Recent Trends on Patterned Vertical Alignment (PVA) and Fringe-Field Switching (FFS) Liquid Crystal Displays for Liquid Crystal Television Applications

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(Invited Paper)

***Abstract*—This paper reviews the recent trends on super-patterned vertical alignment (S-PVA) and fringe-field switching (FFS) technologies for liquid crystal display (LCD)-television (TV) applications. For PVA mode, Samsung originally announced S-PVA technology in 2004 to enhance off-axis viewing quality of conventional PVA mode. S-PVA is a new technology which enables screen quality advantages over super-in plane switching (S-IPS) and multi-domain VA (MVA), including high transmittance, >2300:1 contrast ratio, and wide viewing angle with no off-axis image inversion. This paper explores and updates Samsung's latest developments toward its goal of ultimate LCD-TV performance. For FFS mode, the technology appeared in 1998 by HYDIS and now it has been commercialized in all kinds of display applications, implying its technical importance. This paper reviews recent developments and performance of LCD-TV using the FFS mode based on published papers and our knowledge.**

***Index Terms*—Fringe-field switching (FFS), liquid crystal display (LCD), patterned vertical alignment (PVA), television.**

I. Introduction

MARKET of large-area flat panel display television (FPD-TV) has dramatically increased recently. Among the various FPD-TVs, plasma display panels (PDPs) and projection TVs have been in the market for years. The launch of thin-film transistor (TFT)-LCD television market occurred in 2002. The image quality of TFT-LCDs is strongly dependent on LC modes which are classified into three groups: homogenous alignment (HA), vertical alignment (VA), and splay [1], [2]. IPS and FFS modes are representative in the HA mode [3], [4], and MVA and PVA modes are representative in the VA mode [5], [6]. Among these, FFS and PVA technologies focusing on how to improve the display performances are mainly discussed in this paper. The FFS mode invented in 1998 has evolved into ultra-FFS (U-FFS) in 2001 [7] and advanced-FFS (AFFS) in 2004 [8] while the PVA mode in 1998 has evolved into S-PVA in 2004 [9], [10].

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II. Reviews on S-PVA Technology

A. Overviews on PVA Technology

PVA is a practical wide viewing angle mode, which is characterized by a multi-domain structure using a fringe-field effect and optical compensation by retardation films. Samsung Electronics entered the LCD-TV market in earnest, using PVA technology [11].

TFT-LCDs have the advantages of high resolution, light weight, slim size, and low power consumption compared with other FPD-TVs, such as PDP and projection TV. However, the conventional TFT-LCDs have the drawbacks of limited viewing angle performance, slow response time and high manufacturing cost. These problems must be improved for mass production. This paper reviews Super PVA (S-PVA) technology, which has upgraded properties and overcomes those issues successfully. We have developed a new polarizer and optimized cell parameters in order to achieve better off-axis image quality and higher contrast ratio. We also applied DCC-II and motion compensated frame interpolated driving technology in order to minimize motion blur. In addition, we obtained high transmittance ratio through new cell structure.

B. Off-Axis Image Quality

LCDs have the problem of 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. TN mode is usually utilized for note PC and monitor rather than TV applications because the off-axis image deterioration of TN mode is so severe compared to other wide viewing angle modes such as PVA and S-IPS. However, these PVA and S-IPS modes still have some unresolved weak points.

In order to achieve the better off-axis image quality, lower off-axis black level and minimized color changes corresponding to the viewing directions are needed. To obtain the minimized color changes corresponding to viewing angle, Samsung optimized the cell structures.

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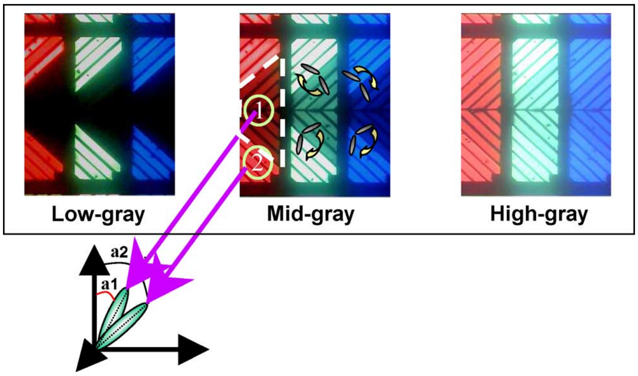

Fig. 1. Multi-domain S-PVA cell. (Permission for Reprint, courtesy Society for Information Display.)

As illustrated in Fig. 1 [10], S-PVA divides each sub-pixel into two separate sub-domains, zones 1 and 2. Different electric fields are applied in zones 1 and 2, and, therefore, they have different tilt angles. The main- and sub-zones effectively construct an 8-domain cell, which can compensate and minimize gamma distortion for images viewed at off-axis. [12]

To evaluate the off-axis image quality, an off-axis image distortion index $(\mathrm{D}(\theta,\varphi))$ was defined as

$$D(\theta,\varphi)=\left\langle \frac{\left|\Delta B_{i,j(on-axis)}-\Delta B_{i,j(off-axis,\theta,\varphi)}\right|}{\Delta B_{i,j(on-axis)}} \right\rangle_{i,j=0\sim 255}.$$

Here, $\Delta B_{i,j}$ means brightness difference between gray-i and gray-j, and $\langle\ \rangle$ means the average for all cases of arbitrary grays. $\mathrm{D}(\theta,\varphi)$ value ranges from 0 to 1. A smaller value means the smaller image distortion, i.e., the better off-axis image quality.

