How to Set your Monitor

Part I: Cathode Ray Tube

by Jean-Pierre Huber
Color'n'Code Sàrl

(www.colorncode.com - www.colorwizzard.com)

Table of content

Chapter 1: Introduction

In an industry in which development is so rapid, it is somewhat surprising that the technology behind monitors and televisions is 100 years old. The cathode-ray tube (CRT) was developed by Ferdinand Braun, a German scientist, in 1897 but wasn't used in the first television sets until the late 1940s. Although the CRTs found in modern monitors have undergone modifications to improve picture quality, they still follow the same basic principles.

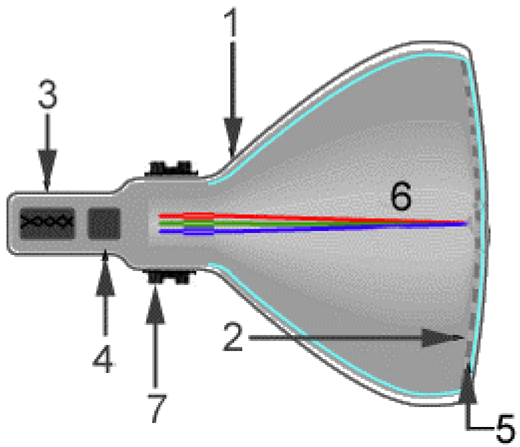
Several characteristics affect the way monitors display images. Very often monitors taken out of the box are not set properly. Because bright screens are more impressive, a lot of manufacturers crank the settings to their maximum value. This is not good. When brightness is set too high, there is a lack of details in the blacks and when contrast is set to high there is a lack of details in the whites. Furthermore while standards claim CRT correlated color temperature (CCT) is 9300K, most manufacturers 'pump up' the green to get a brighter screen, thus boosting the CCT and modifying the color balance.

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 drivers disks. If a disk came with your monitor, even if it claims to be plug-and-play, use the hardware setup and install it, it gives you all the correct refresh rates and color depths and screen resolutions possible. This 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, keep in mind it is a generic ICC profile, it can only assume average ambient conditions that are not likely to be yours.

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.

Chapter 2: CRT technologies

A CRT is essentially a sealed glass bottle turned on its side with no air inside (1). It begins with a slim neck and tapers outward until it forms a large base. The base is the monitor's 'screen' and is coated on the inside with a matrix of thousands of tiny phosphor dots (2). Phosphors are chemicals, which emit light when excited by a stream of electrons: different phosphors emit different colored light. Each dot consists of three blobs of colored phosphor: one red, one green and one blue. The three phosphors are so close together that the human eye perceives the combination as a single colored pixel. In the neck of the CRT is the electron gun, which is composed of a cathode (3), heat source, and focusing elements. Color monitors have three separate guns, one for each phosphor color, red, green and blue.



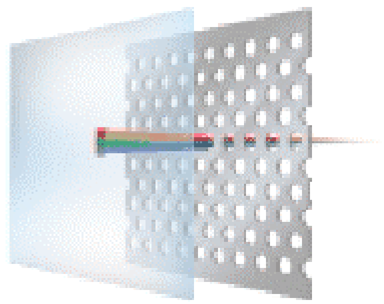
The gun radiates electrons when the heater is hot enough to liberate electrons from the cathode, which are then narrowed into a tiny beam by the focus elements (4). The electrons are drawn toward the phosphor dots by a powerful, positively charged anode, located near the screen (5). Images are created when electrons converge to strike their respective phosphor blobs and each is illuminated. When this happens, light is emitted, in the color of the individual phosphor blobs. The electron gun continually sends out very precisely aimed beams of electrons (6), moving from pixel to pixel. The beams are moved around the screen by magnetic fields generated through a deflection yoke (7). It starts in the top left corner (as viewed from the front) and flashes on and off as it moves across the row. When the energetic electrons collide with the phosphors, energy is converted into light. Once a pass has been completed, the electron beam moves down one raster line and begins again. This process is repeated until an entire screen is drawn, at which point the beam returns to the top to start again. In practice, the emitted light quickly fades away; the electron beam 'visits' again, before there is any visible fading of the light. Combinations of different intensities of red green and blue phosphors can create the illusion of millions of colors. This is called additive color mixing and is the basis for all color CRT displays.

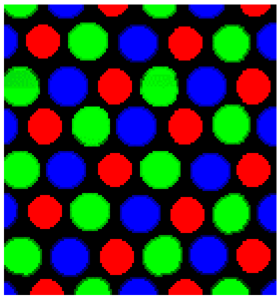
CRTs were historically made so that the front display surface was a section of a sphere. Later, so-called 'flat' screens were created from sections of a much large sphere. The resulting display surface was less noticeably curved, but they were still not absolutely flat. Today, the display surface is absolutely flat in all directions. But in order to reduce glare even more, Toshiba's Microfilter CRT places a separate filter over each phosphor dot and makes it possible to use a different color filter for each color dot. Filters over the red dots, for example, let red light shine through, but they also absorb other colors from ambient light shining on screen - colors that would otherwise reflect off as glare. The result is brighter, purer colors. Other companies are offering similar improvements. Panasonic's Crystal Vision CRTs use a technology called dye-encapsulated phosphor, which wraps each phosphor particle in its own filter and ViewSonic offers an equivalent capability as part of its new SuperClear screens.

