# 71.5: Stencil-FSC Method for Color Break-Up Suppression and Low Power Consumption in Field-Sequential LCDs

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## Abstract

*Field sequential color liquid crystal displays (FSC-LCDs) are still facing a serious artifact, color break-up (CBU), which degrades image quality. Consequently, we propose the "Stencil-FSC" method, applying local color-backlight dimming technology to FSC-LCDs with a 240 Hz field rate which not only suppresses CBU efficiently but also enhances the contrast ratio of images in using ultralow average power consumption. The Stencil-FSC method was demonstrated on a 32-inch FSC- LCD and effectively suppressed CBU, resulting contrast ratio of more than 5,500:1, and average power of less than 45 Watt.*

## 1. Introduction

Field-sequential-color LCDs (FSC-LCDs) without color filters have been proposed to enhance light efficiency and color gamut [1]. R, G, and B fields for each frame in an FSC-LCD are sequentially displayed which differ from conventional color- filter type LCDs. By rapidly flashing different colors, the human eye can perceive full-color images. Thus, the main advantages of FSC-LCDs are low material cost, three times increase in possible screen resolution, wide color gamut, and high light efficiency (low power consumption).

However, a well-known intrinsic visual artifact, color break-up (CBU), is perceived when a relative velocity exists between the object on the screen and the observer's eyes. CBU occurs when the eye follows a moving object (smooth pursuit) or scans an image on the FSC-LCD quickly and sporadically (saccade) [2-3]. CBU reduction methods were studied for the digital light projector (DLP). As a result, several effective methods were proposed to reduce CBU in FSC-LCDs based on the DLP observations, such as increasing the field rate, inserting black fields (RGBKKK), inserting multi-color fields (RGBCY), adjusting color elements method (ACE) [4], and the four color-fields arrangement method (4-CFA) [5]. However, the limited response time of liquid crystal at higher field rates or the uncertainty of eye movement increases the complexity of these methods on large size FSC-LCDs.

Consequently, we propose the "Stencil Field-Sequential-Color (Stencil-FSC)" method to effectively suppress CBU with a field rate of 240 Hz (four sub-frames) which is easier to be implemented. In this method, a clear luminance, rough color image is displayed in the first sub-frame. Then, the other three primary-color (R, G, and B) images are combined, and a full-color image is completed. By using the Stencil-FSC method, not only is CBU suppressed, but our method also reaches high contrast with ultralow power consumption for a 32-inch FSC-LCD.

## 2. Stencil-FSC Method

### 2.1 Algorithm and Simulation

The conventional FSC-LCD presents three primary-color (R, G, and B) sub-frames on the same pixels of an LCD in time sequence to form a full-color image (Fig. 1(b)). When the eyes look at three high luminance images sporadically, CBU can easily be seen which reduces image clarity. Our idea comes from the recreation of "Stencil," like a kid who paints an undertone on his "Peter Pan" first, and then paints other colors over it to complete a vivid, colorful Peter Pan (Fig. 1(c)).

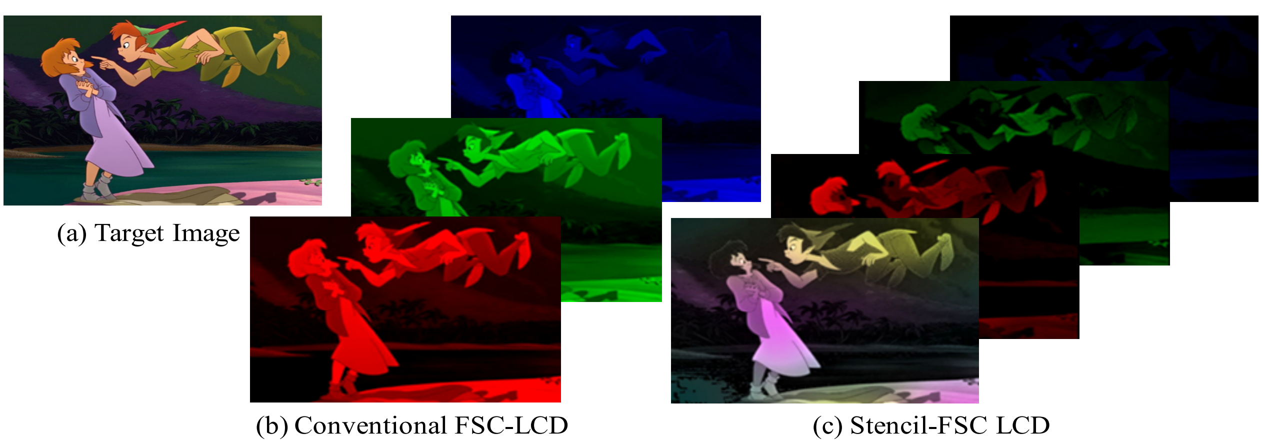


**Figure 1 -** (a) Target image_ *Peter Pan* (©Disney), each sub-frame image by using the (b) conventional FSC- LCD and (b) Stencil- FSC method.

