22^{nd} International Symposium INFOTEH-JAHORINA, 15-17 March 2023

LED backlight lifetime:

Key influencing factors and experimental results

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Abstract—**Display light output (luminance level, chromatic performances) during the lifetime is one of the most important performances in the case of ruggedized AMLCD displays design. The backlight reliability and lifetime definitions and influencing factors are discussed. The experimental set-up for LED backlight lifetime testing is described. The LED backlight lifetime determination is based on the experimental set-up using room temperature testing during prolonged time for several backlight designs. Experimental results are presented and discussed in the light of the current standards related to lifetime definition of the solid state light sources and luminaries.**

Keywords - Ruggedized displays, Backlight, LED backlight, LED lifetime

I. INTRODUCTION

LED technology is well suited for AMLCD (**A**ctive **M**atrix **L**iquid **C**rystal **D**isplays) backlight applications. LED back lightning is widely used in ruggedized LCD displays due to: (i) long life time, (ii) low voltage operation, (iii) wide operation temperature range, (iv) fast response, (v) wide color gamut, (vi) suitability for both side and direct illuminated backlights, (vii) wide dimming range, (viii) convenience for dual mode lightning, (ix) all solid state electronics and (x) easier automatic luminance and color balance control [1]-[4].

LED backlights require efficient heat sinking for long term reliable operation and lifetime at higher operation temperatures [5]-[7]. Also, the LED driving current should be selected to support required lifetime.

Reliability and lifetime are not the same terms (synonyms). *Reliability* [8] is related to failures that ends the operation of the specific product or component. Reliability is the ability of a system or component to perform its required functions under stated conditions for a specified period of time. It is often reported as **M**ean **T**ime **B**etween **F**ailures (**MTBF**). MTBF is an especially useful measure when the system is repairable, as it will determine the maintenance interval.

Lifetime is related to selected property depreciation, means product is still operating but required property value is lower than desired [9]-[11]. Lifetime is an estimate of how long any single product is expected to operate as intended, given a specific set of environmental and mechanical requirements. Lifetime does not consider any repair or replacement of the components. The physical processes that lead to component deterioration are the same one that will cause failure at the end of life. LED manufacturers usually report the both values, but LED illumination system designer should consider application of environmental influences profile to estimate lifetime value.

In the case of illumination sources (luminaires, backlights) where the basic components have a high reliability value, but light output should keep predefined value, lifetime is very important parameter. In the case of ruggedized avionic display, it is one of the key parameters limiting design options [12], [13].

In this article we are presenting experimental results obtained during backlight lifetime testing and discuss these results in the light of the current knowledge and applicable standards regarding LED devices lifetime determination, that were not available in the time of testing. The work and results described in this paper were done more than 10 years ago. At that moment no defined procedure was developed. Because of that experimental results could be used for qualitative analysis rather than quantitative predictions.

The test is related to several backlight designs that were used in our ruggedized displays. The intention of the test was to show what backlight life time could be expected. Because of that the normal room operation temperature and real backlight operation driving current were used as it was designed for display operation. The key role of the test was to show our customers, using simple results, that they could expect long lasting backlight application in our ruggedized displays.

In the meantime, LED application in the luminaries was widely accepted causing development of the new standards related to LED and LED luminaries testing. The LED lifetime is relatively long (tens of thousands of hours), and technology is developing and improving fast so it is not convenient to use real lifetime testing. Because of that there were not much natural aging lifetime test results, published in open literature. On the other hand, LED lifetime prediction is very important for the users.

Since breakthrough in application of white LED in illumination at the beginning of 21th century, the interest for LED life time resulted in lot of research effort to define methodology and metrics for lifetime estimation [14]-[19]. During 2008 the standardized criteria and procedure for white LED lifetime and illumination fixture were defined [20] - [22]. The detail review of the publications related to LED luminaires life time could be found in [23].

New standards define measurement procedures and techniques for LED luminaries' lifetime prediction based on the accelerated testing techniques application. Using the new standards some of experimental results regarding backlight lifetime could be better understood.