CRT monitors can be classified in different technology types:

Shadow mask

Standard monitors have three dots at each location on the screen: red, green and blue. There is a corresponding electron gun for each color, which emits an electron beam of varying intensity - this corresponds to color brightness. To ensure that the electrons from each gun strike the corresponding phosphor, a 'shadow mask' is used. Because the three electron beams arrive at slightly different angles, it is possible to construct and align the shadow mask such that the electron beam from one gun strikes the correct phosphor dot, but the other two phosphors are in shadow. This way, the intensity of red, green and blue can be separately controlled at each dot triad location. The shadow mask is usually a metal screen (invar = 64% iron & 36% nickel), which is a thin plate with small holes punched in it.

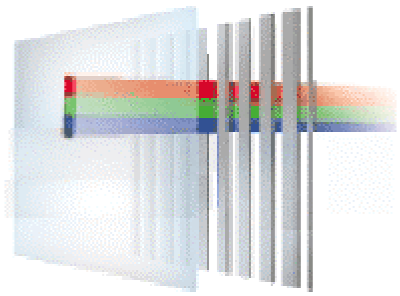


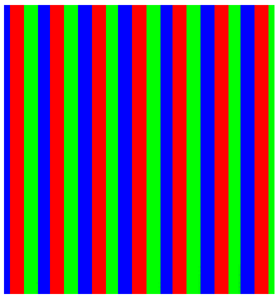


Although this method keeps the image sharp, it diminishes the potential brightness of the screen. Only about 20-30% of the electron beam actually passes through the holes in the mask and hits the screen phosphor, so the rest of the energy is dissipated as heat from the mask.

Aperture grill

Original Trinitron tubes were easily recognized because they were curved only in the horizontal plane, but were flat vertically. Most people find that this reduces glare and results in a more pleasant and less distorted image. Today, like other monitor types the latest Trinitrons are completely flat. Trinitrons have a single electron gun instead of three to improve electron beam aim, in fact it combined the three separate electron guns into one device: the Pan Focus gun. The Trinitron patent recently expired, which is why one sees Trinitron technology in other manufacturer's monitors now.





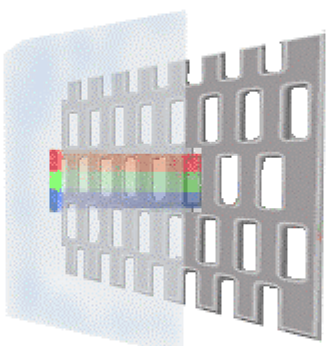
Instead of a metal screen, the aperture grill consists of tiny vertical wires. The pixels on the phosphor layer are arranged in uninterrupted vertical stripes instead of triangular groups. When the electron guns scan across a row, the wires isolate the pixels that the individual beams focus on. This approach has a couple of advantages over conventional shadow masking. For example, it allows the phosphor strips to be placed closer together than conventional dot triads, and the fine vertical wires block less of the electron beam than traditional shadow masks, resulting in a brighter image, and less thermal buildup and distortion. But as the phosphor lines have no horizontal breaks, Trinitron must rely on the accuracy of the electron beam to define the top and bottom edges of a pixel. But, there is also a significant problem. To maintain equal spacing between the vertical, wires which are so fine that they can be set into motion when contacted by the electron beam, the aperture grill has one to three horizontal damper wires, depending on screen size, which hold the vertical wires in place. Even if only 15 microns in diameter, these wires cast a faint shadow on the phosphor layer that customers often take for a fault but they are necessary to avoid a shimmer on the screen which would be much more annoying.

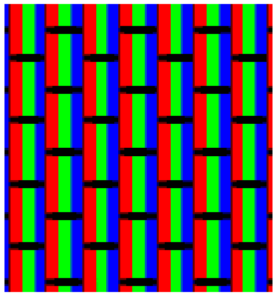
Several companies have also developed hybrid variations that combine features of the aperture grill and the shadow mask (Mitsubishi, Samsung and Ilyama DiamondTron).

Slotted mask

Capitalizing on the advantages of both the shadow mask and aperture grill approaches, NEC has developed a hybrid mask type which uses a slot-mask design borrowed from a TV monitor technology originated in the late 1970s by RCA and Thorn. Virtually all non-Trinitron TV sets use elliptically shaped phosphors grouped vertically and separated by a slotted mask.

