Seminar 2:

Display devices and their characterization for vision research

Caterina (Katia) Ripamonti, Tom Robson, and Jakob Thomassen

CAMBRIDGE RESEARCH SYSTEMS

Introduction

With few exceptions (CRS and VPixx), display devices are not designed for vision experiments, but for broadcasting videos, colour reproduction, gaming, and general purpose computing.

In these fields, the important properties of a display are:

- Correspondence between television cameras and studio monitors, as well as between studio monitors and broadcasting monitors (e.g. home TVs).
- Comply with some standards to guarantee good image quality and the correct reproduction of colour-calibrated images.
- (In gaming) Speed and size, but not colour accuracy.

- Price.

Overview

The main objective of this workshop is to provide some information regarding the various display technologies implemented in display devices available today (CRT, LCD, OLED, and DLP).

We will discuss their differences by looking at the displays’ features that are relevant for vision science, such as:

- the relationship between video input signal and output intensity for each primary
- the chromaticity invariance of each primary
- the primaries’ temporal independence and stability
- spatial uniformity and spatial independence
- the independence and inter-dependence between primaries
- the ability to display black

How to calibrate and characterize them.

Describe their performance as visual displays as reported in the literature.

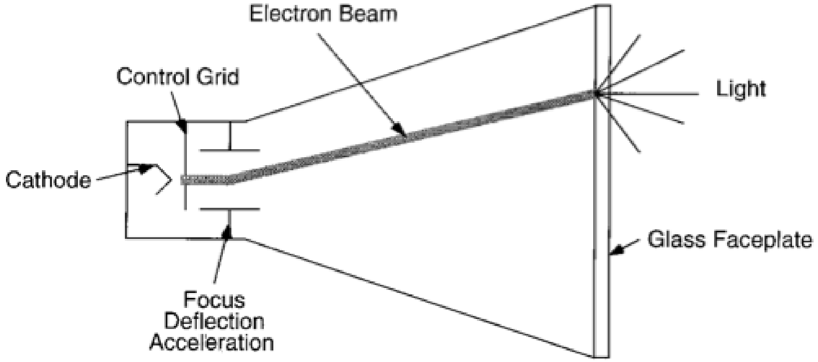
Display technology

It refers to the way in which displays generate their light output:

- Emissive (from light sources: CRT, OLED)
- Transmissive (Light is transmitted: LCD)
- Reflective (Light is reflected: DLP)

Display technology: Cathode Ray Tube (CRT)

Monochrome CRT



Source: Cowan (1995)

The tube is a sealed glass envelope from which all the air has been evacuated.

A cathode is an electrode through which electric current flows out of a polarized electrical device.

Electrons are emitted from the cathode, which is heated hot.

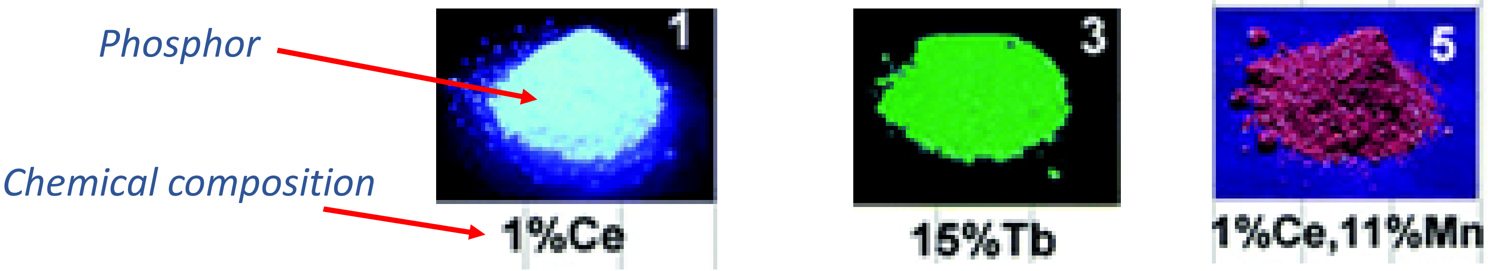
The beam strikes a layer of phosphor on the inside of the CRT depositing power.

Some of this power is converted to light by the phosphor.

What is a phosphor?

A solid inorganic material that emits light, or fluoresces, when exposed to radiation such as ultraviolet light or an electron beam.

The spectral power distribution of the emitted light is determined by the chemical composition of the phosphor.



As a consequence, different compositions have a different chromaticity (colour) and a different period of time, known as persistence, during which the light emitted ceases.

Chromaticity coordinates of phosphors

Ideally, the phosphors used by the CRT primaries should be widely separated in colour space to produce a large gamut of visible colours.

And their persistence (decay) should be reduced to a minimum.

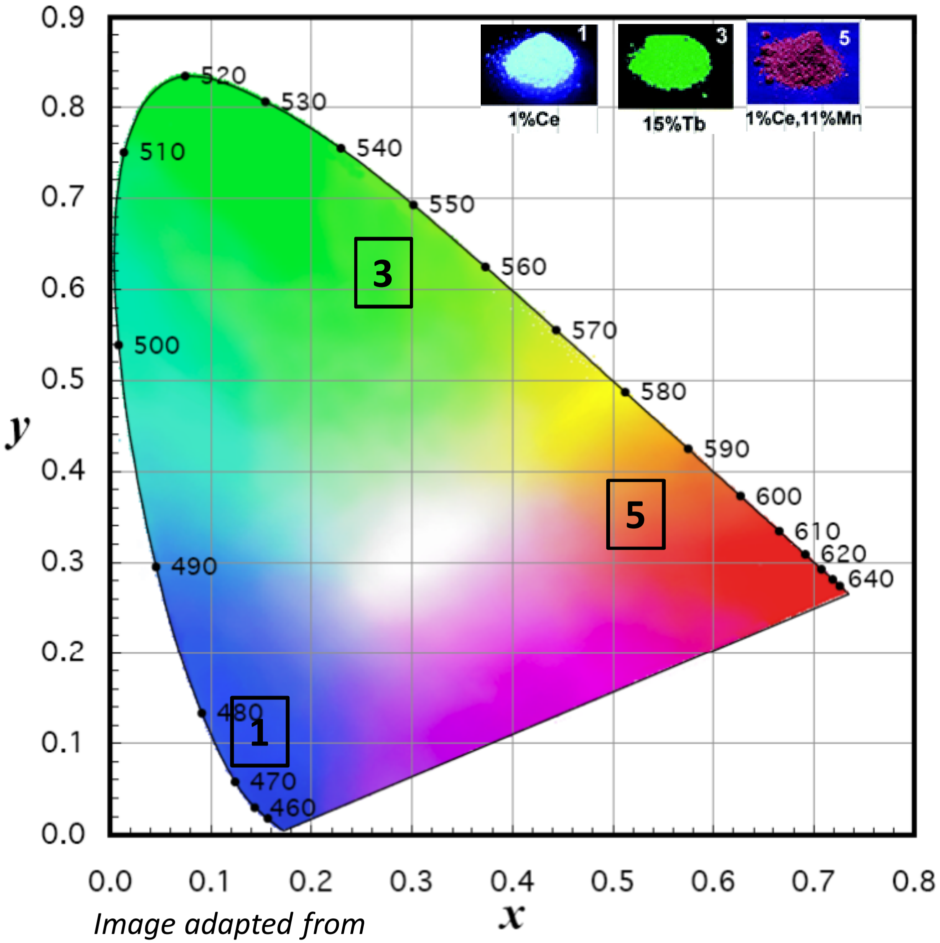


Image adapted from http://pubs.rsc.org/en/content/articlelanding/2013/dt/c3dt52328d#!divAbstract

Colour Gamut

The three vertices correspond to the three phosphors used by this SONY Trinitron CRT.

The device can only display the colours that fall within the monitor's colour gamut and its luminance range.

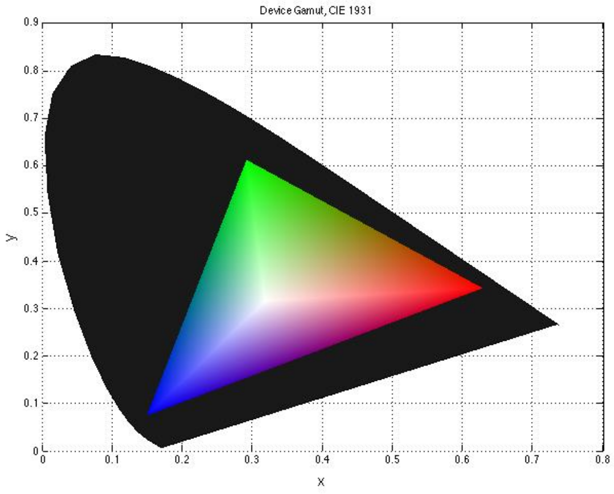


Image: CRS Colour Toolbox for MATLAB

The three functions below represent the three SPDs for the Red, Green, and Blue phosphors.

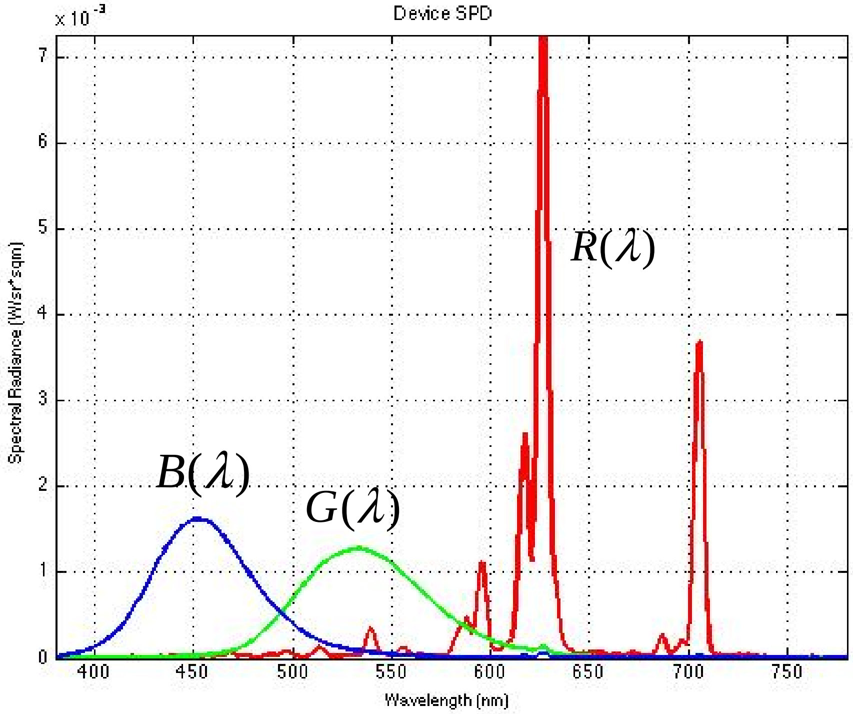


Image: CRS Colour Toolbox for MATLAB

Monochrome CRTs

Some monochrome CRTs (like the Clinton Monoray) use a yellow/green phosphor (development phosphor, DP104) which has a very short persistence and high brightness.

The short persistence (or fast decay) makes this phosphor an ideal candidate for experiments requiring, for example, dichoptic stimulation.

These experiments use frame-sequential presentations, in which the two eyes are stimulated by alternate frames. The fast decay is crucial if you want to present dichoptic images with no cross-talk between the left and the right eye.

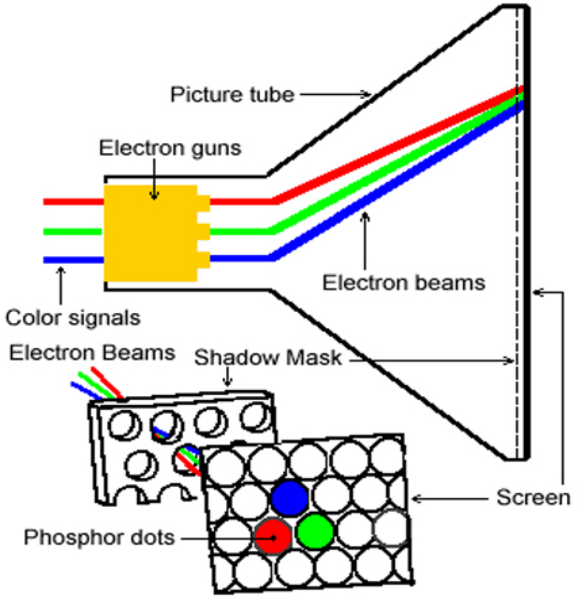
Fast decay is also important in motion and flicker stimuli.

[An additional requirement is fast refresh rate]

Image: http://www.keithmay.org/equipment_specs.html

Colour CRTs: Shadowmask

A colour CRT uses the same display technology as a monochrome CRT.



The underlying principle is based on additive colour mixture: the sum of several monochromatic images that differ in hue will produce a colorful image.

In a typical CRT, there are three guns (or electron beams) instead of only one as for the monochrome CRT.

The three beams pass through a shadow mask at a different angle.

The geometry is distributed so that each beam hits a different phosphor which will emit either red, green, or blue light.

