# *Invited Paper*: Super PVA Achieves Ultimate LCD-TV Performance Leadership

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## Abstract

*We have achieved 180-degree angle of view performance using Super-PVA (S-PVA) technology first time in TFT-LCD industry. 82" full high definition (1920 x 1080) TFT- LCD panel, the world's largest TFT-LCD, have been developed. In addition to the size breakthrough, this product achieves 600nits brightness, over 1200:1 contrast ratio, viewing angle free, 92% color gamut, and 8ms response time. Several key enabling technologies were developed to achieve these specifications, including two transistor direct driven independently controlled S-PVA sub-pixels, non even area ratio sub-pixels for optimal off-axis gamma, gate overlap driving for larger driving margin, new CCFL technology for higher color gamut, and advanced fabrication techniques including the use of Samsung's new 7th generation line.*

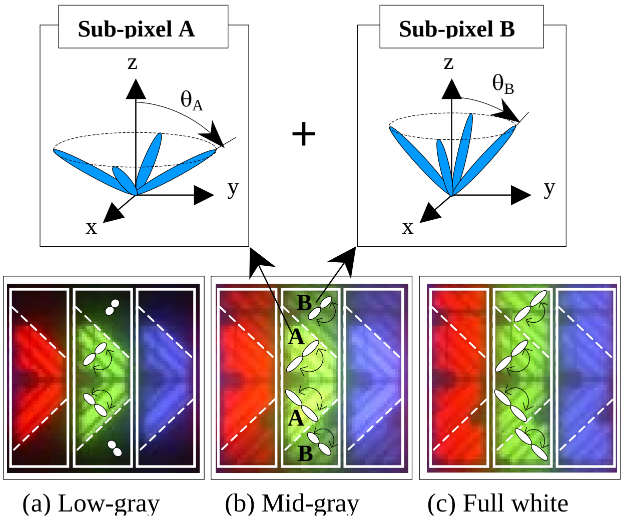
## 1. Introduction

Demand for large-area flat panel display television (FPD-TV) is surging as a result of expansion of the digital TV market. Compared to other FPD-TVs, TFT-LCDs have the advantages of high resolution, light weight, slim size, and low power consumption. Still, to realize full market potential, LCD-TVs must also show superior screen performance, including high contrast ratio with ultra-low black, uniform color over the entire range of grays, color and luminance uniformity over a wide angle of view, and faithful motion image reproduction. At SID 2004 [1], we reported the development of S-PVA, which is a combination of technologies designed to deliver unparalleled screen performance. We are now announcing further improvements to S-PVA. We have also announced the world's largest TFT-LCD, an 82-inch model incorporating all of the latest S-PVA technologies.

## 2. S-PVA Technology Advancements

### 2.1 S-PVA Cell Structure

As a vertically aligned LC technology, PVA is normally-black. PVA is a multi-domain (4-domain) VA mode. In its on-state, fringe fields are formed by patterned ITO. These fields cause the LC molecules to tilt according to the ITO patterns, forming the multi-domain LC cell. Other VA technologies rely on protrusions in order to form the multi-domain LC cell. Unlike IPS, no rubbing process is required for VA technologies. As a conventional VA mode, PVA has a viewing angle dependence which causes off-axis performance limitations. This problem can be solved by introducing more domains, as we have done with S-PVA. Off-axis image quality is critical factor for LCD-TV. The screen must maintain consistent luminance and color as viewed from any angle. Last year [2], we reported the cell structure of S-PVA for the first time.



