DEUTSCHES ELECTRONEN SYNCHROTRON

SUMMER STUDENT PROGRAM

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REPORT

Characterization and Optimization of ADCs for PERCIVAL P2M

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Abstract

PERCIVAL ("Pixelated Energy Resolving CMOS Imager, Versatile and Large") is a 2D monolithic active pixel sensor (MAPS) based on CMOS technology, intended for soft X-ray imaging. Here a characterization and optimization is performed by varying some of the system biases and evaluating the data. This work aims to provide an optimized regime of operation and also, to describe some issues. This work was carried in the frame of the DESY Summer Student program in the FS – DS group.

Contents

1. Introduction

1.1. DESY

Deutsches Elektronen-Synchrotron (DESY), is a national research center in Germany and one of the leading accelerator centers in the world. The main directions of the research:

- **Particle accelerator** development, construction and operation.
- **Particle physics** research to explore the fundamental characteristics of matter and forces, including astroparticle physics.
- **Photon science** research in surface physics, material science, chemistry, molecular biology, geophysics and medicine through the use of synchrotron radiation and free electron lasers [1, 2].

1.2. CFEL and FS-DS group

DESY, the Max-Planck-Gesellschaft, and the University of Hamburg established together the Center for Free-Electron Laser Science (CFEL) on the Hamburg University site. CFEL focuses on developing and exploiting the scientific applications of new light sources with outstanding properties [3].

An important aspect for the scientific success of these new sources will be the availability of well adapted detectors. The Photon Science Detector group (officially called: "FS-Detector Systems") is responsible for the support and development of all detectors for photon science at DESY. Therefore, the tasks of the group include: - Development of novel detectors - Acquisition and adaptation of the best available detectors - Consultation to application (beamline) scientists - Operation of a detector loan pool [4].

2. PERCIVAL

PERCIVAL (“Pixelated Energy Resolving CMOS Imager, Versatile and Large”) [5, 6] is a monolithic active pixel sensor (MAPS), intended for soft X-ray 2D imaging and based on CMOS technology. A back-thinning and back-processing combined with back-side illumination, yields to high quantum efficiency (QE) in the photon energy range of 125–1000 eV. Single photon sensitivity with high confidence at moderate frame rates in the range of 10–300 Hz is expected. In Figure 1 an overview of the system is shown. Also, the key parameters are shown on Table 1. This developed by DESY, RAL/STFC, Elettra, DLS, and PAL to address the various requirements of detectors at synchrotron radiation sources and Free Electron Lasers (FELs) in the soft X-ray regime.

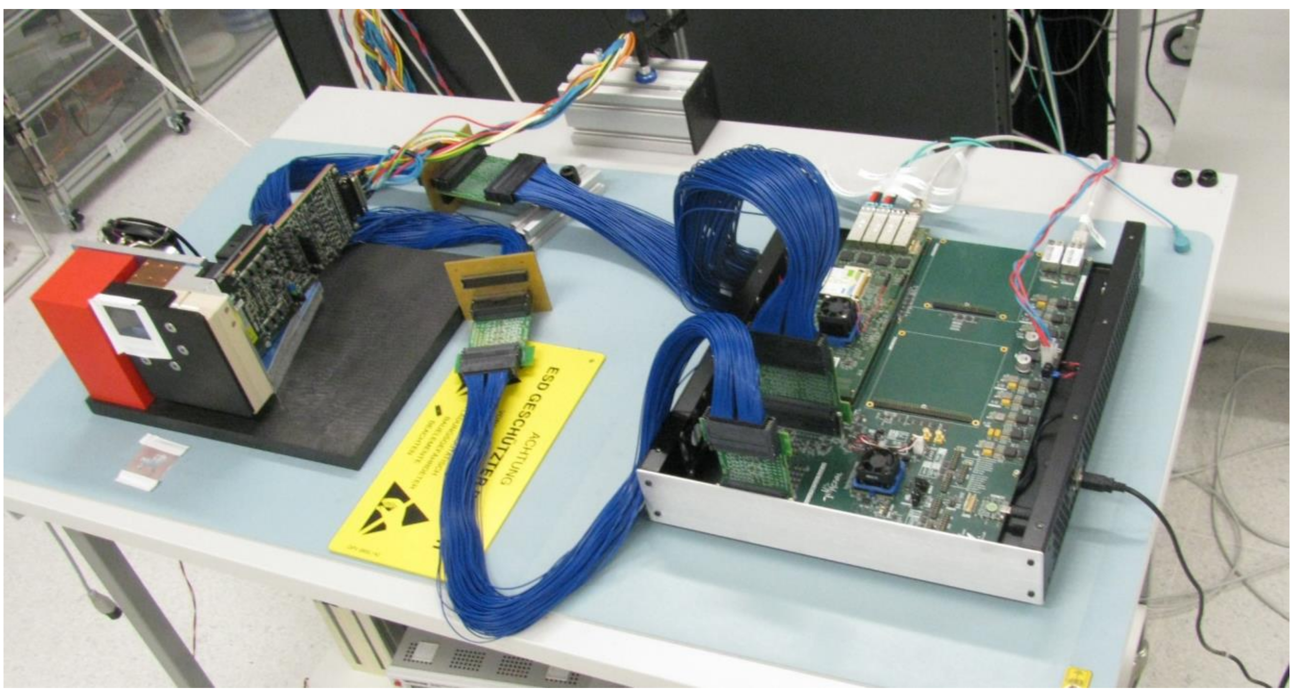


Figure 1. The PERCIVAL system.

