How to Set your Monitor

Part II: Liquid Crystal Display

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Chapter 1: Introduction

Since 1999, at the beginning of each year, journalists were claiming: “Next year is going to be LCD flat panel’s year!”. They were wrong for a couple of years, but LCDs market share regularly increased every year and soon reached important milestones for the display market:

- In 2003, more money was spent on LCDs than on CRT monitors.
- In 2004, LCD unit sales eventually overtook those of CRTs.

In 2004, for the first time, notebook computer sales exceeded desktop sales.

One of the biggest problems with monitors is most people never calibrate them and just use them straight out of the box. A lot of people don’t even use their monitor's driver disks. This is very important with LCDs because they span a broad range of characteristics. Using the LCD drivers allows getting the most out of the monitor while preventing damage. Also, the hardware setup may create an ICC monitor profile that Windows or the Mac OS can use with its Color Management System; ICM for Windows and ColorSync for Mac. While generally better than nothing, generic profiles can only assume average settings and viewing conditions that can be far from reality. Some monitor manufacturers bundle really bad generic profiles too!

Local monitor calibration is the only solution to get a fully working color management system. But before coming to monitor calibration it is very important to thoroughly check and properly set a few monitor characteristics.

Color ‘n’ Code advice:

- *If a disk came with your monitor, even if it claims to be plug-and-play, insert it when prompted by Windows or use the hardware setup to install it. That will provide the system with all the correct refresh rates, color depths, and screen possible resolutions*
- *Keep in mind that generic ICC profiles coming with monitors only assume average settings and ambient conditions that are not likely to be yours. It is always better to calibrate a monitor in its working environment.*

Chapter 2: Liquid Crystals

Interestingly, the most important elements that make LCD possible, the liquid crystals themselves, are quite an old discovery. Here is a bit of history:

Since 1850, researchers in different fields such as chemistry, biology, medicine and physics found that several materials behaved strangely at temperatures near their melting points. It was observed that the optical properties of these materials changed discontinuously with increasing temperatures.

In 1888, an Austrian chemist, Friedrich Reinitzer, was conducting experiments on an organic substance trying to figure out the molecular weight of cholesterol. When he tried to measure the melting point, he was surprised to find two! At 145.5°C the solid crystal melted into a milky liquid that existed until 178.5°C where the opacity suddenly disappeared, giving a clear transparent liquid. Puzzled by his discovery, Reinitzer asked help from a German physicist, Otto Lehmann, who was an expert in crystal optics. Lehmann became convinced that the milky liquid had a unique kind of order. In contrast, the transparent liquid had the characteristic disordered state of all common liquids. He named this new state of matter "liquid crystal", to explain that it was something between a liquid and a solid.

It was only 80 years later, in 1969, that Robert B. Meyer, an American scientist, described the relationship between curvature strains and electric polarization in liquid crystals. A year later James L. Fergason, an American inventor, built the first operating Liquid Crystal Display (LCD) after his discovery of the twisted nematic field effect. But LCD technology really took off in 1973 after Georges Gray, a British scientist, discovered "Biphenyl", a highly stable liquid crystal material.

In the early 1980's, Terry Scheffer and Jürgen Nehring came up with the super twisted nematic liquid crystal, which has a twist of 270° instead of 90°. They produced a display with a much better contrast ratio; a better viewing angle and their degree of twist was much easier to control, giving them quite good gray-scale properties. Since then there have been major advances in liquid crystal materials and in display manufacturing. Technical achievement has resulted in brighter displays, higher resolutions, reduced response times, and cheaper manufacturing processes. These advances have also allowed a significant increase in screen size.

To understand how a LCD flat panel works, it is important to first study the structure of the liquid crystals themselves and then some of their most important characteristics.

Color 'n' Code note:

If you are not interested in chemistry and physics details, you can directly jump to Chapter 3: LCD technologies

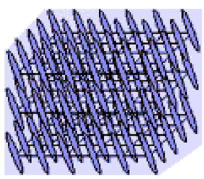
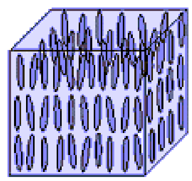
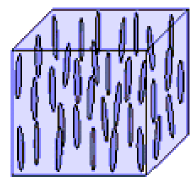
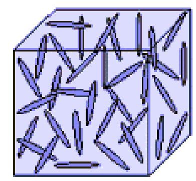
There are three common states, or phases, of matter that most people know about: solid, liquid, and gas. Liquid crystal is a fourth state that certain kinds of organic matter can exhibit under the right conditions.
The molecules in solids exhibit both positional and directional order; in other words, the molecules are constrained to point only certain directions and to be only in certain positions with respect to each other.
In liquids, the molecules do not have any positional or directional order, the direction the molecules point and their positions are random.

Liquid crystals

Definition: Liquid crystals are partly ordered materials, somewhere between their solid and liquid phases. Their molecules are often rod or disk-shaped and align themselves with a long-range order along a certain direction.

Liquid crystals have partial ordering of molecules similar to solids, while maintaining the ability to flow like liquids. The molecules in a liquid crystal do not exhibit any positional order, but they do possess a certain degree of directional order. The molecules do not all point in the same direction all the time. They merely tend to point more in one direction over time than in other directions.

There is a continuum between the various phases of matter; when increasing the temperature of a material it goes through the different structure arrangements. Most materials do not present a mesophase but all liquid crystals have one or more mesophases, with characteristics intermediate between solid and liquid. Liquid crystals to be used in displays must exist in their mesophase form at ambient temperatures.

Crystal	**Liquid crystals (Mesophase)**		**Liquid**
			
3D lattice Anisotropic Solid	**1 or 2D lattice Anisotropic Fluid**	**No lattice Anisotropic Fluid**	**No lattice Isotropic Fluid**

Liquid crystal molecules are broadly categorized as either:

Lyotropic

Definition: Lyotropic liquid crystals, which are used in the manufacture of soaps and detergents, react to changes in temperature and concentration. Their characteristics depend on the type of solvent they are mixed with. Biological membranes show lyotropic behavior.

Thermotropic

Definition: Thermotropic liquid crystals react to changes in temperature or, in some cases, pressure. Thermotropic liquid crystals are either isotropic or anisotropic. The key difference is that the molecules in isotropic liquid crystal substances are random in their arrangement, while anisotropic have a definite order or pattern.

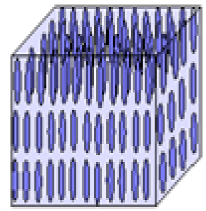
Color 'n' Code note:

In this document, we will focus on thermotropic liquid crystals.

Just as there are many varieties of solids and liquids, there are also a wide variety of liquid crystal substances. Depending on the temperature and particular nature of a substance, liquid crystals can be in distinct phases:

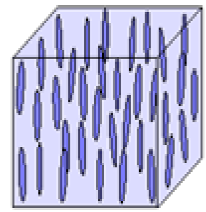
Smectic

Definition: The smectic phase is close to the solid phase. The liquid crystals are ordered in layers. Inside these layers, the liquid crystals normally float around freely, but they cannot move freely between the layers. The molecules tend to arrange themselves in the same direction.



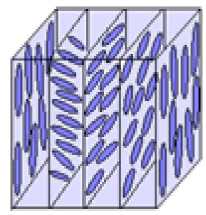
Nematic

Definition: The nematic phase is the simplest phase and is close to the liquid phase. The molecules float around as in a liquid phase, but are still ordered in their orientation.



Cholesteric

Definition: Also known as twisted nematic. In this phase, the molecules naturally twist slightly from one layer to the next, resulting in a spiral formation.

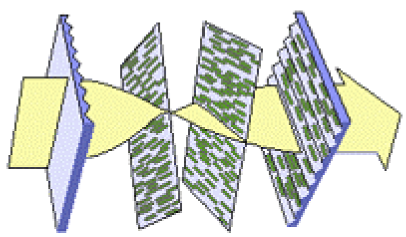


Color 'n' Code note:

In this document, we will only focus on liquid crystals in the twisted nematic phase, (cholesteric) the liquid crystals that make LCDs possible.

In nematic liquid crystals, the molecules in a layer are all facing in about the same direction, but have no definite spatial organization. They are free to move, but like to line up in about the same direction.

