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A 2.5pJ/b Readout Circuit for 1000fps Single-bit Quanta Image Sensor

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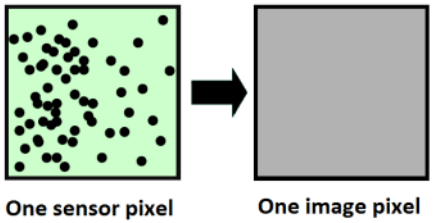
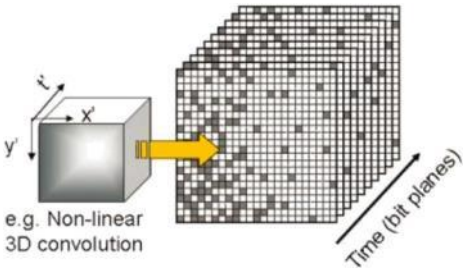
Quanta Image Sensor (QIS)

- Conventional CMOS image sensors:
  - Tens of million accumulative pixels
  - < 120 fps readout speed
- QIS: count photoelectrons
  - Billion of tiny pixels
  - > 500 fps readout speed





QIS:

- Counting photoelectrons
- Non-linear readout
- No read noise
  - Nature of photons is binary
- Access to temporary information of absorbed photons

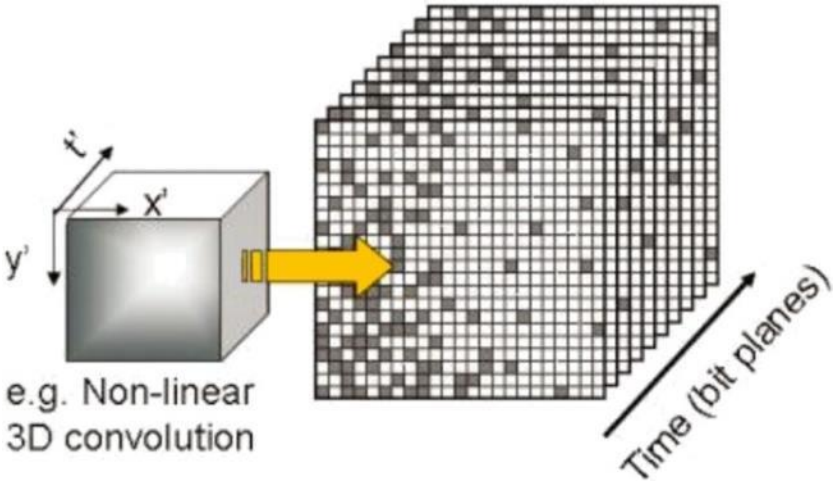
- High-Dynamic range imaging
  - Pixels get saturated

- Low-light imaging
  - Readout noise

- Blur-free imaging
  - Moving objects

Challenges

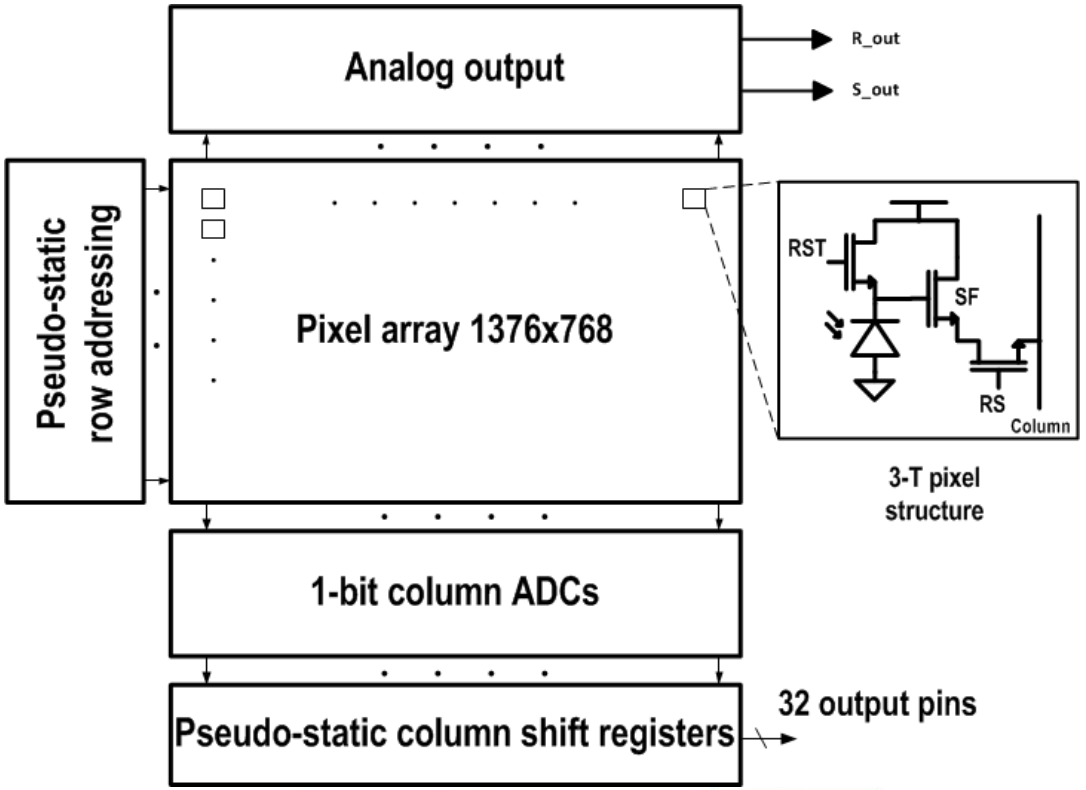
- Realizing tiny pixel (jot)
- Forming images based on jots data
- **Readout**
  - **High-speed**
  - **Low-power**

