Chapter 2

Background Knowledge of Thin-Film Transistor Liquid Crystal Displays

2.1 LIQUID CRYSTAL DISPLAY STRUCTURE

2.1.1 Material and Display Theory of Liquid Crystal [7], [8]

Most liquid crystals consist of molecules shaped like the rod. The direction of long axis is called the *director*, given by the vector $\vec{n}$, which is an apolar vector as $\vec{n}$ and $-\vec{n}$ are equivalent. Rod-shaped molecules are also termed *calamitic*.

We focus on calamitic (Bahadur, 1990; Demus *et al*., 1998a,b) liquid crystals as they are important for applications. One characteristic of the phase variation of liquid crystal materials is "the twice melting" showing in Fig. 2.1. Below the melting point (T_m) they are solid, crystalline and anisotropic, when above the clearing point (T_c) they are a clear and isotropic liquid. The material has the appearance of a milky liquid between T_c and T_m but still exhibit the ordered phases.

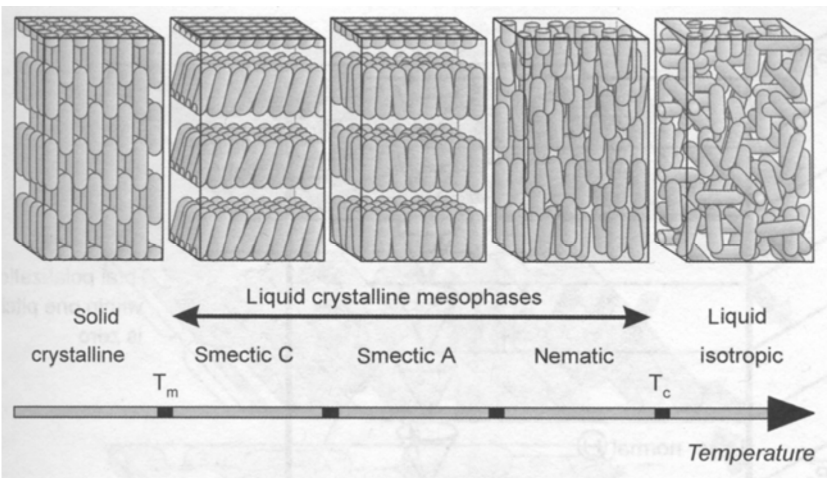
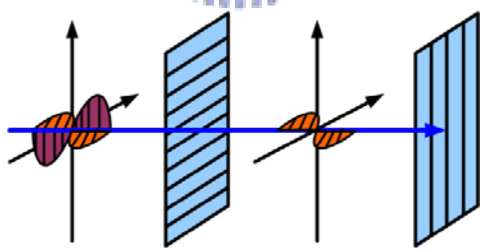


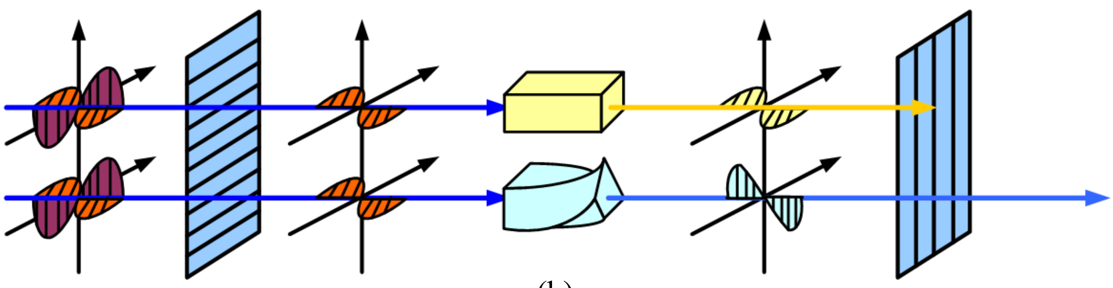
Fig. 2.1 Phases of liquid crystal materials versus temperature.

The phases during T_c and T_m can roughly be divided into smectic phase and nematic phase by its molecules arrangement. The molecules are ordered in two dimensions in smectic phase and appeared with only a one-dimensional order in nematic order. Most LCD materials' nematic phase is the basis and widely used as Twisted Nematic (TN) cell with active matrix addressing. Because the twist of liquid crystals can be controlled by the electric field that is applied across it, liquid crystals are used as a switch that passes or blocks the light.

The polarizer can block or pass the specific light by changing the phase of the polarizer. In general, the first polarizer of a couple of polarizers is called *polarizer* and the second polarizer of these is called *analyzer*. The light can be blocked by a couple of polarizers with 90° phase error, is shown in Fig. 2.2 (a). If we twist the liquid crystal molecule by applying the specific electric field across it, the light still can pass the polarizer. This is because the direction of liquid crystal molecules varies with electric field and it can guide the light along the long axis, shown in Fig. 2.2 (b).



(a)



(b)

Fig. 2.2 (a) A couple of polarizers with 90° phase error. (b) A couple of polarizers with liquid crystals.

