OLED Aging Characteristics for Digital Still Camera Applications

Ronald S. Cok, Felipe Leon, Joshua Silbermann
Eastman Kodak Company, 1999 Lake Avenue, Rochester, New York, USA
Telephone 585-722-5122; Fax 585-722-6222; E-mail ronald.cok@kodak.com

Abstract

A series of images were displayed on an OLED display placed within a digital still camera body to characterize the aging of the OLED display in a realistic environment and with an image set that matches actual consumer usage as closely as possible. The aging characteristics of the OLED display were measured and shown to meet the requirements of a digital still camera application by a wide margin.

1. Introduction

Organic light-emitting diode (OLED) flat-panel displays face a variety of technical challenges. Power requirements, lack of uniformity, and decreased efficiency caused by aging must be overcome before this promising technology can be commercially successful. In particular, changes in OLED efficiency over time must be overcome [1]. Despite the challenge of decreasing efficiency caused by material aging, OLED devices can meet the requirements of popular portable display applications. In particular, the authors evaluated the suitability of OLED displays for digital camera applications.

Most aging and lifetime experiments performed on OLED panels address specific OLED characteristics, such as time to half-brightness at a given drive signal. Because these tests can take a long time, they are typically performed under more strenuous conditions than are typically found in normal use. For example, OLED display tests are commonly performed at 80 mA/cm^2, at 80 ºC, and at 80% relative humidity (RH). Moreover, the displays are typically driven continuously. In actual use, displays may be driven intermittently and at current densities averaging 5 mA/cm^2. Hence, while useful for comparison, such laboratory lifetime tests may not accurately predict the expected lifetime of a display in actual use in a specific application and at ambient temperature and humidity. Therefore, it is crucial to gain an understanding of how lifetime, aging, color shift, and image stick issues are likely to affect a typical OLED device in normal use, rather than how they affect high-demand laboratory experiments.

Moreover, many OLED display tests are performed in the same manner as they are performed on LCDs. Failure testing on an LCD requires driving the LCD at a peak luminance until such time that the backlight causes the display to dim to some fraction of its initial luminance. Unlike LCDs, OLED displays are self-emissive and do not require a backlight or inverter. Every pixel in an OLED does not need to be driven at full luminance at all times. The necessary pixel brightness and resulting power consumption are *image* dependent. Therefore, conventional LCD-like tests performed on AMOLEDS may substantially underestimate the lifetime of OLED displays in real-world applications.

2. Experimental Setup

To address these issues, a digital still camera usage scenario was developed based on real-world usage data and tested in a digital still camera body. A commercial AMOLED display employed in the Kodak EasyShare LS633 zoom digital camera was mounted flush with the display opening in the body of an empty Kodak EasyShare DX7630 zoom digital camera with a small, flexible silicone heater to simulate the heat load from operating electronics. An automated data acquisition system recorded overall OLED display current usage, average luminance for a single image, average OLED surface temperature, and temperature within the camera body, as well as providing overall control of the experiment and conditions. Other measurements including spectral measurements and digital image records of the OLED display screen were made manually. To avoid ambient light measurement error, the entire apparatus was encased in a Plexiglas box with a removable top, thereby keeping the environment light tight and helping to eliminate the accumulation of dust on the front of the OLED.

An external computer cycled the OLED display through an extensive image set of 3,611 digital still camera images. This image set comprised a subset of images captured by real consumers as part of a digital still camera usage study conducted by Eastman Kodak

Company in the year 2003. The usage study provided a variety of images in a wide range of setting and lighting conditions and an estimate of the number of pictures that a typical digital still camera user takes in a year, about 250. A representative set of menu screens typically encountered in camera use, as well as a black frame representing a powered display with no image, were also included. The selection of images, frequency, brightness, and display time were chosen to emulate actual usage, and the OLED display was operated under typical conditions. The display and heater were periodically turned off to simulate inactive periods.

The test proceeded by first characterizing the display performance and then powering the display and heating the interior of the camera body to the expected steady-state operating temperature. The image series was displayed at the brightness mandated by the user scenario for the desired period of time and the display recharacterized. The display performance over time can then be analyzed by comparing the performance of the display before and after operation.

