Techniques for Reducing the Hardware Complexity and the Power Consumption of Drive Electronics

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Abstract: *Demand for high quality images in mobile phones has set a new standard for displays in such portable devices. Active matrix liquid crystal displays (LCDs) are replacing the passive matrix LCDs in these applications. One of the reasons is the lack of simple techniques for displaying a large number of gray shades. Our goal was to develop new addressing techniques to fill this void and it has been achieved without increasing the hardware complexity of the drive electronics. Various techniques that are capable of displaying a large number of gray shades and a technique to reduce the power dissipation in the drive electronics are presented. Salient features of these techniques that were developed in our laboratory are discussed.*

Keywords: wavelets; LCD drivers; power dissipation; multiplexing; matrix addressing.

Introduction

In our era of global warming, diminishing energy sources and increasing energy cost, conserving energy is of prime importance. Liquid crystal displays are found in high volume consumer products like cell phones, digital cameras, personal computers and television. Unlike CRTs, the flat panel displays have a large number of drivers. Number of drivers is equal to the sum of the rows and columns in the matrix displays and high-resolution displays have a few thousand electrodes connected to the drivers. Let us first consider the energy consumed during the manufacturing of these integrated circuits (ICs). About 800 kWh of power is consumed in a semiconductor manufacturing plant when ICs are fabricated on a 200 mm substrate [1]. While one cannot do away with drivers, reducing the hardware complexity of the drivers will go a long way in reducing the power consumption during the manufacturing of these integrated circuits because more integrated circuits can be manufactured on the same substrate. Hence, the average power consumed to manufacture a driver IC can be reduced. One can do away with the manufacturing driver ICs separately if they are fabricated along with the thin film transistors in the active matrix LCDs. Although a small percentage of active matrix LCDs have drivers incorporated in them, most of the large sized active matrix liquid crystal displays have the drivers external to the glass substrate and they are standard driver ICs that are fabricated separately. It is also worthwhile to improve the performance of the passive matrix liquid crystal displays because they have a simple structure and are easy to manufacture. It has less number of steps and consumes less power, chemicals etc., during the manufacturing process as compared to the active matrix displays. Adequate research for improving the performance will yield results just as the enormous effort that has gone in to the research and development of active matrix LCDs has paid dividends. Some simple solutions to improve the performance are: Incorporating black matrix to improve contrast, developing new materials to reduce response times, develop new addressing techniques to increase the number of gray shades, reduce hardware complexity as well as power dissipation etc. We have reduced the hardware complexity and the power dissipation in the drive electronics and the salient features of these techniques are presented in this paper.

Techniques for Displaying Gray Shades

In the conventional addressing techniques for displaying gray shades either the number of time intervals or the number of voltages in the data waveforms increases linearly with the number of gray shades. Frame modulation and pulse width modulation needs $(G-1)$ time intervals for displaying G gray shades. The smallest time interval in the addressing waveforms could become comparable or even less than the RC (resistance of the switches in the drivers and capacitance of the pixels) time constant of the driver circuit. Distortion in the addressing waveforms will contribute to lack of uniformity among pixels that are driven to the same state. The number of voltages in the data waveforms is large i.e. $2\,(G-1)$ when amplitude modulation is used for displaying G gray shades. A comparison of several gray shade techniques can be found in [2]. The data is multiplexed either by modulating the time or the amplitude of the voltage for displaying gray shades. It is evident that a different approach is necessary to surmount the problems associated with these techniques. We have considered "**energy-multiplexing**" for displaying gray shades and that has led to drastic reductions in the drive circuit as illustrated in this paper.

Principle of Energy Multiplexing

Liquid crystal display's response is slow when the voltage across the pixels changes rapidly. Hence, the response of the pixels is less sensitive to the shape of the waveforms across them. The state of the pixels is determined by energy delivered to the pixels. State of the pixels can be controlled by proper choice (depending on the electro-optic response) of the root mean square (RMS) voltage across the pixels. Instead of applying a voltage that will deliver an energy corresponding to a gray shade, voltages corresponding to quantized energies

