Detection of Light

See http://www.strw.leidenuniv.nl/~brandl/DOL/Detection_of_Light.html for more info

CCDs

C. Performance: CTE

Charge Transfer Efficiency (CTE)

High CTE = transfer all charges

Poor CTE = blurring of the image (charges trailing behind)

Time-dependent mechanisms that influence the CTE:

1. Electrostatic repulsion causes electrons to drift to the neighbouring electrode with time constant for charge transfer τ_{SI}.
2. Thermal diffusion drives electrons across the storage well at τ_{th}.
3. "Fringing fields" due to dependency of the well on the voltages of neighbouring electrodes (τ_{ff}).

For a properly designed CCD with partially filled wells: $\tau_{th} \gg \tau_{SI}, \tau_{ff}$
Hence, electrostatic repulsion and fringing fields will dominate.

Approximation for the CTE of a CCD with m phases: $CTE = \left(1 - e^{-t/\tau}\right)^m$

Noise from Charge Transfer

Noise from charge transfer inefficiency: $\varepsilon = (1\text{-}CTE)$

A total of εN_0 charges are "left behind" and the noise on them is $(\varepsilon N_0)^{1/2}$ in each transfer.

In n transfers the net uncertainty is $N_{n,TL} = \left(2\varepsilon n N_0\right)^{1/2}$

Noise from trapping of charge carriers in incomplete bonds in the Si-SiO_2 interface. Traps will be occupied in equilibrium, but subject to statistical fluctuations with noise $N_{n,T} = \left(2kTnN_{SS}A\right)^{1/2}$

(N_{SS} is the density of traps, and A the interface area)

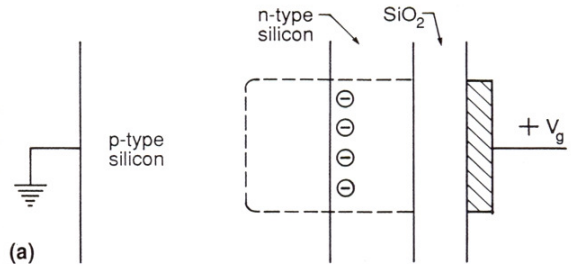
Buried Channel CCDs

A way to reduce the noise from trapping of charge carriers.

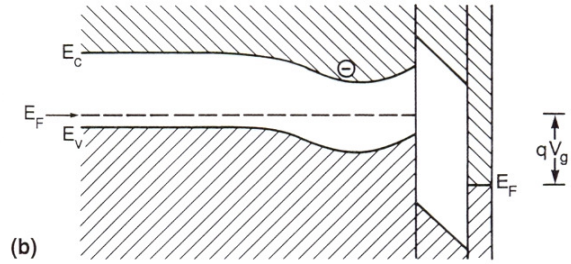
→ Modify CCD structure to keep charges away from the SiO_2 layer → buried channel CCD.

Achieved by adding a 1µm thick n-type doped Si layer between p-type Si and SiO_2.

The two layers form a junction *(see Rieke book p. 165-168 for a detailed discussion).*



Another advantage of buried channel CCDs is, that the distance between electrode and well can be increased above 0.1µm to reduce fringing fields.



Side note:

GAIA and CTE

GAIA: Required Centroiding

Gaia requirements for end of mission parallax standard errors (G2V)

V	10	15	20
μarcsec	7	24	300
pixels in focal plane	1.2×10^{-4}	4.1×10^{-4}	51×10^{-4}

Assuming that each object is observed 75 times in 9 CCDs (= 675 CCD transits), then the residual centroiding error per CCD transit is equivalent to…

