

LCD (Liquid Crystal Display) Color Monitor Introduction

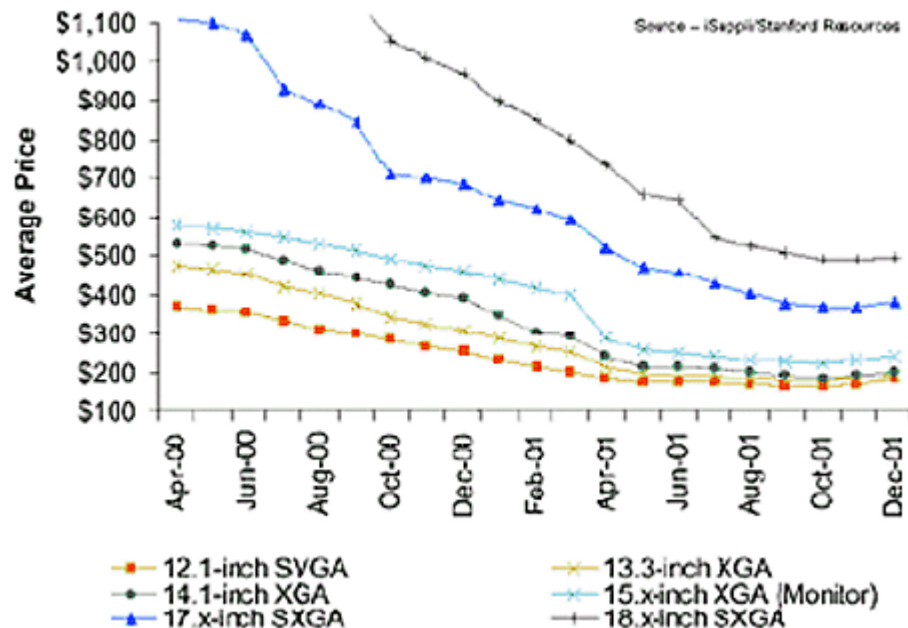
The LCD “flat panel” display is a display newcomer. LCD technology displays originated in military displays in the 1960s. Commercially LCD displays became available in watches and calculators in the early 1970s. Since its advent in 1971 as a display medium, LCDs have moved into a variety of fields, including miniature televisions, digital still and video cameras and monitors. Today many believe that the LCD is the likely technology to replace the CRT monitor. It certainly has a good start and holds an apparently unassailable position in notebook and handheld PCs.

Early LCD computer displays were clumsy, monochrome boxes offering limited gray scale graduations, poor saturated colors, narrow viewing angles and, slow response. The current state-of-the-art LCD panels are evolving rapidly and approach or exceed CRT performance in these categories. Additional improvements are forth coming.

LCD Color Displays, when compared to other display technologies are thin and lightweight and run on low voltage power supplies and drive signals. Low voltage drive signals enable LSI (Large Scale Integration) circuitry to drive the display directly. The LCD display panel consumes very little power making portable, battery operation possible. Manufacturing techniques have reduced the cost of the displays lowering consumer pricing.

According to research firm iSuppli, worldwide revenue for LCD panels is expected to reach \$47 billion in 2004, up 32% from 2003. In 2003, the worldwide LCD market rose 27.9% to \$35.7 billion. Market research firm Display Search predicts LCD monitor growth in 2004 to 14 million units worldwide and will grow to more than 46 million by 2005.

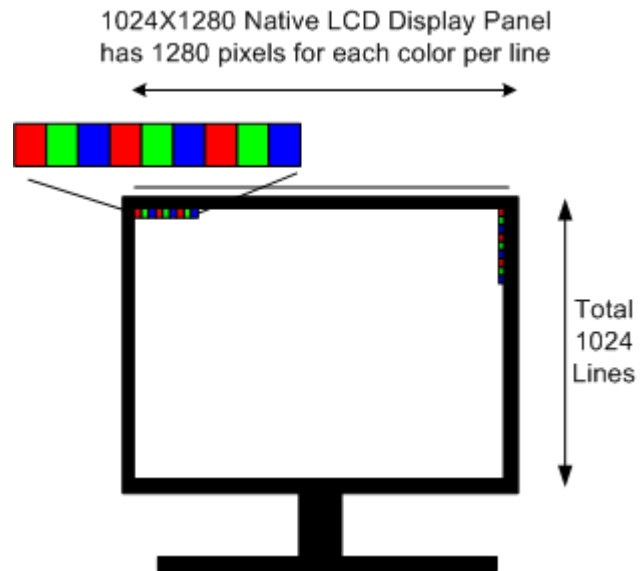
LCD Color Monitor prices continue to fall fueling increasing sales.



LCD Display Resolutions

CRT Monitors are capable of displaying a range of input signal resolutions without modification. In a CRT the scanning circuits are made to change rates or frequencies in accordance with the input signal format to display it. A VGA input signal (640x480) is scanned on the screen at a horizontal scanning frequency or 31.5 kHz. A 1280x1024 input signal is scanned onto the full screen at a much higher horizontal scanning frequency. In this manner the input signal resolution determines the displayed resolution.

An LCD panel has a fixed number of liquid crystal cells and can display only one resolution at full-screen size using one cell per pixel. This is the LCD panel's native resolution. Lower resolutions could be displayed without changing the resolution by using only a portion of the screen. For example, a 1024x768 panel can be displayed at a resolution of 640x480 by using only 66% of the screen. As this would not be acceptable by most users, modern LCD monitors are capable of rescaling lower-resolution images to the LCD's native display resolution and displaying it full screen. This is accomplished by electronic sampling of the image and a scaling processor. A limited number of input signal resolution formats can be scaled and displayed at the LCD's display's native resolution.



