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AGIPD: A fast X-ray imager for the European XFEL

The AGIPD (Adaptive Gain Integrating Pixel Detector) collaboration - consisting of Deutsches Elektronensysnchrotron (DESY), University of Hamburg, University of Bonn and the Paul-Scherrer-Institute (PSI) - is currently developing a 2D hybrid pixel detector system capable to fulfill the requirements of the European XFEL (XFEL.EU).
At the XFEL.EU photons will arrive in bunch trains every 100 ms (or at a rate of 10 Hz). Each train consists of 2700 bunches that arrive within 600 µs (i.e. a bunch spacing of 220 ns, meaning 4.5 MHz frame rate) followed by 99.4 ms without pulses. Each single pulse consists of 10^12 X-ray photons arriving in less than 100 fs with an energy tunable between 250 eV up to 25 keV.
In order to cope with the large dynamic range, the first stage of each pixel in the AGIPD ASIC is a charge sensitive preamplifier with three different gain settings that are dynamically switched during charge integration allowing to have both single photon resolution at 12.4 keV (with SNR>10) and to cover a dynamic range up to 10^4 x 12.4 keV photons. This gain switching is automatic and per pixel. The high frame rate (4.5 MHz) requires an on-pixel storage of every frame before the readout takes place during the gap between bunch trains.
The full scale chip (AGIPD1.0), received at the end of 2013, is a 64 x 64 pixel matrix. Each pixel (area 200 x 200 µm^2) is equipped with 352 storage cells. A long period of testing (almost 3 years) showed that even if the main performance parameters already match the requirements of the XFEL.EU a resubmission of the chip was necessary to fix all the design flaws spotted that make the actual chip not easy to calibrate and operate.
The new AGIPD1.1 design has been submitted in December 2015 and the chip was received in March 2016. Since then the ASIC is under test and a pre-characterization shows that many of the problems and limitations of the old chip are solved and the overall performance has strongly improved.
In this contribution the complete characterization activity on AGIPD1.0 will be shown with both experimental and simulation results. A detailed discussion about the choices made for the redesign of the AGIPD1.0 chip will follow. At the end results of the characterization of the new chip AGIPD1.1 will be shown in comparison with AGIPD1.0.

Summary

The AGIPD (Adaptive Gain Integrating Pixel Detector) collaboration - consisting of Deutsches Elektronensysnchrotron (DESY), University of Hamburg, University of Bonn and the Paul-Scherrer-Institute (PSI) - is currently developing a 2D hybrid pixel detector system capable to fulfill the requirements of the European XFEL (XFEL.EU).
The XFEL.EU is a free electron laser that is being built at DESY (Hamburg, Germany). The first light is foreseen for early 2017. This machine shows many new and innovative features [1]. These features will open the way to new scientific opportunities in many fields of science and at the same time set many challenges in the detector design [2], in particular its extremely high frame rate.
At the XFEL.EU photons will arrive in bunch trains every 100 ms (or at a rate of 10Hz). Each train consists of 2700 photon pulses that arrive within 600 µs –which corresponds to a frame rate of 4.5MHz - followed by 99.4 ms without pulses. This extremely high frame rate sets a critical constraint on the design of the readout electronics. Since the readout of every single frame at 4.5 MHz is impossible, the signals must be stored on-pixel by means of an array of storage cells. The number of storage cells is a trade off between the number of frames that one wants to record per bunch train and the pixel area. The AGIPD detector [3][4] offers the possibility

to store up to 352 images per bunch train by means of 352 analog storage cells per pixel.
Another important feature of the XFEL.EU is the extremely high peak brilliance of 5 x 10^33 ph./s/mm^2/mrad^2/0.1% bandwidth. Such a brilliance means that each single pulse consists of 10^12 X-ray photons squeezed in less than 100 fs with an energy tunable between 250 eV and 25 keV. From the point of view of the detector design this translates into three challenges. First, since a potential high number of photons will impinge on the detector pixels at the same time (<100fs) the single photon counting principle is not feasible. Second, a high dynamic range is required to be able to measure both a large photon signal and at the same time have single photon resolution in the areas of the detector where the intensity is low. The approach used by AGIPD to cope with these challenges is already included in its acronym. AGIPD is a charge integrating detector with multiple gain stages that are dynamically switched per pixel depending on the number of incoming photons, allowing to have both single photon resolution at 12.4 keV and to cover a dynamic range up to 10^4 x 12.4 keV photons.
The third challenge imposed by the brilliance regards the radiation tolerance. A total ionizing dose (TID) of 1 GGy is foreseen for 3 years of operation of the machine. At the target energy of 12.4 keV a fraction equal to 90% of the radiation is absorbed by the sensor therefore 100 MGy are expected on the readout electronics. This unprecedented level of irradiation forced to choose a radiation tolerant technology (IBM 130nm) and use a radiation tolerant design for the major part of the chip.
The design of such a complex chip is not trivial and the characterization and debugging phase to arrive to a final working system with the required performance can require several years. The first full scale chip (AGIPD1.0), received at the end of 2013, is a 64 x 64 pixel matrix and has been fully characterized and debugged for almost three years in order to assess its performance [5]. This long period of testing showed that even if the main performance parameters already match the requirements of the XFEL.EU a resubmission of the actual chip was necessary to fix all the design flaws spotted that makes the actual chip not easy to calibrate and to operate. One of the flaws regard the cross-talks between the analog voltages and the fast digital control signal lines that allow to access the different memory cells and that can be well described with an aggressor-victim model. The result of such a coupling is an evolution of different reference voltages in time that can limit the possibility to calibrate the detector. Moreover the resistive coupling between the last four parallel stages (offchip drivers) of the amplification chain cause the so called 'ghosting'effect. The ghosting effect consists in the appearance of three spurious images (ghosts) on the chip in the three homologous positions with respect to the real one. To finish, the power distribution is another critical point of the design of this ASIC. As it has been seen a voltage drop of few tens of mV across the chip can cause non negligible problems during the gain switching.
As already mentioned the actual chip performance, even if non-optimal, has proven to be suitable to successfully build the first 1Mega-pixel detector system matching the specification given by the XFEL.EU. The 1M system is now in construction and will be delivered to the XFEL.EU at the beginning of August 2016 and will be equipped with AGIPD1.0 chips and will be then upgraded with AGIPD1.1 chips in the future.
The new AGIPD1.1 design has been submitted in December 2015 and the chip was received in March 2016. Since then the ASIC is under test and a pre-characterization shows that many of the problems and limitations of the old chip are solved and the overall performance has strongly improved.
The results of the careful testing activity - that will be shown in this contribution - together with the simulations of such a complex chip are useful to arrive to a final version of the ASIC and are a very valuable experience for the future development of such kind of detectors.

[1] European XFEL: http://www.xfel.eu/en/index.php
[2] H. Graafsma, Requirements for and development of 2 dimensional X-ray detectors for the European X-ray Free Electron Laser in Hamburg, JINST 4 P12001, DOI: 10.1088/1748-0221/4/12/P12011 (2009).
[3] X. Shi et al, "Challenges in chip design for the AGIPD detector", Nucl. Instr. Meth. A 624, p.387 - 391 (2010).
[4] D. Greiffenberg et al., Towards AGIPD1.0: optimization of the dynamic range and investigation of a pixel input protection, 2014 JINST 9 P06001.
[5] D. Mezza et al., Characterization of AGIPD1.0: the full scale chip, Submitted to Nucear Instruments and Methods A

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