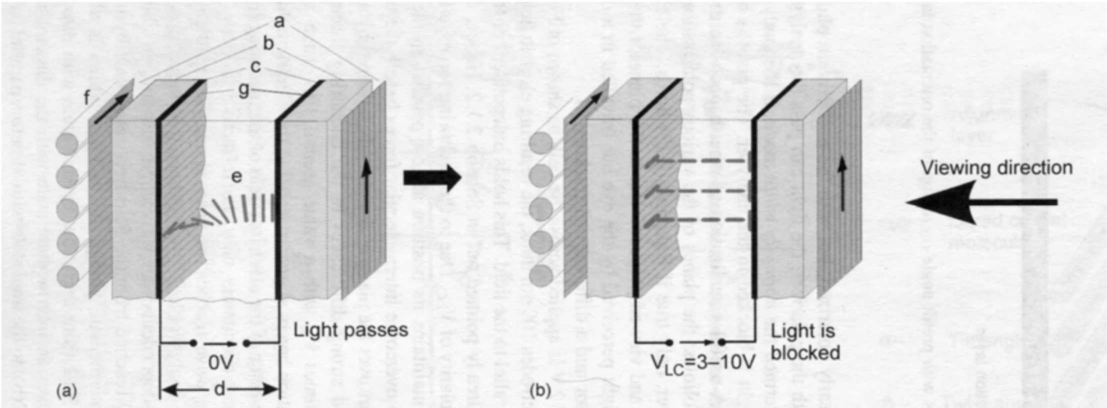


Fig. 2.3 The structure of a TN-LCD (a) while light is passing, and (b) while light is blocked. a: polarizer; b: glass substrate; c: transparent electrode; g: orientation layer; e: liquid crystal; f: illumination.

Fig. 2.3 (a) shows a pixel of a transmissive twisted nematic LC-cell with no voltage applied. The white backlight *f* passes the polarizer *a*. The light leaves it linearly polarized in the direction of the lines in the polarizer, and passes the glass substrate *b*, the transparent electrode *c* out of Indium-Tin-Oxide (ITO) and the transparent orientation layer *g*. In this case, the analyzer is crossed with polarizer. The light can pass the analyzer without applied voltage due to the twisted nematic LC-cell and the pixel appears white. If a voltage V_{LC} of the order of 10 V is applied across the cell, as shown in Fig. 2.3 (b), all molecules aligned parallel to the electric field. In this state, the wave that reaches the crossed analyzer is polarized in the same direction as at the input. Therefore, the analyzer blocks the light and the pixel appears black. This operation is termed the *normally white* (NW) *mode*. On the contrary, if the analyzer is rotated by 90°, paralleled with polarizer, the light is blocked in the analyzer. The pixel is black. This is called the *normally black* (NB) *mode*. The transmitted luminance, also termed *transmittance*, of the light. Fig. 2.4 shows the transmitted luminance versus the normalized voltage (V_{LC}/V_0) across the LC cell for the normally white mode and the normally black mode, respectively.

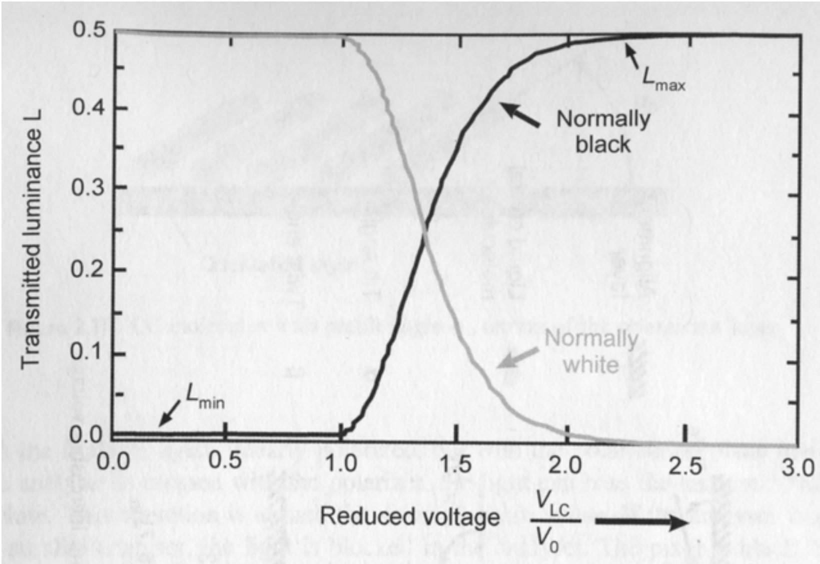


Fig. 2.4 The transmitted luminance versus the normalized voltage (V_{LC}/V_0) across the LC cell for the normally white mode and the normally black mode.

2.1.2 Liquid Crystal Display Module Structure

The cross section structure of TFT-LCD panel is shown in Fig. 2.5 particularly. It can be roughly divided into two part, TFT array substrate and color filter substrate, by liquid crystal filled in the center of LCD panel. We still need a backlight module including an illuminator and a light guilder since liquid crystal molecule cannot light by itself. However it usually consumes the most power of the system, some applications such as mobile communications try to exclude or replace it from the system. In TFT array substrate, we need a polarizer, a glass substrate, a transparent electrode and an orientation layer. In color filter substrate, we also need an orientation layer, a transparent electrode, color filters, a glass substrate and a polarizer. Most transparent electrodes are made by ITO, and they can control the directions of liquid crystal molecules in each pixel by voltage supplied from TFT on the glass substrate. Color filters contain three original colors, red, green, and blue (RGB). As the degree of light, named “gray level”, can be well controlled in each pixel covered by color filer, we will get more than million kinds of colors.

