Numerical Simulation of Halo Artifact Caused by Local-Dimming and its Validation on AMOLED Displays

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Abstract

Halo is the most severe artifact associated with locally dimmed LCDs for automotive HMIs. This paper is about the influence of backlight design on Halo. Since prototypes of backlight units are a costly operation, light leakage surrounding a bright spot may be simulated for different backlight units based on the SSC algorithm and visually evaluated on an AMOLED display.

Author Keywords

Halo artifact; local dimming; FALD; FALD simulation; backlight simulation; light leakage; automotive HMI; AMOLED; color conversion.

1. Introduction

Automotive application is a promising field for local dimming technology. At the same time, it poses high demand for local dimming of LCDs. For achieving high performance, the backlight unit (BLU) is construed as full array leading to the acronym FALD for full array local dimming. While the contrast ratio may significantly be lifted, Halo artifact may appear due to the high contrast of HMIs under night drive conditions. (1) The undesirable Halo is a result of a dimmed Backlight Unit (BLU) and a phenomenon which is called light-leakage (LL), that is an expression for a non-ideal off-state of the LC-panel. The Halo artifact depends highly on the BLU arrangement (3). As it is also a natural phenome and can never be completely eliminated from local dimming, it is always a trade-off between Halo perception and cost of a BLU like number of LEDs used. Further, not only local dimming produces a Halo artifact, but also a similar phenomenon is known in human perception. If a bright content is surrounded by a dark area, the human eye cannot resolve and scattered light on the retina is perceived as Halo. That implies if the BLU produces less Halo as the explained eye Halo, the goal is achieved. Thus, a simulation kit is helpful which can calculate the light leakage of a locally dimmed image and make the numerical results visible to subjects of user tests.

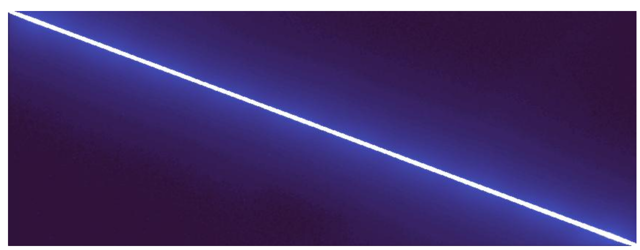
2. FALD Simulation Program

Based on the SSC Algorithm a simulation program, which is also able to simulate different backlight structures, has been evolved. To ensure this tool is simulating a real display with physical outputs, the following color conversion model (1) is applied.

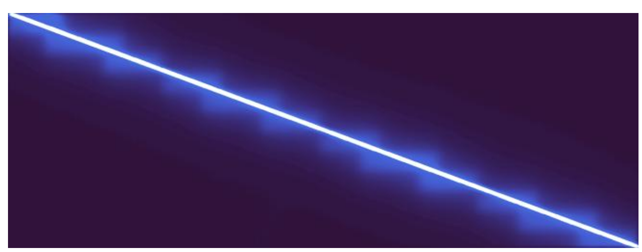
$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = D_{BL} \cdot \begin{pmatrix} R_X & G_X & B_X \\ R_Y & G_Y & B_Y \\ R_Z & G_Z & B_Z \end{pmatrix} \cdot \begin{pmatrix} t_r \\ t_g \\ t_b \end{pmatrix} + D_{BL} \cdot \frac{1}{CR} \cdot \begin{pmatrix} X_L \\ Y_L \\ Z_L \end{pmatrix} \qquad (1)$$

The tristimulus (XYZ) of a pixel can be calculated by the equation above. The color conversion matrix as well as the light leakage X_L, Y_L, Z_L are property of the display, as well as the contrast ratio CR. t_r, t_g and t_b are transmission values of the subpixels that are normalized linearized gray values. At the pixel compensation step of the FALD processing, gray values of an image may be altered to meet the luminance objective. D_{BL} stands for a normalized backlight intensity which is in case of local dimming no longer position invariant, but individual for every pixel and is calculated by the LD simulator. For areas with low gray values, D_{BL} may be much lower than the backlight without dimming (e.g. 100%). CR may be varied for analyzing the influence of the contrast ratio on Halo. Thus, pixelwise tristimulus (XYZ) of a locally dimmed image on a specific LCD are determined. It is worth mentioning that luminance causing Halo artifact is several magnitudes smaller than the luminance for white and dependent of CR.

