The novel design for improved off-axis gamma curve in vertically aligned liquid crystal cell

Dong-Eon Lim, Wan Seok Kang, Byung-June Mun, Seung-Yeol Hur, and Gi-Dong Lee

Department of Electronics Engineering, Dong-A University, Pusan 604-714, Korea

ABSTRACT

we propose a novel optical compensation structure, which shows eliminating light leakage in the dark-state for wide viewing angle, as well as featuring that it can control the middle gray level transmittance so that it decreasing off-axis gamma distortion in the vertically aligned (VA) liquid crystal (LC) cell.

1. Introduction

Currently, a lot of liquid crystal displays (LCDs) have shown dramatic increase because of excellent properties such as low power consumption, small thickness, and light weight. As the case stands, the LCDs market has been expanded in the field of monitor and mobile phone market. In order to achieve remarkable optical properties, many display modes such as VA mode [1], in-plane switching (IPS) mode [2], and twisted nematic (TN) mode [3] have been developed in the display market. Particularly, the greatest advantage of VA LCD is an excellent contrast ratio in the on-axis direction due to zero retardation in that direction. However, in the single domain VA mode, there exist many problems of decreased optical properties with changed viewing direction [4]. So, single domain VA mode is still limited to expanding in the display market. To improve the possibility of expanding single domain mode, we research the method of enhancing optical properties by using optical compensation film.

We introduce that the novel optical configuration can effectively eliminate light leakage for a wide viewing angle and also decreasing gamma distortion in the off-axis direction by using optical compensation plates. In the proposed configuration, the light leakage is eliminated by negative *C*-plate, a *λ/2* biaxial-plate and gamma distortion is decreased by controlling two *O*-plates.

In this paper, the key point is that gamma curve is improved by compensating middle gray level transmittance effect of two *O*-plates with maintaining wide viewing angle and contrast ratio which were proved by conventional configuration composed of negative *C*-plate and *λ/2* biaxial-plate [5].

2. Design for compensating middle gray level transmittance

2.1 Conventional configuration

As a vertically aligned LC technology, the single domain VA mode is causing light leakage in the off-axis direction. This vulnerable characteristic is resolved by using optical compensation plates to the VA LC cell (rubbing direction=45°). Figure 1 represents conventional configuration applying negative *C*-plate and *λ/2* biaxial plate. Therefore, it could show decreased light leakage and improved contrast ratio in the off-axis direction. Although those could be improved, as we can notice in the Figure 2(b), there is serious gamma distortion between on-axis direction (θ=0°, φ=0°) and off-axis direction (θ=60°, φ=135°&315°). Particularly, the gamma curve of off-axis direction at middle gray level is severely different from on-axis direction. Through investigation of the gamma distortion phenomenon, we can know that the gamma curve highly depends on the voltage-transmittance (V-T) curve [6]. The V-T curves at on-axis and off-axis direction are as shown in Figure 2(a). The results indicate that there exists the transmittance difference between on-axis and off-axis direction.

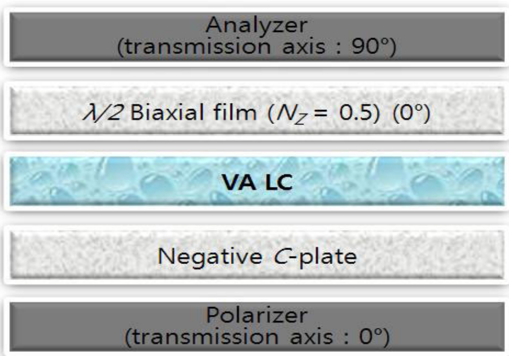

Fig. 1 Configuration of conventional single domain VA LC cell

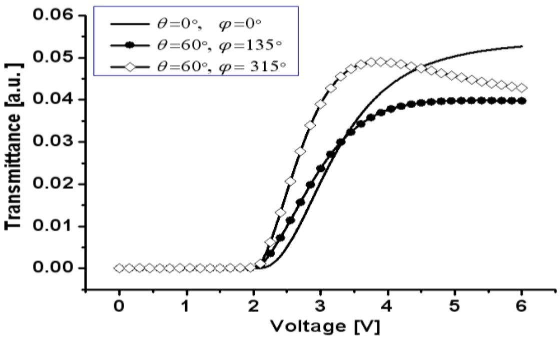

Fig. 2(a)

