

LCD (Liquid Crystal Display), Definition, Types, LCD vs LED

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LCD (Liquid Crystal Display) is the dominant display technology used in most electronic devices today. LCDs consist of **liquid crystals sandwiched** between **polarising filters** and **glass substrates**. Applying electric current alters the crystal alignment to modulate light transmission. LCD pixels are organised in a matrix to form images and text.

LCD technology has evolved tremendously with innovations like LED backlighting, in-plane switching, and OLED displays. With their portability, image quality, and wide applicability, LCDs have become ubiquitous as the display of choice for the digital world.

Evolution of LCD

The phenomenon of liquid crystals was first observed in the late 19th century by Austrian Botanist **Friedrich Reinitzer**. However, practical LCDs took many decades of research and development to realise commercially.



• Early Research into Liquid Crystals:

- **1904:** German physicist **Otto Lehmann** coined the term '**liquid crystals**'.
- **1920s:** Liquid crystals were found to alter polarised light based on temperature and applied voltage.
- **Development of Electro-Optic LCDs:**
- **1927:** **Vsevolod Frederiks** demonstrated electrically controlled light transmission effects in liquid crystals.
- **1962:** RCA Corporation demonstrated the first dynamic scattering LCD.
- **1964:** **George H. Heilmeyer** invented the twisted nematic field LCD.
- **1968:** First commercial LCDs became available but with very low resolution and unreliable operation.

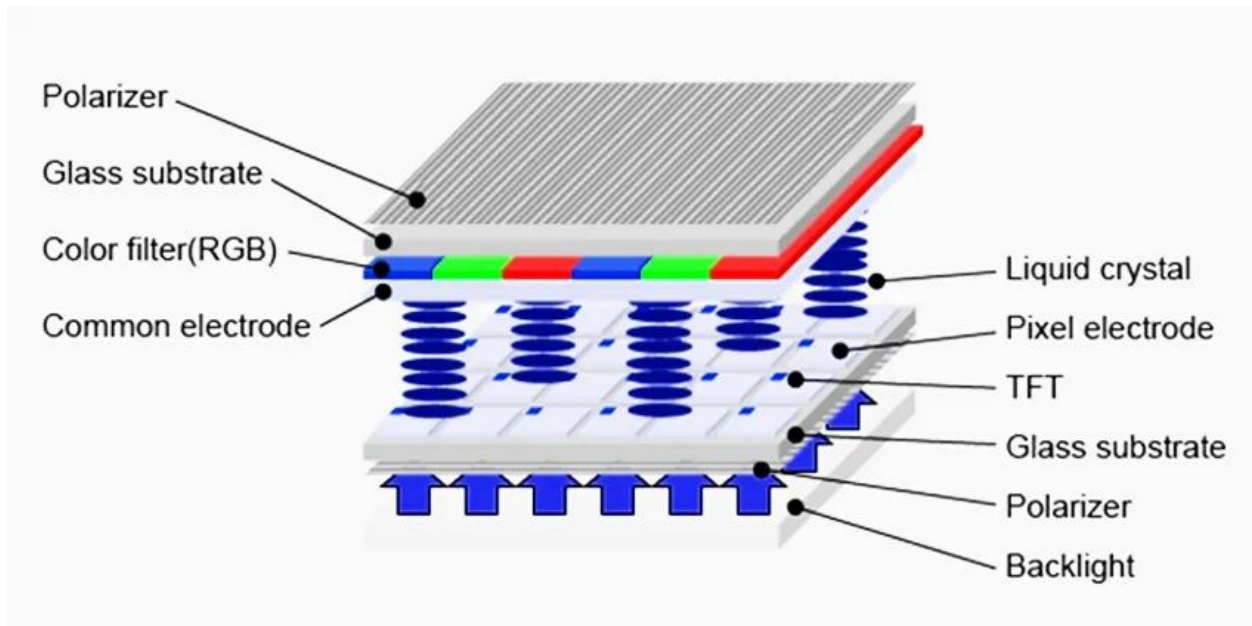
• Commercialisation in Consumer Electronics:

- **1980s:** **Thin film transistor (TFT)** active-matrix addressing allowed higher-resolution colour displays.
- **1990s:** Widespread adoption of laptops, televisions and portable devices.
- **Recent:** Use of quantum dots, curved displays, etc.

