Characterization of 128x128 MM-PAD-2.1 ASIC : A Fast Framing Hard X-ray Detector

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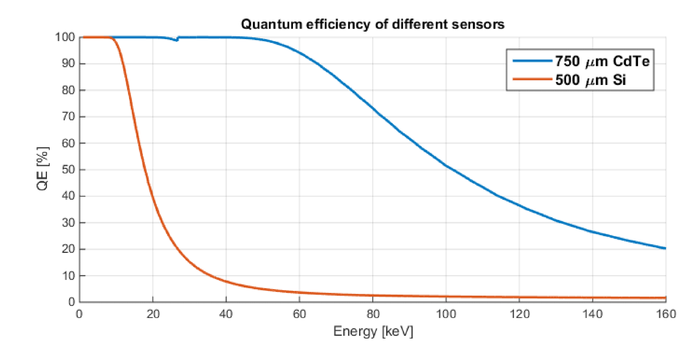
CHESS

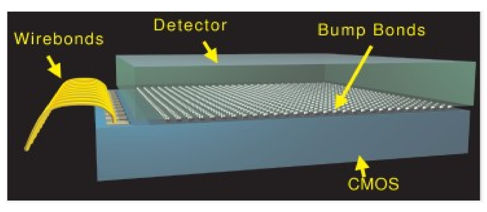
Abstract

Modern direct detection Pixel Array Detectors are built around **MODULES** consisting of an x-ray **SENSOR** bonded pixel-by-pixel to an Application Specific Integrated Circuit (**ASIC**). The sensor, typically of Si or CdTe, absorbs x-rays resulting in mobile charges; these are conveyed to the ASIC, each pixel of which has its own processing electronics. A full detector consists of an array of modules, control electronics, operating system and associated hardware in an appropriate housing. We characterize a new x-ray Mixed-Mode Pixel Array Detector (MM-PAD-2.1) ASIC developed at Cornell. Using an integrating pixel front-end with dynamic charge removal architecture, the MM-PAD-2.1 ASIC extends the maximum measurable x-ray signal (in 20 keV photon units) to > 10^7 x-rays/pixel/frame while maintaining a low read noise across the full dynamic range, all while imaging continuously at a frame rate of up to 10 kHz. We use both laboratory x-ray sources and the Cornell High Energy Synchrotron Source (CHESS) to characterize two single ASIC prototype detectors for both low (single x-ray) and high incident flux detection. In the first detector the ASIC was solder bump-bonded to a 500 μm thick Si sensor for efficient detection of x-rays below ~20 keV, whereas the second detector used a 750 μm thick CdTe sensor for x-rays above ~ 20 keV.

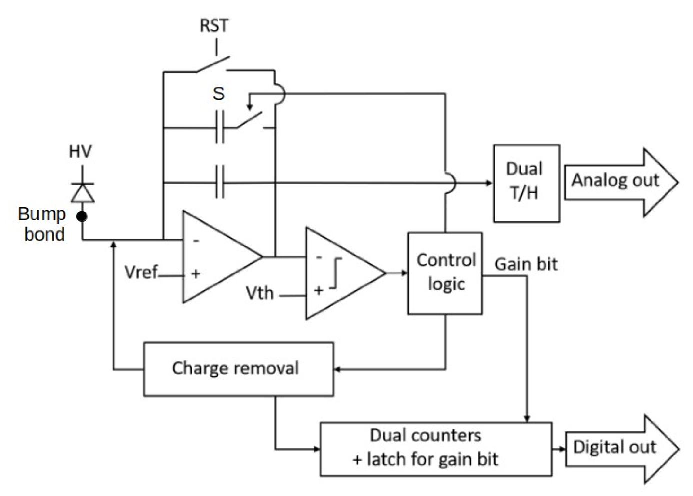
1. Motivation



- Synchrotron x-ray facilities moving towards higher energies, high repetition rate, increased brilliance
- Developing x-ray detectors with :
  - Wide dynamic range
  - High stopping power for x-rays of in the 20 to > 100 keV range
  - High frame rate
  - Low noise



2. Pixel Design



MM-PAD-2.1 is based on existing MM-PAD-1 design
- 128x128 pixels/module
- Two-stage adaptive gain (40 fF, 880 fF)
- Dual track-and-hold circuit
- Dual in-pixel counters
- Divided into 16 banks

