

**Inside the Digital Camera: The technology of Digital Photography  
895-g200-3 (Graduate) (3-0-0)**

**Professor:**

Glenn Chapman, Rm ASB 8831, Phone: 778-782-3814,  
email: glennnc@cs.sfu.ca

**Web Address for class**

<http://www.ensc.sfu.ca/~glennnc/e895out.html>

**Class Email:**

ensc894-g200

**Description**

- Theory and practice of Digital Photography
- How the camera works from the inside out
- Hardware – how the imaging sensor works
- Software within the camera

**Class Time**

Tuesday: 5:00 6:20 pm Thursday 5:00-6:20 pm, ASB9847

## **Course Outline**

### **Week 1: Overall digital Photography**

- How the camera works

### **Week 2: CMOS APS operation and design**

- Active Pixel Sensor operation
- Microlenses

### **Week 3: Autofocus**

- How autofocus works in the camera

### **Week 4: Demosaicing – Getting colour from the camera**

- Extrapolating colours from RGB pixels

### **Week 5: Pixel Noise reduction**

- Hardware and software noise reduction

### **Week 6: White balance**

- Getting correct white balance on images

### **Week 7: Optical correction**

- Correcting lens distortion with software

### **Week 8: Theory of High Dynamic Range Imaging**

- Multi images to create higher Dynamic Range

### **Week 9: Focus Stacking**

- Gaining Depth of focus with multiple images

### **Week 10: Computational Photography**

- Software techniques to improve image
- Removing reflections

### **Week 11: Computational requirements for cameras**

- Why cameras need high computing power

### **Week 12: Digital Memory**

- How SD/ CF memory cards work -
- Implications for camera

### **Week 13: DSLR vs mirrorless camera**

- Mirrorless cameras substitute the LCD display for eyepiece
- What are relative advantage

## **Text Book**

Course notes will be the major text. Downloaded from the web

## **Assignments & Academic Honesty**

Assignments every 2-3 weeks after 2nd week of class.  
emailed to the students.

Separate assignment: same questions: different parameters  
emailed a solution set to your specific questions.

**If you used someone else's numbers you get zero on question**

**If you do that twice zero on the assignment.**

**Copy labs and you get zero on all labs**

**Cheat on Midterm or Final – get an FD**

## **Marking**

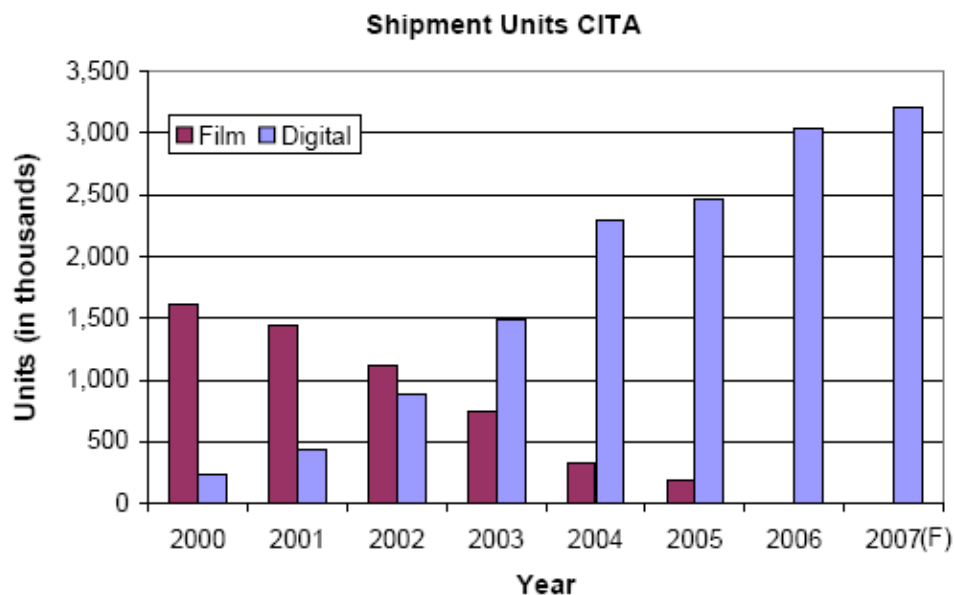
**Graduates: Best of**

15% Weekly Assignments, 15% Midterm test, 40% Final Exam,  
30% Project/Labs

20% Assignments, 20% Midterm test, 20% Labs, 40% major project

## Digital Cameras vs Film: the Collapse of Film Photography

- Can Your Digital Camera reach Film Photography Performance?
- Film photography started in early 1800's – almost 200 years
- Commercial Digital Cameras started late 1995
- By 2000 digital “point & shoot” fell <\$400
- Digital Single Lens Reflex Cameras  
(Nikon D1) appeared in 1999 at \$10,000
- Canon 10D in 2002 first semipro DSLR <\$2000
- Digital Rebel in 2003 first <\$1000
- By 2006 film camera almost stopped
- Kodak effectively destroyed by the move to digital
- Fujifilm, only major film manufacturers but Kodak is coming back
- But now many special producers eg Lomography