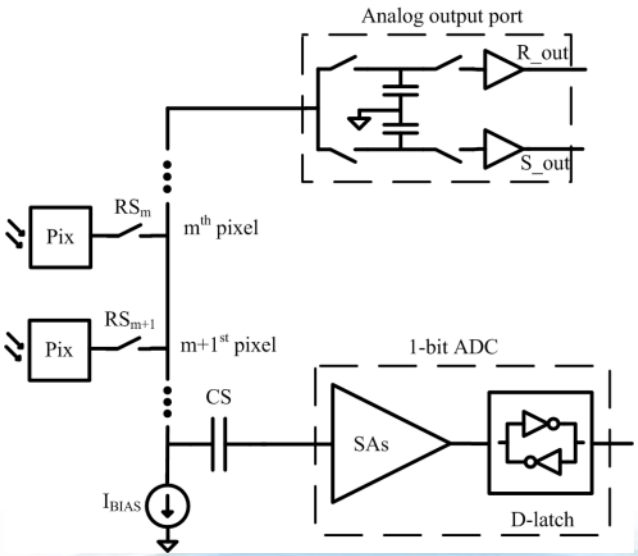


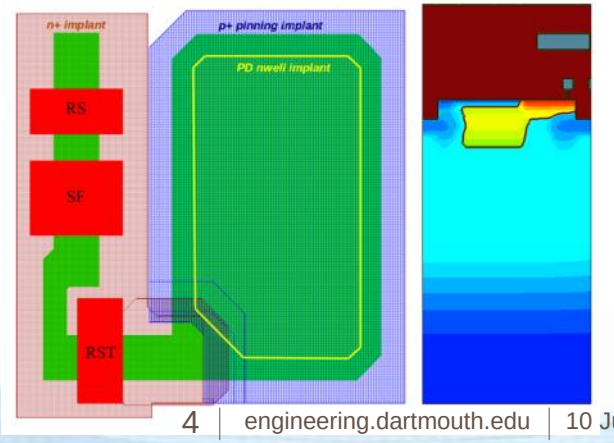
- 10 to 100 time faster
- Giga-pixel resolution

Design

- 1376Hx768V pixel array (1Mpixel)
- 1000 frames/s
- 0.18µm XFAB process
- 1376 parallel ADCs
- Output data rate: 1Gb/s

