



Understanding Liquid Crystal Displays

An Online Continuing Education Course for Engineers

Course Number: E-2067

Credit: 2 Hours / 2 PDH / 2 CPD

Understanding Liquid Crystal Displays

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Introduction

We all interact with electronic displays daily. Displays allow us to further experience the advancements and capabilities of the modern world. The performance and technology contained in displays (and how they are manufactured) have advanced significantly over the past 30 years. We have gone from barely readable, power-hungry, bulky monochrome displays to beautifully colorful, high-resolution, compact, lower power displays. Displays are fun to learn about because they combine several engineering disciplines: electrical, chemical, optical, mechanical, and software, all brought together with applied physics and advanced manufacturing.

This course begins with definitions of several technical concepts common to most displays. Then a brief history of the most impactful and well-known display types is presented, along with high-level theories of operation. This helps bring context and appreciation for the more advanced displays covered later in this course.

Next, the course goes deep into the technology and physics behind the Liquid Crystal Display (LCD). These displays are incorporated into nearly every interactive electronic device on the market today and are especially prominent in TVs, laptops, tablets, cell phones, and appliances.

This course discusses the optical, mechanical, and electrical properties that make liquid crystal fluid unique, and how advances in clear conductors printed on glass enabled the success of the technology. Details about the numerous display architectures and electronic circuits that drive these complex displays will be covered as well. This course reviews the math behind the driving of displays that interestingly parallels wireless communications theory. We will discuss how displays are powered and interfaced with via microcontrollers, and how advanced manufacturing techniques allow incorporating circuitry right onto the glass.

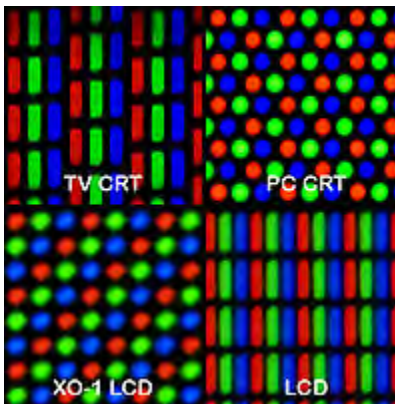
When this course is completed, an engineer of any discipline will be familiar with the “magic” that happens when a display is used in a design and viewed by a person.

Concepts & Definitions

There are several underlying concepts and definitions that are common to nearly all display technologies.

Pixel

Pixel is short for “Picture Element” and represents the smallest individual element in a display screen. Pixels are usually arranged in a matrix and are small enough that the human eye cannot resolve them at a distance. Instead, the eye sees the array of pixels as a blended image. Pixels are created in a variety of shapes and sizes. Below is a close-up of various display screens showing their pixels:



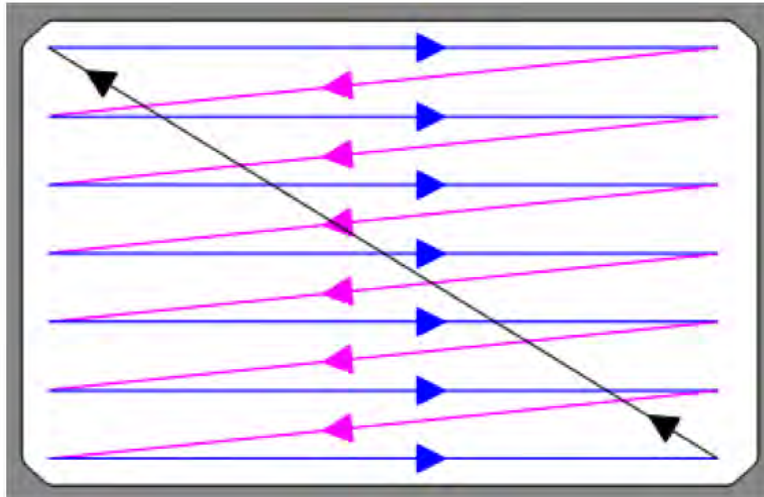
When viewed from a little further away, one can see how individual pixels come together to form an image:



Pixels are commonly used in groups of three – Red, Blue, and Green. These colors can be “mixed” together in different amounts to create a wide range of colors. When viewed from a distance, the eye mixes the individual colors to perceive a unique color.

Rastering

Rastering is the technique of illuminating pixels in a sequence. Below is an example raster pattern going from upper-left to lower-right.



Rastering happens fast enough that the eye smooths out the flickering, and the image appears as a static picture. Rastering is a natural approach to driving a display, as incoming video images are transmitted in a time-based stream. Whether the video is analog broadcast, or digitally stored in the memory of a digital device, a display receives the video stream sequentially and uses rastering to present the image.

Resolution

The resolution of a display represents the number of individual pixels in each the X and Y dimensions. Often each pixel (in a color display) is composed of 3 sub-pixels - red, green, and blue. Screen size also plays a big role in image quality. As one might expect, the denser the pixels, the “better” a display will look to the viewer (at the same distance). This is known as “dots per inch.” Viewing distance is another factor in perceived image quality. The smaller the screen’s diagonal size, the more densely packed its pixels will be, and the closer one would need to sit in order to discern a visible difference between lower and higher resolutions.

Brightness

Brightness refers to the intensity of a pixel’s light output. It is usually measured in nits or lumens, and obviously, the higher the measured number, the brighter the pixel appears to the human eye. When the brightness is specified for a display, it usually refers to the maximum output possible.

