Enhancing the Brightness of Parallax Barrier Based 3D Flat Panel Mobile Displays Without Compromising Power Consumption

Wallen Mphepö, Yi-Pai Huang, and Han-Ping D. Shieh, *Fellow, IEEE*

***Abstract*—This paper presents an alternative approach for achieving higher optical efficiency in conventional parallax barrier 3D mobile displays. The method entails modifying and enhancing the protrusion structure of conventional Multi-Domain Vertical Alignment (MVA) pixel arrays plus the Storage Capacitors (Cst) of the pixel circuitry which increase effective pixel transmission area by a factor of 1.07. Hiding the modified storage capacitor under the parallax barrier strip increases the barrier gap or slit size by a factor of 1.52. The result is a structure that enhances mobile displays' optical efficiency by a compounded factor slightly over 60% without compromising power consumption.**

***Index Terms*—Crosstalk, optical efficiency, parallax barrier, three dimensional (3D).**

I. Introduction

MOST autostereoscopic parallax barrier three dimensional (3D) displays use a method where conventional flat panel displays [1], [3], such as liquid crystal displays, plasma display panels, organic light-emitting diode displays (OLEDs) etc., as their image source. There has been some notable successes using this method, however, the optical efficiency in particular among other factors affecting this technology have so far proved daunting. This is in part due to the known fact that optical efficiency is directly related to the greatly undesirable image crosstalk. This paper presents a configuration of liquid crystal panel whose pixel array properties and layout have been improved for parallax barrier based autostereoscopic 3D displays to enhance brightness without increasing image crosstalk.

II. Parallax Barrier Based 3D Displays

A. Conventional Pixel Structure and Its Light Distribution Simulation

The panel used in our experiments was a 2.83″ AU Optronics Corporation (AUO) panel with a pixel array of 640 × 480 and pixel size of 90 μm × 90 μm (i.e., 30 μm × 90 μm red, green, and blue (RGB) sub pixels), and the liquid crystal mode was multidomain vertical alignment-bright (MVA-b) [4], [5]. The pixel layout is as shown in Fig. 1. By using slanted parallax barrier as shown in Fig. 3 to make a six view 3D display, the slanted barrier needs to have a maximum aperture ratio of only 8.9% or less in order to limit crosstalk to an average tolerable level of 5% according to our simulations. Whereby, the conventional crosstalk definition and computation for a viewing zone was used as shown in Fig. 2. This definition for Viewing Zone A with peak brightness magnitude 'a' centered at x_A next to Viewing Zone B whose brightness profile value at x_A is equal to 'b' would give $\mathrm{Crosstalk} = b/a$.

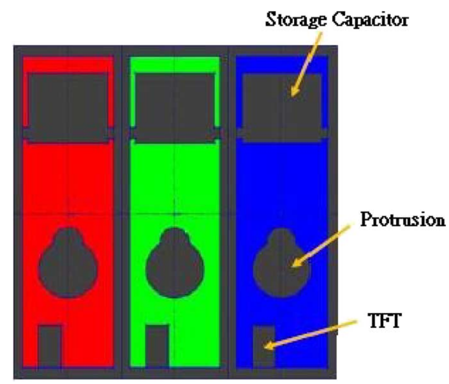

Fig. 1. An illustration of the conventional multi-domain vertical alignment pixel structure.

III. Liquid Crystal Pixel for Spatially Multiplexed Parallax Barrier 3D Displays

The emission profile of a typical pixel in a wide-viewing angle liquid crystal panel is close to a Lambertian distribution [1], [6]. However, when being used in a spatially multiplexed autostereoscopic 3D display based on a parallax barrier, only a limited cone of rays is effectively utilized. This is because the pixel should only be seen from a specific viewing direction or virtual viewing window. The rest of the energy is mostly blocked out [6], [7] resulting in significant optical inefficiencies. In a barrier 3D display, the aperture ratio of the barrier is normally used as the parameter for reducing cross talk between two adjacent viewing zones. Reducing the aperture ratio of the parallax barrier reduces crosstalk to tolerable levels, but simultaneously lowers display brightness. Thus, the crosstalk problem can be eliminated with a barrier design, but often at the expense of optical efficiency. However, barriers are not the