We are presenting a short review of the LED backlight lifetime influencing factors, and currently used LED lifetime predicting methodology. The scientific base of the backlight lifetime estimation is described and discussed. Experimental set-up is described and selected experimental results are presented. The presented experimental results are revisited and discussed using modern LED illumination standards and related conclusions are derived.

II. LED BACKLIGHT LIFETIME INFLUENCING FACTORS

The simplified LED backlight structure [3], [4], [13] is illustrated in Figure 1. This illustration includes important LED backlight design features providing proper operation and required light output: thermal managements, power management and optical management.

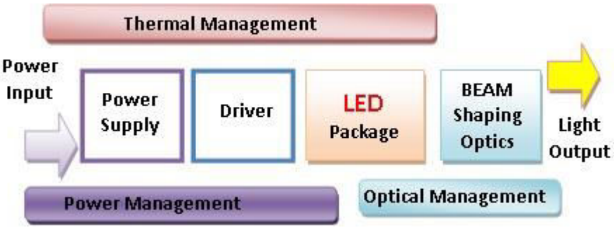

Figure 1. LED backlight simplified structure

There are a number of factors that affect the useful LED backlight lifetime. By ensuring that the LED is protected from adverse conditions it is possible to ensure the maximum lifetime is maintained.

Temperature: One of the major issues in ensuring the maximum life is obtained from a LED is keeping the LED junction temperature as low as possible. Excess junction temperature will considerably shorten the LED life and backlight lifetime accordingly. To provide low junction temperature one needs to provide proper thermal management in design: (i) good thermal path from LED chip to mount (ii) good bonding between LED and external mount and (iii) good heatsink to whole backlight

LED drive level: To obtain the best LED backlight lifetime, the LED should be driven well within its ratings. Overdriving a LED will drastically reduce its lifetime, although it will increase the light output. Means, when longer backlight lifetime is required it could be achieved using lower LED driving current and increased number of LEDs, but at the higher backlight cost.

Power supply: The power supply needs to match the light emitting diode for optimum LED life expectancy. Not only should the voltage be regulated, but the current also needs to be closely controlled to ensure the LED does not run outside its ratings, or even too close to its maximum ratings. The modern electronics technology applied for power supply design could have very long lifetime, so it is not considered as critical for LED backlight lifetime.

Environment: General conditions such as vibration and temperature extremes place mechanical stresses on the diode which will reduce the LED lifetime. Ideally, a LED backlight should be operated within a stable dry environment.

To determine LED backlight lifetime, it is necessary to quantify the contribution of the influencing factors and define application conditions profile during the anticipated life. LED backlight lifetime prediction is important part of the design process.

It is obvious that the LED backlight life should be as long as possible, but the reality is that LED backlight light output is more important. Generally speaking, the definition of the LED backlight requirements is iterative process involving compromise between light output specification, thermal and power management capabilities and project budgetary constraints.

III. LED BACKLIGHT LIFE PREDICTING METHODOLOGY

The LED backlight lifetime predicting is nowadays based on application of accelerated deterioration testing [24]-[26] that take care about LED failure modes and degradation processes [27]-[30].

The key step is to define deterioration model suitable for selected influencing factor. It is shown that deterioration model could be connected to junction temperature [18], [31]-[33] as temperature caused degradation.

It is shown that heat (temperature) caused degradation in the LED light efficacy could be treated as Arrhenius process and described using Arrhenius' equation [34].

Arrhenius' equation gives the dependence of the rate constant, λ, for reaction dependent on temperature:

$$\lambda = e^{\frac{-E_A}{k_B \cdot T}} \tag{1}$$

Where

- E_A is the activation energy for the reaction (in the same units as $k_B{*}T$)
- k_B (k) is the Boltzmann constant

In that case depreciation rates (λ_1, λ_2) on different temperatures are connected as described in equitation (2).

$$\lambda_2 = \lambda_1 \cdot \exp\left[\frac{E_A}{k} \cdot \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right] \tag{2}$$

Once when depreciation rate is known the selected property deterioration could be calculated using equation (3).

$$R(t) = e^{-\lambda \cdot t} \tag{3}$$

The LED backlight lifetime could be defined according required light output luminance (lumen maintenance). In addition, LED backlight color shift (chromaticity coordinates changes) could be set as criteria.

