Color Shifting in High Dynamic Range OLED Displays†

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Abstract

Displaying High Dynamic Range (HDR) video on an organic light emitting diode (OLED) display aged for 1200 hours produced noticeable color shifting in the HDR mode playback. The experiment and measurements on commercial high end OLED panels from two different companies prove the damaging effect and introduces a proposed measurement system to quantify the color shift in aged OLED panels.

Author Keywords

Image Retention; HDR; OLED aging; Display metrology.

1. Introduction

The work presented in [1], detailed an in-depth controlled aging experiment of sixteen 55-inch OLED panels. These displays were operated at maximum brightness with panel protection measures turned off. These displays were cycled on for four hour-intervals with an hour turned off. After 1200 hours of continuous aging in Standard Dynamic Range (SDR) mode, the resulting effects of the aged subpixels in HDR mode were studied.

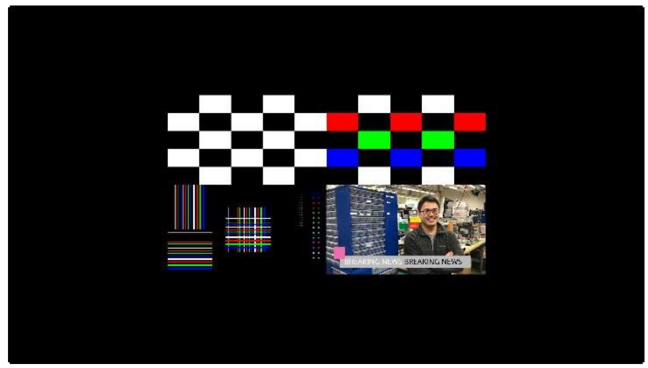
Currently, displays capable of rendering HDR video have gained popularity as a next generation technology. The HDR displays on the market have demonstrably greater bit depth, luminance, and color range than the SDR displays of the past [2]. While the quality improvements of HDR video combined with the inherently high contrast and brightness of OLED displays are an optimal pairing [3][4], OLED lifetime issues have not been studied in an HDR test environment.

In this work, we build upon the work presented in [1] and [5] by building an HDR testbench for preaged OLED panels. We will demonstrate the color and luminance shifting changes in the aged display in HDR viewing mode. Our methodology and test parameters will be detailed and proposed as a simple method to analyze OLED displays in HDR mode.

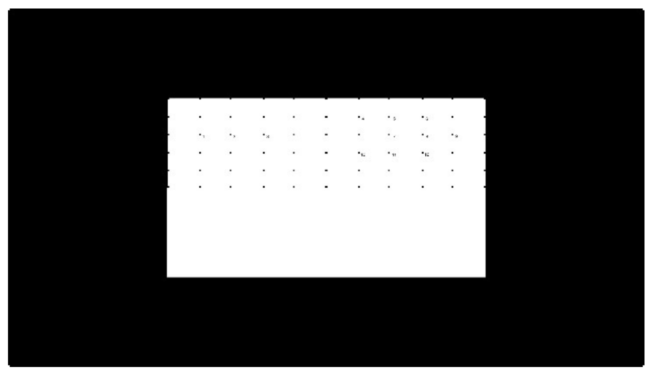
2. Methods

After 1200 hours of aging detailed in [1], two televisions, Sony OLED XBR55A8F and LG OLED55B8 were received. These displays were aged in SDR mode, with the burn-in target shown in Figure 1a. Once a week, luminance and color measurements were taken using the measurement target shown in Figure 1b. To repurpose these targets for our HDR testing, both images in Figure 1 were made into an HDR video file in the HDR10 standard. HDR10 was chosen as it is currently the established default standard for many 4K video applications. As opposed to Dolby Vision, HDR10 does not require licensing fees for its hardware standards [3].

The HDR10 videos were created in Premier Pro and adjusted using the Lumetri Color tools to make the target in HDR format. The tone was adjusted in the basic color correction, and the plain white image was made the brightest. The newly created targets were downloaded and exported as High Quality 2160p 4K MP4. To verify the newly downloaded videos were HDR10, the targets were uploaded to YouTube. The uploaded videos were tagged with "HDR" proving that the videos were HDR. Additionally, as a second check, both the HDR image and the SDR image were uploaded onto an HDR compatible display and the luminance was measured in the same location for both targets using a Konica Minolta CA210 color analyzer. On one of the LG OLED, one of the white checkerboard spots on the HDR version of Fig 1a was measured as 605 nits in HDR mode and only 284 nits in SDR mode.