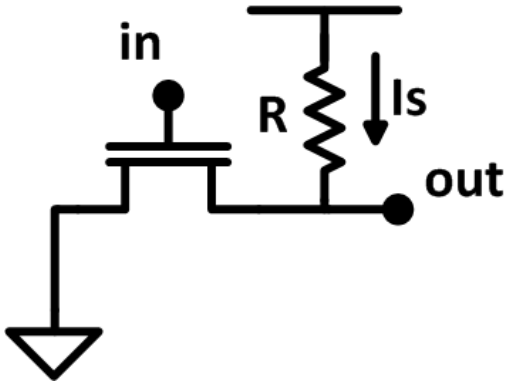




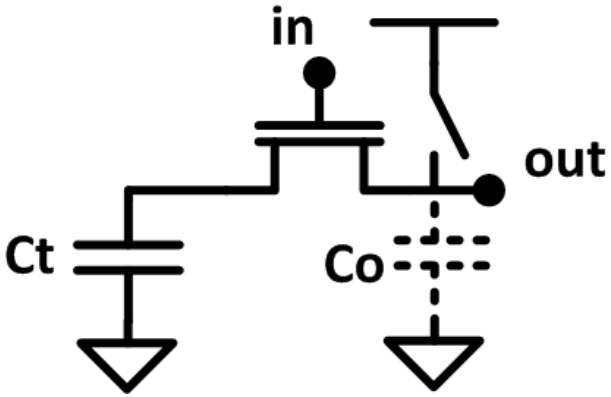


Solution

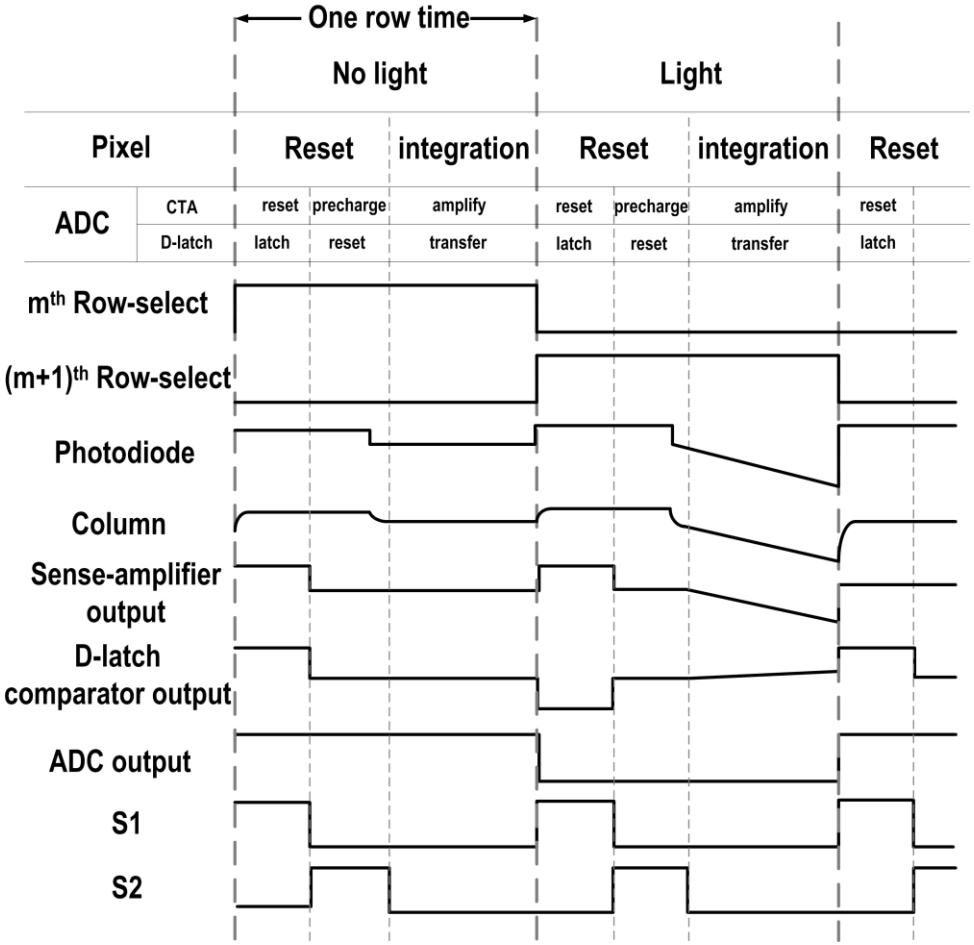
- Conventional imagers use continuous-time circuits:
  - High static power consumption



