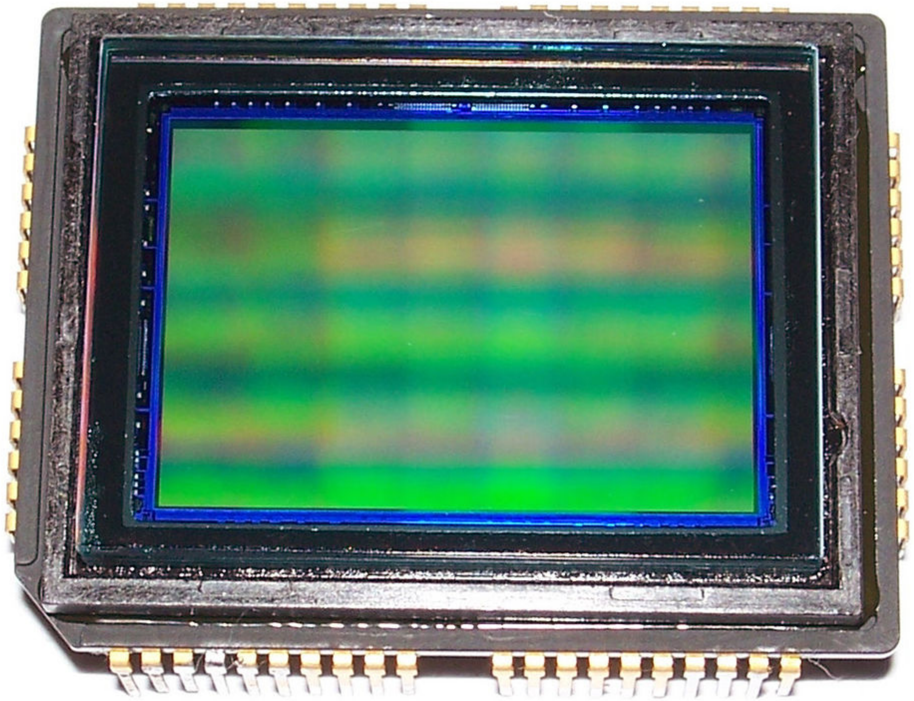
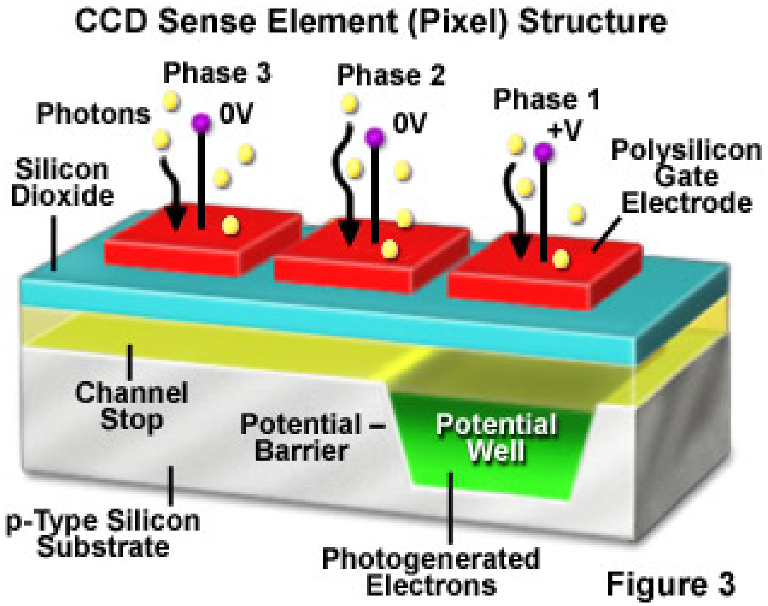
Detectors

- Last class
  - Lattice sheet imaging
- This class
  - CCDs and fancy CCDs
  - Signal to noise
  - sCMOS

CCD cameras

- Integrated circuit etched onto a single piece of silicon
- Silicon is doped to be photo-sensitive
- Photons convert energy into electrons which are stored throughout the entire exposure
- Electrons are then transferred and read out via an analog to digital converter (ADC)
- This digital signal, for each pixel, then forms the image that we show in Matlab





