P-123: A Method to Achieve Uniform Gray Scale to Gray Scale Response Times in LCDs

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Abstract
Uniform gray scale to gray scale response times is achieved in liquid crystal displays for a large number of gray shades with wavelets based addressing technique. The method is demonstrated for 64 gray shades and it can be extended to other addressing techniques.

1. Introduction
Grayscale to grayscale response times in liquid crystal displays (LCDs) i.e., the time taken to switch pixels from one gray shade to another depends on several factors; viz. liquid crystal mixture, thickness of display cell, electro-optic effect, waveform across pixel etc. Color purity of pixels can be preserved and motion related artifacts can be reduced if RGB sub-pixels switch at the same rate; i.e., if switching times are independent of initial and final gray shades. Waveform (sequence of instantaneous voltages) across a pixel plays an important role in determining its response times. Uniform switching times was achieved with modified discrete cosine transform to drive LCD and was demonstrated in SID'08[1]. Main objective of this work is to achieve uniform switching times with multi-line addressing techniques like wavelets based techniques[2-4] that are capable of displaying a large number of gray shades without flicker.

2. Effect of Scanning Sequence
Liquid crystal displays exhibit RMS (root-mean-square) response when the period of addressing waveforms is small as compared to response times of the display. Liquid crystal molecules' response to transitions in the addressing waveform can be seen; especially when amplitude of the transitions is large even though they are slow to respond. We were interested to study the effect of scanning sequence (i.e., waveform) on response time. Line-by-line addressing techniques have limited scope to vary the scanning sequence. On the other hand, multi-line addressing techniques have high flexibility and it is possible to achieve the desired RMS voltages across pixels with different waveforms based on the choice of scanning sequence i.e., the order of selecting address lines with multiple select pulses of the addressing waveforms.

2.1. Wavelets based Addressing Technique
Wavelets based addressing technique can display a large number of gray shades without flicker. Hardware complexity of display drivers and the supply voltage are low for wavelets based multi-line addressing techniques. Wavelets based addressing technique is described briefly with an example. Waveforms derived from an orthogonal matrix shown in (1) are used to display 64 gray shades[2] in matrix LCDs. Wavelets in the 1st, 2nd and 3rd rows are used to deliver energies that are proportional to weight of gray shade bits d_5, d_2 and d_4 respectively; where as a combination of 3-wavelets in 4th row are used to deliver energies that are proportional to bits d_3, d_1 and d_0 respectively. Here, d_5 is the most significant bit and hence, it has eight non-zero elements. Wavelets corresponding to lower bits either have less number of elements (for example row-3) or elements of lower amplitude as in the case of row-2 and to some extent row-4.

$$\begin{bmatrix} +4 & -4 & +4 & -4 & +4 & -4 & +4 & -4 \\ 0 & +2 & 0 & -2 & 0 & +2 & 0 & -2 \\ +4 & 0 & -4 & 0 & +4 & 0 & -4 & 0 \\ +4 & +1 & -2 & -1 & -4 & -1 & +2 & +1 \end{bmatrix} \quad (1)$$

Bits corresponding to each element of the orthogonal matrix are shown in (2).

$$\begin{bmatrix} d_5 & d_5 & d_5 & d_5 & d_5 & d_5 & d_5 & d_5 \\ 0 & d_2 & 0 & d_2 & 0 & d_2 & 0 & d_2 \\ d_4 & 0 & d_4 & 0 & d_4 & 0 & d_4 & 0 \\ d_3 & d_0 & d_1 & d_0 & d_3 & d_0 & d_1 & d_0 \end{bmatrix} \quad (2)$$

A cycle of scanning is complete when each and every group of rows in the matrix display is selected with voltages (select pulses) that are proportional to each and every element of the orthogonal matrix in (1). Data waveforms are also applied simultaneously to columns of the matrix display as described in reference 2. Some of the many possible sequences of scanning the matrix display are described in the next section.