Energy Range	Primary: 250 – 1000 eV Extended: 100 – 3000 eV
QE over Primary Energy Range	> 85 %, uniform over pixel
Frame Rate	300 Hz
Pixel size	27 (prototype: 25) μm^2
Sensor size	2M – 1408 x 1484 pixels, 4 x 4 cm^2
Noise RMS	< 15 e^-
"Full Well"	> 5 Me^-
Resulting Dynamic Range	> 10^5 photons at 250 eV
ADC Conversation	On-chip/per column/ 12 bits
Sensor Output	Digital, LVDS
Buttability	2-side (adjacent edges)

Table 1. Main parameters of PERCIVAL.

2.1. Sensor architecture

PERCIVAL employs a lateral overflow approach to enable automatic gain adjustment on a per-pixel basis. The pixel schematic is shown in Figure 2. It is based on the standard 3T structure (source-follower, reset, and select transistor) which is enhanced by the addition of a series of switches (SW0-2, AB) and capacitors (C0-C2). At low photon fluxes, during the charge integration, no current flows between the transistor and the capacitors and the system behaves as a regular 3T Active Pixel Sensor (APS). Switches SW0-2 and AB are biased at intermediate voltages. At higher fluxes, corresponding to a lower voltage on the diode, the current starts flowing through SW0 charging the first additional capacitor. This process repeats when additional photons arrive charging the subsequent capacitors. During readout, the switches S0-2 are sequentially opened, the source-follower output compared to a threshold, and both ADC'd voltage and gain recorded for the best gain setting.

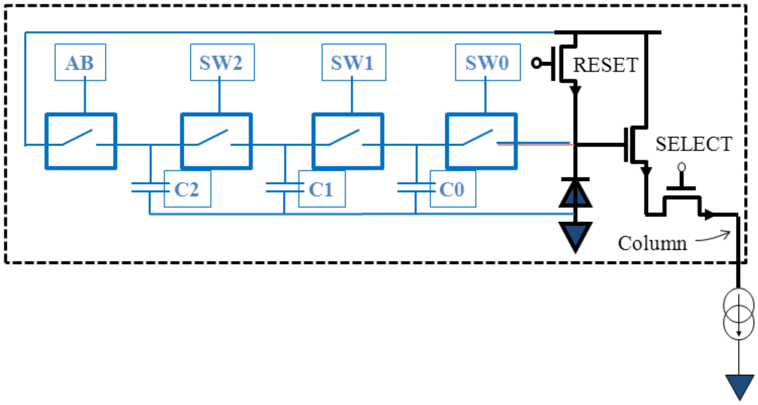


Figure 2. The PERCIVAL pixel. In black the basic 3T pixel, in blue the added overflow structure.

Each of the 1440 column is equipped with 7 ADCs (plus 1 spare). The ADC consists of a coarse and fine stage with two different current ramps (see example in Figure 3), allowing for a total of 12-bit (plus one bit over range and 2-bit for gain information) conversion. In total 15-bits per pixel. More details can be found [1, 2].

