A Charge-integration Pixel Detector Readout Chip Features High Frame Rate with in-pixel ADCs

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Introduction

Figure 1 Location of SHINE (Top View)

- SHINE (Shanghai HIgh repetition rate XFEL aNd Extreme light facility) is the first hard-Xray Free Electron Laser facility in China.
- Photon Energy: 0.4~25 keV
- Pulse Duration: 20~50 fs (5~200 fs)
- Repetition Frequency: 10 kHz (1 MHz)
- Peak Brightness: 10^{32} ~10^{33} photons/μm^2/rad^2/s/0.1% BW

- To make use of the excellent properties, a pixel detector system is being developed, named STARLIGHT. The Specifications of the detector is shown in table 1.
- Single photon counting detectors are not capable to deal with such a high dynamic range. Instead, charge-integration detectors have to be adopted.
- HYLITE (High dYnamic range free electron Laser Imaging deTEctor) is the pixel readout chip of the STARLIGHT detector.

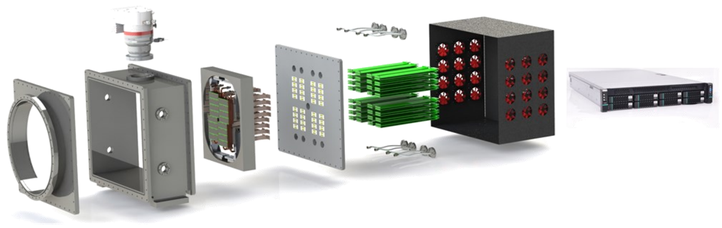

Figure 2 The STARLIGHT Detector System

Table 1 Specifications of the STARLIGHT Detector System

Specs	Parameters
Sensor	320 μm silicon PIN
Pixel size	100μm × 100μm
Pixel Array	128 × 128
Dynamic range	1 ~ 10000 photons/pulse @12 keV
Frame rate	12 kHz (continuous readout)
Detector	A 4M pixel detector in vaccum, quadrant movable

Pixel Architecture

- Working in Pump-Probe mode, sync-ed with the beamline.
- Three Gains
  - Auto Gain Switching
- Three Working Phases
  - Analog Phase (less than 1 μs)
  - Conversion Phase (16 μs)
  - Readout Phase (~66 μs in full size chip)
- Power down feature involved
  - Total average power: 34 μW/pixel
    - Analog：21.96 μW
    - Digital：14.76 μW

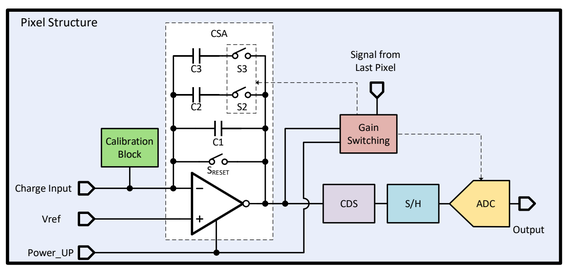

Figure 3 Block Diagram of the HYLITE Pixel Structure

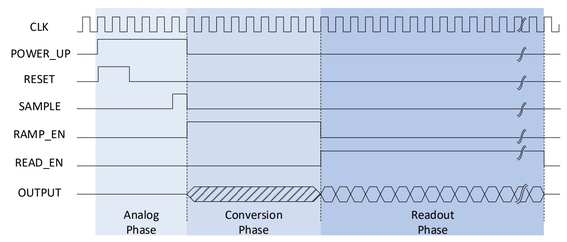

Figure 4 Work Timing of the HYLITE Pixel

Chip Architecture

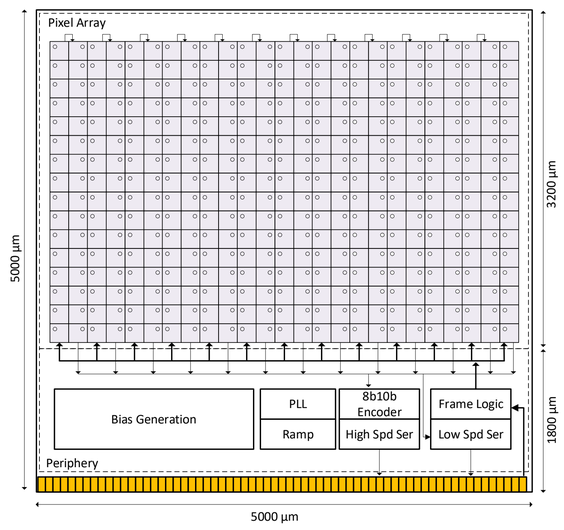

Figure 5 Block Diagram of the HYLITE200S Chip

- The third prototype chip of HYLITE.
  - Array Size: 16×25
  - Pixel Size: 200μm×200μm
- Correlated Double Sampling (CDS) circuit is added.
  - To improve the noise performance
- A PLL is integrated in the periphery.
  - High Speed Serializer with 8b10b balanced encoder
  - Low Speed Serializer for wafer test and debug

