An Addressing Technique to Drive Blue Phase LCDs

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ABSTRACT

Bit slice addressing (BSA) is proposed to preserve color purity of images at all angles in fast responding liquid crystal displays with simple data drivers. About 80% reduction in data driver circuit and an average 26.9% reduction in backlight power are achieved with BSA!

1. INTRODUCTION

Blue phase [1] liquid crystal display (BPLCD) exhibits sub-millisecond response times even with large (13μm) cell gap [2], has wide viewing angle, and do not require surface alignment.. However, high drive voltages (40 to 200 volts) limit adoption of BPLCD into main stream. Conventional data drivers of LCD have digital to analog converters (DACs) that are too complex for high voltage drivers. On the other hand, BPLCD can be driven like a device with instantaneous response because it has short response times. Bit slice addressing (BSA) has just two voltages in data waveforms and therefore it eliminates DACs in data drivers. High output voltage can be achieved with simple level shifters. Color purity of images due to a viewing angle characteristic that is independent of gray shades, low cost of data drivers and low power consumption of backlight are some advantages of BSA.

2. BIT-SLICE ADDRESSING (BSA)

2.1 Principle

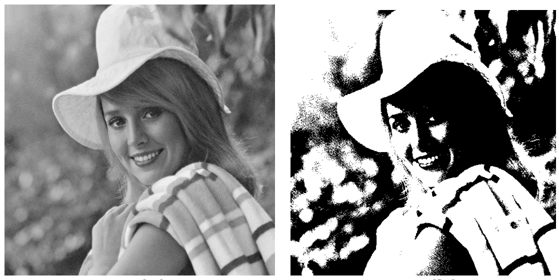
BSA combines electrical and optical mean addressing. A wide range of intensities can be obtained by adding a few (≤ *g*) discrete intensities based on binary representation of intensity ($I_{x,y}$)as shown in (1).

$$I_{x,y} = \sum_{i=0}^{g-1} b_i \cdot 2^i \qquad (1)$$

Wherein b_i is either 0 or 1 and g is the number of bits. For example, 256-intensities can be obtained with just 8 discrete intensities as shown below:

$$I_{x,y} = 2^7 b_7 + 2^6 b_6 + 2^5 b_5 + 2^4 b_4 + 2^3 b_3 + 2^2 b_2 + 2^1 b_1 + 2^0 b_0$$

Each bit-b_i of pixels is used to construct a mask called 'bit plane frame' (BPF) that allows light to pass through when bit- b_i is logic-1 and blocks light when bit- b_i is logic-0 as shown in Fig. 1 (b) for bit-b_7 of the image in Fig. 1.a. Similarly, bit-plane-frames (BPFs) of color images can obtained for the 3-primary colors. BPFs of bits b_7 and b_6 of green are shown in Fig. 2 (b) and (c). LCD with fast response can be used as a **dynamic mask**. In bit slice addressing (BSA), BPFs of g-bits are displayed sequentially and intensity of backlight of LCD is controlled



(a) (b)

Fig. 1 (a) Monochrome image "Elaine" and (b) bit-plane-frame (BPF) of bit-b_7 of the image.

(a) (b) (c)

Fig. 2 (a) Color image of "Lena", (b) bit-plane-frame (BPF) of bit-b_7 of green and (c) BPF of bit-b_6 of green of the same image.

simultaneously to be proportional to the bit-weight (2^i). Sequential and rapid display of BPFs with intensity modulation will be perceived as gray scale image due integration in the eye. Color images can be displayed either with sub-pixels of primary colors or by employing color sequential mode in combination with BSA if the response times of LCD is short enough. Thus BSA relies on binary representation of intensity, fast response of LCD, fast response of backlight for intensity modulation, and persistence of vision. Apart from BPLCD; Ferro-electric displays [3] and even bi-stable displays with fast response times may also driven with BSA.

2.2 Bit-slice addressing

It is a sequential process wherein each bit of a gray shade is used (one at a time) to drive a display. Intensity of backlight for each BPF is determined by its bit weight. For example; to display 256 shades of gray, the bit- b_7 is used to drive pixels in LCD with fast response so that light is transmitted when b_7=logic-1 and light is blocked when b_7=logic-0. Intensity of backlight is set to the maximum (100%) when BPF (bit-plane-frame) of b_7 is displayed on LCD for a duration T_a. Next, BPF of bit b_6 is displayed for an equal duration of time (T_a) by using just

b_6 to drive LCD and intensity of backlight is set to 50% of the maximum. BPFs of subsequent bits viz. b_5, b_4, b_3, b_2, b_1, and b_0 are displayed with backlight intensities of 25%, 12.5%, 6.25%, 3.13%, 1.56%, and 0.78% respectively; i.e., intensity of backlight is reduced to 50 % for each successive lower bit in descending order. Backlight intensities to display 256 gray shades in 8-time intervals are shown in Fig. 3 (a). If F is the frame frequency of conventional LCD to avoid flicker, then frame frequency of BPFs has to be at least $g \cdot F$ for monochrome images and $3 \cdot g \cdot F$ for color images.

