A Hybrid Spatial-Temporal Color Display With Local-Primary-Desaturation Backlight Scheme

Yuning Zhang, Erno H. A. Langendijk, Martin Hammer, and Fang-Cheng Lin

***Abstract*—Field-sequential-color mode has benefits on energy efficiency, because colors are made by flashing the backlight red, green, and blue and the color filters are not needed, leading to increased light transmission. However, field-sequential-color mode causes annoying color breakup. In previous studies, a spatio-temporal display has been proposed as a hybrid solution to balance the increase of light transmission and the suppression of color breakup. However, color breakup remains visible for critical image content. In this paper, a 120-Hz liquid crystal display with two-color filters mounted with a backlight consisting of a light emitting diode matrix is introduced. The backlight colors are locally desatured according to the local image content, so the color difference between fields is reduced, and the perceived color breakup is effectively suppressed. Various examples with different color filter and backlight settings are described and analyzed, aiming at different display–performance objectives.**

***Index Terms*—Backlight, color breakup, field sequential color (FSC), liquid crystal displays (LCDs), spatial-temporal color.**

I. INTRODUCTION

LIQUID crystal displays (LCDs) have become mainstream in the flat-panel display industry [1]. However, they are not energy-efficient due to the relative low light transmission. Currently, LCDs are based on spatial color synthesis, by using a continuous-spectrum white backlight combined with colored subpixels formed by red (R), green (G), and blue (B) color filters [2]. The color filters only pass one-third of the light and the effective resolution is only one-third of the addressable subpixel resolution [3], [4].

Instead of using spatial color synthesis, a field-sequential-color (FSC) display applies temporal color synthesis [5], [6]. An FSC display operates without color filters, but rather flashes the backlight sequentially to R, G, and B. Colors are formed by modulating the transmission of each pixel in each field (R, G, or B). As an FSC display does not need color filters, the light transmission is three times higher. Using the same active matrix and subpixel resolution, the spatial resolution of an FSC display is also potentially three times higher. However, FSC displays suffer from serious color breakup [7] and require a high refresh rate of the LCD panel. To synthesize full color and avoid luminance flicker, an FSC display needs to operate at a refresh rate of 180 Hz [8]–[11]. Even higher refresh rates above 600 Hz are needed to suppress color breakup below the perceptible threshold [4].

To reduce color breakup, a hybrid solution with two temporal fields (2F) and two color filters (2CF) has been proposed [3], [4], [12]. This class of displays is often called spectrum-sequential displays or spatio-temporal color (STC) displays. As indicated in previous studies, a 2CF2F display has a 50%–200% higher light transmission and potentially a 50% increase of spatial resolution compared with a conventional LCD with RGB color filters. It inherently exhibits less color breakup than a conventional three-field (RGB-field) FSC display. However, it still suffers from perceivable color breakup [12].

In this paper, an improved STC display with an adaptive backlight is introduced, which uses a 120-Hz LCD with two-color filters and a backlight consisting of a matrix of addressable (RGB-) light-emitting-diodes (LEDs). It controls the backlight color according to the image content to reduce the color difference between fields. It efficiently suppresses the perceived color breakup while preserving the image fidelity and keeps the advantages of high light transmission, high spatial resolution, and wide color gamut, like a normal STC display.

II. STC DISPLAYS

A. *Configuration of a STC Display*

A hybrid STC synthesis distributes the color synthesis function across both the spatial and temporal domains. For example, in the case of a 2F2CF LCD, each pixel has two subpixels with two different color filters and two temporal fields with different backlight colors [3], [4]. By changing the spectra of the color filters and the backlights, different color combinations can be achieved. Figs. 1 and 2 show two typical examples that both result in three primaries R, G, and B.

In the first case (Fig. 1), yellow and cyan are applied as the backlight colors, while the subpixel color filters are green and magenta. The required backlight can be generated directly by the yellow and the cyan backlight, or generated by the combination of RGB LEDs, as shown in Fig. 1. So in the first field, with the combination of a yellow backlight and green–magenta color filters, red and green subpixels are formed. In the second field, with the combination of a cyan backlight and green–magenta