## Why Digital Cameras Succeed

- Digital has clear advantages in many areas
- Immediate image view – can correct picture
- Film takes hours/days (or minutes with polaroids)
- Cost: Film >50¢ photo,
- Storage – film bulky,
- Digital 32GB cards now \$22, <0.03¢/photo
- Largest cards now 1TB for video
- If use DVD 4GB disk cost 25¢, holds ~4000, 0.006¢/picture
- 2TB usb drives give 400 million photos at  $2.5 \times 10^{-5}$  ¢/picture
- Digital SLR's now near film in price



EOS Rebel K2 film ~\$400



Digital Rebel X5Ti ~\$900



Canon 5DsR – pro end \$4000

## **Why some Top Pro Photographers have not fully Converted**

- Journalist & sports professional photographers have converted
- Need rapid turnaround of pictures
- But high end Portrait, advertisement have not fully – Why
- Also rise in interest in amateur (just like classic records/players)
- Film still has advantages in several area:
- Resolution
- Colour accuracy
- Sensitivity
- Dynamic Range
- Special photographic conditions: cold climates & long exposure
- Let us look at why & where digital is responding



## Why Did Kodak Die

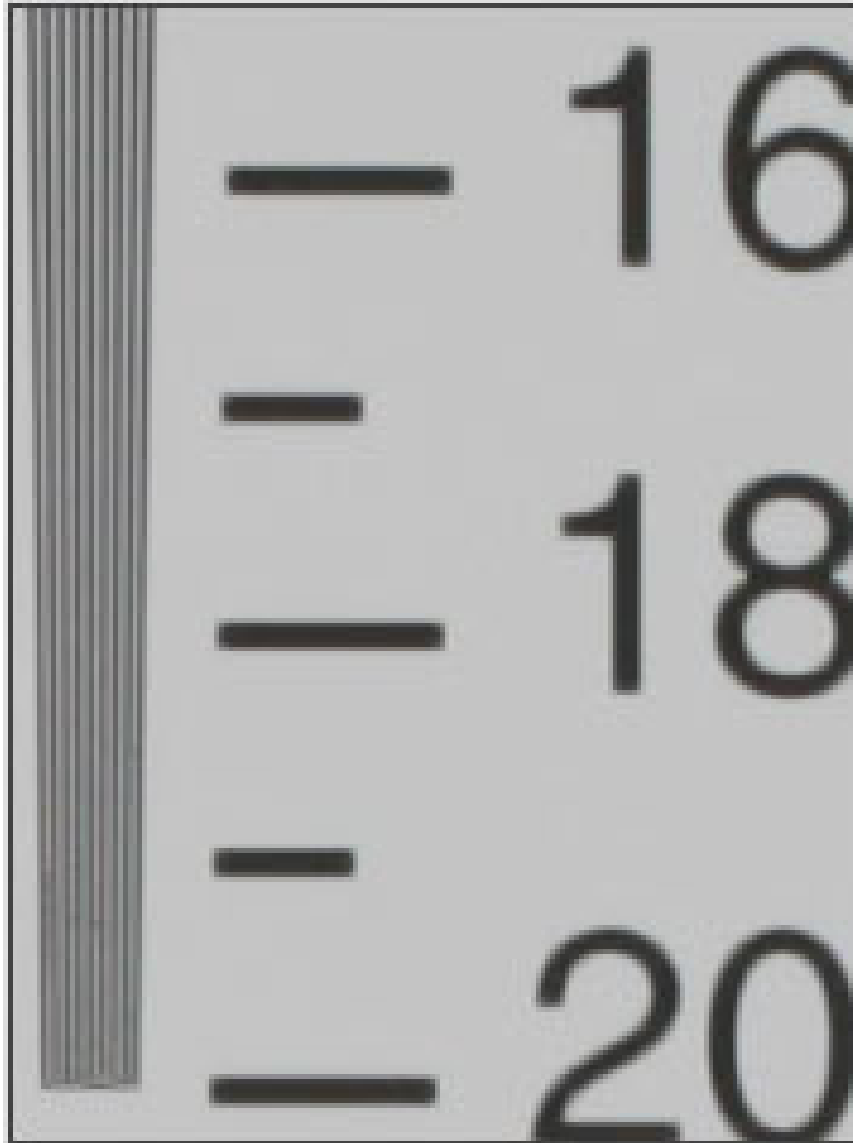
- Kodak was 900 lb gorilla of film companies
- Why did it die
- Here is a video showing why