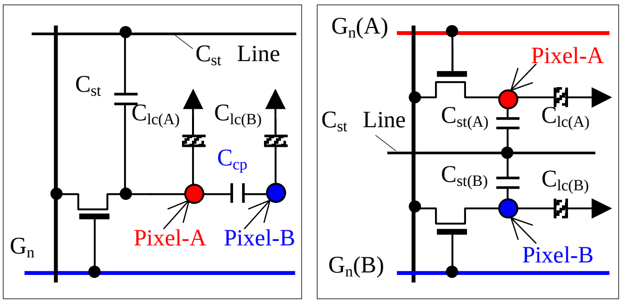
(a) Low-gray (b) Mid-gray (c) Full white

**Figure 1. 8-domain VA cell in S-PVA**

Compared to PVA, S-PVA divides each pixel into two parts, so S-PVA has twice as many domains as PVA. This concept is illustrated in Figure 1. The pixels consist of two separate sub-pixels, zones A and B. Sub-pixels A and B have different applied voltages and therefore different tilt angles. The two divided domains effectively construct an 8-domain VA cell, which can compensate and minimize gamma distortion for images viewed off-axis. As reported last year, the S-PVA structure can use an integrated capacitor to charge the secondary (B) sub-pixel from the primary (A) sub-pixel. We refer to this structure as capacitively-coupled S-PVA, or CC type S-PVA for short.

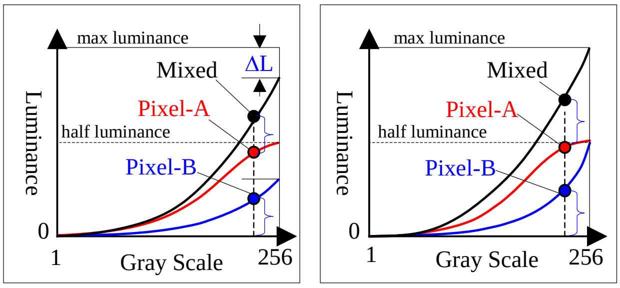
## 2.2 Two Transistor S-PVA

To enable complete and independent control over the A and B sub-pixels, we have developed a new type of S-PVA called two transistor type S-PVA, or TT S-PVA. In TT S-PVA, we double the number of gate lines, then multiplex A and B sub-pixel drive levels over a common data line. TT S-PVA preserves peak luminance, and enables maximum performance by providing independent control of each of the sub-pixels. The equivalent circuits and a comparison of luminance performance in CC type and TT type S-PVA are shown in Figure 2 and 3, respectively. In CC S-PVA, peak luminance of the secondary sub-pixel B is always lower than that of sub-pixel A because sub-pixel B can not reach its full white saturation condition. Note that although we have doubled the number of gate lines in TT type S-PVA, the number of row drivers has not increased. We are able to use multi-channel gate driver ICs to effectively address the double density gate line structure without any increase in number of driver ICs compared to that of conventional LCDs.



(a) CC type S-PVA (b) TT type S-PVA

**Figure 2. Equivalent circuits of CC type and TT type S-PVA**

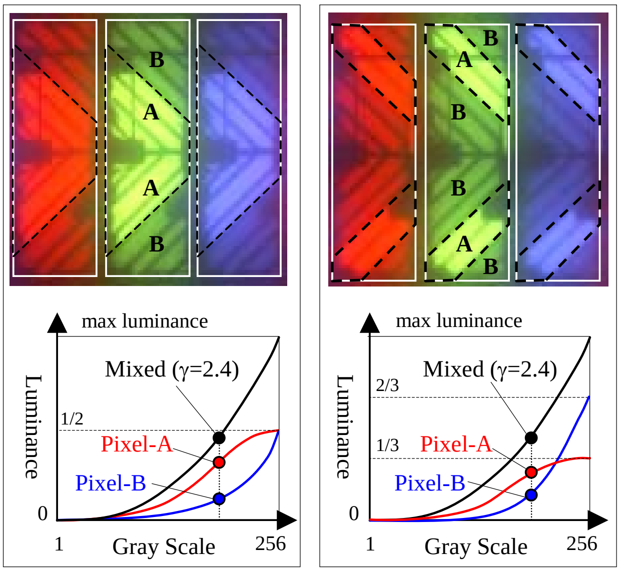


(a) CC type S-PVA (b) TT type S-PVA

**Figure 3. Comparison of luminance performance in S-PVA**

## 2.3 Sub-Pixel Area Ratio Effect

Optimal gamma over the range of viewing angles is achieved when sub-pixel B, which has a higher gamma value than sub-pixel A, is larger than the A sub-pixel. Figure 4 shows how we have changed the A:B sub-pixel area ratio from 1:1 to 1:2. Note that the luminance curves versus gray scale for sub-pixels A and B are representative of the gamma characteristics



