TFT-LCD Panel Fundamentals

Thin-film transistor liquid-crystal displays (TFT-LCDs) are a variant of LCDs that offer improved image quality. Find out what goes into their making.

Daniel A. Figueiredo, Harshal R. Patil

Demand for bigger-screen TV receivers is growing. In the past, while efforts were made to increase the screen size of CRT TVs, because of limitations of the CRT glass tube technology it had not been possible to go beyond 102cm (40-inch) screens. As such, research work had been going on to develop screens bigger than possible with CRTs.

Liquid-crystal display (LCD) was the first to emerge as an alternative and initially found applications in display boards of various equipment, computer monitors, laptops, personal digital assistants, advertisement boards, etc. Plasma panels also allowed large-screen TV viewing. Both LCD and plasma TVs offer the advantage of a wider viewing angle. However, LCD TVs score over plasma TVs in that these consume lesser power and last longer.

Liquid crystal was discovered by Austrian botanist Fredreich Rheinizer in 1888. In mid 1960s, scientists discovered that applying an external electric charge could change the properties of liquid crystals, i.e., the luminance of light passing through them, and demonstrated the first liquid-crystal display.

A thin-film transistor liquid-crystal display (TFT-LCD) is a variant of LCD that offers improved image quality.

**Structure of a TFT-LCD**

TFT-LCDs have a sandwich-like structure with liquid crystal filled between two transparent glass electrode plates coated with indium tin oxide (ITO) as shown in Fig. 1.

Fig. 2 shows a colour TFT-LCD module. It consists of a TFT-LCD panel, a backlight unit and a driving unit (source driver and gate driver). The TFT-LCD panel has TFTs, liquid crystal, pixel electrodes, storage capacitors and colour filter. The colour filter has a colour resin film containing three primary colour pigments (red, green and blue).

As shown in Fig. 3, the backlight unit consists of a CCFL lamp with inverter, a light guide panel, a diffuser, and bottom and top prisms. The light guide panel guides the light from the lamp. The diffuser uniformly diffuses the light received from the light guide. The prism concentrates the light and increases the luminance of light up to 1.55 times of the light guide.

**Working principle**

Liquid-crystal molecules are arranged randomly when there is no electric field.
between ITO electrodes and light is allowed to pass through with molecules twisted by 90°, changing the polarisation of light from vertical to horizontal. When an electric field is applied between ITO electrodes, liquid-crystal molecules get aligned by removing the 90° twist and light is blocked. When a smaller voltage is applied, the twist is less than 90° and lower-intensity light is passed. Thus the applied electric field determines the luminance of light passing through the liquid crystal and various grayscales can be obtained.

Types of TFT-LCDs
There are two types of TFT-LCDs: passive-matrix and active-matrix.

A passive-matrix LCD uses one transistor for each row and each column. Each transistor is switched on in sequence and the column transistors are turned on/off according to the image to be displayed. When a transistor is turned off, the respective element or pixel loses its charge and blocks the passage of light. Because of this scanning and the slow response (response time greater than 150 ms), passive displays are not very bright and have low contrast ratio. The addressing technique causes crosstalk, which results in blurred images as non-selected pixels are driven through secondary voltage.

An active-matrix LCD uses a separate transistor for each unit pixel. This allows the pixels to stay ‘on’ longer and thus produce a brighter image. Therefore active-matrix LCDs are used in computer monitors, laptops, TVs, mobile screens, etc.

Driving methods for TFT-LCDs
There are two ways to produce images on a liquid-crystal display: segment driving and matrix driving.

The segment-driving method is mostly used for simple displays, such as segment-type LCDs that are directly connected to the drivers.

The matrix-driving method is used for high-resolution displays. In this method, displays can be either statically driven or dynamically driven. In the static, or direct, driving method, each pixel is individually wired to the driver. But, as the number of pixels increases, wiring becomes complex. In the dynamic driving method, a voltage is applied at the intersections of specific horizontal-scanning electrodes and specific vertical signal electrodes in time-division multiplexing mode using pulse drive.

Equivalent circuit of a unit pixel
A liquid-crystal capacitor (C_LC) and a storage capacitor (C_s) are connected
as a load on the TFT. (A liquid-crystal capacitor is a liquid crystal that acts as a capacitive load.) A pixel is selected by applying pulse signal $V_{\text{SEL}}$ to particular gate line $G_n$ from the gate driver. At the same time, data signal in the analogue positive voltage $V_{\text{DAT}}$ is transferred to the drain of the transistor from the source driver. When the TFT is ‘on,’ the source and the drain short, which directly applies $V_{\text{DAT}}$ to the liquid crystal and the storage capacitor ($C_S$). $C_S$ charges and sustains the charge when the TFT is ‘off.’ The main function of $C_S$ is to maintain voltage across the liquid crystal until the next select line voltage is applied for refreshing the picture.