The Working of LCD

LCDs operate by rotating the polarised light via the **matrix of liquid crystal pixels** based on the voltage applied across them.

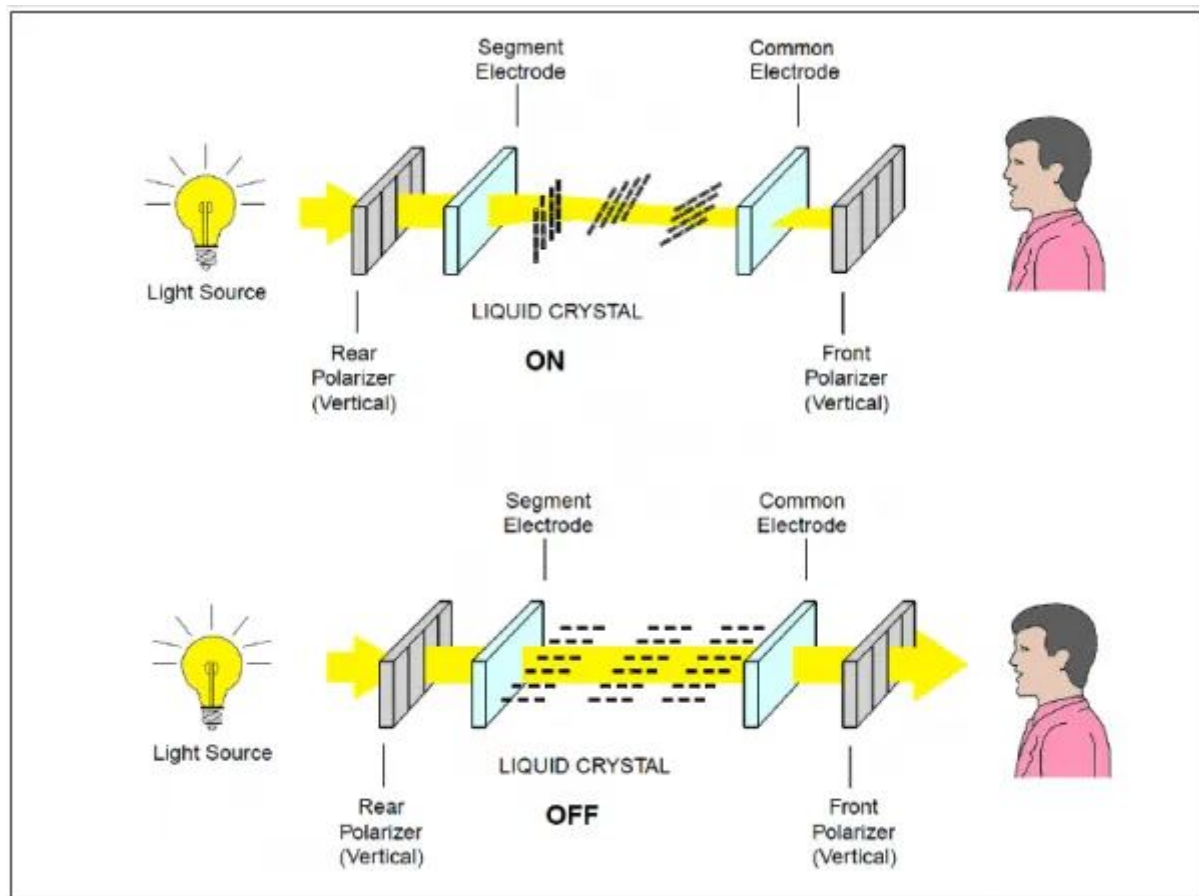
Components and Operating Principle



- **Components:**

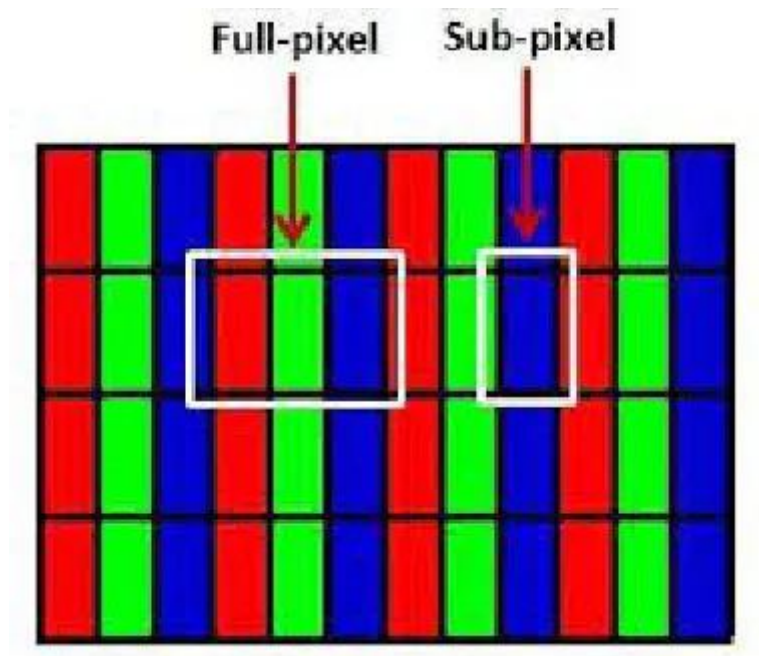
- **Backlight:** Thin fluorescent lamps and LEDs are used as the illumination sources at the back.
- **Polarisers:** Special filters at 90° angles to polarise the backlight.
- **Colour filters:** Red, Green and Blue filters for sub-pixels.
- **Liquid crystals:** Rotates light based on the applied voltage. Generally, aromatic compounds like biphenyls and terphenyls are used.
- **Transistors:** Forms grid to control pixel voltages.

- **Working:**



- In the **OFF state**, the liquid crystal molecules are arranged in a **twisted helical structure** within the cell.
- This causes the polarised light to be **rotated by 90°** as it passes through the **liquid crystal layer**, allowing it to pass through the **second perpendicular polariser**.
- In the **ON state**, when voltage is applied, the electric field causes the **rod-shaped molecules** to untwist and align along the field direction.
- Now the liquid crystal layer does not rotate the light's polarisation. The perpendicular polarisers block light transmission, making the pixel appear darker.
- By controlling the voltage, the molecular untwisting can be varied, thereby modulating the **luminance from the backlight** for each pixel to create images.
- Adding **Red, Green and Blue** colour filters creates **sub-pixels** with controllable intensities. By combining the coloured sub-pixels produces a full-colour display.

