Considerations regarding LED lighting concepts for high-quality white-only applications

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Abstract:

General cabin illumination for aircrafts has been and is still constantly changing over the last years: Starting from functional oriented fluorescent tube lighting, passenger comfort is receiving increasing attention. Introduction of smart RGB lighting schemes drives the realization of mood lighting systems which is supporting a pleasant atmosphere during flight by supporting the passenger's biorhythm with sophisticated lighting scenarios. In addition mood lighting can be used for airline branding aspects (corporate identity) to differentiate from the competition. These sophisticated all-LED mood lighting RGB solutions are realized for long-range aircrafts such as the Boeing 787 or the Airbus A350XWB.

Nowadays a further trend to replace fluorescent lighting for single-aisle short range aircrafts with all LED white-only lighting applications is present, driven by the need to reduce the fuel consumption of air transport and subsequently to reduce power consumption which is accompanied by the development of new LED technology with higher performance and efficiency. It is the challenge in developing white-only lighting applications to target the right balance between achieving quality requirements for cabin lighting and strong commercial requirements what will be the focus of this contribution.

Introduction

Especially if only monochromatic light is considered different technical options are viable, each one having its pros and cons, as they are putting different emphasis on the well known characteristics of LEDs such as aging in terms of color and brightness, varying initial performance depending on production statistics and in general operational characteristics depending on ambient conditions.

It is a matter of fact that virtually no LED is identical to another. Each and every LED shows deviations from the intended performance properties due to influences during the production process. In order to overcome this issue the LED manufacturer sell their products in classes (typically called binnings). LEDs within a bin are characterized to be between a minimum and maximum boundary for a certain parameter. Typically LED bins are classified in terms of lumen output at a certain current density (equivalent to efficiency), forward voltage (depending on the internal semiconductor threshold value) and emission color (bandgap and - in case of white LEDs - deviations in phosphor coating).

Besides performance differences following production variations and variances, LEDs are also known to change their emission behaviour related to either operational temperature or operation time, the latter one being referred to as aging. While changes in operational characteristics as a consequence of changes in the temperature are reversible in short-term, changes due to prolonged stressing are irreversible. Both effects are reflected in color and brightness alterations typically visible by the naked eye.

DC-Current Driving Realization

In the simplest case white-only all LED light fixtures consist of LED boards populated with white LEDs of a certain selection (one bin or selection of multiple neighbour bins) and extremely simplified electrical circuit with the possibility to control brightness via changing the magnitude of a static DC current as depicted in Figure 1.

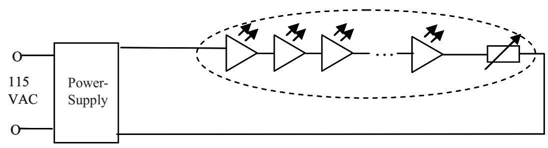

Figure 1: Schematics of a DC current driving circuit

In this realization the LEDs are used without any further selection as received from the LED manufacturer. By use of a calibration resistor (as depicted in Figure 1 brightness variations in different LED chains caused by different luminance bins are avoided. Since all LEDs are linked together in a chain without any possibility to attenuate single LEDs in the chain, color and brightness accuracy depend completely on the quality of the selected LED bins with respect to color and luminance.

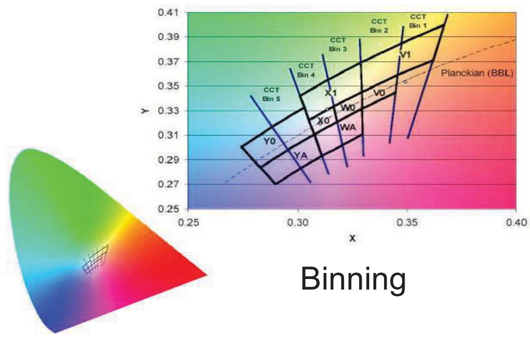

Figure 2: Color distribution

Figure 2 shows as an example the color distribution for a specific white LED. It is obvious that combining for instance V1 and YA binning in subsequent LED chains or even within an LED chain causes a severe inhomogeneous color distribution.