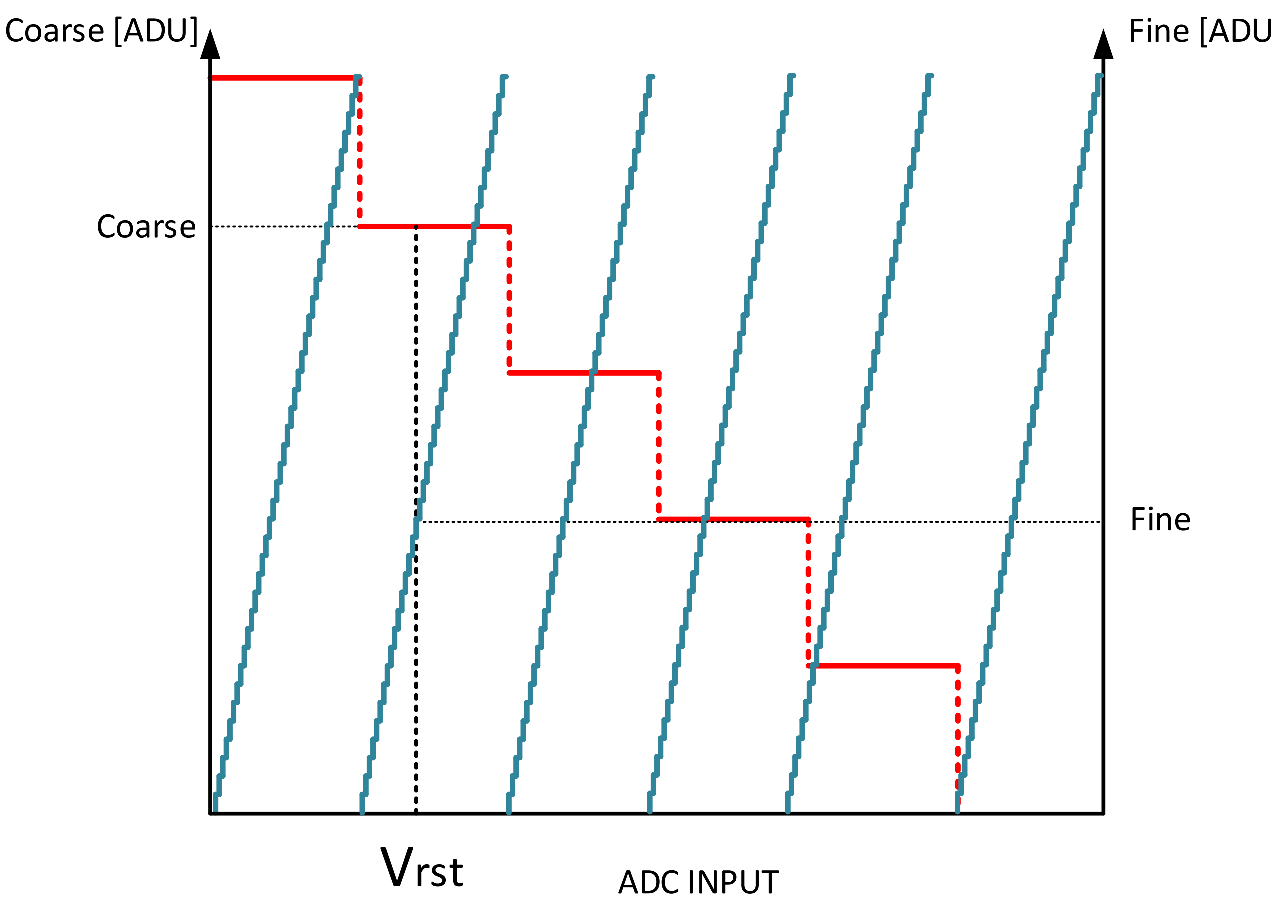


Figure 3. Sample example of ADCs counting.

3. Characterization of ADCs and Optimization

The goal is to characterize the system and possibly to optimize it.

A number of biases can be modified. The biases used in this work are the following:

- Vrst — Reset voltage of pixel
- VDD_A1V8 — Analogue supply to analogue readout
- VDD_D1V8 — Digital supply to analogue readout
- VDD_A3V3 — Analogue supply to analogue readout.

300 frames have been taken for each value of the VDD's. Characterization has been done with the goal of estimating noise of pixels. For a given Vrst, two of the other three biases are kept constant. The last one is then modified in small steps. At each step 300 frames are taken. The output for coarse and fine is shown in Figure 4. Using the fine output we can build a distribution. This is shown in Figure 5.

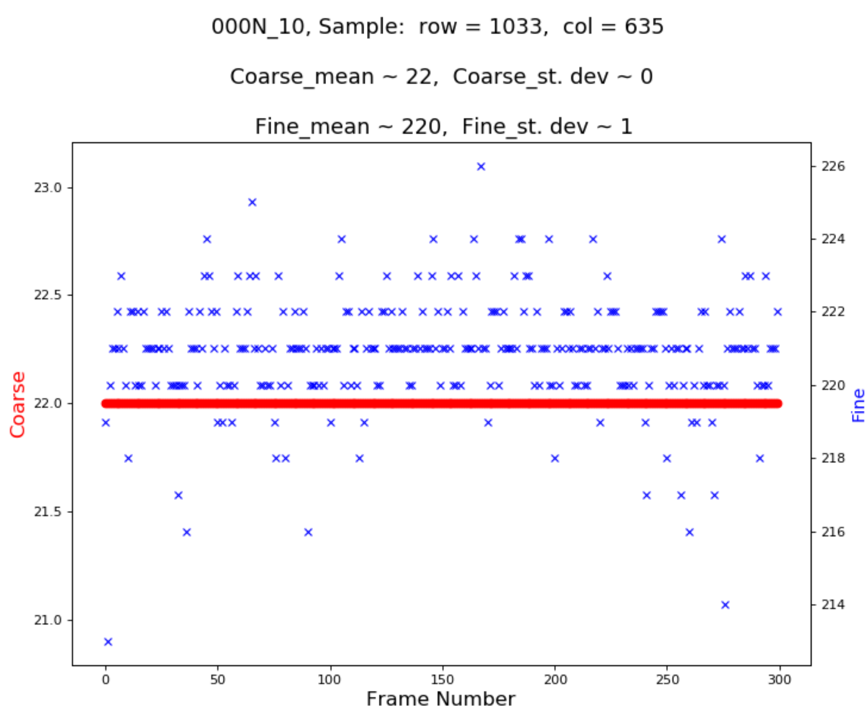


Figure 4. The coarse and fine values for one particular pixel and 300 frames.

Several values can be extracted from this distribution. For this work we will only focus on the standard deviation. It is calculated in the following way:

$$\text{St.} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(fine_i - mean)^2} \ ,$$

where N is number of frames and equal to 300, $fine_i$ is fine value of pixel in each frame and $mean$ is a mean of fine values.

