RECENT DEVELOPMENTS IN ADDRESSING PASSIVE MATRIX LCDs

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Introduction

Liquid Crystal Displays (LCDs) can be classified as Active matrix LCDs or Passive matrix LCDs on the basis of addressing. Active matrix displays have a nonlinear element (Thin Film Transistor or diode) incorporated into each pixel. While it is possible to achieve a performance level close to CRT displays, the cost of active matrix remains high due to complex production process and relatively low yields. Passive matrix displays exploit the intrinsic nonlinear characteristics of LCDs. They are simple to produce and cost considerably less than active matrix LCDs.

Matrix Displays and Matrix Addressing

In most of the flat panel displays the picture elements are arranged in the form of a two dimensional matrix array. While it is possible to connect individual elements to the drive electronics when the number of picture elements is small, it is extremely difficult in a display with large number of pixel (for example VGA display with 640 x 480 pixel). Hence a group of pixel is made to share a common lead or address line. Every pixel in the matrix display is connected to a row address line and a column address line. Therefore the row and the column address lines form a matrix with the individual pixel at their intersections. These pixel can be uniquely addressed as in the case of a two dimensional matrix array. A matrix display with R rows and C columns can have (R*C) pixel, while the number of external connections is just (R+C).

In a display it should be possible to change the state of each pixel without altering the state of the other pixel. The process of transmitting information to all the pixel and hence activating the appropriate ones is called addressing. This is similar to multiplexing in communication engineering. Hence the addressing technique is also referred to as multiplexing.

Block diagram of general multiplexing [1] is shown in figure 1. A set of orthogonal signals are used as carriers. Each signal to be multiplexed is multiplied with an orthogonal function. All such multiplied signals are added using summer and transmitted through the channel. At the receiver the combined signal is multiplied with replica of the orthogonal functions and the original signal is recovered after low pass filtering.

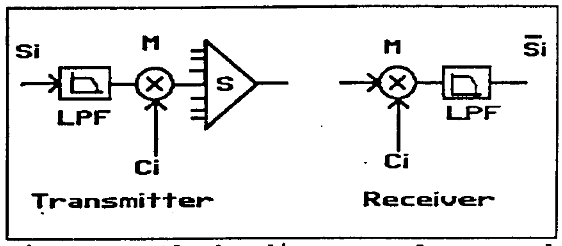

Figure 1 Block diagram of general multiplexing.

In matrix displays the row waveforms are a set of orthogonal functions. The column waveform is generated by multiplying the data to be displayed with the corresponding orthogonal function and adding them using a summer. The individual pixel located at the intersection of the rows and columns of the matrix LCD are the detectors for demultiplexing the data as explained below.

Let X(t) and Y(t) be periodic waveforms with the same period (T) that are being applied to the row and column of a matrix display. The rms voltage across a pixel is obtained by integrating and then taking square root of the following expression

$$V^2 = (X(t)-Y(t))^2 \qquad [1]$$

$$= X^2(t)-2X(t)Y(t)+Y^2(t) \qquad [2]$$

There are three terms in the expression. The mid term giving the cross product of the voltages applied to the row and column, takes care of the multiplication. Slow response of the LCD (rms behaviour) takes care of the integration. Hence the LCD pixel can be used as a detector for demultiplexing provided the first and last terms are constant. The polarity of the column voltage can be changed without affecting the last term. This influences the sign of the mid term only. Hence the rms value across the pixel can be changed by changing

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the sign of the column voltage. Here the sign of the column is the data and -1 and +1 correspond to ON and OFF respectively. The amplitudes of the row and column waveforms are optimized to obtain good discrimination between ON and OFF pixel.

Conventional Addressing

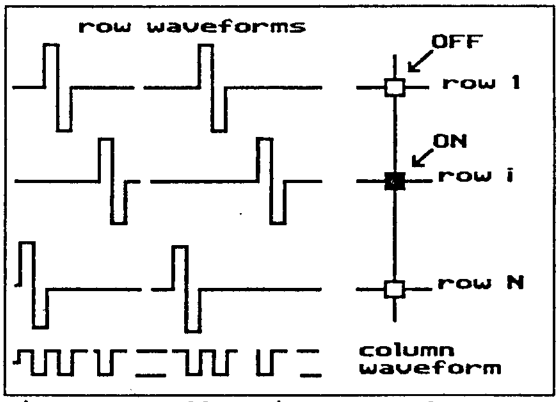

Figure 2 Addressing waveforms - Conventional Technique.

