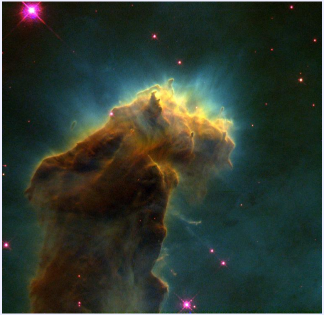
Outline

1. CCD Review
2. CMOS and CMOS Hybrid Detectors
3. Array Detector Properties
4. Array Detector Data Reduction
5. Array Detector Problems



hubblesite.org

Charge Coupled Device (CCD)

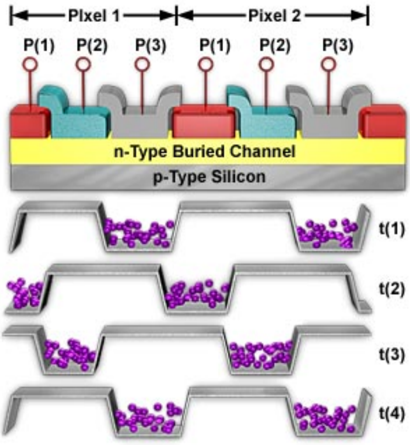


Figure 1

imagingu.com/articles/threephase.html

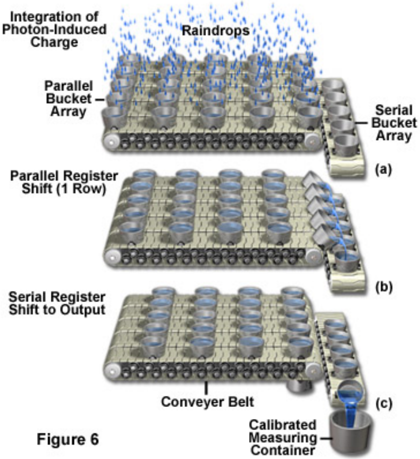
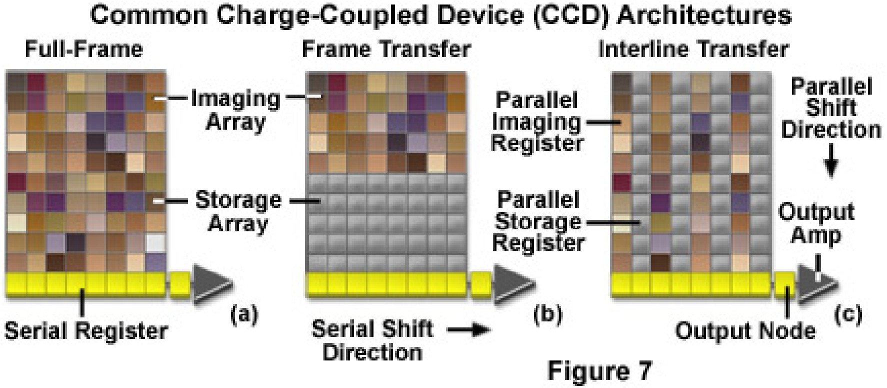


Figure 6

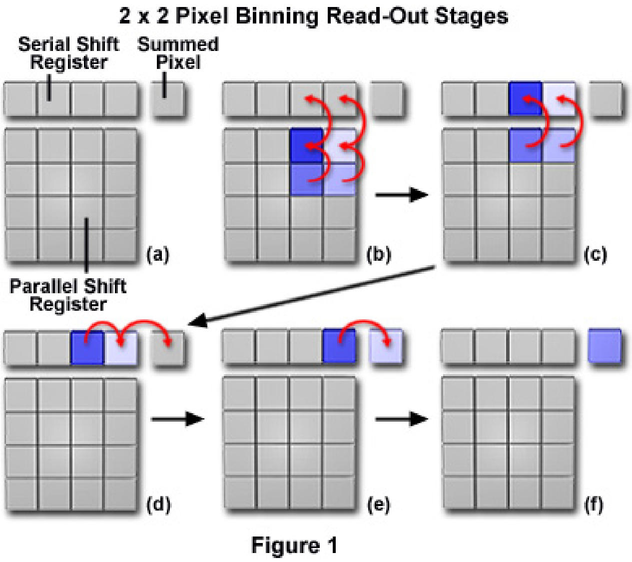
imagingu.com/articles/microscopyimaging.html