[The 'Color signals' are coloured for convenience only]

Source: Cowan (1995)

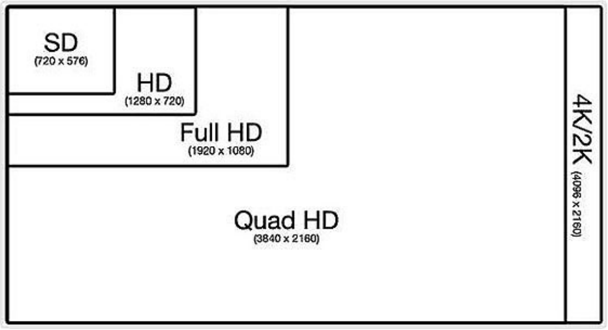
Display spatial resolution

The term resolution is often used to indicate the pixel count of the largest image that can be displayed on the screen, and it is reported as M x N (for example as 1920 x 1080).

The total number of pixels is not the only parameter that counts to obtain high resolution. The size of the pixel is also crucial.

Therefore, spatial resolution is more conveniently described in terms of dots per inch (dpi) for printing devices, or pixel per inch (ppi) for display devices.

Image: www.pinnacledisplays.com



Four resolutions compared: standard definition, full high definition, Quad HD and 4K/2K.
(Credit: Derek Fung/CNET)

Bit depth

In general, each pixel has three primary components (sub-pixels), each of which can be specified by a number of bits called the bit depth or colour depth.

For example:
If each primary has 8 bits, the bit depth will be specified as either an 8-bit per channel system or a 24-bit system

8 (bits) x 3 (primaries) = 24

Which sounds even more attractive if you specify it as a 16.8 million colours system (from 2^{24}).

When reading monitors' specifications, pay attention to whether the number of bits reported refers to the total number of bits (24-bit as above) or the number of bits per channel (8-bit as above).

Bit depth

16.8 million colours sounds like a large number of colours.
However, if you are planning to measure visual thresholds, you should consider whether those colours or luminance levels will allow you to vary your stimulus using steps that are small enough.

At low light levels, the contrast threshold for a 3 c/deg grating is about 0.3%.

n-bit per c. system	*Smallest step*
8-bit ($2^8 - 1 = 255$)	1/255 = 0.4%
10-bit ($2^{10} - 1 = 1023$)	1/1023 = 0.1%
12-bit ($2^{12} - 1 = 4095$)	1/4095 = 0.02%

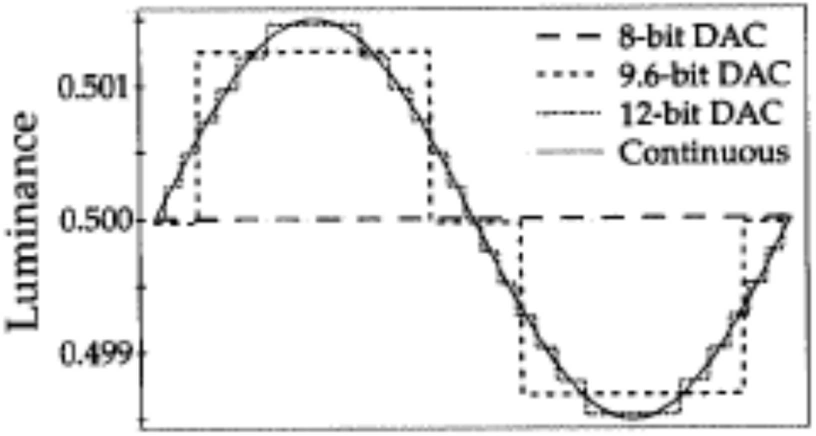


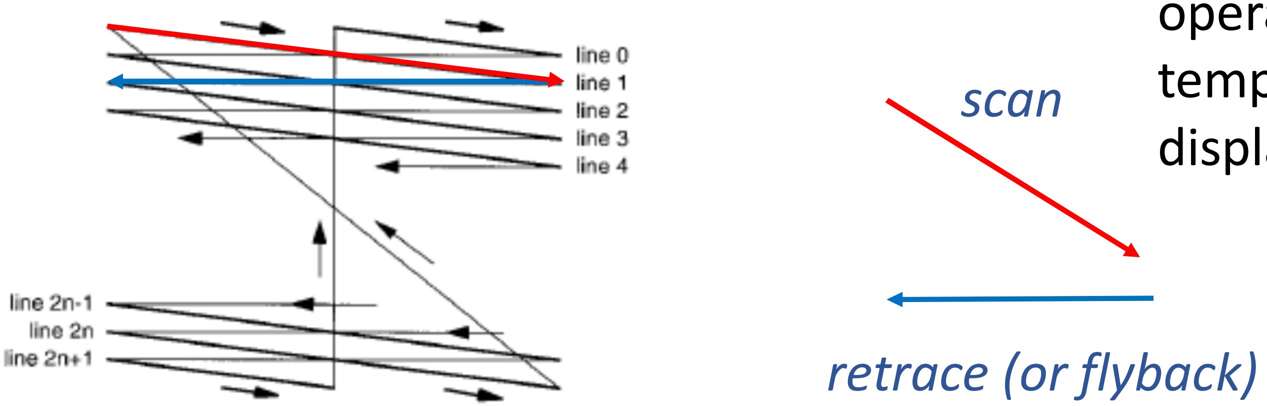
Fig. 1. Rendering of a 0.3% contrast sinusoid by ideal 8-, 9.6- and 12-bit DACs, compared with a true sinewave.

We assume that the output of the display has been linearized.

Source: Pelli and Zhang (1991)

CRT: How does it display images?

The CRT forms an image on the screen by scanning the electron beam from place to place, modulating the beam current to change the brightness from one part of the image to another.



The way in which the scanning is operated contributes to the temporal properties of the display.

Source: Cowan (1995)

Calibration and characterisation

Calibration is the process of setting the device to a known state or desired configuration (for example: white balance, brightness, contrast, etc.).

Characterization is the process of profiling the device and measuring its properties to allow accurate image reproduction from its numerical representation (for example: gamma function, primaries’ SPDs, uniformity, temporal and spatial resolution).

Calibration

Adjust the following: focus, brightness, contrast, and colour balance.

Focus: display a uniform grey field and shrink the beam size until raster lines are clearly visible. Then adjust the beam size until the raster lines are just visible.

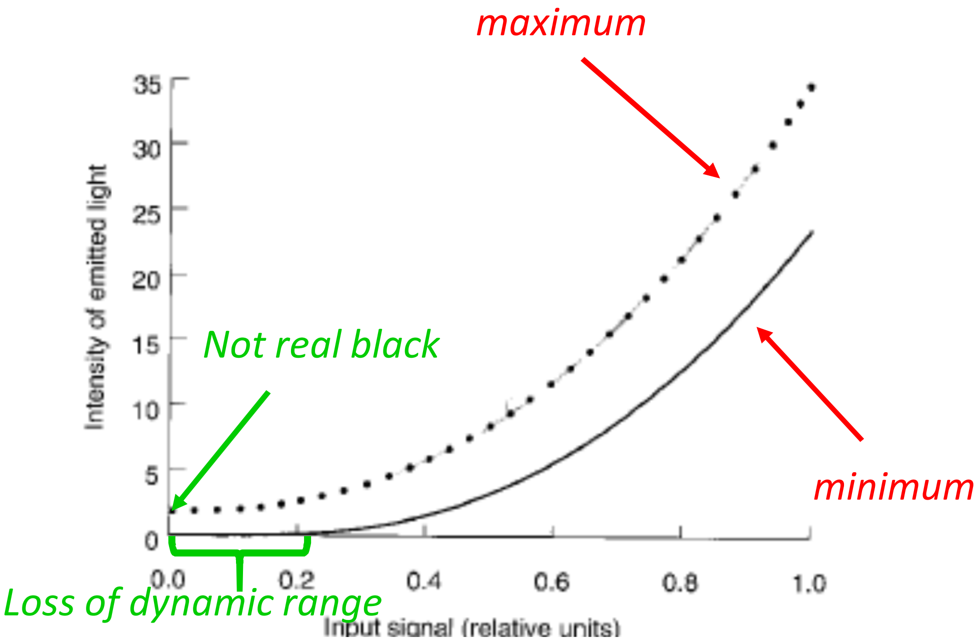
Brightness (or black level): the aim is to present a stimulus that gives a visual impression of black. Adjust brightness under the same lighting conditions you are going to use in your experiment. Set it to zero brightness and then slowly increase it until you see grey, then decrease it until you see black.

Contrast: Set all guns to the max luminance, and avoid blooming.

Colour balance: choose your reference white and adjust the red, green and blue guns to match it. It might then be necessary to readjust the brightness, and then the colour balance in iteration, until the match is satisfactory.

Source: Cowan (1995)

Example of brightness variation



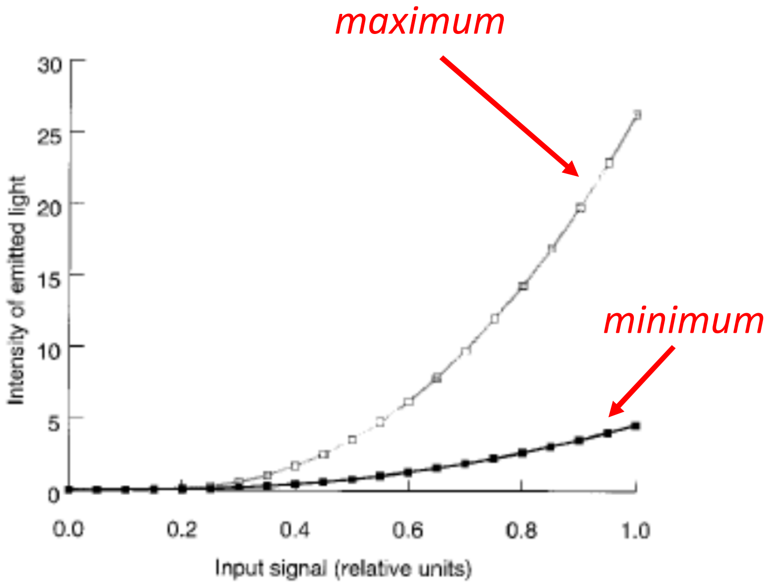
Variation of the light intensity as a function of the input voltage when the brightness (black level) control is varied.

The lower curve shows the relationship with brightness set near its minimum; the upper one with brightness set somewhat higher.

Measurements from a Tektronix CRT (SR690).

Source: Cowan (1995)

Example of contrast variation



Variation of the light intensity as a function of the input voltage when the contrast is varied.

The lower curve shows the relationship with contrast set near its minimum; the upper curve with contrast near its maximum.

Measurements from a Tektronix CRT (SR690).

Source: Cowan (1995).

Device characterisazion

Any device (not only CRTs) should be characterized before running an experiment.

You want to know whether your device is able to display the stimulus that you request BEFORE you measure the observer’s response to that stimulus.

This will also give you an idea of the noise in your system, which will help you to define the level of accuracy you can expect in the stimulus reproduction.

What to measure:

- Temporal stability
- Spatial uniformity
- Pixel independence
- Channel independence
- Channel linearity
- Phosphor constancy (maintain a constant relative spectral distribution as intensity is varied)

Temporal stability over a short period (24h)

Temporal stability reflects the constancy of the light emitted during the same input signal.

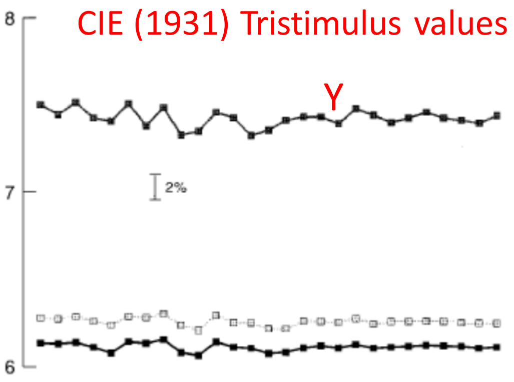


FIGURE 12 Variation of light output from a color CRT over 24 hours of continuous operation. This graph shows the three tristimulus values when a neutral color is displayed. The latter part of the graph is at night when almost all other equipment in the building is turned off.

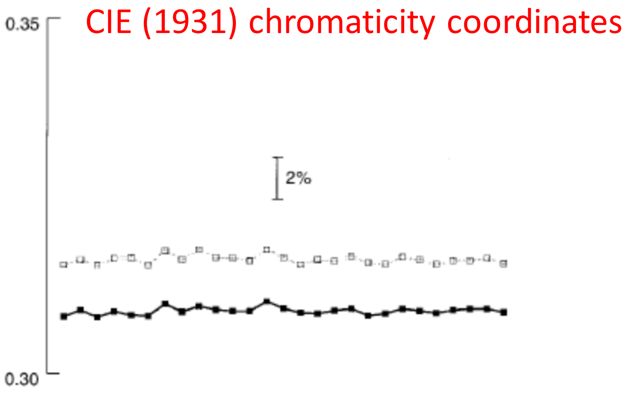


FIGURE 13 Variation of light output from a color CRT over 24 hours of continuous operation. This graph shows the chromaticity coordinates corresponding to Fig. 12. They show less variation than the tristimulus values which covary considerably.

Note that the variation attenuates from the evening to the next morning.

Cowan attributes this effect to the temporal instability of the building power.

Take home message: some variations are inevitable, and they should be taken into account when considering the precision of the calibration. There is no point in calibrating to a greater precision than the variation in colorimetry over the period between calibrations.

Source: Cowan (1995).

