Noble measurement method for color breakup artifact in FPDs

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Abstract

Motion artifact of Display devices has a huge interest from industries and users recently. Among those artifacts, color break up (CBU) is one of the key degrading characteristic in field sequential type displays. Unfortunately, there are no objective measurement methods for CBU. Here we introduce two different kinds of CBU and its measurement methods. The CBU characteristic of LCD, DLP, and PDP was measured and compared.

1. Introduction

Since Flat Panel Displays (FPD) are widely used in various application areas like entertainment, advertisement, office, etc. Users want higher display picture quality not only luminance, contrast, and color reproducibility but also motion performance. With this circumstance, the basic display quality characteristics are well defined and known for users, but most of this picture quality is mentioned in static image. Since the FPD TV market is spreading widely, quality and performance of video contents are just start to bring big concerns. Unfortunately most this motion artifacts are targeted to LCDs because of the slow response time which is known as a main cause for motion blurring phenomenon[1][2]. But the response time is not a big major cause for motion blurring, major cause for blurring is mechanism of sample and hold type driving in LCD display. Most Users experience four different technologies in TV application ; CRTs, LCDs, PDPs, DLPs. Color break up can be normally seen in DLP and some field sequentially driven LCDs. CBU is defined that the time sequence of colors which is constructing white color of the display are broken by some reasons then it produces color aberration visually in motion contents[3][4].

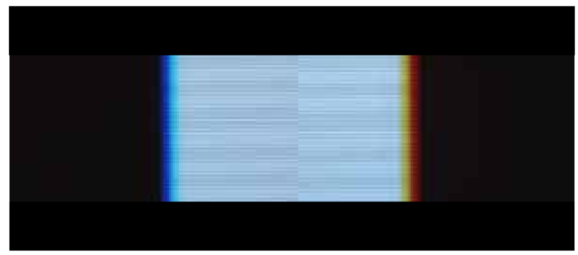


Figure 1. Example of color break up in field sequential displays

We can experience two different kinds of CBU. First is dynamic CBU and the other is static CBU. Those CBUs give a same amount of discomfort analogous to motion blurring. This is shown in Figure 1.
Most evaluation works of CBU have been done by doing human subjective test[5][6]. These results can be used as a reference to understand current CBU status but not engineering-wise objective data to develop better display performance. Eventually, evaluation of motion artifacts should be quantified then it gives users benefit to make a decision to select a right product.

2. Background of CBUs

CBUs could be classified into two different types, dynamic CBU and static CBU illustrated in Figure 2. Each CBU has a different mechanism to occur color aberration artifact.

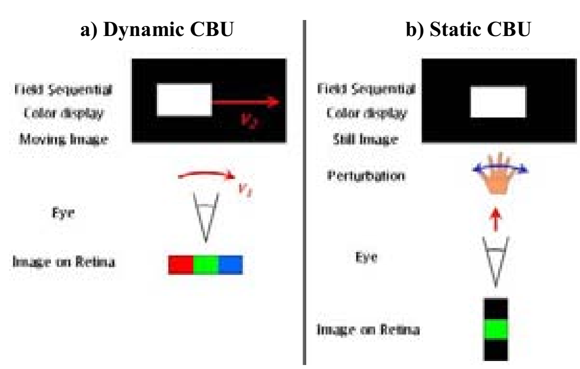


Figure 2. Two different CBU phenomena.

The dynamic CBU is mostly occurred at edges of moving objects on a field sequential display. The colors which consist of white (in here R,G,B) launch into the human retina sequentially. Because of the human after image characteristic, those sequentially input colors could be recognized as a white without color separation. When the RGB sequence is moved by certain motion vector, eyes are tracking the same motion vector smoothly. This is called Smooth Pursuit Eye Movement (SPEM) of human vision system for motion[1][7]. While this movement, the colors in sequence are broken on a retina. This is explained in Figure 3.