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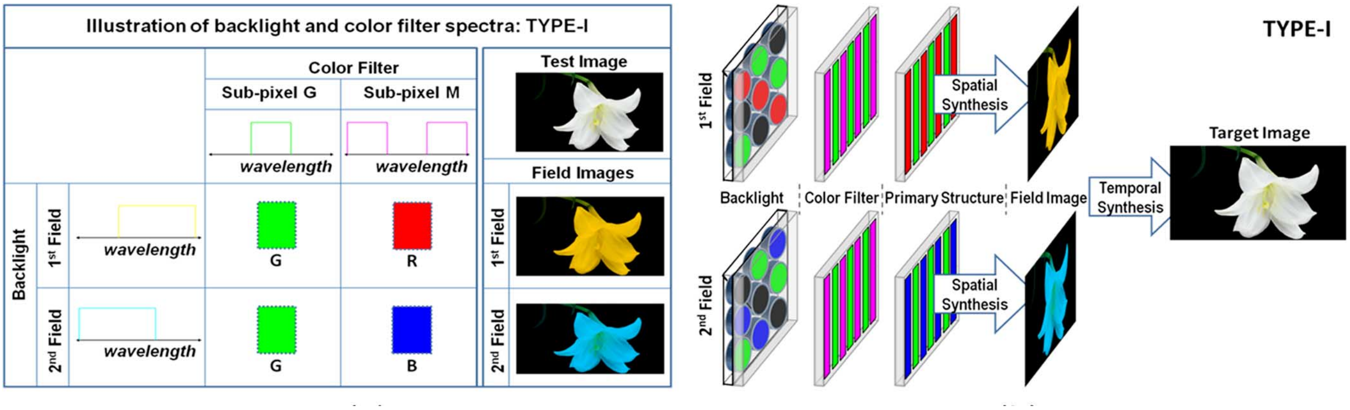
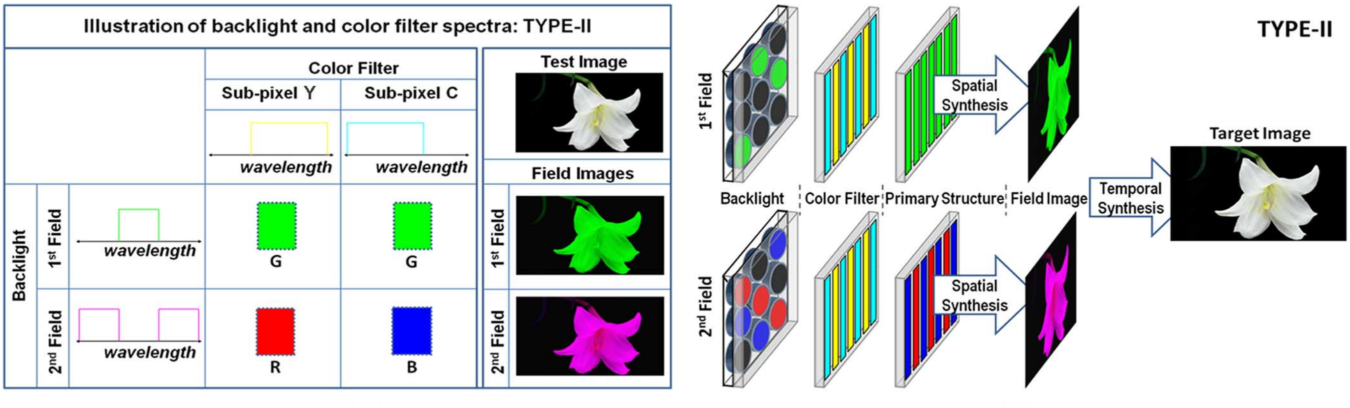


(a) (b)

Fig. 1. A 2F2CF LCD (TYPE-I) with yellow–cyan (Y-C) backlights and green–magenta (G-M) color filters. (a) Spectrum-level illustration for the color synthesis procedure. (b) Configuration of this 2F2CF LCD. (Backlight spectra and color filter transmission spectra are ideal.)



(a) (b)

Fig. 2. A 2F2CF LCD (TYPE-II) with green-magenta (G-M) backlights and yellow-cyan (Y-C) color filters. (a) Spectrum-level illustration for the color synthesis procedure. (b) Configuration for this 2F2CF LCD.

color filters, green and blue subpixels are formed. By adjusting the *LC* driving level for each subpixel at each field, a colorful image can be displayed.

Other conceptually similar combinations exist, like yellow–magenta backlights combined with red–cyan color filters, and magenta–cyan backlights combined with blue—yellow color filters. All of these combinations are characterized by wide backlight spectra; both field backlights cover about 2/3 of the visible spectrum, like the yellow and cyan backlight in Fig. 1. They have a narrowband color filter, which passes about 1/3 of the visible spectrum, like the green color filter in Fig. 1, and a broadband color filter, which passes about 2/3 of the visible spectrum, like the magenta color filter in Fig. 1. For each field for each backlight component (like R in field 1), one subpixel (magenta) passes and the other (green) absorbs it, while in a normal RGB LCD one subpixel passes and the other two absorb the backlight, so the light transmission is 50% higher than in a normal LCD. Such configuration is marked as TYPE-I in this paper.

In the second case (Fig. 2), green and magenta are applied as the backlight colors for two sequential fields; yellow and cyan color filters are applied to form subpixels. In the first field, the green backlight will pass through both the yellow and cyan color filters, and form a green field. Hence, for green, the light transmission is 3 × higher compared with a conventional LCD with RGB color filters. In the second field, with the combination of a magenta backlight and yellow–cyan color filters, red and blue subpixels are formed, so, for red and blue, the light transmission is 1.5 × higher compared with a normal LCD. Similarly, there are also other conceptually similar combinations, like red–cyan backlights with yellow–magenta color filters, blue–yellow backlights with cyan–magenta color filters. In such kind of configurations, two broadband color filters are applied, like the yellow and cyan color filters in Fig. 2. Such configurations are marked as TYPE-II in this paper. Depending on the image content, the overall light transmission is about 1.5 ×–3.0 × higher compared with a normal LCD, that is, a 2F2CF LCD with the configuration like Fig. 2 is even more efficient than that of Fig. 1 for particular colors.

B. Color Breakup in STC Displays

It is well understood that, when the frame frequency is beyond the temporal acuity of the human visual system (often taken to be 60 Hz) and the viewer does not move his/her eyes,

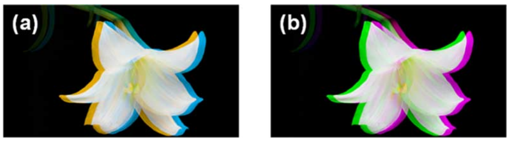


Fig. 3. Simulation of color breakup when displaying an image of "Lily" with different 2F2CF LCD configurations. (a) Yellow–cyan backlights and green–magenta color filters. (b) Green–magenta backlights and yellow–cyan color filters.

the human visual system will fuse the two field images and perceive a normal color image, as shown in Figs. 1 and 2. However, when the viewer moves his/her eyes, the field images will displace on the retina and annoying color breakup will be perceived [10]–[15]. Since the color breakup is difficult to record by a camera, a simulation model based on smooth-pursuit eye tracking and light integration is applied to illustrate the color breakup [4], [12]. By shifting and overlapping the field images, Fig. 3(a) and (b) illustrates a simulation of perceived color breakup in the 2F2CF LCD with the configuration of Figs. 1 and 2, respectively.