Fluctuations over a shorter period (180 min)

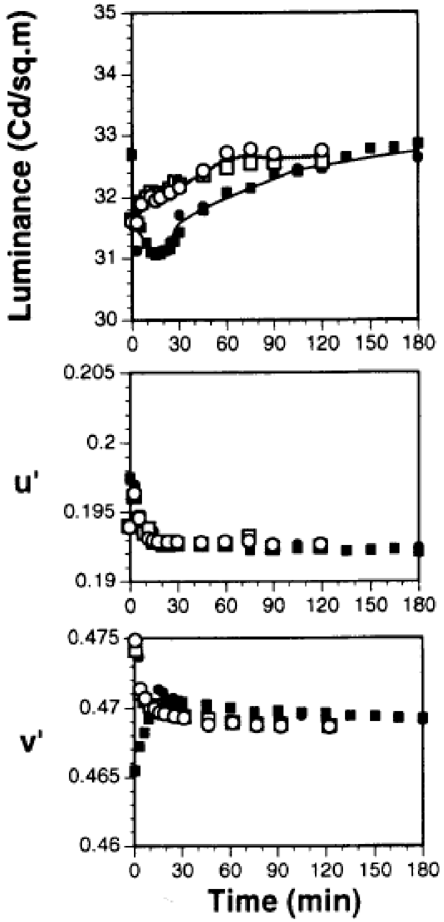


Figure 3. Colorimetric data of the warm-up process. The squares indicate results from the first data set and the circles represent data collected 2 days later. The filled symbols refer to "cold" starts, and the open symbols represent data for "warm" starts. Refer to the text for definitions.

CRTs need a warm-up period, before they reach a relatively stable temporal response.

General advice: Warm-up the monitor for at least 60 minutes from “warm start” or 150 minutes from “cold start”.

From Metha et al. (1993)
“cold start“ : off period > 14hrs
"warm start“: restart after 20 min from off (having being on for 3-hrs)

RESULTS from a BARCO CRT (CDCT6551)
Asymptotic values were similar in all cases, but were achieved earlier for warm starts.

A stable luminance was achieved only after some 60 and 150 minutes following warm and cold starts, respectively.

The greatest variability was found within the first 20 minutes of a “cold start”.

Source: Metha et al. (1993)

Channel independence

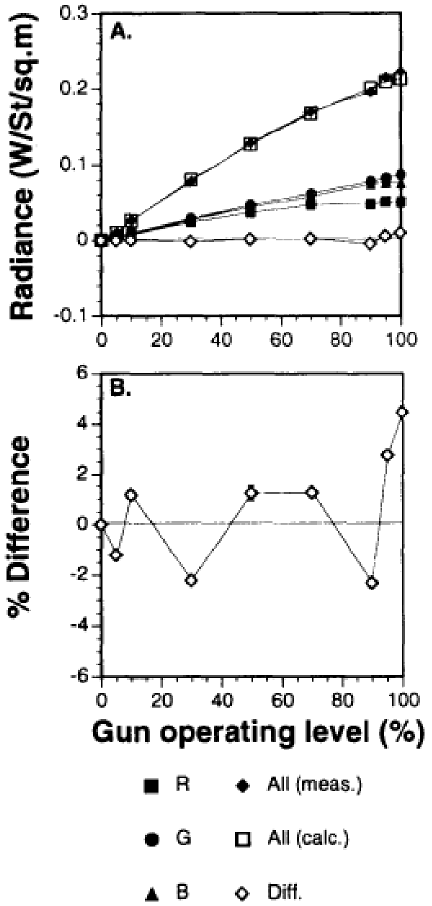


Figure 6. Gun independence as a function of operating level. (A) Radiance of individual and combined gun outputs at a range of operating levels. (B) The difference between calculated and actual radiances [(measured − calculated)/measured] expressed as a percentage of actual radiance values.

The spectral power distribution of the light emitted by the three guns when they operate together, should be equal to the sum of their spectral power distributions when they operate in isolation.

SPD white = SPD Red + SPD Green + SPD Blue

Lack of independence may be due to blooming, which happens when the brightness is set too high.

Results: gun independence holds within ±3% for operating levels between 0 - 95%.

Source: Metha et al. (1993)

Pixel independence

26.4: Artifacts of CRT Displays in Vision Research and Other Critical Applications

Eli Peli[1]
Schepens Eye Research Institute, Harvard Medical School
Miguel A. García-Pérez[2]
Facultad de Psicología, Universidad Complutense

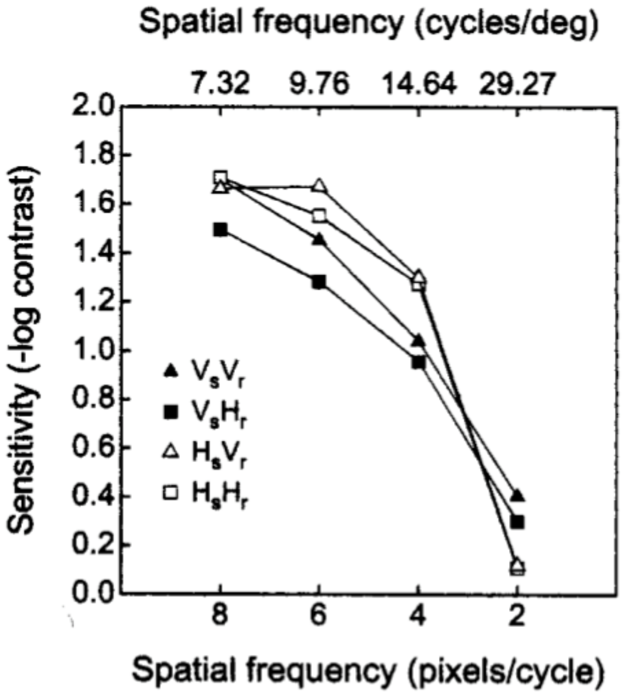


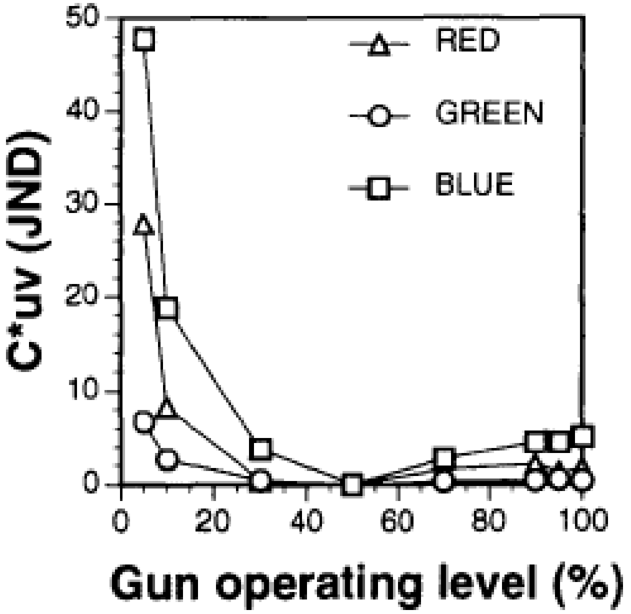
Figure 2. Contrast sensitivity for retinally horizontal and vertical stationary gratings whose bars are oriented either along or across raster lines, as a function of their spatial frequency. V_s: vertical on the screen; H_s: horizontal on the screen; V_r: vertical on the retina; H_r: horizontal on the retina. Note that curves for open symbols (where grating bars are aligned with raster lines) are very similar regardless of whether the gratings turn out to be horizontal or vertical on the retina. The same is true for the curves for filled symbols (where grating bars are orthogonal to raster lines). At the same time, the two pairs of curves differ markedly from each other.

Source: Peli and Garcia-Perez (2000)

Phosphor constancy

The spectral power distribution of the three phosphors is independent of the intensity level.

As a comparison, the Colour difference C*uv of adjacent caps in the Fansworth D15 panel test for colour vision is 12 JNDs, and normal trichromats find these discriminations easy.



Source: Metha et al. (1993)

Thus, the current measurements from the BARCO monitor below 10% are an alert that the phosphors may not achieve constancy below this level.

Thus, if you are doing an experiment in which colour reproduction is crucial and you need to be using your device at these low levels, you should consider to stay in the medium range and use neutral density filters to decrease the luminance, while maintaining good phosphor constancy.

Spatial uniformity

Spatial uniformity represents the distribution of light over the screen area.

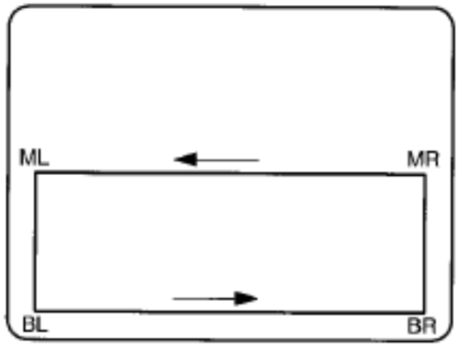


FIGURE 15 The measurement path used for the measurements shown in Fig. 14.

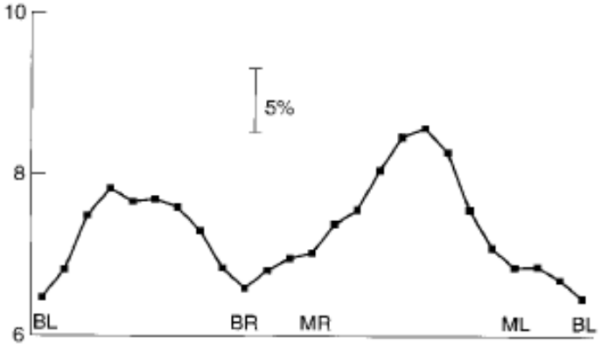


FIGURE 14 Variation of light output when different parts of a CRT screen are measured from a fixed point. Horizontal lines mark variations of about 5 percent.

Causes of non-uniformity:

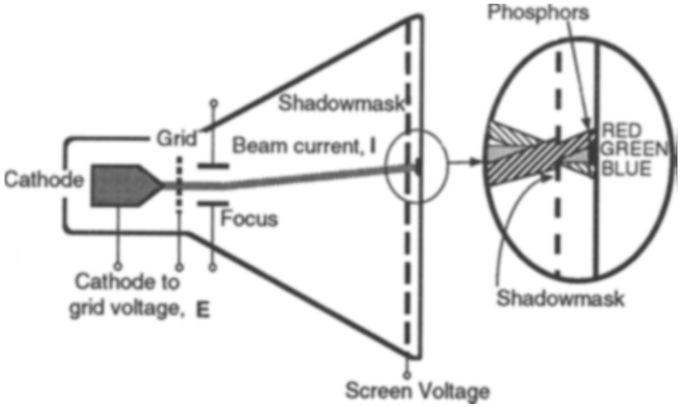
The beam scans the edges at an angle, making the holes effectively smaller. Light is emitted in a non-lambertian distribution, preferring directions closer to the normal to the tube face. The effects in Fig. 14 occur in all CRTs. How large they are, however, depends strongly on the type and setup of the monitor. Correcting for this nonuniformity is usually impractical. Doing so requires very extensive measurements.

Source: Cowan (1995).

Gun linearity and gamma correction

CRTs do not behave like linear devices (Rodieck, 1983).

This means that the voltage applied to the guns is not linearly related to their output in terms of screen luminance or photons emitted (Metha et al, 1993).



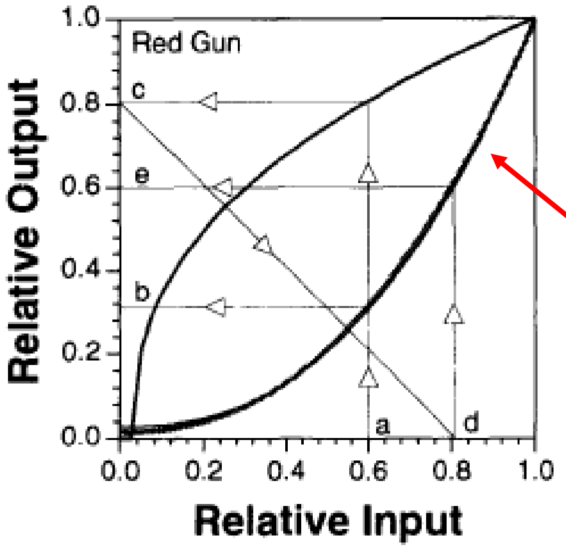
Source: *Metha et al. (1993)*

The beam current (*I*) is controlled by the cathode-to-grid voltage E by a power law relationship, which is the basis for the nonlinearity as:

gamma function $$\theta(E) = \beta E^{\gamma}$$

Where $\theta(E)$is some physical measure of output (*e.g.* luminance), E is the applied voltage, β is a constant, and γ is the exponent of the power function, usually equal to 2.2.

The optoelectronic transfer function (OETF) or Gamma function



gamma function

Figure 11. Input–output relationship (gamma function) and its inverse for the red gun. The lower curves are the actual and modeled gamma functions. The top curve is the inverse of the model. Without linearization, a call for 0.6 units would result in an output of 0.31 units (a – b). Using the correction look-up table, a call for 0.6 units (a) would be sent to the look-up table containing a value of 0.81 (c). Applying this number to the DACs (d) would result in an output of 0.6 units (e), as requested.

