



## Application Note

AN15733

### ***Power Management - RGB Color Mixing Hardware For EZ-Color™ LED Controllers***

**Author:** Patrick Prendergast

**Associated Project:** Yes

**Associated Part Family:** CY8CLED16, CY8CLED08

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**Software Version:** PSoC Designer™ 4.4, PSoC Express™ 3.0

**Associated Application Notes:** [AN14406](#), [AN16035](#)

[PSoC Application Note Index](#)

## Abstract

This application note describes methods for driving multiple high power LEDs with EZ-Color™. Example projects using the CY8CLED16 EZ-Color device are included to demonstrate LED dimming and color mixing using the CY3261A-RGB demonstration board.

## Introduction

The solid state lighting industry is in the midst of rapid change and advancement. New developments appear almost daily. Because of these advancements and changes in solid state lighting, many lighting applications are moving away from fluorescent, halogen and incandescent lighting.

Solid state lighting includes high brightness LEDs, high power LEDs, and organic LEDs (OLEDs). For each new technology, LED driver requirements change and present designers with unique challenges. This application note is organized to help designers overcome these challenges by using EZ-Color devices. The appendix at the end of this application note describes some of the terms and units associated with the mathematics of light and color.

## High Power LED Considerations

High power LEDs have three temperature dependent characteristics:

- Dominant wavelength
- Forward voltage
- Luminosity

Working with high accuracy color mixing applications requires a detailed knowledge of the precise dominant wavelength, forward voltage, and luminosity to accurately

design color mixing algorithms. The rated current characterizes the luminous flux and dominant wavelength (color) of high power LEDs. If the LEDs operate at a different current, the color and luminous flux are imprecise or unknown.

There are two methods you can use to create highly accurate mixed colors over temperature. The first method uses a junction temperature feedback loop and the second method uses a color sensor feedback loop.

### Junction Temperature Feedback

There are two types of junction temperature feedback. One type uses the LED manufacturer's forward voltage data, such as the forward voltage bin. The other type 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.

### Color Sensor Feedback

The color sensor feedback loop method relies on the accuracy of the converter and the light bandwidth for each of the photo detectors (usually red, green, blue, and wideband or ambient). The accuracy considerations of the color sensor feedback loop are the data converter accuracy (quantization accuracy) and photo detector bandwidth (detection accuracy). Both considerations are characterized and published parameters. Because the minimum or maximum values for each parameter are characterized for color sensors and LED temperature

coefficients are only typical values, the color sensor provides a feedback loop with less total error. Still, the temperature feedback loop is cheaper and does not require precise optical design. EZ-Color devices can implement either high-accuracy mixed color method.

### LED Color and Light Error

There are several sources of error for LED color and light output:

- Junction temperature ( $T_J$ )
- LED forward current ( $I_F$ )
- Stress time, which refers to the LED flux output over time, junction temperature, and driver current

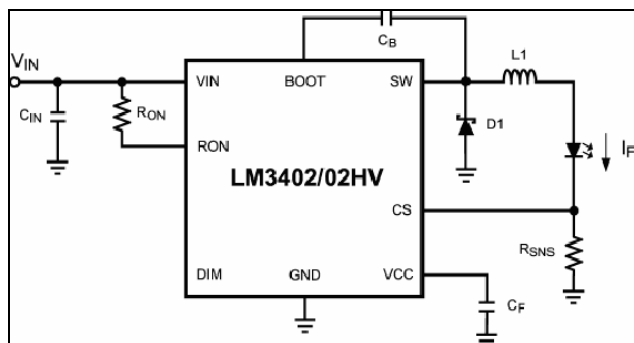
By driving the LEDs at a constant current, one source of error is eliminated. This simplifies the firmware design, reduces the burden (or CPU Load) on the controller, and enables faster calculations.

## Constant Current Driver

There are three basic circuit topologies for driving constant current into LEDs: linear, inductor based switching, and capacitor based switching. Use linear current drivers when efficiency and thermal design are less important than component costs. Inductor based switching circuits are the most versatile and efficient circuits, but also the most expensive. These circuits may be used to step up voltage, step down voltage, or do both, depending on the configuration. Capacitor based switching circuits, or charge pumps, are more efficient than linear circuits, and generally less efficient and versatile than inductor-based supplies. The CY3261A-RGB board uses National Semiconductor's inductor-based step-down converter, the LM3402, which is specifically designed for LED driving.

