Driver Solutions for LED Backlighting

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Introduction

White LEDs (WLED) are increasingly becoming the light source of choice for backlighting applications due to their attractiveness in power efficiency and form factor. Display solutions in portable handheld systems like smartphones and tablets use LEDs for backlighting due to their higher reliability, lower DC operating voltage, higher color gamut, higher operating temperature range, localized light dimming control and higher system efficiencies.

Some key properties of the LEDs are:

a. The brightness of the LED depends on the current flowing through the LED. Figure 1 shows a typical plot for relative luminous intensity vs. LED forward current.

b. The LED requires a minimum voltage across it to sustain a specified current. Figure 2 shows typical plot for LED forward voltage vs. LED forward current.

A LED backlight system requires a driver solution which powers the LEDs with the desired current for a specified brightness while maintaining the voltage drop required for sustaining the current. A typical driver solution consists of a switching regulator system to efficiently power the LEDs. Additional circuitry may be required to gain fine control over the brightness of LEDs.

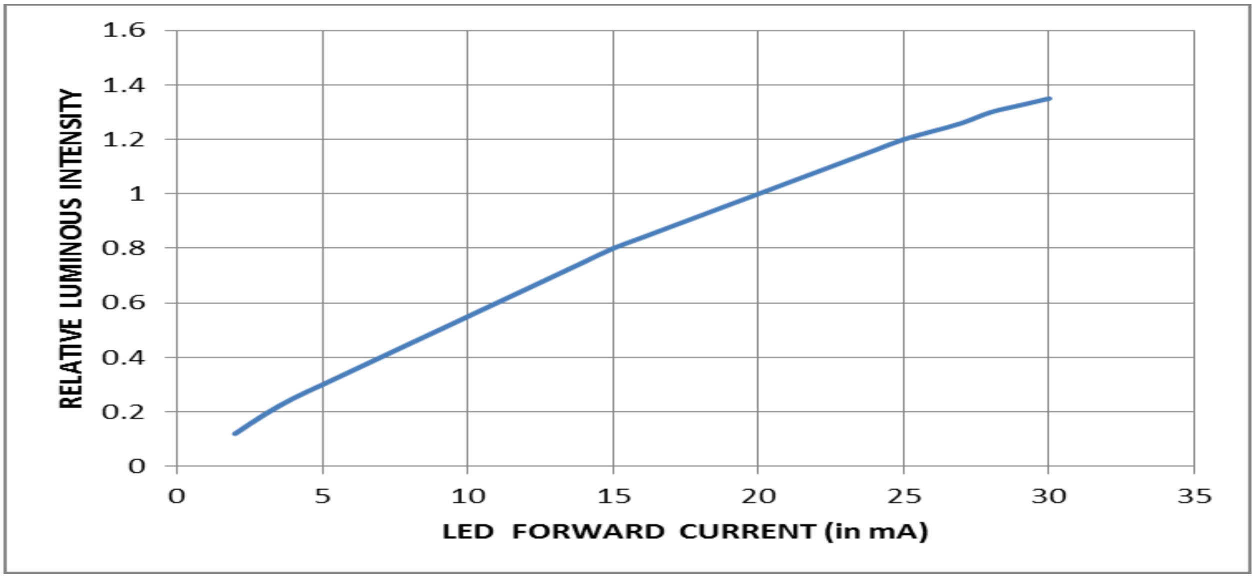

Figure 1: LED Relative intensity vs. Forward current

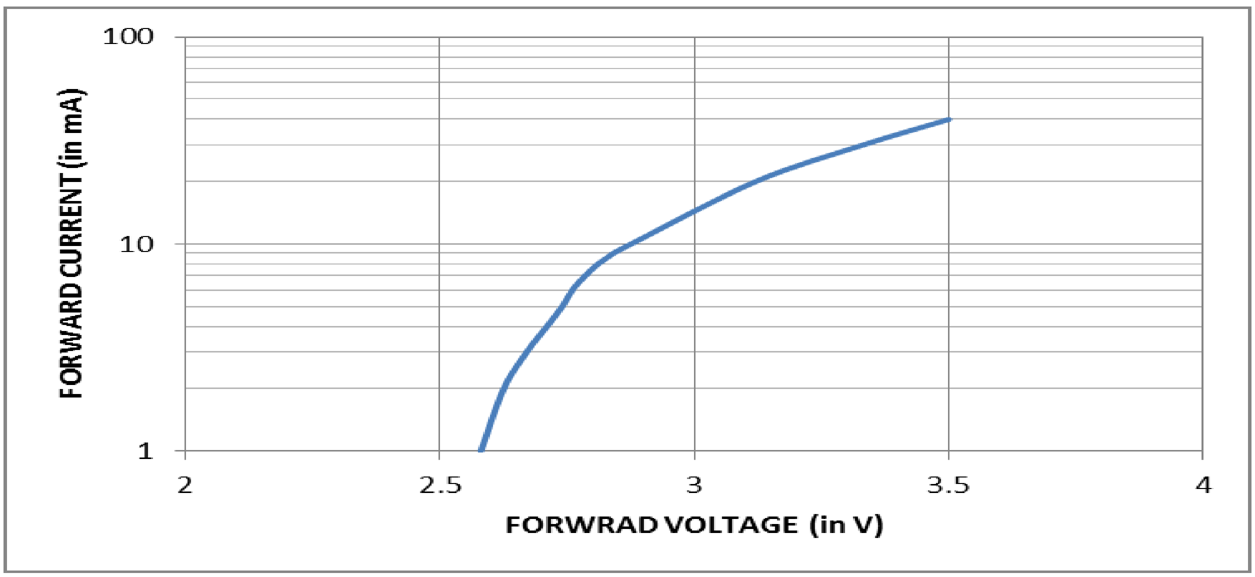

Figure 2: LED forward voltage vs. LED Forward current

This white paper looks into the design specifications and constraints for an LED driver for backlighting solutions. Architectural methods would be discussed to address these constraints.

System specifications

A typical LED backlighting system is shown in Figure 3. The number of LEDs required depends on the size of the display and the required brightness. As the brightness of the

