Improved LCD color performance using RGB gamma curve control

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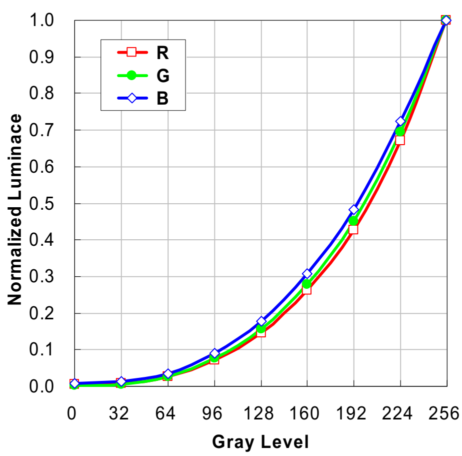
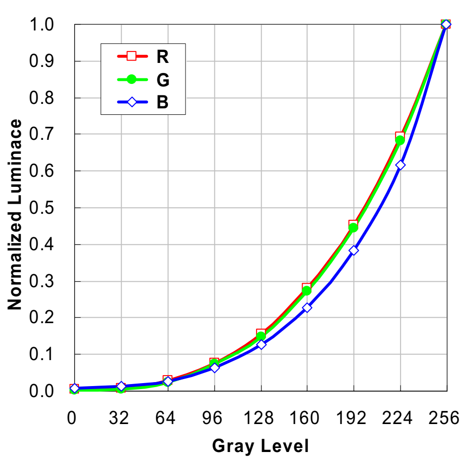
Abstract

The technique presented in this paper maximizes LCD color performance by way of advanced gamma control technology. First, two gamma curves corresponding to two sub-pixels are mixed to minimize gamma distortion off-axis, then RGB gamma curve control is used to establish accurate on-axis color. Independent RGB curve control for each sub-pixel improves the LCD's performance both on- and off-axis.



(a) Before ACC



(b) After ACC

Fig. 1 RGB gamma curves before and after ACC

1. Introduction

Recently, tremendous progress has been made to improve the color performance of liquid crystal displays (LCDs). We originally proposed a method, Accurate Color Capture (ACC), to reduce color shift of LCDs by counteracting the wavelength-dependent transmission characteristics of LCDs over the range of gray levels [1]. ACC is a simple but powerful technology to minimize color shift. The principle of ACC is to intentionally modify the red, green, and blue (RGB) gamma curves as shown in Fig. 1. The significant improvement in color shift over the range of grays is shown in Fig. 2. However, ACC only corrects on-axis color variations.

At SID'05, Samsung reported enhancements to Super-PVA technology, including two transistor S-PVA driving and optimized sub-pixel area ratio to minimize gamma distortion [2]. The main concept behind S-PVA is that two sub-pixels have two different associated gamma curves, which are mixed as shown in Fig. 3(a). As shown in Fig. 3(b), off-axis gamma distortion is minimized.

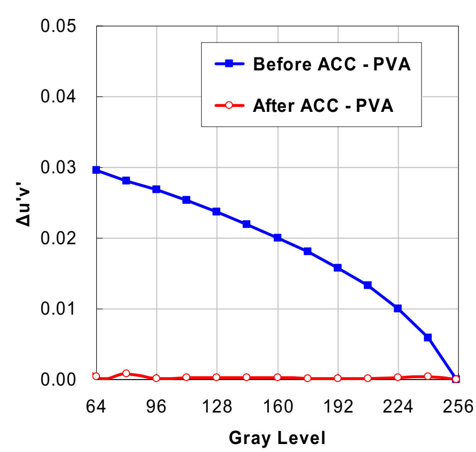
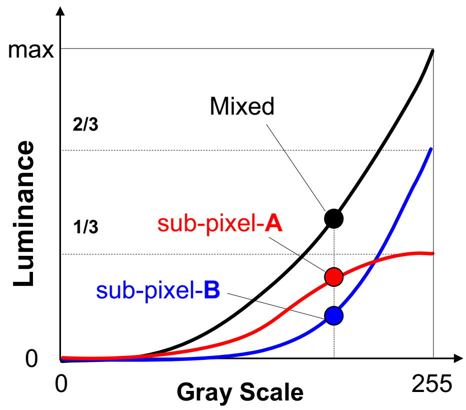
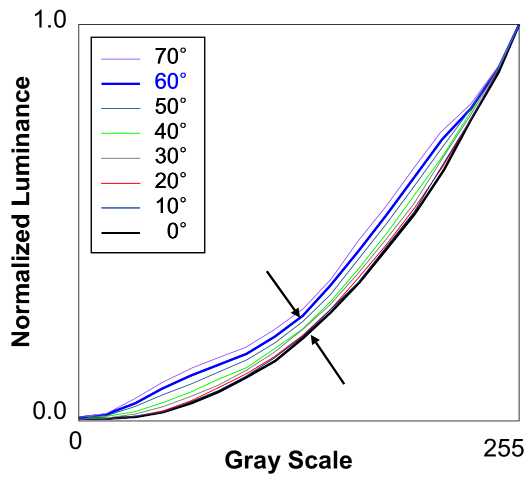


