Color Performance of a MVA LCD Using LED Backlight

Ruibo Lu, Xiangyi Nie, and Shin-Tson Wu; College of Optics and Photonics, University of Central Florida; FL 32816, USA

Abstract

The color performances such as color gamut, color shift, and gamma curve of a MVA LCD using LED backlight are calculated quantitatively. Simulation results indicate that LED backlight exhibits better angular color uniformity and smaller color shifts than CCFL backlight. Color gamut can be further widened and color shift reduced when using color-sequential RGB-LED backlight without color filters. In the meantime, the angular-dependent gamma curves are less influenced using different backlights. The obtained quantitative results are useful for optimizing the color performances and color management of high-end LCD monitors and LCD TVs.

1 Introduction

Liquid crystal displays (LCDs) using light emitting diode (LED) backlight unit show evident performance advantages over the conventional cold-cathode fluorescent lamp (CCFL) in wider color gamut, higher brightness, tunable backlight white point control by separate red, green and blue (RGB) colors, real-time color management, etc. [1, 2, 3]. For high-end LCD monitors and TVs, weak color shift, fast response time, wide viewing angle, high contrast ratio, and high optical efficiency are critically important. To meet these technical challenges, the multi-domain vertical alignment (MVA) LCDs have been developed and widely used [4].

In this paper, the color performance of a film-compensated MVA LCD using LED backlight is quantitatively evaluated in terms of color gamut, color shift, and gamma curves. These results are compared with the MVA LCD using a conventional CCFL backlight. We calculate the color shift based on the color difference in CIE-1976 uniform chromaticity scale. The optical properties of the LCDs are simulated with a 3-D simulator and imported during the color performance calculation. A two-cell approach filled with two different LC materials is proposed to improve the off-axis gamma curves of the MVA LCD.

2 Modeling of Color Shift

The CIE 1976 uniform chromaticity scale (UCS) diagram, which is also called (*u', v'*) diagram, has been commonly used to present the equidistant chromaticity scales [5, 6]. The (*u', v'*) coordinates are related to the (x, y) coordinates in CIE 1931 by the following equations:

$$u' = \frac{4X}{X+15Y+3Z} = \frac{4x}{-2x+12y+3}$$
$$v' = \frac{9Y}{X+15Y+3Z} = \frac{9y}{-2x+12y+3} \qquad (1)$$

Based on Eq. (1), $\Delta u'v'$ at any two positions (1 and 2) can be calculated using the following formula

$$\Delta u'v' = \sqrt{(u'_2-u'_1)^2+(v'_2-v'_1)^2}\ . \qquad (2)$$

To characterize the color shift in a LCD TV, [u'_2, v'_2] represent the [u', v'] values at an oblique viewing angle while [u'_1, v'_1] are usually referred to the [u', v'] values at normal viewing angle.

3 Device Structures and Simulation Methods

Figure 1 shows a typical device structure of the MVA LCD [7]. In our design, the cell gap of the MVA LCD is d=4 μm, the width of the chevron-shaped slit is *w*= 6 μm, the gap between the neighboring slits on the bottom and top substrates is *g*= 18 μm on the projected plane, and the chevron arm length is ℓ= 62 μm. The bending angle is at α=45°, and LC pretilt angle is 90° with respect to the substrate surface. As an example, we simulate the MVA LCD using a Merck negative LC mixture MLC-6608.

In the wide-view MVA LCD, phase compensation films are required [8]. Here, two sets of uniaxial films, a positive A-plate (dΔn= 93.2 nm) and a negative C-plate (dΔn=−85.7 nm), are placed after the polarizer and before the analyzer, respectively. The positive A-plate has n_e=1.5124 and n_o=1.5089 at λ=550 nm, and the negative C-plate has n_e=1.5089 and n_o=1.5124 at λ=550 nm [9]. During simulations, we assume the phase-matched compensation films have the same color dispersion as that of the LC material employed [10].

The simulation sequence is to obtain the dynamic 3-D LC director distributions first and then calculate the detailed electro-optics of the LCD. We used a 3-D simulator to calculate the LC director distributions. Once the LC director distribution profiles are obtained, we then calculate the electro-optic properties of the LCD using the extended Jones matrix method [11].