The off-axis gamma distortion of S-PVA was greatly reduced as a result of the above improvements. As shown in Fig. 2, the off-axis gamma curves for S-PVA are much closer to the on-axis curve compare with those of conventional PVA. At (60°, 0°) viewing direction, a typical PVA panel has a D value of about 0.30, but this figure has been improved to below 0.20 in S-PVA mode.

S-PVA technology is a successful method for improving off-axis image quality, which achieved superior viewing angle performance in comparison to other LCD modes.

C. Improvement of Motion Blurring

Motion blur is another important factor that influences the image quality of LCD-TVs. TV images generally comprise moving pictures, however, most LCDs have the motion blur problems because LCD is a hold-type display contrary to CRT. In order to reduce the response time, over-driving compensation techniques are generally used in these days. Samsung has already developed and reported dynamic capacitance compensation (DCC) technology to reduce the response time of PVA mode [13]. DCC technology enables sub-8 ms gray-to-gray transitions. However, even with over-driving technique, the response time from black to other gray is still slow. The cause of this slower response time is specific to vertical alignment mode. In VA mode, the liquid crystals are vertically aligned (i.e., normal to the glass) when there is no applied electric field [position 1 in Fig. 3(b)]. When strong electric field is applied,

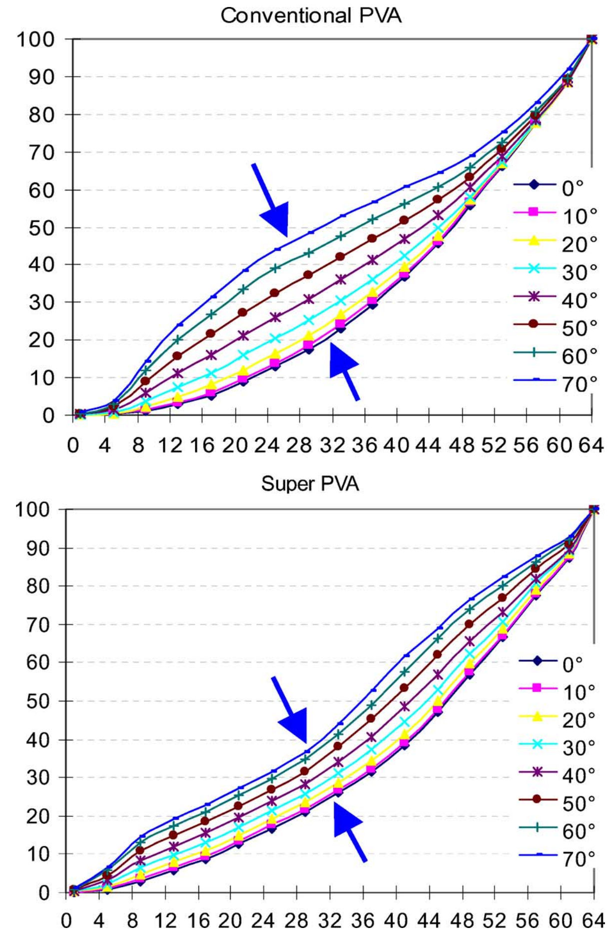

Fig. 2. Comparison of off-axis gamma between conventional PVA and S-PVA. (Permission for Reprint, courtesy Society for Information Display.)

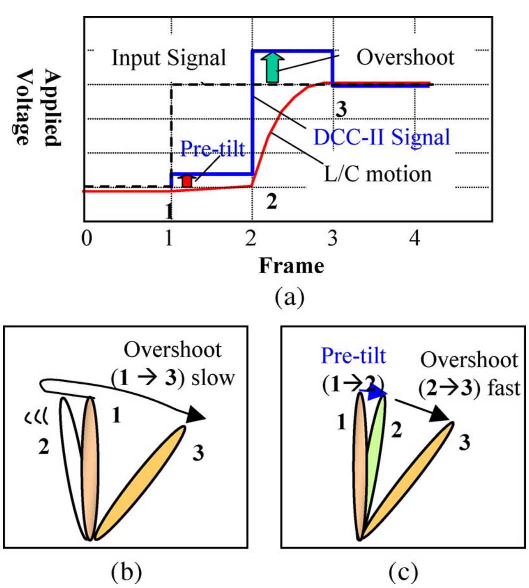

Fig. 3. Basic concept of DCC-II technology. (a) DCC-II signal and response. (b) LC action: no pre-tilt. (c) LC action: with pre-tilt. (Permission for Reprint, courtesy Society for Information Display.)

the first step motion, polar rotation, occurs quickly. However, the subsequent realignment process [position 2 in Fig. 3(b)] opposite to the desired direction, which is a slower azimuthal