**Active addressing of a 3×3 matrix in active-matrix LCD**

The TFT-LCD panel of the AMLCD is scanned sequentially line-by-line from top to bottom. Each line is selected by applying a pulse of +20V to gate line $G_n$, which turns on the TFTs in that specific row. Rows are deselected by applying –5V to $G_{n-1}$ and $G_{n+1}$, which turns off all the TFTs in the deselected rows and then the data signal is applied from the source driver to the pixel electrode.

The voltage applied from the source driver, called ‘gray-scale voltage,’ decides the luminance of the pixel. The storage capacitor ($C_S$) maintains the luminance of the pixel until the next frame signal voltage is applied. In this way, the next line is selected to turn on all the TFTs, then the data signal is fed from the source driver and hence scanning is done.

**TFT-LCD panel controller/driver**

The TFT-LCD controller/driver unit consists of a TFT-LCD timing controller with low-voltage differential signaling (LVDS) receiver, reduced-swing differential signaling (RSDS) transmitter, oscillator, gray-scale reference voltage generator, gate driver, and source or column driver as shown in Fig. 9.

For large panel size, high resolution and high gray-scale, high-speed data transmission is required between the TFT-LCD timing controller and the source driver. To achieve high-speed data transmission, low-voltage techniques such as mini-LVDS and RSDS having differential voltage of 350 mV across the 100-ohm termination resistor at clock frequency of 85 MHz to 170 MHz are used. The LVDS receiver transfers data serially bit-by-bit over a single pair of wires. This allows fast pixel individually in sync with the gate driver and source driver and, at the same time, the RGB video signal is passed through the source driver to TFT-LCD cells through the source driver. The controller generates control signals to address each
the gate of TFTs in a specific row and thus allows line-by-line scanning from top to bottom.

The source driver consists of a shift register, data latch, level shifter, digital-to-analogue converter (DAC) and output buffer.

Digital data is loaded and stored in data latches until conversion takes place. Because each output has an independent DAC, data conversion is required only once per line. The DAC converts the digital gray-scale value into an equivalent analogue voltage with very fast conversion rate and this analogue voltage is fed to TFT-LCD cells through the output buffer.

The DAC also allows gamma correction. In a TFT-LCD, TFTs are used to control on/off state of the displayed pixel. But this on/off function is insufficient to display images correctly. Gamma correction is essential because the image is either breached out or too dark. It controls the overall brightness of images displayed on the screen.

**Gray-scale and colour generation**

The luminance of light depends on the voltage applied between the two transparent electrodes of a liquid crystal. Gray levels are an intermediate level of brightness between the brightest and the darkest of dark that a unit pixel can generate by varying the voltage between the electrodes. This gray-scale voltage can be generated either in analogue or digital form. Gray-scale voltage in analogue form, i.e., continuous range, is generated using a voltage divider. The DC-DC converter can also be used to obtain in-between voltages for gray-scale generation.

In the digital method, gray-scale voltage is defined in 8-, 10- and 12-bit forms. Hence the number of gray levels is determined by the number of bits used to represent the gray-scale voltage. For example, if eight bits are used to represent gray-scale voltage, the number of possible gray levels will be \(2^8 = 256\).

The colour filter of a TFT-LCD consists of three primary colours: red, green and blue. In a colour TFT-LCD, each pixel is a combination of three subpixels having red (R), green (G) and blue (B) colours. Because the subpixels are too small to distinguish them independently, practically any colour produced is a mixture of these primary colours. The video signal is composed of R, G and B colour signals and ‘n’ bits are used to represent each colour. The number of colours produced is determined by the combinations of R, G and B that are possible with the number of gray-scale levels: If an LCD displays images with 8-bit gray-scale, it will display \(2^8 = 256\) shades for red, green and blue colour each. Thus the total number of different colours, known as TrueColour, is \(2^8 \times 2^8 \times 2^8 = 16.78\) million.

If you compare 8- and 10-bit gray-scale displays, you’ll find that 10-bit gray-scale images are softer and more natural than 8-bit gray-scale images. This is because 10-bit gray-scale gives \(2^{10} = 1024\) shades for each primary colour and the total number of colours (natural colours) is \(2^{10} \times 2^{10} \times 2^{10} = 1.07\) billion). A 12-bit gray-scale has also been tried. It gives much more realistic picture.

Daniel A. Figueiredo, an M.Tech in electronics design and technology from C.E.D.T. of India, Aurangabad, is a member of IEEE, USA, and has 29 years of experience in varied roles. Harshal R. Patil is pursuing M.Tech in electronics design and technology at DOEACC Centre (Formerly C.E.D.T. of India), Aurangabad.