Challenges of ADC design for CMOS image sensors

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Evolution of Image Sensor Technology*

*Source: Yole Development (2012)
Image sensor Architecture for Mobile Application

Samsung published design (2010):*
- 8 Mpixel
- 90 nm technology
- 1.4 μm pixel size
- 2.5 Transistor pixel (2-shared 4T pixels)
- Linear 110 μV/e- conversion
- 4100 e- full well capacity
- 10/12 bit resolution
- Dual CDS

* Lim et al. “A 1.1e- Temporal Noise 1/3.2-inch 8Mpixel CMOS image sensor using pseudo-multiple sampling” - ISSCC 2010
Column Parallel ADC Architecture

- APS (~1M)
- CDS (~1K)
- DBUS (~1K)
- APS LOAD (~1K)
- RAMPGEN (1)

Diagram showing thecolumn parallel ADC architecture with components labeled and connections highlighted.
Back Side illumination

Front side Illuminated Imager

Backside Illuminated Imager

- Light collection (fill factor) limited by transistors & metal wiring BEOL

→ Backside illumination enables ~ 100% Fill-factor, open the window area of CMOS sensor to:
- Higher Sensitivities
- or Higher Resolution

*Source: Yole Development (2013)
Stacked Sensor

Separate chips for pixel array and analog/digital circuitry.

Advantages:

✓ Optimal process for circuitry
✓ Noise isolation
✓ Reduced area
✓ Flexibility in development.
✓ No need for supporting substrate.

*Source: Sukegawa et al. (Sony) ISSCC 2013
Global Shutter

CMOS image sensor typically utilize an electronic rolling shutter. This means that each line of pixels is exposed at a slightly different time than other lines.

Global shutter can be achieved by adding a memory node within the pixel. However, this requires a larger pixel than standard 4T pixel and its performance is limited by leakage currents and light “contamination” (*Global Shutter Efficiency*).

*Sources: Aptina 2012, CMOSIS 2008*
Wide Dynamic Range

Typical CMOS image sensors provide dynamic range of about 60dB. For many applications, including automotive, security, a wider dynamic range is required.

Possible solutions:
- Logarithmic, lin-log, or piecewise linear pixel response.
- Multiple readout from pixel.
- Smart reset pixels
- Interleaved patterns
- Multiple exposure patterns

*Source: CMOSIS 2008
Example*: A White-RGB CFA-Patterned CMOS Image Sensor with Wide Dynamic Range

- White color filter used to increase low light sensitivity.
- Single-frame double exposure is used to increase dynamic range with low image lag.
- Processing algorithms are used to separate W data to RGB and to merge and compress the short and long exposure data.
- This kind of technology is aimed at mobile applications, adding about 20dB to DR.

* Egawa et al. (Sony) - ISSCC 2008
Non-vision sensors

• As CMOS cameras become cheaper, they are increasingly used for non-vision applications.
• In these applications, the image quality requirements may be different from current cameras, while other metrics, e.g. power consumption, area, or IR sensitivity become critical.
• Some random examples:
   Automotive: Headlight control, Traffic sign recognition, Obstacle recognition, Lane departure, Black box recorder, Adaptive cruise control, Driver recognition, Driver drowsiness monitoring
   Human interface: Gesture recognition, Proximity detector, Distance measurement, Light sensor, Face detection, Eye tracking
   Security: Heat sensing, Motion sensing, Face recognition, Biometric identification
   Other: Spectroscopy, Machine vision,
Example*: Motion triggered object-of-interest Imaging

- **Motion sensing**, 1-b motion image
- Motion triggered → 8-b feature for the **object detection**
- OOI identified → **Imaging** initiated, 8-b image

* Choi et al. (U. Michigan) - ISSCC 2013
Sensor Arrays

Advantages:

✓ Uses standard pixel architecture
✓ Depth of field
✓ No auto-focus required
✓ Power
✓ Thin modules
✓ Dynamic range
✓ Low light performance

But, requires sophisticated computation for image reconstruction!

*Source: Pelican Imaging
3D Imaging

6 Technologies currently commercialized

3D camera

Single sensor
- Triangulation methods
  - Structured light camera
  - Laser triangulation
  - Plenoptic camera

Multiple sensors
- Interferometric camera
- Time-Of-Flight (TOF) camera
- Passive stereoscopic camera

*Source: Yole Development (2012)