Adding the dark light*, the equation becomes:

$$\theta(E) = \alpha + \beta E^{\gamma}$$

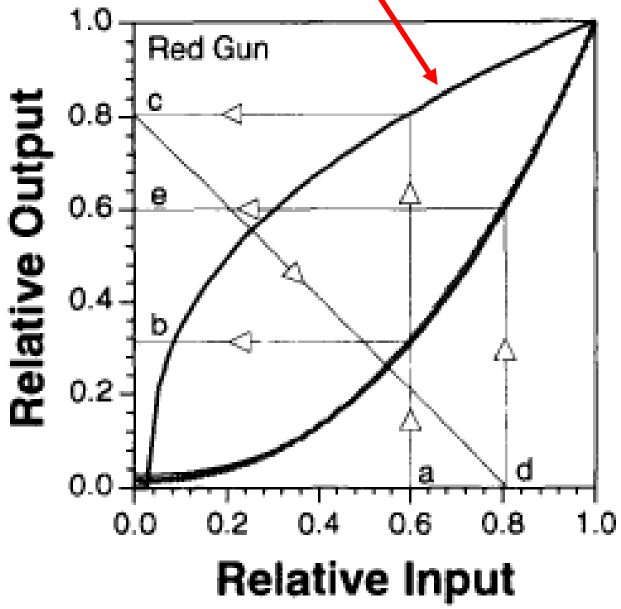
*Dark light is the output of the screen when zero voltage is applied to it. This may originate, for example, from ambient light reflected off the face place, or the phosphorescence of the phosphors.

Source: Metha et al. (1993)

Gamma correction

In general, gun voltages are controlled by a computer graphics system that needs to be linearised with respect to the output intensity (Metha et al., 1993). This gamma correction can be performed in a variety of ways:

Inverse of the gamma function



1) It can be produced by hardware in the form of fixed electronic circuitry that assumes an apriori gamma relationship.

2) By generating compensating "look-up" tables. This consists in finding the inverse of the gamma function for each gun.

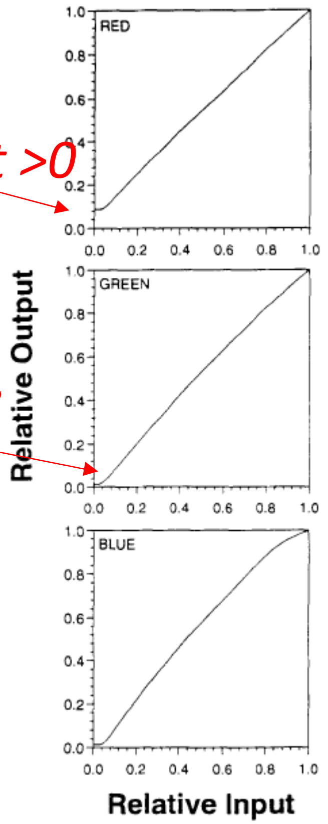
Inverse function:

$$\text{LUT}\ (x) = \left[\frac{x-\alpha}{\beta}\right]^{1/\gamma}$$

Where x is the desired output, and α , β and γ are as defined previously.

Source: Metha et al. (1993)

Results from the gamma correction



intercept >0

departure from linearity

Figure 12. Input-output relationships for all guns 2 days after gamma correction had been applied. Note the "dark light" at the lower left of each curve.

The intercept >0 is the consequence of dark light.

Notice that there is a sharp departure from linearity at levels below 5% of the operating range due to the dark light of the CRT.

The departure at the upper end of the operating range may be due to gun interactions.

Same advice as before: if you need to operate at low light levels, it is better to use ND filters.

Source: Metha et al. (1993)

CRTs for vision research

Limitations:

- The light is not presented continuously, but discretely in flashes (through scanning). The transition from white to dark can generate an unwanted flicker in electrophysiological recordings.
- Lack of independence between neighboring pixels (visible with horizontal and vertical gratings, see Pelli 1997).
- Can produce electromagnetic radiation which can introduce noise in electrophysiological recordings (Wang & Nicolić, 2011).
- Unused examples are becoming difficult to find.

So … what next?

Alternative display devices

Displays based on digital light projection (DLP) or mechanical shutters.

However these solutions need complex and relatively expensive set-ups.

Liquid crystal displays seem to offer an affordable solution.

Unlike CRTs:

- Images are presented virtually continuously
- Offer pixel independence
- Produce negligible electromagnetic noise
- Are broadly available
- Can be brighter than CRTs

Source: Wang & Nicolić (2011)

Display technology: Liquid Crystal Display (LCD)

A Liquid crystal display (LCD) is a flat panel display that uses the light modulating properties of liquid crystals.

Liquid crystals do not emit light directly, but can transmit light generated by the backlight.

CRS Display ++

BenQ XL2410T

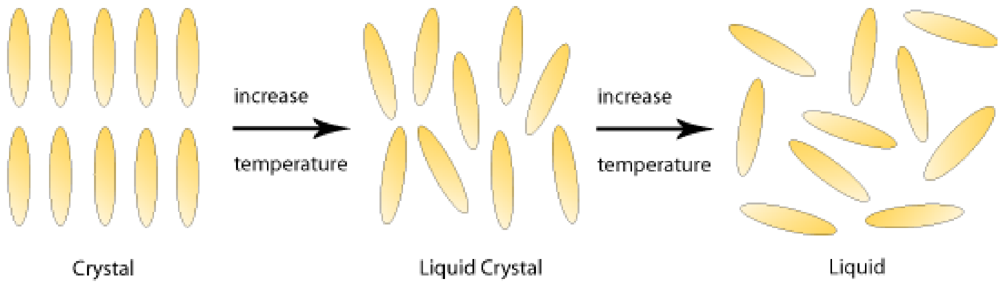
SAMSUNG 2233RZ

What are liquid crystals?

Are special substances that exhibit both the properties of solids and of liquids.

For example, their molecules have a rigid structure like solids, but can move around like liquids.

Their molecules are long and thin, and even if their positions are random, their *orientations* can be aligned with one another in a regular pattern.

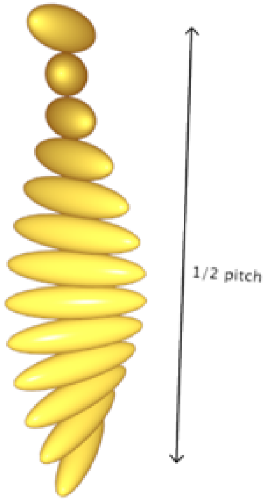


Source: http://www.doitpoms.ac.uk/tlplib/liquid_crystals/printall.php.

Most liquid crystals are *thermotropic*; their degree of orientational and positional order depends on temperature and so their liquid crystalline phase occurs within a limited temperature range between the solid and liquid phase.

Nematic liquid crystals

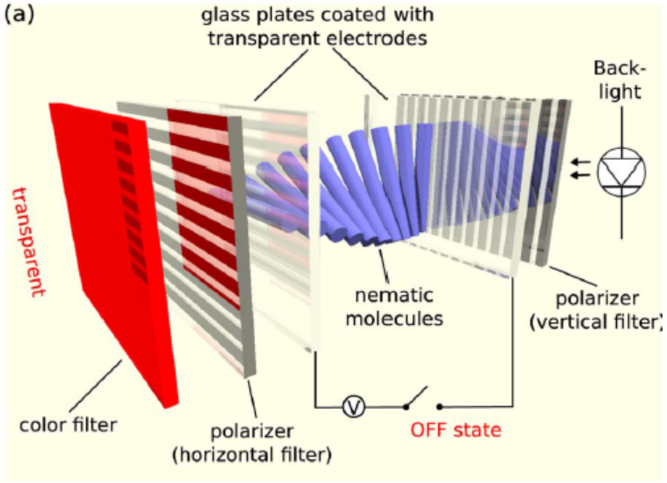
Liquid crystals have different phases. A common LC phase used in LCD panel technology is nematic.



Nematic liquid crystals have *no positional order*, they only have *orientational* order.

Source: http://www.doitpoms.ac.uk/tlplib/liquid_crystals/printall.php.

LCD Panel Technology: Twisted Nematic

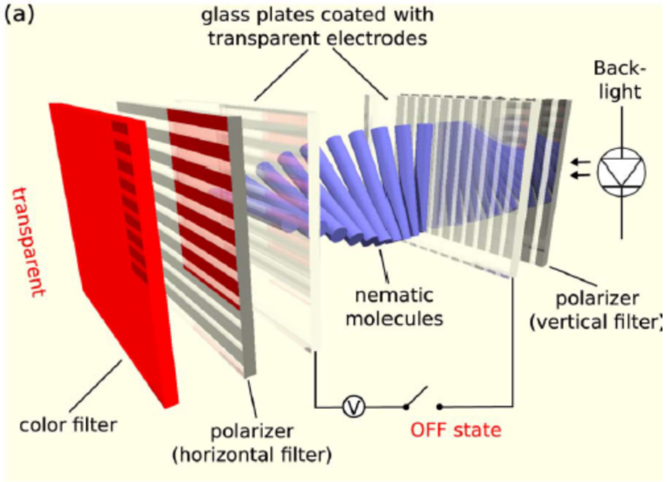


A nematic liquid crystal is sandwiched between:

- Layers of polymer substrate
- Transparent electrodes
- Glass
- Polarizers (perpendicular to each other)

Source: Elze & Tanner (2012).

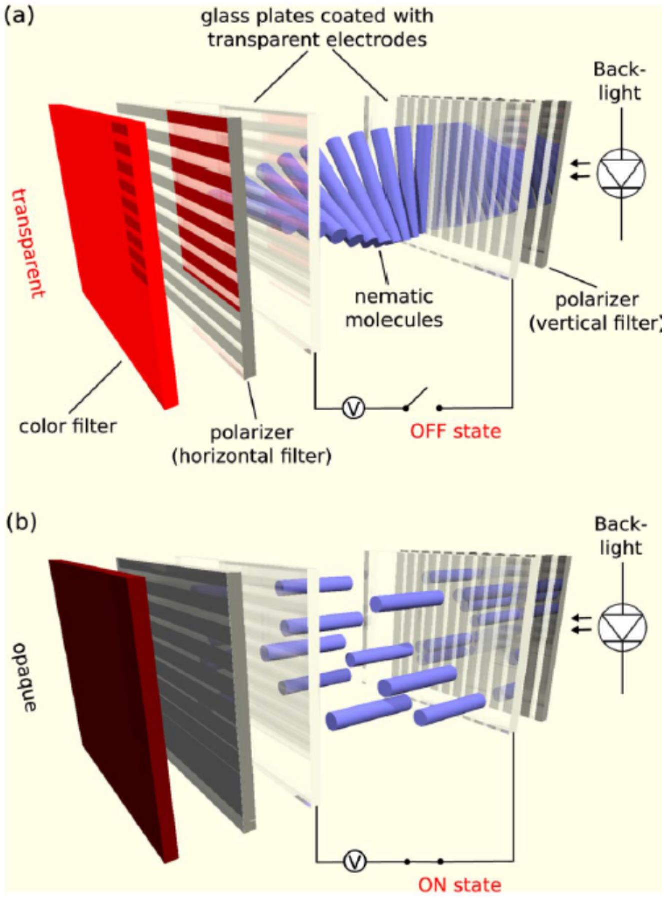
LCD Panel Technology: Twisted Nematic



When no electric field is applied (a), the helical structure of the LC molecules rotates the vertically polarized light so that it can pass through the second, horizontal polarizer.

Source: Elze & Tanner (2012).

LCD Panel Technology: Twisted Nematic



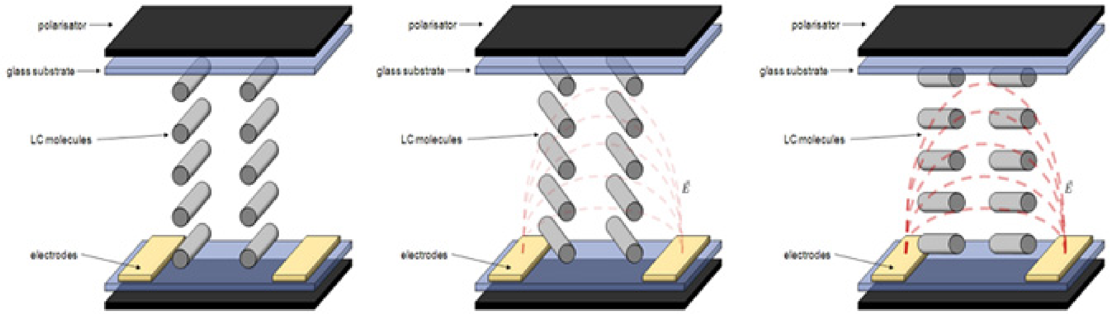
Source: Elze & Tanner (2012).

When no electric field is applied (a), the helical structure of the LC molecules rotates the vertically polarized light so that it can pass through the second, horizontal polarizer.

When an electric field is applied (b), the molecules tend to align with the electrical field, distort and finally break the helical structure so that the backlight is blocked by the horizontal polarizer and the respective subpixel appears opaque.

LCD Panel Technology: In-Plane Switching

The crystals in the cells of the IPS panel lye always in the same plane, which is always parallel to the panel’s plane.



IPS-OFF (100% Brightness) IPS-ON (50% Brightness) IPS-ON (0% Brightness)

Source: http://www.tftcentral.co.uk

When voltage is applied to a cell, the crystals of that cell all make a 90-degrees turn.

An IPS panel lets the backlight pass through in its active state and blocks it in its passive state (when no voltage is applied). Thus, if a thin-film transistor crashes, the corresponding pixel will always remain black, unlike with TN matrices.