Compared with a conventional FSC display with three (RGB) fields, a STC display will exhibit less color breakup [12]. However, the perceived color breakup is still annoying for high-contrast image content, like white characters on a dark background or the image "Lily" shown in Fig. 3. Such annoying color breakup distorts the image quality and limits the practical application of the STC displays. In Section III, a method is proposed to reduce perceived color breakup of these 2F2CF LCDs.

III. Backlight Primary Desaturation

The color synthesis procedure for a 2F2CF LCD is analyzed. In this paper, CIE 1976 $u'v'$ chromaticity coordinates are used [16], the algorithm can be applied in the same way in other color spaces, like CIE1931-*xy* chromaticity plane. Fig. 4(a) shows the color synthesis when displaying a white color in a 2F2CF LCD with yellow–cyan backlights and green–magenta color filters (corresponding to Fig. 1). Suppose the intensity of the backlight is tuned such that, when displaying a full white patch, the LCD is in fully transmissive mode in both fields and both subpixels. In the first field, backlight is set to yellow; through the green–magenta color filters, R and G components are passing, resulting in a yellow-like color; see point "F1" in Fig. 4(a). In the second field, backlight is set to cyan; through the green–magenta color filter, G and B color components are passing, resulting in a cyan-like field; see point "F2" in Fig. 4(a). If the eyes of the viewer are not moving, the light in the two fields are fused and a white color is perceived, as shown in Fig. 1. However, when the eyes of the viewer move, the yellow and cyan fields are displaced at the retina causing yellow–cyan color breakup at the edge of the white content, as shown in Fig. 3(a). Displaying other colors by adjusting the subpixel gray level, the color of the first field is varying along the R-G edge of the display gamut, and the color of the second field is varying along the edge G-B. Thus, in the TYPE-I configuration, the colors of the fields are always located in two edges of the gamut.

Fig. 4(b) shows another display configuration of green–magenta backlights and yellow–cyan color filters. In the first field, the backlight is green. Only green light is passing through the color filters resulting in a green field, indicated by point "F1" in Fig. 4(b). In the second field, the backlight is magenta; through the yellow–cyan color filters, red and blue color components are passing, resulting in a magenta field indicated by point "F2" in Fig. 4(b). White color is formed when fusing green and magenta fields if there is no eye movement. However, if the eyes of the viewer are moving, green–magenta color breakup is perceived at the edge of a white patch, as shown in Fig. 3(b). While the first field is always green, the second field can be modulated along the R-B edge of the display gamut. So there is also visible color breakup when displaying colors far from the point G and the edge R-B. Thus, in the TYPE-II configuration, one field color is fixed and the other field color is always located on the opposite edge of the gamut.

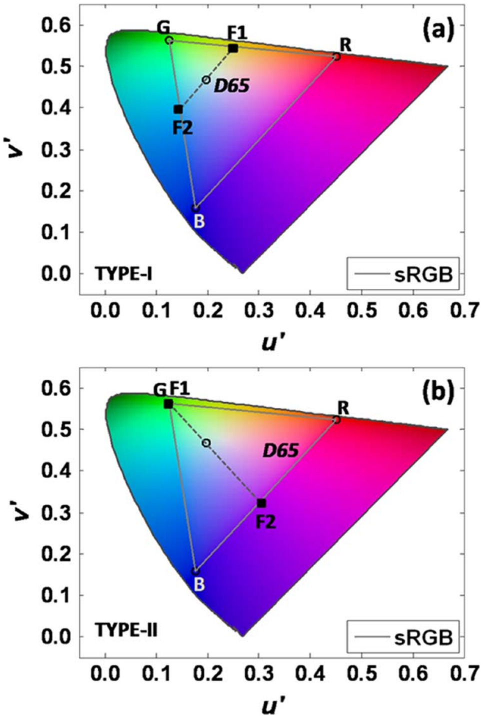
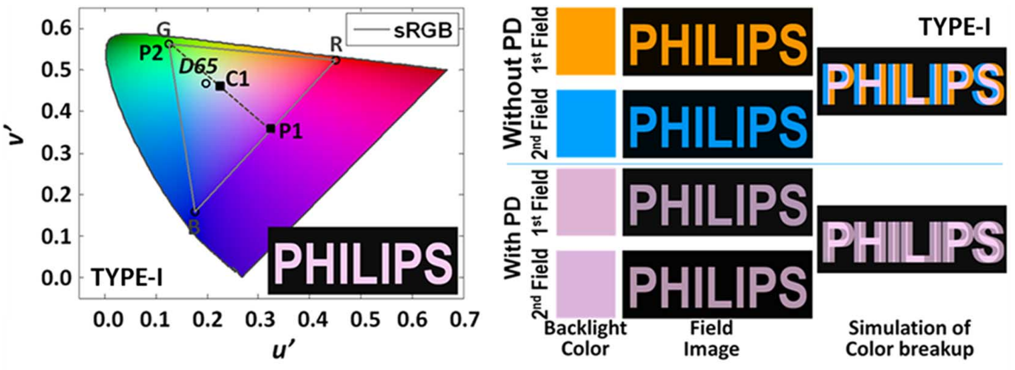


Fig. 4. Color synthesis when displaying a white color in a 2F2CF LCD. (a) With yellow–cyan backlights and green–magenta color filters (TYPE-I). (b) With green–magenta backlights and yellow–cyan color filters (TYPE-II).