Typical addressing waveforms of conventional addressing technique [2] is shown in figure 2. A set of block pulses, which are orthogonal are used. The rows of the matrix display are sequentially selected with bipolar pulses. The polarity reversal in the pulses is to achieve a dc free operation which is essential to ensure a long life of the display. The column waveform corresponds to the state of the pixel in the selected row. The column signal is in phase with the row select pulse for an OFF pixel and out of phase with the row select pulse for an ON pixel. The amplitude of the row select pulse must be $N^{1/2}$ times the amplitude of the column waveforms for maximum selection ratio, where N is the number of lines multiplexed. Selection ratio is the ratio of rms voltage across ON pixel to that of OFF pixel. The maximum selection ratio is given by $[(N^{1/2}+1)/(N^{1/2}-1)]^{1/2}$ which is the maximum possible value for any addressing technique. This is due to the fact that a signal applied to a column for activating a pixel in a selected row appears across all the pixel connected to that column. Hence the display should have non linear characteristics if they are to be multiplexed The selection ratio decreases rapidly as N increases. For example the selection ratio is infinity for N=1, 1.414 for N=9 and 1.105 for N=100. Hence highly nonlinear characteristic is desired if a large number of lines are to be multiplexed as in the case of VGA display.

Super Twisted Nematic LCDs (STN LCDs)

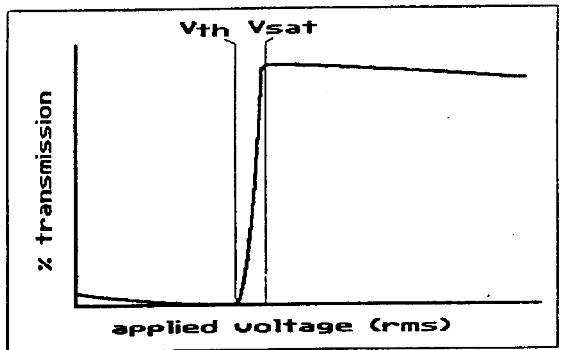

Figure 3 Electro optic characteristics of STN LCDs.

Super Twisted Nematic (STN) LCDs are the most popular passive matrix LCDs. Typical electro optic response of STN LCD is shown in figure 3. There is a threshold voltage below which there is no response to the electric field. The steepness of this characteristic above threshold voltage determines the size of the matrix display that can be multiplexed. Large matrix displays demand a sharp threshold characteristic.

STN LCDs are relatively slow responding devices with typical switching times in the range of a few hundred milliseconds. The performance of these displays is satisfactory when conventional addressing technique [2,3] based on selecting one row at a time is used. The response times of STN LCDs can be lowered by reducing the thickness of the cell and increasing the optical anisotropy and decreasing the viscosity of the liquid crystal mixture used in the display. STN Displays with average response time less than 50 ms have been demonstrated recently. However the contrast ratio is poor when these displays are driven with the conventional addressing techniques. This is due to the frame response phenomenon explained below.

Frame Response

LCDs respond equally well to positive and negative voltages and are slow responding devices and hence their behaviour is characterised by the root-mean-squared (rms) value of the applied voltages. The addressing techniques for passive matrix LCDs are based on the rms behaviour and this condition is easily satisfied when the period of the addressing waveform to achieve the same rms voltage across the pixel.

The number of voltage levels in the column waveform is (N+1), where N is the number of lines multiplexed. For example 241 voltage levels are necessary in the column voltages if the pixel are driven either to ON or OFF state (no grey level display). This demands the use of analog type LCD drivers (with sample and hold circuit for each output) that are used in Active matrix LCDs. The same analog type drivers are adequate for displaying grey shades where the number of voltage levels in the column waveform increases considerably.

The hardware complexity of Active addressing is high since the column voltages are to be computed in a short time using hard wired logic gates. Let N be the rows and M be the columns in a matrix display. M column voltages have to be computed within a row select time (about 64 microseconds). This means N EX-OR gates are used for the 1 bit multiplication of data to displayed in a column with the orthogonal matrix. Several stages of summers are necessary to add the outputs of N EX-OR gates. M such computations of column voltage have to be carried out before selecting the row with voltages corresponding to a column of the orthogonal matrix. This also demands that the data to be displayed in a frame be available in row select time. It is not possible to achieve this cost effectively with memories available today. Hence a buffer memory is provided where in the computed values of column voltages are stored so that M column voltages are accessed during each row select time.