Pixels and Sub-Pixels



- **Pixels:** The LCD screen comprises thousands to millions of tiny dots called **pixels**, arranged in a **grid or matrix**. Pixels are the smallest controllable element in a display.
 - The **number of pixels** determines the resolution - more pixels allow for sharper image rendering and finer details.
 - Ultra-high definition 4K and 8K displays have resolutions of **3840x2160** and **7680x4320** pixels respectively.
- **Sub-Pixels:** Each pixel consists of **three sub-pixels - red, green and blue**.
 - By varying the intensity of these sub-pixels, pixels can produce a wide gamut of colours.
 - Displays use algorithms called **subpixel rendering** to enhance apparent resolution and antialiasing by taking advantage of the geometry of RGB stripes.
- **Function:** Millions of pixels working together create complex images and videos on a display.

Passive vs. Active Matrix Addressing

To independently control each pixel in a matrix LCD, the display needs matrix addressing. There are two such approaches.

- **Passive Matrix:** It has **parallel row and column electrodes** with pixels at intersections. To address a pixel, corresponding row-column lines are activated, which is a simple but slow response. These were used in early LCDs.
- **Active Matrix:** It has transistors and capacitors built-in at each pixel, which allows constant voltage control for faster response.
 - Nearly all modern LCDs use **thin film transistor (TFT)** active-matrix technology.

Types of LCD

Many LCD variants have emerged over the years, optimising key parameters like viewing angles, response time, contrast and colour gamut.