LCD Panel Technology: Differences

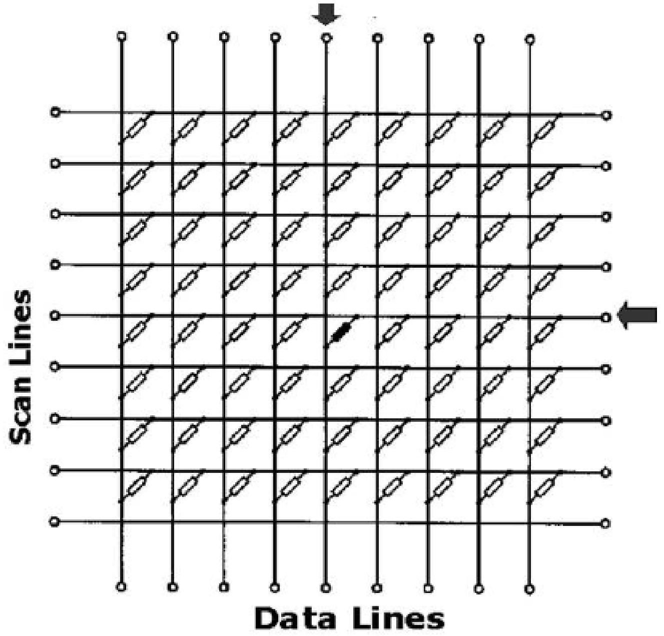
There are several LCD panel technologies (see also Super IPS, Advanced fringe field switching, Vertical alignment, Blue phase mode) which differ according to their properties, performance, and price.

For example, TN panels show the most restrictive viewing angle (especially vertically). They are only true 6-bit colour panels but can stretch to 8-bit thanks to dithering and Frame Rate Control methods.

IPS panels have a wider viewing angle, better “real” black, but slower response time and higher voltage consumption.

LCD Matrix Technology: Passive

Passive-matrix LCDs use a simple grid to supply the charge to a particular pixel on the display; the grid is made of two glass layers called substrates. The LCD panel is positioned in between the two layers.



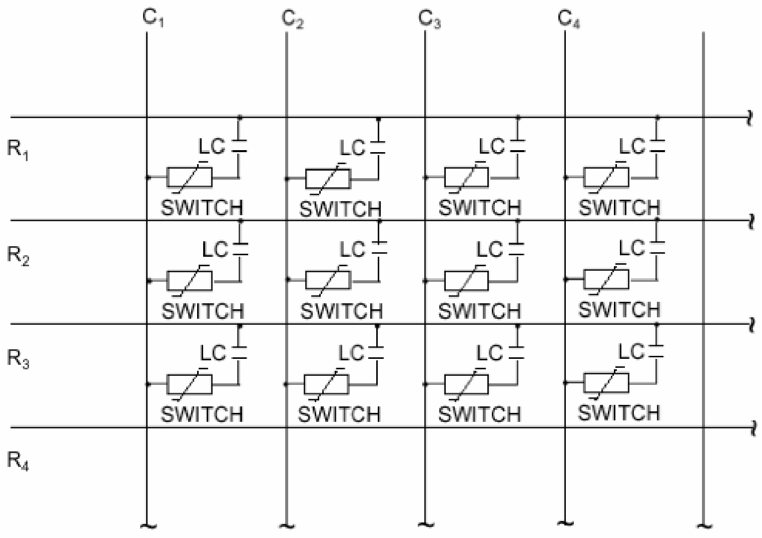
Source: http://www.koe.j-display.com

To turn on a pixel, the integrated circuit sends a charge down the correct column of one substrate and a ground activated on the correct row of the other. The row and column **intersect** at the designated pixel, and that delivers the voltage to untwist the liquid crystals at that pixel.

The simplicity of the passive-matrix system is beautiful, but it has significant drawbacks, notably **slow response time** and **imprecise voltage control**.

LCD Matrix Technology: Active or Thin Film Transistor

Active-matrix (or TFT) LCDs use electronic switch device in each LC pixel, controlling the charging of the LC cell to the desired grey level.



An active switch is placed in each pixel of an LCD that controls the charging of the LC capacitance to the voltage corresponding to the desired grey level, and storing it there until the next frame refresh. This is done usually by the “one line at a time” method of addressing.

Source: http://www.koe.j-display.com

LCD: Backlight

The backlight in an LCD is positioned behind the first polarizer.

There are several types of backlight (CCFL, WLED, RGB LED, QDEF) which will provide different colour gamuts.

The two most popular backlight technologies are: Cold Cathode Fluorescent Lamps (CCFL) and Light Emitting Diodes (LED).

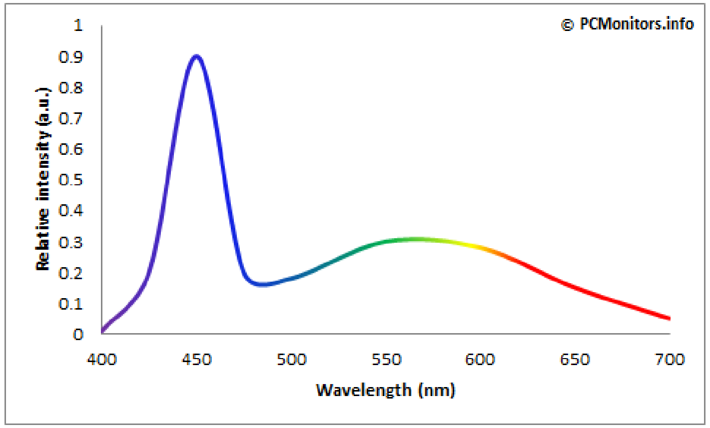
CCFL

LED

LCD: WLED Backlight

Despite being called ‘white’ LEDs they actually emit a blue light which passes through a yellow phosphor to give a more neutral white and provide the red and green components of the image.

WLED



A WLED backlight has a smaller colour gamut compared to an RGB LED backlight. However the drawback of RGB LED is the differential degradation of the LEDs and the optical design to achieve colour balance is more complicated.

Source: http://pcmonitors.info/

LCD: WLED Backlight and colour gamut

The backlight passes through the Red, Green, and Blue filters of the LCD panel to produce a wider range of colours and a the display native white point.

Because of the filtering, a large amount of light is lost.

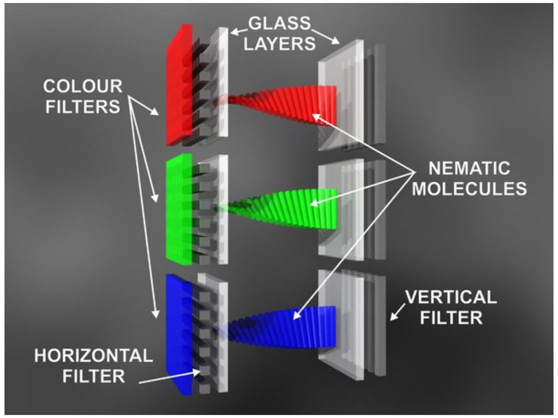
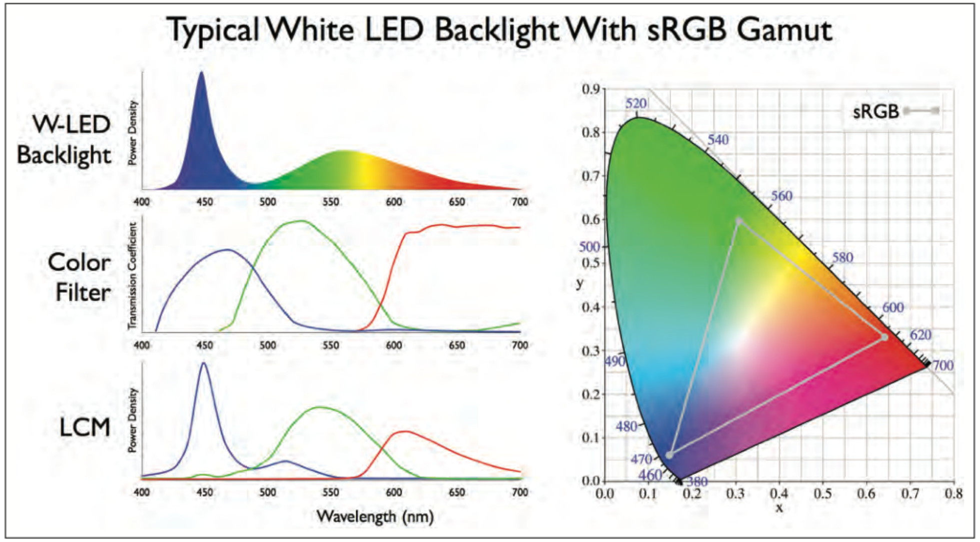


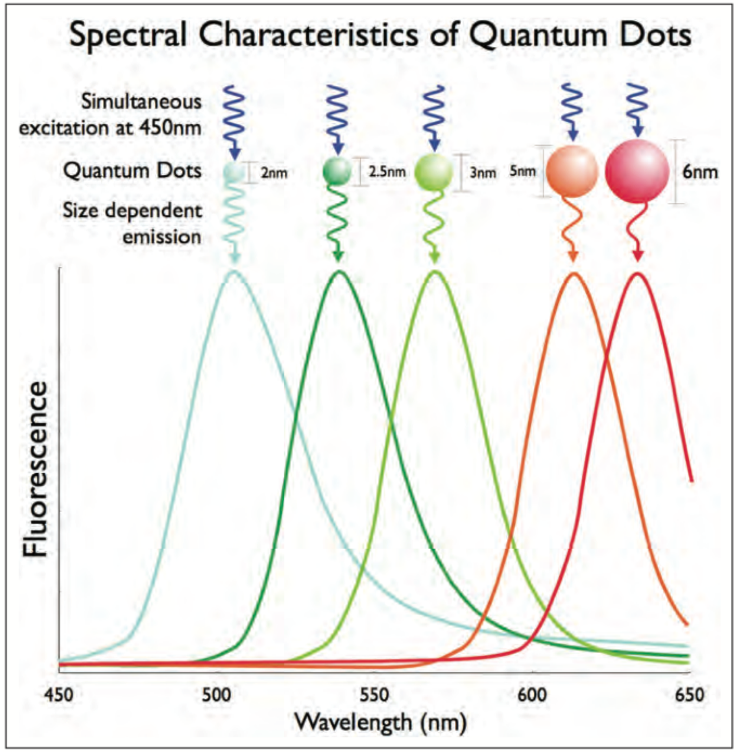
Image: www.tested.com/tech/868-researchers-develop-more-efficient-color-filter-for-lcds/



Source: *www.nanosysinc.com//*

Quantum Dot Enhancement Film (QDEF) is the future

Quantum dots comprise a new class of material that can be tuned to emit light very efficiently at short, medium and long wavelengths, thus creating an ideal light spectrum for LCDs.



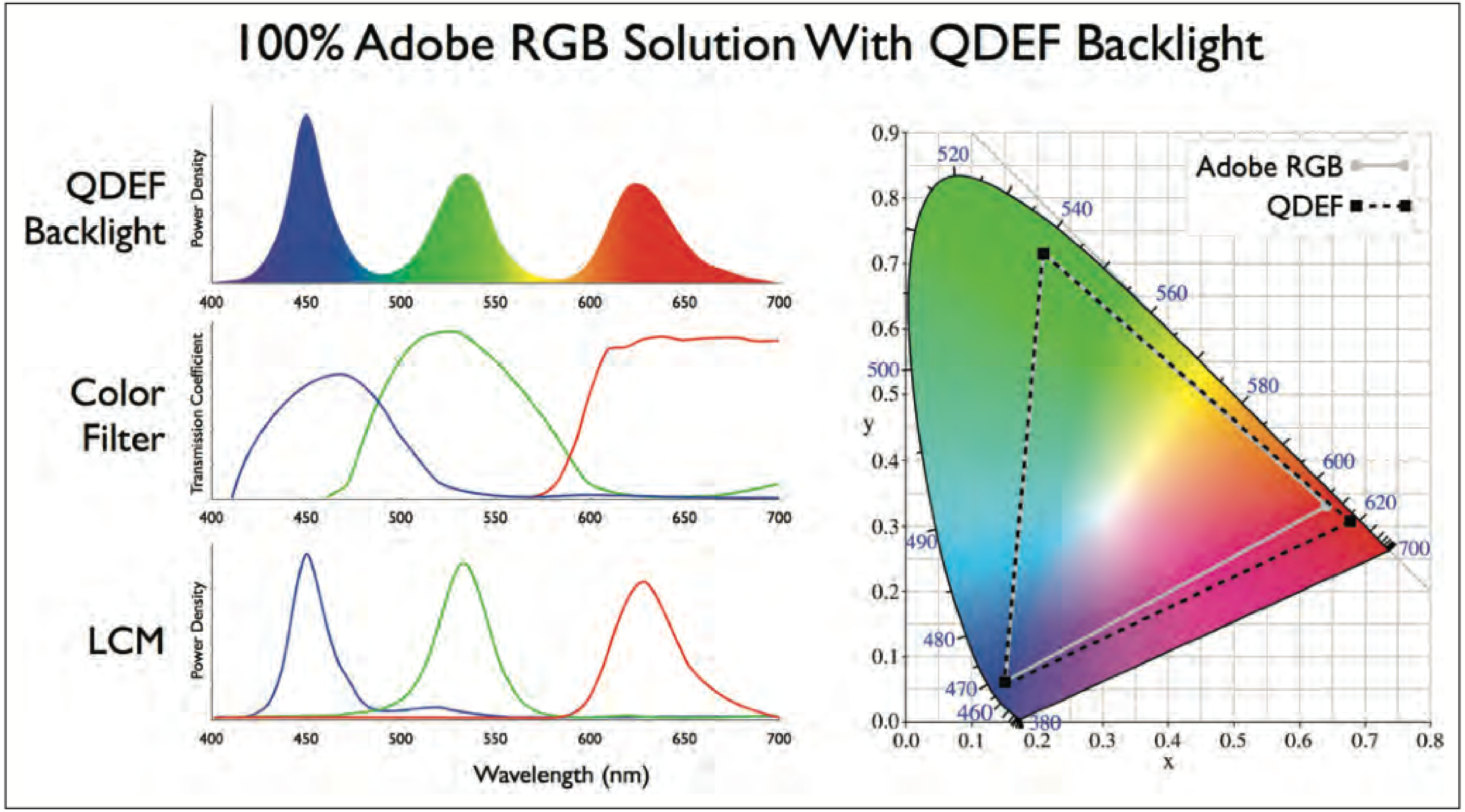
Unlike conventional phosphor materials, quantum dots, which are just nanometers in diameter, can be fabricated to convert short-wavelength light (*i.e.*, blue light) to nearly any color in the visible spectrum.