(a) Area ratio (A:B) = 1:1 (b) Area ratio (A:B) = 1:2

**Figure 4. Area ratio effect and the optimum γ setting in S-PVA**

when the display is viewed on-axis. When viewed off-axis, gamma of the B sub-pixel decreases to an optimal gamma and will dominate, therefore a non-1:1 area ratio is needed for best performance at off-normal viewing positions. Based on our experiments, the optimum A to B area ratio is close to 1:2.

## 2.4 Sub-Pixel Driving Method

With TT S-PVA, it is possible to exactly and independently control the voltage relationships of each of the A and B sub-pixels. However, since the two sub-pixels share a common data line, the bandwidth necessary to charge both sub-pixels is fundamentally doubled. To increase the pixel charging time margin, we have developed gate overlap driving technology, shown in Figure 5.

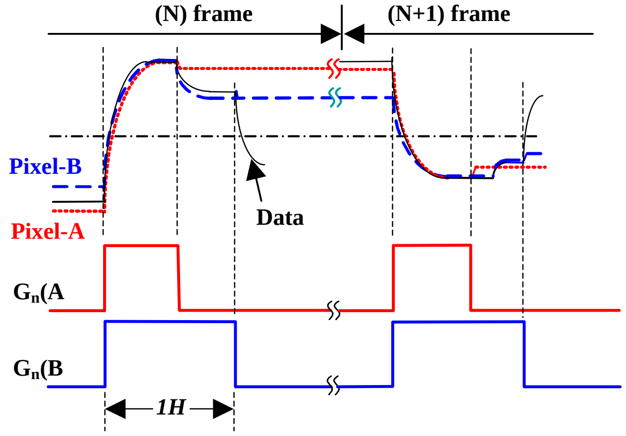
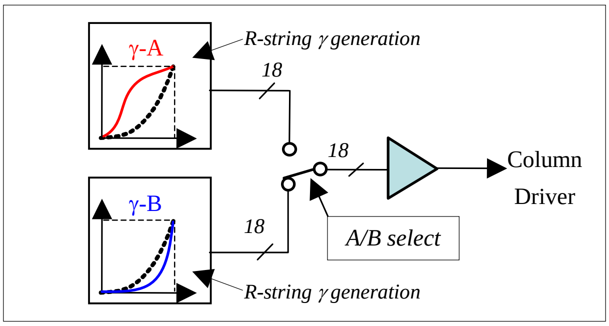
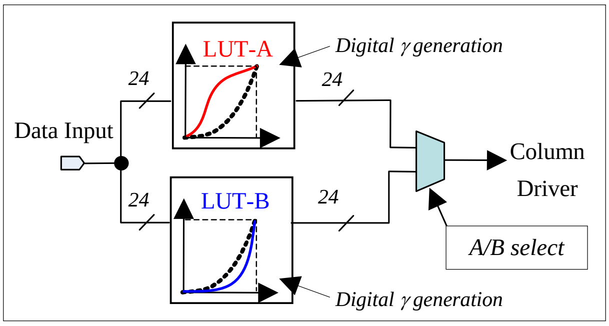


**Figure 5. Gate overlap driving in TT S-PVA**

Gate overlap driving takes advantage of the voltage relationship between primary and secondary sub-pixels. Given that the two sub-pixels have the same polarity, the first pixel voltage can be used as a pre-charge voltage for the second sub-pixel. Using this technique, a greater portion of the overall line time is devoted to charging the primary sub-pixel. Therefore, gate overlap driving reduces the bandwidth requirement from the 2x impact that would otherwise be required to charge two sub-pixels independently. To drive sub-pixels, there are two approaches toward optimal gamma (γ) control, namely analog γ switching and digital γ switching as shown in Figure 6. The basic difference is in which domain the input data is changed. The analog approach uses two different sets of R-string networks as the γ reference voltages. Each component generates different gamma reference voltages for sub-pixel A and B. The analog switch alternates between their outputs, and then the final references are amplified by a buffer. In the digital approach, the digital data is modified in digital domain using a lookup table (LUT). Two LUTs create modified data for A and B gamma values, and their output data is time-multiplexed to the column driver. In the case of digital gamma generation, the digital data has to be transmitted at double speed, but only a single set of γ reference voltages need to be used.



