Super-PVA (S-PVA) Technology for HDTV Application

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Abstract

S-PVA is a new technology which enables screen quality advantages over S-IPS and MVA, including high transmittance, >1000:1 contrast ratio, sub-10ms response time, and wide angle of view with no off-axis image inversion and undetectable gamma distortion. This new technology will be described in detail. This paper also addresses the other remaining performance issues facing LCD-TV, including Samsung's plans for addressing these challenges. For example, until recently, inter-gray response time and associated motion blur were significant issues for achieving LCD-TV images quality. Samsung has invented DCC-II technology to achieve sub-10ms response time, and this achievement is described herein. Other technology advancements, including next-generation color performance and ultra-low black performance and improvement of off axis image quality are also discussed in this paper.

1. Introduction

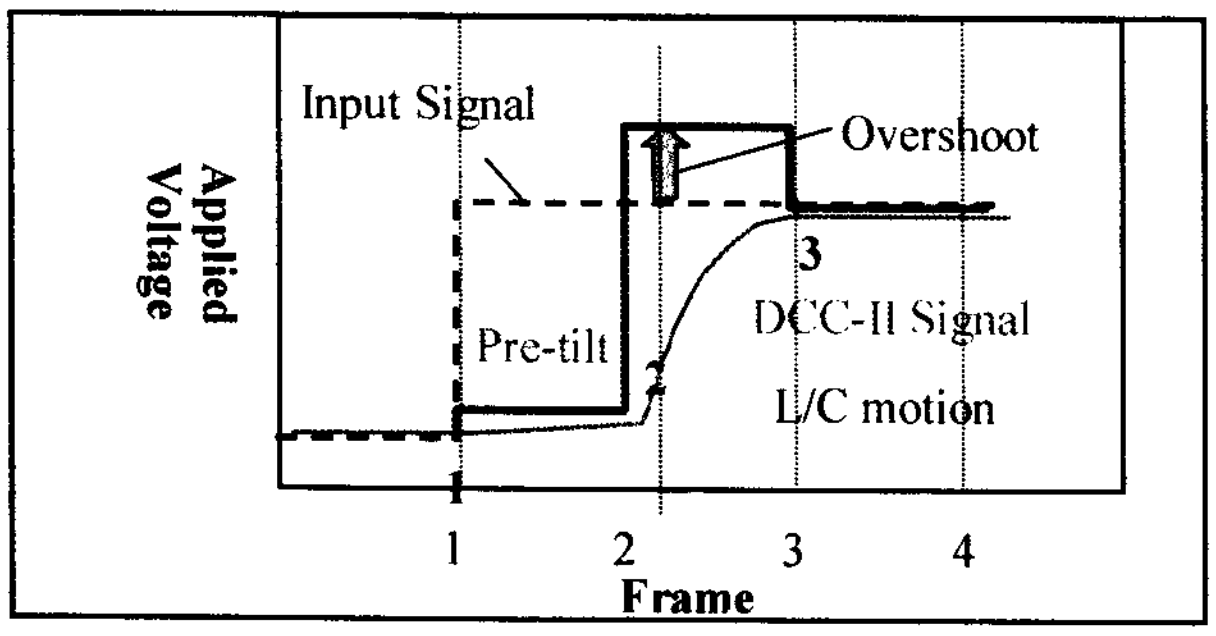
LCD-TV is an important emerging area for the LCD business [1] because of the potential market size. The market launch of TFT-LCD television occurred in 2002, when Samsung Electronics also decided to enter the LCD-TV market in earnest, using PVA technology [2, 3] in a wide range of HDTV products including 17", 19", 23", 26", 32", 40" WXGA. Samsung's 46" and 57" full HD resolution (1920x1080) [4] models have also commenced initial volume production.

