Computer Graphics

- Display and Imaging Devices -

Hendrik Lensch

Overview

- **Last Week**
  - Volume Rendering
- **Today**
  - Display and Imaging Devices
- **Exam**
  - Monday, 18th
    - **please be there at 8:00 sharp**
    - starts at 8:15 will end at 10:00.

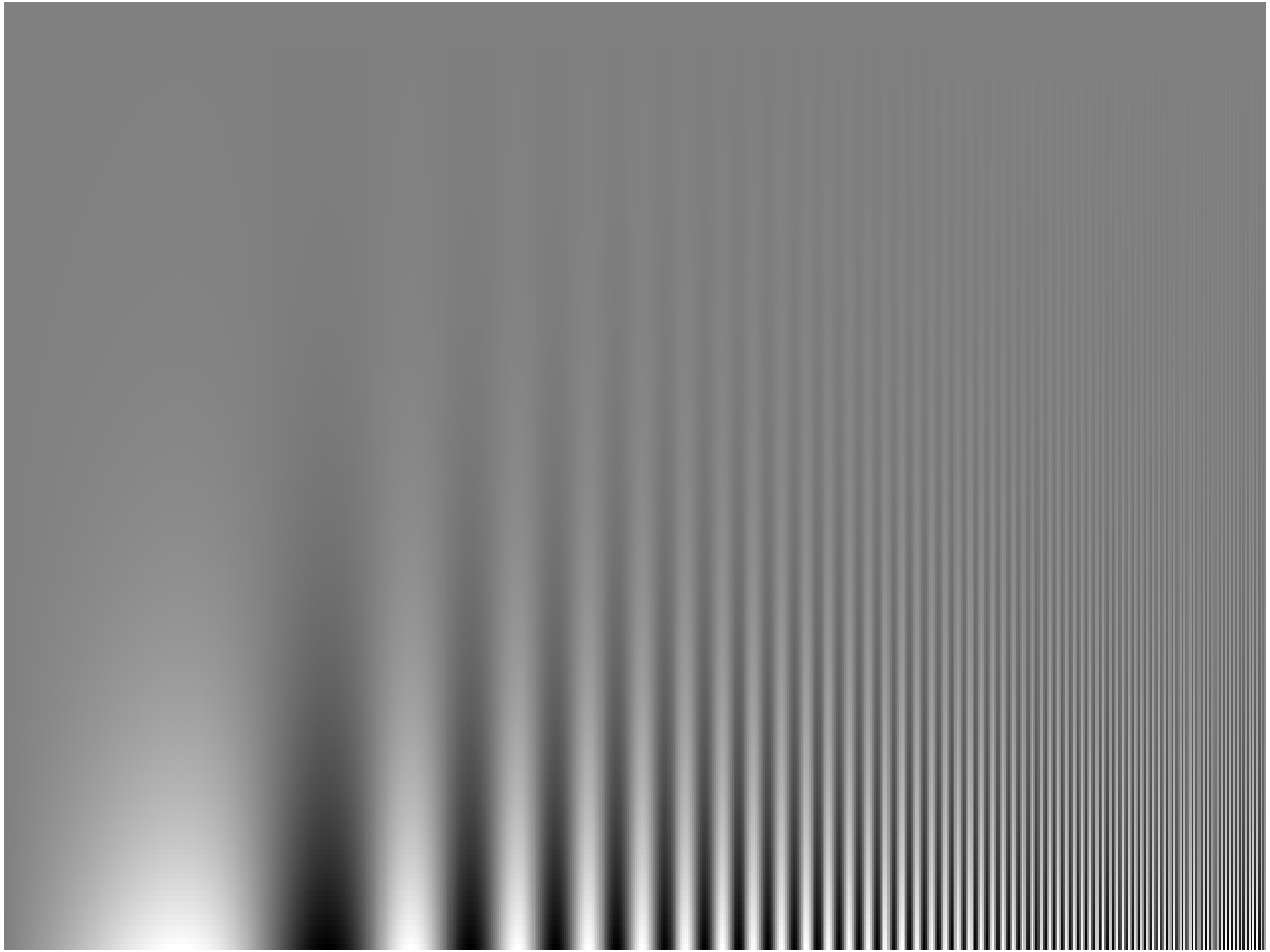
Displays

Resolution

- **World is continuous, digital media is discrete**
  - see lectures on color, human visual system

- **Three aspects:**
  - Color and intensity resolution:
    - see lecture on color
    - Physical limits: color “pigments”, 1-bit vs n-bit tones
    - Human limits: just-noticeable-differences, tricromaticity
  - Spatial resolution: (x,y)
    - Physical limits: pixel size and resolution (overall size)
    - Human limits: photoreceptor density + optics
  - Temporal resolution:
    - Physical limits: film transport, channel bandwidth
    - Human limits: neuronal response time

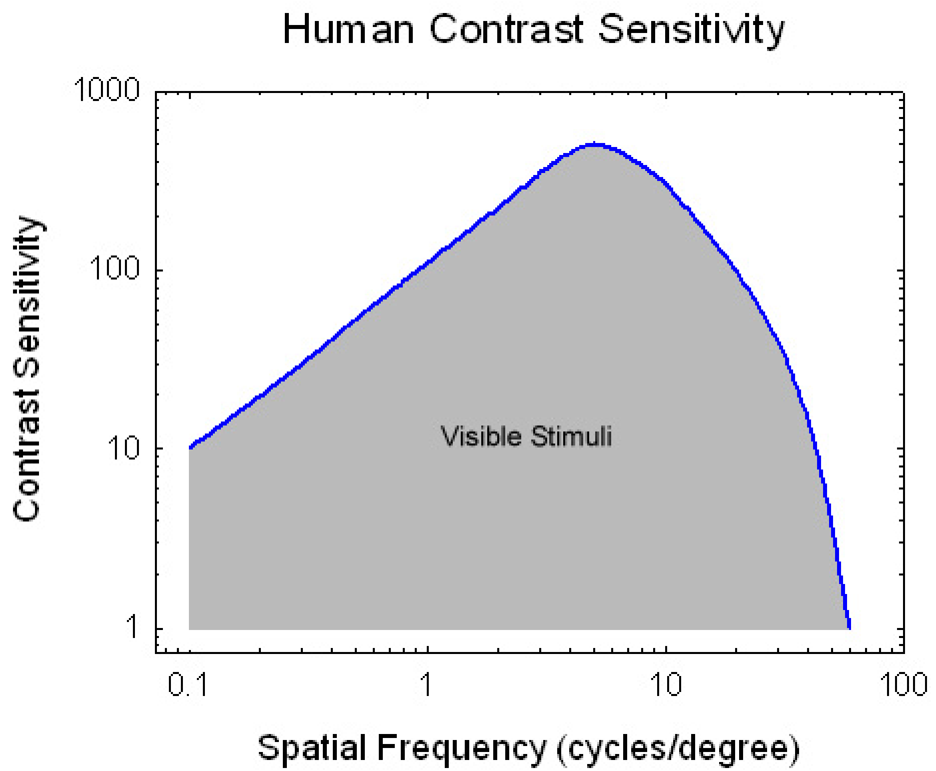
Luminance Contrast Sensitivity



Campbell-Robson contrast sensitivity chart

Contrast Sensitivity

- **Sensitivity:**
  1 / threshold contrast
- **Maximum acuity at**
  5 cycles/degree (0.2 %)
  – Decrease toward low frequencies: lateral inhibition
  – Decrease toward high frequencies: sampling rate (Poisson disk)
  – Upper limit: 60 cycles/degree
- **Medical diagnosis**
  – Glaucoma (affects peripheral vision: low frequencies)
  – Multiple sclerosis (affects optical nerve: notches in contrast sensitivity)



www.psychology.psych.ndsu.nodak.edu

Image Resolution in Practice

Television

NTSC	640x480x8b	1/4 MB
HDTV-1	1280x720x8b	~1MB
HDTV-2	1920x1080x8b	~2MB

Computers

VGA	640x480x24b	~3/4 MB
XGA	1024x768x24b	~2.5 MB
SXGA	1280x1024x24b	~4 MB
UXGA	1600x1280x24b	~6 MB

Laserprinters

300 dpi	(8.5"x300)(11"x300)x1b	1.05 MB
2400 dpi	(8.5"x2400)(11"x2400)x1b	~64 MB

Film (line pairs/mm)

- 35mm (diagonal) slide (ASA25~125 lp/mm) = 3000

  3000 x 2000 x 3 x 12b ~27 MB

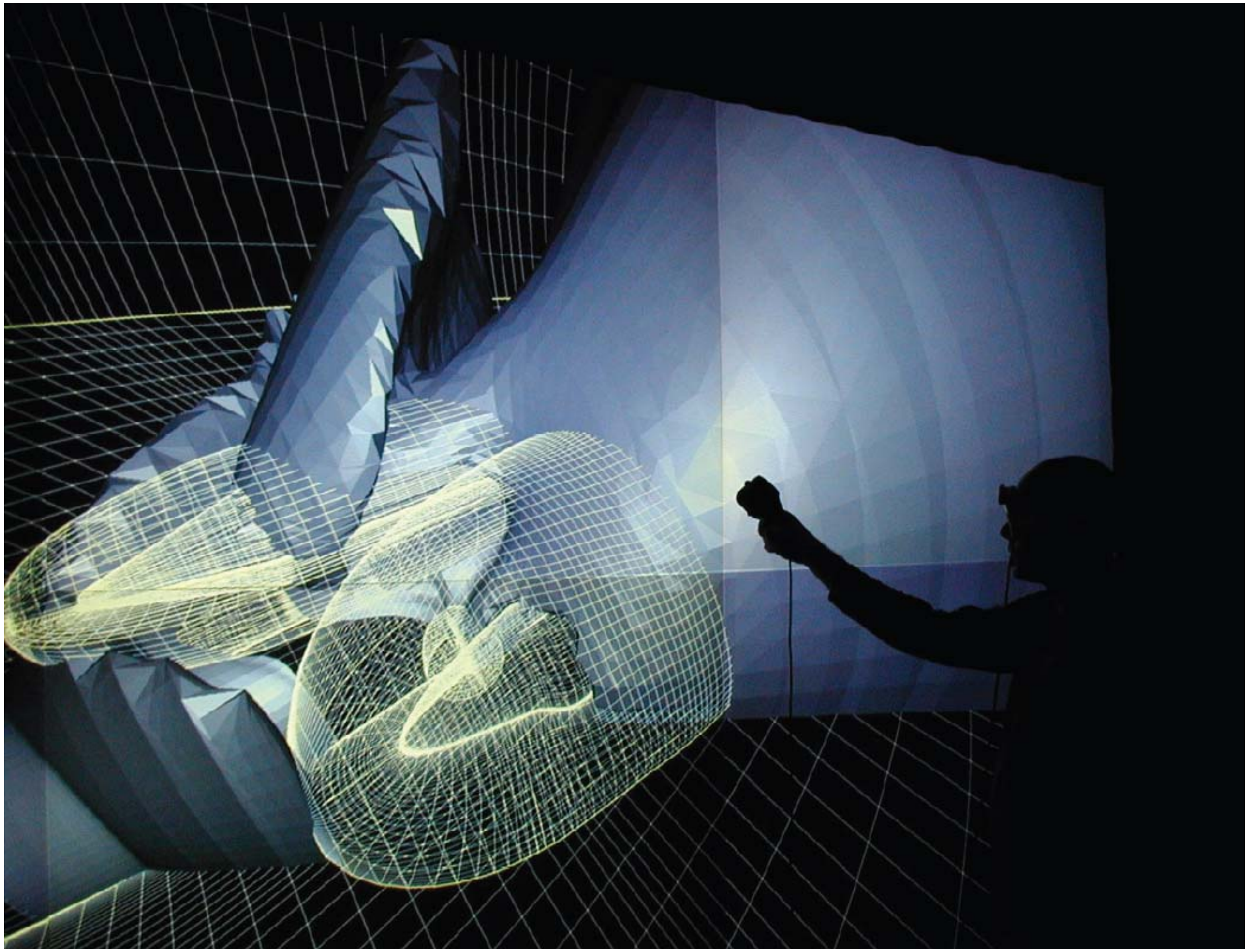
CS148 Lecture 11 Pat Hanrahan, Winter 2007

IBM T221

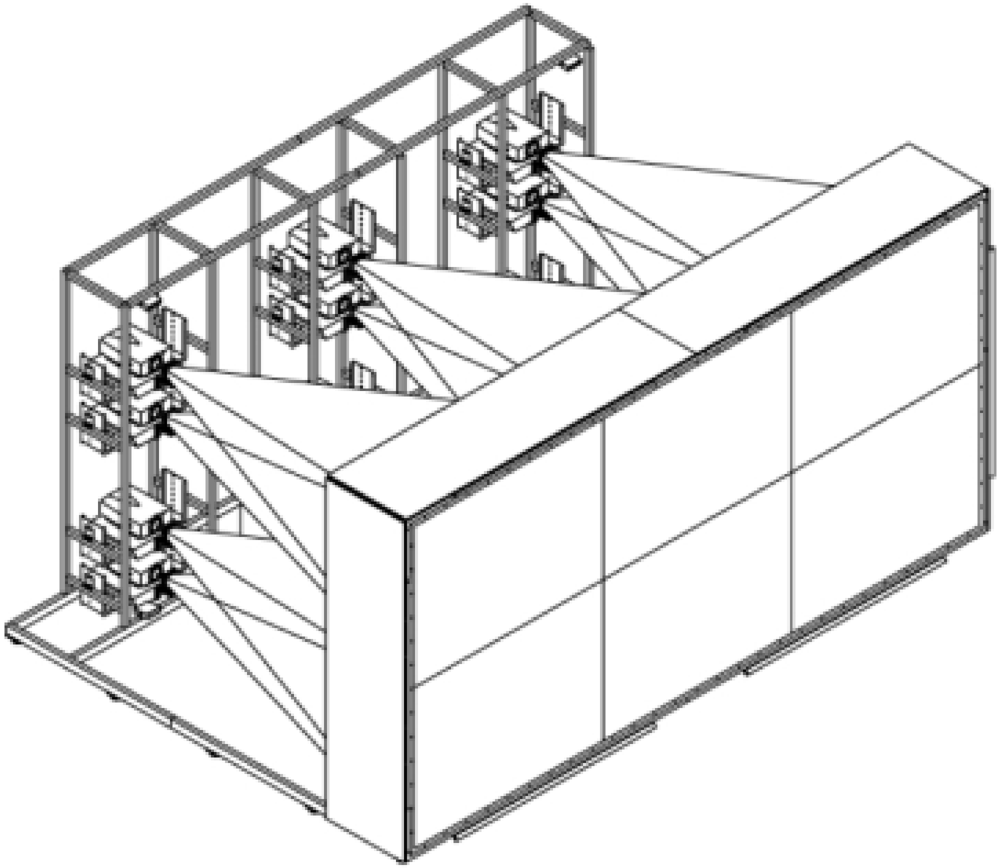
- **Resolution: 3840 x 2400 (QXGA)**
- **Size: 21,5’’ x 17,3” (204 dpi)**

Powerwall

- **[UC Davis]**



Powerwall



- **Resolution: 3*1280 x 2 * 1024 = 3840 x 2048**
- **Size: 18’ x 9’ (18 dpi)**

Sony SXRD 4K Projector

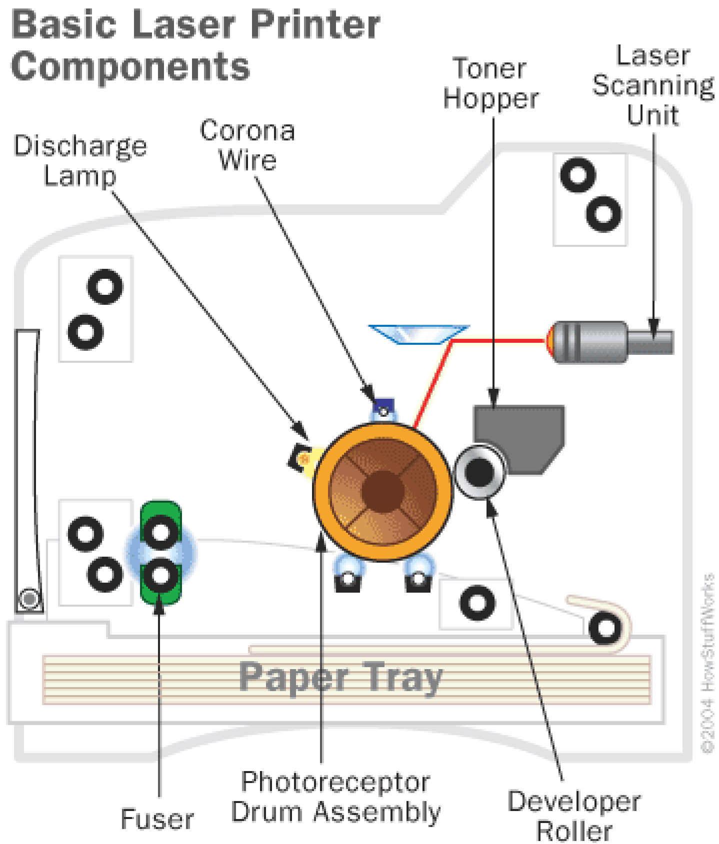
- **resolution 4096x2160**
- **contrast: 1800:1**
- **10000 Lumens**

