimension is regulated by the system and X is free) or in both dimensions (i.e. X and Y dimensions are regulated by the system). When the PID controller acts only in one dimension, the setpoint is a line pointer, otherwise when it acts in two dimensions the setpoint is represented by as a blue cross pointer (as it can be seen in **Figure 8**, where the target point is at origin of both axis).

The green rectangle within the Graph XY window represents the Region Of Interest (ROI), i.e. the area where the user is freely allowed to position the feedback setpoint. The red rectangle (always larger than the green one) shows the Region Of Convergence (ROC), i.e. the area where the PID controller still acts on the beam position. If, for ny reason, the beam position leaves the ROC, the feedback regulation is stopped. The dimension of these two regions can be freely set by the user in the corresponding configuration window (see section 2.7).

It is also possible to perform "Point and Click Positioning" within the Graph XY window. This feature allows the user to move the beam to any desired setpoint position by simply clicking on the XY graph area. To enable this feature it is necessary to select the "Target Enable" button. An example of this feature is shown in **Figure 10**.

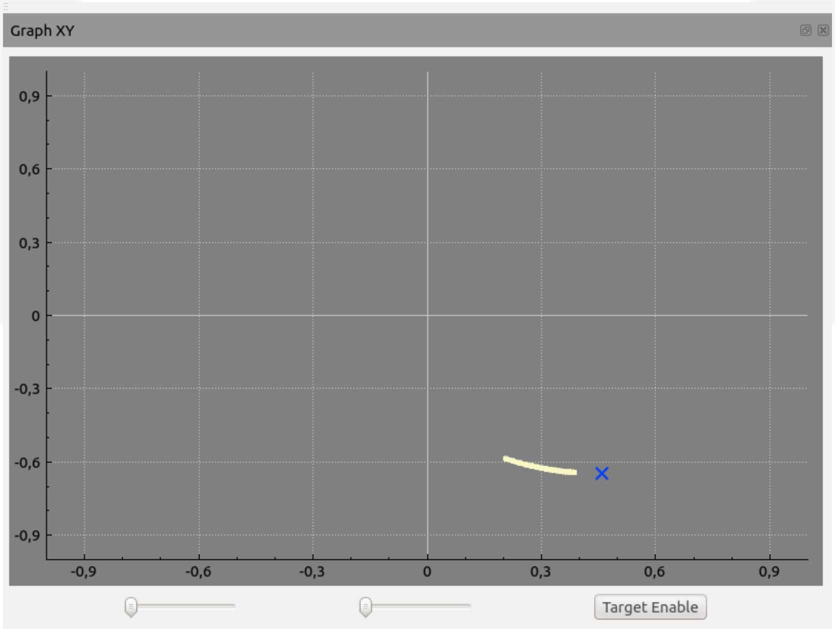


Figure 10: Point and Click Positioning

2.1.2 Feedback Control Panel

The main settings of the PID feedback control are placed in the *feedback control* panel on the top-right part of the GUI main window.

The *feedback control* panel can show two tabs:

- The *statistics* section tab (**Figure 11**), where the real-time mean value of the encoder readout (X-Y) and its related standard deviation are visualized;
- The *control* section tab (**Figure 13**), which groups all the main feedback control input/output parameters.

The *statistics* section tab reports mean values and standard deviations of X and Y of the encoders readout data at the maximum sampling frequency (5 kHz). The standard deviation of X and Y at 100 Hz (average of 50 samples) is also reported.

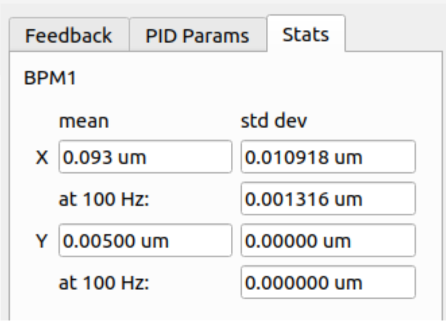


Figure 11: Feedback statistics section.

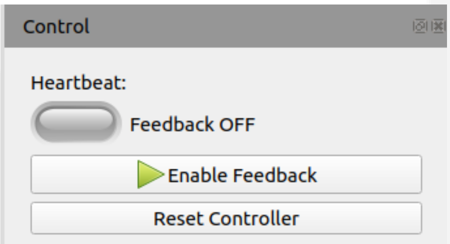


Figure 12: Heartbeat, Enable/Disable Feedback and Reset controller

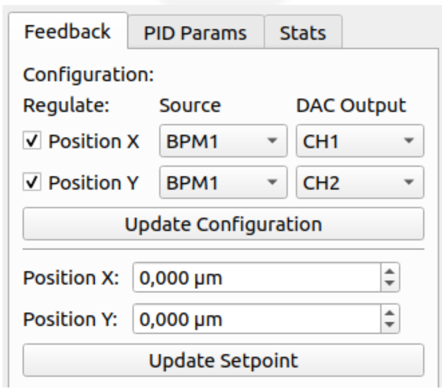


Figure 13: Feedback control section

The *control* section is composed by a "Heartbeat" indicator (**Figure 12**), which shows the feedback status. There are three possible statuses:

- *Feedback OFF* – the feedback loop is disabled and on output there are only user defined offsets (user defined offset is the *PID offset* field in the PID configuration panel, see section 2.1.3). This mode can be used to manually position the beam in a desired location by changing the *PID offset* field.
- *Feedback ON* – the feedback is enabled and the output is calculated by the PID algorithm (see **Figure 15** for a visual representation of the PID structure).
- *Fault: Out of ROC* – this is an error message which means that the beam position has moved outside the user defined ROC; as a consequence the feedback is automatically stopped. Before starting again, the feedback with the "Enable feedback" button it's necessary to set back the PID status and its output to the initial values; this can be done with the "Reset Controller" button.

The "Enable/Disable Feedback" button allows to start or to stop the feedback regulation of beam position to the selected setpoint.

The "Reset Controller" button resets all internal states (e.g. the integrated value of error) of the PID controller.

The feedback configuration options are placed below the "Enable/Disable Feedback" and "Reset Controller" buttons:

- *Regulate* – select which PID to enable;
- *Source* – select which BPM to use as source for the PID;
- *DAC output* – assign the PID output to the desired PreDAC output.

The feedback configuration options come into force after pressing the "Update Config" button.

Lastly, the beam position setpoint can be changed manually by specifying the "beam position" ("Position X" and "Position Y") in µm. New values come into effect after pressing the "Update Setpoint" button.

2.1.3 PID Configuration Panel

The PID parameters of the two independent PID loops available from the BEST-ENC system when a single EnBOX is used are all accessible from the GUI main window. To modify a parameter simply change its value and click the "Update" button to make the changes effective.