However, all LCD-TV manufacturers face a challenge in meeting demanding performance requirements. Drawbacks of TFT-LCDs have included slow response time, high manufacturing cost, and limited viewing angle performance, all of which have needed improvement for mass production. In this paper, Samsung presents S-PVA (Super PVA) technology, which has upgraded properties and overcomes those issues successfully. To achieve better off-axis image quality and greater angle of view, we have developed a new retardation compensator and have optimized cell structure, and to minimize motion blur, we have developed DCC-II technology. We have also achieved higher contrast ratio over 1000:1 for the first time in LCD industry, greatly improved black state uniformity, and unprecedented color performance.

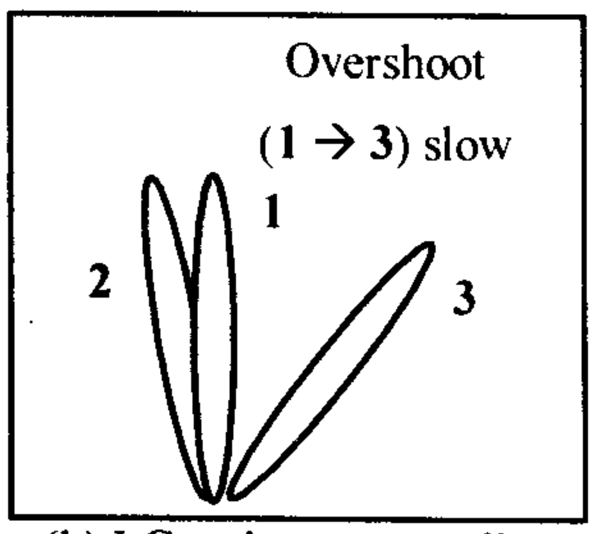
2. Improvement of motion blurring: DCC-II

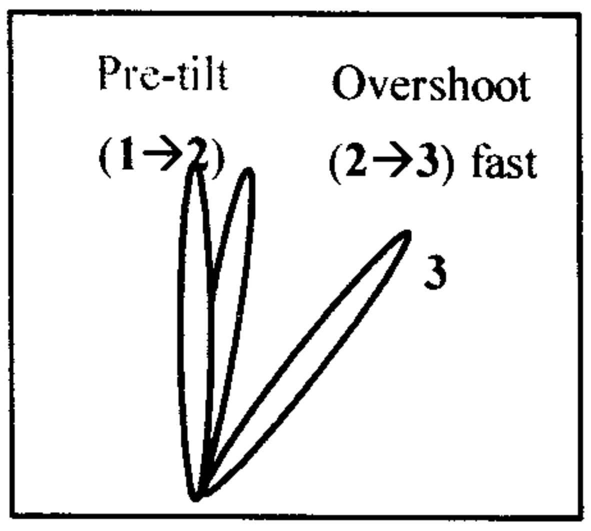
Response time is a key factor in LCD-TV application for blur-free and accurate representation of fast moving image, because most LCDs have slow response time, compared to other display devices. We have already developed and reported dynamic capacitance compensation (DCC) technology to reduce the motion blur problem [5]. DCC technology enables sub-10ms gray-to-gray transitions. However, even with DCC overdriving, the transition from black to white still requires 16ms. This transition time is not adequate to eliminate motion blur. The cause of this slower response time is specific to vertical alignment mode.

When the strong electric field is suddenly switched on in VA panels, it is possible that the liquid crystals fall down in random direction prior to the propagation of the tilting wave throughout the VA sub-domains [6]. The first step motion, polar rotation, occurs quickly. However, the subsequent re-alignment process, which is a slower azimuthal rotation, takes time. This results in a delayed response time as shown in Fig. 1 (b). Samsung has upgraded DCC technology to DCC-II, such that all response times, including the black to white transition, occur in less than 8ms (Fig. 2) [6]. The basic concept of DCC-II technology is to apply a pre-tilt voltage just prior to application of the conventional overshoot voltage. This pre-tilt voltage allows the liquid crystals molecules to align to the tilting plane in advance, thereby enabling a rapid transition upon application of the actual white state signal. DCC-II enables faster PVA mode response time without impacting other aspects of panel quality. Consequently we have obtained a response time of less than sub-10ms for all image transition.