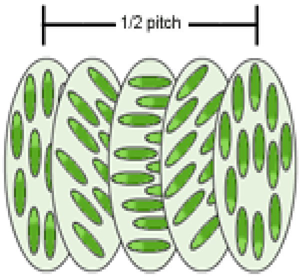
The orientation of the molecules in the nematic phase is based on a director. The director can be anything from liquid crystal molecules interactions to external forces, like electric or magnetic fields. In the cholesteric (twisted nematic) phase, the molecules twist slightly from one layer to the next. This leads to a spiral structure that can be visualized as a stack of very thin 2-D nematic-like layers with the director in each layer twisted with respect to those above and below.



An important characteristic of the cholesteric mesophase is the pitch.

Pitch

Definition: The pitch is defined as the distance it takes for the director to rotate one full turn in the helix.



To understand how a LCD flat panel works, it is also important to understand the concept of light polarization. Light is made out of particles called photons and at the same time, it behaves like an electromagnetic wave.

Photon

Definition: In some ways, visible light behaves like a wave phenomenon, but in other respects it acts like a stream of high-speed, submicroscopic particles. The energy in any electromagnetic field is made up of discrete packets that are called photon (meaning "visible-light particle"). All electromagnetic radiations consist of photons, each of which contains a particular amount of energy that depends on the wavelength.

Wavelength

Definition: The wavelength is the distance between identical points in the adjacent cycles of a waveform signal propagating.

Light can be represented as a transverse electromagnetic wave made up of mutually perpendicular, fluctuating electric and magnetic fields. The following diagrams show the electric field vector as it propagates. Traditionally, only the electric field vector is dealt with because the magnetic field component is essentially the same. While moving, a photon and its associated wave vibrate in a plane that is perpendicular to their direction, for normal light the vibration direction within this plane is random. Some materials, affect the direction of vibration through a process called polarization.

Normal light

Polarized light

Polarization

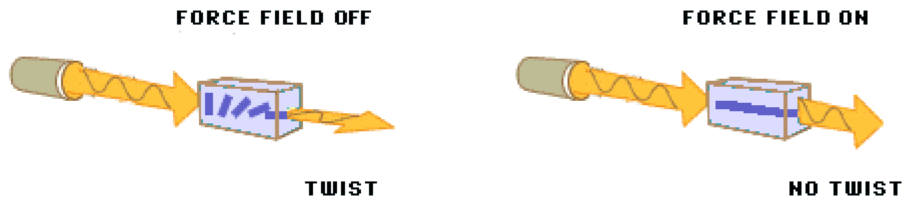
Definition: Process by which a material, called polarizer, affect the transversal plane of vibration of a wave, absorbing almost all vibration components except along a certain direction, such selecting a preferred and unique vibration orientation.

So what has this to do with liquid crystal?

By their very nature, liquid crystal molecules “guide” the light and if the light is already polarized they may change its plane of polarization. Liquid crystals are complicated to describe optically. Their elongated shape enables light to propagate at a different speed parallel and perpendicular to the elongated molecules, therefore liquid crystals are said to be bi-refringent. This characteristic, when controlled, allows modifying a light path.

Another important feature of liquid crystals is their sensitivity to magnetic and electric forces.

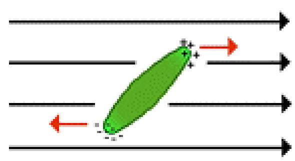
Applying an electric field to cholesteric liquid crystals untwists them to varying degrees, depending on the voltage. Some liquid crystal molecules react very predictably to the voltage; they are used as “light directors” to control light passage in LCDs.



The molecule movement is a consequence of the atomic arrangement in the elongated molecule. Each liquid crystal molecule constitutes a dipole, which is responsible for its alignment with the external electric field.

Dipole

Definition: A pair of equal and opposite electrical charges separated by a small distance. A dipole will align itself, if possible, in the presence of other electrical charges according to the attraction of opposite and repulsion of identical charges.



Some liquid crystal molecules, called permanent electric dipole, can be intrinsically slightly positive on one end and equally negative on the other end. Some others, called induced electric dipole, do not possess this type of separation of charge, but the electric field can displace positive charges to one end of the molecule and negatives charge to the other end of the molecule.

Most liquid crystal molecules respond to electric field by aligning their elongated direction parallel to the direction of the field. But, it is possible for certain molecules to align their elongated axis perpendicular to the field, depending upon the kind of molecules and where they segregate charges in their structure.

Chapter 3: LCD technologies

The are two main types of Liquid Crystal Display:

Passive-matrix

Passive-matrix LCDs have all their columns and rows connected to outside circuitry. This passive type has advantage of flexibility and economy and is a good option for low-cost applications. But this technology cannot be used for large displays because it does not provide high-enough contrast and generates very disturbing image “ghosts”.

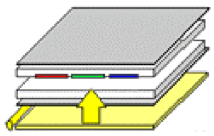
Active-matrix

Active-matrix LCDs have their driving circuitry built into the substrate. The display also maintains a small charge at each pixel that keeps the pixel state until the next change,, No need for a refresh! Most flat panel computer monitors use this technology. It is also commonly called TFT for Thin Film Transistor.

The term active-matrix is sometimes misleading, liquid crystals are not emitting light by themselves, they are just used to control the amount of light passing through them. LCDs are based on various lighting sources and can use different technologies:

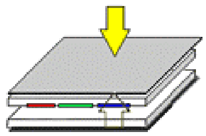
Transmissive

Definition: A type of LCD screen in which the pixels are illuminated from behind. Such displays have a clear polarizer on the front and the back. They offer high contrast and deep colors and are well suited for indoor environments and low-light circumstances. They are not good in very bright light, such as outdoors in full sunlight.



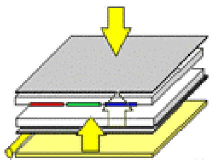
Reflective

Definition: A type of LCD screen in which the pixels are illuminated from the front, most of the time by ambient light but sometimes by front lighting. The rear polarizer of these displays includes a diffuse reflector, such as brushed aluminum. This layer reflects polarized ambient light that has entered from the front. They are well suited for bright outdoor environments and medium light conditions. However, they have lower contrast because the light passes through the monitor’s screen twice.



Transflective

Definition: A type of LCD screen in which the pixels are illuminated from both the front and from behind the screen, combining the illumination characteristics of both transmissive and reflective technologies. The rear polarizer includes a translucent material, which reflects part of the ambient light, and also transmits backlighting. They work under any lighting condition, from complete darkness to bright sunlight.



Some small devices, like PDA or cell phones, use reflective displays or hybrid transflective (transmissive-reflective) displays with backlighting based on LEDs. But almost all computer monitors are transmissive displays using fluorescent backlighting systems. In the future, large hybrid transflective displays may be developed to increase brightness and contrast for indoor and outdoor use.

Color 'n' Code note:
In this document, we will focus on active-matrix LCD, and we will only speak about transmissive screens using fluorescent backlighting.

TFT flat panel complex technology is based on a few simple concepts:

- Uniform light can be generated using low power and without dissipating much heat.
- Light can be polarized.
- Liquid crystal can twist the plane of polarization.
- Liquid crystal molecule's orientation can be controlled by an electric field.
- Two stacked polarization filters, with their admitting direction perpendicular to each other will not let any light through.

Fluorescent backlighting systems are generally based on cold cathode fluorescent lamps (CCFL), these lamps can be bent and shaped to conform to almost any configuration.

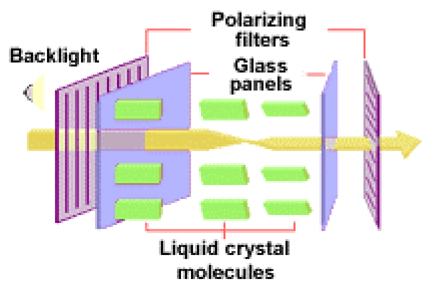
Cold Cathode Fluorescent Lamp

Definition: In cold cathode lamps, the cathodes are not heated to encourage electrons to travel through the gas. Instead, a voltage greater than the total resistance of the gas of all the tubes in the circuit is typically used to initiate the discharge.