Unlike CRT monitors, the diagonal measurement of an LCD is the same as its viewable area, so there's no loss of the traditional inch or so behind the monitor's faceplate or bezel. The combination makes any LCD a match for a CRT 2 to 3 inches larger: By early 1999 a number of leading manufacturers had 18.1 inch TFT models on the market capable of a native resolution of 1280x1024.

Native resolutions for LCD Display panels.

VGA:	640 x 480
SVGA:	800 x 600
XGA:	1024 x 768
SXGA:	1280 x 1024
SXGA-Wide:	1600 x 1024
UXGA:	1600 x 1200
HDTV:	1920 x 1080
UXGA-Wide:	1920 x 1200
QXGA:	2056 x 1536

Understanding LCD Display Technology

For many years CRTs have been the standard display device. The development of the first LCD (liquid crystal display) by RCA Laboratories in 1968 ushered in a new era of displays. Since then, LCDs have been incorporated into all types of digital devices from small watches and calculators to video displays and projection televisions.

Early LCD displays suffered from limited gray scale graduations, poorly saturated colors, narrow viewing angles, and slow response times. Today's LCD panels have greatly improved, and are beginning to rival CRTs in most performance areas. But, in terms of size, weight and power consumption, LCD displays are far superior. This article introduces you to LCD technology and LCD displays.

How LCD panels work

The basic function of the LCD is a light "valve", either blocking light or allowing light to pass through. LCD video displays are "transmissive" meaning that an LCD is an active filter that works by varying the amount of light (from a fluorescent light source called the backlight) that is able to pass through to the viewing screen. An LCD display is really a large collection of thousands of these small filters called liquid crystal cells. Arranged together in rows and columns, these cells form an LC panel. Cells are combined into groups of three containing a uniquely addressable "red", "green" and "blue" cell. These cells or subpixels, working together, create one pixel or picture element.



A complete LCD display contains thousands of these tiny liquid crystal panels or cells. Its native resolution refers to the resolution that the LCD monitor is designed for (i.e. 800 x 600 or 1024 x 768) and is determined by the actual number of liquid crystal cells in the display. To produce color, every pixel location in an LCD display consists of three LC cells - one each for red, green, and blue. Each LC cell, or subpixel, can be individually addressed with a control voltage. This means, for example, that a 15" 1,024 x 768 video display contains 2,359,296 subpixels (1,024 x 768 x 3).

Fixed pixel displays can provide the best image only in their native resolution.

A CRT monitor can easily display a variety of input resolutions without any loss in image quality; it is capable of producing a white or color dot at virtually any location on the screen. Fixed pixel displays such as LCD displays (all display types except CRTs are fixed pixel displays) can provide the best image only in their native resolution. While you can input an image having a resolution other than the display native resolution, the display can only reproduce a white or colored dot at the fixed physical pixel locations. To view an image at some other resolution, it needs to be scaled up or down in order to fill the screen. Fixed pixel displays are sometimes called "addressable displays" because each pixel can be addressed directly.

An LC panel is composed of several layers of different materials. The light from the backlight source passes through a layer of polarized glass. The polarized light then passes through liquid crystal cells. Electrical voltage applied to the liquid crystal causes them to reorient themselves up to 90° to either pass or block light. This liquid crystal layer is followed by a layer of red, green, and blue filters and then by a second layer of polarized glass.

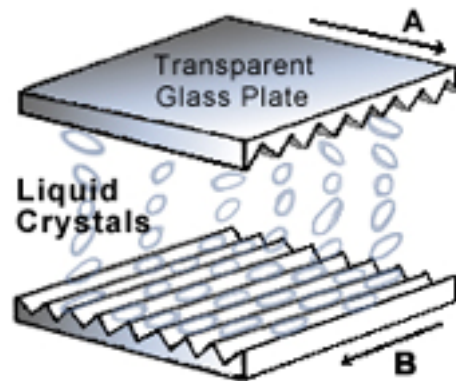
Basic principles to understand the operation of an LC panel:

1. alignment of liquid crystal molecules can be controlled by
 - a. fine grooves etched into a glass plate
 - b. electric current/voltage
2. light follows liquid crystal molecules polarizing filters block light

What is a Liquid Crystal?

Liquid crystals have the physical properties of both a solid and a liquid. As a liquid they are able to flow over and around small grooves and can change their position depending on applied voltage. However, liquid crystal also has the properties of a solid because light passing through it follows the alignment of the liquid crystal molecules.

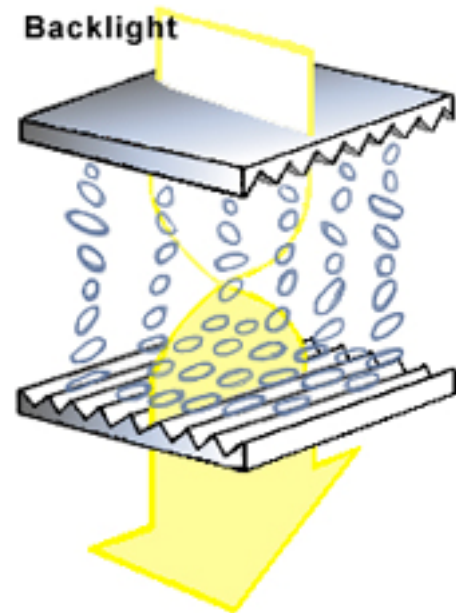
A liquid crystal panel with the liquid crystals aligning in a random tilt.