(a) DCC-II signal and response

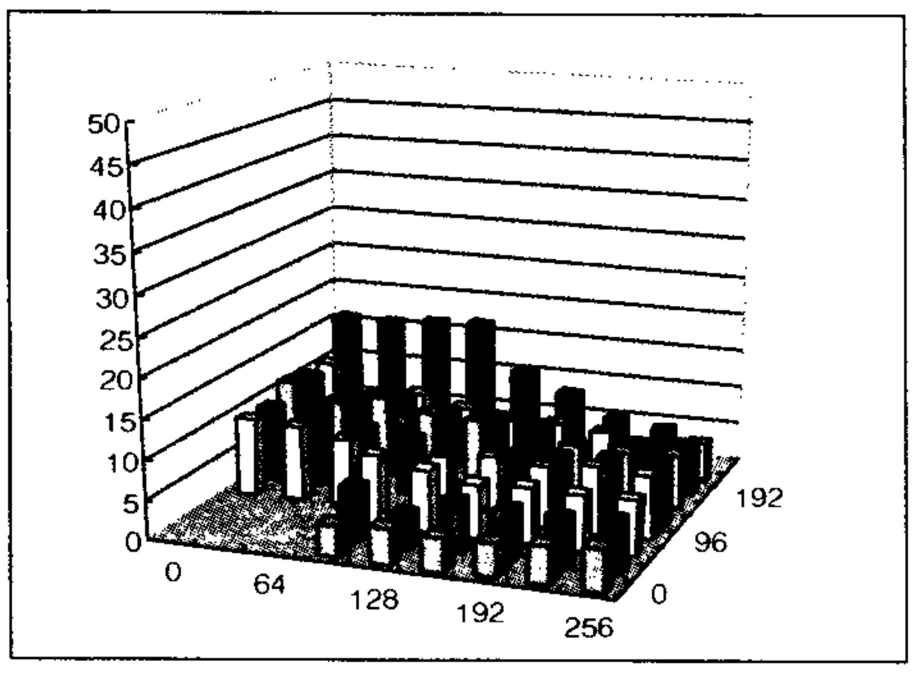




(b) LC action: no pre-tilt (c) LC action: with pre-tilt

Fig.1 The Basic concept of DCC-II

(a)



(b)

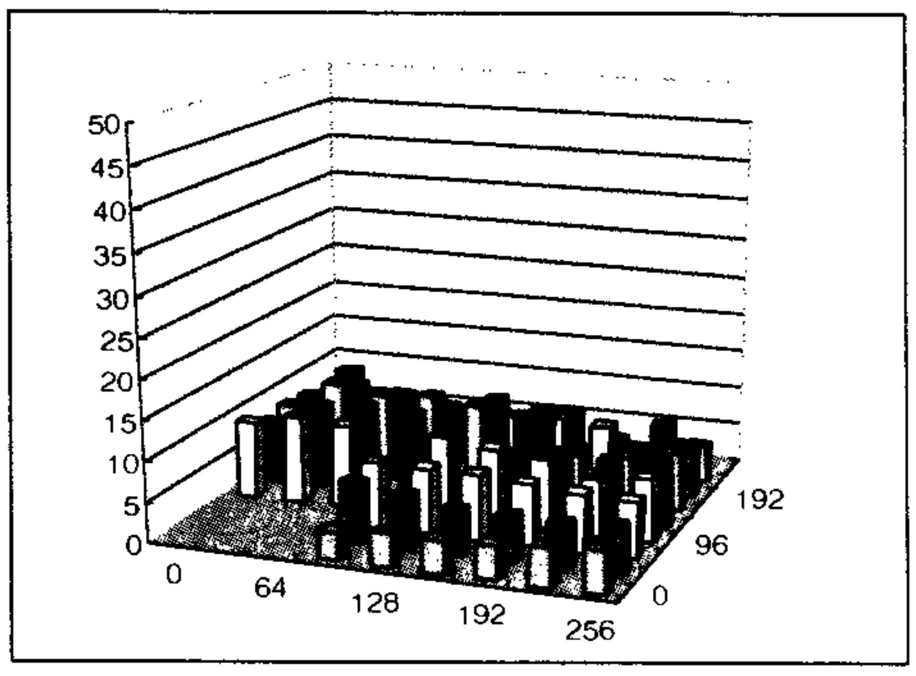


Figure 2 Response time performance improvement by DCC techniques. (a) DCC (b) DCC-II in PVA panels. DCCII accelerates the response time to less than 8ms for all image transitions.

