A liquid crystal display (LCD) is a flat panel display, electronic visual display, video display that uses the light modulating properties of liquid crystals (LCs). LCs do not emit light directly.

They are used in a wide range of applications, including computer monitors, television, instrument panels, aircraft cockpit displays, signage, etc. They are common in consumer devices such as video players, gaming devices, clocks, watches, calculators, and telephones. LCDs have displaced cathode ray tube (CRT) displays in most applications. They are usually more compact, lightweight, portable, less expensive, more reliable, and easier on the eyes. They are available in a wider range of screen sizes than CRT and plasma displays, and since they do not use phosphors, they cannot suffer image burn-in.

LCDs are more energy efficient and offer safer disposal than CRTs. Its low electrical power consumption enables it to be used in battery-powered electronic equipment. It is an electronically modulated optical device made up of any number of segments filled with liquid crystals and arrayed in front of a light source (backlight) or reflector to produce images in color or monochrome. The most flexible ones use an array of small pixels. The earliest discovery leading to the development of LCD technology, the discovery of liquid crystals, dates from 1888. By 2008, worldwide sales of televisions with LCD screens had surpassed the sale of CRT units.

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[edit] Overview

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Each pixel of an LCD typically consists of a layer of molecules aligned between two transparent electrodes, and two polarizing filters, the axes of transmission of which are (in most of the cases) perpendicular to each other. With no actual liquid crystal between the polarizing filters, light passing through the first filter would be blocked by the second (crossed) polarizer. In most of the cases the liquid crystal has double refraction.

The surface of the electrodes that are in contact with the liquid crystal material are treated so as to align the liquid crystal molecules in a particular direction. This treatment typically consists of a thin polymer layer that is unidirectionally rubbed using, for example, a cloth. The direction of the liquid crystal alignment is then defined by the direction of rubbing. Electrodes are made of a transparent conductor called Indium Tin Oxide (ITO).

Before applying an electric field, the orientation of the liquid crystal molecules is determined by the alignment at the surfaces of electrodes. In a twisted nematic device (still the most common liquid crystal device), the surface alignment directions at the two electrodes are perpendicular to each other, and so the molecules arrange themselves in a helical structure, or twist. This reduces the rotation of the polarization of the incident light, and the device appears grey. If the applied voltage is large enough, the liquid crystal molecules in the center of the layer are almost completely untwisted and the polarization of the incident light is not rotated as it passes through the liquid crystal layer. This light will then be mainly polarized perpendicular to the second filter, and thus be blocked and the pixel will appear black. By controlling the voltage applied across the liquid crystal layer in each pixel, light can be allowed to pass through in varying amounts thus constituting different levels of gray. This electric field also controls (reduces) the double refraction properties of the liquid crystal.
LCD with top polarizer removed from device and placed on top, such that the top and bottom polarizers are parallel.

The optical effect of a twisted nematic device in the voltage-on state is far less dependent on variations in the device thickness than that in the voltage-off state. Because of this, these devices are usually operated between crossed polarizers such that they appear bright with no voltage (the eye is much more sensitive to variations in the dark state than the bright state). These devices can also be operated between parallel polarizers, in which case the bright and dark states are reversed. The voltage-off dark state in this configuration appears blotchy, however, because of small variations of thickness across the device.

Both the liquid crystal material and the alignment layer material contain ionic compounds. If an electric field of one particular polarity is applied for a long period of time, this ionic material is attracted to the surfaces and degrades the device performance. This is avoided either by applying an alternating current or by reversing the polarity of the electric field as the device is addressed (the response of the liquid crystal layer is identical, regardless of the polarity of the applied field).

Displays for a small number of individual digits and/or fixed symbols (as in digital watches, pocket calculators etc.) can be implemented with independent electrodes for each segment. In contrast full alphanumeric and/or variable graphics displays are usually implemented with pixels arranged as a matrix consisting of electrically connected rows on one side of the LC layer and columns on the other side which makes it possible to address each pixel at the intersections. The general method of matrix addressing consists of sequentially addressing one side of the matrix, for example by selecting the rows one-by-one and applying the picture information on the other side at the columns row-by-row. For details on the various matrix addressing schemes see Passive-matrix and active-matrix addressed LCDs.