CCD Quantum Efficiency

- Quantum efficiency – the likelihood an absorbed photon will be transmitted into an electron
- Varies across visible spectrum, but mostly pretty good
- Peak QE ~500-600 nm
- Back thinning increased QE by reducing the number of absorbed photons on the electronic components
- Back thinning is expensive

Electron Multiplying and Intensified CCD Quantum Efficiencies

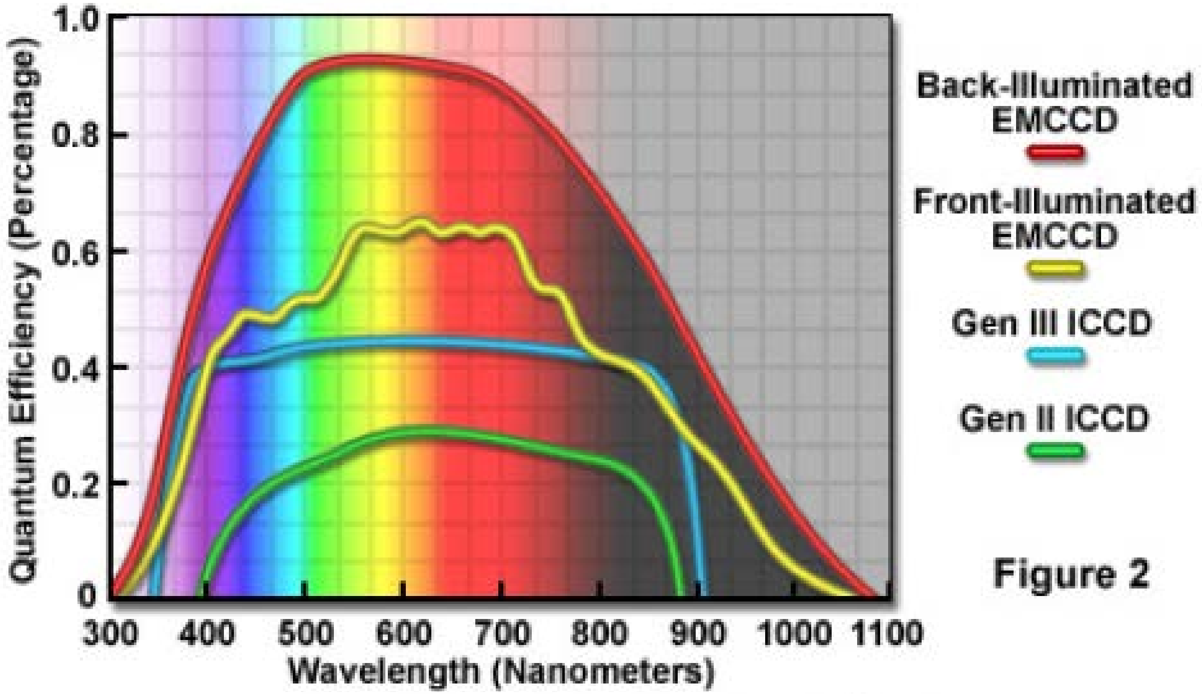


Figure 2

Frontside and Backside Illuminated CCDs

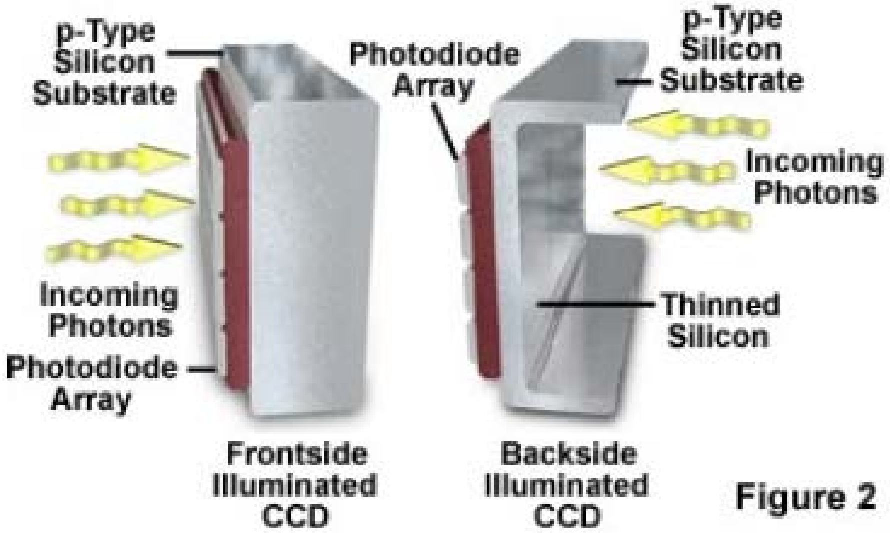
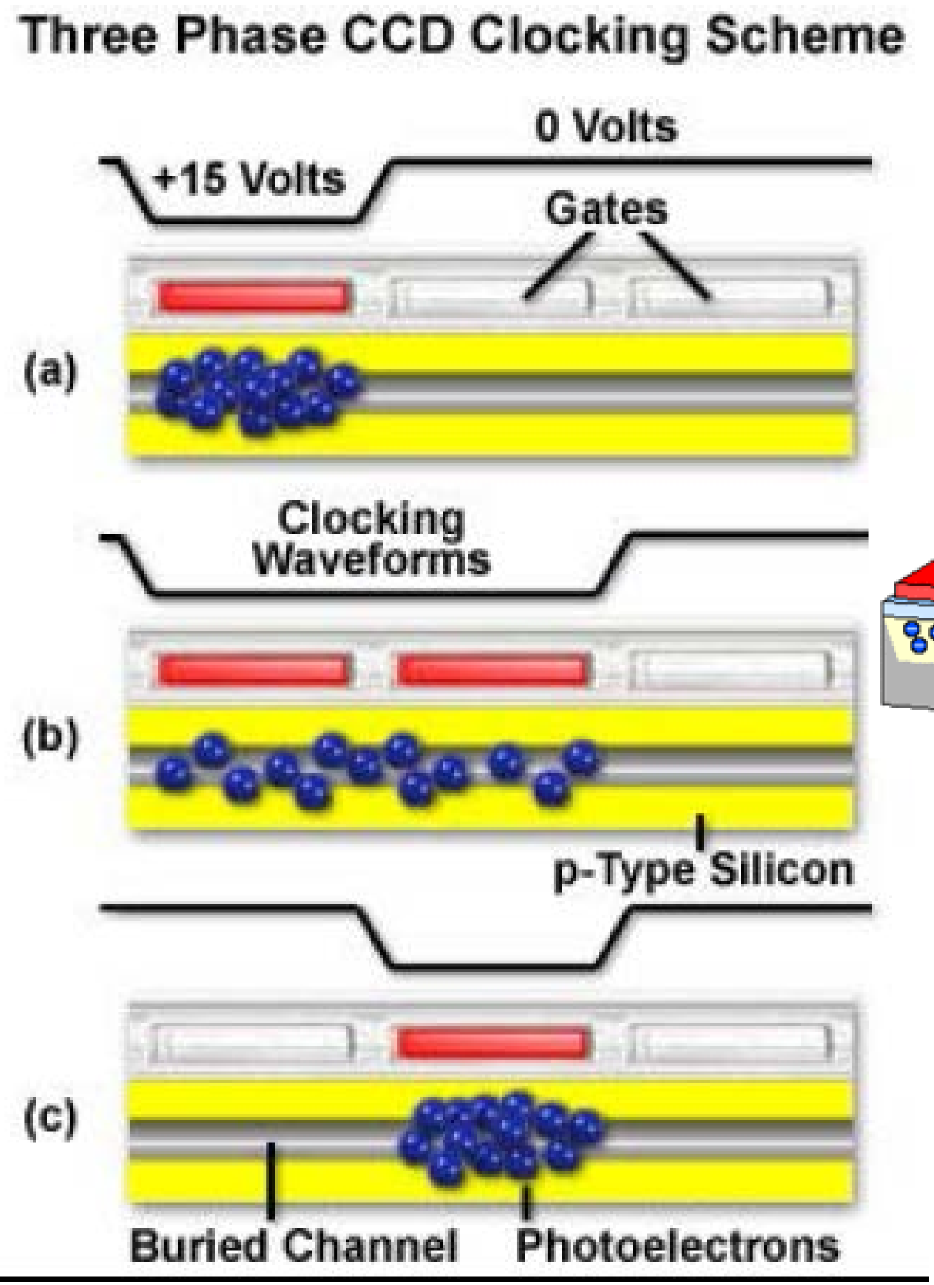
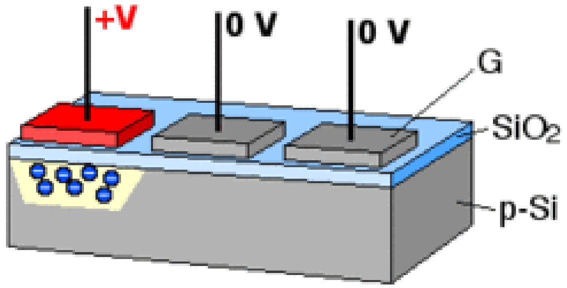