The Active addressing technique can be used to display grey shades using Pulse Height Modulation [8]. The displays driven with Active addressing have high contrast ratio. However the hardware complexity, memory bandwidth requirement and power consumption of the display (due to the additional hardware, speed of operation and analog type column drivers) are higher than the conventional addressing techniques. Hence it is desirable to find a suitable alternative for suppressing the frame response. In fact, the Improved Hybrid Addressing Technique (IHAT) proposed by the author [9] in the year 1988 is well suited for suppressing the frame response in fas STN LCDs.

Improved Hybrid Addressing Technique

In Improved Hybrid Addressing Technique (IHAT) only a few lines are selected simultaneously as compared to all the lines being selected in Active addressing. Hence the address duty factor is (L/N), where L is the number of lines selected simultaneously. This results in considerable reduction in the hardware for computing column voltages, memory bandwidth and the number of voltage levels in the column waveform.

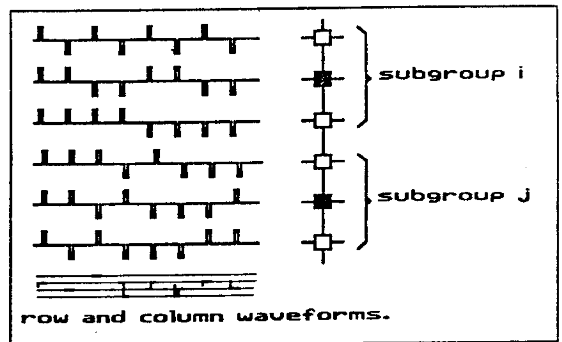

Figure 6 IHAT (L=3) - Addressing waveforms.

The N lines to be multiplexed in a matrix display are divided in to a number of subgroups each consisting of L address lines. These subgroups are individually selected with a set of L orthogonal functions one after another. Rademacher functions, a set of orthogonal functions consisting of square waveforms of different frequencies (output of a L stage counter) are used to select the subgroups. The subgroups are in turn selected sequentially one after the another. This is equivalent to combining frequency and time division multiplexing.

Fgure 6 gives the typical addressing waveforms of IHAT when L=3. The subgroups i and j are selected sequentially, while the lines in the subgroups are selected simultaneously. The subgroup i is selected with all possible combinations (2^3=8) in natural order while the subgroup j is selected with the same eight combinations arranged in the form of pseudo random binary sequence. This does not alter the rms voltage across a pixel. The frequency spectrum and the number of transitions in the addressing waveforms depend on this order of the binary sequence. The use of pseudo random binary sequency is preferable from the point of brightness uniformity of the display. Good brightness uniformity is achieved here since the frequency spectrum of all the row waveforms are same since they are identical except for the phase shift. The selection ratio is maximum when the ratio of the row select voltage to maximum amplitude of the column is is small as compared to the response times of the display. In the conventional addressing techniques based on selecting one line at a time, the instantaneous voltage across a pixel (both ON as well as OFF pixel) is very large as compared to the threshold voltage when the corresponding row is selected. The period of the addressing waveform is comparable to the response times in a fast responding STN LCD. Hence the light transmission in the cell starts following the instantaneous voltage across the cell to some extent as shown in figure 4.

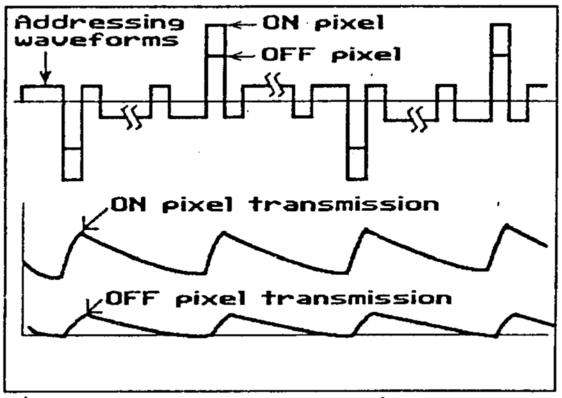

Figure 4 Frame response phenomena

Light transmission through ON pixel (which is high when a row is selected) decreases rapidly due to relaxation of the liquid crystal. Light transmission through the off pixel increases during the row select time which is not desirable and this causes considerable reduction in the contrast ratio of the display. Hence the frame response [4] observed in fast responding LCDs is mainly due to large amplitude of pulses in the addressing waveforms and relatively large separation between these pulses. Reducing the amplitude of the row select pulses [5] decreases the selection ratio (ratio of rms voltage across an ON pixel to that of an OFF pixel) and hence this is not a good solution. Alternatively the period of the addressing waveform can be decreased by increasing the frame frequency [6]. However this results in poor brightness uniformity of the display. This is due to relatively narrow pulses in addressing waveforms wherein the distortion in the waveforms arising from RC time constant becomes significant. Hence it is clear that a different approach is necessary to suppress the frame response problem.