[edit] Brief history

- 1888: Friedrich Reinitzer (1858–1927) discovers the liquid crystalline nature of cholesterol extracted from carrots (that is, two melting points and generation of colors) and published his findings at a meeting of the Vienna Chemical Society on May 3, 1888 (F. Reinitzer: *Beiträge zur Kenntniss des Cholesterins, Monatshefte für Chemie (Wien) 9, 421-441 (1888)).[2]
1904: Otto Lehmann publishes his work "Flüssige Kristalle" (Liquid Crystals).

1911: Charles Mauguin first experiments of liquids crystals confined between plates in thin layers.

1922: Georges Friedel describes the structure and properties of liquid crystals and classified them in 3 types (nematics, smectics and cholesterics).

1927: Vsevolod Frederiks devises the electrically switched light valve, called the Fréedericksz transition, the essential effect of all LCD technology.

1936: The Marconi Wireless Telegraph company patents the first practical application of the technology, "The Liquid Crystal Light Valve".

1962: The first major English language publication on the subject "Molecular Structure and Properties of Liquid Crystals", by Dr. George W. Gray.

1962: Richard Williams of RCA found that liquid crystals had some interesting electro-optic characteristics and he realized an electro-optical effect by generating stripe-patterns in a thin layer of liquid crystal material by the application of a voltage. This effect is based on an electro-hydrodynamic instability forming what is now called “Williams domains” inside the liquid crystal.

1964: George H. Heilmeier, then working in the RCA laboratories on the effect discovered by Williams achieved the switching of colors by field-induced realignment of dichroic dyes in a homeotropically oriented liquid crystal. Practical problems with this new electro-optical effect made Heilmeier continue to work on scattering effects in liquid crystals and finally the achievement of the first operational liquid crystal display based on what he called the dynamic scattering mode (DSM). Application of a voltage to a DSM display switches the initially clear transparent liquid crystal layer into a milky turbid state. DSM displays could be operated in transmissive and in reflective mode but they required a considerable current to flow for their operation. George H. Heilmeier was inducted in the National Inventors Hall of Fame and credited with the invention of LCD. Heilmeier's work is an IEEE Milestone.

1960s: Pioneering work on liquid crystals was undertaken in the late 1960s by the UK's Royal Radar Establishment at Malvern, England. The team at RRE supported ongoing work by George Gray and his team at the University of Hull who ultimately discovered the cyanobiphenyl liquid crystals (which had correct stability and temperature properties for application in LCDs).

1970: On December 4, 1970, the twisted nematic field effect in liquid crystals was filed for patent by Hoffmann-LaRoche in Switzerland, (Swiss patent No. 532 261) with Wolfgang Helfrich and Martin Schadt (then working for the Central Research Laboratories) listed as inventors. Hoffmann-La Roche then licensed the invention
to the Swiss manufacturer Brown, Boveri & Cie who produced displays for wrist watches during the 1970s and also to Japanese electronics industry which soon produced the first digital quartz wrist watches with TN-LCDs and numerous other products. James Fergason while working with Sardari Arora and Alfred Saupe at Kent State University Liquid Crystal Institute filed an identical patent in the USA on April 22, 1971. In 1971 the company of Fergason ILIXCO (now LXD Incorporated) produced the first LCDs based on the TN-effect, which soon superseded the poor-quality DSM types due to improvements of lower operating voltages and lower power consumption.

