ePix documentation

Release 0.1

M. Cascella

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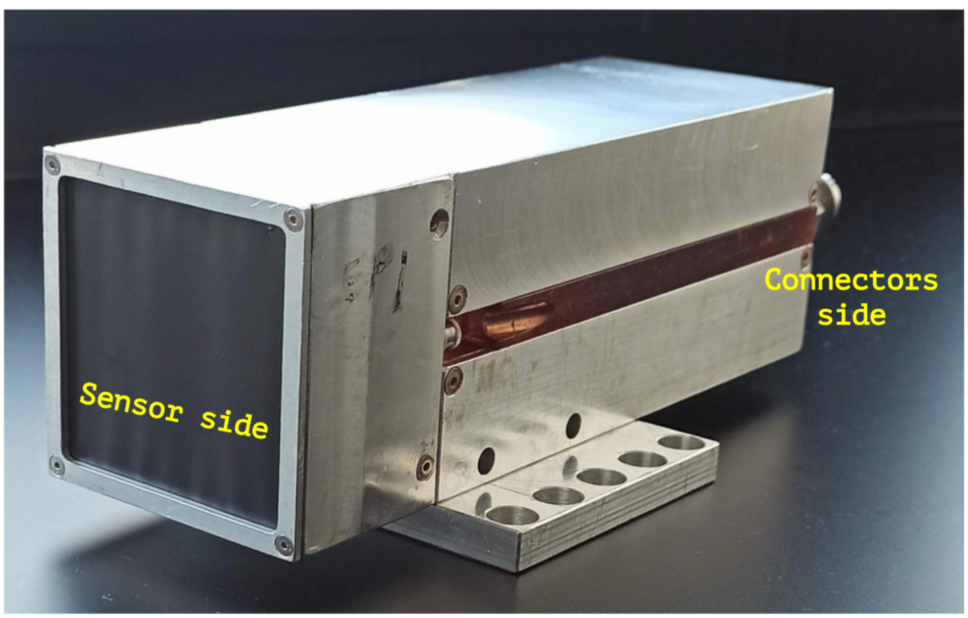
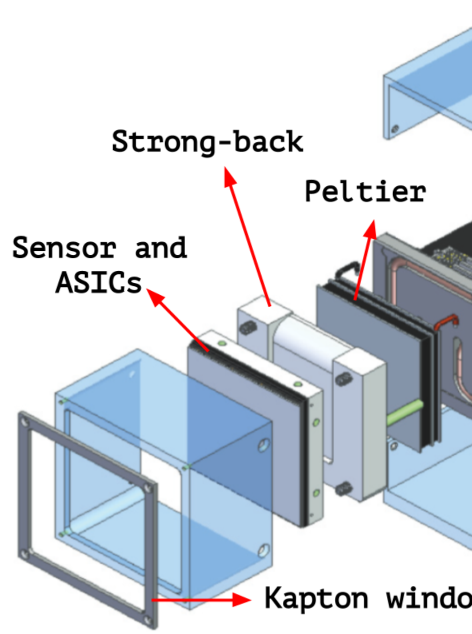
CHAPTER 1

ePix100 Overview

This documentation is meant to provide a general overview of the ePix100 detector, covering its functionality and operation, serving as a resource for detector support.

The ePix100 detector[1] is a backside illuminated charge-integrating hybrid pixel detector with single photon resolution capability and a dynamic range of up to ~100 8keV photons (without dynamic gain switching). It belongs to the family of ePix detectors developed at SLAC National Accelerator Laboratory.





[1] G. Blaj, et al. *X-ray imaging with ePix100a: a high-speed, high-resolution, low-noise camera*, Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XVIII. Vol. 9968. SPIE, 2016.

Presently, there are two operational modules which are regularly used at MID. Two other modules have previously been used at HED but are currently non-operational. Therefore, parts of this documentation (such as karabo device names) are focused on the ePix100 detectors of MID.

1.1 Specifications

The main specifications of the ePix100 detector are listed below:

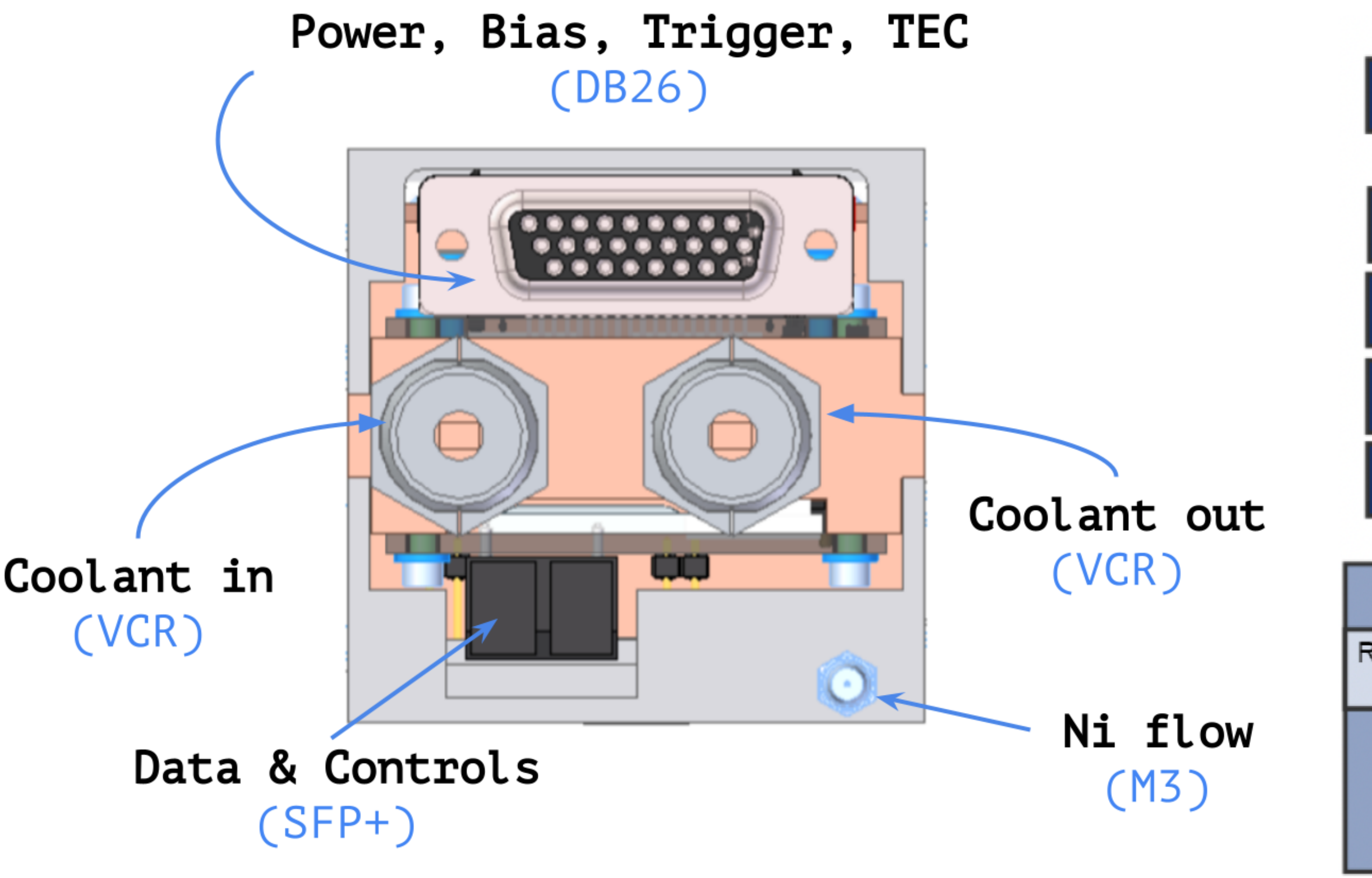
Parameter	Value
Sensor	500 μm Si
Pixel size	50×50 μm^2
Pixel distribution	384×352 (×4 ASICs)
Active Area	38×35 mm^2
Noise (ENC)	50 e
Dynamic Range	100 photons (8 keV)
Max Frame Rate	120 Hz

The detector consists of 3 main components:

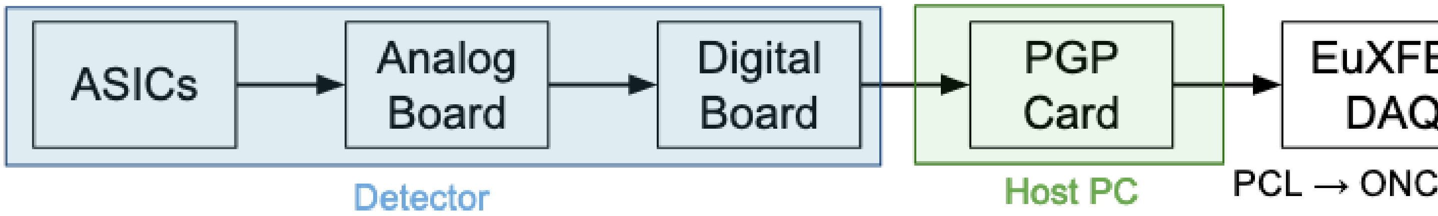
- **Camera head**: A 500 μm silicon sensor bump-bonded to 4 ASICS (2x2), making for ~0.5 Megapixels. Each ASIC is divided into 4 banks (super-columns) of 96 columns which are multiplexed into a single analog signal, each is then digitized by a single ADC channel.
- **Analog board**: Containing two 16-channel, 14-bit ADCs to digitize the analog signals from the ASICS as well as other critical signals. The analog board is also responsible for receiving and distributing power supply for the PCB boards and ASICS, bias to the sensor, trigger and the signal from the thermoelectric controller (TEC) to monitor and adjust the camera head temperature. It connects to the camera head via a 160-pin flex-lead and to the digital board via high-density board-to-board connectors.
- **Digital board**: Accommodates the FPGA that is responsible for system control, data collection and first-level interfacing with the DAQ. It features an SFP+ module for controls and data transmission via optical fibre to a PCIe card installed in a rack-mounted computer.

1.2 Connections & Network flow

All necessary connections are established in the back of the module, with the connectors depicted below:

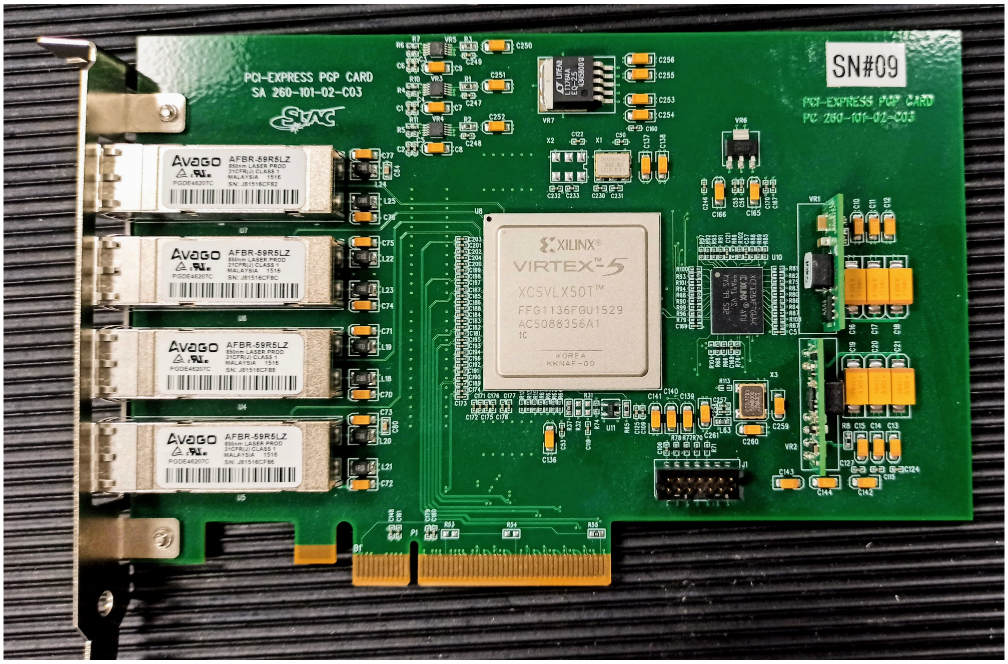


The DB26 bus connector and a SFP+ fibre connection transmit all the input and output signals. A single DB26 connector provides power, bias voltage, TTL trigger signals and the temperature feedback and TEC control signal for temperature monitoring and adjustment. The analog signals from the front-end module (sensor + ASICs) are transmitted to the analog board where they are digitized. After digitazion, data is transfered to the digital board and subsequently o a rack-mounted host computer over fibre optics and through a patch panel.



Communication between the digital board and the host computer is established via the SLAC Pretty Good Protocol (PGP)[2], and requires the installation of a PCIe PGP card (depicted below) on the host. Each PGP card can communicate with up to 4 ePix100 modules, so the same host is used to control and receive data from both ePix100 detectors at MID.

[2] Pretty Good Protocol (PGP)



1.3 References

CHAPTER 2

Operation

This section summarizes the fundamental requirements and procedures for operating the ePix100 detector.

2.1 Cooling

A thermoelectric cooling (TEC) module (Peltier TE-127-1.4-1.5, TE Technology, Inc.) is coupled to the detector head, capable of cooling the sensor down to -15°C. Pins 23/14 on the DB26 connector are connected directly to a spare thermistor which is used for fast temperature monitoring and adjustment via a PID (Proportional-Integral-Derivative) TEC controller, namely the Thorlabs TED4015. The cold side of the Peltier element is in contact with the sensor and ASIC assembly while the hot side is in contact with the camera body. The ePix100 provides readings of both the hot and cold side temperatures which should be continuously monitored for safe operation. A relative humidity reading from the hot side is also featured, to be able to precisely calculate the dew point.

Water cooling is used in parallel, supplied via the VCR connectors in the back, to dissipate the heat arising from the hot side of the Peltier element and the analog and digital boards. The detector body temperature measured from the hot side of the Peltier should be maintained within the recommended operational range of 15–25°C.

To avoid condensation on the sensor plane when operated in air, a constant flow of nitrogen should be provided via the M3 barbed fitting also present in the back. Nonetheless, TEC voltage and current must be set so that the operating temperature is above dew point. If providing a nitrogen flow is not possible, the cold side of the Peltier should not be cooled below 15°C.

2.2 Vacuum compatibility

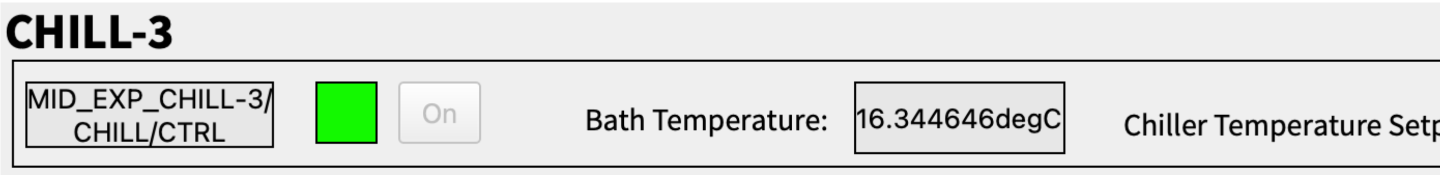
The ePix100 is vacuum compatible and can be operated in vacuum down to 10^{-6} Torr. When used in vacuum, nitrogen flow is not necessary.

2.3 Trigger

Two independently processed triggers (RUN and DAQ) must be provided (also via the DB26 connector), both consisting of a +3.3 V TTL signal with a minimum pulse width of 100 ns. When the detector processes the RUN trigger, its front-end electronics start the acquisition of one image. The DAQ trigger, if received within 100 µs of the RUN trigger, triggers the back-end system to read out the image. To assist with the timing synchronization, a software delay can be configured between the arrival of the external triggers and the start of the firmware procedures. An External Trigger Adapter (ETA) box is used to provide both triggers to the detector, controlled by the Karabo devices MID_EXP_EPIX-[1,2]/TSYS/RUN_TRG and MID_EXP_EPIX-[1,2]/TSYS/DAQ_TRG.

2.4 Powering Procedure

Before powering the ePix100, make sure the water pipes are connected and the chiller is running (MID_EXP_CHILL-3/CHILL/CTRL). This can be easily checked in Karabo in the top of the EPIX[1,2] scene of the MID_EXP_EPIX project (see image below). The chiller temperature setpoint is typically 16°C, and the bath temperature read should be continuously updating. On the top left side of the scene, the H2O Flow sensor (MID_EXP_CHILL-3/ASENS/FM5) should also continuously update with a value around 4.4. If there is no flow, the displayed value is 4.