Fig.2 Color shift comparison before and after ACC



(a) Principle of S-PVA



(b) Gamma curves of S-PVA at off-axis

Fig. 3 Gamma curves of S-PVA

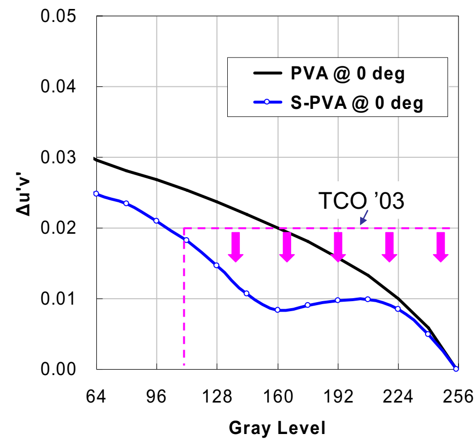


Fig. 4 Color shift of S-PVA and PVA at on-axis

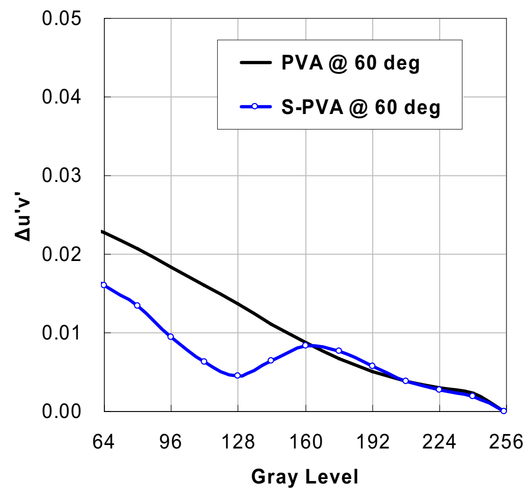


Fig. 5 Color shift of S-PVA and PVA 60° off-axis

This paper takes S-PVA performance to the next level by developing extended gamma control technologies for enhanced color performance.

2. Gamma curve mixing technology

By mixing two sets of gamma curves, LCD color performance advantages are realized both on- and off-axis. Fig. 4 graphs the on-axis color performance improvement of S-PVA over PVA, and shows that S-PVA panels satisfy the color gray-scale linearity requirements of TCO '03. Note that this performance improvement is achieved even prior to application of ACC. At the same time, the off-axis color-shift performance gains of S-PVA over PVA are not as significant, as shown in Fig. 5

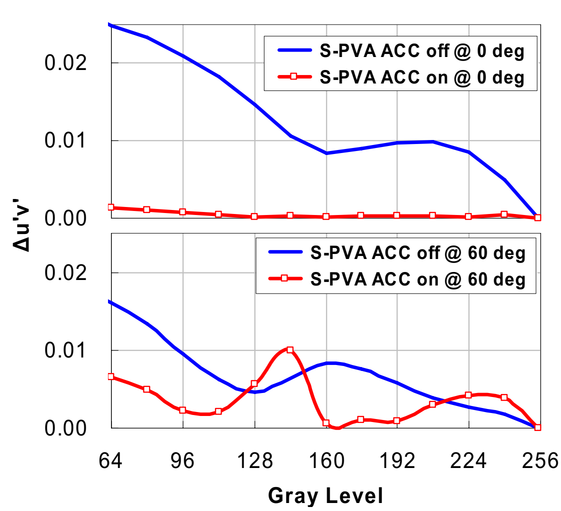
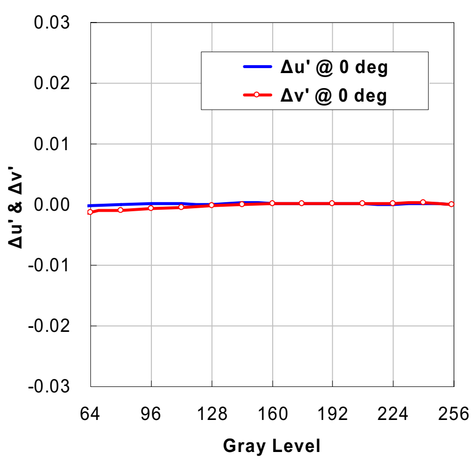