V	10	15	20
pixels in focal plane	0.003	0.011	0.13

GAIA: Radiation Damage ⇔ PSF

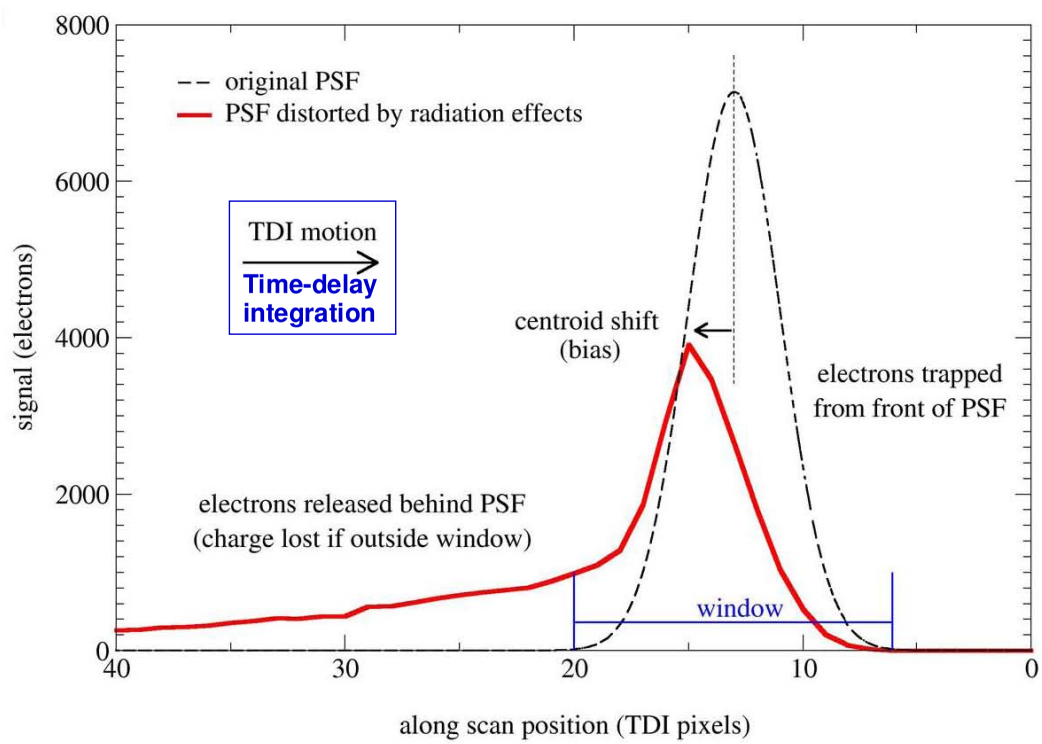
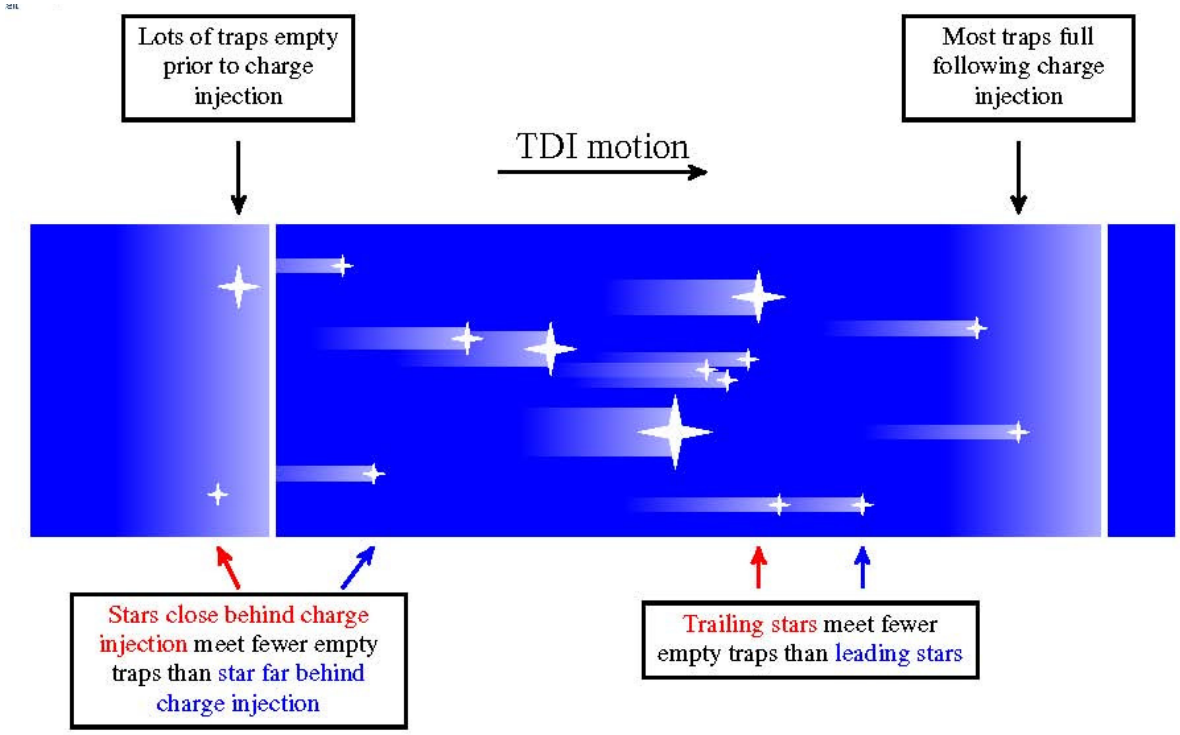


Figure courtesy of Alex Short, ESA

GAIA: Radiation Damage (2)



Using "charge injection" to get rid of traps.