	MM-PAD-1 (8 keV equivalent)	MM-PAD-2.1 (20 keV equivalent)
Format	128×128	128×128
Pixel pitch	150 μm	150 μm
Sensor	Si,CdTe	Si,CdTe
Charge Collection	holes only	electrons or holes
Frame rate (FR)	1.1 kHz	10 kHz
Duty Cycle, max FR	0%	99%
Read noise	0.16 photon	0.13 photon
Well capacity	4.7×10^7 photons	2.2×10^7 photons
Instantaneous count rate	$> 10^{12}$ ph/pix/s	$> 10^{12}$ ph/pix/s
Sustained count rate	4×10^8 ph/pix/s	$> 3\times10^{10}$ ph/pix/s

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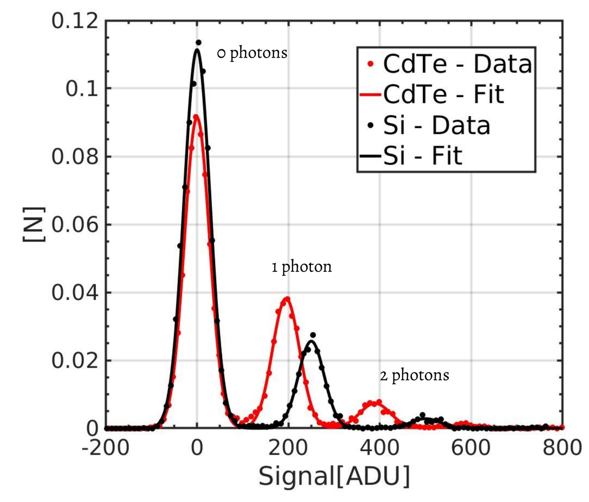
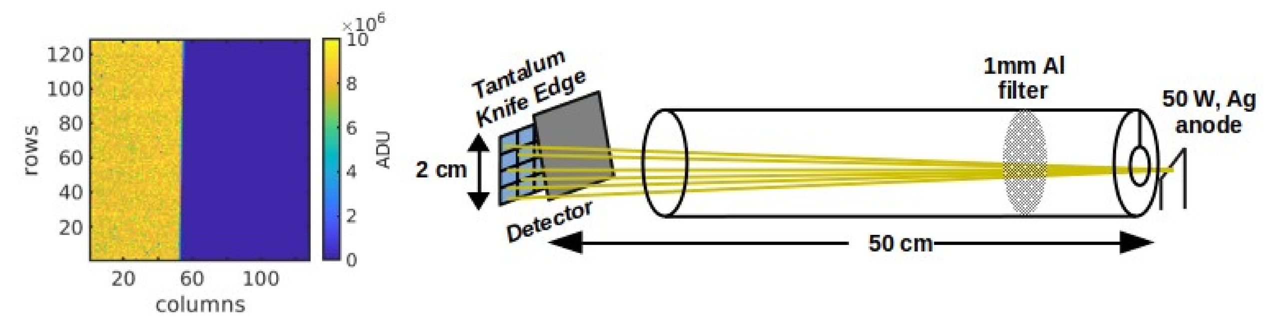
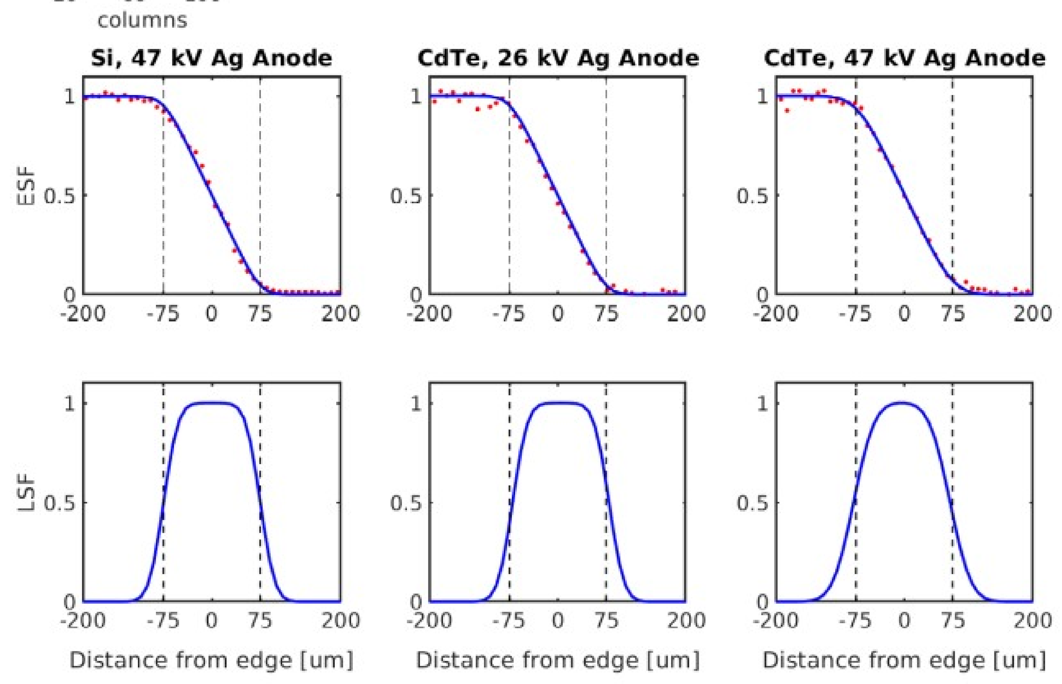
3. In-house Characterization