The spectral output of a quantum dot is determined by its size.

Currently only available for TVs and tablets.

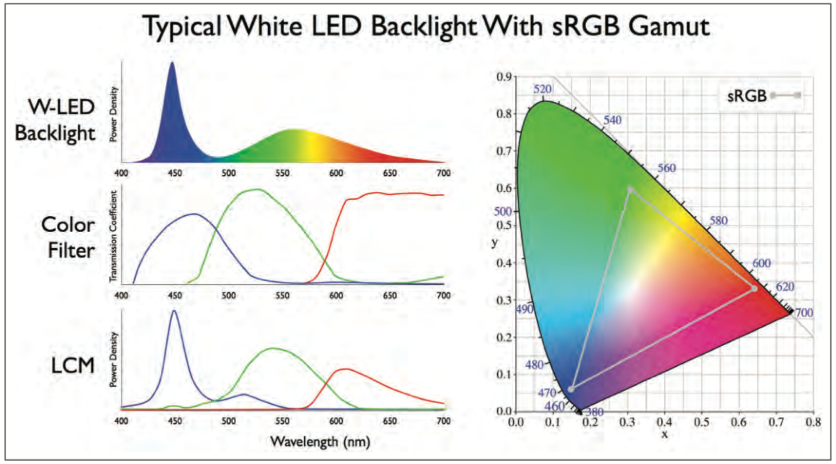
Source: www.nanosysinc.com//

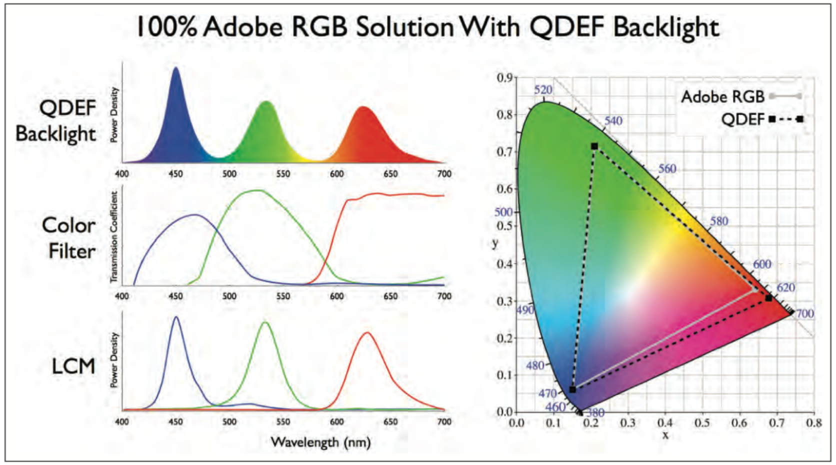
Quantum Dot Enhancement Film (QDEF) is the future



Source: www.nanosysinc.com//

Quantum Dot Enhancement Film (QDEF) is the future





Source: www.nanosysinc.com//

LCD: Backlight controls

In an LCD, the light output is generated in a rasterized manner, by scanning the video lines one by one.

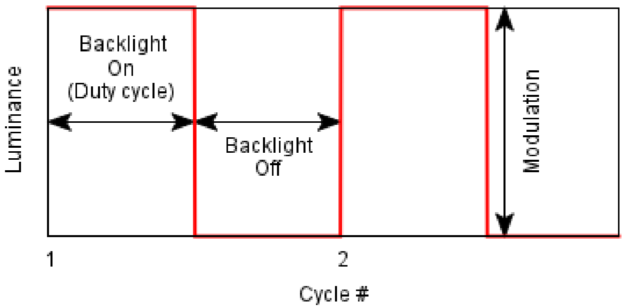
This would in principle generate some visible flicker, unless the total light output of the backlight is adequately controlled.

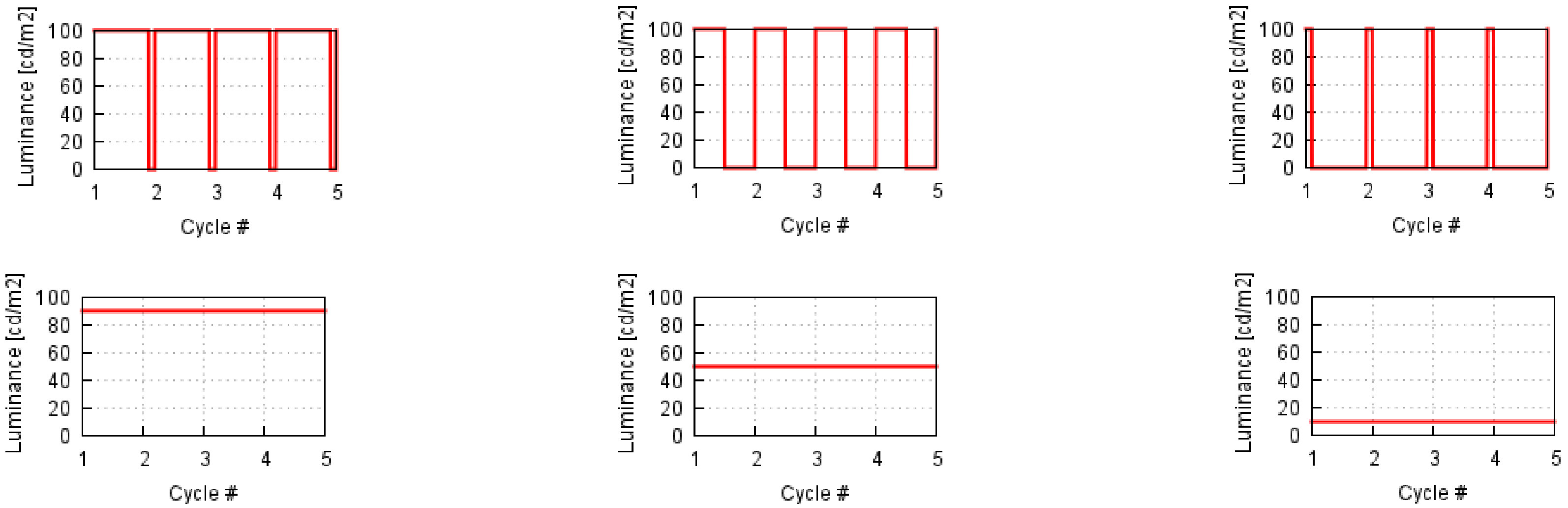
This can be achieved in at least two ways:

1) The backlight is always on, and the light output is modulated by changing the amplitude of the current (i.e., by varying the voltage).
2) The amplitude of the current is kept to a fixed value, and the backlight is switched on and off very rapidly at a fixed frequency. In this case, the output of the backlight is varied by varying the duty cycles of the on and off phases.

Pulse-Width Modulation (PWM)

One technique for dimming the backlight is the PWM.





LCDs for vision science

Wang and Nicolić (2011) have compared the performances of a SAMSUNG TN WLED LCD (SAMSUNG 2233RZ, referred to as LCD-1), a CRT (ViewSonic P227f, referred to as CRT) and an older IPS CCFL LCD model (DELL 3007WFPt, referred to as *LCD-2*).

Spatial uniformity:

Luminance variations across the screen were found in all displays, but LCD-1 showed the smallest variation.

Viewing angle dependence:

CRT reported the smallest variation.

LCDs for vision science

Pixel independence:

LCD-1 showed good independency (the luminance of the black-and-white gratings whether vertical or horizontal was half the luminance of the white stripes). No independence for the CRT.

Temporal response:

LCD-1 faster in the first frame. But CRT was faster in rising to the maximum brightness (black to white) over the first 2-3 frames, while LCD-1 was faster in falling to blackness (white to black) as the CRT phosphors showed a longer decay.

Motion blur:

In both. CRT for dark-object/bright-background (consistent with slow rising time. Opposite for LCD-1)

However …

LCD technology has moved forward significantly since the paper was published.

Disregard the model type and consider the performance of the display technology implemented.

In particular, consider the display performance according to what kind of stimuli you wish to present.

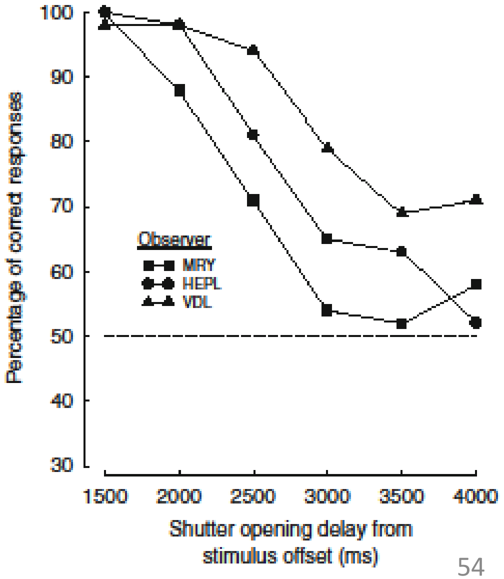
LCDs for vision science

The offset of a stimulus (its disappearance) is an important display property in some vision experiments (for example, visual memory and attentional blink).

Some CRT phosphors (e.g., P15) have virtually no persistence; others (e.g., P31) have persistence that can remain visible for several seconds (Di Lollo, Seiffert, Burchett, Rabeeh, & Ruman, 1997).

Lagroix, Yanko, and Spalek (2012) have investigated visibility of display persistence on both CRT (AccuSync 120 by NEC) and LCD (BenQ XL2410T) monitors under light-adapted and dark-adapted viewing.

A vertical or horizontal bar was displayed on the monitor behind a closed mechanical shutter. The shutter opened rapidly at varying intervals following the offset of the bar. Therefore, any image still visible on the screen was the result of display persistence. The observers' task was to identify the bar's orientation.



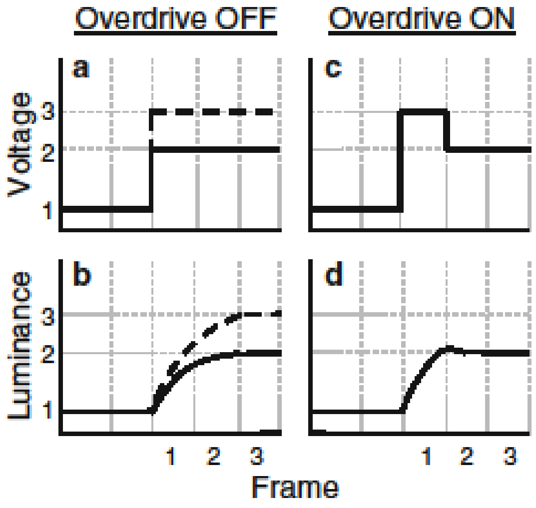
For white on black, BenQ screen never produced any display persistence.

Source: Lagroix, Yanko, and Spalek (2012)

LCDs – Overdrive technology

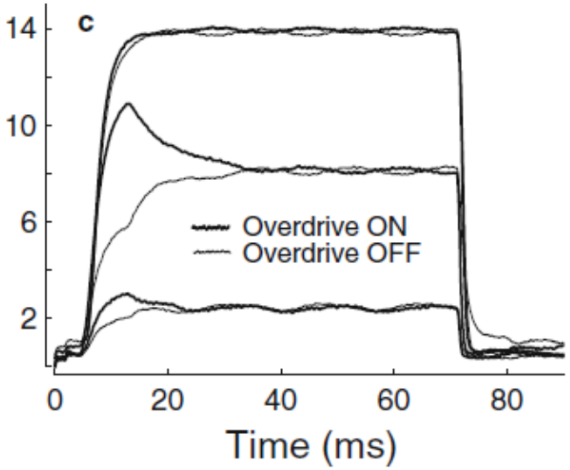
It aims to speed the transition from one grey level of luminance to another (for example, from dark to brighter).

The rate of change in luminance is faster for a higher voltage (panel b, segmented line), however consider overshoot.
This phenomenon is used in overdrive technology to achieve a faster transition between different levels of luminance.