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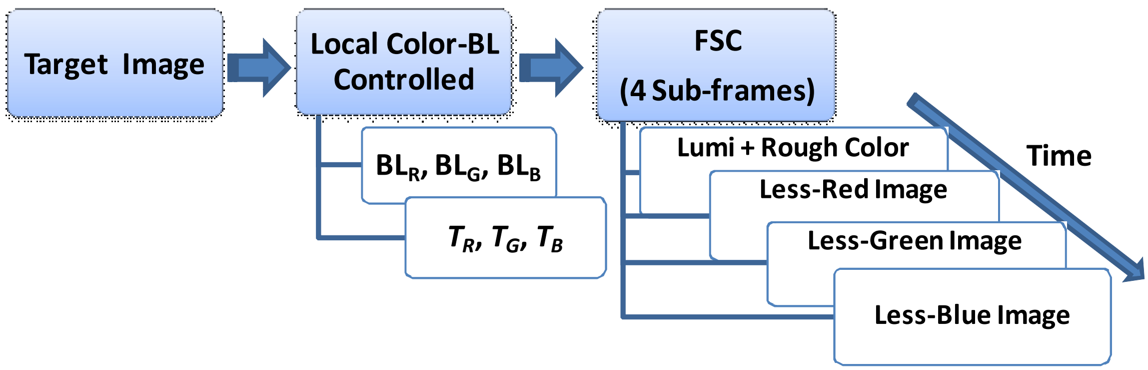



**Figure 2 -** Algorithm processing of the Stencil-FSC method.

Therefore, we propose a method displaying high luminance with rough color on the first sub-frame image, and then the luminance of the other three primary-color images can be reduced to form a vivid color image. Accordingly, less primary- light is seen, and CBU can be suppressed. We call the method "Stencil-FSC."

Local color-backlight dimming technology was used to obtain high luminance with rough color on the first sub-frame image. The Stencil-FSC algorithm is shown in Fig. 2. First, the target image was recalculated by using backlight localizing controlled technology (HDR) [6] to obtain backlight signals for the three primary-colors, $BL_R$, $BL_G$, and $BL_B$ (Fig. 3(a)), according to the information in the target image. Moreover, the LC transmittance values of R, G, and B sub-frames, $T_R$, $T_G$, $T_B$, were compensated according to the backlight signals ($BL_R$, $BL_G$, and $BL_B$) [7]. Then, we took the minimum transmittance value of each LC pixel, $T_{min}$ (Eq. 1), as the LC signal for the first sub-frame as shown in Fig. 3(b). From Eqs. 1(a)-(c), the new LC signals, $T_R'$, $T_G'$, and $T_B'$, for the R, G, and B sub-frames were determined.

After determining signals of backlight and LC, the backlight signals of the three primary-colors ($BL_R$, $BL_G$, and $BL_B$) and the minimum LC signal ($T_{min}$) were combined to display high luminance with rough color information in the first sub- frame image (Fig. 3(c)). Likewise, combining the $BL_R$ with $T_R'$, $BL_G$ with $T_G'$, and $BL_B$ with $T_B'$, creates three other primary- color images as shown in Fig. 1(c). Finally, displaying these four sub-frame images in 1/60 second makes CBU almost invisible in a full-color image. Additionally, each primary color has two sub-frames to show its information; therefore, the clipping effect [7] does not appear in our method. Moreover, the Stencil-FSC method can also heighten dynamic contrast and lower power consumption.