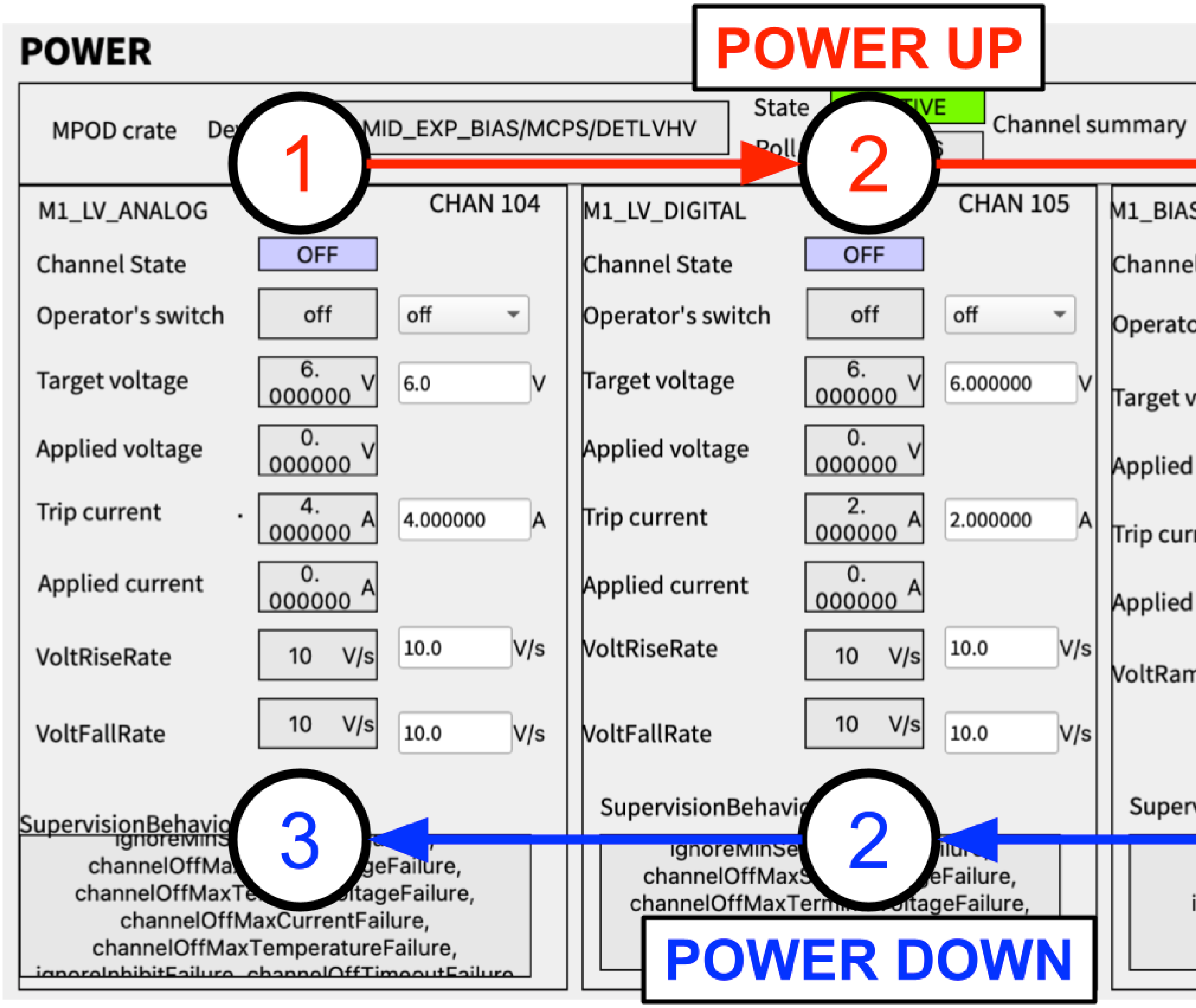
The TEC controller (Thorlab TED4015) should also be switched on before powering the detector. The bottom-left button on the front panel powers the TED4015 and the centre button starts the Peltier. If the DB26 cable is connected to the detector, it should readout a temperature. Each ePix100 has its own TEC controller, the Karabo devices are MID_EXP_PI/TCTRL/TED_EPIX[1,2].

2.4.1 Powering ON

After the checks above are performed, the detector may be powered. For each ePix100, two low-voltage channels (one for the analog and one for the digital board) and a high-voltage to bias the sensor are needed. Are all supplied using the MPOD crate MID_EXP_BIAS/MCPS/DETLVHV. The used channels are listed in the table below:

Board	Channel	Signal	Specs
WIENER MPV8016	U104	EPIX-1 Analog LV	4.5 - 6.6 V, 4 A max
WIENER MPV8016	U105	EPIX-1 Digital LV	4.5 - 6.6 V, 0.6 A max
WIENER MPV8016	U106	EPIX-2 Analog LV	4.5 - 6.6 V, 4 A max
WIENER MPV8016	U107	EPIX-2 Digital LV	4.5 - 6.6 V, 0.6 A max
ISEG E08F2	U300	EPIX-1 Bias HV	20 - 200 V, 250 µA max
ISEG E08F2	U301	EPIX-2 Bias HV	20 - 200 V, 250 µA max

Each ePix100 is powered using the POWER section of their main scene (EPIX[1,2] in project MID_EXP_EPIX). Below is shown the example for EPIX-1, but both scenes are identical.