VGA PDA

- **Resolution: 640 x 480 (VGA)**
- **Size: 3,5” x 2,6” (182 dpi)**

Printer

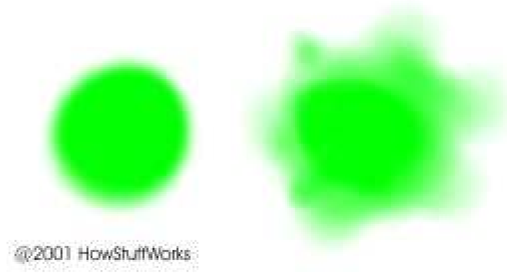
[from http://computer.howstuffworks.com]



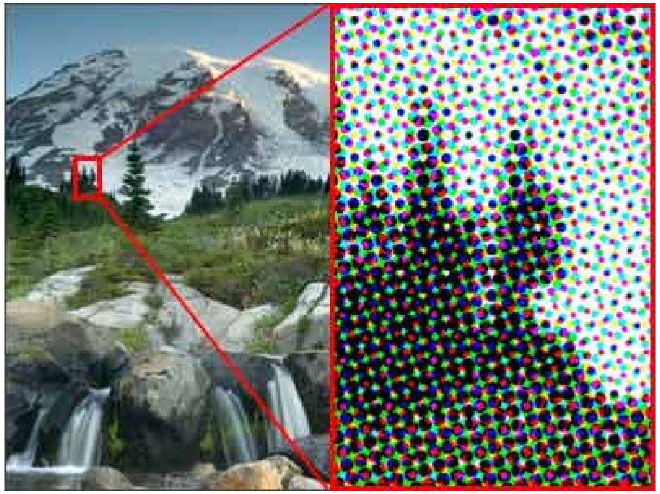
- **resolution: about 600 dpi**
- **magazines: ~300 dpi**
- **newspapers: 150-200 dpi**

Inkjet Printers

- http://computer.howstuffworks.com/inkjet-printer3.htm



coated and copier paper

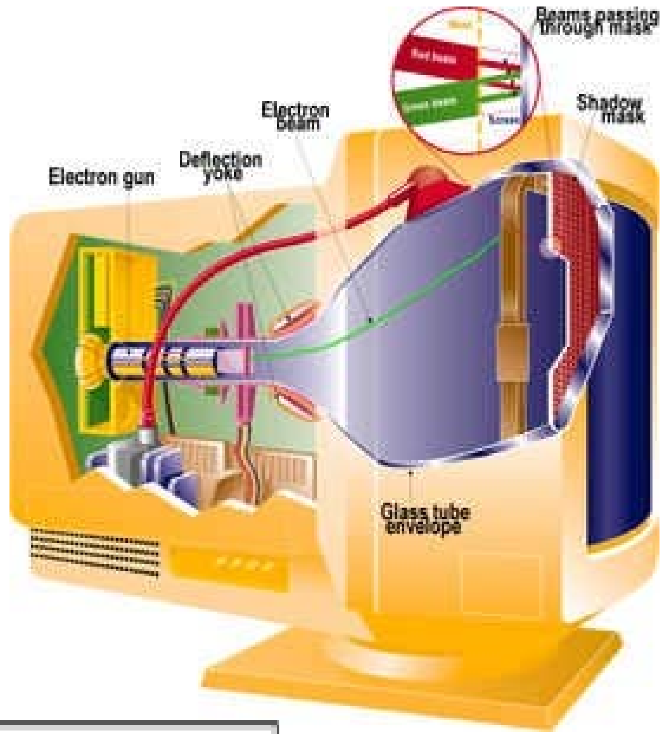


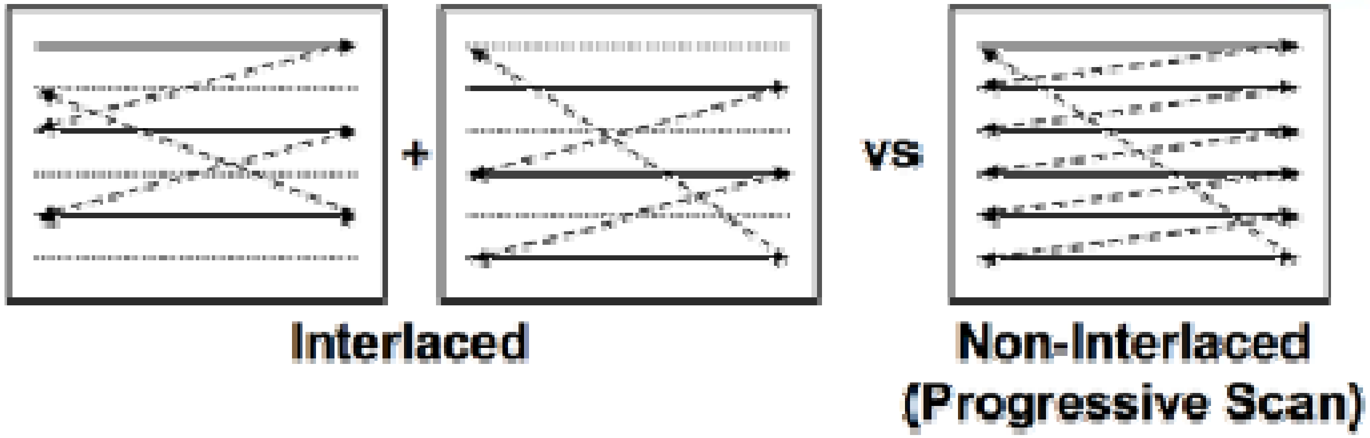
- **resolution: >= 2880 dpi**
- **“Gigapixel” displays**

CRT

- **Critical flicker fusion rate**
  - higher ambient light, large field: ~80 Hz
  - low ambient light: 20-30 Hz

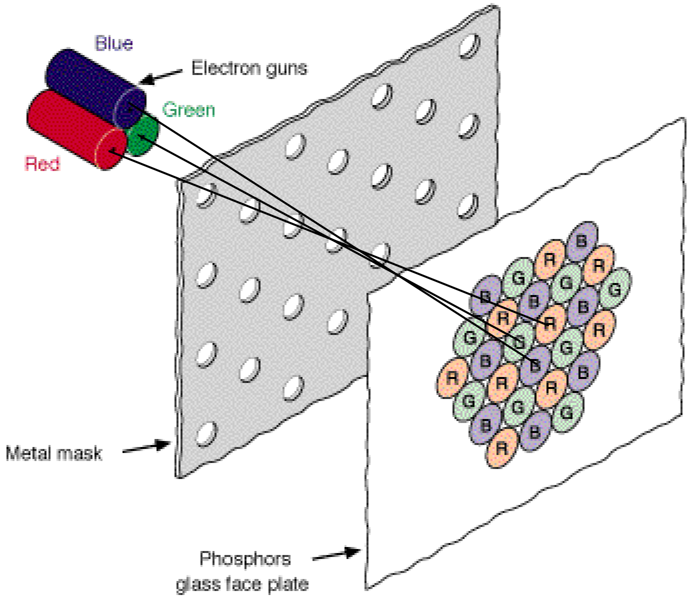
- **Frames per second (FPS)**
  - Film 24 FPS
  - TV (interlaced) 30 FPS x ¼ = 8MB/s
  - Workstation 75 FPS x 5 = 375MB/s

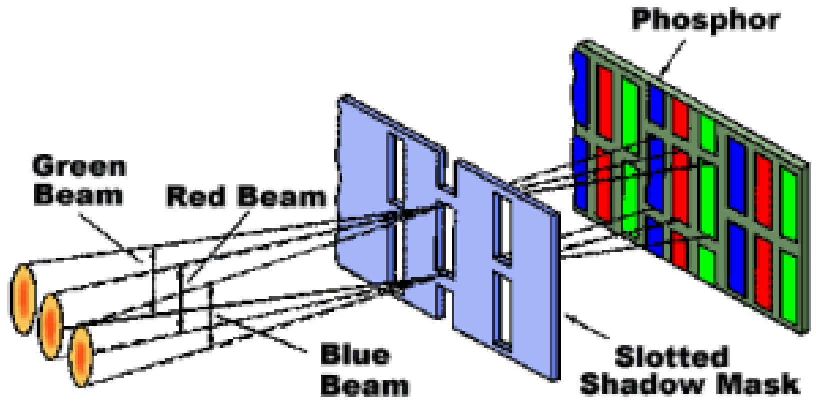


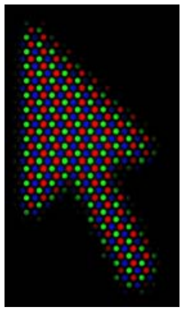


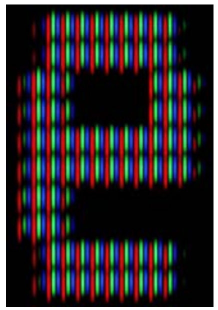
Technology

Cathode Ray Tube





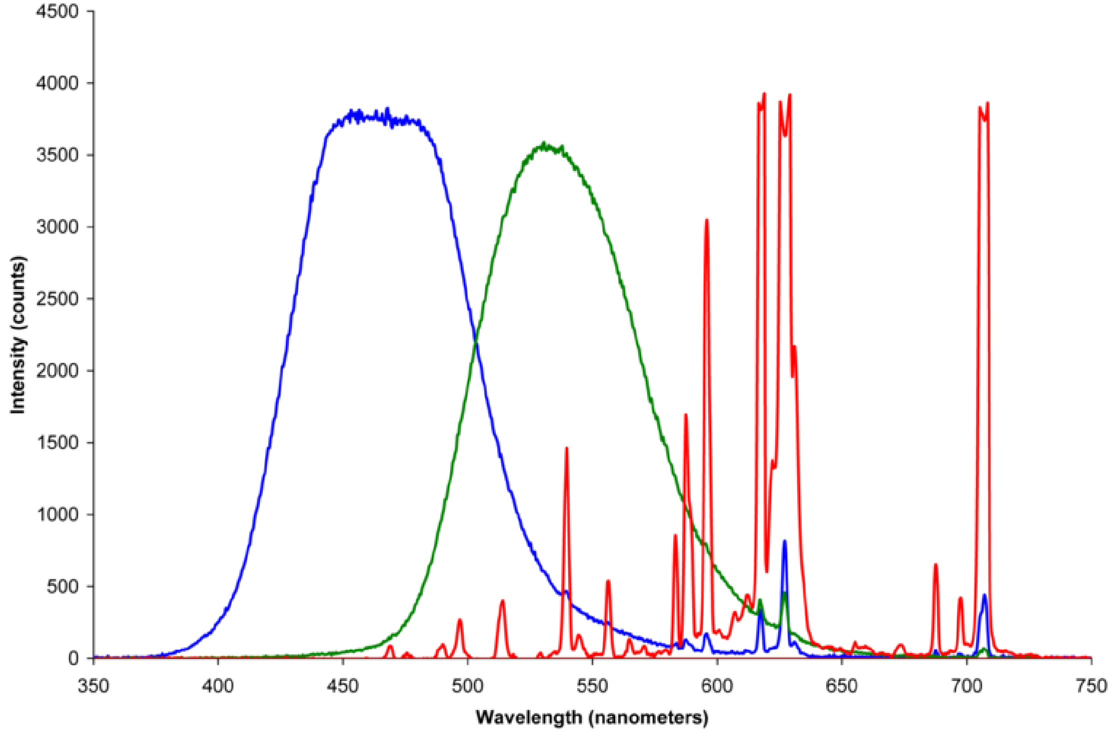




[from wikipedia]

Spectral Composition

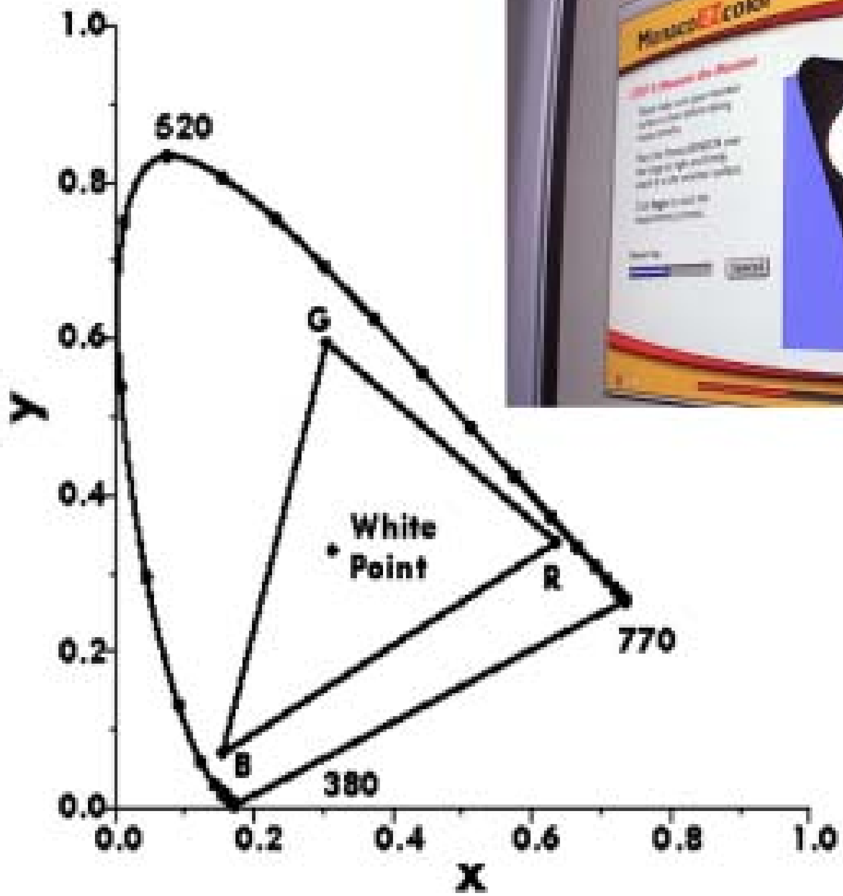
- **three different phosphors**



[from wikipedia]

- **saturated and natural colors**
- **inexpensive**
- **high contrast and brightness**

Monitor Calibration



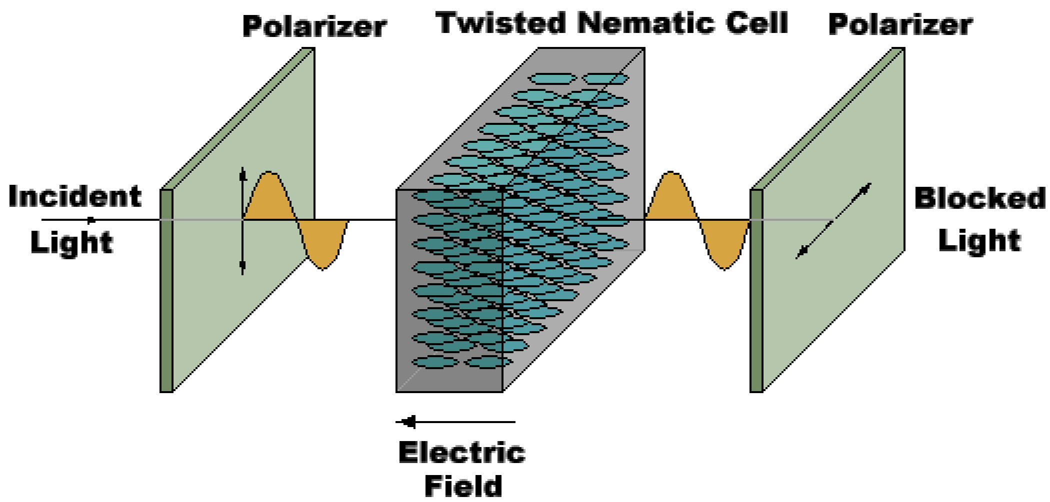
slide021

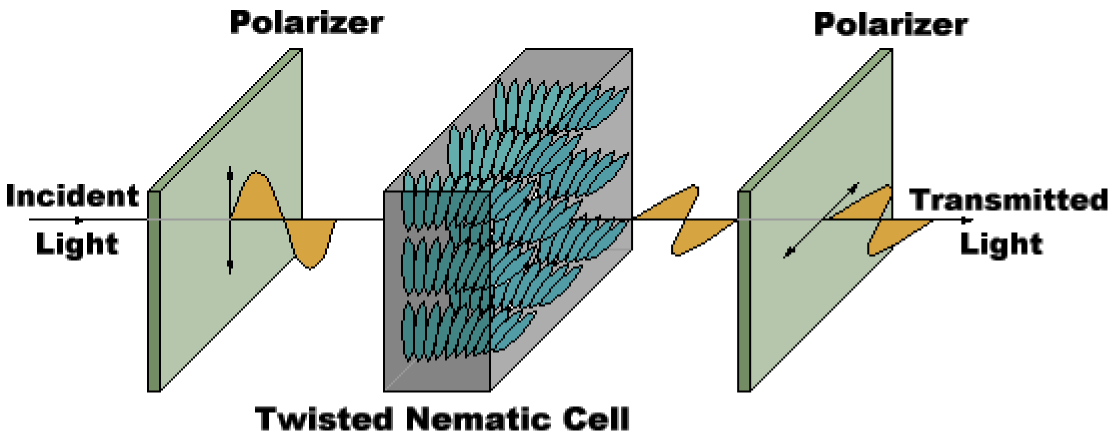
Monitor Phosphors

	x	y
R	.635	.340
G	.305	.595
B	.155	.070
W	.313	.329

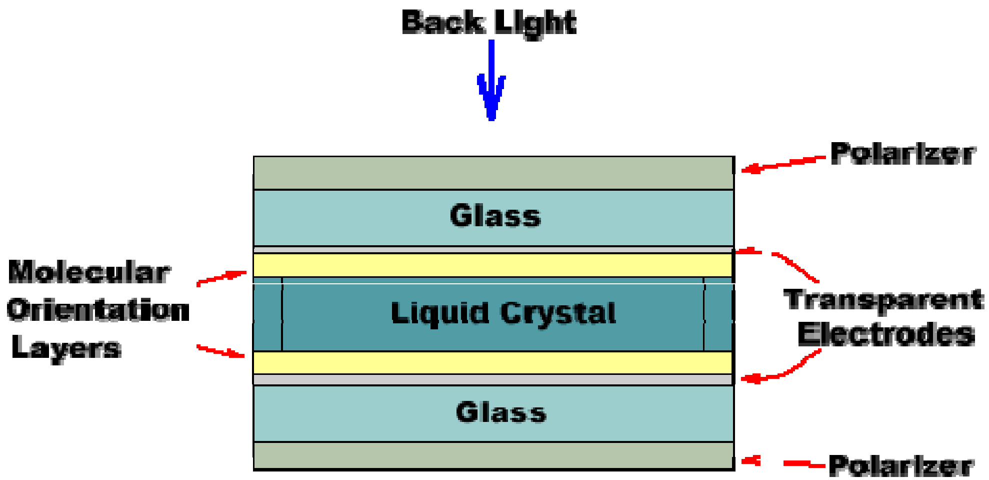
Liquid Chrystal Displays (LCD)

