Investigation of the Temperature Dependency of AGIPD's Gain Ratios

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1 Introduction

The adaptive gain integrating pixel detector (AGIPD) is develop to cope with the challenges of the European XFEL. In order to obtain a high dynamic range it comes along with 3 dynamic gain stages.
The aim of this project is to investigate the temperature dependency of AGIPD's gain stages. This has the potential to perform the temperature depending calibration of the detector more efficiently.

2 AGIPD

European X-ray Free Electron Laser(Eu X-FEL) is a linear x-ray generator in Hamburg. Eu X-FEL is able to produce x-ray trains which contain 2700 pulses at 100 fs separated by 220 ns. Also trains will be produced every 99.4 ms. Each pulse has 10^{12} photons at 12.4 keV(cite here from 1/3). Obviously, electronic system of the detector is not able to process data within 0.6 ms while the pulses are coming. The detector stores data during pulse train at the analog memory cell and process data during idle time and make an image.

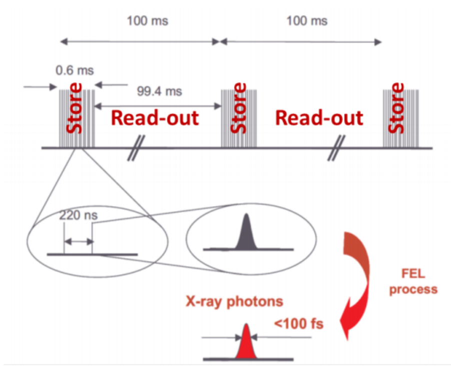


Figure 1: Time Structure of EU X-FEL[1])

2.1 Inner Design

An AGIPD's front-end module is made up of a sensor and 2×4 ASICs (can be easily seen at Figure **??**-a) attached sensor. This technology is called hybrid technology. Every ASIC has 64×64 pixels. Each pixel's dimension is $200\mu m \times 200\mu m$. AGIPD uses silicon as sensing material. The 500 μm thick silicon sensor provides more than 90 percent quantum efficiency for 12.4 keV X-ray photons.[1]
Each pixel has its own electronics (see Figure 2).
The light blue block at the left is common for all pixels. There can be seen an adaptive gain preamplifier stage at the beginning. Adaptive gain is provided by 3 capacitors with

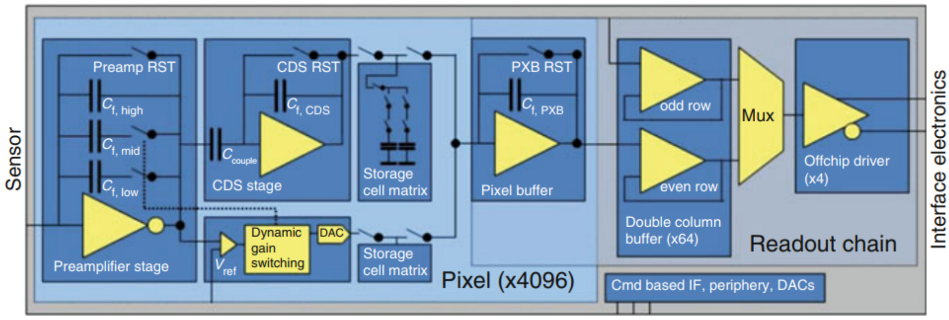


Figure 2: Inner Circuit Schematic of AGIPD[2]

different capacitance values. $C_{f,high} = 60$ fF, $C_{f,mid} = 3$ pF and $C_{f,low} = 10$ pF. If the output of the preamplifier is saturated, means that too many photons come to the corresponding pixel, the gain of the preamplifier decreases by adding another capacitor. After preamplifier, CDS takes the output of preamplifier and gets rid of reset noises and reduces the low frequency noise[2]. The output of CDS goes to random access memory (RAM). Memory geometry of this memory cell is a 32×11 matrix. The ASIC has a current source in order to inject a charge into the pixels. By using those data, calibration process can be done before experiments. Those data are taken as analog data in the software.
Similarly, there is another memory cell for the gain stage. This memory cell stores the information, which gain stage was used for data taking.
The reason behind the adaptive gain is that the X-Fel beam is very intense but also single photon sensitivity is necessary for the experiments.

