Dimming control of LEDs

Abstract: Many solid-state lighting applications require control over the emitted intensity of light for both functional and aesthetic requirements. Some of these applications also require a full dimming capability from fully on to fully off. This paper looks at the two main methods for implementing these and discusses the advantages of such approaches.

Introduction

There are two methods generally used to reduce the intensity of the light emitted by LEDs

- Current reduction
- Pulse reduction

Each method has its own benefits and drawbacks, and so for each application it is important to identify the critical characteristics. In this way the dimming methodology which is best suited to the task at hand can be determined.

Dimming Methodologies

Current Reduction (CR)

Current reduction (also known as analog or linear dimming) works by driving the LED at the lowest possible forward current and voltage point in order to achieve a desired light output. Current reduction requires a very accurate current control to be effective, and so unless you choose the right controller it can be somewhat difficult to implement.

Pulse Reduction(PR)

Pulse reduction is achieved by switching LEDs fully-on and fully-off at a frequency greater than the human eye can perceive. For a stationary light source this is 100 to 120 Hz, a moving light source requires a higher frequency in order to avoid a strobing effect. As long as the frequency is kept above this 'flicker fusion threshold' the eye integrates the pulses and so perceives a steady but dimmer light source which is roughly equal to the pulsed brightness averaged over time. If the frequency is any lower the eye will be able to see the individual pulses. Pulse reduction is the most common approach to dimming as it is simpler to implement than current reduction

Within pulse reduction there are three different methods of pulse reduction:

1. Pulse width modulation (PWM): A constant current pulsed at variable pulse duration and at a constant frequency.
2. Pulse frequency modulation (PFM): A constant current pulsed at fixed pulse duration and at a variable frequency.
3. Pulse code modulation (PCM): A constant current pulsed at random pulse durations.

The luminous output of an LED is directly proportional to the duty cycle (or 'on time') that the LED is driven at. Therefore by varying the duty cycle from 0 to 100%, the luminous output is also scaled from 0 to 100%. PWM is by far the most common method currently used for LED pulse dimming, but PFM dimming possesses a number of properties that will be discussed later that could prove to be very useful in certain applications. PCM is not a widely used method.

Current reduction vs. Pulse reduction

There are several pertenant points on which either current or pulse dimming methods can be compared. These are efficiency, colour fidelity, resolution, stability, reliability and EMI. We look at each of these in the sections below.

Efficiency

When driven at full power (pulse reduction at 100% duty cycle and current reduction driven at full current) the two methods are more or less identical in terms of power consumption.

However, since the efficiency of driving LEDs is higher at lower current levels (due to LED self-heating), current reduction always operates at the highest possible efficiency. Pulse reduction always operates at a fixed higher current level (and therefore operates at a relatively constant, higher *instantaneous* self-heating level), it will operate at a relatively constant, lower efficiency, regardless of the duty cycle.

As can be seen in Figure 1, the decrease in intensity due to self-heating is the smallest, and so possesses

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the best efficiency levels. The reduction in intensity due to self-heating in PFM mode is smaller than in the PWM mode, and in fact is almost linear. The reason for becomes apparent when comparing the heating profiles of PFM and PWM (Figure 2).

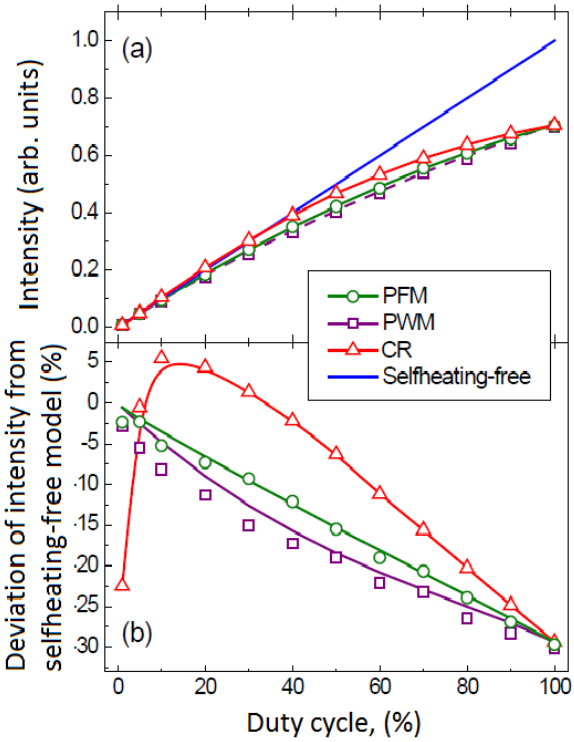

Figure 1: Output Characteristics Under Different Driving Modes [1]