In Section III-A, the paper will introduce an algorithm to tune the backlight color and intensity to suppress the perceived color breakup. Corresponding to the color filter configuration of TYPE-I and TYPE-II, there will be two different color synthesizing processes, so the paper classifies the discussion below in two categories of color filter settings.

A. 2F2CF With One Narrowband and One Broadband Color Filter

In either of the cases above, the color breakup is perceived because there are color differences between fields, like the color difference between the points of F1 and F2 in Fig. 4. If it is possible to reduce the color difference between fields, the color breakup can be suppressed or ideally even be eliminated. For example, when displaying white image content on a 2F2CF LCD with green-magenta color filters, if the backlights are switched ON at half intensity in both two fields and the subpixels are fully



(a) (b)

Fig. 5. (a) Color rendering on a 2F2CF LCD with green-magenta color filters (TYPE-I) when its backlight is set to be the same color in the two fields. P1 indicates the color formed by the magenta color filter in both fields, while P2 indicates the color formed by the green color filter. (b) Field images and the simulated color breakup when displaying one-color pattern on a 2F2CF LCD with PD and without PD.

ON in both two fields, two gray (half intensity white) fields are formed and a fully white image content is displayed. Obviously, in this case, the color breakup is completely eliminated. In fact, this approach works for the image content which has only colors on a line that goes through the G point of the color gamut.

See Fig. 5 as an example. When displaying the color of C1, assuming the backlights in the two fields are set to be the same, that is, with the new method, B component is added to the first field backlight and R component is added to the second field backlight. See Fig. 1(a). In both fields, R and B backlights component are well tuned such that subpixel magenta (with magenta color filter) forms the color of P1. By adjusting green and magenta subpixel, the colors along the line P1-G can be displayed. If the magenta subpixels are fully ON and the green subpixel is fully OFF, the color of P1 is displayed; if the magenta subpixels are fully OFF and the green subpixels are fully ON, the color of green is displayed.

Due to the freedom of the subpixel gray value, a 2F2CF LCD, with only one backlight color, is essentially a two primary (P1 and G) system. So G is also marked as P2 in Fig. 5. By tuning the transmission ratio between green and magenta subpixels, any color on the line P1-P2, like C1, can be displayed, while the color variation can be eliminated between fields, so no color breakup will be perceived. With such an approach, the original primaries of R and B are desaturated and merged to one color (P1), so we call this primary desaturation (PD). Fig. 5(b) shows an example. When displaying a one color pattern on a dark background, with PD backlight, the backlight settings, the field images, and the simulated color breakup are illustrated, compared with the original case without PD.

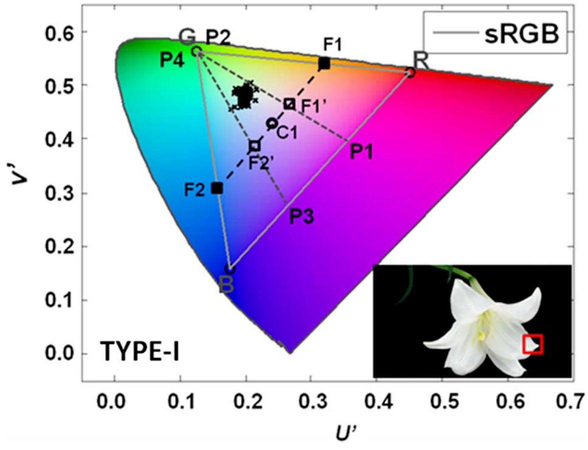


Fig. 6. Local primary desaturation for a 2F2CF LCD with green–magenta color filters (TYPE-I). P1 indicates the color formed by the magenta color filter in the first field, while P3 indicates the color formed by the magenta color filter in the second field. ("x": colors included in the area marked with red rectangular; "o": a target color as an example. "□": field colors after applying local primary desaturation; "■": field colors with original backlight).

Such an approach works for the image which contains only the colors located on one line going through the G point of the color gamut. A more realistic image may contain different colors. For example, even the red square part of the image "Lily" contains the colors as illustrated in Fig. 6. To render all of these colors, the backlights cannot be set to one color as in Fig. 5. However, they are not necessarily set yellow and cyan as a normal STC display illustrated in Fig. 1, which suffers from color breakup. However, to render all of these target colors in Fig. 6, it is not necessary to use R-G-B primaries. In fact, there is a smaller triangle of P1-P3-G which covers all of the target colors, so it is possible to use P1-P3-G as the new primaries for these target colors. Thus, in the case of Fig. 6, the backlight components R and B are tuned to the color P1 for the first field and P3 for the second field. Different from Fig. 1, with the new method, some amount of B component are added to the first field backlight and R component are added to the second field backlight, In the first field, the magenta subpixels display the color is P1, and the green subpixels display the color P2 (G). In the second field, the magenta subpixels display the color P3, and the green subpixel displays the color P4 (G). Both P2 and P4 are for the color of green, we may consider this as a three-primary display system. By adjusting the gray level of each subpixel and each field, all of the color inside the triangle P1-G-P3 can be rendered. Since there are green subpixels in both fields and the intensities can be modulated independently, P2 stands for green subpixel in the first field and P4 stands for green subpixel in the second field.