The LM3402 is a controlled "on" time hysteretic buck converter. It uses a grounded LED topology (Figure 1), which means that the forward voltage of the LED is referenced to ground. This simplifies the forward voltage measurement with an ADC. Forward voltage measurement is important and is discussed in the Temperature Measurement section.

Figure 1. LM3402 Schematic



The LM3402 buck converter operates by comparing voltage on a current sense resistor with a 200mV reference. If the sense signal is less than the reference, a comparator triggers a one-shot that turns on the internal

N-channel MOSFET switch for a set amount of time. The on-time is programmed by the input voltage and the  $R_{ON}$  resistor. By making the on-time dependent on the input voltage, the switching frequency can be held relatively constant. After the on-time has elapsed, the LM3402 turns off the switch for a minimum of 300 ns to ensure that the inductor does not saturate. After this minimum off-time has elapsed, the comparator commences sensing current.

The current sense resistor is set such that the LM3402 regulates the LED current to 350 mA. There are three LED controllers on the board for 1.05A of total LED current. Each LED has a forward voltage of about 3.7V which corresponds to about 4W of output power.

With 4W dissipated on the board, consider thermal issues in your design. For heat dissipation the LEDs on the CY3261A-RGB are thermally coupled to a heatsink. The LEDs have thermal slugs that are soldered to the PCB. The PCB has plated vias running to the opposite side of the board with copper planes used to spread the heat. Finally, a heatsink is attached to the board, using thermally conductive tape, to provide a low thermal-resistance path to ambient.

The EZ-Color connects to the LM3402 at the DIM pin. This pin accepts TTL logic level inputs that turn the buck converter control circuitry on and off. If the pin is driven at a frequency greater than about 60 Hz, the light emitted from the LED appears as if it is on continuously. The luminous flux output of the LED is proportional to the average "on" time, or signal density, of the waveform on the DIM pin. PrISM drives this pin high and low based on the state of digital peripherals. These peripherals include:

- Pulse Width Modulator (PWM)
- Precise Illuminated Signal Modulation (PrISM)
- Firmware state machine, such as an interrupt driven modulation scheme

The example projects in this application note use PrISM blocks.

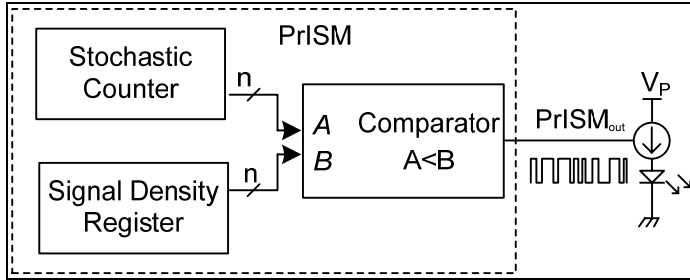
## LED Control for Color Mixing

By combining and diffusing the light from different color LEDs, a set of LEDs is able to create an array of colors. Intelligently create each new color by setting the luminous flux for each LED in the system, such that the combination of the individual colors is the same as the targeted color. The luminous flux output of an LED is directly proportional to the signal density that modulates the current through the LED. To determine the signal density, review the process documented in, *AN16035, Firmware - RGB Color Mixing Firmware for PrISM*. This section describes how to control the average "on" time or luminous flux of LEDs using PrISM blocks.

A PrISM block consists of a stochastic counter, a signal density register, and a logical comparator. When the value of the stochastic counter is less than the signal density register, the output is high. Similarly, when the counter value is greater than or equal to the signal density register, the output is low. To accomplish luminous flux control, the

output of the PrISM gates the DIM pin of the LM3402 as shown in Figure 2 (the LM3402 circuit is represented by a current source symbol).

Figure 2. PrISM Circuit



The SSDM method of dimming provides incentives over other dimming techniques such as PWM. One incentive is a reduction in radiated electromagnetic interference (EMI) as shown in the spectral plots for the respective signals (Figure 3 and Figure 4). PWM signals contain periodic edges that cause radiated EMI to peak at particular frequencies (the fundamental frequency and odd harmonics). SSDM signals have edges with random periods so the radiated EMI has peaks with lower amplitude (a 15 dBm improvement) and more frequency content.