Aligning Liquid Crystal Molecules & Rotating Light

The molecules in a liquid crystal are basically a rectangular shape, and without any outside influence they align themselves in a random tilt with their long axes parallel. When they come into contact with a grooved surface, the liquid crystal molecules easily orient themselves to be parallel to the grooves. This makes it possible to precisely control the “at rest” alignment of the molecules. Since the alignment of the molecules exactly follows the grooves, if the fine grooves are exactly parallel, the alignment of the molecules is also exactly parallel.

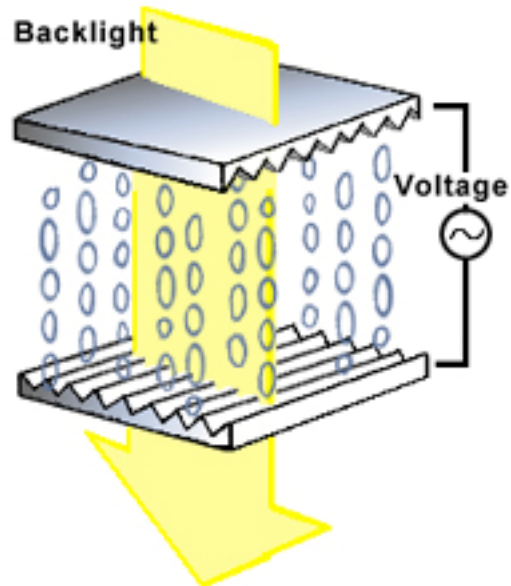
To make a basic “twisted” LC panel, liquid crystal is sandwiched between two transparent plates. Each plate contains very fine grooves, with the grooves in each panel placed exactly perpendicular. The liquid crystal molecules along the upper plate align in direction A, while those along the lower plate align in direction B. This is called a twisted structural arrangement. As light passes through liquid crystals, it follows the direction that the molecules are arranged. This means that as the light passes through the two panels, it twists 90° as it passes through the liquid crystals.



As light passes through liquid crystals, it follows the direction of the crystals.

An important key to the operation of an LCD panel is that liquid crystal molecules can be easily rearranged by applying an external voltage to them. As voltage is applied between the two grooved panels, the liquid crystal molecules begin to rearrange themselves with the electric field. In this illustration they align vertically or stand up out of the grooves. As the voltage increases, the molecules rotate, until they are standing completely upward. Remember that as light passes through liquid crystal, it follows the direction that the molecules are arranged. So, with full voltage applied the light passes through the panels following the arrangement of the molecules without being rotated 90°. At lower voltages the molecules are not all fully aligned, so some light is directed at different directions.

With full voltage applied, the light passes through the panels without being rotated 90°.



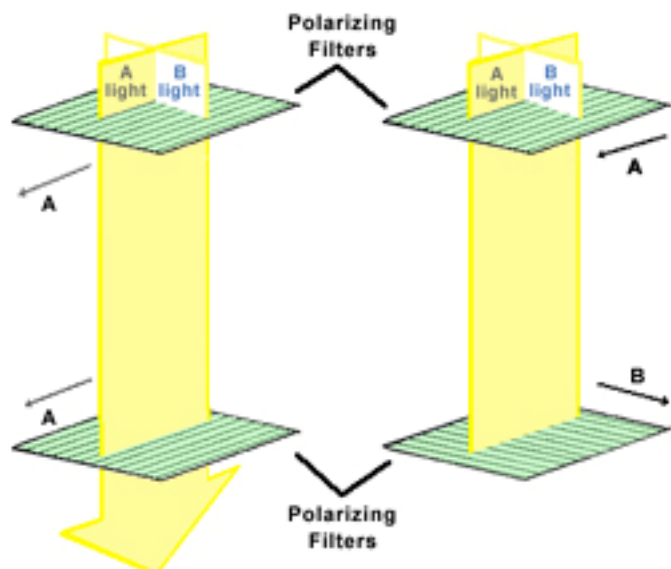
Blocking Light with Polarizing Filters

Natural light travels in waves that are oriented at random angles. This is why an object has the same color and brightness when viewed from different angles (unless it has a shadow or other lighting differences).

A polarizing filter is simply a set of extremely closely spaced parallel lines. These lines allow only the light waves that are parallel to them to pass through – light from all other directions is blocked. (This is how polarized sunglasses work.)

If you were to lay two polarizing filters on top of each other with the lines in one parallel to the lines in the other, direct light would pass through each, with little loss. However, as you begin to rotate one filter, more and more light is blocked because only the light waves that have the proper orientation to both filters can get through. When you have rotated the filter so that the lines in one are perpendicular to the lines in the other, all light will be blocked.

This figure illustrates how two polarizing filters can be used to block light. In both the left and right drawing, light is applied to the top of the filter pair. The incoming light has waves oriented at all directions, but for simplicity, only two orientations, “a” and “b” are shown. In the left diagram, the polarizing filters are oriented so that their “A” filter lines are parallel. Incoming light waves that have orientation “A” are able to pass through both the first and second filter, but light waves that are “B” orientation are blocked by both filters.



Polarizing filters allow light waves that are parallel to them to pass through.

In the right drawing the two polarizing filters are oriented so the filter lines in one

are perpendicular to the lines in the other. Again, light waves that are “A” orientation pass through the top filter, and “B” oriented waves are blocked. But in this case, when the “A” oriented waves reach the bottom polarizing filter, they are the wrong orientation compared to the filter lines, and they are unable to pass through. The result is: no light gets through the polarizing filters.