In fact, with such kind of backlight settings, all of the possible colors in the first field are along the line of P1-P2, and all of the

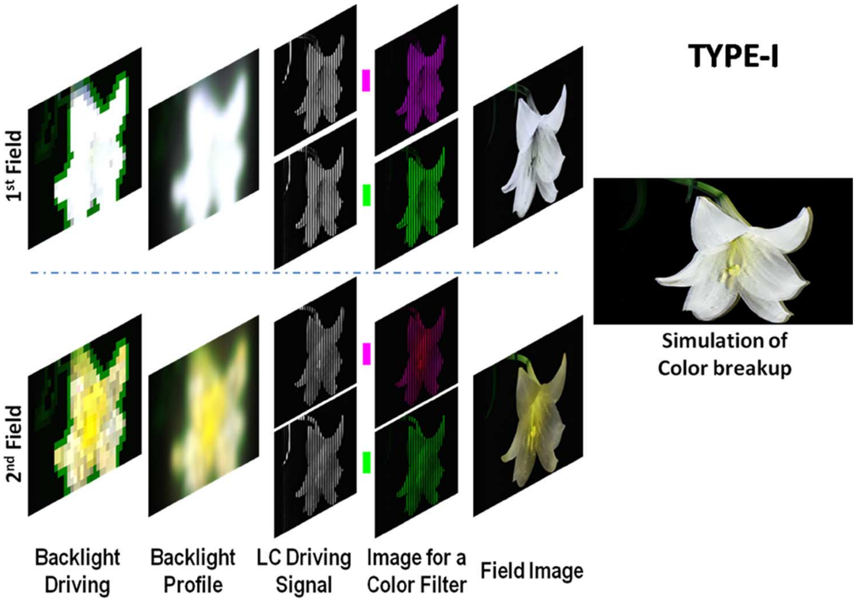
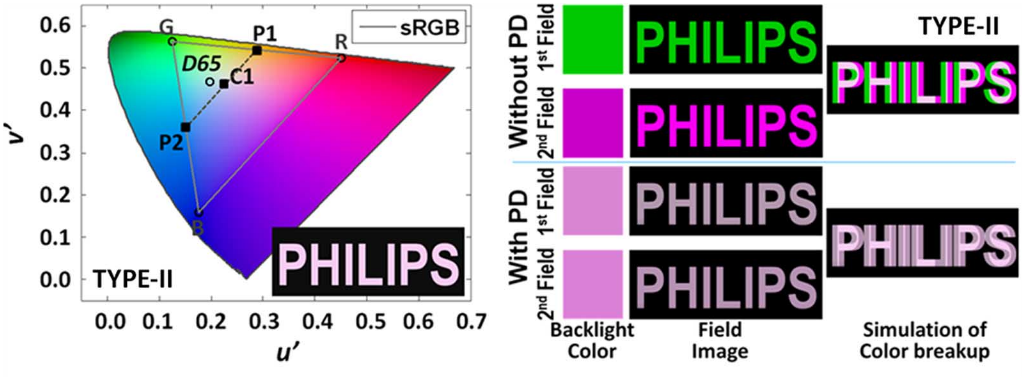


Fig. 7. Application procedure and the corresponding results for the 2F2CF LCD with green–magenta color filter (TYPE-I) combined with LPD backlight settings.



(a) (b)

Fig. 8. (a) Color rendering on a 2F2CF LCD with yellow–cyan color filters (TYPE-II) when its backlight is set to be the same color in the two fields. P1 indicates the color formed by the yellow color filter in both fields, while P2 indicates the color formed by the cyan color filter. (b) Field images and the simulated color breakup when displaying one-color pattern on a 2F2CF LCD with PD and without PD.

possible colors in the second field are along the line of P3-P4. Thus, it is possible to use F1′ and F2′ to synthesize color C1. Compared with the original case of F1 and F2, the color difference between fields is much less and so is the perceived color breakup. If the backlight is spatially controllable, like that used in LCD with local dimming per color channel [17], the color for each backlight segment can be adjusted according to the image content right on it, like in the way of Fig. 6. In the actual application, due to the spatial extending effect of the backlight, image content around the backlight segment is also taken into account [10], [11], [18], [19]. As shown in Fig. 6, the primaries P1 and P3 are desaturated compared with the original primary of R and B, and the desaturated primaries are determined based on local image content, so we call this approach as local primary desaturation (LPD). Since the backlight is spatially controllable, local dimming can be applied to reduce the power consumption as well [20]. Fig. 7 shows the application procedure and the results for a 2F2CF LCD with green–magenta color filters and local primary desaturation backlight solution. It is comparable with Fig. 1. Obviously, the color breakup in Fig. 7 is much less than that in Fig. 3(a). More comparisons are to be discussed in Section IV.

B. 2F2CF With Two Broadband Color Filters

LPD is also applicable for the 2F2CF LCDs with two broadband color filters, like that illustrated in Fig. 2. Fig. 8 shows the color synthesis and simulation results when applying primary desaturation for a one-color pattern on a 2F2CF with yellow–cyan color filters. As discussed above, in a normal 2F2CF LCD with yellow–cyan color filters, the green–magenta backlights are applied, so the color breakup between green and magenta field is perceived. However, if the backlight color is set to be the same, as shown in Fig. 8, when displaying the color C1, the backlight components of R and G are tuned to P1, while B and G are tuned to P2 in both fields. Thus, there is no color difference between fields and the resulted color breakup is completely eliminated. By adjusting the subpixel gray values, all colors on line P1-P2 can be displayed.

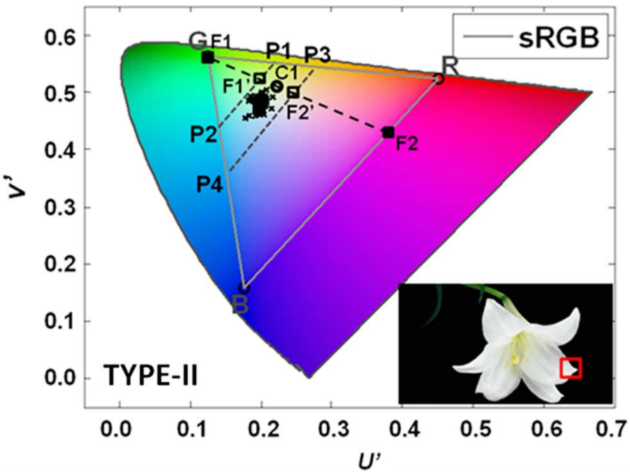


Fig. 9. LPD for a 2F2CF LCD with yellow–cyan color filters (TYPE-II). P1 indicates the color formed by the yellow color filter in the first field; P2 indicates the color formed by the cyan color filter in the first field. P3 indicates the color formed by the yellow color filter in the second field; P4 indicates the color formed by the cyan color filter in the second field. ("x": colors included in the area marked with red rectangular; "o": a target color as an example. "□": field colors after applying LPD; "■": field colors with original backlight).