- http://computer.howstuffworks.com/monitor5.htm



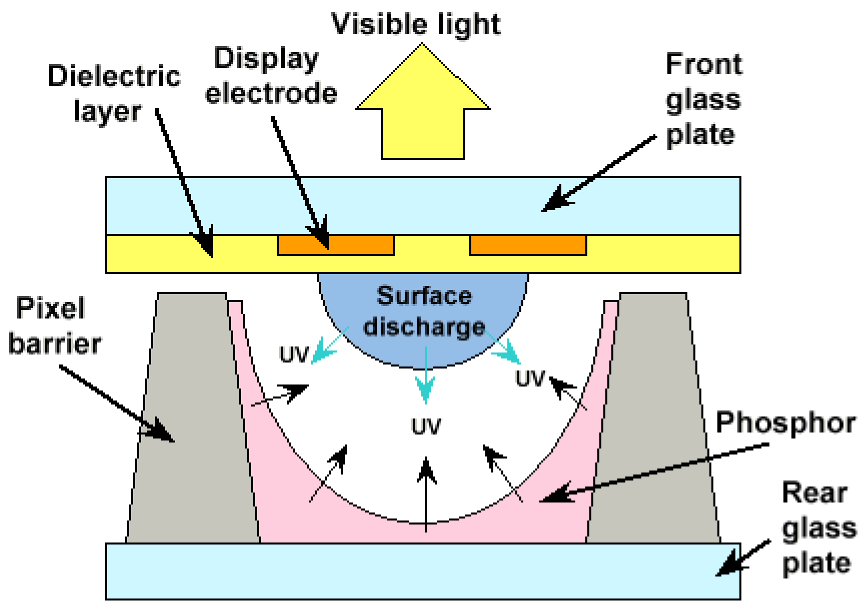


LCD



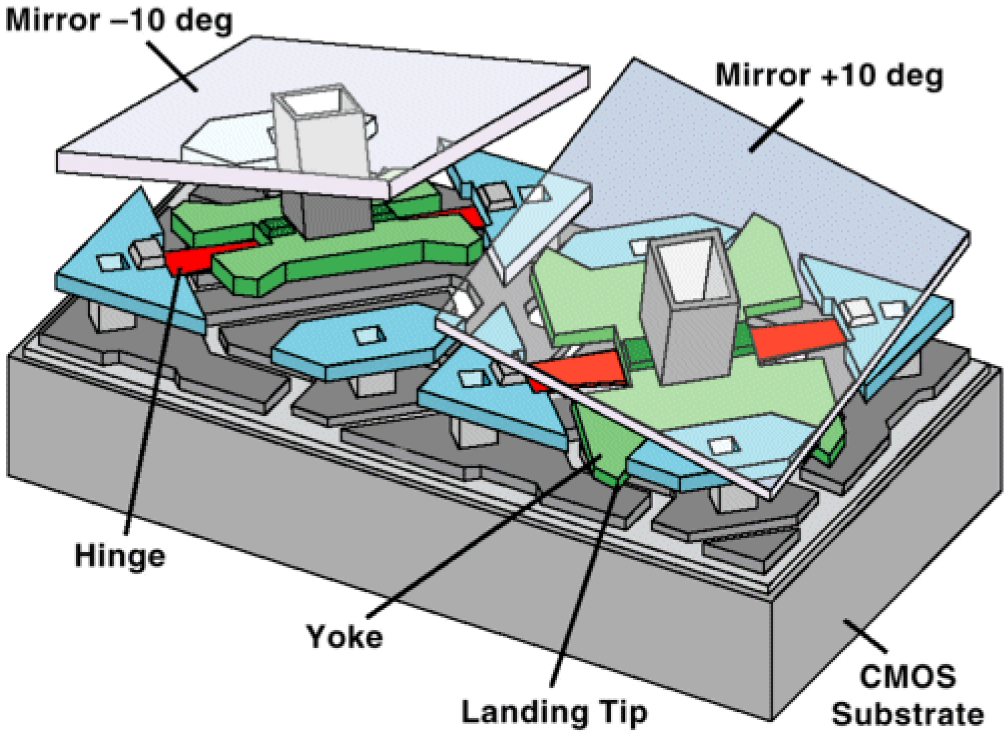
- **narrow viewing angle**
- **low contrast**
- **light weight**
- **for monitors and projectors**

Plasma

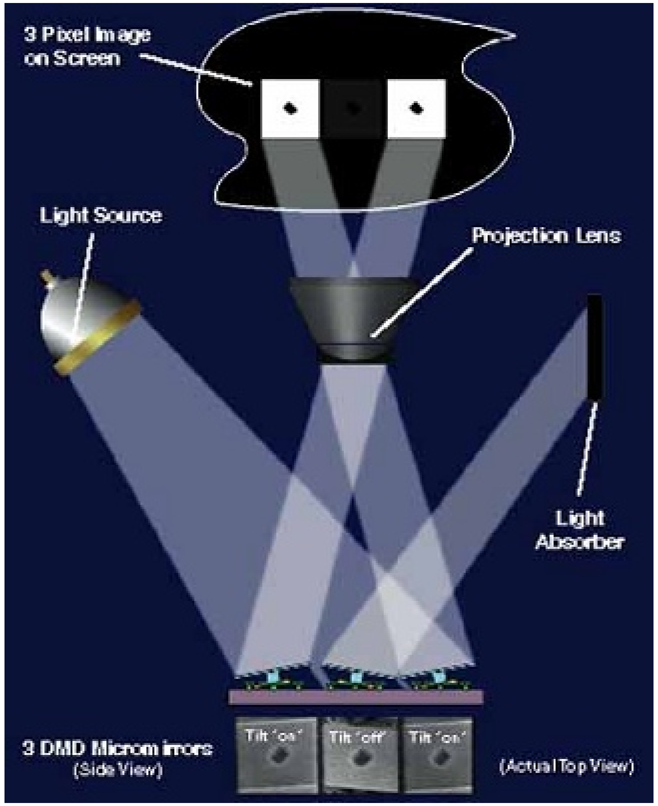


- **basically fluorescent tubes**
- **large formats possible**
- **UV light excites phosphors**
- **large viewing angle**

Digital Micromirror Devices (DMDs/DLP)



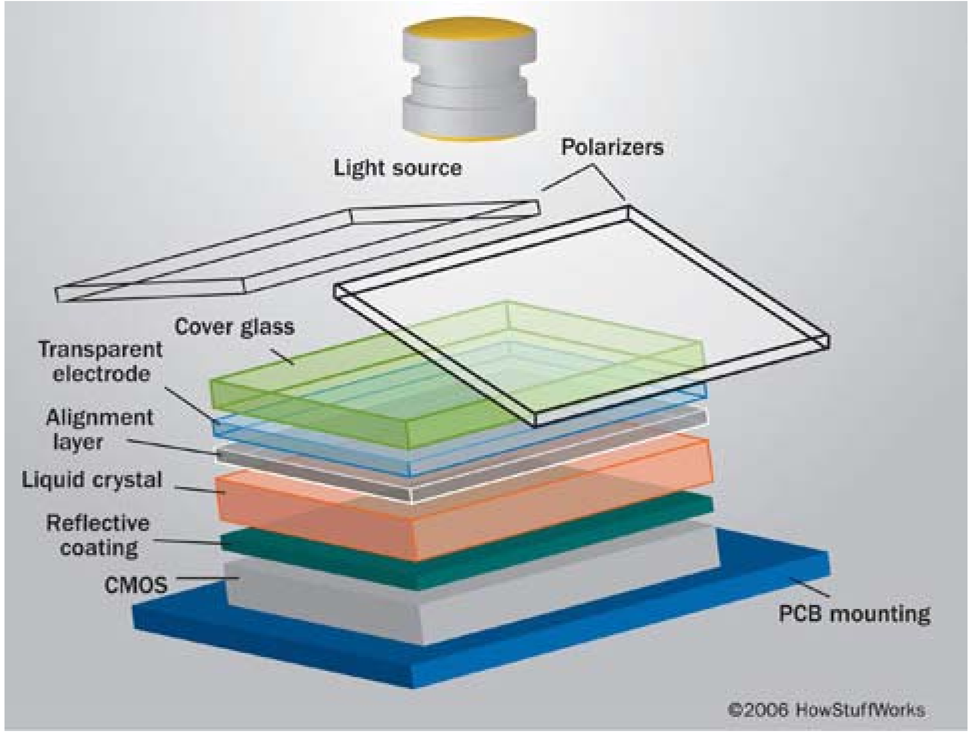
Texas Instruments

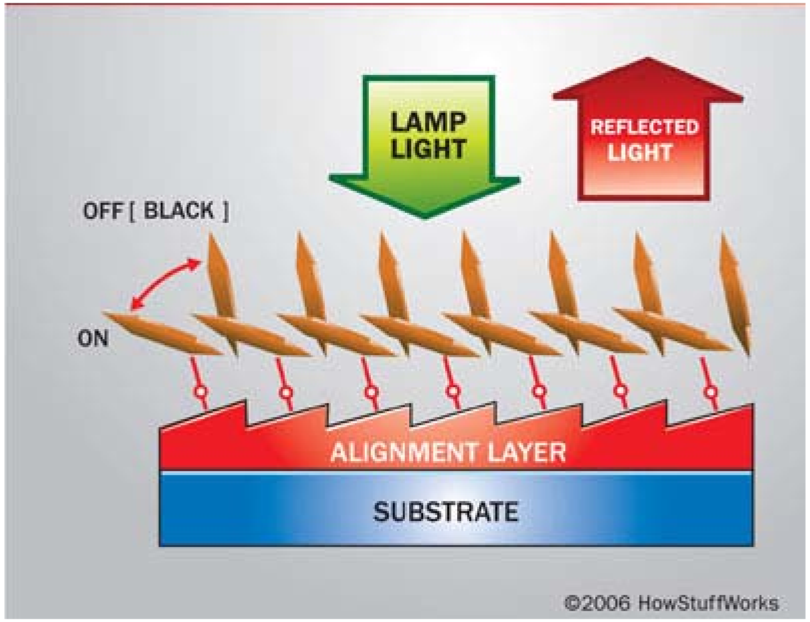


- **2-D array of mirrors**
- **Truly digital pixels**
- **Grey levels via Pulse-Width Modulation**

Liquid Crystal on Silicon LCOS

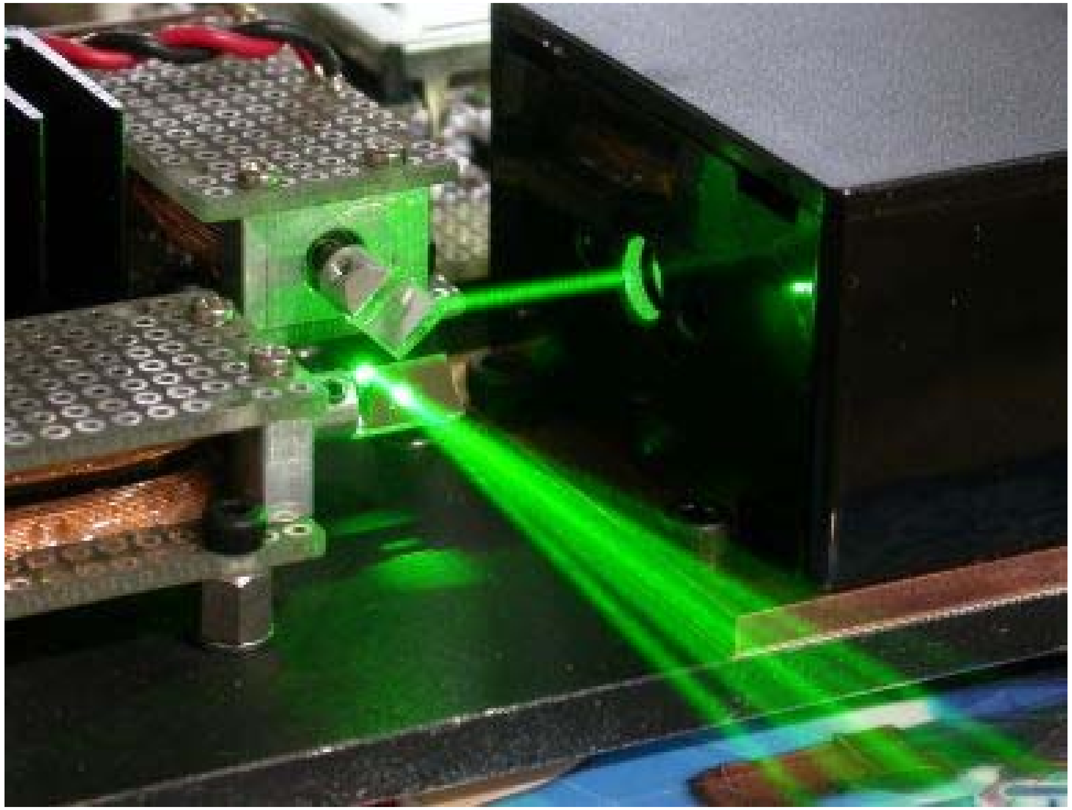
- http://electronics.howstuffworks.com/lcos3.htm





- **high fill factor**
- **high resolution**
- **low contrast (for now)**

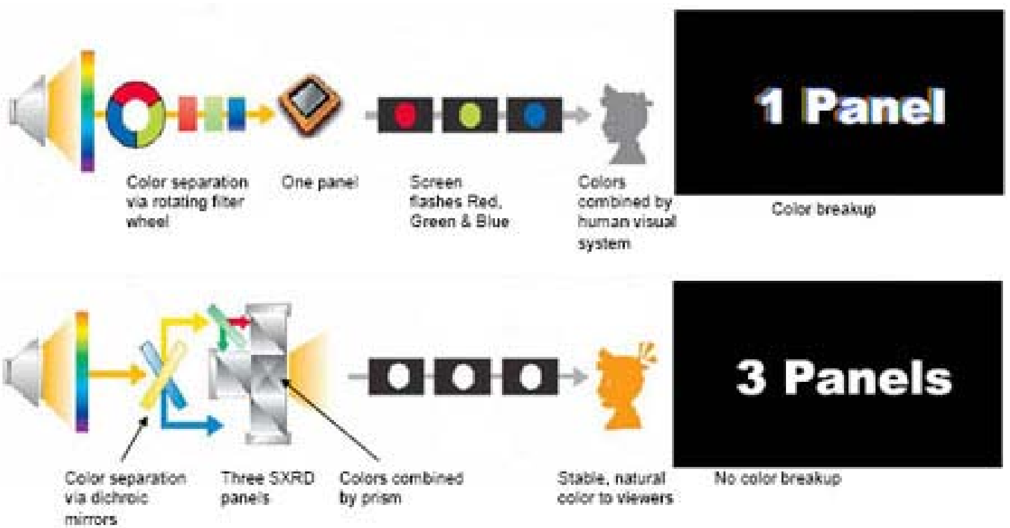
Laser Projector

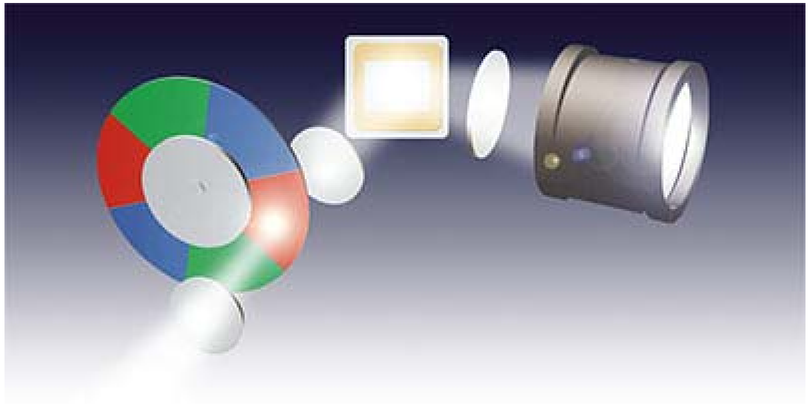


http://elm-chan.org/works/vlp/report_e.html

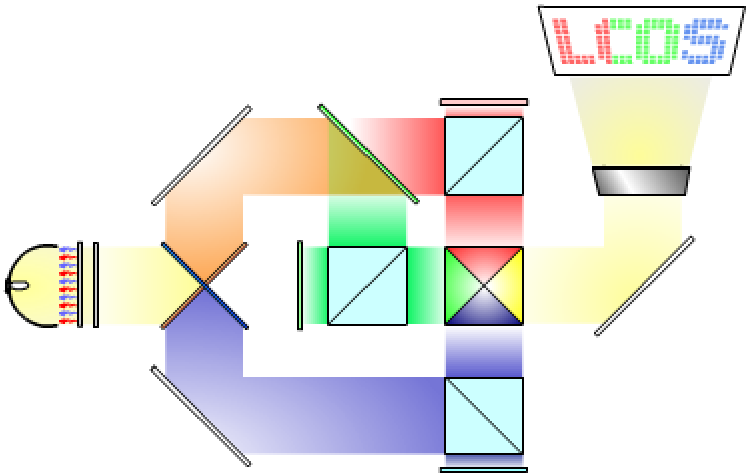
- **maximum contrast**
- **scanning rays**

