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WHITE PAPER

Enabling High Efficiency Street Light Designs with Cree® XLamp® LED Arrays

TABLE OF CONTENTS

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INTRODUCTION

The lighting industry has been transitioning to LEDs for more than a decade to improve product reliability and increase efficacy in terms of lumens per watt (LPW). LED technologies have dramatically improved and regulatory bodies such as the DesignLights Consortium® (DLC®) and ENERGY STAR® have challenged lighting manufacturers by increasing the required minimum efficacy of lamps and luminaires to qualify for rebates. See Figure 1. Today the minimum system LPW requirements for high-power lighting are between 100 and 130 LPW depending on the application and rebate class.

The goal for this project was to create a high-efficiency street light that produces a Type III beam pattern and can be used in place of a 100-W high-pressure sodium (HPS) fixture.

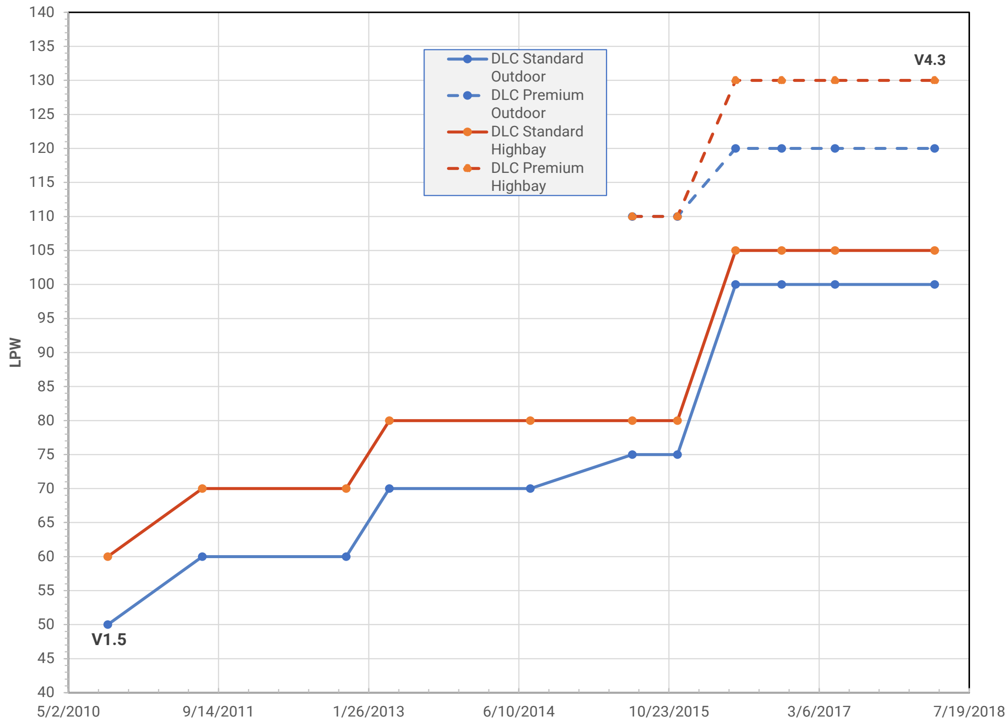

Figure 1: DLC LPW requirements over time

Advanced lighting systems must manage inefficiencies from optics and driver systems that total losses of 18% or more. Accounting for these losses requires LED efficacy to be greater than 155 LPW targeting a DLC Premium high-bay rebate or 146 LPW for DLC Premium street light products. Driver and optic losses are necessary evils in a well-designed lighting system. There are numerous examples of optical control being sacrificed to gain higher LPW values but the result always diminishes the system's target efficacy that measures wattage versus light delivered to the target.[1] Removing optics increases LPW specifications on paper, which is attractive to customers, but a real-world example shows the true value of optical control. The left side of Figure 2 shows uneven and uncontrolled spill light with no optical control; the right side shows optical control producing even illumination and a cutoff to reduce spill light on the house side of the street.