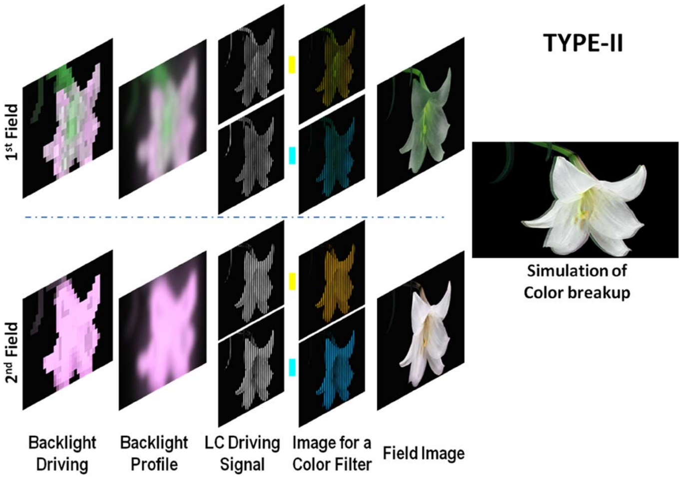


Fig. 10. Application procedure and the corresponding results for the 2F2CF LCD with yellow–cyan color filters (TYPE-II) combined with LPD backlight settings.

For a natural image, taking the image of "Lily" as example, Fig. 9 indicates all of the colors to render in the part marked with the red square. In a normal STC approach, the first field backlight color is green, and the second field backlight color is magenta, so it results in the perceived color breakup as shown in Fig. 3(b). In fact, to render all of these target colors, instead of R-G-B, the new primary of P1-P2-P3-P4 can be applied. In this case, the backlight components are well tuned, such that R and G form the color of P1 for the first field and P3 for the second field; G and B form the color of P2 for the first field and P4 for the second field. Different from Fig. 2, with the new method, some amount of R and B components are added to the first field backlight and G component is added to the second field backlight. Hence, in first field, the yellow subpixels display the color of P1 and the cyan subpixels display the color of P2. In the second field, the yellow subpixels display the color of P3 and the cyan subpixels display the color of P4. So it forms a four primary system and all the target colors covered within the region P1-P3-P4-P2 can be rendered [21]. For example, with the new backlight setting, to render the color of C1, F1′ and F2′ can be applied as the field colors, instead of F1 and F2 used in a normal 2F2CF LCD with green and magenta backlights. Obviously, the color difference between F1' and F2' is much less than that between F1 and F2, so is the perceived color breakup.

Fig. 10 shows the implementation procedure and results for a 2F2CF LCD with yellow–cyan color filters and LPD backlight. This corresponds to Fig. 2. Obviously, compared with Figs. 2 and 3(b), a 2F2CF with LPD backlight has much less color difference between field images and sequentially less perceived color breakup.

IV. SIMULATION RESULTS

A. Simulation Conditions

To evaluate the performance of a 2F2CF LCD with LPD backlight, simulation work was conducted and will be discussed here. As mentioned above, a LPD-2F2CF LCD consists of a 120-Hz LCD and a spatially addressable backlight. The 120-Hz LCD has two color filters, but there are several possibilities for the color filter settings. Comparable with the green–magenta color filters, it is possible to use red–cyan color filters or a blue–yellow color filters. With all of these three color filter settings, the light transmission ratio is improved by a factor of 1.5. Comparable with the yellow–cyan color filter, it is also possible to use a yellow–magenta color filter or a magenta–cyan color filter. With all three color filter settings, the light transmission ratio is improved by a factor between 1.5 and 3.0 (depending on color to display). Thus, the simulation was done for all six color filter settings within two categories to evaluate the performance of the LPD in suppressing color breakup.

For the application of LPD, an RGB LED matrix backlight is applied in this paper. The parameters of the backlight are set to be the same as that we applied in our previous study, which was verified in both measurement and perceptual experiment [10], [11]. That is, the backlight consists of 19 × 35 addressable segments and fit for a 32-in LCD with a resolution of 1360 × 768. Each segment has RGB LEDs. Due to light spreading effect, the backlight segments have overlap between each other. This is included in our simulation study. Fig. 11 shows the applied light spreading function which we measured on our demo system [10], [11]. Actually, the backlight overlapping effect was also indicated in Figs. 7 and 10. As mentioned before, primary desaturation is not only based on the pixels right in each backlight cell but also on the pixels around the backlight cell. On the other hand, the actual backlight profile is the accumulation of all of the backlight cell contributions, which is in general considered as a convolution of backlight driving signals and the point spread function of the backlight cell [8], [10], [11], [18].