3-chip vs. Color Wheel Display



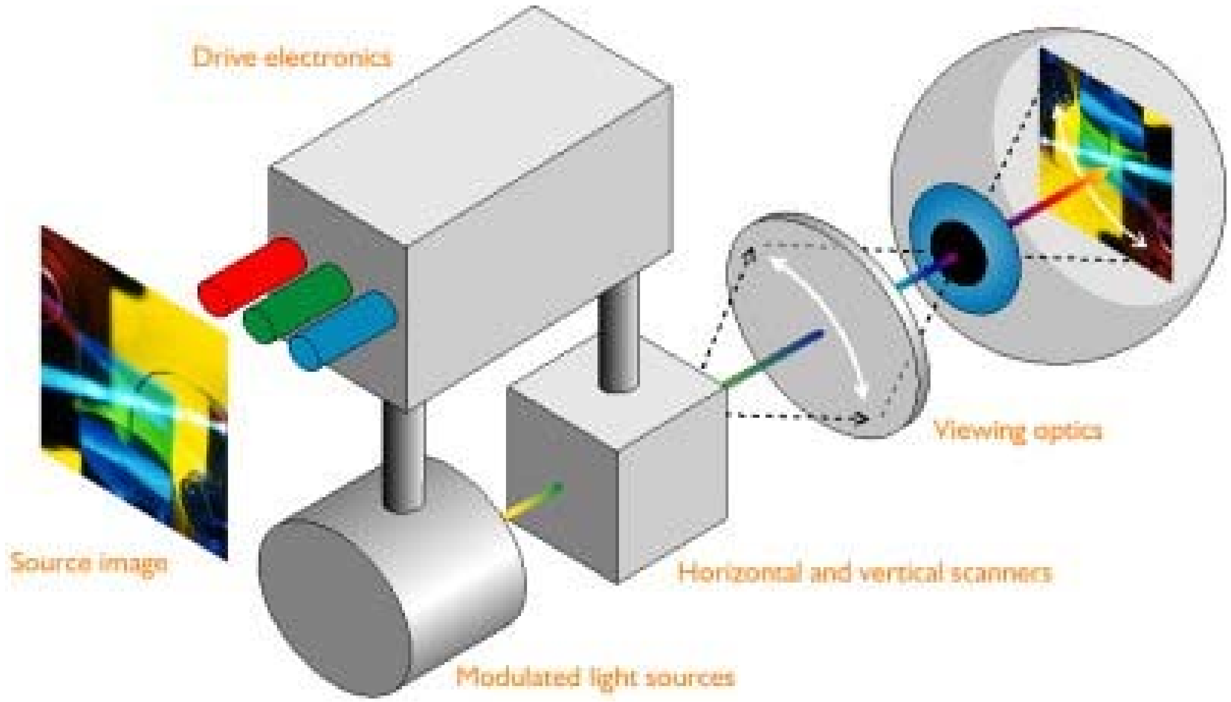


- **color wheel**
  - cheap
  - time sequenced colors
  - color fringes with motion/video
- **3-chip**
  - complicated setup
  - no color fringes



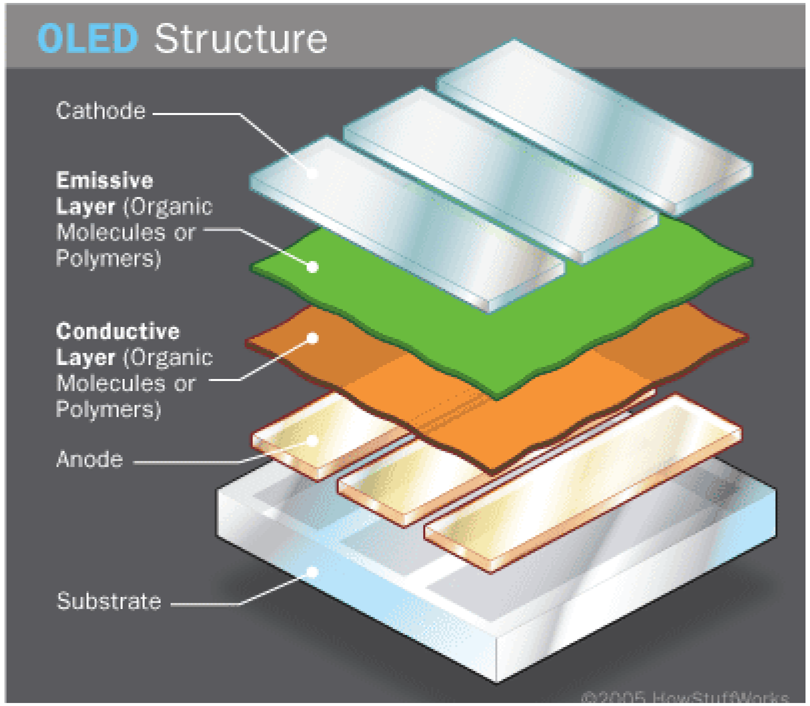
[redacted]

Virtual Retinal Display



- **projection onto the retina**

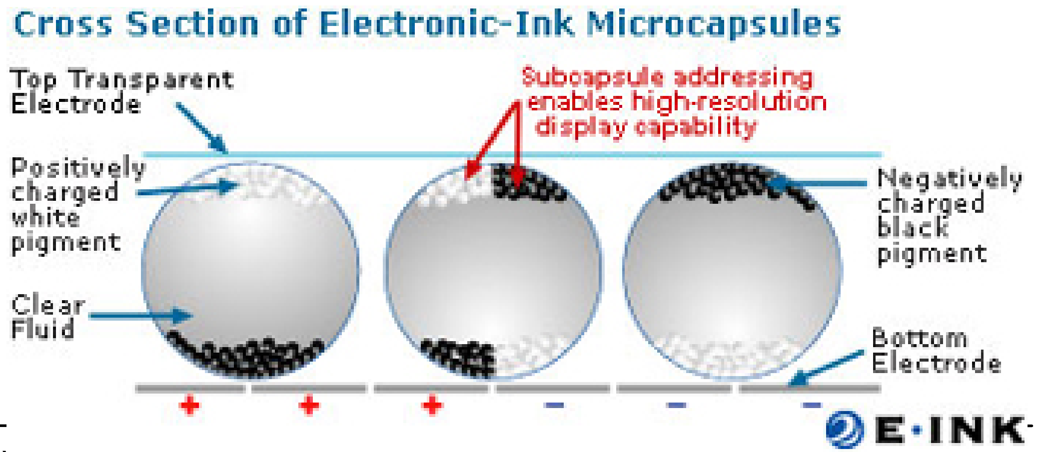
OLED



- **based on electrophosphorescence**
- **large viewing angle**
- **efficient (low power/low voltage)**
- **fast (< 1 microsec)**
- **arbitrary sizes**

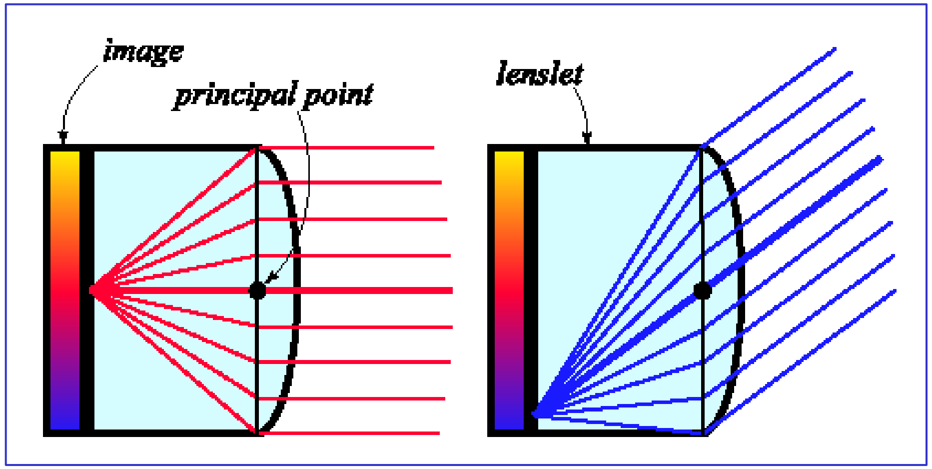
Electronic Paper

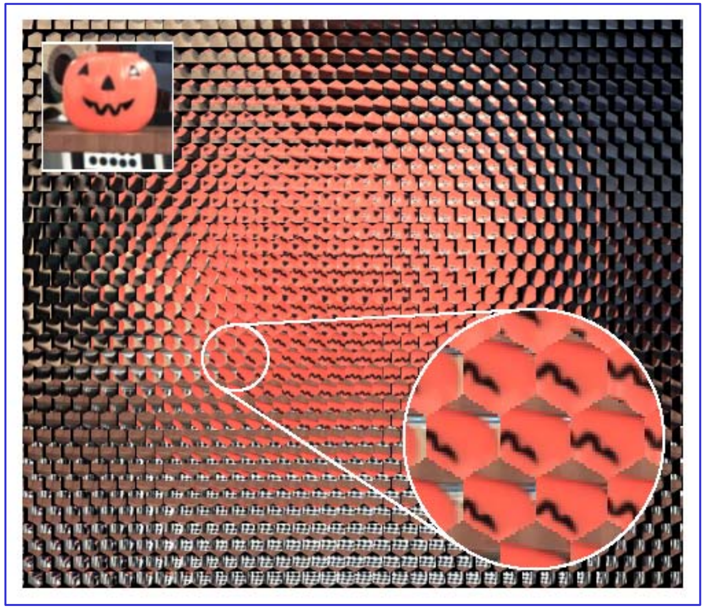
www.eink.com



Display Technologies – 3D Displays

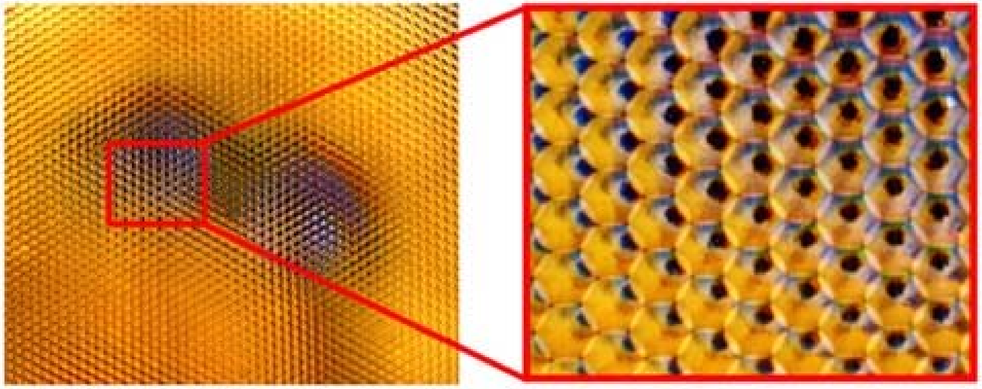
- **integral photography, e. g. [Okano98]**
- **micro lens-array in front of screen**
- **screen at focal distance of micro lenses**
  - → parallel rays for each pixel
  - → every eye sees a different pixel



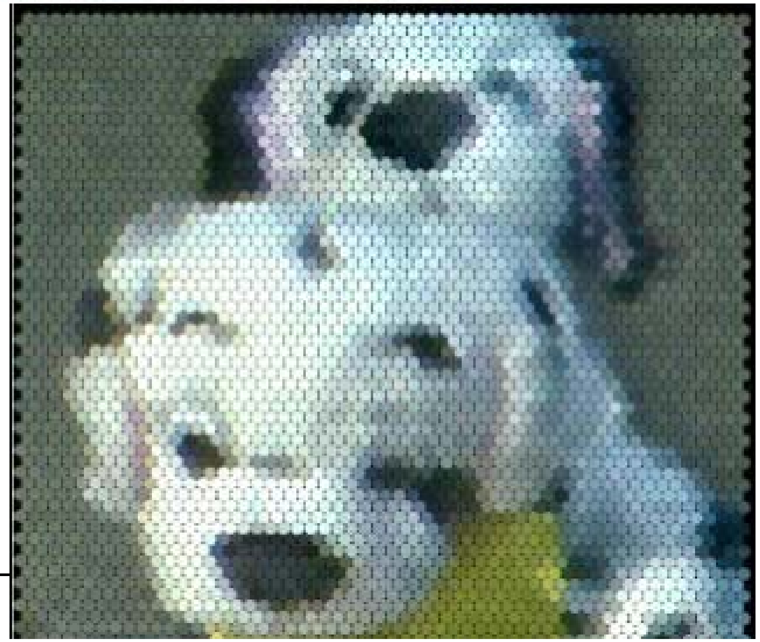


Display Technologies – 3D Displays

integral photograph close-up



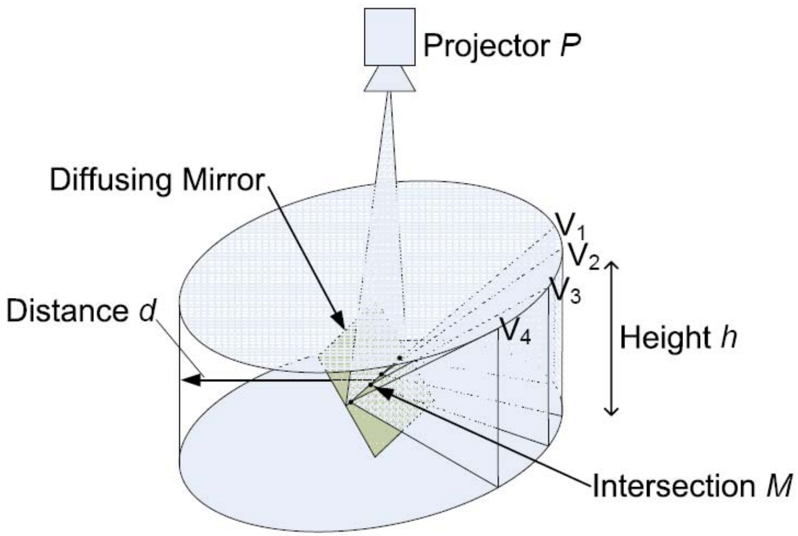
one particular view

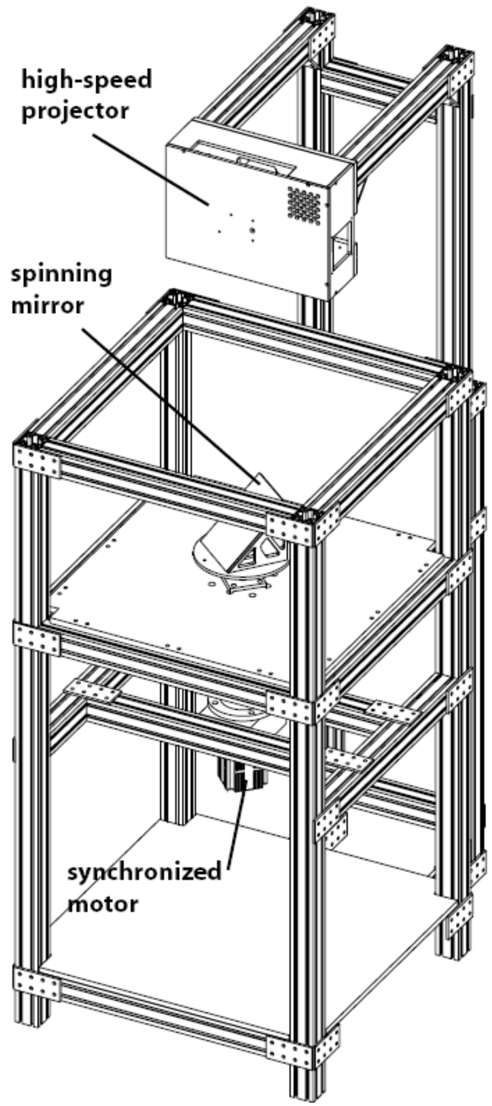


- need high resolution images
- taken with micro lens array
- arrays of graded index (GRIN) lenses
- screen is auto-stereoscopic
  → no glasses, multiple users

