TFT-LCD Employing RGBW Color

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ABSTRACT

Last year, we introduced a TFT-LCD with RGBW color system. The primary advantage of the RGBW system is that its optical efficiency is at least 50% higher than the RGB system. However, it is not a simple task to incorporate the new color system into the infrastructure of the RGB system: the driving circuitry, fabrication of color filter, and color conversion. In this report, the practical hurdles are discussed and the solutions are presented.

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INTRODUCTION

We published a report on a new TFT-LCD with RGBW color system [1]. The RGBW LCD has 50% higher luminance, 10% higher color temperature, and 20 ~ 40% higher contrast ratio than the equivalent RGB LCD. LCD-TVs are known to be lack of "punch", an industry term describing high spatial contrast. With the ample luminance and high contrast, RGBW LCDs are capable of delivering such "punches". However, even with these merits, the RGBW system was not immediately commercialized because it was not a simple task to implement the RGBW color system in the RGB world. An RGBW system must fit into the hardware infrastructure designed around the RGB stripe pixel and be able to reproduce colors that were digitized in the first place by the RGB color system. This report describes the problems encountered and suggests the solutions.

CROSSTALK

The first difficulty in implementing RGBW system into the RGB infrastructure comes from the driving circuitry. The majority of the commercial TFT-LCDs (10.4 inches and larger) employ the so-called "dot inversion" data driver ICs, of which each channel is of opposite polarity from its neighbors. With this type of data driver ICs, any combination of polarity is possible along the vertical direction. However, the polarity *must* alternate horizontally. In other words, these data driver ICs are capable of "N x 1" inversion, with N being any integer. In the RGB stripe system, this inversion per subpixel also produces inversion per pixel [FIGURE 1a], because the number of subpixels is odd. On the other hand, in the RGBW system, it does not produce inversion per pixel [FIGURE 1b], because the number is even (four). Every subpixel with same color in a given row has same polarity. This type of configuration is prone to produce line flicker and horizontal crosstalk [FIGURE 2].