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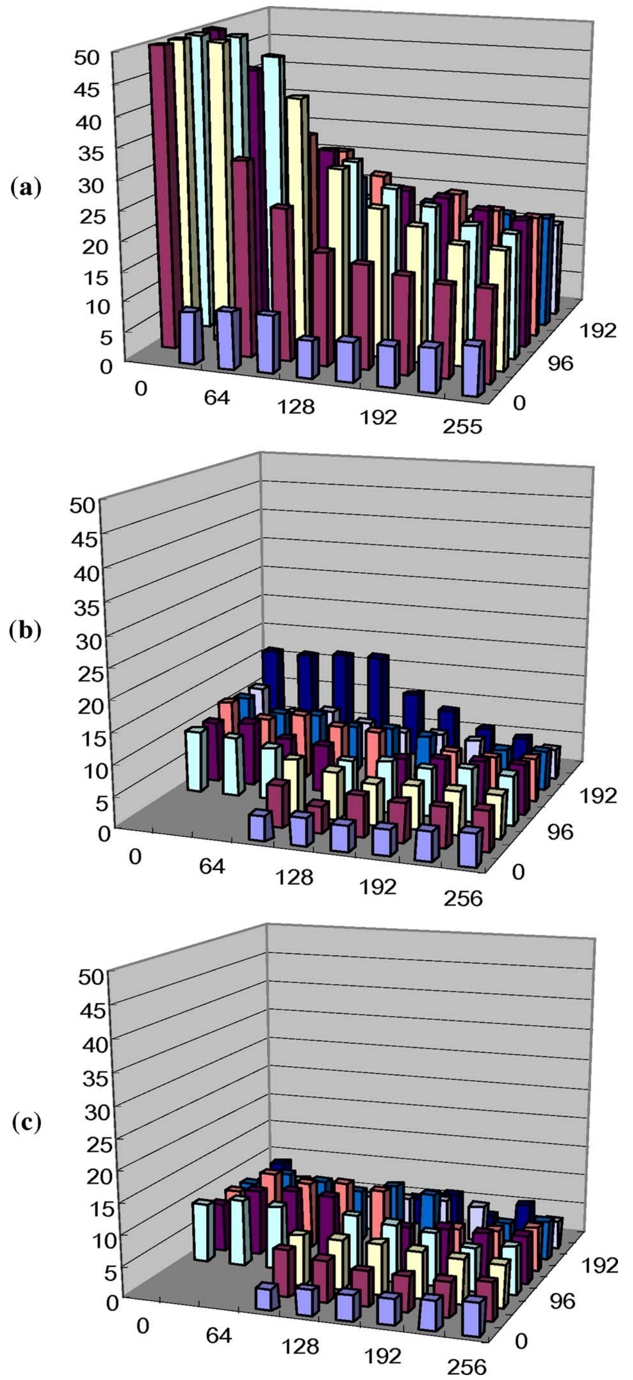

Fig. 4. Response time performance improvement by DCC techniques: (a) no DCC, (b) DCC, and (c) DCC-II in PVA panels. DCC-II accelerates the response time to less than 10 ms for all image transitions. (Permission for Reprint, courtesy Society for Information Display.)

rotation, takes additional longer time. This results in a delayed response time as shown in Fig. 3(b).

In order to eliminate instantaneous backward polar rotation of the LC director, Samsung has upgraded DCC technology to DCC-II with applied waveform shown in Fig. 3(a). DCC-II reduces all response times, including the black to white transition, to under 8 ms (see Fig. 4) [14]. The basic concept of DCC-II is to apply a pre-tilt voltage just prior to application of the conventional overshoot voltage of DCC. The liquid crystal molecules were aligned quickly through polar rotation by this pre-tilt voltage, which enables a rapid transition upon application of the actual white state signal. DCC-II contributes to the faster response time of PVA mode without impacting other aspects of panel quality such as no loss of contrast ratio.

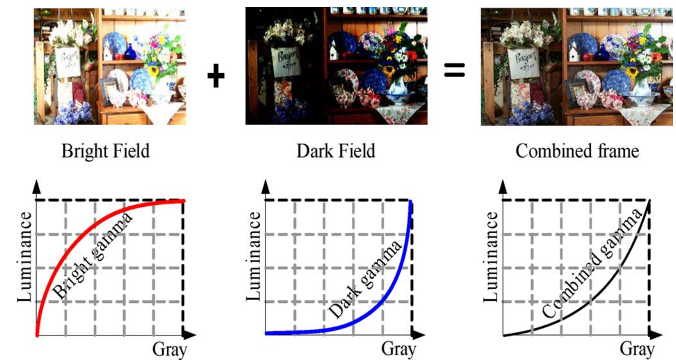

Fig. 5. Quasi-impulsive scan method. (Permission for Reprint, courtesy Society for Information Display.)

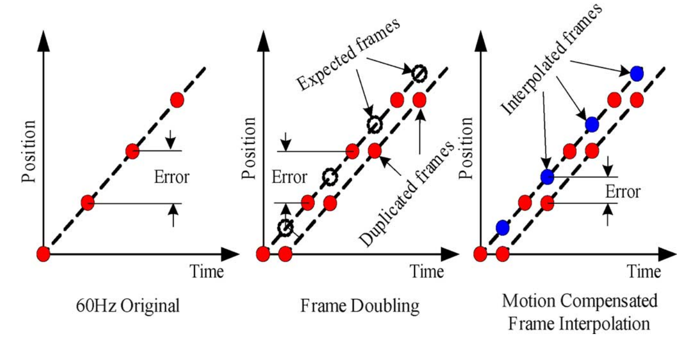

Fig. 6. Motion compensated frame interpolated driving. (Permission for Reprint, courtesy Society for Information Display.)

To achieve blur-free moving images, various methods of high speed driving were developed in addition to DCC-II because of the limitation of hold type display. One of these methods is double frame rate driving either at 120 Hz in the case of NTSC sources, or at 100 Hz in the case of PAL. And another method is *Quasi-impulsive scanning* (also called alternate frame driving, or flexible black data insertion), which presents the same data to the screen twice in each 60 Hz interval, once at bright gamma and again at dark gamma, mixing each to achieve target gamma. Fig. 5 shows the concept of quasi-impulsive driving. Its main advantage is that it does not require a source of motion interpolated frames, while its disadvantage is not able to eliminate motion blur in cases where there is significant high luminance content.

Samsung has developed another method, *super impulsive technology* (SIT). This technique is pure *motion compensated frame interpolated driving*, which works by inserting interpolated frames between incoming frames to minimize spatial-temporal integration time. Fig. 6 depicts this method as ultimate solution for overcoming motion blur.