1 U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Top Efficacy Performers: An Investigation into High-Achieving LED Luminaires, June, 2018

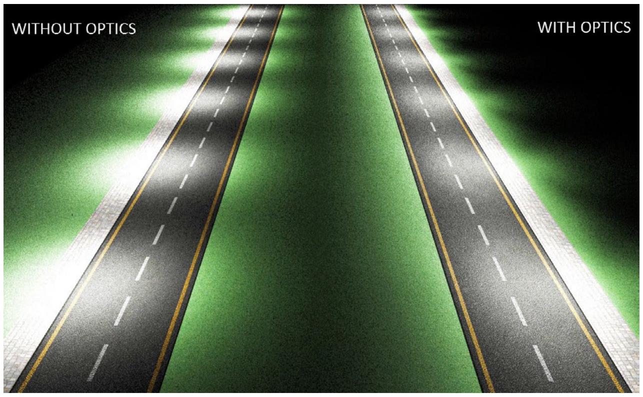

Figure 2: Comparison of uncontrolled and controlled spill light

WHY DID WE PICK COBS?

Cree's ceramic-based XLamp® chip-on-board (COB) LEDs (CXA2 Family) were chosen for this design because they offer the right combination of efficacy, light output and affordability.

Cree tested samples of the largest CXA2 COB LEDs (CXBxxxx) to find the LED that offered the highest peak efficacy to support the project's very high target system efficacy. As shown in Figure 3, this testing found the CXB3050 LED to have the highest efficacy value of about 230 LPW at 100 mA.

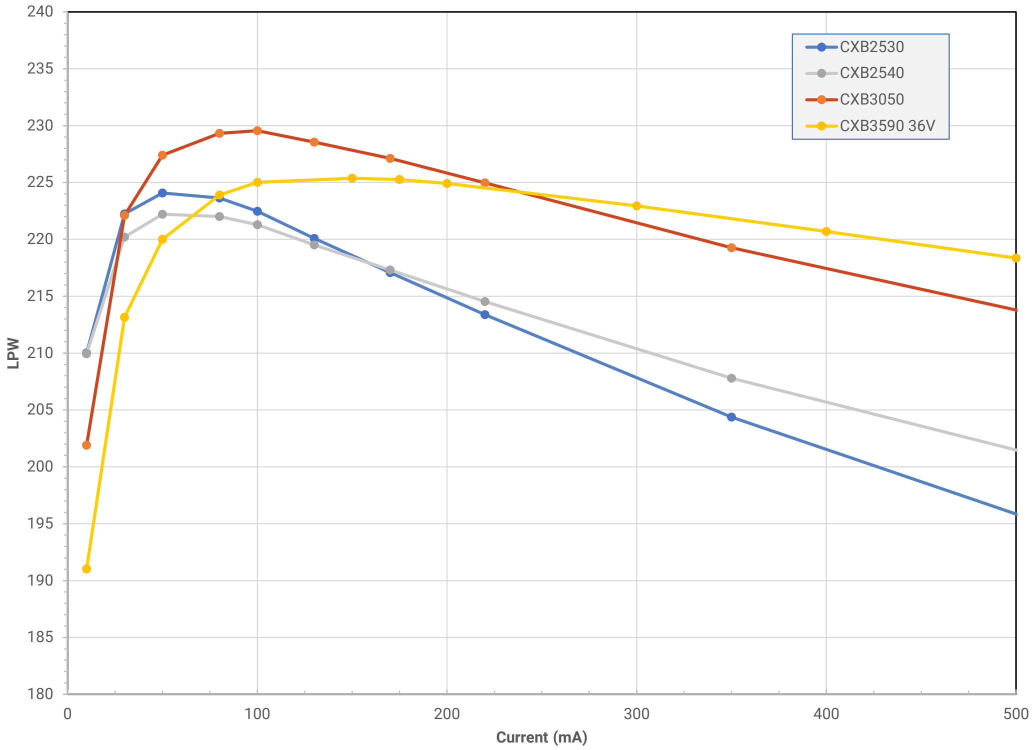

Figure 3: Efficacy (LPW) vs. current (mA) for 4 XLamp CXA2 LEDs at steady-state operation, T_s = 25 °C

Other types of LEDs were considered for this design:

- Ceramic-based surface-mount arrays, such as the XLamp MH Family, are another viable choice since they share the same core technology base as the CXB3050. However, the surface-mount arrays had fewer optics choices available on the market that met the design targets at the time of this development, so COB LEDs were chosen instead.
- High-power ceramic-based LEDs, such as the popular XLamp XP-G3 LED, offer terrific optical control advantages over the COB-based approach, usually resulting in much smaller optical solutions. However, these high-power LEDs do not reach the same levels of peak efficacy that were measured from the CXB3050 LED and can be quite expensive when used at low drive currents.
- High-power plastic-based LEDs, such as the Cree J Series 5050 LED, are becoming a very popular choice for cost-effective outdoor lighting designs due to their small size and high lumens-per-dollar. Just as with the surface-mount arrays, at the time of this design development, there were few optical solutions available for this LED type to meet street lighting targets. In addition, by driving these LEDs at low currents to achieve peak efficacy, the light output of each LED is quite low, making the count of LEDs required to get acceptable light output relatively high. More optics are becoming available and if a lower efficacy level is the target, these types of LEDs may be a good design choice.

DESIGN GOALS

The goal of this street light reference design was to develop an efficient 6000-lm luminaire weighing under 3 lbs to both replace the typical 100-W high-pressure sodium (HPS) fixture, generally weighing in excess of 20 lbs, and to keep pace with the ever increasing DLC requirements for street lighting. Cree wanted to use reliable, efficient and readily available off-the-shelf components for the design knowing high efficiencies would play a key role in meeting the design goals. Also, the use of Cree LED Arrays were to be considered as they are proven to provide high efficiency at low drive currents with available optics. The project's overall design targets were as follows:

- Efficacy: 200 LPW
- Light output 6000 lm
- CRI 70
- CCT 5000 K

ABOUT THE DESIGN

Electrical

The electrical design was straightforward. Cree's Product Characterization Tool (PCT) was used to estimate how many LEDs would be needed to produce 6000 lumens, factoring in both optical and electrical losses. Cree selected the CXB3050 LED Array for the design because of its performance, ceramic-based substrate reliability, compatibility with LEDiL optics, and cost. The CXB3050 LED Array can produce 9000 lm at a maximum drive current of 2.5 A and can be under-driven significantly to meet high efficacy targets. Cree wired 6 CXB3050 LEDs in parallel (see Figure 4) to avoid the high forward-voltage requirement of a series configuration. The 36-V typical forward voltage of this part made driver selection manageable. There are several drivers on the market that fit this 36-V Vf while providing a wide range of drive currents. Cree selected a total drive current of 1050 mA and chose to use an Energy Recovery Products (ERP) ESP050 series driver. At 175 mA per LED the overall system efficacy was 201 LPW (without driver loss). Using COB holders from TE Connectivity to make the necessary connections with the electrical pads on the LED arrays avoided any need for soldering. These holders also allowed plenty of room to fit the LEDiL optics discussed below.

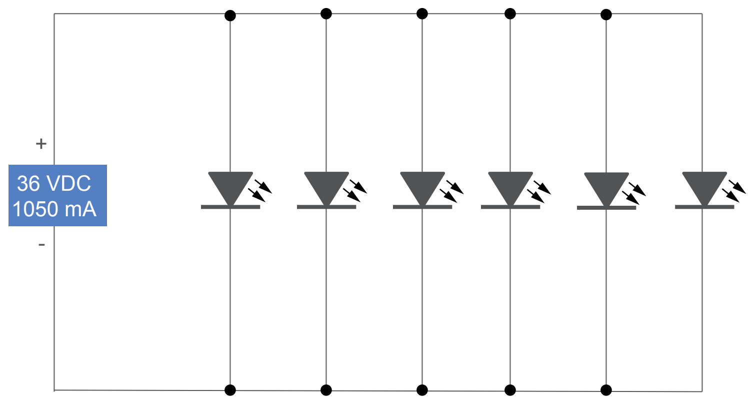

Figure 4: Electrical schematic

Optical

This optical design leverages the expertise of LEDiL® with their STELLA-G2 Type III optics for street lights (see Figure 5). These silicon lenses are IP67 self-sealing and are compatible with COBs up to a 30-mm LES size, easily accommodating the 23-mm LES size of the CXB3050 LED used in this design. The optical control characteristics are shown in the spatial distribution diagram in Figure 6, provided by LEDiL. This diagram shows a tight cutoff in one direction to minimize light pollution while providing a 60-degree beam on the opposite side of the optic. Most of the light spills onto the street, which is the desired goal.