Controlling Light with an LCD Panel

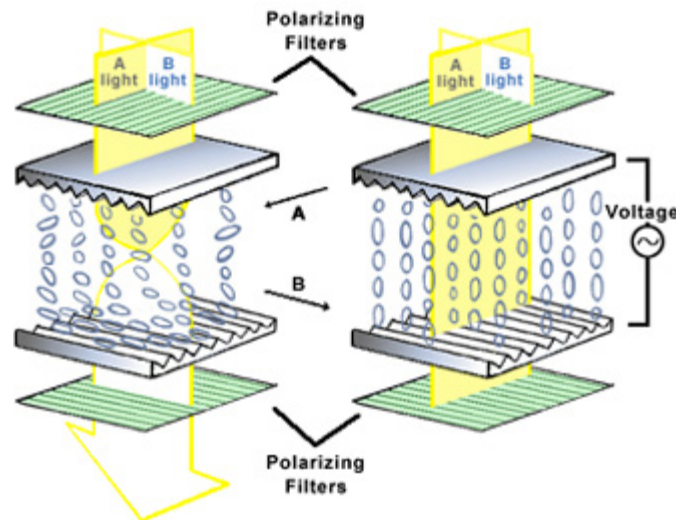
You cannot physically rotate polarizing filters to pass or block light in a video display, but we can use the properties of liquid crystal to rotate light. Let’s add some liquid crystal between the two polarizing filters, as illustrated in figure 5.

In both of these illustrations the polarizing filters are oriented perpendicular, which as we saw in the previous figure, prevents all incoming light from getting through. Also notice that a liquid crystal panel is inserted between the polarizing filters. This panel has a twisted structural arrangement (the molecules along the top plate are rotated 90° from those along the bottom plate).

Figure 5 left, illustrates how the liquid crystal allows light to pass through the polarizing filters. Light waves that have an “A” orientation pass through the 1st (top) filter. These light waves are then rotated 90° by the liquid crystal in the twisted structural arrangement. Notice that this re-orientates the light waves so that they are now properly aligned to pass through the 2nd (bottom) polarizing filter.

In Figure 5 right, a voltage is applied to the liquid crystal, causing the molecules to re-align themselves vertically. Again light waves that have an “A” orientation pass through the 1st filter, but this time they travel straight through the liquid crystal without being reoriented. Because they are perpendicular to the 2nd polarizing filter, they are blocked and no light makes it through the liquid crystal panel.

Note that varying the amount of voltage applied to the liquid crystal determines how much it twists. With a lesser voltage applied the molecules don’t fully rotate, and some light waves will be able to pass through the bottom polarizing filter. By changing the voltage in very small increments, LCDs can create a gray scale (or different intensities of R, G or B light). Most displays today offer 256 levels of brightness.



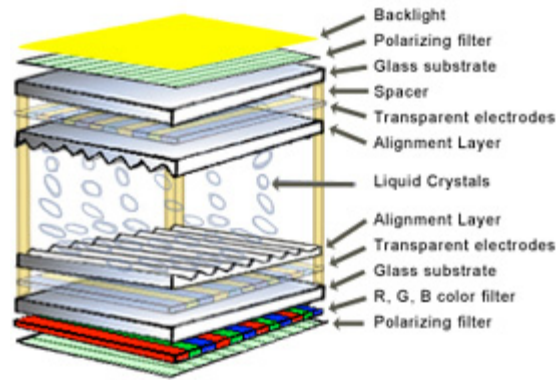
Voltage applied to the liquid crystal causes the molecules to realign vertically.

LC Cell Construction

The complete structure of a liquid crystal cell is illustrated in Figure 6. If you were to look at this structure, it resembles a sheet of glass in terms of transparency and thickness, but it is much more complex. This illustration shows the basic structure of a single liquid crystal cell.

1. Backlight: light source, usually several fluorescent tubes, and a diffuser.
2. Polarizing filter: two polarizing filters establish the orientation of the light waves that are able to pass through the LC cell.

3. Glass substrate: provides mechanical support for the cell.
4. Transparent electrodes: conduct the control voltage to the liquid crystal.
5. Alignment layer: contains the fine grooves that align the liquid crystal molecules in a fixed direction. In dual scan screens, the orientation varies between 90° and 270°.
6. Liquid crystal: molecules realign to applied voltage, light waves follow molecules.
7. Spacer: maintains uniform spacing between glass plates.
8. Color filter: determines what color of light is transmitted by the LC cell.

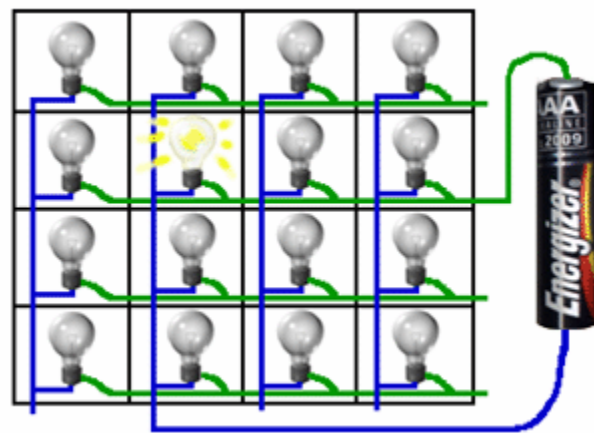


A liquid crystal cell resembles a sheet of glass, but is much more complex.

