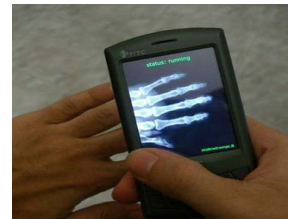

Noise in Image Sensors



Noise in Image Sensors

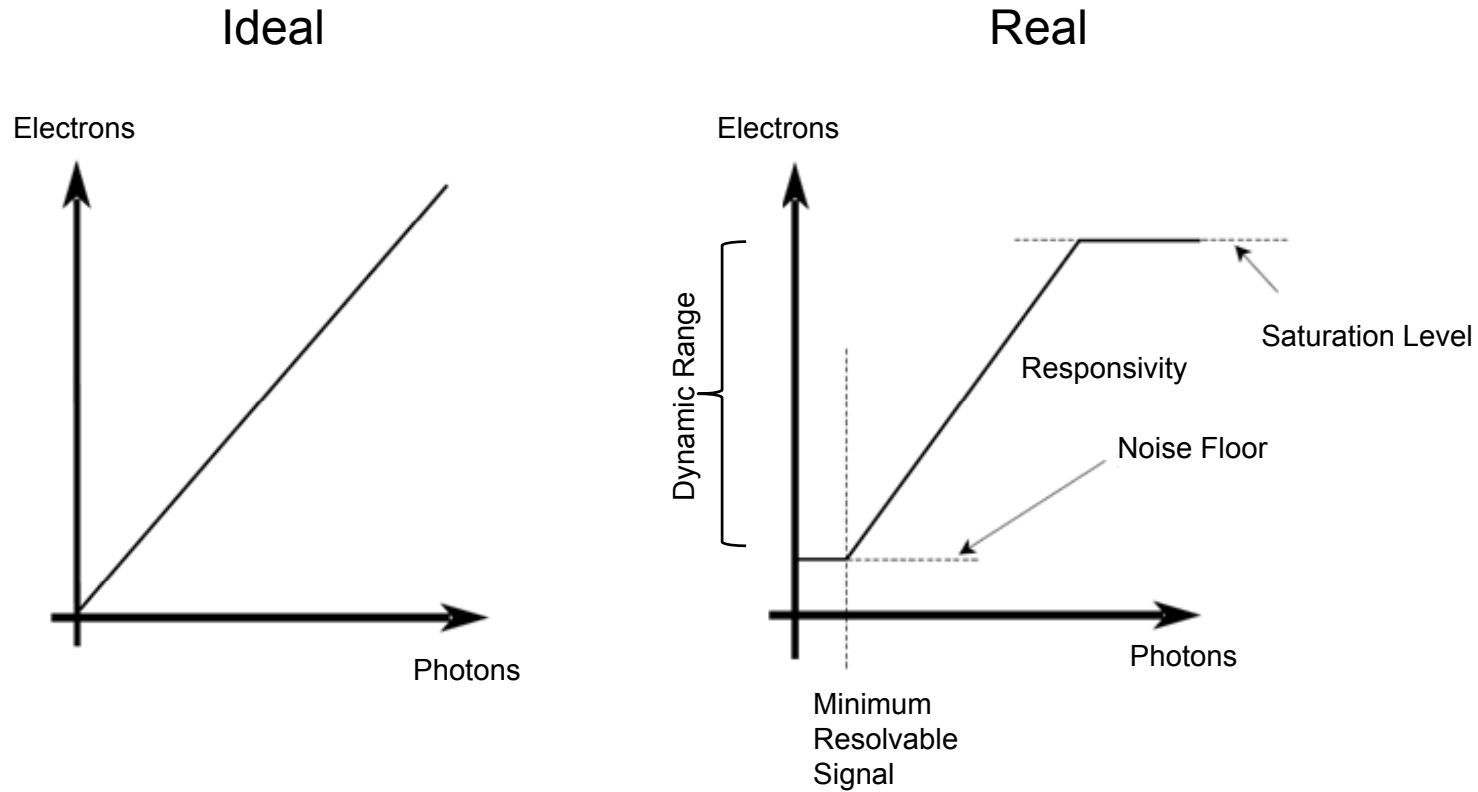
Characteristics of ideal Image Sensors

- No sensor noise
- Infinite dynamic range
- High (spectral) responsivity
- Infinite high frame rate
- Infinite number of pixels
- Zero energy consumption
- Low manufacturing cost