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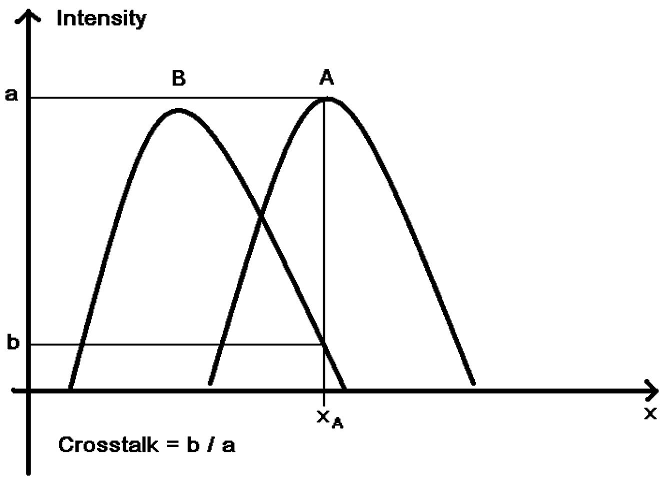


Fig. 2. Definition for Crosstalk in Viewing Zone A with peak brightness magnitude 'a' centered at x_A next to Viewing Zone B whose brightness profile value at x_A is equal to 'b' would give $\mathrm{Crosstalk} = b/a$.

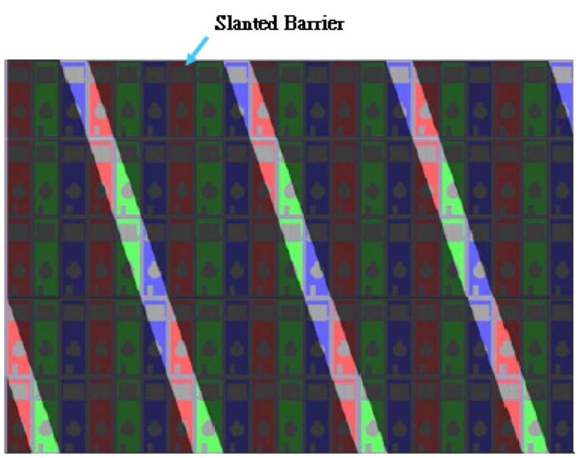


Fig. 3. An overview illustration of the conventional parallax barrier based 3D panel's barrier positions and the underlying pixels.

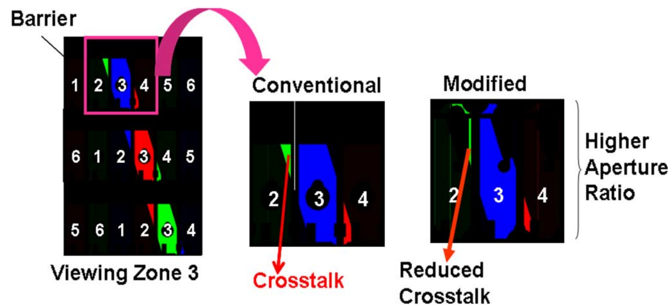


Fig. 4. Zoomed-in illustration of the conventional and proposed pixel design's differences in crosstalk and aperture ratio.

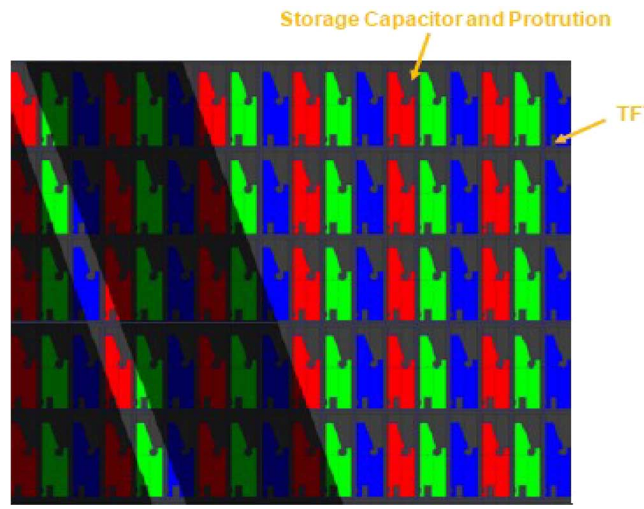


Fig. 5. An enlarged area illustration of the new proposed pixel array as applied in a parallax barrier 3D display.

only needed design components that happen to also block light. Liquid crystal pixels normally have components that block light as well, these include TFTs, protrusions, electrodes and storage capacitors, etc. [2], [5], [6] However, prior arts in ray tracing show that light from certain parts of the pixel tend to cause more cross talk than others. Armed with this information we located the light blocking components on the pixels and where the emitted light tends to cause more cross talk. We thus hypothesized that modifying the location of these components to better fit a 3D display profile would result in an improved optical efficiency at tolerable crosstalk levels.