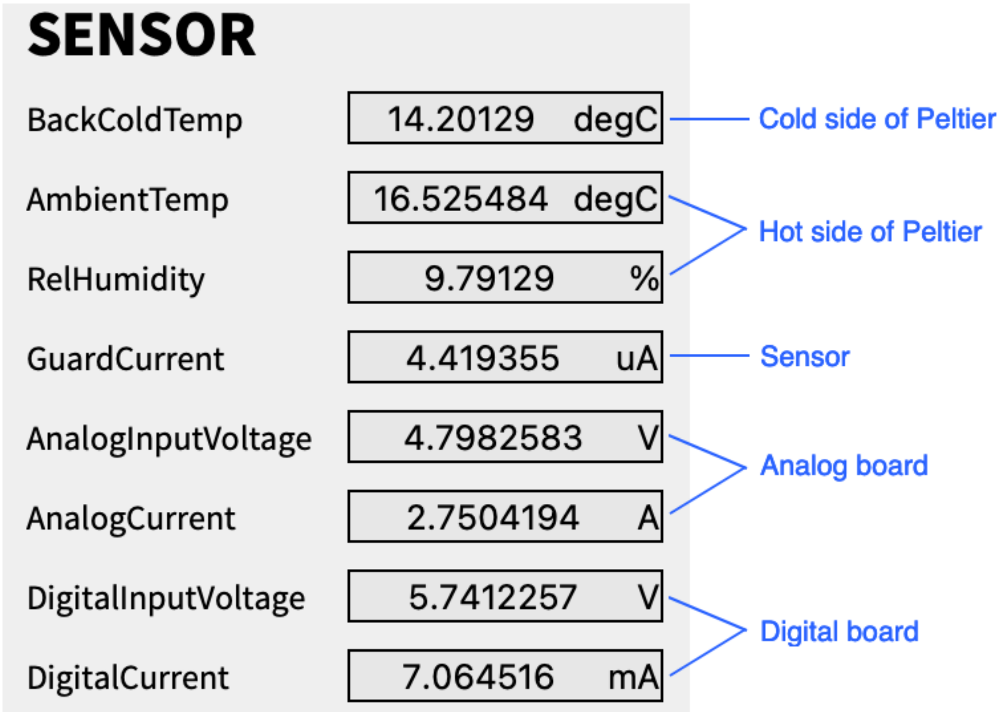


As suggested by the figure, the power-up procedure is as follows:

0. Make sure MPOD device (MID_EXP_BIAS/MCPS/DETLVHV), and the detector controller (MID_EXP_EPIX-[1,2]/DET/CONTROL) and receiver (MID_EXP_EPIX-2/DET/RECEIVER) are instantiated
1. Switch the Operator's Switch of the **Analog LV** channel to **ON**. (Keep target voltage and trip current at 6V and 4A)
2. Switch the Operator's Switch of the **Digital LV** channel to **ON**. (Keep target voltage and trip current at 6V and 2A)
3. Switch the Operator's Switch of the **Sensor Bias HV** channel to **ON**. (Keep target voltage above 20 V). **Important:** Always use a bias voltage within the operating range (20-200 V). Biasing below 20 V may damage the ASICS. Do not supply low voltage for long times without biasing the sensor.

Wait a few seconds in between steps 1, 2 and 3, to give time for the voltages to settle.

The detector is now ready to acquire images. As soon as the Digital LV is provided, the detector feedback metrics on the left part of the scene should start updating. These can be monitored to guarantee the safe operation of the detector.



2.4.2 Powering OFF

To power off the detector, the inverse order of the power-on procedure should be carried out:

1. Switch **Sensor Bias HV** channel to **OFF**. Wait until the feedback Applied Voltage feedback value from the MPOD is close to zero.
2. Switch **Digital LV** channel to **OFF**.
3. Switch **Analog LV** channel to **OFF**.

The MPOD boards are configured to ramp down (and up) the voltages, so simply switching the Operator's Switch is safe.

The detector should not be left running for long periods unsupervised. If the detector is no longer being used, it should be powered off.