Addressing the Pixels

To produce an image on the display, each of the subpixels must be made to turn on and off at the correct time. In addition, to produce shades of gray and different colors, the voltage applied to each LC cell must be variable. Since it is physically impossible to have a unique wire going to each of the 2.3 million pixels, another method of addressing the pixels is needed - LCD pixels are controlled using a matrix.

To understand how an LCD matrix works, consider the small 4 x 4 checkerboard illustrated in figure 14.7, which has a light bulb in each square. The bulbs in each horizontal row are connected together to a common wire, giving us 4 separate rows of wire. At the end of each wire attach a terminal so that we can connect a battery. Likewise, connect the bulbs in each vertical column to a common wire, for a total of 4 column wires. Now connect a battery between one of the row wires and one of the



column wires – notice that only the bulb that corresponds to the intersection of the row and column wire is lit. By connecting to different combinations of row and column wires, we can individually turn on each light bulb.

Connecting a battery to different combinations of row and column wires turns on each light bulb individually.

The matrix addressing in an LCD works just like this, except on a much larger grid. In a color LCD display, the intersection of each grid wire corresponds to a single LC cell, or subpixel (remember a 1,024 x 768 display contains 2,359,296 subpixels). The intersecting grid of horizontal and vertical conductors are etched onto the glass plates or substrates of the LC cell – the row conductors are etched onto one plate and the column conductors are etched on the other plate. These conductors are made of a transparent material, such as indium-tin oxide. Large scale integrated circuits (LSICs) control the timing of the signal voltage that is applied to each individual LC cell, one cell at a time. Connections to the transparent conductors are made through bonding pads that are located at the ends of the rows and columns on the LCD assembly.

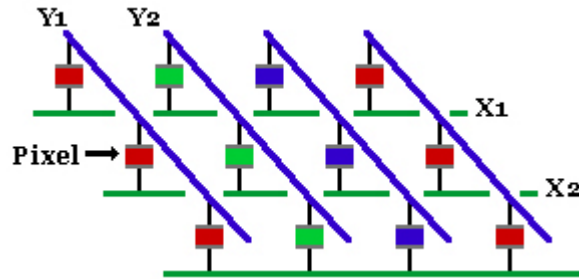
Two different ways to apply drive voltages to an LCD screen:

- *Passive matrix*
- *Active matrix*

Depending on the applied voltage, the LC cell can either pass or block all light, or partially pass light. There are two different ways of applying the drive voltages to an LCD screen using this matrixing process: passive matrix and active matrix. Simple displays, such as those used in calculators or clocks, only need to address pre-defined patterns. These displays use segment drive where each pattern segment is addressed directly.

Passive Matrix LCD (PMLCDs)

Passive matrix is the simplest way to address LCD pixels. The voltage on a conductor is applied directly to one plate of the LC cell, and the voltage on the other conductor is applied directly to the other plate of the LC cell. To maintain the on or off state, each cell must be addressed for more than one frame time. The effective voltage applied to the cell is an average of several signal voltage pulses, which results in a slow response (>150 msec), low brightness, and poor contrast ratio.

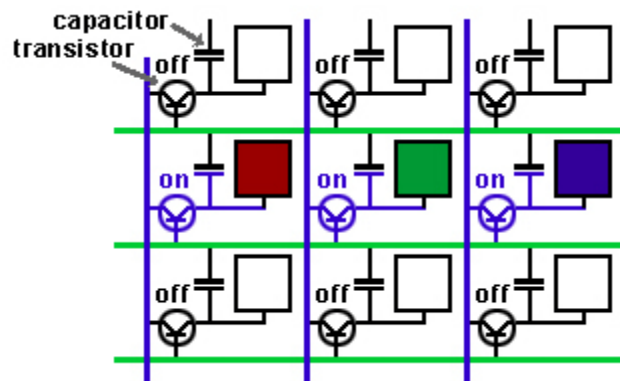


The voltage is applied directly to each plate of the LC cell in a passive matrix.

Passive matrix addressing also produces ghosting or blurred images because some of the drive voltage spills over onto non-selected pixels. Consequently, passive matrix addressing is used for still image applications (i.e. calculators and word processors), but not for video or computer LCD monitors. Twisted Nematic (TN) and Dual-Scan Twisted Nematic (DSTN) use passive matrix addressing.

Active Matrix LCD (AMLCDs)

Video and computer LCD monitors use active matrix drive. This method also uses an intersecting horizontal and vertical grid, but tiny transistors and capacitors are etched onto the glass substrate at the intersection of each row and column. It is these transistors and capacitors that actually control the charge on each liquid crystal cell.



Tiny transistors and capacitors control the charge on each liquid crystal cell in an active matrix.

This means that the switching occurs right at the cell, rather than at the end of a long conductor. The result is faster response times, and less crosstalk between cells.

Additionally, higher drive signals can be used which creates much brighter and higher contrast images. Because the transistors are fabricated directly on the cell's substrate using thin film, these displays are often called thin-film transistor LCDs.

Liquid crystal must be driven with an alternating current to prevent any deterioration of image quality resulting from dc stress. This is usually implemented with a frame-reversal drive method, where voltage that is applied to each pixel varies from frame to frame.

LCD Types

The basic twisted nematic LCD technology has several limitations that prevent its use in video and computer monitor displays – primarily limited viewing angle, poor contrast ratio and slow speed. Manufacturers are constantly working to improve the performance characteristics of LCDs by modifying the common LCD technologies. For example supertwisted & dual supertwisted nematic (DSTN) twists the light 180 to 270 degrees to improve contrast and viewing axis shortcomings. In-Plane Switching (IPS) uses polarizing filters in a perpendicular arrangement to widen the viewing angle and improve contrast ratio. Vertical Alignment (VA) structure improves viewing angles, contrast, and color reproduction while using less power compared to IPS. Multi-Domain Vertical Alignment is similar to VA with ridges added to the glass surface to provide more uniform brightness over the 160 degree viewing angle. Note that different manufacturers use different trade names, and may have slight variations in their designs.