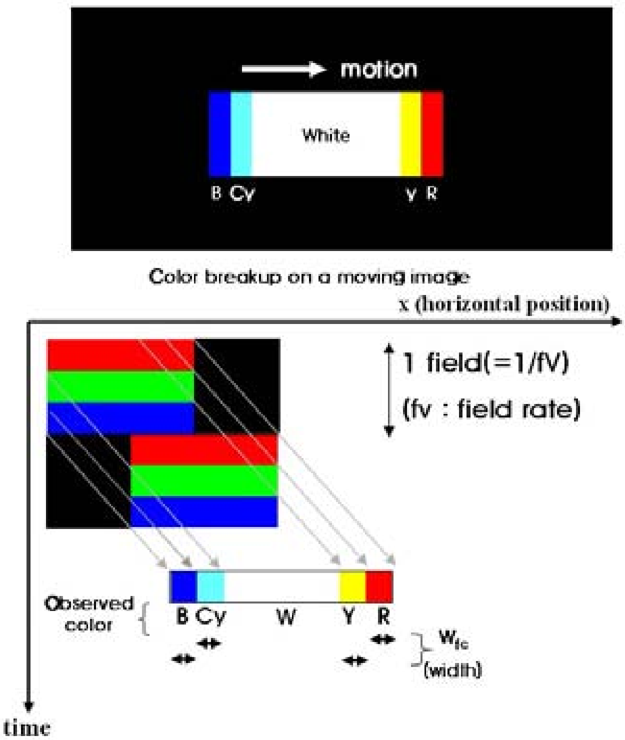


Figure 3. Perception mechanism of dynamic CBU

Broken colors are varied with colors of object and background and moving direction. This means dynamic CBU can be anticipated by knowing above conditions. There is one method to reduce dynamic CBU using Motion Estimation and Motion Compensation (MEMC). Unfortunately, most video contents are too complicate to take into account all motion vectors in a real situation. The other technique to reduce dynamic CBU is high speed driving which is widely used in DLP display.

The Static CBU can be occurred by abrupt perturbation which produces destructed color sequence to human vision system, mechanism is shown in Figure 4. This effect is much easier to be seen rather than dynamic CBU. Most users have uncomfortable feeling caused by this static CBU.

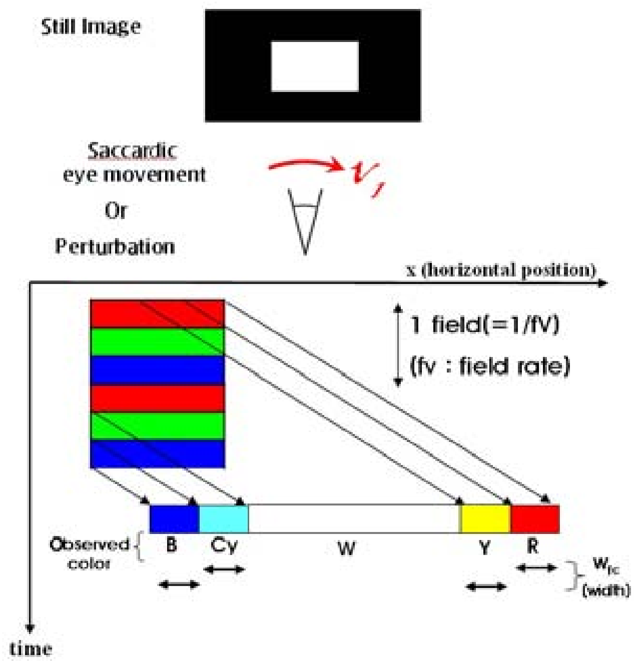


Figure 4. Perception mechanism of static CBU

In this case, there are no motion objects on the display but external moving perturbed objects whether it can be your hand or your friends. There is one more thing to make this happen. That is Saccadic eye movement. This eye movement can be easily experienced when you rotate your head or your eye fast. Those causes give a retina broken RGB color sequence. The static CBU is caused by originality of the color sequential display. Therefore, only way to reduce this artifact is to increase sequential speed.

3. Measurement methods

Two types of CBU need different measurement methods to mimic human vision system.

A) Dynamic Color Break Up

Measurement device should have a function of Smooth Pursuit Eye Movement (SPEM). Pursuit tracking camera system was used to measure dynamic CBU. This pursuit camera system consists of a rotation mirror to mimic eye movement and a color CCD. This device has been using widely to measure monochrome motion blurring in a LCD display, called MPRT-1000. This device has a monochrome CCD, while CBU measurement needs a color CCD. The captured image on a CCD is similar to the one on the retina. The cross section profile information from the captured image is analyzed into luminance and chromaticity information

There are several factors to be taken into account. The number of CCD pixels, display size, resolution, and pattern scroll speed.

The rectangle color box with a certain colored background is used for a test pattern. In Figure 3, a white box pattern was moved along in black background for instance. This shows a simple example of CBU test patterns, which can be varied by different foreground and background colors.

B) Static Color Break Up

The static CBU is strongly related to the color sequential operating frequency of the display. The higher operating frequency, the lower the amount of static CBU. One of the simple methods to measure this is to use a wheel chopper. This wheel chopper is used to use to modulate optical beams. Static CBU measurement result of a DLP rear projection TV is shown in Figure 5. Based on the number of color and kind of color information, amount of static CBU can be varied.