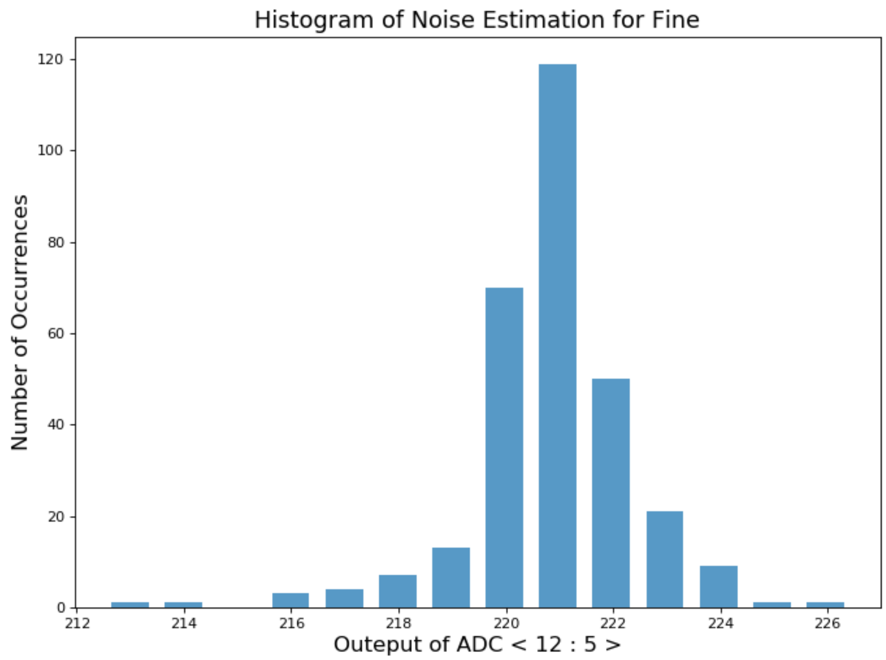


Figure 5. Histogram for fine values in Figure 3.

4. Results

The previously described method has been applied to the data for Vrst = 1.419 V. Figures 6, 7 and 8 show the standard deviation as a function of the input voltages for each of the biases.

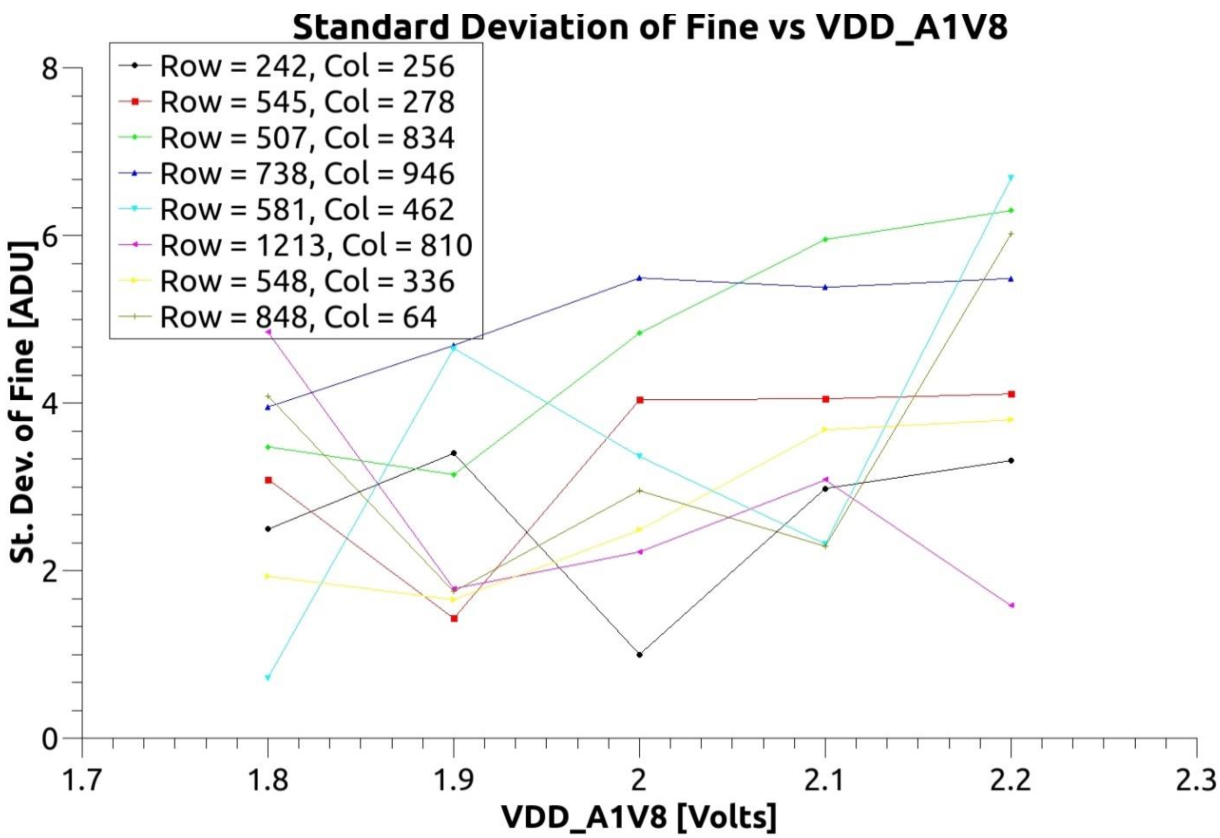


Figure 6. Standard deviation of (a selected number of pixels) as a function of the input voltages for VDD_A1V8.

