5.3: *Invited Paper:* Low Power by Energy Multiplexing in Liquid Crystal Displays

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Abstract: *Low power consumption and low hardware complexity of drivers can be achieved by scanning the matrix display with data corresponding to one bit of gray shade at a time. Approach to realization of low power in liquid crystal displays with high efficacy will be discussed.*

Keywords: multiplexing; matrix addressing; successive approximation.

Introduction

A matrix liquid crystal display (LCD) is equivalent to a two-dimensional array of capacitors that are located at the intersections of row address lines and column address line as shown in figure 1. A stage of row drivers and a stage of column drivers are also shown in figure 1. Power dissipated in output resistances (R_r & R_c) i.e., the 'ON' resistances of switches in analog multiplexers in row and column drivers respectively; when pixels are charged or discharged to voltages as determined by the addressing technique. Marks analyzed power consumption of multiplexed LCD [1] and also proposed a simple method [2] to reduce power consumption in non-multiplexed LCD. We proposed a multi-step waveform [3] to reduce power consumption in multiplexed matrix LCD. Power dissipation is a minimum when triangular waveform is used in the addressing techniques [4]. But, supply voltage of the driver circuit is twice that of conventional techniques. Low supply voltage is preferred because liquid crystal displays are extensively used in portable products. Trapezoidal waveform and multi-step waveform with flat-top were proposed to reduce the supply voltage of the drivers [4]. Waveform across pixels will be distorted if the time constant of driver circuit is comparable to the select time. Cross talk due to a large time constant is eliminated if the voltage across pixels is forced to zero for short period at the end of select time [5]. Main objective of this paper is to introduce some simple methods that can be easily incorporated into almost all the addressing of matrix LCDs to reduce power dissipation in the drivers.

Strategy for Low Power Dissipation in Drivers

Low power dissipation in the drivers of LCD can be achieved by:

1. Selecting simple addressing techniques with low hardware complexity of drivers.
2. Choosing waveforms without sharp transitions
3. Reducing the amplitude of abrupt transition even if leads to addition of a few more small transitions.

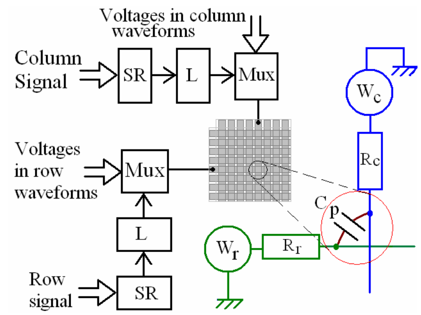

Figure 1. Schematic of a matrix LCD and an equivalent circuit of a pixel in matrix LCD.

Energy Multiplexing in Matrix LCD

A large number of gray shades are essential to ensure color purity and high quality of images. Frame modulation and pulse width modulation are not useful for displaying a large number of gray shades. Each bit of gray shade (of pixels) is multiplexed separately by modulating the parameters that control energy viz., amplitude and duration of waveforms [6] in "energy multiplexing" to reduce the number of time intervals to complete a cycle from $(2^g - 1)$ of frame modulation to about 'g' when 2^g gray shades are to be displayed. Examples of the techniques based on "energy multiplexing" are successive approximation techniques (SAT) [7]-[8] and wavelets techniques [9]-[11].

Successive Approximation for Low Power

Successive approximation can be combined with any addressing technique (designed for bi-level images) to incorporate gray shades; by substituting the select and data pulses in the addressing waveforms with multiple select pulses of SAT. A large number of gray shades can be displayed by adding a few resistors and an analog multiplexer in a matrix LCD that is designed for displaying bi-level images as shown in figure 2. The analog multiplexer (g:1) modulates the select and data voltages that are applied to the drivers according to bit weight of each bit. The row driver consists of one bit shift register of length N to shift in row select data, N-numbers of one-bit-latch to hold the data bits during select time and N-numbers of 2:1 analog multiplexers to apply the select and non-select voltages to the row electrodes. Similarly, the column driver consists of a shift register of length M to shift in one

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bit of gray shade, M-latches to hold the data during the select time and M-numbers of 2:1 analog multiplexers to apply one-of-two data voltages to the column electrodes. Hardware complexity is the least; and hence SAT is a good choice for low power dissipation.

