Reference Design: Dim-to-Warm with Cree LED Tunable White COBs

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INTRODUCTION

Solid-state light emitting diodes (LEDs) have evolved to become the leading lighting technology offering best lighting efficiency, color quality, and emission control. One inherent and desirable feature of the technology that LEDs have replaced, incandescent lighting, is the dim-to-warm emission versus input power that offers a generally pleasing quality of light across the power range. At lower currents, the incandescent emits warmer white at relatively lower color correlated temperature (CCTs), and at higher input currents the color temperature increases to a higher CCT and cooler white. This feature creates both aesthetically pleasing and circadian-friendly lighting in a range of applications including residential lighting, hospitality, retail, and architectural lighting. This reference design presents two approaches for creating a dim-to-warm LED lighting source using the tunable white COB series from Cree LED.

ELECTRICAL SCHEMATIC, BOM, AND EXPLANATION

Two different approaches are presented to create a dim-to-warm light source using the dual channel Cree LED XLamp® CTW09010 (4000 K/90 CRI and 1800 K/90 CRI) COB LED. The approaches outlined in this reference design can be applied to any of tunable white COBs offered by Cree LED.

LES Diameter	**9 mm**
XLamp LED	**CTW0910**
Substrate Size	15.9 x 15.9 mm (CxB15xx)
Voltage Class	36 V
Bin Current per channel **(A)**	0.300
Max Current per channel **(A)**	0.400
Max Power total **(W)**	~29

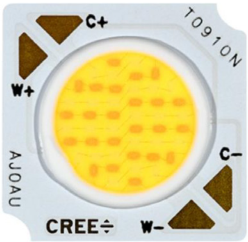

Figure 1: General details and overview of the Cree LED CTW09010 tunable white COB

PASSIVE IMPLEMENTATION

One implementation of dim-to-warm behavior using the CTW0910 LED is achieved via only a few passive components. A resistor (or a network of resistors) is placed in series with the warm LED string, and a diode or multiple diodes are placed in series with the cool LED string. This design takes advantage of the difference in V-I curves for the ohmic and non-ohmic devices and produces a current ratio between the LED strings which varies in response to the combined drive current.

The behavior of the circuit can be modeled by creating combined V-I curves of the LED/diode string and for the LED/resistor string then setting the two strings to a matched input voltage. This setup can then be used to predict the ratio of current between the warm and cool LED strings at various total drive currents to estimate the CCT vs. current response of the system. An example behavior of this setup is shown in Figure 2.

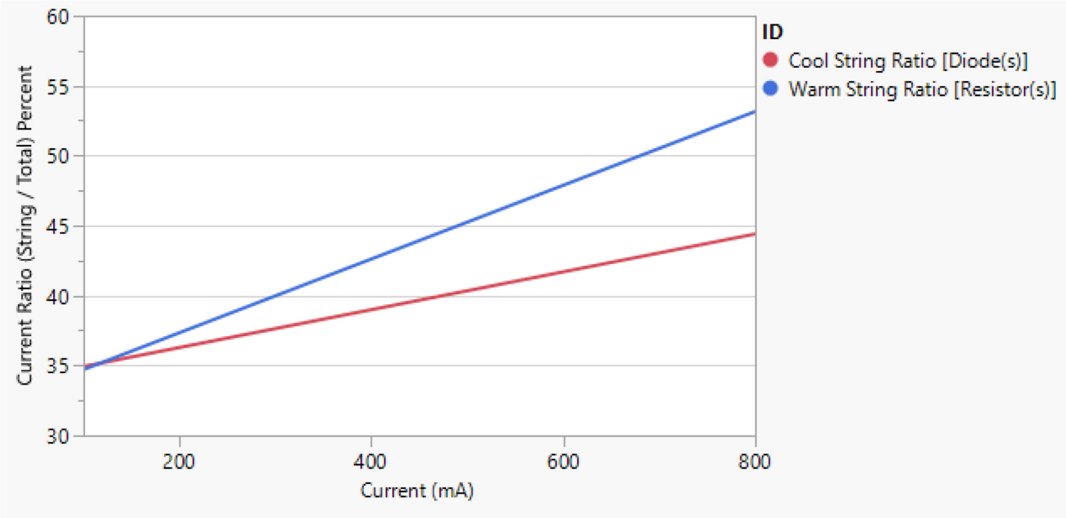

Figure 2: Predicted performance of a simple passive control of a dim-to-warm device using resistors and diodes.