(a)



(b)

Figure 1. a) Burn-in Target used for both SDR and HDR modes **b)** Measurement Target used for both SDR and HDR modes.

The substantial difference in luminance is a clear indicator that HDR mode was working.

As a final check, the same white checkerboard spot in Fig 1a. that was measured with the colormeter was measured under a macro lens of a Canon DSLR camera. The pixels were photographed at the exact same location set by a standing tripod. Figure 2 shows the difference in subpixels for the HDR (2a) and SDR (2b). As expected, the HDR subpixels employed all three RGB primaries and the white subpixel found in OLED displays. The SDR mode did not use all the subpixels, causing a much dimmer image at full brightness.

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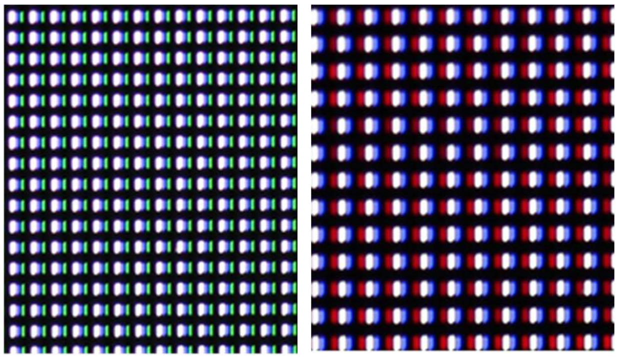
To project the HDR videos onto the display a new method was needed. During the burn-in experiments, USB sticks housed the SDR targets for each television. However, HDR is not able to be displayed from a USB source. To solve this, an Amazon Firestick was used. The Firestick was connected to the display under test via HDMI connection. A saved MP4 video file of both the aging target (1a) and the measurement target (1b) were uploaded to the available memory. As opposed to streaming the video on YouTube, this was done to keep all the test targets offline in the event of network failure. A simple block diagram of the test set up is shown



(a) (b)

Figure 2. a) Microscope image of panel in HDR viewing mode **b)** Microscope image of panel in SDR viewing mode.

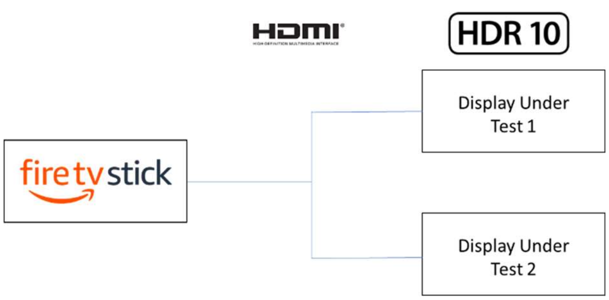


Figure 3. Block diagram of HDR measurement setup.

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3. Measurement Setup

Once the HDR measurement targets were properly placed on the televisions, both displays were set to a standard setting. This is done to remove as much of the variables introduced by the differences between the different TV software and user interfaces. Before any measurements were taken the TV panel characteristics were set. Most importantly, the TVs were set to a standard viewing mode with pixel shift, local dimming, and any power saving features turned off. Additionally, the brightness was set to its max setting. While there is still some room for variation in the measurements between TVs, all collected data values will be normalized to baseline measurements performed that day. Thus, having variables in the data collection and TV parameters will not change drastically from one measurement to another. To make things easier to read, a summary of the TV panel characteristics is shown in Table 1. These parameters were also set on the Firestick's display options.

Table 1. Display Parameters for Burn-in Experiments

TV Panel Characteristics	State Before Measurement
Viewing Mode	Standard
Pixel Shift	Off
Panel Brightness	Max
Local Dimming	Off
Low Power Mode	Off
Screen Saver	Off

To reduce damage to the OLED displays, both the LG and Sony TVs are equipped with screensavers that are unable to toggle off. This becomes a nuisance when taking measurements on the displays. To counter this, the same setup from [1] was utilized. Through the RS232 serial port on the TVs, we can digitally mimic a button press every minute so that the TVs never enter screen saver mode. On the Firestick, screen saver mode was easily turned off.

