1. INTRODUCTION

Liquid Crystal Displays (LCDs) constitute an important class of electronic displays and are extremely popular in a wide range of applications. Low-voltage operation, low-power consumption, low-cost, good readability in high ambient lighting condition and flat-panel construction are some of their major advantages. A typical LCD consists of an array of display elements or picture elements (pixels) organised in the form of an **X-Y matrix** as in the case of many flat-panel displays. The arrangement of pixels in these matrix displays is similar to that of memory elements in a two dimensional memory array. The pixels in a matrix display should have **non-linear** electro-optic characteristics for being selectively activated or **addressed.** This is known as matrix addressing and is also referred to as **multiplexing.** The **effectiveness** of LCDs in practical applications depends on the **efficiency of the pixel** as an electro-optic transducer and the **addressing technique** employed.

Considerable efforts have been directed towards the development of new electro-optic effects and new liquid crystal materials in order to improve the display characteristics. The Twisted Nematic LCDs (TNLCDs) and the Super-twisted Birefringence Effect Displays (SBE Displays) are the two most popular LCDs available today. Some common features relevant to the addressing of these displays are given below:-

- Non-linear electro-optic characteristics ;
- Long response times (~100 mS) ;
- Identical response to both positive and negative electric fields.

Hence TNLCDs and SBE Displays exhibit **rms** response to the applied electric field.

Some important characteristics desirable in addressing techniques for these LCDs are :

- **Good discrimination** between the **ON** and **OFF** pixels; this ensures a good contrast ratio in the display. The selection ratio defined as the ratio of the rms voltage across an **ON** pixel to that across an **OFF** pixel is a measure of this discrimination and hence it should be high.
- **DC-free operation;** the display should be addressed with ac fields to ensure its long life.
- **Low amplitude of addressing waveforms;** this reduces the supply voltage requirement of the drive electronics.
- **Good pixel-brightness uniformity;** this ensures uniform appearance of the display.
- **Ease of implementation;** this reduces hardware complexity and cost.

The following two approaches are possible for addressing matrix LCDs :-

- **Direct-multiplexing,** wherein the intrinsic non-linear characteristics of the pixels are exploited; this is used in many applications including computer terminals, in which the information to be displayed is bilevel (the pixels are either **ON** or **OFF**).
- **Active-matrix addressing,** wherein an extrinsic nonlinear element is incorporated in association with each pixel; this is commonly used in

small-area TV displays, in which grey scale and colour are important in addition to having a large number of pixels.

The Direct-Multiplexed displays are popular because of their simple construction, high yield and low cost. The development of addressing techniques for these displays with rms response has therefore attracted considerable attention in recent years. Some important developments in direct-multiplexing are given below :-

- Analysis of one-third selection technique (3:1 multiplexing) by Kmetz (1973). The selection ratio of this technique is optimum only when the number of lines multiplexed (N) is 4 and is not a maximum for any other value of N. However the supply voltage requirement of this technique is independent of N.

- Analysis of scanning limitations of LCDs by Alt and Pleshko (1974). This is an important milestone in the addressing of LCDs. The selection ratio of this technique (APT) is a maximum for all values of N, but the supply voltage requirement increases with N. A dc-free operation is ensured by a periodic reversal of the polarity of the row and column addressing waveforms which further increases the supply voltage requirement. Displays addressed using APT have a poor brightness uniformity of pixels when N is large.

- New addressing waveforms proposed by Kawakami, Nagae and Kaneko (1976) are an improvement over those of APT. This technique will be referred to as Improved Alt and Pleshko Technique (IAPT). It achieves the same selection ratio as in APT and a dc-free operation. But, IAPT

requires a lower supply voltage than APT. The brightness uniformity of pixels in displays addressed using IAPT is also poor when N is large.

- A special addressing technique with infinite selection ratio developed for displaying single waveform in Oscilloscopes by Shanks, Holland and Hughes (1978). In this technique, referred to as Pulse Coincidence Technique (PCT), only one pixel is selected (ON or OFF) in each column.

- Analysis of ultimate limits for matrix addressing of rms responding LCDs by Nehring and Kmetz (1979). It has been shown that the selection ratio cannot be improved significantly as compared to APT by any addressing technique, except when N = 2. The selection ratio as a function of the number of selected pixels in a column (restricted patterns) has also been analysed by them.