CCFL are gas discharge light sources, they are filled with argon gas and liquid mercury. They provide excellent illumination at low current. They are powered by high voltage and high frequency AC (500-1000V at 25-75 kHz). When power is on, mercury vaporizes and the gas mixture ionizes, generating large amounts of ultraviolet light. That ultraviolet light excites the phosphors coating the inside of the tube that emit visible light.

In a LCD panel, there can be two to twelve backlight lamps depending on the panel size, on the shape of the lamps and on their location. Various combinations of reflector and diffuser technologies also allow for the creation of a bright and uniform backlighting.

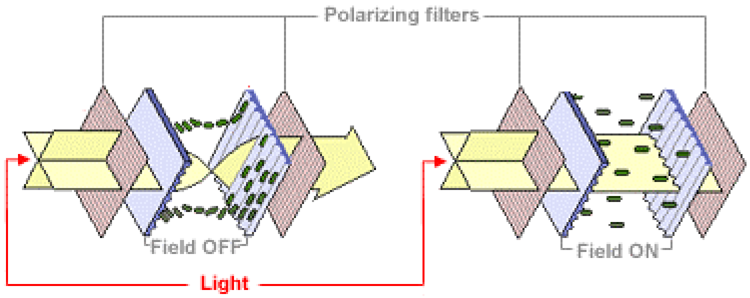
After the backlighting system, a LCD basically consists of a package of two crossed polarizers with a liquid crystal in between. The glass surfaces are treated with a thin polymer coating, which is spread and rubbed in a single direction with a cloth, the liquid crystal molecules in contact with that surface align with the rubbing direction, which is parallel to the admitting direction of each neighboring polarizer. Because these directions are crossed, the molecular direction is confined to a 90° twist from one side of the cell to the other.



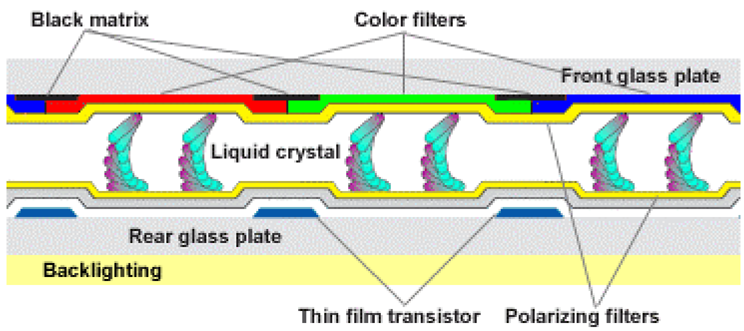
The competition between orientation produced by surface anchoring and by electric field effects is exploited in LCDs. The liquid crystal molecules are aligned parallel to the surface. An electric field is applied perpendicular to the cell. At first, no change in alignment occurs. However at a threshold magnitude of electric field, a deformation occurs and the director changes its orientation from one molecule to the next. Such a change is called a Freedericksz transition.

On the left part of the drawing below, the light vibration follows the liquid crystal molecules twist from one polarizer to the other, so that all light in fact passes the cell, without being absorbed, in spite of the fact that the polarizers are crossed; the cell appears bright.

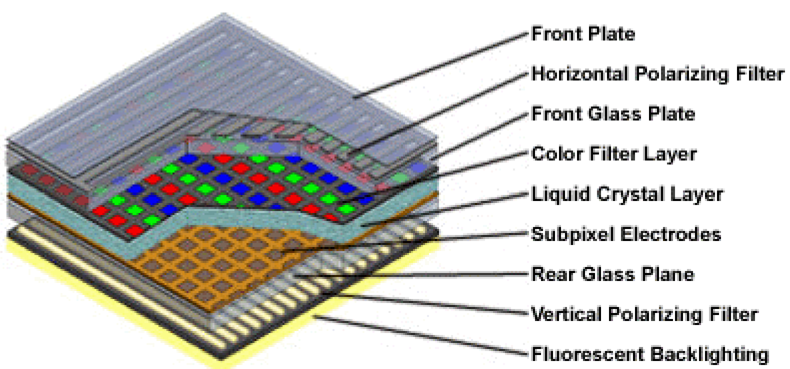
On the right part, a strong electric field is applied across the liquid crystal, along the light direction, that forces the molecules to arrange themselves parallel to the electric field. This destroys the twist and prevents the molecules from rotating the plane of polarization. All light is now absorbed by the crossed polarizers and the cell appears black.



But this is still a monochrome device. In order to get a color device, it is necessary to add filters and create sub-pixel structures, which allow generating a full gamut from 3 primary colors. Each sub-pixel has a characteristic color: red, green or blue. The color filter is the film sheet that supplies this color. Below is a cut of a TFT pixel with its 3 sub-pixels.



By creating a matrix of squares that locally control the state of the twist in their respective area, one gets a LCD containing a large number of individual pixels. The backlighting system generates white light consisting of all colors, and when it passes through the color filter all the other colors are blocked leaving only the specific color of that sub-pixel. A color filter that more aggressively blocks unwanted colors produces a display with more saturated colors.

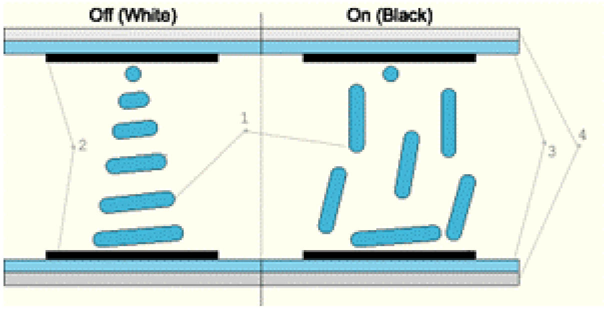


Polarization has an important effect on the viewing angle. Traditional LCD panels used a transversal electric field, while later generations use a horizontal electric field. There are 5 main liquid crystal cell designs:

In all schemas below, 1 = LC molecules, 2 = electrodes, 3 = glass plates, 4 = polarizing filters.

Twisted Nematic (TN)

A TN liquid crystal cell has the molecules arranged in a spiral alignment, with a 90° twisted structure, when off. When turned on, the molecules align at an angle pointed toward the front of the panel. Old monitors based on this technology were often only able to display 6 bit per color whatever the graphic adapter setting. Some inexpensive panels are still using this technology.



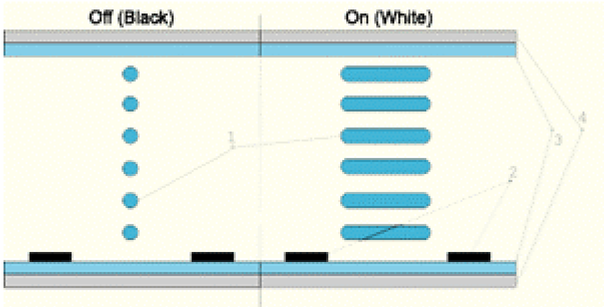
Super Twisted Nematic (STN)

A STN liquid crystals cell has the molecule arranged in a 180° to 270° twisted structure. The higher twist angle provides enhanced contrast and offers more intermediate gradations increasing the number of intensity levels, up to nearly 256. TN and STN panels let the backlight pass through in the passive state and shutter it in the active state.

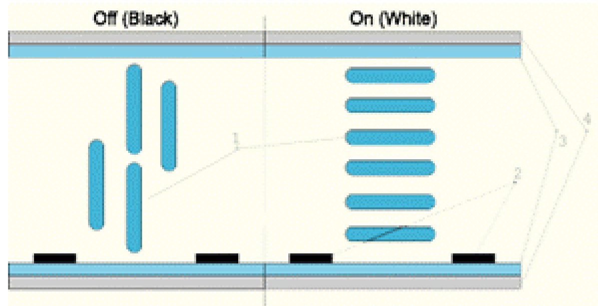
Other technologies were developed by various manufacturers since 1996 to solve the two plagues of TN-matrices: small viewing angles and low-quality color reproduction.