Characterization of modules with 500 μm thick Si and 750 μm thick CdTe sensors

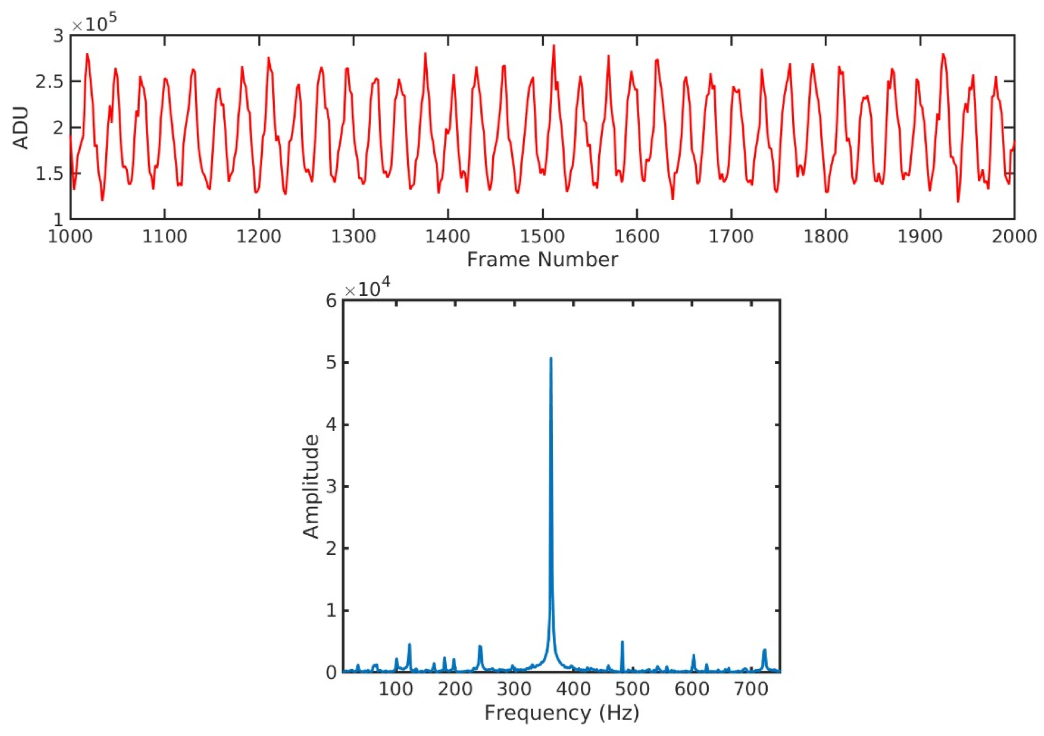


- Measured gain, using pinhole x-ray scan, and read noise :
  - G_{CdTe}/G_{Si} = 0.74±0.01
  - SNR ≥ 2 for x-ray energies > 5 keV (Si) & 8 keV (CdTe)