3. Experimental Tests

3.1 Heating Effects

OLED devices are sensitive to operating temperature. A first test measured the amount of time required for a camera to reach a steady-state operating temperature. By measuring the temperature within the camera body after the heater and display are turned on, a camera temperature profile can be determined and is shown in Figure 1. These data demonstrate that the camera interior did not reach a steady-state operating temperature for approximately 20 min, and required a similar time to cool down. This is a critical observation, as consumers rarely use a digital camera for more than a few minutes at a time. Hence, the display is typically operating at a temperature close to ambient, possibly increasing its lifetime.

3.2 OLED Recovery

OLED recovery is a memory effect that we observed in some OLED devices. While the physical mechanisms underlying the effect are not well understood, the operational effect is to improve the performance of an OLED after the device has been out of use for some time. Such an effect could be a critical issue in overall display performance for an application that frequently turns the display off and on. In order to understand the influence of this effect, an OLED was aged with a red flat field for 20 min at 120 cd/m^2 and then the performance of the OLED measured at intervals after the aging. (The measurement requires only a few seconds and is presumed to have no effect on the OLED performance.)

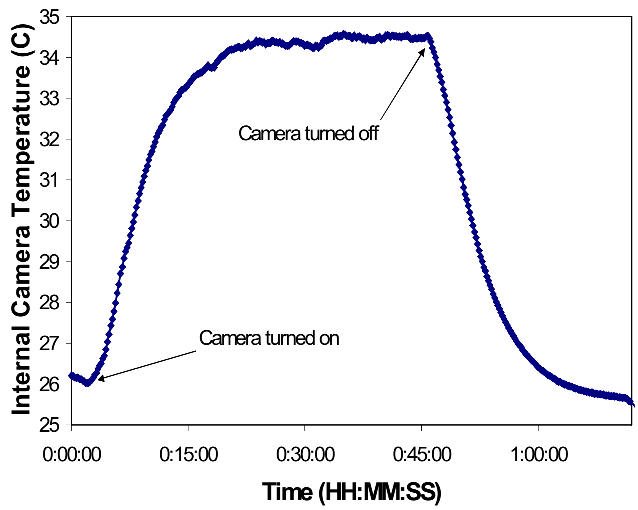

Figure 1. Camera internal temperature vs. time

Figure 2 below illustrates the effect and shows that the recovery process is complete after about 40 min. In Figure 2, the display is aged in cycles. Within each cycle, the display is first aged and then repeatedly characterized at intervals as time passes. In essence, no efficiency recovery could be observed, but the rapid current loss was typically fully recovered, as it is only caused by the temperature changes on the display caused by camera heating and cooling. After 40 min, the current is completely stabilized.

This measurement is helpful in defining the test parameters. Based on these results, we may conclude that a 40-min gap between usage cycles is equivalent to a much longer gap and that a display cycle need not wait any longer than 45 min to begin a new display cycle regardless of the actual real-time consumer usage scenario. Results for green and blue fields were similar. Further tests aged the OLED display for different lengths of time (20, 40, 60, and 120 min) and the recovery duration measured.

These tests also showed that, after about 45 min, recovery was complete. Hence, in long-term tests, the authors presumed that new test cycles could always be started 45 min after the previous test was done.

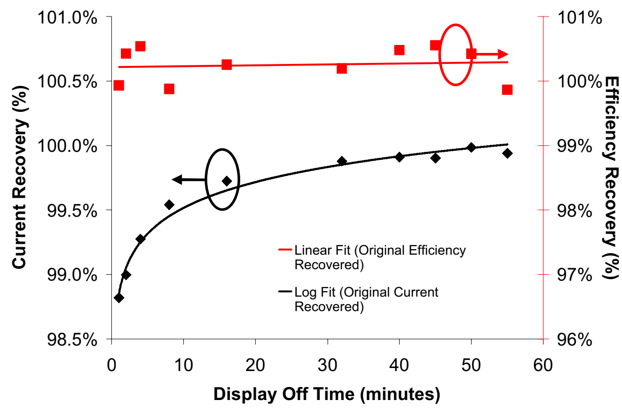

Figure 2. OLED display recovery vs. time elapsed for current and efficiency

4. Experimental Conditions

A series of three experiments were conducted to test the performance of an OLED display in digital still camera applications. The first test attempted to mimic the behavior of a typical consumer; the second test was an accelerated version of the first test; and the third test repeated the first test at twice the brightness. Table 1 lists relevant data for each test. Table 2 lists the performance of the tests, and Table 3 the test cycle conditions.