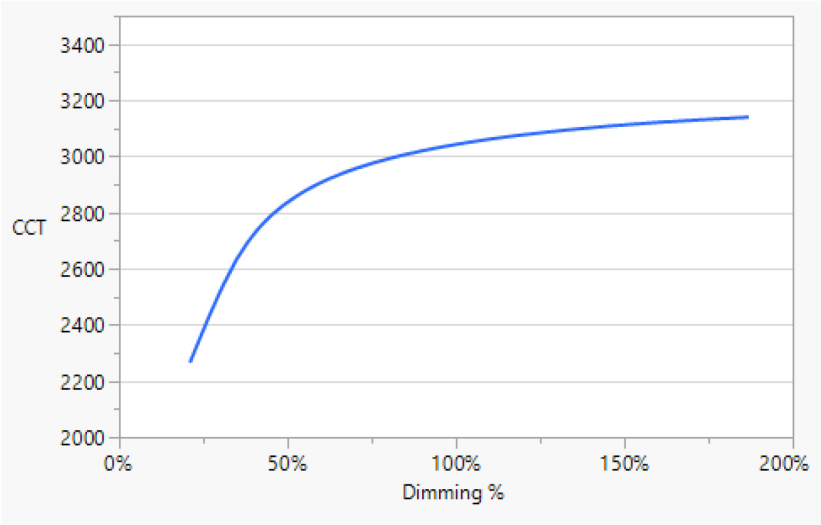

Figure 3: Resultant CCT as a function of dimming percent in a predicted model for the passive implementation.

The passive implementation has the advantage of having a low parts count and being low cost, but it comes with the disadvantage that there is little control over the CCT vs. current response, and that the ratio of current between the LED strings falls within a fairly narrow range. For this prototype, the warm string current vs. total current ratio could only be varied in a range of 40% to 75%.

A schematic and bill of materials for the passive implementation is provided below in Figure 4.

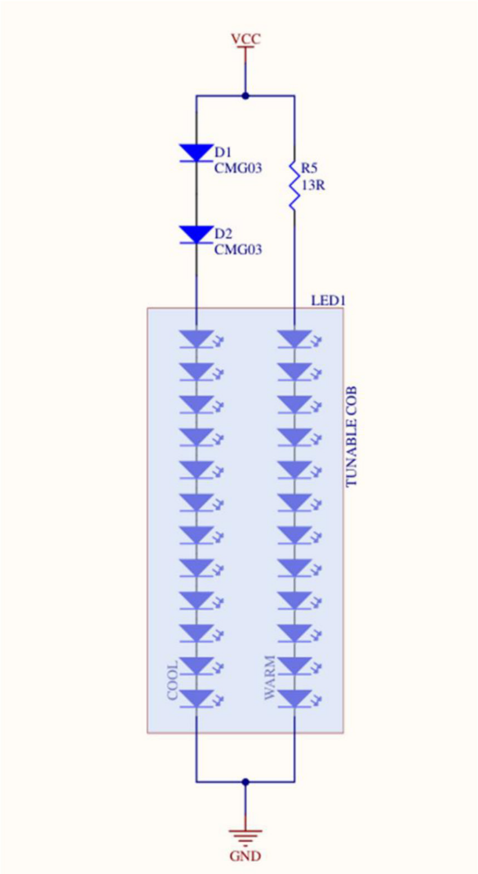

Figure 4: Circuit schematic for the passive implementation of dim-to-warm control.