3. Color Performance and Contrast ratio

Accurate color performance is imperative for TFT-LCDs to display rich and natural images. Therefore RGB color coordinates, white balance, color gamut, and gamma correction which make a big difference in color reproduction have been re-designed for HDTV application.

Generally, white color temperature variation with gray level exists in LCDs because its transmittance is controlled by $\Delta nd_{eff}/\lambda$, i.e. there is a dependence on the light wavelength (λ). However, to more precisely display a natural image, it is very important to maintain constant color temperature (white balance) through the different gray levels. In this sense we have developed an accurate color capture (ACC) technology to compensate color variations across gray levels. ACC driving technology changes the RGB gamma curves separately to maintain white color balance at a fixed level. It comprises a data expansion step for suitably changing the gamma curve, and a bit reduction step to driver IC data format. Moreover, performance of the color filter and polarizer have also been re-designed so as to achieve true black color that cannot be controlled by ACC driving alone. Figure 3 shows color temperature variation with gray. Variation of white color tracking for PVA with ACC driving has been improved dramatically, to a level superior to that of other wide viewing modes.

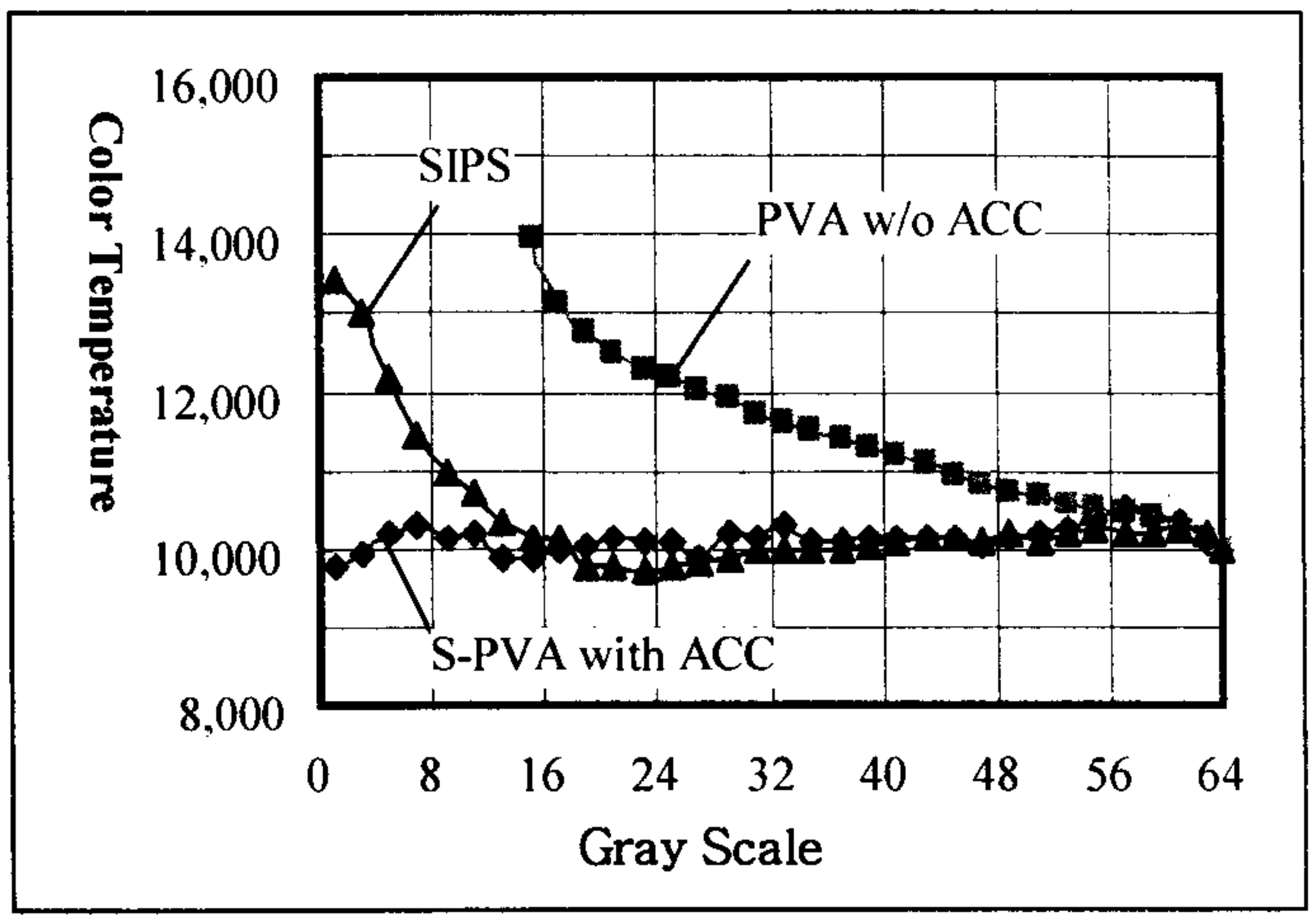


Figure 3. White color temperature dependence on gray level.

In addition, there is a critical market requirement for true black image quality in LCD-TV panels, as they are compared against CRTs with very high contrast ratio. There are two ways to improve black image performance. One is to enhance the contrast ratio itself. The other is to improve black uniformity across the entire LCD screen.