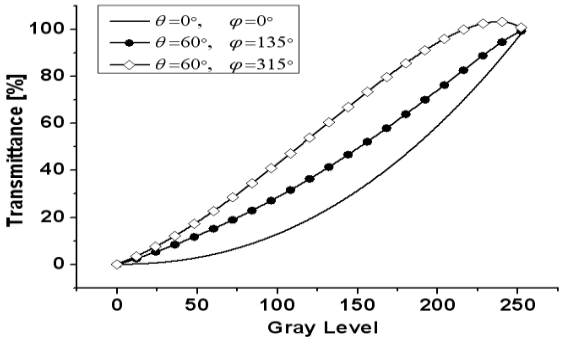

Fig. 2(b)

Fig. 2 Optical properties in the conventional single domain VA LC cell: (a) Transmittance-voltage curve (b) gamma curve

2.2 Analyzing polarization state

When we watch the display screen in the on-axis direction, we can perceive high color performance whose most fundamental gamma index is briefly 2.2 [7]. However, if observed viewing angle is not on-axis but off-axis direction, the transmittance does not increase exponentially by the increase of the voltage. Therefore, the gamma curve can't keep gamma index of 2.2 in the off-axis direction. In order to reduce the gamma distortion at the off-axis direction, we have analyzed particular voltage point among middle gray levels, its point is approximately LC=2.5V and gray level is roughly 90 level.

First of all, we have to analyze the polarization state which can be represented by Stokes parameters (S_1, S_2 and S_3). To obtain reference stokes parameter value, we investigate stokes parameter that the light is passing through the input polarizer and VA LC layer in the on-axis direction at LC=2.5V state. The state is depicted on the Poincaré sphere showed in Figure 5. The start position when light passing through input polarization is $P_H=(1,0,0)^T$. The polarization state of the light passing through VA LC layer at LC=2.5V is $P_K=(0.8252,\ 0,\ 0.5648)^T$ (=550nm) and analyzer absorption position is same as the input polarization position. Then polarization difference between two states of P_K and analyzer position (=P_H) can be described as below [8]:

$$\Delta P_{(H-K)}=\sqrt{\left(S_{1\_(H)}-S_{1\_(K)}\right)^2+\left(S_{2\_(H)}-S_{2\_(K)}\right)^2+\left(S_{3\_(H)}-S_{3\_(K)}\right)^2} \quad (1)$$

Where $S_{1\_(H)}$, $S_{2\_(H)}$, $S_{3\_(H)}$, $S_{1\_(K)}$, $S_{2\_(K)}$, and $S_{3\_(K)}$ are the Stokes parameters of P_H, P_K respectively that S_1+S_2+S_3=1. $\Delta P_{(H-K)}$ is within the range from 0 to 2. A smaller $\Delta P_{(H-K)}$ implies to a smaller transmittance. Therefore, we can know that the polarization difference between P_H and P_K is $\Delta P_{(H-K)}$ =0.591. However, in the off-axis direction, (θ=60°, φ=135°) and (θ=60°, φ=315°) are $\Delta P_{(H-B=135°)}$ =0.909, $\Delta P_{(H-B=315°)}$ =1.200. Here, $P_{B=135°}$ and $P_{B=315°}$ are last polarization position in the conventional configuration. In that polarization difference, it causes the transmittance distortion in the off-axis. To resolve this distortion, we suggest the novel optical configuration and compensation method.