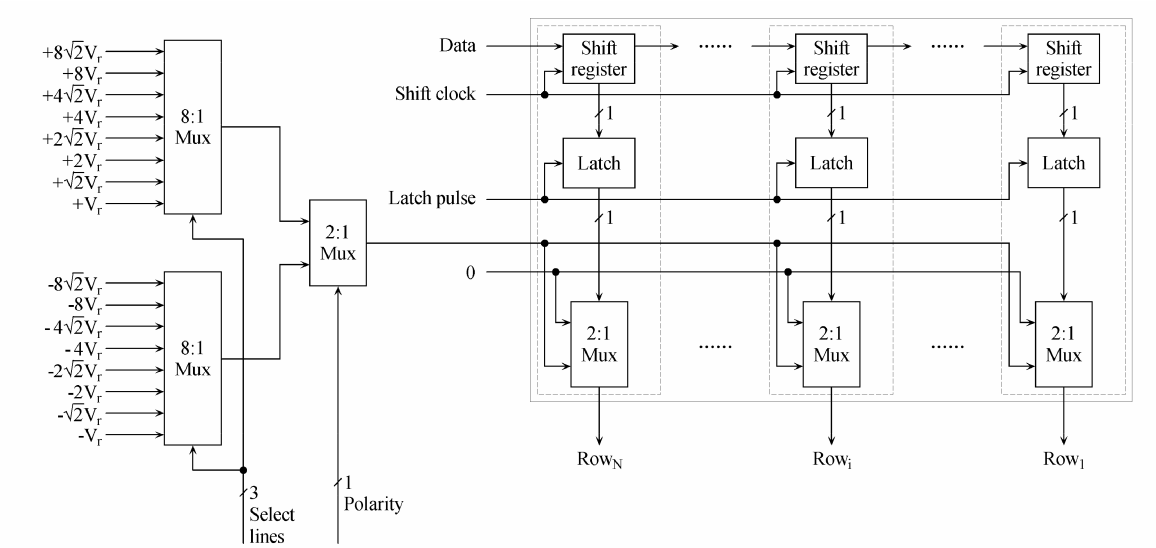

Figure 1. Row drivers of alphanumeric displays can be used to display a large number (256) of gray shades by incorporating two (8:1) and a (2:1) analog multiplexers when successive approximation technique that is based on line-by-line addressing is used to drive the liquid crystal displays.

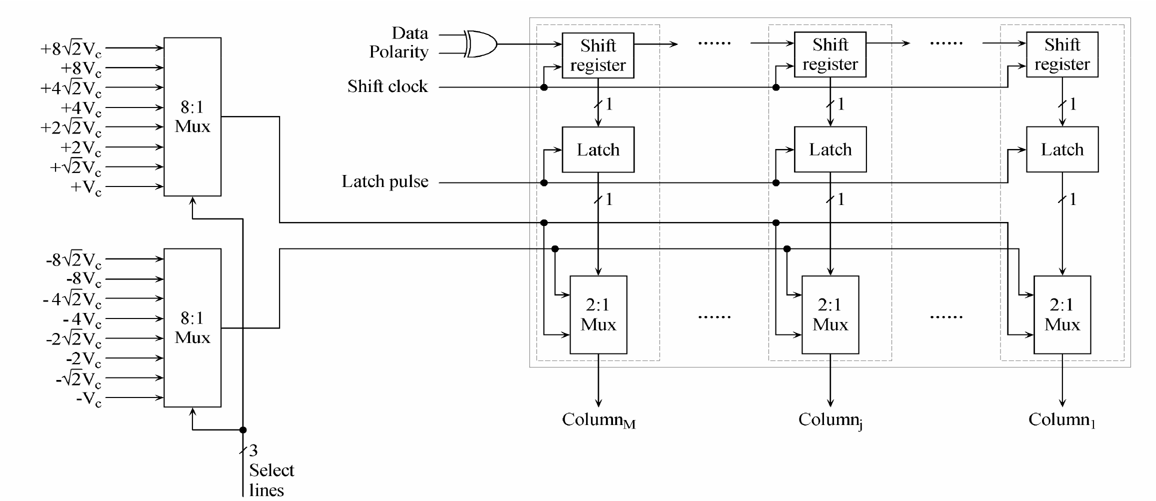

Figure 2. Column drivers of alphanumeric displays can be used to display a large number (256) of gray shades by incorporating two (8:1) analog multiplexers when successive approximation technique that is based on line-by-line addressing is used to drive the liquid crystal displays.

to the pixels either sequentially (as in successive approximation technique) or by clubbing a few of them together (as in wavelet addressing techniques). Number of voltages in the data waveforms is reduced at the cost of a slight increase in the number of time intervals that are necessary to scan the display as compared to amplitude modulation. It is similar to reducing the (2^g-1) comparators in a flash analog to digital (A/D) converter to just 1 and replacing the code converter with (2^g-1) inputs and g-outputs by the successive approximation register of g-bits and simple control logic when successive approximation technique is used. Number of time intervals to convert an analog signal to digital number is also high by a factor 'g' when successive approximation is used for A/D conversion. A similar increase in time intervals is encountered in energy multiplexing. A successive approximation technique for displaying a large number of gray shades in root mean square (RMS) responding displays is described next.