One of the strengths of PVA mode is an inherently high contrast ratio, as PVA mode has perfect vertical alignment of liquid crystals at the black state. Unlike other LCD modes, PVA has no residual retardation. For example, MVA mode is also a vertically aligned mode, but it has residual retardation near the protrusions because of uneven surface geometry. Unlike IPS mode, PVA mode does not require a rubbing process to align liquid crystals at the alignment layer. Therefore, PVA does not have light leakage owing to non-uniform rubbing scratches, a key cause of light leakage in IPS mode.

However, when light passes through the color filters, contrast ratio is reduced due to light scattering in the color filters. This effect increases transmittance in the black state. The light scattering is mainly due to aggregated pigment particles in the color filters which are larger than the wavelength of visible light. Therefore to obtain even higher contrast ratio, new color filter material have been developed. Namely new color filters reduce light scattering by controlling aggregated pigment particles from the material and coating process. Use of these materials has further reduced light leakage in the black state.

Figure 4 compares viewing angle dependent contrast ratio for previous and latest PVA samples. Compared to old color filters (open circles), the new color filters (solid circles) provide a ~25% increase in contrast ratio, over 1000:1 on axis.

For black uniformity, the optical structure of the retardation films is very important. Biaxially oriented films have been mainly used in LCD-TV panels, and are a good optical compensator for PVA mode. But these films are not perfect, because they are stretched in two directions and are easily affected by mechanical variation during the stretching process. So another optical film structure, using uniaxially oriented films, has been developed for better darkness uniformity independent of panel size. Moreover, the on-axis contrast ratio and viewing angle performance along the diagonals have also been improved by the new optical design and optimized compensation films.

By employing new color filters and the uniaxially oriented retardation film, the PVA LCD-TV can provide >72% NTSC color gamut, >10,000 degrees K color temperature and a contrast ratio of over 1000:1 for the first time in the LCD industry.

