Halo Measurements: OLEDs vs. FALD LCDs

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Halo mura (spreading of bright pixel into the neighboring dark areas) reduces the visual quality of (automotive) displays. We report a new 5-step quantitative method to measure halo by using various test patterns to compare the impact on OLEDs and FALD (full array local dimming) LCDs. Results show that halo of state-of-the-art FALD LCD is almost 10 times higher than that of an automotive OLED.

1 Introduction

Automotive displays are shifting today from LCDs to OLEDs for better image quality, such as true blacks. “Full array local dimming” (FALD) LCDs enable “true black” outside bright content. However, an effect called “halo” is very likely to occur: Luminance from bright objects spread into the adjacent dark areas which as a result appear brighter than the true black. Consequently, it affects the visual quality of the display. Halo (mura) occurs in displays due to the internal reflections e.g. in the front glass, cover lens etc., see Fig. 1. Limited CR of LCDs also forces halo. In literature, the perception of halo has been evaluated by subjects and measured via luminance profiles. Advanced contrast methods (e.g., [1]) are not suitable for halo measurements. Lens and eye glare make it difficult to measure the luminance of black areas accurately with neighboring bright content. However, for quality assessment and towards standardization, quantitative halo measurements are essential. This is one motivation for our work; another was to use two different methods to measure halo and to compare them. Furthermore, we want to achieve “single pixel halo” values via macro lens and algorithms as input for simulations of halo on any GUI content.

2 Halo Measurement Method

It is obvious that halo luminance measurements should be performed with a luminance imager. However, “direct” measurement of bright content and its halo (dark) suffers of e.g. lens glare (Fig. 1 brown).

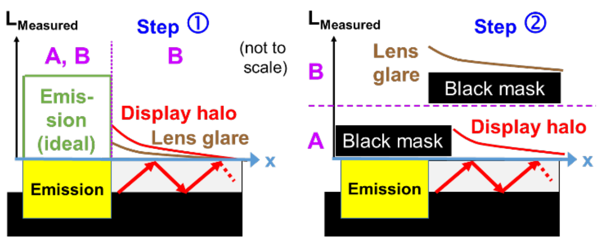

***Fig. 1**: Methods “A” (direct measurement) and “B” (indirect by subtracting lens glare from step ①) to measure halo without (left, step ①, also reference for “A”) and with (right) black mask to deal with lens glare (step ②).*

Halo and lens glare luminance are typically in the same range. We propose a new step-based method with two approaches (“A” and “B”, see Fig. 1) and different analysis tools. There are up to five steps possible, but the first two are mandatory. First four steps are visualized by measurements in the figures of § 3 (for visualization of Step ⑤ see [2]):

- **Step** ①: Method A: the luminance of the test pattern (we used a large box and small lines) is measured (Fig. 1 left, green box). Method B: luminance is measured next to the test pattern (Fig. 1 left, after the green box), which is the sum of both halo and lens glare.
- **Step** ②: A black mask is placed on top of the display. Method “A”: The mask covers the bright content (Fig. 1 right bottom) so that only the luminance profile (luminance over distance, x-axis) of halo is measured. To avoid direct light due to the thickness of the display glass, the mask covers also a part of the dark region. This will be compensated by curve fits of the luminace profile. For method “B” the halo region is blocked to acquire the lens glare profile (right top).This is then subtracted from the luminance profile of step ①.
- **Step** ③: The relative halo in % is calculated by L_{Halo} of step ② divided by $L_{Display}$ of step ①.
- **Step** ④: Fit curves of measurements to extract the relative luminance and decay, see Fig. 4.
- **Step** ⑤: Extract single pixel halo by simulations using results of Step ④, details see [2].

Method “B” in step ② seems to be easier than “A”, but lens glare effects can depend on the location of bright objects relative to the lens and imaging chip.

3 Results

We have made measurements for halo evaluation with an OLED (LG, 1,888 x 1,728), a FALD (Apple iPad Pro 2021; 2,732 x 2,048, 2,596 zones) and a standard LCD (Lincoln, 1,920 x 1,200). All measurements were performed using Instrument Systems LumiCam 1300 (luminance imager) in dark room conditions for standard and macro lens.

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The grey level of ON patterns ranges from 0 (to capture other effects) to 255 (white) in steps of 32; a large box of 200 x 200 pixel was used to generate more halo than for a small line. The results in Fig. 2 were captures with standard lens using method "A". The halo luminance profile of the OLED using method "A" is depicted on the left. It is clearly visible that the halo increases with raising grey levels (= luminance). As expected the curves decays with distance from the ON pixel.

Fig. 2 right shows relative halo luminance (step ③) as the ratio of halo luminance (L_{Halo}) to the ON pixel" display luminance ($L_{Display}$) plotted from right edge of the black mask (see Fig. 1 right). The relative halo of the automotive OLED does not depend on the luminance level as assumed (halo ~ luminance). This is also true for lower grey levels, which are not plotted here due to noise modulations.