For validation two 12.3" LCD prototypes with two different LC glasses and two different BLUs respectively have been used. One BLU consists of 80X30 LEDs with Lambertian characteristic and CR is 1250. The other BLU comprises 32X12 LEDs and CR is 1580. For each LED, a cavity structure is made.



(a) 80x30 Lambertian BLU



(b) 32x12 BLU with cavities

Figure 1: Halo of a diagonal line

In Figure 1, a critical case highlighting Halo artifact is shown. A thin diagonal line is displayed on the two prototypes. Halo is clearly visible on the BLU with 2400 LEDs (Figure1a), while not being negatively perceived by most viewers. On the contrary, Figure 1b) shows the same line on the BLU with cavity structure. This Halo is perceived as a disturbing artifact.

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3. Displaying Halo Simulation

To enable visual evaluation of the FALD simulation results, an AMOLED display placed in a dark chamber is provided as shown in Figure 2) on the left. This way, very low leakage may be produced and perceived.

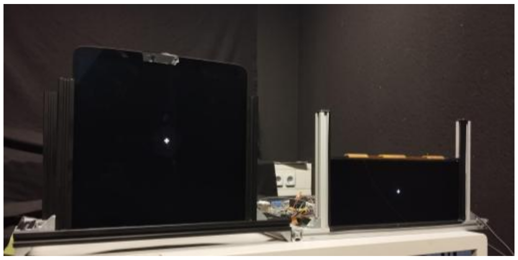


Figure 2: displays for user tests

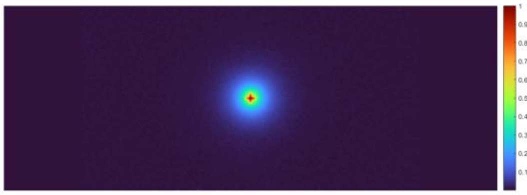
The tristimulus values of each pixel are firstly simulated by FALD simulation for the LCD shown in Figure 2 right. For providing proper image data for AMOLED, a further color conversion is needed. Therefore the AMOLED display was characterized. Its tristimulus (XYZ) are measured in dependence of linearized and normalized RGB-values lv_r, lv_g and lv_b. The electro-optical transfer function (EOTF) for an AMOLED pixel is described by equation 2.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{OLED} = GF \cdot \begin{pmatrix} R_X & G_X & B_X \\ R_Y & G_Y & B_Y \\ R_Z & G_Z & B_Z \end{pmatrix}_{OLED} \cdot \begin{pmatrix} lv_r \\ lv_g \\ lv_b \end{pmatrix} \qquad (2)$$

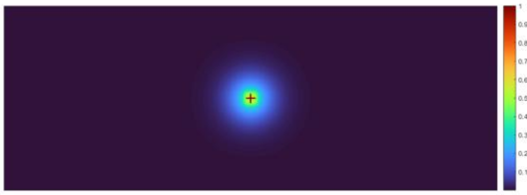
AMOLED effectively features an ideal EOTF. Due to this nature of AMOLED, the light leakage part of equation 1 is obsolete. GF may be a global brightness factor and may be set to unit.

For simulating Halo on AMOLED, the processing is in the opposite direction. FALD simulation delivers tri-stimuli (XYZ) which are now the input, while RGB image data for AMOLED are the output of this processing. This means that the color conversion matrix of AMOLED is inverted. The outputs are the linear gray values. By applying the inverse gamma function of the AMOLED display, RGB gray values for the simulated image comprising possible Halo artifact may get available. These two processing steps, from FALD simulation to XYZ color-space and back from XYZ to AMOLED-RGB will make a visual evaluation feasible.