Side note:

End

CCDs

D. Variants and other types of CCDs

CCDs at λ<0.3μm

1. Extremely short photon absorption lengths → charge collection problems

2. Many "transparent" electrode materials become absorbing

3. Anti-reflection coatings problematic (strong f(λ), and at λ<0.2 μm → n(Si) <1)

4. Specifically developed UV/blue CCDs need a blocking filter for visible light

5. Photons at λ<0.3 μm generate more than one electron → for X-rays the number of free electrons generated is a measure of the energy of the X-ray photon.

Orthogonal Transfer CCDs (OTCCD)

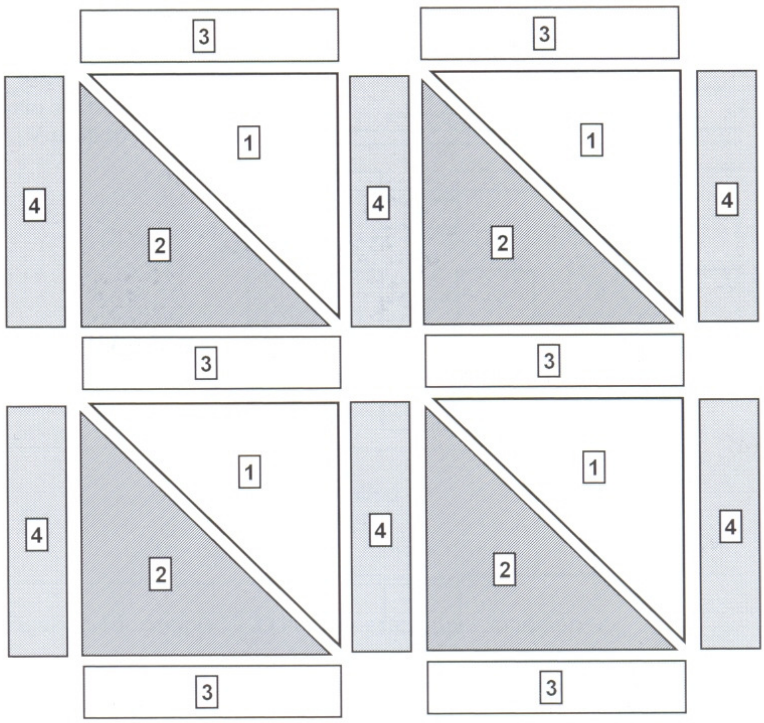
For TDI it would be desirable to move the charges in *any* direction to follow the image motion. This can be done with the OTCCD.

OTCCD operation:

To move a charge to the right, `3' is negative to act as channel stop, `1', `2', and `4' are operated as a conventional CCD.

To move a charge up, `4' is negative to act as channel stop, `1', `2', and `3' are operated as a conventional CCD.

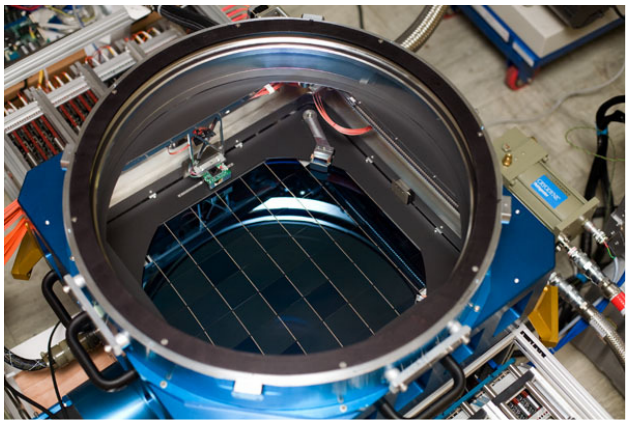
Moving to the opposite directions: reversing the clocking.



Side note: Pan-STARR and OTCCDs

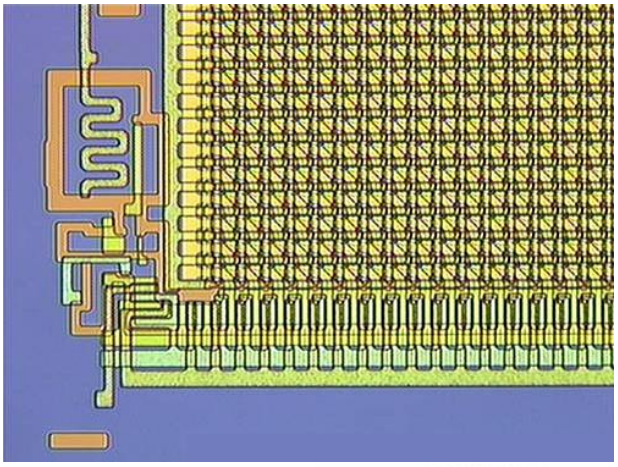
The Panoramic Survey Telescope & Rapid Response System (Pan-STARRS) is a wide-field imaging facility that will observe the entire available sky several times each month.