That is, if light blocking components are strategically placed under the calculated opaque segments of the parallax barrier it would increase the panel's optical efficiency. Blocking the pixel light emissions from crosstalk causing sections would also reduce this adverse artifact (see Figs. 4 and 5).

IV. Aperture Ratio of Pixel Array

The factors that affect the aperture ratio directly impact the optical efficiency of the 3D display as already mentioned earlier. However, the most obvious visible factors affecting the aperture ratio in the pixel array that we decided to focus our research on were:

a) center positioned protrusion structure used to obtain multi-domains;
b) square shaped storage capacitor of the pixel circuitry

Enhancing these factors to blend in with the slanted parallax barrier 3D display structure was the bulk of our experimental research work. Then fabrication of the desired simulated display structure was conducted by AUOptronics, Hsinchu, Taiwan. The measurements from the fabricated device were then compared to the simulation results and are reported below.

V. Simulation Results

Fig. 6 shows the simulation results for all the six views of our designed parallax barrier 3D panel to fit the modifications. From the simulation results in Fig. 6 the average increase in optical efficiency due to parallax barrier aperture ratio increase only 36%. The average increase in pixel array aperture ratio was from 16% to 18%. This was due to changes in protrusion and storage capacitor. The average decrease in crosstalk from the simulation results was 50%.

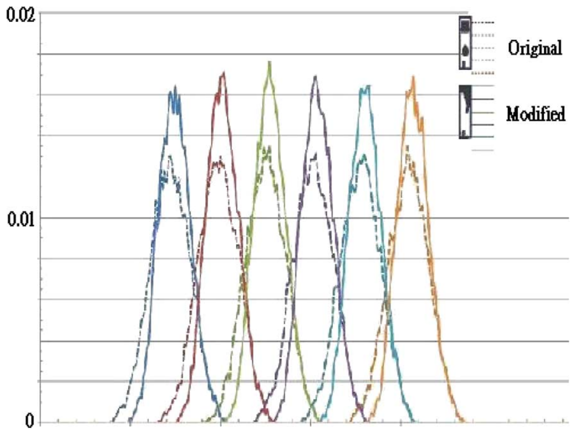


Fig. 6. Luminance distribution across six viewing zones at viewing the viewing distance of 0.3 m. The average improvement which is due to only increase in barrier aperture ratio is about 36%.

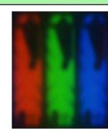
	Conventional MVA-b Based 3D Fabricated Panel [Reference]	Our Modified MVA Based 3D Fabricated Panel
Microphotographs of Pixel (Multi-domain VA)		
Brightness	100%	163%
Crosstalk	X_{t0}	$0.51{*}X_{t0}$
Fabricated 3D Displays Images From Viewing Zone 3		

Fig. 7. Comparison between the fabricated conventional parallax barrier 3D display and the fabricated proposed design parallax barrier 3D displays' measured properties.

VI. Measured Results

A. Review Stage

The measured results are shown in Fig. 7. The measured increase in optical efficiency was 63% and the measured decrease in the image crosstalk was 51%.

The itemized contrast and comparison between simulation and conoscope measurement results from our fabricated 2.83″ mobile 3D display whose specs are shown in Fig. 8 are elaborated on below.

The measurement results can be categorized into two parts:

A) brightness;

B) crosstalk.

The conventional and proposed pixel images were observed by optical microscope, as shown in Fig. 7 above.

B. Brightness

The brightness increase ratio of the 3D display with pixel which has slanted storage capacitor is shown in Fig. 9.

	CONVENTIONAL 3D DISPLAY	PROPOSED 3D DISPLAY
PARALLAX BARRIER SLIT (μm) [by NTHU]	19	26
SPATIAL FREQUENCY =180 μm / cycle		
PIXEL LAYOUT (30 μm X 90 μm)		
RESOLUTION	640 X 480	640 X 480
THICKNESS OF GLASS SUBSTRATE (μm)	300	500
THICKNESS OF POLARIZER (μm)	180	180

Fig. 8. Specifications of the parallax barrier and 2.83″ LCDs (NTHU: National Tsing Hua University).

	SIMULATION	MEASUREMENT
A.R. OF BARRIER (%)	136	152
BRIGHTNESS OF LCD (%)	117	107
COMBINED BRIGHTNESS (%)	160	163

Fig. 9. Brightness increase ratio of the proposed pixel layout compared to 3D display with conventional MVA-b pixel layout (A.R.: aperture ratio).