The PID parameters (**Figure 14**) are used in the FPGA logic for the BEST-ENC fast feedback computation algorithms. The BEST-ENC system can control and stabilize up to two variables, which are usually associated to:

1. **X**: horizontal position;
2. **Y**: vertical position.

A digital filter (simple average) is applied to the input data received from the EnBOX before entering the PID calculation. This filtering is performed to maximize the signal-to-noise ratio and to reduce the feedback actuation frequency that can be set using the field "Freq" in the PID Configuration menu. This parameter is of paramount importance and is correlated to the dynamical performances of the positioning mechanics driven by the PID. Certain positioners are stiff, lightweight and fully backlash-free, therefore they can be actuated to track the setpoints generated by the PID at relatively high frequencies of 100 Hz and above. Other positioners may be intrinsically slower, therefore they can be actuated at frequencies of only a very few tens of Hz. Slow thermal drifts are easily compensated by running the PID at just around 1 Hz.

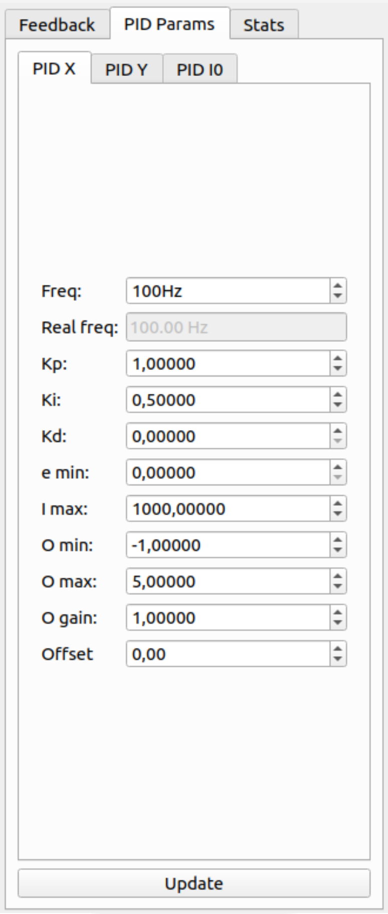


Figure 14: PID Parameters window

The feedback actuation frequency ("Freq" in the PID configuration menu) is obtained by averaging the encoder source signal (always sampled at 100 kHz) by an integer number of samples. For this reason, only a discrete range of frequencies ("Real freq" in the PID configuration menu) corresponding to integer multiple of samples in the averaging algorithm can be obtained. If, for example, the user selects Freq = 100 Hz the averaging is performed on 1000 samples and "Real freq" will exactly be 100 Hz, while if the user selects 90 Hz the average is performed on the closest possible integer number of samples (1112) and "Real freq" of the PID will be 89.928 Hz, slightly different from the one required by the user. In other words, the "Real freq" field shows the nearest, real and applicable actuation frequency value based on the required "Freq" setting.

The usual K_p, K_i and K_d parameters are needed to calculate the well-known PID algorithm (**Figure 15**). There are also several other parameters available to the user; they can further optimize, tailor and fine tune the PID controller and therefore improve system performances.

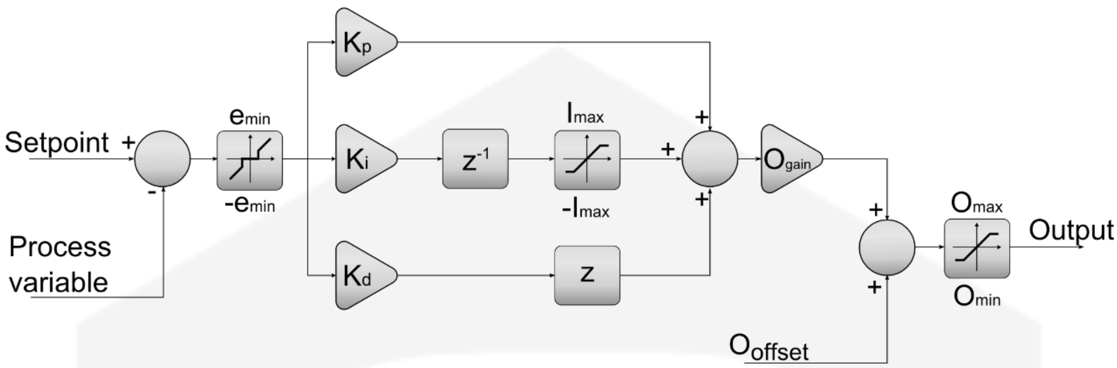


Figure 15: PID Regulator architecture

The "e_{min}" value set the smallest error value which is taken into account for the PID calculation. All smaller values are trimmed to zero. In most cases this parameter should be set at zero, although it can be used to stop the controller if a predefined error from the loop target is reached and the user wants to freeze the system and avoid continuous very small corrections. It sets the minimum tuning bandwidth of the closed-loop feedback.

The "I_{max}" parameter sets the saturation limit of the integral part of the PID controller.

The PID output (in Volts) is limited between the set "O_{min}" and "O_{max}" values. It is recommended to set these values carefully in order to prevent any potential damage to the input stage of the piezoelectric actuator driver/amplifier or even to the actuator itself. For example, piezoelectric actuators often have asymmetric input voltage ranges, much wider in a given polarity than in the opposite. N.B.: we point out that it is possible to set further limits for the minimum and maximum value of the PreDAC output, which are set in a lower level firmware and therefore provide an additional protection layer. Please refer to the PreDAC User's Manual, "MIN" and "MAX" Commands.

The output of the PID controller is multiplied by the "O_{gain}" value to change the gain of the closed loop and, mainly, to invert the PID response. Normally this parameter is only set either to 1 or -1.

"O_{offset}" can be used to steer the beam to a selected working point. Furthermore, In order to benefit from the maximum excursion in both direction of the piezoelectric actuator, it is suggested to set O_{offset} at the center of the piezo driver/amplifier input range.

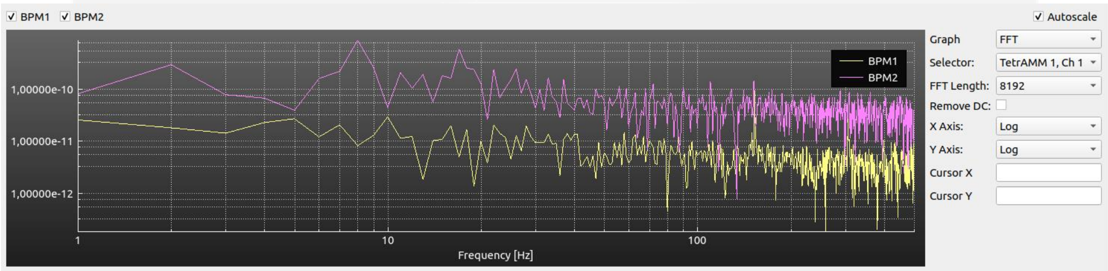
By pressing the "Update" button, all new parameters are downloaded to the controller on the FPGA and they take effect immediately.

