Pixel Sensor Noise Sources
Shot Noise

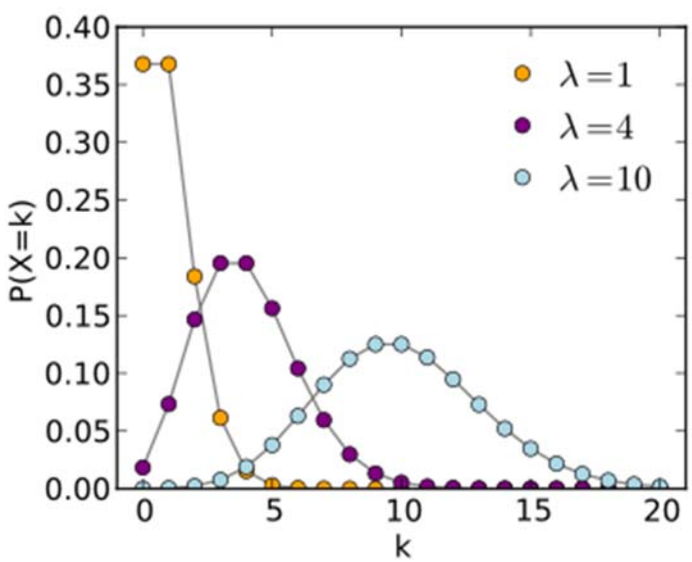
- Comes from random generation of carriers
- discrete nature of electrons or photon (photo current)
- Appears as random fluctuations in current
- Shot noise formula:

$$q_{shot} = \sqrt{\frac{I_{gen} t}{q_e}}$$

- $q_{sho}t$ = noise in electrons (ie stored electons)
- I_{gen} is the generated current (eg photocurrent)
- t = exposure time
- q_e charge on an electron
- Consider photons arriving a λ per sec in a pixel
- Photons follow a Poisson distribution

$$f(k, \lambda, t) = \frac{(\lambda t)^k e^{-\lambda t}}{k!}$$

- k = number of photons
- Eventually looks like Gaussian distribution as k increases