In-Plane Switching (IPS) - Hitachi

In an IPS cell, both electrodes are mounted parallel to each other on the lower substrate and therefore in the same plane. In the off position, the molecules lie parallel to the glass substrates and to each other. They are also aligned to be parallel with the cell's electrode pair. Molecules are not anchored to the lower substrate. When a voltage is applied across an electrode pair, the LC molecules can all rotate freely through 90° to align themselves with the field, while remaining parallel to the substrates and other molecules above and below them. The display's viewing angles are then greatly increased (to about 140° in all directions) and color reproduction remains consistent. An IPS panel lets the backlight pass through in its active state and shutters it in its passive state.

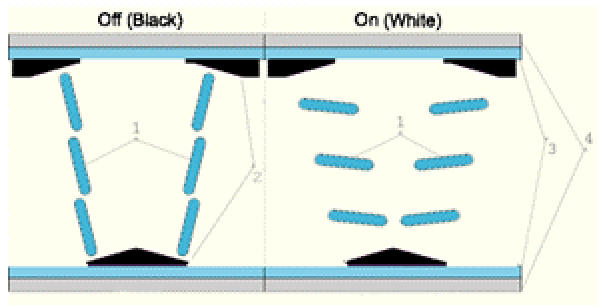


Vertical Alignment (VA)



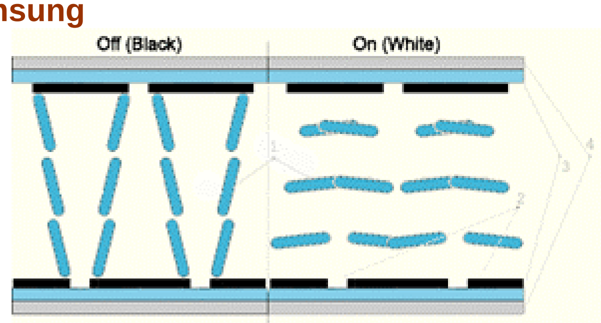
In a VA cell, the molecules of liquid crystal are normally aligned vertically at right angles to the substrates, swinging through 90° to lie parallel with the substrates in the presence of an electric field. Like IPS, VA produces displays that have a wide viewing angle (140° in all directions) and high contrast but with the added bonus of higher brightness and better response time.

Multi-domain Vertical Alignment (MVA) - Fujitsu



MVA is based on VA but each cell is also separated in 2 or 4 sub-cells by the addition of pyramid-shaped protrusions, the surfaces of which make up a separate "domain" in which the molecules are aligned differently from those in the other domains. The result is an all-round increase in viewing angles, at the price of an overall reduction in brightness, but with no variation in color tone. Like with IPS matrices, an inactive pixel doesn't pass light through.

Patterned Vertical Alignment (PVA) - Samsung



The liquid crystals in a PVA matrix have the same structure as an MVA. Domains with varying orientation of the crystals allow keeping the same color, almost irrespective of the user's line of sight. In fact, the viewing angles (as traditionally measured by the reduction of the contrast ratio to 10:1) are limited not by the matrix, but rather by the plastic framing around the screen. PVA matrices feature a better contrast ratio, typically of 800:1, and they can show a real deep black color.

The original IPS technology became a foundation for several improvements: Super-IPS (S-IPS).
S-IPS panels have gained wide recognition. The response time was among the serious drawbacks of the IPS technology; first panels were as slow as 60 ms. Now, the full response time is down to 25 ms, and equally divided between pixel rise and pixel fall times. Moreover, the response time doesn't greatly increase on black-to-gray transitions.
In fact, S-IPS matrices are generally superior to other LCD technologies in color-reproduction quality. They have soft and pleasant colors, which are natural and close to high-quality CRT monitors. The only real problem of the S-IPS technology is its low contrast ratio.

The latest developments are Super-PVA (S-PVA) and True Wide IPS (TW-IPS), both of which are improvements over their predecessors.

Color'n'Code advice about LCD technology:

All the latest technologies are better than older ones, but it is difficult to make a choice.

- *S-PVA has an excellent black state over a wide viewing angle.*
- *TW-IPS has excellent color constancy in the mid-tones out to wide viewing angles.*

Chapter 4: Influencing factors

Following are some of the factors that influence the quality of the image produced by the LCD panel, and therefore, how well it will do the job for you.

Glare

Definition: the contrast lowering effect of stray light in a visual scene. Glare forms a veil of luminance that reduces the contrast and thus the visibility of dark, or "shadow" areas of an image is decreased.

Most CRTs were subject to glare because their polished glass were excellent mirrors. LCD panels are all flat, which already reduces glare. LCDs generally have a matte surface with a very low reflective index. Some of them are even coated with an anti-glare polarizer that is extremely effective in eliminating virtually all external reflections. The incorporation of low reflection rated materials to black matrix parts lowers internal reflections too. In the end, these materials make LCDs quite insensitive to glare.

Color 'n' Code advice to minimize glare's effects:

- *Install uniform indirect lighting.*
- *Prefer dark matte finish walls.*
- *Select a monitor with a dark colored matte finish bezel.*

Glare is normally not a major concern with LCDs, but some notebook screens are protected by a glass, which makes them sensitive to reflections. Maybe more importantly, a lot of users install screen filters to either protect the LCD display surface, which can be easily damaged, or to keep their work secure from prying eyes. The optical quality of these protection filters is essential to minimize light reflections. Only advanced display calibration takes viewing conditions into account.

Color 'n' Code advice on using screen filters:

- *Avoid add-on contrast enhancers.*
- *If you need to use a privacy filter, be sure to purchase a high quality device.*
- *If you really want to protect your LCD surface, be sure the filter does not affect brightness, contrast, or color purity.*

True Aspect Ratio

Definition: ratio of the width by the height on a display.

Most LCD panels still use a 4:3 aspect ratio, matching the aspect ratio of most popular screen resolutions. But 16:9 or even 16:10 aspect ratio monitors can be found. They are generally used for multimedia and home theatre applications. There are no distortion problems, all objects keep the proper proportion of height to width.

Maximum Luminance

Definition: the highest level of luminance for a display.

LCDs maximum luminance is generally higher than for CRTs, between 200 and 400 cd/m^2 compared to only 100 cd/m^2. The overall luminance level of the LCD backlight will tend to decrease over time but aging takes longer than for CRTs.

Contrast Ratio

Definition: Contrast ratio is defined as the ratio of the luminance of a white image to the luminance of a black image on a given display. It is a measure of how many different brightness levels a display can have.

Because of their high Maximum Luminance, LCDs seem to have high contrast ratios, 400:1 to 800:1, but measurements, as reported in the data sheets, are often made in unrealistic conditions. Measurements performed under working conditions make the contrast ratio closer to 200:1, slightly below CRT 250:1 average value. Minimum Luminance is also a key factor for contrast ratio. A CRT monitor needs only to dim its beam in order to display a black pixel; with a properly adjusted black level, black is really black. A LCD panel, on the other hand, uses a constant backlighting level and only plays with light blocking; some amount of light always leaks resulting in a poor black. Latest models are far better at generating deeper black.

Color Purity

Definition: property of a color related to its hue (dominant wavelength) and its white content.

If you have ever seen a CRT and a LCD side by side displaying the same image, you have discovered how dramatically different colors can appear on different displays. This is already true among CRTs but to a much lower extent. It is even worse with notebooks because battery-operated computers often use backlighting at a lower power than main-powered systems to save energy. To compensate, the filter primary colors are often less saturated than those found on desktop equipments. This restores a part of brightness, but reduces the available color gamut. Some recent panels use a fourth white pixel, along the standard three red, green, and blue ones, to boost brightness but this can greatly affects color purity too.

Monochrome Purity

Definition: capability to display levels of gray without any colorcast or color fringes.

Most LCD panels have a blue cast at low luminance levels and a tan cast at high luminance levels. Latest panels are far better at avoiding color cast. See White point or Color Balance for further explanations.

Viewing conditions

Definition: the set of external elements affecting vision such as illuminant type, light intensity, surrounding material type and color.

Lighting and surrounding conditions affect image quality. Most LCD panels have a matte finish that prevents light from reflecting off the screen. Panels with dark or neutral colored matte bezel are better.

Viewing angle

Definition: this is the direction from which the display will look the best. It is set during the manufacturing process, and cannot be changed later by rotating the polarizers.

When viewing a LCD monitor from the side, one can sometimes notice a loss of screen brightness and possibly a change of displayed colors. Viewing angle can be one of the most confusing specifications regarding LCD monitors. Viewing angle is directly related to contrast ratio. Other factors such as the display's brightness, ambient light and contrast conditions all play a part in the readability of the display.