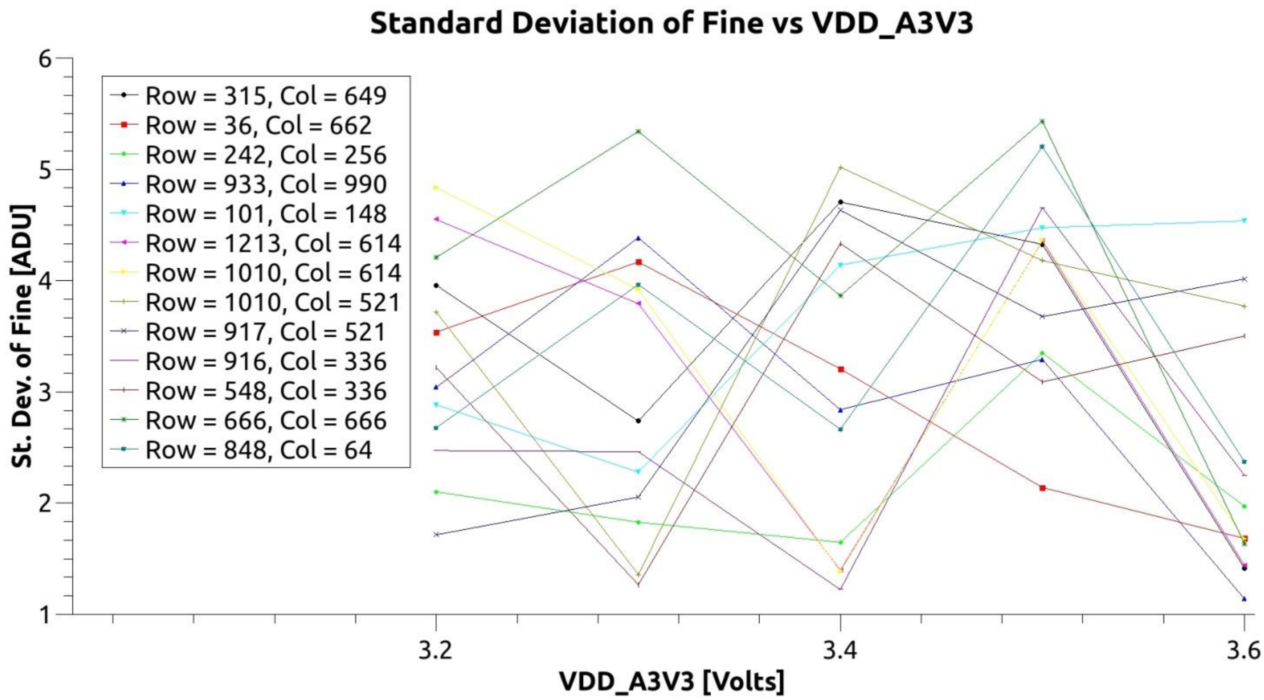


Figure 7. Standard deviation of (a selected number of pixels) as a function of the input voltages for VDD_A3V3.