(a) Analog γ-voltage switching



(b) Digital γ-voltage switching

**Figure 6. Two different γ-voltage switching**

## 3. S-PVA Performance Results

### 3.1 Wide Viewing Angle Performance

We can compare PVA to S-PVA and measure the benefit of the S-PVA improvements using an off-axis image Gamma Distortion Index (D(θ ,ϕ ))[1] 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($\theta$, $\phi$) can range from 0 to 1. A smaller value means smaller image distortion, that is, better off-axis image quality.

As a result of the above improvements, S-PVA delivers a gamma distortion index of 0.144 at 60 degrees off-axis, minimizing color shift and enabling 180 degree angle of view for the first time ever in an LCD. The improved off-axis gamma distortion performance and the resulting off-axis color uniformity are shown in Figure 7 and 8, respectively.

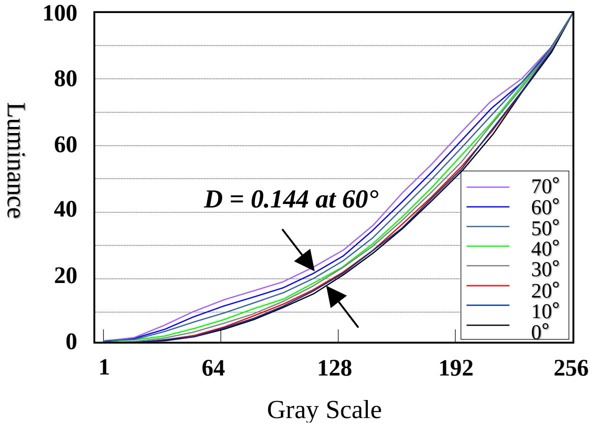
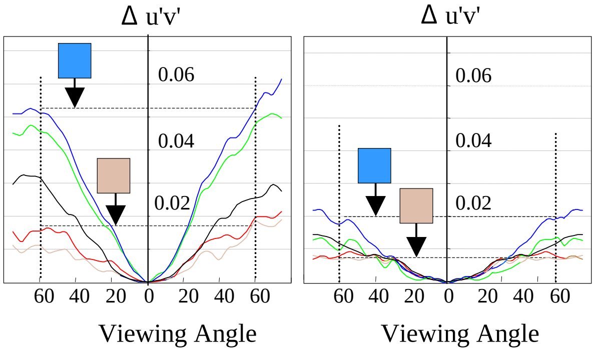


**Figure 7. Gamma distortion performance**



(a) Conventional VA (b) TT type S-PVA

**Figure 8. Color uniformity performance**

## 3.2 Ultra Black Performance

As we have reported [1,2], PVA cells have a protrusion-less structure, enabling perfect vertical alignment with no residual retardation at the black state. PVA and S-PVA do not require a rubbing process, therefore compared to IPS, they are easier to manufacture and do not suffer from rubbing defects and light leakage issues. PVA and S-PVA are also protrusion-less. Therefore, unlike MVA, PVA and S-PVA have no residual retardation, so as to deliver the highest possible contrast and most faithful reproduction of low light images.

As a result, PVA and S-PVA offer the highest possible contrast ratio of all wide viewing angle LCD modes. We have applied advanced color filter technology to extend the contrast ratio of S-PVA to >1200:1.