3 BACKLIGHT MODULATIONS

Intensity modulation is for the entire backlight unit that illuminates LCD. Light emitting diodes (LED) are replacing florescent tubes as backlight source of LCD. Pulse width modulation can be used for intensity modulation LED. Dynamic range of backlight intensity is $(2^{(g-1)}-1)$ when all BPFs of g-bits are displayed for equal durations of time (T_a) as shown in Fig. 3(a). Dynamic range can be reduced by about 44% when BPF of b_7 is displayed for a period T_a'=1.78T_a and rest of the seven BPFs are displayed for a period 0.89T_a as shown in Fig. 3(b). Total period to display 8-BPFs is conserved (8T_a); so that, the image refresh rate is same for both cases shown in Fig. 3. Intensity of LEDs is usually controlled by pulse width modulation. Hundreds of LEDs are used in backlight of a large LCD and number of LEDs that are switched ON and OFF may also be varied to achieve the intensity modulation of backlight.

4. LOW POWER WITH BACKLIGHT SWITCHING

BPF of higher bits of all images have clusters of 'OFF" pixels that are black as shown in Figs. 1(b), 2(b) and 2(c). Backlight can be switched 'OFF' selectively if all pixels are OFF in a predefined mosaic of cluster (for example: 16 x 16 pixels) or clusters in BPIs. It is similar to 2-D dimming techniques of backlight [4], [5]. Major saving in power can be achieved by switching OFF backlight for BPFs of most significant bits. ***A maximum of 41.85% and an average of 26.9% reduction in power consumption of backlight were achieved in an analysis of 27 standard images***.

5. CONCLUSION

Several advantages of BSA are listed below:

1) ***Cost and complexity of data drivers is reduced (~80% by eliminating DACs)*** when BSA is used to drive LCD. Simple drivers with voltage level shifters that increase the output voltage for logic-1 to high voltage (100-200 volts) are adequate to drive each column of LCD.

2) ***Viewing angle characteristics of LCD driven with BSA is independent of gray shades*** because pixels are driven either to 'ON' state or 'OFF' state even when gray shades are displayed. It is helpful to maintain the ***color purity over the entire viewing angle of LCD***.

3) ***Voltage margins to drive pixels is large*** because

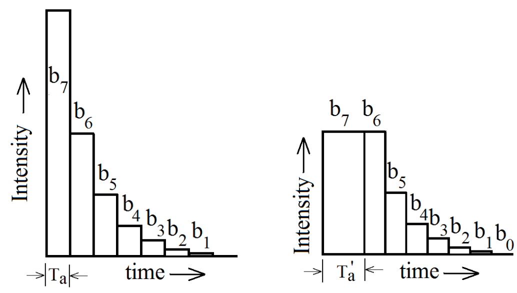


Fig. 3 (a) Intensity modulation of backlight for 256 gray shades and (b) increased duration for b_7 to reduce the peak intensity by about 44%.

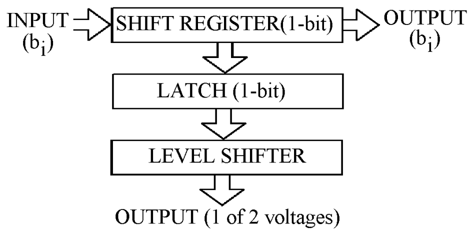


Fig. 4. Data driver for bit slice addressing to drive a column in the display. Output has two voltages to either switch "ON" or "OFF" pixels

pixels are driven to either ON or OFF state in BSA and the electro-optic response curve is almost flat above the saturation voltage and also below the threshold voltage.

4) ***Bi-stable displays can also be driven with BSA***.

5) ***Bit-slice addressing (BSA) eliminates motion blur*** in video because intensity of backlight is less than 1% of the maximum for b_0, and it has the same effect as interleaving blank frames to suppress motion blur [6].

6) ***Critical flicker frequency can also be reduced*** by reordering bit sequences for displaying BPFs. For example, the following sequences will reduce flicker and also eliminate motion blur: $b_7, b_0, b_6, b_1, b_5, b_2, b_4, b_3$ OR $b_7, b_3, b_6, b_2, b_5, b_1, b_4, b_0$.

7) ***Lower power consumption of backlight*** can be achieved by selectively switching OFF backlight to small clusters of pixels in BPFs. For example, ***26.2% reduction in backlight power is achieved even for a static image with full contrast*** (shown in Fig. 1(a)).

REFERENCES

[1] Kikuchi H et al "Polymer stabilized liquid crystal blue phases", Nature Mat., Vol. 1, pp 64-68, (2002).
[2] Kuan-Ming Chen et al "Sub-millisecond gray level response time of a polymer stabilized blue-phase liquid crystal", IEEE/OSA JDT, Vol.6, No. 2, pp 49-51, (2010).
[3] N A Clark and S T Lagerwall, "Sub-microsecond bistable electrooptic switching in liquid crystals", Appl. Phys. letters 36, 899, (1980).
[4] T. Shiga and S. Mikoshiba, SID'03 Technical Digest, p. 1364 (2003).
[5] Pierre de Greef, JSID 14/12, p.1103 (2006)
[6] T. Yamamoto, LCD Backlights, John Wiley, (2009).