CCD Readout Architectures



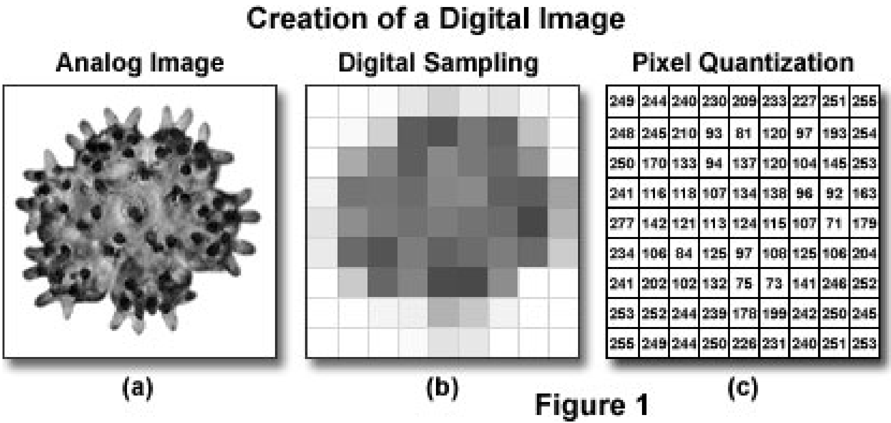
imagingu.com/articles/microscopyimaging.html

Binning



imagingu.com/articles/binning.html

Digital Imaging



imagingu.com/articles/digitalimagebasics.html

CMOS and CCD Pixels

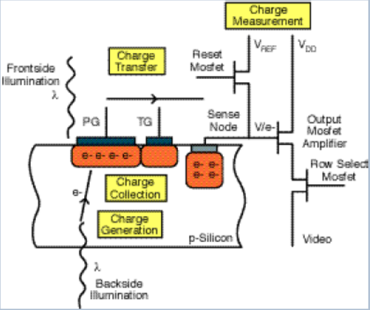


FIGURE 1 A cross-section of a CMOS pixel shows the four major functions required to generate an image.

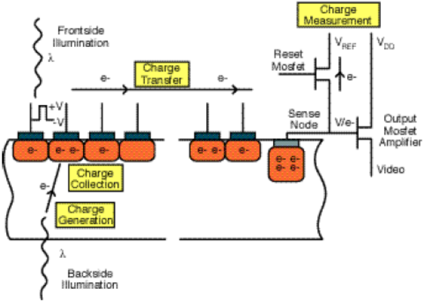
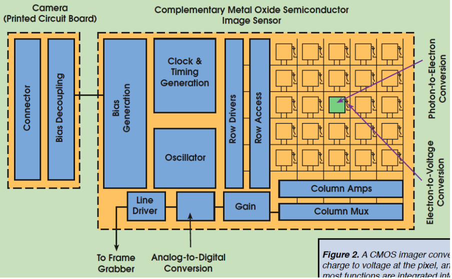
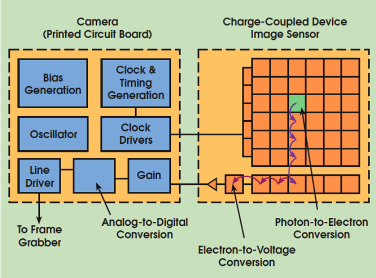


FIGURE 2 A cross-section of a CCD pixel shows the four major functions required to generate an image.

www.dalsa.com/shared/content/OE_Magazine_Dueling_Detectors_Janesick.pdf

CMOS and CCD Cameras



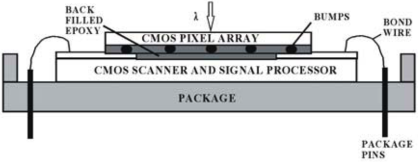


www.dalsa.com/shared/content/Photonics_Spectra_CCDvsCMOS_Litwiller.pdf

CMOS vs. CCD

- CMOS advantages over CCD:
  - standard semiconductor processing
  - low power consumption ($\approx$ 1% of CCD)
  - random access to regions of interest
  - blooming and streaking much reduced compared to CCDs
  - additional electronics can be integrated on chip and in pixel (smart sensor)
  - non-destructive readout
- CMOS disadvantages:
  - small geometric fill factor (microlenses can help)
  - typically larger read noise