The IES LM-80-08 [21] define lumen maintenance and LED luminaire lifetime prediction setting desired depreciation of 70% or 50% and limited time testing (6000 hours) under defined conditions. Using test results and defined method of calculation based on Arrhenius' model the life time could be determined. All standards related to LED luminaire lifetime could be applied on LED backlight, too. Currently defined LED luminaires lifetime determination do not consider color shift as factor influencing "end of life".

In the case of LED backlight allowed lumen depreciation rate could be different than generally defined for LED luminaires, depending on Display application requirements, but the same testing methodology could be applied. Also, LED backlight color shift (chromaticity coordinate tolerances) could be strictly defined depending on display application. Usually, chromaticity tolerance for display is set to 0,05 for both chromaticity coordinates, meaning that defined chromaticity should be inside circle of radius 0,05 around nominal value during LED backlight lifetime.

IV. EXPERIMENTAL SET-UP

During experimental backlight lifetime testing, the simple experimental set-up was used consisting of:

- Integration box – internally covered by high reflectivity layer (Kimoto paper) aimed to collect emitted light.
- Photometer – Minolta CS100 for light output luminance and chromaticity measurements.
- IR thermometer – used for LED backlight temperature measurement during test
- Power supply unit – providing required LED biasing power.

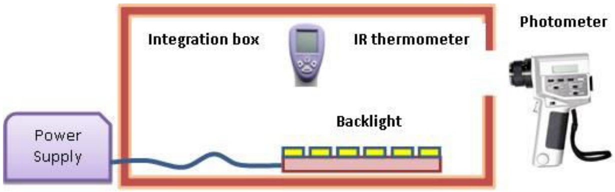

Figure 2. LED backlight lifetime measurement integration box measurement set-up.

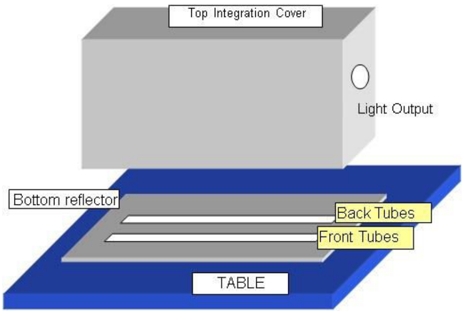

Figure 3. CCFLtube backlight lifetime measurement integration box measurement set-up.

The selected basic data on LED backlight properties used in test are presented in TABLE 1.

TABLE I. LED BACKLIGHT BASIC PROPERTIES

No	**Backlight basic properties**	
	Type	***Description***
1	ARC 3	There are two sets of five tubes, placed in parallel.
2	4ATI	There are 8 rows of 4 LEDs in series. • red LED driving current is 19 mA, what is about 27% of the maximal rating (70 mA) • green LED driving current is 27.5 mA, what is about 55% of the maximal rating (50mA) • Blue LED driving current is 28.2 mA, what is about 56% of the maximal rating (50 mA) • White – NVIS LED driving current is 18.5 mA, what is about 92% of the maximal rating (20 mA)
3	ATK	There are 24 White LEDs connected in parallel. • LED driving current is about 100 mA, what is approximately 30% of the maximum rating

LED backlights used in the test were slightly "over designed" using driving currents and applied thermal management to provide as long as possible backlight lifetime. It was reasonable approach because at the moment of LED backlight design there were not enough data or experimental results regarding LED lifetime.

The experimental set-up and backlight lifetime test were designed as natural aging test [35], using related drivers or LED driving conditions as in real display and lasting until backlight failure.

V. EXPERIMENTAL RESULTS

The presented test results could be useful as qualitative data showing only some influences and trends of LED backlight lifetime. These results could not be used for quantitative calculations and LED backlight life time predictions. These results could be useful as a guide for future tests planning.

The relative luminance of the CCFL tubes during the test is presented in Figure 4, and recorded color shift values are presented in Figure 5.