2.1.4 Additional Graphs

On the bottom part of the main window, further additional graphs of the main physical quantities are grouped into tabs. When two EnBOXes are connected to the BEST Central Unit, the graph of the second BPM (usually in pink) is added to the same graph tab of the first BPM (usually in yellow), with except for the "Currents Graph Tab", where an additional graph tab is created for the second BPM.

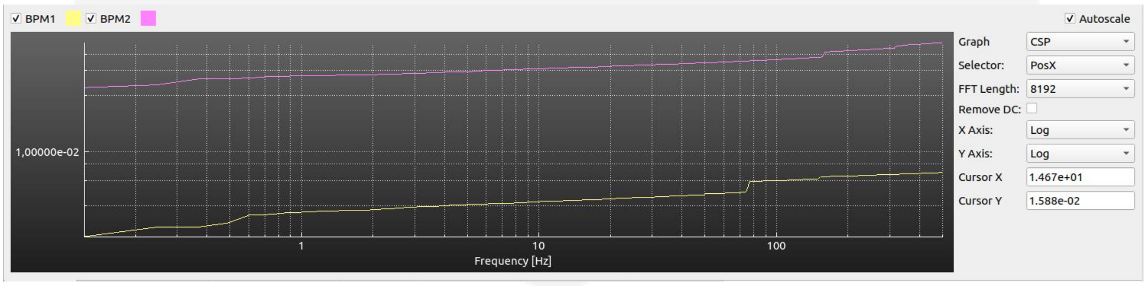
2.1.4.1 FFT Graph Tab

The FFT Graph Tab shows the real-time FFT of the main physical quantities. The User can dynamically select the physical quantity on which the FFT is performed on. Available quantities are currents, position and intensity.



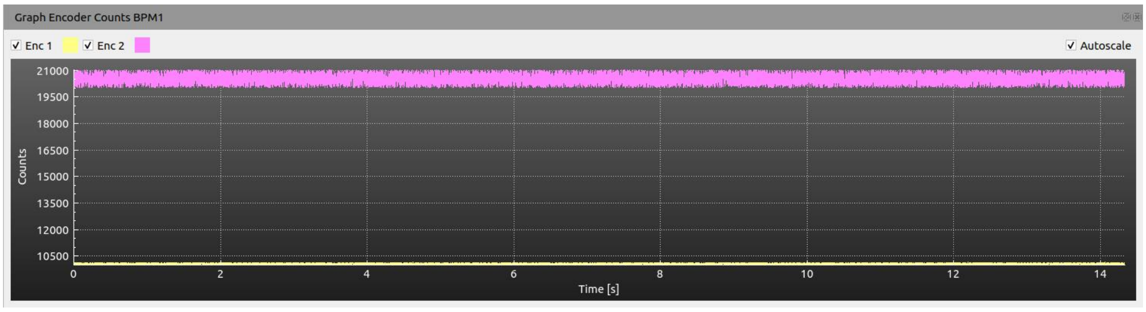
Additionally, instead of the FFT graph, it is possible to plot the real-time CSP (Cumulative Spectral Power) which is calculated as:

$$CSP(y) = cumsum\left(\frac{FFT(y)^2}{2}\right)^{1/2}$$



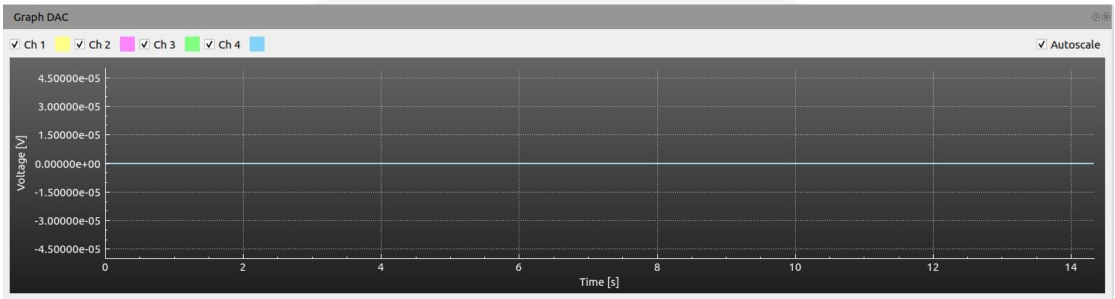
2.1.4.2 Encoder Counts Graph Tab

This graph shows the raw encoder counts as they are ready and used by the system. A separate graph is generated if a second EnBOX is connected to the Central Unit.



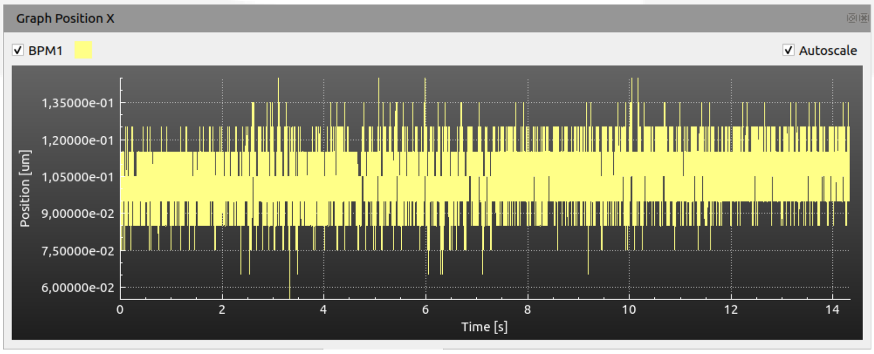
2.1.4.3 DAC Graph Tab

This graph shows the voltage output of the PreDAC channels.



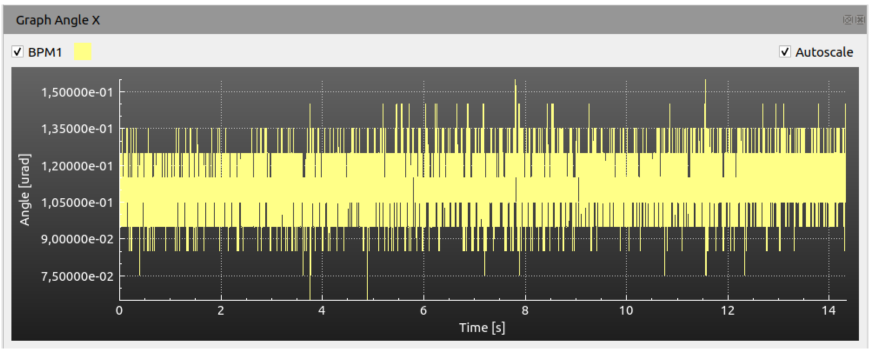
2.1.4.4 Position Graph Tab

This graph shows the X position obtained from the encoder counts multiplied by a scaling factor. This approach has been designed in order to plot the beam position at a given distance from an optical element whose angular vibrations are directly monitored by the encoder read by the system. If a second EnBOX is connected an additional line graph will be added to the graph.