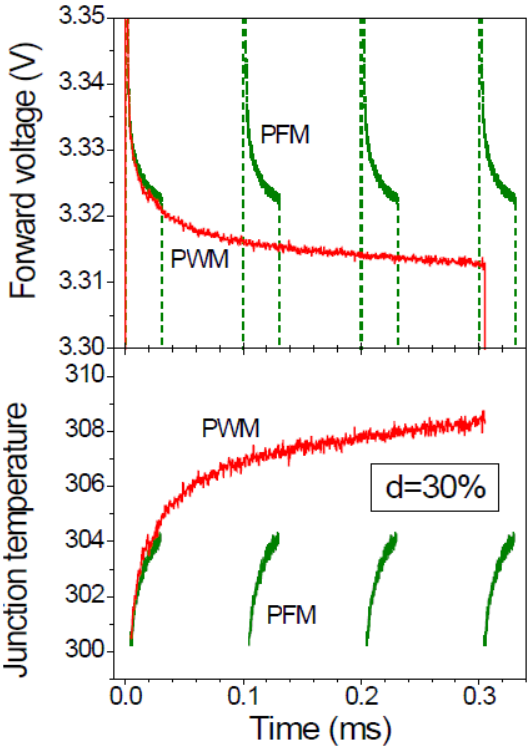

Figure 2: LED Junction Temperature [1]

Since the PFM dimming method uses constant current pulses with constant pulse duration, the instantaneous junction temperature due to self-heating is relatively constant. This means that the deviation from the self-heating free model is almost linear. The PWM dimming method does not use constant pulse duration. During longer pulse durations, the more sustained self-heating will lead to slightly higher junction temperatures than shorter duty cycles. Since the instantaneous temperature varies with differing duty cycle, the deviation from the self-heating free model will not be linear, and the higher junction temperatures mean a slightly lower efficiency.

Colour Fidelity

The colour of the light emitted from an LED is dependant on its wavelength, and so depends in turn upon the band gap of the LED. The band gap is proportional to temperature and so can be altered by different junction operating temperatures. The junction operating temperature itself is, of course, raised by self-heating. Therefore, if self-heating is kept at a constant level, then the wavelength of emitted light will also be kept at a constant level (this is only if very robust heat-sinking is used so that a build up of heat does not occur.)

Self-heating is linked to the efficiency of the LED. As efficiencies increase, the self heating effect is reduced. It then follows that the dimming methodology that results in the greatest efficiency change will also possess the largest change in wavelength, and spectral shift.

Current reduction constantly operates at the most efficient point possible. That means that there is a distinct increase in efficiency as the LED is dimmed, leading to a reduction in self-heating. This will increase the band gap energy, shortening the wavelength of the emitted light. As can be seen in Figure 3, the dimming method with the most pronounced shift as it is dimmed from 100% is current reduction, only levelling off when close to 0%.

When using current reduction it is also important to consider the binning method used by the manufacturer. Since it is impossible to create two LEDs that behave identically in all conditions, LEDs are binned due to their behaviour at a set test current level. The implication of this is that LEDs can behave very differently at current levels other then this specific level. This can become particularly evident at very low current levels, when

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some LEDs may turn off while others continue to emit light.

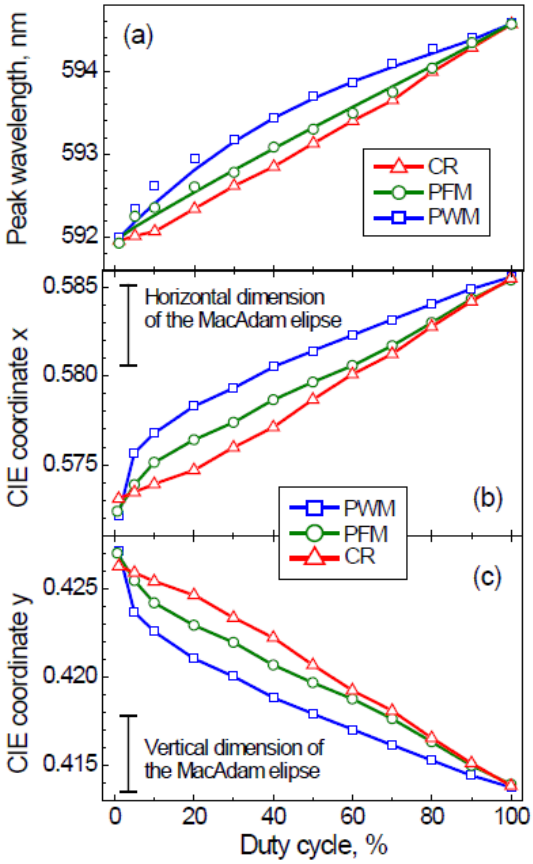

Figure 3:Wavelength and Chromaticity Shift [1]

Theoretically, since PWM dimming maintains a constant efficiency throughout the whole dimming cycle, the level of instantaneous self heating should also be kept constant, and so the emitted light should have a constant wavelength. In reality, the time taken to heat the LED introduces a lag in the temperature profile (see Figure 2) which forms a greater proportion of the pulse duration as the duty cycle decreases. This will lower the junction temperature, and rapidly change the wavelength close to 0% duty cycle.