Figure 2

CCD pixels

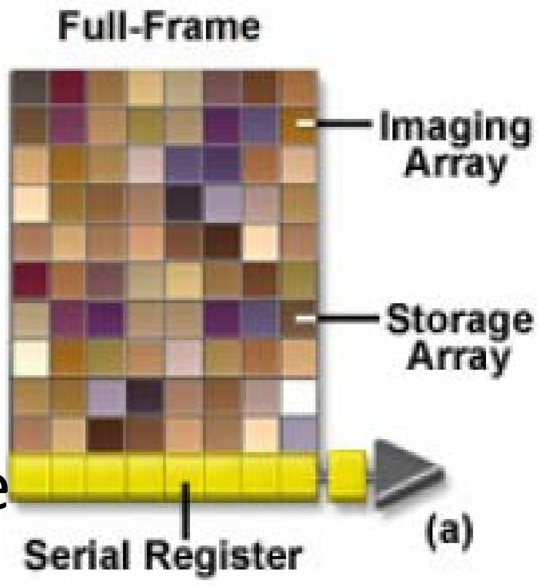
- CCD pixel sizes are defined by thin strips of transparent electrodes called gates
- Individual pixels are isolated by insulating channel stops
- Charges can then be moved by applying voltage across the pixel gates
- Illumination fraction for CCDs is very high
- There is a maximum number of electrons that can be stored – sets dynamic range, typically 12 or 16 bit





CCDs use serial charge transfer

- A CCD typically has only 1 ADC, so every pixel has to be read one at a time
- Dead time when pixels are being read
- ADC speed and total number of pixels set the read time
- Faster ADC means faster frame rate, but more noise