$$T_{min} = \min(T_R, T_G, T_B) \ldots\ldots 1$$

$$T_R' = T_R - T_{min} \ldots\ldots 1(a)$$

$$T_G' = T_G - T_{min} \ldots\ldots 1(b)$$

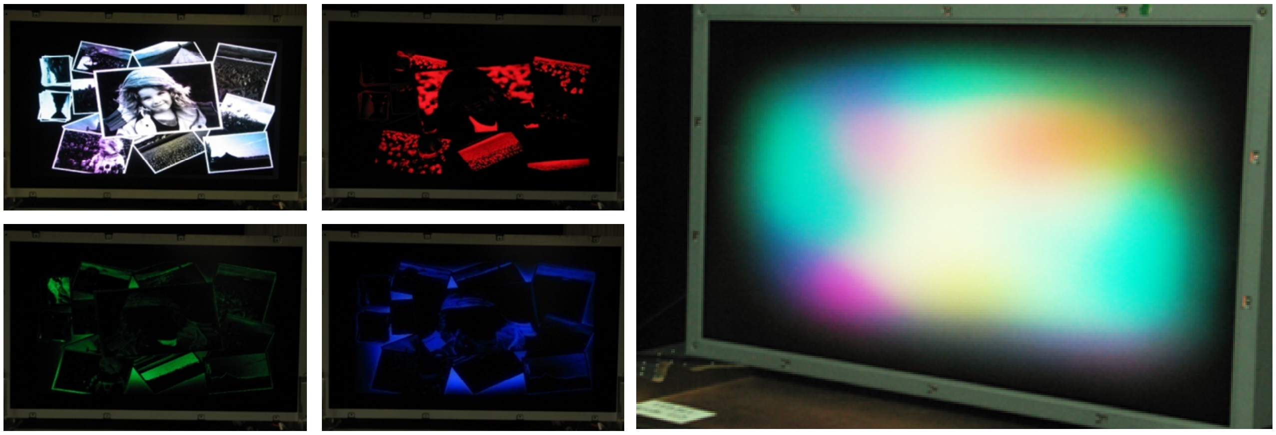
$$T_B' = T_B - T_{min} \ldots\ldots 1(c)$$

## 2.2 Experiments on a 32-inch FSC-LCD

The Stencil-FSC method was implemented on a 32-inch local color-backlight dimming FSC-LCD with 1366×768 image resolution and 12×16 backlight zones (Fig. 4). The picture of *Girl* was used as the test image. In Fig. 4(a), the first sub-frame photo presents a high luminance, rough color image. The other three sub-frames display low luminance colors to complete a full color image. Hence, the CBU phenomenon can be reduced by using the Stencil-FSC method (Fig. 5(b)). At the same time, the dynamic contrast ratio of *Girl* was enhanced to 5,973:1 at power consumption of 44 Watt. The contrast ratio, power consumption, CBU, and color gamut of three 32-inch LCDs (commercial IPS-CCFL, conventional RGB driving FSC, and Stencil-FSC) with the test image_ *Girl* were measured and shown in Table 1.

(a) Color BL image (b) Minimum LC image (c) First sub-frame image

**Figure 3** - Simulation results of the first sub-frame image. (a) A color backlight image, (b) a minimum LC image, and (c) the first sub-frame image.



(a) Four sub-frame images (b) Stencil-FSC LCD

**Figure 4 -** (a) Demo photos of four sub-frames of *Girl* (©2007 Microsoft Corporation) on a 32-inch FSC-LCD by using the Stencil- FSC method. (b) A Stencil-FSC LCD.

(a) Conventional FSC-LCD (b) Stencil-FSC method

**Figure 5** - Experimental results of CBU by using the (a) conventional FSC-LCD and (b) Stencil-FSC method.

**Table 1 -** Comparison of three 32-inch LCDs of IPS-CCFL, conventional FSC, and Stencil-FSC method with the test image_ *Girl*. (*: The maximum NTSC ability of the LCD)

| | 32" IPS-CCFL | Conventional FSC | Stencil-FSC |
|---|---|---|---|
| CR | 579:1 | 442:1 | 5,973:1 |
| Power (W) | 105 | 67 | 44 |
| Color Breakup | ------ | Serious (Fig. 5a) | Slight (Fig. 5b) |
| NTSC (%)* | 72% | 114% | 114% |
| PS: Power of a conventional 32-inch LED backlight LCD: ~180W | | | |

## 3. Conclusion

We proposed the "Stencil-FSC" method to suppress the color break-up (CBU) phenomenon in field-sequential-color (FSC) LCDs. By using the first sub-frame to show a high luminance, rough color image; the luminance of three other primary-color images can be greatly reduced making CBU almost invisible. The first sub-frame can be compiled by a low resolution color image utilizing a locally controlled LED backlight and a high resolution LC image. Therefore, the Stencil-FSC method can not only reduce CBU, but also increase dynamic contrast and lower power consumption. The Stencil-FSC method has already been implemented on a 32-inch FSC-LCD to yield the dynamic contrast of 5,973:1, average power consumption of less than 45 Watt, color gamut of 114% NTSC, and suppressed color breakup. Consequently, the proposed ultralow power FSC-LCD without CBU may be very promising for next generation large size LCD applications.

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