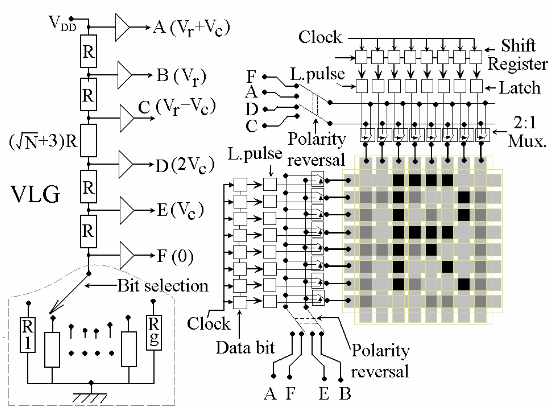

Figure 2. A display that is driven by the conventional line-by-line addressing can be modified to display a large number of gray shades by modulating the voltage applied to the voltage level generator with an analog multiplexer and a few resistors.

Waveforms for Low Power

Pulse is the basic building block in most of the addressing techniques; and both scanning and data waveforms are concatenation of pulses of different amplitude. Plot of current in an RC circuit with a pulse as input waveform is shown in figure 3. Large amplitude of the transient current due to the pulse is responsible for high power dissipation in the matrix LCD. Rate of change of amplitude is controlled in trapezoid and the effect of slope on power dissipation in RC circuit is illustrated in figure 4. Select and data pulses in SAT can be replaced with trapezoidal waveforms to reduce power as shown in figure 5. Power dissipation in matrix LCD will also be less by same factor as shown for multi-step waveform [3]. The power dissipation decreases with the slope of the ramp; and it is a minimum for the triangular waveform (limiting case of trapezoid). However, supply voltage of the driver circuit will be twice that of conventional SAT that is based on pulses. Clustering the select pulses will also lead to reduction power dissipation. This approach is simpler because displays for bi-level images can be modified to display gray shades as shown in figure 2. Clustered select pulses of SAT with its amplitude in geometric progression (a factor of $\sqrt{2}$) are amenable to reduction in power consumption to a lesser extent as compared to the multi-step waveforms of equal step size (arithmetic progression) for bi-level images [3]. Select pulse of conventional addressing technique is shown in figure 6(a). Multiple select pulses of SAT that are clustered and arranged in descending order of amplitude are shown in figure 6(b). It is referred to as discrete version of ramp for the sake of convenience. Power dissipation of the clustered waveforms will depend on the image; however average power dissipation can be estimated by assuming that all gray shades are equally probable.

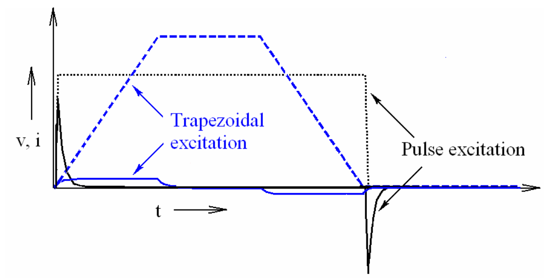

Figure 3. Plot of current (solid lines) in an RC circuit when the input is a pulse and a trapezoidal waveform (dotted lines).

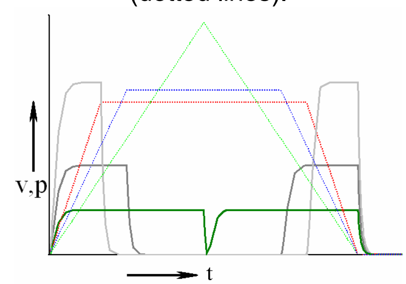

Figure 4. Power dissipated (solid lines) in the resistor of an RC circuit when it is excited by trapezoidal and triangular waveforms.