The brightness of 2.83″ 3D display with the slanted storage capacitor was improved by 63% compared to that of the conventional 3D display. For the aperture ratio of the parallax barrier, the measured increase ratio is higher than that of the simulation of the design. The parallax barrier was fabricated by printing process with 20000 dpi by Taiwan Kong King Company, Ltd., of Taoyuan, Taiwan (http://www.tkk.com/website/). The brightness of the proposed LCD is increased due to the increased aperture ratio. These measurement results imply that the brightness of the 3D display with our proposed pixel design is significantly improved.

C. Crosstalk

The crosstalk of each view was measured by inputting the patterns in Fig. 10.

For instance, Fig. 10 (bottom) illustrates how we measured the crosstalk of viewing zone 5 and 3 resulting from the light leakage from pixel 4.

The input pattern, BBWBBB, represents that white image can be observed within viewing zone 4 and the rest of viewing zones show black images in the ideal case (0% crosstalk). After inputting these six patterns in Fig. 10 respectively, the crosstalk of 3D displays based on conventional and proposed pixel layouts were measured by Conoscope. The results of these conoscope measurements are as shown in Table I.

The results in Table I demonstrate that the 3D display with proposed pixel layout has lower crosstalk even if parallax barrier slit size is wider (26 μm). Therefore, the image quality of each viewing zone can be improved due to the noticeably lowered crosstalk.

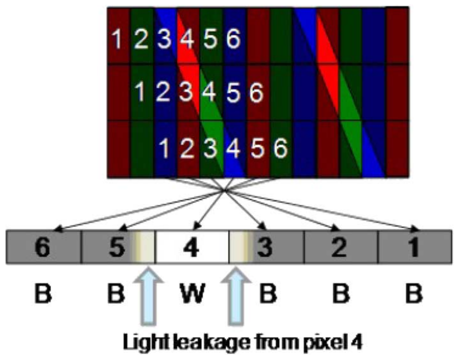


Fig. 10. Illustration of the crosstalk measurement approach for the input test pattern (BBWBBB). (B stands for Black and W stands for White).

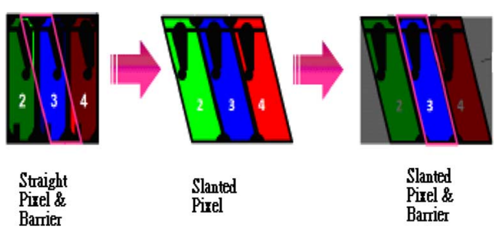


Fig. 11. Slanted pixel layout structure proposed for our future work which will exhibit higher levels of brightness and lower levels of crosstalk.

TABLE I
SHOWS CROSSTALK MEASUREMENTS FROM CONOSCOPE FOR THE CONVENTIONAL PARALLAX BARRIER DISPLAY AND THAT OF OUR MODIFIED PIXEL DISPLAY

	Conventional	Modified
Barrier Slit Size (μm)	19	26
Crosstalk	~37	~19

VII. OBSERVATIONS AND DISCUSSION

The simulation results and measured results are clearly indicating a noticeable improvement in display optical efficiency and reduction in crosstalk, hence validating our hypothesis. Thus from a device level, modifying the protrusion structure and shifting it to a different position enabled us to increase the pixels' aperture ratio. Also changing the shape of the Storage Capacitor reduced crosstalk while also increasing aperture ratio. These changes together improve the average aperture ratio by 16% to 18%. By strategically placing the modified storage capacitor we were able to enlarge the barrier gap or slit size by 36%. The overall compounded effect of these two increments then produced a 60% optical efficiency since a factor of $1.36 \times 1.17 =\sim 1.6$. This was also coupled with a 51% reduction in image crosstalk compared to the conventional configuration. The measured results using conoscope were slightly above 60% as well. This result however is clearly not the best it can be. It can be improved even further with use of a slanted whole pixel structure to fit the slanted parallax barrier as shown is Fig. 11. Thus this will potentially constitute the bulk of our future work on this project, apart from more ray tracing iterations of each new pixel modification we perform and have performed. Also of significant importance to be tackled in our future work is taking into account and analyzing the liquid crystal mode used in order to improve the inherent directionality of the pixel projection angle. This would then further drastically reduce the thickness of the parallax barrier strip and increase aperture ratio dramatically, hence the brightness too.

VIII. CONCLUSION

The impact of a 60% improvement in display brightness without a corresponding 60% increase in power consumption is most pronounced in mobile devices where lasting battery power is among the most precious of commodities. The herein presented solution not only directly tackles the brightness, circuitously power consumption, problem which affects virtually all multi-view parallax barrier based 3D Flat Panel Displays, but also manages to simultaneously lower the 3D image crosstalk significantly as well.

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