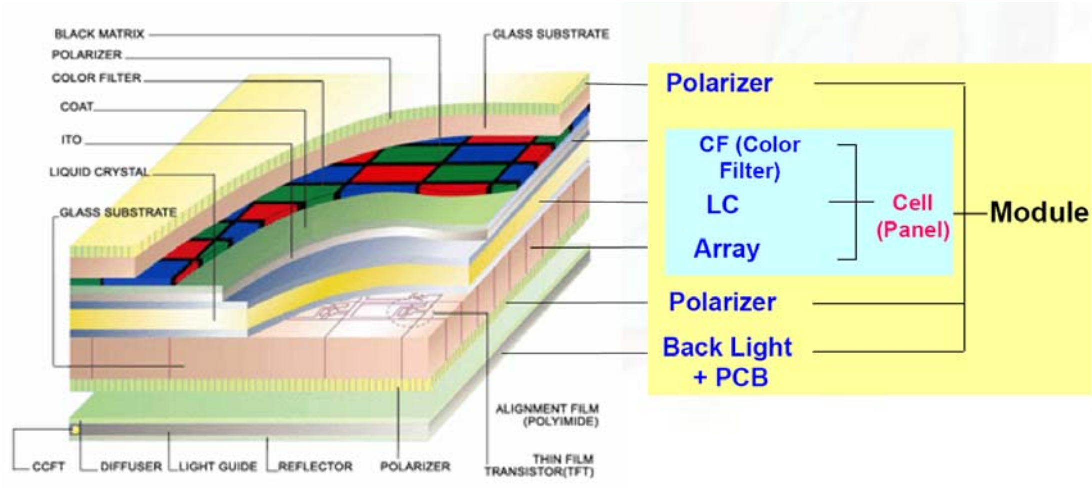


Fig. 2.5 The cross section structure of TFT-LCD panel.

2.1.3 Equivalent Model of Dot in each Pixel Cell

One dot is the most fundamental unit of LCD panel and each dot can express one kind of original color. Because one full color should be mixed with three original colors, each pixel contains three dots. As a result, if the resolution of gray level of each dot is 8 bits, then the whole panel can show 16,777,216 ($2^8 \times 2^8 \times 2^8$) kinds of colors at all. Fig. 2.6 shows the basic layout and cross section of an AMLCD sub-pixel. The equivalent circuit of a TFT in the sub-pixel with voltages, currents, and parasitic capacitances is shown in Fig. 2.7 [7].

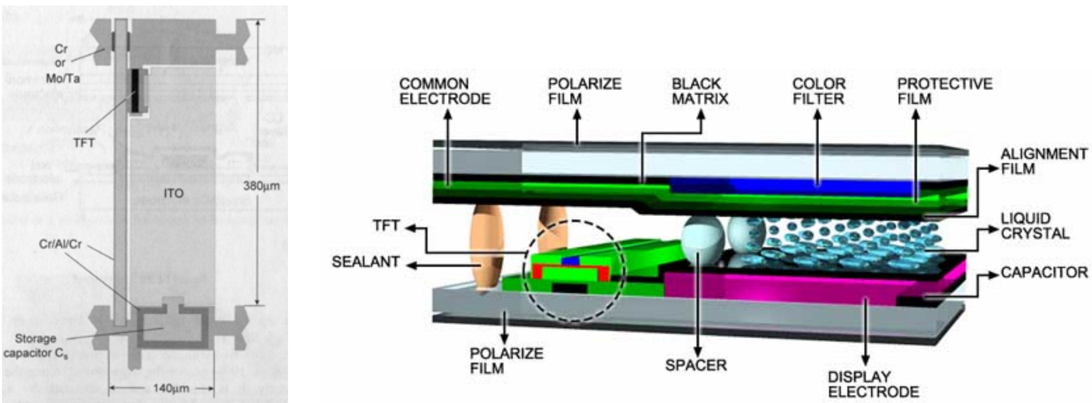


Fig. 2.6 The basic layout and cross section of an AMLCD sub-pixel.

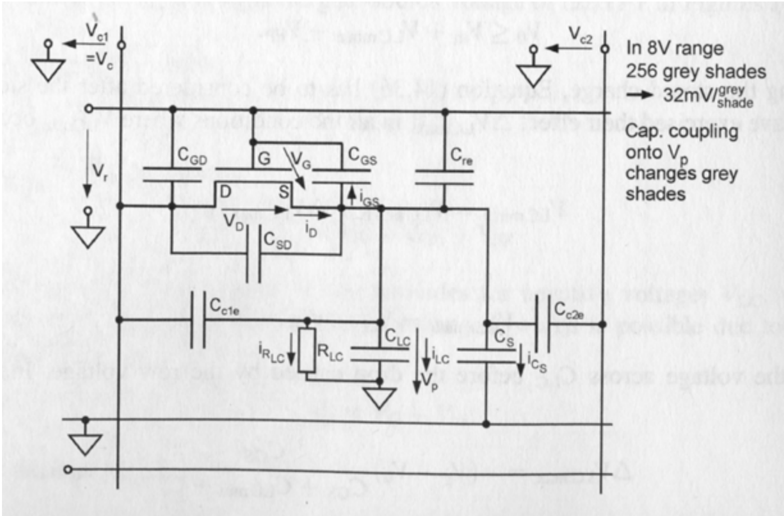
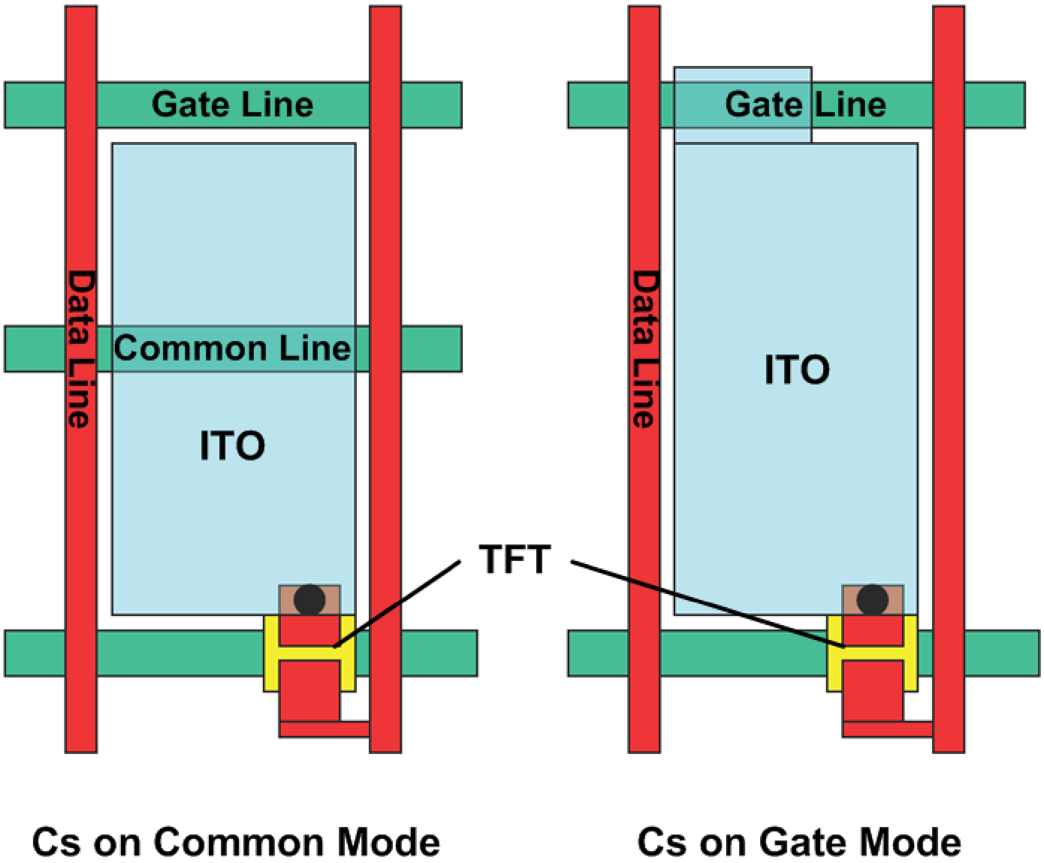