Some of these characteristics are controlled by the graphic adapter:

Resolution	**Color depth**	**Refresh frequency**

The others are controlled by the monitor. All LCD monitors use an On-Screen-Display (OSD) user interface to give access to all these controls.

Brightness	**[Contrast]**	**Color balance**
Color temperature		

Analog monitors offer geometry settings that have no meaning for fully digital displays.

[Position]	**Horizontal Phase**	**Vertical Clock**

Some monitor manufacturers (Philips, …) bundle software that automatically attempts to set some of the controls.

Chapter 5: Graphic adapter settings

Resolution

Definition: the amount of pixels that are displayed on a screen measured in pixels horizontal by pixels vertical.

While CRTs can accommodate various resolutions, which are adjusted through the software driver that the operating system uses to control the graphics adapter card, LCDs can only display one resolution that corresponds to the number of physical pixels making the screen (the so-called native resolution). Lower resolutions typically require signal interpolation that often generates artifacts. LCD cannot display resolutions higher than their native resolution because there is no rescaling. Resolution is given in pixel, such as 1024 x 768, which means monitor's screen, has 1024 pixels on the long horizontal side and 768 pixels on the short vertical side. Popular sizes are listed below:

Resolution	Acronym	Full name
1024x768	XGA	e*X*tended *G*raphic *A*rray
1280x960	SXGA	*S*uper e*X*tended *G*raphic *A*rray
1400x1050	SXGA+	*S*uper e*X*tended *G*raphics *A*rray
1600x1200	UXGA	*U*ltra e*X*tended *G*raphic *A*rray
2048x1536	QXGA	*Q*uad e*X*tended *G*raphics *A*rray
2560x2048	QSXGA	*Q*uad *S*uper e*X*tended *G*raphics *A*rray
3200x2400	QUXGA	*Q*uad *U*ltra e*X*tended *G*raphics *A*rray
1366x768	WXGA	*W*ide e*X*tended *G*raphics *A*rray
1600x1024	WSXGA	*W*ide *S*uper e*X*tended *G*raphics *A*rray
1680x1050	WSXGA+	*W*ide *S*uper e*X*tended *G*raphics *A*rray
1920x1200	WUXGA	*W*ide *U*ltra e*X*tended *G*raphics *A*rray
3200x2048	WQSXGA	*W*ide *Q*uad *S*uper e*X*tended *G*raphics *A*rray
3840x2400	WQUXGA	*W*ide *Q*uad *U*ltra e*X*tended *G*raphics *A*rray

LCD panels come in different sizes, from 15" (36 cm) to 23" (58 cm), some notebooks or sub-notebooks use smaller screens but often at resolutions higher than desktops. The size of a monitor usually refers to the size of the diagonal measurement of its screen, for LCD it directly corresponds to the usable area. That means a LCD panel of a given size offers 1.5 to 2" more than a CRT of the same size.

Two physically different sized monitors running at the same display size have different pixel sizes. For example, at 800 x 600, a 15" monitor has pixels that are 1/75" in size and a 17" monitor, pixels that are 1/64". But on the same 17" monitor running at 1024 x 768, the pixels are 1/86".

They get smaller because more of them must fit into the same space. Higher resolution means smaller pixels and finer details.

From a technical point of view, resolution is often called pixel addressability, it is defined as the smallest sized object that can be displayed on a given monitor. The dot pitch of a LCD is also an indication of the panel's resolution ability.

Color 'n' Code advice:

- *Always use a LCD panel at its native resolution. All other resolutions, if available, will be interpolated to either enlarge of shrink the image to fit the display. This generally results in very disturbing artifacts.*
- *When choosing a panel, select one having at least a size/resolution ratio of 100dpi. It is computed as the ratio of the number of horizontal pixels by the screen width in inches. To compute the width from the diagonal, you must know the aspect ratio and then multiply by 0.80 for 4/3, 0.87 for 16/9, and 0.85 for 16/10 monitors. For example: for a 20", 4/3, 1600 x 1200 monitor, width is 20" * 0.80 = 16", and 1600 / 16" finally gives 100 dpi.*
- *Never push a monitor farther than its limits.*

Color Depth

Definition: the number of possible colors that can be represented by a device.
Color depth is also adjusted through the software driver that the operating system uses to control the graphics adapter card. Color depth describes how many colors that can be displayed on a monitor's screen. Color depth is usually specified in bits.

Each of the three filter primary colors (Red, Green, and Blue) has a number of bits that describes its color "depth", or the number of shades of that particular color that can be displayed. The number of colors is usually described in exponential notation, such as the number 2 raised to the eighth power (2^8=256). The more bit depth a color has, the more shades of that color can be displayed.

"True" color is also called 24-bit color. Here, each color is 8 bits, for a total of 24 bits. Since each color has 256 shades, we can multiply 256 for red, times 256 for green, times 256 for blue and get millions of colors, (256 x 256 x 256 = 16,777,216). Millions of colors are pretty much what's accepted for a monitor's colors to look "true" to the human eye.

32-bit color does not provide more colors; it is a convenience for processor to access memory faster. There is also 16-bit, 5 bits for red, 6 bits for green and 5 bits for blue or "hi" color, which represents thousands of colors., Most of the time 16 bit color does not look too bad except in areas of subtle shading and tonal change; like in a large area of featureless sky, such as in a sunset photo, where the lack of a deeper color depth will show up as banding in the sky.

Interestingly, early LCDs could only display 6 bits per color, for a total of 18 bits, whatever the graphic adapter setting. This was a limitation created by the limited number of steps the liquid crystal molecules can move. Some recent cheap panels still present this limitation.

Resolution and color depth are intimately tied together in a monitor's display. The amount you can have of each is dependant on the amount of video memory that your video card has. Note that video memory is different than regular system ram memory, some new systems reserve parts of main memory for video, this does not provide very high performance. Naturally, higher resolution and deeper color depth require more video memory.

Color 'n' Code advice about color depth:

- *Before purchasing a LCD panel, be sure it can display 8 bit per color for a total of 24 bit and not only 6 bit per color for a total of 18 bit.*
- *Always use the highest color mode available. Only color modes at least equal to 24-bit can represent enough hues for real world image display.*

- *32-bit mode generally allows for better performance.*

Refresh rate

Definition: the maximum number of frames that can be displayed on a monitor in a second.

Refresh frequency (vertical scan rate or vertical refresh rate) is also adjusted through the software driver that the operating system uses to control the graphics adapter card. This parameter defines how often the screen is refreshed or how many frames are displayed per second. It is measured in Hz. While plug and play (PnP) monitors and graphic adapters generally negotiate automatically the optimal refresh frequency for a given resolution, some hardware combinations still require manual setting.

LCD panels generally offer only one to three refresh rates (60, 72, 75 Hz). As there is no refresh required, this is not a very important parameter. Even DVD will be reproduced correctly. But this may limit the number of frames per second rendered by 3D games running on advanced graphic adapter (sometimes > 85 f/s).

The latest LCD panels can be connected to the graphic adapter either through an analog standard VGA cable or through one of the digital DVI cables.

Color'n'Code advice about connection type:

If your monitor and your graphic adapter offer DVI connectors, use the digital link.

- *DVI does not require tuning.*
- *It brings more sharpness.*
- *It avoids most artifacts.*

Analog Mode

The standard VGA link uses the classical analog video signals. A computer's graphics circuitry creates a signal based on the Windows desktop resolution and refresh rate. This signal is known as the horizontal scanning frequency or horizontal scanning rate (HSF or HSR), and is measured in KHz. Raising the resolution and/or refresh rate increases the HSF signal.

The horizontal scan rate, the number of scan lines drawn per second is generally expressed in KHz and determines the resolution. The HSR is controlled by the horizontal sync signal generated by the video controller.

The pixel rate (dot clock) is the clock frequency, measured in MHz, used by the video controller chip. It determines the maximum amount of throughput that a video controller can sustain. A higher dot clock generally means that higher screen resolutions, color depths and vertical refresh rates are possible.

