Cree® XLamp® B10 Candelabra Reference Design

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INTRODUCTION

The B10 lamp designation defines a variety of primarily decorative lamps. They are used in ornamental luminaires such as chandeliers, sconces and pendants, in which the lamp is typically visible and contributes to the aesthetics of the luminaire. Because the lamp shape is intended to resemble a candle flame, B10 lamps are commonly called candelabra lamps.

To date, B10 lamps based on a single LED have been unable to match the light output of incandescents. Multi-LED configurations complicate the overall system and packaging design. Several vendors have developed multi-LED B10 lamps, attempting to focus on features that mimic the appearance of filament-style bulbs. The focus on the aesthetics of these bulbs has been at the expense of efficacy and light output. Testing of LED-based B10 lamps conducted by the

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Department of Energy (DOE) Commercially Available LED Product Evaluation and Reporting (CALiPER) program showed inconsistent lamp performance and quality and instances of inflated performance claims.[1]

This application note details prototype B10 lamps based on three Cree XLamp parts:

1) XLamp XM-L EasyWhite (EZW), a conventional LED with unique color consistency features
2) XLamp XM-L High Voltage White (HVW), a high-voltage LED, capable of supporting high efficiency, high-voltage device drivers
3) XLamp XT-E HVW, another, smaller-form high-voltage LED.

The several designs we created allow for the evaluation of two distinct styles of lamp development: the first conventional in supporting standard voltage LEDs, the second creating high-voltage designs that support smaller and more efficient device drivers.

Using the XM-L EZW LED enables a single LED component to deliver the performance and design simplicity needed for a 25-watt equivalent B10 replacement lamp that conforms to ENERGY STAR® requirements and matches or exceeds the light characteristics of existing incandescent lamps. Cree's EasyWhite technology provides excellent LED-to-LED color consistency, reducing LED-to-LED color variation to within a 2-step Mac Adam ellipse.

The XM-L HVW and XT-E HVW LEDs offer advantages in light output, efficacy and current. These high-voltage LEDs present an opportunity to use drivers that are smaller and more efficient than drivers for lower voltage parts. In addition, high-voltage LEDs can perform at lower operating temperatures, thereby extending the lifetime of both the LED and the driver. We consider XLamp, high voltage LEDs and correspondingly more efficient drivers to be enabling technology for high efficacy, small form-factor LED replacement lamps.

This design effort shows it is possible to create an XLamp LED-based B10 lamp delivers system efficacy comparable to the best larger-format LED replacement lamps.

1 DOE Solid-State Lighting CALiPER Program, Summary of Results: Round 8 of Product Testing
apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_round_8_summary_final.pdf
DOE Solid-State Lighting CALiPER Program, Summary of Results: Round 9 of Product Testing
apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_round-9_summary.pdf
DOE Solid-State Lighting CALiPER Program, Summary of Results: Round 11 of Product Testing
apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_round-11_summary.pdf

DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide" application note, Cree advocates a 6-step framework for creating LED luminaires.[2] All Cree reference designs use this framework, and the design guide's summary table is reproduced below.

Step	Explanation
1. Define lighting requirements	• The design goals can be based either on an existing fixture or on the application's lighting requirements.
2. Define design goals	• Specify design goals, which will be based on the application's lighting requirements. • Specify any other goals that will influence the design, such as special optical or environmental requirements.
3. Estimate efficiencies of the optical, thermal & electrical systems	• Design goals will place constraints on the optical, thermal and electrical systems. • Good estimations of efficiencies of each system can be made based on these constraints. • The combination of lighting goals and system effiiciencies will drive the number of LEDs needed in the luminaire.
4. Calculate the number of LEDs needed	• Based on the design goals and estimated losses, the designer can calculate the number of LEDs to meet the design goals.
5. Consider all design possibilities and choose the best	• With any design, there are many ways to achieve the goals. • LED lighting is a new field; assumptions that work for conventional lighting sources may not apply.
6. Complete final steps	• Complete circuit board layout. • Test design choices by building a prototype luminaire. • Make sure the design achieves all the design goals. • Use the prototype to further refine the luminaire design. • Record observations and ideas for improvement.

Table 1: Cree 6-step framework

THE 6-STEP METHODOLOGY

The goal of this design is to create XLamp LED-based B10 replacement lamps that deliver performance equivalent to 25- and 40-watt incandescent B10 lamps and conform to ENERGY STAR requirements.

1. DEFINE LIGHTING REQUIREMENTS

Because B10 lamps are decorative, aesthetics is perhaps the most important design criterion. In addition, the light source and the associated components must fit in the space-constrained B10 form factor. Although aesthetics is a subjective assessment, there are specific metrics, listed in Table 2 below, that can quantify lamp performance.

2 LED Luminaire Design Guide, Application Note AP15, www.cree.com/~/media/Files/Cree/LED%20Components%20and%20Modules/XLamp/XLamp%20Application%20Notes/LED_Luminaire_Design_Guide.pdf

Importance	Characteristics	Metric
Critical	Aesthetics	N/A
	Form factor	N/A
	Luminous flux	Lumens (lm)
	Luminance/illuminance	Foot candles (fc)/lux
	Electrical power	Watts (W)
	Price	$
Important	Lifetime	Hours
	Correlated color temperature (CCT)	Kelvin
	Color rendering index (CRI)	100-point scale
	Manufacturability	$
	Comply with ENERGY STAR	Has label

Table 2: Design criteria

As shown in Figure 1, B10 lamps have a torpedo shape and are blunt or flame tipped. They typically have a candelabra (E12) or medium (E26) base.