<https://www.dpreview.com/news/6335982376/video-diving-into-the-demise-of-kodak>



## Resolution Measurements

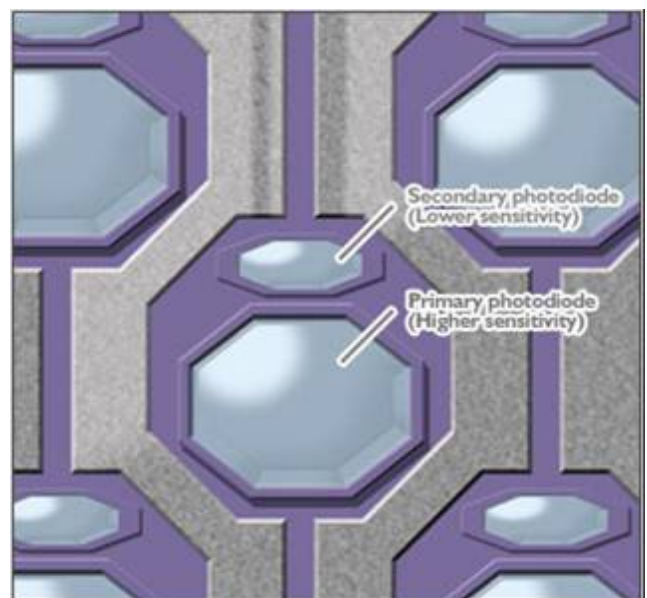
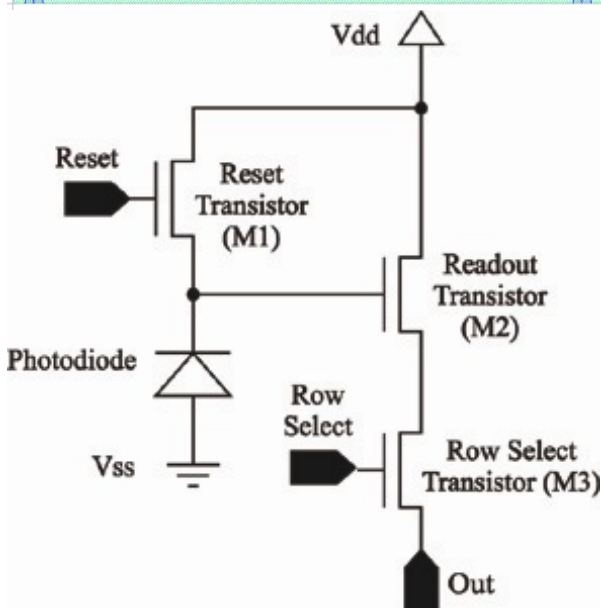
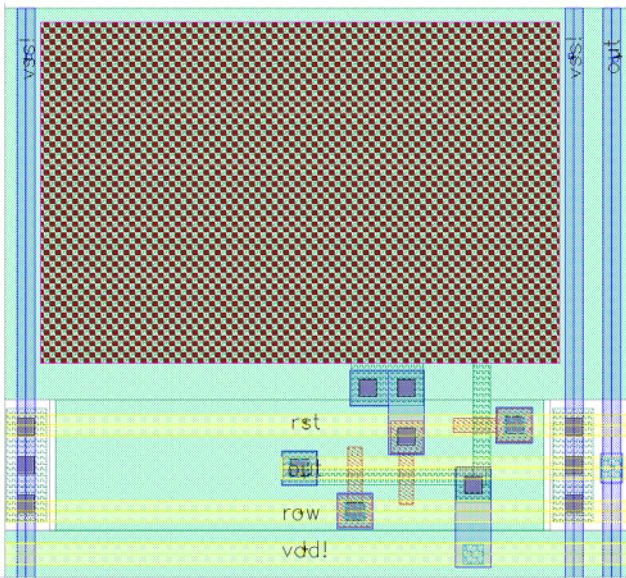
- Measure resolution in line pairs per millimeter (lp/mm)
- This is called MTF type measurement
- One line and space per line pair
- Nyquist theorem: need minimum of 2 pixels per line pair
- So size of pixel limits resolution