- 1972: The first active-matrix liquid crystal display panel was produced in the United States by Westinghouse, in Pittsburgh, PA.[11]

- 1983: Researchers at Brown, Boveri & Cie (BBC), Switzerland, invent the super-twisted nematic (STN) structure for passive-matrix addressed LCDs. H. Amstutz et al. were listed as inventors in the corresponding patent applications filed in Switzerland on July 7, 1983, and October 28, 1983. Patents were granted in Switzerland CH 665491, Europe EP 0131216, US 4634229 and many more countries. Scientific details are published in the referenced article.[13]

- 1990: Under different titles inventors conceived electrooptical effects as alternatives to twisted nematic field effect LCDs (TN- and STN- LCDs). One approach was to use interdigital electrodes on one glass substrate only to produce an electric field essentially parallel to the glass substrates (Abstract).[14]. To take full advantage of the properties of this In-Plane Switching (IPS) technology further work was needed. After thorough analysis, details of advantageous embodiments are filed in Germany by Guenter Baur et al and patented in various countries (Abstract).[15]. The Fraunhofer Institute in Freiburg, where the inventors worked, assigns these patents to Merck KGaA, Darmstadt, the world's leading supplier of LC substances.

- 1992: Shortly thereafter, engineers at Hitachi work out various practical details of the IPS technology to interconnect the thin-film transistor array as a matrix and to avoid undesirable stray fields in between pixels (Abstract).[16]. Hitachi also improves the viewing angle dependence further by optimizing the shape of the electrodes (Super IPS).

- NEC and Hitachi become early manufacturers of active-matrix addressed LCDs based on the IPS technology. This is a milestone for implementing large-screen LCDs having acceptable visual performance for flat-panel PC monitors and TVs.

- 1996 Samsung develops the optical patterning technique that enables multi-domain LCD. Multi-domain and In Plane Switching subsequently remain the dominant LCD designs through 2010.[17]
• 2007: In the 4Q of 2007 for the first time LCD televisions surpass CRT units in worldwide sales.\[18\]

• 2008: **LCD TVs** become the majority with a 50% market share of the 200 million TVs forecast to ship globally in 2008 according to [Display Bank].\[19\]

A detailed description of the origins and the complex history of liquid crystal displays from the perspective of an insider during the early days has been published by Joseph A. Castellano in *Liquid Gold: The Story of Liquid Crystal Displays and the Creation of an Industry*.\[20\] Another report on the origins and history of LCD from a different perspective until 1991 has been published by Hiroshi Kawamoto, available at the [IEEE History Center].\[21\]

**[edit] Illumination**

As LCD panels produce no light of their own, they require an external lighting mechanism to be easily visible. On most displays, this consists of a cold cathode **fluorescent lamp** that is situated behind the LCD panel. Passive-matrix displays are usually not backlit, but active-matrix displays almost always are, with a few exceptions such as the display in the original [Gameboy Advance].

Recently, two types of **LED backlit displays** have appeared in some televisions as an alternative to conventional backlit LCDs. In one scheme, the LEDs are used to backlight the entire LCD panel. In another scheme, a set of red, green and blue LEDs is used to illuminate a small cluster of pixels, which can improve contrast and black level in some situations. For example, the LEDs in one section of the screen can be dimmed to produce a dark section of the image while the LEDs in another section are kept bright. Both schemes also allows for a slimmer panel than on conventional displays.

**[edit] Passive-matrix and active-matrix addressed LCDs**

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A general purpose alphanumeric LCD, with two lines of 16 characters.

Monochrome passive-matrix LCDs were standard in most early laptops (although a few used plasma displays) and the original Nintendo Game Boy until the mid-1990s, when color active-matrix became standard on all laptops. The commercially unsuccessful Macintosh Portable (released in 1989) was one of the first to use an active-matrix display (though still monochrome).

Passive-matrix LCDs are still used today for applications less demanding than laptops and TVs. In particular, portable devices with less information content to be displayed, where lowest power consumption (no backlight), low cost and/or readability in direct sunlight are needed, use this type of display.

Displays having a passive-matrix structure are employing super-twisted nematic STN or double-layer STN (DSTN) technology (the latter of which addresses a color-shifting problem with the former), and color-STN (CSTN) in which color is added by using an internal filter.