Figure 5: LEDiL STELLA-G2 Type III optic

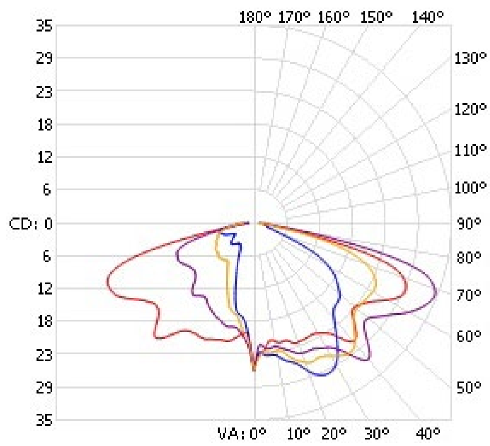

Figure 6: LEDiL optic spatial distribution

Thermal

Under-driving the LEDs meant there was little to no heat dissipated. Little heat sinking was going to be required so the luminaire uses the LED mounting plate as the heat sink. The mounting plate is made of 6032 aluminum having dimensions of 3.3 mm X 295 mm X 327 mm. Cree used a FLIR thermal camera to take images of the mounting plate and LEDs on a laboratory bench to verify the thermal performance with the overall system current set at 1050 mA (see Figure 7, Figure 8 and Figure 9). The street light ran cool with a case temperature of

39 °C and an LES temperature of 41 °C over a period of 2 hours. The street light generated so little heat, consideration was given to using a thermoplastic material for the heat sink to lower the overall luminaire weight even further.

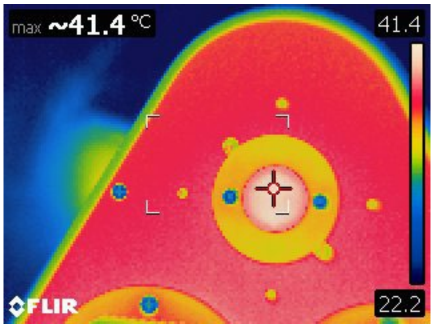

Figure 7: T_{LES}

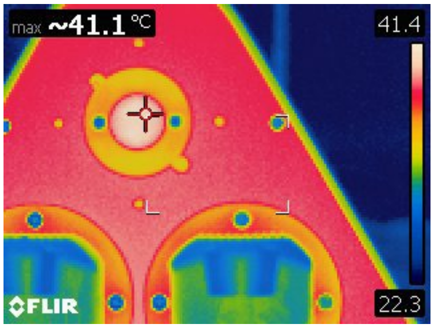

Figure 8: T_C front panel

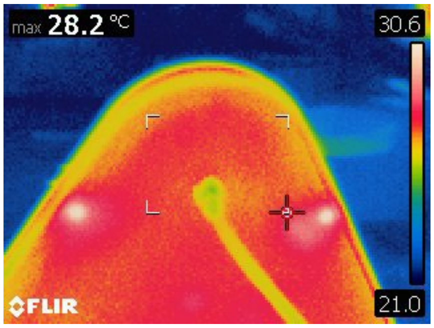

Figure 9: T_C rear panel

The thermal interface material (TIM) was the .25-mm non-adhesive eGRAF[2] HITHERM™ foil made by NeoGraf Solutions. Its thermal conductivity of 150 W/m-K was more than adequate for this design and much cleaner to use during final assembly than a typical thermal paste.

Mechanical

The mechanical design consisted of a mounting plate, a 3D-printed fixture ring and a 3D-printed backing plate to contain and hide the wiring (see Figure 10). Everything screws to the mounting plate to avoid any unnecessary stresses on the plastic parts. The design was developed using SOLIDWORKS, then 3D printed and assembled.