Successive Approximation Techniques (SAT)

Instead of selecting each row with a pulse, multiple (g) voltages that correspond to the bits of the gray shade are used to select the rows [3], [4]. Amplitude of the select pulse is $\left(\sqrt{2}\right)^i.V_r$ corresponding to the bit-i of the gray shade data. The data voltages that are applied during this time interval are either $+\left(\sqrt{2}\right)^i.V_c$ or $-\left(\sqrt{2}\right)^i.V_c$. Sign of the data voltage is same as that of the select voltage when the bit-i is 'logic-0' and opposite to that of the select voltage when the bit-i is 'logic-1'. Rest of the (N-1) address lines in a matrix display with N scanning electrodes are held at ground potential. Addressing is completed when each address line in the matrix display is selected with voltages corresponding to all the bits i.e.'g' voltages for displaying 2^g gray shades. Sign of the select voltages are reversed periodically to ensure DC free waveforms across the pixels because life of the display is reduced if DC voltages are applied to the pixels. Number of voltages is $(2g+1)$ and $(2g)$ in the scanning and the data waveforms respectively. However, at any given instant of time just two voltages are applied to the address electrodes and the data electrodes. They are as follows:

- One of the select voltages to an address line (row).
- Non-select voltage to rest of the address lines.
- Data voltage having the same polarity as the select voltage when the gray shade bit of the pixel in the selected row is 'logic 0'
- Data voltage that has the opposite sign of the select voltage when the data bit is 'logic-1'.

Hence, simple drivers that are used in alphanumeric displays can be used along with four (g:1) analog multiplexers that are external to the display drivers as shown in Figures 1 and 2. It is adequate to have the row and column drivers that are capable of applying one of the two voltages of the internal bus. Supply voltage of this technique increases with the number of gray shades [3]. It is about twice that is necessary for the bi-level (ON or OFF states) displays when the number of gray shades is 256. Supply voltage can be reduced by shifting both select and data voltages in a polarity so that peak-to-peak voltage in the modified waveforms is confined within the voltages of the other polarity. Supply voltage can also be reduced if the successive approximation is implemented with multi-line addressing [4]. Advantages of multi-line addressing (due to a higher duty cycle) is also achieved at the cost of increasing the number of voltages in the data drivers to (s+1) when's' address lines are selected simultaneously.

Salient features of Successive Approximation

Salient features of successive approximation techniques are as follows:

1. Hardware complexity of the drivers does not increase linearly but increases logarithmically with the number of gray shades.
2. Drivers that are capable of applying just two voltages (at a given instant of time) are adequate even when the number of gray shades is large. Hence, the hardware complexity is about the same as that of the simple alphanumeric displays that are capable of driving the pixels to just two states (either ON or OFF).
3. A few multiplexers that are common (and located outside) to all the drivers are adequate to increase the number of gray shades from 2 to any large number.
4. Number of time intervals increases by a factor $\log_2 G = g$. Hence the increase in the number of time intervals is small as compared to the increase in the number of gray shades
5. A flicker free display is feasible even when the number of gray shades is large.
6. Supply voltage can be reduced either by applying voltage transformations similar to that proposed by Kawakami et al [5] or by using multi-line addressing.

Supply voltage of the drive electronics increases with the number of gray shades. Successive approximation technique with multi-line addressing [4] can reduce the supply voltage of the drive electronics. However, the main advantage viz. extremely simple row and column drivers will be lost as the row drivers will have to switch three voltages as compared to two for the line-by-line addressing. Hence row drivers will need 2-bit shift register, 2-bit latch and 3:1 analog multiplexer for each row of the display. Hardware complexity of the column drivers will depend on the number of address lines (rows) that are selected simultaneously. Number of voltages in the column waveforms is (s+1) when 's' address lines are selected simultaneously. For example 3-bit shift register, 3-bit latch and 8:1 analog multiplexer is necessary for each column in the display when seven rows are selected simultaneously. In summary, the hardware complexity of the multi-line successive approximation technique is the same as that of the multi-line addressing techniques for displaying bi-level images with pixels driven to either ON state or OFF state. Wavelet based techniques are another option to reduce supply voltage and salient features of this technique are presented in the following section.