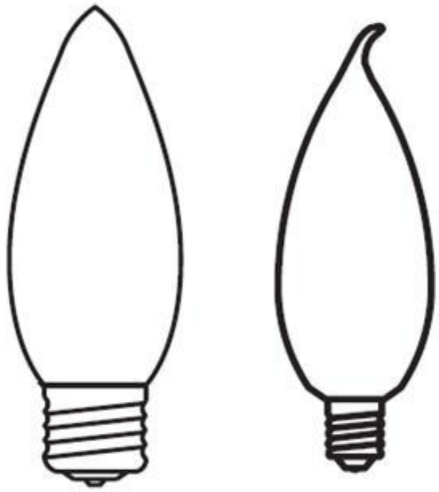


Figure 1: Blunt (left) and flame-tipped (right) B10 lamp shapes

There are many incandescent B10 lamps on the market today. They typically operate at low wattages and produce warm light. Like all incandescent lamps, they are energy inefficient and have a relatively short lifetime. A number of CFL B10 lamps are also available. They offer energy savings and longer life than incandescents, but are not able to achieve the higher levels of efficacy found in linear fluorescent bulbs.

Cree measured the photometric and electrical performance of one incandescent and three comparison CFL B10 lamps.[3] Table 3 presents a summary of the data.

Characteristic	Unit	Incand.	CFL 1	CFL 2	CFL 3
Luminous flux	lm	198.8	172	145	154
Efficacy	lm/W	8.0	33.1	27.0	29.1
Input power	W	25	5.20	5.25	5.28
CCT	K	2538	2701	2683	2718
CRI		99.7	82	83	82
Power factor			0.56	0.55	0.56

Table 3: Comparison B10 lamp test results

The CFL lamps are more efficient than the incandescent but do not match the incandescent lamp's CRI. All the lamps produce warm white light. The goal of this design is to mimic the color performance and light output of an incandescent lamp while providing energy, and therefore cost, savings.

Cree measured an incandescent B10 lamp and a CFL B10 lamp to obtain polar candela distribution graphs, shown in Figure 2, to serve as baselines for the XLamp B10 lamps.[4]

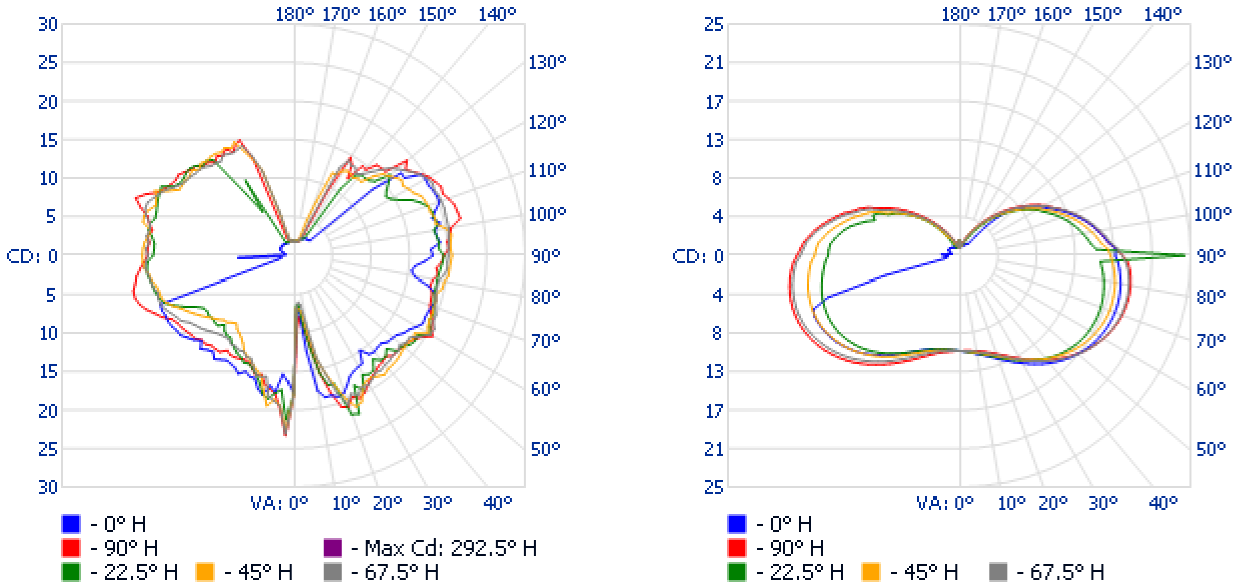


Figure 2: Polar candela distribution for B10 incandescent (left) and CFL (right) B10 lamps

3 Photometric performance was measured in a 2-meter integrating sphere. Electrical performance was measured using an AC power analyzer. Measurements were taken at the Cree facility in Durham, NC.

4 Measurements were taken using a type A goniophotometer at the Cree facility in Durham, NC.

The following tables summarize requirements an LED-based B10 replacement lamp must meet to be eligible to qualify for the ENERGY STAR program.

