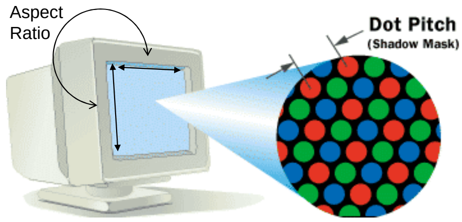
Lecture 8

Display Devices

Cathode Ray Tube (CRT)
Liquid Crystal Displays (LCD)
Light-Emitting Diode (LED)
Gas Plasma
DLP

Display Devices

Display technology - CRT or LCD technologies.
Cable technology - VGA and DVI are the 2 common.
Viewable area (usually measured diagonally)
Aspect ratio and **orientation** (landscape or portrait)
Maximum resolution
Dot pitch
Refresh rate
Color depth
Amount of power consumption



Display Devices

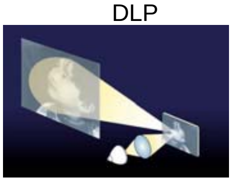
LCD

CRT

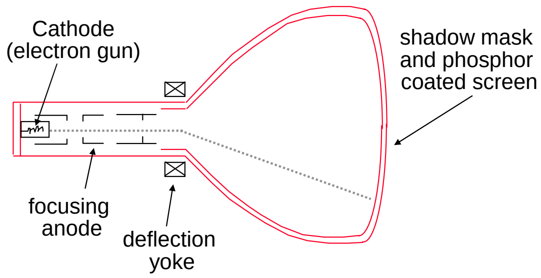
Gas Plasma

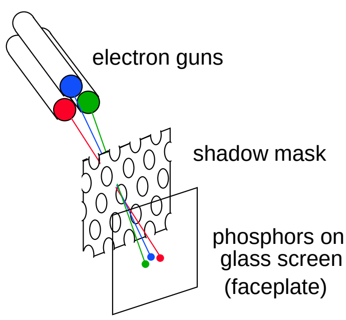
LED

DLP

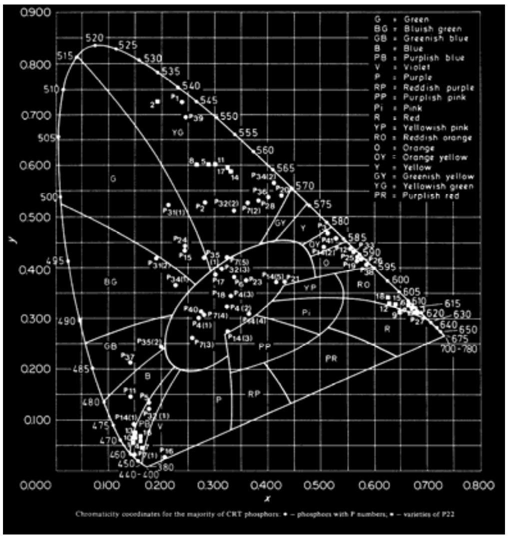


CRT - Cathode Ray Tube





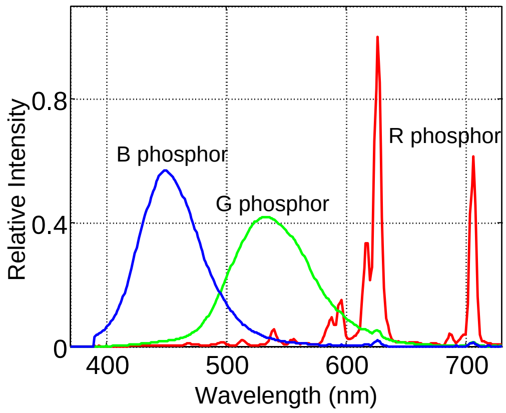
CRT Phosphors



(courtesy L. Silverstein)

CRT Phosphors

Display Spectral Power Distribution

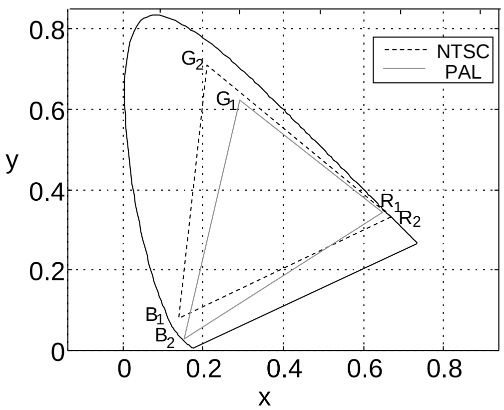


CRT Gamut

Gamut (color Gamut) = the subset of colors which can be represented in a given device..

$R_1G_1B_1$- Primaries used for PAL

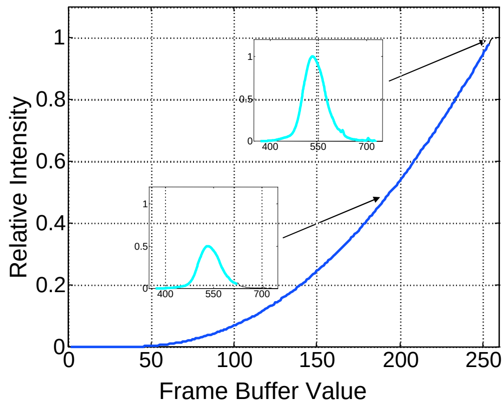
$R_2G_2B_2$- Primaries used for NTSC



CIE Chromaticity + Gamut applet :
http://www.cs.rit.edu/~ncs/color/a_chroma.html

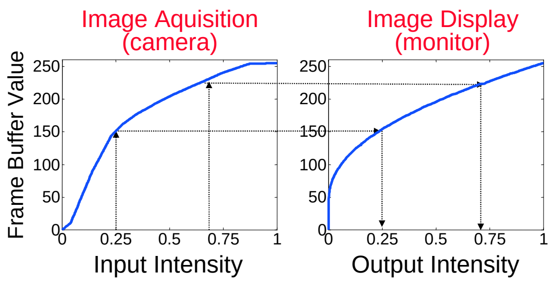
CRT Phosphors and Gamma

Display Intensity



Display Intensity

Camera and monitor nonlinearities cancel out

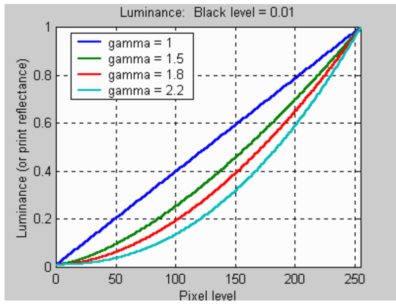


Gamma Encoding/Decoding
Gamma Correction

Gamma describes the nonlinear relationship between pixel values and luminance.