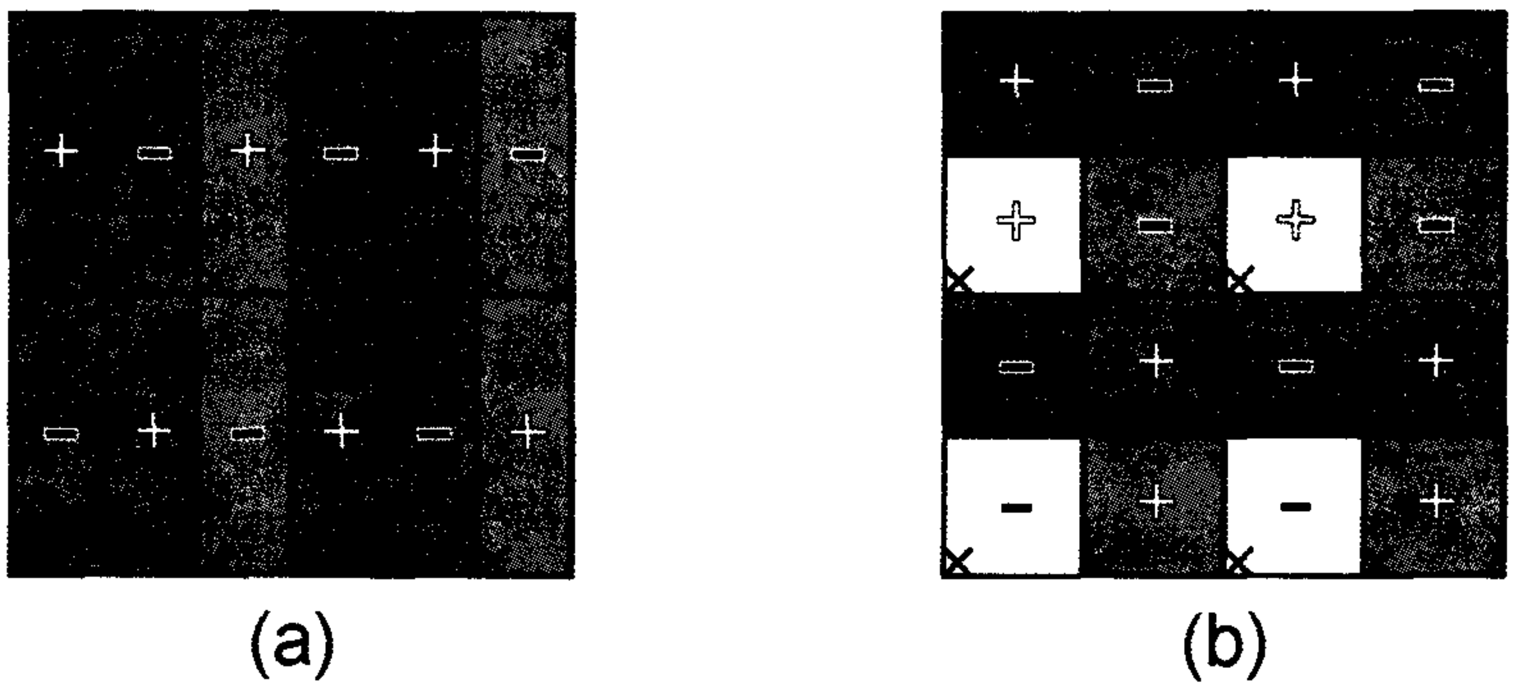

FIGURE 1. Inversion scheme in (a) RGB stripe (1x1), and (b) RGBW checkerboard (2x1). 'X's denote the location of TFTs.

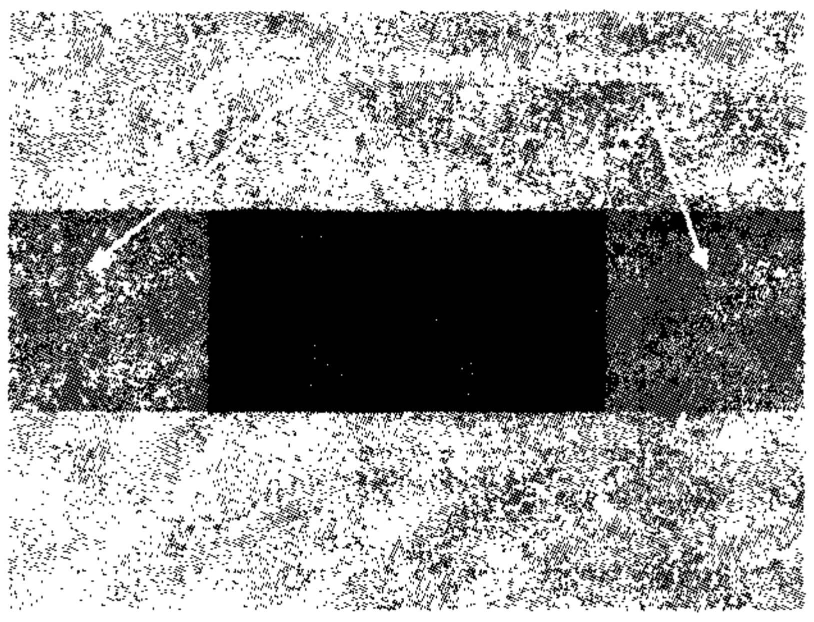

FIGURE 2. Horizontal crosstalk appears when a pure colored (a primary color or any combination of two primary colors) solid box is displayed on a gray background.

The most obvious way to solve this problem is to use a data driver IC capable of "N x 2" inversion, which is not yet available commercially. Actually, it is not difficult to make one. Only a small modification on the conventional "dot inversion" driver is required. However, with the new drivers, you cannot get the cost reduction from the economy of scale, since their application may be ultimately limited to RGBW checkerboard TFT-LCDs. In addition, subpixels located between data lines of same polarity may require additional separation from the lines to avoid coupling-induced vertical crosstalk. This will reduce the aperture ratio.

Facing these challenges, we found a novel method of arranging TFTs that enables pixel-wise inversion with the conventional "dot-inversion" drivers. There are four corners in which a TFT can be placed within a subpixel. In the conventional TFT-LCDs, the locations of TFTs are identical for all subpixels. In the new scheme, the location of a TFT differs from subpixel to subpixel. One example is shown in FIGURE 3. We call this arrangement AAT (Alternately-Arranged TFT).