The LCDs circuitry must convert the analog video signal to digital because flat panels are digital devices. This is achieved by an analog-to-digital converter, which samples the signal. As explained later at the beginning of Chapter 6: Monitor settings, this is a complex process that must be fine tuned to give optimal results.

Color'n'Code advice about analog connection:

- *Be sure to use a high quality shielded VGA cable with gold plated connectors.*
- *Use the shortest possible cable to minimize interferences.*
- *Verify the cable is fully wired. This allows for DDC signal transmission and more precisely EDID information containing LCD color specification.*

Digital Mode

The standard DVI links use digital video signals. A DVI display system consists of a transmitter and a receiver.

DVI

Definition: Short for Digital Visual Interface. The DVI signal protocol is based on the TMDS high-speed serial interface to send data to the monitor.

TMDS

Definition: Short for Transition Minimized Differential Signaling. *Transition minimized* refers to a reduction in the number of high-to-low and low-to-high swings on a signal. *Differential* describes the method of transmitting a signal using a pair of complementary signals.

At the graphic adapter end, the TMDS transmitter produces a series of characters, which are encoded to minimize the number of transitions. This avoids electromagnetic interferences on the cable, thereby increasing the transfer rate and improving accuracy.

At the display end, the TMDS receiver synchronizes itself to character boundaries in each of the serial data streams, and TMDS characters are recovered and decoded. All synchronization signals are contained within the TMDS data stream.

There is a physical limit in the amount of data that can be transmitted through a wire, for copper wire it is about 165 MHz. The bandwidth of a single-link DVI configuration is therefore capable of handling UXGA (1600x1200 pixels) images at 60Hz. The DVI standard allows for up to two TMDS links that provide sufficient bandwidth to handle digital displays capable of QUXGA (3200x2400) resolutions. The two links share the same clock so that bandwidth can be divided evenly between them.

DVI also takes advantage of other features built into existing display standards. For example, provisions are made for both the VESA Display Data Channel (DDC) and Extended Display Identification Data (EDID) specifications, which enable the monitor, graphics adapter, and computer to communicate and automatically configure the system to support the different features available in the monitor.

Color 'n' Code advice about digital connection:

- *For high resolution panels, always download the latest graphic adapter driver and utilities, as standard Windows graphic drivers often cannot drive 1600x1200 panels in digital mode.*
- *For even higher resolutions, be sure both graphic adapter and LCD are implementing he required dual-link connection. Also verify you have a DVI dual link cable with 24 pins.*
- *Some graphic adapters, generally those having both VGA and DVI-D connectors instead of one combined DVI-I connector, cannot display the computer boot up sequence through DVI, in the case you need to access BIOS or SCSI setup, you have to use the VGA connection and set the panel to analog mode if it does not switch automatically.*

Flicker

Flicker, as observed on CRT monitors at low refresh rates or in interlaced mode, does not occur with LCDs because LCD pixels do not need to be refreshed. But there are potentially other sources of flicker for LCDs, though it seems only 10% of the population is affected. In liquid crystal pixel cells, it is only the magnitude of the applied voltage that determines light transmission. To prevent polarization and permanent damage of the liquid crystal material, the polarity of the cell voltage is reversed on alternate video frames. Unfortunately it is very difficult to get exactly the same voltage on the cell in both polarities, so the pixel-cell brightness will tend to flicker to some extent at half the frame-rate. If the polarity of the whole screen were inverted at once then the flicker would be highly objectionable. Instead, it is usual to have the polarity of nearby pixels in anti-phase, thus canceling out the flicker over areas of any significant size.

Color 'n' Code advice about flicker:

- *The best solution is to look at another model to see if flicker can be detected. There are different polarization schemes and each person sensitivity is different.*
- *Increase the vertical refresh rate if possible but never set the refresh rate higher than the minimum required. Increasing the refresh rate too high reduces image sharpness.*
- *Reduce the background room lighting.*
- *Avoid using fluorescent room lighting.*

Response time

Definition: Response time is a characteristic of a LCD. It is measured in milliseconds and refers to the time it takes each pixel to respond to the command it receives from the panel controller.

Advances in LCD technology have significantly improved LCD video response time. The best LCD monitors now clock in with response times well under 20ms, resulting in smoother on-screen presentations. Slower response times can cause the image on the panel to lag and appear jerky, an effect known as "streaking" or "trailing." Another phenomenon associated with slower response times is "ghosting." This occurs when the display is made to switch quickly from light to dark states. In these instances, on-screen images may appear to stay on the screen belatedly.

Color 'n' Code advice on response time:

Always choose the LCD panel with the fastest response time but keep in mind data sheets can be misleading because they generally only consider black to white transitions and gray-to-gray transitions are often much slower.

Chapter 6: Monitor settings

Analog (VGA) or Digital (DVI)

The latest LCD monitors are all providing a digital entry. This means that graphics cards with digital outputs don't have to convert the graphics information into analog form as they would with a typical analog monitor. Theoretically, this makes for more accurate color information and pixel placement. Digital video signals do not suffer from phase shifting, as the Pixel Clock is one of the signals that are fed directly from the graphics generator to the display. Since an LCD display is a digital device, it makes much more sense to feed it with digital data directly via.

Problems occur when LCD panels are used with analog graphic adapters. The graphic signal generated by the PC is digital and is converted by the graphic card to an analog signal. It is then fed to the LCD panel where it has to be converted into a digital signal again because LCD panels are digital devices. For this whole process to work properly, the two converters must be adjusted so that their conversion clocks are running at the same frequency and phase. This requires that both the clock and the phase of the converter inside the LCD panel are continuously adjusted to match those of the graphics card.

Since a CRT is an analog device, and due to the nature of writing the image on the screen, both a Horizontal and a Vertical Synchronization signal are generated by the graphics card and fed to the display to control the electron beams deflection. There is no need for a Pixel Clock signal.

In an LCD display, the pixels are addressed in a discrete way, there is no deflection and then no need for Horizontal and Vertical Synchronization signal. But legacy graphic adapters only provide these signals to the LCD display, together with the analog RGB. The Pixel Clock needs to be reconstructed at the display side using the HS & VS timing information, and the total number of pixels per line. And that is where the problem comes in. The slightest phase shift of the HS signal implies a shift of the Pixel Clock with possible missampling resulting in a noisy low quality image.

Phase and Clock Adjust is relevant in case of analog video inputs only:

Horizontal Phase

Use monitor's auto-adjust or manual phase control, if necessary, to eliminate shimmering horizontal streaking.

Vertical Clock

Use monitor's auto-adjust or manual clock/pitch control, if necessary, to eliminate broad vertical banding.

Color'n'Code advice about analog clock and phase controls:

If no clock/phase combinations are very satisfactory:

- *Try selecting a different refresh rate on the PC using only values that are in the list.*
- *External factors may affect the sampling clock stability, look at the cable, move the display.*
- *Upgrade to a newer graphic adapter, the latest cards have a far better signals stability.*

Dot Pitch

Definition: the distance between a dot and the closest dot of the same color on a LCD flat panel.

One issue affecting the overall quality of the picture reproduced on LCDs has to do with dot pitch. This term refers to the distance between sub-pixels of the same color in adjoining pixel triads. The closer these "dots" are to one another, the sharper the image will be. This is especially true when displaying computer signal images and graphs. And the picture in front of you will be more realistic and detailed. Higher dot pitches increase the viewing angles of LCD panels. A good rule of thumb is this: smaller dot pitches make for sharper images.