STN LCDs have been optimized for passive-matrix addressing. They exhibit a sharper threshold of the contrast-vs-voltage characteristic than the original TN LCDs. This is important because pixels are subjected to partial voltages even while not selected. Crosstalk between activated and non-activated pixels has to be handled properly by keeping the RMS voltage of non-activated pixels below the threshold voltage, while activated pixels are subjected to voltages above threshold. STN LCDs have to be continuously refreshed by alternating pulsed voltages of one polarity during one frame and pulses of opposite polarity during the next frame. Individual pixels are addressed by the corresponding row and column circuits. This type of display is called passive-matrix addressed because the pixel must retain its state between refreshes without the benefit of a steady electrical charge. As the number of pixels (and, correspondingly, columns and rows) increases, this type of display becomes less feasible. Slow response times and poor contrast are typical of passive-matrix addressed LCDs with too many pixels.

New zero-power (bistable) LCDs do not require continuous refreshing. Rewriting is only required for picture information changes. Potentially, passive-matrix addressing can be used with these new devices, if their write/erase characteristics are suitable.

High-resolution color displays such as modern LCD computer monitors and televisions use an active matrix structure. A matrix of thin-film transistors (TFTs) is added to the electrodes in contact with the LC layer. Each pixel has its own dedicated transistor, allowing each column line to access one pixel. When a row line is selected, all of the column lines are connected to a row of pixels and voltages corresponding to the picture information are driven onto all of the column lines. The row line is then deactivated and the next row line is selected. All of the row lines are selected in sequence during a refresh operation. Active-matrix addressed displays look "brighter" and "sharper" than passive-matrix addressed displays of the same size, and generally have quicker response times, producing much better images.
[edit] Active matrix technologies

![TFT LCD](image)

A Casio 1.8 in color TFT LCD which equips the Sony Cyber-shot DSC-P93A digital compact cameras.

Main articles: Thin film transistor liquid crystal display and Active-matrix liquid crystal display

[edit] Twisted nematic (TN)

See also: twisted nematic field effect

Twisted nematic displays contain liquid crystals which twist and untwist at varying degrees to allow light to pass through. When no voltage is applied to a TN liquid crystal cell, polarized light passes through the 90-degrees twisted LC layer. In proportion to the voltage applied, the liquid crystals untwist changing the polarization and blocking the light's path. By properly adjusting the level of the voltage almost any grey level or transmission can be achieved.

[edit] In-plane switching (IPS)

In-plane switching is an LCD technology which aligns the liquid crystals in a plane parallel to the glass substrates. In this method, the electrical field is applied through opposite electrodes on the same glass substrate, so that the liquid crystals can be reoriented (switched) in the same plane. This requires two transistors for each pixel instead of the single transistor needed for a standard thin-film transistor (TFT) display. Before LG Enhanced IPS was introduced in 2009, the additional transistors resulted in blocking more transmission area, thus requiring a brighter backlight, which consumed more power, and made this type of display less desirable for notebook computers. This newer, lower power technology can be found in the Apple iMac, iPad, and iPhone 4, the Hewlett-Packard EliteBook mobile workstations and the Nokia 701. Currently Panasonic is using an enhanced version eIPS for their large size LCD-TV products as well as Hewlett-Packard in its WebOS based TouchPad tablet.

IPS LCD vs Amoled
LG claimed the smartphone LG Optimus Black with an IPS LCD (LCD NOVA) has the brightness up to 700 nits, while the competitor has only IPS LCD with 518 nits and tumble an Amoled display with 305 nits. LG also claimed about the NOVA display which 50 percent more efficient than regular LCD and consumes only 50 percent of Amoled consumes when producing white on screen. But, when it comes to contrast ratio, Amoled display still performs best due to its underlying technology where the black levels are displayed as pitch black and not as dark grey. On the 24th of August 2011, Nokia announced the Nokia 701 and also made the claim of the world's brightest display at 1000 nits. The screen also had Nokia's Clearblack layer which improved the contrast ratio, bringing it closer to that of the AMOLED screens.

**Advanced fringe field switching (AFFS)**

Known as fringe field switching (FFS) until 2003, advanced fringe field switching is similar to IPS or S-IPS offering superior performance and color gamut with high luminosity. AFFS was developed by Hydis Technologies Co., Ltd, Korea (formally Hyundai Electronics, LCD Task Force).

AFFS-applied notebook applications minimize color distortion while maintaining a wider viewing angle for a professional display. Color shift and deviation caused by light leakage is corrected by optimizing the white gamut which also enhances white/grey reproduction.