- General theory of matrix addressing of LCDs by Clark, Shanks and Patterson (1979). The binary addressing waveforms, possibility of displaying grey scale and restricted patterns in LCDs have been analysed.

- Addressing method for Non-multiplexed liquid crystal Oscilloscope display proposed by Shanks and Holland (1979). This technique can be used to display a single waveform with an infinite selection ratio and will be referred to as Pseudo Random Technique (PRT). The supply voltage requirement of this technique is almost independent of N.

- Switching bias voltage technique for multiplexing LCDs proposed by Lorteije (1981). This technique used simple LCD drivers with bilevel output and yet achieves the results of IAPT. The hardware complexity of this technique is lower than that of IAPT.

- New polarity reversal scheme for IAPT proposed by Ideno, Horikiri and Arai (1983). This improves the brightness uniformity of pixels in displays addressed using IAPT.

- Investigation of contrast variations in high-level multiplexed TNLCDs by Hughes (1986). The effects of dielectric relaxation in liquid crystal materials and the polarity reversal schemes on the brightness uniformity of pixels have been analysed in displays addressed using IAPT.

- Complex polarity sequences proposed by Maltese (1987). This technique again improves the brightness uniformity of pixels in displays addressed using IAPT.

In the present state of the art, the IAPT is widely used to address matrix LCDs for displaying general patterns. Although it is well known that the selection ratio cannot be improved over that of APT or IAPT, there is **scope for improvements** in the following areas : -

- Reducing supply voltage requirement ;
- Obtaining good brightness uniformity of pixels ; and
- Lowering of hardware complexity of the drivers.

In addition to this, the selection ratio of any new addressing technique **should not be significantly lower** than that of APT or IAPT, especially when N is large.

In the case of displaying restricted patterns the PRT proposed by Shanks and Holland (1979) is suitable for displaying a single waveform with

an infinite selection ratio. Only one-pixel is selected in each column here. However the horizontal resolution or the selection ratio is compromised if multiple waveforms are to be displayed. There is **scope for increasing** the selection ratio even when the number of selected pixels in each column is more than one. Any new addressing technique with a higher selection ratio and without any compromise in the horizontal resolution will be useful for displaying multiple waveforms in Oscilloscopes and Logic Analyzers.

Therefore, an in-depth study of the addressing techniques for rms responding LCDs was undertaken in order to achieve these goals. New addressing techniques developed as a result of this study form the main theme of this thesis.

The thesis is divided into five chapters. Following this introduction, Chapter 2 gives a brief introduction to the liquid crystals, important electro-optic effects in liquid crystals, matrix displays and multiplexing. This is followed by a survey of various addressing techniques for multiplexing LCDs with rms response. The chapter ends with a discussion on the need for new addressing techniques for rms responding LCDs.

Some new addressing techniques for multiplexing matrix LCDs with rms response are proposed in Chapter 3. While the conventional addressing techniques are based on line-by-line scanning, the Binary Addressing Technique (BAT), Hybrid Addressing Technique (HAT) and the Improved Hybrid Addressing Technique (IHAT) presented here are the outcome of **selecting more than one line** at a given instant of time. The IHAT-S3 and IHAT-S4 discussed are special cases of IHAT. Hardware reduction in the column drivers is achieved here by restricting the number of voltage levels in the column

waveforms. All these techniques are suitable for displaying general patterns. A comparison of these techniques with IAPT is presented next to show the usefulness of these techniques for addressing matrix LCDs. The Restricted Pattern Addressing Techniques (RPATs) proposed next are based on the line-by-line selection of rows in a matrix display. However the column signals are different from those of the conventional techniques (APT and IAPT). Apart from a detailed analysis of all these new addressing techniques a comparison of their performance with that of the conventional techniques is also presented in this chapter.

The practical implementation of these new addressing techniques is covered in Chapter 4. Their performance is evaluated experimentally and the results are compared with the theoretical analysis given in the previous chapter.

In the concluding Chapter, the implications of these new addressing techniques on LCD technology are reviewed and the scope for further work is briefly discussed.

A few Appendices giving some important physical parameters of liquid crystals and LCDs follow References. Some derivations related to the techniques discussed in Chapter 3 and the author's publications on the new addressing techniques presented in the thesis are also reproduced in the Appendices.