2.2. Some Scanning Sequences
Rows in a matrix display are grouped so that each group has a pre determined number of rows (four rows in our example). Columns of the orthogonal matrix are called select vectors because several rows in a matrix display are selected simultaneously by applying voltages that are proportional to the elements of select vector. A scanning cycle consists of selecting each and every group of rows (in the display) with all select vectors in the orthogonal matrix and its rotated versions once; i.e., 32-select vectors in our example. A few possible select sequences are as follows:

- Each group is selected sequentially with all the select vectors and their rotated versions once and the groups are also selected sequentially to complete a cycle. The 32-select pulses are clustered together in our example.
- Each group is selected with any one select vector and the groups are selected sequentially one after another. A cycle is complete when all the groups are selected once with all the select vectors. Here, all the 32-select pulses are distributed without any clusters.
- Each group is selected with a few select vectors and the groups are selected sequentially till all the select vectors are used to select the groups once. Select pulses in the addressing waveforms will be partially clustered and such clustered pulses are also distributed equally in the addressing waveforms.

 ISSN/009-0966X/09/3903-1584-$1.00 © 2009 SID

In yet another approach; each group of rows can be selected with a select vector and its rotated versions before selecting other groups sequentially and a cycle is complete when all the select vectors in the orthogonal matrix is used once to select the groups. Here, there is a possibility of clustering select pulses corresponding to different gray shade bits and avoiding clusters of pulses of same bit in a systematic manner. We have used this scanning sequence to achieve a reasonably uniform gray scale to gray scale response times.

3. Measurement of Response Times

Liquid crystal displays exhibit RMS (root-mean-square) response to the electric field when the period of addressing waveforms is smaller than the time taken by the molecules to reorient to the electric field. Hence, the period of addressing waveforms of passive matrix LCD is chosen to be smaller than the response time of the display to achieve RMS response. Light transmission through a pixel (in a matrix LCD) that was captured using a photo detector and a digital storage oscilloscope is shown in Figure 1.

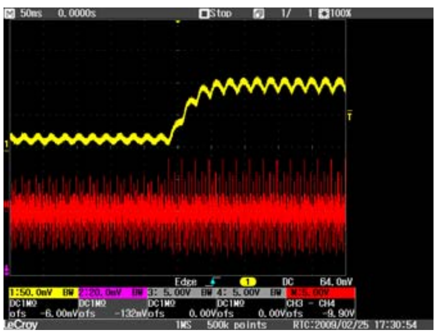

Figure 1 Transmission of light through a pixel in a matrix LCD when the pixel is switched from one gray shade to another. Intensity of light falling on the detector to some extent follows the instantaneous voltage across the pixel; whereas the average light throughput depends on the RMS voltage.

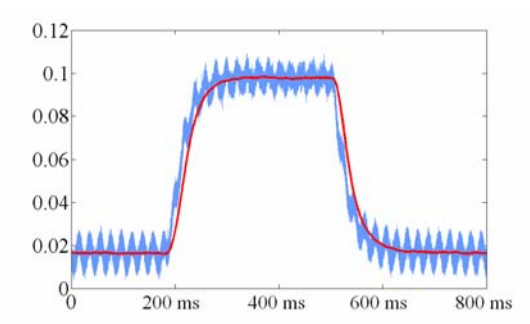

Figure 2 Transmission of light through a pixel that is captured using a digital storage oscilloscope (blue) and the plot of response time after filtering (moving average of data captured during 20ms) is shown in red line.

Fluctuations in light transmission seen in the figure are due to response of the liquid crystals to transitions in the addressing waveform. We have used a moving average filter to average the samples of detector output during a period of 20 ms (equal to the period of a frame i.e. time taken to address the display once) to obtain a smooth response curve as shown in Figure 2. The moving average filter is also useful to eliminate the interference from the power line frequency of 50Hz. We have used the conventional definition of response time and measured the time taken for the light transmission to change from 10% to 90% of the total change in light transmission from one gray shade to another.

4. Effect of Select Sequence

Light transmission through a pixel in two extreme cases of select sequences are shown in Figures 3 and 4 respectively when a pixel is driven from one gray scale to another with wavelets based addressing technique.