In order to allow a greater amount of electrons through the shadow mask, the standard round perforations are replaced with vertically aligned slots. The design of the triads is also different, and features rectilinear phosphors that are arranged to make best use of the increased electron throughput.



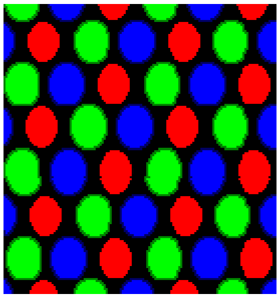


The slotted mask design is mechanically stable due to the criss-cross of horizontal mask sections and exposes more phosphor than a conventional dot-trio design. The result is not quite as bright as with an aperture grill but much more stable and still brighter than dot-trio. It is unique to NEC.

Enhanced Dot Pitch

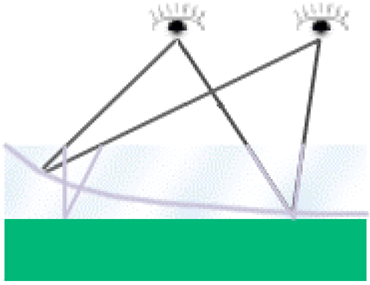
Developed by Hitachi, the largest designer and manufacturer of CRTs in the world, EDP is the newest mask technology, coming to market in late 1997. This takes a slightly different approach, concentrating more on the phosphor implementation than the shadow mask or aperture grill.

On a typical shadow mask CRT, the phosphor triads are more or less arranged equilaterally, creating triangular groups that are distributed evenly across the inside surface of the tube. Hitachi has reduced the distance between the phosphor dots on the horizontal, creating a dot triad that's more akin to an isosceles triangle. To avoid leaving gaps between the triads, which might reduce the advantages of this arrangement, the dots themselves are elongated, so are oval rather than round.

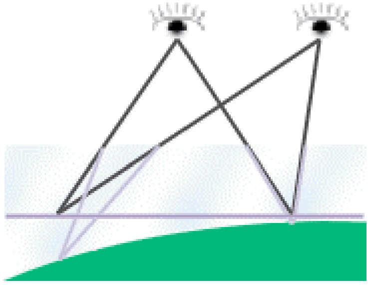


The main advantage of the EDP design is most noticeable in the representation of fine vertical lines. In conventional CRTs, a line drawn from the top of the screen to the bottom will sometimes 'zigzag' from one dot trio to the next group below, and then back to the one below that. Bringing adjacent horizontal dots closer together reduces this and has an effect on the clarity of all images.

Interestingly, the image from a pure flat screen is perceived to be concave by the human eye.



A slight inner curvature of the phosphor area can cancel out this concave effect and give a visually flat image to the very edge of the tube.



Chapter 3: Influencing factors

Following are some of the factors that influence the quality of the image produced by the monitor, 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 which reduces the contrast and thus the visibility of dark, or "shadow" areas of an image is decreased.

The screen of any display acts somewhat like a mirror, the reflections are superimposed upon the display's own image, reducing contrast and washing out the intended image particularly in dark image areas. Monitors employ different chemical treatments and other techniques to reduce or eliminate surface glare. Today, almost all new monitors are flat, which reduce glare.

Flicker

Definition: to appear for a short time or to make a sudden movement. Flicker generates visual instability.

Flicker arises because the video display images are not generated continuously, but are rather redrawn at a rate between 50 to 85 times per second (Hz), in a process called screen refresh. The screen brightness decays between the refresh cycles. The resulting flutter in brightness, called flicker, causes visual fatigue. It also depends strongly on the persistence of the screen phosphors. Too long a persistence will produce another problem called image lag, that is afterimages and image trails that can last a few seconds in dim lighting. The threshold for detecting flicker varies from person to person, with the persistence of the screen phosphor, and with the observing conditions. For most people, flicker is not apparent beyond 70 Hz.

Sharpness / Focus

Definition: evaluation of details in the clarity of an image. Sharpness represents the thinness of edges and fineness of points.

One of the most important quality factors is how sharp images are. Virtually every decent monitor will produce a sharp image at lower resolution and in the center of the screen. Better ones will also produce sharp images at higher resolution and in the corners. If you bring up graphics or text in the corners and the focus is noticeably worse than similar images at the center, the monitor is probably of lesser quality. If the monitor has a focus control however, make sure it is properly adjusted.

Straightness

***Definition*:** perfectly horizontal or vertical; level or even.

Vertical lines should be vertical, and horizontal lines horizontal. This isn't always the case, especially near the edges of the screen, where lines may bow inward or outward. Most monitors have a ‘pincushion’ control that can be used to correct for this, but many do not.

Distortion

***Definition*:** tendency for vertical lines to bend inward (pincushion) or outward (barrel) the center of a display. Also lack of parallelism (trapezoid) between otherwise straight lines.

Many cheaper monitors have noticeable image distortion at their edges. Magnetization and aging introduce image distortion even in the most expensive monitors.