In 2004, Hydis Technologies Co.,Ltd licensed AFFS to Japan's Hitachi Displays. Hitachi is using AFFS to manufacture high-end panels. In 2006, HYDIS licensed AFFS to Sanyo Epson Imaging Devices Corporation.

Hydis introduced AFFS+ with improved outdoor readability in 2007. AFFS panels are mostly utilized in the cockpits of latest commercial aircraft displays.

**Vertical alignment (VA)**

Vertical alignment displays are a form of LCDs in which the liquid crystals naturally align vertically to the glass substrates. When no voltage is applied, the liquid crystals remain perpendicular to the substrate creating a black display between crossed polarizers. When voltage is applied, the liquid crystals shift to a tilted position allowing light to pass through and create a gray-scale display depending on the amount of tilt generated by the electric field.

**Blue Phase mode**

Main article: [Blue Phase Mode LCD](#)

Blue phase mode LCDs have been shown as engineering samples early in 2008, but they are not in mass-production yet. The physics of blue phase mode LCDs suggest that very short switching times (~1 ms) can be achieved, so time sequential color control can
possibly be realized and expensive color filters would be obsolete. For details refer to Blue Phase Mode LCD.

[edit] Quality control

Some LCD panels have defective transistors, causing permanently lit or unlit pixels which are commonly referred to as stuck pixels or dead pixels respectively. Unlike integrated circuits (ICs), LCD panels with a few defective transistors are usually still usable. It is claimed that it is economically prohibitive to discard a panel with just a few defective pixels because LCD panels are much larger than ICs, but this has never been proven. Manufacturers' policies for the acceptable number of defective pixels vary greatly. At one point, Samsung held a zero-tolerance policy for LCD monitors sold in Korea. As of 2005, though, Samsung adheres to the less restrictive ISO 13406-2 standard. Other companies have been known to tolerate as many as 11 dead pixels in their policies. Dead pixel policies are often hotly debated between manufacturers and customers. To regulate the acceptability of defects and to protect the end user, ISO released the ISO 13406-2 standard. However, not every LCD manufacturer conforms to the ISO standard and the ISO standard is quite often interpreted in different ways.

LCD panels are more likely to have defects than most ICs due to their larger size. For example, a 300 mm SVGA LCD has 8 defects and a 150 mm wafer has only 3 defects. However, 134 of the 137 dies on the wafer will be acceptable, whereas rejection of the LCD panel would be a 0% yield. In recent years, quality control has been improved. An SVGA LCD panel with 4 defective pixels is usually considered defective and customers can request an exchange for a new one. Some manufacturers, notably in South Korea where some of the largest LCD panel manufacturers, such as LG, are located, now have "zero defective pixel guarantee", which is an extra screening process which can then determine "A" and "B" grade panels. Many manufacturers would replace a product even with one defective pixel. Even where such guarantees do not exist, the location of defective pixels is important. A display with only a few defective pixels may be unacceptable if the defective pixels are near each other.

LCD panels also have defects known as clouding (or less commonly mura), which describes the uneven patches of changes in luminance. It is most visible in dark or black areas of displayed scenes.

[edit] Zero-power (bistable) displays

See also: Ferro Liquid Display

The zenithal bistable device (ZBD), developed by QinetiQ (formerly DERA), can retain an image without power. The crystals may exist in one of two stable orientations ("Black" and "White") and power is only required to change the image. ZBD Displays is a spin-off company from QinetiQ who manufacture both grayscale and color ZBD devices.
Kent Displays has also developed a "no power" display that uses Polymer Stabilized Cholesteric liquid crystal (ChLCD). A major drawback of ChLCD screens are their slow refresh rate, especially at low temperatures\cite{citation needed}. Kent has recently demonstrated the use of a ChLCD to cover the entire surface of a mobile phone, allowing it to change colors, and keep that color even when power is cut off.\cite{citation}

In 2004 researchers at the University of Oxford demonstrated two new types of zero-power bistable LCDs based on Zenithal bistable techniques.\cite{citation}

Several bistable technologies, like the 360° BTN and the bistable cholesteric, depend mainly on the bulk properties of the liquid crystal (LC) and use standard strong anchoring, with alignment films and LC mixtures similar to the traditional monostable materials. Other bistable technologies (i.e. Binem Technology) are based mainly on the surface properties and need specific weak anchoring materials.