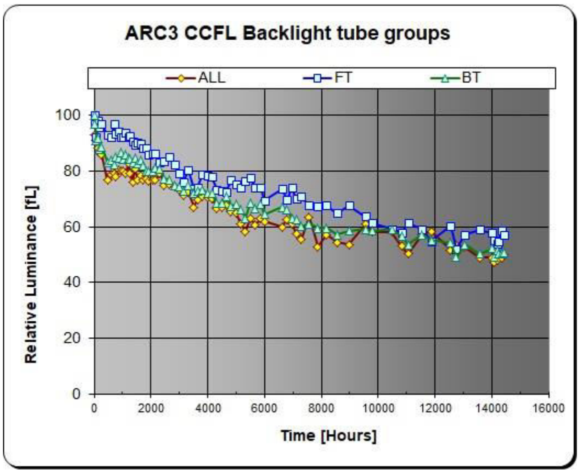

Figure 4. CCFLtube backlight relative luminance changes during test.

The relative luminance depreciation show that 50% depreciation is achieved after 14000 hours what was known as CCFL backlight lifetime that is normally achieved.

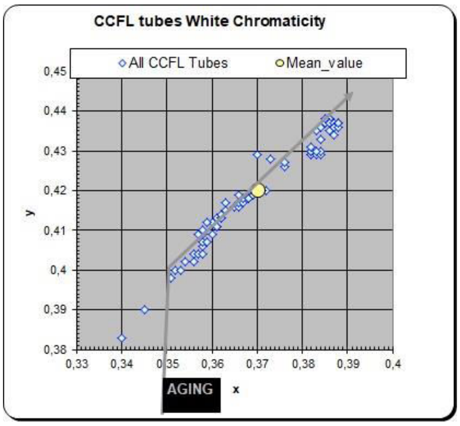

Figure 5. CCFL tube backlight chromaticity changes during test.

The CCFL tube white point chromaticity change during the test was kept inside chromaticity tolerance circle.

The relative luminance of the 4ATI multicolor LED backlight during the test is presented in Figure 6, and recorded color shift values for selected colors are presented in Figure 7.

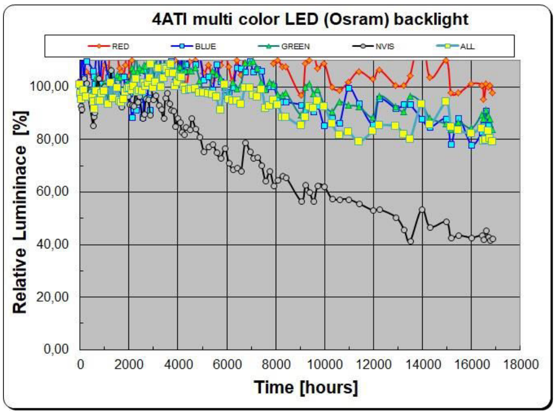

Figure 6: 4ATI LED backlight relative luminance during the test

The relative luminance depreciation show that 80% depreciation is achieved after 18000 hours for R, G, and B LEDs, but white NVIS LED deteriorated to 40%.

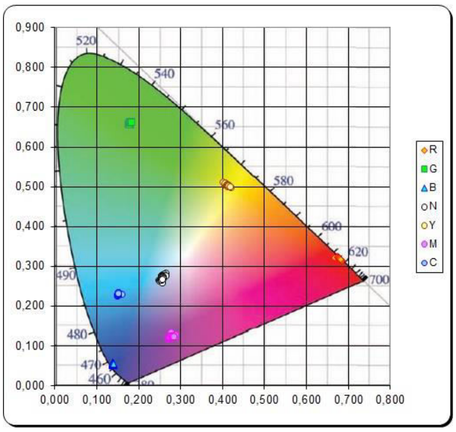

Figure 7: 4ATI LED backlight chromaticity changes during the test

The 4ATI chromaticity change for selected colors (white red, green, blue, cyan, magenta, and yellow) during the test was much less than related chromaticity tolerance circle.

The relative luminance of the Lumileds LED backlight bar during the test is presented in Figure 8, and recorded color shift values are presented in Figure 9.

