30.1: *Invited Paper:* OLED Lifetime Issues in Mobile Phone Industry

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Abstract

Lifetime issues have been hot topic through the history of OLED. Escpecially blue color has been problematic. A lot of research work has been carried out in OLED industry to improve the lifetime figures and results have been encouraging. However, it has been difficult to the mobile phone terminal makers to define, what is the acceptable lifetime in phone application. The limited lifetime is visible in the first place in the form of burn in images. These two issues have been the focus of this study.

1. Introduction

Lifetime targets were placed for LCD long time ago, and in the first discussions concerning OLED lifetime with terminal makers, the answer was same as for LCD, 50 000 hours. It was natural that, 5 years ago, it was felt totally impossible to reach, when the lifetime figures for blue were at the level of 500 hours. The requirement from terminal maker´s point of view was calculated from the assumption that a phone is on and the display as well is on for 7 years.,mainly without backlight using reflective mode of LCD display.

With OLED displays there was need to rethink the requirement, and therefore this study has been made. The other phenomenon, which came into the discussion was the burn in effect. It became very rapidly visible from those first OLED samples. This study was aimed to clarify the burn in effect from human perception point of view, and to define the threshold for acceptable luminance reduction causing burn in effect. The aim was also to find out the threshold for perceptible but not annoying and for annoying behaviour in consumers eyes.

2. Usage Profile

All applications are using displays in very different ways. TV usage has been requesting long usage times, while mobile phone displays have been in active stage only a short time. However, this situation is changing due to increased use of multimedia content in mobile phones. Mobile phones are changing to multimedia terminals including mobile TV.

In order to understand the burn in behaviour, the usage profile of typical mobile phone daily usage was defined. There was also interest in what kind of effects from "black user interface" is having to burn in effect. Therefore also "Dark UI" images were taken into the analysis, even though those are not used in phones.

The following figures are representing the use cases.

20 times/6 s 20 times/12 s 8 times/1 min 2times/12 s

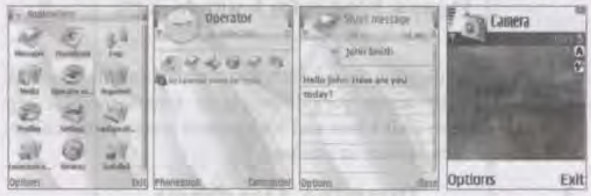

Figure 1. User Interface and camera application

Camera picture is an average from several shots during a day.

Figure 2. Dark UI and camera application

The usage times for these screens in analysis are printed above the images, *i. e.* the menu screen is used 20 times during one day, and each time screen in shown 6 seconds before dimming. Similar times are used in LCD screens today not for preventing burn in effect, but in order to save energy.

One time/5 min 5 times/5 min 5 times/12 sec

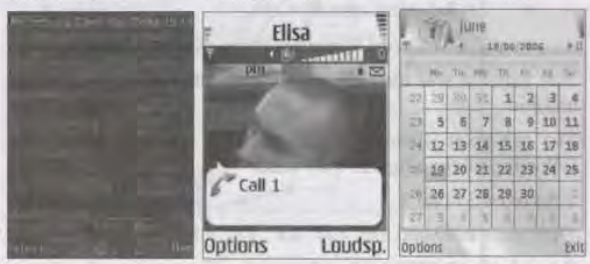

Figure 3. Multimedia content, phone call and calendar applications

Multimedia is the average from all multimedia frames during a day. These are like mobile TV and internet browsing. Multimedia content is very friendly from burn in point of view, because there are not big contasts.

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Figure 4. Same as Fig 3. with Dark UI.

Phone call application is the only one, where the dimming is done during the active period. In phone screen there is big contrast between Call 1 box and background image of the caller. This can be seen in burn in images.

3. Dimming Algorithms

During a phone call the dimming of display is done in 3 steps after 15 sec. each from 100% to 0% luminance level. In addition to this ambient light level is used to dim the display.

15% of time display is using 100% luminance. This represents outdoor usage. 70% of time 75% of luminance is used. This represents indoor and office usage, and finally 15% of time 50% of luminance is used representing environments, where too bright display may be disturbing.