**[edit] Specifications**

Important factors to consider when evaluating a Liquid Crystal Display (LCD):

- **Resolution versus Range**: Fundamentally resolution is the granularity (or number of levels) with which a performance feature of the display is divided. Resolution is often confused with range or the total end-to-end output of the display. Each of the major features of a display has both a resolution and a range that are tied to each other but very different. Frequently the range is an inherent limitation of the display while the resolution is a function of the electronics that make the display work.

- **Spatial Performance** LCDs come in only one size for a variety of applications and a variety of resolutions within each of those applications. LCD spatial performance is also sometimes described in terms of a “dot pitch”. The size (or spatial range) of an LCD is always described in terms of the diagonal distance from one corner to its opposite. This is a historical aspect from the early days of CRT TV when CRT screens were manufactured on the bottoms of a glass bottle. The diameter of the bottle determined the size of the screen. Later, when TVs went to a more square format, the square screens were measured diagonally to compare with the older round screens.\cite{citation}

The spatial resolution of an LCD is expressed in terms of the number of columns and rows of pixels (e.g., 1024×768). This had been one of the few features of LCD performance that was easily understood and not subject to interpretation. Each pixel is usually composed of a red, green, and blue sub pixel. However there are newer schemes to share sub-pixels among pixels and to add additional colors of sub-pixels. So going forward, spatial resolution may be more subject to interpretation.

One external factor to consider in evaluating display resolution is the resolution of your own eyes. For a normal person with 20/20 vision, the resolution of your eyes is about one minute of arc. In practical terms that means for an older standard definition TV set the ideal...
viewing distance was about 8 times the height (not diagonal) of the screen away. At that
distance the individual rows of pixels merge into a solid. If you were closer to the screen
than that, you would be able to see the individual rows of pixels. If you are further away,
the image of the rows of pixels still merge, but the total image becomes smaller as you get
further away. For an HDTV set with slightly more than twice the number of rows of pixels,
the ideal viewing distance is about half what it is for a standard definition set. The higher
the resolution, the closer you can sit to the set or the larger the set can usefully be sitting at
the same distance as an older standard definition display.

For a computer monitor or some other LCD that is being viewed from a very close
distance, resolution is often expressed in terms of dot pitch or pixels per inch. This is
consistent with the printing industry (another form of a display). Magazines, and other
premium printed media are often at 300 dots per inch. As with the distance discussion
above, this provides a very solid looking and detailed image. LCDs, particularly on mobile
devices, are frequently much less than this as the higher the dot pitch, the more optically
inefficient the display and the more power it burns. Running the LCD is frequently half, or
more, of the power consumed by a mobile device.

An additional consideration in spatial performance are viewing cone and aspect ratio. The
Aspect ratio is the ratio of the width to the height (for example, 4:3, 5:4, 16:9 or 16:10).
Older, standard definition TVs were 4:3. Newer, HDTV’s are 16:9 as are most new
notebook computers. Movies are often filmed in much different (wider) aspect ratios which
is why there will frequently still be black bars at the top and bottom of a HDTV screen.

The Viewing Angle of an LCD may be important depending on its use or location. The
viewing angle is usually measured as the angle where the contrast of the LCD falls below
10:1. At this point, the colors usually start to change and can even invert, red becoming
green and so forth. Viewing angles for LCDs used to be very restrictive however, improved
optical films have been developed that give almost 180 degree viewing angles from left to
right. Top to bottom viewing angles may still be restrictive, by design, as looking at an
LCD from an extreme up or down angle is not a common usage model and these photons
are wasted. Manufacturers commonly focus the light in a left to right plane to obtain a
brighter image here.