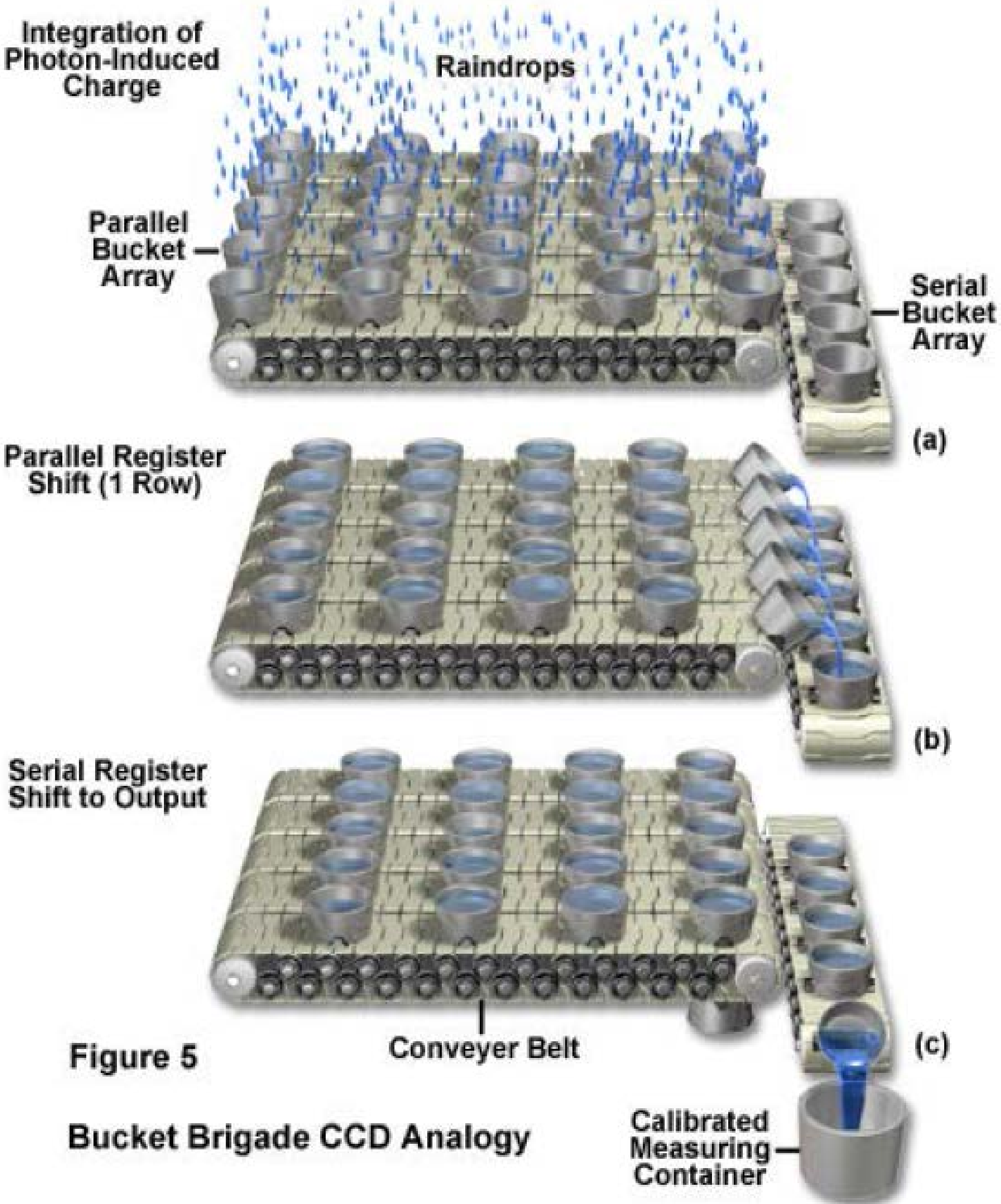