The ENERGY STAR requirements for all lamps:[5]

<table>
<tr><th>Characteristic</th><th>Requirements</th></tr>
<tr><td>CCT and Duv</td><td>Lamp must have one of the following designated CCTs (per ANSI/NEMA/ANSLG C78.377-2008) consistent with the 7-step chromaticity quadrangles and Duv tolerances listed below.
<table>
<tr><th>Nominal CCT</th><th>Target CCT (K) and Tolerance</th><th>Target Duv and Tolerance</th></tr>
<tr><td>2700 K
3000 K
3500 K
4000 K</td><td>2725 ± 145
3045 ± 175
3465 ± 245
3985 ± 275</td><td>0.000 ± 0.006
0.000 ± 0.006
0.000 ± 0.006
0.001 ± 0.006</td></tr>
</table></td></tr>
<tr><td>Color maintenance</td><td>The change in chromaticity over the minimum lumen test period (6000 hours) shall be within 0.007 on the CIE (u', v') diagram.</td></tr>
<tr><td>CRI</td><td>Minimum CRI (RA) of 80. In addition, the R9 value must be greater than 0.</td></tr>
<tr><td>Dimming</td><td>Lamps may be dimmable or non-dimmable. Product packaging must clearly indicate whether the lamp is dimmable or not dimmable.</td></tr>
<tr><td>Warranty</td><td>A warranty must be provided for lamps, covering material repair or replacement for a minimum of three (3) years from the date of purchase.</td></tr>
<tr><td>Allowable lamp bases</td><td>Must be a lamp base listed by ANSI.</td></tr>
<tr><td>Power factor</td><td>For lamp power < 5 W and for low-voltage lamps, no minimum power factor is required.
For lamp power > 5 W, power factor must be > 0.70.
Note: Power factor must be measured at rated voltage.</td></tr>
<tr><td>Minimum operating temperature</td><td>Integral lamp shall have a minimum operating temperature of 20 °C or below.</td></tr>
<tr><td>LED operating frequency</td><td>≥ 120 Hz
Note: This performance characteristic addresses problems with visible flicker due to low-frequency operation and applies to steady-state as well as dimmed operation.</td></tr>
<tr><td>Operating voltage</td><td>Lamp shall operate at rated nominal voltage of 120, 240 or 277 VAC or at 12 or 24 VAC or VDC.</td></tr>
</table>

Table 4: General ENERGY STAR requirements

The ENERGY STAR requirements for B10 lamps:[6]

<table>
<tr><th>Characteristic</th><th colspan="2">Requirement</th></tr>
<tr><td>Minimum luminous efficacy</td><td colspan="2">40 lm/W</td></tr>
<tr><td rowspan="3">Minimum light output</td><td colspan="2">Lamp shall have minimum light output (total luminous flux) at least corresponding to the target wattage of the lamp to be replaced, as shown below.</td></tr>
<tr><td>Nominal wattage of lamp to be replaced (watts):</td><td>Minimum initial light output of LED lamp (lumens):</td></tr>
<tr><td>25
40
60</td><td>150
300
500</td></tr>
<tr><td>Maximum lamp diameter</td><td colspan="2">Not to exceed target lamp diameter.</td></tr>
<tr><td>Lumen maintenance</td><td colspan="2">> 70% lumen maintenance (L70) at 15,000 hours of operation.</td></tr>
<tr><td>Rapid-cycle stress test</td><td colspan="2">Cycle times must be 2 minutes on, 2 minutes off. Lamp will be cycled once for every 2 hours of L70 life.</td></tr>
</table>

Table 5: ENERGY STAR requirements for B10 lamps

5 ENERGY STAR Program Requirements for Integral LED Lamps Eligibility Criteria - Version 1.4, Table 4. www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf

6 Ibid., Table 7B

2. DEFINE DESIGN GOALS

The design goals for this project:

Characteristic	Unit	Minimum Goal	Target Goal
Light output	Lm	150 for 25 W lamp 300 for 40 W lamp	220 for 25 W lamp 330 for 40 W lamp
Illuminance profile	Lux	Better than incandescent	Better than incandescent
Power	W	< 25	4
Lifetime	Hours	25,000	50,000
CCT	K	2600	2700
CRI		80	85
Maximum ambient temperature	°C	30	40

Table 6: Design goals

3. ESTIMATE EFFICIENCIES OF THE OPTICAL, THERMAL & ELECTRICAL SYSTEMS

Thermal Requirements

An XLamp LED operating at 4-5 watts of power, at steady state temperature, needs a heat sink to dissipate the thermal load. In this design, the heat sink must not only dissipate the heat generated by the LED, but also provide a mechanical frame for the LED, optic, driver and base and fit into the B10 standard enclosure. The small size of the B10 form factor limits the choices for a heat sink and makes it a challenge to fit the heat sink into the available space. After testing several designs, Cree chose an off-the-shelf heat sink from Cooliance for this B10 design.[7] The heat sink is black anodized aluminum with cooling pins.

Figure 3: Anodized aluminum heat sink

As shown in Figure 4, to make space for the driver, we removed pins from the heat sink, leaving the two outer rings of pins and creating a cavity in which to mount the driver.

7 Cooliance model CML32301-30-3-101, website: www.cooliance.com

A STEP file for the heat sink is available on the Cree website.[8]

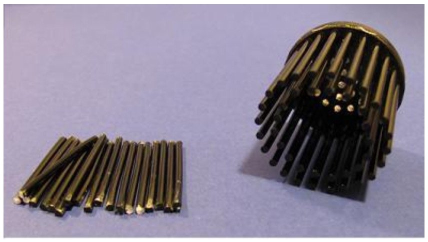


Figure 4: Heat sink with pins removed

Cree performed thermal simulations to verify the effectiveness of this design.[9] Figure 5 shows the temperature distribution between the junction and the heat sink. The peak temperature on the scale occurs at the junction of the LED. Figure 6 shows the temperature distribution between the printed circuit board (PCB) and the heat sink.