Wavelets Addressing Techniques (WAT)

Each address line in the matrix display can also be selected with a set of wavelets for displaying gray shades [6]. Each wavelet has energy that is proportional to a bit of the gray shade data. A technique for displaying 64 gray shades using integer wavelets was demonstrated [7]. We have shown that drivers that are capable of applying one out of four voltages to the rows and one out of eight voltages to the columns are adequate when a few analog multiplexers are used to select the voltages that are to be connected to the drivers depending on the select vector [7]. Schematic of the drive circuit for the row and column are shown in Figures 3 and 4. The same hardware (drivers and the controller) can be used to display 128 gray shades if the integer constraint is not imposed. It can be achieved by incorporating some simple modifications in the controller, the external multiplexers (that select the voltages to be fed to the drivers) and the voltage level generator. The row drivers that are capable of applying one out of four voltages and the column drivers that are capable of selecting one out of eight voltages are adequate even for displaying 128

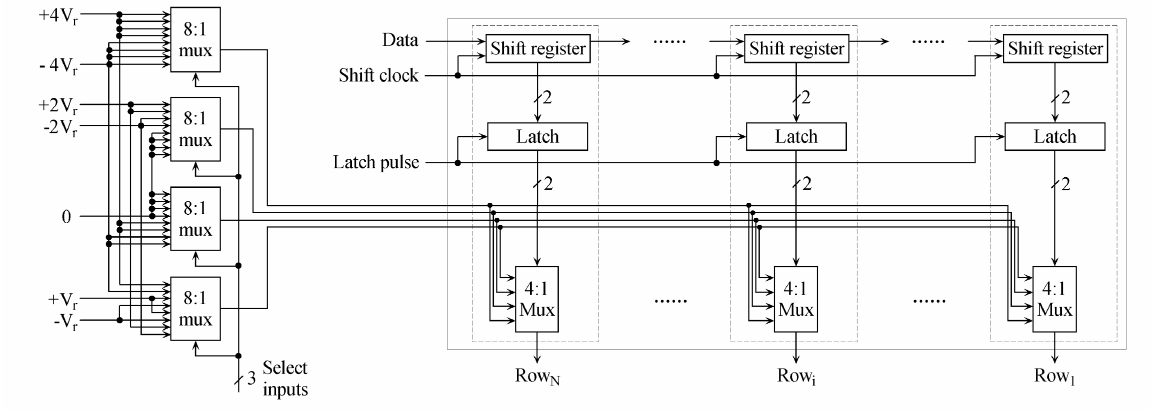

Figure 3. Typical row driver circuit (for displaying 64 gray shades) of the wavelet based addressing technique. Majority of the circuit i.e. the shift registers; latches and the (4:1) analog multiplexers (shown inside a box) remain unaltered when 8 to 128 gray shades are displayed by selecting 3 rows at a given instant of time. The multiplexers (on the left hand side) that are connected to the voltage bus are the part of the driver circuit that changes with the number of gray shades to be displayed.