2.1.4.5 Angle Graph Tab

This graph shows the X angle obtained from the encoder counts multiplied by a suitable scaling/calibration factor. If a second EnBOX is connected an additional line graph will be added to the graph.


Graph Angle X
BPM1
Autoscale
1,50000e-01
1,35000e-01
1,20000e-01
1,05000e-01
9,00000e-02
7,50000e-02
Angle [urad]
0
2
4
6
8
10
12
14
Time [s]

2.2 Login

This dialog allows access at different levels of the BEST-ENC Local GUI. Having different access levels prevents inexperienced users from changing accidentally system-critical settings.

The user interface allows three different access levels:

- **Administrator mode:** provides authorization to set and modify freely all the beamline related settings, as well as to change setpoints and feedback parameters and configuration. Username for this mode is: *admin*, and the password is: *WeAreTheBest*.
- **User mode:** does not allow changing the beamline related settings, but provides authorization to change setpoints and feedback parameters and configuration. Username for this mode is: *user*, and the password is: *BeamlineUser*.
- **Cruise mode:** it is a mere visualization access, does not allow to change any configuration of the BEST system. It is only possible to visualize the acquired data. Username for this mode is: *cruise*, and it has no password.

An example of a login dialog is shown in **Figure 16**. Users can access this window by clicking on *Settings->Login*. The "Current level" field shows current access level and is changed whenever a new correct combination of username and password is entered.

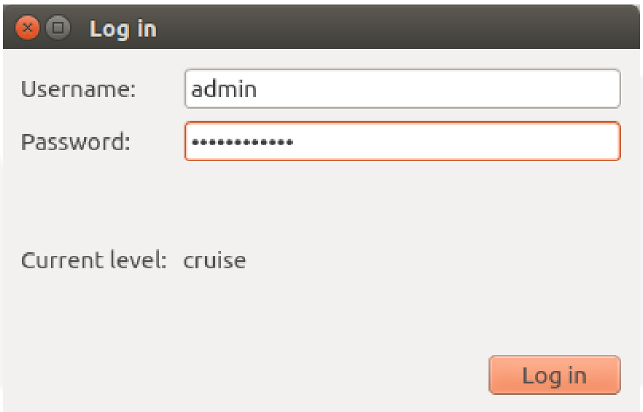
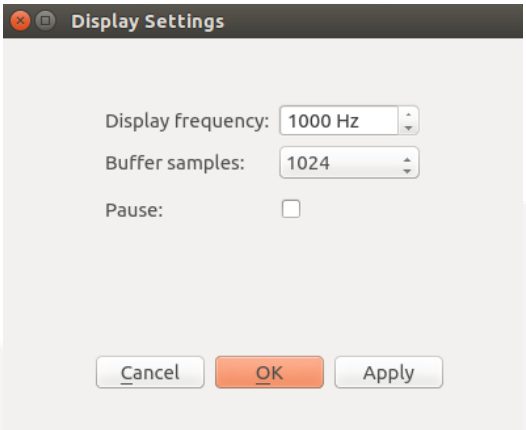


Figure 16: Login window

2.3 Display Settings

From *Settings->Display Settings* the user can customize the display settings of all the quantities that are shown in the bottom graphs of the "Main Window". These settings concern only the quantities displayed on the graphs, they do not affect the feedback controller quantities.

- Display frequency: the EnBOX sends the encoder readings to the BEST Central Unit at 5 kHz, meaning that the maximum display frequency is 5 kHz; for all values below 5 kHz the displayed data is subject to decimation, there is no averaging in the displayed data.
- Buffer samples: this is the quantities of samples been displayed in the graphs. Buffer samples divided by Display frequency gives the display window in units of seconds.
- Pause: pause the display task, not the feedback.



2.4 Beamline Configuration

The "Beamline Configuration" window allows the user to configure the BEST-ENC system in order to exactly match the actual beamline configuration. User can access to this window by from: *Settings->Beamline*.

From the "Encoder Type" dropdown box the user can select which type of encoders are connected to the EnBOX (Relative or Absolute).

From the "Encoder Math" dropdown box the user can select if the individual encoder readings are directly sent to the feedback controller (Single) or if they are combined together (Combined) before sending them to the feedback controller. See section 2.5 for more information.

The "Encoder increment" dropdown box can be set as "angular" steps (nrad/cts, nanoradiants over encoder counts) or as "linear" steps (nm/cts, nanometers over encoder counts). See section 2.6 for more information.

In the bottom part of the menu the user can then specify the "conversion ratio", the "sample distance" in [mm], and an additional "offset" in [µm], for both X and Y directions.

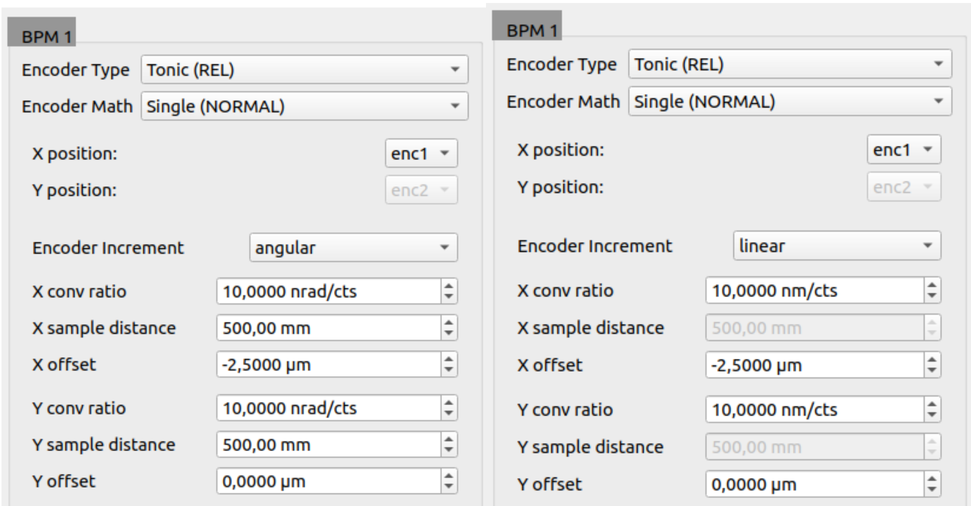


Figure 17: Beamline configuration.

2.5 Mathematical Combination of Encoder Readings

Two inputs of a single EnBOX unit (REL1 and REL2 or ABS1 and ABS2) can be combined together from the "Encoder Math" dropdown box. With this option selected, two "pseudo-encoder" signals are calculated by the EnBOX unit, namely the sum (enc1+enc2) and the difference (enc1-enc2) of the two encoder readings. These two pseudo-encoder signals are then treated as X and Y positions, hence used by the feedback controller to calculate the correction setpoints for the actuator unit.