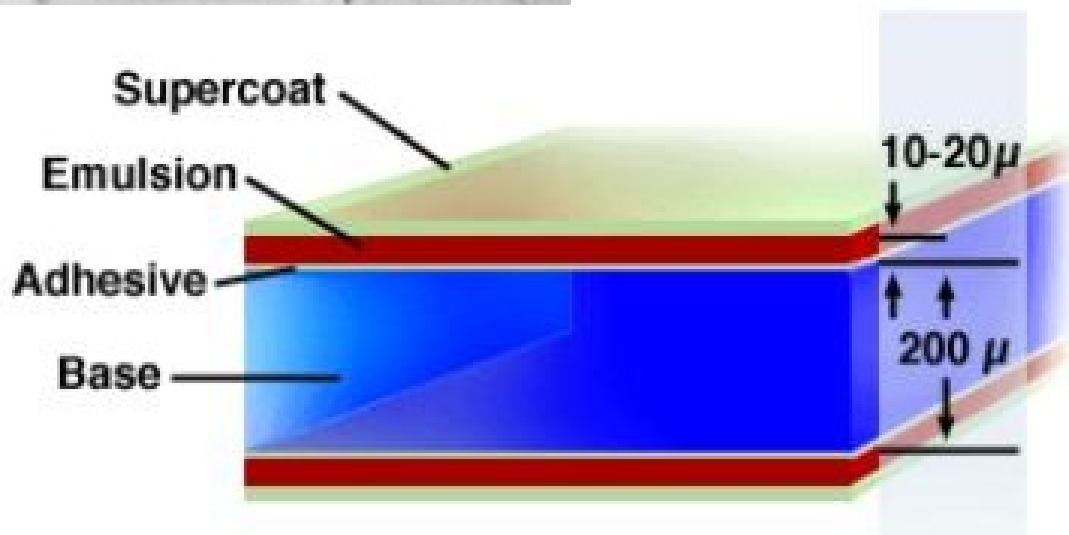
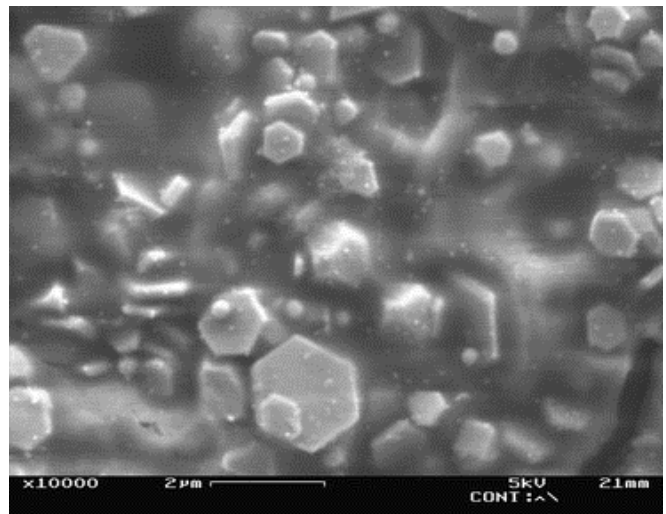
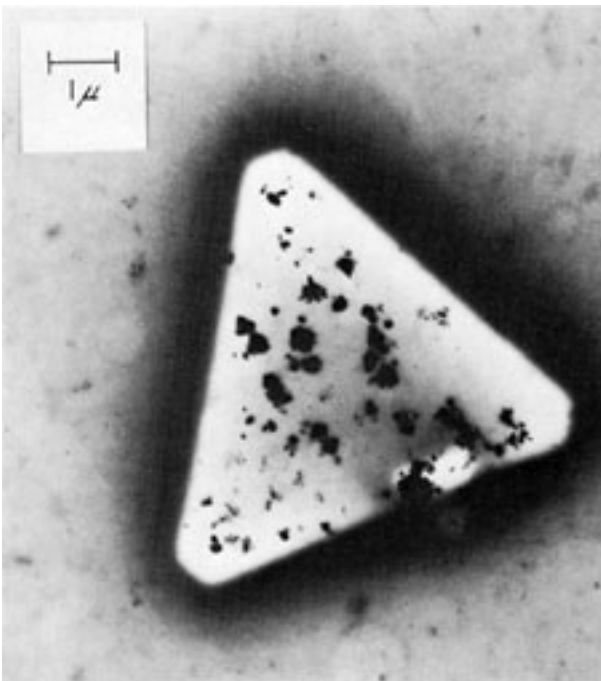
## Digital Resolution

- Digital sensors of two types
- CCD: Charge Coupled Device
- Active Pixel Sensor (CMOS) resolution set by pixel size
- Typical size 4-8 microns – cell phones down to 1.5 microns
- Sensor area (fill factor) ~25%-50%
- Use microlenses to get collection near 95% of pixel area
- Will explore how the CMOS pixel sensor works
- Best Digital resolution ~35 line pairs/mm
- Smaller pixels do not generate better resolution
- Digital noise/spread limits resolution



## Film Resolution set by Grain size

- Film sensor is silver halide grains in emulsion 10-20  $\mu\text{m}$  thick
- Resolution in film set by silver halide grain size
- Typical grain is  $\sim 1\text{-}2\ \mu\text{m}$
- Large grain  $\sim 20\ \mu\text{m}$
- Ultra fine grain  $0.015\ \mu\text{m}$  (done in 1920's!)
- Single photon activates all the silver halide in a grain
- Thus larger grains more sensitive, smaller less sensitive
- Creates Latent Image – can be stored for years before fading



