Displaying Gray Shades In Passive Matrix LCDs Using Successive Approximation

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ABSTRACT

The gray shades to be displayed in each pixel are represented as a g bit binary number and g time intervals are used to display any one of the 2^g gray shades. Amplitudes of the row and column waveforms of a passive matrix LCD are varied in different time intervals depending on the bit value of the gray shade data. Row and column voltages are reduced by a constant factor $1/\sqrt{2}$ as one scans the display using the most significant bit to the least significant bit. This results as a variation of RMS voltage across the pixels depending on the data and hence its gray shade. This has been achieved without any compromise on the selection ratio. In fact the standard drivers used for displaying bi-level (no gray shades) information are adequate if the voltage level generator is modified. For a given number of gray shades the flicker in the display is substantially less as compared to frame rate control method of displaying gray shades. Successive Approximation method has been used in conjunction with multi-line addressing (MLA) so as to keep the supply voltage low. The paper will describe the technique and present the experimental results.

Keywords: passive matrix, addressing technique, gray shade,

BACKGROUND

In the Super Twisted Nematic (STN) LCDs Frame Rate Control (FRC) [1] is widely used to display gray shades. In FRC f frames are used to display $(f+1)$ gray shades. FRC uses standard row and column drivers to display gray shades. Flicker become visible as the number of gray shades increases. Pulse Width Modulation (PWM) [2] is also used to display gray shades. Here, each row select time is divided in to p time intervals to display $(p+1)$ gray shades. Width of the pulses decrease as the number of gray shades increases. This leads to presence of high frequency components across the pixel resulting in brightness non-uniformity. Hence, the number of gray shades are limited in both these techniques. Amplitude Modulation (AM) [3] and Pulse Height Modulation (PHM) [4] may be used to display a large number of gray shades. However, the number of voltage levels in the column waveforms is high. Hence, analog type column drivers are necessary for displaying gray shades. The supply voltage of all these techniques while displaying gray shades is same as that for displaying bi-level information. Mano *et al.*, proposed the partial dispersion driving method [5] to display eight gray shades. Here. the amplitudes of the row waveforms were varied in the successive time intervals. The amplitude was reduced by a factor 2 in the successive time intervals from the most significant bit to the least significant bit. The selection ratio of this technique is lower than the maximum. The supply voltage increases when the amplitude of the row waveform is modulated in the successive time intervals. Hence they had demonstrated this technique in combination with multi-line addressing (MLA) to reduce the supply voltage and suppress the frame response. A Successive Approximation method is proposed in this paper to display gray shades without any compromise on the selection ratio.

TECHNIQUE

The N rows in a matrix display are divided into (N/s) non-intersecting subgroups. Each subgroup consists of s address lines. At a given instant of time a subgroup is selected with a row select pattern. The row select patterns are columns of an orthogonal matrix. This matrix is based on either hadamard matrices or walsh functions. The rest of the rows in the $(N/s - 1)$ subgroups are grounded. Here, a frame corresponds to selecting all the subgroups with all the row select pattern once. Only one of the g bits (of gray shade data) is considered during a frame. The column data is computed by taking the dot product between the row select pattern and the one bit of the data in the selected subgroup. Column data for all the columns are computed and shifted into the column drivers. The row and column voltages are multiplied by a factor C_f, wherein f corresponds to the bit position of the gray shade data. Both the row and column voltages are applied simultaneously to the matrix display for time duration τ. One frame is completed when all the subgroups are scanned with all the row select patterns once. As one can see, the scanning of the display is same as that for bi-level image except for the modulation of the row and column waveforms by C_f. In the next frame the scanning sequence is repeated by using the next bit as the data and the amplitudes of the row and column waveforms are multiplied by $C_{(f+1)}$. A cycle is complete when all the g bits of data and the corresponding g frames are used to scan the display once. Figure 1 shows the typical addressing waveforms of the Successive Approximation method in combination with the multi-line addressing technique. The waveforms in Figure 1 correspond to selecting a subgroup with all the row select patterns before moving on to the next subgroup. This has been shown to illustrate the waveforms of Successive Approximation clearly. However, both the subgroup and the row select

ISBN: 981-04-6983-7

patterns were changed after selecting a subgroup with a row select pattern to ensure good brightness uniformity of pixels as shown in Figure 2.