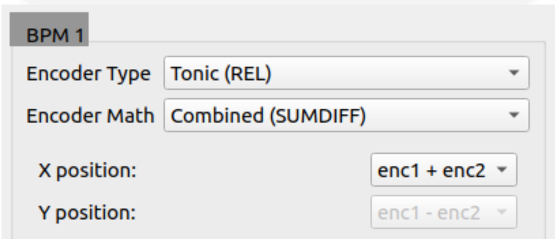


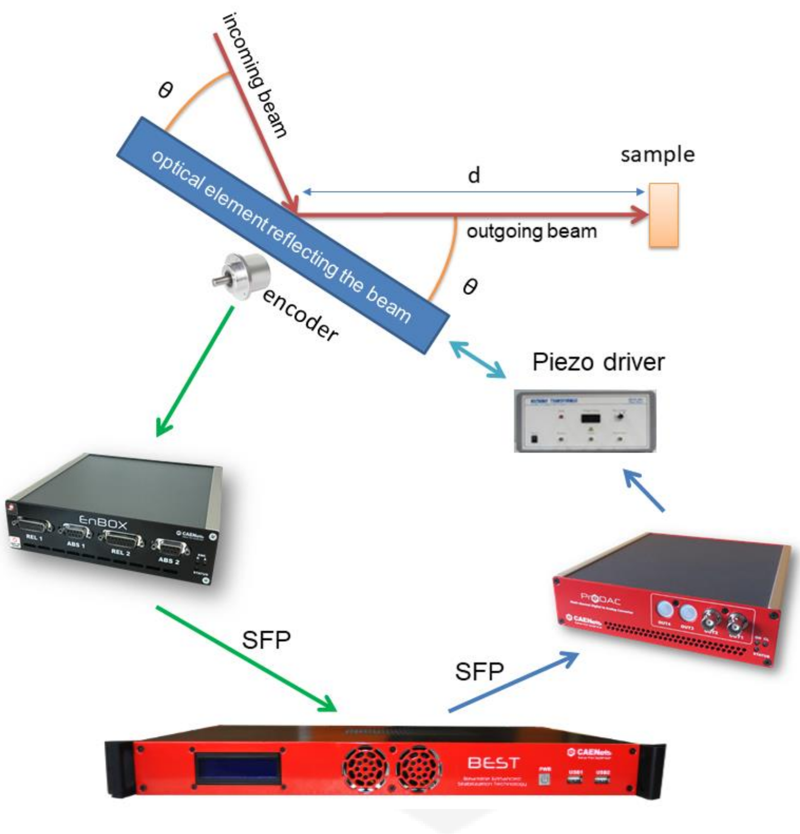
Figure 18: Beamline configuration: encoder math.

2.6 Encoder Conversion Ratio

If a rotation is directly encoded and the BEST Central Unit reads the associated angular encoder data, it can then calculate the X/Y (typically horizontal and vertical) beam positions at a plane positioned at a given distance *d* from the optical element(s) using the following simple equation:

$$Pos_{X/Y} = 2 \cdot \theta \cdot conv\_ratio_{X/Y} \cdot d$$

Where θ is the encoder angle read by the EnBOX (in counts), $conv\_ratio_{X/Y}$ is the conversion ratio (expressed in radians over encoder counts) given by the encoder calibration and *d* is the distance of the plane where typically the sample is located and therefore where users want to evaluate amplitude of the beam vibrations.



2.7 Region of Convergence and Region of Interest

Before enabling the PID controller, the user should set precisely the region of convergence and the region of interest areas. By clicking on *Settings->ROC/ROI* a new window shows up which enables user to set the desired values (see **Figure 19**).

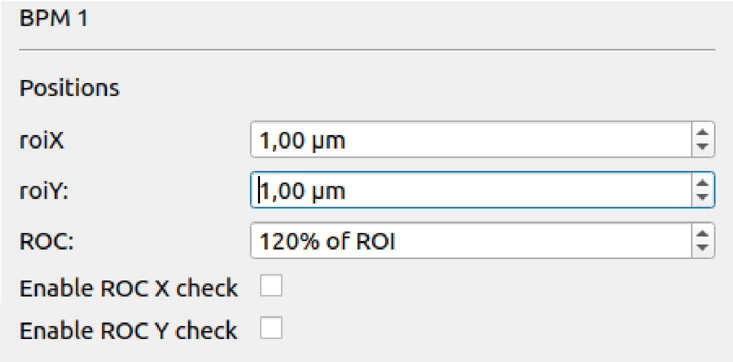


Figure 19: ROC/ROI Settings window

The Region of Convergence (ROC) is the maximum area where the PID controller stabilizes the beam to a defined setpoint. If for any reason the beam position goes outside of this area, the controller stops and shows the error: Beam out of ROC.

The Region of Interest (ROI) defines the area where the target beam position can be set by the user, either by pointing and clicking (**Figure 10**) on the XY graph or by entering the desired values. The ROI can be, at most, as large as the ROC, whilst typically the ROC includes a larger area than the ROI in the X-Y space.

2.8 Frequency Analysis Tool

The "Frequency Analysis Tool" window, which is accessible from *Tools->Frequency Analysis Tool*, allows the user to perform a detailed dynamical frequency analysis of the mechanical system to be coupled to the BEST-ENC by determining its Bode plots (phase and amplitude). The Bode plot is a graph of the frequency response of a mechanic system. It is usually a combination of a Bode magnitude plot, expressing the magnitude of the transfer function (in [m]/[V]), and a Bode phase plot, expressing the phase shift (in degrees). Both axis in the Bode magnitude plot are in logarithmic scale, while only the x-axis in the Bode phase plot is in logarithmic scale.

We follow the established, classic approach to carry out this analysis: a sinusoidal stimulus of constant amplitude generated by the PreDAC is swept through a pre-defined frequency range and, in parallel, the system response is read by the EnBOX and analyzed by the Central Unit. The embedded Frequency Analysis Tool uses the I/Q modulation/demodulation principle to extract magnitude and phase of the system response.

We provide a very simple graphical interface allowing the user to:

- Set the start and stop frequency of the test;
- Set the spacing and the number of points for the frequency analysis;
- Set the PreDAC output channel to use as frequency signal stimulus;
- Set the EnBOX input channel for the I/Q demodulation; this allows studying both direct correlation (i.e.: stimulus and response applied and read on the same variable, either X or Y) and cross-correlations (e.g.: stimulus on X Vs. response on Y);
- Set the fixed amplitude of the sinusoidal stimulus in Volts p-p. It is recommended to minimize the amplitude and keep it in the 1 to 10 mV range, in order to avoid possible damage when eigenfrequency values are crossed during the scan.