In the conventional addressing technique [2,3] a pixel gets meaningful information only when a row is selected. Thus the address duty factor is low (1/N where N is the number of lines multiplexed). The amplitude of the pulses and the relative time between the pulses in the addressing waveforms can be reduced without affecting the selection ratio if the address duty factor is increased. This is the basic motivation for the development of new addressing techniques (referred to as Active Addressing) with higher duty factor as compared to the conventional addressing technique.

Active Addressing

Active addressing was proposed by Scheffer and Clifton [7] in the year 1992. Here all the rows to be multiplexed are selected with walsh functions. The walsh functions are periodic functions and are orthogonal to each other. The amplitude of these functions is either +1 or -1 and hence the multiplicationnecessary for generating the column voltage reduces to either addition or subtraction. The walsh functions can also be represented in matrix form. A set of walsh functions are shown in Figure 5. All the rows in the matrix display are selected with voltages corresponding to a column vector of the orthogonal matrix. Hence the address duty factor is unity in active addressing. The column voltage is computed by multiplying the data to be displayed in the column with the corresponding element in the column vector of the orthogonal matrix and then adding all such products. The selection ratio is a maximum when the maximum amplitude of the column voltage is $N^{1/2}$ times the amplitude of the row select voltage. The probability of occurrence of maximum amplitude of the column voltage however is very low and most of the time amplitude of the column voltage is relatively small.

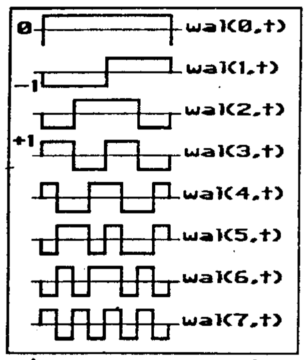

Figure 5 Walsh functions.

Active addressing is effective in suppressing the frame response. This is due to the low amplitudes of addressing waveforms. The energy that is concentrated in a single pulse in the conventional waveform is redistributed into N time intervals in Active addressing

$(N^{1/2}/L)$.

The frame response can be easily suppressed by selecting just seven rows simultaneously[10] even when the number of lines multiplexed is a few hundreds. The number of voltage levels will be eight (L+1) and most suited for the digital type LCD column drivers wherein a limited number of voltage levels are switched using an analog multiplexer for each output.

The hardware complexity of IHAT is low since only L one bit multiplications using EX-OR gates and L bit summer for addition are necessary for generating the column voltage. The memory band width requirement is also low since only L•M data are to be accessed within one row select time as compared to N•M in the case of active addressing. Here M is the number of columns in the matrix display.

The number of time intervals to complete a cycle is large for IHAT since Rademacher functions are used. Hence it is not possible to extend frame modulation technique to generate grey shades. The amplitude modulation technique[11] may be used in combination with IHAT for displaying grey shades. However the number of voltage levels in the column waveform is large and the advantage of limited voltage levels is lost. Dither technique may be used for displaying grey shades without increasing the complexity of IHAT. Alternatively the number of time intervals to complete a cycle can be reduced by changing the orthogonal function as in the case of Sequency Addressing Technique discussed below.

Sequency Addressing Technique (SAT)

The sequency addressing technique is based on using Hadamard matrices for selecting L rows simultaneously. This technique is similar to IHAT in all other aspects like dividing the N address lines in subgroups with L lines, computation of column voltages etc. The number of time intervals in SAT is comparable to the conventional addressing technique. Grey shades can be displayed by using frame modulation technique without increasing the hardware complexity.

Conclusion

All the new addressing techniques discussed above are based on selecting more than one line at a given instant of time. All these technique have better brightness uniformity of pixel and lower supply voltage requirement as compared to the conventional addressing technique. The hardware complexity of these techniques vary considerably. The choice of a particular technique also depends on the number of grey levels necessary for a given application. Frame modulation or dither technique can be used in combination with IHAT or SAT to reduce hardware complexity when less than 16 grey shades are displayed. The amplitude modulation is necessary when more grey shades are to be displayed. The analogy between matrix addressing and the better known multiplexing in communication engineering, presented in this paper will hopefully lead to a better understanding of these new addressing techniques for passive matrix LCDs.

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