SIT exploits the advantages of S-PVA to enable 120 Hz driving of a conventional panel structure by using an efficient charging method [15]. The main challenge of this approach is the need of creating interpolated frame data between incoming

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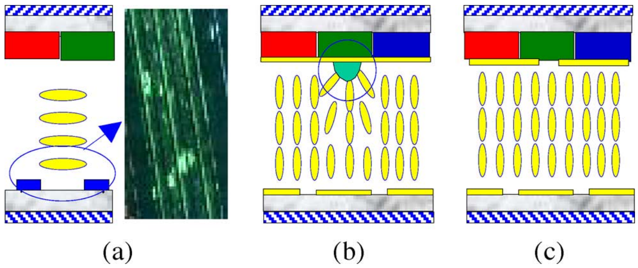

Fig. 7. Cross-sectional diagram of the various liquid crystal cell structures in the black state. (a) IPS mode. (b) MVA mode. (c) PVA mode. (Permission for Reprint, courtesy Society for Information Display.)

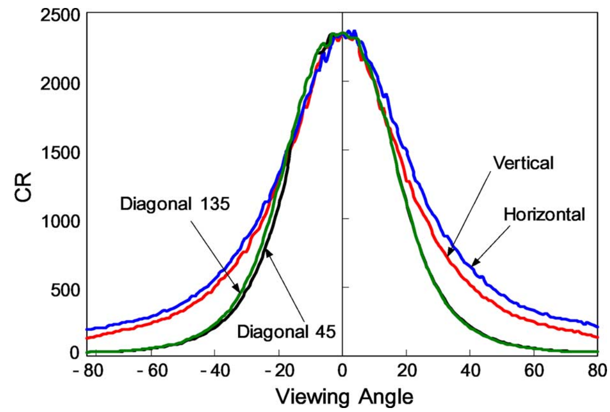

Fig. 8. New S-PVA panel contrast ratio versus viewing angle. (Permission for Reprint, courtesy Society for Information Display.)

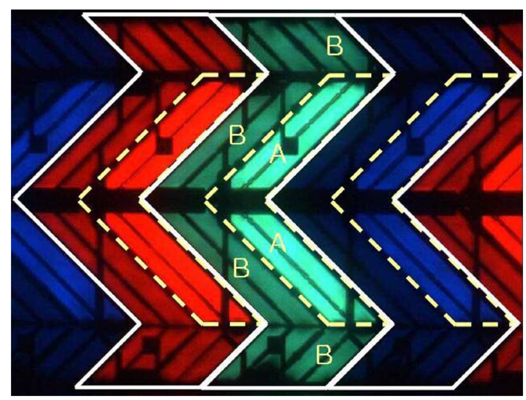

Fig. 9. A4 pixel structure of S-PVA cell. (Permission for Reprint, courtesy Society for Information Display.)

frames. It is the most difficult approach to eliminating motion blur as it requires both motion interpolated frames as well as a fast driving panel [16]. However, this approach can contribute to the better LCD motion image performance of all the different methods.

D. Contrast Ratio

High luminance is one of the most important requirements for TV applications. Therefore, LCD-TVs generally employ bright backlights. However, the bright backlight can create an undesirable amount of light leakage at the black state unless the display has high contrast ratio. In order to create better dark detailed images, high contrast ratio for ultra-low black level is a critical factor for LCD-TV.

PVA mode has inherently high contrast ratio due to perfect vertical alignment of liquid crystals at the black state. However, other LCD modes have residual retardation contrary to PVA mode. For example, MVA mode is also a vertically aligned mode, but it has residual retardation near its protrusions because of uneven surface geometry, as shown in Fig. 7(b). In addition, 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 issue from the non-uniform rubbing scratches, which is an important factor of light leakage in IPS mode, as shown in Fig. 7(a).

Black luminance is greatly affected by polarizer, residual retardation, and internal light scattering which reduce polarization efficiency. We have developed a new polarizer film which attains 99.99% polarization efficiency by optimizing the polyvinyl alcohol layer and optimized the TFT pattern structure and electrode taper angle so as to minimize light leakage from residual retardation. Additionally, to avoid scattering-induced depolarization by the polarizer film, particle size of the color filter photo-resist has been reduced in half. As a result, these technologies have enabled us to achieve over 2300:1 static contrast ratio. This is a true CR through the optimization of panel, that is, it has been achieved without any backlight modulation [17].

Fig. 8 shows the contrast ratio performance of the S-PVA LCD using the new polarization film with the reduced particle size color filter photo-resist. Samsung is continuing to devote energy toward continued reductions in color filter particle size and minimization of light scattering for ultimate CR enhancement.

E. High Brightness Pixel Structure

Wide viewing angle mode including PVA mode have generally shown lower transmittance compared to TN mode. However, the luminance requirement for LCD-TV panels is much higher than that of notebook or monitor LCDs. In order to meet the luminance requirement, LCD-TV has applied very bright backlights with expensive brightness enhancing optical films, resulting in higher cost and relatively higher power consumption. Consequently, the improvement of cell transmittance is definitely needed to reduce power consumption and to achieve lower system cost. So far, Samsung has developed a new pixel design which they call the A4 structure [17]. As shown in Fig. 9, a single pixel of the A4 pixel structure consists of multiple parallelogram-shaped pixel electrodes. A4 structure, like its predecessor, uses an organic insulation layer and it maintains the A/B sub-pixel structure of S-PVA. A single pixel is divided into two individual double-zones, A and B. The smaller zone is the brighter, lower gamma A sub-pixel, and the larger zone is the darker, higher gamma B sub-pixel. The A/B area ratio is maintained at approximately 1:2.