Source: Lagroix, Yanko, and Spalek (2012)

Three luminance transitions from the same BenQ LCD monitor with the overdrive turned on and off.



Display technology: Organic Light-Emitting diode (OLED) display

The contemporary technology was developed by Eastman-Kodak and works via electroluminescence, whereby a bright light is emitted whenever current is applied to conductors surrounding organic thin films.

These displays do not require backlighting and can be manufactured in very thin, compact designs, which can operate with just 2-10 volts.

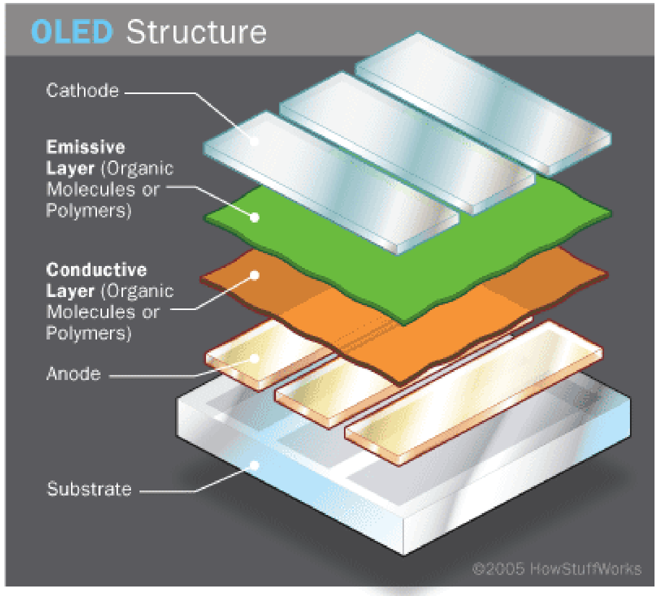


Image: http://electronics.howstuffworks.com/oled1.htm

What is an OLED?

An OLED is an Organic Light-Emitting Diode containing thin flexible sheets of an organic electroluminescent material.

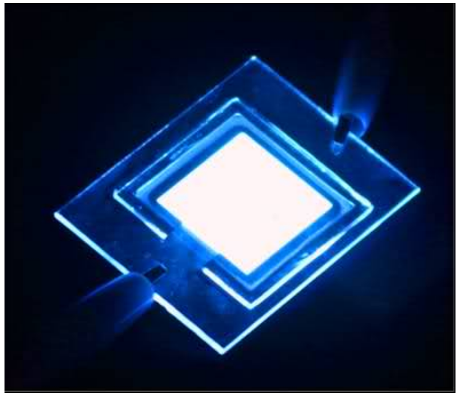
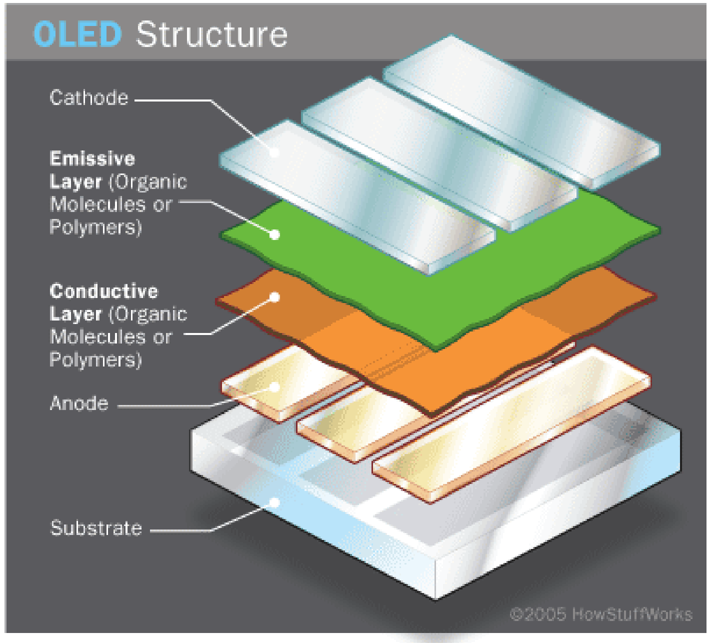


Image: www.avsforum.com

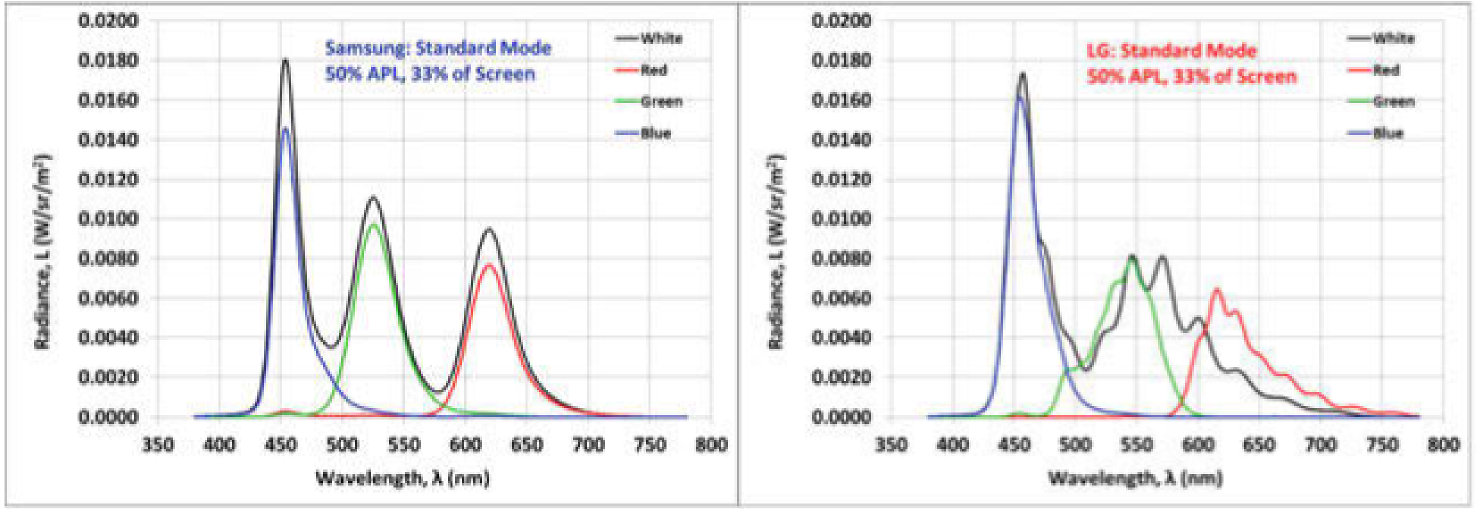
These organic molecules create light with the application of electricity.



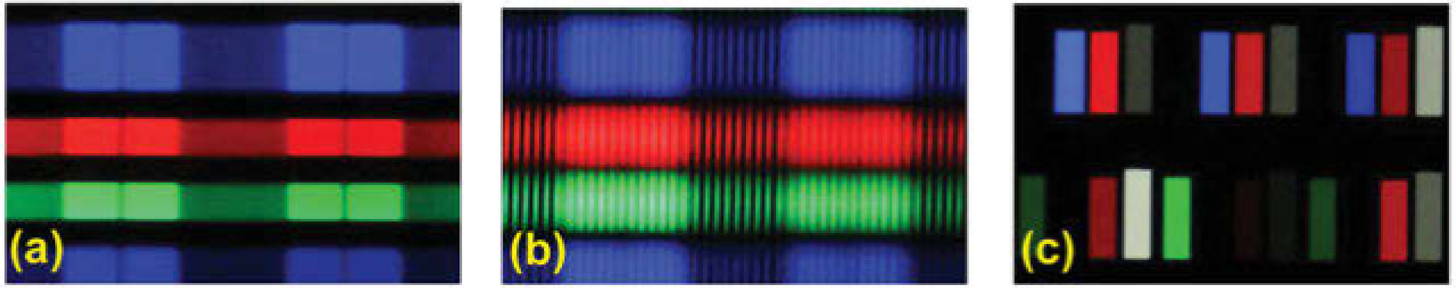
OLED display

The R, G, and B subpixels are OLEDs tailored to emit specific spectra.

The R, G, and B subpixels are white OLEDs covered with colour filters.



Horizontal configuration



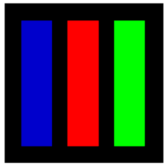
Vertical configuration

Image: Curved OLEDs described in SID, June 2013

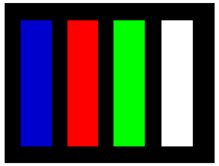
OLED display

In general, each pixel on the OLED display consists of three subpixels, emitting red, green, or blue light, but there are many variants just like for LCDs.

RGB

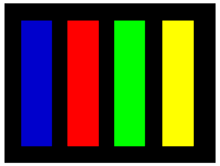


RGBW



Lower power consumption
Brighter colours
Complex remapping RGB->RGBW

(LCD) RGBY



Wider colour gamut
Brighter colours
Pixels are bigger
Remapping RGB->RGBY is hard
Is it a significal improvement?

OLED display

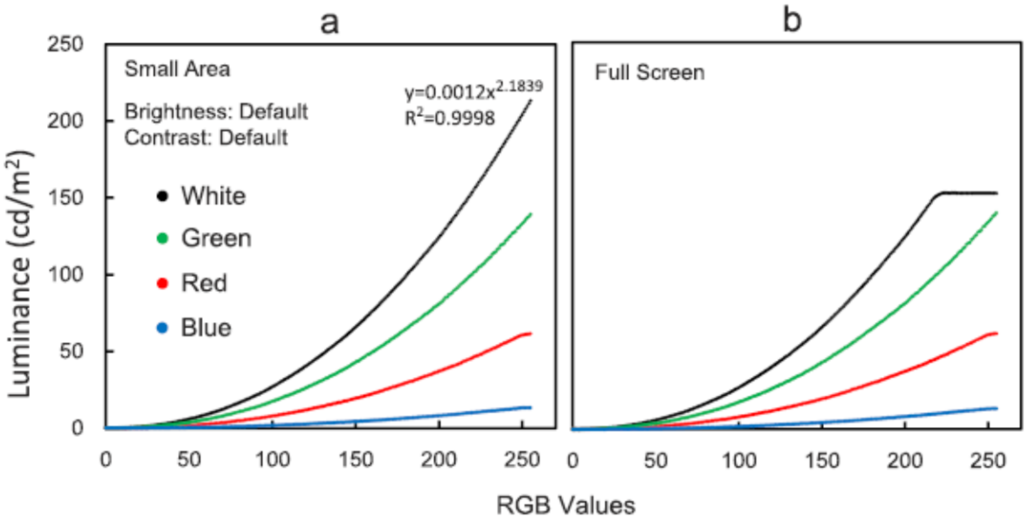
There are several advantages for being a self luminous display, among which:

- rapid rise/fall luminance level
- each pixel and subpixel are independent
- spatially uniform
- viewing-angle independent
- “real” black

Source: Ito, Ogawa, and Sunaga (2013)

OLED display – Luminance response and target size

A small (2x2 deg) or large (full screen) stimulus was displayed on the monitor and luminance was recorded at various RGB levels (gamma function setting = 2.2).



For RGB=(0,0,0) the display could not be detected in the dark.

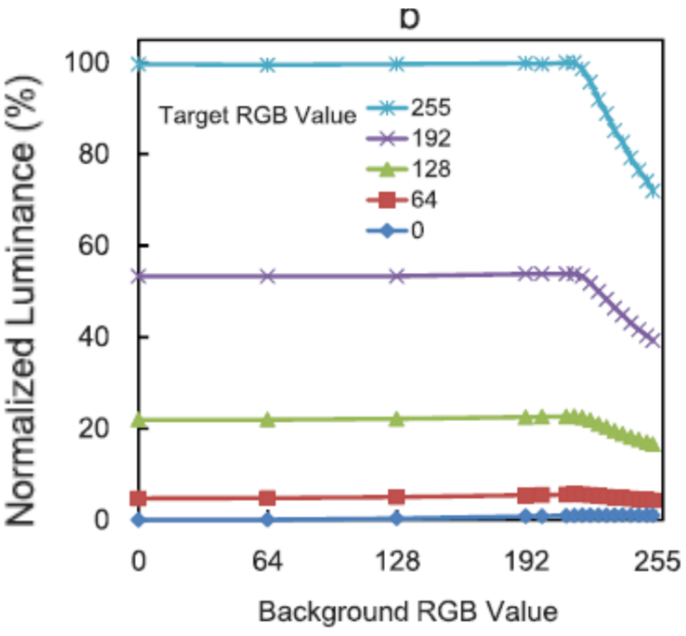
In the full-screen stimulus condition, the white signal saturated at RGB (220,220,220) which corresponded to 153 cd/m^2 .

This saturation effect can occur in some CRTs as well, if the contrast is set to the maximum. It doesn’t happen with LCDs, because the backlight is constant and each pixel is independently controlled.

Source: Ito, Ogawa, and Sunaga (2013)

OLED display – Luminance response and surround

A small (2x2 deg) target was displayed on a variable luminance background.