Display Technologies – 3D Displays

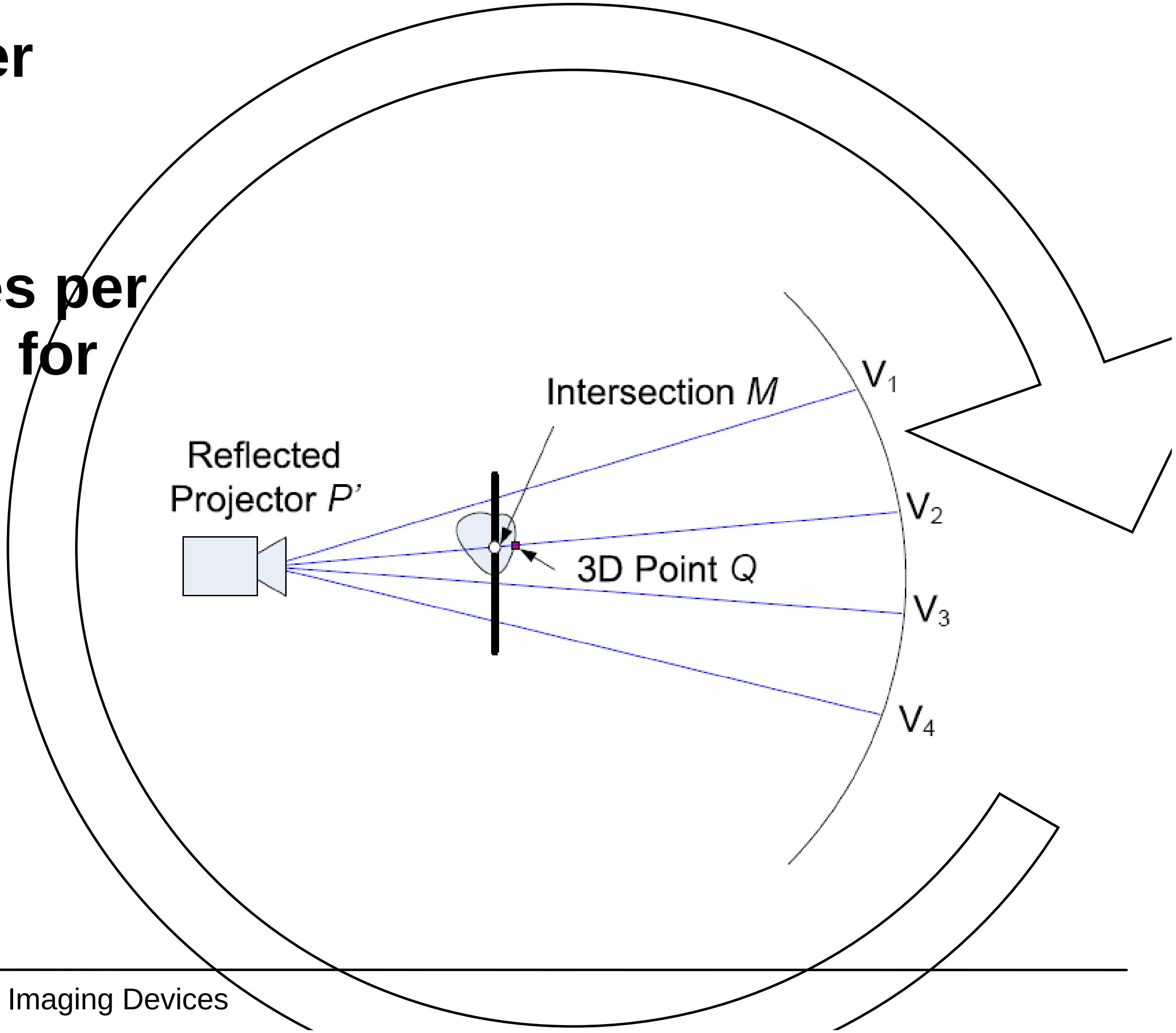
- **rotating front surface mirror with anisotropic diffusion filter on top**
- **diffuses light**
  - in vertical direction perfectly
  - in horizontal direction only in a very limited angle





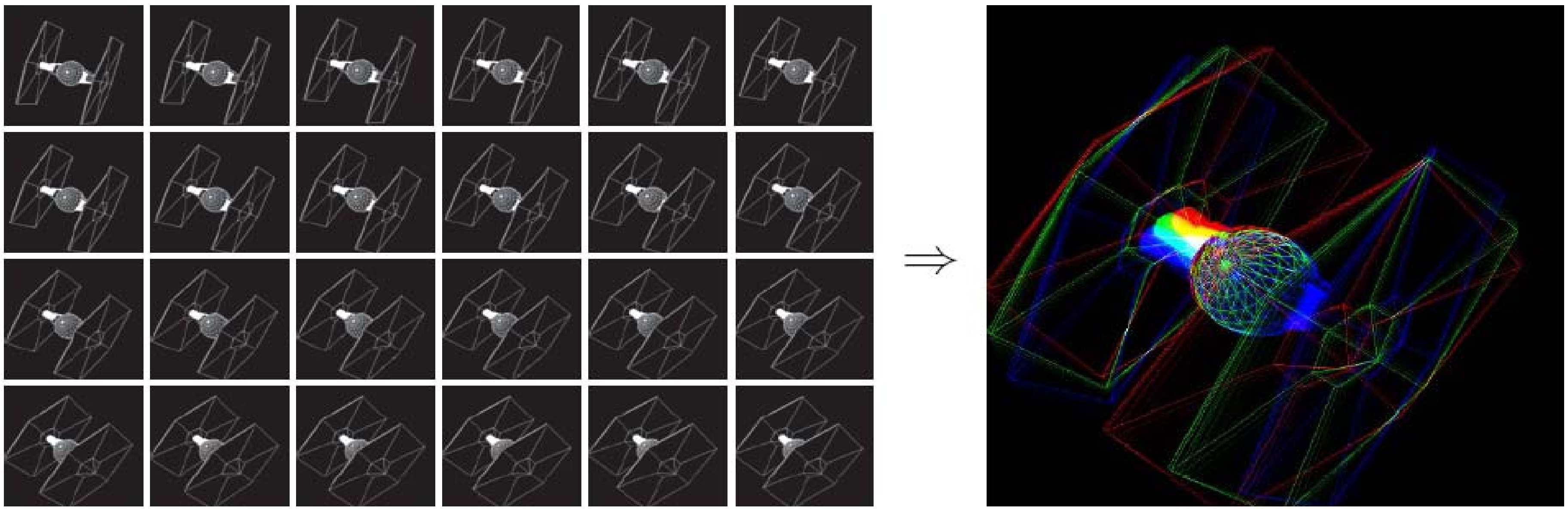
Display Technologies – 3D Displays

- **can be regarded as a rotating projector**
- **~17 3D frames per second**
- **288 angular bins**
- **need ~5000 frames per second rendering for the projector**



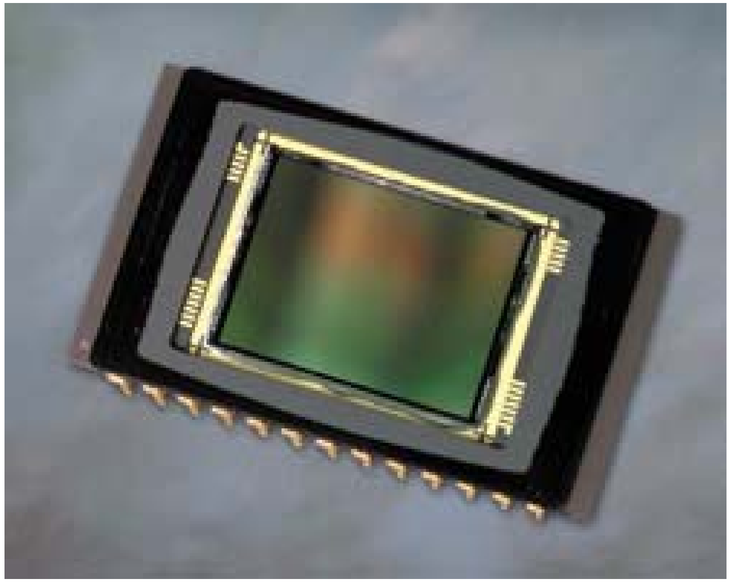
Display Technologies – 3D Displays

- **render only binary images (dithered)**
- **specially encoded DVI signal (every bit is a pixel instead of RGB value → 24 pixels per normal color pixel)**
- **200 Hz refresh rate (GeForce 8800) = 4800 fps**
- **special decoder chip necessary**

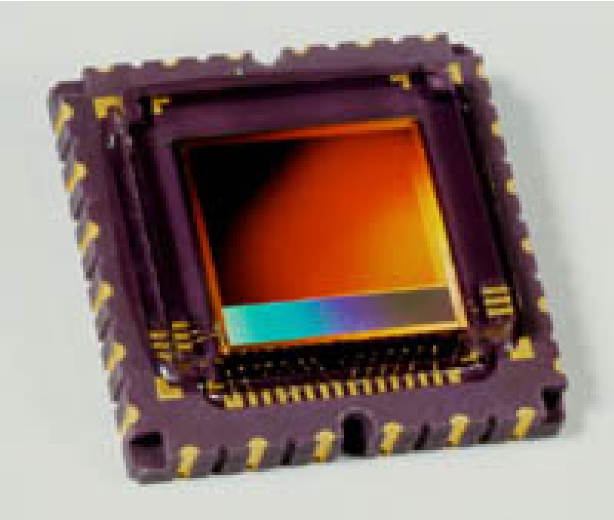


Imaging Devices

Image Sensors



CCD



CMOS

Photodetectors

- **(a) photodiode, (b) photogate**
- **All electrons created in *depletion region* are collected, plus some from surrounding region.**

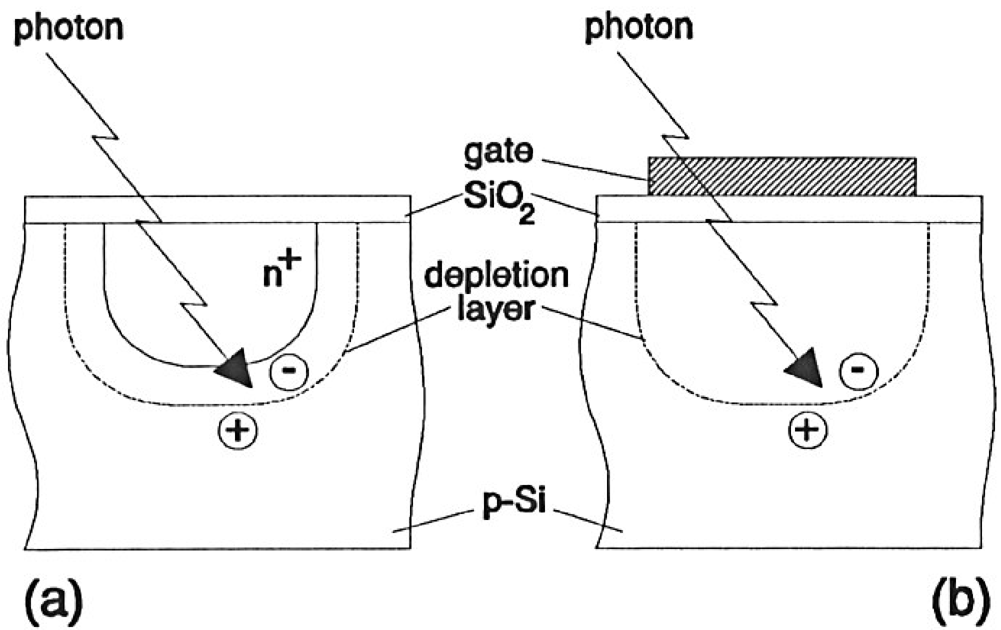


image: Theuwissen

Photodetector Performance Metrics

- **Pixel size**
- **Fill factor**
- **Full well depth**
- **Spectral quantum efficiency**
- **Sensitivity**
- **(Saving noise & dynamic range for later)**

Lenslets

- **Increase effective fill factor by focusing light**
- **Can double or triple fill factor**

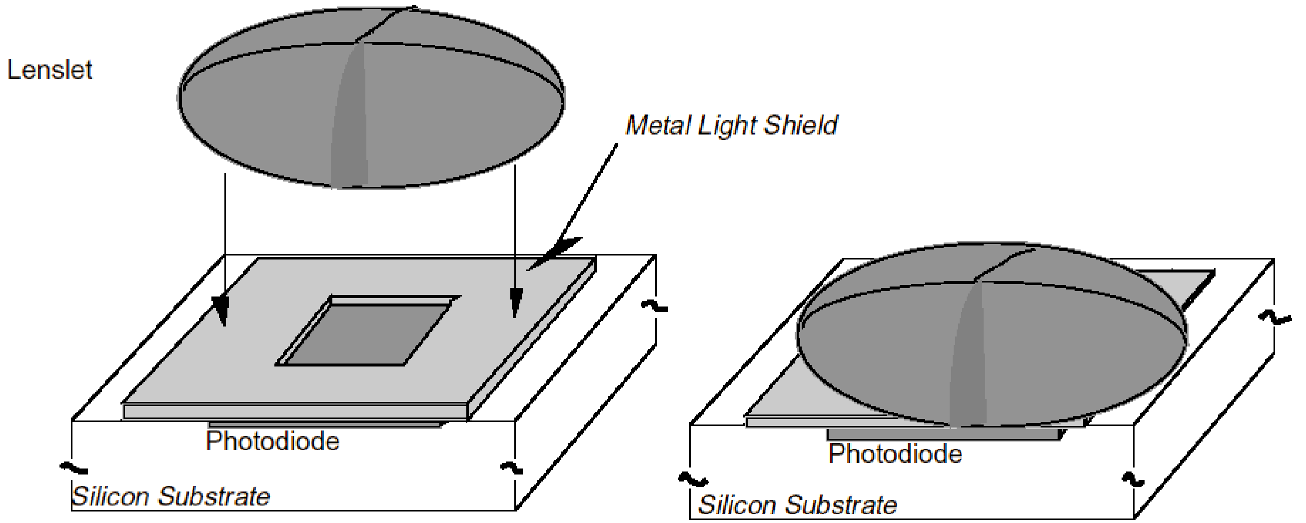
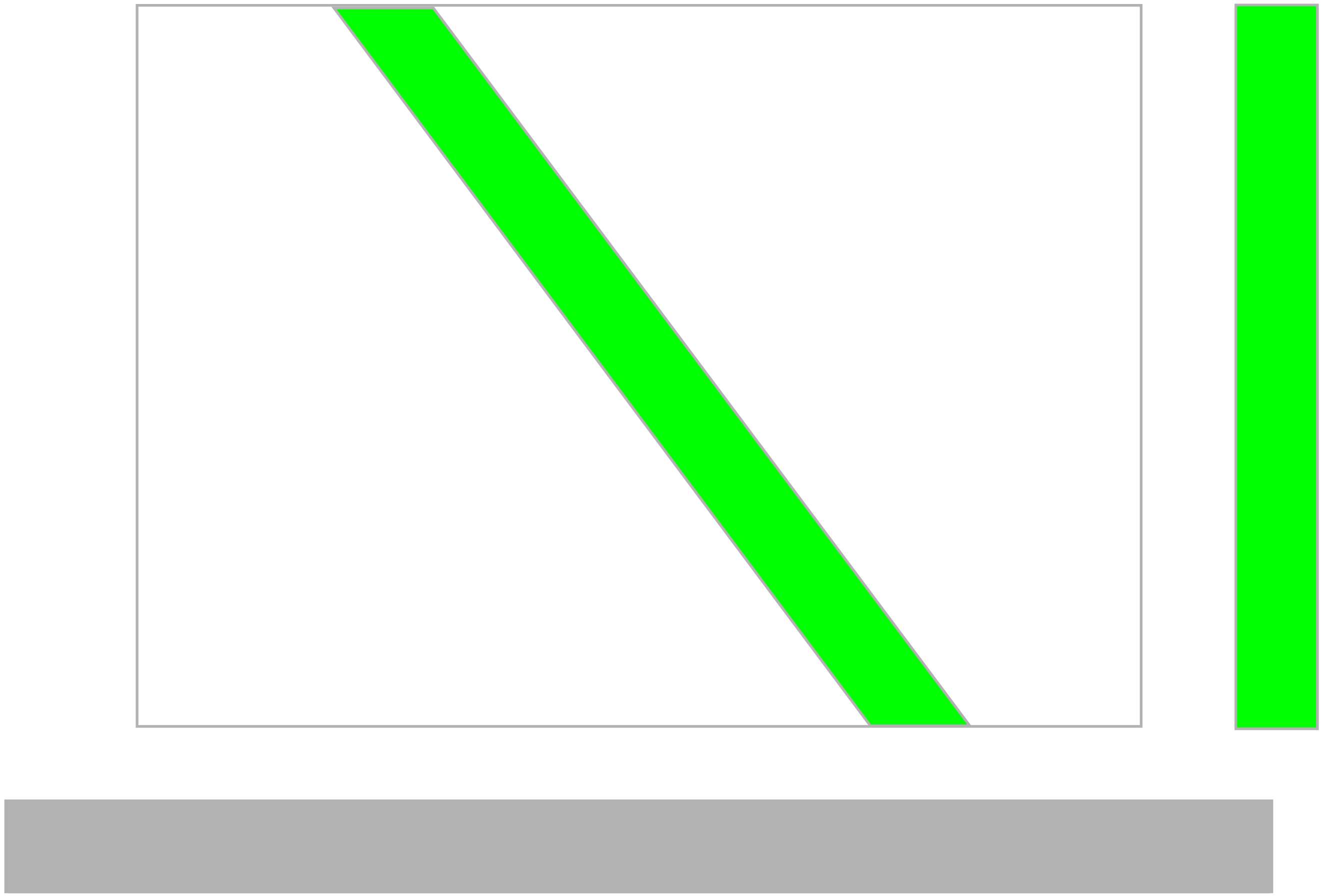
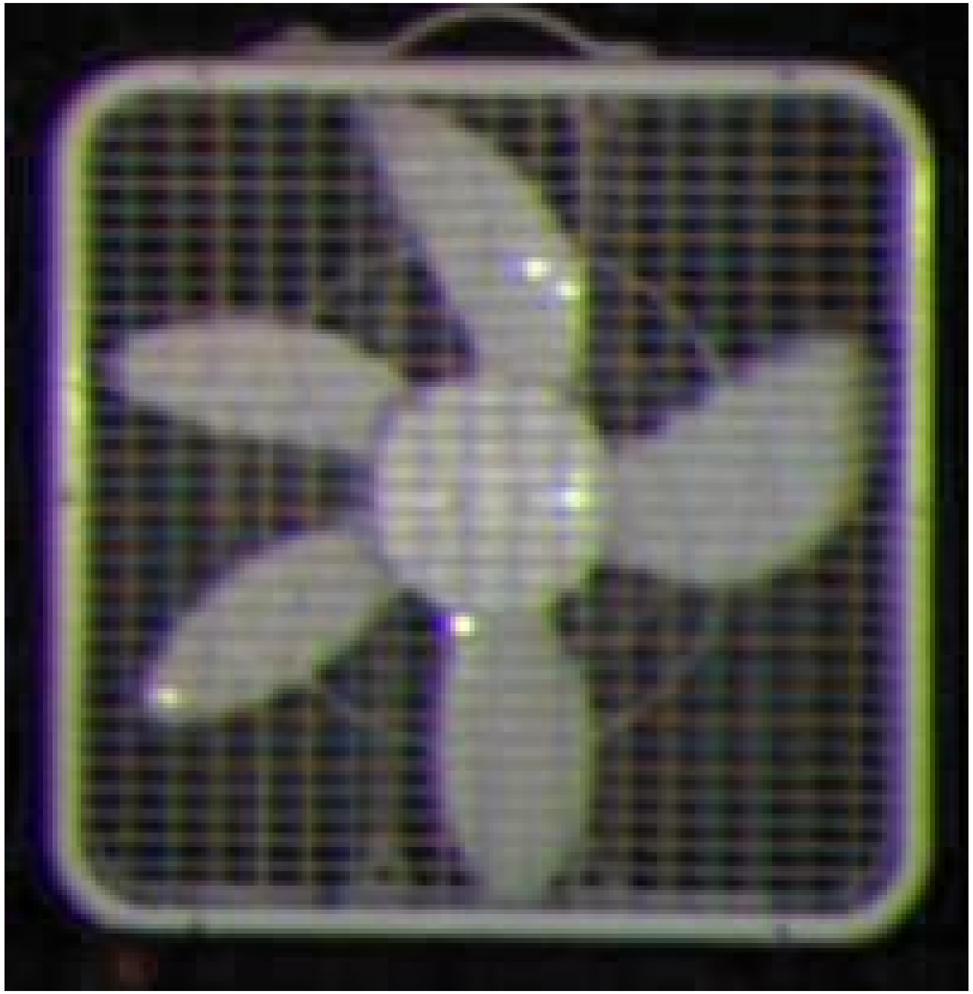