Compared to the conventional chevron pixel structure, the A4 pixel enables significantly increased aperture ratio. Fig. 10 shows a cross-sectional comparison of the old and new structures. In the conventional structure, the electric field along the data bus line disturbs the motion of liquid crystal molecules at

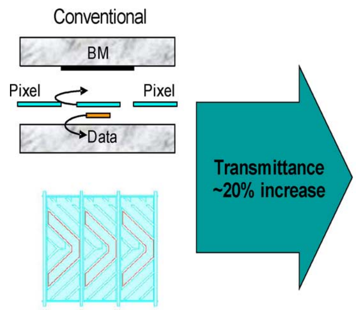

Fig. 10. Cross-section of old and new pixel structures. (Permission for Reprint, courtesy Society for Information Display.)

the edge of the pixel, and black matrix must cover the entire data line to prevent light leakage from this disturbance. However, the A4 structure has higher orientation efficiency because the pixel boundaries of adjacent pixels, when driven with opposite polarity voltages, are such that edge fields are aligned with the internal LC directors within the pixel. As a result, disturbance of the LC directors by the edge fields is minimized, and a narrower z-shaped black matrix is applied only at the pixel boundary. In addition, the data bus line is located below the pixel electrode area in the A4 structure.

The A4 pixel structure enhances transmittance by about 20%. Therefore, power consumption can be reduced with the A4 structure because equivalent output luminance can be achieved with reduced backlight current. Further refinement of the new pixel structure for even higher transmittance is underway.

F. ACC (Accurate Color Capture)

Recently, as the performance of LCD is improved in the area of brightness, contrast ratio, response time, and color saturation, color accuracy of TFT-LCD's has become an important issue. The main reason of this color shift is the different transmittance characteristics of liquid crystal molecules with respect to red, green, and blue light. Accurate Color Capture (ACC) is a novel driving scheme to eliminate color shift in LCDs [18].

In typical LCD, the correlated color temperature (CCT) rises up to 10 000 K at 64-gray in 256 Gray from 6500 K at white. As shown in Fig. 11, blue gamma curve is located slightly above green and red curves. Because the relative higher portion of blue gives a bluish image, that is, a color shifted image, gray images actually appear to be bluish on the LCD. The essential idea of ACC for improving color shift is to reduce blue portion and to increase red portion. In order to optimize the gamma curve in each color, blue and red gamma curves have to be moved independently downward and upward, respectively.

ACC changes RGB gamma curves separately to reduce color shift. Fig. 12 shows how to change the original gamma curve to a new target gamma curve. For example, to move a gamma curve to lower location, we can find a new image data to get the luminance of the target gamma curve. As shown in Fig. 12, 122 and 123 input data must be changed to 120.3 and 121.5, respectively. The only way to express 120.3 and 121.5 is extension of the data bit to 9 or 10 bit data. Therefore, selection of 256 data with extended data bit is the first step in ACC. Because driver IC has 6 or 8 bit data input, 9 or 10 bit data must be transformed to 6 or 8 bit data. The bit reduction is carried out through the temporal and spatial averaging (FRC: frame rate control). Accordingly, ACC should be consisted of a data expansion step for changing gamma curves adaptively and a bit reduction step for data format of drive IC.

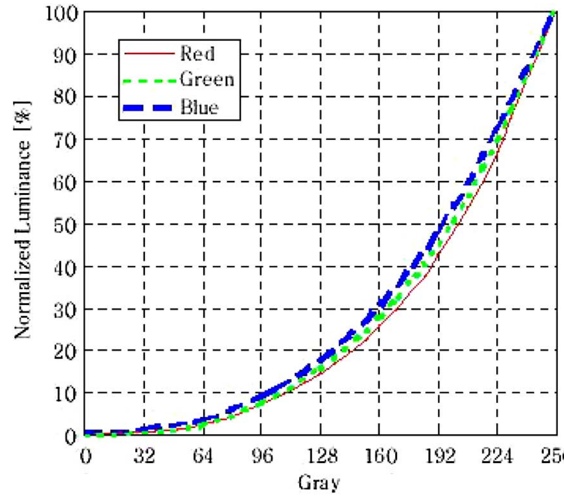

Fig. 11. Gamma curves of red, green, and blue. (Permission for Reprint, courtesy Society for Information Display.)

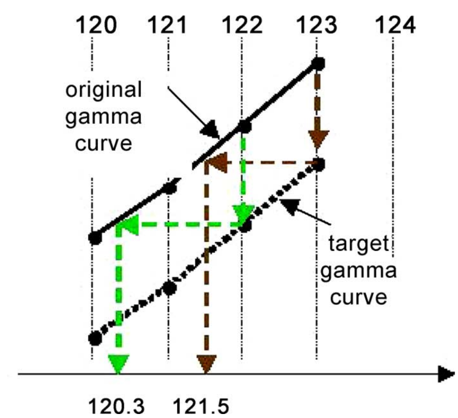

Fig. 12. Schematic diagram of gamma curve modification. (Permission for Reprint, courtesy Society for Information Display.)

Fig. 13 shows the performance of ACC about the color shift. Before ACC, there were color coordinate shifts of 0.033 and 0.041 in Δx and Δy, respectively. But after ACC, the maximum shifts were 0.001 and 0.003 in Δx and Δy, respectively.

