Application Note AN14406

Temperature Compensation for High Brightness LEDs using EZ-Color™ and PSoC Express

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Software Version: PSoC Designer™ v. 4.2 or PSoC Express™ 3.0
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PSoC Application Notes Index

Abstract

This application note discusses the challenge of managing heat when designing with High-Brightness LEDs and describes a robust, code-free solution using EZ-Color™ HB LED Controllers and PSoC Express 3 Visual Embedded Design Tool.

Introduction

Due to advancements in solid-state lighting, many lighting applications are moving to color mixing high brightness LEDs (HB LEDs). These LEDs typically draw a minimum of 350 milliamps of current and dissipate large amounts of heat through the mounted surface of the diode, resulting in an unstable temperature environment for the HB LEDs. Since the output of HB LEDs change with temperature, designers must compensate to maintain the desired color by regulating the color or luminosity. This application note helps designers control the color through the use of an EZ-Color HB LED Controller and PSoC Express 3.

HB LEDs have 3 temperature dependent characteristics: dominant wavelength (color), forward voltage, and luminosity. In high-accuracy color mixing applications, knowledge of the precise dominant wavelength, forward voltage, and luminosity is required for accurate color mixing algorithms. Note that manufacturers characterize the luminous flux and dominant wavelength of high power LEDs at a rated current. If they operate at a different current, the color and flux will be imprecise or unknown.

Two High-Accuracy Solutions

There are two methods used to achieve high accuracy mixed colors over a temperature range. One method uses a junction temperature feedback loop and the other uses an optical feedback loop. There are two types of junction temperature feedback loops. One type uses the LED manufacturer's forward voltage bin information, while the other type actually measures the LED forward voltage. It is more precise to measure the forward voltage of the LED than to rely on the forward voltage bin. With flexible analog and digital resources, EZ-Color™ can implement both optical feedback as well as temperature compensation..

Optical Feedback

The accuracy of the optical feedback method depends on the quantization accuracy and detection accuracy, which are both characterized and published parameters. Quantization accuracy refers to the data converter accuracy and detection accuracy refers to the bandwidth and response of the photo detectors (usually red, green, blue, and wideband or ambient). The minimum, maximum, and typical values for each parameter are characterized for color sensors. Optical feedback produces the best results with least total error and also simultaneously solves binning issues with HB LEDs.

Junction Temperature

The junction temperature method of compensation is done using the manufacturer's measured data for luminous flux variations based on junction temperature. This temperature is estimated using the following equation:

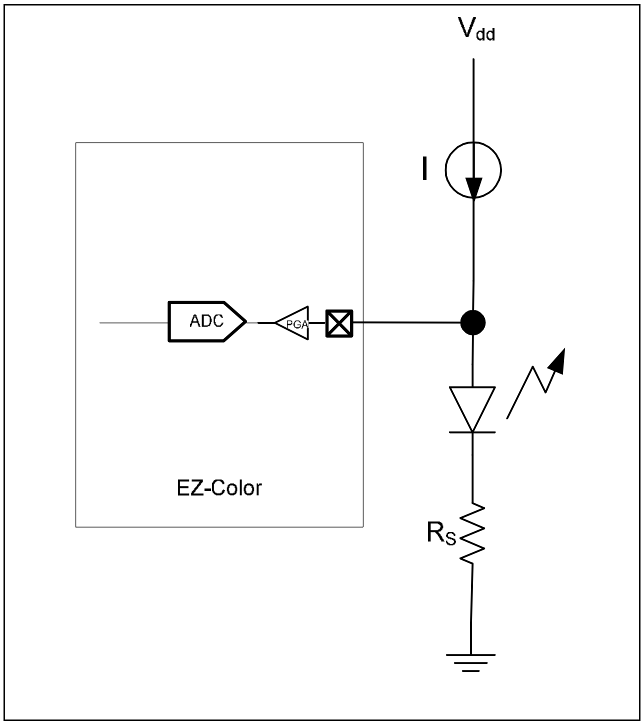
$$T_J = T_B + \theta_{JB} I_{LED} V_f \quad \textit{Equation 1}$$

T_J is the junction temperature, T_B is the temperature of the circuit board, θ_{JB} is the thermal coefficient for junction-to-board temperature, I_{LED} is the current through the LED, and V_f is the forward voltage of the diode. The LED manufacturer supplies the value of θ_{JB}, I_{LED} is a design parameter, the EZ-Color device and a thermal sensor measures the V_f and T_B values.

