Novel PVA pixel design for mobile application with excellent off-axis image quality

Jae Hyun Kim*, Gee Bum Kim, Ji Youn Choi, Yong-Kyu Jang, Seon Hong Ahn, Kyeong-Hyeon Kim, and Sang Soo Kim
LC Technology Group, LCD Technology Center, LCD Business, SAMSUNG ELECTRONICS CO., LTD
San #200, Myeongam-Ri, Tangjeong-Myeon, Asan-City, Chungcheongnam-Do, Korea
Phone: +82-41-535-2844, E-mail: maxs1@samsung.com

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Abstract

We developed a novel PVA pixel design for mobile application with excellent off-axis image quality and optical performance by introducing Active Level Shift technology and optimizing pixel structure. Our new pixel design enables better off-axis image quality without sacrificing other optical properties compared with a conventional mPVA structure.

1. Introduction

Recently, customer's needs for high optical performance such as wide viewing angle, high contrast ratio and fast response time have dramatically increased in mobile market. Thus, various LC modes such as vertical alignment (VA), optically compensated bend (OCB), in-plane switching (IPS) and fringe-field switching (FFS) have been suggested for mobile applications. Patterned-ITO vertical alignment (PVA) technology has the advantage of providing wide viewing angle and high contrast ratio for various LCD applications such as monitor, TV and mobile devices [1], [2], [3], [4], [5], [6]. However, conventional PVA mode has a serious gamma distortion at large viewing angles. To overcome this limitation of the PVA mode, Samsung Electronics Co., Ltd has proposed super-PVA (S-PVA) technologies using tools of capacitance coupling (CC), two transistor (TT), and charge sharing (CS) [7], [8], [9] for large-size flat panels, and gamma distortion at large viewing angles has been significantly improved as a consequence. Nevertheless, S-PVA technologies are not suitable for mobile devices with high resolution due to a great loss of aperture ratio. Mobile PVA (mPVA) LCD utilizes donut-shaped pixel structure and circular polarizers instead of chevron shaped pixel structure and linear polarizers to achieve maximum light transmittance. On the other hand, mPVA mode has bigger dark leakage at large off-axis angles than normal PVA mode because of using circular polarizers. This leads to the gamma distortion at off-axis angles.

In this paper, we introduce a novel PVA pixel design for mobile applications, which has high resolution features, to solve the drawback at off-axis angles. This pixel design integrated with ALS (Active Level Shift) circuit is very promising candidate to improve the aperture ratio as well as off-axis image quality.

2. Results and discussion

Figure 1 shows the on-axis ($\theta = 0^{\circ}$) and off-axis ($\theta = 60^{\circ}$) transmittances of a conventional 2.2 inch QVGA mPVA LCD as a function of gray scale. As we can notice, there is big difference between the two curves. Particularly, the gamma of off-axis at mid-gray levels shifts severely from that of on-axis, and gray scale inversion exists at high gray levels. These gamma distortions cause poor image quality such as

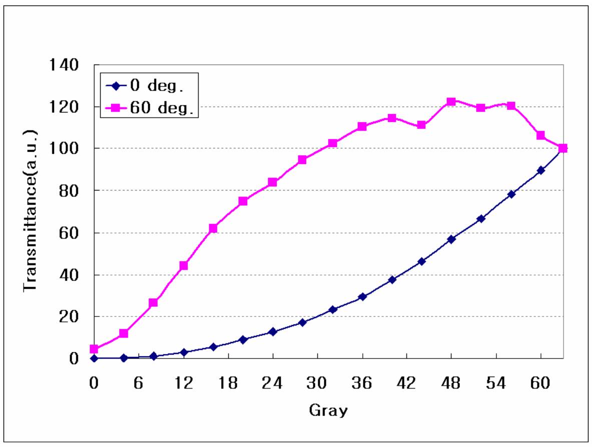


Fig. 1. Gamma curves of conventional mPVA LCD.

whitish color and color shift at large viewing angles.