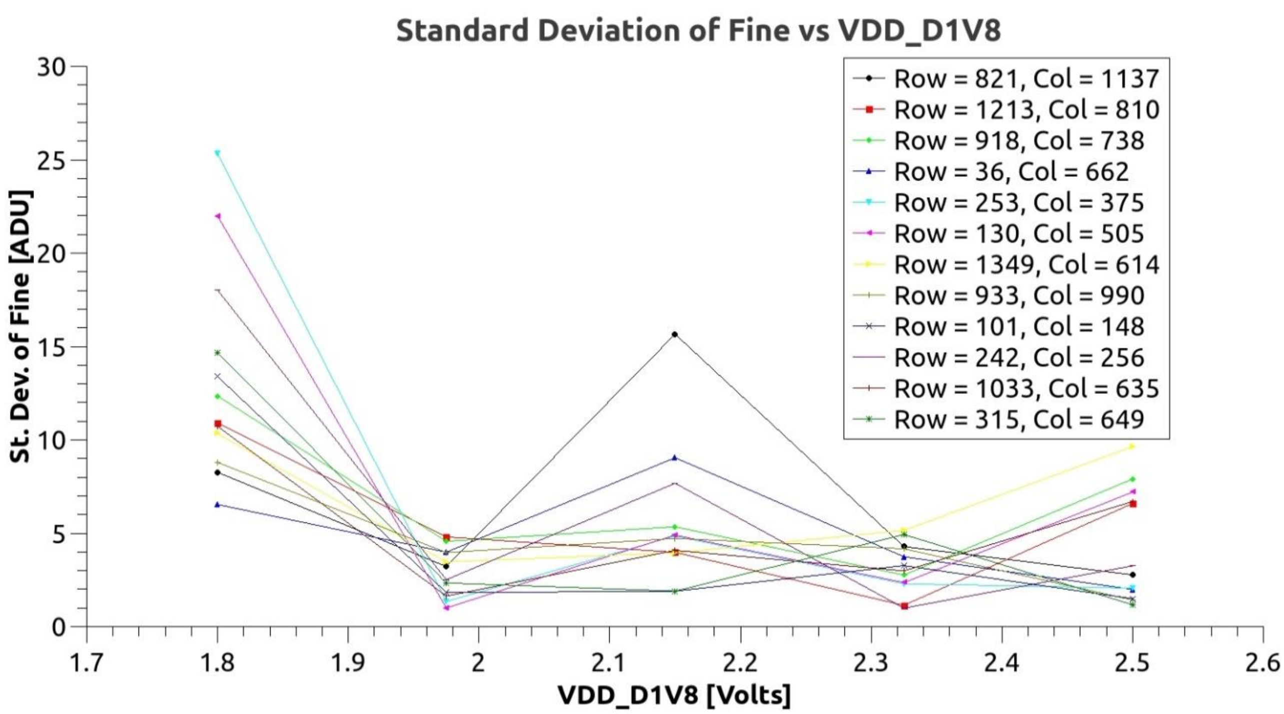


Figure 8. Standard deviation of (a selected number of pixels) as a function of the input voltages for VDD_D1V8.

All measurements have been done at room conditions. But we can see that changing VDD_A1V8 and VDD_A3V3 doesn't seem to alter the standard deviation. For VDD_D1V8 however, an optimal value of 2 V found. This seems to agree with other experiments done from colleagues.

It can be seen from the graphs that statistics is low and the reason for that is that, in many cases, only one coarse is hit. Then the fine follow only one distribution. This can be seen in Figures 8, 9.

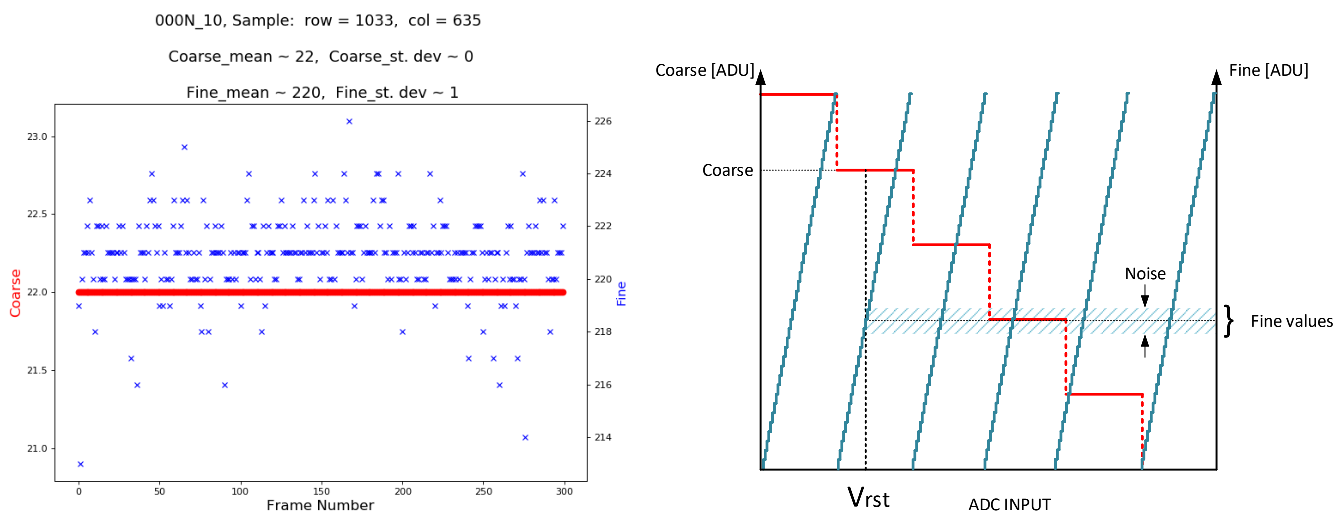


Figure 9. Situation with one course.