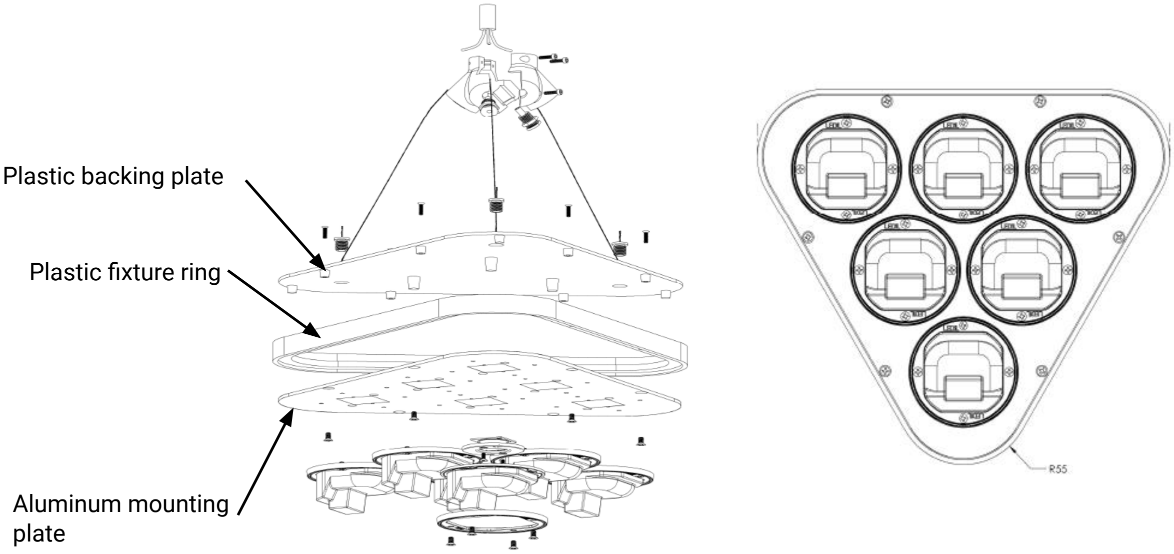

Figure 10: Luminaire mechanical drawings

2 P/N: GMTOEG0015 HT1210

RESULTS

Table 1: Measured results for street light

LED	6 Cree CXB3050
Footprint - LWH (inches)	13 x 13 x 1
Weight (lbs)	3
Lumens (lm)	6000
Efficacy (LPW) with DC supply and no optics	220
Efficacy (LPW) with DC supply and optics	201
Efficacy (LPW) with driver and optics	172
CCT (K)	4700
CRI	70

CONCLUSION

Innovation in Cree's ceramic-based XLamp COB LEDs is enabling high-efficiency designs with the right combination of efficiency, light output and affordability. This combination is especially important considering the ever increasing DLC requirements for street lighting. This street light project identified new design possibilities in terms of reducing size, reducing weight and exploring heat sinking options married with structural design. The results showed a total luminaire efficacy (including all driver and optical losses) of 172 LPW, which is above current DLC Premium requirements. Efficiency combined with the true value of optical control made this a worthwhile real-world exercise.

An interesting possible extension to this project would be to explore the use of thermoplastic materials (mentioned earlier) as heat sinking options. While their thermal conductivity numbers are much lower than that of typical metals, thermoplastic materials offer significant advantages in weight reduction.

For more information regarding Cree's entire COB product family, please visit the Cree website.

BILL OF MATERIALS

Table 2: Bill of materials

Component	Order Code/Model Number	Company	Web Link
LED	CXB3050-50E-AB-NOB-00B1	Cree, Inc.	CXB3050 product page
Driver	ESP050-1050-42	ERP	https://www.erp-power.com/
Optics	STELLA-G2 Type III	LEDiL	https://www.ledil.com/
TIM	GMTOEG0015 HT1210	NeoGraf Solutions	http://www.graftech.com/
Aluminum mounting plate	Custom	Cree, Inc.	CXB3050 design file
Plastic fixture ring	Custom	Cree, Inc.	CXB3050 design file
Plastic backing plate	Custom	Cree, Inc.	CXB3050 design file
Connector	2213480-2Z50 LED Holder 2727	TE Connectivity	http://www.te.com/usa-en/home.html