## 3.3 Development of 82-inch TFT-LCD

Samsung has announced development of an 82-inch full-HD (1920x1080) TFT-LCD, the world's largest, based on S-PVA technology. Figure 9 shows the picture image of the world's largest TFT-LCD panel. The LCD's diagonal screen size is over 2m. Its fabrication has been enabled by Samsung's new 7th generation fab, where the panel can be built two to a single mother glass substrate (2-up). The design concept block diagram and the logical block diagram of the 82-inch TFT-LCD module are shown in Figure 10 and Figure 11, respectively. Data enters at the panel's DVI input, where it is separated into odd and even pixel data by the TMDS receiver. Then, the data is reformatted into left and right data for each of the left and right timing controller boards. The timing controller boards in turn reformat this data into S-PVA data for each of the A and B sub-pixels, using two lookup tables to generate each of the A and B data values. DCC is then applied for reduced gray to gray transitions, and the data is transported to the column drivers over RSDS.

**Figure 9. The world's largest (82-inch) TFT-LCD**

The gate signal lines in this panel are about 1.8m long; therefore dual-bank row driving is used. In the 82” TFT-LCD panel, gate pulse RC-delay has been improved by 40% compared to that of conventional gate bus-line design by using pure Al. Each RGB pixel is divided into two sub-pixels, and each sub-pixel is independently controllable with its own dedicated TFT as in TT S-PVA described earlier. In contrast to the TT S-PVA described above, the A and B sub-pixels have dedicated data lines as shown in Figure 12. Data for both sub-pixels is loaded simultaneously under the control of a single gate line per row of sub-pixel pairs. Therefore, in spite of the large size, only a single-bank of data drivers is needed. These drivers are placed along the top edge of the panel. With this driving arrangement, two times the number of source driver ICs are needed.

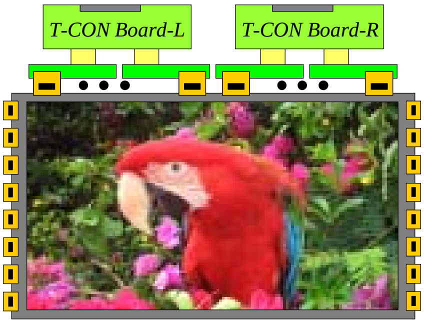


**Figure 10. Structure of the 82-inch LCD**

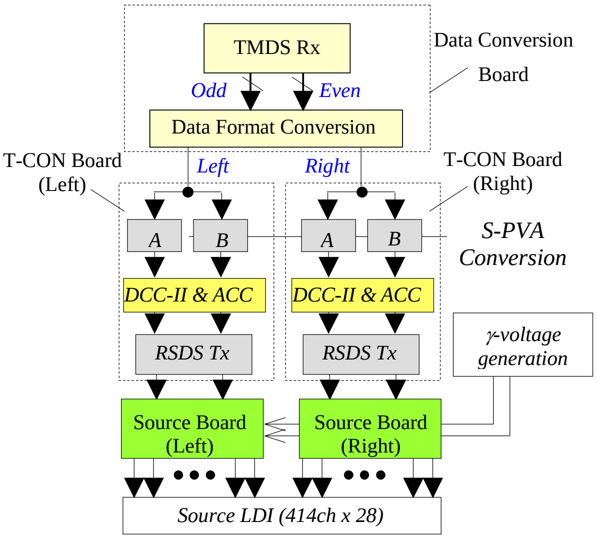
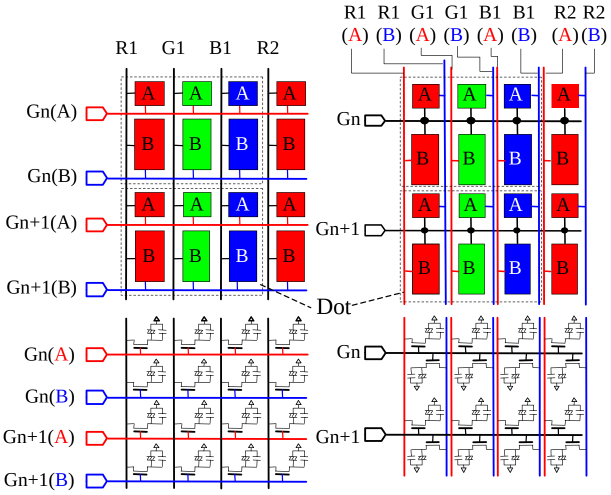


**Figure 11. Logical block diagram**



(a) Double gate line (b) Double data line

**Figure 12. Pixel layout and equivalent circuit**

A total of 28 column drivers (414 channel) and 16 row drivers (135 channel) are used in the 82-inch TFT-LCD module. Double column drivers actually results in optimal spacing between the ICs, so that conventional TCP components can be applied. Throughout the design of the 82” TFT-LCD, off-the-shelf components were used; no new silicon had to be developed for the 82” TFT-LCD.