CMOS Hybrid Detectors



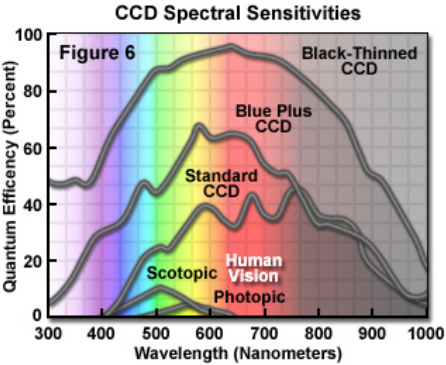
- combine CMOS readout multiplexer bonded to a photosensitive material layer pixel by pixel
- combines sensitivity of CCD with CMOS readout flexibility
- can also use HgCdTe or InSb for infrared sensitivity
- disadvantages:
  - expensive due to pixel-by-pixel bonding
  - differential thermal expansion of materials
  - image lag

Array Detector Properties

Overview

- quantum efficiency
- bias
- dark current
- flat field

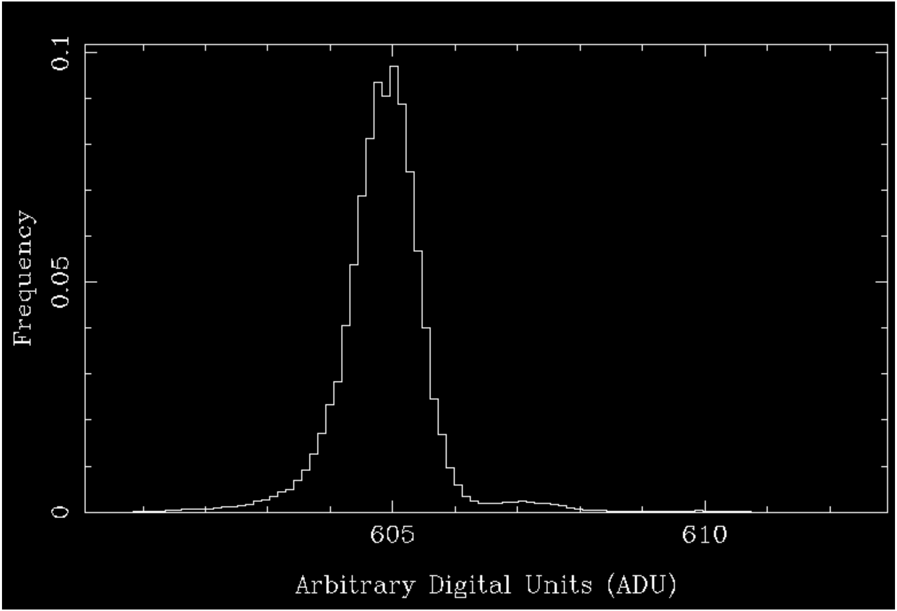
Quantum Efficiency



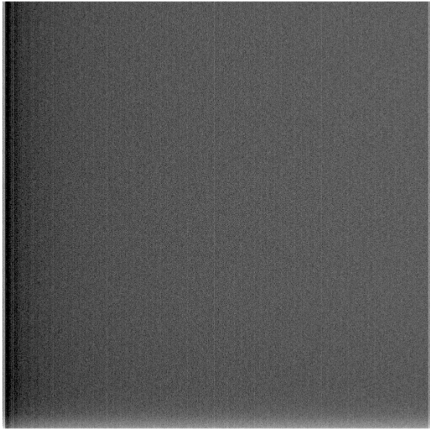
imagingu.com/articles/microscopyimaging.html