The acquired data can be exported in .csv format for further analysis.

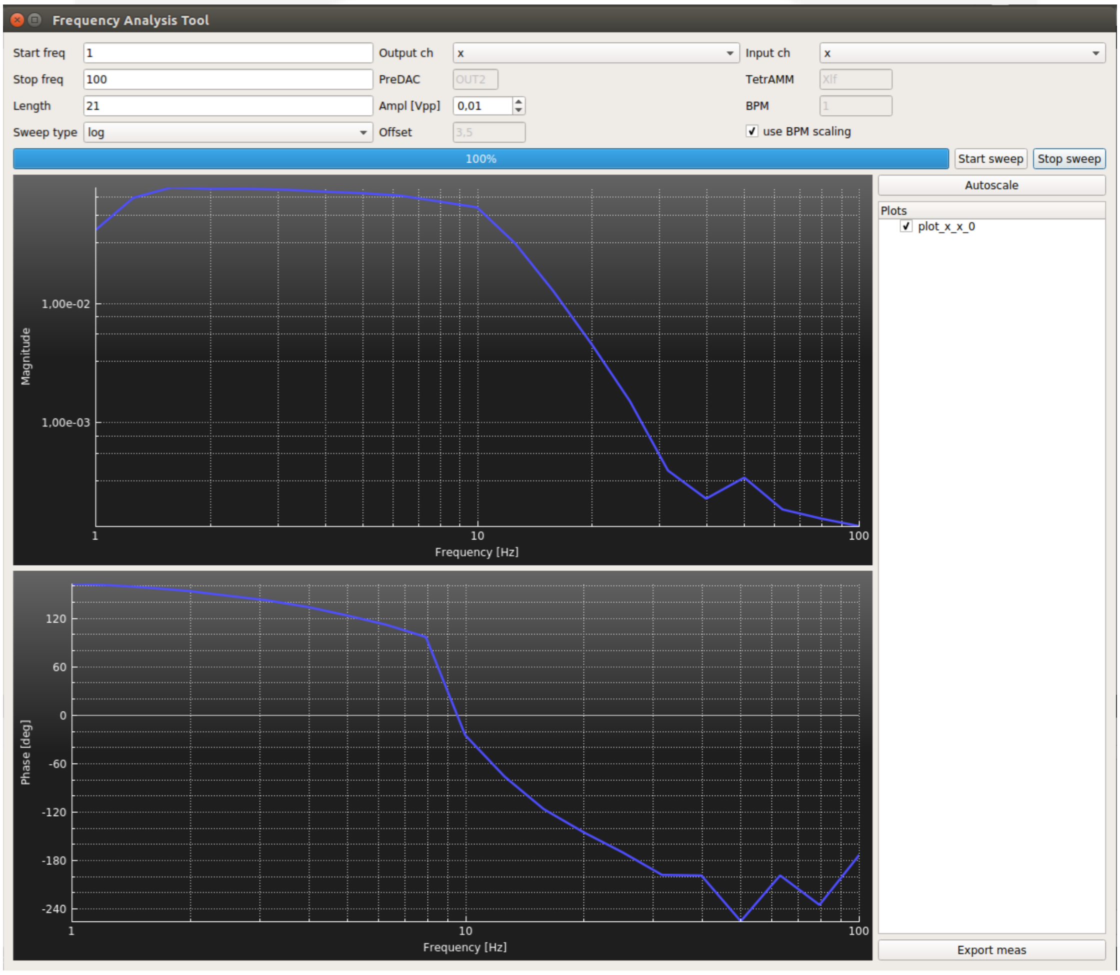


Figure 20: Frequency analysis tool window

3. EPICS IOC

EPICS is a software environment widely used in accelerators facilities to remotely operate and monitor a given set of instruments/modules.

Using a client/server technique, where servers (and ioc controllers) collect data from the instrumentation in real-time and clients access those data via the channel access network protocol, EPICS allows integration of instruments with a given set of commands.

In order to do so, **BEST-EPICS-IOC** is an open-source software available on the **github** platform. It is based on the functionalities offered by the BEST library that is part of the BEST software suite and constantly updated with new features. An API reference manual of the BEST library is available at CAEN ELS website.

BEST-EPICS-IOC offers a wide set of instructions to query and configure the BEST Central Unit. A specific command's reference manual with a full list and description of EPICS commands is available at CAEN ELS website.

The BEST system is compatible with EPICS-7 (base-7.0.6.1). To show the basic EPICS functionalities we will monitor the EPICS commands from the BEST Local User Interface. The **BEST-EPICS-IOC** source code is available at https://github.com/CAENels/best-epics-ioc.

3.1 EPICS IOC Integration

Start the BEST Local User Interface

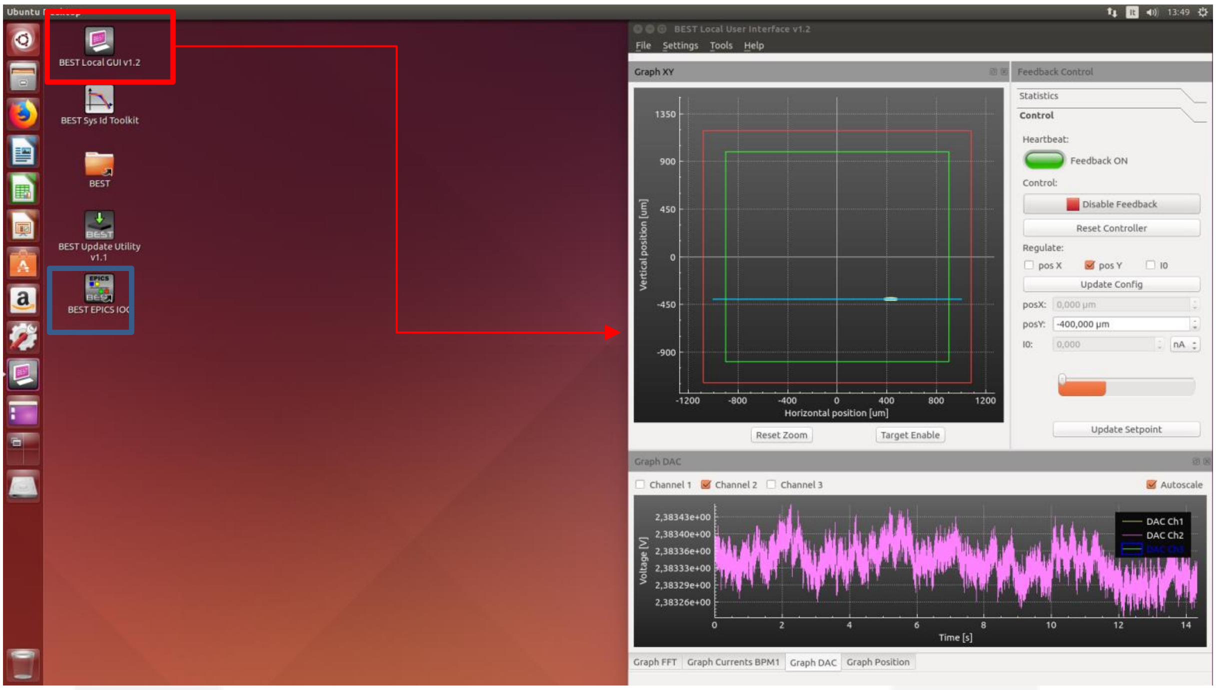


Figure 21: Run the BEST Local User Interface.