True Aspect Ratio

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

Most monitors still use a 4:3 aspect ratio, matching the aspect ratio of most popular screen resolutions. This is done to ensure that objects have the proper proportion of height to width. But 16:9 or 16:10 aspect ratio monitors can be found.

Maximum Brightness

Definition: the highest level of brightness for a display.

Most all monitors are limited in the maximum brightness level they can be set to. This can sometimes be a problem when using the monitor in a bright room. Also, the overall brightness level of the CRT will tend to decrease over time.

Color Purity

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

A full screen of red, green or blue should appear red, green or blue. If you've ever gone to a retail store with a wall of television sets all showing the same channel, you've seen how dramatically different colors can appear on different screens. The same is true of monitors but to a lesser extent.

Monochrome Purity

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

Some monitors do a poor job of displaying black text on a white background, or vice-versa: they can show color at the edges of letters. Since this is something you will probably be doing quite a bit, especially if you do word processing, it's important to check.

Magnetization

Definition: effect of external magnetic fields on a display.

Magnetization manifests itself through splotches of color on the screen, especially in the corners. This can happen from exposure to a magnetic field (by putting a magnet such as that in a stereo speaker near the monitor's surface) or through physical shock to the CRT, and sometimes even by something as simple as changing its orientation.

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, there should be no light reflecting off the screen, as glare does severely hamper image color. Only advanced display calibration takes viewing conditions into account.

Some of these characteristics are controlled by the graphic adapter:

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

Most recent monitors use an On-Screen-Display (OSD) user interface to give access to all these controls. Some CRT monitors still offer a few mechanical controls for frequently used functions.

Some are controlled from the front of the monitor:

Brightness	**Contrast**	**Color balance**
Color temperature	**Degauss**	

On older monitors these are sometimes controlled from the rear of the monitor or through controls hidden behind a faceplate:

Position	**Size**	**Rotation (tilt)**
Pincushion (barrel)	**Parallelogram**	**Trapezoid**
Convergence		

Chapter 4: Graphic adapter settings

Resolution

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

Resolution is adjusted through the software driver that the operating system uses to control the graphics adapter card. In the mainstream usage, resolution refers to the number of pixels a screen can display. It 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**
640x480	VGA	*V*ideo *G*raphic *A*rray
800x600	SVGA	*S*uper *V*ideo *G*raphic *A*rray
1024x768	XGA	e*X*tended *G*raphic *A*rray
1280x960	SXGA	*S*uper e*X*tended *G*raphic *A*rray
1600x1200	UXGA	*U*ltra e*X*tended *G*raphic *A*rray

Monitors come in different sizes, from 12” (30 cm) to 21” (53 cm). The size of a monitor usually refers to the size of the diagonal measurement of its screen, although the actual usable area for CRT is always less, usually by 1” (2.5 cm).

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. Resolution is actually the ability of a monitor to show fine detail, it is related mostly to the size of the electron beam within the CRT, but also to how well the focus is adjusted, and whether the video bandwidth is high enough. Note that the dot pitch of a CRT is generally an indication of the tube's resolution ability, but only because the manufacturers try to maintain a spot size larger than the dot pitch to prevent Moiré' patterns from appearing.

Color ‘n’ Code advice:

- *Never push a monitor farther than its limits.*
- *High resolution brings more pixels. But if the screen is too small details disappear because of human eye's resolution power sets the 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 talked about in bits.

Each of the three primary (phosphor) 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 talked about 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.

Of course you can have more than 24-bit color, such as 48-bit color, which can represent even more colors and is better, but only experts can see the difference. 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, and most of the time 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. Then the lack of a deeper color depth will show up as banding in the sky.

You can also have fewer colors, such as 4-bit color with only 16 total colors, or 8-bit color with 256 total colors. Continuous tone images will usually look terrible at these low color depths because there are more real colors in the image than can be displayed.

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. If you have at least 2 megabytes of video memory on your video card, you should be able to run 24-bit true color at 800 x 600 resolution, if your monitor supports it.

Nb of Bits	Nb of Colors	Full Name	Resolution	Required Memory
1	2	Monochrome	320 x 240	9,600
4	16	EGA	640 x 350	112,000
8	256	VGA palette	640 x 480	307,200
15	16,768	Hi-Color	800 x 600	960,000
16	65,536	Hi-Color	800 x 600	960,000
24	16,777,216	True Color	1024 x 768	2,359,296
32	16,777,216	True Color	1600 x 1200	7,680,000
48	281,474,976,710,656		1600 x 1200	15,360,000

Color 'n' Code advice about color depth:

- *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 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. The higher the frequency the less eyestrain, with 72 Hz considered a minimum, and 75, 85 or 95 Hz being preferred choices when available. The screen image appears steadier with higher refresh rates. Large screens require higher refresh rates to avoid noticeable flicker. . The higher the refresh rate, the better quality monitor you need.