2.3 Proposed configuration

In order to diminishing transmittance difference caused from polarization difference in the middle gray levels, we suggest the novel optical configuration showed in Figure 3. This construction was achieved by adding Negative *O*-plate and Positive *O*-plate in the conventional configuration. Here, the *O*-plate has its molecular axis uniformly tilted at off-axis direction. It is a reason for using the *O*-plate that which plays an essential role to adjust compensation in the middle gray levels transmittance and has the advantage of less dependence in the viewing angle on setting of optical axis and phase retardation than other optical films [9]. In this proposed configuration, there are two conditions existing.

$$\sum \mathrm{Re}t\ (Negative\_O + Positive\_O) = 0 \quad (2)$$

$$\sum \mathrm{Re}t\,(VALC + Negative\_C) = 0 \quad (3)$$

Those things being equal, we can design the optimal transmittance in the middle gray levels while keep the optimal wide viewing angle properties. To adjust polarization difference in the off-axis direction to the reference value (=0.591) at the middle gray levels (LC=2.5V), we perform the analysis of

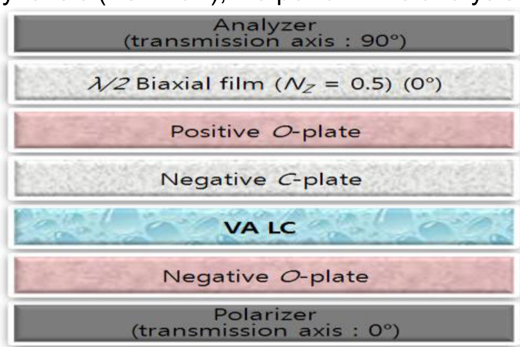

Fig. 3 Configuration of proposed single domain VA LC cell

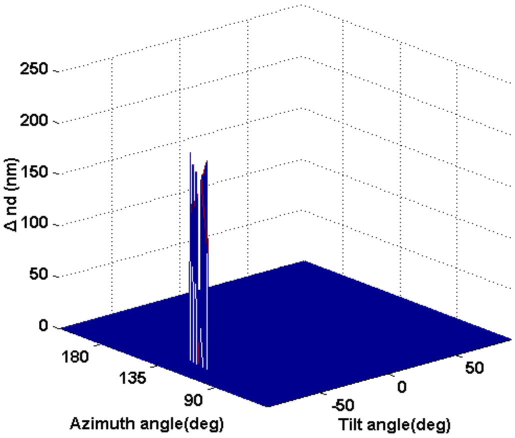

Fig. 4 The optimization graph from the variation of the *O*-plates conditions

polarization difference according to the *O*-plates conditions deal by azimuth angle, tilt angle and *Δnd*. Here, the variation of the azimuth angle is from 45° to 225°, tilt angle is from -90° to 90°, and *Δnd* is from 10nm to 250nm. Figure 4 plots the effect of the polarization difference contented with that polarization difference is higher than 0.57 and lower than 0.61 when the *O*-plate conditions are variable. It have been progressed within a ±0.2 permissible range from reference value of 0.591. After analyzing the result from variable *O*-plates conditions, we can find the optimal *O*-plates conditions that (*azimuth angle*=120°, *tilt angle*=-73°, *Δnd*=±192nm) is highly satisfied with the polarization difference for reference value. Therefore, for viewing angle (θ=60°, φ=135° & 315°), the polarization difference is $\Delta P_{(H\text{-}F=135°)}$ =0.579 and $\Delta P_{(H\text{-}F=315°)}$ =0.571 respectively. Here, $P_{F=135°}$ and $P_{F=315°}$ are last polarization position in the proposed configuration. By so diminishing polarization difference value between on-axis and off-axis directions, we could be verified by numerical value. And also we can be confirmed by the Poincaré sphere showed in Figure 5. Here, Circle j is the radius of the reference value. So, before compensating middle gray levels of the