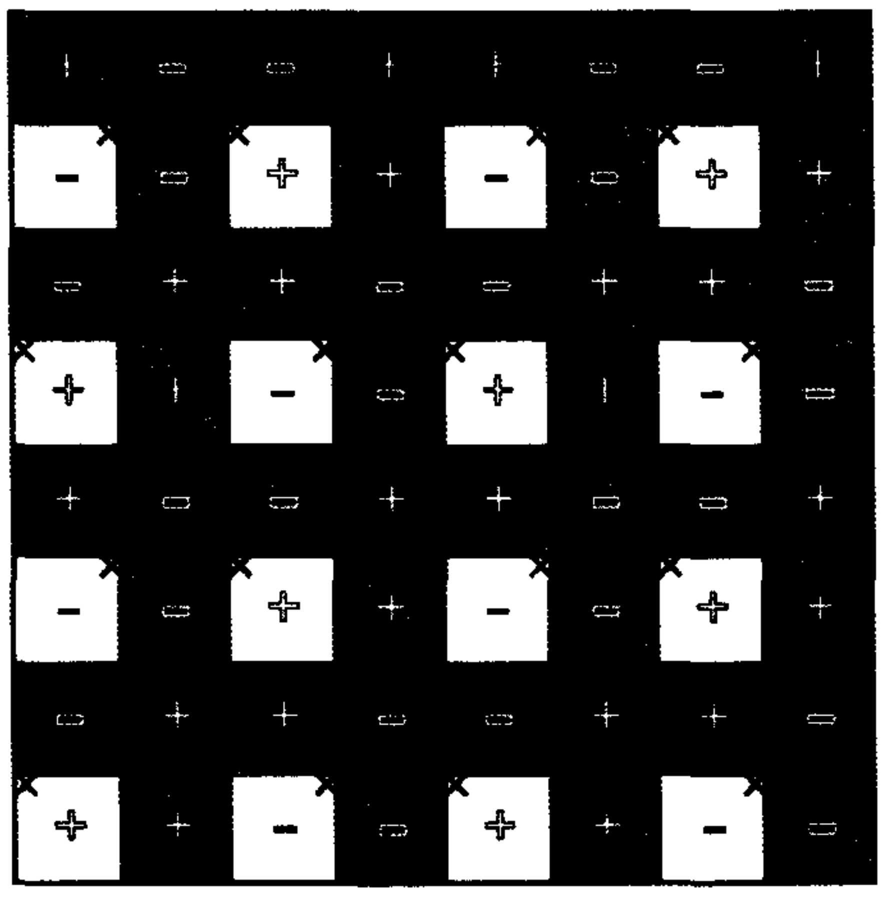

FIGURE 3. The AAT (Alternately-Arranged TFT) structure in the RGBW checkerboard.

Simultaneous Contrast

The color space represented by the RGB system is cubic: for 24-bit color, any color of (r, g, b) where $0 \leq r, g, b \leq 255$ can be displayed. The RGBW system extends the cubic RGB space diagonally. The resulting color space is very different from the original RGB cubic space. Our color conversion algorithm ensures that the hue and saturation of the original color be preserved. However, the luminance of the color does change, which is the purpose of the RGBW system in the first place. The problem is that the scale of the change is different for some colors, especially, colors with high luminance and high saturation.

When two colors are scaled differently and placed next to each other, they look different. This phenomenon is called "simultaneous contrast" [2] and an example is shown in FIGURE 4. The yellow squares in FIGURE 4(a) and (b) are exact copies of each other. Yet, the perceived colors are different on backgrounds of different luminance. In our RGB-to-RGBW conversion algorithm, colors such as pure yellow with maximum luminance, (r, g, b) = (255, 255, 0), are not scaled because any addition of white would change the saturation. On the other hand, colors with low saturation are scaled by adding a proper amount of white. For example, the full white, (r, g, b) = (255, 255, 255) is scaled by a factor of two with the addition of W = 255, thus becoming twice as brighter. An image like FIGURE 4(a) on an RGB display will look like FIGURE 4(b) on an RGBW display.

These kinds of patterns are relatively rare in moving, natural pictures. However, whey they do appear, colors look extremely unattractive. Among all pure colors, yellow on white seems to be most severe. We believe that is because yellow has the highest luminance, very close to full white. We tried a slight modification of the color conversion algorithm so that the luminance of yellow does increase by adding a little amount of W. However, the resulting combinations did not alleviate the problem and only had the disadvantage of decreased saturation.