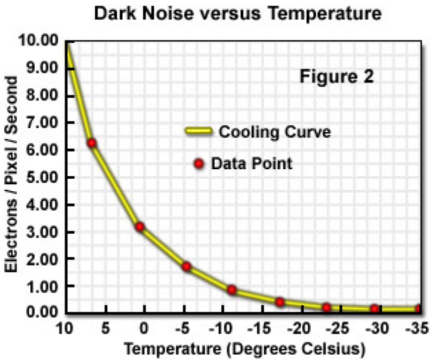
- quantum efficiency: conversion of photons ⇒ electrons
- absorption: avoid opically dead structures above or within pixel
- reflection: 70% loss at 250 nm without anti-reflective coating
- transmission: no photons generated in photosensitive volume (problem in near-infrared and soft X-rays)

Bias



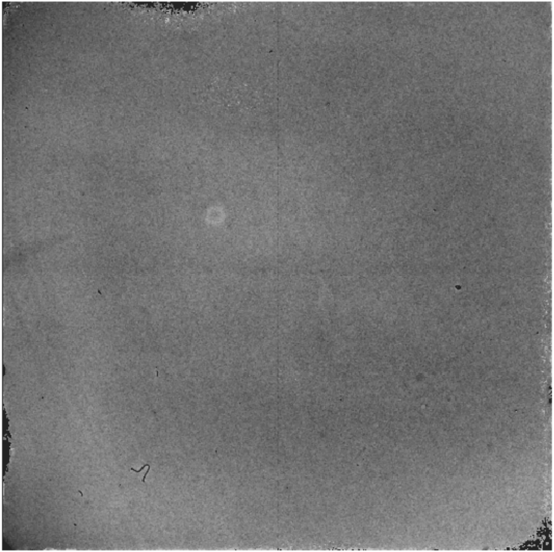
Dark Current





imagingu.com/articles/ccdsnr.html

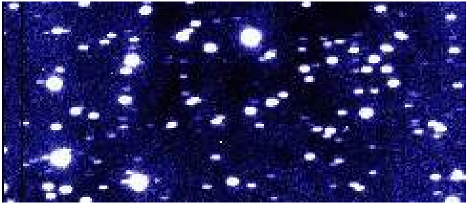
Flatfield



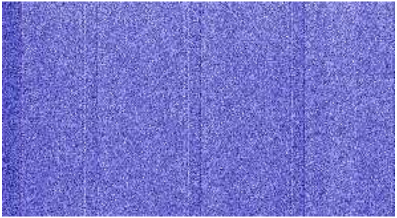
http://www.not.iac.es/instruments/notcam/sci-grade-arr.html

Array Detector Data Reduction

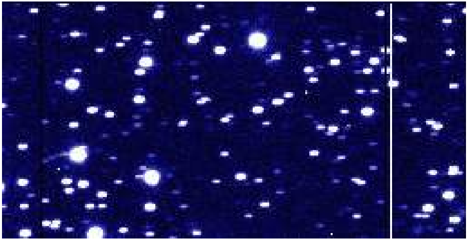
Raw Frame



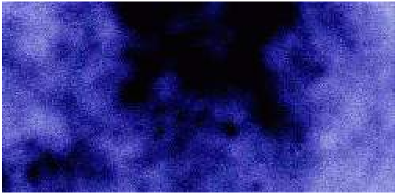
Bias + Dark



Reduced Frame



Flat Field



www.sc.eso.org/~ohainaut/ccd/

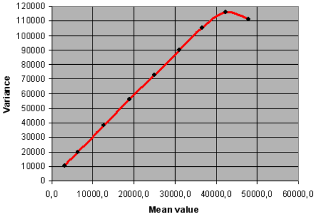
Typical Array Detector Data Reduction

- science frame S, exposure time t_S
- dark frame D, exposure time t_D
- bias frame B, zero exposure time
- flat field frame F, exposure time t_F
- corrected (calibrated) image

$$S' = \frac{S - \frac{t_S}{t_D}(D - B) - B}{F - \frac{t_F}{t_D}(D - B) - B}$$

- $F - \frac{t_F}{t_D}(D - B) - B$ often normalized such that mean of S' = mean of S

Gain, Read Noise, Saturation Determination



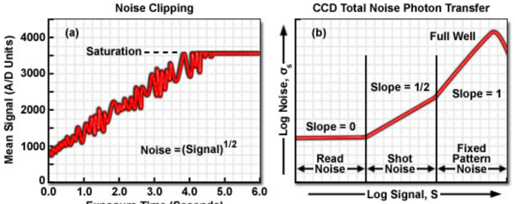


Figure 2

- gain (G) between arbitrary digital units (ADU, A) and number of photo-electrons (e): $A = G \cdot e$
- noise in e is given by $\sigma_e^2 = e$
- and therefore $\sigma_A^2 = G^2 \sigma_e^2 = G^2 e$
- gain G determined from $G = \frac{\sigma_A^2}{A}$