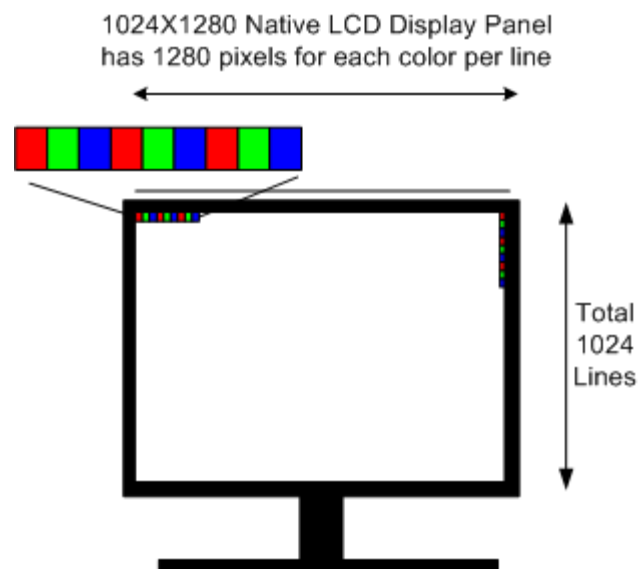
Producing Colors

A liquid crystal cell by itself has no color and cannot differentiate between colors. In order to reproduce color the light that passes through an LC cell must pass through a color filter. Each pixel in a color LCD is made up of three subpixels. Each subpixel is simply a liquid crystal cell that has a red, green, or blue filter in front of it. This filter blocks all wavelengths of light except those within the range of that subpixel. The color filters are integrated into the upper glass, and the area in between the filters is printed black to increase contrast.

The subpixels are so close together that our eyes only see a mixture of the three colors. When the three subpixels of a color “triad” are all on, our eyes see white. The subpixels can be controlled to pass more or less light of each color. This allows the LCD to reproduce different color saturation levels, different tints, or a gray scale. (Color and gray scale reproduction in an LCD is similar to the three electron guns in a CRT; except that the LCD subpixels work by blocking light, rather than by creating light.)

Most active matrix panels use digital signal controllers. Since an 8-bit controller can

produce 256 luminance steps, an LCD is capable of reproducing 256 shades of red x 256 shades of green x 256 shades of blue or 16,777,216 colors. While this sounds like a lot, it is considerably fewer colors and grayscale steps than CRT displays can reproduce.



Each pixel in a color LCD is made up of three subpixels. Each subpixel is simply a liquid crystal cell that has a red, green, or blue filter in front of it.

LCD Color Displays vs. CRT Displays

LCD Color displays are commonly compared to current CRT technology displays of similar size. CRT shortcomings are well known. They are larger, use more electricity and suffer from focus, color convergence, color variations across the screen, magnetic fields and produce electromagnetic radiation. Here are some of the issues and the pros and cons of the LCD color monitor compared to a CRT.

Advantages/Disadvantages LCDs Vs CRT

Misfocus and Color Convergence: CRT displays have focus voltages and the need to converge colors with permanent magnets and magnet positions. LCD displays require no focus or convergence.

Physical Size & Weight Differences: LCD displays hold a large advantage in size and weight. A CRT is heavy and requires depth to the display.

Geometry Adjustments: CRTs have many geometry adjustments to offset for CRT and magnetic deflection characteristics (trapezoid, pincushion, etc). LCD displays do not require geometry adjustments.

Display Resolutions: CRT displays show the incoming signal resolution across the screen. LCD displays scale the input signal resolution to fill the screen in the LCDs native resolution. Lower resolution is boosted to the displays native resolution.

Dead Pixels: LCD displays are likely to have bad pixels from imperfections in the manufacturing process. CRT displays do not have bad pixel.

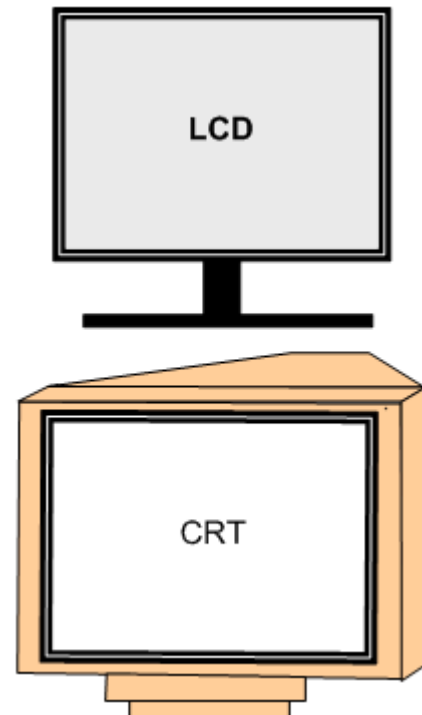
Viewable Area: LCD displays utilize the entire screen area while CRTs have some CRT edge area behind the mounted cabinet decreasing the viewable area.

Screen Image Brightness: LCD monitors easily offer more brightness than CRT displays offering better daytime or high light area viewing.

