LCDs: Liquid Crystal Displays

How (and why) they work

A document for curious TV watchers

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Audience and Scope:
This technical document is intended for any layman TV watcher or computer user who has ever wondered how an LCD displays images. This document is not meant to be used as a guide for engineering or designing LCDs. It does not cover specific components or the electronic design of any specific LCD. Process information for an auxiliary function (i.e., powering an LCD) is beyond the scope of this document. The reader is assumed to have watched a movie or images using an LCD (hint: many computer and television monitors in use today are LCDs).
Introduction:
An LCD, Liquid Crystal Display, is an electronic and optical device that uses liquid crystals to illuminate millions of individual pixels to show an electronically stored image. Light, provided by LEDs, is polarized by filters, then twisted or left untwisted by liquid crystals, and then given color by adjusting intensity of adjacent blue, red, and green color filters. This process constitutes one pixel (one tiny portion of an image). Each pixel is activated by transistors in a scheme and at a speed such that the stored image is displayed.
It Starts with Light:
LEDs, Light Emitting Diodes, along one or two edges at the back of the display provide the light that is eventually seen in the form of an image on the front of an LCD (much like in Figure 1).

Figure 1. Source:

This light is spread out evenly using a light guide plate (Figure 2).
Diffuser and prism films help eliminate the appearance of the dots on the light guide plate and brighten the light, respectively, to create an evenly lit surface, as shown below (Figure 3).

![Figure 3](image)

Once the light is evenly spread out it can enter the back of each pixel unit, as shown below (Figure 4).

![Figure 4](image)
A Pixel:

We discussed how light is evenly spread out in the back of an entire LCD monitor. Now we will focus on what light does as it enters one pixel. There are millions of pixels that make up an entire LCD screen. Each pixel functions to display part of the larger image that is to be displayed on the screen.

![Close-up of an LCD display panel](image)

![Diagram of a pixel](image)

The picture above, on the left (Figure 5), shows a zoomed-in image of the front of an LCD. The diagram on the right (Figure 6) shows a three-dimensional view of one pixel. The area, parallel to the front of the monitor, is about 90,000 squared microns. A typical 42-inch LCD TV has an area of 472,257,120,000 squared microns. That means over 5.2 million pixels compose such a monitor's screen.
**Polarized Light:**
The light that enters the back of a pixel is unpolarized, meaning it has more than one directional component to it. This light is polarized using a polarizing filter. As we will see shortly, polarized light is the key to the functioning of a pixel.

![Figure 7](image)
The light entering the filter from the left is unpolarized. Once it passes through the filter only the component of the unpolarized light that is parallel to the polarization direction of the filter remains, and, thus, is called polarized light.
**Liquid Crystals:**
The polarized light then passes through liquid crystals. LCDs use twisted nematic liquid crystals. Liquid crystals are a type of physical state (like liquid or solid) that exhibit properties of both liquids and solid crystals. Twisted nematic liquid crystals remain in a helix (twisted) type orientation unless an electric field is present. These crystals allow light to propagate along its orientation (straight or twisted). They will twist light if they are twisted. Or, if an electric field is applied, the liquid crystals will straighten and light will not be twisted and instead simply be passed along as it entered. Twisting of light is important here: this will change the polarization direction of the light by 90 degrees. Now when the light enters the second polarization filter, set at 90 degrees to the first polarization filter, it will be able to pass through. Applying an electric field across the liquid crystals shows up as a black spot on the screen. Whereas, with no electric field, light passes through, unchanged, and can represent one speck of color of a larger image.

![Figure 8.](image)

**Figure 8.**
Left: no electric field allows the polarized light to be twisted 90 degrees and thus pass through the second polarizing filter
Right: an electric field is applied. This straightens the orientation of the liquid crystals. The polarized light is left unchanged and thus it does not pass through the second polarizing filter because it is 90 degrees from the first polarizing filter.
Colored Light:
Once the light passes through the second polarizing filter it hits three adjacent color filters: blue, green, and red (each color representing one of three subpixels in one pixel). Here the light exiting a color filter simply takes on the color of the filter it passes through. These three colors and the respective intensity of light passing through them (controlled by how much the liquid crystals are twisted, between 0 and 90 degrees) blend to create any color, because they are so tiny compared to the human eye.

Figure 9.
The color and intensity of light exiting each pixel is determined by the image that we want to display. Thin Film Transistors, TFTs, are electronic switches that allow each subpixel to be updated with the image’s information (this information dictates the intensity of the electric field across the liquid crystals). There is one Thin Film Transistor per subpixel, and, so, a TFT sheet is superimposed onto the sheet housing the liquid crystals. Because of design constraints (i.e., limited power supply, and size of product) only one row of pixels is on at any given moment. Thus only one row of TFTs is addressed at any given time. But, the switching among the rows is done so fast that to the human eye the large image looks like one fluid image.
Conclusion:
The above is the basic process by which an LCD monitor operates. LCDs first came into play in the 1960s and have since become the dominant technology used in TVs, computer monitors, tablets, and cell phones. LCDs are rapidly advancing: transistors are getting smaller, the material used to build polarizing and color filters are lighter and more flexible. But, the basic process remains the same: the electrically adjustable orientation of liquid crystals dictates the intensity of colored light to produce an image.
Works Cited:

https://www.youtube.com/watch?v=k7xGQKpQAWw

https://www.youtube.com/watch?v=jiejNAUwcQ8


"HowStuffWorks "Nematic Phase Liquid Crystals"

Figure 1.

Figure 2. (cropped)
http://www.forhs.com/upload/media/product/product_3-1.jpg

Figure 3. (cropped/arrows removed)

Figure 4.

Figure 5. (arrows removed)
http://www.hk-phy.org/energy/commercial/office_phy/images/display_unit.jpg
Figure 6
http://www.olympusmicro.com/primer/images/polarization/polfilters.jpg

Figure 7
http://www.displaywars.com/32-inch-16x9-vs-42-inch-16x9

Figure 8

Figure 9

Figure 10
http://homework.uoregon.edu/pub/class/155/tft2.gif