Noise in Image Sensors

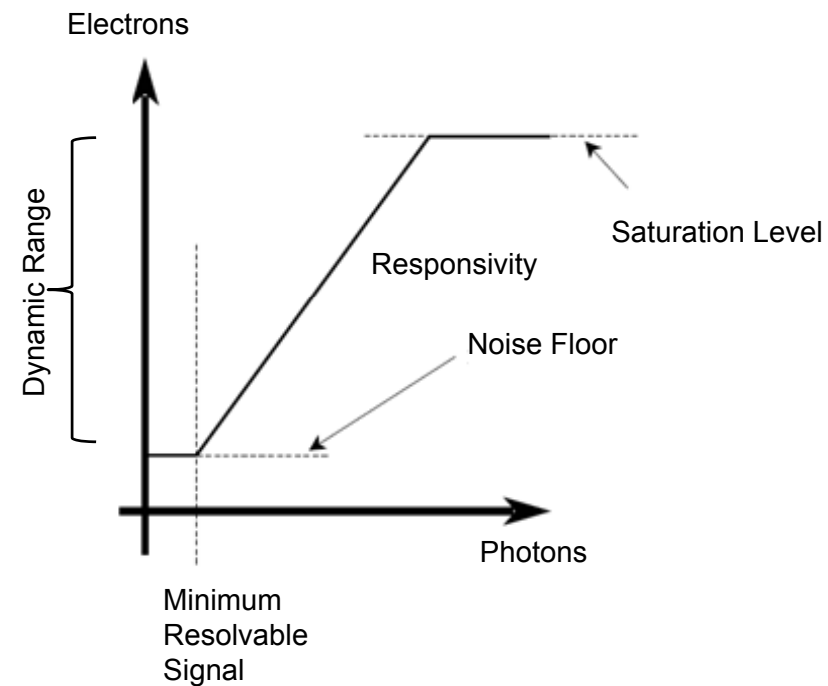
Characteristics of ideal and real Pixel Cells



Noise in Image Sensors

How does Noise effect Dynamic Range

- Ratio of maximum signal to minimum detectable signal.
- What is the maximum signal?
 - Full-well capacity (electrons)
 - Saturation signal (mV)
 - Saturation illumination at a specific exposure time
- What is the minimum signal?
 - Noise floor electrons
 - Noise equivalent illumination
 - Minimum illumination



Noise in Image Sensors

Perception of Noise

- Perception based differentiation of noise in image sensors:
 - Random noise: Location and time of occurrence not predictable
 - Fixed pattern noise (FPN): Occurrence is location based due to underlying structure
- Perception in still imaging:
 - Underexposed images contain more visible noise due to proximity to noise floor
 -
 - Random noise averaged by eye (perceived amplification at 5fps)
 - Stationary noise more noticeable (dark FPN, pixel FPN, column FPN)
 - Line noise or column FPN level noticeable at above 0.5% RMS
 - Random noise of 5% RMS barely visible
 - Noise less noticeable at high temporal frequency
 - Noise less noticeable at high spatial frequency



Noise in Image Sensors

Perception of Noise – Random Noise



10% Pixel Random Noise [1]



Noise in Image Sensors

Perception of Noise – Random Noise



25% Pixel Random Noise [1]



Noise in Image Sensors

Perception of Noise – Fixed Pattern Noise



0.5% Column Fixed Pattern Noise [1]



Noise in Image Sensors

Perception of Noise – Fixed Pattern Noise



2% Column Fixed Pattern Noise [1]



Noise in Image Sensors

Perception of Noise

Noise:

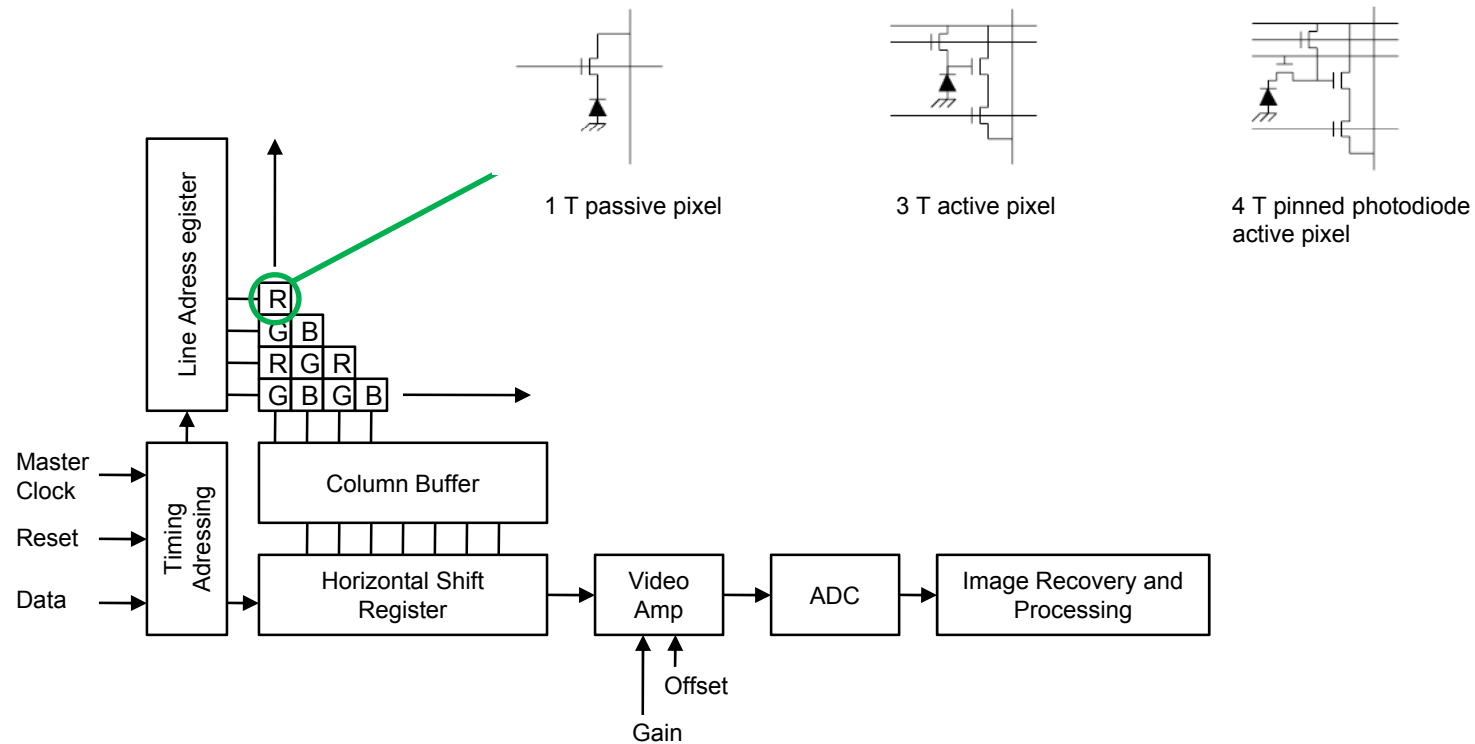
- Random noise
- Fixed pattern noise:
 - DSNU - Dark Signal Non-Uniformity
 - DSNU is seen as an offset between pixels in dark
 - Corrected by subtracting a dark frame
 - Measured in the absence of light
 - PRNU - Pixel Response Non-Uniformity
 - PRNU is seen as a responsivity variation between pixels under illumination
 - Corrected by offset and gain for each pixel (which is mostly done off-chip)



Noise in Image Sensors

Recapitulation Structure of Image Sensors (CMOS)

Underlying structure determines parameter value of noise

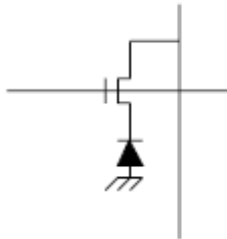


[1]



Noise in Image Sensors

Underlying Structure determines Parameter Value of Noise (CMOS)



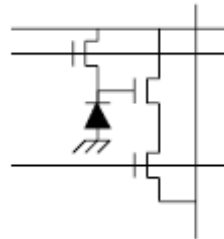
1 T passive pixel

Advantages:

- Simple addressing
- High fill factor (cheap sensor high pixel count)

Disadvantages:

- Small output swing (bigger noise)
- Low Signal Noise Ratio



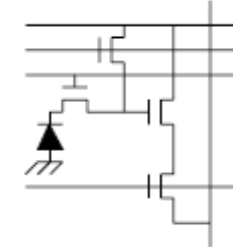
3 T active pixel

Advantages:

- High Signal-Noise-Ratio

Disadvantages:

- Smaller fill factor
- More complicated addressing
- Source follower adds FPN and V_t drop



4 T pinned photodiode active pixel

Advantages:

- High Signal-Noise-Ratio
- No kT/C noise
- Low dark current

Disadvantages:

- Smaller fill factor
- More complicated addressing
- Source follower FPN and V_t drop

Pixel cell designs are often patent pending, above examples refer to VLSI Online (left), Lucent (center), Kodak (right).

[1]



Noise in Image Sensors

Overview

- Temporal Noise
 - Photon shot noise
 - Dark shot noise (leakage current, maximum at hot pixels)
 - kT/C reset noise (thermal noise in capacitors)
 - Thermal noise
- Spatial Noise
 - Dark FPN
 - Pixel source-follower FPN (offset and gain)
 - Column FPN (offset & gain)
- System Noise
 - ADC quantization noise
 - Line noise / crosstalk



Noise in Image Sensors

Summary sources of interference

Effect	Technology	Design	Bigger Pixels!
Dark Current	YES	NO	-
Uniformity	YES	NO	-
Defectivity	YES	YES	-
FPN	YES	YES	-
kTC noise	YES	YES	-
Photon Shot	NO	NO	YES



Noise in Image Sensors

Questions?



Noise in Image Sensors

Literature

- [1] CMOS Image Sensor Design, Robert Henderson (2001)
- [2] Noise in Image Sensors, R.I. Hornsey