Fig. 12 represents the four examples of the images we used for the simulation. "Lily" has very high contrast (between white flower and dark background) and large area of lowly saturated colors and some detail colors; "Parrot" has both highly saturated (like red, yellow, and green) and lowly saturated colors (like the gray background). "Train" has many details with high spatial frequency information. "Mountain" is characterized by

TABLE I
POWER CONSUMPTION COMPARISON FOR DIFFERENT COLOR FILTER CONFIGURATIONS. LPD IS APPLIED IN BOTH TYPE-I AND TYPE-II SETTINGS

		1F3CF LCD			2F2CF LCD: TYPE-I			2F2CF LCD: TYPE-II		
Color Filter Type		**Red-Green-Blue (RGB)**			**Red-Cyan**	**Green-Magenta**	**Blue-Yellow**	**Yellow-Magenta**	**Yellow-Cyan**	**Magenta-Cyan**
Backlight Setting		**White Backlight**		**RGB Backlight**	**RGB Backlight**					
		No Dimming	**Dimming**	**Dimming per Channel**	**Dimming per Field**					
Image	**Lily**	100%	42.7%	41.9%	34.2%	33.6%	29.7%	24.9%	21.4%	26.3%
	Parrot	100%	59.0%	50.3%	35.8%	35.3%	34.7%	27.7%	29.4%	33.6%
	Train	100%	99.8%	99.7%	93.1%	95.0%	86.0%	66.4%	67.8%	71.3%
	Mountain	100%	83.2%	78.7%	64.0%	64.8%	58.2%	44.6%	47.5%	53.4%

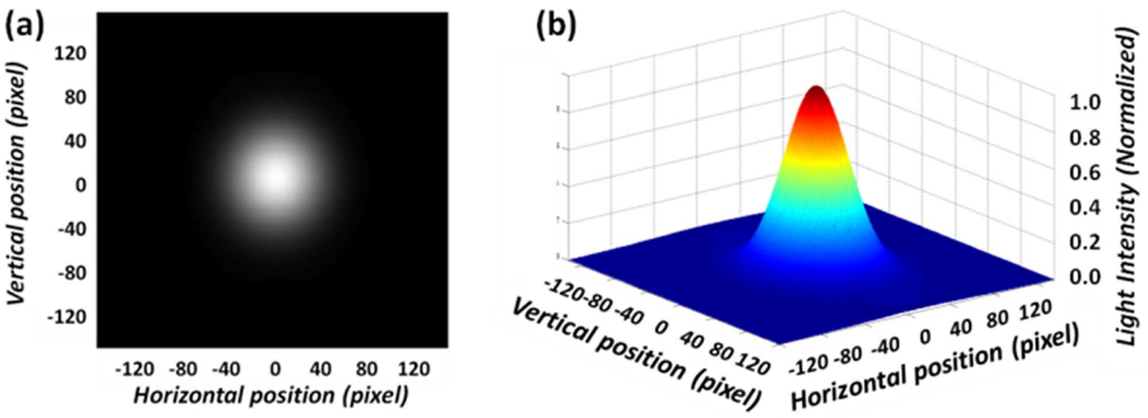


Fig. 11. (a) Spatial spreading profile for an active backlight cell. (b) Spatial spreading function for a backlight cell.

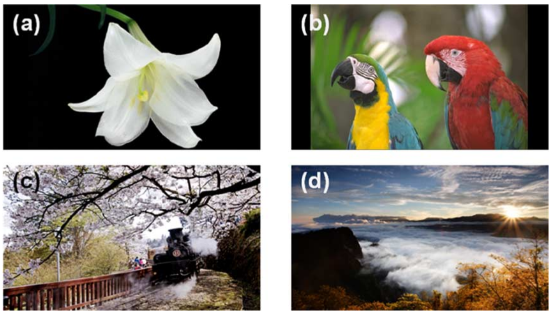


Fig. 12. Test Images used in the simulation study. (a) “Lily.” (b) “Parrot.” (c) “Train.” (d) “Mountain.” (Images of “Train” and “Mountain” are provided by Taiwan Tourism Bureau. http://tiscsvr.tbroc.gov.tw/en/index.htm.)

low spatial frequency and less saturated colors and low contrast content.

B. Simulation Results

Fig. 13 shows the simulation of color breakup for the test images with red–cyan, green–magenta, blue–yellow, yellow–magenta, yellow–cyan, and magenta–cyan color filter settings with LPD backlight (as shown in Figs. 7 and 10) and normal backlight (as shown in Figs. 1 and 2). The simulation is based on shifting the two fields which correspond to an eye moving w.r.t. a still image and summing the result [4], [8]–[11]. It is obvious that, for the image of “Lily,” without LPD, for the red–cyan color filter, there is serious yellow–magenta color breakup. When using LPD, the color differences between fields are becoming fewer and so is the perceived color breakup. The LPD algorithm works for different testing images and all of those possible color filter configurations. This is illustrated in the simulation in Fig. 13 and verified by the informal inspection by expert viewers.

Table I lists the power consumption of different color filter and backlight settings for a number of images. We have assumed power consumption to be proportional to the pulsewidth of the LEDs driven at a constant current level. Due to the higher transmission ratio and local diming backlight, for all of the test images, the power consumption was much reduced in these 2F2CF LCDs. As shown in the table, the actual power consumption is related to the image content. Due to spatial cross talk between the backlight cells and avoiding clipping, even for TYPE-I configurations, the actual power efficiency is not just 1.5 × higher compared with a conventional LCD with RGB color filters. However, even with the high intensity image of “Train,” whose dimming ratio is close to 1, but due to high light transmission of 2F2CF configuration, around 1/3 power is saved in TYPE-II configurations. It is also seen in Table I that TYPE-II configurations have 1 ×–2 × higher power efficiency, compared with TYPE-I configurations, even with LPD backlight settings.