To achieve higher color gamut, a new CCFL has been developed with improved red and green emission spectra. Side peaks in the CCFL spectra have been eliminated near the primary green wavelength, enabling a purer green peak. Also, the red peak has been relocated toward longer wavelengths to obtain a more saturated red.

As a result, 92% NTSC color reproduction has been achieved. The 82” TFT-LCD has 80 CCFLs in vertical orientation. These lamps are actually the same length as those used in our 46-inch LCD-TV. Including panel driving and the backlighting system, total power consumption of the module at 600 cd/m$^2$ luminance is currently at 650W, but it is expected to be about 500W for the commercial product. The key electro-optical performance characteristics of the 82-inch full-HD S-PVA TFT-LCD panel are summarized in Table 1.

**Table 1. Key characteristics of FHD 82-inch S-PVA TFT-LCD**

| Items | Values |
|---|---|
| Resolution | 1,920 x RGB x 1,080 (Full HD) |
| Screen Size | 82 inches (diagonal) |
| Aspect Ratio | 16:9 (horizontal to vertical) |
| Number of Pixels | 2.073M (12.44M sub-pixels) |
| No. of Colors | 16.7 million shades (24-bit color) |
| Max. Brightness | 600 cd/m$^2$ |
| Contrast Ratio | 1,200:1 (static contrast ratio) |
| Color Saturation | 92% NTSC standard |
| Response Time | 8ms (max), gray to gray |
| Viewing Angle | 180° (all directions) |
| Power Consumption | 650 Watt (max) |
| Module Size | 1,875mm x 1,080mm x 45mm |

## 4. Challenges for the Future of LCD-TV

Consumers want the high resolution, slim form factor, low power, and lighter weight offered by LCD-TV. However, they also demand no-compromise screen performance from their television. Compared to competing LCD-TV technologies, S-PVA offers the highest possible contrast ratio, darkest black state, consistent color over the range of grays, and widest angle of view with no off-axis image inversion. S-PVA excels above other LC modes for dark state and lowlight performance specifications. In our labs, we have achieved >1500:1 contrast ratio and further improvements are anticipated. This value is static contrast ratio, not dynamic contrast ratio as is sometimes reported by other manufacturers. Use of backlight dimming and other techniques would enable system contrast ratio several times that of the panel's static value. Also, the latest S-PVA technology has fully eliminated any past concerns of color and luminance shift as a function of viewing angle. Extension of color gamut well beyond the 72% NTSC broadcast standard is here today. As this standard was set based on 50 year old technology, we encourages adoption of a higher standard as the technology is ready now.

## 5. Conclusion

In conclusion, Samsung has announced several advancements of S-PVA technology, including independently controlled S-PVA sub-pixels, non even area ratio sub-pixels for optimal off-axis gamma and better viewing angle performance, gate overlap driving for larger driving margin, new CCFL technology for higher color gamut, and advanced fabrication techniques. Samsung has announced the world's largest TFT-LCD, an 82-inch model with over 1200:1 contrast ratio, 180° angle of view, 92% NTSC color gamut, and other high performance characteristics. This new model is fabricated on Samsung's new 7th generation line, which is now operational. Samsung LCD is committed to achieving greater technological innovations to drive LCD-TV to new levels of performance and affordability.

## 6. References

[1] S. S. Kim, "Super-PVA Sets New State-of-the-Art for LCD-TV," SID Symposium Digest, Vol. 35. pp. 760-763, 2004.

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