Figure 3. PWM Spectral Plot

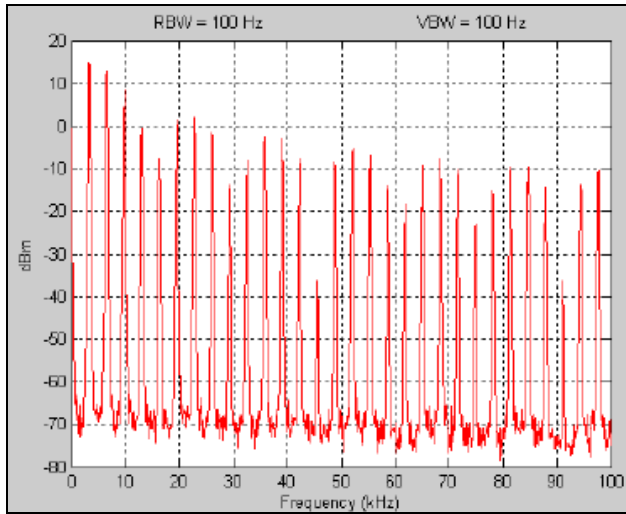
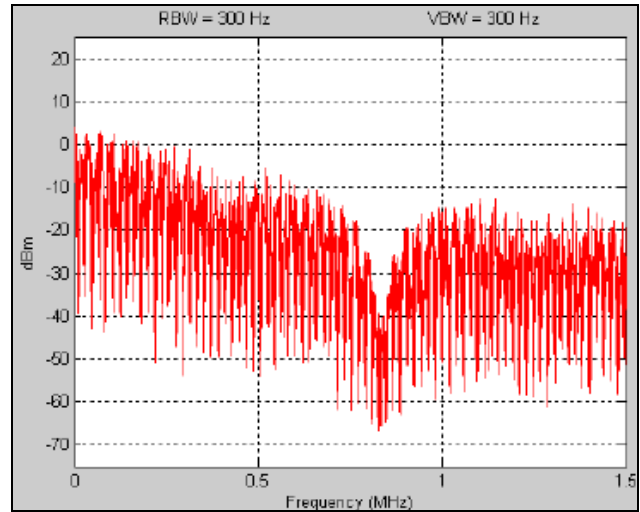


Figure 4. PrISM Spectral Plot



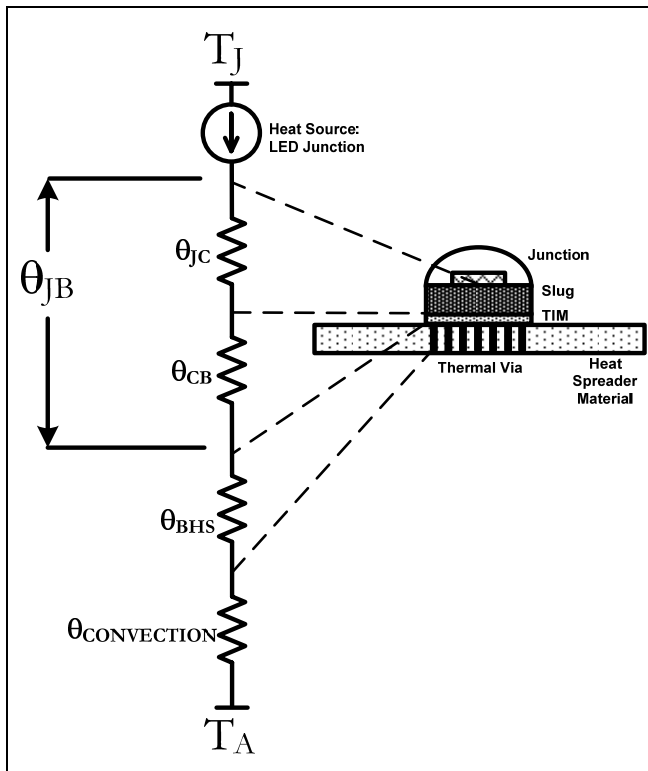
*Temperature Measurement*

The luminous flux and the color of LEDs depend upon the junction temperature. As temperature increases, an LED's maximum luminous flux output decreases and the dominant wavelength increases. So, to keep a set of LEDs at the same color as environmental conditions change, it is important to have an accurate measurement of the junction temperature. The junction temperature is approximated using equation 1.

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

The thermal resistance from junction-to-board ( $\theta_{JB}$ ) is the sum of the thermal resistance from the LED junction to the thermistor on the board. The relationship is shown graphically using the electrical analogy (Figure 5), where a heat source is modeled with a current source and voltage is analogous to temperature.