$$\text{ValueOut} = \text{ValueIn}^{\gamma}$$

$\gamma < 1$ → Gamma Encoding
$\gamma > 1$ → Gamma Decoding

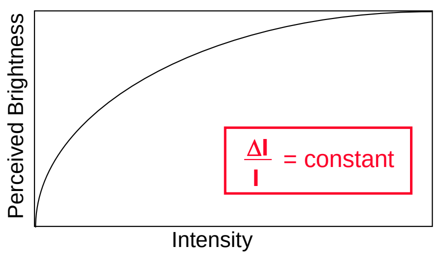


Gamma Encoding/Decoding
Gamma Correction

Typically image files are created by cameras, stored on computers and communicated over the internet with gamma encoding.

Why?

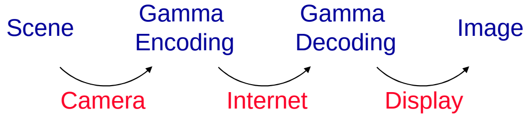
The eye does not respond linearly to light; it responds to *relative* brightness or luminance differences. **Weber's Law**

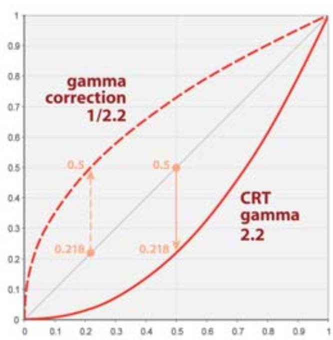


gamma encoding = uniform perceptual coding

Gamma Encoding/Decoding
Gamma Correction

Input Device to Output Device
(Camera to Display)





Want: Encoding Gamma = Decoding Gamma

Gamma Encoding/Decoding
Gamma Correction

Wrong Gamma:

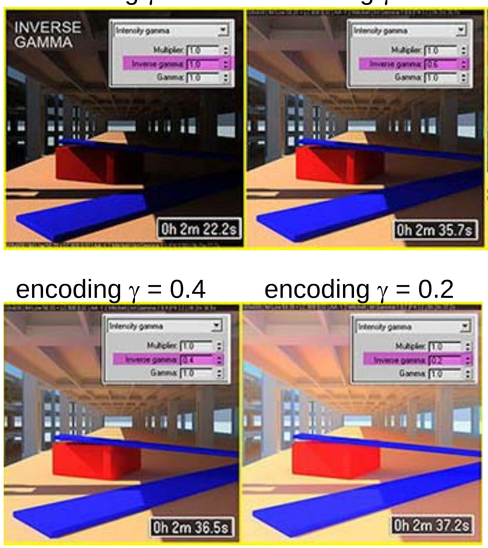
Linear gamma on
2.2 gamma Display

1/2.2 gamma on
2.2 gamma Display

Gamma Encoding/Decoding
Gamma Correction

encoding $\gamma = 1$ | encoding $\gamma = 0.6$

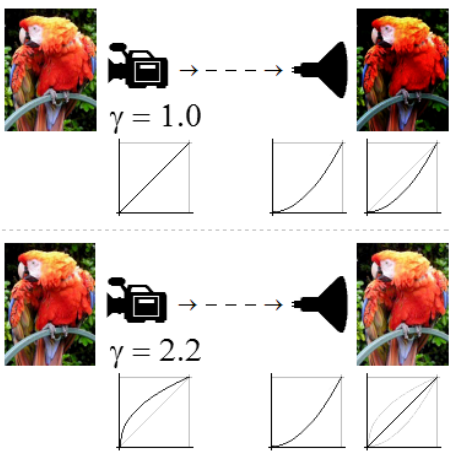
encoding $\gamma = 0.4$ | encoding $\gamma = 0.2$



Demo

Gamma Encoding/Decoding
Gamma Correction

CRT displays have inherent Gamma Correction
(Gamma Decoding)



What is the display Gamma?

Gamma Encoding/Decoding
Gamma Correction

Display Standards:

NTSC	$\gamma = 2.2$
PAL	$\gamma = 2.8$
SECAM	$\gamma = 2.8$
MAC	$\gamma = 1.8$

sRGB $\gamma = 2.2$

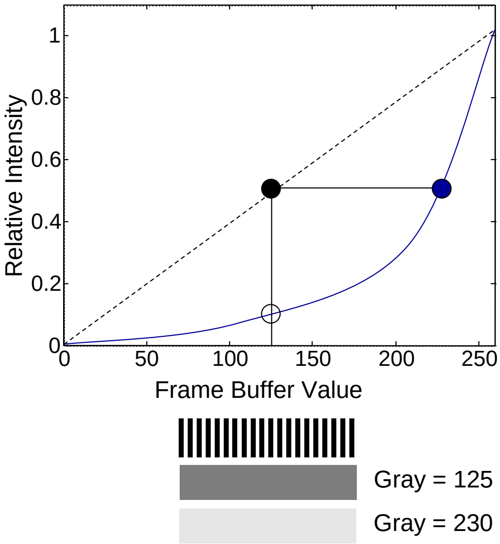
Actually*:

for $x_{Linear} <= 0.03928$;
$X_{\gamma\text{-encoded}} = X_{Linear}/12.92$

for $x_{Linear} <= 0.03928$;
$X_{\gamma\text{-encoded}} = ((0.055+x_{Linear})/1.055)2.4$

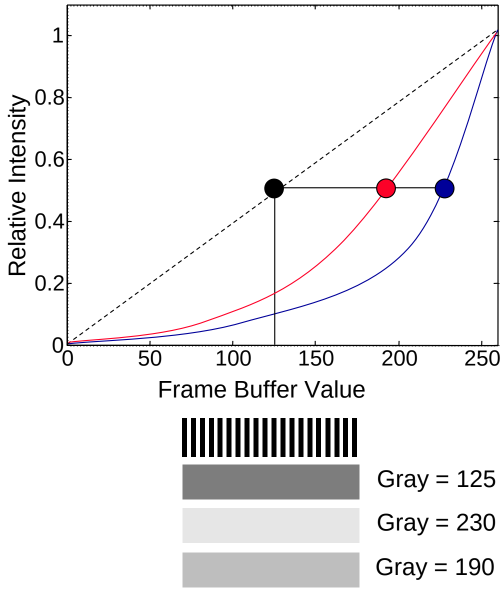
Gamma Encoding/Decoding
Gamma Correction