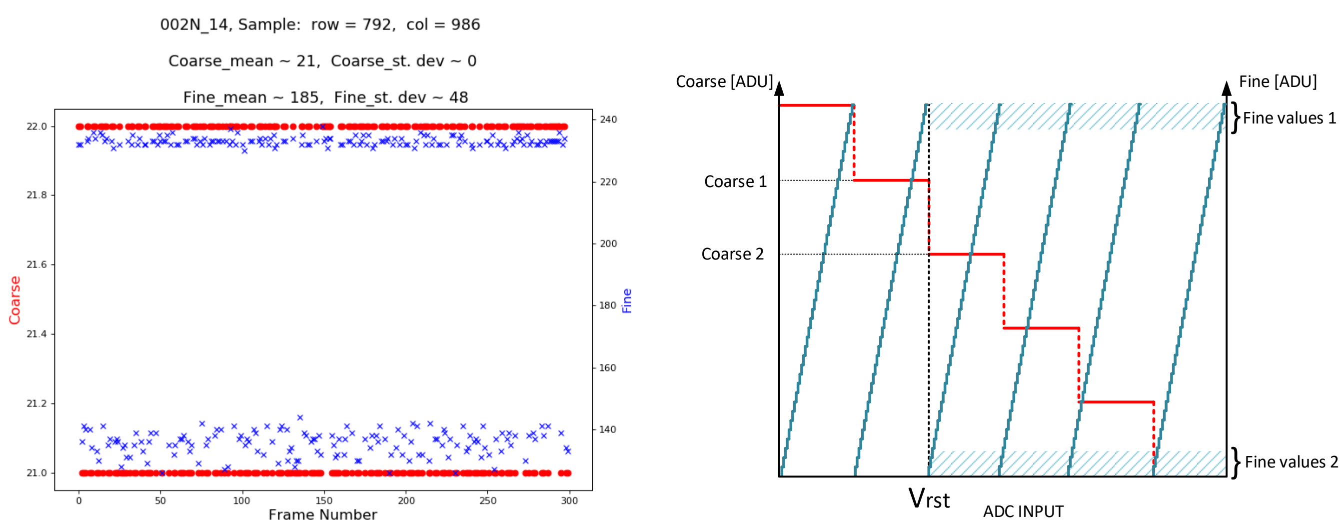


Figure 10. Situation with two courses.

Situation with two courses as we can see (Figure 9) gives two different distributions for fine values and an estimation of noise using standard deviation will not work. Because of lack of time a solution to this problem has not been found there for statistics are rather low.

4.1. Un expected results

When VDD_A1V8 have been set from 2.2 V to 1.8 V a strange behavior was found. This is shown in Figure 11.

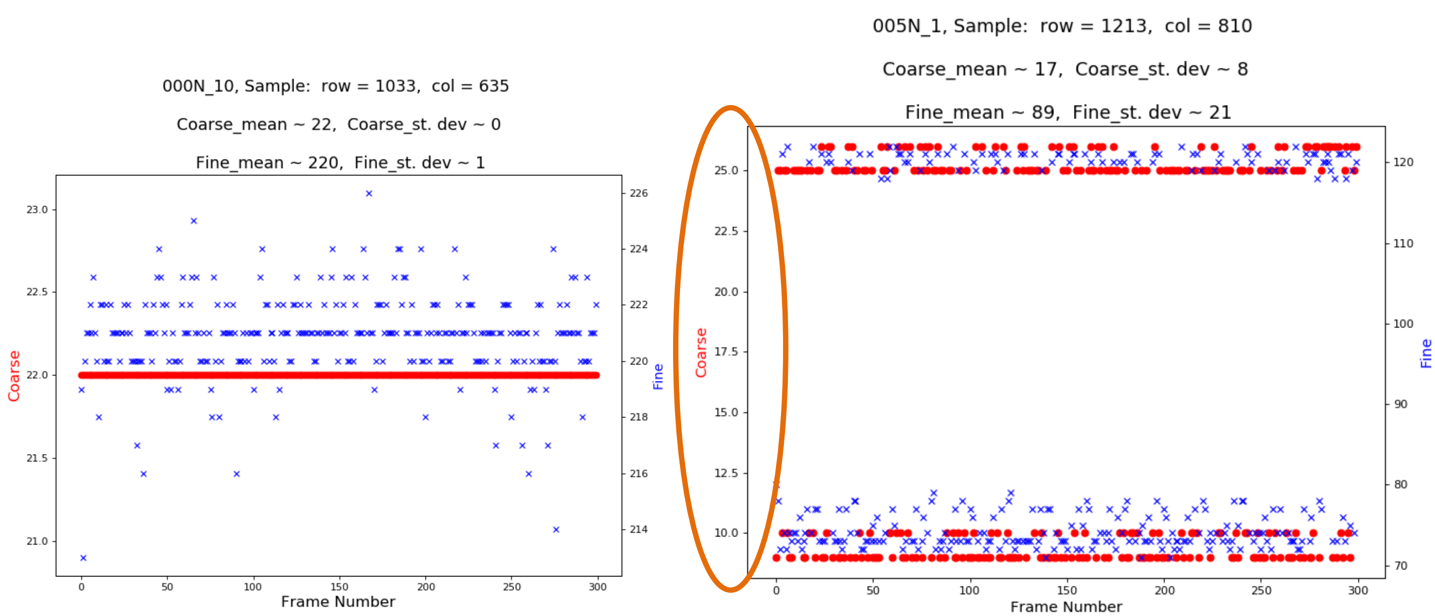


Figure 11. In left side VDD_A1V8 = 2.2 V in left side VDD_A1V8 = 1.8 V.

System stays in that state until it has been turned off and turned on again. A difference of 16 ADU for the coarses can be seen. We believe this is due to a bit shift in 15-bit data which comes from those pixels.

- Another issue was found when VDD_A1.8 reaches 2 V border (see Figure 12).