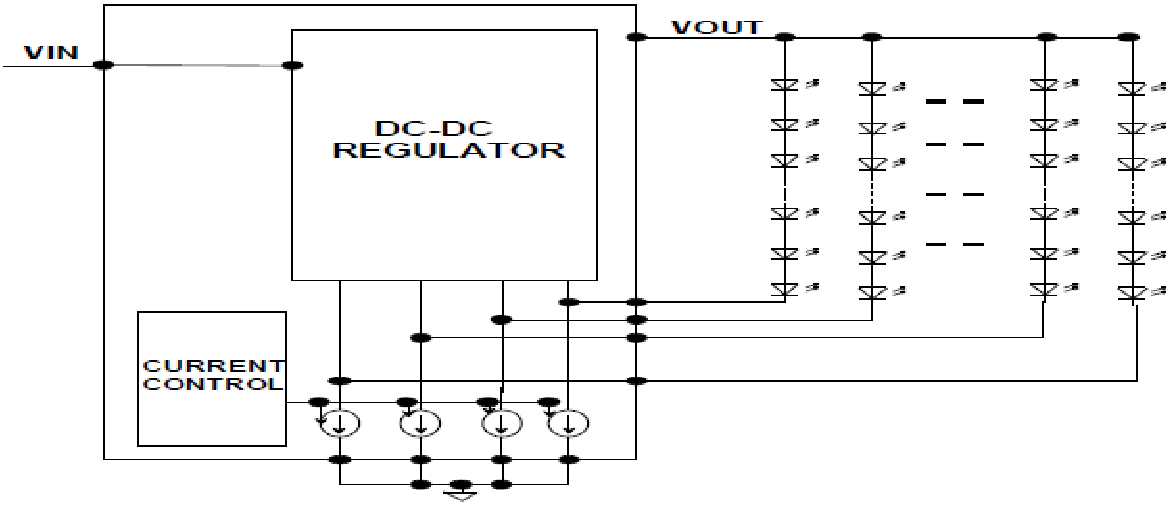

Figure 3: Typical WLED backlighting system

LEDs is proportional to its current, a controlled current source is used to regulate the current in the LEDs. Brightness control of LEDs is implemented either through directly controlling the magnitude of the current source, or through PWM duty cycle control whereby the current source is turned on and off at a specified duty cycle.

A combination of series and parallel connected LEDs form a grid of backlights. To maintain uniform backlighting, it is important that the LEDs provide same light across the strings. This implies that the current sources should be matched to very high accuracy. The accuracy needs to be ensured for mismatches in LED forward voltage, in addition to inherent mismatch in current sources.

The driver implementations utilize some type of DC-DC regulator to efficiently deliver power from supply to LEDs. Regulator efficiency as well as system efficiency becomes important specifications for design, both to improve power utilization and to reduce thermal constraints on design.

Thermal considerations for driver become important when the driver and LEDs are put together in a single casing. Color temperature describes the color of the LED and it changes with temperature. The LED light intensity also depends on temperature and degrades significantly with increase in temperature. Figure 4 shows a typical plot for

LED intensity vs. temperature. Care should be taken to ensure that the LED junction temperature remains within specified range for the required color temperature and light intensity. Increased converter efficiency helps reduce the burden on the thermal management system.