Testing Gamma of your Monitor:



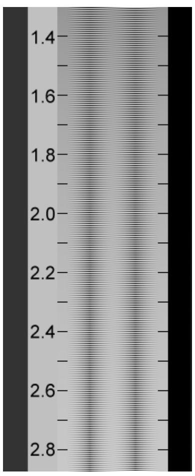
Gamma Encoding/Decoding
Gamma Correction

Testing Gamma of your Monitor:



Gamma Encoding/Decoding
Gamma Correction

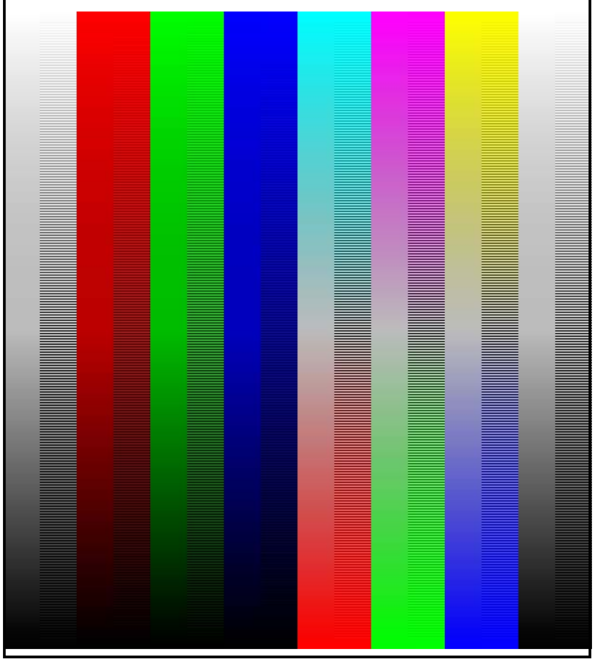
Testing Gamma of your Monitor:



NormanKorenGammaTest.jpg

From: http://www.normankoren.com/makingfineprints1A

Gamma Encoding/Decoding
Gamma Correction



Gamma Encoding/Decoding
Gamma Correction

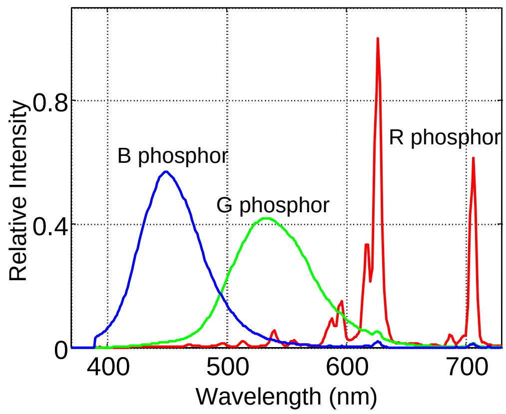
Displays:

Luminance = C * value$^\gamma$ + black level

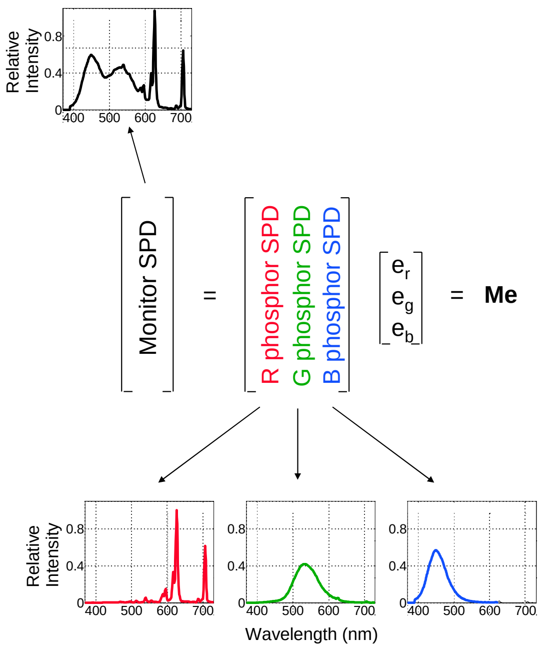
C is set by the monitor Contrast control.
Value is the pixel level *normalized* to a max of 1.
Black level is set by the monitor Brightness control.

The relationship is linear if gamma = 1.

Display SPD Response

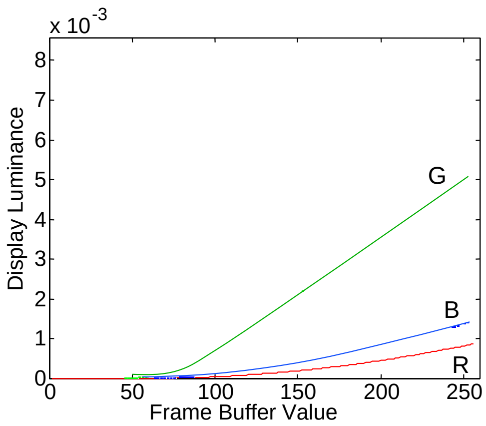


Phosphor Spectral Additivity

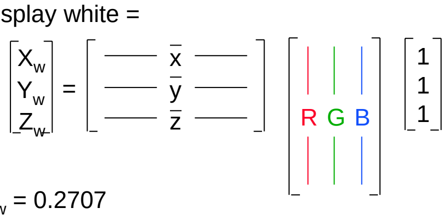


Note: **e** = relative intensities and NOT frame buffer values

Display Luminance and White Point



Display white =

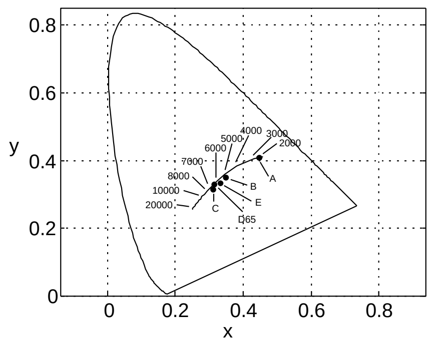


$x_w = 0.2707$
$y_w = 0.3058$

Display White Points

Display Standards:

NTSC (1953)	white point = C
NTSC (1979)	white point = D65
PAL	white point = D65
SECAM	white point = D65
ISO 12646	white point = D50
CIE	white point = E



Color Temperature

Display Calibration

calibration matrix =

$$H = \begin{bmatrix} \text{—— } \bar{x} \text{ ——} \\ \text{—— } \bar{y} \text{ ——} \\ \text{—— } \bar{z} \text{ ——} \end{bmatrix} \begin{bmatrix} | & | & | \\ R & G & B \\ | & | & | \end{bmatrix}$$

calibration matrix relates the linear relative intensity to sensor absorption rates (XYZ or LMS):

$$\mathbf{r} = \mathbf{He}$$

Example: CIERGB-to-XYZ (?)

$$H = \begin{bmatrix} 0.2172 & 0.3028 & 0.1926 \\ 0.1230 & 0.5862 & 0.0960 \\ 0.0116 & 0.1033 & 1.0000 \end{bmatrix}$$

Examples using calibration matrix:

1) Calculate XYZ (LMS) of frame buffer values:

Frame buffer = (128, 128, 0)
Relative intensities **e** = (0.1524, 0.1524, 0.0)

$$\mathbf{r} = \mathbf{He}$$

r = (0.0813, 0.1109, 0.0180)

2) Calculate the frame buffer values required to produce a given XYZ value:

r = (0.3, 0.3, 0.3)

$$\mathbf{e} = \mathbf{H}^{-1}\mathbf{r}$$

e = (0.7030, 0.3220, 0.2586)

frame buffer = (222, 166, 153)

3) Calculate frame buffer values for a pattern with changes only in S-cone direction:

Create calibration matrix using cone sensitivities:

$$H = \begin{bmatrix} \text{—— L ——} \\ \text{—— M ——} \\ \text{—— S ——} \end{bmatrix} \begin{bmatrix} | & | & | \\ R & G & B \\ | & | & | \end{bmatrix}$$

Start with background pattern:

e = (0.5, 0.5, 0.5)

This produces cone absorptions:

$$\mathbf{r} = \mathbf{He}$$

r = (0.7060, 0.6564, 0.5582)

Now create second color ΔS from background:

r2 = **r** + (0 0 0.1418) = (0.7060, 0.6564, 0.7)

$$\mathbf{e} = \mathbf{H}^{-1}\mathbf{r}$$

e2 = (0.5388, 0.4742, 0.6022)

4) Calculate calibration matrix under new white point:

Original calibration matrix = **H**

Original white point calculation:

$e_1 = (1, 1, 1)$

$r_1 = He_1$ Original white

New white point calculation:

r_2 New white

$e_2 = H^{-1} r_2$

Denote

$e_2 = (e_{2R}, e_{2G}, e_{2B})$

New calibration matrix =

$$H_{new} = \begin{bmatrix} H \end{bmatrix} \begin{bmatrix} e_{2R} & & \\ & e_{2G} & \\ & & e_{2B} \end{bmatrix}$$

Flat Panel Displays

- Liquid Crystal Display (LCD) technology - blocking light rather than creating it. Require less energy, emit less radiation.
- Light-Emitting Diode (LED) and Gas Plasma light up display screen positions based on voltages at grid intersections. Require more energy.

Liquid Crystal Display (LCD)

Discovered in 1888 by Austrian botanist Friedrich Reinitzer. RCA made the first experimental LCD in 1968.

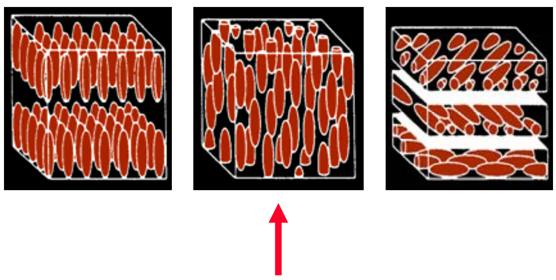
Liquid Crystals are used to make thermometers and mood rings because heat changes absorbance properties.

http://computer.howstuffworks.com/lcd2.htm

Liquid Crystal Display (LCD)

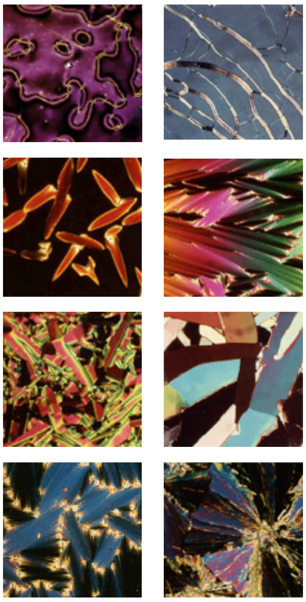
- Liquid crystals (LC) are complex, organic molecules
  - fluid characteristics of a liquid and the molecular orientation order properties of a solid
  - exhibit electric, magnetic and optical anisotropy
- Many different types of LC optical configurations
  - nematic materials arranged in a twisted configuration most common for displays
- Below are shown three of the common LC phases

Smectic Nematic Cholesteric

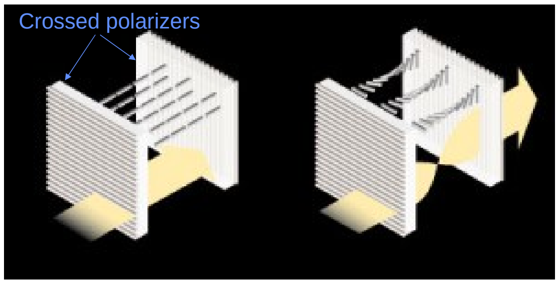


Twisted Nematic
= most common
for displays

Liquid Crystal Images



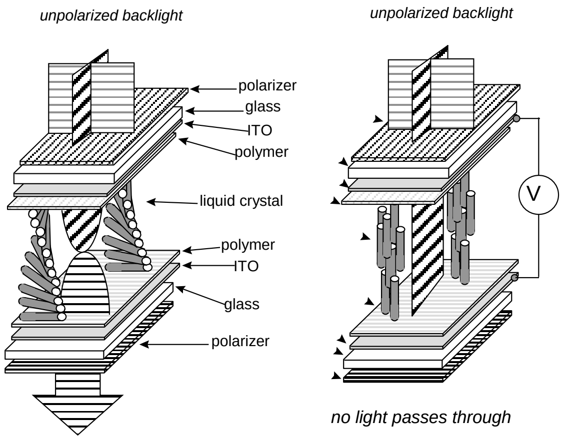
LCD Polarization



Liquid crystal (off state) Liquid crystal (on state)

Liquid Crystals are affected by **electric current**. Twisted Nematics (TN) = kind of nematic liquid crystal, is naturally twisted. Applying an electric current to it will untwist it. Amount of untwisting depends on current's voltage.