image: Kodak application note DS00-001

Rolling Shutter



Rolling Shutter Distortion



CCD’s vs CMOS Image Sensors

- **Differ primarily in readout—how the accumulated charge is measured and communicated.**
- **CCD’s transfer the collected charge, through capacitors, to *one* output amplifier**
- **CMOS sensors “read out” the charge or voltage using row and column decoders, like a digital memory (but with analog data).**

Charge Transfer for CCD’s

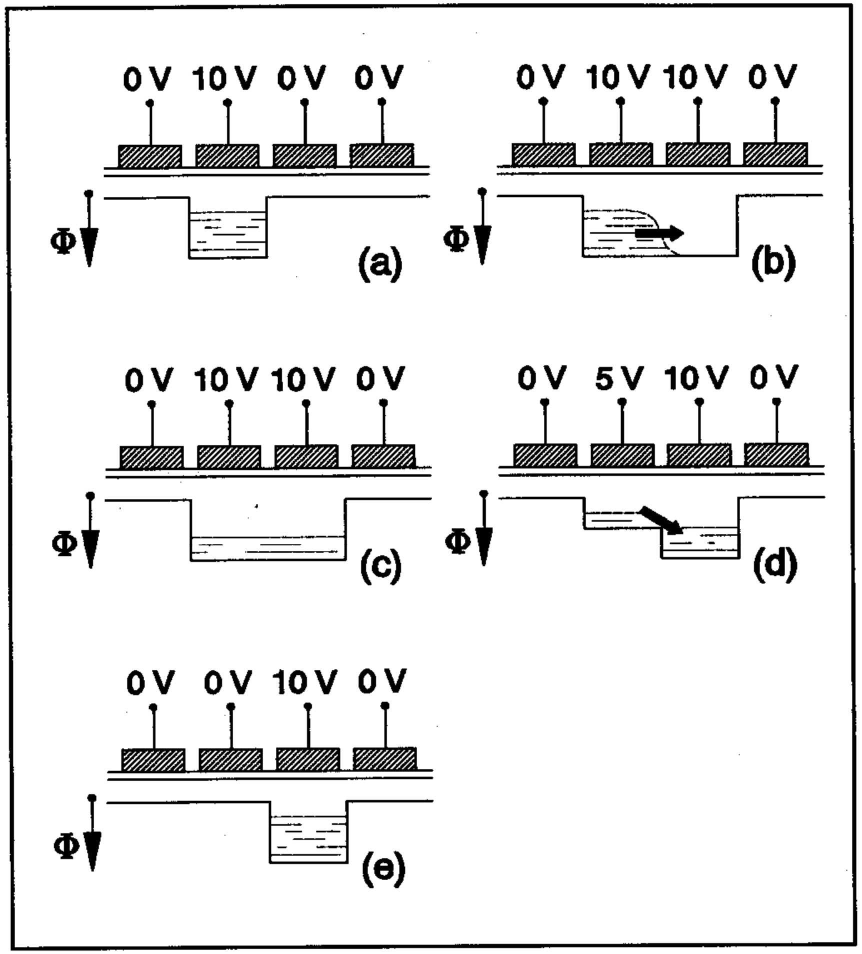


FIGURE 1.8. Illustration of the charge transport in a CCD. The charge packet of minority carriers is moved through the silicon by means of digital pulses on the CCD gates.

image: Theuwissen

Example:Three Phase CCD's

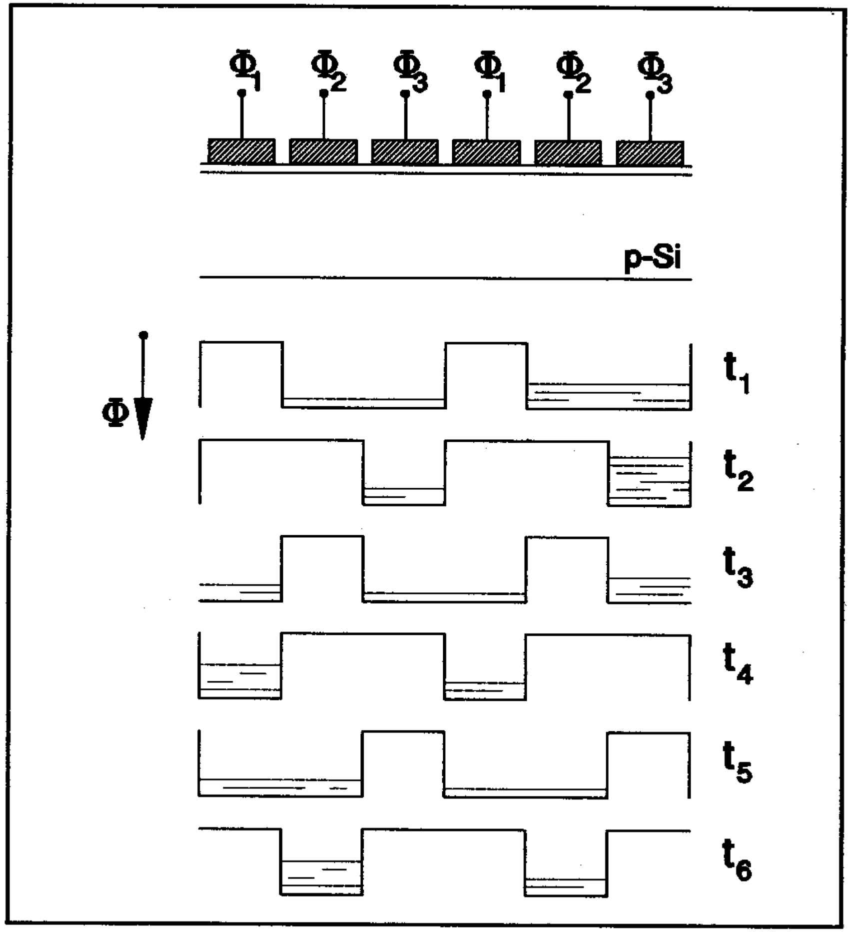


FIGURE 2.5. Cross section of a CCD transport section driven by a three-phase-clocking system.

image: Theuwissen

Full Frame CCD

- **Photogate detector doubles as transfer cap.**
- **Simplest, highest fill factor.**
- **Must transfer quickly (or use mechanical shutter) to avoid corruption by light while shifting charge.**

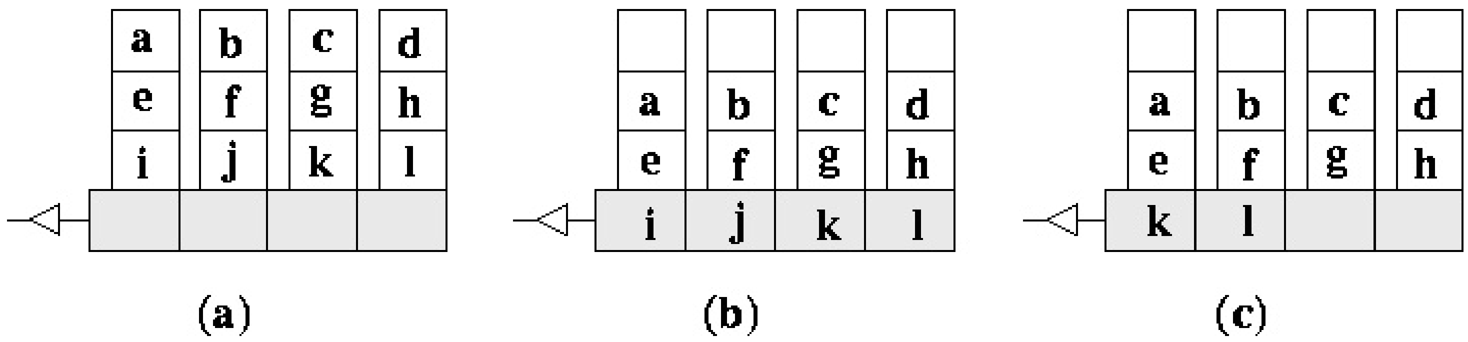
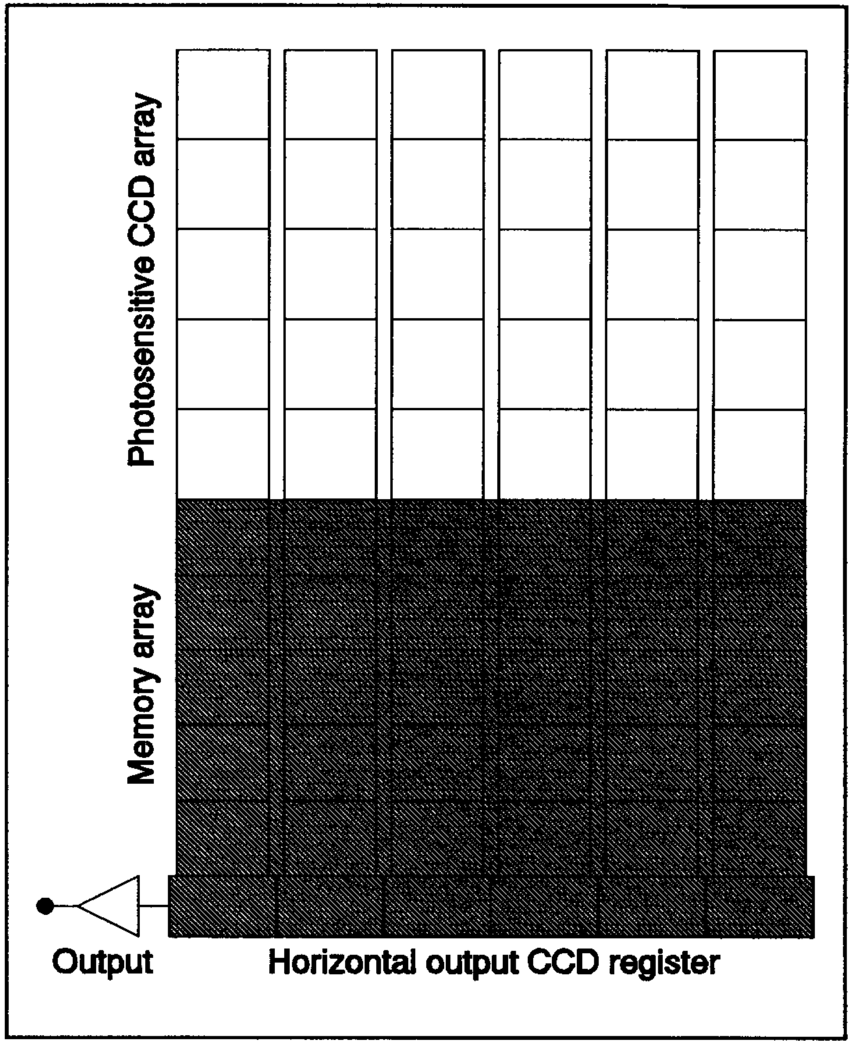


image: Curless

Frame Transfer



memory area is shielded

FIGURE 4.4. Device architecture of a frame-transfer image sensor.

image: Theuwissen

Smearing

vertical streak

wikipedia

Smearing

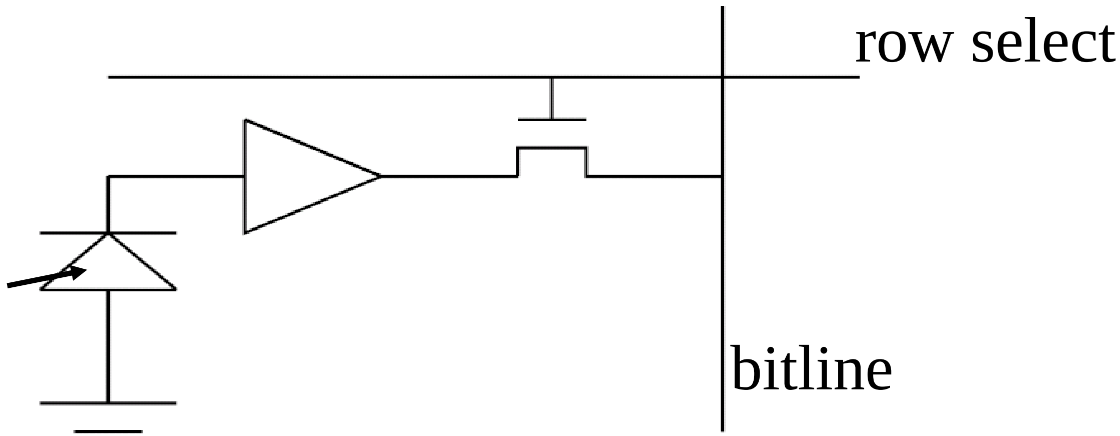
http://www.astrosurf.com/maugis/topo_ccd/smearing.jpg

Advantages of CCD’s

- **Advantages:**
  - Optimized photodetectors (high QE, low dark current)
  - Very low noise.
  - Single amplifier does not introduce random noise or fixed pattern noise.
- **Disadvantages**
  - No integrated digital logic
  - Not programmable (no window of interest)
  - High power (whole array switching all the time)
  - Limited frame rate due to charge transfer

CMOS Sensors (active pixel sensor - APS)

- charge converted to a voltage at the pixel
- pixel amp, column amp, output amp.