Array Detector Problems: Read Noise

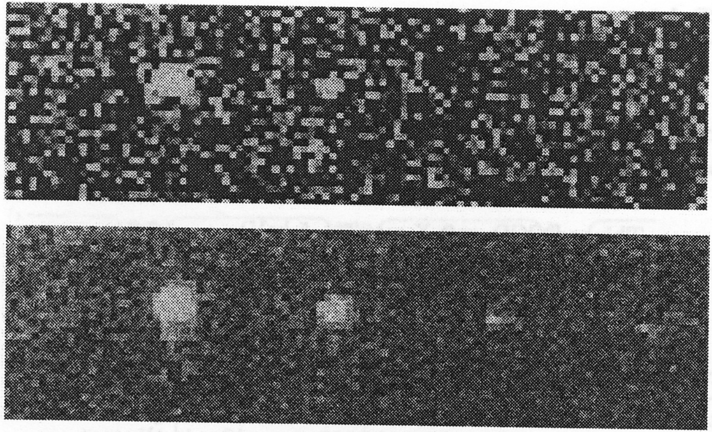
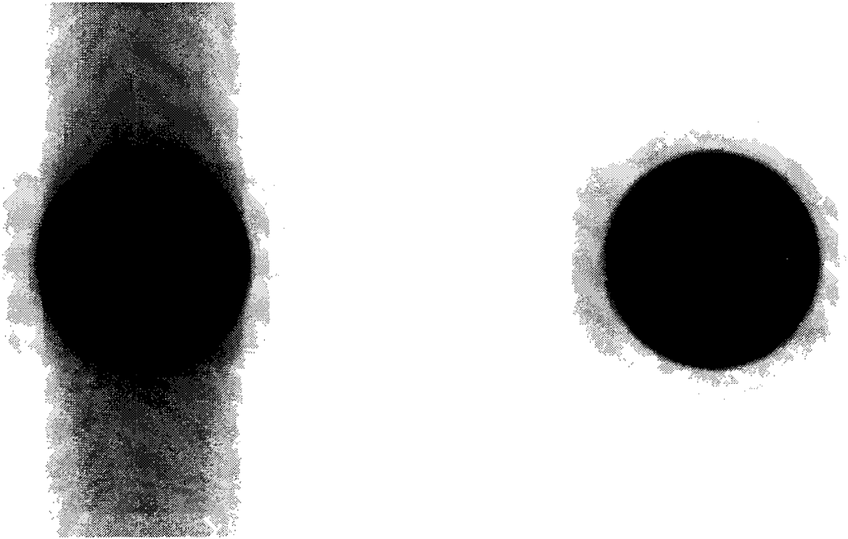


Fig. 7.28. **(a)** Image of four source points, by a CCD with $\sigma_R = 7.6\,e^-$ rms. **(b)** The same image in multiple readout ($N = 64$), where $\sigma_R = 0.97\,e^-$ rms. The faintest source corresponds to a signal of 3.5 photocharges. (After Janesik et al., in *The CCD in Astronomy*, ASP Conf. Ser. **8**, 1989)

Array Detector Problems: Bias Shift



Array Detector Problems: Cross Talk

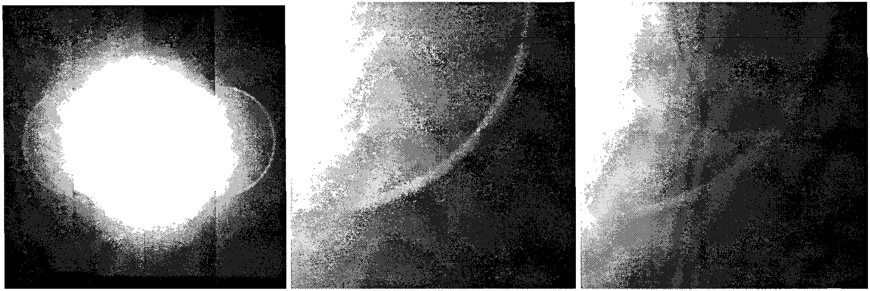


Figure 2: (left) Image similar to Figure 1 except shown in positive contrast and a range from 0 to 0.005 of the maximum illumination level. (center) Detail of left image channel 4 exposed at low light level. (right) Detail of channel 4 exposed at high light level.