Brightness Uniformity: LCD monitors must disperse the backlight across the screen resulting in more or less light at the top and/or bottom compared to the center. CRT displays have more uniform light across the CRT screen.

Ghosting or Streaking:

Contrast Ratio: The difference between black and a white image on the display is contrast ratio. CRTs can achieve ratios of 700:1 while most LCDs are commonly in the range of 200:1 or 250:1. While some LCDs approach 450:1, CRTs still hold the advantage.



Power Consumption: LCD comes out ahead as LCD displays offering the same viewing size consume less power.

Viewing Angles: CRT monitors hold a large advantage as they can easily be viewed over 160 degrees. LCD monitor technologies have greatly improved viewing angles but are still limited.

Magnetic Interference: CRT displays use magnetic deflection for scanning the picture onto the screen. A magnetic field near the CRT causes severe picture wavering and a picture distortion. LCD displays are not affected by magnetic fields.

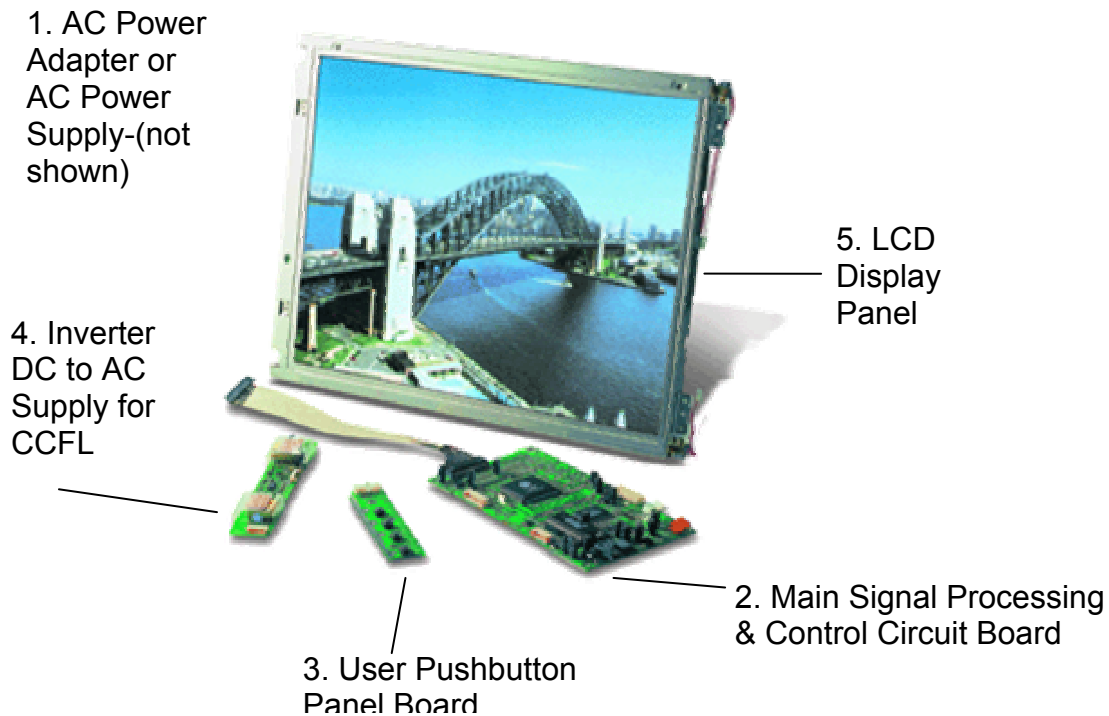
Response Time: Response time refers to the time the screen takes to update or change color pixels. Change is slow in LCD displays compared to CRTs as the best LCD monitors offer is now about 20 milli-seconds. A slow update leaves a trailing effect on moving video items on the screen.

Screen Flicker: LCD screens refresh the display every 25 milli-second and are not known for the flicker seen on CRT displays. In the past, CRT displays updated the screen at rates that produced noticeable flicker. Since refresh or vertical rates have been increased to 70 Hz or higher the flicker is not a problem.

Screen Burn-In: LCD monitors do not suffer screen burn-in that occurs in CRT displays when a nonmoving image is displayed for long periods of time.

Color Purity & Quality: CRTs are still believed to hold an advantage in color saturation and true color production. However, recent improvements in LCD provide bold brilliant colors that the average user is hard pressed to note the difference for basic computing use or image reproduction. CRTs must be properly aligned to maintain a good color purity across the screen where there is not adjustment for LCD.