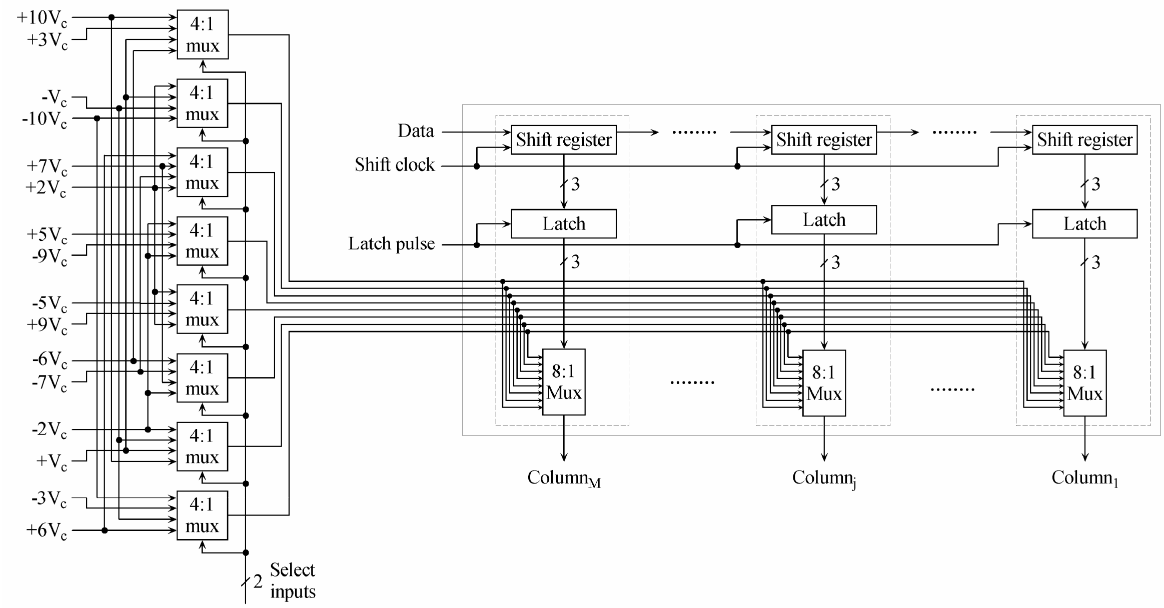

Figure 4. Typical column driver circuit (for displaying 64 gray shades) of the wavelet based addressing technique. Majority of the circuit i.e. the shift registers; latches and the (8:1) analog multiplexers (shown inside a box) remain unaltered when 8 to 128 gray shades are displayed by selecting 3 rows at a given instant of time. The multiplexers (on the left hand side) that are connected to the voltage bus and their input from the voltage level generator depend on the number of gray shades to be displayed.

gray shades. An example of a matrix based on integer wavelets for displaying gray shades is shown in equation 1. It is not unique and several such matrices can be constructed easily by selecting the wavelets and constructing an orthogonal matrix with them.

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

The non-integer wavelet matrix for displaying 128 gray shades is shown in the following equation.

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

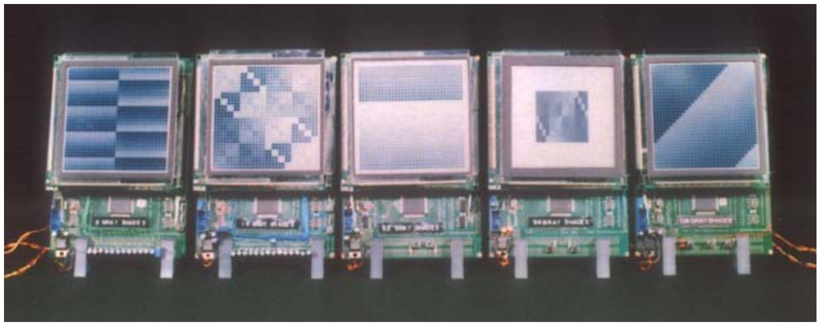

Figure 5. Photographs of the five prototypes of passive matrix liquid crystal displays that are capable of displaying 8 to 128 (from left to right) gray shades using wavelets. Hardware complexity of the drive circuit is about the same for all the prototypes.

Integer wavelets (transforms) are preferred to reduce computations in digital signal processing. However, it is not necessary when wavelets are applied to scan matrix liquid crystal displays. We have shown that it is not necessary to compute the dot product and hence wavelets with non-integer elements can also be used with out increasing the hardware complexity of the drivers as well as the controller [8]. A matrix for displaying 32 gray shades is shown as an example in the following equation.

$$\begin{bmatrix} +4 & -4 & +4 & -4 & +4 & -4 \\ +2\sqrt{6} & 0 & 0 & 0 & -2\sqrt{6} & 0 \\ 0 & +2\sqrt{3} & 0 & 0 & 0 & -2\sqrt{3} \\ +\sqrt{2} & +1 & -2\sqrt{2} & -2 & +\sqrt{2} & +1 \end{bmatrix} \quad (3)$$

Wavelets are well suited for multi-line addressing wherein several address lines are selected simultaneously. It is also possible to use wavelets and scan the display by selecting one address line at a time [9].

Salient features of WAT

Salient features of wavelet based addressing techniques are as follows.