III. Reviews on FFS Technology

A. Overviews on FFS Technology

As mentioned above, several wide-viewing-angle technologies are competing with each other at present. The IPS mode has a serious intrinsic problem in transmittance and the VA mode requires much more complicated driving or pixel structure to realize 8-domain. In addition, the VA cell requires high precision of assembly between top and bottom substrates, due to patterned electrodes or protrusion on both substrates.

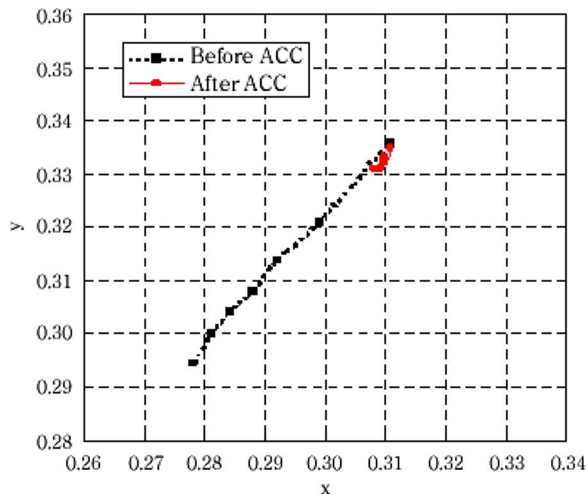

Fig. 13. Comparison of color coordinate before (black color) and after (red color) ACC. (Permission for Reprint, courtesy Society for Information Display.)

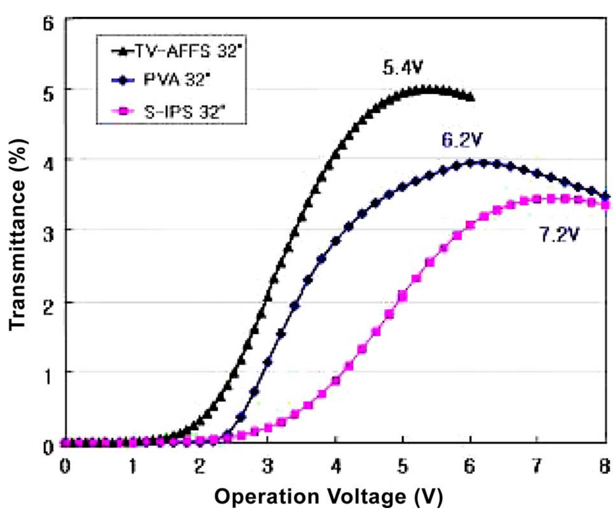

Fig. 14. Comparison of V-T Curves in FFS, S-IPS and PVA for large TV. (Permission for Reprint, courtesy Society for Information Display.)

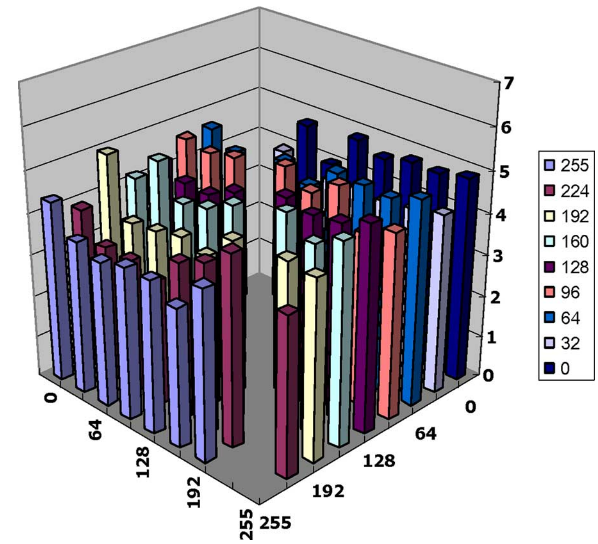

Fig. 15. Fast response properties of FFS mode at 26″ WXGA [22].

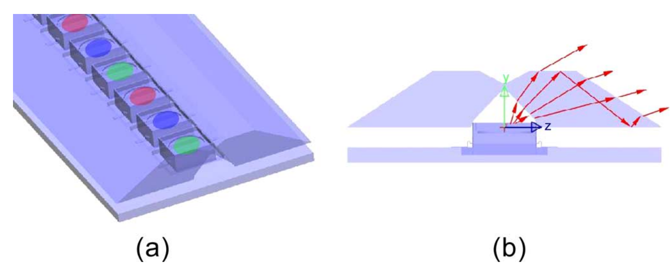

Fig. 16. Optic-structure of top emitting type LED in BOE-HYDIS 32″ AFFS-TV [24]. (a) LED array on PCB. (b) color mixing optic-system (side view).

Unlike other LC modes, the FFS mode could achieve intrinsically a high transmittance and a high image quality owing to three dimensional self-compensation effects such that the LC orientation including twist and tilt can be periodically changed along the cell gap and electrode directions. Therefore, additional action to form 8-domain or any new driving scheme is not required.

Since the FFS technology appeared in 1998 by HYDIS, now it has been known that several companies such as BOE-HYDIS, BOE-OT, Hitachi and Sanyo Epson, produce FFS display products for mobile phones, tablet PCs, notebooks, monitors, LCD-TVs, medicals and avionics.

B. Panel Transmittance

In LCD-TVs, the panel transmittance is also very important in addition to fast response time and high image quality, which is directly related to cost. The panel transmittance is mainly determined by transmittance of polarizer, aperture ratio of the panel, light efficiency of LC, and transmittance of color filter. At present, the companies are trying to remove backlight sheet by increasing aperture ratio with the help of resin technology.