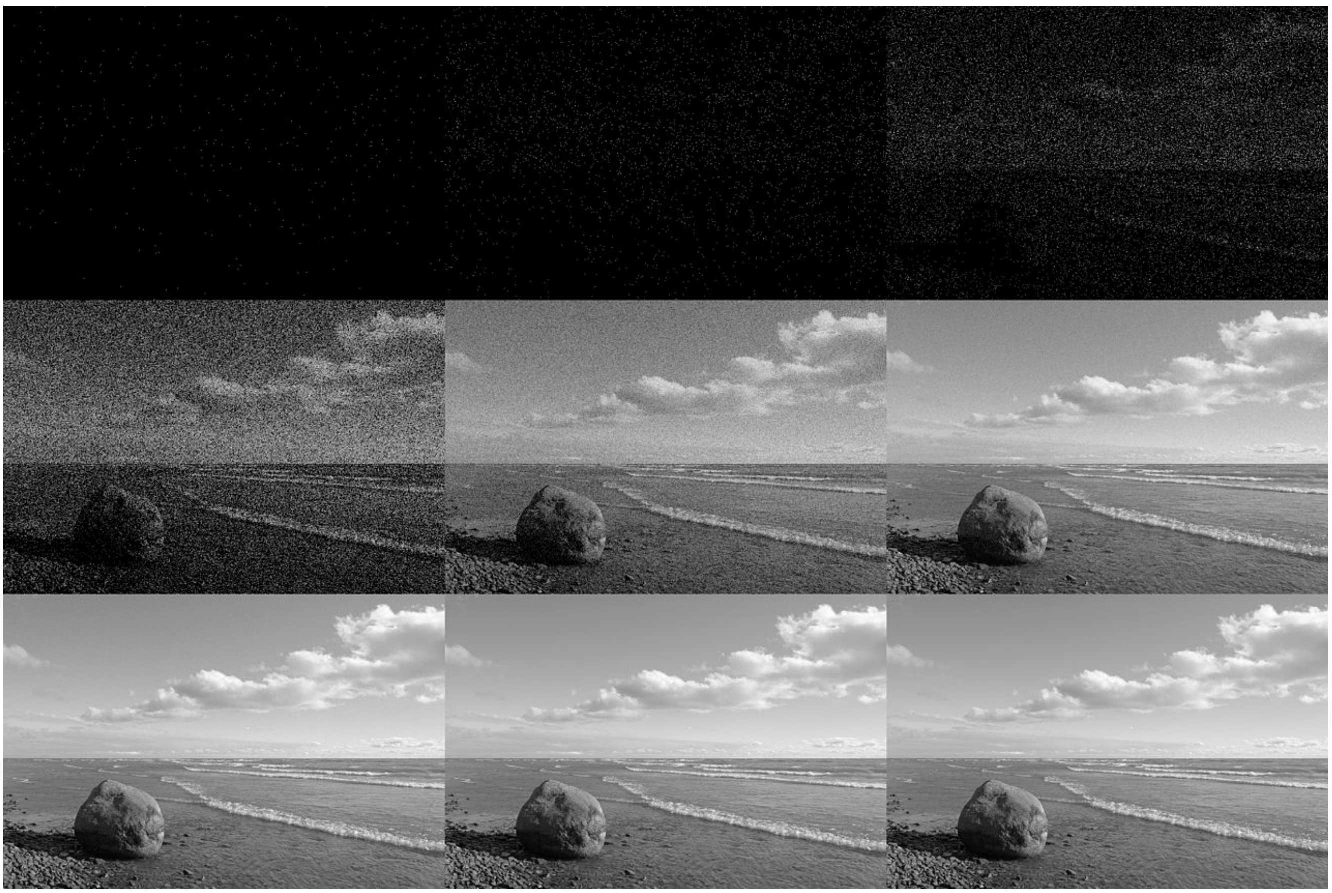


Shot Noise

- Shot noise signal to noise ratio goes with number of photons N

$$SNR = \frac{N}{\sqrt{N}} = \sqrt{N}$$

- Thus as number of light level increase SNR grows larger
- Hence other noise sources dominate
- 2 sources of noise in APS pixel
- Optical shot noise: variation in photons
- Thermal generation of carriers in the depletion region of PD
- Creates dark current and hence shot noise in it
- Dark current is small so current shot noise is small



Shot noise in image as light level increase

Thermal Noise

- Thermal noise: thermal agitation of electric charge in conductors
- White noise whose power constant over frequencies
- For a resistor thermal noise is:

$$v_{therm} = \sqrt{4kTRN_{BW}}$$

- V_{therm}= root mean square (rms) voltage thermal noise
- k = Boltzman's constant 8.63 ev/K
- T=temperate in Kelvin
- R = resistance in ohms
- Also called Johnson noise or Nyquist noise

