

Chapter 2

Circuits and Drives for Liquid Crystal Devices

Hideaki Kawakami

2.1 Circuits and Drive Methods: Multiplexing and Matrix Addressing Technologies

Hideaki Kawakami

2.1.1 Introduction

The liquid crystal display (LCD) has been put to practical use in the early 1970s, and the following remarkable development progress led to today's prosperity. The LCD was driven from the early stage of practical use by complementary metal-oxide-semiconductor large-scale integration (CMOS LSI). In the early 1970s, the great market for electronic watches and electronic calculators was created. Then, CMOS LSIs and LCDs were developed as key components to realize low-power electronics.

The drive electronics was invented at the beginning of LCD development. The main drive electronics was followed from the passive matrix LCD (PM LCD) to active matrix LCD (AM LCD). Even if the main products moved to active matrix LCDs, the rms-responding characteristics peculiar to nematic liquid crystals remained as the drive electronics progressed.

B. J. Lechner of the American RCA Lab. suggested the AM LCD in 1971 [1]. However, we had to wait for the practical use of the AM LCD until the progress of Si film technology in the 1980s.

Here, I survey the progress of the multiplexing and the matrix addressing technologies.

H. Kawakami (✉)
Hitachi Ltd., Tokyo, Japan
e-mail: khideaki@tbb.t-com.ne.jp

2.1.2 Multiplexing Technologies

It was the electronic watches and electronic calculators that exploited the consumer market during the development of the CMOS LSI in the early 1970s. Because all those devices used button cells as power supply, the low power consumption of the display was important. In response to it, the segment-type LCD with a μW order power consumption was put to practical use at this time. There was limitation of the number of the output pins in the package of the LSI, and the multiplexing technologies of the LCD were developed to reduce the number of external terminals. This was the beginning of matrix addressing technologies of the LCD.

In the beginning of the 1970, with solely nematic liquid crystals in use, the twisted nematic TN-LCD became mainstream for LCDs in electronic watches and calculators. The multiplexed LCD incorporates capacitors in their matrix circuits which led to crosstalk between the matrix elements. Therefore the amplitude selection method was developed to create a uniform bias voltage to control the crosstalk such as 3-to-1 or 2-to-1 amplitude selection. This model was known as the matrix addressing technology of inorganic electroluminescent devices. In order to apply this to TN-LCDs, the two next characteristics have to be considered.

(1) The accumulation response

The electro-optical response when voltage pulses are applied to LCDs in a chronological order is cumulative and saturates after several voltage pulses.

(2) The rms-responding characteristics [2]

The relative luminance that is reached in (1) depends on the effective value of the applied voltage to LCD.

It was the two-frequency drive method on the basis of rms-responding characteristics that was proposed at first, but it was an immature drive method in those days and problems because of bad temperature characteristics did not lead to a practical use [3, 4].

On the other hand, the electro-optical response showed accumulated response on the temporal axes, and this slowed the electro-optical response (see Fig. 2.1). Hence the amplitude selection technologies were developed for driving LCDs. Regarding the driving spectrum, the amplitude selection technologies require that V_{th} is approximately constant in the bandwidth of driving frequency. In summary, it was clear that the transient response in electro-optical performance of nematic LCDs originally showed the accumulated response and the frequency response in the steady state of electro-optical performance required that V_{th} of LCD be approximately constant in the bandwidth of the driving frequency.

In the early amplitude selection, the number of scan lines was 2–4, and the frame frequency f_F was 50–60 Hz. Because of a frame inversion for the AC drive, the minimum driving frequency of the drive voltage applied to the LCD was $1/2 f_F$, which means 30 Hz. The effective dielectric constant under such low frequencies fluctuated because the ionic conduction mainly fluctuated which led to malfunctions. More than $10^{10} \Omega \text{ cm}$ were required as the specific resistance of the bulk liquid crystal material.