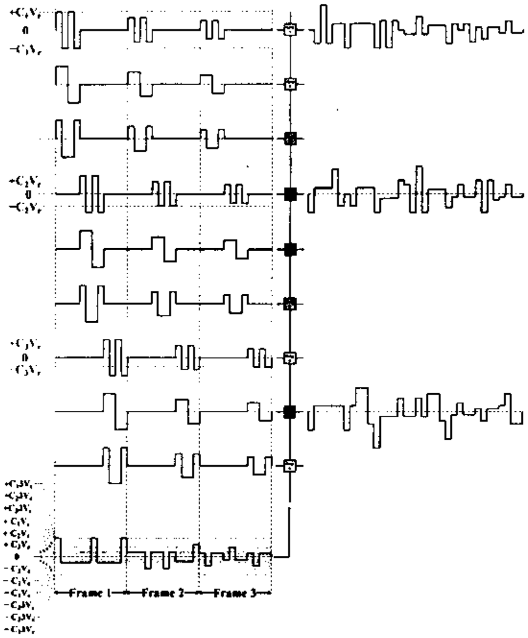

Figure 1. Typical addressing waveforms of Successive Approximation method in combination with MLA when N = 9, s = 3 and g = 3.

ANALYSIS

Gray shade of a pixel may be represented by

$$\sum_{f=1}^{g} d_{(g-f)}\ 2^{(g-f)} \qquad (1)$$

In the Successive Approximation technique the desired RMS voltage across the pixel is achieved by using g successive frames. The matrix display is scanned using one of the g bits (representing the gray shade value of the pixel) in each frame. The g frames corresponding to g bits (from MSB to LSB) form a cycle. The column signals are computed just as in the case of displaying bi-level information using one of the g bits. However, the amplitude of the row voltages are modified to $\pm C_f V_r$ instead of $\pm V_r$ and similarly the column voltages are multiplied by C_f corresponding to the f^{th} bit of the gray shade data. The matrix is scanned with these modified voltages. A cycle is complete when the matrix display is scanned by using the most significant bit to the least significant bit of the gray shade data with corresponding modulation (C_f) in the amplitudes of the row and column waveforms. The expression for square of the voltage across the i^{th} pixel in the k^{th} subgroup during a frame, when the matrix display is scanned with multi-line addressing[6] by selecting s rows and one bit data is given by the equation 2.

$$V_{ks+i}^2 = \left[\frac{q\ V_r^2 - 2\ q\ V_r V_c\ d(ks+i) + q\ N\ V_c^2}{q\ \left(N/_s\right)}\right] \qquad (2)$$

Wherein, $d(ks+i)$ represents the data bit for the i^{th} row in the k^{th} subgroup for a given column. q is the number of columns in the orthogonal matrix.

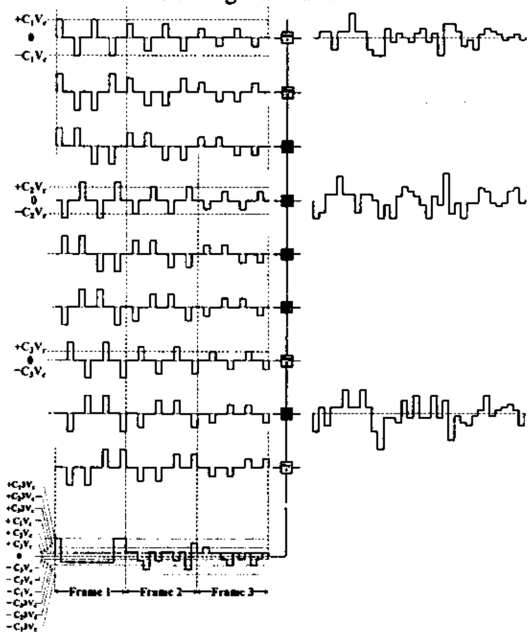

Figure 2. Typical addressing waveforms of Successive Approximation method in combination with MLA (N = 9, s = 3 and g = 3) when row select pulses are distributed in the frames.

Square of the voltage across the pixel during a frame with the modified row ($C_f V_r$) and column ($C_f V_c$) voltages is

$$V_{ks+i}^2 = \left[\frac{C_f^2\ q\ V_r^2 - 2\ C_f^2 q\ V_r\ V_c\ d_{(g-f)}(ks+i) + C_f^2 q\ N\ V_c^2}{q\ \left(N/_s\right)}\right]$$

$$V_{ks+i}^2 = \left[\frac{C_f^2\left(\ q\ V_r^2 - 2\ q\ V_r\ V_c\ d_{(g-f)}(ks+i) + q\ N\ V_c^2\right)}{q\ \left(N/_s\right)}\right] \qquad (3)$$

The expression for the RMS voltage across a pixel in a cycle consisting of g frames is

$$V_{ks+i} = \sqrt{\frac{\sum_{f=1}^{g} C_f^2\left(\ q\ V_r^2 - 2q\ V_r V_c d_{(g-f)}(ks+i) + q\ N\ V_c^2\right)}{q\ g\ \left(N/_s\right)}} \qquad (4)$$

The following condition needs to be satisfied

$$\frac{C_f^2}{C_{f+1}^2} = 2\ , \quad \text{wherein} \quad C_f = \sqrt{2^{(g-f)}}$$