- Charge transfer amplifier technique:
  - No static power consumption

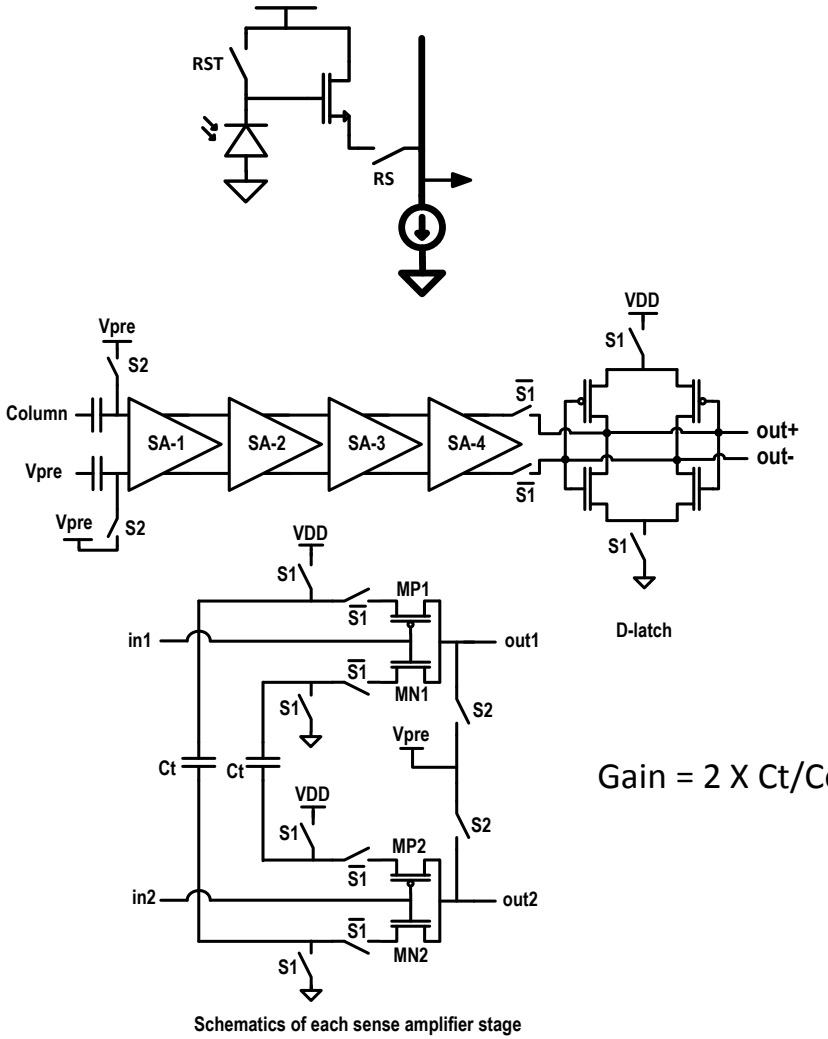


4-Stage Sense Amplifier



T_{int}

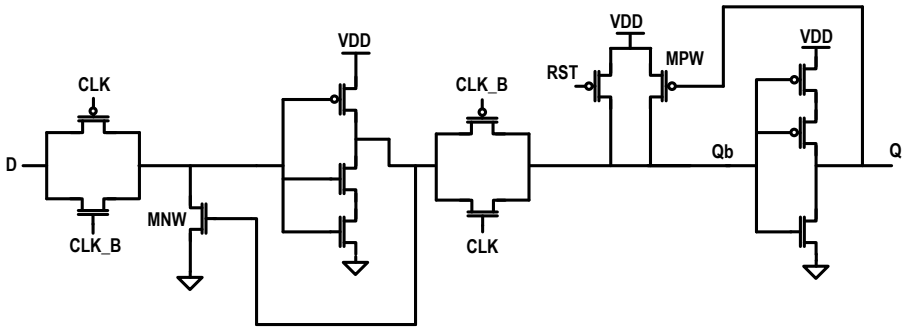
0.9 µsec



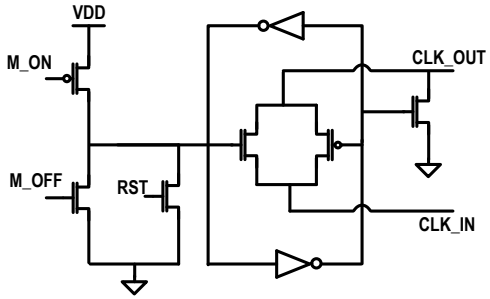
Gain = 2 X Ct/Co

Pseudo-Static Digital Circuits

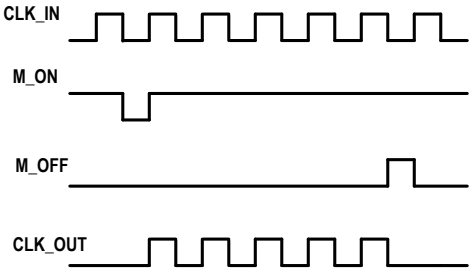
- Pseudo-static flip-flop:
  - Lower power consumption than static flip-flop
  - More reliable than dynamic flip-flop
- Clock gating:
  - Provide clock only for a group of flip-flops