Table 1: Bill of Materials (BOM) for the passive implementation of dim-to-warm.

Description	Designator	Part Number	Quantity	Value	Comment
COB LED	LED1		1		
SMD Resistor	R2		1	13R	2-W rating. Consider splitting to multiple parts
Rectifier Diode	D1, D2	CMG03	2		Choose a part with high voltage rating to get higher Vf

DIGITAL IMPLEMENTATION

A digital implementation of dim-to-warm functionality allows complete control over the CCT vs. current response as well as for color adjustment across the entire range of current ratios between LED strings (that is, each string can be adjusted fully from 0% to 100% without range limitations). In this example circuit, the overall drive current is measured by a current sense resistor, whose voltage is amplified by an op-amp in a non-inverting amplifier configuration. This signal is then measured by the analog to digital converter in a microcontroller. The microcontroller uses this information to adjust the duty cycles of the two LED strings, which have their relative currents controlled by PWM via N-channel MOSFETs. A 5-V LDO regulator provides power to the microcontroller and op-amp so that they can be supplied by the ~36 V powering the COB LED.

In the digital implementation, the CCT vs. current response can be programmed to any arbitrary curve. In this case, the system is designed to mimic the dim-to warm effect that incandescent bulbs exhibit, which is a fairly shallow near-linear response across most of the current range followed by a rapid roll-off at the bottom end of drive currents. A flat tail section at the bottom end of the dimming range is included to ensure that any dimmer can reach the warmest CCT regardless of the floor of its dimming range.

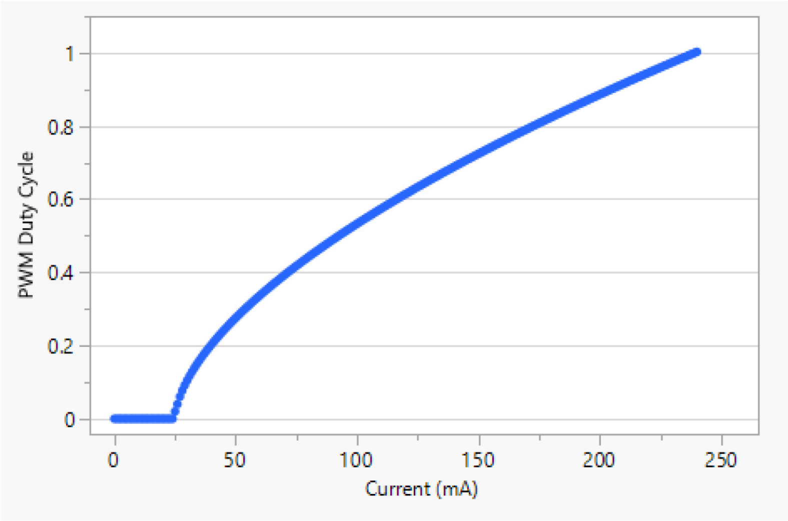

Figure 5: Example of a lookup table for PWM duty cycle based on the sensed current for a digital implementation of dim-to-warm.

This output curve is converted into a lookup table in the firmware, which takes a current measurement value and returns a PWM duty cycle value. The PWM channels for the two LED strings are configured as complementary signals, such that any time one string is off, the other is on, and the sum of the two duty cycles is always 100%. After configuring the peripheral hardware, the firmware's only function is to measure the current via ADC, put the value through the lookup table, and load the result out to the PWM hardware. This task is repeated as fast as possible to eliminate any visible artifacts that might be caused by the warm/cool ratio lagging behind changes in drive current. The digital implementation has the advantage of being able to adjust the relative LED currents across the full range, as well as using any desired curve for the CCT vs. current response. This comes with the disadvantages of a larger BOM, parts cost, and more complexity.

A schematic and bill of materials for the digital implementation is provided below in Figure 6.