ISBN: 981-04-6983-7

The selection ratio is maximum when $V_r = \sqrt{N}\ V_c$ and the maximum selection ratio is $\sqrt{\frac{\sqrt{N}+1}{\sqrt{N}-1}}$. The RMS voltage across the ON and OFF pixels differ by a factor $\left(\sqrt{\frac{2^g-1}{g}}\right)$ as compared to the RMS voltages without any modulation. The OFF pixels in the display are biased near threshold voltage (V_{th}) in order to obtain a good contrast ratio. Hence, $V_{off} = V_{th}$

$$V_{off(RMS)} = \left(\sqrt{\frac{2^g-1}{g}}\right)\sqrt{\frac{\left[V_r^2 - 2\ V_r\ V_c + N\ V_c^2\right]}{\left(N/s\right)}} = V_{th}$$

$$V_c = \left(\sqrt{\frac{g}{2^g-1}}\right)\sqrt{\frac{N}{2\ s\left(N-\sqrt{N}\right)}}\ V_{th} \qquad (5)$$

Supply voltage requirement depends on maximum swing in the addressing waveforms across rows and columns. The maximum swing in the row waveform is greater than column waveforms when $N \geq s^2$ and is lesser than the column waveforms when $N \leq s^2$. The supply voltages for these two cases are given below.

Case I:

$$V_{sup} = 2\ C_1\ s\ V_c = 2\ \sqrt{2^{(g-1)}}\ s\ V_c \quad \text{for } N \leq s^2$$

$$V_{sup} = \sqrt{\frac{2\ s}{\left(1-\frac{1}{\sqrt{N}}\right)}\left(\frac{g\ 2^{(g-1)}}{2^g-1}\right)}\ V_{th} \quad \text{for } N \leq s^2 \qquad (6)$$

Case II:

$$V_{sup} = 2\ C_1\ V_r = 2\ \sqrt{2^{(g-1)}}\ \sqrt{N}\ V_c \quad \text{for } N \geq s^2$$

$$V_{sup} = \sqrt{\frac{2\ N}{s\left(1-\frac{1}{\sqrt{N}}\right)}\left(\frac{g\ 2^{(g-1)}}{2^g-1}\right)}\ V_{th} \quad \text{for } N \geq s^2 \qquad (7)$$

The supply voltage increases with g, i.e., gray shades being displayed. It increases by a factor $\sqrt{\frac{g\ 2^{(g-1)}}{2^g-1}}$ as compared to the bi-level display. Figure 3 shows the increase in the supply voltage with respect to the number of bits g. This scaling factor is independent of the addressing technique used to scan the display. The supply voltage increases almost linearly with g. Supply voltage for displaying 256 gray shades is twice that of bi-level display. Supply voltage can be kept low by using MLA technique as compared to the conventional addressing technique. The number of voltage levels in the column waveform in a frame is (s+1), same as that of bi-level display.

The main advantage of Successive Approximation method is that both the row and column drivers used to drive the bi-level display can be used with a small modification in the voltage level generator (VLG) as shown in Figure 4.

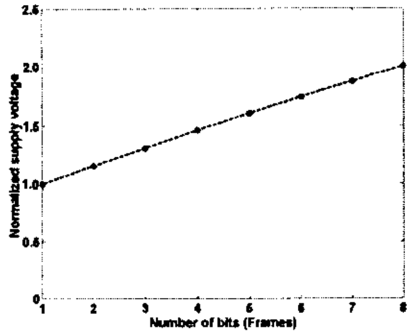

Figure 3. Supply voltage normalized to that of bi-level display versus number of bits.

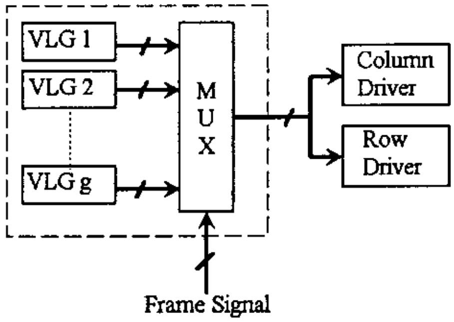

Figure 4. Modified voltage level generator for the Successive Approximation method to display gray shades.

RESULTS

The technique has been implemented using a 32x32 matrix TN-LCD by selecting three rows at time for displaying 16 gray shades. Figure 5 shows electro-optic response measured when Successive Approximation method is used for generating 16 gray shades. The RMS voltages across the pixels were measured using a logging multimeter (HP 3467A). Figure 6 shows the RMS voltage measured across the pixels versus supply voltage for these gray shades.