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. A multi-scanning or 'auto scan' monitor is capable of locking on to any signal, which lies between a minimum and maximum HSF. If the signal falls out of the monitor's range, it will not be displayed.

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, but is limited by the speed with which the monitor can scan the electron beam horizontally across the screen and then return it to the beginning of the next line. If too much data (i.e. too many horizontal pixels) is sent to the monitor, it exceeds its ability to modulate the electron gun, and the signal will be displayed incorrectly and the monitor may even be damaged. For example, to display a screen with 640 pixels horizontally and 480 vertically, a monitor with a HSR of 31.5kHz would take 480/31.5k = 15.2 ms to scan the entire screen once. In one second, this monitor could be refreshed 1000ms/15.2ms = 65.6 times. However, the vertical sync - movement of the electron gun to the upper left corner of the screen - requires some time, so the resulting vertical refresh rate is only 60 Hz.

Resolution	**Refresh rate**	**Horizontal scan frequency**
640 x 480	60 Hz	31.5 KHz
640 x 480	72 Hz	37.8 KHz
800 x 600	75 Hz	46.9 KHz
800 x 600	85 Hz	53.7 KHz
1024 x 768	75 Hz	60.0 KHz
1024 x 768	85 Hz	68.8 KHz
1152 x 864	85 Hz	77.6 KHz
1280 x1024	75 Hz	80.0 KHz
1280 x 1024	85 Hz	91.2 KHz

Built into the horizontal and vertical refresh rate are the horizontal and vertical blanking intervals, respectively. During horizontal blanking, the electron beam is moved back across the screen from the right end of one scan line to the beginning of the next scan line on the left of the screen. This occurs once for each scan line displayed. The vertical blanking interval occurs after the last scan line is displayed, and the electron beam is directed back to the upper left corner of the screen to begin displaying the next screen image.

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.

It is very important to make sure that you are not being affected by flicker or subliminal flicker. Since the perception of flicker is often not obvious, it is sometimes necessary to create special conditions for its detection:

- Increase the screen intensity
- Increase the background room lighting

- Move closer to the screen
- Use your peripheral vision by looking at the screen off-axis.

If flicker is detected, try to prevent it by increasing the refresh rate settings or reducing the ambient light level.

Color ‘n’ Code advice to prevent flicker:

- *Use a vertical refresh rate of at least 72 Hz but never set the refresh rate higher than the minimum required. Increasing the refresh rate too high reduces image sharpness. Make sure to never exceed the capabilities of the monitor.*
- *Reduce the background room lighting.*
- *Avoid using fluorescent room lighting.*

Interlacing

Definition: display an image built in two phases, each consisting in odd or even horizontal lines.

Interlacing is a holdover from television standards which use it as a way of putting more information on the screen than would otherwise be possible. Original television technology could handle 30 (25 in Europe) full frames of video per second. However, a 30 Hz refresh rate results in highly annoying flicker, so the video signal was divided into two fields for each frame. This is accomplished by displaying first the odd scan lines for 1/60 (respectively 1/50 for Europe) of a second, and then displaying the even scan lines for the next 1/60 of a second. When the displayed images vary smoothly, such as in a television picture, the eye perceives the flicker frequency to be at the field rate, which is twice the frame rate. The entire image is still transmitted at the frame rate, so the flicker frequency has been doubled without doubling the data rate or increasing the cost of the system.

Computer images are highly structured, the information on the even lines is often different from the adjoining odd lines. As a result, interlace smoothing doesn't work well, and the perceived flicker rate falls back down to the frame rate. Modern monitors are non-interlaced (NI) and display at high vertical refresh rates. Non-interlaced is where every line is drawn before returning to the top for the next frame, resulting in a far steadier display. A non-interlaced monitor with a refresh rate of 70Hz or over is necessary to assure a stable display.

Almost all monitors and graphic adapters are now non-interlaced and all TV sets, except HDTV, are interlaced. Interlaced displays flicker which is especially noticeable with thin horizontal lines because the scan line is alternating between the line and background colors. This is less perceivable with TV sets, which are intended to display motion pictures, than with monitors, which mostly display steady images.

Color ‘n’ Code advice about interlacing:

Interlacing allows monitors to operate at higher resolutions that they could in non-interlaced mode. But before setting a system to such a video mode, always consider flicker and especially subliminal flicker that can become a problem.

Chapter 5: Monitor settings

Glare

Displays with polished glass screens are the worst because they are excellent mirrors. Fortunately, virtually all displays sold now include a screen treatment to reduce glare and reflections.

Tinted screens are generally used in combination with other methods. The most effective use of tinted glass is when it is incorporated directly into the glass used to make the display itself. Add-ons, tinted screens introduce additional reflections at the back of the tinted layer.

A black mesh screen is one of the least expensive forms of glare reduction available. It works by absorbing any light that isn't traveling perpendicular to the screen. A disadvantage is that the mesh can interfere with the screen image unless it is extremely fine. Mesh screens may also produce Moiré patterns.