CHAPTER 3

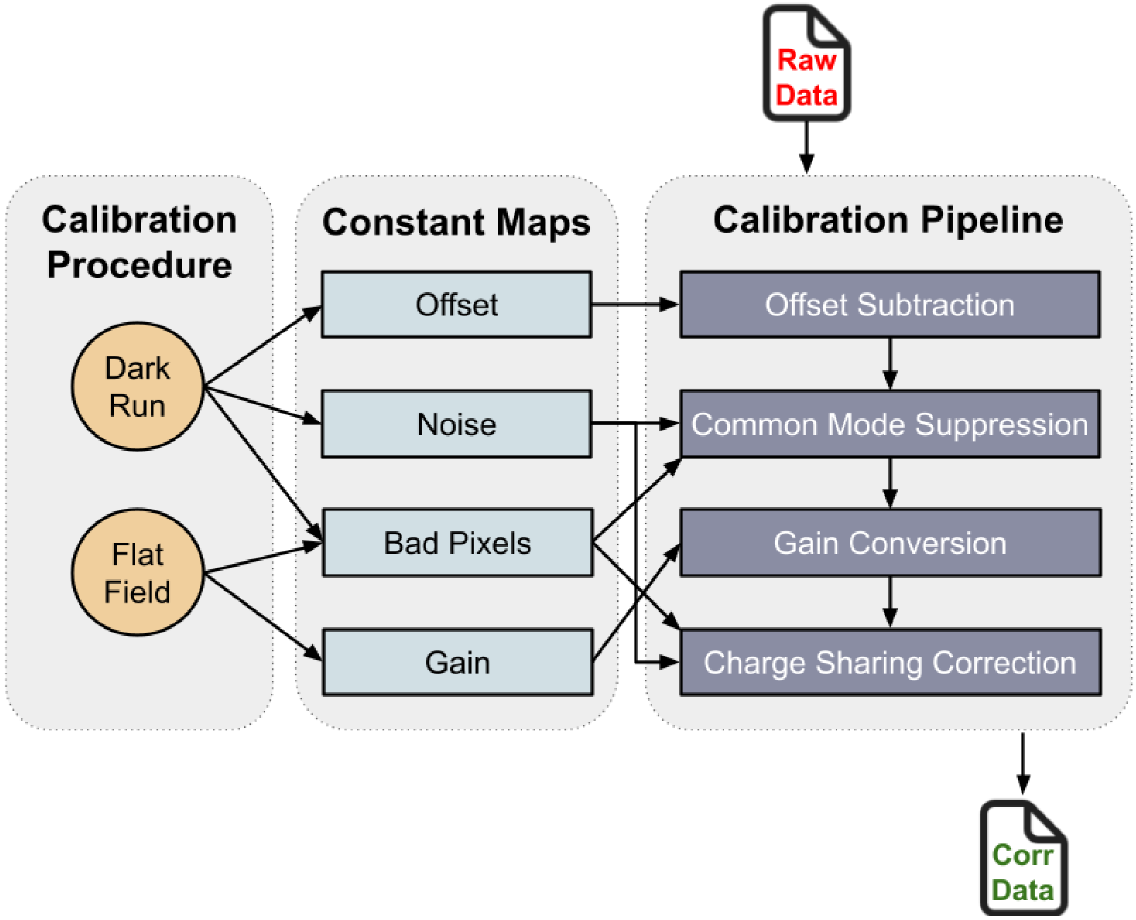
Calibration & Correction

An outline of the correction pipeline deployed to convert *raw* data into corrected *proc* data is given in this section. The general processes for generating calibration constants via darks and flat-field acquisitions are similar to other detectors, as are the typical offset subtraction and gain conversion steps. Here are only emphasized the less usual common mode and charge sharing correction. A more detailed overview of the calibration and data correction procedures of ePix100 at the European XFEL detectors can be found in[1].

3.1 Correction pipeline

The figure below illustrates a scheme of the correction pipeline used to correct data from ePix100, and the respective constant maps used at every stage.

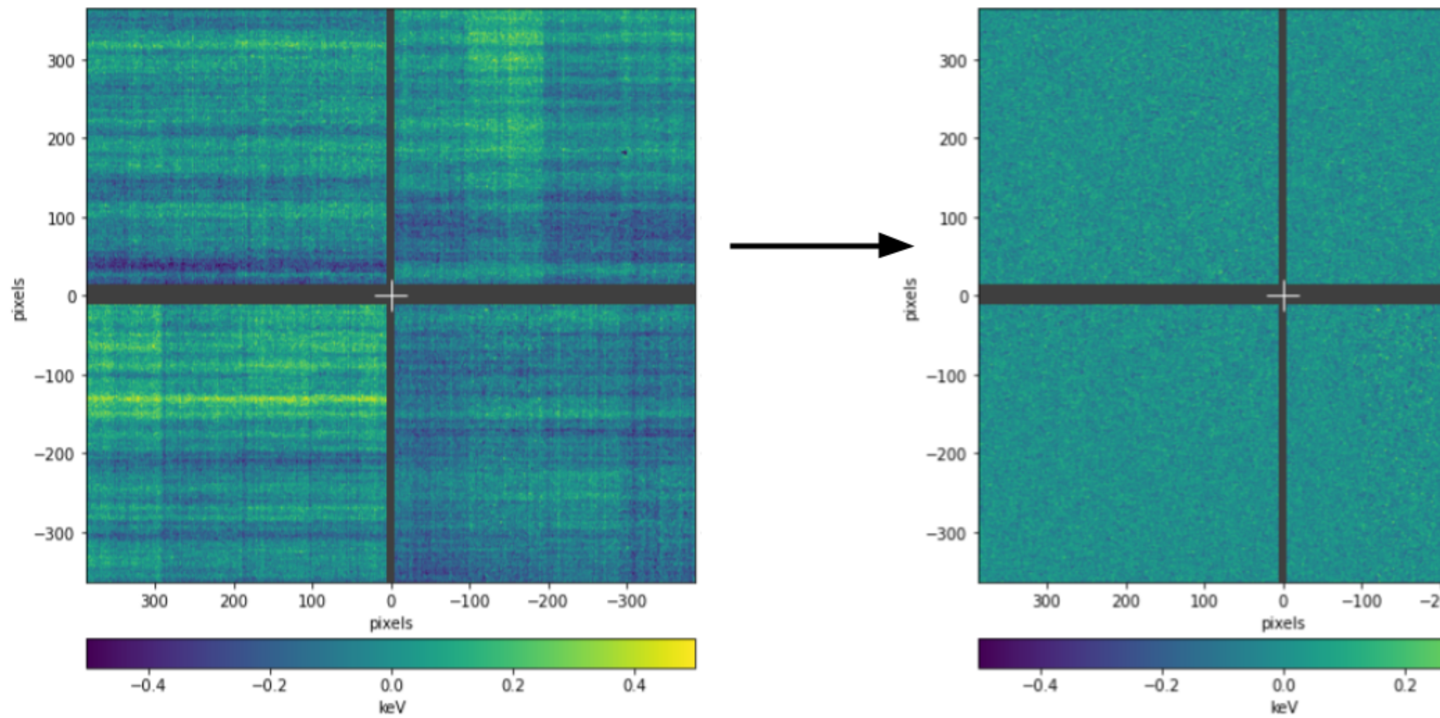
[1] N. Duarte, et al. *Calibration procedures and data correction of ePix100 detectors at the European XFEL*, JINST 18.11 (2023) C11008



Because offset depends on bias voltage, temperature, and exposure time, a new set of dark runs must be taken whenever at least one of these conditions changes. In particular, the exposure time has the most significant influence on the offset, following a linear dependence. It is also recommended to take darks whenever the detector is power cycled, and regularly throughout a shift. Offset maps generated many hours ago may no longer be adequate for offset subtraction. In particular, a ring pattern on each ASIC may start to be visible in the corrected images if the offset map is relatively old (see Troubleshoot section).

3.1.1 Common Mode Correction

Common mode is a specific type of noise that originates from voltage fluctuations in the readout electronics. Consequently, pixels that share part of the electronic chain are affected similarly, resulting in a pattern of vertical and horizontal stripes superimposed on the measured signal. Since this pattern changes from frame to frame, a constant map cannot be calculated and applied to correct for it. Nonetheless, common mode can still be corrected by calculating the median value of each row/column of pixels and subtracting it from the respective row/column. This is done separately for each ASIC since they have independent readouts, looping over every column and then over every row. The figure below illustrates the effect of common mode on a dark image and how correcting it helps reducing the overall detector noise. Overall noise reduction after common mode correction can be as high as 20%.