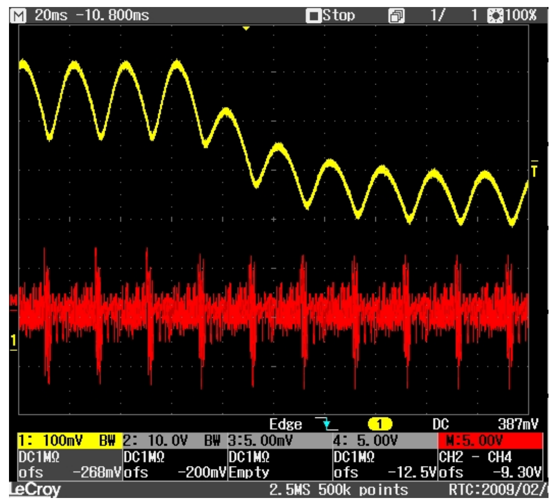

Figure 3 Transmission of light through a pixel (yellow) when it is switched from one gray shade to another by using 32-select pulses that are clustered (red).

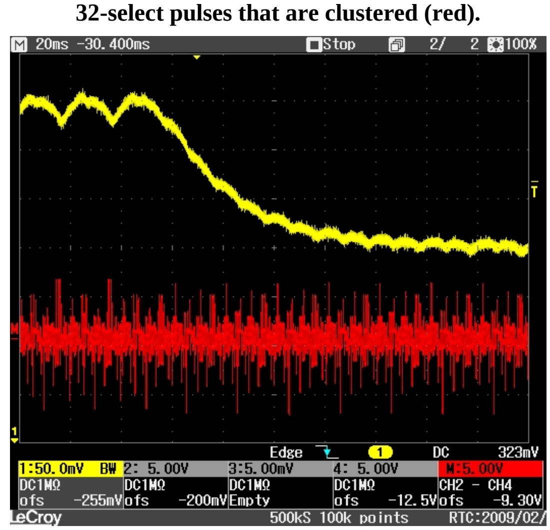

Figure 4 Transmission of light through a pixel (yellow) when the scanning sequence is chosen to distribute all the select pulses in the addressing waveform(red).

4.1. Clustered Pulses in Select Waveforms

Select pulses corresponding to eight columns of the orthogonal matrix are clustered and subsequent 3-sets of eight pulses are obtained by rotating the matrix vertically to obtain clustered select pulses in the select (row) waveforms. For example; amplitude of select pulses for the first row is as shown here:

{4,-4,4,-4,4,-4,4,-4,0,2,0,-2,0,2,0,-2,4,0,-4,0,4,0,-4,0,4,1,-2,-1,-4,-1, 2,1} and the voltage will be 0 (non-select voltage) during 224 time intervals in a cycle of 256 time intervals. Distribution of response times is shown in Figure 5.

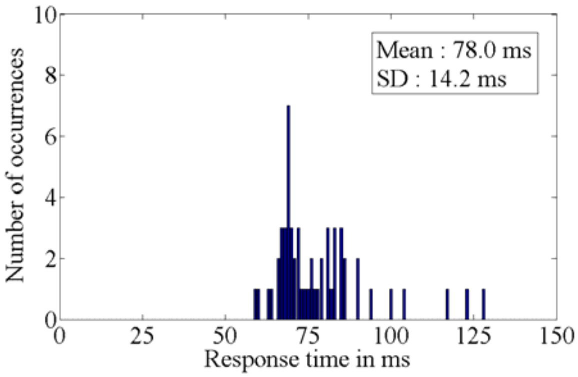

Figure 5 Number of occurrences of response time vs response time in ms when the scanning sequence has 32-select pulses clustered.

Response times range from 59 to 127 ms with a mean of 78ms and standard deviation of 14.16ms. Spread in response times is reduced with the select sequences described next.

4.2. Small Cluster of Pulses by Rotation

We found that small cluster of pulses obtained by rotating one or few select vectors that are separated by a relatively long duration of non select voltage, are better way from the point of response times. We have measured the response times when 1, 2 and 4 select vectors and their rotated versions are used to select the address lines. For example; the select pulses are proportional to{4,0,4,4,-4,2,0,1} during 8 time intervals and it is followed by application of non-select for a duration of 56 time intervals when two select vectors are used to get the clustered pulses.