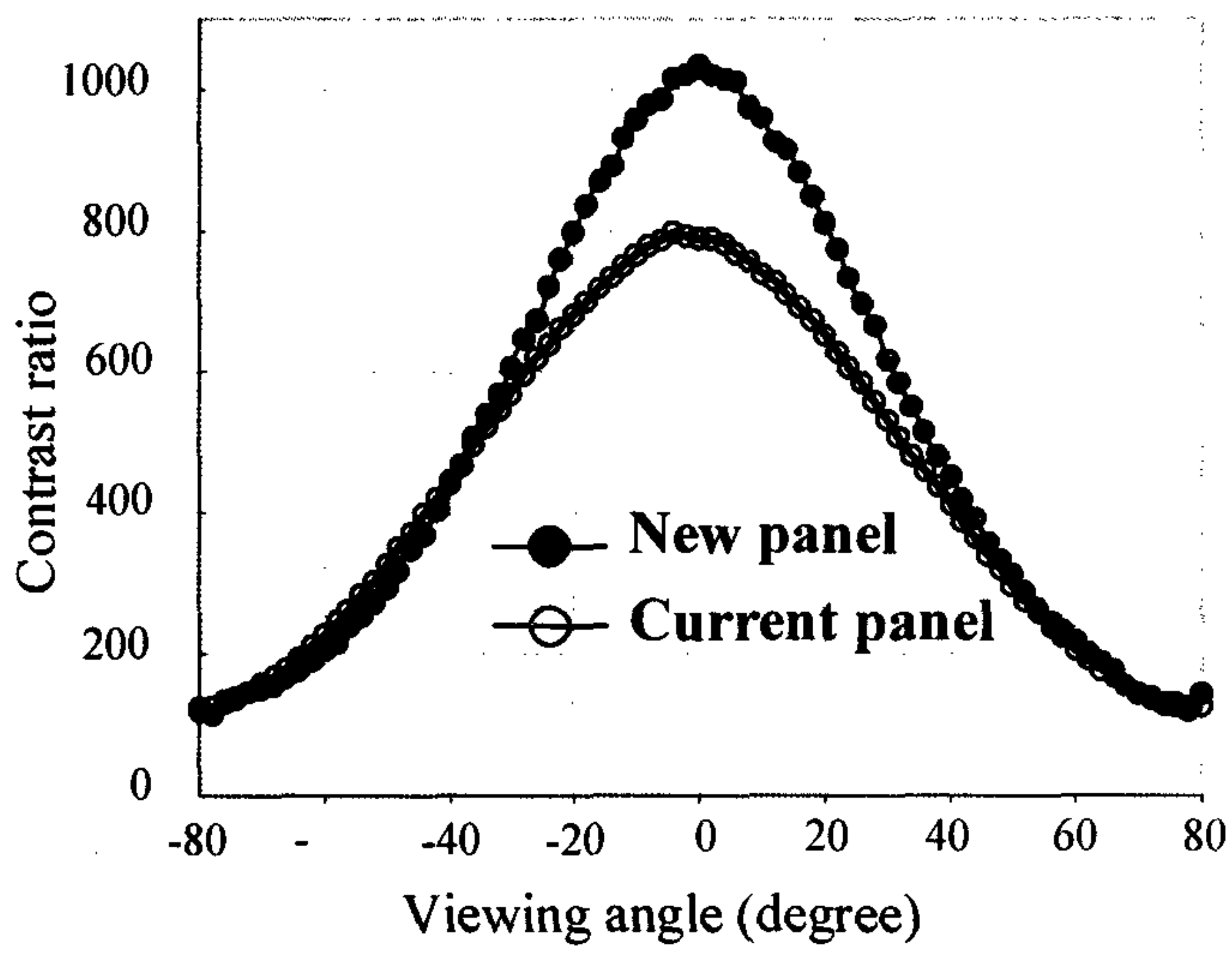


Figure 4: Contrast ratio shown as a function of viewing angle. Front contrast ratio is >1000:1 in newly developed PVA panels, an increase of ~25% compared to current devices.

4. Improvement of off-axis image quality

LCDs have had a key limitation compared to other display devices, namely, image quality deterioration as a function of viewing direction. Image consistency over a wide angle of view is one of the most important properties needed for TV applications. For TN mode, off-axis image deterioration is so severe that TN is rarely utilized for large size TV applications. PVA and S-IPS modes have significantly improved off-axis image integrity, however, these modes still have some unresolved weak points.