To improve the off-axis image quality, we design a novel pixel structure integrated with ALS circuit. Figure 2(a) shows the schematic diagram of the conventional mPVA pixel. The pixel is divided into two sub-pixels which have a patterned ITO hole in color filter side. Each of the sub-pixels has the same pixel voltage because they are electrically connected by ITO bridge in TFT side. In contrast, our new mPVA pixel structure consists of two separate sub-pixels which are electrically independent by eliminating ITO bridge and dividing TFT, as illustrated in Fig. 2(b). Moreover, the contact hole of each sub-pixel locates at the center of sub-pixels, and CF ITO holes cover the pixel contact holes to stabilize LC texture. Therefore, new pixel design enables us to increase 15% of the aperture ratio (A/R) compared to the conventional design of the mPVA pixel.

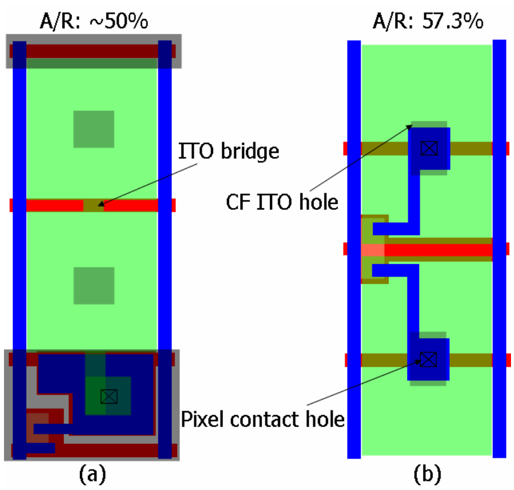


Fig. 2. Schematic diagrams of the (a) conventional and (b) new mPVA pixel structures.

Figure 3 shows the equivalent electric circuit and the gamma mixing principle of the novel mPVA pixel, which uses the ALS driving method. Firstly, a gate pulse turns on sub-pixel transistors. Then, a data voltage (Vd) is applied to sub-pixel electrode, which charges storage capacitors (Cst) and liquid crystal capacitors (Clc). After the gate pulse turns off the sub-pixel transistors, the final voltage applied to the sub-pixel is determined by the boosting voltage (ΔVboost) and the ratio of the Cst to the total capacitance of the sub-pixel (Ctotal = Clc + Cst + Cgd). Here, the sub-pixel voltage can be amplified by changing the magnitude of the ΔVboost.

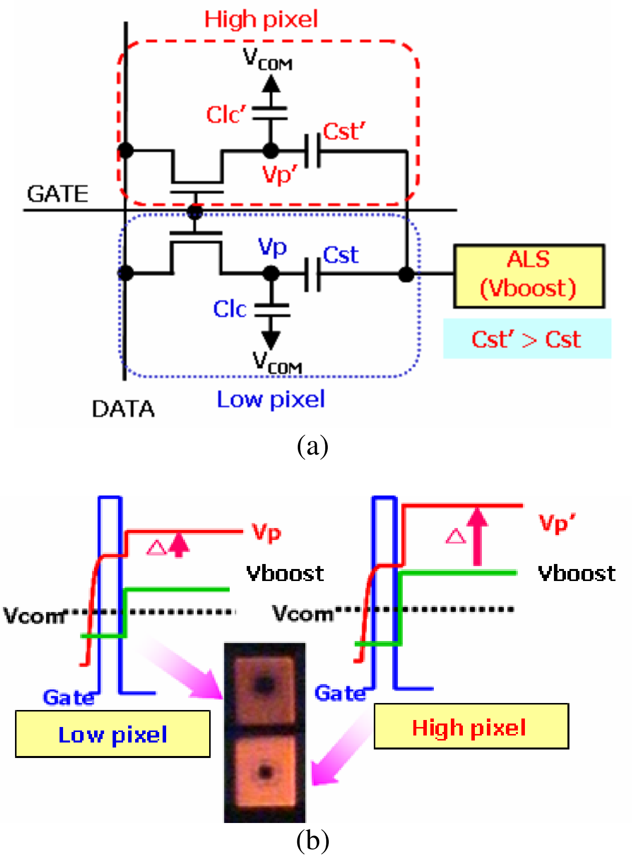


Fig. 3. (a) Equivalent electric circuit and (b) principle of ALS driving method for novel mPVA pixel.

In case of the same ΔVboost for the both sub-pixels, we can obtain different pixel voltages for each high and low sub-pixel by using the different Cst at sub-pixels, as shown in Eq. (1). To make high pixel have bigger voltage, we use bigger Cst at high pixel than that of the low pixel. After all, high and low pixels have different voltages and LC tilt angles, which can optically compensate each other and minimize the gamma distortions occurring at the off-axis viewing directions.