In order to start the EPICS server, double-click the BEST EPICS IOC application (framed in blue in the picture above).

After launching the application, a terminal appears and the EPICS server will return the EPICS server shell:

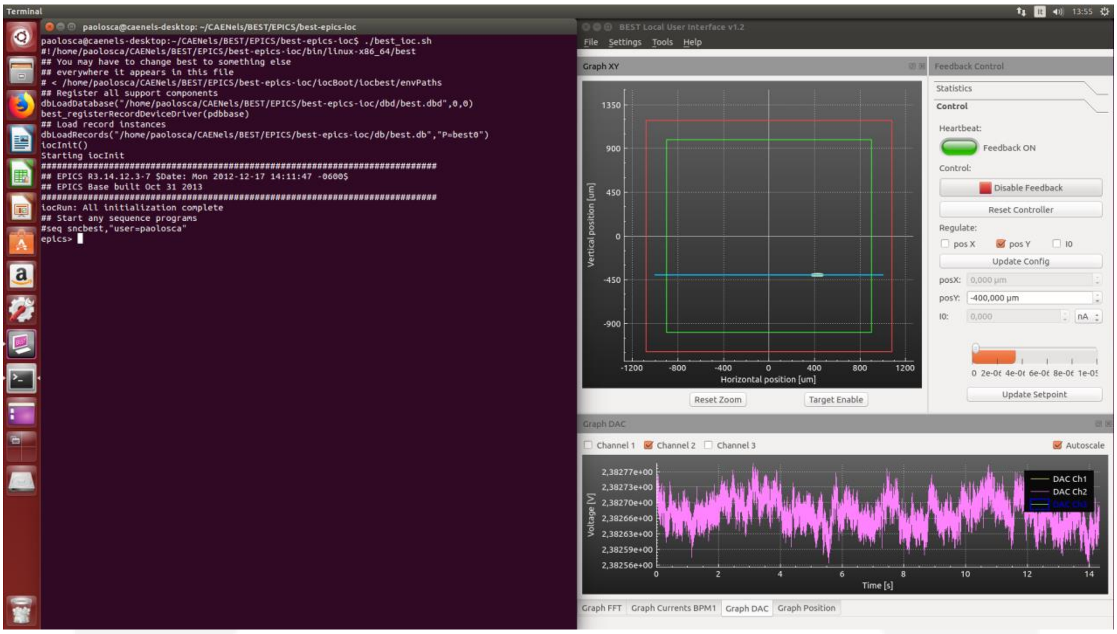


Figure 22: Run the BEST EPICS server.

The system shows that the procedure is completed, therefore EPICS control is allowed:

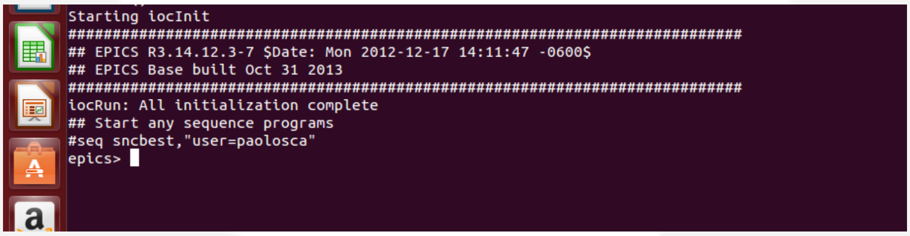


Figure 23: BEST EPICS server initialization.

By typing “dbl” it is possible to see the complete list of the BEST EPICS commands.