Contrast

Contrast is represented by the ratio of the brightness of a full-on pixel to the brightness of a full-off pixel. Low contrast makes an image seem washed out, and high contrast makes an image seem artificial. An exception to this is with e-Ink displays intended to present text like a book. In this case, a high contrast display presents a beautifully crisp image, just like if you were reading the printed page.

Refresh Rate

The refresh rate represents the rate by which an entire display screen is rastered. This rate is usually specified in hertz and must be fast enough to avoid flicker perceived by the viewer.

Frame Rate

The frame rate is not the same as the refresh rate. The refresh rate includes the repeated drawing of identical frames, while frame rate measures how often a video source can feed an entire frame of new data to a display.

Response Time

The time it takes for a pixel to switch from one intended state to another. This is usually measured going from completely “on” to completely “off.” A typical LCD response time is about 10ms. Fast response times are required in order to view motion video.

Viewing Angle

The angle at which a display can be viewed with acceptable visual performance. This tends to be a subjective specification, and the definition of measurement is usually defined by the manufacturer.

History of Displays

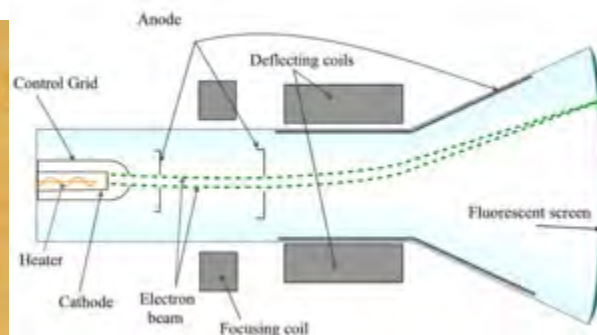
Cathode Ray Tube

The Cathode Ray Tube (CRT) is one of the earliest display types, introduced in the late 1800s / early 1900s. This display technology impressively survived the test of time, as the primary form of TV and computer monitors for over 70 years.

The CRT screen contains an array of pixels to present an image. A vacuum tube containing electron guns generate electron beams that are directed to hit the back of the screen. Electronic circuits create the electron beams and steer them using magnetic and/or electrostatic fields. The screen contains a phosphorescent layer that glows when excited by the electron beam. The control electronics create a rastering pattern on the screen to display the image. The intensity of the electron beams is also controlled, which varies the intensity of the pixels (required to render an image).



A small CRT



The inner workings of a CRT



A 14" CRT



A 1950s TV using a CRT

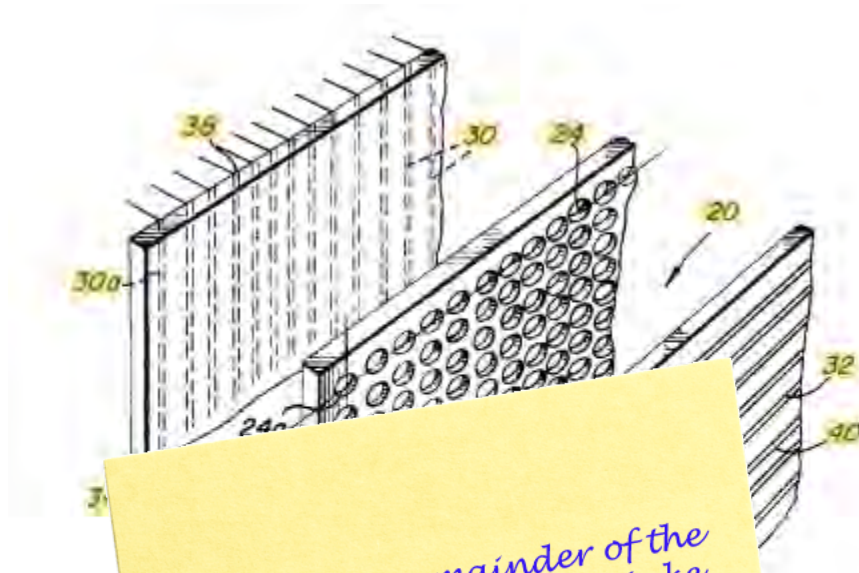
Early CRTs were black and white, only capable of representing the luminance of a picture. Later, color CRTs emerged that used colored phosphorescent coatings on the pixels to form the red, green, and blue pixels. Note that CRTs do suffer from a “burn-in” effect where a static image (displayed without any motion for a period of time) remains seen afterward. This happens because the phosphorescent coating

in each pixel slowly wears out over time, becoming less sensitive to the electron beam. This gives the appearance of a “burned in” image as you see darker areas where the static image used to be.

CRTs remained popular for so long because they were relatively compact, could be manufactured for a reasonable cost, and had ample resolution, power, brightness, and refresh rates.

Plasma Display

Plasma displays were first created in the 1960s to compete with CRTs. These displays use small cells containing neon or xenon gas to create the pixels. Each cell is coated with a phosphorescent material. Similar to a fluorescent bulb, when electricity flows into the cell, gas atoms are ionized and form plasma. Ultraviolet light is created during this process and gets turned into visible light when it hits the phosphorescent coating. As depicted below, the intensity of each pixel is controlled by an array of horizontal and vertical electrodes.



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The original plasma display

Plasma display

Similar to CRTs, plasma displays were limited to a rastering pattern.

Plasma displays were limited to a rastering pattern.

Plasma TVs avoided popularity because they consumed too much power, were very heavy, and were too expensive to manufacture commercially. Technological