3 Calibration

The raw output of the detector, which is a voltage, has to be converted to number of photons.

3.1 Dark Image Correction

The output of the detector in a dark image (no photons impinging on the sensor) is called pedestal.
For a pixel, the pedestal value of each memory cell is different. Therefore, a large number of dark images are taken for all memory cells. The histograms show a Gaussian envelope. The mean of the data, which is the pedestal, is determined. Finally the pedestal is subtracted from each raw detector image.
The width of the Gaussian envelope itself is called noise. This noise should be very narrow (standard deviation should be quite small). Other wise, this Gaussian envelope can overlap with the other Gaussians for 1 photon and 2 photons. This phenomena is explained at X-ray calibration.

3.2 X-ray Calibration

The next step of the calibration process is to determine the gain. Therefore, a x-ray source is used to take x-ray data for one memory cell. The histograms of this data show multiple peaks, which corresponds to 0 photons, 1 photon, 2 photons and so on. The distance between the 0 photons peak and the 1 photon peak is determined and used as gain of the high gain stage.[3]

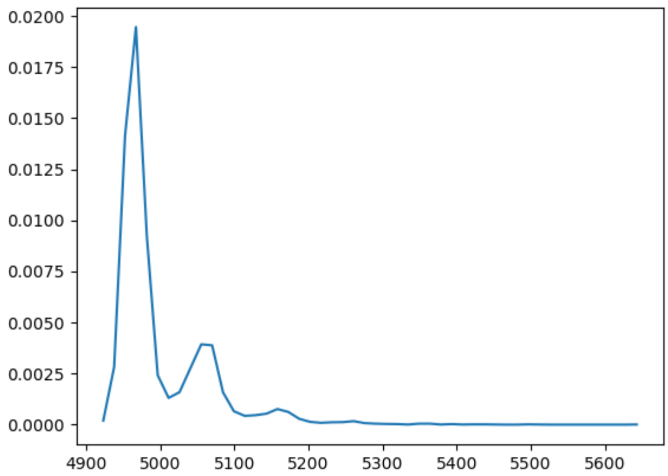


Figure 3: Fitted lines to histogram of x-ray calibration

3.3 Dynamic Range Scan

In order to determine to gains of medium and low gain stage and to determine the memory cell variation the current source is used to perform a dynamic range scan for all memory cells. Figure 4 shows such a dynamic range scan. By fitting linear functions to the gain regions 3 offsets and 3 slopes are determined.

4 Temperature Dependency

Since the gain is also depending on the capacitors, the gain changes with temperature. Therefore, the gain has to be determined for different temperatures. The goal of this project is to investigate the temperature dependency of the gain ratios. If the gain ratios are not depending on the temperature, the dynamic range scans do not have to be taken at different temperatures. This would reduce the calibration time dramatically.