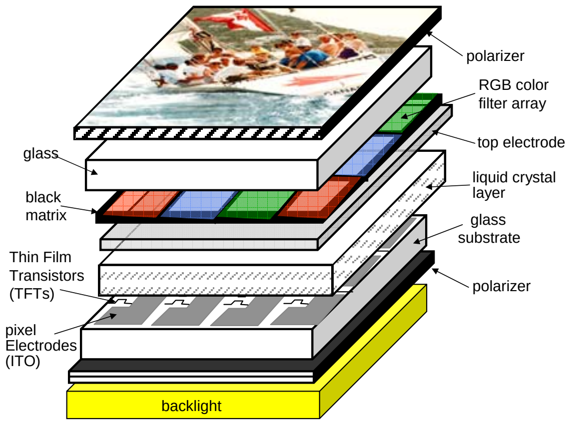
LCD Voltage Control



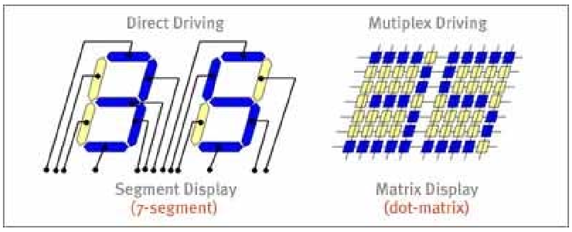
Voltage Field Off (V=0)

Voltage Field On ($V>V_{threshold}$)

LCD System

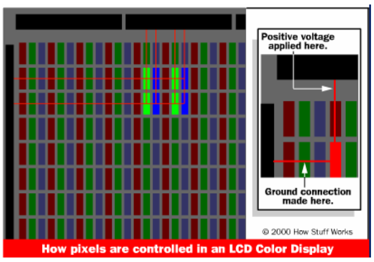


Direct vs Multiplex Driving



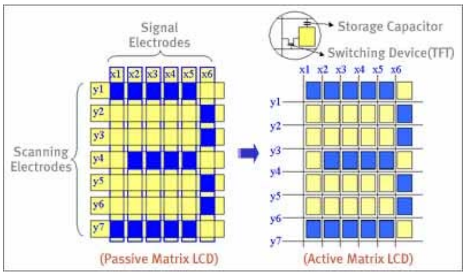
Direct Driving - every element is wired separately.

Multiplex Driving – wires are shared e.g. in a matrix.



Multiplex Driving

Passive vs Active Matrix

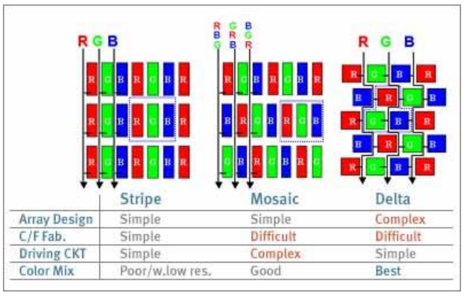


Passive Matrix – a simple grid supplies the charge to a particular pixel on the display.
Slow response time and imprecise voltage control.

Active Matrix – every pixel has switch and capacitor. A row is switched on, and then a charge is sent down a column. Capacitor holds charge till next cycle. Faster response time, less pixel crosstalk.

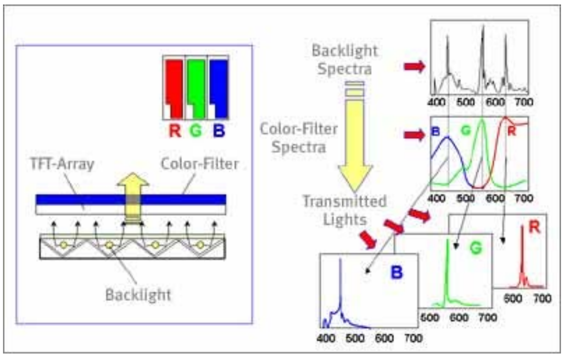
An enormous number of transistors are used. e.g.for laptop:
1,024x768x3 = 2,359,296 transistors etched onto the glass!
A problem with a transistor creates a "bad pixel".
Most active matrix displays have a few bad pixels.