To achieve the best off-axis image quality, lower off-axis black level and minimized color changes according to viewing direction are needed. We adopted a new polarizer structure to the S-PVA panel, consisting of optimized c-plate and a-plate compensation films. PVA mode has traditionally used two biaxial films to compensate off-axis viewing anomalies. The biaxial film has had a limited retardation range owing to material properties, so the viewing angle of PVA panels had been not fully optimized. However, the c-plate used in the S-PVA panel has a wide retardation range. So, it is possible to more precisely optimize viewing angle. The S-PVA panel, using this new polarizer system, has a lower and more uniform off-axis black level, enabling better off-axis dark images.

Moreover, for minimized color changes according to viewing angle, we optimized the cell structures. Namely, cell structure including panel retardation has been re-designed to reduce color changes. Viewed off-axis, TN mode has very serious color inversion, and IPS mode has less serious but visible dark image inversion, while S-PVA has no image inversion at any gray level [7]. S-PVA technology is so effective for improving wide viewing angle performance that off-axis image degradation in this mode is barely detectable. S-PVA has achieved superior viewing angle performance in comparison to other LCD modes.

We have defined an off-axis image distortion index ($D(\Theta,\Phi)$) as

$$D(\theta,\varphi) = \left\langle \frac{\left|\Delta B_{i,j(on-axis)} - \Delta B_{i,j(off-axis,\theta,\varphi)}\right|}{\Delta B_{i,j(on-axis)}} \right\rangle_{i,j=0\sim255}$$

Here, $\Delta B_{i,j}$ means brightness difference between gray-i and gray-j, and < > means the average for all cases of arbitrary grays.

$D(\Theta,\Phi)$ value can range from 0 to 1. A smaller value means smaller image distortion, that is, better off-axis image quality.

At (60° , 0°) viewing direction, a typical PVA panel has a D value of about 0.27~0.30, but this figure has been improved to 0.20 in S-PVA mode. Figure 5 shows the off-axis image views of S-PVA mode,