Dynamic change of brightness respectively dimming in the circuit in Figure 1 is obtained by changing the DC current fed to the LED chain. The effect of changing the LED current and thus changing the brightness level on the resulting color coordinate of the LED is shown in Figure 3 in terms of CIE 1936 color coordinates. The deviation exhibits a magnitude sufficient for recognition by naked eye.

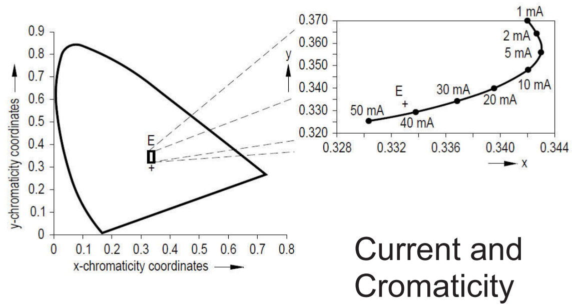

Figure 3: Color vs. Brightness

A further effect is shown in Figure 4 where the color coordinates change over time as well as the brightness level decreases with increasing stressing respectively with increased operational time of the LED. Whereas this effect is negligible for the first few thousand operational hours, there is a considerable brightness reduction well above 10,000 hours.

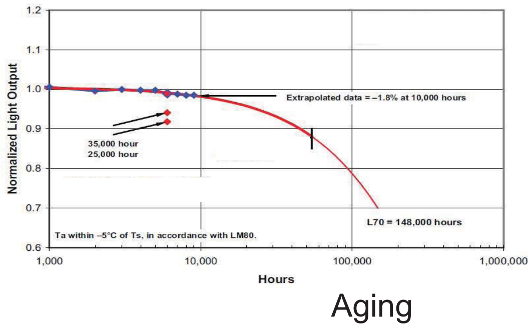

Figure 4: Brightness/Color vs. Time

Using a pulsed driving scheme

Going up the complexity ladder several of the properties shown before can be suppressed if the LED is powered constantly with the same current density. Ignoring aging and changes in the environment the operational characteristics of such an array would be constant. However on the other side the brightness level would be fixed without a possibility for dimming.

To overcome this problem while taking advantage of the stable performance at fixed current density, one can make use of the rather slow reaction of the human eye. If for example light pulses are emitted instead of a steady light stream the human eye would not recognize any difference as long as the frequency of the pulsed light is sufficiently high. Using frequencies in the range of hundreds of Hertz a – for the human eye – constant brightness level can be created while the LED is now operating in a digital chopped “on/off” mode at constant operational conditions (as long as aging is neglected) instead of an analog mode at a given current density.

This scheme of pulsed driving is typically referred to as pulsed-width-modulation (“PWM”). The deployment of PWM in an LED driving circuit is shown in Figure 5. The DC voltage as the output of the power supply is fed into the PWM modulator. Within the PWM modulator the time axis is divided into intervals with the length of *T*. Within *T* the DC voltage is switched on for a time period t_P. The duty cycle ratio D = t_P/T can vary between 0 and 100%, whereas the maximum value characterises the maximum light output of the system.

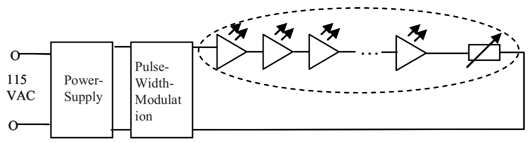

Figure 5: Schematics of a PWM driving circuit

As it can be seen in Figure 6, a pulsed driving scheme like PWM has an advantageous influence on the properties of the final light assembly: Whereas the LED current is constant, the color of the total device does not change. Nevertheless the brightness level linearly depends on the PWM duty cycle *D*, which can be easily controlled by a micro-controller. However, deviations in initial performance as well as any existing aging-impact remain present.

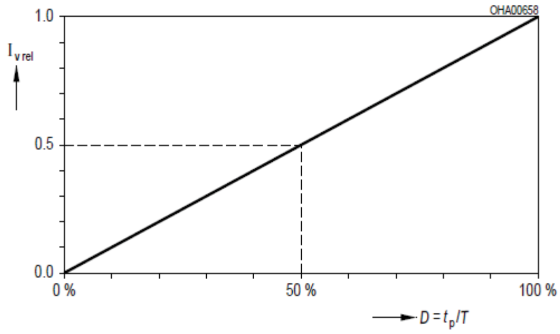

Figure 6: Linearity of duty cycle D vs. relative brightness level for a PWM driving circuit

Feed-back loop

In order to overcome the subject of aging the best possible solution is to use a compensation loop. This loop can either be based on the distinct knowledge about the device's performance at a given time or the measurement of actual performance.