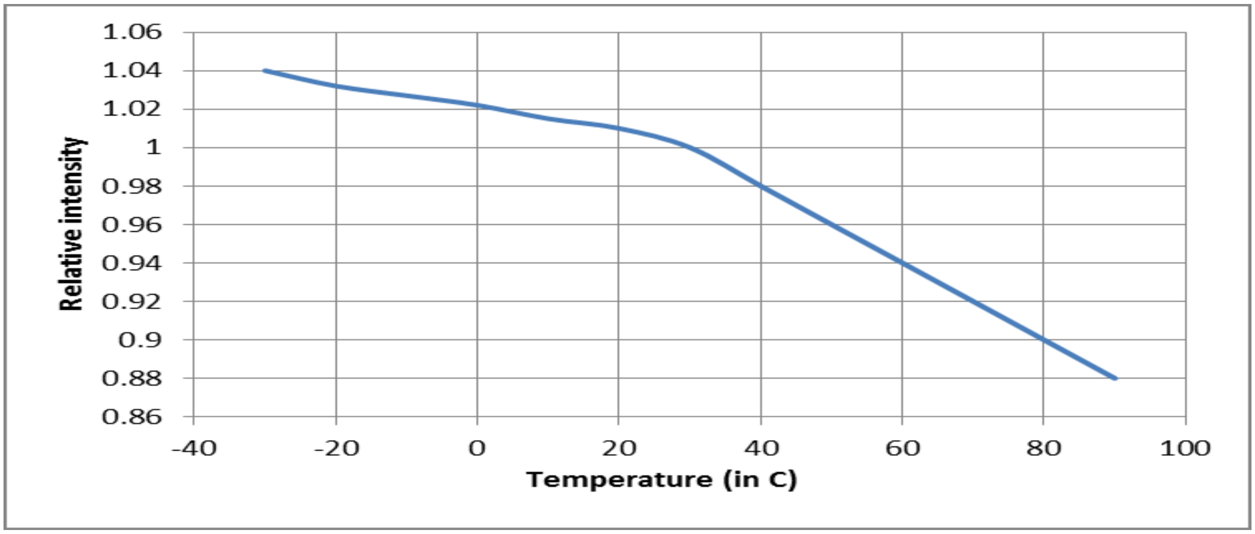

Figure 4: LED relative intensity vs Temperature

In addition to the above, LED driver solution needs to be tolerant to fault conditions like LED open/short failures.

Series/parallel LED configuration

The LEDs are normally realized in a grid of series/parallel connection. A WLED has a forward voltage in the range of 3.5V ~ 4.5 V for a forward current of ~20 mA. Putting more series LEDs in a string require a higher voltage requirement across a string. This implies a higher output to input ratio for the DC-DC regulator. Putting fewer LEDs in series require more parallel string which increases the output current requirement of the converter which again increases the loss.

Also putting a large number of parallel strings increases the number of connectors which in turn increases the cost.

The number of series LEDs in a string and the number of strings in parallel are decided based on the configuration which gives the best overall system efficiency and cost.

High Efficiency DC/DC Converter

The switching converter's design needs to ensure efficient and reliable operation of the LED driver. 7" -10" panel sizes commonly used in media interface devices normally use a grid of 18-36 LEDs. If the driver supports 6 parallel strings, this implies 3 – 6 series LEDs per string. As each WLED requires 3.5 -4.5V for carrying a forward current of ~20mA, the DC-DC converter should be able to support an output voltage range of 9V -28V. Normally in portable applications the supply for the driver is given from a single Li-ion cell which has a safe operating range of 3V- 4.2V. The driver needs to have a step up converter. The switching converter is realized either as an inductive boost or a capacitive boost. The type of switching regulator used depends on which one gives best efficiency for the no of LEDs used in the system.

Efficiency requirements require low switch resistance for switching transistor. Switching frequency of the order of 1-2MHz is used to reduce size of external inductor and capacitor elements. Reliability specifications like over-temperature and current-limit are incorporated into the design.

Current Control

The integrated LED current control circuits specify the minimum operating voltage required for the current sources to work. The circuit also needs to ensure that incase of LED shorting, leading to current source voltage rising to output voltage, the IC should not suffer damage.

The multiple strings of LEDs need to have matched currents to ensure uniform brightness. This translates to constraints on current source matching. Further, it needs to be ensured that all the current sources are biased at the minimum voltage required to reduce the loss in the current sources.

LED Brightness/Dimming Control

The two commonly used techniques for controlling the LED brightness is analog dimming and PWM dimming. Figure 5 shows the LED current profiles in these two types of dimming. Analog dimming is a very straightforward method where the LED string currents are changed based on a input voltage. In PWM dimming the LED current is pulsed between two known levels and the required brightness is achieved by controlling the duty cycle of the pulsed waveform. E.g. in Figure 5, for the analog dimming case the LEDs carry a DC current of 0.25*Imax whereas in the PWM dimming case the LED currents are pulsed between Imax and 0 with 25% duty-cycle to give an average LED current of 0.25*Imax. The kind of dimming technique used depends on the brightness range the driver needs to support.