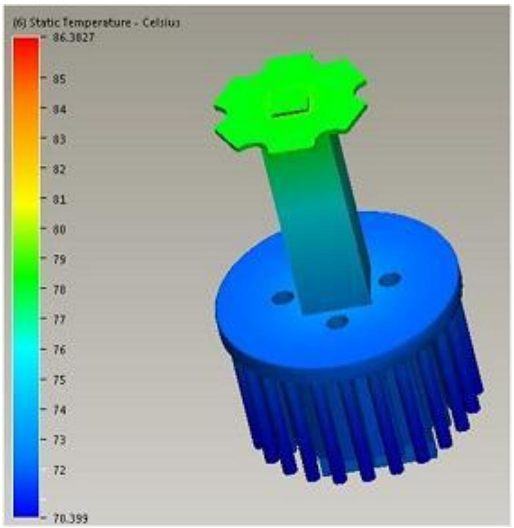


Figure 5: Junction-to-heat-sink temperature distribution

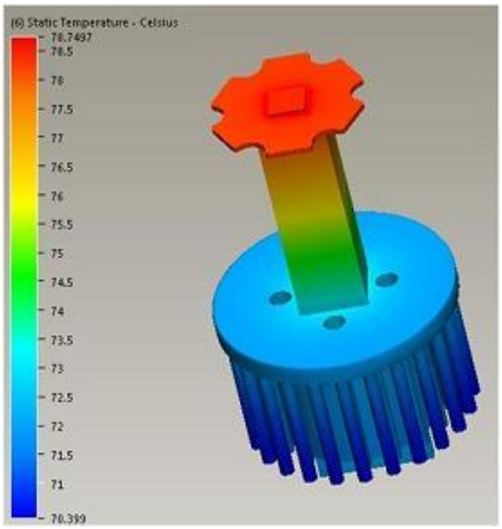


Figure 6: Board-to-heat-sink temperature distribution

Figure 7 is a thermal simulation showing a cross section of the lamp at steady state in a 25 °C ambient operating environment. The solder point temperature (T_{SP}) in the simulation is 79 °C.

8 www.cree.com/~/media/Files/Cree/LED%20Components%20and%20Modules/XLamp/XLamp%20Reference%20Designs/Design%20files/XLamp_B10_STEP

9 Cree used Cfdesign Spring,-2011 release, www.cfdesign.com

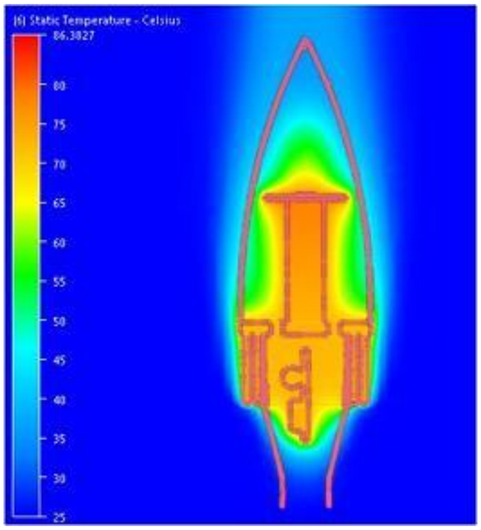


Figure 7: Thermal simulation

Table 7 shows the thermal resistance and calculated junction temperature (T_J) for the XLamp B10 lamps.

Lamp	T_{SP}	Power	Thermal Resistance	T_J
XM-L EZW B10	79 °C	4 W	2.5 °C/W	89 °C
XM-L HVW B10	79 °C	4 W	3.5 °C/W	93 °C
XT-E HVW B10	79 °C	4 W	6.5 °C/W	92 °C

Table 7: Thermal simulation data

Drive Electronics

Fitting a driver into the constrained space within the B10 form factor is also a design challenge. Moreover, in this design, the driver must fit into the cavity created in the heat sink. For the XM-L EZW lamp, Cree chose a CE/UL certified constant current driver from Wayjun Technology that provides efficiency of 80% and a power factor of 0.53.[10]

For the XM-L HVW lamp, Power Integrations developed a non-isolated buck boost LED driver that provides efficiency of 86% and a power factor of 0.97.[11]

For the XT-E HVW lamp, Cree chose a constant current driver from iWatt that provides efficiency of 86% and a power factor of 0.55.[12]

10 Wayjun Technology website: www.wayjun.com
11 Power Integrations driver: www.powerint.com/sites/default/files/PDFFiles/der297.pdf
12 iWatt iW1678 driver: www.iwatt.com/iw1678.php