In both cases a feedback loop is established. To compensate aging the initial maximum brightness level of the LED lighting system is reduced by a factor equivalent to the brightness reduction at the assumed end of life of the system. Using the feedback loop the initial brightness reduction is gradually lowered equivalent to the actual status of the LED brightness reduction, which means that the maximum PWM duty cycle of 100% is reached at the end of life.

In the "timer" based version the information to be fed back is the cumulated operation time (integral of time multiplied by driving current). This information is processed via e.g. a micro-controller ("µC") storing the a priori – statistical - behaviour of the LEDs used in look-up tables. The timer input refers to a known degradation state being compensated by an increase in current pulse-width to regulate the brightness level back to initial state.

In the "sensor" based version the same idea is realized however using an active measurement of the LEDs' actual performance instead of statistical pre-known data. Here e.g. a photodiode is used to monitor the actual brightness and to adjust the current density back to initial value by means of PWM.

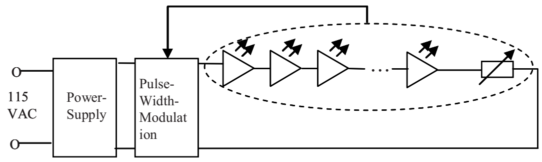

Figure 7: Schematics of a PWM driving circuit using a feed-back loop

As to be noted in Figure 7 the brightness of the final device can be stabilized over time to a certain extend. The feedback loop together with the PWM driver is able to compensate the brightness degradation as long as it is possible to further enlarge the driving pulses – therefore the maximum time of constant operations is depending on the maximum increase of pulse width (design issue) and time dependency of the degradation. Nevertheless besides the impact of color degradation and initial binning, the final device can provide a truly stable performance over a long period of time.

Multi-color device

In the last section of this contribution also the challenge of color is addressed. Color – at initial state as well as during operation – can only be changed by default as long as at least two different colors can be mixed and therefore operated separately. Consequently, if the color is to be influenced more than one independently operating LED color must be available within the device like shown in Figure 8. The distance or area between the two or three colors respectively (referred to as primaries) e.g. in a CIE 1931 diagram, denotes the array of potential colors to be adjusted.

Using such an arrangement of two or three primaries in the device the same considerations of using feed-back loops applies as discussed in the previous chapter. Again the color can either be controlled on the knowledge of statistic behaviour and given stress level as well as using active sensory to benchmark the actual performance.

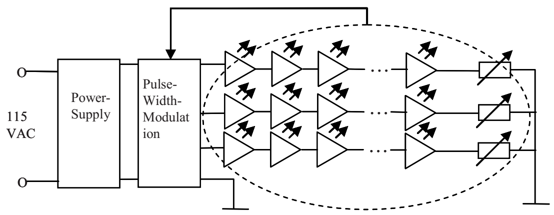

Figure 8: PWM current driven LED assembly with feed-back loop using multiple LED primaries

Conclusion

In this contribution it has been pointed out that several technical realizations do exist in order to create white-only lighting solutions each of which having different levels of complexity and resulting operational characteristics.

Any of the above shown implementations create its own distinct level of complexity vs. resulting quality/performance therefore all having unique cost-benefit ratios. The decision which kind of implementation to chose is subsequently depending on the demands of the application. I.e. in an application where the total time of operation is comparably low but color homogeneity is of highest interest a different circuitry may be chosen than in a case where long term operation performance is ruling the technical implementation.

The above shown variants span a huge variety of potential resulting performance level all having its benefits, distinct advantages and complexity. However, in the understanding of the authors no solution is given that should be neglected or declared as standard as different application needs give rise for different solutions – especially if seen across different industries.

Nevertheless all of the above mentioned issues depend on the initial performance and the operational characteristics of the LEDs. As progress in LED technology can be expected a different view on the picture may be applied in the future regarding these challenges.