4. Burn in Effect and Definition

The aging of luminance values of pixels were calculated using the well known equation:

$$I = \left(\frac{1}{2}\right)^{pt/T} I_0 \qquad (1)$$

- *I = Aged luminance value of sub-pixel*
- *I_o = Original luminance value of sub-pixel*
- *p = Relative and gamma corrected sub-pixel value*
- *t = Sub-pixel operation time*
- *T = Sub-pixel lifetime (different for each color)*

Test material was made with both user interface styles, normal and dark.

The sub-pixel lifetimes T are different for each color. The following lifetime figures were used:

T for red = 37 000 h

T for green = 49 000 h

T for blue = 13 500 h

These values were not the best in thin OLED industry, but the target was to see, how well the current technology is usable [1]. Since this analysis, much better values for blue color have been reported, and those new values are used in business decisions. These results are discussed in section 9.

The target was to calculate aging results having certain luminance drop percentages. To get those some estimated operational times were taken, for example 1 year. Daily usage was just multiplied by 365 to get one year operational time. The images were named based on the highest luminance drop level of a pixel. The result from one year usage was around 3.2% in normal user interface.

The targeted luminance drop values were from 1.5% to 50%. This could have been obtained through iteration process, but instead of iterations close enough values were accepted.

The result was 0.8%, 3.2%, 4.8%, 8%, 9.6%, 13.6%, 19%, 28% and 39% values with normal UI and 0.8%, 2.4%, 4%, 8%, 9.6%, 20%, 29% and 40% with Dark UI.

5. Test Images

After having aged pixels for different luminance drop categories from 0.8% to 40% these pixels were used to produce test images for test person's evaluations.

The following test images were selected. The criteria for test image selection was to use images, where burn in effect would be easy to see (e.g. large uniform color areas).

Colorbar Fence Flower White Operator Operator

Normal UI Dark UI

Figure 5. Test images

Examples of aged test images are shown in Fig 6.

Figure 6. 40% burned in test images. 1st and 2nd normal UI, 3rd and 4th with Dark UI

Clearly from these images the burn in effect can be seen. In dark UI it can be noticed that even if there is a clear burn in effect, the color at the sky has not changed due to lower usage of pixels.

In the Operator screen in the case of Dark UI (3rd image) burn in is hardly visible even there is 40% burn in because of dark background. But in the 4th image burn is effect is really annoying in dark UI case.

Each test image was made using above mentioned 9 luminance drop grades for both normal and dark UI. This means that the overall amount of test images produced was 2x5x9= 90 plus 6 originals. Example from those is shown in the Figure 7.

Figure 7. Test images representing different aging categories from 0% to 40%

6. Test Set-up

Test persons were selected having normal visual acuity (standard eye chart) and normal color vision (Ishihara's test). 10 people were selected to do the test, 7 males and 3 females, aged 30 years old on average.

The test took place in a laboratory, where the ambient light was able to be adjusted. The ambient light was kept in 650 lx level .The monitor, where the images were presented was a 22" 1920x1200 high quality monitor (: EIZO ColorEdge CG220 TFT LCD).

Two separate tests were performed to find out the level of luminance drop causing annoying burn in effect.

In the first test the test persons were asked to rank the aged test images including also the originals shown one by one in random order with the following scale:

0 = Imperceptable burn in effect

1 = Perceptable, but not annoying

2 = Slightly annoying

3 = Annoying

4 = Very annoying

Rating data was analysed using analysis of variance and Post-hoc comparisons were performed with Bonferroni procedure [2].

The second test was test carried out by comparing two images side by side. This test is able to reveal small differences. Luminance drop levels from 0% to 14% were used, resulting in 210 paired comparisons. Test persons were asked to rank the images as follows:

0 = Image A much better

1 = Image A slightly better

2 = Images are equal in quality

3 = Image B slightly better

4 = Image B much better

Paired comparison results were analysed according to Thurstonian procedure (case III) [3].

7. Test Results

Test results are shown in Figures 8 – 11. Figures 8 and 9 are showing the results from the first test with normal and dark UI.

Figure 8 shows, that fence image is most tolerant to burn in effect while the white image reveals everything most rapidly. However, the differences are very small in 3.2% and 4.8% categories. The level of annoying was at the score =2, taking place between 9.6% at white image and 13.6% with fence and colorbar.

Results are very similar to normal UI case except Operator image, which is very dark, and therefore it is difficult to see the aging and burn in effect in that one.

Figures 10-12 are showing the results from second test.