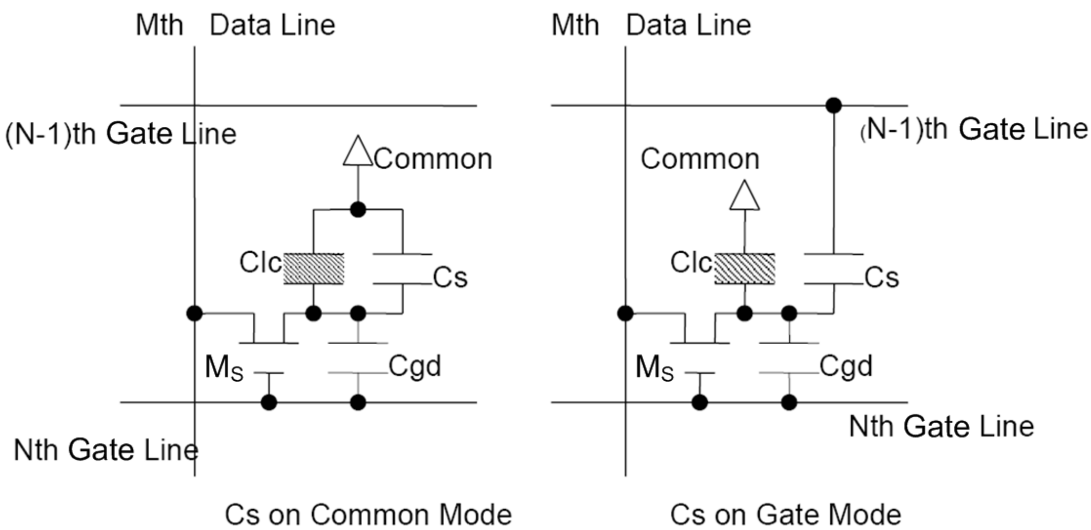
Fig. 2.7 The equivalent circuit of a TFT in the sub-pixel with voltages, currents, and parasitic capacitances.

Fig. 2.8 and Fig. 2.9 show the layout and equivalent circuit of each sub-pixel, including two major structures, the C_S on common mode and C_S on gate mode. The right-down region of the sub-pixel layout is the TFT switch, and the region of each sub-pixel area excluding TFT switch and storage capacitor (C_S) is called aperture region, which is the largest window for light passing. So the larger ratio of aperture region to pixel area is the better performance of the TFT-LCD panel. In Fig. 2.9, the M_S is a thin film transistor as a switch. The C_{lc} is the effective capacitor of liquid crystals, and C_S is the storage capacitor used to maintain the voltage level of liquid crystals during the hold time of frame transitions. The C_{gd} is the parasitic capacitor between gate line and effective liquid crystal capacitor. The structure, C_S on gate, which connects the bottom of the storage capacitor to the previous row of the gate line has some benefits. By this structure, we can compensate the unstableness of voltage level due to the clock feed-through effect from C_{gd}. Furthermore, this structure also has larger aperture ratio. But the trade-off with the C_S on gate method is an increase in the RC time constant of the gate line, which reduces the TFT switching performance.



(a) (b)

Fig. 2.8 The layout view of a TFT-LCD sub-pixel: (a) C_S on common mode and (b) C_S on gate mode.



(a) (b)

Fig. 2.9 The equivalent circuit of a TFT-LCD sub-pixel: (a) C_S on common mode and (b) C_S on gate mode.

2.2 DRIVING METHOD IN TFT-LCD PANEL

2.2.1 Driving Method

Liquid crystal molecules can't be under a fixed voltage in the long period. The DC blocking effect and the DC residue (stick image) will be appeared under this condition. Therefore, the electric field polarity should be inversed every period to avoid the destruction of liquid crystals. The torque caused by electric filed is dependent on the magnitude of electric filed, not dependent on the polarity of electric filed. Therefore, the polarity of electric filed would not affect the twisting of the liquid crystal molecules. When the frame picture will be kept on the same gray level, the electric field across liquid crystals is changed into two polarities (positive and negative), alternately. As electric field is higher than common mode voltage the polarity is called positive polarity, otherwise it is called negative polarity. By this way, the liquid crystal molecules will avoid defection in the fixed applied voltage. In term of above description, the polarity inversions of LCD panel can be principally divided into four general types: frame inversion, row inversion, column inversion, and dot inversion [9]. They are listed in Fig. 2.10. Frame inversion is that all the adjacent pixels of the LCD panel have the same polarity. Row inversion (column inversion) is that each adjacent row pixels (adjacent column pixels) have different polarity. Finally, all the adjacent pixels of LCD panel have different polarity is called dot inversion. Dot inversion is the major driving method of LCD panel. This polarity inversion method has some benefits. By this method, we can achieve to higher quality image due to the reduction in both horizontal and vertical cross-talk. The flicker of image also can be reduced due to the spatial averaging of pixels. But the penalty of dot inversion method is an increase of the power consumption due to the line inversion component. This method is also incompatible with common voltage modulation.