When performing the measurements, the CA210 colormeter is placed in a box on the measurement target (1b) corresponding with the color LED one wants to measure. The burn-in target (1a) has areas of RGB burn in (upper right-hand corner of 1a) and white (all RGB and W subpixels in HDR mode) burn-in (upper left-hand corner of a). When studying the affects of pixel aging in HDR mode, we can see how each color subpixel is affected. To maintain uniformity, all measurements are taken in reference to a neighboring black (no burn-in, all pixels off) area.

4. Results and Analysis

Before beginning to analyze the data, both the LG and Sony OLED displays were given a codename. This allowed for ease of use when working with 16 different displays. The two showed in this work are the all-pixel burn-in displays called 2W for the Sony and 3W for the LG. This information is shown in Table 2 as an easy reference.

Table 1. Reference Designators for TVs Under Test

TV Model Number	Designator
Sony OLED XBR55A8F	2W
LG OLED OLED55B8	3W

The first measurement that was taken on each of the displays was color. Upon switching the SDR mode to HDR the first thing that became apparent was that many of the colored pixel areas on the HDR version of Fig 1a were visibly discolored. This result was most notable in the white areas of the lower right-hand corner. The "breaking news" image was placed on the burn-in target to mimic real world usage such as a person leaving their TV on with a news broadcast playing in the background. The difference in this image between the SDR viewing and the HDR viewing is clearly shown in Figure 4. The areas of white in the background of the photo and in the model's face are not at the white point. Unlike the white in the checkered test areas, the pixels in the "breaking news" section represent a more diverse color array with whites at different xy coordinates and luminance values. The discrepancy in color when translated to HDR is caused by the aging of the RGB sub pixels that were not active in the SDR burn-in. Thus, through aging the RGB subpixels, the addition of the white unaged pixel drastically shifted the colors. With this logic, it is easy to see that the most common victims of color shifting were in the HDR white areas. This is also apparent in Figure 4, as the blue shelf next to the model remains roughly the same color in both SDR (4a) and HDR (4b) images.

(a)

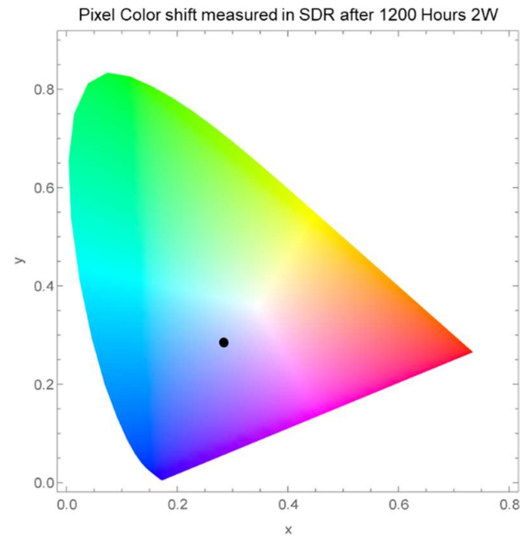
(b)

Figure 4. Color difference in SDR and HDR mode of the same image **a)** SDR **b)** HDR

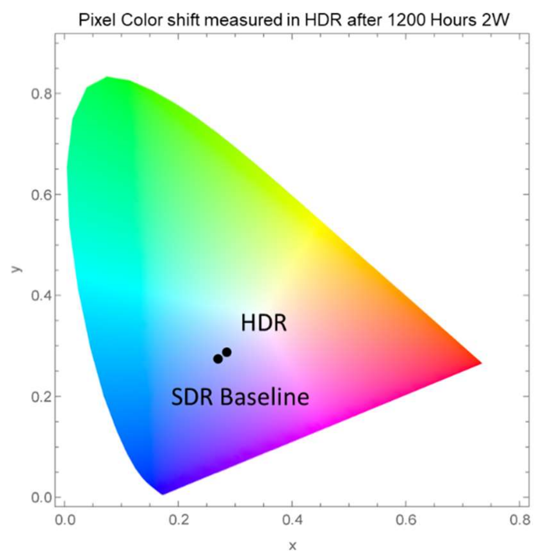
To characterize this color shift, the color of one of the white pixel squares (Fig 1a) in the top left quadrant were measured before aging (color at 0 hours) and after (color at 1200 hours) for both the SDR and HDR measurement targets. The results for 2W are shown in Figure 5. The color coordinates were plotted on the CIE 1931 colorspace. The HDR and SDR points are labelled on the graph.