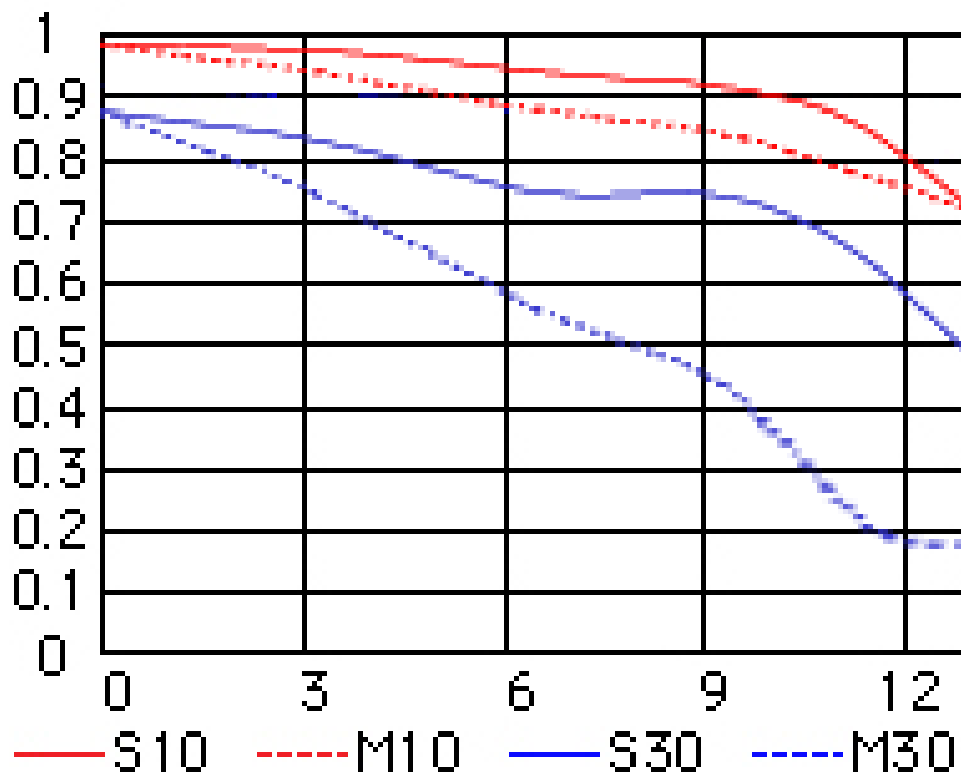
## Photographic Process

- Development process (done in dark or container)
- Film placed in developer solution
- Developer eg Metol and hydroquinone in high pH solution
- Put in developer for ~1-3 min: agitate to move solution over film
- Reduces the activated grains leaving metallic silver (black)
- Thus image is negative: exposed area black
- Then put in a “Stop Bath”, e.g. water: to stop the reaction (30 sec)
- Then in fixer: sodium thiosulfate (hypo) or ammonium thiosulfate
- After ~5 min removes unexposed silver halide: leaves black silver
- Removed grains leaves transparent film
- Then final wash in water to remove all chemicals ~ 10 min
- Print uses then uses paper covered with emulsion
- Project negative on paper & develop to get image



## Resolution Limit by Lens

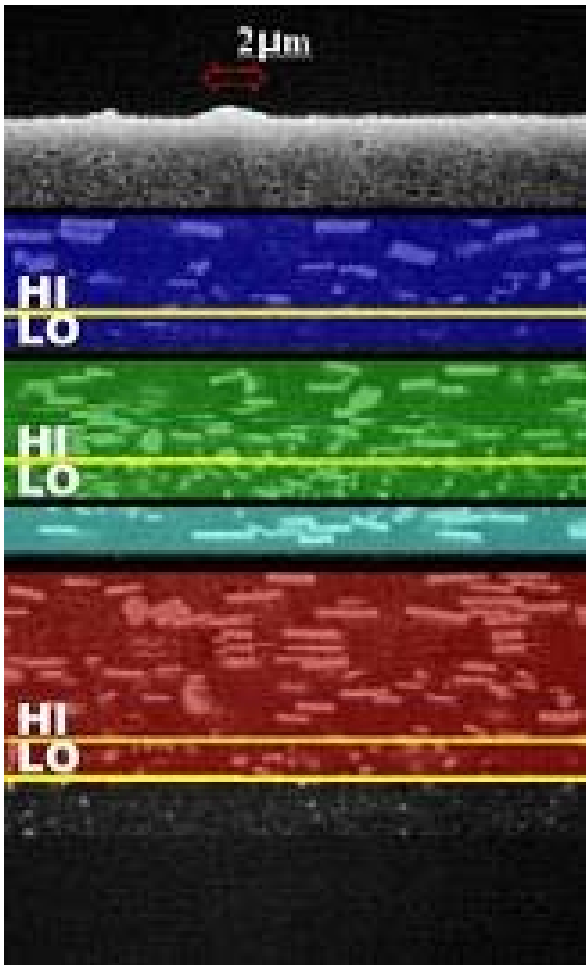
- Best resolution is usually limited by the lens
- For digital point and shoot lens and imager about same resolution
- But for DSLR lens still better than detector
- Resolution limit of DSLR fines lenses 200 lp/mm
- Requires at lest 1.2 um pixels
- Top Digital end 50 Mpix (~8700x5800 pix)
- Film limit on 35 mm ~29,000x19,000 pixels = 552Mpix
- In film days some large cameras had much bigger lenses
- Eg Medium format Hasselbald 6x 4.5 cm was portrait standard
- 4x5" (10x12.7cm) graphic, 8x10 (20x24 cm) sheet film cameras
- Even higher resolution could make bill board sized photos
- Exploring the resolution limits of images