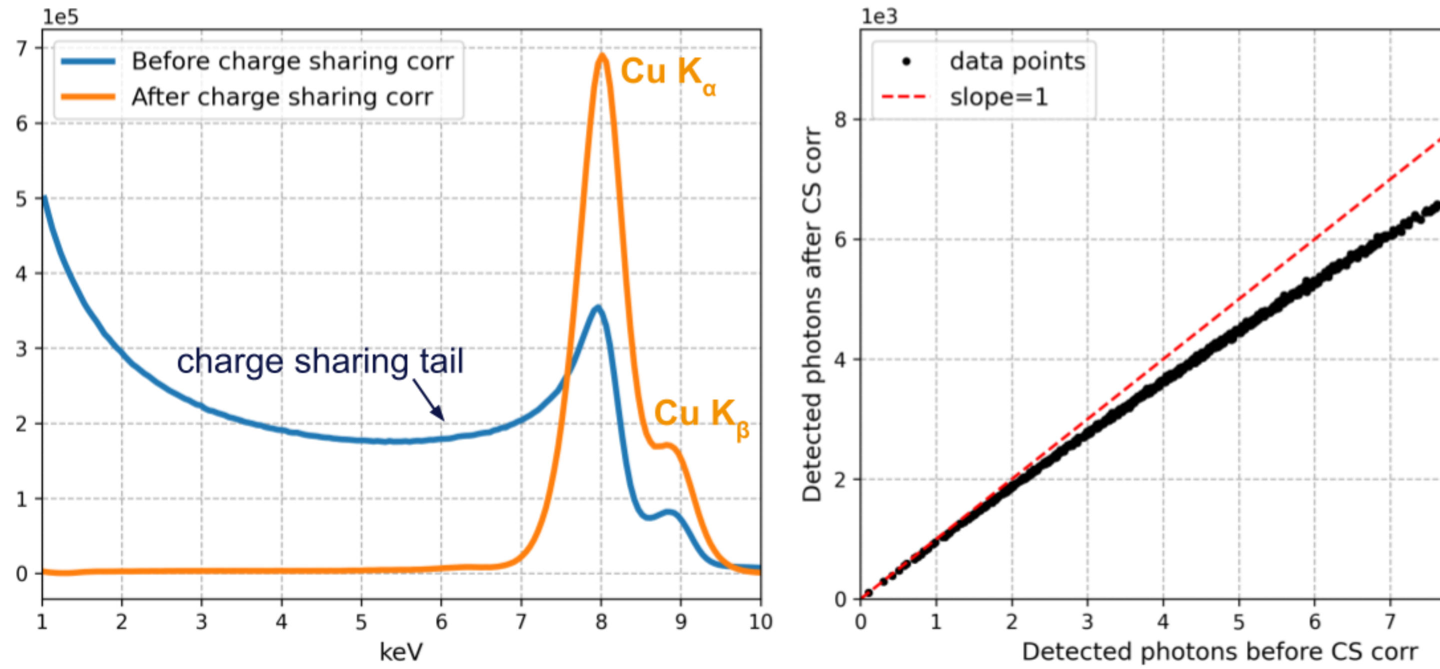


To apply common mode correction to photon-illuminated images, lit pixels, defined as those with signal above a set threshold, are masked to exclude them from the computed medians. Common mode correction is only applied if a representative sample of pixels in a given column/row (at least 25%) are dark.

3.1.2 Charge Sharing Correction

Although the electron-hole pairs generated by the photoelectric effect have a negligible initial spread, the charge cloud progressively expands as charges drift towards the pixels due to electrostatic repulsion and diffusion in the sensor. Consequently, some photon hits may result in charge being shared by clusters of up to 4 pixels, depending on the photon absorption position. With a pixel size of 50 µm, charge sharing effect is typically clearly noticeable on ePix100.

The full energy photon peak can be reconstructed using an algorithm that starts by identifying pixels with energy above a primary threshold and defining a 3×3 pixel mask around them. If two neighbouring pixels meet this condition, the mask is centred around the pixel with higher value. Within the mask, all pixels with energy above a lower secondary threshold are identified. If their distribution matches a valid charge sharing pattern geometry, their values are summed, and the result is assigned to the central pixel, while all others are set to zero. However, if separate charge patterns overlap or are adjacent, meaning that some of these pixels likely captured charge from at least two different photons, charge sharing correction is not applied, as it is impossible to discriminate the contribution of each individual photon to each of the clusters. Consequently, these pixels are also set to zero. This limitation implies that charge sharing correction is most effective for low photon fluxes, where the probability of finding overlapping or adjacent clusters is minimal. As the photon flux increases, more individual photons cannot be resolved, and they are lost after this correction step. This effect is illustrated in the right-side plot of the figure below.



Processed CORR data files are exported with two sets of corrected data: one with charge sharing correction applied (`data.image.pixels_classified`) and one without (`data.image.pixels`), so that the most adequate dataset may be chosen for each specific case.

3.2 References

CHAPTER 4

Troubleshooting

Here are described some potential sources of issues and how to act on them.