Forward Voltage

Change in junction temperature of the LED causes a change to the LED's forward voltage. The forward voltage can be approximated using the bin number of the LED or directly measured using an ADC (see Figure 1). In practice, the forward voltage usually changes very little with temperature and approximating the voltage will often suffice. In equation 1 above, T_B tends to dominate the sum and in most cases, θ_{JB} can be designed to minimize the effect of forward voltage on junction temperature. In cases where very precise control is required, EZ-Color can be easily configured to read V_F using an ADC with a Programmable Gain Amplifier.

Figure 1. Connection for Constant Current and Measuring Forward Voltage

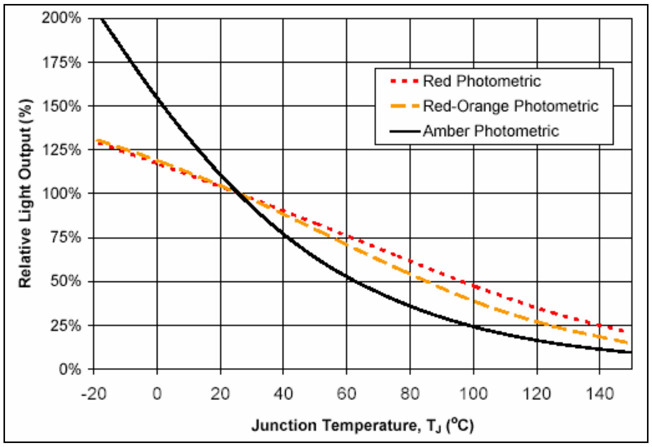


Since temperature does not change quickly and the range of potential values are limited, selecting an 8-bit ADC in PSoC Designer will enable sufficient resolution. From there, operating the ADC is as easy as calling on built-in API functions to calibrate, start the ADC, check for a data ready flag, get the data, clear the flag, and stop the ADC. Another option is to design with PSoC Express and use the pre-configured and pre-tested temperature compensation algorithm.

Luminosity Control

The relative light output varies between the different LEDs. For some of the devices, this parameter is non-linear, as shown by the amber trace in Figure 2.

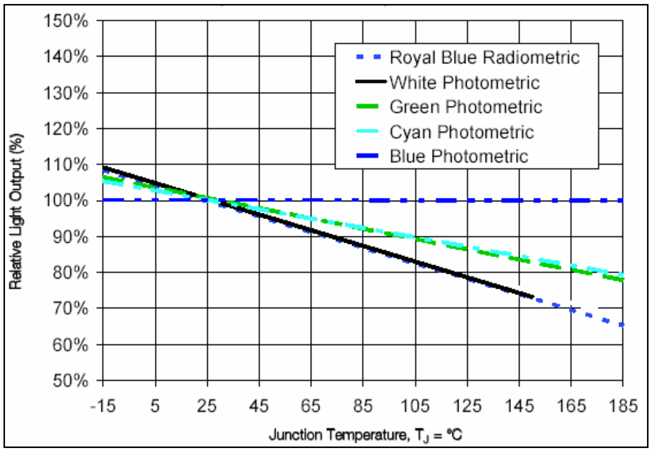
Figure 2. Relative Light Output vs. Junction Temperature for Red, Red-Orange, and Amber Luxeon® K2 LEDs



From 20°C to 110°C, the light output coefficient for these diodes is non-linear and requires the use of either a memory lookup table or a polynomial to calculate the light output from the junction temperature. For other LEDs, this coefficient can be estimated by using a linear equation. The red diode is relatively linear up to 130°C. Selecting the proper mix of diodes to create the desired colors can reduce the dependency on compensation due to temperature. Selecting an amber LED over a red LED increases the need for compensation due to the junction temperature.

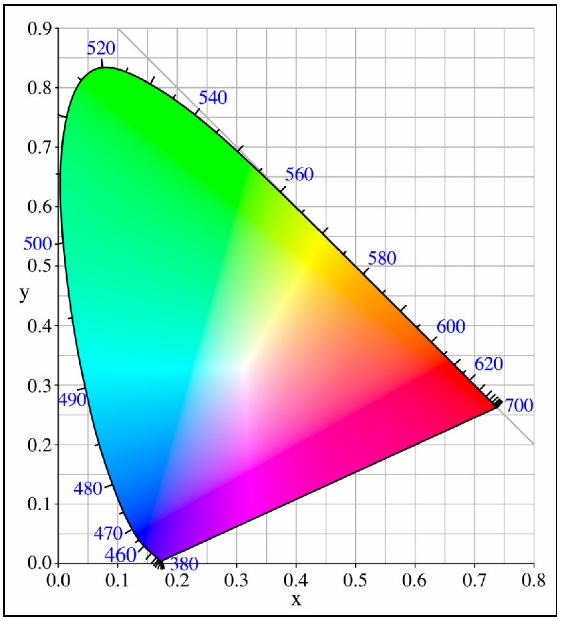
In some instances, the effects from the thermal changes are non-existent, as shown by the blue LED in Figure 3. Choosing a blue LED over the royal blue LED simplifies the processing that needs to be done to compensate for thermal effects.