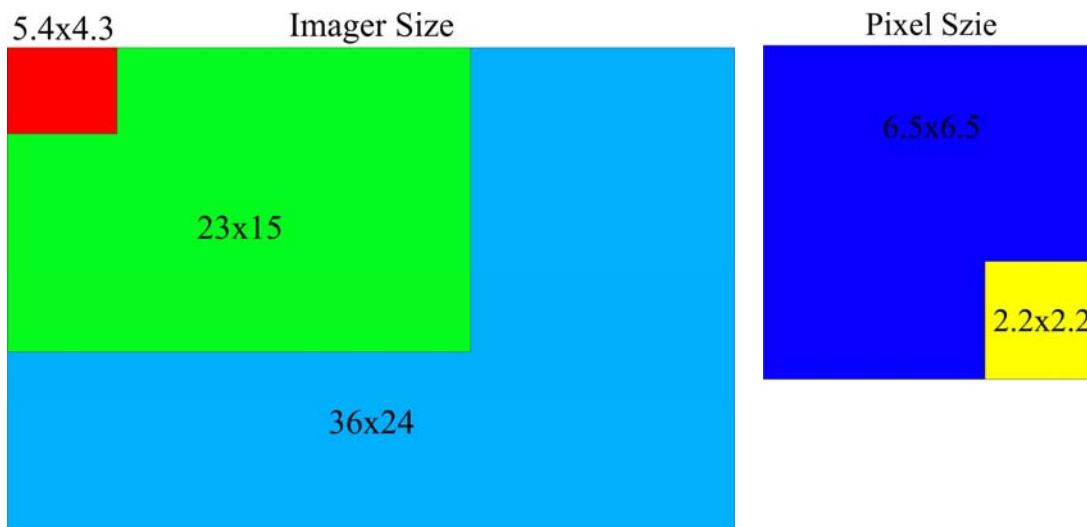
## Film Resolution

- Film has many layers of gain, with several sizes
- Often have coarse layer & fine grain layer
- Grain size also distributed in film
- Resolution also set by developer:
- fine grain developer better resolution for same film
- Typical film has 80-100 lp/mm
- Ultra fine grain films very high
- Panatomic Areographic
- Regular developer 120-200 lp/mm = 1.25  $\mu$ m pixels
- Fine grain developer 400-500 lp/mm = 0.5  $\mu$ m pixels
- Best films 1000-2000 lp/mm = 0.25-0.12  $\mu$ m pixels



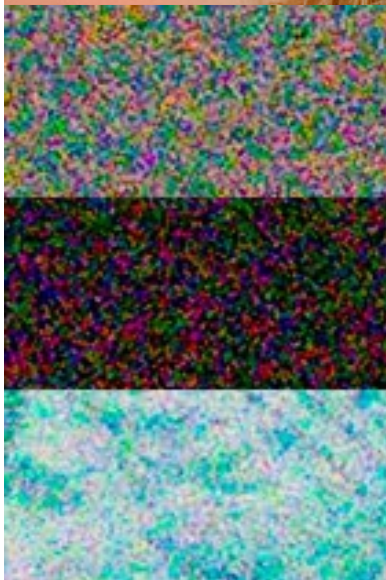
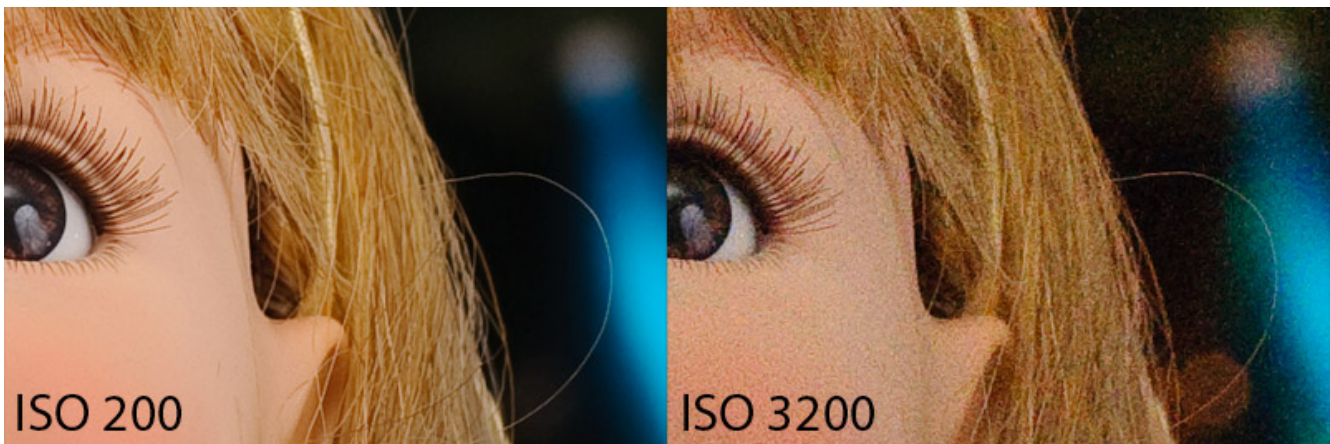
## Sensor Size