Flicker Noise

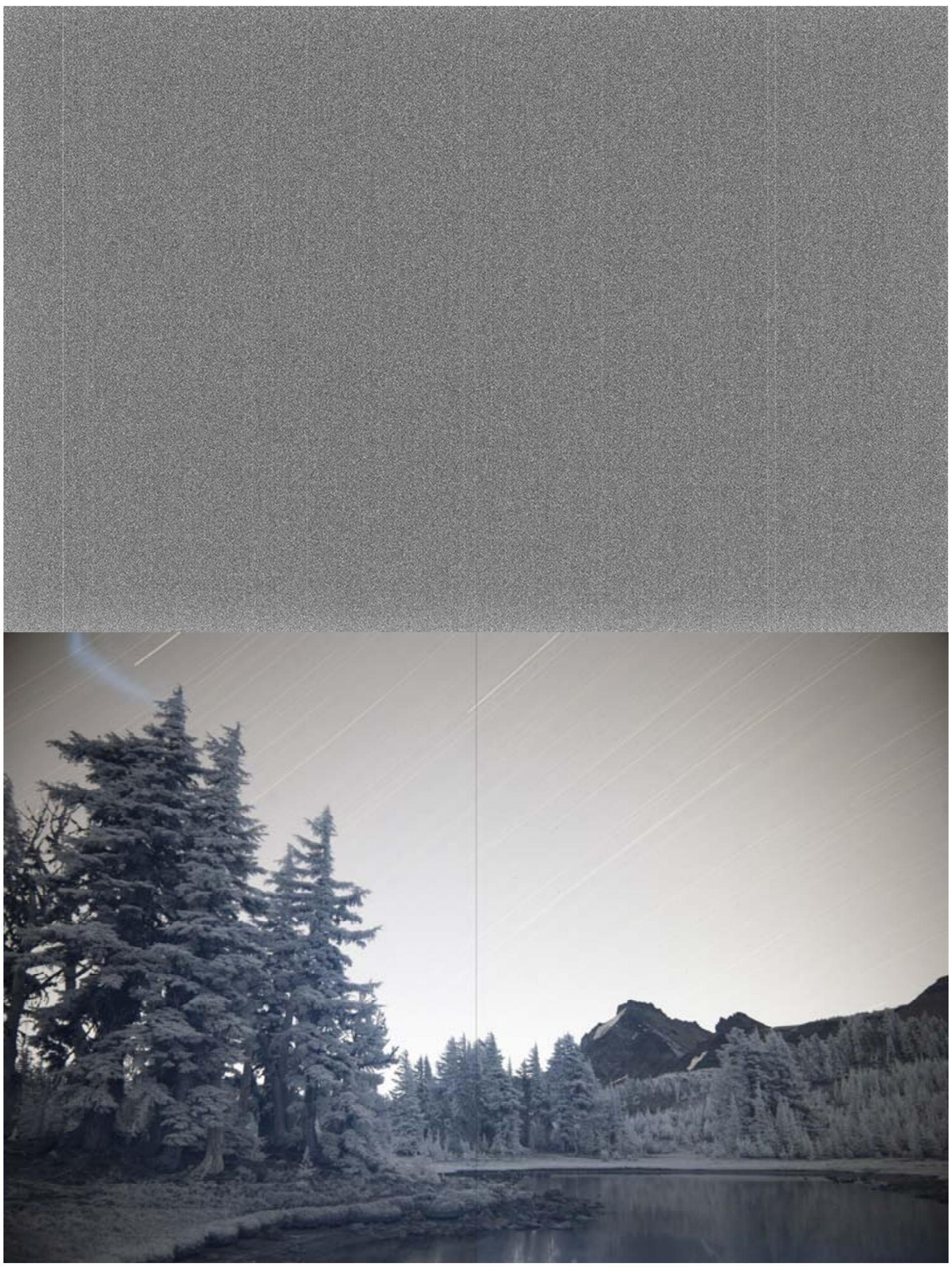
- Flicker noise comes due to semiconductor junctions
- Conductivity fluctuations that occur at a junction due to traps
- Flicker noise has a 1/f dependence
- Dominate at low frequencies
- Flicker rms current i_{flick} related to DC current
- Equivalent noise bandwidth is

$$i_{flick} \propto I_{DC}\sqrt{\frac{N_{BW}}{f}}$$

- I_{dc} is the DC current
- In APS trapping and de-trapping of electrons mainly
- Occurs at the Si-SiO_2 interface (ie top of photodiode)
- To minimize transistor flicker noise in transistors,
- Reduce the device area or
- use a buried channel device reducing Si-SiO_2 interface are
- APS already uses small transistors
- Often cannot use buried channel devices.

Long Exposures: Dark Frame Subtraction

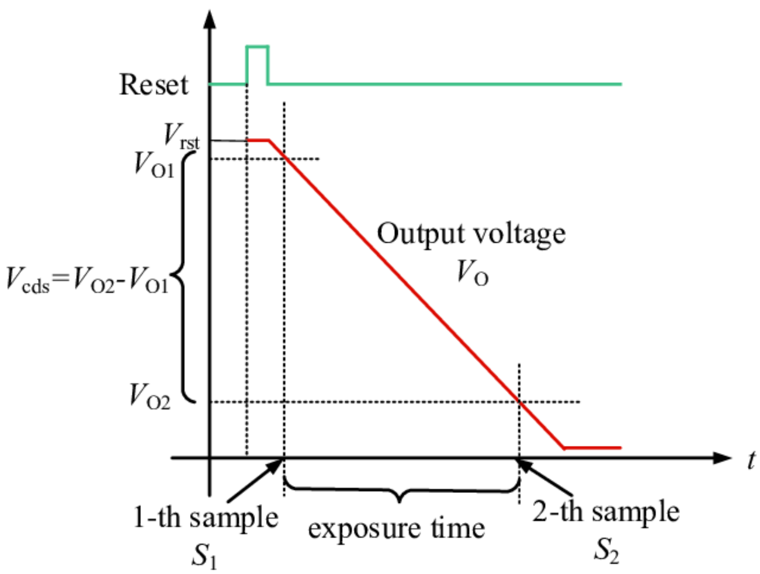
- For long exposures can minimize noise by dark frame subtraction
- Usually useful in exposures longer than several seconds
- Take the exposure with illumination for time t
- Take same exposure for time t but no illumination
- Subtract two images
- Many DSLRs do this automatically for exposures of >2s