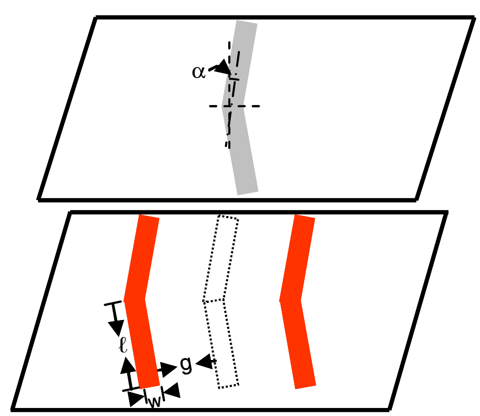
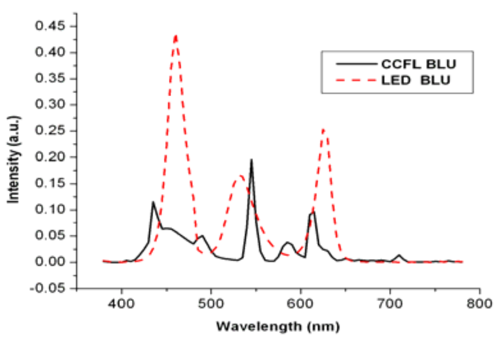


Figure 1 *A typical electrode configuration of the multi-domain LCD.*

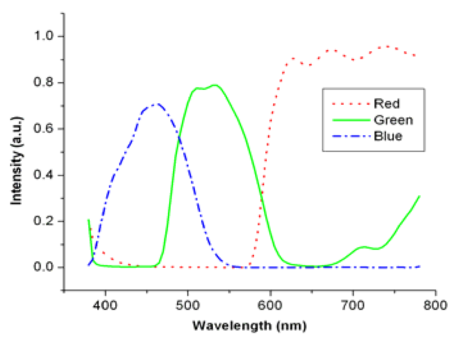
4 Results and Discussion

4.1 Color Gamut of LCD Panels under LED and CCFL Backlights

Figure 2 shows the transmission spectra of the CCFL and LED backlight units and color filters. The LED-BLU consists of a series of separate RGB LEDs, and the color filters have their average peak transmittance at R~650 nm, G~550 nm and B~450 nm. It can be seen that the RGB peak wavelengths of LED-BLU match better to those of color filters (CFs), and its respective bandwidth is narrower and without side-lobes as compared to that of CCFL-BLU.



(a)



(b)

***Figure 2** The emission spectra of (a) CCFL- & LED-BLU, and (b) the transmission spectra of CFs.*

Figure 3 is a plot of the RGB primaries through the MVA LCD panel using CCFL-BLU, LED-BLU with color filters or RGB LED without color filters. The color gamut defined by the RGB LED color points from LED-BLU with color filters in the color diagram is larger than that of the CCFL primaries and the National Television System Committee (NTSC) standard primaries. It means that it is possible to obtain a greater than 100% NTSC color gamut by properly selecting the LED colors and color filters. As for the primaries of the separate RGB LED without color filters, the color space can be further widened from 112.3% to 128.6% NTSC color gamut. The color gamut of a LCD device using the conventional CCFL-BLU is usually about 75% NTSC [12]. Meanwhile, even though a wide gamut CCFL-BLU has been commonly adopted by LCD industry, the color gamut achieved by the CCFL backlight is 93.5% of the NTSC standard, which is still narrower than that of LED backlights. This is because the peak transmittance of the RGB primary colors of LED-BLU match better with those of color filters and their respective bandwidth is narrower. Although a wider color gamut is desirable, good color saturation and natural color are equally important. Color is not just a science but also an art.

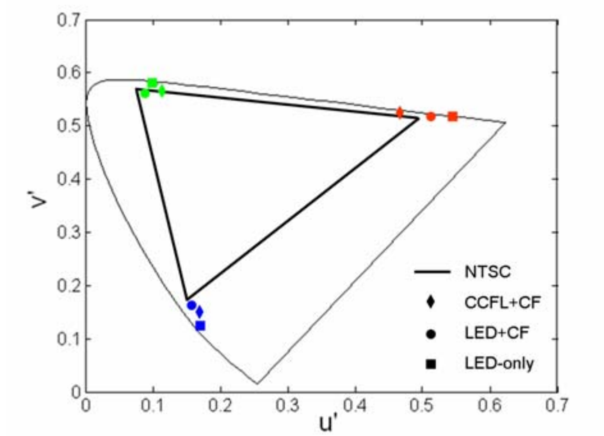


***Figure 3** The RGB primaries through the MVA-LCD panel for different backlights and NTSC standard primaries on the CIE 1976 UCS diagram.*

4.2 Color Shift of RGB Primaries at Different Incident Angles

To calculate the angular color uniformity under different backlights, we redefine Eq. (2) as

$$\Delta u'v' = \sqrt{(u'_{max} - u'_{min})^2 + (v'_{max} - v'_{min})^2}\ , \qquad (3)$$

where [u'_{max}, v'_{max}] and [u'_{min}, v'_{min}] represent the maximum and minimum [u', v'] values at the full-bright state between 0-80^o viewing range. The detailed results are shown in Table 1.