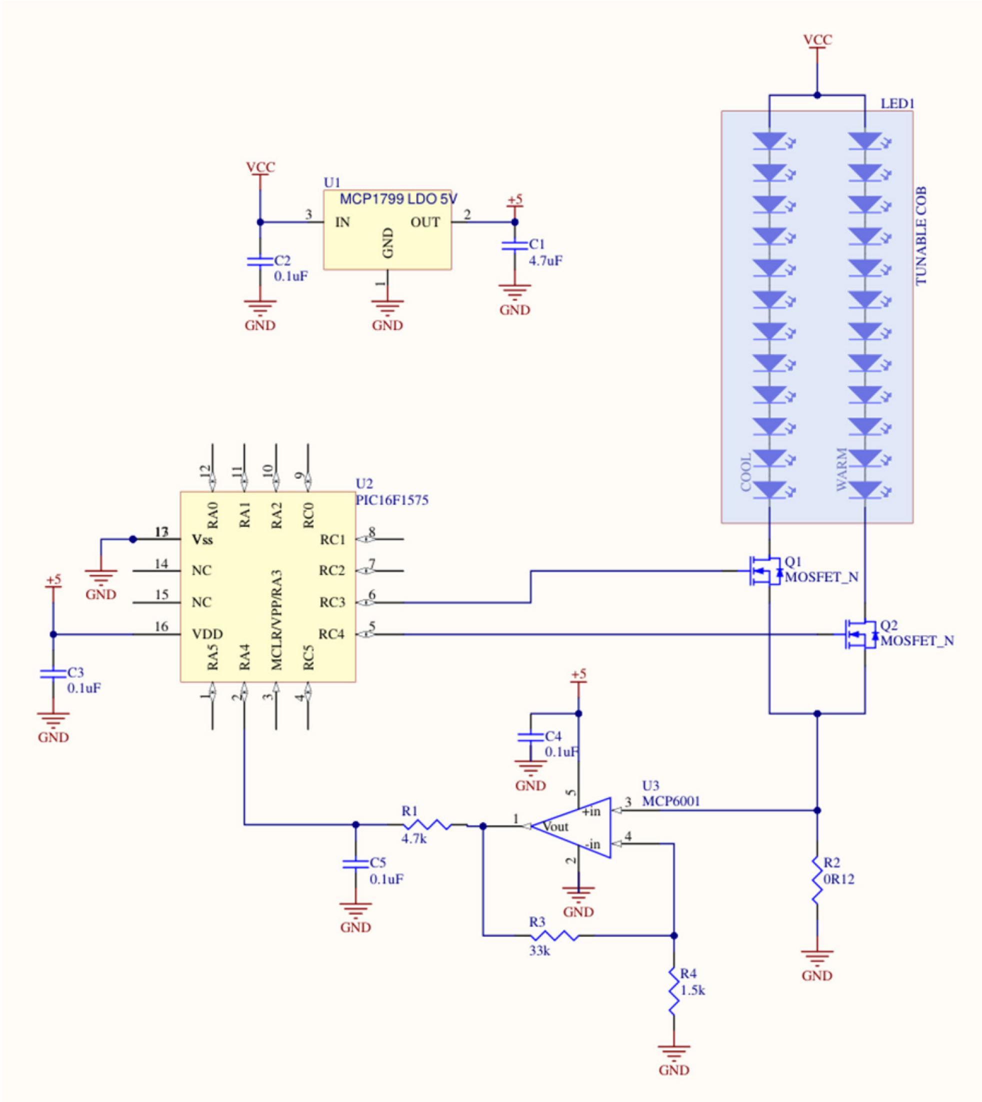

Figure 6: Circuit schematic for the digital implementation of dim-to-warm control.

Table 2: Bill of Materials (BOM) for the digital implementation of dim-to-warm.