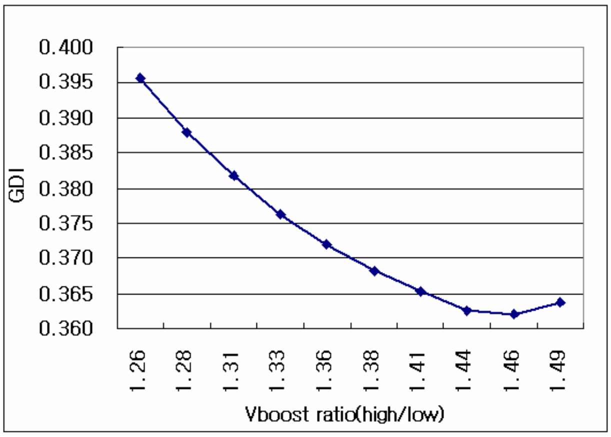
$$V_{lc} = V_d \pm \frac{C_{st}}{C_{lc} + C_{st} + C_{gd}} \times \Delta V_{boost} - V_k - V_{com} \quad (1)$$

Vlc: applied voltage to liquid crystal
Vd: data voltage
Clc: capacitance of liquid crystal
Cst: storage capacitance of sub-pixel
Cgd: capacitance between gate and drain
ΔVboost: boosting voltage
Vk: kickback voltage
Vcom: DC voltage of C/F common electrode

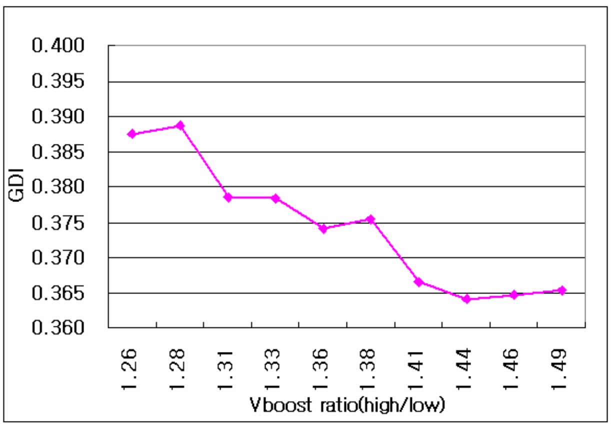
We define a gray distortion index (GDI) as follows:

$$GDI = AVG\left\{ \frac{\left| \frac{L_{ij}'}{L_{ij}} - 1 \right| - \left(\frac{L_{ij}'}{L_{ij}} - 1 \right)}{2} \right\}, \qquad (2)$$

where, L_{ij}, L_{ij}' is the difference of the lightness between i^{th} and j^{th} gray levels at the normal and off-axis direction, respectively. The magnitude of the GDI ranges from 0 to 1, and smaller GDI means the smaller off-axis gray distortion and better image quality. For the convenience, we first find the best Vboost ratio (high/low) with a constant Cst, which gives the lowest GDI, and then calculate the corresponding Cst ratio with the condition of constant Vboost for both high and low sub-pixels.



(a)

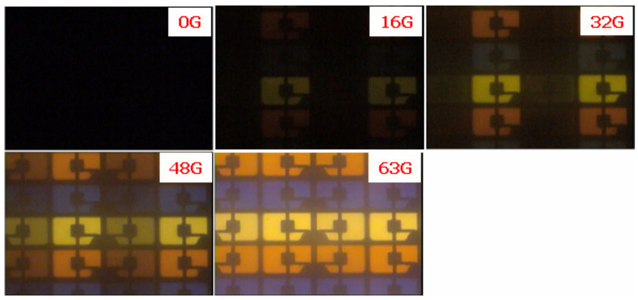


(b)

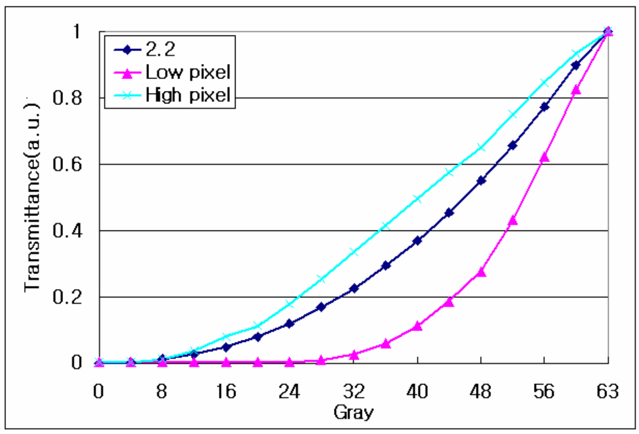
Fig. 4. (a) Calculation and (b) measurement results of the GDI with a constant Cst ratio for high and low sub-pixels.