Table 1: The calculated values of the film-compensated MVA LCDs with three different backlights

	CCFL+CF	LED+CF	LED-only
R	0.0159	0.0110	0.0083
G	0.0343	0.0274	0.0254
B	0.1271	0.1115	0.0511

For the angular color shift of the film-compensated MVA LCD under LED-BLU with CFs, we obtain Δu'v'= (0.0110, 0.0274, 0.1115) at RGB primaries. To compare the angular color uniformity of the film-compensated MVA LCD with different backlights, we obtain Δu'v'= (0.0159, 0.0343, 0.1271) for CCFL-BLU with CFs, and Δu'v'= (0.0083, 0.0254, 0.0511) for RGB LED-BLU without CFs at the respective RGB primaries. The LED backlit MVA-LCD shows ~1.35X better angular color uniformity in green and ~2X in red and blue primaries than the CCFL-based MVA-LCD.

4.3 Color Shift in the Horizontal Direction

Figure 4 shows the simulated angular dependent Δu'v' of MVA LCD backlit by different light sources as observed from the horizontal (ϕ=0°) viewing direction at the full-bright state. The RGB curves are more or less symmetric along θ=0° and the Δu'v' value increases as the theta angle increases. No matter which backlight is used, blue color always has the largest Δu'v' value, followed by green and then red. In the region that |θ|>0, the Δu'v' of LED backlit MVA LCD with CFs is smaller than that of the CCFL-BLU with CFs for the respective RGB primaries. At θ= ±80º, Δu'v'= (0.0099, 0.0235, 0.0981) for LED and Δu'v' = (0.0139, 0.0292, 0.1090) for CCFL at the respective RGB primaries. From Fig. 4, it can be seen that LED backlight is helpful for reducing color shift.

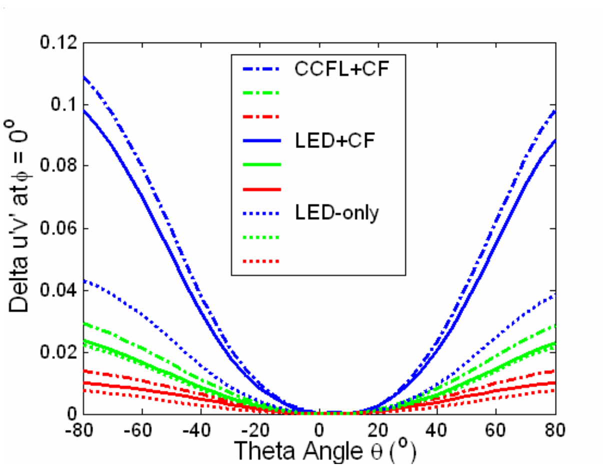


Figure 4 Color shift for RGB primaries under different backlights along the horizontal direction.

Also found in Fig. 4, for each RGB primary the color shift of LED-only is much smaller than that of LED and CCFL with color filters. At θ= ±80º, the Δu'v' values for the RGB primaries of the LED-only system are as low as (0.0073, 0.0222, 0.0431), which is ~1.3-2.5X smaller than the conventional CCFL-BLU system. This advantage is attributed to the narrower spectral bandwidth and less overlap of the RGB LED light sources.

4.4 Gamma Curves at Different Viewing Angles

Figure 5 plots the gamma curves of the MVA LCD at different oblique viewing angles under different backlights. Here, a light skin color of [R, G, B] = [241, 149, 108] is used where the azimuthal angle is set at 0° and the polar angle varies from 0° to 60° and γ= 2.2. It can be seen that the MVA LCD has a fairly large gamma variation when the oblique viewing angle is larger than 40°, especially in the low and middle gray levels, no matter what kind of backlight is used. It indicates that MVA LCD has color-washout effect when observed from oblique angles. By contrast, the in-plane switching LCD has smaller color washout. However, its contrast ratio at normal viewing direction is lower than that of MVA LCDs.

5 Conclusions

The color performance of a MVA LCD is quantitatively evaluated in terms of color gamut, color shift and gamma curves using RGB LEDs and CCFL as backlights. The LED backlit LCDs not only exhibits a wider color gamut but also has a ~1.3-2.5X smaller color shift than that of CCFL-BLU especially when no color filters are used. A two-cell approach filled with two different LC materials is proposed to improve the off-axis gamma curves of the MVA LCD. The obtained quantitative results are useful for optimizing the color performances and color management of high-end LCD monitors and LCD TVs.