- 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)
- Cost dropping – latest full frame is ~\$2K
- Best Digital Hasselblad 40x54 mm (60 Mpix)
- Pixel Size: 5-7 $\mu$ m for high end, 2 $\mu$ m for lower price
- Smaller pixels have more noise lower sensitivity
- What limits the size of sensors



## Film/Pixel Sensitivity

- Film or digital cameras measure sensitivity as ISO
- ISO=100 gives a picture in sunlight at ~F#16 and 1/60<sup>th</sup> sec
- Double ISO can cut exposure time in half or go up 1 F stop
- Film ranged from ISO 20 to ISO 1600: 100 was typical
- (1600 ISO is 4x more sensitive than 100 ISO)
- At high ISO films were very grainy
- Colour films much gainer than B&W
- DSLR's get 50-409,600 ISO these days
- But at highest ISO get digital noise
- Examine both design for noise reduction and software reduction
- Makes the pictures look grainy
- Gets colour (Chromenance) – where it comes from & reduction



12,800 ISO



12,800 ISO

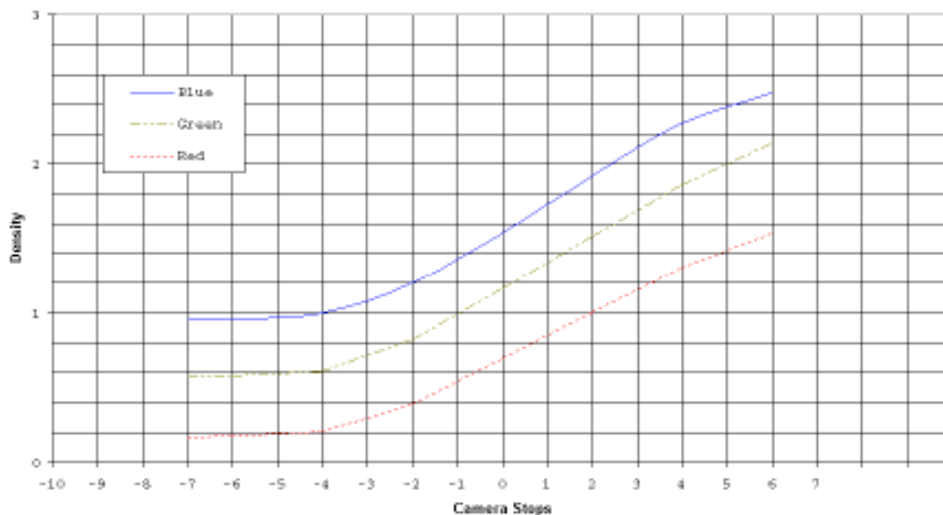


409,600 ISO

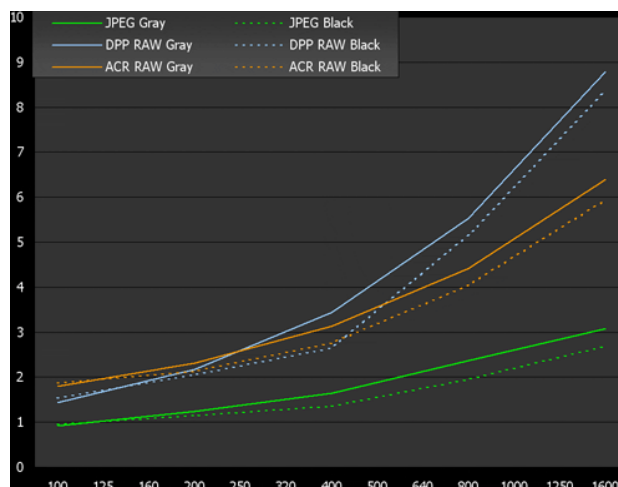


## Dynamic Range

- Digital 8 bit (256 levels) is the standard
- High end Digital cameras do have 10-14 bit conversion
- But noise limit is about 8-10 bit at best ISO
- How do we reduce noise with software in digital system
- Film records a max dynamic range of 20,000:1 (~15 bit)
- Top and bottom saturation
- Comes from distribution of grains
- At most sensitive end film has some large grain halides
- This extends sensitivity at low exposure end
- Similarly distribution of small grains
- Hence extension of sensitivity at high exposure end
- Best film 3 layer XR from EGG 10<sup>8</sup>:1 – better than the eye



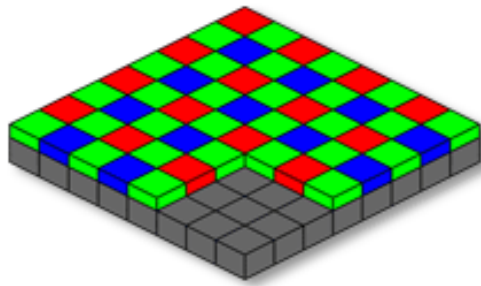
Notice: While the data presented are typical of production coatings, they do not represent standards which must be met by Eastman Kodak Company. Varying storage, exposure, and processing conditions will affect results. The company reserves the right to change and improve the product characteristics at any time.