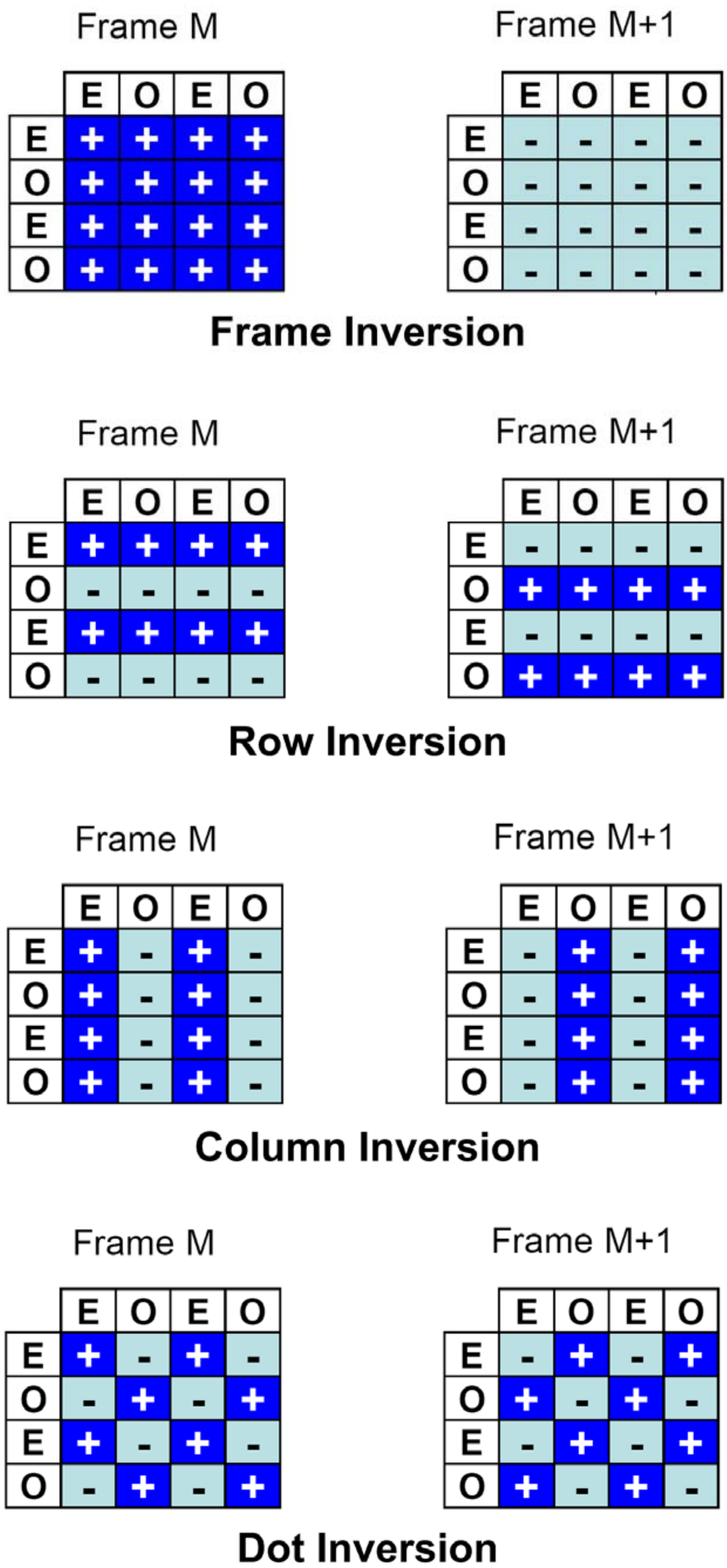


Fig. 2.10 The polarity inversions of TFT-LCD panel.

Based on the operational type of common mode voltage, the driving method can also be classified into direct driving and AC modulation driving. They are shown in Fig. 2.11 and Fig. 2.12, respectively. Direct driving method would keep its common voltage on a constant level. However, the common mode voltage of AC modulation driving method is not a constant level, is a period voltage. The characteristics of two driving methods are listed below:

- Direct driving method:

  – Frame, row, column, and dot inversion are all available.

  – Crosstalk and flicker can be eliminated.

- AC modulation driving method:

  – Frame and row inversion are available.

  – Low power dissipation in data driver.

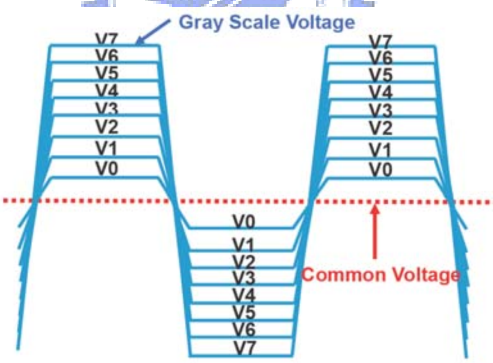


Fig. 2.11 The operation waveform of direct driving method.