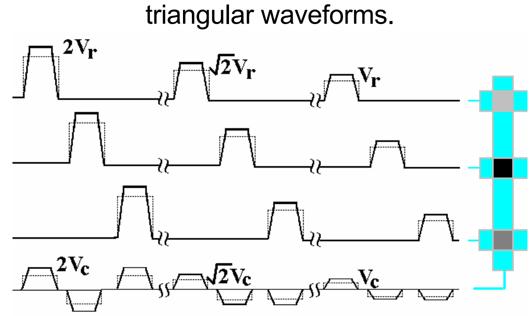

Figure. 5. Typical waveforms of successive approximation technique (SAT) with distributed select and data pulses.

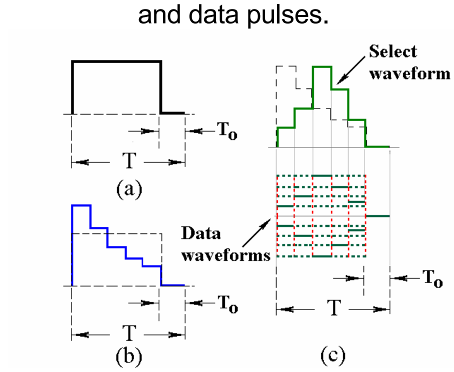

Figure 6. (a) Select pulse for bi-level images, (b) Clustered waveform of SAT for gray shades, and (c) Clustered waveform of low power SAT.

Power dissipation of discrete ramp is high due to the large transition (proportional to $2^{(g-1)/2}$) at the beginning of the ramp (or at the end in ascending ramp) as shown in figure 7. Select pulses of SAT are rearranged to obtain a discrete version of triangular waveform [12] by starting with the pulse of small amplitude (LSB) and placing the pulses of alternate bits from LSB to MSB to be adjacent to each other to form the ascending part; followed by picking and arranging pulses corresponding to rest of bits in reverse order (higher to lower bits) to obtain the descending part of the waveform as shown in figure 6(c). Data waveforms will have transitions that are in phase with the corresponding select pulse for 'logic-0' and out of phase with select pulse for logic-1 of the gray shade bits as shown by dotted lines in 6(c). Hence, power dissipation of column driver will be independent of the select sequence because all the gray shades are equally probable; but the power dissipation in row drivers will depend on the select sequence and it is lower than that of discrete version of ramp as shown in figure 8. Supply voltage of the drivers is high for successive approximation technique and it is twice that of conventional techniques for bi-level images when 256 gray shades are to be displayed. A simple technique to reduce supply voltage and power dissipation is proposed next.

Low Supply Voltage and Low Power

Supply voltage is high because the amplitude of select pulses for the most significant bits are large and they can be reduced by increasing the duration of select pulses and reducing their amplitude such that the energy is conserved. It is achieved by pulse-width modulation for the most significant '*k*'-bits and retaining the amplitude modulation for (*g*-*k*) bits by modifying the select waveform as shown in figure 9. The peak amplitude will be proportional to $2^{(g-k)/2}$ and its duration (T_f) will be (2^k-1) time intervals and the number of time intervals increases from '*g*' to $(g-k+2^k-1)$. Power dissipation of discrete versions of triangle and ramp are compared in figure 10. Column waveforms will have just one transition of amplitude viz., $2^{(g-k)}$ (twice the amplitude of peak column voltage). Supply voltage is reduced by the factor:

$$2^{\frac{-(k-1)}{2}}\sqrt{(g-k+2^k-1)(T-T_{o\_old})/(g(T-T_{o\_new}))}$$

Elimination of largest transition(s) in the row waveforms and reduction of number of transitions in the data waveform during T_f contributes to reduction in power dissipation of row as well as column drivers. Power dissipation of waveforms based on triangle (*k*=1) and trapezoid (for *k*=2 to 4) is compared with that of ramp with the ratio $\left(P_{trapezoid}(k)/P_{ramp}\right)\cdot 100\%$. Reduction in power consumption is summarized in Table I. Reduction in supply voltage is also given within parenthesis in the same table. Reduction in power dissipation is not much for the discrete version of the triangle (see table 1) but it paves way to trapezoidal waveforms with good reductions power as well as supply voltage. Power dissipation is 47% and supply voltage is 54% as compared to that of discrete ramp waveform when k=4 i.e. when three most significant bits are subjected to pulse width modulation. This reduction is achieved with a simple modification to the waveforms and it is important to note that the number of voltages in the addressing waveforms also decreases with increase in '*k*'.