Pseudo-static flip-flop

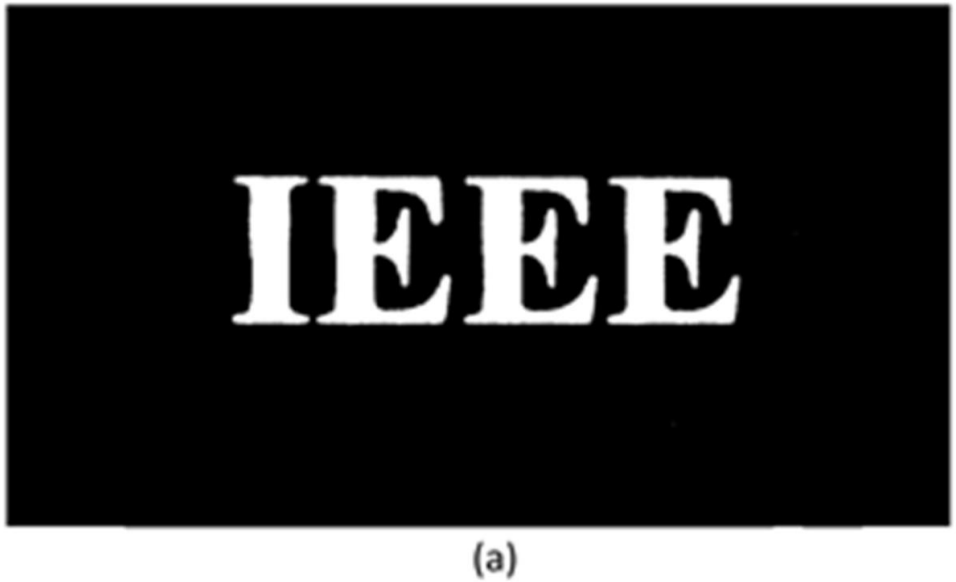


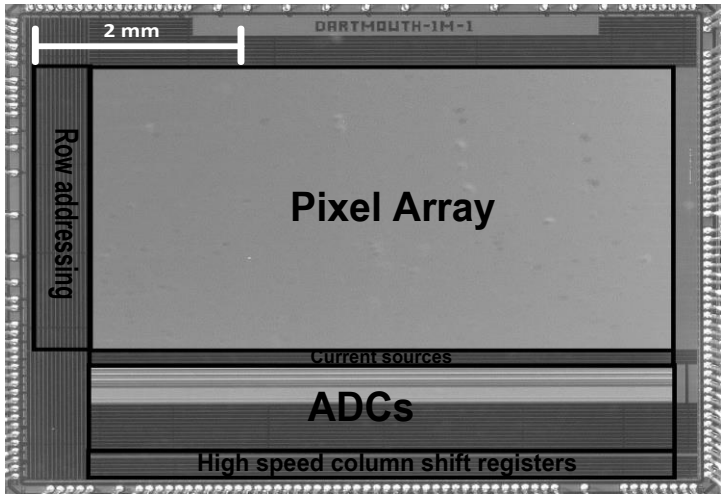
Clock gating unit (CGU)