- **Temporal/Timing Performance**: Contrary to spatial performance, temporal
  performance is a feature where smaller is better. Specifically, the range is the pixel
  response time of an LCD, or how quickly you can change a sub-pixel’s brightness
  from one level to another. For LCD monitors, this is measured in btbb (black to
  black) or gtg (gray to gray). These different types of measurements make
  comparison difficult. Further, this number is almost never published in sales
  advertising.

Refresh rate or the temporal resolution of an LCD is the number of times per second in
which the display draws the data it is being given. Since activated LCD pixels do not flash
on/off between frames, LCD monitors exhibit no refresh-induced flicker, no matter how
low the refresh rate. High-end LCD televisions now feature up to 240 Hz refresh rate,
which requires advanced digital processing to insert additional interpolated frames between the real images to smooth the image motion. However, such high refresh rates may not be actually supported by pixel response times and the result can be visual artifacts that distort the image in unpleasant ways.

Temporal performance can be further taxed if it is a 3D display. 3D displays work by showing a different series of images to each eye, alternating from eye to eye. For a 3D display it must display twice as many images in the same period of time as a conventional display and consequently the response time of the LCD becomes more important. 3D LCDs with marginal response times, will exhibit image smearing.

The temporal resolution of human perception is about 1/100th of a second [citation needed]. It is actually greater in your black and white vision (rod cells) than in color vision (cone cells). You are more able to see flicker or any sort of temporal distortion in a display image by not looking directly at it as your rods are mostly grouped at the periphery of your vision.

- **Color Performance** There are many terms to describe color performance of an LCD. They include color gamut which is the range of colors that can be displayed and color depth which is the color resolution or the resolution or fineness with which the color range is divided. Although color gamut can be expressed as three pairs of numbers, the XY coordinates within color space of the reddest red, greenest green, and bluest blue, it is usually expressed as a ratio of the total area within color space that a display can show relative to some standard such as saying that a display was “120% of NTSC”. NTSC is the National Television Standards Committee, the old standard definition TV specification. Color gamut is a relatively straight forward feature. However with clever optical techniques that are based on the way humans see color, termed color stretch [38] colors can be shown that are outside of the nominal range of the display. In any case, color range is rarely discussed as a feature of the display as LCDs are designed to match the color ranges of the content that they are intended to show. Having a color range that exceeds the content is a useless feature.

**Color Depth** or color support is sometimes expressed in bits, either as the number of bits per sub-pixel or the number of bits per pixel. This can be ambiguous as an 8-bit color LCD can be 8 total bits spread between red, green, and blue or 8 bits each for each color in a different display. Further, LCDs sometimes use a technique called dithering which is time averaging colors to get intermediate colors such as alternating between two different colors to get a color in between. This doubles the number of colors that can be displayed; however this is done at the expense of the temporal performance of the display. Dithering is commonly used on computer displays where the images are mostly static and the temporal performance is unimportant.

When color depth is reported as color support, it is usually stated in terms of number of colors the LCD can show. The number of colors is the translation from the base 2-bit numbers into common base-10. For example, an 8-bit, in common terms means 2 to the 8th power or 256 colors. 8-bits per color or 24-bits would be 256 x 256 x 256 or over 16
Million colors. The color resolution of the human eye depends on both the range of colors being sliced and the number of slices; but for most common displays the limit is about 28-bit color. LCD TVs commonly display more than that as the digital processing can introduce color distortions and the additional levels of color are needed to ensure true colors.

There are additional aspects to LCD color and color management such as white point and gamma correction which basically describe what color white is and how the other colors are displayed relative to white. LCD televisions also frequently have facial recognition software which recognizes that an image on the screen is a face and both adjust the color and the focus differently from the rest of the image. These adjustments can have important impact to the consumer but are not easily quantifiable; people like what they like and everyone does not like the same thing. There is no substitute for looking at the LCD you are going to buy before buying it. Portrait film, another form of display, has similar adjustments built in to it. Many years ago, Kodak had to overcome initial rejection of its portrait film in Japan because of these adjustments. In the US, people generally prefer a more color facial image than is reality (higher color saturation). In Japan, consumers generally prefer a less saturated image. The film that Kodak initially sent to Japan was biased in exactly the wrong direction for Japanese consumers. TV sets have their built in biases as well.