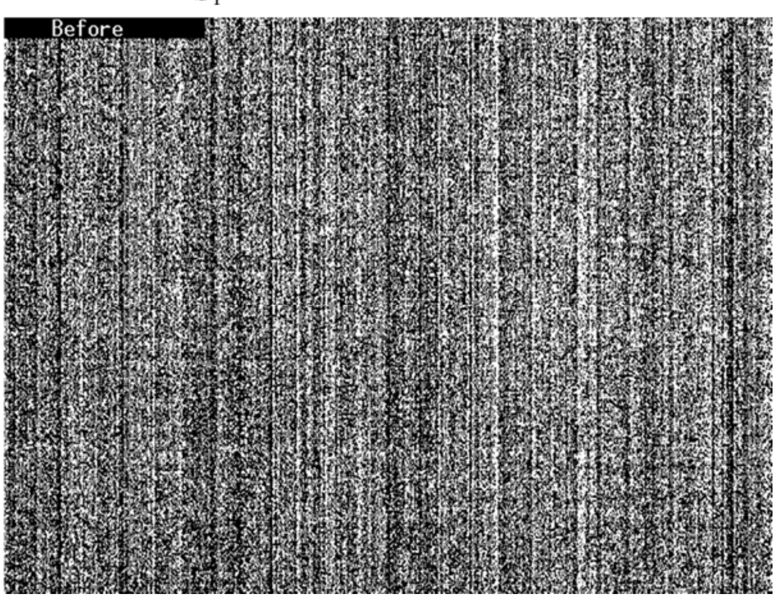


Dark image subtraction on left half

Correlated Double Sampling

- Problem is that each Pixel resets to a different level
- Do a reset and sample image
- Store this value (sometimes in capacitor)
- Then do exposure and record photo value
- Subtract the values
- Reduces fixed pattern noise
- Eliminates DC offset from pixel
- (sometimes done at end of cycle)