- **Twisted Nematic (TN):** It is the most common and inexpensive LCD type.
 - It has fast response times but poor viewing angles and colour reproduction.
 - It is used in low-end devices.
- **In-Plane Switching (IPS):** It provides improved viewing angles up to 178° via an in-plane electric field.
 - It has a slower pixel response.
 - It is used in mid-range devices.
- **Vertical Alignment (VA):** VA panels fall somewhere in between **IPS and TN** panels.
 - They are more accurate than IPS panels but have better colour reproduction than TN panels.
- **Advanced Fringe Field Switching (AFFS):** These displays are optimised for **video speed** and **gaming monitors**.
 - They enable superb viewing angles and response time.
- **Blue Phase LCD:** These displays have a very fast response time without crosstalk, which is enabled by **3D blue phase liquid crystals**.
 - They are being developed as the next-gen displays.
- **Quantum Dot LCD:** These LCDs use **quantum dot colour filters** for a wide gamut.
 - They are high-dynamic-range televisions.

Applications of LCD

LCD screens have become popular across a multitude of devices and sectors. Following are the applications of the LCDs.

- **Consumer Electronics:** Mobile phones, tablets, laptops, desktop monitors and televisions. Also, digital cameras, handheld gaming devices, and e-readers.
- **Automotive Displays:** Center consoles, infotainment systems, instrument clusters, heads-up displays, and rearview cameras.
- **Industrial:** Test equipment, **medical monitors like ECG**, industrial human-machine interfaces (HMIs) and rugged displays.
- **Digital Signage:** Advertising displays, billboards, retail information screens, product promotions.
- **Military:** Highly rugged LCDs used in avionics, naval systems, tactical equipment, and armoured vehicles. Replacing legacy CRTs.
- **Wearables:** Smartwatches, health/fitness trackers and head-mounted AR/VR systems.
- **Smart Homes:** Interactive touchscreens, smart mirrors and appliance interfaces.

Advantages of LCD

Some of the major benefits offered by LCD technology include:

- **Energy efficiency:** LCDs consume much less power compared to legacy CRT and plasma displays. It enables slimmer, cooler and more portable designs.
- **High resolution:** LCDs can achieve 4K and even 8K Ultra HD resolutions by shrinking pixel sizes. They are difficult in self-emissive displays.

- **Thinner form factors:** LCD panel thickness is typically 4-10 mm whereas CRTs are bulky. They are essential for slim devices.
- **Lightweight:** Lighter than CRTs and plasmas allowing easy portability and wall mounting.
- **Reliability:** Long operating life of over 60,000 hours in modern LCDs while maintaining image quality.
- **Low manufacturing cost:** Mature fabrication techniques like thin film transistors on glass substrate make LCD cost-effective.
- **Environmentally friendly:** Unlike CRTs, LCDs do not use lead or other hazardous materials. They are easier to recycle.
- **Viewing angle improvements:** IPS, VA and other enhancements have significantly improved viewing angles close to 180°.

Limitations of LCD

Some downsides and limitations associated with LCD technology include:

- **Contrast limitations:** LCDs cannot produce deep blacks seen in OLED/plasma displays as the backlight is always active to some extent.
- **Motion blur:** Slow pixel response times of LCDs can lead to blurring artefacts in fast-moving video content.
- **Needs backlighting:** It cannot produce light on its own, hence needs backlighting.
- **Colour shifts:** Colour saturation and accuracy vary with viewing angle, especially on cheaper TN-LCD panels.
- **Reflectance and glare:** Front polarisers and glass layers can reflect ambient light thereby reducing visibility.
- **Limited flexibility:** It is difficult to make highly flexible LCDs compared to OLEDs due to glass substrates and thin-film transistor limitations.
- **Non-emissive:** External backlighting power and assembly requirements make LCDs thicker than self-lit OLED alternatives.

Comparison of LCD and Other Displays

The strengths and weaknesses of LCD technology stand out sharply when compared to alternative display approaches.

- **LCD vs LED displays**
 - LCDs utilise a **separate backlight like CCFL or LED arrays**, making them lightweight, thinner and more power-efficient compared to self-emissive LED or OLED pixels, especially in larger screen sizes.
 - However, the liquid crystal layer response time is slower than direct LED emitters. **Upcoming mini LED** and **micro LED** technologies aim to bridge this gap.
- **LCD vs Plasma displays**
 - LCD technology has now mostly replaced plasma displays due to higher attainable resolutions, improved viewing angles using IPS/VA panels and thinner, cheaper and easier large-scale manufacturing.
 - Plasmas had better contrast but suffered from permanent burn-in issues, bulkiness and higher power consumption, especially in large television sizes.

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