Direct etching of the screen surface with silica coating produces diffuse reflections that scatter the light. But this frosting also diffuses the screen's own image. Add-ons of this type noticeably degrade the image.

The best method, is a thin-film ¼ wave refractive anti-reflection optical coating. Such coatings reduce reflections by moderating the increase in the index of refraction at the surface by a series of small steps.

Another popular solution, is the ¼ wave circular polarizer which absorbs screen reflections because the reflected light goes through the polarizer twice and has its sense of rotation reversed. Internal display light is unaffected because it travels through the polarizer in reverse order and only once.

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

- *Orient the screen perpendicular to any sources of light, such as windows or lamps*
- *Install uniform indirect lighting*
- *Prefer dark matte finish walls*
- *Prefer flat screens, curved screens catch much more light*
- *Select a monitor with a dark colored matte finish bezel*
- *Select a monitor with multi-layer refractive anti-reflection optical coating*
- *Avoid add-on contrast enhancers*
- *Use dark characters on a light background*

Dot Pitch

Definition: the distance between a dot and the closest dot of the same color on a color CRT.

A monitor has a physical characteristic named dot-pitch. This value represents the distance between any two phosphor centers of the same color and is given in millimeters. Values are generally between 0.20 and 0.30 mm, where lower values mean higher RGB dot "blob" density and capability to display finer details.

Images on a color monitor are made up of glowing blobs of phosphor. The smallest discrete picture element consists of three phosphor blobs, one each of red, green and blue. These elements are called dot triads. On most monitors the blobs are arranged in rows and columns, often with every other row staggered.

While pitch specifies the distance between phosphor triads, there are also spaces and borders between adjacent phosphors elements, which are the guard band and black matrix areas, and vary significantly with tube design. The guard band is used to protect against beam misalignment and the black matrix improves contrast.

Dot pitch is a very important number because it determines the highest available resolution. The formula is dot-pitch <= physical dimension / number of pixel. But to make things fuzzy, dot-pitch is specified diagonally for shadow mask based monitors and specified horizontally for aperture grills monitors. A rule of thumb tell: horizontal = diagonal * 0.866.

Color 'n' Code advice to get the finest details:

- *Choose a monitor with the lowest dot-pitch*
- *Prefer black-matrix to get better contrast*
- *Use the following resolutions for various monitor sizes and dot-pitches:*

Monitor	Real	Size (mm)	Dot-pitch (mm)	Max Resolution (pixel)
14”	13” - 330mm	264 x 198	0.34	640 x 480
			0.31	800 x 600
			0.28	800 x 600
15”	14” - 355mm	284 x 213	0.31	800 x 600
			0.28	800 x 600
			0.25	1024 x 768
16”	15” - 380mm	305 x 227	0.31	800 x 600
			0.28	1024 x 768
			0.25	1152 x 864
17”	16” - 406mm	352 x 244	0.31	1024 x 768
			0.28	1152 x 854
			0.25	1280 x 960
19”	18” - 457mm	366 x 274	0.25	1280 x 960
			0.23	1440 x 1080
			0.21	1600 x 1200
20”	19” - 483mm	386 x 290	0.25	1280 x 960
			0.23	1600 x 1200
			0.21	1793 x 1344
21”	20” - 508mm	406 x 305	0.25	1280 x 960
			0.23	1600 x 1200
			0.21	1920 x 1440

Geometry

Definition: the control of parameters defining the size, shape and location of the image on a display.

Several graphic adapter device drivers offer geometry controls for image position and size, but it is much better to properly set all available geometry parameters directly on the monitor. This allows getting more out of the hardware through a larger usable distortion free screen area that can also reduce eyestrain by correcting overall and corner miss-convergence.

Color 'n' Code advice to get optimal geometry settings:

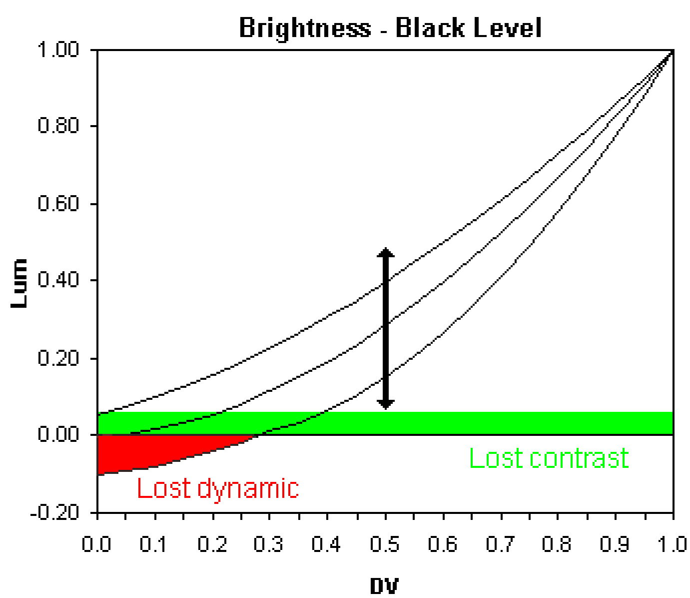
- *You must always let your monitor warming up for at least 30 minutes before changing geometry settings.*
- *Try to get the largest, undistorded image to maximize the use of your display.*
- *Take your time to set all geometry controls to their optimal value. There is no magic here, it just takes time to get everything properly set.*

Brightness and Contrast

Definition: Brightness is the location of a visual perception along the black-to-white continuum. Contrast is the range of tones from the darkest to the brightest.