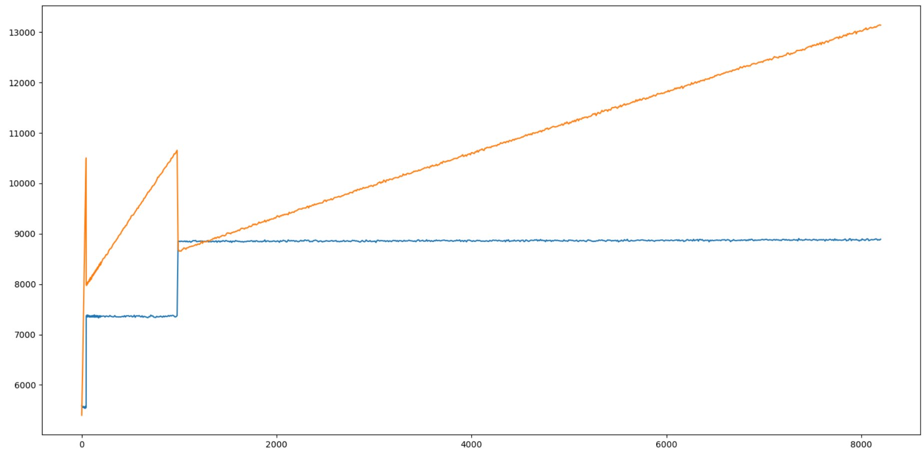


Figure 4: Dynamic Range Graph Analog (orange) and Digital (blue) data

4.1 Measurement

Data has been taken at FSDS laboratory in CFEL. As explained in the inner design of AGIPD, each pixel has a current source. This current sources are used to take data for calibration. However, one can not inject into all the pixels at once without any problems. The solution of this problems is exciting pixel 2 columns at once. AGIPD front-end module is made up of 16 ASICs, and each ASIC (64 pixels $\times$ 64 pixels) is made up of sub chips which are 8 pixels $\times$ 8 pixels. Just 2 columns of this sub chip are excited at the same time, and they are 1^{th} and 5^{th} columns. If all pixels are wanted to be excited, it will take nearly 5 hours for one temperature. This process was done for 3 different temperatures 15 Celsius degree, 23 Celsius degree and 33 Celsius degree.

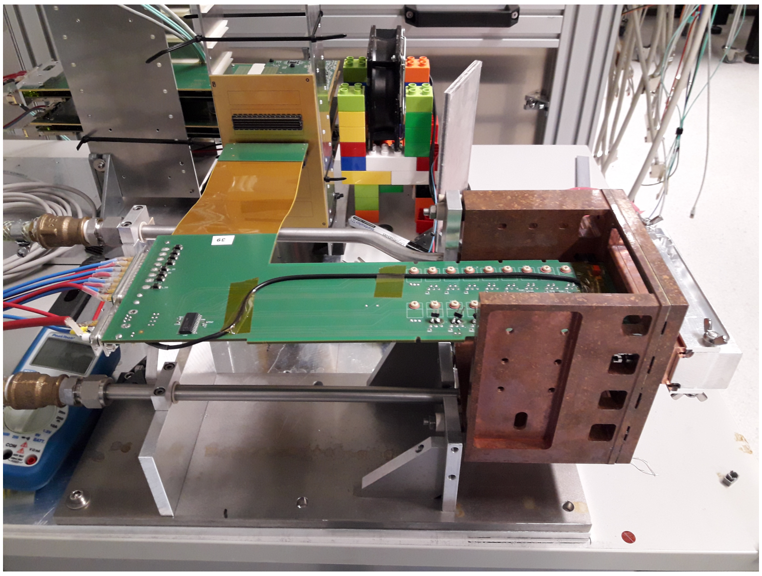


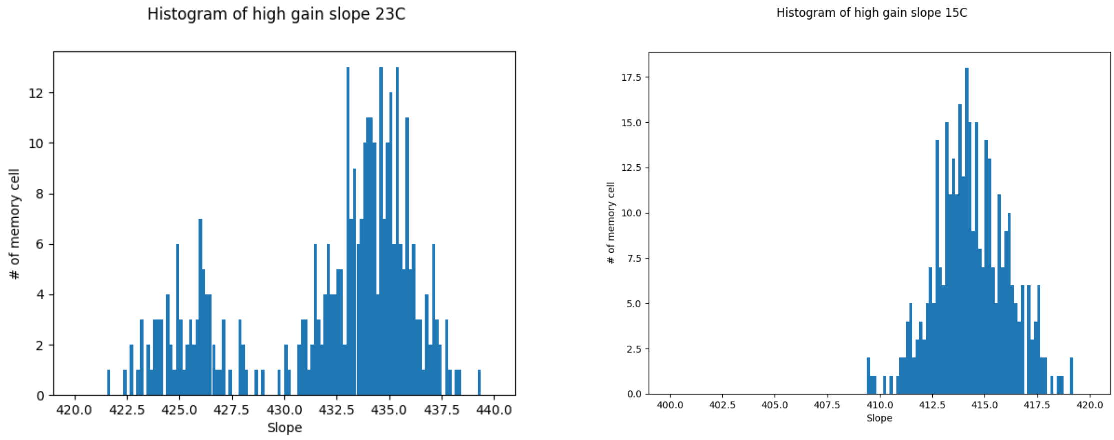
Figure 5: AGIPD board while data taking

4.2 Data Processing

From measurements, there are 4 data sets. In order to have the data for whole module, one should gather those columns properly. Also, the module should be separated to its ASICs. This process is called gathering.
After gathering, the raw data is used for getting information about slopes, offset and any other properties for the different gain stages. This is called processing. However, in processing, it is hard to determine the slope of low gain. A trick was used by script writer Manuela Kuhn. The low gain line is separated to 5. The mean of 3 in the middle is used as slope value of low gain.
The ratios between different gain stages' slopes and offset are obtained by using python. The plots and some problems will be discussed in the next section.