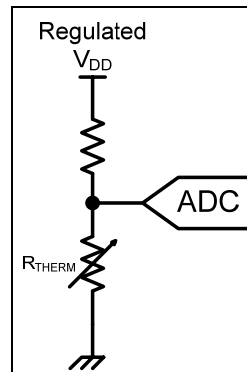
Figure 5. LED Junction Temperature



Equation 1 on page 3 states that if you know the board temperature, the thermal impedance from the LED junction to the board, and the power dissipated by the LED, then you can determine the LED junction temperature. The board temperature is measured using a thermistor on the board placed in the middle of the three LEDs. The thermal impedance is the sum of the junction-to-case impedance (from the LED manufacturer) and the bonding material thermal impedance, in this case, solder. The power dissipated in the LED is the product of the forward current and the forward voltage. The forward current is constant and the voltage changes with temperature. So the only unknown value is the LED forward voltage, which is approximated using a set value or binning data, or measured using a differential ADC.

Measure the LED forward voltage using an internal ADCINC (Figure 6). This project uses the ADCINC because it is an integrating ADC and returns the average value of the forward voltage over a set period of time, the sample period. Using an integrating ADC eliminates the need for the extra step of multiplying the peak power dissipated in the LED by the signal density of the waveform.

Figure 6. Thermistor Circuit



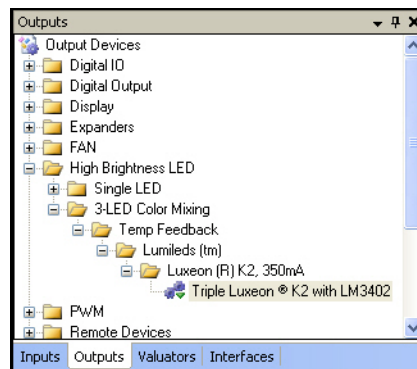
## PSoC Express

Download PSoC Express from the Cypress web site at <http://www.cypress.com/PSoCExpress>.

PSoC Express helps you to simply and intuitively design and develop color mixing applications. The CY3261A-RGB board has a silkscreen on the board to let you know which pins connect to particular signals. This simplifies the process of selecting the custom pinout in PSoC Express. The following describes the design procedure for a color mixing application in PSoC Express.

1. Start and name a new PSoC Express project using PSoC Express 3.0 or greater.
2. Choose the Triple Luxeon® K2 color mixing driver from the list of Output Drivers list (Figure 7) and drag it to the workspace.

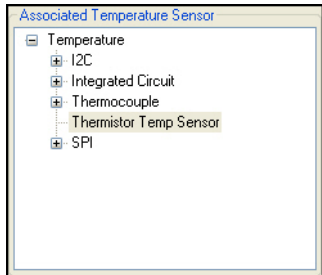
Figure 7. Output Driver List



3. When the Add Output Driver window opens name the driver **ColorMixer** and click **OK**.

- When the HBLEDD window opens, select the Thermistor Temp Sensor from the Associated Temperature Sensor pane.

Figure 8. Associated Temperature Sensor Pane



- In the Temperature Sensor Properties pane (Figure 9), set the parameters to those in Table 2.

Figure 9. Temperature Sensor Properties Pane

Temperature Sensor Properties	
CONST_A	0.00110278
CONST_B	0.00023726
CONST_C	8.45E-08
REF_RESISTANCE	40000

Table 1. Temperature Sensor Parameter Values

Parameter	Value
Const A	1.10278E-03
Const B	2.3726E-04
Const C	8.45E-08
Resistance	40000

- Set the LED1, LED2, and LED3 panes (Figure 10) to the values in Table 1.

Figure 10. LED Property Panes

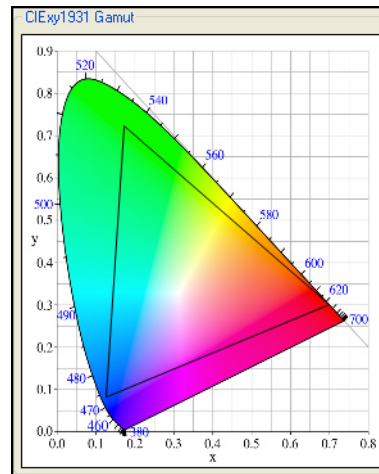


Table 2. LED Colors and Bins

Color	Flux Bin	Color Bin
LXK2-PD12 Red	Q	4
LXK2-PD12 Green	R	2
LXK2-PR12 Blue	M	3

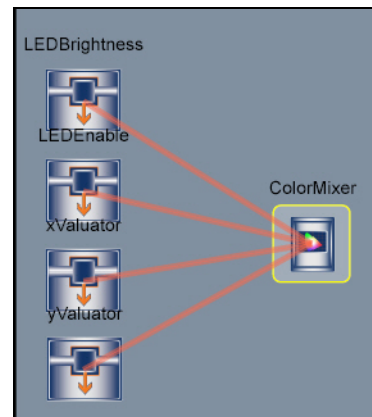
Figure 11 shows the CIE 1931 gamut with the colors available determined by the previous settings.