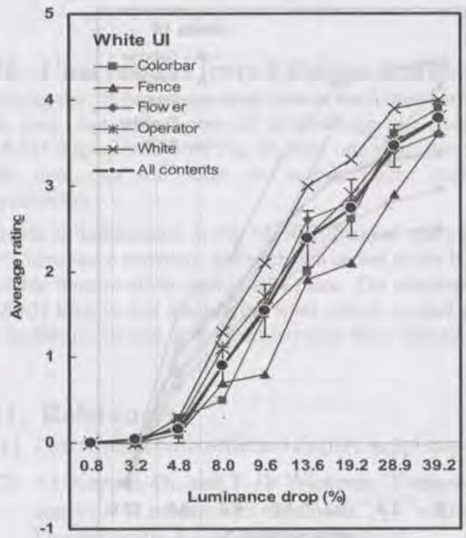

Figure 8. Results from the first test with normal UI.

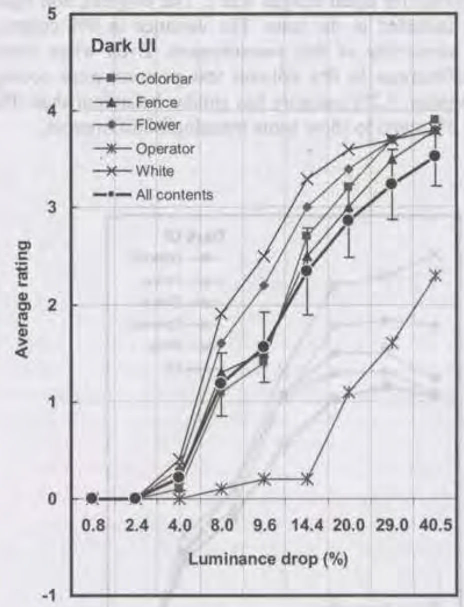

Figure 9. Results from the first test with Dark UI.

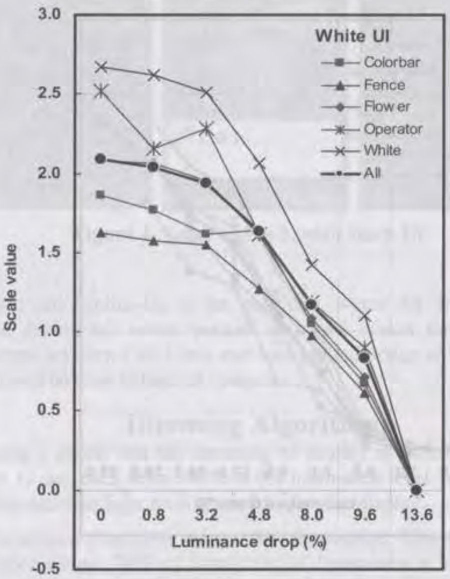

Figure 10. Results from the second test with normal UI.

Here the scoring for equal images was 2. The original, non aged image was included in the tests. The variance in 0% column shows the sensitivity of this measurement. Even when there were no differences in 0% column test persons were seeing some differences. 3.2% category has similar behaviour than 0% category. 4.8% starts to show some meaningful differences.

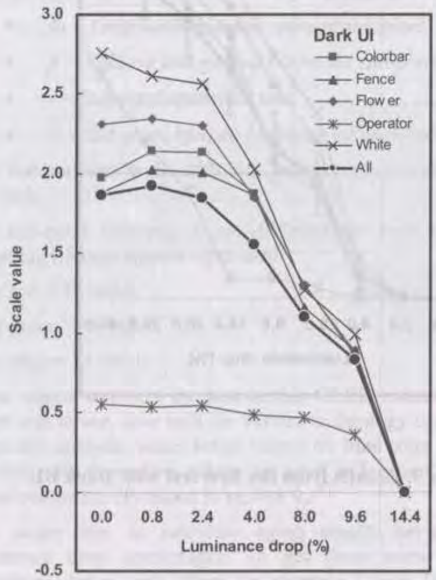

Figure 11. Results from the second test with Dark UI.

This is showing similar behaviour than in normal UI except in Operator image, where 14.4% luminance reduction was needed to cause a perceptible burn in effect.

8. Conclusions from Burn in Tests

Normal and Dark UI are giving very similar response in the first test as shown in Figure 12.