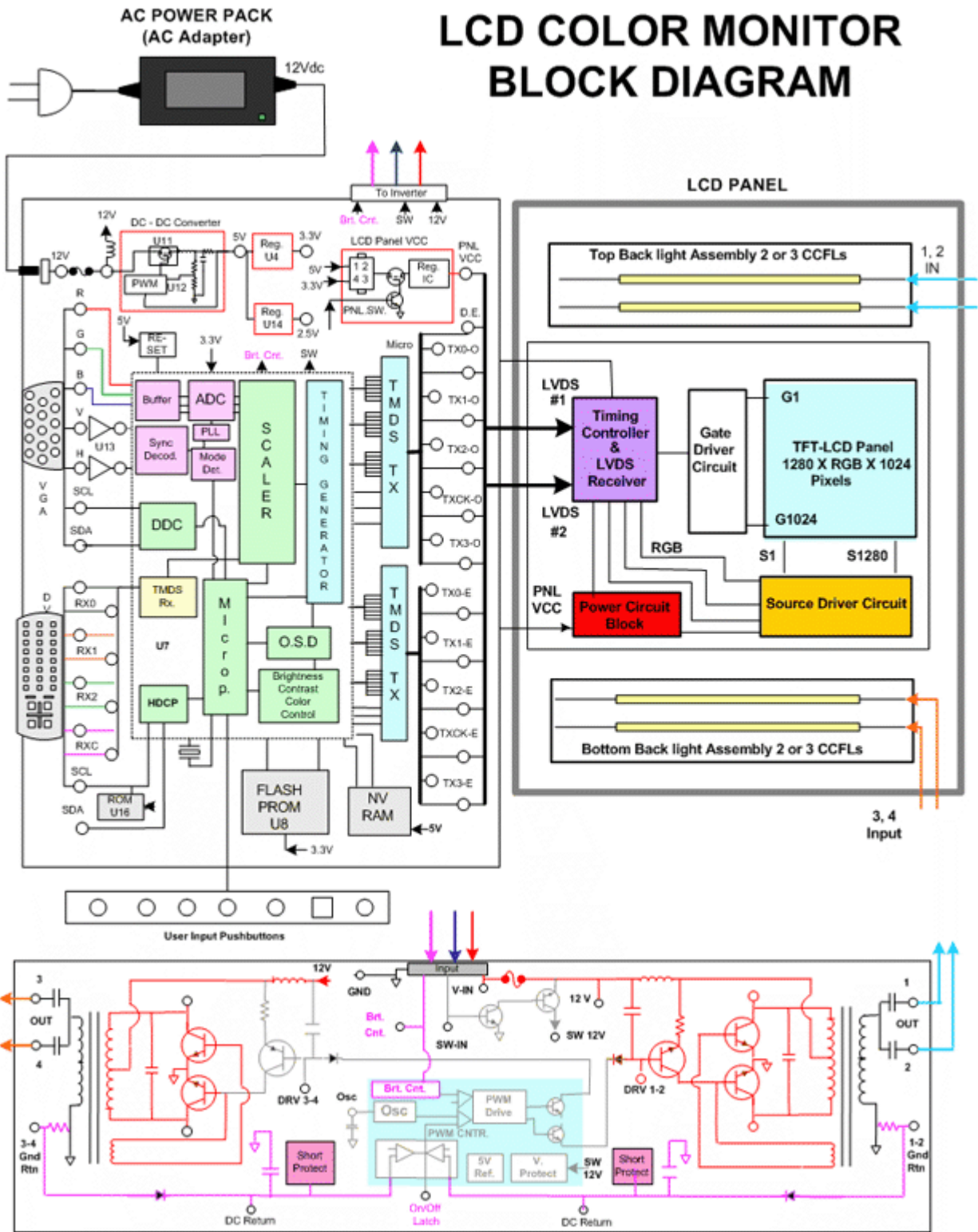
Typical LCD Monitor Circuit Boards



In a typical LCD Color Monitor you will find 5 circuit boards and/or modules.

1. **AC to DC power supply or Power Adapter:** The AC to DC supply may be a circuit board mounted within the LCD display (Not shown) or a conventional power adapter that is self contained such as the one used with the Sencore LCD Color Monitor Trainer.
2. **Main Signal Processing & Control Circuit Board:** Contains the low voltage power supplies to power all of the LCD monitors circuits including the main signal processor board, LCD panel and backlight inverter power supply. Contains signal inputs typically a standard VGA input plug and an optional DVI input. Contains signal processing needed to scale the input signal resolutions to the native resolution for display by the LCD panel. Derives the LVDS output used to interface digital signals to the LCD panel. Generates user control menus and accepts inputs from user key board.
3. **User Pushbutton Board:** Links to the main signal processing and control board via cable assembly. It provides user pushbutton entry or adjustment to the on-screen menus.
4. **Backlight Inverter Power Supply Board:** Supplies high voltage AC sine-waves to CCFL bulbs contained in the LCD panel.
5. **LCD Display Panel:** Contains the individual pixel elements and red, green, blue sub-pixels in a grid (Example 1280 x 1024) to produce a picture. Contains electronic circuits needed to derive voltage needed to apply to the rows and columns of pixels from the LVDS input to produce the display pictures. Contains CCFL lights to produce light needed to illuminate the pixels.

LCD COLOR MONITOR BLOCK DIAGRAM



Backlight Inverter Power Supply

LCD Color Monitor Block Diagram

AC Power Adapter or “Power Pack”: Takes 120VAC input voltage from electric outlet and converts to a DC voltage (12V) output to power the LCD color monitor.

Main Signal Processing Circuit Board: Contains the low voltage power supplies to power all of the LCD monitors circuits including the main signal processor board, LCD panel and backlight inverter power supply. Contains signal inputs and processing circuits to derive the LVDS output used to interface to the LCD panel. Generates user control menus and accepts inputs from user key board.

User Input Pushbutton Panel: Contains the pushbuttons that permit a user to change picture adjustments etc.

Backlight Inverter Power Supply: Produces multiple high voltage, high frequency AC sine-wave outputs from a low voltage DC input to power all the backlight bulbs.

LCD Display Panel: Produces the picture image by sequentially and repeatedly lighting each pixel element to its proper proportion of red, green and blue light. Accepts an LVDS digital signal representing pixel information and converts to signals to drive the individual pixels in the display panel.

CCFL: (Cold Cathode Florescent Lamp) Light bulbs – long skinny florescent tubes that line the top and bottom rear of the LCD display panel. Provide the light that illuminates the face or screen of the LCD panel to illuminate red, green and blue pixels.

Suggested Activity: LCD Color Monitor Input/Output Signal Familiarization