The FFS mode has a high LC light efficiency, and in addition, with the approach of U-FFS, the light leakage between data and pixel is automatically blocked so that the width of black matrix becomes minimized. Further, the disclination lines at the edge of pixels are minimized with A-FFS concept, which increases LC light efficiency. In other words, the FFS mode could achieve the highest transmittance compared with other LC modes, even without employing resin technology. In fact, the FFS mode requires two transparent electrode layers, which compensates the resin process in term of number of masks in the array process. From these viewpoints, the FFS mode has strong advantages in cost and the lowest operating voltage compared with other LC modes in 32″ LCD-TV, as shown in Fig. 14. As indicated, the FFS mode has the highest transmittance as well as a low operating voltage of only 5.2 V [19].

C. Improvement in Response Time

One of the solutions to realize a perfect moving picture in LCDs is increasing frame frequency to 120 Hz, which implies that all gray-to gray-scale response time of the LC cell should be within 8 ms.

One of the effective approaches to improve response time is to reduce the cell gap. In the FFS mode, an optimal cell retardation value is much higher than that in the IPS mode [20]. Therefore,

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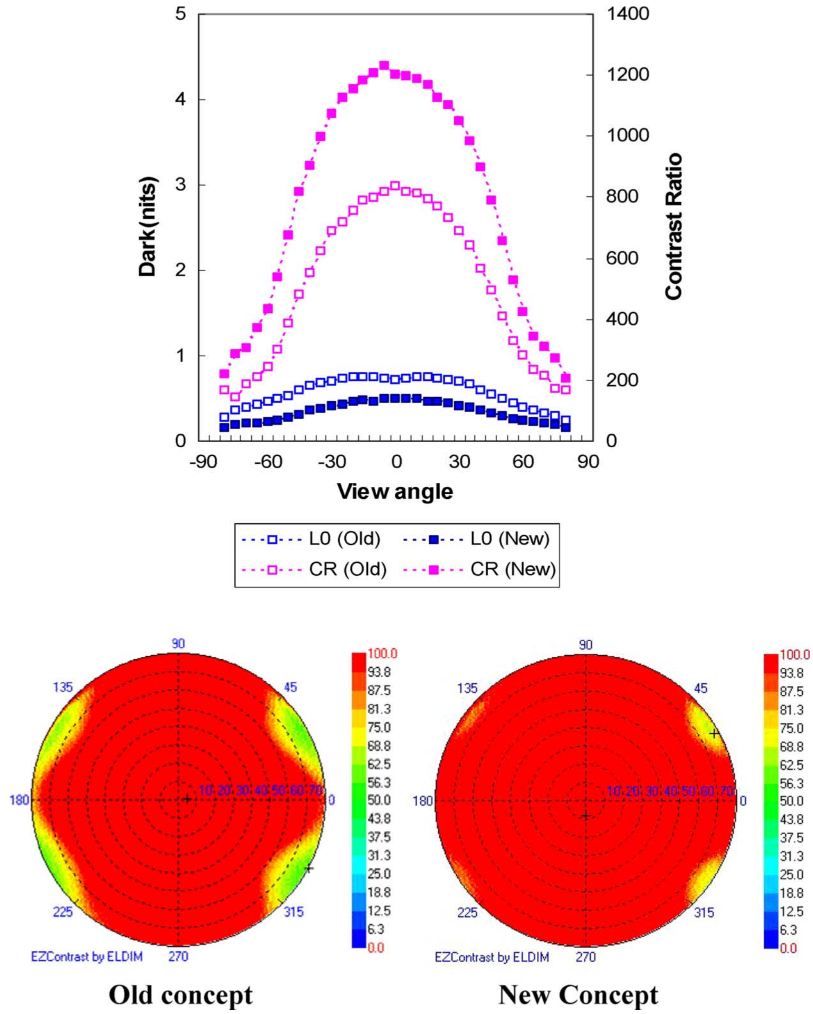

Fig. 17. The CR, dark luminance, and iso-CR contour in old and new concept polarizer in 26$''$ TV-AFFS.

lowering cell gap requires for LC to have a relatively high birefringence $(\Delta \mathrm{n})$, and low rotational viscosity (γ). Further advantage of the FFS mode compared to the IPS mode is that the decrease cell does not increase the operational voltage [21], so that the FFS mode could use a LC with low dielectric anisotropy $(\Delta\varepsilon)$. This is a critical key parameter for the LC to have low γ since the LC with high $\Delta\varepsilon$ cannot yield low γ intrinsically.

One fortunate fact in LCD-TV to achieve a fast response time is that the panel temperature increases to about $40 \sim 45$ °C due to the use of direct type backlight. The γ decreases by over 30% when the temperature increases by 10°C $(44$ mPa.s$/30$ °C $\rightarrow$ 30 mPa.s$/40$ °C$)$, so that the total response time can be reduced to 30%. However, the other physical properties such as $\Delta \mathrm{n}$ and $\Delta\varepsilon$ also decrease $(\Delta \mathrm{n} = 0.0931/30$ °C $\rightarrow \Delta \mathrm{n} = 0.0883/40$ °C; $\Delta\varepsilon = 5/30$ °C $\rightarrow \Delta\varepsilon = 4.4/40$ °C$)$, with increasing temperature, which affects transmittance and operating voltage. To achieve a best performance, all these should be considered. Fig. 15 shows gray-to-gray response time of the FFS mode with over driving circuit, achieving gray-to-gray response time under 5.5 ms in all grey levels [22].