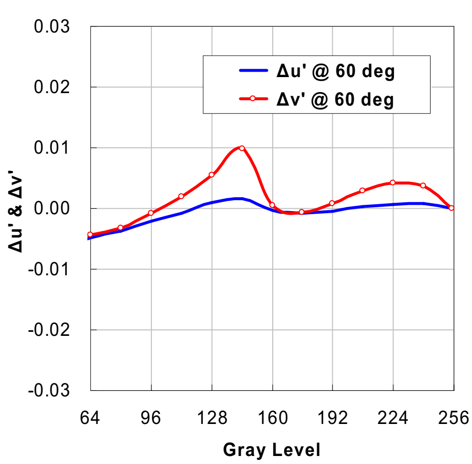
Fig. 6 On- and off-axis color shift performance comparison

before and after application of ACC

Fig. 6 shows the on and off-axis color performance before and after application of ACC. Still, in the off-axis case with ACC on, there are two small color fluctuations. The fluctuation near gray level 224 is basically imperceptible because the luminance is too bright. However, the fluctuation between gray level 96 and 160 has to be considered. Fig. 7 shows individual Δu' and Δv' plots with ACC on (a) on-axis and (b) 60° off-axis. Fig. 7(b) shows u' and v' of the mid-gray is slightly higher than white (i.e., Δu' and Δv' > 0), which means the display as viewed off-axis may have a slight cast near the mid-gray range (96-160).



(a) on-axis



(b) 60° off-axis

Fig. 7 Color shift measurements

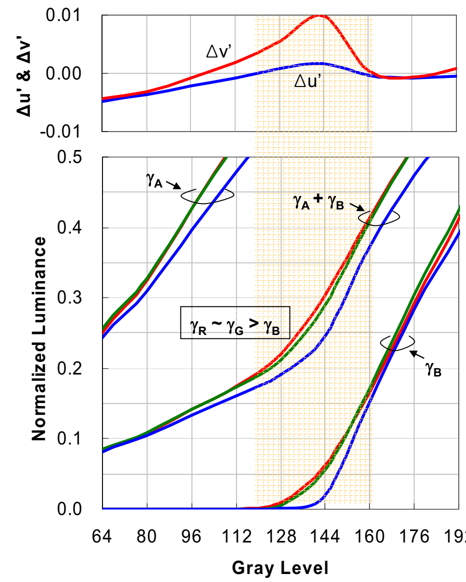


Fig. 8 RGB gamma curves of A, B, and A&B at off-axis

3. Gamma mixing plus independent RGB gamma control

Fig. 8 shows normalized S-PVA luminance curves vs. gray level for the A sub-pixel only, B sub-pixel only, and the A+B sub-pixel combination at off-axis. Fig. 8 shows the following: (1) the color shift fluctuation range begins at the same point as the turn-on point for the B-curve (γ_B), (2) red and green curves are almost identical while the blue curve is lower than the red and green curves. We need to maintain these relationships for the combined A sub-pixel and B sub-pixel gamma ($\gamma_A+\gamma_B$) in order to preserve color performance on-axis, which is done using ACC. Each R, G, and B curve is generated by the combination of A and B sub-pixel gamma curves, as R_{A+B}, G_{A+B}, and B_{A+B}. Therefore, there are unlimited combinations of the two A and B sub-pixel curves that will result in the target A+B curve for each primary. In other words, we can control the individual R, G, and B gamma curves of A and B while $\gamma_A+\gamma_B$ is not affected at on-axis.