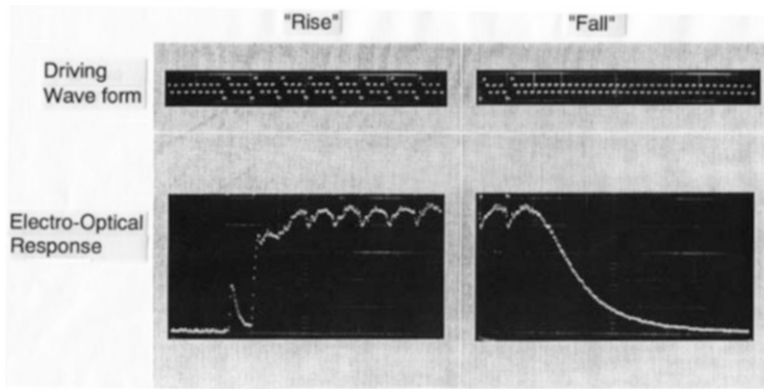


Fig. 2.1 Example of an accumulation response in TN-LCDs, when 3-to-1 amplitude selection was used at 1/4 duty drive

On 3-to-1 amplitude selection, the ratio of on-voltage V_S and off-voltage V_{NS} depends on the number of scanning lines, and $V_S/V_{NS} = \sqrt{(1 + 8/n)}$. The formula shows the margin allowing the deviation of V_{th} . At that time, deviation of V_{th} was caused by the deviation of the cell gap, molecular orientation factors, and others. Also, the margin suggested the demand on the material specifications of liquid crystalline materials that became a molecular design and production guideline.

2.1.3 Matrix Addressing Technologies for Passive Matrix LCDs

2.1.3.1 A-to-1 Amplitude Selection Technologies

From the first days of the LCD, there was the dream to make a flat panel LC TV, but the development of practical use active matrix LCD progressed too slowly. Development of the PM LCD became popular in the 1970s, and the necessary drive methods were developed. The basis in TN-LCDs, put to practical use in the early 1970s, was the root mean square value dependence (rms-responding) characteristics, and the drive methods were developed accordingly [5, 6].

For twisted nematic LCDs, the line inversion drive was used in the passive matrix display in which the number of scanning lines n was from 8 to 40. The driving frequency $f_F \times n$ for those devices was a few kHz. With the scale of the matrix growing bigger, and the number of scanning lines n reaching 200, the bandwidth of the driving frequency reached from a few 10 Hz to a few 10 kHz. The dielectric anisotropy $\Delta\epsilon$ of nematic LCs used in TN cells was wide enough, and the threshold voltage V_{th} to trigger the electro-optical response was constant, and there was no upper limit level of the frequency bandwidth in principal.

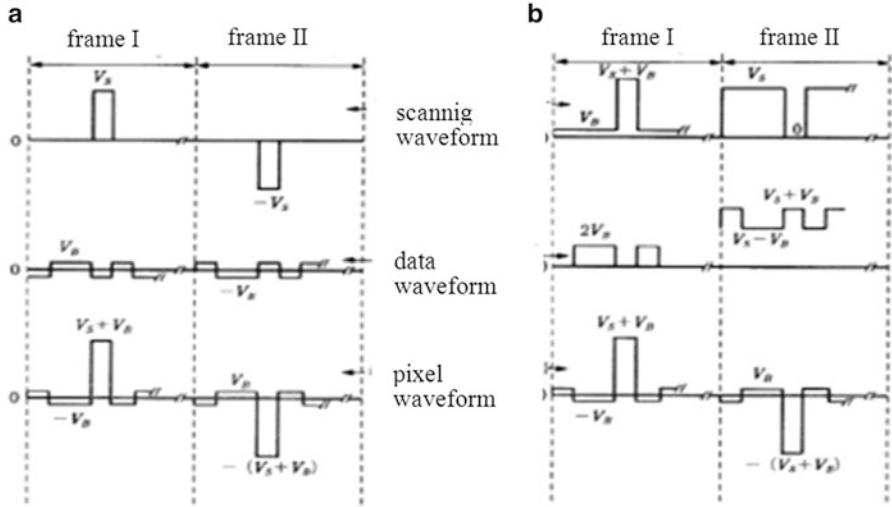


Fig. 2.2 The optional amplitude selection technologies. Driving wave forms of a-to-1 amplitude selection, such as (a) Alt-Pleshko (AP) method and (b) amplitude selection (AS) method

In other words, the optimization of the amplitude selection was accomplished with the rms response in the frequency bandwidth where V_{th} was approximately constant (see Fig. 2.2).