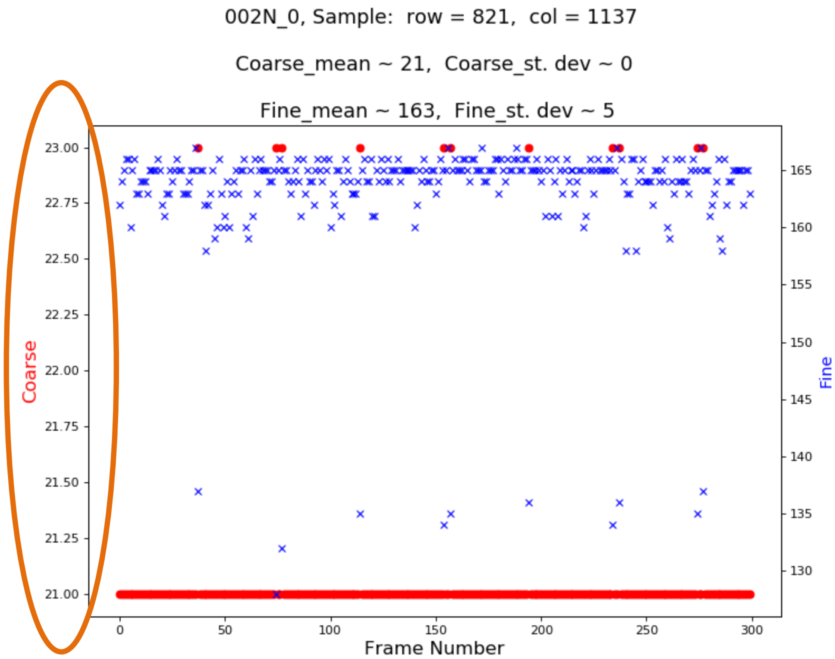
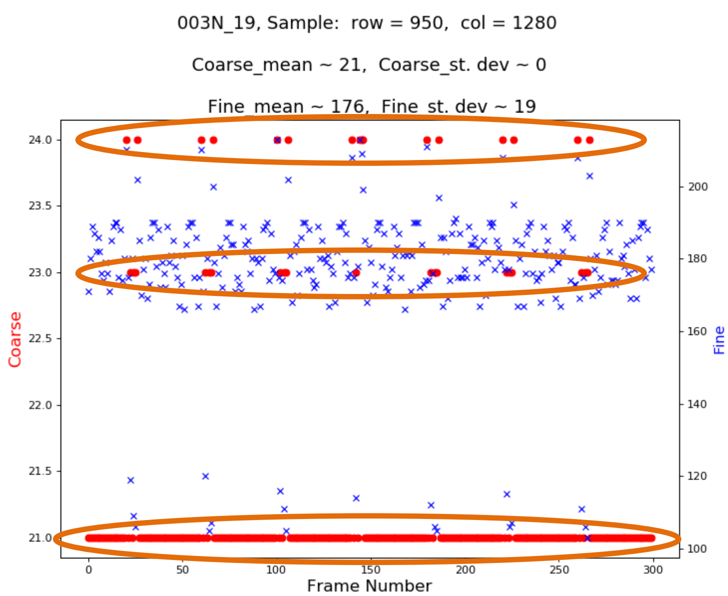


Figure 12. Coarse difference is 2 ADU.

Coarse difference here is equal to 2 ADU.

- And in higher voltages than 2 V have been seen more than 2 coarses (see Figure 13).



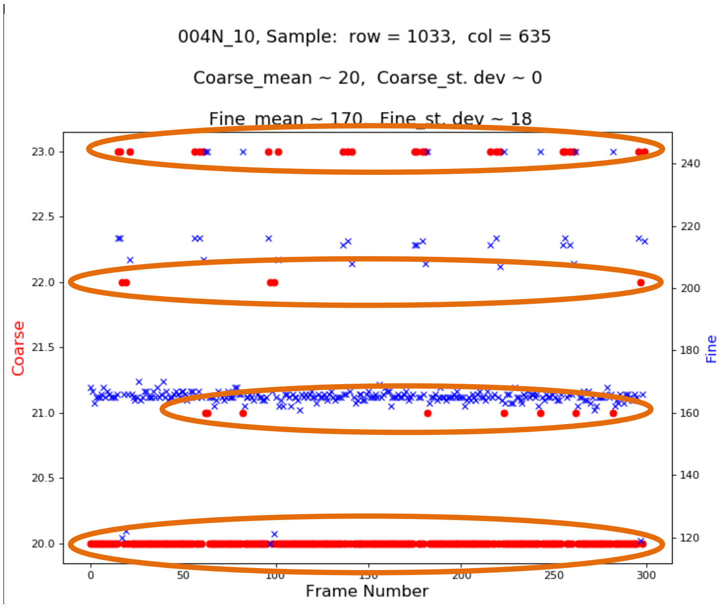


Figure 13. Three coarses in left and four coarses in right picture.

5. Conclusions

- Changing VDD_A1V8 or VDD_A3V3 doesn't seem to change the noise of the system but it should be taken into consideration that in this work statistics are low.
- For VDD_D1V8 an optimal value of 2 V was found.
- The whole investigation has been done for one Vrst value. Further analyses at different Vrst is recommended.
- Setting the value for VDD_A1V8 from high to low voltage makes system unstable.
- Values for VDD_A1V8 higher than 2 V makes system work unstable.

6. Acknowledgments

This work has been done in the frame of DESY Summer Student program (with duration of 8 weeks) in the FS – DS group under the direction of the head of the group Heinz Graafsma and the supervisor, Jonathan Correa. Special thanks to Alessandro Marras, Jonathan Correa and the rest of the group who helped during of this program, also to the Summer Student program organizers.

7. References

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