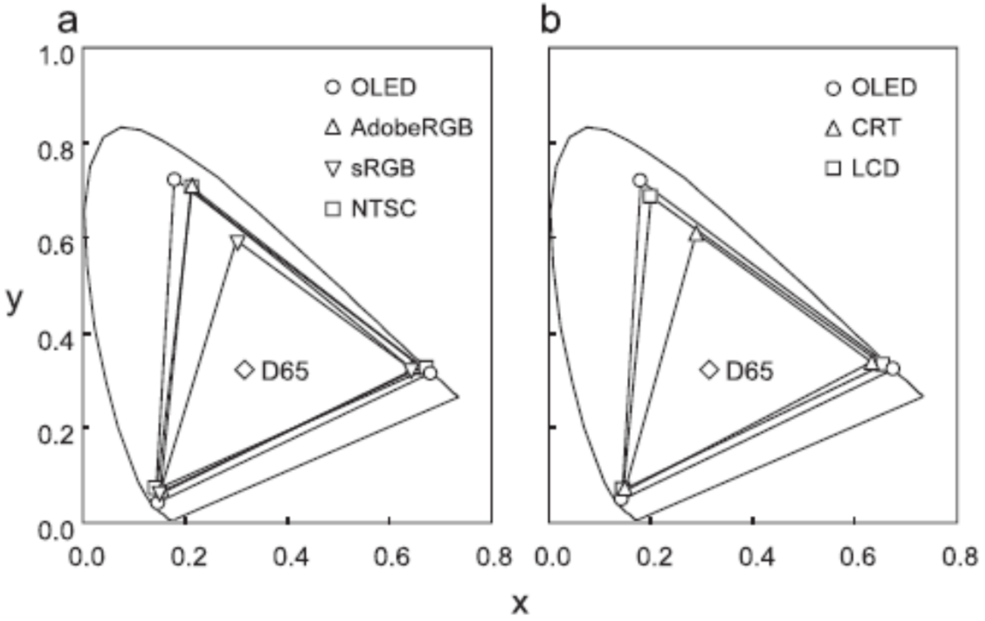
Source: Ito, Ogawa, and Sunaga (2013)

When the background RGB values where greater that (220, 220, 220) the luminance of the target area in each RGB value decreased to approximately 73% of its initial luminance.

As the background luminance was changing as well, the overall contrast was constant. In many natural viewing conditions you wouldn't probably notice the difference. But this behavior might not be acceptable in some vision experiments.

OLED display – Colour gamut

A small (4x4 deg, 40% screen size) target was used for the colorimetric measurements.



OLED: SONY (PVM-2541)
CRT: Mitsubishi (RDF193H)
LCD: Eizo (ColorEdgeCG241W)

The OLED has a wider colour gamut that expands in the direction of the green primary.

Remember that the CIE 1931 colour space is non uniform, thus those differences might not be perceptually big!

Source: Ito, Ogawa, and Sunaga (2013)

OLED display – Additional information

Soon after Ito, Ogawa, and Sunaga (2013) publication, another paper on OLED displays was made available on JoV.

Journal of Vision (2013) 13(12):16, 1–13 http://www.journalofvision.org/content/13/12/16 1

Assessment of OLED displays for vision research

Emily A. Cooper Department of Psychology, Stanford University, Stanford, CA, USA

Haomiao Jiang Department of Electrical Engineering, Stanford University, Stanford, CA, USA

Vladimir Vildavski Department of Psychology, Stanford University, Stanford, CA, USA

Joyce E. Farrell Department of Electrical Engineering, Stanford University, Stanford, CA, USA

Anthony M. Norcia Department of Psychology, Stanford University, Stanford, CA, USA

It describes:

1) Additional measurements on two SONY OLED displays
2) A MATLAB tutorial for estimating the luminance and radiance produced by any image on the two OLED displays that were examined (which relies on a toolbox developed by Wandell et al, 2013).

OLED display: Pros and Cons

Advantages:

- Rapid warm-up (15 min, Ito et al., 2013)
- Spatially uniform
- Pixel independence
- Wide colour gamut
- Native 10-bit per channel resolution
- Fast response time
- Luminance independence between frame presentations (due to the rapid rise/fall response time)

OLED display: Pros and Cons

Disadvantages:

- The SONY models available are only 60 Hz (unsuitable for some motion experiments)
- The target luminance changes above RGB=(220, 220, 200) with target sizes larger than 40% (luminance drops from 213 to 153 cd/m^2, or even 147 cd/m^2).
- The target luminance changes according to the background colour.
- May have short life expectancy (especially blue) – although not fully tested.
- Differing life expectancies for each colour resulting for potential of color shift over time (needs to be controlled via electronics) – apparently solved in the latest versions of the PVM and BVM.
- Currently prototype-only for larger screen sizes - most OLED displays are for small portable devices.

Display technology: Digital Light Projectors (DLP)

DLP technology is based on an optical semiconductor, called a **Digital Micromirror Device (DMD)**, which uses mirrors made of aluminum to reflect light to make the picture.

The DMD is often referred to as the **DLP chip**. The chip can be held in the palm of your hand, yet it can contain more than 2 million mirrors each, measuring less than one-fifth the width of a human hair. The mirrors are laid out in a matrix, much like a photo mosaic, with each mirror representing one pixel.

The number of mirrors corresponds to the resolution of the screen. DLP 1080p technology delivers more than 2 million pixels for true 1920x1080p resolution, the highest available.

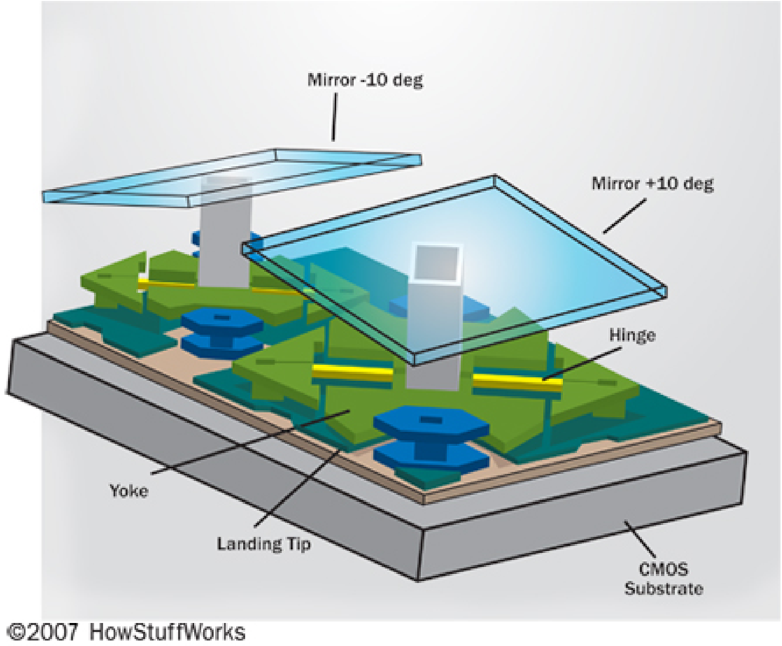
Source: www.howstuffworks.com

Display technology: Digital Light Projectors (DLP)

The mirrors are mounted on tiny hinges that enable them to tilt either toward the light source (ON) or away from it (OFF) up to +/- 12°, and as often as 5,000 times per second.

When a mirror is switched on more than off, it creates a light gray pixel. Conversely, if a mirror is off more than on, the pixel will be a dark gray.

DLPs also produce the deepest black levels of any projection technology using mirrors always in the off position.



Source: www.howstuffworks.com

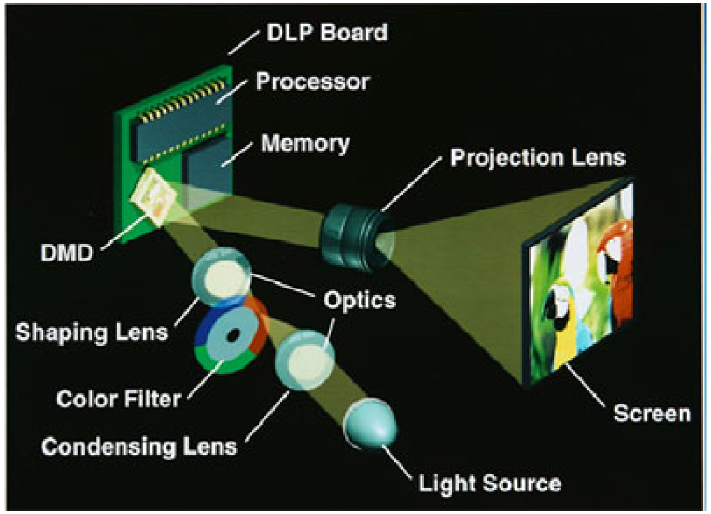
DLP: Displaying colour

To generate colour stimuli, the white light from the light source passes through a transparent, spinning color wheel, and onto the DLP chip.

A single chip DLP projection system can create 16.7 million colors.

Each pixel of light on the screen is red, green, or blue at any given moment.

The DLP technology relies on colour fusion: to create a purple pixel, red and blue will be projected onto alternative fast frames (faster than the visual system can resolve).



Source: www.howstuffworks.com

What should you expect from a display for vision research?

Consider the display performance in terms of your needs:

- ***Spatial resolution***: the pixels should be small enough so that they are not resolved by the observer at the requested viewing distance.
- ***Decay rate***: fast to minimize the visibility of persistence (note that some phosphors might have a different decay and thus different persistence)
- ***Spatial uniformity***: it’s difficult to achieve total spatial uniformity, but at least it should be minimized and kept the same for the three channels.
- Maintain a ***stable output*** throughout the experiment, and from day to day (warm-up before starting an experiment, check extraneous magnetic and electric fields).

A few tips …

- ***Warm up*** your display device with a dynamic pattern.
- ***Calibrate*** (set brightness, contrast, etc. to a known state) before performing the device characterization.
- Once you have performed the characterization, ***lock the settings***!
- ***Characterize*** the light output.
- Characterize ***frequently***.
- ***Customize your characterization*** in terms of the stimuli you are going to generate in your experiment.

A few tips (*cont*) …

- Expect differences between devices, even if they are the same model.
- Sometimes it is difficult to characterize the device properties described earlier on (e.g. pixel independence, phosphor constancy, etc.). In those cases avoid problematic stimuli that stress the display (Brainard et al. 2002).
- Use the information presented as guidelines and in relative terms. In the interest of time, sometimes we have compromised clarity and details.

References

Brainard, D. H., Pelli, D. G., and Robson, T. (2002). Display characterization. In J. Hornak. (Ed.), *Encyclopedia of imaging science and technology* (pp. 172–188). New York, NY: Wiley.

Cooper, E. A., Jiang, H., Vildavski, V., Farrell, J. E., & Norcia, A. M. (2013). Assessment of OLED displays for vision research. *Journal of Vision*, *13*(12):16, 1–13.

Cowan, W. (1995). Displays for vision research. In M. Bass (Ed.), *Handbook of optics, volume 1: Fundamentals, techniques, and design* (pp. 27.1–27.44). New York, NY: McGraw-Hill.

Peli, E., Garcia-Perez, M. A. (2000). Luminance artifacts of cathode-ray tube displays for vision research. SID Symposium Digest of Technical Papers, *31*(1): 396–399

Elze, T., & Tanner, T. G. (2012). Temporal properties of liquid crystal displays: Implications for vision science experiments. *PLoS One*, 7(9), e44048.

Ito, H., Ogawa, M., and Sunaga, S. (2013). Evaluation of an organize light-emitting diode display for precise visual stimulation. *Journal of Vision*, 13(7):6, 1–21.

Lagroix, H. E. P., Yanko M. R., and T. M. Spalek (2012). LCDs are better: Psychophysical and photometric estimates of the temporal characteristics of CRT and LCD monitors. *Atten. Percept. Psychophys*. 74, 1033–1041.

Metha, A. B., Vingrys, A. J., and Badcock, D. R. (1993). Calibration of a color monitor for visual psychophysics. *Behavior Research Methods, Instruments, & Computers*, 25, 371–383.

Pelli, D. G., & Zhang, L. (1991). Accurate control of contrast on microcomputer displays. *Vision Research,* 31, 1337-1350.

Pelli, D. G., (1997). Pixel independence: Measuring spatial interactions on a CRT display. *Spatial Vision,* 10, 443-446.

Wang, P., and Nikolić, D. An LCD monitor with sufficiently precise timing for research in vision. *Frontiers in Human Neuroscience*, 5, 1-10.

Suggested readings

Crognale, M.A., Webster, M.A., and Fong, A. (2009). Application of digital micromirror devices to vision science: shaping the spectrum of stimuli. *Proc. SPIE 7210, Emerging Digital Micromirror Device Based Systems and Applications*, 721005.

Garćıa-Pérez, M. A., and Peli, E. (2001). Luminance artifacts of cathode-ray tube displays for vision research. *Spatial Vision*, 14(2), 201–215.

Packer, O., Diller, L.C., Verweij, J., Lee, B.B., Pokorny, J., Williams, D. R., Dacey, D.M., and Brainard D.H. (2001). Characterization and use of a digital light projector for vision research. *Vision Research*, 41, 427–439.

Robson, J. (2003). *Light sources*, in Vision Research – A practical guide to laboratory methods, 50 –80.

Robson, T. (2003). *Topics in computerized visual-stimulus generation*, in Vision Research – A practical guide to laboratory methods, 81 –106.

Watson, A. B. (2010). Display motion blur: comparison of measurement methods. *J. Soc. Inf. Disp.* 18, 179–190.

The end ☺

For additional information please contact Caterina (Katia) Ripamonti at c.ripamonti@crsltd.com