Figure 11. CIE 1931 Chromaticity Diagram with Gamut



- Click **OK**.
- Prior to defining the transfer function for ColorMixer, **define each input to the driver**. The example projects, accessible from the Start Page in the Express Design Catalog pane in the CY3261A-RGB EZ-Color Demo Kit folder provide two examples of where these inputs may come. Figure 12 shows the 3-LED Color Mixing with Tuner over I2C sample project.

Figure 12. 3-LED Sample Project



- Right-click the Output Driver icon and select **Transfer Function** to open the Transfer Function dialog box. Table 3 lists the four inputs for this driver.

Table 3. ColorMixer Driver Inputs

Input	Scale/Input Type
Enable	Boolean
X Coordinate	10,000:1
Y Coordinate	10,000:1
Relative Luminous Flux	1000:100%

### 3-LED Color Mixing with Tuner Over I2C Example Project

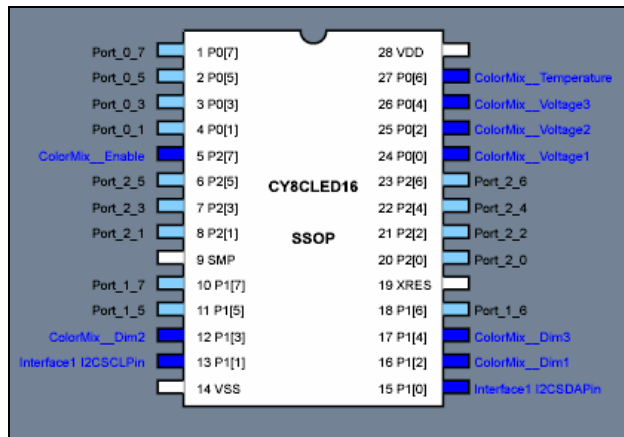
This example project provides an example of how to set up a simple I<sup>2</sup>C controlled color mixing project in PSoC Express. The I<sup>2</sup>C interface provides the inputs for four valuator. Valuator are transfer function variables that process input data.

### 3-LED Color Mixing with State Machine Example Project

This example project builds on the previous project by adding a state machine. The state machine feeds into a set of priority encoders, which work like valuator except the values change depending on the input, which controls the inputs of the color mixing driver. This mixed color output of this project follows a path around the chromaticity chart.

After the PSoC Express project is built, begin selecting the pinout for the various inputs and outputs (Figure 13). The CY3261A-RGB board had this step in mind when the pins and signals were labeled on the board in silkscreen.

Figure 13. Pin Selection



After building the project you are able to program your board and have a working RGB design without writing a single line of code. See the *Express Example Project* documentation on the CY3261A-RGB kit CD for detailed instructions for building this project.

## Summary

This application note demonstrates simple methods of creating color mixing designs using Cypress EZ-Color devices. Two PSoC Express example projects are included; each design uses good PSoC Express design practices. Custom firmware can be added to increase the usefulness of the project using information provided in AN16035, *RGB Color Mixing Firmware for PrISM* and AN14406, *Temperature Compensation for High Brightness LEDs*.

## Appendix A. SI Photometry Units

Table 4. Photometry Units

Quantity	Symbol	SI Unit	Abbreviation	Notes
Luminous Energy	Q	lumens second	lm*s	Units are also called talbots
Luminous Flux	F	lumens = cd/sr	lm	Units are also called luminous power
Luminous Intensity	I <sub>v</sub>	candela = lm/sr	cd	
Luminance	L <sub>v</sub>	candela per square meter	cd/m <sup>2</sup>	Units are also called nits
Illuminance	E <sub>v</sub>	lux = lm/m <sup>2</sup>	lx	
Solid Angle	sr	steradian	m <sup>2</sup> m <sup>-2</sup> = 1	Used to describe angular spans - a radian is to a circle as a steradian is to a sphere

### About the Author

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**Title:** PSoC Application Engineer

**Background:**

Patrick has been working in the Cypress PSoC Applications group since 2005. He received his BSEET from Western Washington University in Bellingham, WA.

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