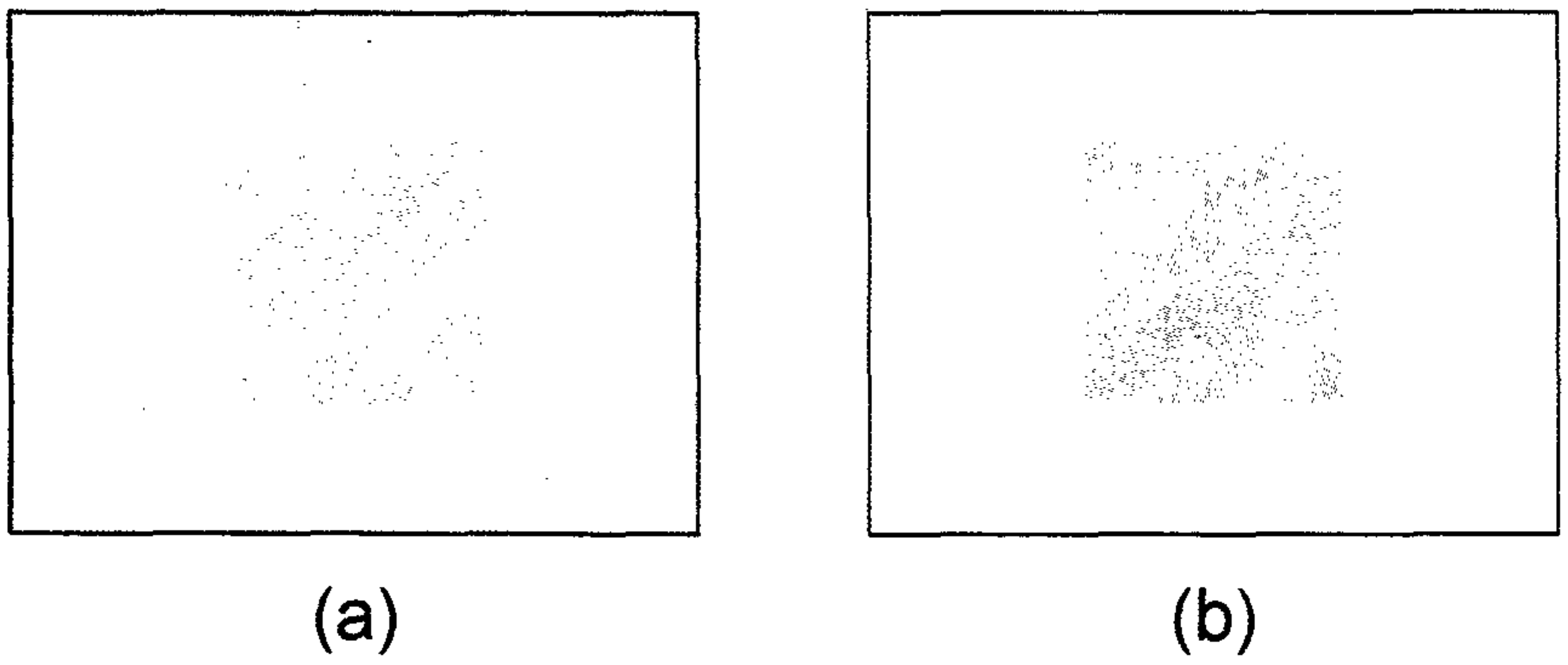

FIGURE 4. The yellow squares in (a) and (b) are identical. However, their colors look different because the background of (b) is twice as bright as that of (a).

We found that any deformation of the color space always makes the situation worse. Therefore, we chose to scale the luminance adaptively, depending on the content. We call this algorithm AWS (Adaptive White Scaling) and the scheme is shown in FIGURE 5. A scale factor, w is introduced. When $w = 0$, there is no scaling and when $w = 1.0$, the luminance is increased twice as much. Incoming RGB data is converted to RGBW with a given w. When $w > 0$, there will be some color distortion in the process, depending on the content. This distortion is analyzed and the "color distortion analyzer" in FIGURE 5 produces a variable e, which is supplied to a "w controller". If e is larger than a certain criteria (high threshold), w is decreased incrementally. If e is smaller than a low threshold, w is increased and supplied back to the RGBW converter and the color distortion analyzer. The high and low thresholds were determined by subjective evaluation. The w adjustments are done by frame. This adaptive scaling method will produce a less bright display than the "fixed" scaling method on some occasions. However, as discussed in the previous paper [1], those occasions are relatively rare.