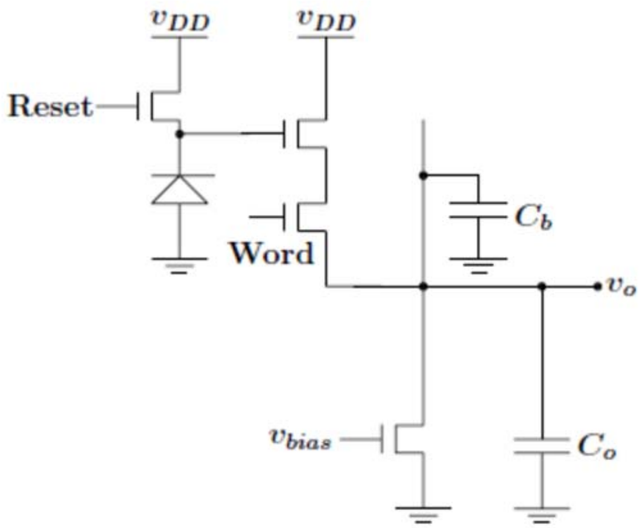




Correlated Double Sample Capacitanc

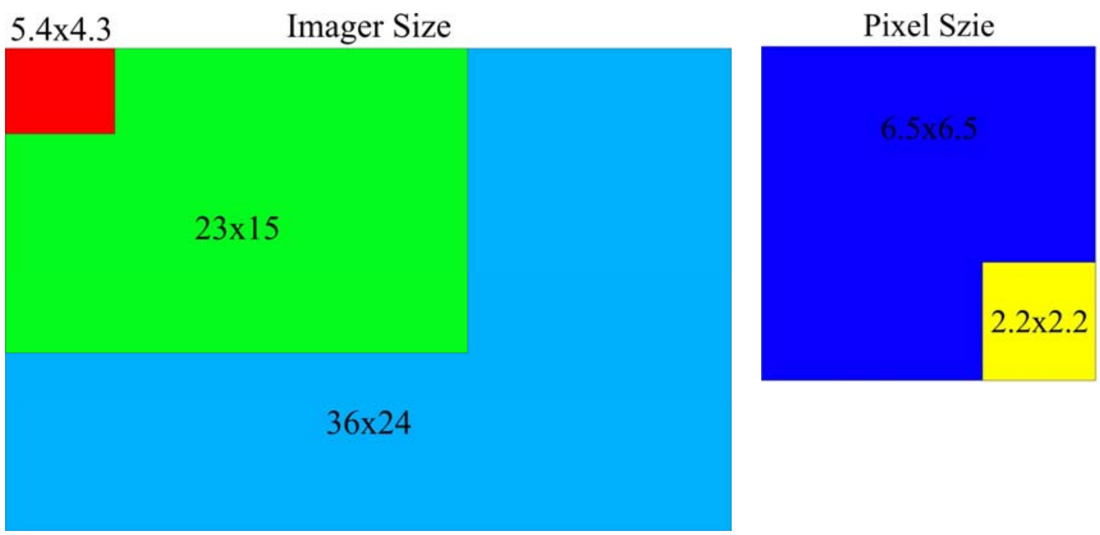
- Sometimes store reset in a capacitor in column
- Does require that take picture and readout row by row

Colour



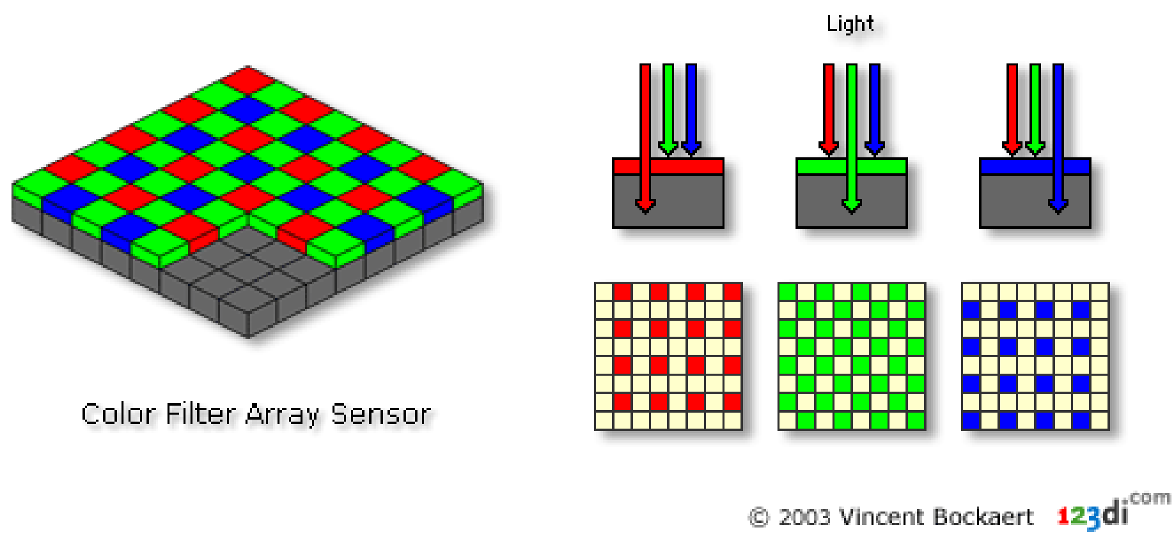
Sensor Size

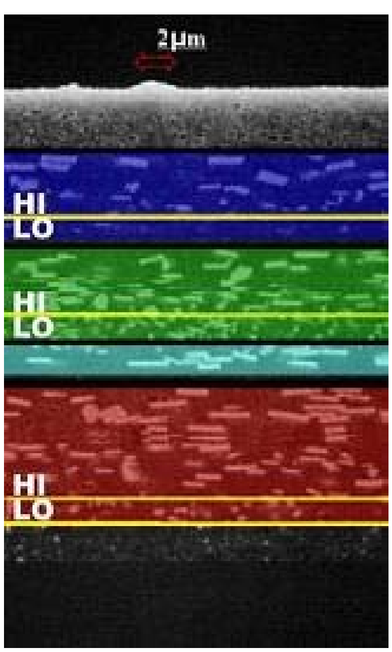
- Typical film 36x24 mm
- High end 57x57 and 100x127 mm but really no limit
- Some camera film 60x100 cm
- Digital point & shoot & cell phone about ~3-5 mm
- Semi pro 24x15 mm
- Full pro 36x24 mm (but ~$3K cost)
- Larger sensor takes more silicon area to fabricate
- Thus more expensive
- Also yield drops rapidly as imager size grow
- Cost dropping – latest full frame is ~$2K
- Best Digital Hasselblad 40x54 mm (60 Mpix)
- Pixel Size: 5-7µm for high end, 2µm for lower price
- Smaller pixels have more noise lower sensitivity