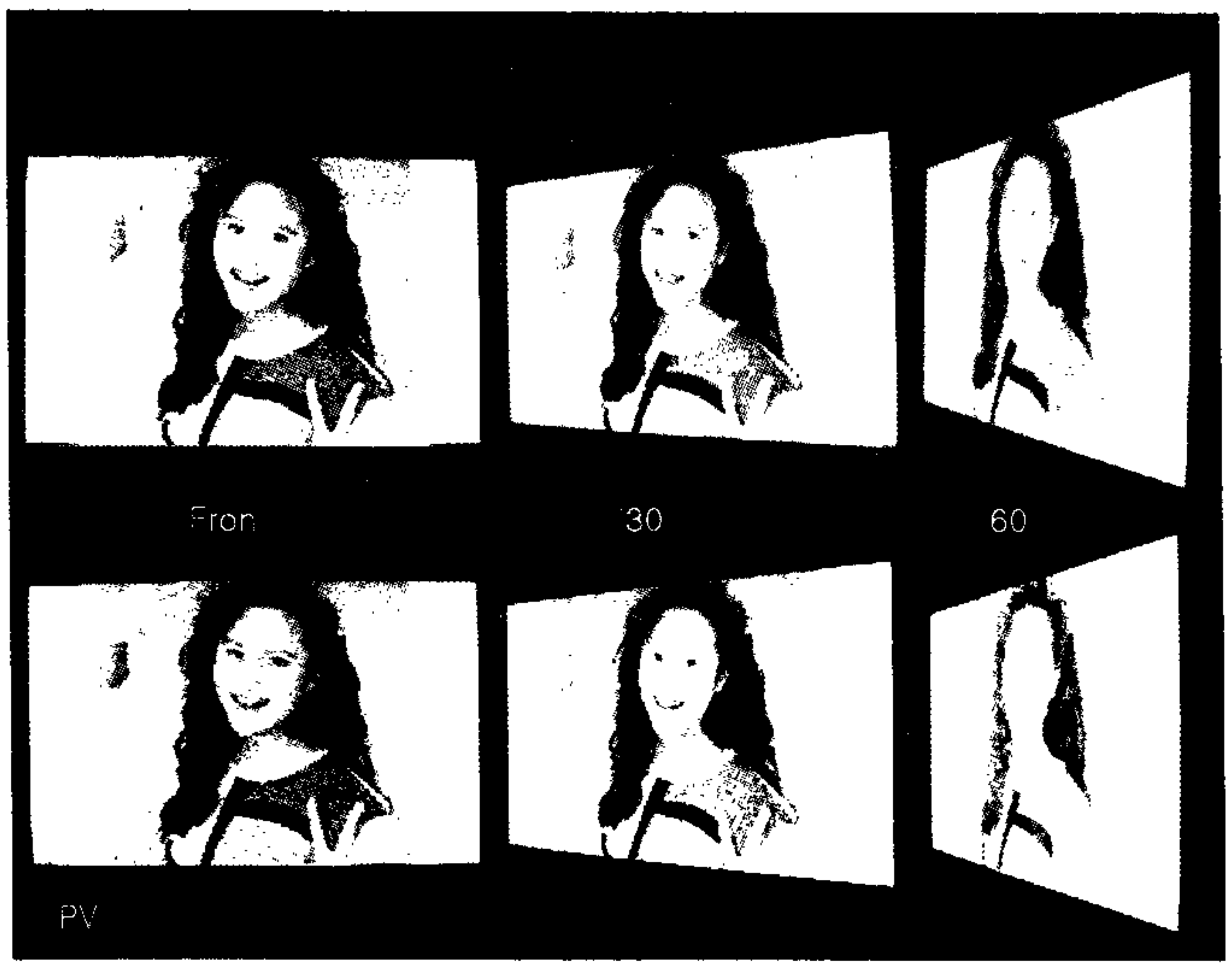


Fig.5 Off-axis image view of S-PVA panel.

demonstrating minimal deterioration of color and contrast ratio.The typical performance characteristics of PVA and S-PVA panels are summarized in Table 1.

Characteristics	PVA	S-PVA
Brightness (typ)	450 nit	500 nit
Black level	< 0.65 nit	< 0.5 nit
Contrast ratio (min.)	>700:1	>1000:1
Response Time (g-g)	<12ms	< 8 ms
Response Time (b-w)	16ms	< 8ms
Gray inversion (any direction)	None	None
Off axis image distortion index	<0.27	<0.20
Color gamut	72% NTSC	72% NTSC

Table 1. Performance improvement of S-PVA

5. Conclusion

In conclusion, Samsung has developed several technologies to make a quantum improvement in LCD-TV performance. S-PVA technology improves the quality of images viewed both at normal incidence and off-axis, resulting in next-generation color performance and ultra-low black level. As a result of these new technologies, the next S-PVA LCD-TVs will deliver more distinct and accurate color image reproduction. DCC-II, in combination with S-PVA, has resulted in sub-10ms response time, enabling blur-free motion pictures. Samsung's 57" LCD-TV, the world's largest, is the culmination of technology and process development on multiple fronts. Samsung is also building the world's first 7th generation line at Tangjung to offer the most cost-efficient production capability.

References

[1] M. Fujiwara, SID'01 Digest, p.251 (2001)

[2] K. H. Kim at. al., 18th IDRC Proceedings, p.383 (1998)

[3] K. H. Kim, J.H. Souk, 19th IDRC Proceedings, p.115 (1999)

[4] K. H. Kim et al., SID'04 Digest, p. 106 (2004)

[5] B. W. Lee, D. S. Sagong and J. H. Souk, Proceeding of IDW2000, p.1153 (2000)

[6] J. K. Song et al., SID'04 Digest, p.1344 (2004)

[7] S. S. Kim et al., SID'04 Degest, p.760 (2004)