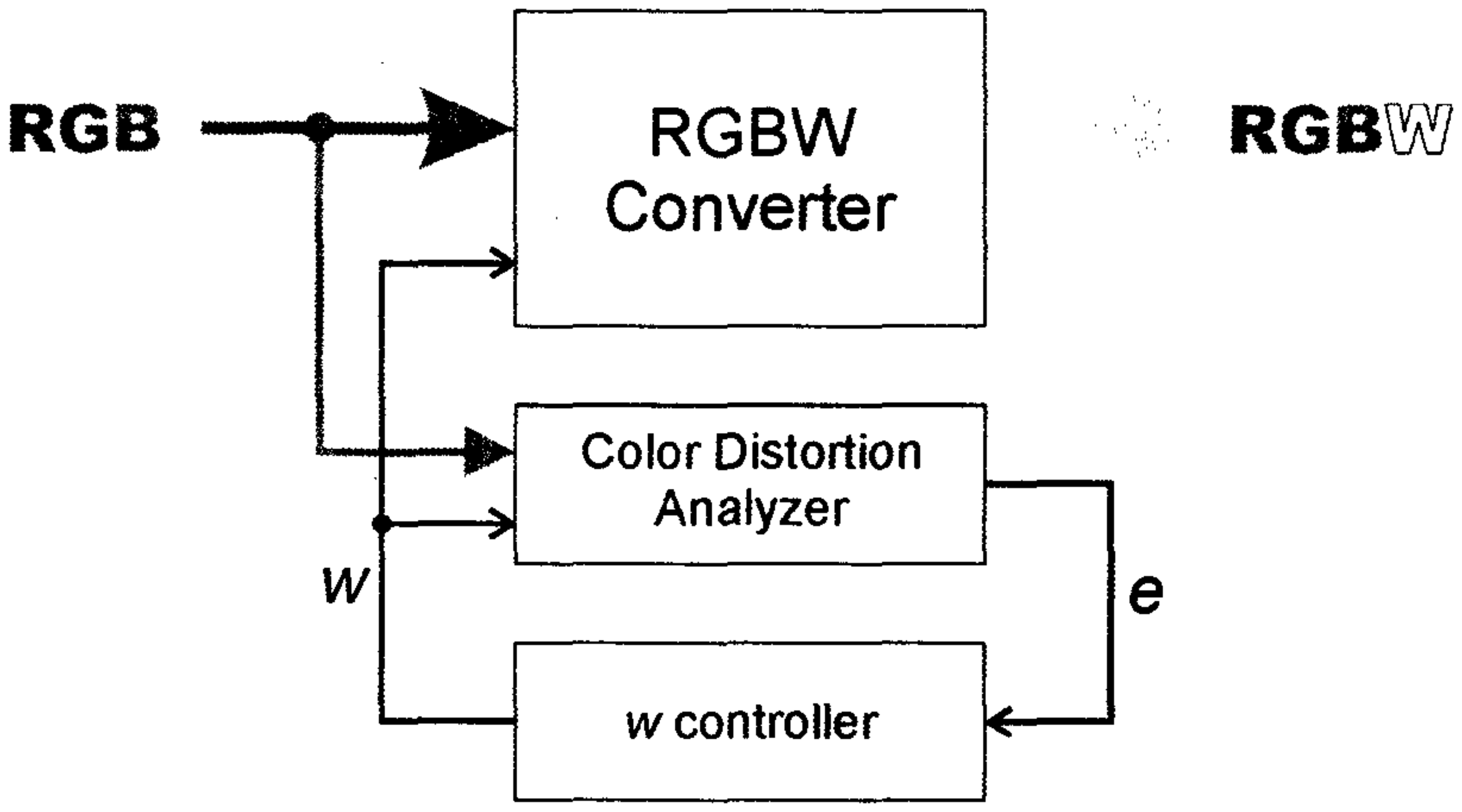

FIGURE 5. Adaptive White Scaling.

CONCLUSION

The RGBW LCD has very attractive advantages over the conventional RGB LCDs. However, the advantages alone do not warrant immediate commercialization, because the new display must use the existing infrastructure founded on RGB. The two most significant problems are (1) horizontal crosstalk due to the fact that the number of subpixels is even and (2) change in the simultaneous contrast resulting from the distorted color space. We devised a new TFT arrangement scheme to eliminate the H-crosstalk and an adaptive luminance scaling algorithm to minimize the change in the simultaneous contrast. With these efforts, the RGBW LCD can be realized economically.

Prior Publication

This work has never been published.

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1 Baek-woon Lee *et al.*, *SID 03 Digest*, 1212 (2003).
2 Rafael C. Gonzalez *et al.*, *Digital Image Processing*, 2nd ed., pp. 40-41, Prentice Hall, New Jersey (2002).