A challenge is the limited gray scale (8 bits) of this AMOLED. Details of very dark gray values may get lost. Smooth transition may be displayed like contours. For a better representation of Halo on an AMOLED, FRC and ED are to be applied to gain two more bits. This way, 10 bits are available to display a vast dynamic range needed. In order to ensure a similar perception, the content shown on both devices is scaled to a same pixel-density.



a) measurement



b) simulation

Figure 3: Comparison measurement vs simulation

As Figure 3a) and b) shows, a measurement is compared with the simulated image. Both are perceptively similar and have similar shapes. The measurement has been processed by a Gaussian filter for noise reduction.

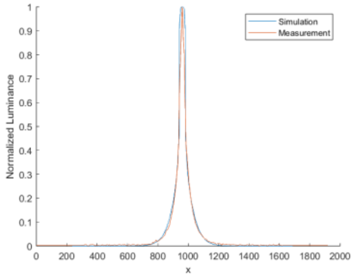


Figure 4: a simulated and a measured LSF

In Figure 4, a horizontal central cut through both, measurement and simulation are plotted. The shapes and appearances are similar. The important part for Halo is around the image content. The simulation fits well in this area. Those considerations show that a user test with this simulation program shown on an AMOLED device may be a reasonable and practicable approach.

4. Halo Simulation Kit

The test bench for Halo user tests is shown in Figure 2. The FALD simulation program as well as the image processing for displaying on an AMOLED enable user tests for various BLUs. Visual evaluation with emphasis on Halo may be conducted.

In addition to it, specific test patterns are needed which should be relevant for automotive applications and allow measurement with standard instruments (2).

For this purpose, a working group of DFF (German flat panel forum) has proposed few patterns., like in Figure 5 exemplarily shown. The triangle covers 3x3 dimming zones, whereas the cross is smaller than one dimming zone and is varied in position for being directly on an LED center or exactly between 4 LEDs.

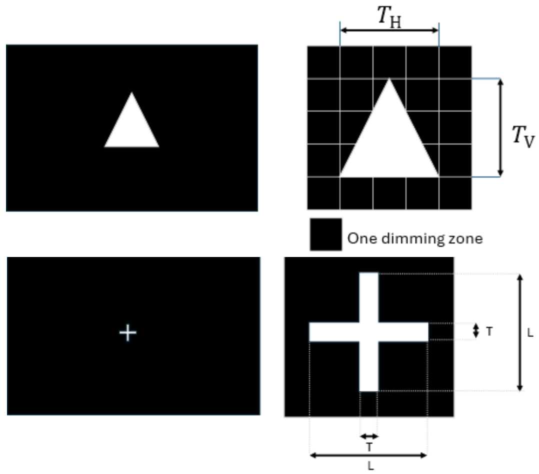


Figure 5: DFF Triangle and Cross

These and some further patterns may be simulated for many different BLU arrangements. The simulation results of these test patterns will be converted into images on an AMOLED for visual evaluation.

Further, the AMOLED and the LCD have different pixel densities. This is equalized by resizing the simulated Halo image to a same physical size as that on the LCD. A simulation kit is setup and comprises simulation program and displaying on an AMOLED.

Images displayed on AMOLED may contain a test pattern in two fashions, e.g. one pattern without Halo simulation and one pattern with Halo simulation in left/right part of the display. Although original image data have no Halo artifact, Halo may still be perceived due the human physiology and is called eye Halo. The difference between simulated FALD image and original image may be evaluated by subjects.

5. User Tests and Results

Since Halo is an artifact which is perceived differently by individuals, a user test was performed. Both, our simulation kit and the real Halo are aimed to be evaluated. This is why the user test is separated into two steps: a) validation of the simulation; b) simulation-based analysis of BLU impact on Halo.

In the first step, a real prototype with 384 LEDs and cavities was compared with its simulation on AMOLED, as shown in Figure 2. The subject looks on both simultaneously and gives rating to the operator. The scale of rating is from 1 to 5 (very good to bad). Figure 6 shows those first results for the diagonal line, which is seen as the most critical test pattern. When comparing the AMOLED simulation with real FALD, the ratings are similar. The simulation results deliver slightly worse rating than the FALD prototype. This means that this simulation kit is adequate but may be improved in future. Further, in this figure, a comparison to a simulated Lambertian LSF is given, which is rated slightly better than the rectangle one. Our reference is the AMOLED device, which is validated by the user as perfect.