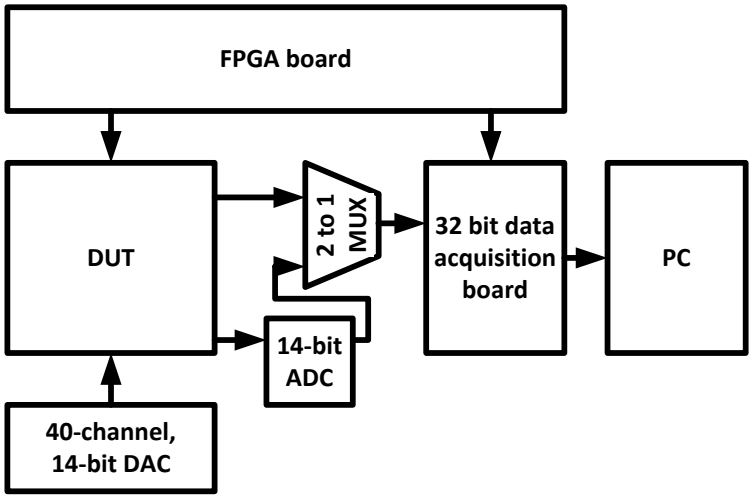


Timing of CGU

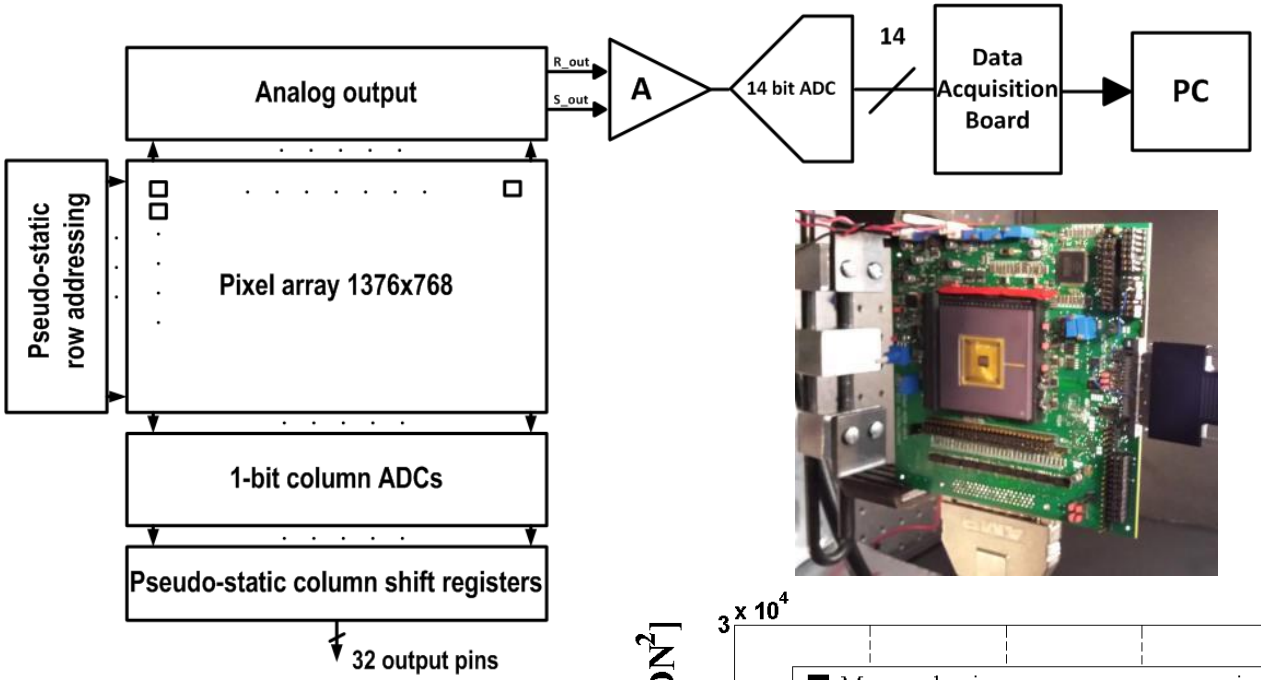
Sensor and Test System



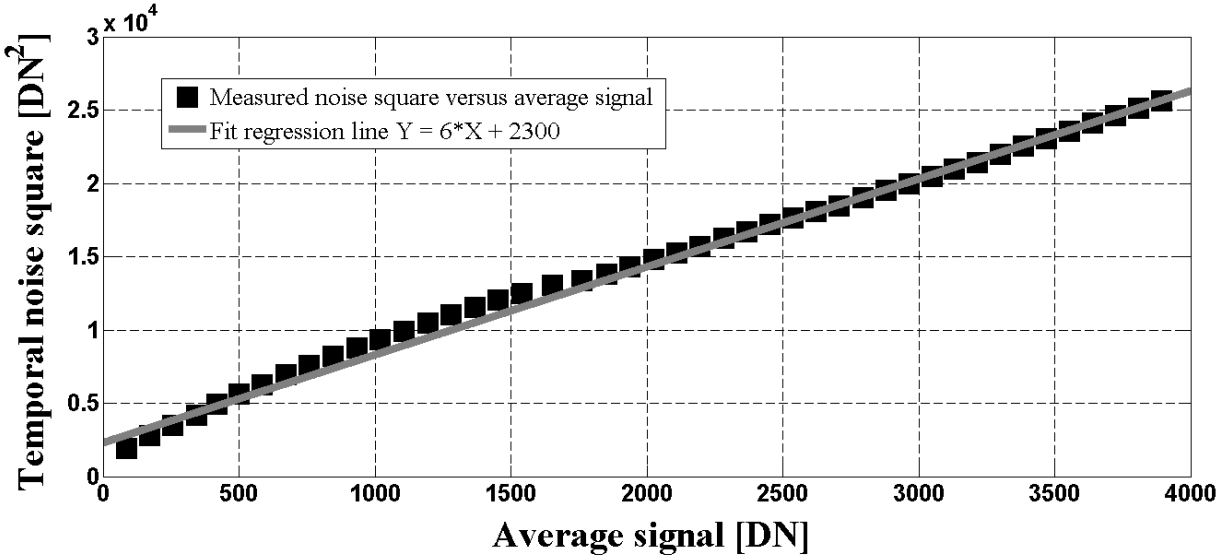




Pixel Characterization



Pixel type	3T-APS
Pixel pitch	3.6 µm
Photo detector	Partially pinned photodiode
Conversion gain	119 µv/e-
Dark current	~1000 e-/s
Column noise	2 e-



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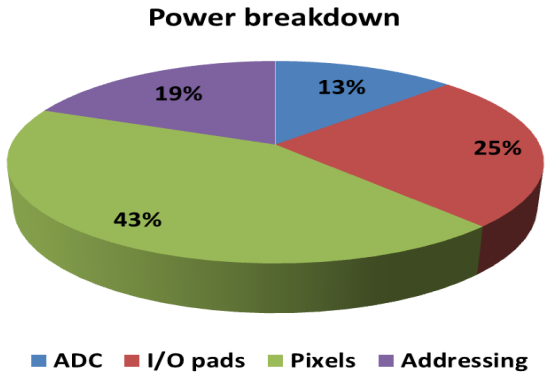
Summary of Test Results

Process		XFAB, 0.18 µm, 6M1P (non-standard implants)
Supply voltage		1.3 V (core), 2 V (Array), 3 V (I/O pads)
Pixel type		3T-APS
Pixel pitch		3.6 µm
Photo detector		Partially pinned photodiode
Conversion gain		119 µv/e-
Array		1376 (H) X 768 (V) (WXGA 16:9 ratio)
Field rate		1000 fps
ADC sampling rate		768 KSa/s
Readout noise		2 e-
Output data rate		1 Gb/s
Package		PGA with 256 pins
Power	Pixel array	8.6 mW
	ADCs	2.6 mW
	Addressing	3.8 mW
	I/O pads	5 mW
	Total	20 mW
FOM_{ADC}		2.5 pJ/b

	ISSCC11 [1]	ISSCC12 [2]	TED13 [3]	**This work**
Process (nm)	90	180	180	**180**
N_{ADC} (bit)	12	12	11	**1**