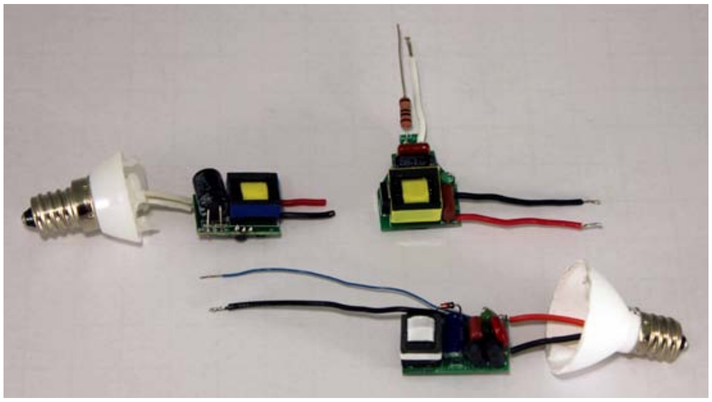
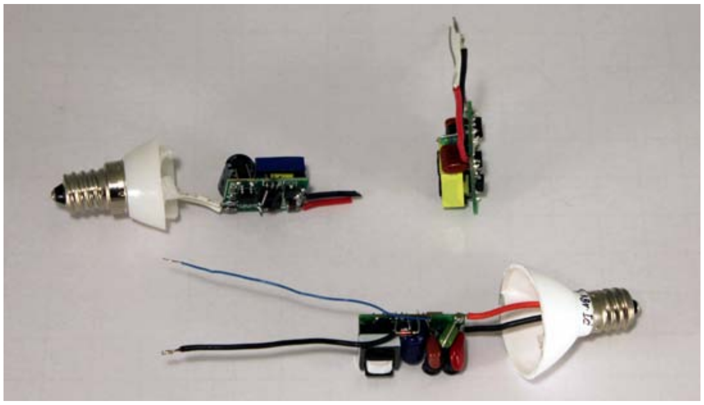



Figure 8: Views of B10 lamp drivers

Secondary and Tertiary Optics

The design uses a white Khatod diffuser lens to diffuse the light from the LED and produce the omnidirectional light output desired of a B10 lamp.[13] The white lens obscures the single light source and produces a uniform light pattern.

An existing standard glass lamp case was used to enclose the lamp components.

Figure 9: Khatod diffuser lens and lamp glass enclosure

4. CALCULATE THE NUMBER OF LEDS NEEDED

Figures 10 and 11 show basic LED electrical data and optical output from Cree's Product Characterization Tool (PCT).[14] The lumen target is 200 lumens and the optical and electrical efficiencies are both 80%.

13 Khatod Optoelectronics PLJT20 series, website: www.khatod.com
14 Available at pct.cree.com

Current (A)	LED 1				LED 2			
	Model: Cree XLamp XM-L 6V {EZW}				Model: Cree XLamp XM-L 12V {EZW}			
	Flux: T6 [280]		Tsp (ºC): 79		Flux: T6 [280]		Tsp (ºC): 79	
	Price: $ -				Price: $ -			
	SYS # LED	LED lm/W	LED Vf	SYS lm tot	SYS # LED	LED lm/W	LED Vf	SYS lm tot
0.100	6	90.6	5.26	230.4	3	84.8	10.71	217.7
0.150	4	87	5.31	222.7	2	80.2	10.9	210.5
0.200	3	84.8	5.36	217.7	2	76.8	11.08	272.9
0.250	3	82.5	5.41	267.2	2	73.9	11.25	332.3
0.300	2	80.2	5.45	210.5	2	71	11.4	388.7
0.350	2	78.8	5.5	242	1	68.4	11.55	221.1
0.400	2	76.8	5.54	272.9	1	65.9	11.68	246.4
0.450	2	75.4	5.58	302.9	1	63.6	11.81	270.2
0.500	2	73.9	5.62	332.3	1	61.4	11.92	292.7
0.550	2	72.3	5.66	360.9	1	59.3	12.03	313.7
0.600	2	71	5.7	388.7	1	57.3	12.12	333.3
0.650	1	69.7	5.74	207.9	1	55.4	12.2	351.5
0.700	1	68.4	5.77	221.1	1	53.6	12.27	368.4
0.750	1	67.1	5.81	234	1	51.9	12.33	384
0.800	1	65.9	5.84	246.4	1	50.2	12.39	398.3
0.850	1	64.7	5.87	258.5	1	48.7	12.43	411.2
0.900	1	63.6	5.9	270.2	1	47.2	12.46	422.9
0.950	1	62.4	5.93	281.6	1	45.7	12.48	433.4
1.000	1	61.4	5.96	292.7	1	44.3	12.49	442.6

Figure 10: Cree PCT data For XM-L EZW LED

Current (A)	LED 1				LED 2			
	Model: Cree XLamp XM-L {HVW}				Model: Cree XLamp XT-E {HVW}			
	Flux: S6 [182]		Tsp (ºC): 79		Flux: P3 [73.9]		Tsp (ºC): 79	
	Price: $ -				Price: $ -			
	SYS # LED	LED lm/W	LED Vf	SYS lm tot	SYS # LED	LED lm/W	LED Vf	SYS lm tot
0.020	3	102.9	44.2	217.3	4	74.7	45.67	217.4
0.030	2	96.2	44.97	207.8	3	68.1	47.15	230.4
0.040	2	91.3	45.69	267.4	3	62.4	48.44	290.5
0.050	2	87.2	46.35	323.8	2	57.7	49.56	229
0.060	2	83.5	46.96	376.9	2	53.6	50.5	259.6
0.070	1	80.1	47.5	213.4				
0.080	1	77	48	236.7				
0.090	1	74.1	48.44	258.4				
0.100	1	71.4	48.82	278.6				
0.110	1	68.7	49.15	297.2				
0.120	1	66.3	49.42	314.3				

Figure 11: Cree PCT data For XM-L HVW and XT-E HVW LEDs

Figure 12 shows basic LED electrical data and optical output from Cree's PCT for one XT-E HVW LED. The lumen target is 150 lumens and the optical and electrical efficiencies are both 80%.