- **Brightness** and **Contrast ratio**: Contrast ratio is the ratio of the brightness of a full-on pixel to a full-off pixel and, as such, would be directly tied to brightness if not for the invention of the blinking backlight (or burst dimming). The LCD itself is only a light valve, it does not generate light; the light comes from a backlight that is either a florescent tube or a set of LEDs. The blinking backlight was developed to improve the motion performance of LCDs by turning the backlight off while the liquid crystals were in transition from one image to another. However, a side benefit of the blinking backlight was infinite contrast. The contrast reported on most LCDs is what the LCD is qualified at, not its actual performance. In any case, there are two large caveats to contrast ratio as a measure of LCD performance.

The first caveat is that contrast ratios are measured in a completely dark room. In actual use, the room is never completely dark as you will always have the light from the LCD itself. Beyond that, there may be sunlight coming in through a window or other room lights that reflect off of the surface of the LCD and degrade the contrast. As a practical matter, the contrast of an LCD, or any display, is governed by the amount of surface reflections not by the performance of the display.

The second caveat is that the human eye can only image a contrast ratio of a maximum of about 200:1. Black print on a white paper is about 15-20:1. That is why viewing angles are specified to the point where the fall below 10:1. A 10:1 image is not great, but is discernable.

**Brightness** is usually stated as the maximum output of the LCD. In the CRT era, Trinitron CRTs had a brightness advantage over the competition so brightness was commonly
discussed in TV advertising. With current LCD technology, brightness, though important, is usually the same from maker to maker and is consequently not discussed much except for notebook LCDs and other displays that will be viewed in bright sunlight. In general, brighter is better but there is always a trade-off between brightness and battery life in a mobile device.

[edit] Military use of LCD monitors

LCD monitors have been adopted by the United States of America military instead of CRT displays because they are smaller, lighter and more efficient, although monochrome plasma displays are also used, notably for their M1 Abrams tanks. For use with night vision imaging systems a US military LCD monitor must be compliant with MIL-STD-3009 (formerly MIL-L-85762A). These LCD monitors go through extensive certification so that they pass the standards for the military. These include MIL-STD-901D - High Shock (Sea Vessels), MIL-STD-167B - Vibration (Sea Vessels), MIL-STD-810F – Field Environmental Conditions (Ground Vehicles and Systems), MIL-STD-461E/F – EMI/RFI (Electromagnetic Interference/Radio Frequency Interference), MIL-STD-740B – Airborne/Structureborne Noise, and TEMPEST - Telecommunications Electronics Material Protected from Emanating Spurious Transmissions.

[edit] Advantages and disadvantages of LCD

[edit] LCD

Further information: Comparison CRT, LCD, Plasma

Pros:

- Very compact and light.
- Low power consumption.
- No geometric distortion.
- Little or no flicker depending on backlight technology.
- Not affected by screen burn-in.
- No high voltage or other hazards present during repair/service.
- Can be made in almost any size or shape.
- No theoretical resolution limit.

Cons:

- Limited viewing angle, causing color, saturation, contrast and brightness to vary, even within the intended viewing angle, by variations in posture.
- Bleeding and uneven backlighting in some monitors, causing brightness distortion, especially toward the edges.
- Smearing and ghosting artifacts caused by slow response times (>8 ms) and "sample and hold" operation.
• Only one native resolution. Displaying resolutions either requires a video scaler, lowering perceptual quality, or display at 1:1 pixel mapping, in which images will be physically too large or won't fill the whole screen.
• Fixed bit depth, many cheaper LCDs are only able to display 262,000 colors. 8-bit S-IPS panels can display 16 million colors and have significantly better black level, but are expensive and have slower response time.
• Input lag
• Dead or stuck pixels may occur either during manufacturing or through use.
• In a constant on situation, thermalization may occur, which is when only part of the screen has overheated and therefore looks discolored compared to the rest of the screen.
• Not all LCDs are designed to allow easy replacement of the backlight.
• Cannot be used with light guns/pens.