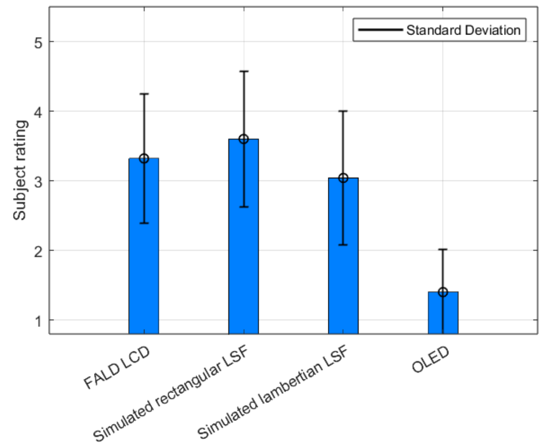


Figure 6: Validation of simulation kit

It may be concluded, that our simulation kit was accepted by the viewers and can be used for further tests.

Thus, further user tests are solely based on the simulation kit and shall exemplarily exhibit an analysis, in this particular case the impact of BLU design on Halo perception.

Besides the diagonal line, cross and triangle, further test images like HMIs, abstract HMIs and single-color test images for pure R, G, B and an automotive orange in (R, G, B – 247,174,20), are shown to subjects. They are collected in Figure 7.

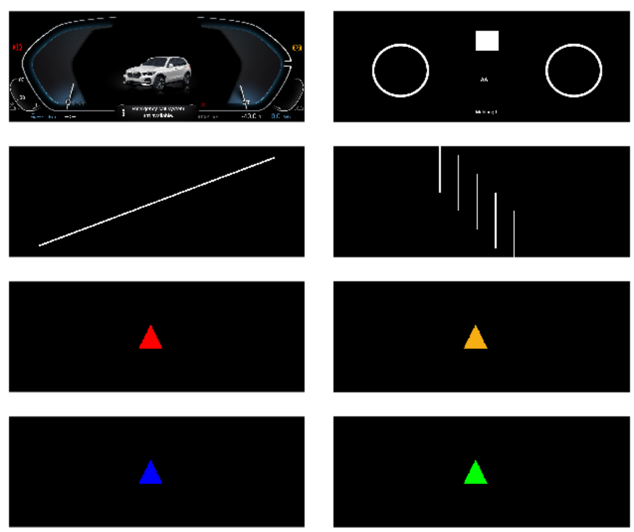


Figure 7: Test images

Figure 8 is to get a first impression of Halo perception. The 384 FALD prototype is simulated and compared with the real. Images with and without Halo are shown on the AMOLED. As shown, in some cases, the Halo artifact is rather critical, in others imperceptible. Among other things, the perception of halo also depends on the contents of HMI. Thus, the simulation kit may be also a tool for HMI design which delivers numerical results like power saving and contrast enhancement by FALD as well as evaluation of the Halo artifact arisen.

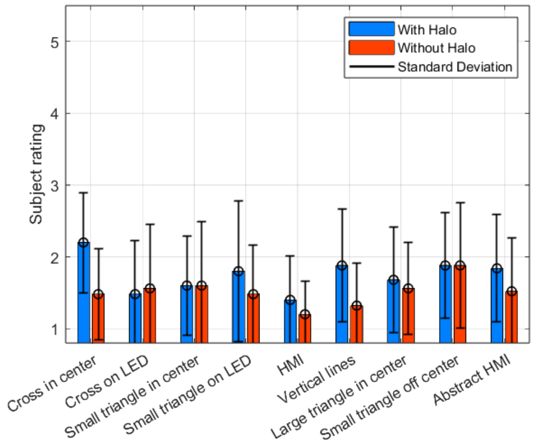


Figure 8: Halo vs AMOLED

In a further test, the influence of color on Halo has been considered in Figure 9. As to be expected, the artifact is more critical for the red color, since this color is perceived by humans as the darkest color and so, the difference between the desired image luminance and light leakage is reduced. In a future user test, a combination of colors shall be explored.