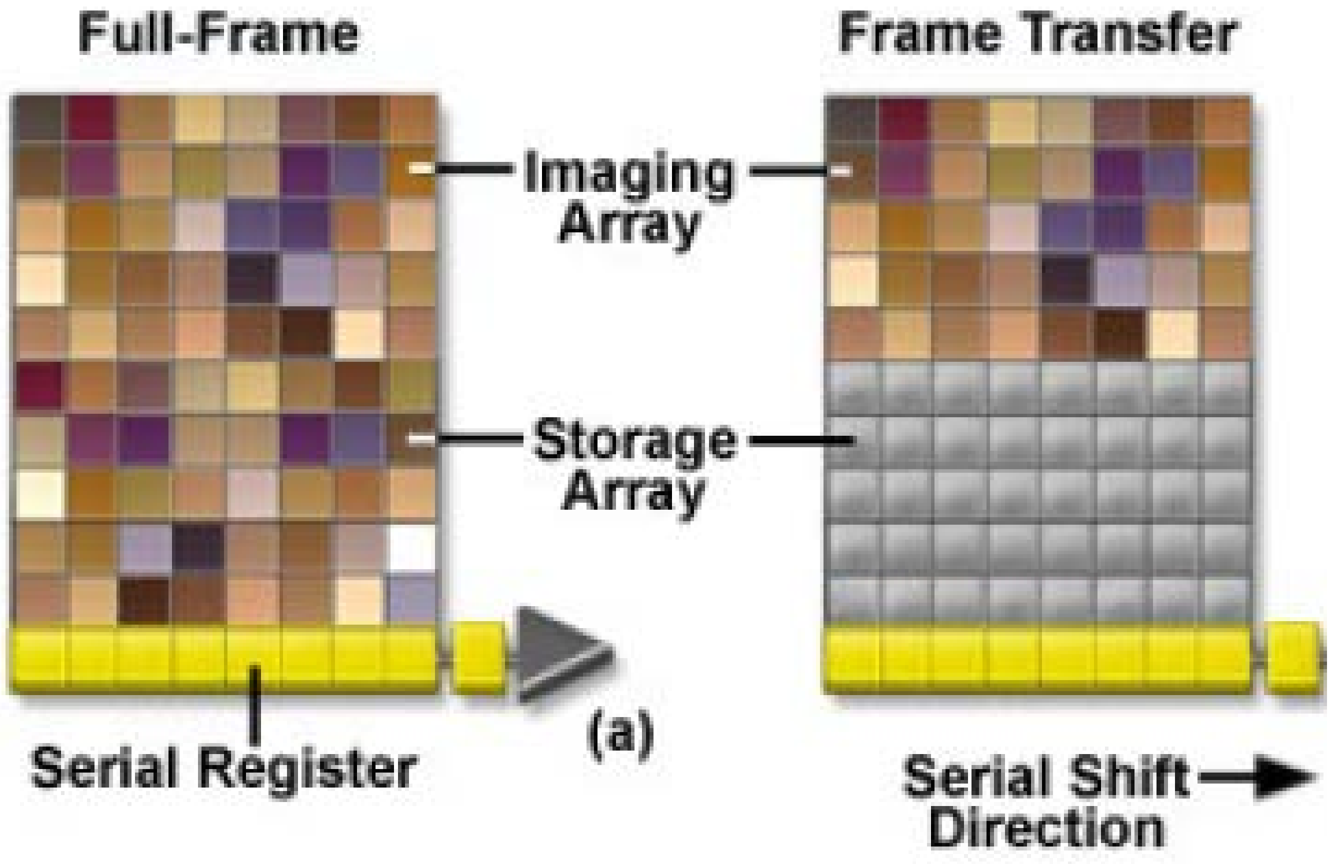