Figure 5a shows the comparison of the baseline white color measurement that was taken before any aging had occurred with the same section after 1200 hours of aging. Looking closely at the image, both dots are essentially overlapping. In SDR, over the course of 1200 hours there was no noticeable color shifting on TV 2W.

Interestingly, when the SDR baseline color measurement was compared to the 1200-hour aged HDR target, the measured color for the HDR mode diverged from the SDR baseline. While the change was still rather subtle, two distinct points appear. As expected, the SDR baseline stays in the same location, however, the HDR color point shifted towards the green/yellow area of the curve. At first, this result seems unexpected. However, the addition of the extra white subpixel to the existing RGB aged pixels heavily shifted the color point.



(a)



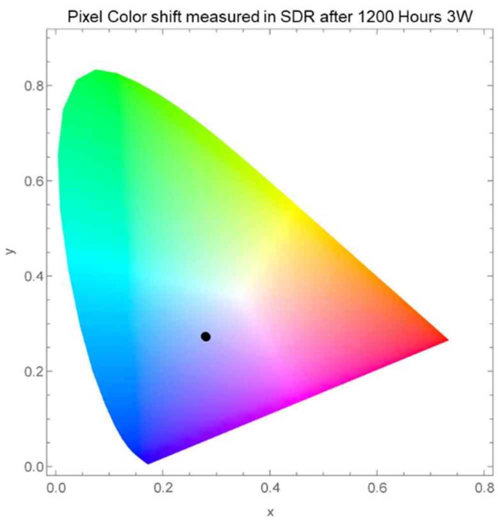
(b)

Figure 5. Color shift measurements after 1200 hours of aging on TV 2W. a) SDR baseline vs SDR aged measurement. Color remains virtually the same. b) SDR baseline vs HDR aged measurement. Color shift is more noticeable.

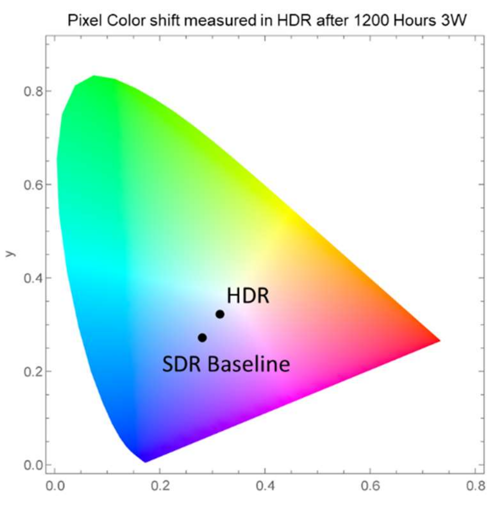
Similarly, the color shift in TV 3W was shown in Figure 6.

showed the same effect. Figure 6a showed the SDR baseline color compared to the SDR aged color. As expected from TV 2W, the color did not show a noticeable change in color. Both points are indistinguishable on the graph. However, just like with TV2W, TV 3W showed a sizable change in color when measured with the HDR target. While the mechanisms for this discrepancy are the same for 3W as for 2W, it should be noted that the color shifted much further on TV 3W than 2W.

The color change in 3W is so evident that it was easily visible upon inspection of the HDR target. Figure 4 was taken on TV 3W, and the color shifting is very exaggerated. From the color in Figure 6b, the HDR color shifted very far to the yellow/green spectrum This made the whites parts of the targets take on a yellow or gold hue, very similar to the color shown in Figure 4b.



(a)



(b)

Figure 6. Color shift measurements after 1200 hours of aging on TV 3W. a) SDR baseline vs SDR aged measurement. Color remains virtually the same. b) SDR baseline vs HDR aged measurement. Color shift is more noticeable.

5. Conclusion

In conclusion, this experiment showed color shifting in an aged OLED display operating in HDR mode. This is important because HDR capabilities are becoming an important benchmark in OLED display quality. Having a method of diagnosing an OLED panel's ability to perform high quality HDR video is directly related to the aging on its individual subpixels. This work showed that more aging on the pixels causes a large shift in color. Future work for this project includes analyzing the affects of aging on RGB specific burn-in and studying the differences in gamma curves for the SDR and HDR measurement targets

6. Acknowledgements

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7. References

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