Description	Designator	Part Number	Quantity	Value
LDO Regulator	LED1		1	
Op Amp	U1	MCP1799	1	5 V
MOSFET N-channel	U3	MCP6001	1	
Microcontroller	Q1, Q2-	Si2308	2	
SMD Resistor	U2	PIC16F1575	1	
SMD Capacitor	R2		1	0R12
SMD Resistor	C2, C3, C4, C5		4	0.1 µF
SMD Resistor	R4		1	1.5 k
SMD Capacitor	R1		1	4.7 k
SMD Resistor	C1		1	4.7 µF
Rectifier Diode	R3		1	33 k

The passive implementation produced results that were close to the model's prediction, with a CCT adjustment range of about 1800 to 3000 K. The performance is good but has the expected narrow range of CCTs and cannot go cooler than 3000 K despite using LED components organized in a 4000-K string. The lumen response in the passive implementation is quite linear with respect to dimming percent.

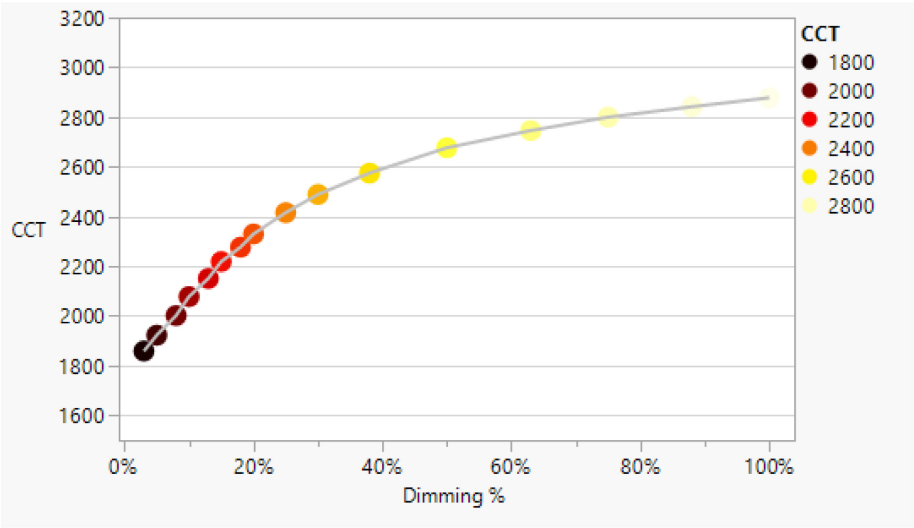

Figure 7: CCT as a function of dimming percent for the passive implementation of dim-to-warm.

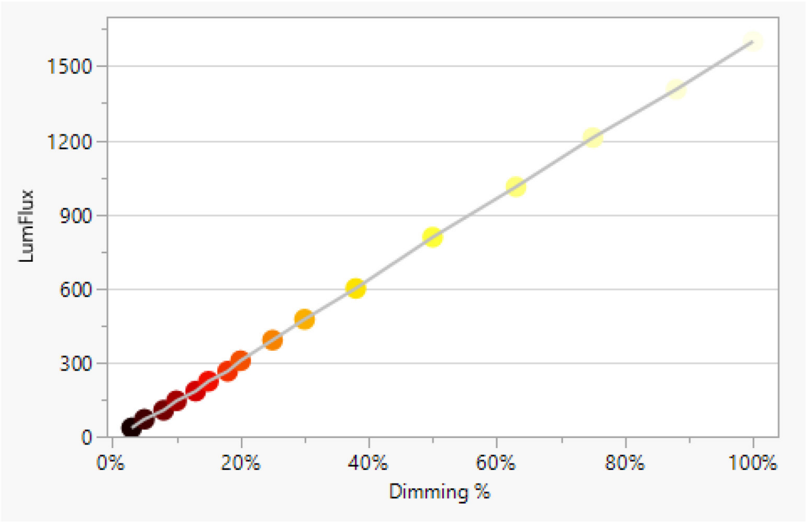

Figure 8: Luminous flux as a function of dimming percent for the passive implementation of dim-to-warm.