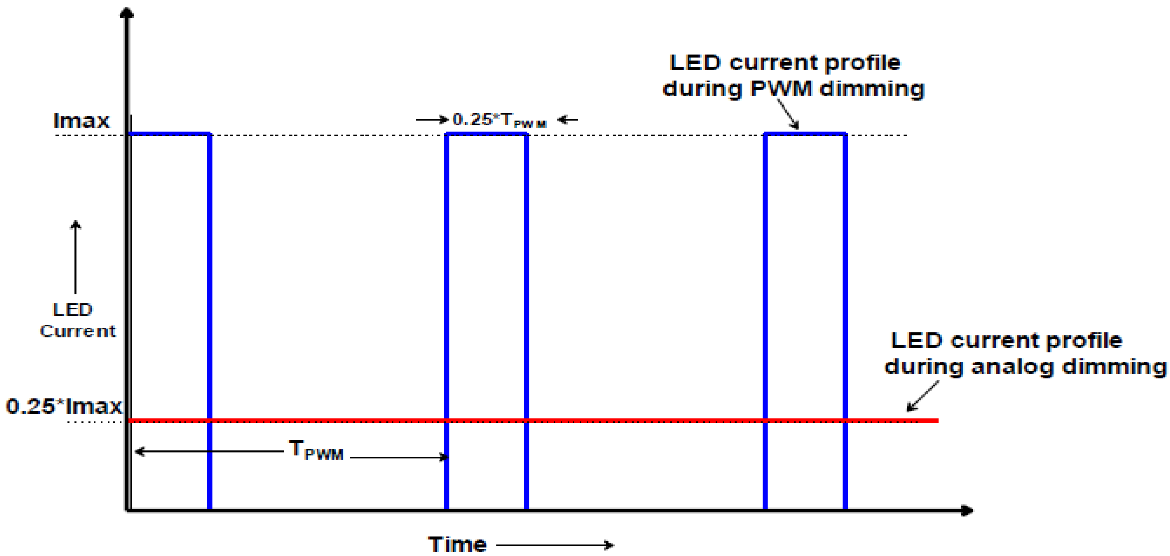

Figure 5: LED current profile

Analog dimming has a lesser range and is limited by the offsets present in the current sinks. The LED brightness to current relation may not be linear and hence analog dimming doesn't give a very accurate brightness control over a large dimming range. Also as the LED color temperature depends on the LED forward current, analog dimming exhibits visible color shift in the LED.

PWM dimming on the other hand can support a very high brightness range. The brightness to duty-cycle ratio is inherently linear in PWM dimming. The PWM frequency should be higher than 200 Hz to eliminate any visible flicker during PWM dimming control. PWM dimming can also create an unwanted audible noise due to the periodic charge/discharge of the switching regulator output capacitor. This is known as piezoelectric buzz and care should be taken in the PWM control implementation and the output capacitor dielectric choice to avoid this problem in the system.

Table 1 below compares these two types of dimming.

Analog Dimming	PWM dimming
Easy to Implement	More complex implementation - need to create a PWM signal
Dimming produces color shift across dimming levels	Color remains relatively constant across dimming levels
Relatively inaccurate brightness control as brightness and forward current has nonlinear relationship	Very accurate brightness control as the brightness is pulsed between a known brightness and zero.
Low dimming range	Very high dimming range
No flicker	Can have a visible flicker if PWM frequency is low(<200 Hz)
No piezoelectric buzz	Can have audible piezoelectric buzz if not designed carefully
Issues similar to any switching power supply	Can have additional EMI issues due to the current source turning on/off with fast rise/fall times

Table1: Analog Dimming Vs. PWM Dimming

Reliability Concerns

The driver should be protected against fault conditions like LED open/short and current source shorts. The current sources should be made tolerant to the maximum voltage possible at the regulator output to take care of LED short conditions. The controller should be able to detect an open LED in any of the strings to take that string out of the control loop. The controller should have a current limit to protect against shorts in the current sources.

EMI Concerns

The switching converters will be operating in the 1-2 MHz range and the switching waveforms can have very fast rise/fall times. This can create EMI issues in the system. Care should be taken in the PCB design to minimize the routing of the switching waveforms. Shielded inductors can be used in boost converters to minimize radiation from them. The input and output capacitors should have low ESR to minimize input and output voltage ripple.

Summary

As WLEDs become the predominant choice for backlights, care should be taken in designing the driver to achieve the best performance from the system. As the WLEDs' performance depends heavily on the thermal management, attention should be given to maximize the driver efficiency which in turn would reduce the burden on the thermal management system. Optimal dimming method should be chosen based on the application. The system should be designed to withstand LED open/short fault conditions.