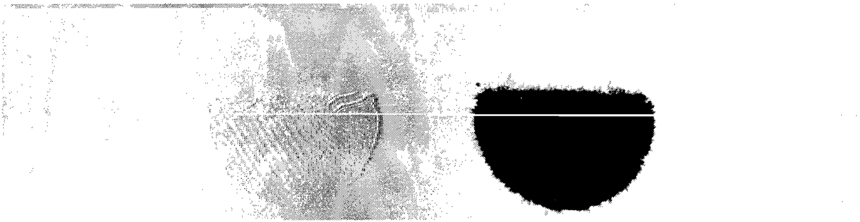
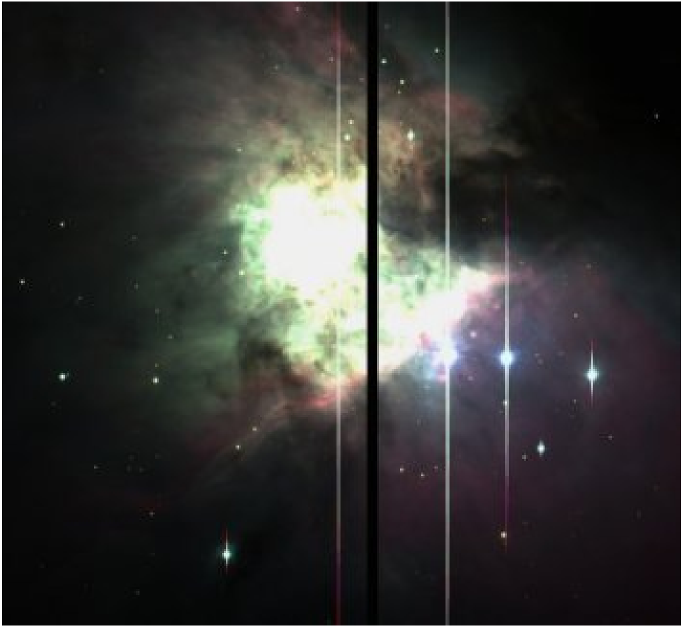
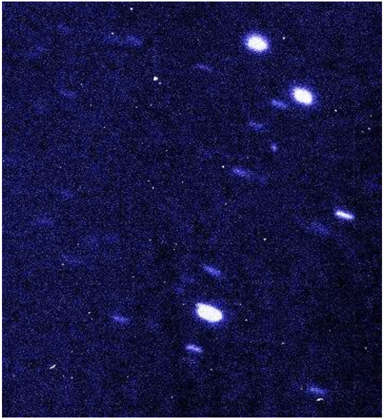


Figure 5: Negative contrast display of cross talk among four quadrants of a Rockwell Scientific Company HyViSI-1024 camera. The

Array Detector Problems: Blooming

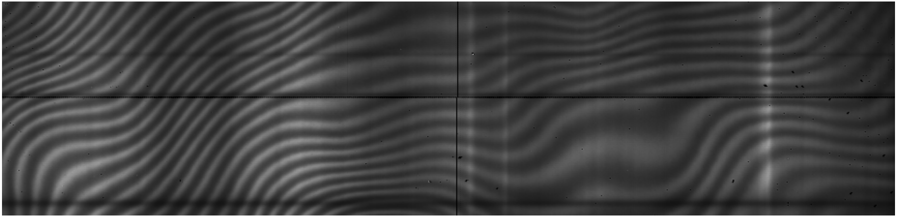


Cosmic Rays



www.sc.eso.org/õhainaut/ccd/CCD_artifacts.html

Array Detector Problems: Fringes



Other Array Detector Problems

- photon (shot) noise
- dark current noise; dark current is reduced by factor of 2 for every 7 K of cooling
- non-linearity of electronic amplification
- image lag