Scientific goal: to discover and characterize Earth-approaching objects, both asteroids & comets, that might pose a danger to our planet.

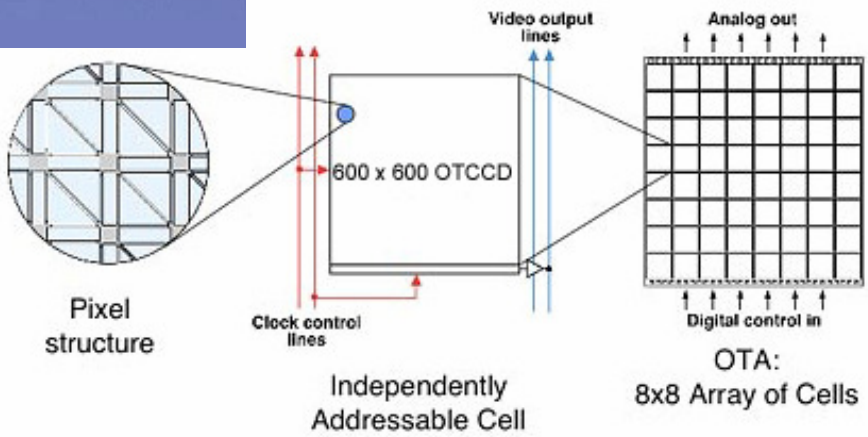


Pan-STARRS combines four 1.8m telescopes with the largest digital cameras ever built. Each camera has a 64 x 64 array of CCD devices, each containing approximately 600 x 600 pixels, for a total of about 1.4 Gpix.

The Pan-STARRS Project (2)



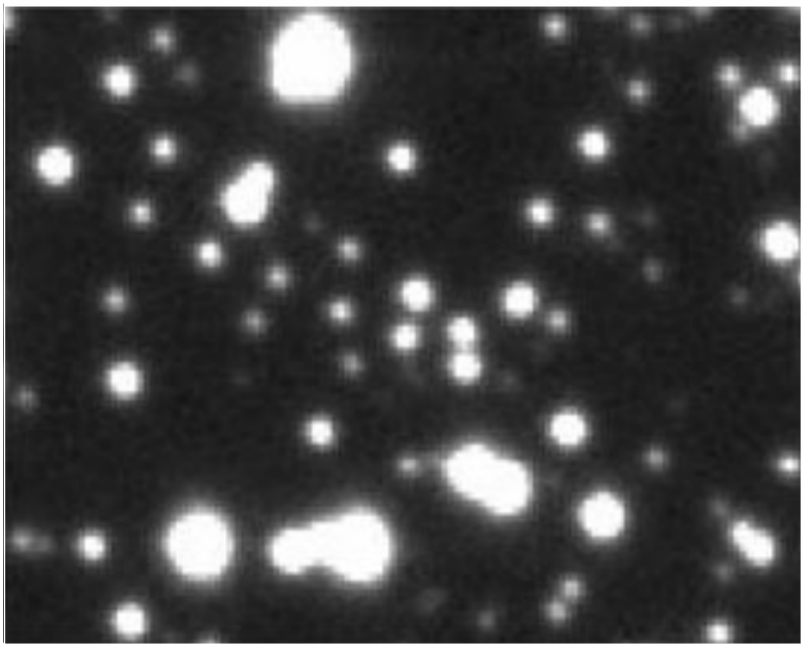
Key-element: uses an Orthogonal Transfer Charge Coupled Device (OTCCD) to compensate for seeing induced image motion.



The Pan-STARRS Project (3)

Gain: significantly improved resolution and sensitivity.

Similar result as with a "tip-tilt" system, but by electronically shifting the image within the CCD rather than by moving a fast mirror.