Figure 5

Bucket Brigade CCD Analogy

Frame transfer mode

- To avoid deadtime, expensive CCDs utilize a frame transfer mode
- Two identical chips, one is exposed to light, and one is covered
- Expose image on upper frame, then transfer that to the covered frame (FAST)
- While that image is being read by ADC, upper frame can be exposed to light again
- Only deadtime is during frame transfer (~500 us)



Electron multiplied CCD (EMCCD)

- Use electron gain in electric field during read out
- Similar to photomultiplier tube
- Multiplies all electrons (signal and dark) before ADC conversion
- Allows imaging of extremely dim samples
- Adding gain necessarily reduces dynamic range
- Charge moving = current. Be careful not to burn out electronics

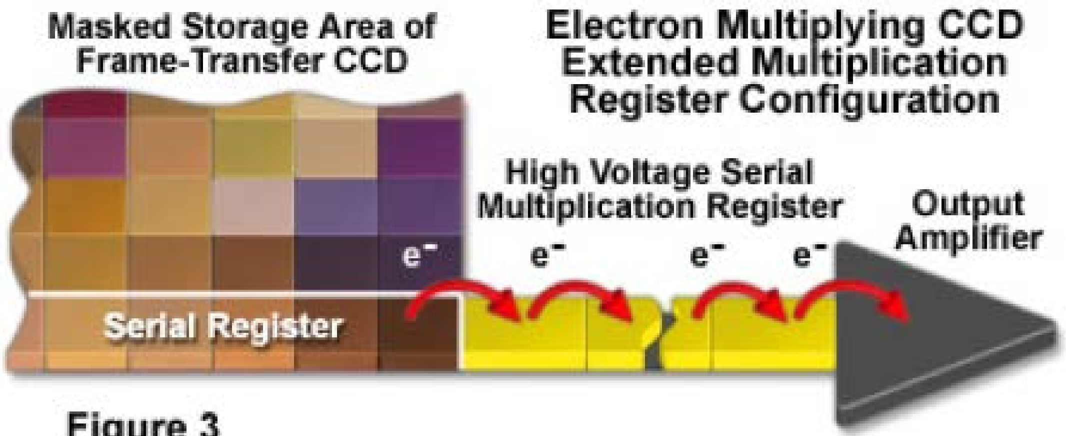
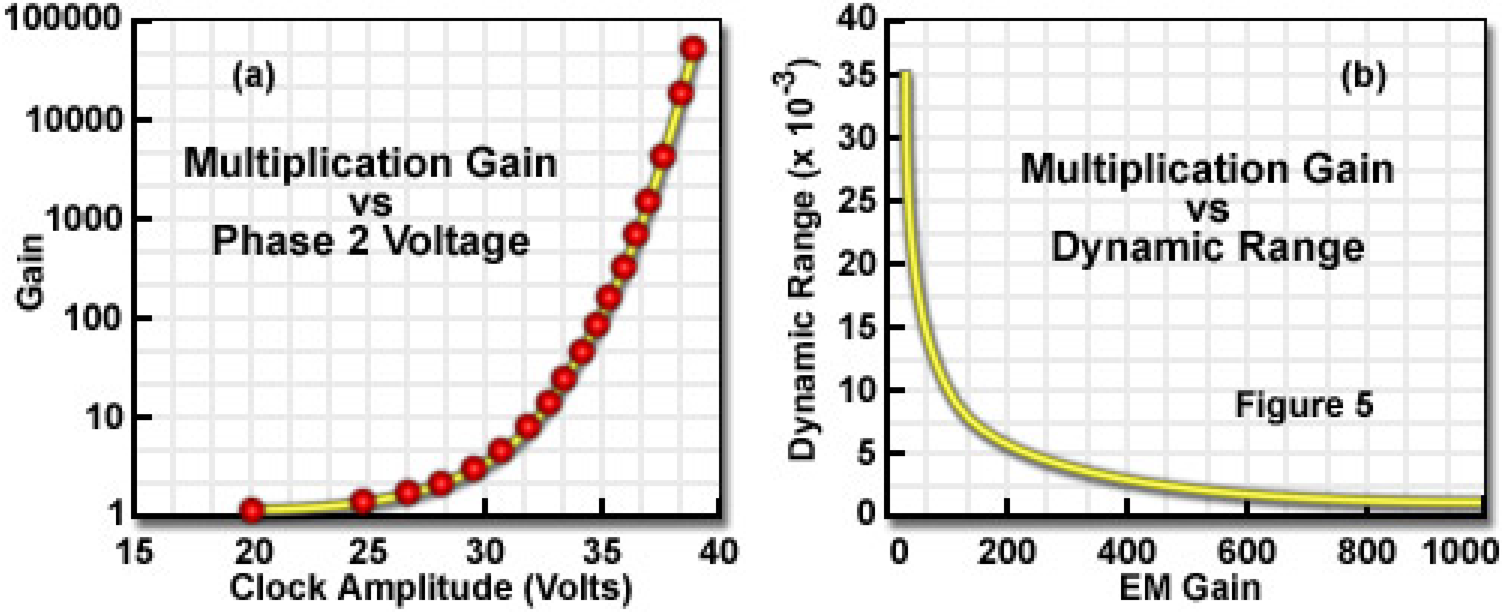


Figure 3

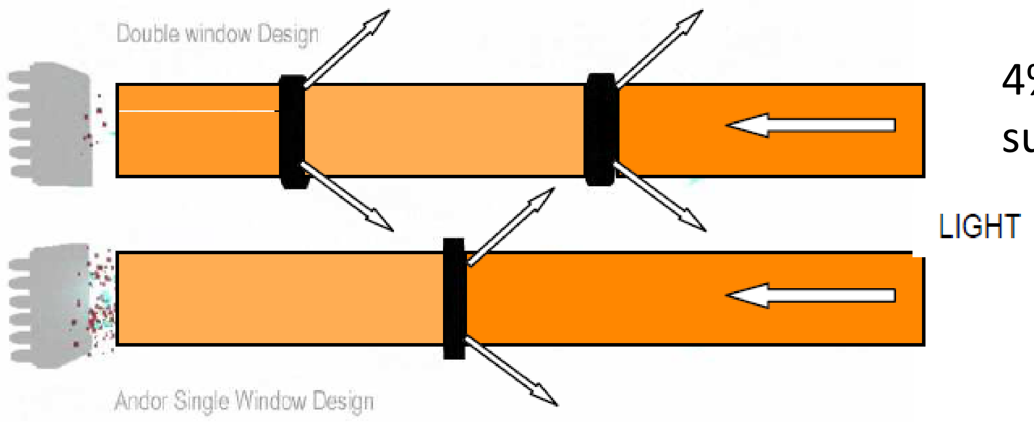


Characteristics of EMCCDs

- Faster the ADC, more read noise
- Electron multiplication will help overcome tha but only if you use it
- Age dependent change in gain
- Have to vacuum seal the chip, window will reduce some incoming light