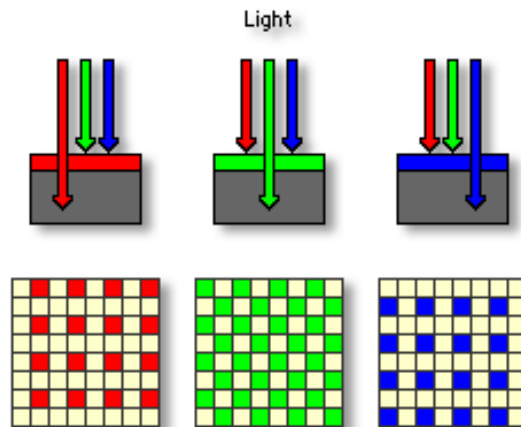


## Colour Limits

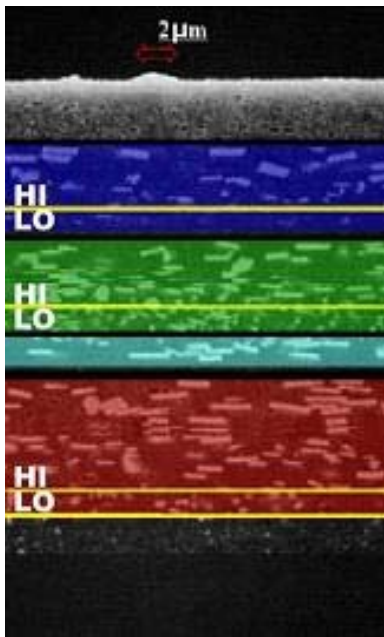
- Digital uses Bayer colour filter of Red, Green & Blue
- Algorithm interpolates colour between pixels called Demosaicing
- Eg for G pixel use neighboring R&B to estimate RGB values
- However if pattern changes rapidly produces colour error
- Film does all 3 colours at same spot- better colour resolution
- Will explore the demosaicing algorithms for doing this



Color Filter Array Sensor



© 2003 Vincent Bockaert [123di.com](http://123di.com)



Colour balance error

## White Balance and Colour Temperature

- Sun has a surface colour temperature of 6100 °K
- What is its peak wavelength?

$$\lambda_{\max} = \frac{2897}{T} = \frac{2897}{5778} = 0.501 \mu m \text{ or Blue green}$$

- In photography call T the colour temperature of the source
- Camera colour balance adjusts RGB ratios for a given T
- Human eye does much better than camera white balance
- 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)
- What are the colour balance algorithms



Model lit on left by Incandescent light, on right by sunlight  
5600K balance (sunlight)                      3200K (Tungstan)



## High Dynamic Range Photos

- Take several pictures: 3 spaced at -2, 0, +2 f stops
- Extends Dynamic range to about 1000
- Called High Dynamic Range or HDR
- Possible now automatically in photoshop CC
- Problem: pictures are typically 0.3 sec or more apart
- OK for still images, bad for scenes with movement
- Also HDR tone maps scene onto 8 bit (256 level) display
- Substitutes overexposed and underexposed areas to get best
- Tone map and alignment of images creates artifacts
- Wide Dynamic Range pixels that do this being researched



Tone map artifacts – halos and ghosting