1. Number of voltages in the data waveform is less as compared to that of amplitude modulation.
2. Number of time intervals to display gray shades is 8N for the wavelet based line-by-line addressing as compared to the 4N for the amplitude modulation.
3. Number of time intervals is small as compared to that of frame modulation.
4. Hardware complexity of the column (data) drivers can be reduced because the number of voltages does not increase linearly with the gray shades.
5. Hardware complexity of the row and the column drivers can be controlled by the choice of number of non-zero elements in the select vectors.
6. Row drivers that are capable of applying one of the four voltages and column drivers than can apply any one of the eight voltages are adequate even when the number of gray shades is 128 when three rows are selected simultaneously.
7. It is not necessary to compute the dot product even though wavelet transform is employed for scanning the matrix displays because voltages corresponding to the dot products are built in to the voltage level generator by computing them once.
8. A few multiplexers are used to feed the voltages corresponding to each select vector to the column (data) drivers.
9. Hardware complexity of the controller can be reduced by selecting the number of addressing lines in a group to be an integer power of two.
10. Hardware complexity of the drivers and the controller does not depend on the type of the wavelets (integer or non-integer types).
11. Wavelet based techniques could be based on line-by-line as well as multi-line addressing.
12. Addressing waveforms can be modified to reduce the supply voltage of the wavelet based on line-by-line addressing technique.
13. Row drivers that are capable of applying one out of two voltages and column drivers that are capable of applying one out of eight voltages are adequate for displaying 128 gray shades when the display is scanned line by line using wavelets.

Techniques for reducing power dissipation

Power is dissipated in the drive circuit when pixels in the passive matrix displays are charged and discharged. Substituting the select pulses in the scanning waveforms with multi-step waveforms [10] will reduce the power dissipation. The rows in the matrix displays are selected with a pulse because they are easy to generate. The power dissipated in the resistors (ON resistance of the analog multiplexers) in the drive circuit can be minimized if a triangular waveform is used. A waveform profile with a few steps is adequate to reduce power dissipated in the drive circuit to a large extent and they are relatively easy to implement. Supply voltage of the drivers increase when triangular (6.a) or multi-step waveforms (6.b) are used to select the address lines. Selecting the address lines with trapezoidal (6.c) or the multi-step profile with flat region at the top (6.d) will lead to a reduction in the supply voltage of the drive

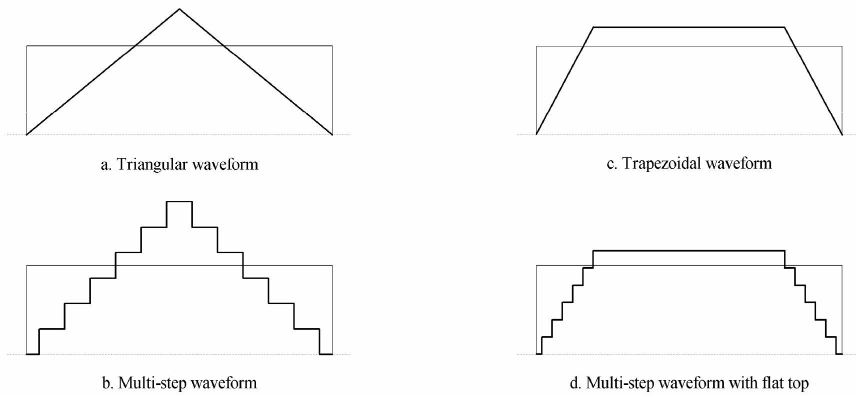

Figure 6. (a) A triangular waveform is ideal for minimizing the power dissipated in the R-C circuit. (b) Multi-step waveform with few steps is adequate to reduce the power dissipation to a large extent. (c) Supply voltage of the drive electronics is less if trapezoidal waveform is used instead of the triangular waveform in liquid crystal displays because the energy delivered is more for the same peak voltage (d) Multi-step waveform with a wide flat region will reduce the supply voltage of the drive electronics and the multi-step is easy to implement with standard drivers as in the case of successive approximation that is based on line by line addressing.

electronics. Standard drivers that are suitable for the alphanumeric displays can be used just as the case of the successive approximation technique based on line-by-line addressing. The waveform profiles proposed here can be used in conjunction with any addressing technique for driving passive matrix displays. Reduction in power dissipation can be achieved in line-by-line and multi-line addressing techniques. Just a few multiplexers that are common to all the drivers (of the bi-level displays) are adequate to achieve reduction in power dissipation in the drive electronics.

Conclusion

All the techniques discussed in this paper are simple and are easy to implement and there is no compromise in the selection ratio. Their elegance lies in the enormous saving of hardware that can be achieved in the drive electronics.

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