Figure 3. Relative Light Output vs. Junction Temperature for White, Green, Cyan, Blue, and Royal Blue Luxeon K2 LEDs



The selection of the diodes needs to reflect consideration of not only the desired colors required from mixing several diodes but also the effects of each diode's thermal effects. If you are able to use the red photometric along with the blue and green photometric you can simplify the calculations required to compensate for temperature. With this selection, only two of the diodes require compensation and both are linear. Use the CIE chromaticity diagram to help select diodes that encompass the desired colors. Also keep in mind the effects on the light output from the thermal changes on the LEDs.

Figure 4. CIE 1931 Chromaticity Diagram



Dominant Wavelength

The wavelength of light that is emitted by the diode has a slight change in it due to temperature. When using the L2K2 - xxx2 - 11 series, LEDs from Lumileds™ have variations that are only 0.04 to 0.05 nm/°C and so that an overall variation of 100°C causes only a 4- to 5-nm shift in the dominant wavelength. Generally, the variations due to the manufacturing process are wider than variations due to temperature. The manufacturer uses bin numbers to reduce the effect of this.

Temperature Compensation (Luminosity)

Of the items that are affected by temperature the most noticeable change is the LED light output. This change is dependent on the LED selected to generate colors. Some of the LEDs, such as the blue shown in Figure 3 on page 2, do not need compensation because the luminosity does not change with temperature. However, others, such as the red and green, require different amounts of compensation. The green LED has a coefficient of -0.145 %/°C of full luminosity at 25°C. The red has -0.719 %/°C of full luminosity at 25°C. Therefore, the most temperature-sensitive color of these LEDs is the red.

Using Equation 1 on page 2 for junction temperature, a temperature sensor (the most inexpensive example being a thermistor) must be mounted to the PCB to measure the temperature of the PCB. This sensor must be placed as near to the LEDs as possible to ensure that the measured temperature is of the LEDs. Thermal joint compound, or solder, must be used when mounting the LEDs.

Calculations are performed using Equation 1 with the temperature sensor providing the board temperature, and the ADC providing the forward voltage and the current. The junction temperature is then calculated and the percentage change in the luminosity. After calculating the luminosity change for each LED, determine the adjustment to the PrISM (Precise Illumination Signal Modulation). See AN16035 and the associated firmware for a fully commented, detailed example.

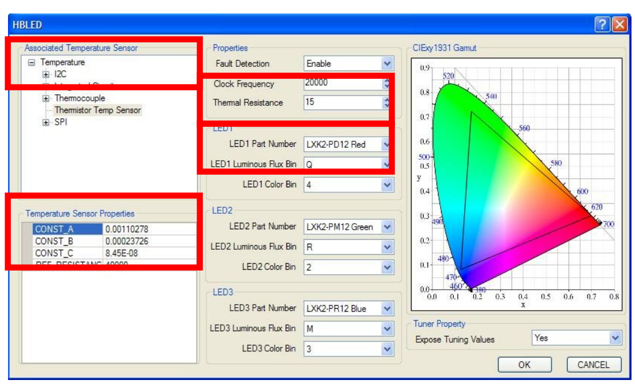
EZ-Color Implementation with PSoC Express

As this application note illustrates, grasping the effects of temperature feedback on LED performance and implementing an appropriate compensation algorithm in software can be very complex. Traditionally, setting up such an algorithm will require figuring out how to work with different temperature sensors, using an ADC or setting up a communication interface, and writing many lines of code that require a painful debug process.

Fortunately, customers designing with EZ-Color HB LED controllers can take advantage of PSoC Express to easily set up temperature compensation without writing any code. As the below screenshot illustrates, setting up temperature feedback is as easy as:

1. Choosing your desired LEDs and bin codes.
2. Picking the desired temperature sensor from the PSoC Express library and entering the temperature sensor parameters
3. Enter the thermal resistance (depends on your board design)

Figure 5. PSoC Express HB-LED Output Driver



To get started today, download the PSoC Express software at www.cypress.com/getexpress and purchase a CY3261A-RGB board at www.cypress.com/cypressstore to develop a robust high brightness LED design.

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