The digital implementation produced results closely matching the target CCT curve and is able to achieve the full range of 1800 to 4000 K while maintaining a pseudo-linear lumen output with respect to dimming percent and correlated color temperature.

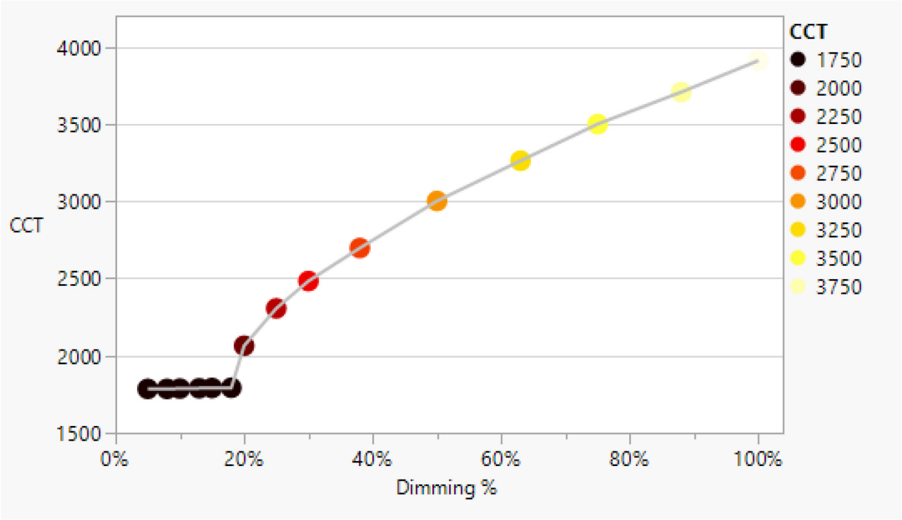

Figure 9: CCT as a function of dimming percent for the digital implementation of dim-to-warm.

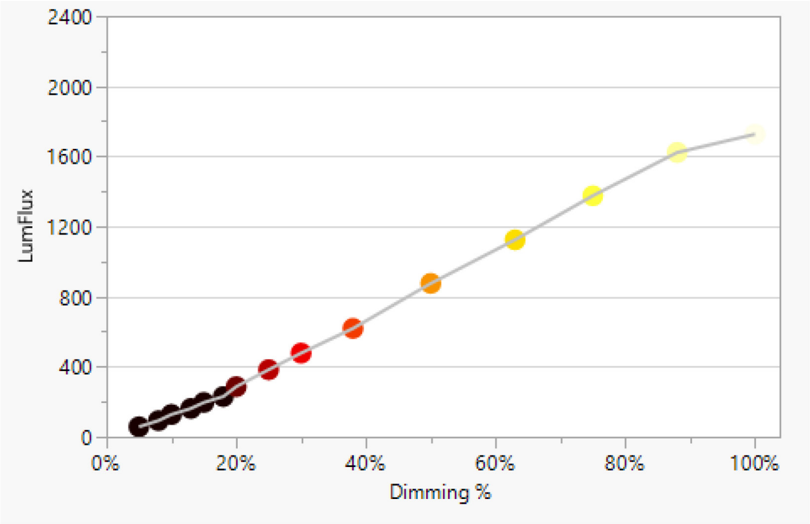

Figure 10: Luminous flux as a function of dimming percent for the digital implementation of dim-to-warm.

Both prototypes follow a similar path through the x/y color space which linearly connects the 4000 K and 1800 K color points of the individual LED strings; however, the passive implementation fails to deliver output at the cool end of the 1800 K to 4000 K range.

RESULTS

Two different techniques for implementing a dim-to-warm output response using the Cree LED tunable white COBs are presented, a passive setup using diodes and resistors and a digital setup with a stored lookup table for dimming control. Both techniques provide a performance vs. cost tradeoff and should be carefully considered when designing the overall circuit.