When the ratio of on-voltage V_S and the off-voltage V_{NS} was maximum, the contrast was maximized, and for this optimization, the conditions are as follows:

$$V_S/V_{NS} = \sqrt{(\sqrt{n} + 1)/(\sqrt{n} - 1)} \quad (2.1)$$

where n is the number of scan lines; V_S is the selection voltage (on voltage); and V_{NS} is the non-selection voltage (off voltage).

Under optimum condition that the contrast becomes high, the on-/off-voltage ratio V_S/V_{NS} depends on the number of scanning lines n and asymptotically reaches unity, which means that not enough contrast is provided when the number of scanning lines increases. This phenomenon is called the scanning limitation. Research and development of the advancement of the PM LCD continued in the 1980s and 1990s, but because of the scanning limitation by Eq. (2.1) we were defeated by this so-called iron law. Thus the use of the TN-LCD was limited to small LCDs at that stage.

In the 1980s, the research and development of AM LCDs were very active, but it had not yet opened great application. On the other hand, STN-LCD (super twisted nematic LCDs) for PCs and Japanese word processors were realized in the 1980s [7], and also colored STN-LCDs for PCs were developed. The electro-optical response increased steeply with increasing applied voltage for those cells and enough contrast was provided even if the number of scanning lines increased, and

the on/off-voltage ratio became small. Its performance of STN-LCD was called threshold sharpness.

However, in the 1990s active matrix (AM) LCDs using thin-film transistors (TFT) with amorphous silicon films were put to practical use, and the superiority of the AM LCD for PC use became obvious once the reliability problems were solved. From there on, the market of the PM LCD was limited to small- to middle-sized LCDs. The root of this is the scanning limitation due to Eq. (2.1). The peculiar threshold sharpness of STN-LCDs gave enough contrast even if the number of scanning lines grew large to some extent. However, there was some difficulty to display half tone images. After some time, superior AM LCDs became mainstream after all.

2.1.4 Active Addressing and Multiline Addressing Methods

The topics of the 1990s for PM LCDs were the active addressing method and the multiline addressing method [8, 9].

$$D_j(t) = c \sum_{i=1}^n I_{ij} S_i(t) \quad (2.2)$$

where I_{ij} expresses the state of the pixel. On = +1, off = -1.

It is clear that on the basis of the rms-responding characteristics, the scanning signal $S_i(t)$, and data signal $D_j(t)$ are orthogonal [10].

This can be expressed by introducing a specific orthogonality function, e.g., Hadamard function into the scanning signal S (Eq. 2.2). By applying S to all lines at the same time, one field at a time scanning methods were developed. The schemes were called active addressing method and they have advanced to scan partial lines at the same time. Also, by scanning several lines at the same time, multiline addressing (MLA) methods were developed.

Techniques to integrate image compression algorithms such as JPEG2000 and MPEG-4 into the MLA have been developed to use STN-LCDs for mobile devices in research and development after 2000 [11].

References

1. B.J. Lechner et al., Proc. IEEE. **59**(1), 1566 (1971)
2. H. Kawakami, JP968570 (Application date: 1973/2/9)
3. P. Wild et al., APL. **19**(9), 335 (1971)
4. C.R. Stein et al., APL. **19**(9), 343 (1971)
5. P.M. Alt et al., IEEE Trans. ED. **ED-21**(2), 146 (1974)
6. H. Kawakami, JP1210998 (Application date : 1973/10/19)

7. T.J. Scheffer et al., SID 1985 Digest, 120 (1985)
8. T.J. Scheffer et al., SID 1992 Digest, 228 (1992)
9. S. Ihara, T.N. Ruckmongatham et al., SID 1992 Digest, 232 (1992)
10. N.A. Nehring et al., IEEE Trans. ED. **ED-26**, 795 (1979)
11. A.A. Lawrence et al., SID 2001 Digest, 98 (2001)

<http://www.springer.com/978-4-431-54858-4>

The Liquid Crystal Display Story

50 Years of Liquid Crystal R&D that lead The Way to the
Future

Koide, N. (Ed.)

2014, XIV, 416 p. 288 illus., 117 illus. in color.,

Hardcover

ISBN: 978-4-431-54858-4