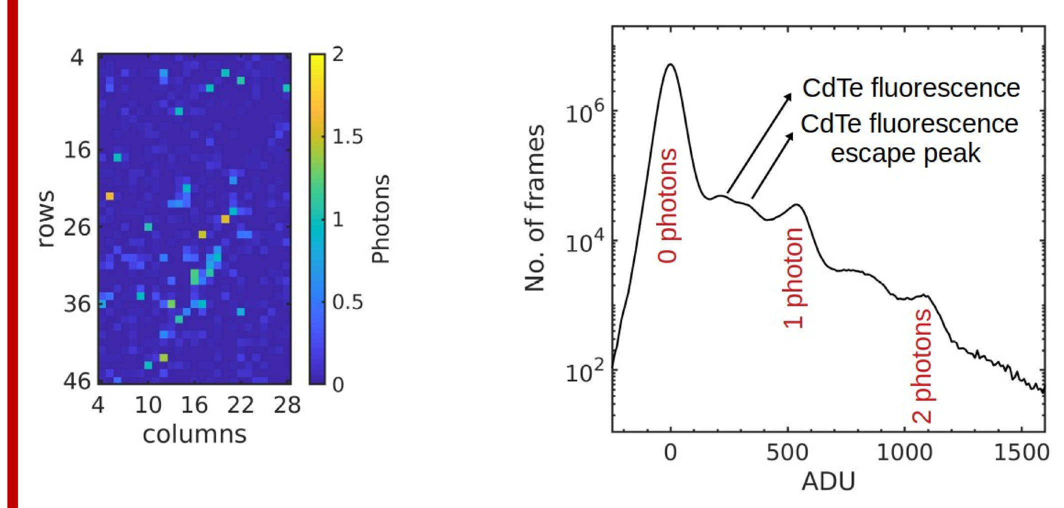
- Spatial resolution measured using Edge Spread Function (ESF) (response to step function)
- Measured charge cloud size of :
  - 20 μm in Si
  - 20 μm in CdTe at 26 kV tube bias
  - 30 μm in CdTe at 47 kV tube bias



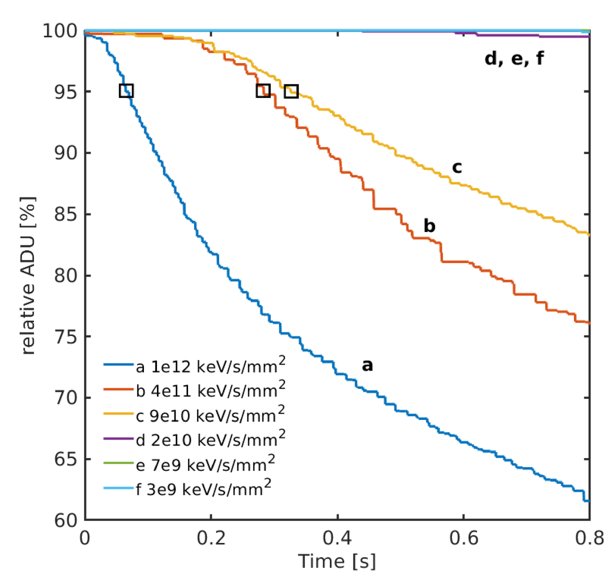
- Incident beam spanning 12x8 (FWHM) pixels, source intensity varying at 360 Hz
- Frame rate of 9.9 kHz
  - Fast fourier transform (FFT) of measured signal vs frame number yields 361 ± 1 Hz

4. Characterization at CHESS

- Performance of CdTe MM-PAD-2.1 measured at CHESS
- Incident energy of 61.332 keV



- Incident flux of << 1 x-rays/frame for 99% of pixels, ~2 x-rays for rest
- CdTe exhibits fluorescence at 23.2 keV (Cd) and 27.5 keV (Te)



- CdTe known to polarize under high flux
  - Count rate deficit
  - Worsened image uniformity
  - Lateral movement of charg
- Incident flux varied using steel attenuators
- Polarization at accumulated doses of 10^{11} keV/mm^2 and above

5. Conclusions

- The MM-PAD-2.1 ASIC extends x-ray detector capabilities well beyond the current state-of-the-art.
- The MM-PAD-2.1 ASIC is a proof-of-concept. A commercially robust ASIC is being developed by Cornell University in collaboration with Sydor Technologies under a DOE grant.
- Sydor's plans include 512x512 and 1kx1k pixel versions, with Si and CdTe sensors.