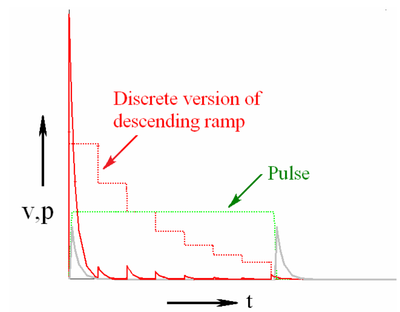

Figure 7. Plot of power dissipation in RC circuit with discrete version of descending ramp. Power dissipation of a pulse for bi-level image is shown for comparison.

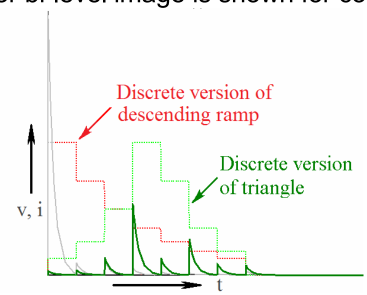

Figure 8. Plot of power dissipation in RC circuit with discrete version of triangle. Power dissipation of discrete version of ramp is also shown for comparison.

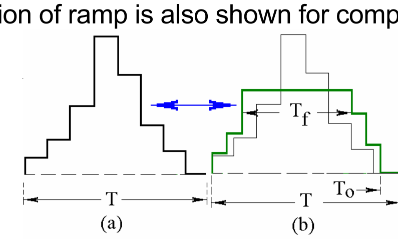

Figure 9. Modified waveforms to reduce supply voltage and power consumption.

Table 1. Comparison of power dissipation of discrete triangle and trapezoid waveform normalized to that of SAT with discrete ramp.

$$\left(P_{trapezoid}(k)/P_{ramp}\right)\cdot 100\%$$

Number of bits	k=1	k=2	k=3	k=4
4	91	82 (79)	-	-
8	89	72 (75)	55 (61)	47 (54)
12	87	69(74)	49(58)	37(49)

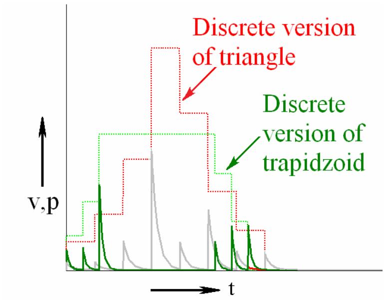

Figure 10. Plot of power dissipation in RC circuit with discrete version of trapezoid as input. Power dissipation of discrete version of triangle is also shown for comparison.

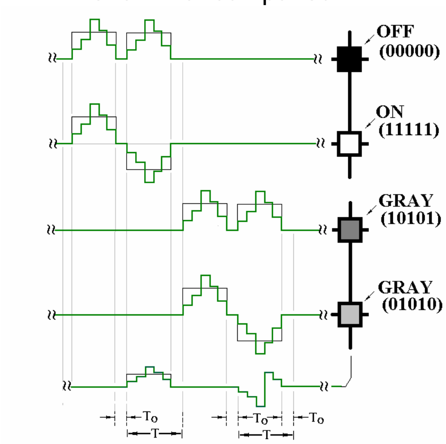

Figure 11. Typical waveforms of multi-line SAT with low power waveforms.

Application to Multi-line Addressing

Pulses in the distributed waveform of any multi-line addressing technique (for displaying bi-level images) can be replaced with the low power waveforms of SAT [13] to display gray shades and the reduction in power consumption will be same as that of line-by-line addressing. Typical waveforms are shown in figure 11, when low power waveform of SAT (discrete version of triangle) replaces the pulses in multi-line addressing based on Hadamard matrix of order 2.

Impact

Low power consumption, low supply voltage and low hardware complexity of drivers are very useful in portable devices and large area displays. Multi-step waveforms introduced in this paper have a wide range of application because they are based on the conserving power when capacitors are charged and discharged and therefore they can be applied to reduce power dissipation in driver circuit of capacitive type devices; for example, electro-luminescent displays, active matrix LCD etc.

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