To eliminate the potential for any color variation, we have developed a new technique for advanced control of off-axis color performance. An additional degree of freedom is applied through the use of RGB independent gamma control, which enables exact control of the gamma curves at any angle of view, thereby eliminating all off-axis color variation. Fig. 9 shows this proposal. At the point where B sub-pixel starts to contribute luminance, the normalized blue luminance of B sub-pixel should have higher portion than red and green. So, the blue curve of sub-pixel B is higher than red and green curves as shown in Fig. 9. We can compare B sub-pixel curves before (inner box) and after controlling as shown in Fig. 9.

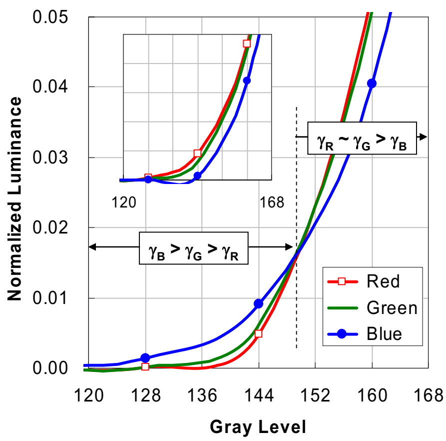


Fig. 9 Independent RGB gamma control of B-pixel

4. Results

Fig. 10 shows the resultant color shift measurement. Nearly all of the Δu'v' fluctuation in the range of interest has been eliminated. Fig. 11 shows γ_A, γ_B, and $\gamma_A + \gamma_B$ (a) before and (b) after controlling B sub-pixel curves. As shown in Fig. 11, the $\gamma_A + \gamma_B$ are not changed, which means the color performance at on-axis is maintained.

5. Conclusions

We have developed a means to perfect off-axis color accuracy based on the concept of gamma mixing and RGB independent gamma control. Off-axis performance has been improved with no degradation of on-axis color performance. Conventional driving technology does not accommodate RGB independent gamma control, therefore We are developing new panel driving technology to enable this capability.

6. References

[1] S.-W. Lee, et al., "Driving Scheme for Improving Color Performance of LCD's: Accurate Color Capture", SID 03

[2] S.S. Kim, "The world's largest (82-in.) TFT-LCD", SID 05

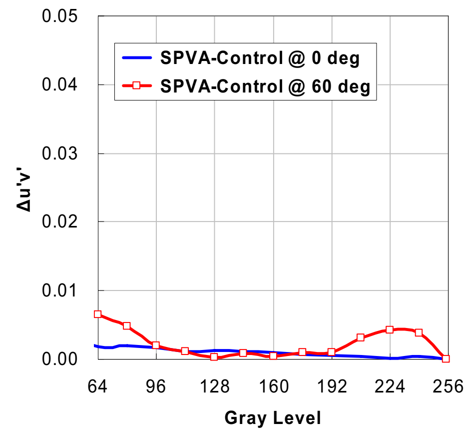
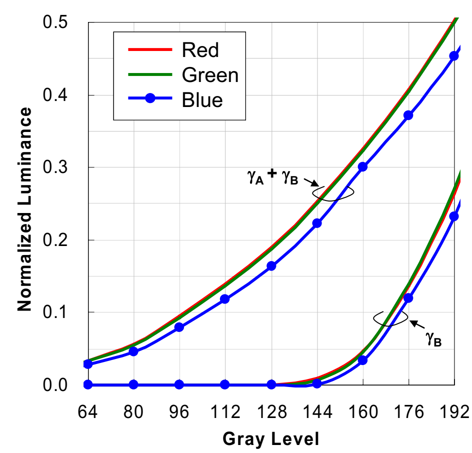
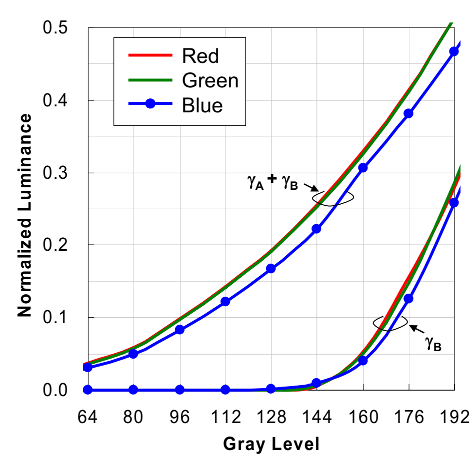


Fig. 10 Off-axis color shift before and after applying RGB independent gamma control



(a) Before controlling



(b) After controlling

Fig. 10 On-axis gamma curves before and after applying RGB independent gamma control