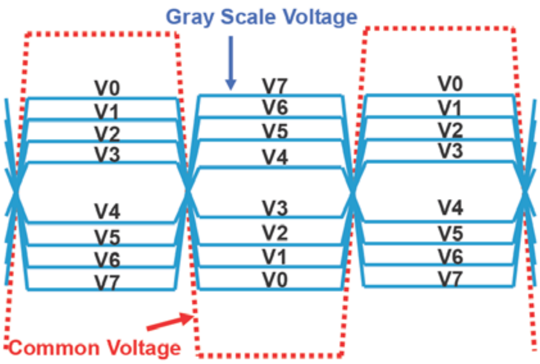


Fig. 2.12 The operation waveform of AC modulation driving method.

2.2.2 Gamma Correction

Gamma correction of liquid crystal displays is involved due to the nonlinearity between luminance and human visual system (HVS). This is because the pupils of the human's eyes would vary automatically for the change of the ambient light. For this reason, a data driver with gamma correction is necessary in TFT-LCD panel. The data driver often is required to compensate for the human visual system's transfer function. Moreover, it must also compensate for the LCD transfer function [9]. Fig. 2.13 shows the operation of the gamma correction for the normally white TN type LCD panel. The gamma correction system is composed of three relationships: luminance vs. HVS brightness, input digital code vs. pixel voltage, and the V-T curve of the NW-TN type liquid crystal. By this system, the relationship between input media codes and brightness in human eye will be more linear.

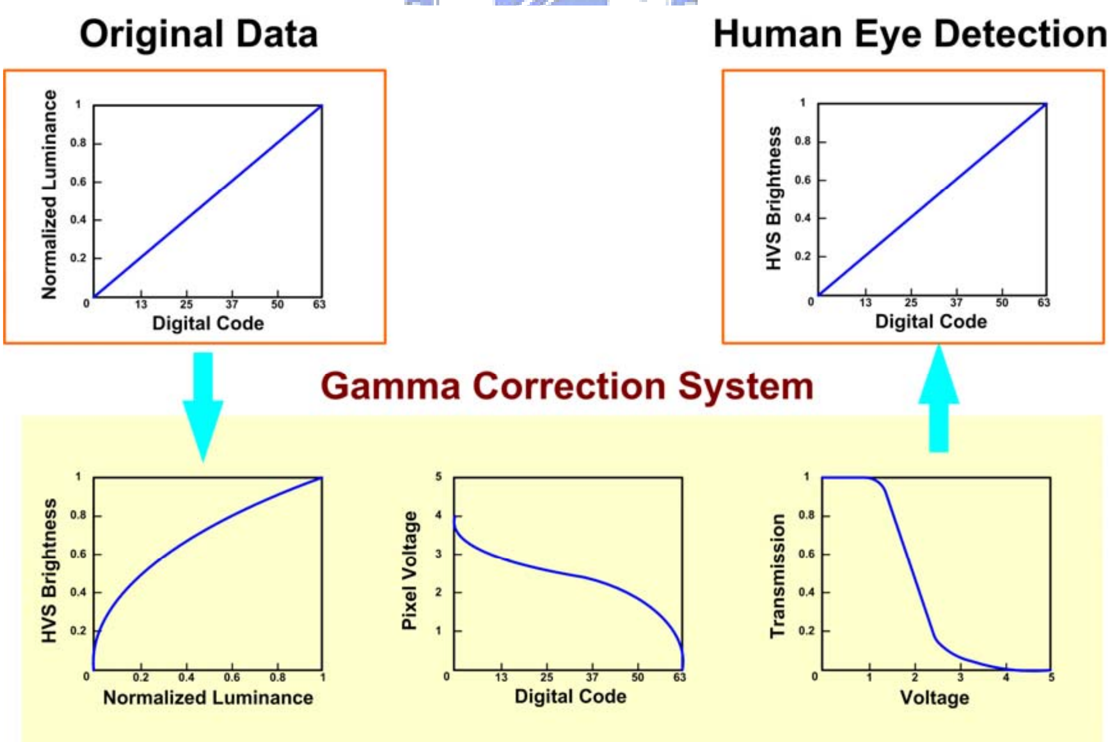


Fig. 2.13 The operation of the gamma correction for the normally white TN type LCD panel. HVS: human visual system.

Furthermore, there are something should be emphasized. In general, the input digital code vs. pixel voltage curve of data driver, in Fig. 2.14, is symmetrical to the common voltage (Vcom) axis. This is because that the permanent deflections of liquid crystal molecules will occur if the DC stress given on the LCD panel sustains a long period. As a result, the LCD panel should be driven by AC (alternating polarity) signal to eliminate the defect on LCD panel.

From previous description, we can get a linear relationship between input media codes and brightness in human eye through a "Gamma Correction Digital to Analog Converter", which will be particularly discussed in the next chapter.