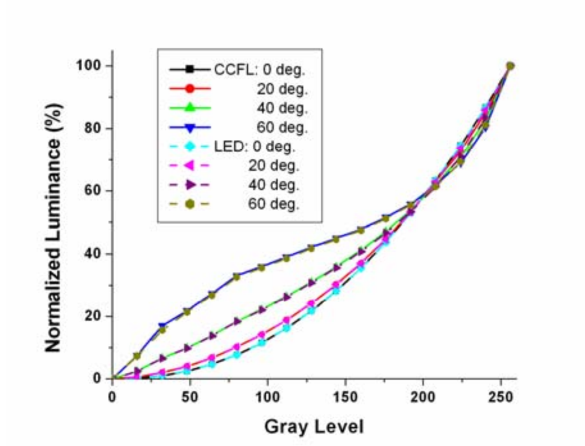


Figure 5 Typical gamma curves for MVA at light skin color.

Acknowledgments

The authors are indebted to the financial support of Chi-Mei Optoelectronics Corporation (Taiwan).

References

[1] G. Harbers and C. Hoelen, "High performance LCD backlight using high intensity red, green and blue light emitting diodes," SID Symposium Digest, 32, 702 (2001).

[2] H. S. Hsieh, C. H. Chou, and W. Y. Li, "Vivid color and clear motion picture 32-inch TFT-LCD TV with scan RGB LED backlight," Proc. Int'l Display Manufacturing Conf., pg. 622. (2005).

[3] R. Lu, Q. Hong, Z. Ge, and S. T. Wu, "Color shift reductions of a multi-domain IPS-LCD using RGB-LED backlight," Opt. Express, 14, 6243 (2006).

[4] R. Lu, X. Zhu, S. T. Wu, Q. Hong, and T. X. Wu, "Ultrawide-view liquid crystal displays," J. Display Tech., 1, 3 (2005).

[5] G. Wyszecki and W. Stiles, Color Science -- Concepts and Methods, Quantitative Data and Formulate (2nd Edition) (Wiley, New York, 1982).

[6] R. Hunt, Measuring Colour (2nd Edition), (Ellis Horwood, West Sussex, 1991).

[7] S. Kim, "Super PVA sets new state-of-the-art for LCD-TV," SID Symposium Digest, 35, 760 (2004).

[8] S. T. Wu and D. K. Yang, Reflective Liquid Crystal Displays (Wiley, New York, 2001).

[9] Q. Hong, T. X. Wu, X. Zhu, R. Lu, and S. T. Wu, "Extraordinary highcontrast and wide-view liquid crystal displays," Appl. Phys. Lett., 86, 121107 (2005).

[10] S. T. Wu, "Phase-matched compensation films for liquid crystal displays," Materials Chemistry and Physics, 42, 163 (1995).

[11] A. Lien, "A detailed derivation of extended Jones matrix representation for twisted nematic liquid crystal displays," Liq. Cryst., 22, 171 (1997).
[12] M. F. Hsieh, K. H. Peng, Y. H. Hsu, M. C. Shih, H. C. Hung, C. P. Hung, H. S. Hsieh, W. Y. Li, M. T. Yang, and C. K. Wei, "Recent improvements of multidomain vertically-aligned-mode LCD TV," SID Symposium Digest, 37, 1942 (2006).

Author Biography

Ruibo Lu received his Ph.D. from Department of Physics, Fudan University, China, in 1998, and his M.S degree in applied physics from East China University of Science and Technology, China, in 1995. He is a resaerch scientist at College of Optics and Photonics, University of Central Florida. His research interests include liquid crystal display technology, liquid crystal components for optical communications and optical imaging using liquid crystal medium. He is a member of SID.

Xiangyi Nie received the B.S. and M.S. degrees in electrical engineering from Nanjing University, Nanjing, China, in 1999 and 2002, respectively. He is currently working toward the Ph.D. degree at School of Electrical Engineering and Computer Science, University of Central Florida, Orlando. His Ph.D. research concentration is in liquid crystal display and surface physics.

Shin-Tson Wu received his Ph.D. from the University of Southern California and his BS in physics from National Taiwan University. He is a PREP professor at College of Optics and Photonics, University of Central Florida. His studies at UCF concentrate in foveated imaging, bio-photonics, optical communications, liquid crystal displays, and liquid crystal materials. He is a Fellow of the IEEE, SID and OSA.