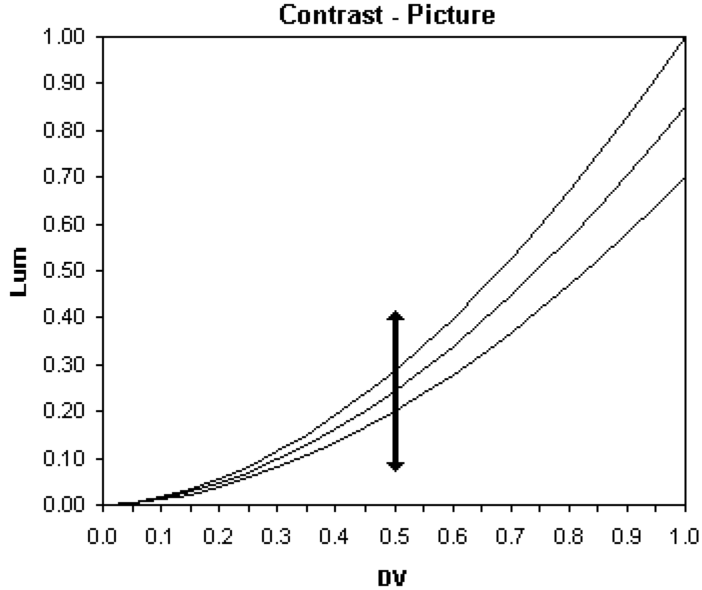
The most important monitor adjustment to worry about is the tonal display (TRC-tone reproduction curve), the way it shows shades of gray and what it shows as black, and white. This is usually controlled by the brightness and contrast settings. This can get complicated and confusing since both controls seem to control the brightness of the screen when you actually play with them. This is why professionals call brightness black level and contrast picture or white level.

The brightness control is the most critical here. It should be adjusted so that a full range of tones from black to white is displayed. Brightness control is set to make the black parts of the picture dark without losing any of the darkest gray picture detail. The drawing below shows TRCs at various brightness settings, the I/O curve goes up when increasing brightness control and down when decreasing.



Except at optimal setting (when black level equals 0), all other settings severely affect the display characteristics. Too high a level and contrast is dimished, it is difficult to detect such a setting visually and impossible to correct it. Too low and there is a loss of dynamic, fortunately it is possible to correct such a setting by detecting the black point (the first visible value).

The contrast control should be set to produce the highest white level possible, without degrading the picture. Excessive white level causes out of focus blooming, picture bending and yellowing of peak white parts of the picture (the blue phosphors run out of steam first).



Traditional screens can provide more contrast than the Trinitron screens, which is important in some technical applications.

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

Brightness is difficult to properly set without an appropriate tool. Brightness directly affects the TRC, you should never change its setting on a calibrated monitor, this definitely voids calibration data.
Contrast can generally be modified without problem. It allows to get a comfortable viewing level. On most monitors you can just set the contrast control to 90% of the maximum.

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. Lower numbers indicate a warmer, yellowish, color temperature.

Most monitors can be set to either 5,000K, 6,500K or 9,300K. These are measures of the color "temperature" and the higher the number the bluer the display appears. CRT factory setting is generally 9,300K. A gray screen at 5,000K will look much more yellowish than at 9,300K. 6,500K corresponds to sRGB. Don't worry if your monitor doesn't have this control.

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:

> *If you are not using a monitor calibrator and if your display offers a color balance setting, select sRGB or 6,500K, this ensures compatibility with most software and improves images viewing.*
> *If you are using a monitor calibrator it is better to keep the monitor factory default color balance setting, which is generally 9,300K 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.

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.

Degaussing

Definition: the process of eliminating magnetization on a CRT, named from mathematician Karl Friedrich Gauss.

Most modern CRTs today include built-in degaussing circuits. Some have a manual switch to activate the circuit, some do it automatically and some offer both as an option. The degaussing circuit uses a coil of wire to neutralize magnetic fields within the CRT.

When the degauss is engaged you'll hear a buzzing sound and the screen image will appear to vibrate for a few seconds; then you'll hear a click, the buzzing will stop and the screen will return to normal. Many monitors do this automatically when you turn them on, as a sort of 'preventive maintenance' measure. If you hear the tell-tale buzzing and click in the first five seconds after turning on your CRT, that's the degaussing circuit in action.