Color Array Organization Options

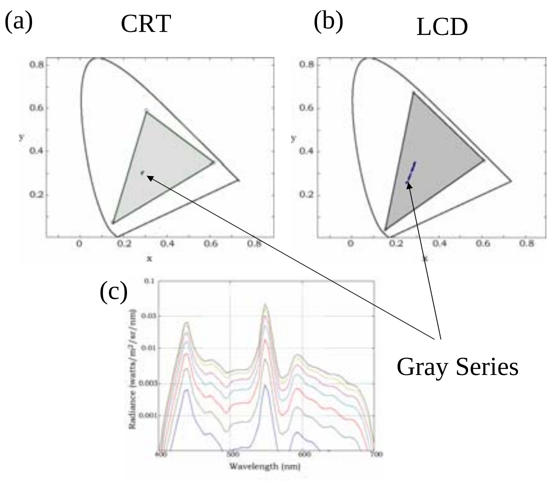


http://www.avdeals.com/classroom/what_is_tft_lcd.htm

Color Pixels in LCD Devices

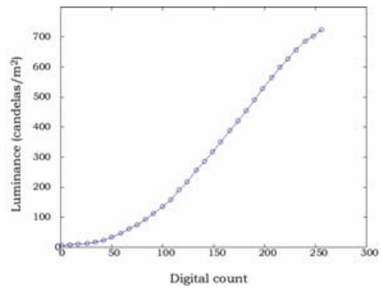


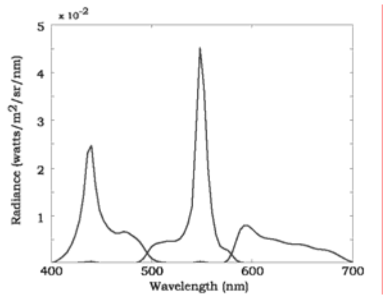
LCD Calibration Issues



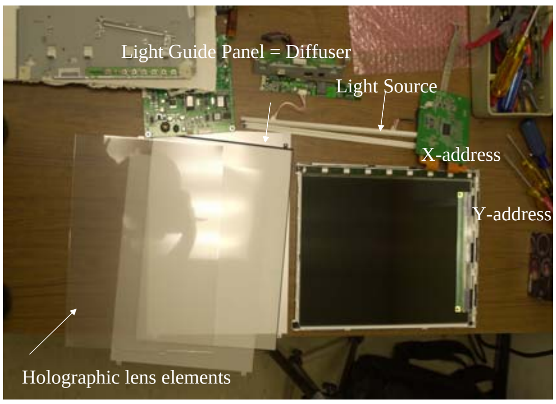
Wandell and Silverstein, OSA Chapter

LCD Calibration Example

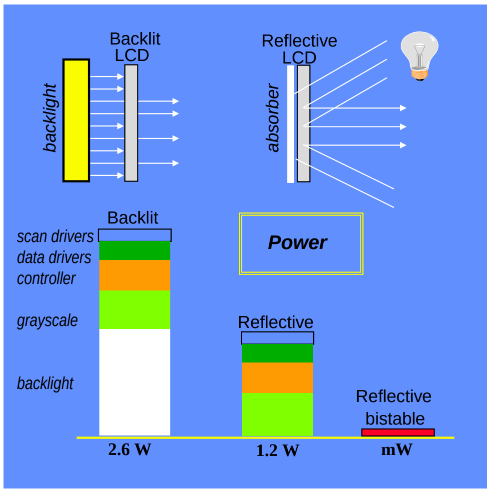




Opened Up LCD



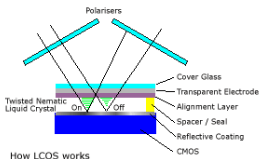
Reflective Color Displays



- Low power
- Low volume and weight
- Naturally adaptive to changes in ambient illumination
- Low cost

Liquid Crystals on Silicon (LCOS)

New reflective LCD technology.



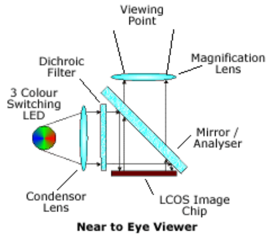
Instead of the crystals and electrodes sandwiched between polarized glass plates, in LCOS devices the crystals are coated over the surface of a **silicon chip**.

The electronic circuits are etched into the chip, which is coated with a reflective surface. **Polarizers** are in the light path before and after the light bounces off the chip.

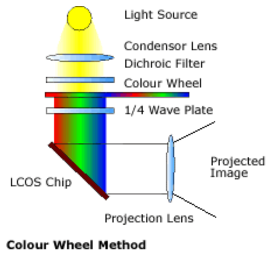
Advantages over conventional LCD Displays:

- Easier to manufacture.
- Have **higher resolution** because several million pixels can be etched onto one chip.
- Can be much **smaller**.

Liquid Crystals on Silicon (LCOS)



The Near-Eye Viewer



Projection Display

Liquid Crystals on Silicon (LCOS)

LCOS microdisplays are small - must be magnified via either a virtual imaging system or a projection imaging system.

Liquid Crystals on Silicon (LCOS)

LCOS rear projection TV

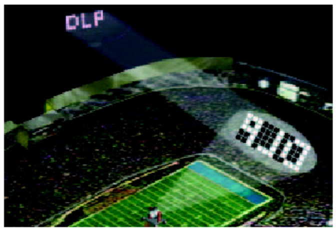
Head mounted displays

Microdisplays – viewfinder

Digital Light Processing (DLP)

Principle of the DLP/DMD

Reflective projection.



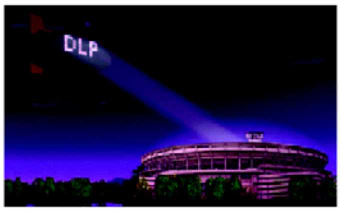
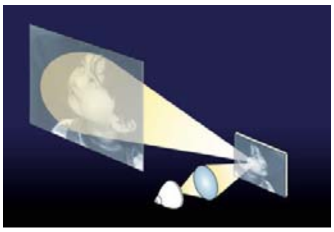


Figure 1. Fans in a stadium reflecting light toward a blimp. (a) Light is projected from a spotlight toward fans in the stadium. When cued by a numbered signal, these fans hold up their reflective seat cushions and tilt them toward or away from a blimp. By doing so, the fans in the stadium are reflecting pixels of light toward the blimp. The result is that the light pattern created by the seat cushions projects an image onto the surface of the blimp. (b) A distant viewer sees the image on the blimp.

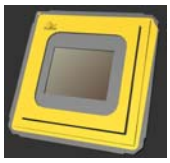
(source, TI, Yoder white paper)

Principle of the DLP/DMD



Projection TV technology can create large screen sizes at a reasonable price

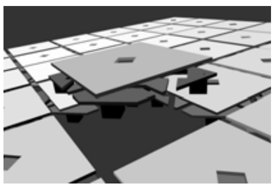
Principle of the DLP/DMD



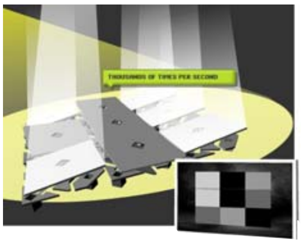
Digital MicroMirror Device (DMD)

The DMD chip, was invented by Dr. Larry Hornbeck of Texas Instruments in 1987.

An array of up to 1.3 million hinged microscopic mirrors. Each micromirror measures 16 µm^2 (1/5 of a human hair). Each mirror creates one pixel in the projected image.

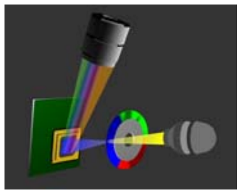


Principle of the DLP

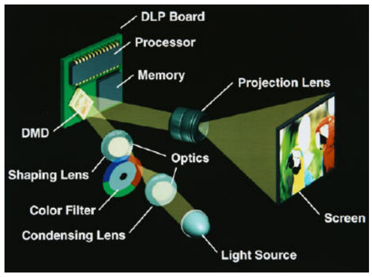


Micromirrors can tilt toward the light source (ON) or away from it (OFF) - creating a light or dark projected pixel. The bit-streamed image code entering the chip directs each mirror to switch on and off up to several thousand times a sec. Frequency of on vs off determines gray level (upto 1024).