There are two factors to affect chopper measurement results. The slit size of the chopper and the spin speed are those factors. The narrower slit would be preferred.

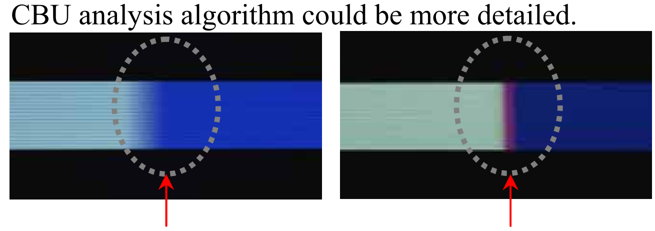
The operating frequency of the most field sequential display consists of a multiple of 10Hz (60Hz in NTSC, 50Hz in PAL). Therefore the chopper spin frequency should be 10Hz but the broken color saturation through the chopper is too low to be analyzed. The reasonable chopping frequency should be selected based on the basic vertical frame rate.

Once the chopper frequency was set to the display sequential operating frequency, the number of primary colors can be seen clearly.

Figure. 5. Example of static CBU measurement method using a wheel chopper.

4. Analysis Algorithm

Before analyzing CBU, one thing must be defined is terminology of CBU. How can CBU be defined? and what is CBU?. Literally color break up means a certain combined color is separated by some reason. Therefore, unexpected color can be seen. Although no CBU is detected with test pattern moving from white to red color, unexpected color might be seen due to existing some amount of blurring like in LCD displays. But this unexpected color is not due to color break up but color mixing perception by human vision system. This is shown in example a) in Figure 6. Blue and white mixed color might be seen in transition region but this is not a unexpected color caused by color break up. Example b) in Figure 6 tells about the typical color break up that magentish color should not be seen in transition region in normal displays. Therefore this can be called color break up phenomenon. Since definition of the color break up has been clear, CBU analysis algorithm could be more detailed.



Normal color transition (a) **Color break up transition (b)**

Figure 6.Example of two different color transitions

Normal transited color between two source color (color A) and destination color (color B) should be on the directly drawn line from color coordination of color A to color coordinate of color B in CIE 1976 u'v' chromaticity diagram. But broken colors are positioned along off-route from the direct line in normal transition. This is shown in Figure 7.

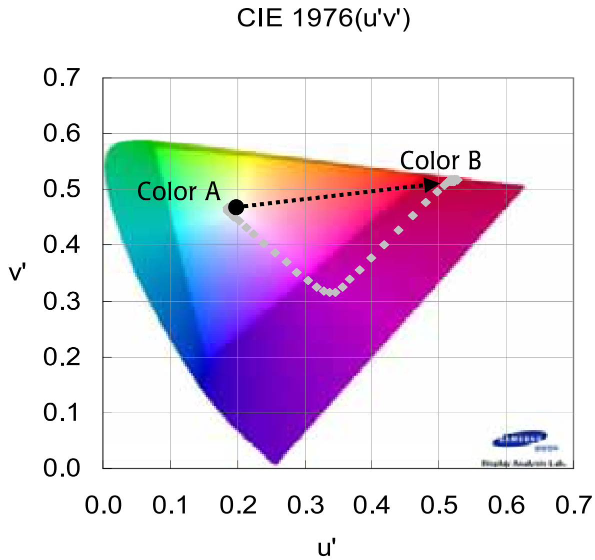


Figure 7. Color transition route in CIE 1976 u'v' UCS diagram

There are two things to consider about to quantify amount of CBU. One is brightness of the broken color and the other is width of CBU. The above chromaticity diagram just shows about the color coordinate information not with brightness which takes a great role to perceive color. This means that two broken colors having same chromaticity values but different intensity could be treated as a same amount of CBU. Generally, more brightly broken color recognizes much stronger even if the chromaticity value are the same. We have to choose perceptually uniform color space which takes into account both brightness and color. In here, L*u*v* space is chosen to analysis CBU plotted in Figure 8.

In L*u*v* space, the amount of CBU could be quantified by color difference metric which is known as delta E (ΔE). This color difference should be accumulated along the off-route color broken line. The red strait line in Figure 8 represents the amount of color difference caused by color break up in transition region. The number of points on the off-route line indicates the amount of color breakup width. The algorithm introduced in here considers the amount of chromaticity deviation, lightness and color broken width. Therefore, the level of CBU can be analyzed more precisely.