Test Results

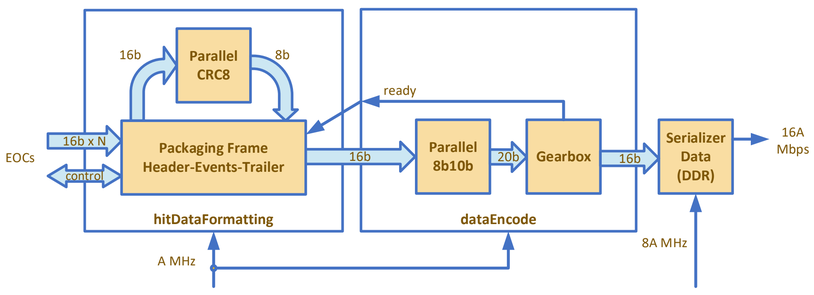

Figure 6 Block Diagram of the 8b10b Encoder

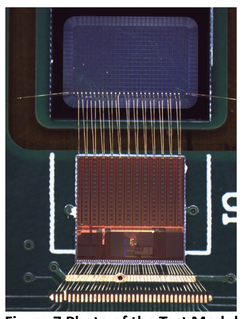

Figure 7 Photo of the Test Module

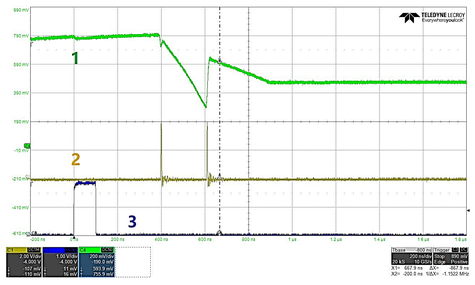

Figure 8 Analog Outputs of the HYLITE200S Pixel (Equivalent 5000-photon charge injections at 12 keV)

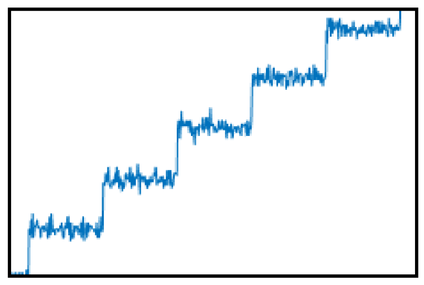

Figure 9 ADC Outputs with Single-Photon Step Inputs

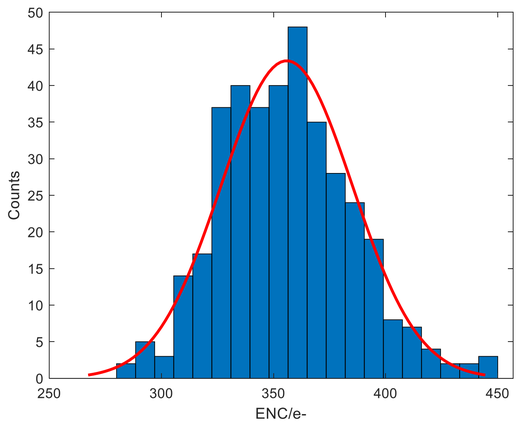

Figure 10 Histogram of Noise of Equivalent Single-photon Charge Injections at 12 keV

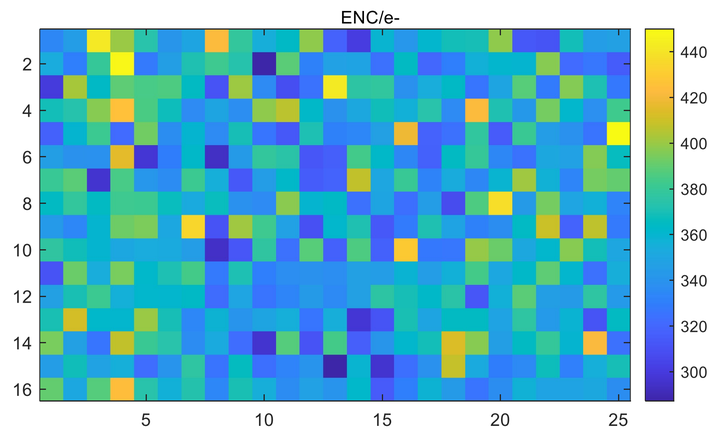

Figure 11 2D Noise Map of Equivalent Single-photon Charge Injections at 12 keV

- CMOS 130nm 1P8M Process.
- A Chip was wire-bonded with a sensor (test module).
- Full functions of the pixel were verified.
- The signal-noise ratio is 9.31
  - ENC: 355 e- @single photon
- The high speed serializer works stable at a speed of 3.125Gbps.
- Data rate of a full-size chip is 4 Gbps (2Gbps DDR×2）
  - Driven capability was tested to be longer than 1.6m by CML.

Summary and Outlooks

HYLITE is a charge-integration readout chip designed for the XFEL pixel detector. In this poster, we present the latest performances of the third prototype chip, HYLITE200S. The noise performance was improved compared with the former chips, and the data interface which will be adopted in the full-size chip was verified. The full-size chip with 100μm×100μm pixel size will be manufactured soon.