Test cycles for Tests 1 and 3 represent a period of typical consumer digital camera use equal to 6 years each. Test 2 is an accelerated test more like a laboratory test without the off-time and cool-down cycles. Of course, other users, such as professionals, may take an equivalent number of pictures in a much shorter time.

Table 1

Test	Images per cycle	Black Frames Included?	Off Time?	Peak White Lum. cd/m^2	Time per Cycle
1	3611	Yes	Yes	120	2 weeks
2	3611	No	No	120	8 hours
3	3611	Yes	Yes	240	2 weeks

Table 2

Test	# of Cycles	Elapsed Time Ddays	Equivalent Usage Years	Initial Lum cd/m^2	Ave. End % Lum
1	4	56	24	120	99%
2	105	35	600	120	92%
3	8	112	48	240	98%

Table 3

Test	Image Time	Dark Time	Off Time	Heating Time
1	2.5%	5.2%	79.2%	13.2%
2	100%	0%	0%	100%
3	2.5%	5.2%	79.2%	13.2%

The actual model of consumer behavior is stochastic, hence the values given in Table 3 are averages over an entire cycle. Although, as shown in Table 3, the actual percent of time that a user spends examining images or menus as a percent of usage time is relatively small, bear in mind that this is based on measurements of actual consumer usage behavior. Actual consumers spend an average of 11.8 s reviewing images and 37.4 s between image captures in a multi-image capture situation [2].

The temperature inside the camera body cycled between ambient room temperature (about 20 ºC) and 34.6 ºC. The latter temperature was chosen as the average, steady-state operating temperature of the camera as measured at Kodak's Research Laboratories.

5. Experimental Results

The results of the first test are shown in Figure 3, measured at 120 cd/m^2. Very similar results were obtained with measurements made at 30 and 60 cd/m^2. Note that the scale in Figure 3 runs from 98.4% to 100.6%, indicating that very little aging took place over the 56 days of the test. The OLED display uses different patterned organic materials for each colored subpixel and the subpixels in the OLED display are of different sizes, chosen to match the presumed relative lifetime of the materials. As we can see from relative lifetime of the materials, sizes of red and green subpixels are approximately correct, but the blue is perhaps too large because it did not age as much as the red and green. Indeed, the blue became slightly more