Several test patterns should be evaluated to represent CBU characteristics correctly. Then those were compared to human subjective test results.

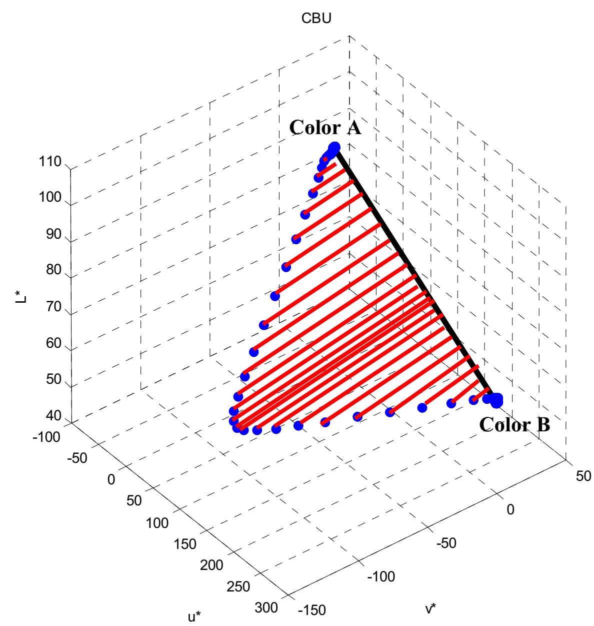


Figure 8. Color variation route in L*u*v* color space

5. Results

Dynamic color break up in DLP, PDP, and LCD have been tested and evaluated. Static CBU results did not be analyzed in this paper. Most people believe PDP does not have CBUs. Unfortunately, CRT and PDP which use phosphors to generate colors are having a color aberration artifact due to asymmetric delay of each phosphor response. This can be seen in black and white moving pattern easily and strongly. This artifact is not a result from color sequential operation but based on the color break up definition, unwanted color can be detected so, this is definitely one of the reasons of color break up artifact and classified as a dynamic CBU. This artifact of asymmetric delay of each RGB phosphor response is captured in Figure 9. The subjective test results gave a good correlation with the results of dynamic CBU measurement method shown in table 1.

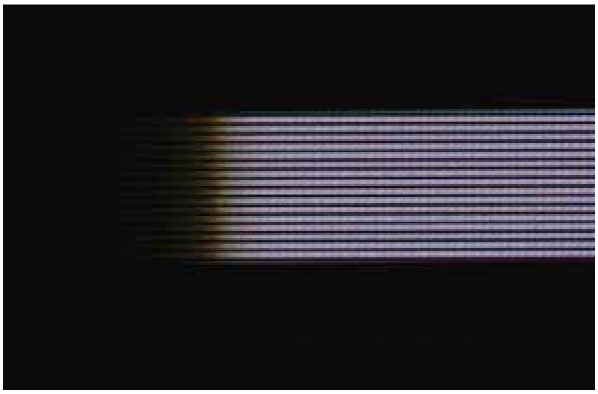


Figure 9. Color aberration artifact based on phosphor response delay in PDP

Table 1. The dynamic CBU measurement results in delta E

Transition color patterns	LCD	DLP	PDP
Black to White	0	20.5	14.3
Cyan to Red	0	9.4	25.2
Blue to Yellow	1.6	1.2	2.9
Magenta to Green	0	0	15.3
White to Red	0	8.2	22.7
White to Green	0	0	9.6
White to Blue	0	0	0

Overall color break up performance of DLP is better than PDP's. This is mainly caused by asynchronous phosphor response in PDPs. In blue to yellow transition color pattern, the amount of CBU of LCD is little larger than DLP's. This is very unexpected case and doesn't have any clear answer. This might be a measurement system noise problem and this will be needed to do more research to make an error free measurement and analysis method.

4. Conclusions

Noble color break up measurement method was introduced. The perceptually uniform color space, L*u*v* domain, was used to analyze color break up. Delta E metric was applied to quantify the amount of dynamic and static CBU. Three different display technologies were compared based on this CBU measurement method.

Color sequential display technology is migrated to LCD displays recently. LED backlight is operating sequentially therefore no color filter is needed in this color sequential display. In color sequential displays, one of the most significant drawbacks is color break up artifact. This first color break up measurement method can be used to understand current quality level of the display and give a proper comparison between competitors.

There are still several motion related artifact in displays. Among those artifacts, a few motion artifacts have been studying to develop measurement method. With a endless effort of experts from various field, this work could be done successfully. Therefore, users could be given better display quality throughout the noble effort of developing new metrology.

4. Acknowledgements

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