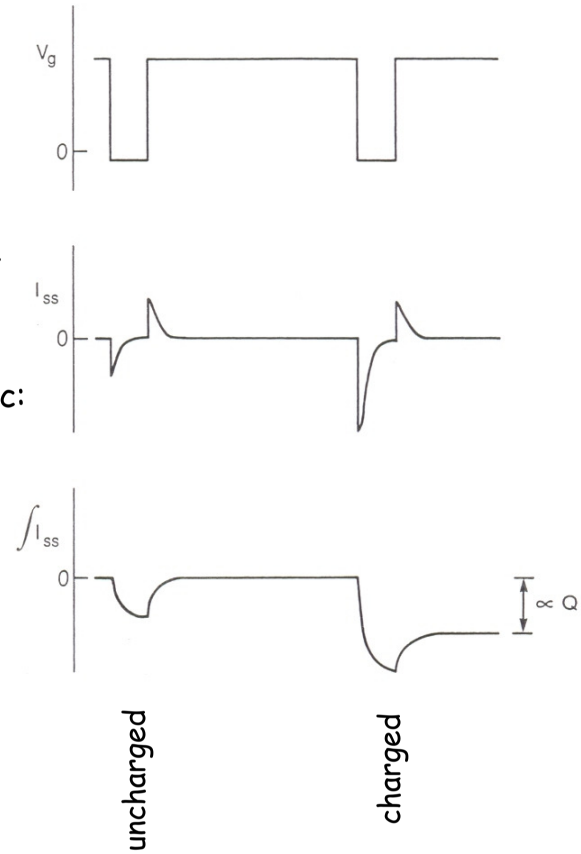
Side note:

End

Charge Injection Devices (CIDs)

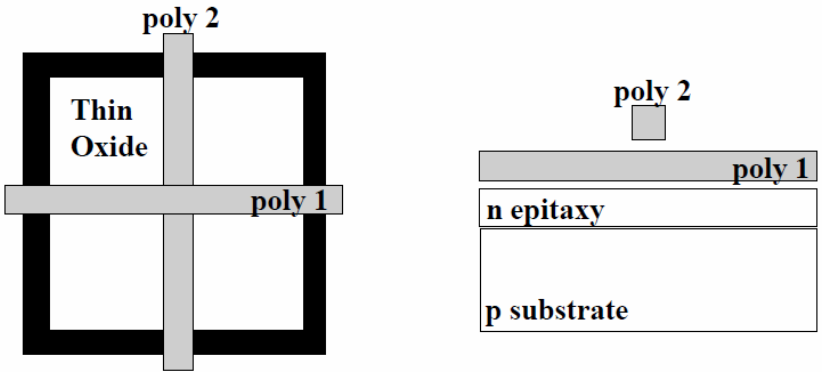
Principle: apply an electric pulse to the capacitor

- if uncharged the response will be symmetric and the integral over the current will be zero
- if charged the waveform will be asymmetric: asymmetry ∝ charge
- → measure integral over I_{SS}



CIDs – Readout

Each pixel consists of a pair of MOS capacitors. The two capacitors run perpendicularly to each other and are known as collection and sense pads



- Random readout of image information is possible
- Nondestructive readout is possible
- Problem: large read noise because an entire row of MOS capacitors is connected at one time.

Taken from a lecture by Dr. L. Fuller, given at RIT – see http://people.rit.edu/lffeee/lec_CCD.pdf

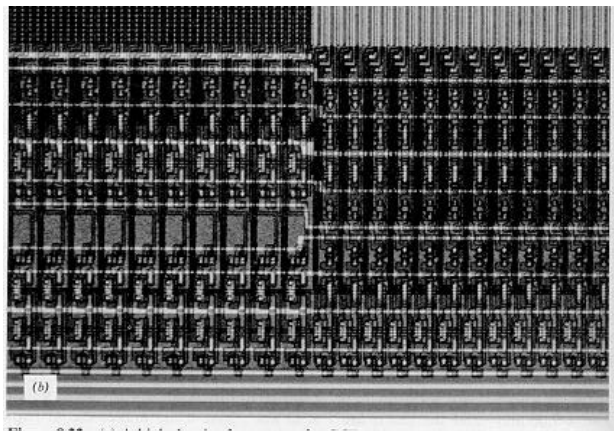
CMOS Imaging Arrays

Nowadays, transistors are tiny and high performance arrays can be manufactured in complementary metal-oxide-semiconductor (CMOS) devices

→ silicon photodiodes + readout circuitry produced on a single silicon wafer (similar to hybrid arrays but in one unit)

- 70 – 80% fill factor ← not great for low-level signals
- < 50 e^- read noise ← not great for low-level signals
- increased fill factors with micro-lens arrays

CMOS advantages:
- much less sensitive to radiation damage
- allow simplified systems design



Color CCDs

Essentially three ways to do it (from Wikipedia):

1. Take three exposures through three filters subsequently – only works for fixed targets (standard for astronomy).

2. Split the input beam in three channels, each with a separate and optimized CCD (*very* expensive cameras).

3. Use a Bayer mask over the CCD – each subset of 4 pixels has one filtered red, one blue, and two green.