Colour Limits

- Digital uses Bayer colour filter of Red, Green & Blue
- Algorithm interpolates colour between pixels called Demosaicing
- Eg for G pixel use neighboring R&B to estimate RGB values
- However if pattern changes rapidly produces colour error
- Film does all 3 colours at same spot- better colour resolution
- Also problem with colour balance: getting the whites correct
- In digital jpg colour balance calculated in camera but frozen in
- But may freeze in wrong balance and only 8 bits of colour
- Shoot Digital Raw (pure sensor data)
- Can do balance after for the light scene

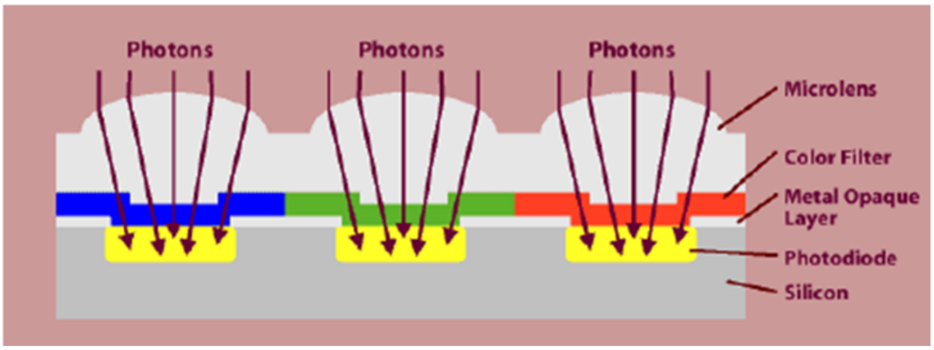




Colour balance error

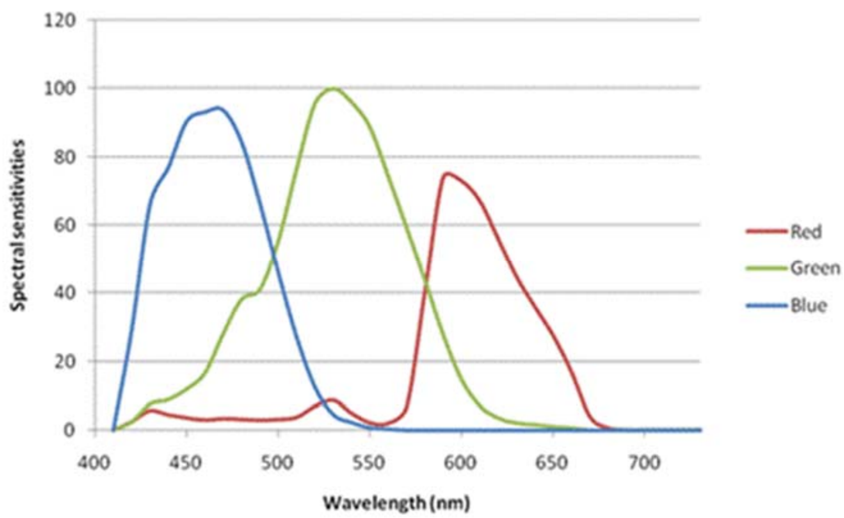
Color and Images

- Pixels are not color sensitive
- So add a color filter layer above each pixel
- Color filters are organic layers
- Deposit each color and pattern them
- Adds lots of complexity



Color Transmission

- Each manufacture has different transmission
- Problem overlap of colors – not sharp spectral edges
- Also all are transparent in NIR (~770-1050 nm)
- Must put a heat mirror to prevent this (cuts off at ~770 nm)
- Allows infrared conversion of camera
- Remove heat mirror



Heat Mirrors in Digital Cameras

- Heat mirror came in ~2003
- Reason IR distorted image
- Can be removed