Current (A)	LED 1			
	Model	Cree XLamp XT-E {HVW} prelim		
	Flux	Q2 [87.4]	Tj (ºC)	79
	Price	$ -		
	SYS # LED	LED lm/W	LED Vf	SYS lm tot
0.020	3	90.6	45.21	195.8
0.030	2	82.8	46.68	185.5
0.040	2	76.4	47.92	234.7
0.050	2	70.9	48.93	278.1
0.060	1	66.2	49.72	157.9

Figure 12: Cree PCT for XT-E HVW LED

The XM-L EZW and XM-L HVW lamps use one LED. We made XT-E HVW lamps using one and two LEDs.

In addition to industry-leading efficacy, the XM-L EZW LED also provides the color consistency of an incandescent lamp without complicated color mixing. We chose to work with the 12-V standard CRI, order code XMLEZW-00-0000-0D0T627F, highlighted in yellow in Figure 13 below, to give the closest possible CCT to an incandescent lamp. The 12-V LED can operate at a lower current than the 6-V LED, enabling the use of a smaller, more-efficient driver.

Color	CCT Range	Base Order Codes Min Luminous Flux @ 350 mA, 85° C		2-Step Order Code		4-Step Order Code	
		Group	Flux (lm)	Chromaticity Region		Chromaticity Region	
Standard CRI EasyWhite	4000 K	U4	340	40H	XMLEZW-00-0000-0D00U440H	40F	XMLEZW-00-0000-0D00U440F
		U3	320		XMLEZW-00-0000-0D00U340H		XMLEZW-00-0000-0D00U340F
		U2	300		XMLEZW-00-0000-0D00U240H		XMLEZW-00-0000-0D00U240F
	3500 K	U3	320	35H	XMLEZW-00-0000-0D00U335H	35F	XMLEZW-00-0000-0D00U335F
		U2	300		XMLEZW-00-0000-0D00U235H		XMLEZW-00-0000-0D00U235F
		T6	280		XMLEZW-00-0000-0D00T635H		XMLEZW-00-0000-0D00T635F
	3000 K	U3	320	30H	XMLEZW-00-0000-0D00U330H	30F	XMLEZW-00-0000-0D00U330F
		U2	300		XMLEZW-00-0000-0D00U230H		XMLEZW-00-0000-0D00U230F
		T6	280		XMLEZW-00-0000-0D00T630H		XMLEZW-00-0000-0D00T630F
		T5	260		XMLEZW-00-0000-0D00T530H		XMLEZW-00-0000-0D00T530F
	2700 K	U2	300	27H	XMLEZW-00-0000-0D00U227H	27F	XMLEZW-00-0000-0D00U227F
		T6	280		XMLEZW-00-0000-0D00T627H		XMLEZW-00-0000-0D00T627F
		T5	260		XMLEZW-00-0000-0D00T527H		XMLEZW-00-0000-0D00T527F
		T4	240		XMLEZW-00-0000-0D00T427H		XMLEZW-00-0000-0D00T427F

Figure 13: XM-L EZW LED binning data

For the XM-L HVW lamp, we chose to work with order code XML-HVW-Q0-0000-0000LSSE7, highlighted in yellow in Figure 14, to closely match an incandescent lamp's CCT.

Color	CCT Range		Base Order Codes Min Luminous Flux @ 44 mA (lm)		Order Code
	Min.	Max.	Group	Flux (lm)	
Cool White	5,000 K	8,300 K	T3	220	XMLHVW-Q0-0000-0000LT351
			T4	240	XMLHVW-Q0-0000-0000LT451
Neutral White	3,700 K	5,000 K	S6	182	XMLHVW-Q0-0000-0000LS6E5
			T2	200	XMLHVW-Q0-0000-0000LT2E5
Warm White	2,600 K	3,700 K	S5	172	XMLHVW-Q0-0000-0000LS5E7
			S6	182	XMLHVW-Q0-0000-0000LS6E7

Figure 14: XM-L HVW LED binning data

Similarly, for the XT-E HVW lamp, we chose order code XTEHVW-Q0-0000-00000L9E7, highlighted in yellow in Figure 15, to closely match an incandescent lamp's CCT.

Color	CCT Range		Base Order Codes Min Luminous Flux @ 22 mA (lm)		Order Code
	Min.	Max.	Group	Flux (lm)	
Cool White	5,000 K	8,300 K	Q5	107	XTEHVW-Q0-0000-00000LD51
			R2	114	XTEHVW-Q0-0000-00000LE51
Neutral White	3,700 K	5,000 K	Q2	87.4	XTEHVW-Q0-0000-00000LAE5
			Q3	93.9	XTEHVW-Q0-0000-00000LBE5
Warm White	2,600 K	3,700 K	P4	80.6	XTEHVW-Q0-0000-00000L9E7
			Q2	87.4	XTEHVW-Q0-0000-00000LAE7

Figure 15: XT-E HVW binning data

The purpose of this design is to demonstrate that single high power LEDs such as the XLamp XM-L can deliver equivalent lighting and substantially greater efficacy than 25-W incandescent B10 lamps currently available.