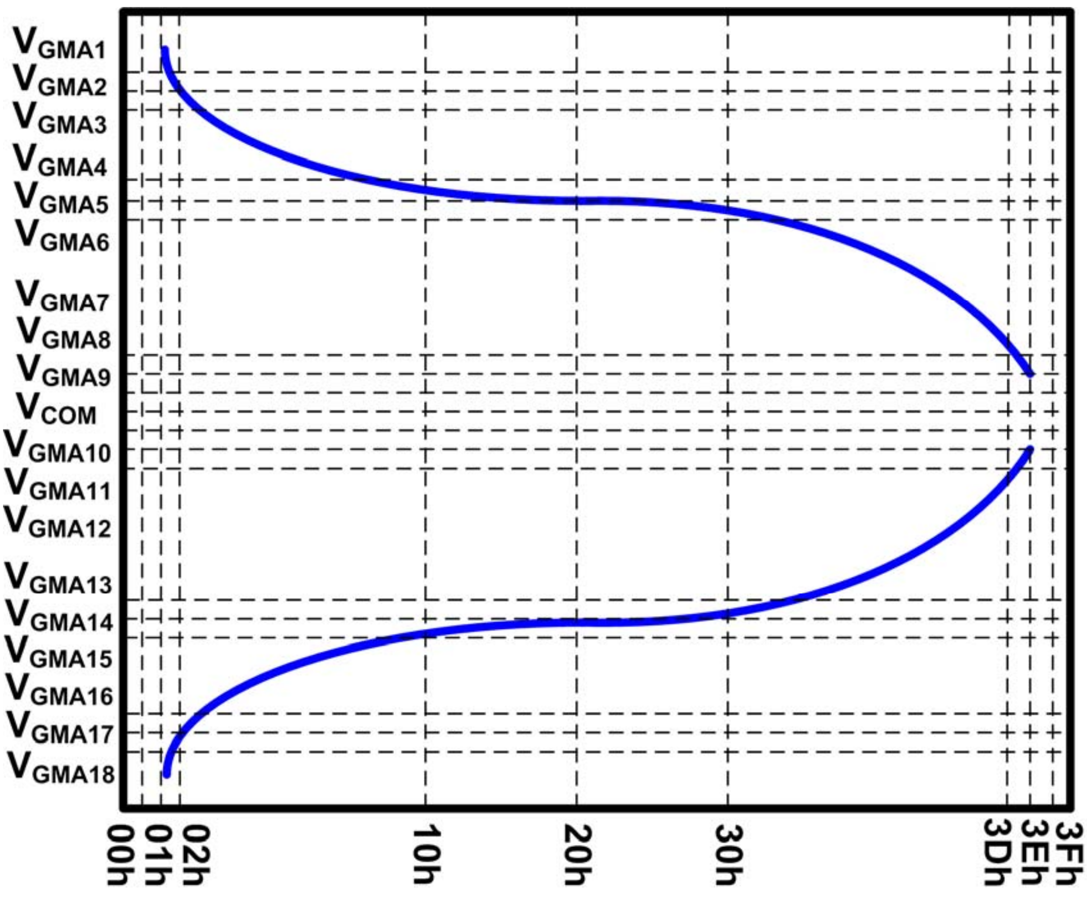


Fig. 2.14 The input digital code vs. pixel voltage curve of data driver in TFT-LCD panel.

2.3 PERIPHERY CIRCUIT BLOCK

The periphery circuit blocks of LCD panel are roughly composed of four parts — display panel, timing control circuit, scan driver circuit and data driver circuit [10]. In Fig. 2.15 is the block diagram of the entire TFT-LCD panel circuits. Display panel is constructed of the active matrix liquid crystals. The operation of the active matrixes is similar to DRAM (dynamic random access memory) which is used to charge and discharge the capacitor of the pixel. Timing controller is responsible for transiting RGB (red, green, and blue) signals to the data driver and controlling the behavior of scan driver. As soon as one voltage level of the scan lines rises, the RGB signals will be transited through the data driver. After a period, the voltage level of this scan line will be disabled and next scan line will be turned on. All voltage levels of those scan lines will be raised in turn. Addressing system, in Fig. 2.16, is composed of scan driver and data driver [7]. These two driver circuits will be further discussed in the following sections.

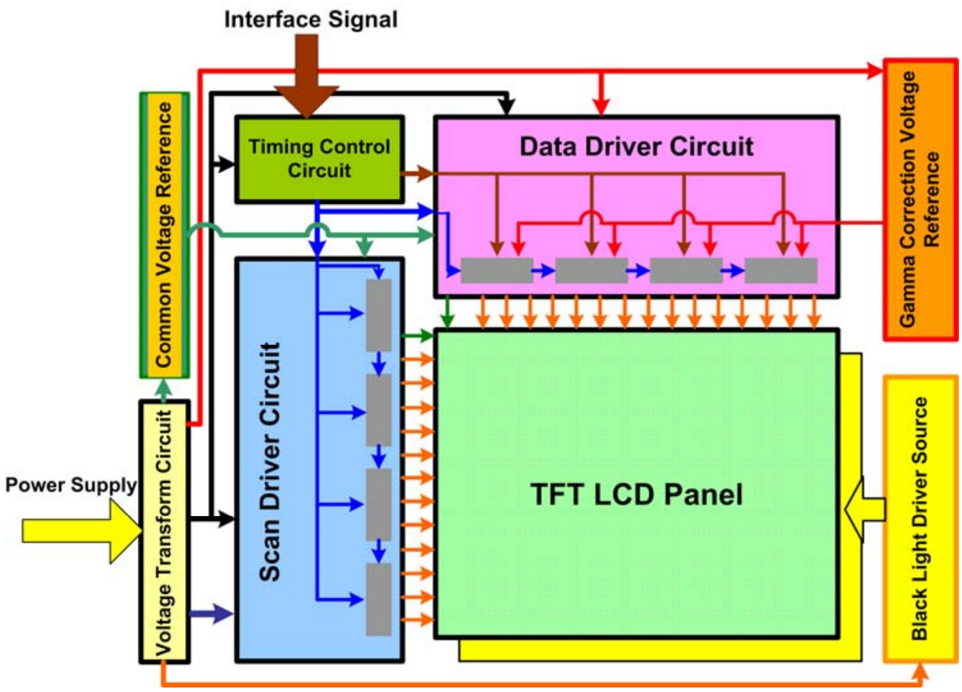


Fig. 2.15 The block diagram of the entire TFT-LCD panel circuits.