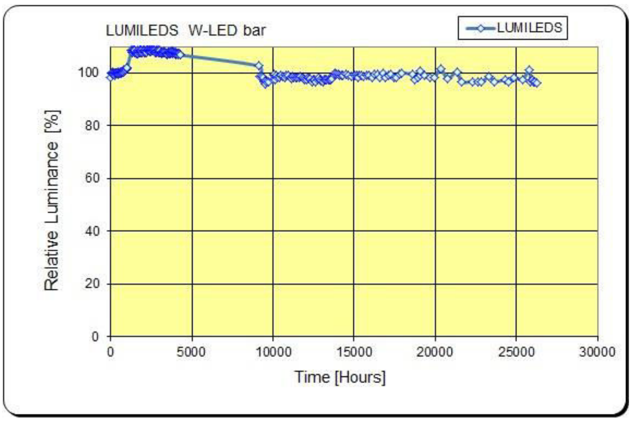

Figure 8: ATK LED backlight relative Luminance values during the test

The relative luminance depreciation show that 5% depreciation is achieved after 26000 hours showing that Lumileds LED backlight have really long lifetime.

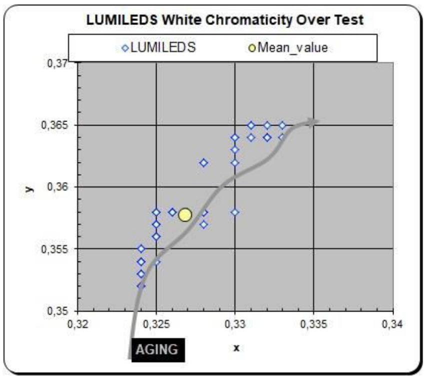

Figure 9: ATK LED backlight white point chromaticity coordinates change during the test

The ATK LED backlight white point chromaticity change during the test was kept inside chromaticity tolerance circle.

VI. DISCUSION

ARC 3 (CCFL) backlight lifetime data collected during this test confirmed known data regarding CCFL lifetime, and accordingly application of the test methodology. On the other hand it shows that application of the LED backlight could be beneficial in the case when long lifetime is desired.

4 ATI backlight design provides a lot of LEDs in small volume so backlight PCB temperature is about 50°C when backlight is on, meaning that all LEDs are driven at elevated temperatures. To provide proper white point chromaticity R, G, and B LEDs are driven at different currents. One can see that red LEDs are driven at lower current so luminance depreciation rate is smallest. The white, NVIS LED in real application will not be on when RGB LEDs are on so its normal operation

temperature will not be elevated. Because of that high depreciation rate do not represent real NVIS LED lifetime.

The ATK backlight is the oldest LED backlight using the first series of the Lumileds high power white LEDs. In this case, the backlight design uses relatively low driving current and excellent thermal management. Because of that the backlight luminance depreciation rate is very low.

LED backlights testing results show that proper compromise between light outputs specification, thermal and power management capabilities was achieved to provide long life using LED backlight optimal operation conditions. In the case of ruggedized displays project budgetary constraints do not limits technical solutions.

VII. CONCLUSIONS

LED backlight is illumination system, so it is very important to have accurate system model accompanied with application conditions profile for LED backlight lifetime prediction. The application condition profile should identify necessary features but do not essentially have to be accurate in all details.

In this paper a simplified general theory applicable for LED backlight lifetime assessment is discussed. This theory is related to accelerated aging test application on LED backlight lifetime estimation. Modern standard procedures for LED luminaries' life time are based on this theory.

The experimental results presented are generated as natural aging data at room temperature operation. These results show LED backlight lifetime only in those conditions. There were not enough additional data to extrapolate this data to other application condition. These qualitative test results show that LED backlight has a long lifetime but the application of the other techniques as accelerated testing, described in modern standards, is necessary to provide LED backlight lifetime assessment after a test procedure is applied during reasonable test time.

LED backlights nowadays dominate in LCD display applications, providing long lifetime and stable operation. For backlight design all the principles defined for solid state lighting [36], [37] could be applied, together with lifetime prediction standards, providing optimal results for lifetime and cost.

ACKNOWLEDGMENT

This work was done during BL engagement with Luxel Technologies, Toronto, Canada.

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