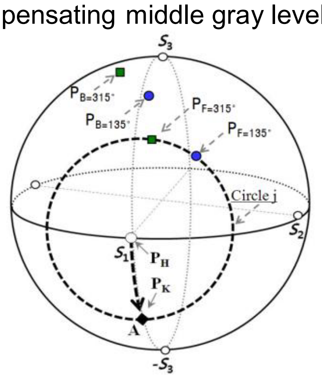

Fig. 5 The polarization state in the LC=2.5V state

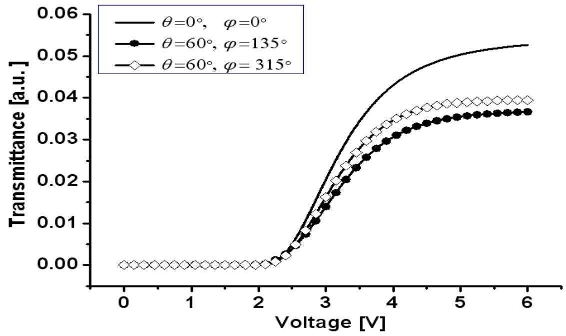

Fig. 6(a)

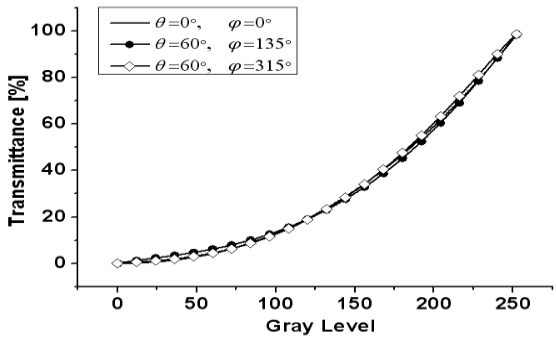

Fig. 6(b)

Fig. 6 Optical properties in the proposed single domain VA LC cell: (a) Transmittance-voltage curve (b) gamma curve

polarization position is out of Circle j as depicted position $P_{B=135°}$ and $P_{B=315°}$. However, after compensating deviated polarization position by two *O*-plates, we can confirm that the polarization position is moved on to the Circle j from ($P_{B=135°}$ & $P_{B=315°}$) to ($P_{F=135°}$ & $P_{F=315°}$) respectively. By diminishing polarization difference between on-axis and off-axis, we verify that the slope of V-T curve of the off-axis direction tends to do what on-axis direction. It can be showed in Figure 6(a). Therefore, result from decreased transmittance difference between on-axis and off-axis direction, we can produce an expected result that the gamma distortion of the off-axis direction was highly reduced. This result showed in Figure 6(b).

3. Results and discussion

From the results, when the off-axis polarization difference value was adjusted to on-axis polarization difference value in the middle gray levels, it could improve gamma curve through controlling V-T curve. In that progress, the simulated gamma correction factor is γ=2.2 and an 8 bit grayscale with 256 gray levels are evaluated

To calculate the gamma distortion phenomenon, we define a gamma distortion index as follows:

$$GDI = AVG\left\langle \left| L_{i(on\text{-}axis)} - L_{i(off\text{-}axis)} \right| \right\rangle_{i=0\sim255} \quad (4)$$

Where $L_{i\ (on\text{-}axis)}$ and $L_{i\ (off\text{-}axis)}$ mean the brightness between i^{th} gray level at the on-axis and off-axis direction, and < > denotes the average for all cases of arbitrary gray levels. The magnitude of the GDI smaller, it means the lower off-axis gamma distortion and better image quality. The calculated results of the GDI between conventional and proposed configuration are highly improved that GDI value are changed from 15.69 to 0.98 at (θ=60°, φ=135°) direction and from 32.21 to 1.98 at (θ=60°, φ=315°) direction. Those are roughly 93% improved while maintaining gamma curve properties in the other direction at (θ=60°, φ=45°&225°). And also we confirm that the proposed configuration effectively eliminates light leakage in the dark state without any decline effect in compared with conventional configuration showed in Figure 7 and Figure 8.

We verified the improved gamma curve and other optical properties of the proposed VA LC cell by using commercial LC software *TechWiz LCD* by SANAYI System Co. in Korea.