Although the LC response time becomes 1 ms, the image blurring in LCD-TV still exists in case of using hold type backlight, which is not acceptable for users accustomed to CRT displays. In other words, to overcome this, blinking backlight technology with improving response time of the LC cell should be applied. There are two ways to achieve blinking backlight effects: 1) inserting black data at 60 Hz and 2) inserting flexible black data at 120 Hz. Hitachi applies the latter method and achieves 11.8 ms of MPRT while keeping the same brightness [23].

D. Color Reproduction

The conventional LCD-TV has a surface brightness of 500 nit and color gamut of 72% using normal CCFL backlight and a color filter with high color reproduction. However, the high color gamut becomes trend as a sales point to the customer nowadays. Recently, the phosphor ratio in the conventional CCFL backlight is adjusted to change its peak spectrum and its corresponding color filter is developed. As a result, a high color gamut of 92% is achieved with minimum loss of brightness. In addition, the performance of RGB-light-emitting diode (LED) is greatly improved and thus LCD-TVs adopting the RGB-LED are developed, which produce a high color gamut of 107%. The key factors in adopting this technology are making this thinness, generating pure white color without color distortion with optimal optic design, and suppressing the heat generated

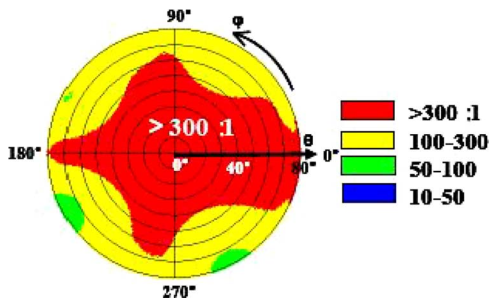

Fig. 18. Viewing angle performance of contrast ratio at 32-in LCD TV with IPS-Pro pixel structure and new compensation film. (Permission for Reprint, Courtesy Society for Information Display.)

by LED with optimal backlight design. In case of BOE-HYDIS, they exhibited 32″ LCD-TV by adopting RGB-LED with a color gamut of 107% in 2006 and one of basic structures in top emitting LED backlight is shown in Fig. 16 [24].

E. Contrast Ratio

In viewpoints of CR at normal direction, the VA mode is advantageous than the HA mode since the transmittance is proportional to $\sin^2(2\psi(V))\sin^2(\pi d\Delta n_{\text{eff}}(V)/\lambda)$, where ψ is a voltage-dependent angle between the transmission axes of the crossed polarizers and the LC director, Δn_{eff} is the effective birefringence of the LC layer dependent on voltage, ψ and λ is the wavelength of incident light. In the PVA mode, ψ is always zero while in the HA mode, it could have some values whether there is misalignment between LC director and polarizer axes. This indicates more efforts in the HA mode is required to achieve a high CR. The CR in the HA mode is influenced by polarization efficiency of polarizer, angle ψ, uniformity of the LC alignment, anchoring force between LC and alignment layer, light leakage by optical layers such as color filter, black matrix, etc. BOE-HYDIS adopted a new concept polarizer and achieved a CR larger than 1200:1 at normal direction and 100:1 in almost all viewing directions as shown in Fig. 17 [22], and Hitachi developed IPS-Pro by adopting the FFS technology, achieving a CR larger than 900:1 [23]. Further, Hitachi adopted compensation films to improve CR at viewing directions as well as normal directions and they achieved a high CR of 300:1 in all horizontal directions and larger than 100:1 in almost all viewing directions, as shown in Fig. 18 [25].

IV. Comparisons Between PVA and FFS Modes

A. Electro-Optical Performance

Considering CR only at normal direction, the PVA mode has intrinsic advantage such that the LC director is perfectly vertically aligned, and thus no phase retardation exists, resulting in an excellent dark state. However, the FFS mode has the highest transmittance among all the wide-viewing-angle LC modes. It means that the FFS could use less bright backlight which is an advantage to have low light leakage. To overcome low transmittance problem in the PVA mode, a high aperture resin process is adopted, improving the transmittance by 20%.

Considering color purity only at normal direction, the FFS mode is advantageous than the PVA mode because in the PVA mode the phase retardation is generated from zero to π, resulting strong wavelength dispersion in grey levels. However, the weakness of the PVA mode is covered by driving technology called ACC.

Considering off-axis image quality associated with CR and color shift, the FFS mode is intrinsically advantageous than the PVA mode since the LC director rotates in plane, even with multi-directional director configuration, i.e., ψ is periodically changing along electrode positions. In the PVA mode, $d\Delta n_{\text{eff}}$ has relatively stronger viewing angle and wavelength dependency compared to those in the FFS mode, resulting in larger shift in gamma curve and color coordinates. Again, this weak point in the PVA mode is improved by TFT and driving technologies adopting 8-domain technologies. However, it will sacrifice the transmittance and cost.

In overall review, the electro-optic performance of the FFS mode has intrinsic advantages compared to the PVA mode except for the CR at normal direction. However, the drawbacks of the PVA mode are being overcome by the optimization of cell structure, TFT and driving technologies.

V. Conclusion

PVA mode is a leading technology in LCD-TV developed by Samsung which has a high market share at present. This review paper describes the detail technology that the PVA mode is adopting to exhibit a high performance. The FFS mode is an interesting and important technology since it intrinsically shows a high performance. As a result, the FFS mode is being applied and commercialized in all kinds of displays.

These two technologies will compete with each other and compete with other technologies such as MVA and IPS mode. Which mode would thrive in ten years will be interesting to watch for the LCD researchers.

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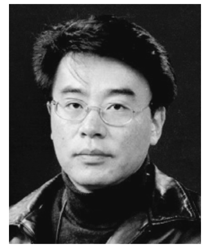

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