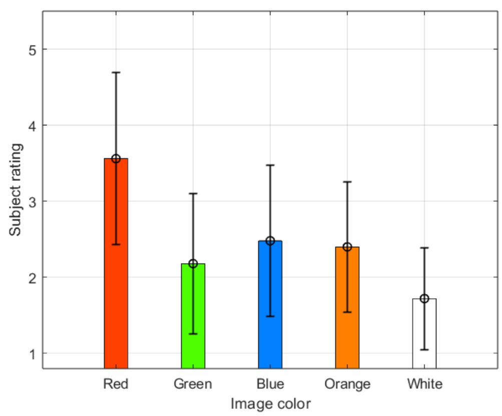


Figure 9: Halo perception vs. color

Based on test results above, it may be justified to simulate and analyze possible Halo artifacts in dependence on various BLUs. One particular interest is the influence of LED resolution and LSF shape on Halo perception. Thus, in the second step, the LED resolution and LSF shape are varied and analyzed.

Figure 10 shows the comparison between a Lambertian LSF, a rectangular one and the reference AMOLED device for 4 test patterns. The two BLUs comprise 384 LEDs. In terms of Halo, subjects rated Lambertian LSF overall better than rectangular LSF. AMOLED imaging is seen as perfect.

Figure 11 shows the result of the critical diagonal at varying backlight resolution, while rectangular and Lambertian LSF are considered. Both BLU designs are optimum and both LSFs have an FWHM to LED-pitch ratio of 1.25. Here, the results evidently prove that Lambertian LSF is superior to rectangular LSF. Additionally, the perceived Halo decreases with higher LED resolutions. At around 2400 LEDs, the subject's rate is comparable to an AMOLED device, which shows that a Mini-LED BLU may deliver a visual quality close to that of an AMOLED.

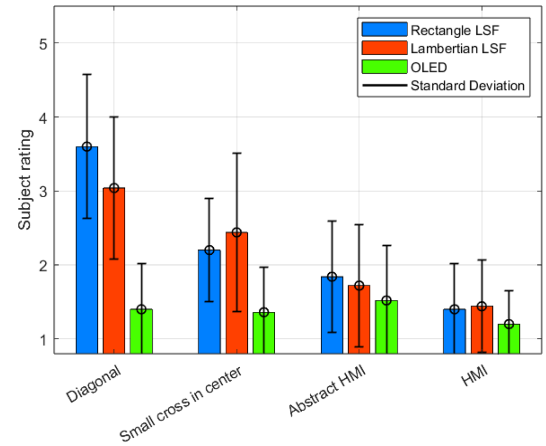


Figure 10: Halo vs. LSF Shape

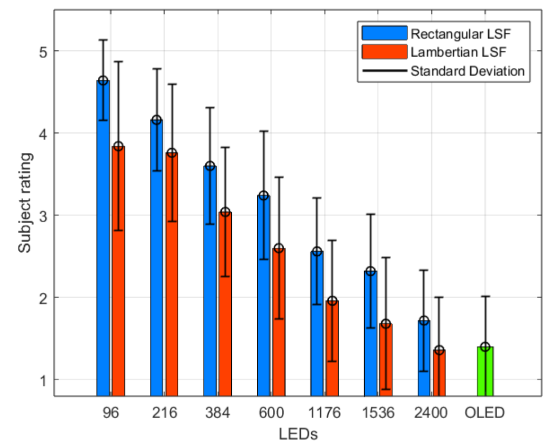


Figure 11: Halo vs. LED resolution for diagonal

6. Conclusion

A program simulating a local dimming algorithm including the simulation of light leakage and the resulting Halo artifact has been developed and validated. Different measurements of displays and simulation have been used for comparisons between different BLU arrangements and for validation of the simulation program. An AMOLED display was measured, modified and calibrated, such that it is suitable for a user study regarding the perception and acceptance of Halo generated in FALD LCDs. Our proposal for a highly qualitative BLU for 12.3-inch automotive display based on these results, is an optimal Lambertian shaped LSF with 2400 LEDs.

7. References

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