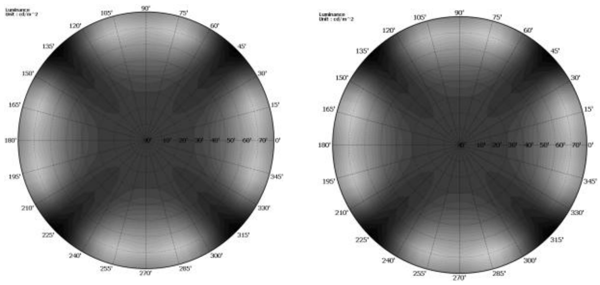

Fig. 7(a) Fig. 7(b)

Fig. 7 Calculated luminance in the dark state: (a) conventional and (b) proposed single domain VA LC cell

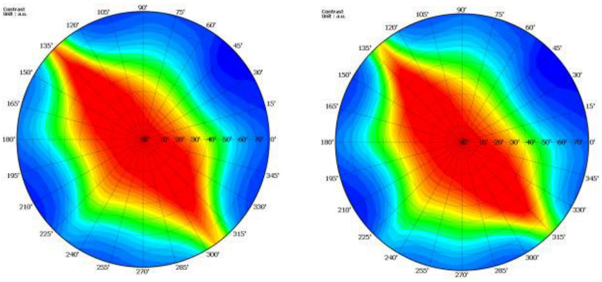

Fig. 8(a) Fig. 8(b)

Fig. 8 Calculated iso-contrast contours: (a) conventional and (b) proposed single domain VA LC cell

4. Conclusion

In conclusion, we have developed a low gamma distortion characteristic with improved off-axis image quality. The polarization difference from off-axis to on-axis level in the middle gray levels, it was possible due to effect of two *O*-plates. By diminishing polarization difference, it can effect to middle gray level transmittance, and then could make possible to improve gamma curve at the off-axis direction. As mentioned our studies, we confirmed that the proposed optical configuration shows excellent wide viewing angle, high contrast ratio and remarkable gamma curve by compensating both light leakage and middle gray level transmittance in the off-axis direction.

5. Acknowledgement

This work was supported by the Samsung Electronics.

6. References

[1] K. H. Kim, K. H. Lee, S. B. Park, J. K. Song, S. N. Kim, and J. H. Souk, “Domain divided vertical alignment mode with optimized fringe field effect,” in Proceeding of Asia Display’98, pp. 383-386 (1998).

[2] M. Oh-e, and K. Kondo, “Electro-optical characteristics and switching behavior of the in-plane switching mode,” Appl. Phys. Lett. 67, 3895-3897 (1995).

[3] M. Schadt and W. Helfrich. “Voltage-dependent optical activity of a twisted nematic liquid crystal,” Appl. Phys. Lett. 18, 127-128 (1971).

[4] K. Ohmuro, S. Kataoka, T. Sasaki, and Y. Koike, “Development of super-high-image- quality vertical-alignment-mode LCD,” SID Dig. Tech. Papers 28, 845-848 (1997).

[5] S. H. Ji, J. M. Choi, G.D. Lee, "Wide-view vertical alignment liquid crystal cell in a visible wavelength range," KLCC'09 OA-6 pp75, January (2009).

[6] J. Ma, Y.C. Yang, Z. Zheng, J. Shi, W. Cao, “A multi-domain vertical alignment liquid crystal display to improve the V-T property,” Displays 30, pp.185-189 (2009).

[7] H. Yoshida, T. kamada, K. Ueda, R. Tanaka, Y. Koike, K. Okamoto, P.L. Chen, J. Lin, “Multi-domain vertically aligned LCDs with super-wide viewing range for gray-scale images, Asia Display/IMID’04 12-2 (2004).

[8] Q. Hong, T. Wu, X. Zhu, R. Lu, and S. T. Wu, "Designs of wide-view and broadband circular polarizers," Opt. Express 13, 8318-8331 (2005).

[9] O. Yaroshchuk, L. Dolgov, J. Ho, H.S. Kwok, V. G. Chigrinov, H. Takatsu, H. Hasebe, “O films with adjustable tilt of optical axis for LCD compensation,” J.SID, 16/9, pp.933-938 (2008).