Figure 4 (a) and (b) is the calculation and measurement results of the GDI as a function of the Vboost ratio (high/low), respectively. From both figures, we see that GDI decreases as the Vboost ratio increases and has a minimum value around the Vboost ratio of 1.44. Therefore, we can mention that our calculation is in good agreement with the measurement data, very well.

On the basis of this simulation result, we converted the best Vboost ratio into Cst ratio (high/low), reversely, and fabricated 2.2 inch QVGA (240×320) mPVA panel, as shown in Fig. 5(a). High pixel with bigger Cst is turned on earlier than low pixel with smaller Cst. Apparently, the V-T curve of high pixel has a lower threshold voltage than that of the low pixel at both normal and off-axis viewing directions, as illustrated in Fig. 5(b). For this reason, the high pixel has higher brightness than that of the low pixel at white gray (63G). Therefore, contrast ratio (CR) of a display is mainly affected by the high pixel of 0^{th} gray, and brightness is chiefly influenced by low pixel of 63^{th} gray. This means if the Cst ratio is optimized, there is no loss of optical properties.



(a)



(b)

Fig. 6. (a) Microscopic images and (b) gamma characteristics at the normal viewing direction.

Figure 7 shows the measured gamma curves for a conventional and new mPVA. For an oblique view, the gamma distortion is greatly improved, and gamma curve is closer to that of ideal gamma 2.2. The GDI, which is averaged for all viewing directions [θ=60°, (φ=0~360°, 45° step)], dramatically reduces from 0.51 to 0.36, as shown in Table 1.

Figure 8 is the photograph comparison of the off-axis image between conventional and novel mPVA LCDs. The color shift of novel mPVA at large viewing angles is significantly improved.

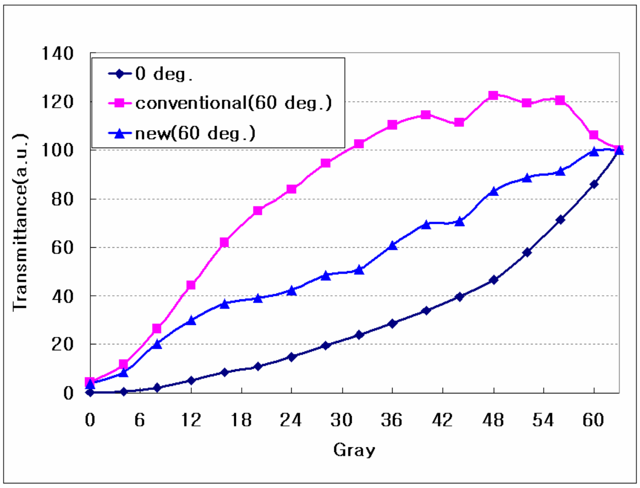


Fig. 7. Gamma characteristics of off-axis angle.

Table 1. Comparison of the GDI between conventional and novel mPVA LCDs.

ϕ(deg.)	0	45	90	135	180	225	270	315	AVG
Conventional	0.49	0.53	0.47	0.55	0.46	0.54	0.46	0.55	0.51
Novel	0.32	0.42	0.29	0.44	0.32	0.39	0.31	0.42	0.36

Fig. 8. Off-axis images of (a) conventional and (b) novel mPVA LCDs.

3. Summary

We have developed 2.2 inch QVGA mPVA LCD with excellent off-axis image quality. The new mPVA pixel design and ALS technology enables us to increase 15% of aperture ratio and more than 30% of the off-axis image distortion index [GDI]. No gray scale inversion and excellent viewing angle performance were also obtained. This novel pixel design makes the mPVA mode possible to have a strong competitiveness for mobile LCD applications.

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