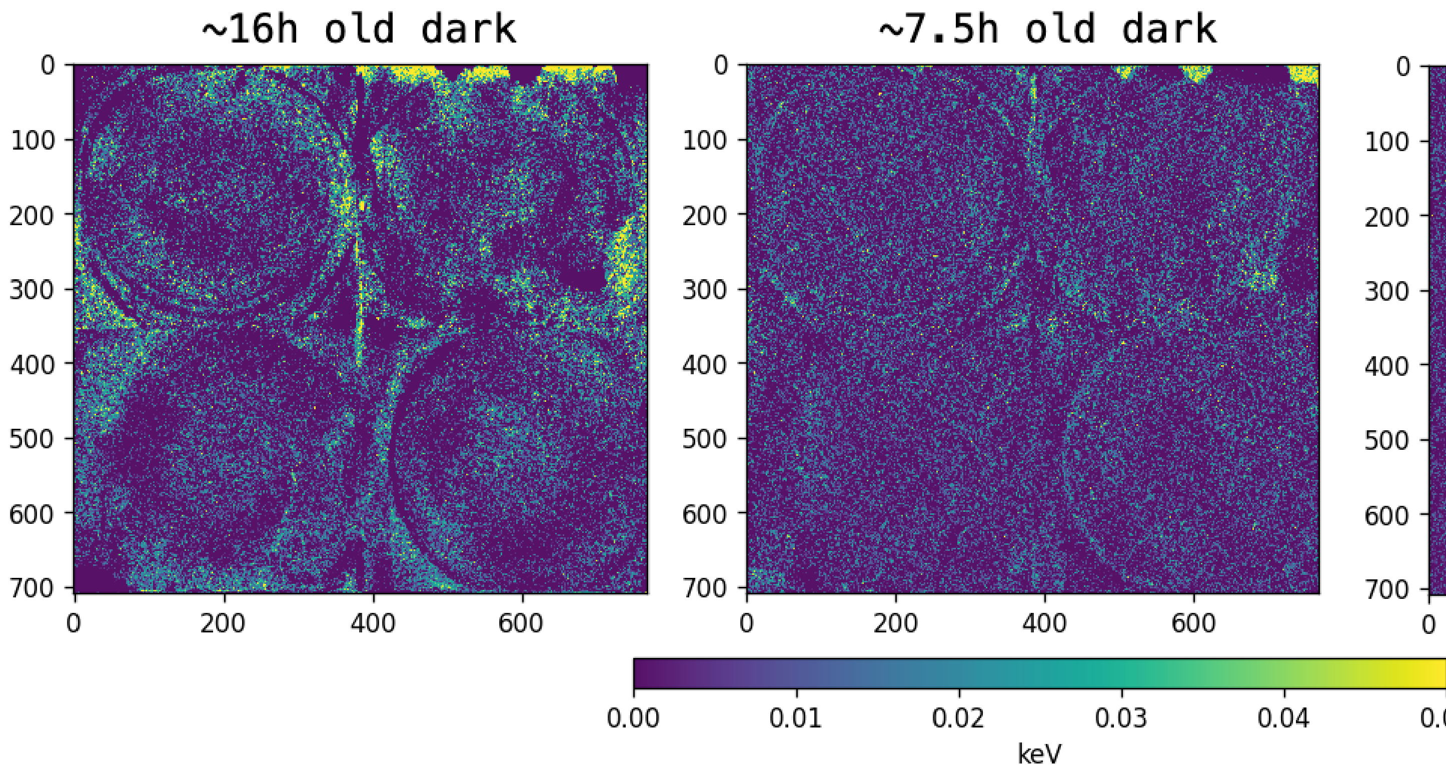
4.1 No data on calng/offline

Unlike other detectors (such as the JUNGFRAU), the point for communication with Karabo is not in the detector itself, but in the PGP card mounted in a rack computer. Because the PGP card is typically always reachable, even if the detector is not powered, it may happen that commands sent via Karabo are apparently successful, i.e. no error message is displayed, but the PGP card is unable to further transmit these commands to the digital board of the detector. One example of this is if the detector is set to acquisition mode when it is not powered: the control device (MID_EXP_EPIX[1,2]/DET/CONTROL) on Karabo will change to `ACQUIRING` without raising an error, although the detector is not actually doing anything.

In case the controller is in `ACQUIRING` but the image on the online preview is not updating or there is no detector data on the raw offline files, most likely the detector is not powered, which can be checked in the power supply section of the main EPIX[1,2] scenes. When the detector truly is in acquisition mode, the receiver device (MID_EXP_EPIX[1,2]/DET/RECEIVER) will change from `PASSIVE` to `ACTIVE`, and the `RxRate` property of the device will update with values fluctuating around 10 Hz.

4.2 Ring patterns on ASICs

A ring pattern in the ASICs such as the ones in the image below can sometimes be visible in the corrected image, particularly when using high exposure times (order of hundreds of microseconds) for which there is a decrease in signal-to-noise ratio. It is not clear if the effect comes from the doping process of the sensor, or defects induced during bump bonding. In practice, there is a slow drift of the pixel offset in this ring structures when the detector is operated for many hours, even if the operating conditions are stable. These effect can however be easily compensated by taking darks frequently, as also demonstrated in the picture below.



4.3 Other general safety considerations

The most crucial aspects to keep in mind for the safe operation of the detector are:

- Do not provide HV before when LV is OFF.
- When providing HV, always use a value within the operating range (20 - 200 V). Biasing below 20 V may damage the ASICS.
- If temperature exceeds 35°C, power down the detector (following the power down procedure). There is most likely a problem with the water cooling. Check that chiller is ON, the H2O flow sensor is updating and values are >4, and the water pipes are properly connected to the VCR connectors.
- If the Peltier element is used to cool the sensor below 15°C, use nitrogen flush and monitor the reading from the humidity sensor in the detector.
- If relative humidity read by the detector sensor is above dew point, power down the detetor (following the power down procedure). Flush with nitrogen for some time before trying to power on again. If humidity is still high, confirm that the nitrogen flow is reaching the detector and that it is sufficient: the N2 flow sensor (MID_EXP_EPIX/ASENS/M1_H1) should be above 200 mL/min, and it maxes out at 262, so that value is also fine.
- When used in vacuum, HV should be OFF during venting/pumping, particularly for pressures between 0.1 - 100 mBar, due to the risk of electrical arcing on this Paschen curve minimum.

4.4 Additional resources:

- ePix100 specifications

- ePix100A camera Handling and Installation Guide
- ePix100A camera Calibration, Operations and Software Development Guide
- MID documentation: ePix System Overview

CHAPTER 5

Indices and tables

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