V. DISCUSSIONS

LPD helps for color breakup suppression. Since it is based on the local image content, the actual performance is affected to the point spread function of the backlight and the number of backlight segments. In general, more backlight segments help for the primary desaturation, but they will increase the production cost. It is important to know how many backlight segments will be sufficient with that the perceived color breakup is acceptable or totally invisible. On the other hand, a narrow backlight

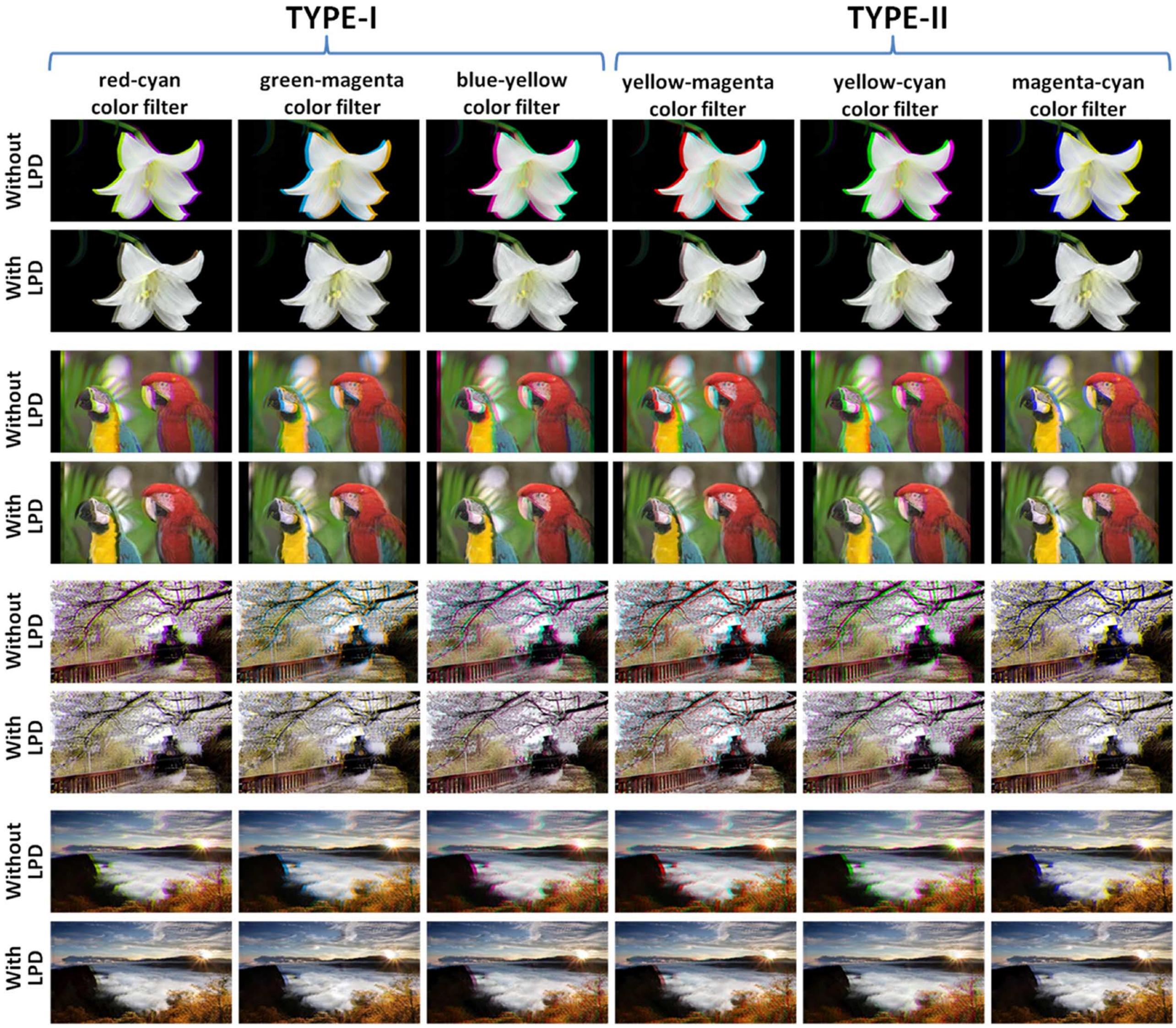


Fig. 13. Color breakup for different image contents and different color filter configurations, with and without LPD backlight scheme.

point spread profile is preferred for the application of LPD, because wider point spread profile requires more pixels included in the calculation for primary desaturation. Thus, the optimization for the number and point spread function of backlight could be valuable work before production.

As to the design of the color filter, for the TYPE-I configurations, the color breakup between yellow–cyan is less visible than the other two combinations. See Fig. 13. Thus, a green–magenta color filter could be preferred, that is, to reach the same level of color breakup suppression, a 2F2CF LCD with green–magenta color filter may need less backlight segments. Besides, a 2F2CF LCD may have green in both two fields, while green contributes most for the luminance, so it may reduce the possible 60-Hz flicker. However, since there is not a widely accepted color breakup measurement method, it is hard to say which setting will be actually preferred and how many backlight segments are sufficient. Many well-designed perceptual experiments can help. However, a widely accepted color breakup measurement method is on demand for the future work in sequential color display design.

VI. CONCLUSION

In this paper, an STC display with adaptive backlight, namely a LPD STC display, is proposed. Two fields and two-color filters (2F2CF) are applied to render different colors. A 120-Hz LCD with two-color filters mounted with a backlight consisting of a light-emitting diode (LED) matrix is used. The resulting light transmission is 1.5×–3.0× high and the resolution is 1.5× high, compared with a conventional LCD with the same subpixel number. With the adaptive backlight, the backlight colors are locally desaturated according to the local image content and subsequently the color differences between fields are reduced. Different configurations of backlights and color filters are simulated and discussed. The results show that the LPD STC efficiently reduces the perceived color breakup for all those possible STC display configurations.

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