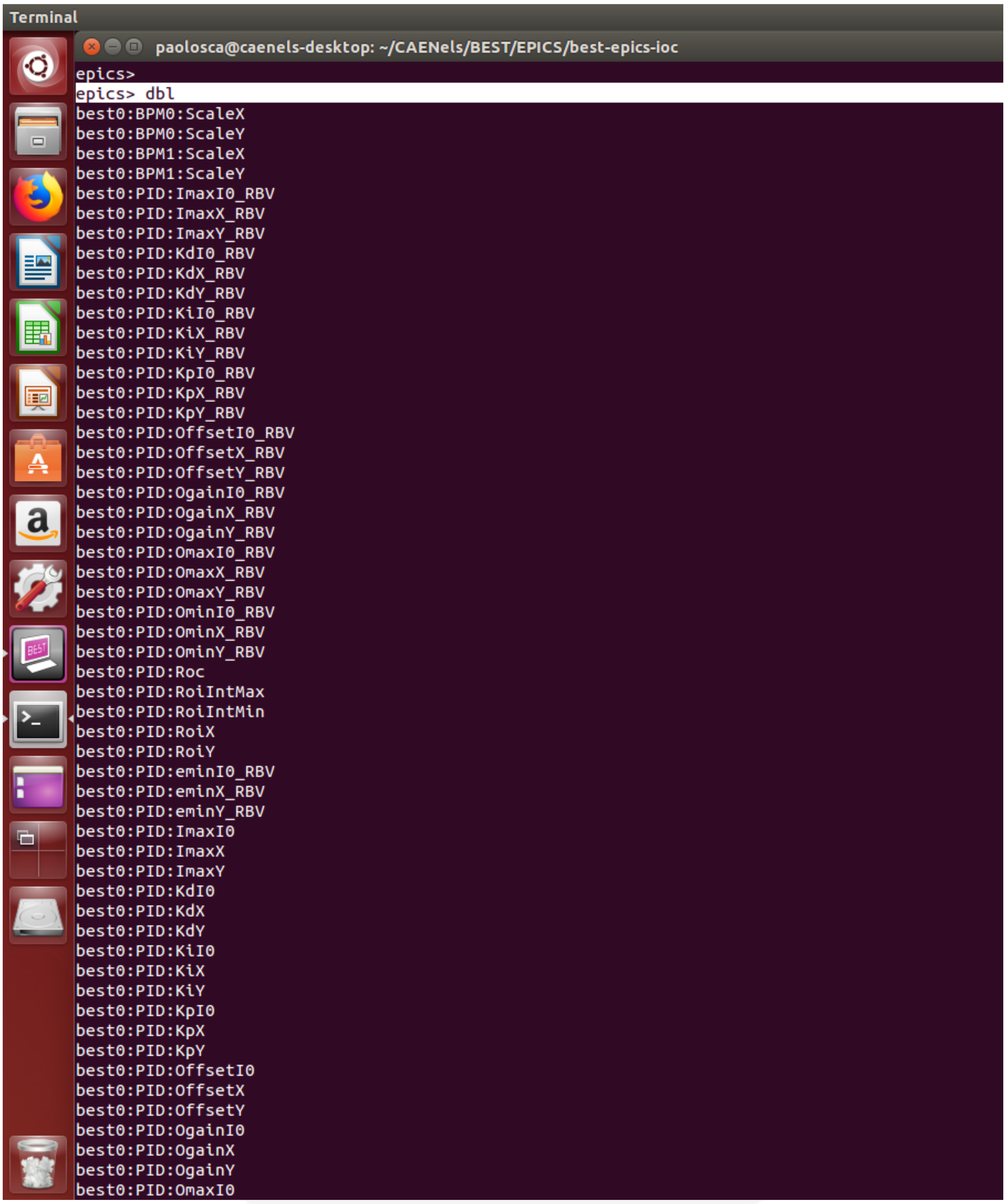


Figure 24: BEST EPICS commands.

From the client side, assuming EPICS is correctly installed, the user has access to all the commands available (e.g. caput, caget, camonitor, etc.).

3.2 BEST login using EPICS

As for the BEST Local User Interface, also EPICS respects the login credentials reported in section 0. To Login do as follows:

```
$ caput best0:Login:UserPass admin:WeAreTheBest
Old : best0:Login:UserPass
New : best0:Login:UserPass            admin:WeAreTheBest
```

3.3 Controlling the PreDAC output in Open Loop

In order to control the PreDAC in open loop, the first operation is to ensure that the feedback controller is disabled:

```
$ caput best0:PID:Enable 0
Old : best0:PID:Enable                OFF
New : best0:PID:Enable                OFF
```

The PreDAC output MUX has to be set to 0. This means that the PreDAC is controlled by software (i.e. from the Linux driver through PCIe).

```
$ caput best0:PreDAC0:OutMux 0
Old : best0:PreDAC0:OutMux            SW via PCIe
New : best0:PreDAC0:OutMux            SW via PCIe
```

Lastly, the user can set the PreDAC output voltage:

```
$ caput best0:PreDAC0:OutCh2 3.25
Old : best0:PreDAC0:OutCh2            0
New : best0:PreDAC0:OutCh2            3.25
```

The PreDAC output voltage can be monitored from the BEST Local User Interface:

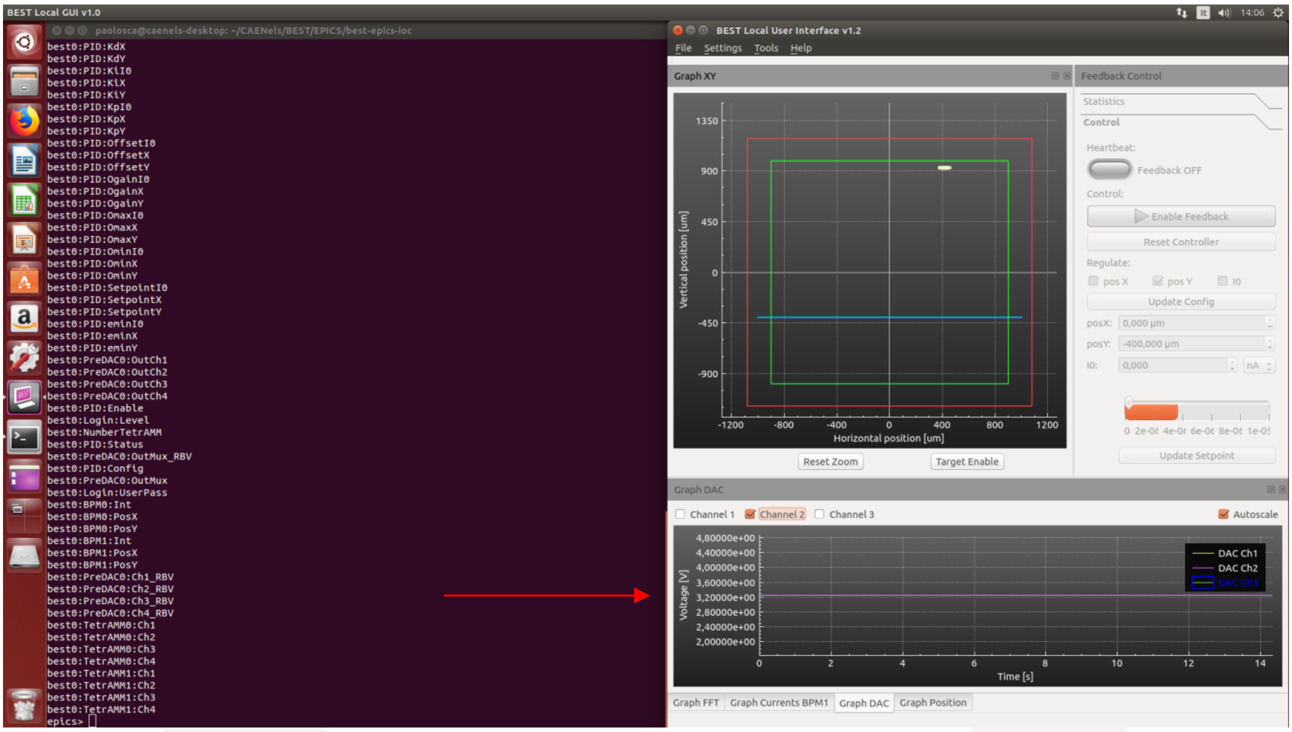


Figure 25: BEST EPICS controlling PreDAC output.

3.4 Controlling the PreDAC output in Closed Loop:

The closed loop configuration is the default configuration where the feedback controller implemented in FPGA logic performs all the calculations in order to get the X/Y positions or intensity to the user defined setpoint.
The user must firstly ensure that the PreDAC output is driven by hardware (i.e. FPGA) and not by software (i.e. through the PCIe):

```
$ caput best0:PreDAC0:OutMux 1
Old : best0:PreDAC0:OutMux           SW via PCIe
New : best0:PreDAC0:OutMux           FPGA
```

Now the feedback controller can be enabled:

```
$ caput best0:PID:Enable 1
Old : best0:PID:Enable               OFF
New : best0:PID:Enable               ON
```

And finally it is possible to control the position in closed loop:

```
$ caput best0:PID:SetpointY -600
Old : best0:PID:SetpointY            0
New : best0:PID:SetpointY            -600
```