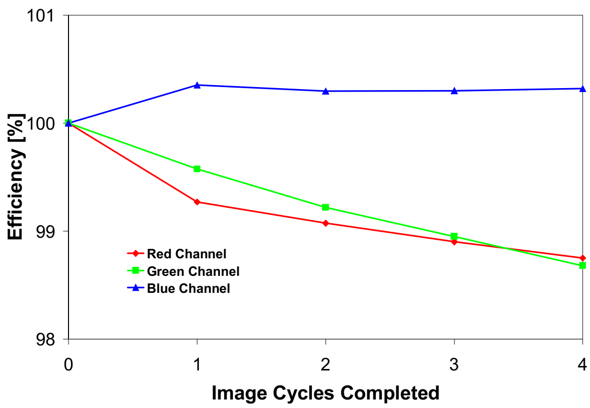

Figure 3. Test 1 OLED efficiency over time

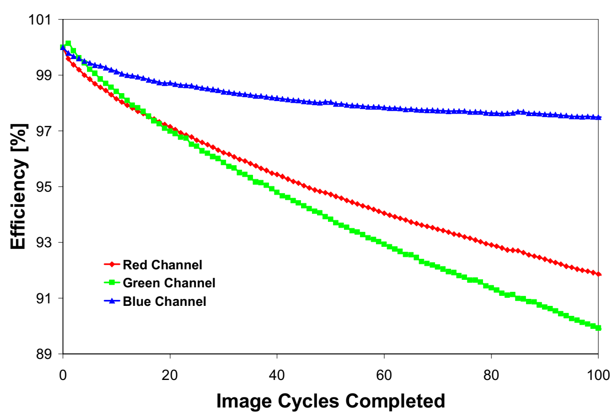

Figure 4. Test 2 OLED efficiency over time

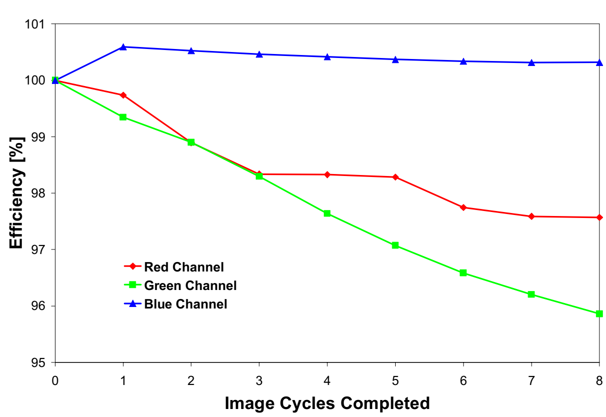

Figure 5. Test 3 OLED efficiency over time

efficient over the lifetime of the test.

Figure 4 illustrates the results of Test 2. In this accelerated test, the OLED display was never turned off and no dark images were used, so that the display was constantly in use. As demonstrated in this test, the long-term performance of displays used according to the Test 1 and 3 scenarios is similar to the performance shown in Test 2. Hence, it is likely that the presence of the dark images and the use of an off state in the test are not significant factors in overall lifetime.

Figure 5 has results similar to those of Figure 3, except that the aging progresses somewhat faster because of the higher luminance. In both cases, measurements were made at 120 cd/m^2 and comparative measurements at 30 and 60 cd/m^2 gave very similar results.

6. Differential Aging Effects

The measurements shown in Figures 3-5 are of the overall average brightness of flat image fields. As is well known, OLED displays may also suffer from localized aging that reduces image quality, for example, from bright icons or repeated use of one part of a display in comparison to another part. Digital camera images are also subject to this problem, despite the fact that images are, on average, gray. The problem arises from the use of menus and images whose aspect ratios do not match the aspect ratios of the display (for example, portrait vs. landscape mode).

The average image presented in this test is shown in Figure 6. As can be seen, the image suffers from some localized differences in use; some menu features are visible and the center of the image is used more frequently than the edges, a result of the capture of portrait images, and a date stamp (not normally present in actual use) can be seen. A final, after-test, flat-field, red-channel image is shown in Figure 7a; Figure 7b shows a greatly enhanced image to make any burn-in more visible. As shown here, any burn-in is not objectionable. Burn-in in the green channel is similar and burn-in in the blue channel cannot be seen even in the enhanced image. (The striations in Figure 7b are due to image sampling artifacts from the camera sensor used to take the photograph and are not present when the image is viewed and when the photograph is made.)

Figure 6. Weighted average test image

Figure 7a. Final test 2 red channel image

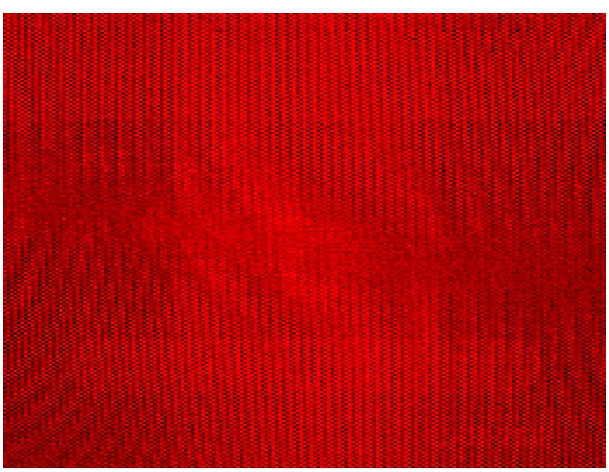

Figure 7b. Final test 2 red channel image (enhanced)

7. Conclusions

OLED displays are well suited to digital still camera consumer applications and other image-centric portable imaging applications in which the displays are used intermittently. The use of variable-format images such as portrait and landscape images and the presence of menus does not cause significant burn-in.

In applications of this type, OLED material aging is not a significant concern; indeed, other failure modes such as humidity or mechanical failure are likely to occur first. The display materials are likely to outlast the device into which they are integrated. Moreover, newer materials are available today with significantly improved performance, further enhancing the display lifetime.

8. Acknowledgments

The authors are grateful for the assistance of Michael Siwinski for development of software to automate the experiments.

9. References

[1] A. Nishioka, Proceedings of the 24th International Display Research Conference (2004), p. 737.