Color 'n' Code advice about dot pitch:

- *You generally want a LCD panel at least a .28mm dot pitch, finer being better*
- *Always match screen resolution with screen size. A large screen with a low native resolution won't provide sharp images, unless you stay farther away. A small screen with a high native resolution may seem sharp but barely readable (you can play with Windows default font size control to get bigger characters)*

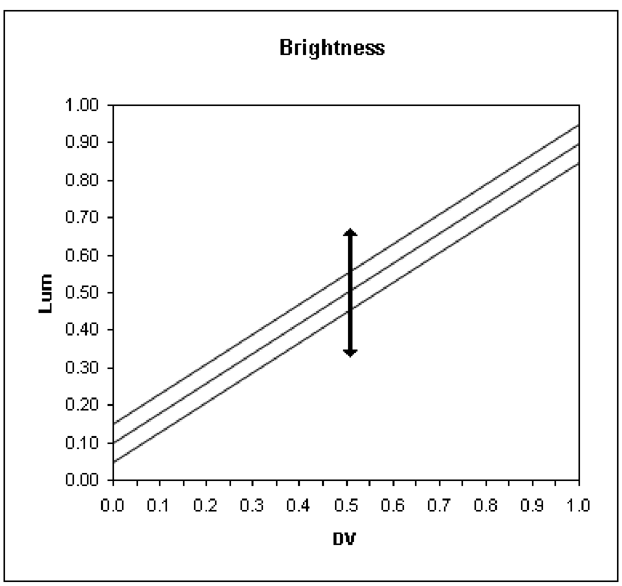
Brightness and Contrast

Definition: Brightness is the visual perception of light along a very bright to dark continuum. Contrast is the range of tones from the darkest to the brightest.

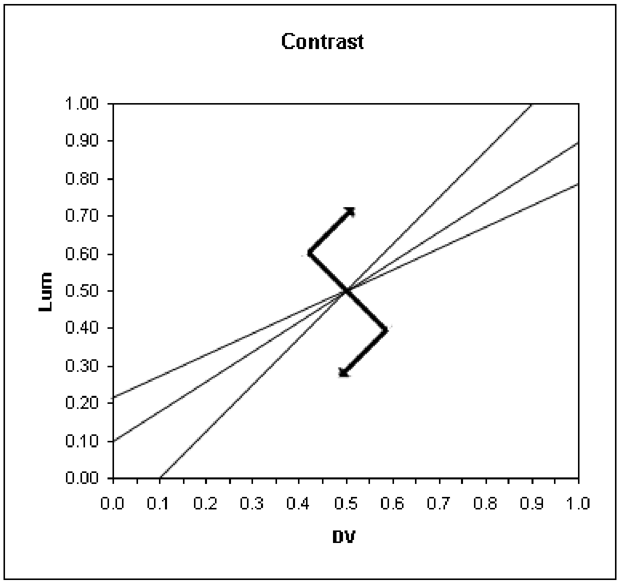
The most important monitor adjustment to worry about is the tonal display (TRC-tone reproduction curve), the way it shows shades of gray and what it shows as black, and white. This is usually controlled by the brightness and contrast settings. While brightness and contrast names are misleading on CRTs, the exact effect of brightness and contrast controls on LCD monitors is very poorly defined and some experimentation may be required.

But on the latest LCD panels, the brightness control generally affects backlight, which directly changes the maximum brightness, almost like CRT contrast. Brightness is regulated by power modulation of the backlight lamps with a low frequency around 200 Hz.

The drawing below shows TRCs at various brightness settings, the I/O curve goes up when increasing brightness control and down when decreasing. The backlight control found on many LCDs allows their dynamic range to remain constant, because the black-level luminance decreases together with the peak luminance.



While all LCD have a brightness control, a few less offer a contrast control. On LCD panels, the contrast control generally affects the liquid crystal current bias. This determines how many different steps can be seen and how much of the dynamic range is used.



Color'n'Code advice for brightness and contrast settings:

- *Brightness can generally be modified without problem. It allows to get a comfortable viewing level. On most monitors you can just set the brightness control to 50% of the maximum.*
- *Contrast is difficult to properly set without an appropriate tool. Contrast directly affects the TRC, you should never change its setting on a calibrated monitor, this definitely voids calibration data.*

White point or Color Balance

Definition: White point is the point of the chromaticity diagram having the tristimulus of a source appearing white under the viewing conditions. Color Balance is the set of controls allowing to equilibrate cyan-red, magenta-green and yellow-blue continuum.

White point "color temperature" describes how "warm" (red-yellow) or "cool" (blue) the picture display looks. Most monitors can generally be set to either 5,000K, 6,500K or 9,300K. The lower the number the yellowish the display appears and the higher the bluish. LCD factory setting is generally 6,500K while CRT is 9,300K.

Don't worry if your monitor doesn't have this control. For most LCD's one should anyway not try adjusting the hardware white point. Some manufacturers try to approximate the effect of changing the hardware white point like on CRTs but this is not possible.

On LCDs, color temperature is generally quite different for white and for gray. Depending on the color temperature setting, white may vary between 5,500K and 7,500K, and gray between 8,000K and 16,000K, hence the changing color cast observed in gray ramp. For LCDs, the display's color temperature is then only an average value.

The human eye is very good at adapting to differences in white-point color temperature. For example, in most homes, normal light bulbs are tungsten, and they produce a very warm light, usually 2,800K. Direct sunshine at noon on a clear day is called "standard daylight" and its color temperature is about 5,500K. Open shade, not in direct sunshine, but illuminated by a clear blue sky is very blue, about 7,000K or more. And still, under all of these different lighting conditions, our eye / brain combination sees things as normal.

Given the tremendous amount of variation from monitor to monitor, even among the exact same brand and model, pictures generally look different even with two monitors set to the same color temperature. The only time this stuff is really critical is if we were going to output the images for printing or reproduction. Then the monitor should be calibrated to the output device.

Color'n'Code advice for white point setting:

To avoid problems, keep the monitor factory default color balance setting, which is generally 6,500K and change color temperature through the calibrator.

Bandwidth

Definition: maximum amount of information that can be transmitted along a channel.

The bandwidth is the amount of data that a monitor can handle in one second. It is measured in MHz. It is limited by the design of the video amplifiers. The maximum bandwidth of a monitor should be matched as closely as possible to the dot clock of the video controller. If there is a mismatch, then capacity of either the controller or monitor may be wasted. It is not as serious for the monitor to lack video bandwidth as it is for a graphics controller to lack the dot clock rate needed for a given video mode.

For analog connections, the maximum bandwidth of a monitor cannot be directly calculated without detailed timing information. In fact, the exact bandwidth required in a monitor at a given resolution and vertical refresh frequency is also dependent on internal timing of the monitor itself. We can calculate an approximation of the required bandwidth for a given pixel addressability and vertical refresh frequency using the following:

Given that the vertical pixel addressability is Y, horizontal pixel addressability is X and refresh rate is R, to account for the additional time required for the vertical blanking interval, Y is multiplied by 1.05. The additional time required for the horizontal blanking interval is about 30% of the scan time, so use 1.3X. Note that 30% is very conservative with most new monitors. In order to do an exact calculation, you would have to know the vertical and horizontal blanking intervals for the mode in question, as well as the horizontal scan frequency. So the resulting approximation is:

$$BW = 1.05Y*1.3X*R$$

i.e. for 1280x1024 at 60 Hz, approx. bandwidth required = 1.05*1024*1.3*1280*60 = 107 MHz

This approximation grossly simplifies the calculation, and should be used with care.

For digital connections, the maximum bandwidth required is easier to calculate and the standards determine the bandwidth for the transmission channels, for example DVI specification states that each component in a link, there can be two links, must support 1600x1200x60 = 115MHz, the theoretical limit for a copper wire is 165MHz. Both transmitter and receiver electronic parts may also affect and limit the bandwidth.

Chapter 7: Characterization

From time to time you will have to go back and recalibrate your monitor settings as monitor phosphors and output devices change with age.

Calibration

Definition: the act of checking or adjusting, by comparison with a standard, the accuracy of a device.

Although the entire process is commonly called "calibration" it is actually a two-part procedure: adjusting the monitor, which is also called "calibration", and creating a monitor profile for the specific monitor being used. When the two steps are done correctly, the chances of coming up with accurate output increase significantly.

Every monitor displays color differently. There are differences between various models when they are new, and these differences can increase as the equipment ages. When not calibrated, even new monitors don't display color accurately. The human eye (in conjunction with the brain) does a wonderful job of interpreting the brightest areas of the screen to look like neutral white and the darkest parts totally black. The reality is, nearly every monitor when shipped has an overall bluish cast because of the initial factory settings.

To understand why requires a little color theory. Scientists describe colors on a color measurement scale that uses degrees Kelvin (K) as a unit of measurement. Colors are described as being of a certain "color temperature" along this scale.