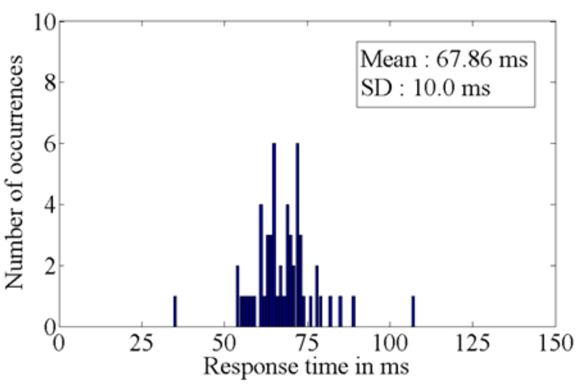

Figure 6 Number of occurrences of response time vs. response time in ms when 4 select pulses i.e., elements of a column of a select vector are clustered and such clusters are separated by 28 time intervals of non-select voltage.

Results of response time measurements are shown in Figures 6, 7 and 8 respectively. Response time ranges from 35 to 107ms with a mean of 68ms and a standard deviation of about 10ms when one select vector is used for clustering pulses.

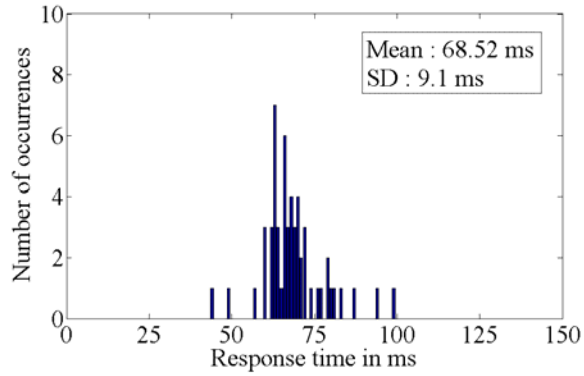

Figure 7 Number of occurrences of response time vs. response time in ms when the cluster of scanning pulses are obtained with 2-select vectors wherein clusters are separated by 56 non-select time intervals.

Response times range from 46 to 100 ms with average response time of 68.5 ms and a standard deviation of 9.1 ms when two select vectors were used at a time to obtain the clusters.

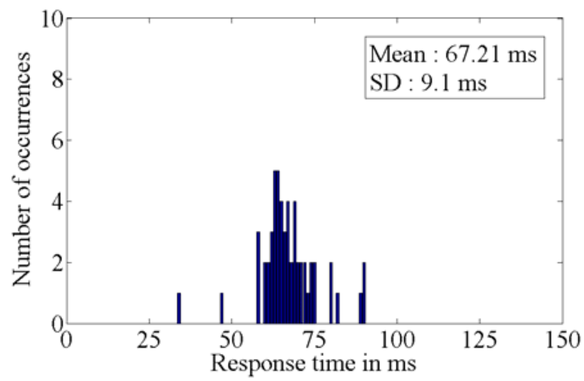

Figure 8 Number of occurrences of response times when four select vectors and their rotated version are used to obtain the clustering of select pulses that are separated by applying non-select voltage during 112 time intervals.

Response times range from 34 to 90 ms with an average response time of 67.2 ms and standard deviation of 9 ms when 4 select vectors and their rotated versions are used to get the cluster of select pulses.

The orthogonal matrix in (1) has eight zeros that are introduced to reduce the hardware complexity of the controller. At a given instant of just three rows are selected even though the groups are formed with 4 rows. We have used the following orthogonal matrix with just 3-rows to address the matrix LCD and the result of the measurements is shown in Figure 9.

$$\begin{bmatrix} +4 & -4 & +4 & -4 & +4 & -4 & +4 & -4 \\ +4 & +2 & -4 & -2 & +4 & +2 & -4 & -2 \\ +4 & +1 & -2 & -1 & -4 & -1 & +2 & +1 \end{bmatrix} \tag{3}$$

Response times range from 42 to 99 ms with a mean of 67.38 ms and a standard deviation of 9.3; which is not very different from the measurements in Figure 8.