Finally, PFM dimming is made up of many pulses of a fixed duration of whose frequency changes as the duty cycle decreases. The lag in heating is therefore constant throughout the whole dimming cycle, and so the temperature will decrease linearly. As the temperature decreases linearly, so too will the wavelength of the emitted light and the shift in chromaticity.

The advantages that PFM has over PWM dimming are then:

- Higher efficiency of emission (due to reduced junction temperature).
- Raises the possibility of feed-forward temperature compensation due to the linear nature of output flux and chromaticity shift in relation to duty cycle.
- The reduction in heat will also result in improved lumen maintenance.

These results assume an ideal heat sink, and so the better the heat management used with any of these methodologies, the more reduced the effect of temperature dependant spectral shift.

Also, an important point to remember is that the majority of high-brightness white LEDs consist of a high power blue LED emitting photons through a coating of yellow phosphor. A portion of the blue photons that hit the phosphor coating are absorbed and the phosphor then spectrally down-converts them and re-emits them over a wide spectrum. When these photons are mixed with the blue photons that make it through the phosphor coating, white light is generated. An example of this is shown in the spectral power distribution chart (a chart that depicts the radiant intensity of a light source across the visible spectrum) seen in Figure 4.

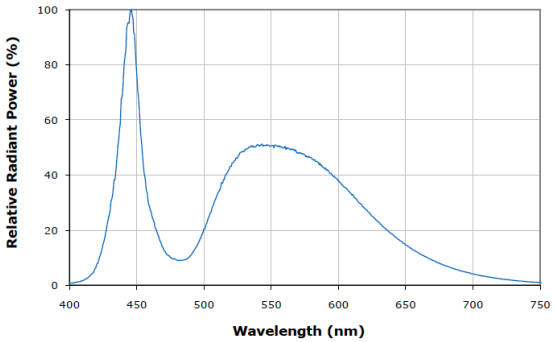

Figure 4: Cree XM-L Spectral Power Distribution [2]

At low currents, the photons emitted by the phosphor dominate and so the light emitted will have a more yellow chromatic appearance. At higher currents, the brightness of the LED will intensify, the blue emission of the LED will dominate, and the light source will be bluer in appearance. This means that the spectral shift of the light emitted by current reduced white LEDs will be more pronounced than the temperature shifted wavelengths alone would predict.

Since pulse reduced LEDs emit light in pulses of constant intensity, this problem does not arise.

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Resolution and Stability

The resolution of pulse reduction is dependant on the accuracy of the pulse width in relation to the cycle time. The resolution of current reduction depends on the resolution of the control signal.

Stability can be achieved through the use of feed-forward or feed-back loops. The linearity of PFM dimming greatly simplifies the use of these loops.

Reliability

LEDs are very resilient, and generally do not suffer catastrophic failure. Instead failures in LEDs are defined as the time taken (on average) for LEDs to lose 30% of their luminous output. The mean time between failure (MTBF) for LEDs are generally somewhere between 50,000 and 100,000 hours.

If all manufacturer limits are met, then the main factor affecting LED lifetime is the level of heat, which is naturally linked to the level of self-heating and efficiency. It then follows that the most efficient dimming methodologies will result in the longest MTBF.

However, it is important to remember that since LEDs have such a large MTBF, that it is much more likely that the driver circuitry will fail, and so the most reliable solution will be the one with the most reliable driver circuitry.

EMI

Current reduction requires no pulse and so the only EMI generated will be from the power supply, which can be filtered and shielded to suppress noise.

The pulse reduced waveforms cannot be filtered as the edges must be relatively sharp in order to preserve accuracy of the dimming methodology.

Implementation

Figure 5: Excelsys drivers.

The Excelsys portfolio has a range of products available to the user to provide a solution for whatever the application requirements may be. We have constant current , constant voltage, and dimmable constant current models available in an extensive power range. These start at 25 Watts and continue up to 300 Watts. Your choice of dimming methodology should depend on the qualities that you consider critical to your application. If efficiency is of utmost importance, and slight chromatic shifts can be tolerated, then current reduction is the obvious choice. If colour fidelity is necessary than PWM dimming is probably the best way to go, with PFM representing qualities from both the other methodologies. Our constant voltage drivers can easily be adapted to dim using these two methods.

REFERENCES

[1] "Output Characteristics of Light-Emitting Diodes under Different Modes of Pulsed Driving", Zenonas Vaitonis, Andrius Stonkus and Arturas Zukauskas, http://next.utu.fi/2010/presentations/Zukauskas%2020101021.pdf

[2] "Cree XLamp XM-L LEDs Data Sheet", Cree

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