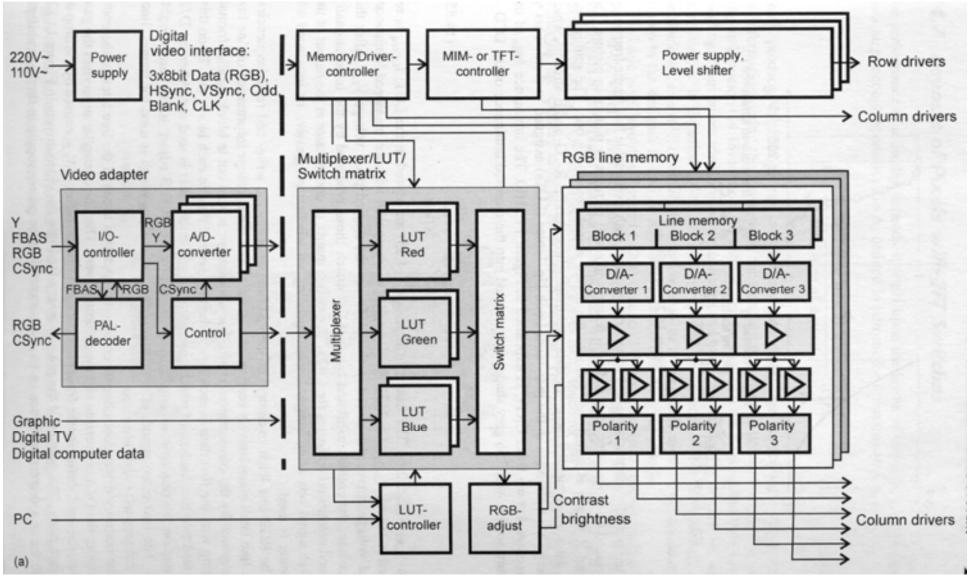


Fig. 2.16 The entire addressing system in detail.

2.3.1 Scan Driver Circuit

Scan driver, shown in Fig. 2.17, consists of shifter register, level shifter, and digital output buffer. Shifter register is used to store digital input signals and transit them to the next stage according to timing clock. Because the turn-on voltage of active matrixes is higher, scan driver should drive the active pixels with a high voltage. The purpose of the level shifter is just to convert the digital signals to a higher level voltage. Finally, since the scan lines can be modeled as RC (resister and capacitor) ladder, the digital output buffer should be used in the last stage for driving the large load [10].

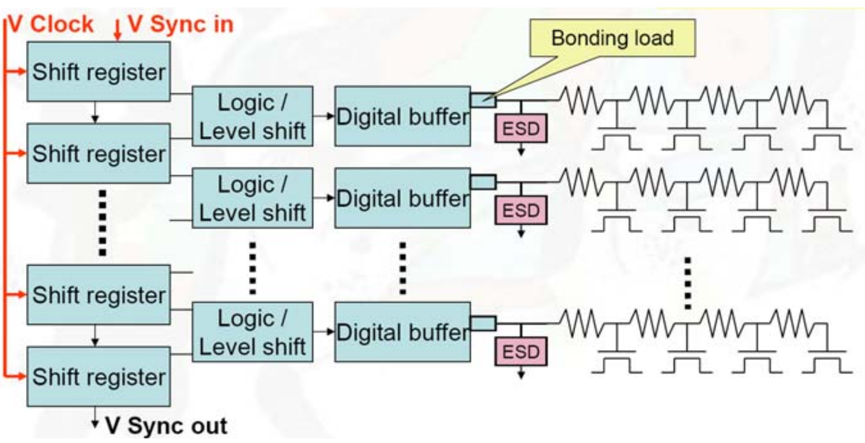


Fig. 2.17 The basic diagram of scan driver circuit.

2.3.2 Data Driver Circuit

Data driver, shown in Fig. 2.18, mainly contains shifter register, data latch, level shifter, digital-to-analog converter (DAC) and analog output buffer [10]. Furthermore, the first three parts classify as digital architectures. The other two parts belong to analog architectures. Shifter register and data latch manage to transit and store the RGB signals. Also, the purpose of level shifter is the same as the one in scan driver. It is applied to translate the RGB signal to a higher level voltage. As implied by the name, digital-to-analog converter is used to convert the digital RGB signal to analog gray level. Its structures can be divided into many types, and there will be much more detailed discussion in the next chapter. As for analog output buffer, its purpose is applied to drive active pixels into a desired gray level. However, The LCD panel usually has large loading, especially in larger panel display or higher resolution display. For this reason, the analog output buffer should enhance the driving capability of the data driver. The corresponding analog output buffer circuit will be described in the later chapter.

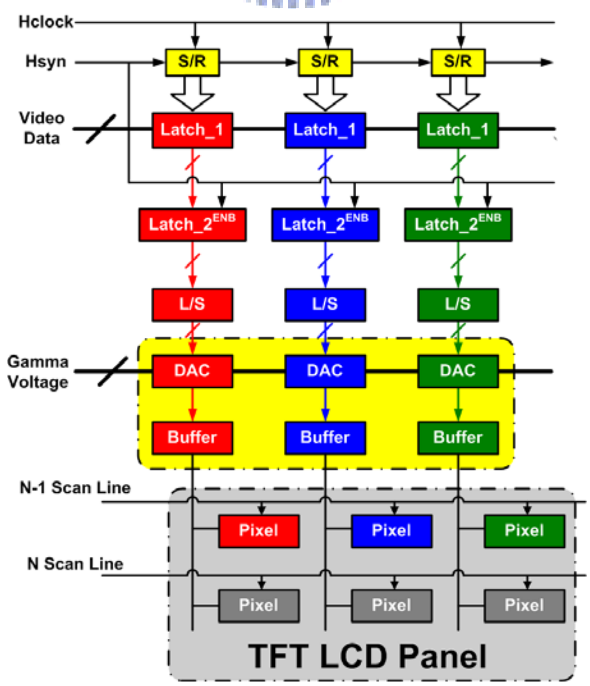


Fig. 2.18 The basic diagram of data driver circuit.