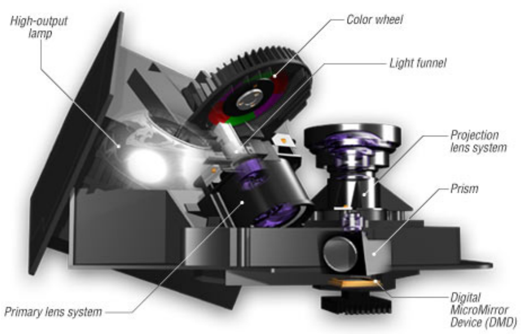
Principle of the DLP



A color filter wheel is inserted between the light and the DMD, and by varying the amount of time each individual DMD mirror pixel is on, a full-color, digital picture is projected onto the screen.

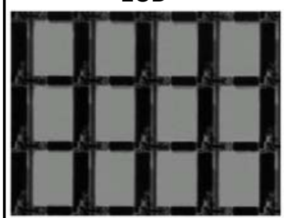
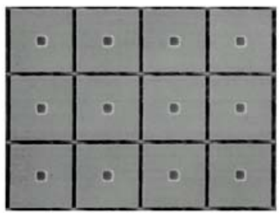
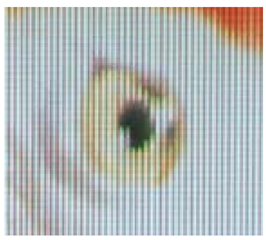
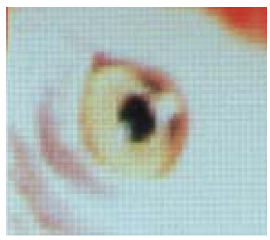


Digital Light Processing (DLP)



http://www.dlp.com/includes/demo_flash.asp
http://www.audiosound.com/whatisdlp.html

LCD vs DLP

LCD	DLP
	
	

Digital Light Processing (DLP)

http://www.dlp.com/projectors/default.aspx

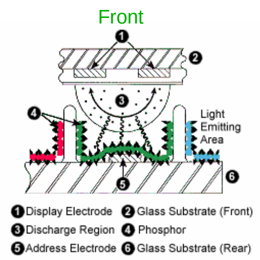
Gas Plasma

Plasma = a gas made up of free-flowing **ions** and **electrons**.

Gas Plasma Display = An array of cells (pixels) composed of 3 subpixels: red, green & blue. An inert (inactive) gas surrounding these cells is then subjected to voltages representing the changing video signal; causing the gas to change into a plasma state, generating ultra-violet light which reacts with phosphors in each subpixel. The reaction generates colored light.

Gas Plasma Displays

Emissive rather than transmitive



Step 1: Address electrode causes gas to change to plasma state.

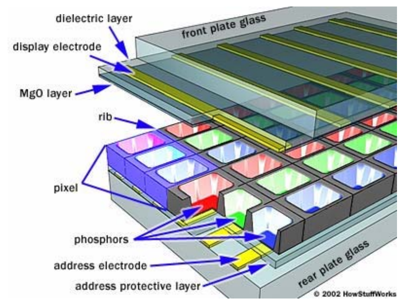
Step 2: Gas in plasma state reacts with phosphors in discharge region.

Step 3: Reaction causes each subpixel to produce red, green, and blue light.

http://www.audiosound.com/whatisplasma.html

http://www.avdeals.com/classroom/learning_resources.htm

Gas Plasma Displays



The Address electrodes sit behind the cells, along the rear glass plate in horizontal rows.
The Display electrodes, which are transparent, are are mounted above the cell, along the front glass plate in vertical columns.

Gas Plasma

- Extremely thin (3"-6" typically), & produce sharp images because do not use complicated optics & lens assemblies.
- Images are relatively bright with very high contrast ratios.
- Have nearly a 180 degree viewing angle with no light drop-off! (LCD and DLP Televisions approx 160 deg).
- Technology is highly complex & relatively expensive.
- Relatively weighty and consumes more power than typical video displays. Sometimes require internal cooling fans (like LCD, DLP, & CRT projectors).

Plasma vs LCD

Advantages Of Plasma Displays Over LCDs

- Viewing angle of Plasma: 160 degrees+, ~ 90 degrees vertically vs. LCDs: up to or less than 160 degrees horizontally.
- Size much larger Plasma 32-61 inches vs LCD 2-28 inches.
- Plasma is Emissive (internal) vs LCDs are Transmissive (External backlight).
- Switching speeds: Plasma <20ms (video rates) vs LCDs>20ms (may have image lag at video rates)
- Color technology: Plasma uses Phosphors (Natural TV colors) vs LCDs use Color Filters (Not the same color system as TV).

Plasma vs CRT and DLP

Advantages Of Plasma Displays Over Regular TV's

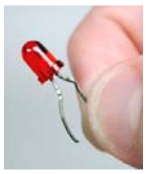
- 4" thick, and can be hung on a wall
- Much larger picture
- Higher color accuracy
- Brighter images (3 to 4 times brighter)
- Better resolution
- High-definition capability
- 16:9 aspect ratio vs. standard 4:3
- Can be used as a monitor for a PC or Mac
- Images don't bend at the edge of the screen
- Reflections from windows or lights are minimized
- Wider viewing angles
- Not effected by magnetic fields

Advantages Of Plasma Displays Over Projection Monitors

- Ideal for any room, even rooms where space may be limited
- 4" thick, and can be hung on a wall
- Can be used as a monitor for a PC or Mac
- Higher color accuracy than most PTV's
- Brighter images than most PTV's
- Better resolution than most PTV's
- Wider viewing angles , not stuck sitting in a sweet spot
- DLP and LCD rear projectors need bulb replacement every 4 to 5000 hours (cheap initially but more expensive in the long run).

Light Emitting Diodes (LED)

LED = a tiny little bulb small, extremely bright and uses little power.

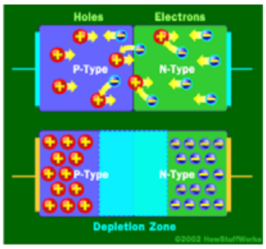


Do not have a filament but are illuminated by the movement of electrons in a semiconductor material.