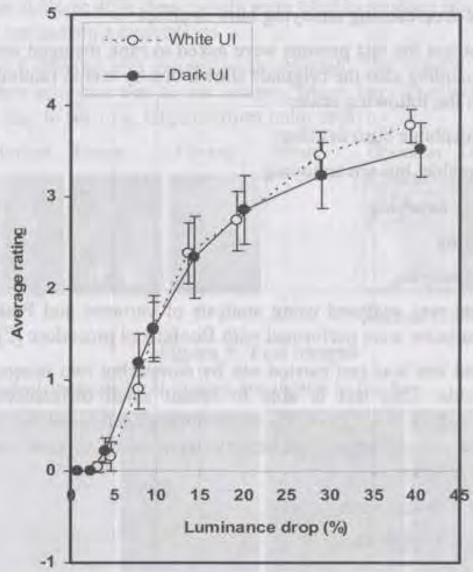

Figure. 12. Summary from burn in effect tests.

Rating 2 was "Slightly annoying", and that will take place between 10% and 15% categories. Rating 1 was "Perceptible, but not annoying" and that level is reached around 7% category.

Engineers like to take some margin for planning purposes, and therefore the level of 5% luminance drop is taken to the level, which is accepted for the display independent from selected UI style.

9. Lifetime simulations

The remaing question is "How long does it take to obtain 5% luminance drop level?"The answer comes from total operating time in equation (1). Operating time was the input value, which caused certain luminance drop levels. The following pictures have been made with different lifetime parameters. The first set of pictures is with 3 years old lifetime figures and the second set with todays figures from few potential OLED suppliers.

3 years old life time figures: T for red = 10 000 hour
T for green = 14 000 hours
T for blue = 3 700 hours

2.5% 5% 9% 15% 26% 42%

6 month 1 year 2 years 4 years 8 years 15 years

Figure 13. Time needed for above mentioned luminance drop levels

Figure 14 will show the usable lifetime figure with today's lifetime figures.

Todays life time figures: T for red = 30 000 hour
T for green = 40 000 hours
T for blue = 26 000 hours

1% 1.5% 2.5% 5% 9%

1 year 2 years 4 years 8 years 15 years

Figure 14. Time needed for above mentioned luminance drop levels.

The times needed for above mentioned luminance drop levels were roughly 50% longer in the case of Dark UI.

10. Conclusions from Lifetime Simulations

Taking the 5% luminance drop limit to the lifetime criteria it can be seen, that with 3-year-old lifetime data the usage time of OLED display was from Fig 13. only one year. It is clear, that the time was too short for mobile phone main display application.

Based on information in Fig 14. it will take 8 years to come to 5% luminance situation, and as shown earlier to the level, where visible burn in effect start to take place. The conclusion is, that OLED lifetime has reached the level, which is good enough for a mobile phone and multimedia terminal main display.

11. References

[1] Discussions with different display suppliers.

[2] G. Keppel, G., and T. D. Wickens. "Design and analysis: A researchers handbook", (4th edition). Upper Saddle River, NJ:Pearson, 2004.

[3] T. Rung-Ching, Psychometrika, Springer New York, Volume 65, Number 2, June 2000.

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Table of Contents

Table of Contents

Poster Session

ACTIVE-MATRIX DEVICES

BOE
Exhibit 1024 Page 10

Table of Contents

EMISSIVE DISPLAYS

Inorganic EL

Phosphors

Table of Contents

Table of Contents

Table of Contents

BOE
Exhibit 1024 Page 14

BOOK 2

Session 14: Novel Projection Light Sources *(Projection)*

Session 15: Medical Displays *(Applied Vision)*

Table of Contents

Table of Contents

Session 40: LC-Based E-Paper *(Liquid-Crystal Technology)*

Session 41: Poly-Si AMOLEDs *(Active-Matrix Displays)*

Session L: Late-News Session

Session 42: Field Emitters and Materials *(FEDs)*

Session 65: Display Manufacturing: Packaging *(Display Manufacturing)*

Session 66: LED Backlight Driving *(Display Electronics / Display Systems)*

Session 67: Emissive Reflective Displays *(Liquid-Crystal Technology / OLEDs)*

Session 68: Transparent TFTs *(Active-Matrix Devices)*

Session 69: Solution-Processible OLEDs *(OLEDs)*