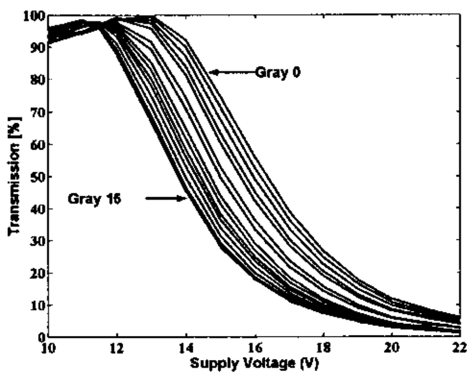

Figure 5. Light transmission versus supply voltage.

ISBN: 981-04-6983-7

The RMS voltage across the ON and OFF pixels are plotted in figure 7 against the supply voltage. The selection ratio is also shown in the same figure. The selection ratio obtained from these measurement agrees within ±0.5% of the theoretical value of 1.1956.

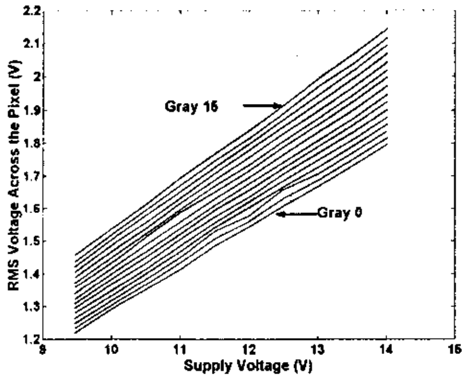

Figure 6. RMS voltage across a pixel versus supply voltage.

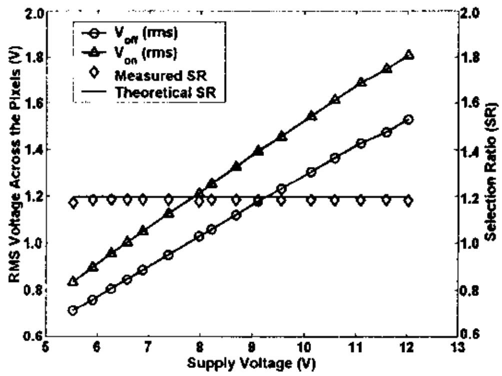

Figure 7. Selection ratio and RMS voltage across the ON and OFF pixels versus supply voltage.

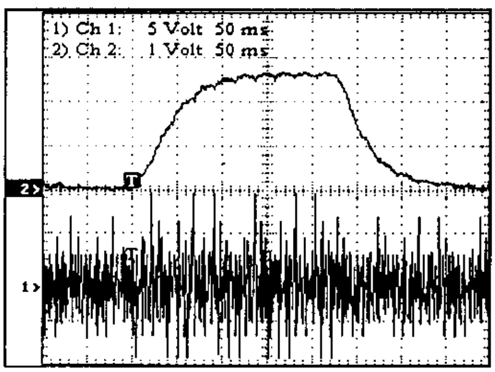

Figure 8. Electro-optic response of a pixel when switched between ON and OFF states.

Electro-optic response when a pixel is switched between On and OFF states is shown in Figure 8. The response time between OFF to ON and ON to OFF states are around 98 ms and 99 ms respectively. The response times when switching the pixels between the gray shades is given in Table 1. The first row and column of the Table 1 are the nine gray shades used for the measurement of the response times. A photograph of a 32×32 TN LCD for displaying 16 gray shades using Successive Approximation with four frames in a cycle is shown in figure 9.

Table 1. Response times (ms) between gray shades.

Gray Shade	0	2	4	6	8	9	11	13	15
0	-	109	122	118	113	109	112	98	98
2	99	-	113	112	95	112	112	101	88
4	117	89	-	98	95	104	89	101	93
6	107	98	110	-	96	92	96	89	87
8	96	86	98	79	-	82	76	84	82
9	97	96	99	102	84	-	83	72	69
11	102	105	94	93	77	79	-	71	62
13	91	91	99	85	74	65	85	-	49
15	99	92	111	92	92	80	52	56	-

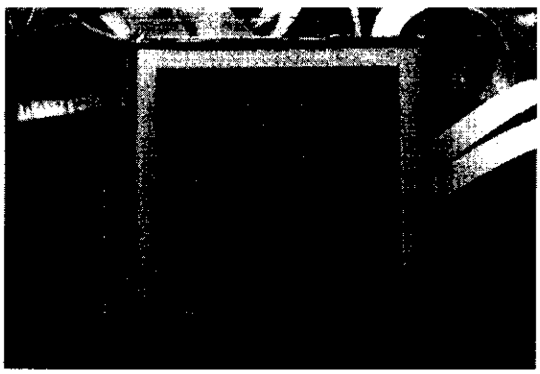

Figure 9. A 32x32 matrix LCD displaying gray shades using Successive Approximation method.

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ISBN: 981-04-6983-7