#pixels (Mega)	17.7	33.2	0.96	**1.06**
fps	120	120	35	**1000**
FOM_{ADC} (pJ/b)	---	16.7	21.6	**2.5**
FOM_{tot} (pJ/b)	118	52	108	**19**



[1] T. Toyama, et al., "A 17.7Mpixel 120fps CMOS image sensor with 34.8Gb/s readout," ISSCC Dig. Tech. Papers, pp. 420-422, Feb., 2011.
[2] T. Watabe, et al., "A 33Mpixel 120fps CMOS image sensor using 12b column-parallel pipelined cyclic ADCs," ISSCC Dig. Tech. Papers, pp. 388-390, Feb., 2012.
[3] F. Tang, et al., "Low-power CMOS image sensor based on column-parallel single-slope/SAR quantization scheme," IEEE TED, V. 60, No. 8, Aug. 2013.

Conclusion and Future Work

- QIS addresses some shortcomings of SOA cameras; incl. photon counting, high resolution, post capture pixel definition, HDR, TDI
- One of the challenges: high-speed and low-power readout circuits;
- 1Mega pixel, 1000fps single-bit QIS designed and tested, reasonable power consumption achieved;
- Partial 1Giga pixel, 1000fps pathfinder QIS imager has been designed, in test phase.

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