4.3 Results

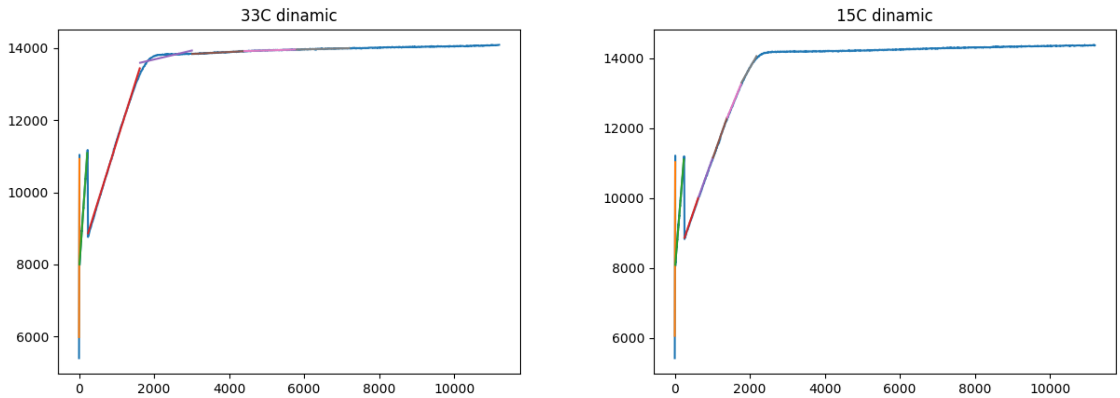
The results were obtained in a few different formats such as histograms and scatter plots. The data were taken at 23 Celsius degree is not usable. The temperature was probably not stable during data taking, as one can see in Figure 6(a).
As seen in the Figure 6 there are 2 Gaussian envelopes rather than one for 23 Celsius degree. However, the 15 Celsius degree data has just one envelope. For each temperature values, there should be only one Gaussian envelope and the mean of it should change according to corresponding temperature.
The script written by Manuela Kuhn works as follows: It fits a line to high and medium gain stages and 5 lines to low gain stage separately. The slope and offset values of high



(a) High gain histogram for all memory cell for 23 Celsius

(b) High gain histogram for all memory cell for 15 Celsius

Figure 6: High gains for 2 different temperatures



(a) Dynamic Scan for 33 Celsius

(b) Dynamic Scan for 15 Celsius

Figure 7: Dynamic scan and fit lines for 15 C and 33 C

and medium gain lines are taken as they are, however for low gain mean of the slopes and the offsets of 3 lines in the middle are taken as slope and offset. Since there is a saturation in the low gain, fitting lines fail sometimes. As seen in the Figure 7, fitting lines in 15 Celsius degree is quite good, but there are some problems with fitting at 33 Celsius degree. When it takes 3 lines in the middle, low gain slope will be roughly zero. In order to solve this problem, the slope and the offset value of first line are taken as offset and slope of low gain.
It is seen in the Figure 8 that, high gain and low gain ratio of 23 Celsius degree is strongly fluctuating. Rather than this, medium gain and low gain ratios for different temperature are quite constant. However, it deviates for the high gain and low gain ratios. It is easy to see a periodic structure in the 33 Celsius high gain and low gain