The white of a new monitor is generally around 9300K, because this is the default factory setting. A 9300K white is considered very blue. The color temperature of output is determined by the color temperature of the light illuminating it. For print output, viewing booths illuminate the press sheets with 6,500K or 5,000K light. Transparencies are viewed on 5,000K color-corrected light boxes. 6,500K is much less blue than 9,300K, and 5,000K looks downright yellow compared to 9,300K! This is just one of the reasons that output will not match the monitor image on an uncalibrated monitor.

Another reason is called "gamma". This is a term used to describe the way in which the CRT display transitions brightness from white to black. The lower the gamma of a device, the brighter the mid-value of gray will appear when reproduced on the device. Macintosh systems have standardized on a gamma of 1.8 while Windows has standardized on 2.2, which explains why images optimized for Windows appear lighter on a Mac display.

But LCD panels do not have a gamma like behavior, their TRCs are generally third order or S-shaped functions, which can be very different from model to model.

With all of the variances between monitors and their tendency to drift from any set value over time, the only way to ensure that images will be consistently displayed is to periodically calibrate them. The problem is compounded in larger imaging labs where the same image may be adjusted by different technicians at different times on different monitors. Unless all of the monitors are calibrated to the same standard, each technician may adjust the image to display "accurately" on the monitor in use, thus degrading the color and perhaps making it impossible to output properly.

The steps in calibrating a monitor include adjusting the brightness and contrast controls on the monitor itself to set or perceived values, setting a white point (color temperature), adjusting or selecting a gamma, and defining the red, green and blue phosphor settings. These adjustments are then saved as an ICC profile that captures the characteristics of the monitor. Macintosh computers store this information as an ICC System Profile while Windows 98, Me, 2000 and XP store it as an ICM System Profile. Windows NT does not support system-wide color profiles, but will save the information for use with ICC-compliant applications and video cards.

Be aware that most output devices have certain "peculiarities" due to things like color crossover, ink properties, etc, that can never be matched perfectly to a monitor display in a calibration routine. You just get it as close as you can and live with the fact that it's not a perfect world.

Monitor calibration and profiling is only the first step in ensuring *W*hat *Y*ou *S*ee *I*s *W*hat *Y*ou *G*et (WYSIWYG) results, but they're important steps. Once the monitor profile is generated and saved in the computer, one last step must ensure that the operating system (OS) will access this information. Profiles must be handled correctly for color management to have any chance of being effective in the production process.

Calibration Devices

- Self-calibrating monitors
  Several high-end monitors provide all the hardware, software and connectors required for calibrating.

- Colorimeters
  Colorimeters are three-color instruments for measuring transmitted or reflected light. They are the devices most often used to calibrate and profile the monitor, though they can be used for generating printer profiles. However, their limitation to reading three colors limits their accuracy for this use.

- Spectrophotometers and spectroradiometers
  Spectrophotometers are more sophisticated instruments for reading the reflectance or transmittance of light at specified increments throughout the visible spectrum. These devices are most commonly used to create output profiles from printers. Spectroradiometers are devices that directly measure the absolute quantity of light and are used for highly accurate monitor calibration and profiling.

- Software solutions
  These are generally based on a sequence of screens, guiding the user to set brightness and contrast, characterize TRC, characterize white point, ambient, etc… The software also offers a control panel to set the monitor in various color spaces. Only ColorWizzard through its patented and patent pending process accurately calibrates LCD panels. Adobe and Apple explicitly say that Adobe Gamma or ColorSync do not support LCD calibration.

Color ‘n’ Code advice about calibration:

- *Your monitor certainly came with a generic ICC profile. This is better than nothing but they never provide satisfactory results. Only characterization and calibration of your system in its running location and environment can ensure perfect results.*
- *Calibration is definitely required for LCDs because they don’t behave naturally as CRTs and most images and movies are prepared according to CRT standards.*
- *Calibrate your system before each important task and at least once every 6 months.*

Chapter 8: Other considerations

Safety and Ergonomy

LCD flat panels produce very low electromagnetic emissions as a result of how they work. There is no high voltage and no big magnetic coils used in LCDs.
Since the early nineties, the Swedish government has been a leading force in developing lower emissions standards for monitors. The TCO (Tjänstmännens Central Organisation) refers to the Swedish Confederation of Professional Employees which defines strong standards for emissions. Screens adhering to the TCO standards are generally more expensive.
First was TCO-92. It limits the permitted amount of low-level radiation and establishes standards for electrical and fire safety.
Then there was TCO-95, which also includes regulations on ergonomics (including refresh rates), maximum energy consumption, environmentally friendly production and recycling facilities.
TCO-99 is the latest version of the standard. The best LCDs comply with this standard.

Color 'n' Code advice about electromagnetic emissions:

You should never buy a monitor that did not receive at least TCO-95 label. This ensures:

- *high luminance and good luminance uniformity.*
- *high contrast ratio.*
- *wide viewing angles.*
- *low energy consumption.*
- *environment-friendly manufacturing.*

Display Power Management System (DPMS)

Definition: a feature which turns off power to the display after a period of inactivity.

Even if they consume far less energy than CRT monitors, about 110 watts for a typical CRT compared to 30 and 40 watts for a typical LCD, LCD flat panels are still implementing several schemes to reduce power consumption and energy use during idle periods. This is especially important for notebooks running on batteries, but a lot of desktop panels also provide options to reduce power consumption. LCD technology is woefully inefficient; in a fully white screen, less than 10 percent of the light shining into the back of the panel from the backlight is being transmitted through the front. The rest is being absorbed. And in general, the backlight represents the largest portion of an LCD display's energy budget.

Most LCD flat panels are compliant with VESA's Display Power Management System protocol, also called DPMS. DPMS is used to selectively shut down parts of the monitor's circuitry after a period of inactivity. With a motherboard or video card and a monitor that support DPMS, power consumption can be greatly reduced.

Some solutions are poorly implemented, for example the screen appears black but the backlighting is still on. Good DPMS solutions must then turn backlighting off. Even if not as long as the warming period required by CRTs (at least 30 minutes), LCDs also have an unstable period when turned on, but most LCDs are stable after a few seconds or a maximum of 30 seconds for very large desktop panels.

The operating system or application software you are using must normally also be set to activate DPMS after a defined idle period. Many monitors have two low-power settings; stand-by mode uses less power than the normal operational state, and then an even lower suspend or "shut down" mode turns the monitor off completely to save even more power. The system monitors the PC for activity and after the determined time, sends the appropriate signal to the monitor. When activity is detected again the monitor is "woken up" by the system.

Color 'n' Code advice about power management:

- *Even if you aren't using DPMS, at the very least no monitor should be left on for hours at a time if not in use, and especially not unattended overnight.*
- *Be careful when selecting the idle time after which the panel is turned off by DPMS. Shutting off and on the backlighting system too often may wear it out.*

Backlight Aging

A backlight provides the LCD monitor's brightness, and generally has a lifespan of approximately 60,000 to 80,000 hours - about 20 - 25 years of daily 8-hour usage.

Screen savers were first invented to address CRT "burn in" problem. A screen saver is simply a software program that, after a specified period of inactivity, either blanks the screen or displays a moving pattern on it. This prevents burn in of the screen phosphor that could occur through the same image being on the screen continuously.

Screen savers themselves continue to be popular on LCD panels, but today they are more of a form of entertainment software than a practical utility. LCD filters do not suffer from aging, at least not for being in use, they are passive devices filtering out wavelengths.

A screen saver is not a replacement for proper power management features. The monitor doesn't care much about what images it is displaying, so it uses power to display the screen saver image as well. If you are using a saver that blanks the screen entirely, the LCD panel may still use full power because its backlight is not turned off, using DPMS is a far better solution.

Color 'n' Code advice about backlight ageing:

Even if they are fun to look at, screen savers are not a good solution. You should always prefer DPMS control for LCD power management.

LCD Pluses and Minuses

All CRT and LCD monitors require calibration for accurate color-critical work, but some are easier to calibrate than others. Based on the current core technologies, CRT monitors are able to display a wider color space than LCD monitors and deliver more consistent brightness uniformity throughout the screen. For these reasons, CRT monitors can more easily be calibrated. LCD monitors also exhibit limitations in making adjustments in brightness, backlight color temperature, contrast and black level. Nevertheless, advances are quickly being made, utilizing different backlight designs to improve the calibration capabilities of LCD displays.