CMOS Sensors

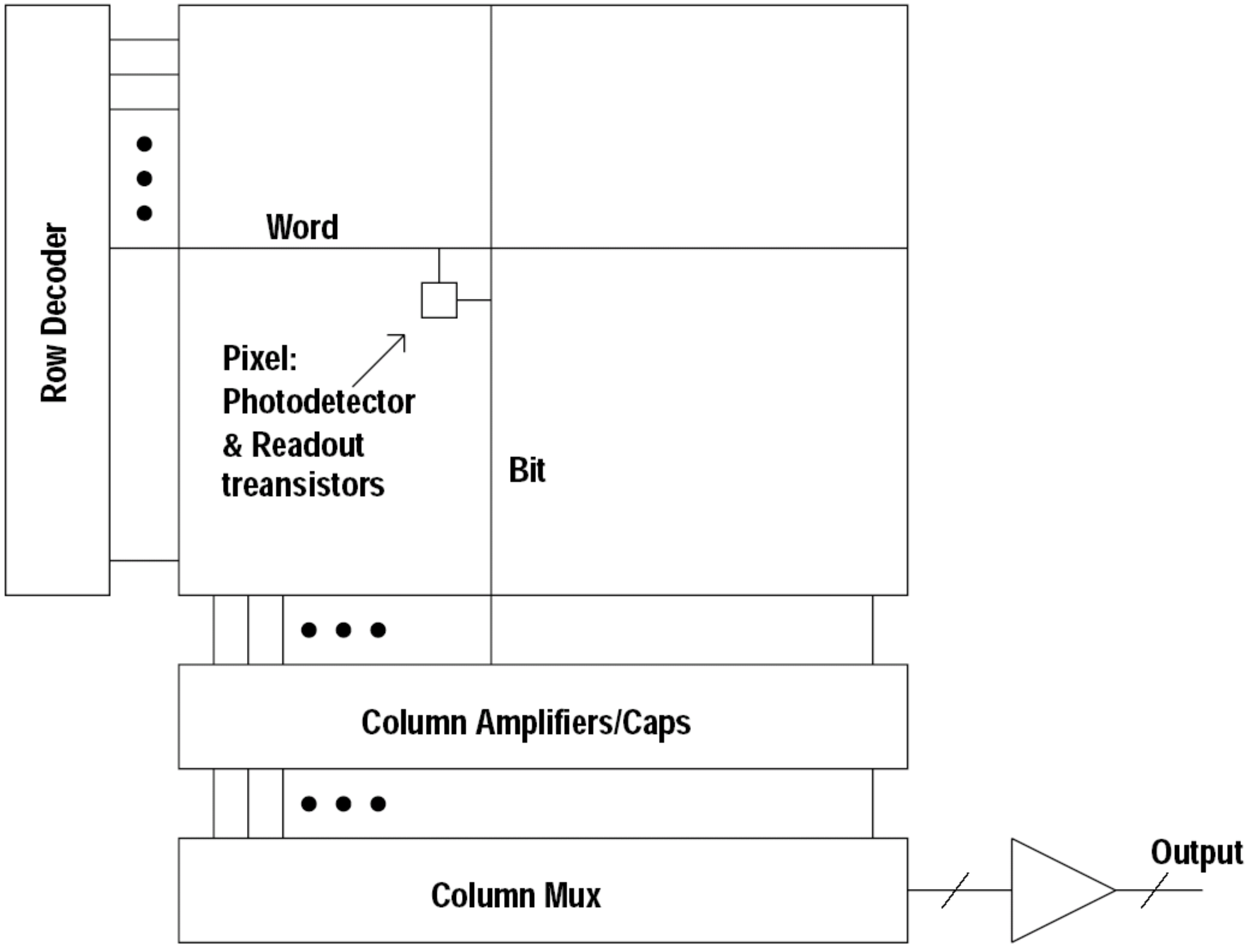
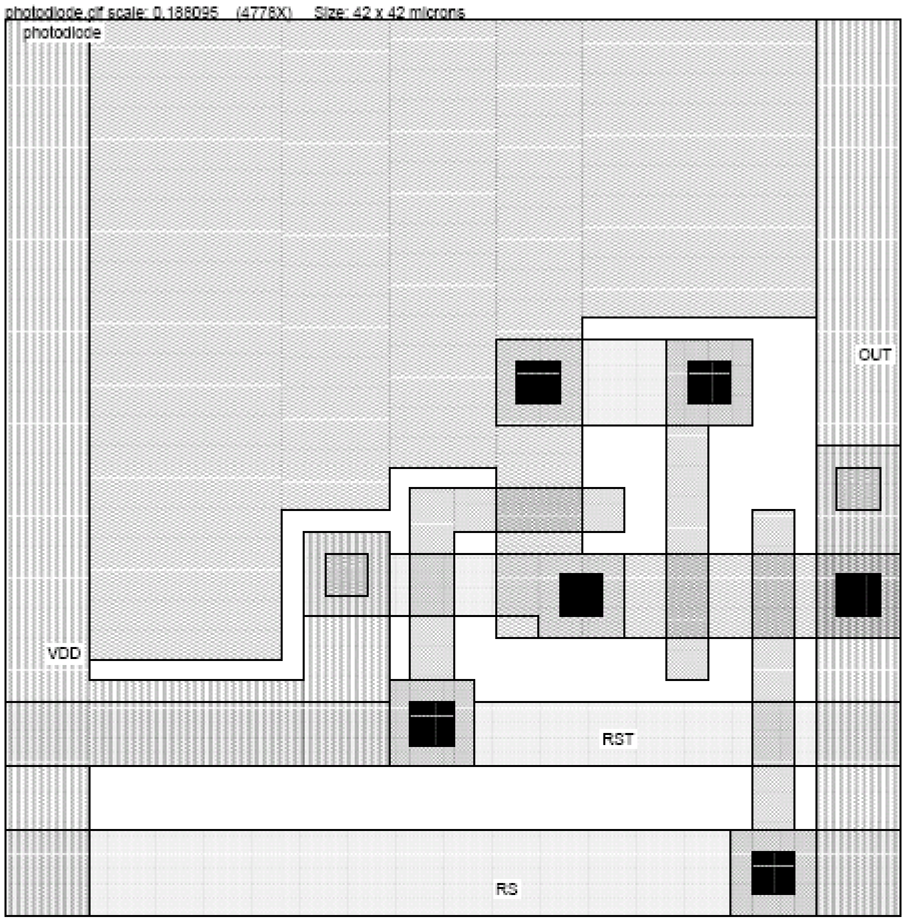


Image : EE392B, El Gamal

Example CMOS Pixel



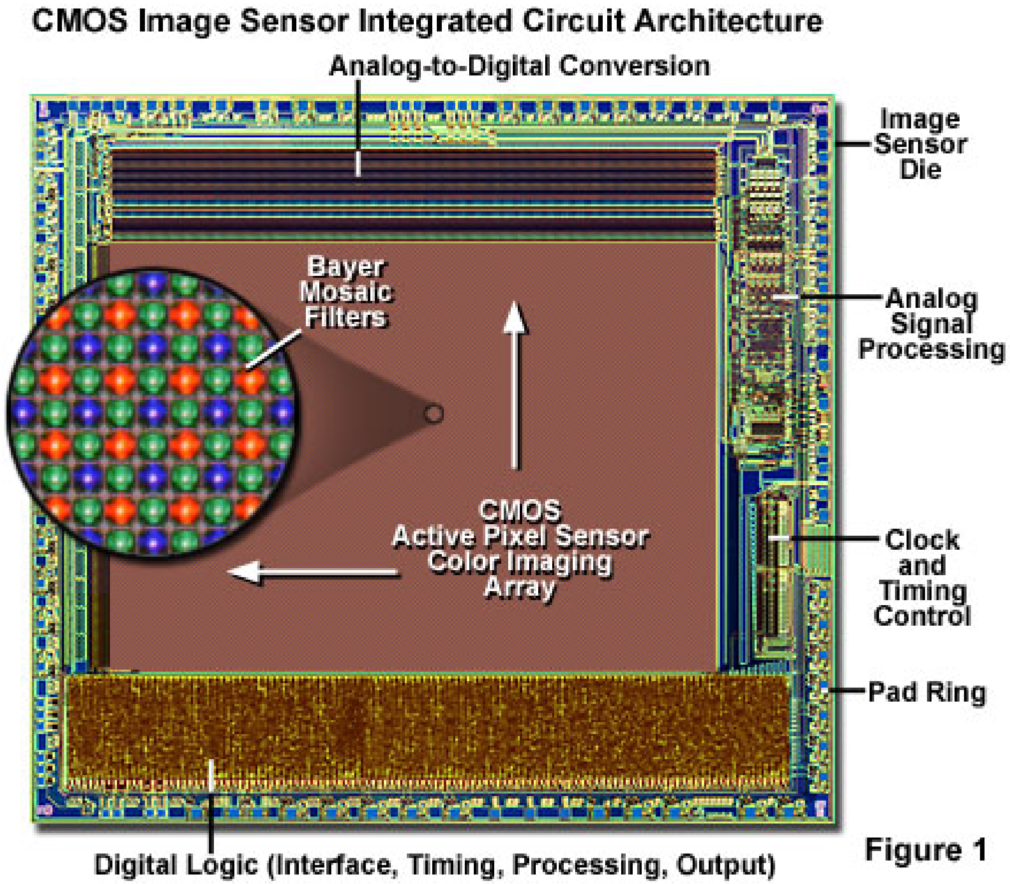
- Photo sensitive area is reduced by additional circuitry.

Source: Stanford EE392B notes

CMOS Sensors

- **Advantages**
  - Integrated digital logic
  - Fast
  - Mainstream process (cheap)
  - Lower power
- **Disadvantages**
  - Noise & quality
- **Most high quality cameras still CCD's.**

CMOS with Integrated Logic



[micro.manget.fsu.edu]

CMOS vs CCD, bottom line

- **CCD's transfers charge to a single output amplifier. Inherently low-noise.**
- **CMOS converts charge to voltage at the pixel.**
  - Read out like a digital memory - windowing
  - Reset noise (can use correlated double sampling CDS)
  - Fixed pattern noise (device mismatch)

Ways to sense color

- **Field-sequential color**
  - simplest to implement
  - only still scenes

Proudkin-Gorskii, 1911
(Library of Congress exhibition)

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(Library of Congress exhibition)

Ways to sense color

- **3-chip camera**
  - dichroic mirrors divide light into wavelength bands
  - does not remove light: excellent quality but expensive
  - interacts with lens design

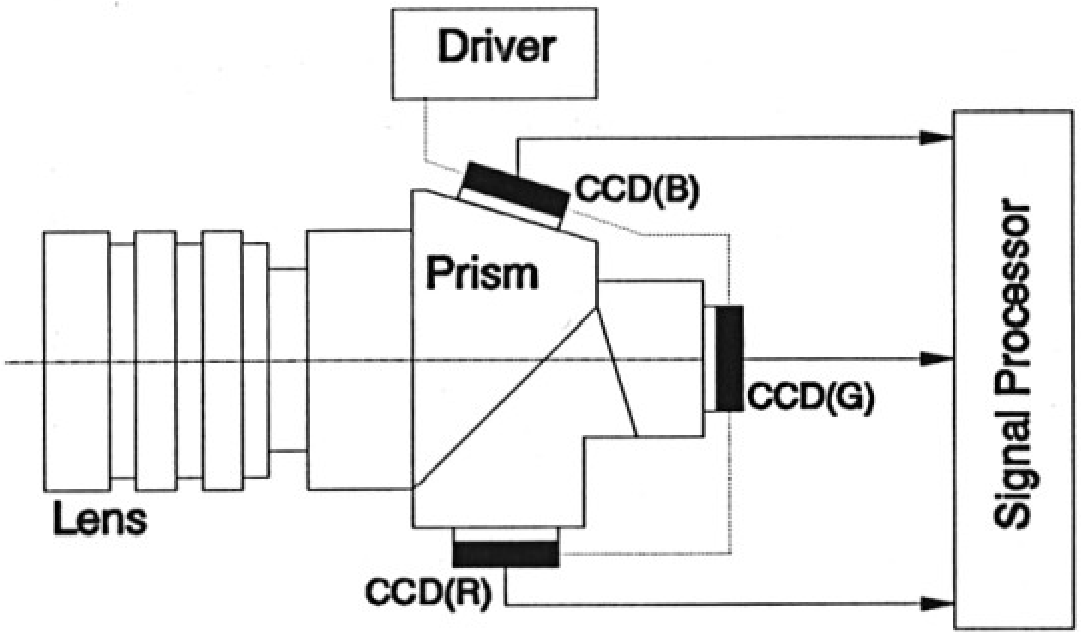
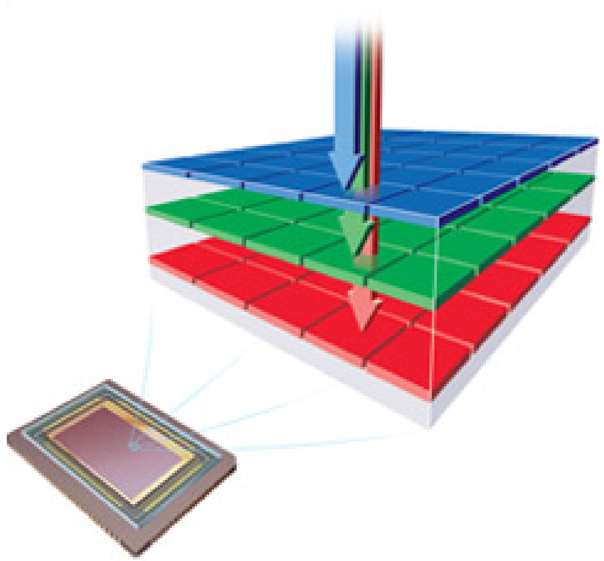


image: Theuwissen

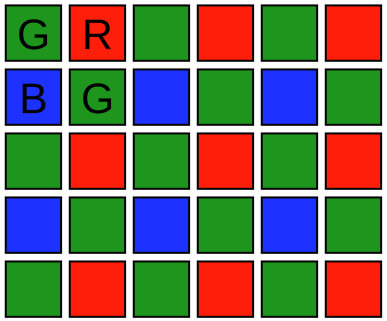
Foveon Technology

- 3 layers capture RGB at the same location
- takes advantage of silicon’s wavelength selectivity
- light decays at different rates
  for different wavelengths
- multilayer CMOS sensor gets
  3 different spectral sensitivities
- don’t get to choose the curves

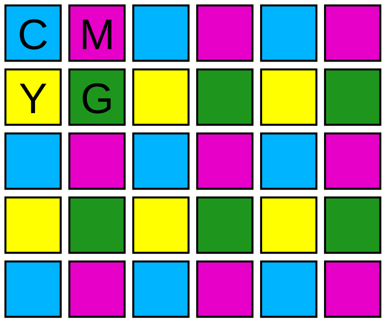


Ways to sense color

- **Color filter array**
  - paint each sensor with an individual filter
  - requires just one chip but loses some spatial resolution
  - “demosaicing” requires tricky image processing