No filament to burn out, so they last very long.
Do not get hot as light bulbs do.
Efficient in terms of electricity (none is wasted on heat)

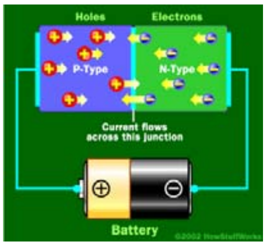
Diodes

Semiconductor material is typically neutral.
When it is doped it becomes charged:
N-type has extra electrons
P-type has missing electrons i.e. extra 'holes'.

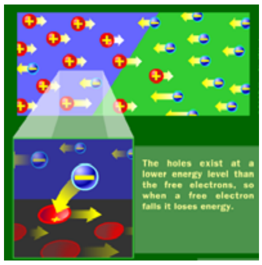


A diode is a section of N-type material bonded to a section of P-type material
Electrons from the N-type material fill holes from the P-type material along the **junction** between the layers, forming a **depletion zone**.

Diodes



When the negative end of the circuit is hooked up to N-type layer and the positive end is hooked up to P-type layer, electrons and holes move and the depletion zone disappears.

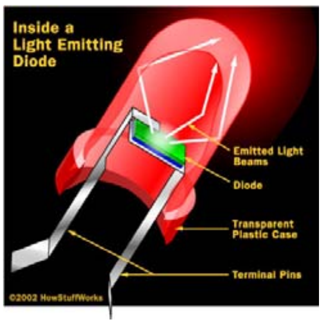


Free electrons moving across a diode fall into holes in the P-type layer. This involves a drop from the **conduction band** to a lower orbital, so the electrons release energy in the form of photons.

Diodes

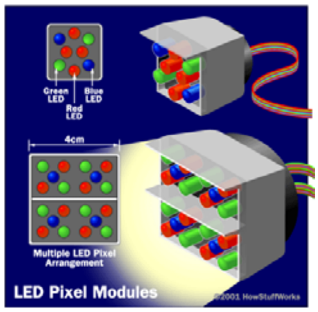
The wider the energy gap – the higher the spectral frequency of the emitted photon.

(silicon has very small gap so very low frequency radiation is emitted – e.g. infra red).



Diodes in LEDs are housed in a plastic bulb that concentrates the light in a particular direction. Most of the light from the diode bounces off the sides of the bulb, traveling on through the rounded end.

LED Displays

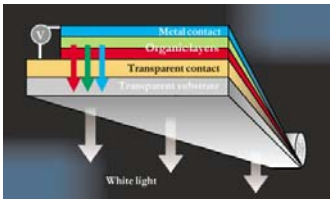


A LED pixel module is made up of 4+ LEDs of RGB.

LED displays are made up of many such modules.

- Several wires run to each LED module, so there are a lot of wires running behind the screen.
- Turning on a jumbo screen can use a lot of power.

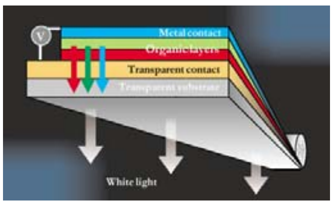
Organic Led Displays (OLED)

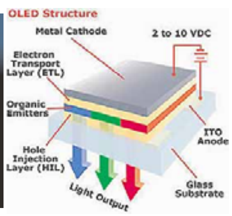


Organic Led Displays (OLED)

An electronic device made by placing organic thin films between two conductors (Anode & Cathode). When electrical current is applied, a bright light is emitted.

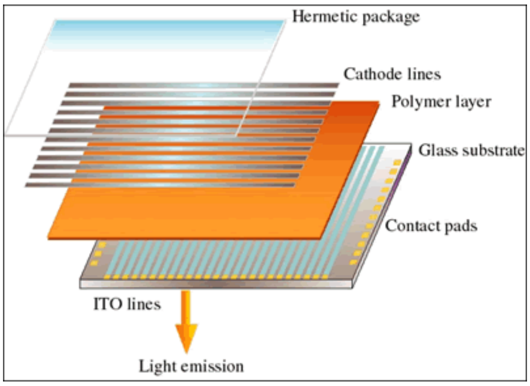
This phenomenon is called **electro-phosphorescence.**





- Can be very thin (organic layers less than 0.1mm).
- Simple to manufacture - In Polymer OLEDs the organic material can be quickly and easily applied to a substrate.

OLED Structure is Simple



- No backlight (low power)
- Simpler to manufacture
- Very fast switching times
- Lifetime issues

Flexible Organic Light Emitting Displays (FOLED)

Instead of glass surfaces, FOLEDs are made on flexible substrates (transparent plastic to opaque metal foils).

Universal Display Corporation (UDC) - A passive matrix display fabricated on a 0.175 mm thick sheet of plastic: resolution of 80 dpi, 64 levels of grey scale and can show full motion video. The FOLEDTM was invented by Professor Stephen Forrest at Princeton University. It is now under development at UDC.

http://www.universaldisplay.com/foled.php

Displays of the Future

The ELumens VisionStation projection TV system

The LCD projector has a **wide-angle lens** that projects the image on to a **hemispherical screen**.

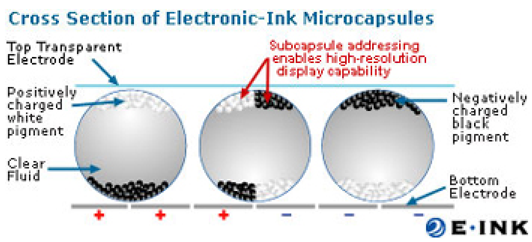
Samsung released the interesting 170 x 127 mm LCD display, that folds like a book.

Displays of the Future

e-books

Displays of the Future

e-books



Ebooks is based on e-ink, a reflective technology relying on millions of microCapsules (diameter of a human hair). Each containing negatively charged black balls and positively charged white balls. Electric charge determines whether the black or white balls will be at the display level.

http://www.eink.com/technology/howitworks.html

http://www.youtube.com/watch?v=Wgh6CM6D-hY

Display Technologies

Projective Displays

Emissive:

- CRT
- Gas Plasma

Transsmitive :

- Liquid Crystal Displays (LCD)
- Liquid Crystal on Silicon (LCOS)

Reflective Displays

Digital Light Processing (DLP)

Organic Led Displays (OLED)

Ebooks

Bit-Depth	Number of Colors
1	2 (monochrome)
2	4 (CGA)
4	16 (EGA)
8	256 (VGA)
16	65,536 (High Color, XGA)
24	16,777,216 (True Color, SVGA)
32	16,777,216 (True Color + Alpha Channel)