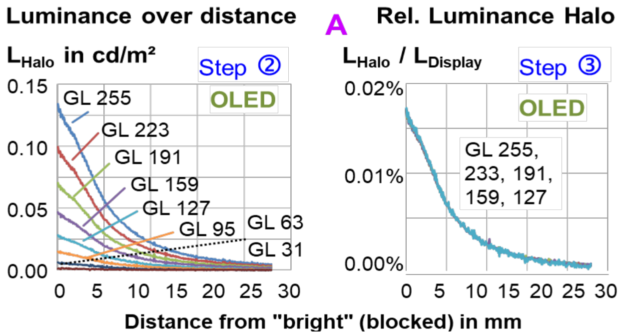

***Fig. 2**: OLED: Luminance profiles (left) of halo by method "A" by using a large box with different grey levels. Relative halo (right) does not depend on grey level.*

Fig. 3 demonstrates that the Apple LCD has a similar behavior like the OLED where halo increases with grey levels (right). However, the relative halo luminance (Fig. 2 right) shows that the distance characteristics are very similar but the percentage value drops with increasing grey level (luminance, e.g. 127 vs. 255). An explanation could be the local dimming algorithm. The standard LCD showed halo (as expected) but it is hardly measureable due to the "finite" contrast ratio resulting in light leakage.

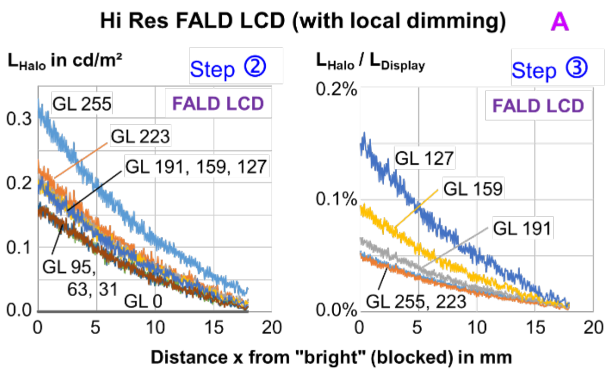

***Fig. 3**: FALD LCD: Luminance profiles (left) of halo by method "A" by using a large box with different grey levels. Relative halo (right, ~10x of OLED) depends on grey level due to local dimming system design.*

After verifying the capability of measuring halo, we have used for all further measurements a line of variable length and a width of four pixels in conjunction with a macro lens (refer [2]). The halo luminance is then measured after the right edge of mask according to Method "A".

Fig. 4 depicts mean values of measured relative halo luminance by using a macro lens (refer [2]) plotted against distance from the mask as step ④. The measured halo of the OLED below a pixel line length of 32 is too small, i.e., less than SNR, therefore only higher lengths are plotted. Due to that decay, "left" pixels of line lengths more than 64 pixels do not contribute to measurements. Halo of FALD, does not depend on a number of ON pixels as relative halo is almost same for line lengths 1-64 pixels due the size of dimming zone which is about 55 pixel. Fitting allows to extrapolate halo values to the mask's edge at "0 mm". Furthermore, halo measurements have been validated by comparing results from both method "A" and method "B" (see [2]).

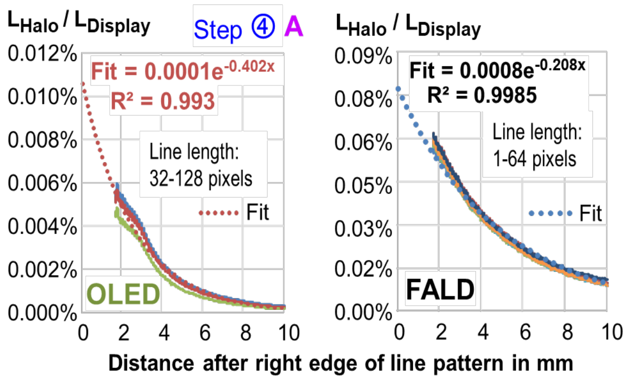

***Fig. 4**: Mean values of measured relative halo (method "A") and exponential fit for 64 pixels line (0 = edge of line).*

4 Summary

We have successfully verified halo measurement methods using a black mask, which are able to extract the halo luminance characteristics of single pixels [2]. Halo was measured for an OLED and two LCDs (FALD and standard). The halo is about 10x larger for a high resolution FALD LCD compared to the OLED. Both have an exponential decay of the halo luminance over about 10 mm from the bright content. Visual assessments show that halo is hardly noticeable for positive mode compared to negative mode GUIs [2]. The highest "visibility" is in dark conditions (e.g. night drive).

References

[1] SID International Committee for Display Metrology (ICDM): *Information Display Measurements Standard (IDMS)*; Version 1.1, July 19, 2021.

[2] K. Blankenbach, and F. Bhatti, "35-1: Halo Mura of OLED and FALD LCD: Measurements and Perception for Automotive Displays."*SID Symposium Digest of Technical Papers*. Vol. 53. No. 1. 2022.

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