Sometimes magnetization won't go away after a degaussing. If your monitor automatically degausses each time it is turned on, sometimes the best course of action is to ignore the color impurity and wait for a week or two to see if, over time, multiple degaussing during power-on cycles will eliminate the problem. The other option is to use a manual degausser, which is a special demagnetizing device that is moved over the surface of the CRT to eliminate magnetic fields.

Color 'n' Code advice about degaussing:

> *If your monitor has a manual degauss button, you can use this to degauss the monitor if you ever have magnetization (color) problems. Just don't do it too many times in a row or you could risk damaging the circuit.*
>
> *When doing important work, always degauss the monitor first and let it warm up for a few minutes.*

Chapter 6: 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 6500K or 5000K light. Transparencies are viewed on 5000K color-corrected light boxes. 6500K is much less blue than 9300K, and 5000K looks downright yellow compared to 9300K! 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 the gamma that the monitor is actually reproducing may or may not be that of the system due to aging of the monitor as well as the characteristics of the video card to which it is attached. Thus the gamma of both the monitor and the video card must be correctly adjusted during calibration.

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 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 absoulute 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.

Color 'n' Code advice about calibration:

Your monitor certainly came with a generic ICC profile. This is better than nothing but does never provide satisfactory results. Only characterization and calibration of your system in its running location and environment can ensure perfect results.

Calibrate your system before each important task and at least once every 6 months.

Chapter 7: Other considerations

Electromagnetic Emissions

Definition: combination of oscillating electric and magnetic fields moving through a medium perpendicular to each other and carrying energy from one place to another.

All monitors produce electromagnetic emissions as a result of how they work. The electron beam that creates the image also produces electrical and magnetic fields as a side effect. (TV sets do the same thing). Radiation is certainly a pollutant but to what extent these emissions are a concern is unknown. Most specialists agree that the less, the better, but there is no agreement on to what extent emissions can be linked to health problems.

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 monitors 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:

- *proper shielding against radiations.*
- *ergonomic refresh rates.*
- *low energy consumption.*

Display Power Management System (DPMS)

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

Because of the tremendous amount of energy consumed by monitors when operating, a couple of initiatives have been started to work on reducing power consumption and energy use of monitors during idle periods.

Most modern monitors 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.

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.

One problem with DPMS is that if used improperly (such as telling the system to shut down after 1 minute of idle time) it can result in a lot of wear and tear on the monitor's internal components, reducing monitor life.

A 17" screen consumes about 100 watts in normal use. With DPMS the screen switches to two energy saving modes. First, power consumption drops to 25 watts and finally again drops to 8 watts.

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.

Aging and Phosphor Burn-In

When the phosphor dots on a CRT are struck by electron beams, they glow. When a particular image is displayed on a screen for a long time, the same dots are struck by the electron beam repeatedly millions of times. If the same exact image is left on some screens for a very long time, it is possible for the surface of the CRT to become damaged. When this happens, "ghosting" can be seen on the surface of the screen, even when the power to the CRT is off. When this happens the phosphor is sometimes said to be "burnt in".

Screen savers were first invented to address this 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, but today they are more of a form of entertainment software than a practical utility. Ironically, many screen savers today use their own images that remain stationary on the screen for long periods of time, which means they don't even do what they were originally supposed to do at all.

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 or is comprised mostly of low-intensity images then slightly less power will be used because the electron gun will be striking the phosphor using less energy, but this still isn't the same as using DPMS, for example.

Color 'n' Code advice about phosphor burn-in:

Even if they are fun to look at and to some extents prevent phosphor burn-in by presenting moving images, screen savers are not a good solution. You should always prefer DPMS control for CRT power management.

Less important but contributing to phosphor burn-in are screen background images and wallpapers. If the monitor stays idle for long periods with always the same static background it will burn quickly. Don't have habits, move windows around!

CRT Pluses and Minuses

CRTs offer numerous advantages over LCD flat panels for some applications.

Today's flat panels cannot compete with CRTs for the prepress market, for example, because the critical color matching requirements of that industry demand more than the flat panels provide. And while flat panels have generally higher contrast ratio than CRTs, the CRT has better black levels. This may sound contradictory, but LCDs leak and as such have a high black level, CRTs black level is very low but their max luminance is much less than that of LCDs. LCDs ratio is then higher.

CRTs also have their drawbacks.

They are heavy, bulky, draw lots of power (typically on the order of 100 watts versus 20 to 40 watts for LCDs), and have related high heat dissipation. While CRTs are well known to radiate electromagnetic fields, flat panels do not emit any radiation. Compared to an LCD, a CRT can require considerable work at setup time to achieve good screen geometry. Tuning is complicated by the fact that CRTs react differently when components are cold compared to when they warm up.