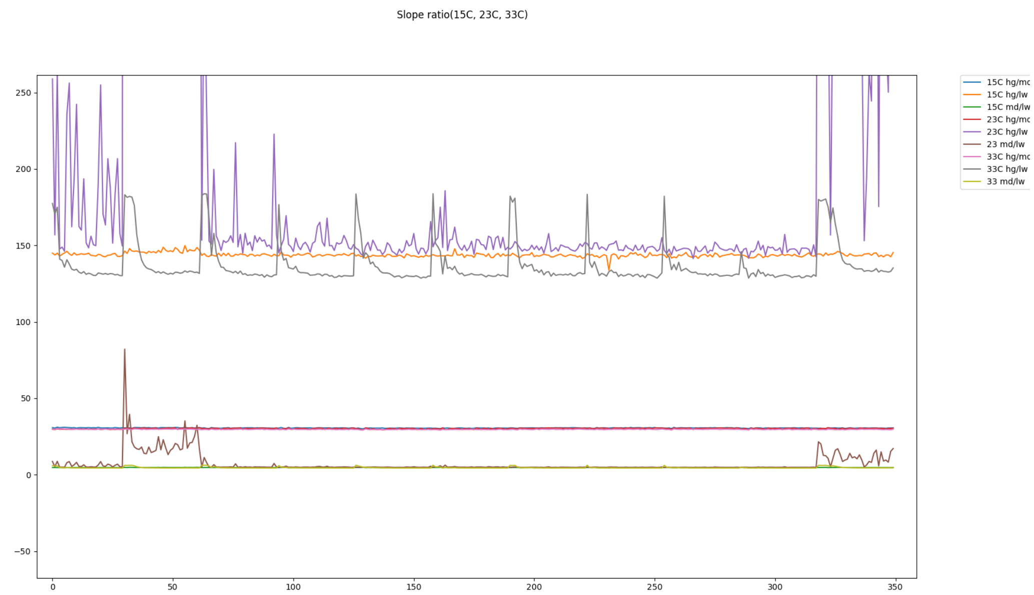
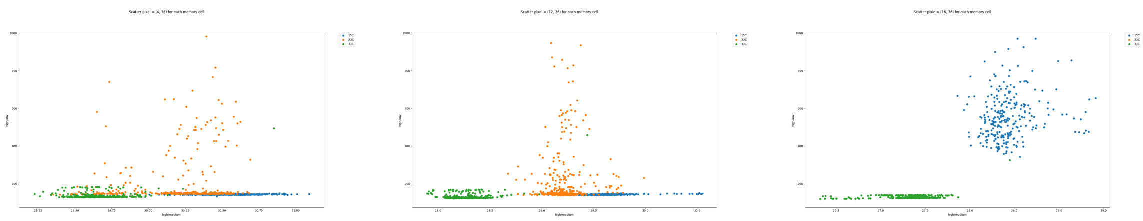


Figure 8: Slope ratios for different temperatures

ratios. There are 11 similar shapes with the period of 32 memory cell. It is nothing but memory geometry.



(a) Scatter plot for pixel 4,36(row, column)

(b) Scatter plot for pixel 12,36(row, column)

(c) Scatter plot for pixel 16,36(row, column)

Figure 9: Scatter plots for 3 different pixels, Each point represents a memory cell

In Figure 9 shows scatter plots -high/low vs. high/medium- for all temperatures and 3 different pixels. The better the points are concentrated the better the quality is. Also data points for different temperature should be very close to each other. However, as seen in the Figure 9, even 15 Celsius and 33 Celsius are quite separated. There was already a problem in 23 Celsius. In the last plot, a problem occurred in 15 Celsius degree. However, the point is they are neither concentrated nor close to each other.
In Figure 10, there are 2 different tables. As seen in the Table (a), there are some problems in 23 Celsius degree. Whenever low gain of 23 Celsius degree is taken into account, the ratio becomes too high. On the other hand, ratios at 15 Celsius degree and

Temp.(C)	H/M gain ratio	H/L gain ratio	M/L gain ratio
15 C	30.56	143.79	4.70
23 C	30.19	....	....
33 C	29.67	137.97	4.64

(a) Gain ratios for different temperatures

Temp.(C)	H/M offset ratio	H/L offset ratio	M/L offset ratio
15 C	0.76	0.72	0.94
23 C	0.76	0.66	0.86
33 C	0.76	0.73	0.95

(b) Offset ratios for different temperatures

Figure 10: Gain and offset ratios for different temperature values

33 Celsius degree are quite close but not equal.

5 Conclusion

After obtained results, it was seen that the gain slope ratios are dependent on the temperature on the order of few percent. In order to determine the characteristic of this dependency further investigations are required.

	Gain			Offset		
	H/M	H/L	M/L	H/M	H/L	M/L
Δ(15C-33C)	0.89	5.82	0.05	0.0003	0.008	0.01
Δ(%)	2.92	4.04	1.18	0.04	1.13	1.17

Figure 11: Dependency Characteristic for 2 different temperatures

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