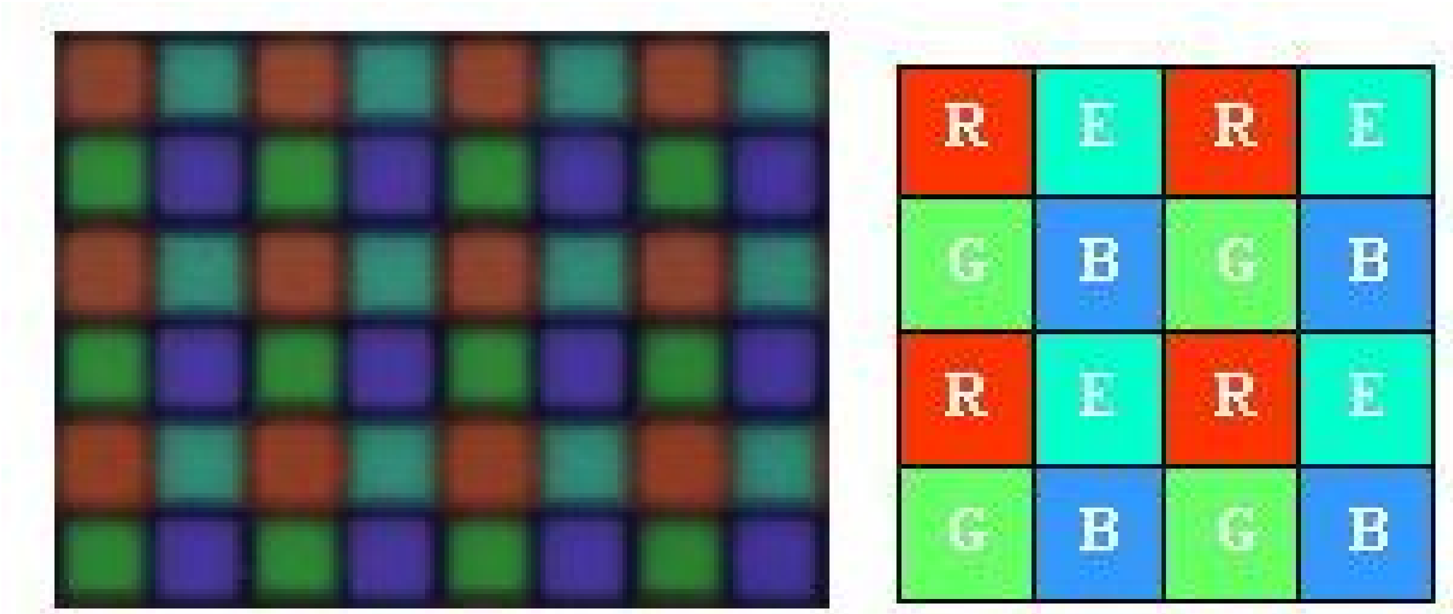
primary



secondary

SONY 4-Color Filter

- **RGB+E (supposedly halves color errors)**
- **Cyber-Shot DSC-F828**



4-color filters

Demosaicing

Original image Bilinear interpolation

Ron Kimmel, http://www.cs.technion.ac.il/~ron/demosaic.html

Demosaicing

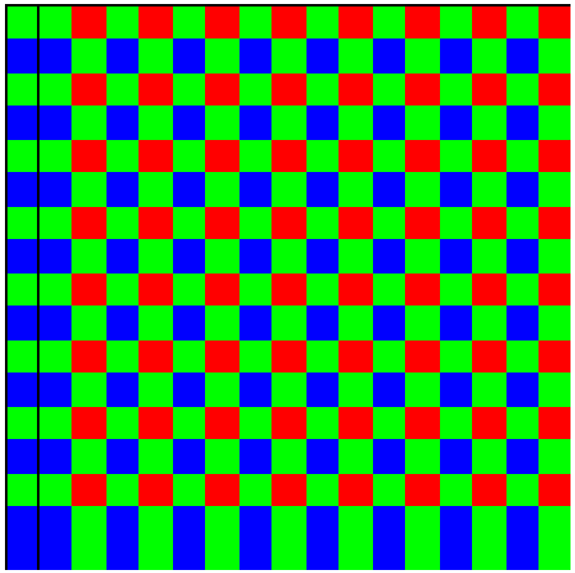
Bilinear interpolation

Edge-weighted interpolation

Ron Kimmel, http://www.cs.technion.ac.il/~ron/demosaic.html

Multi-Shot

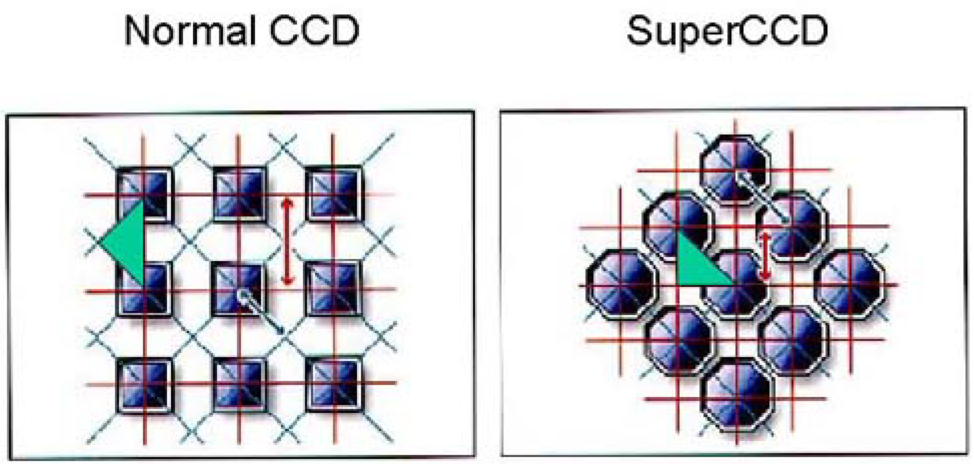
– take four images, moving the sensor by one pixel
– (use fourth image for noise reduction)

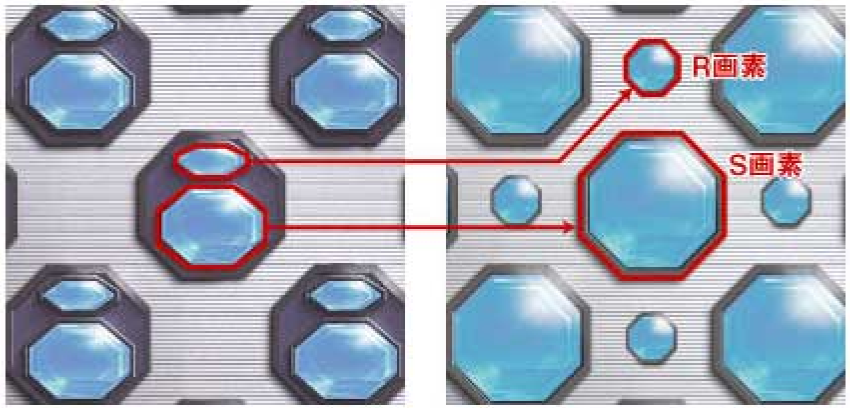


– can be used for supersampling
  (move by ½, ¼ pixel)

Super CCD

- hexagonal grid
- elements with different sensitivity
- extended DR
- better in low light

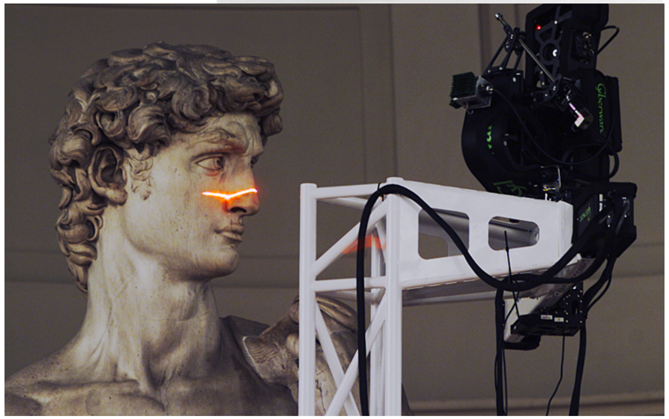




http://www.henner.info/super_ccd.htm

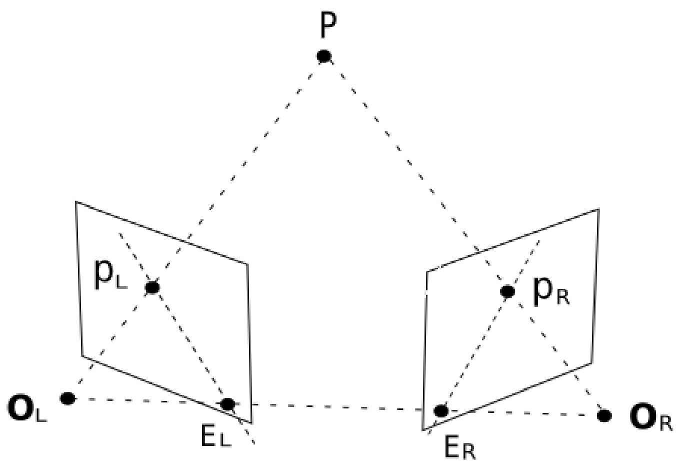
Remote Sensing – Range Scanners

- **Laser Range Scanner**
  - most commonly used range scanner
  - principle of triangulation
  - good accuracy for diffuse surfaces
  - bad for specular surfaces
  - overview in [Blais04]

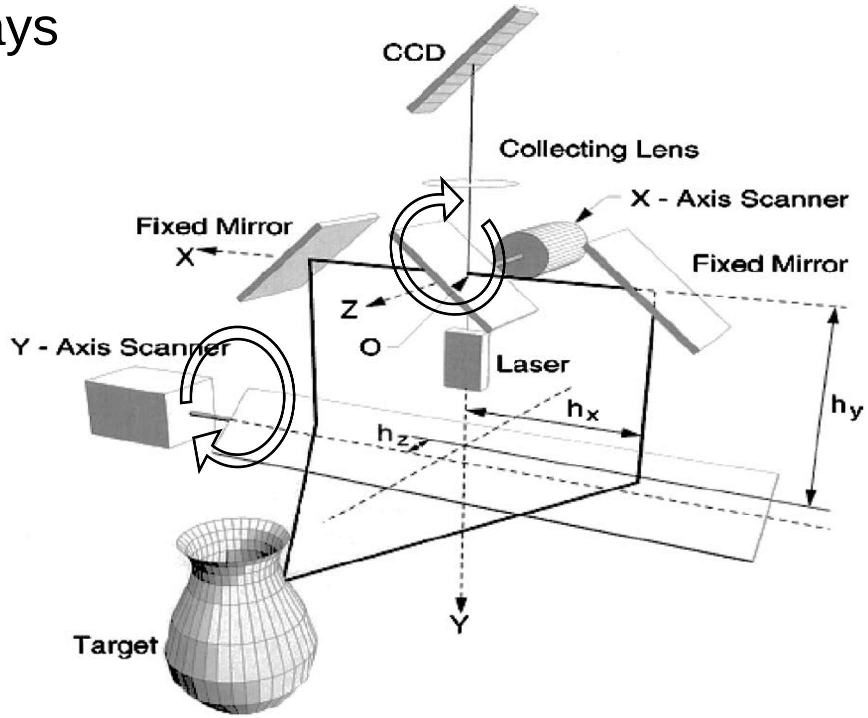


Remote Sensing – Range Scanners

- **Principle of laser range scanner – single point laser scanning**
- **triangulation:**
  - intersect two back- projected rays
  - 2 scanning directions



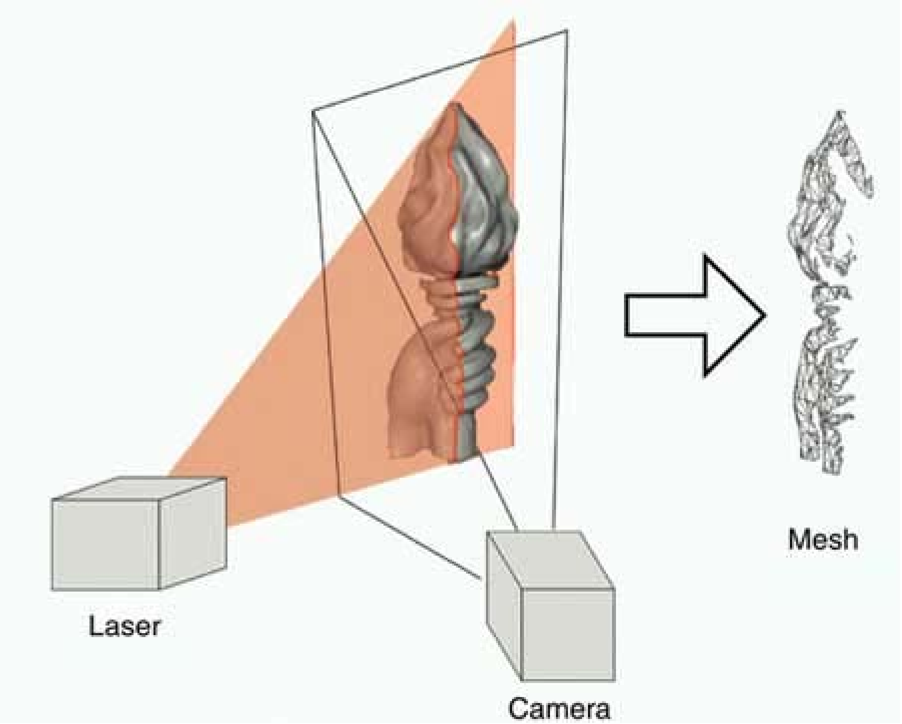
epipolar geometry



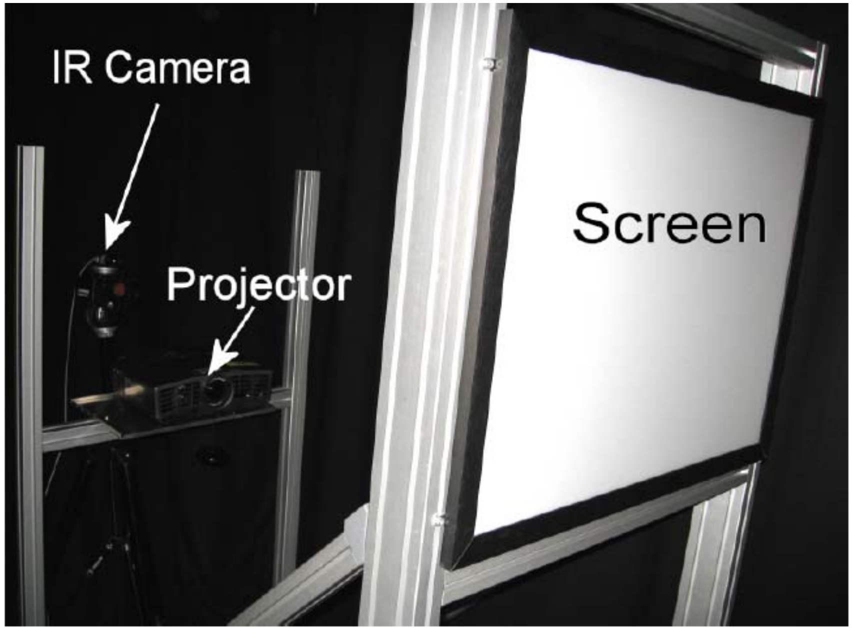
point scanner schematic

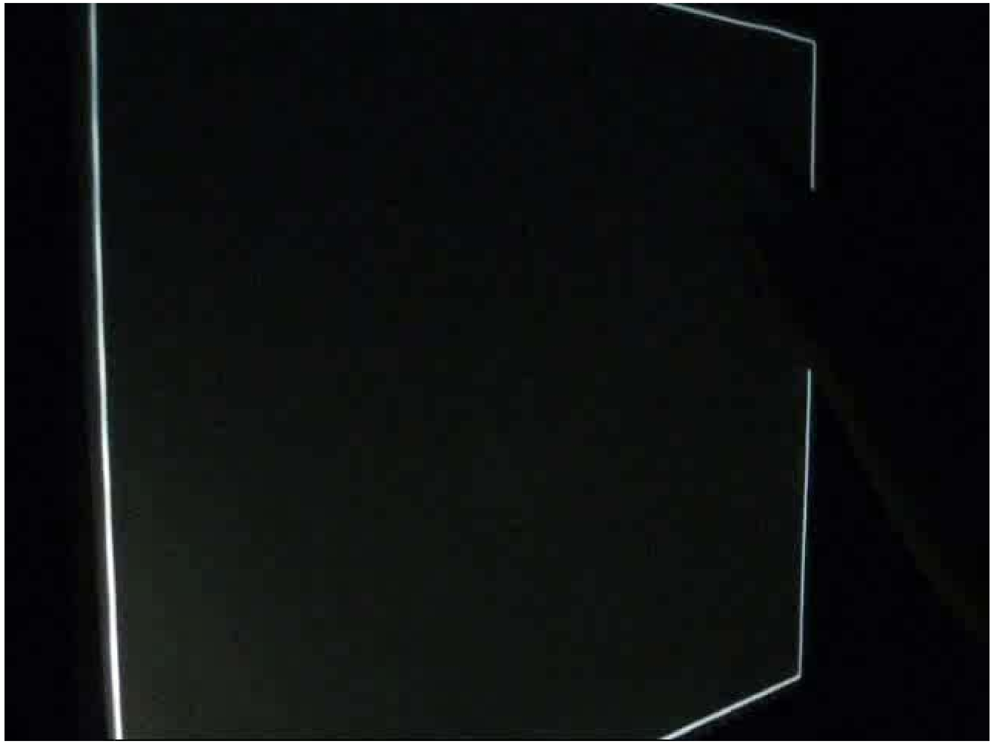
Remote Sensing – Range Scanners

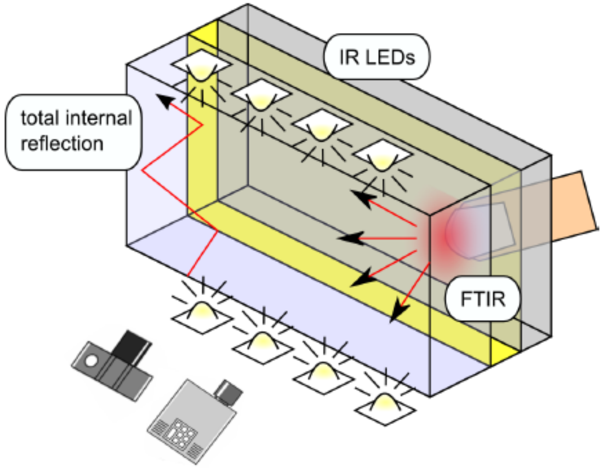
- **Laser range scanner – slit scanner**
  - laser – camera geometry must be known
  - use laser plane instead of ray
  - only one scanning direction
  - triangulation:
    - for each lit pixel, intersect back-projected ray with laser plane



Multi-Touch-Display







tracking: 100Hz
using Cuda

Highlight you should not have missed!

a non-exclusive list of relevant topics of this lecture

Topics (1)

- **ray tracing vs rasterization**
- **recursive ray tracing**
- **ray surface intersections**
- **spatial acceleration structures (dynamics)**
- **shading, reflection, refraction, BRDF, …**
- **radiometry**
- **rendering equation**
- **texture mapping (mip-maps, …)**
- **sampling theory**
- **antialiasing**
- **HDR, contrast, tonemapping**
- **transformations!**
- **rasterization (Bresenham, polygons)**

Topics (2)

- **OpenGL, Cg (basics)**
- **plenoptic function, light fields, panoramas**
- **splines (evaluation)**
- **volume rendering**