5. CONSIDER ALL DESIGN POSSIBILITIES AND CHOOSE THE BEST

Optical Efficiency

Producing omnidirectional light output from a B10 lamp using a directional XLamp LED presents a design challenge. To meet that challenge and minimize light loss within the lamp we mounted the LED and the secondary optic 1 inch (2.5 cm) above the base of the heat sink on an aluminum spacer. As shown in Figures 16 and 17, this design allows light that would otherwise be reflected upward to exit the lamp downward and increases the amount of light in the >90° beam angle. This results in a lamp that can closely approximate the light pattern of an incandescent B10 lamp.

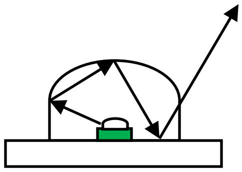


Figure 16: Figure 13: LED and optic mounted on heat sink

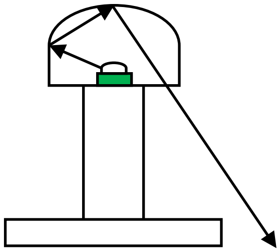


Figure 17: Figure 14: LED and optic mounted on spacer above heat sink

The solid-aluminum spacer not only improves optical efficiency but also provides a thermal path to the heat sink, which in turn dissipates heat.

6. COMPLETE THE FINAL STEPS

This section describes the steps Cree followed to create a prototype B10 lamp using the Cree XLamp XM-L EZW, XM-L HVW and XT-E HVW LEDs and reviews the photometric, electrical and thermal results.

Prototyping Details

The essence of this prototyping design is to assemble the XLamp LED onto a metal-core printed circuit board (MCPCB), mount this PCB onto a spacer attached to a heat sink and assemble these components with the necessary secondary optics and driver to create an LED-based lamp. The prototyping steps are detailed below.

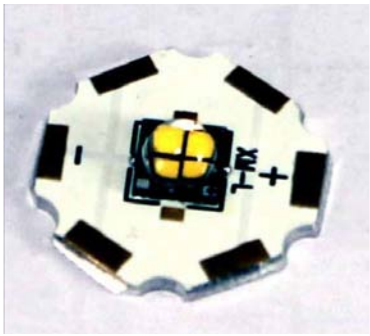
1. We verified the component dimensions to insure a correct fit.

2. We soldered the driver input wires to the E12 base power connection.

3. We wrapped the driver in Kapton silicon adhesive tape to isolate the driver from the heat sink and provide thermal protection.

4. Following the recommendations for the XLamp XM family LEDs, we reflow soldered the LEDs onto the MCPCB with an appropriate solder paste and reflow profile.

5. We cleaned the flux residue with isopropyl alcohol.



6. We attached the 1-inch aluminum spacer to the heat sink using Arctic Silver thermal epoxy.

7. We drilled two thru-holes in the base of the heat sink on its diameter to permit the driver output wires to be connected to the MCPCB.

8. We inserted the driver into the heat sink, fed the DC output wires through the thru-holes and soldered them to the corresponding terminal pads on the MCPCB.

9. We fastened the optic to the MCPCB by heating the pegs of the optic and wrapping them under the MCPCB.

10. We applied a thin layer of thermal conductive compound to the back of MCPCB and secured it to the aluminum spacer.

11. We fastened the lamp case to the heat sink with Kwik Plastic epoxy.

12. We attached the base to the heat sink with Kwik Plastic epoxy.

13. We performed final testing.

Results

Measured T_{sp}

Table 8 shows the measured solder point temperatures and calculated junction temperatures for the XLamp B10 lamps. These results closely match the temperature simulation and show that the heat sink is sufficient to dissipate the heat generated.

Lamp	T_{SP}	Current	Voltage	T_J
XM-L EZW B10	79 °C	340 mA	11.6 V	87 °C
XM-L HVW B10	87 °C	92.3 mA	48.8 V	110 °C
XT-E HVW B10	92 °C	43.8 mA	95.7 V	117 °C

Table 8: System temperature data

Photometric Results

Table 9 shows the photometric and electrical results for the XLamp B10 lamps at steady state (after 30 minutes, powered). The lamps demonstrate luminous flux and CCT comparable to an incandescent lamp with much higher efficacy at 80% less power. The XM-L HVW lamp nearly achieves the ENERGY STAR light output requirement for a 40 W B10 lamp.

Characteristic	Unit	XM-L EZW	XM-L HVW	XT-E HVW (1 LED)	XT-E HVW (2 LEDs)
Luminous flux	lm	204	292	150	235
Efficacy	lm/W	50	57	49	48
Input power	W	4.1	5.2	3.3	4.9
CCT	K	2696	3107	3021	3101
CRI		80.2	81.9	81.8	82.8
Power factor		0.52	0.97	0.56	0.55

Table 9: XM-L EZW B10 lamp photometric results

The XM-L EZW prototype B10 lamp was measured to obtain a polar candela distribution, shown in Figure 18.[15] This omnidirectional distribution is in close comparison to the distributions of example incandescent and CFL lamps. Because they were constructed in the same way as the XM-L EZW lamp, Cree expects the XM-L HVW and XT-E HVW lamps' polar candela distributions to be similar to that of the XM-L EZW lamp.