ADVANCED PERFORMANCE SPECIFICATIONS [*2]

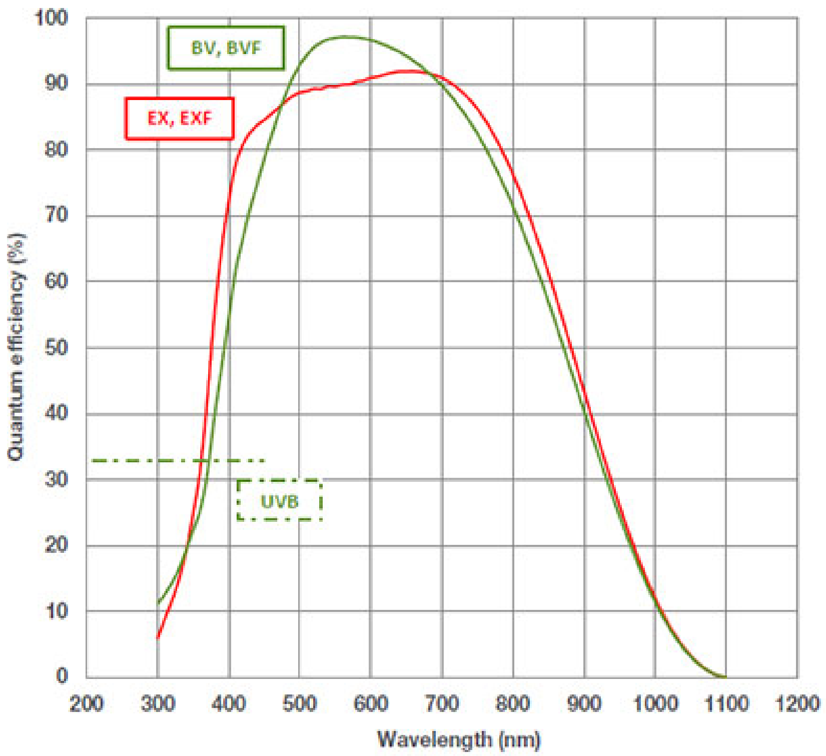
Dark current and background events [*5,6]		
Dark current (e^-/pixel/sec) @ -85°C	0.0005	
Spurious background (events/pix) @ 1000x gain / -85°C	0.005	
Active area pixel well depth	80,000 e^-	
Gain register pixel well depth [*7]	730,000 e^-	
Pixel readout rates	Electron Multiplying Amplifier	30, 20, 10 & 1 MHz
	Conventional Amplifier	1 & 0.1 MHz
Read noise (e^-) [*8]	Without Electron Multiplication	With Electron Multiplication
30 MHz through EMCCD amplifier	130	< 1
20 MHz through EMCCD amplifier	80	< 1
10 MHz through EMCCD amplifier	40	< 1
1 MHz through EMCCD amplifier	12	< 1
1 MHz through conventional amplifier	6	-
100 kHz through conventional amplifier	3.5	-
Linear absolute Electron Multiplier gain	1 - 1000 times via RealGain™ (calibration stable at all cooling temperatures)	
Linearity [*9]	Better than 99%	



4% QE loss per glass surface

Current state of the art

- Several companies make EMCCDs – but they all use the same e2v chips
- Each company puts custom electronics on the backend
- Hamamatsu, Andor, PCI all make EMCCDs
- Best backend ADC runs at 30MHz
- All single molecule experiments
- Good for low signal experiments



Key Specifications

Active Pixels	1024 x 1024
Pixel Size	13 x 13 µm
Image Area (mm)	13.3 x 13.3
Image Area Pixel Well Depth	80,000 e-
Max. Readout Rate	30 MHz
Frame Rate	26 - 9690 fps
Read Noise	< 1 e- with EM gain
QE_{max}	> 90%

On to Matlab…