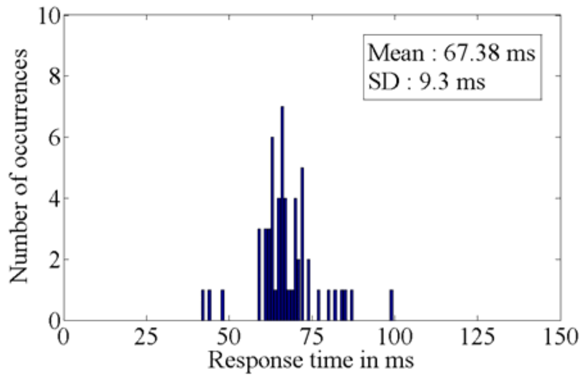

Figure 9 Number of occurrences of response time vs. response time when rows are selected with the orthogonal matrix with 3 rows obtained by eliminating the zeros in (1). Here row waveforms have clusters of 12 select pulses.

4.3. Line-by-Line Addressing-Response Times

For the sake of comparison we have measured the grayscale to grayscale response times when successive approximation technique based on line-by-line addressing[5] is used to drive the display. Response times range from 67 to 145 ms with a mean of 82 ms and standard deviation of 11.8 as shown in Figure 10. The average response time is high as compared to the wavelets based technique wherein the duty cycle of the addressing is 3-times that of line-by-line. Similarly, the standard deviation of wavelets based addressing is 9ms as compared to 11.8 of the successive approximation based on line-by-line addressing.

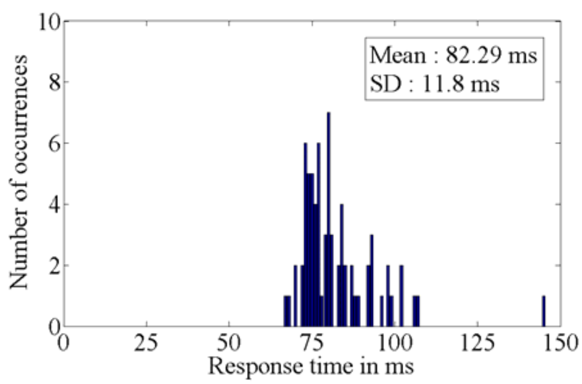

Figure 10 Number of occurrences of response times vs. response times for successive approximation technique based on line-by-line addressing.

4.4. Multi-Line Addressing - Response Times

Result of response time measurements of multi-line successive approximation technique based on sparse matrix that was presented in IDW'08[6] is shown here for the sake of comparison. Here, seven rows are selected at a time and the response times range from 45 to 74 ms with a mean of 61.44 ms and a standard deviation of 5.8ms. All the measurements presented in this paper were performed with TN-LCD having 5.4µm cell gap filled with RO-TN-623 at25˚C with a frame frequency of 50Hz.

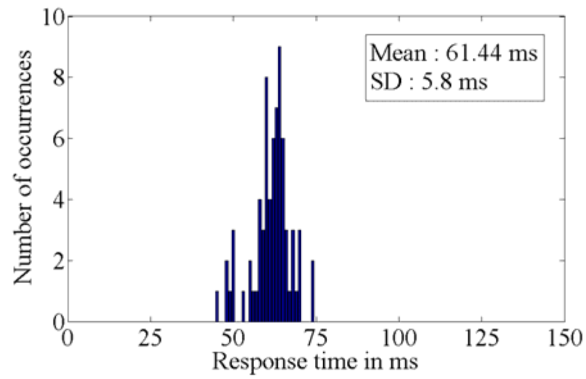

Figure 11 Distribution of response times of multi-line addressing with sparse matrix by selecting seven rows simultaneously (for comparison)

5. Conclusion

From the results presented in this paper it is clear that multi-line selection is advantageous because both the average response time as well as the standard deviation of response times decrease with increase in number of lines that are selected simultaneously.

6. Acknowledgements

I am thankful to Shashidhara for measuring grayscale to grayscale response times.

7. References

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