15 Measurements were taken using a type A goniophotometer at the Cree facility in Durham, NC.

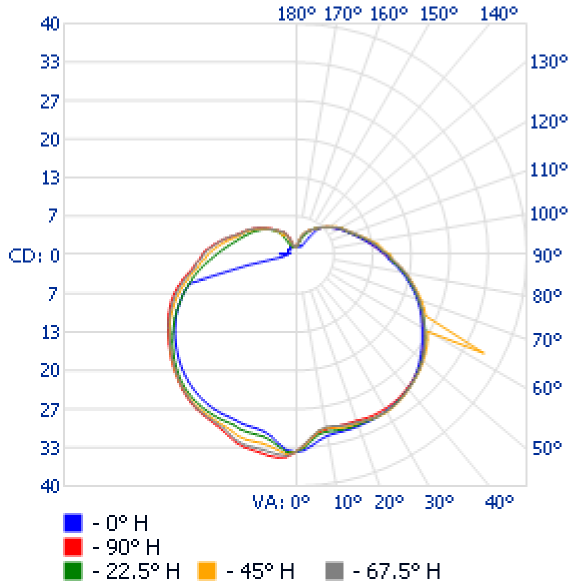


Figure 18: Polar candela distribution for XM-L EZW B10 lamp

Table 10 shows the light distribution of the XM-L EZW B10 lamp compared to that of incandescent and CFL examples.

Zone	Incandescent		CFL		XM-L EZW	
	Lumens	%	Lumens	%	Lumens	%
0-30	14.3	7%	9.7	6.2%	26.6	12.9%
0-40	24.4	12%	18.4	11.7%	45.7	22.1%
0-60	52.3	25.7%	45.6	29%	91.7	44.5%
60-90	57.1	28%	54.0	34.4%	62.5	30.3%
70-100	58.7	28.8%	53.0	33.7%	53.3	25.8%
90-120	56.9	27.9%	41.4	26.3%	34.8	16.9%
0-90	109.4	53.6%	99.6	63.4%	154.3	74.8%
90-180	94.6	46.4%	57.5	36.6%	51.9	25.2%

Table 10: Zonal lumen summary

Tables 11 and 12 show the illuminance of the XM-L EZW B10 lamp at various distances compared to that of incandescent and CFL examples.

Distance		Incandescent		CFL		XM-L EZW	
1.7 ft	0.5 m	6.42 fc	69.1 lux	3.68 fc	39.6 lux	12.27 fc	132.1 lux
3.3 ft	1.0 m	1.61 fc	17.3 lux	0.92 fc	9.9 lux	3.07 fc	33.0 lux
5.0 ft	1.5 m	0.71 fc	7.6 lux	0.41 fc	4.4 lux	1.36 fc	14.6 lux
6.7 ft	2.0 m	0.40 fc	4.3 lux	0.23 fc	2.5 lux	0.77 fc	8.3 lux
8.3 ft	2.5 m	0.26 fc	2.8 lux	0.15 fc	1.6 lux	0.49 fc	5.28 lux
10.0 ft	3.0 m	0.18 fc	1.9 lux	0.10 fc	1.1 lux	0.34 fc	3.7 lux

Table 11: Center beam comparison

Distance		Incandescent (a)		CFL (b)		XM-L EZW (c)		XM-L EZW (d)	
1.7 ft	0.5 m	0.1 ft	0.03 m	3.8 ft	1.2 m	17.7 ft	5.4 m	31.8 ft	5.4 m
3.3 ft	1.0 m	0.2 ft	0.06 m	7.6 ft	2.2 m	35.5 ft	10.8 m	63.6 ft	19.4 m
5.0 ft	1.5 m	0.3 ft	0.09 m	11.4 ft	3.5 m	53.2 ft	16.2 m	95.4 ft	29.1 m
6.7 ft	2.0 m	0.5 ft	0.15 m	15.1 ft	4.6 m	71.0 ft	21.6 m	127.1 ft	38.7 m
8.3 ft	2.5 m	0.6 ft	0.18 m	18.9 ft	5.8 m	88.7 ft	27.0 m	158.9 ft	48.4 m
10.0 ft	3.0 m	0.7 ft	0.21 m	22.7 ft	6.9 m	106.4 ft	32.4 m	190.7 ft	58.1 m

Table 12: Beam width comparison

a Horizontal spread: 4.0°

b Beam spread: 97.2°

c Vertical spread: 158.7°

d Horizontal spread: 168.0°

Cree acknowledges that, as implemented, these B10 lamps have a slightly greater length than a typical B10 lamp. We believe that design adjustments can be made, such as a custom heat sink, to achieve the typical B10 form factor while retaining the electrical and photometric performance illustrated in this proof of concept.

CONCLUSIONS

This reference design demonstrates possibilities for designing a 25-W equivalent B10 lamp that uses a single Cree XLamp XM-L EZW, XM-L HVW, or XT-E HVW LED. Using two XT-E HVW LEDs provides increased performance while taking advantage of the LED’s high voltage capability. This design also demonstrates the possibility of designing a 40-W equivalent B10 lamp using a single XM-L HVW LED. Compared to the XM-L EZW LED, the high voltage LEDs enable the use of physically smaller yet more efficient drivers. The use of this small number of LEDs lowers system costs and the small footprint of these LEDs simplifies fitting the lamp components in the compact B10 form factor. The innovative lamp design, industry-best LED-to-LED color consistency, and high lumen output combine to make this a design for successful 25- and 40-W equivalent, omnidirectional, B10-replacement lamps.

SPECIAL THANKS

Cree would like to acknowledge and thank iWatt, Inc. and Power Integrations for their collaboration on this reference design.