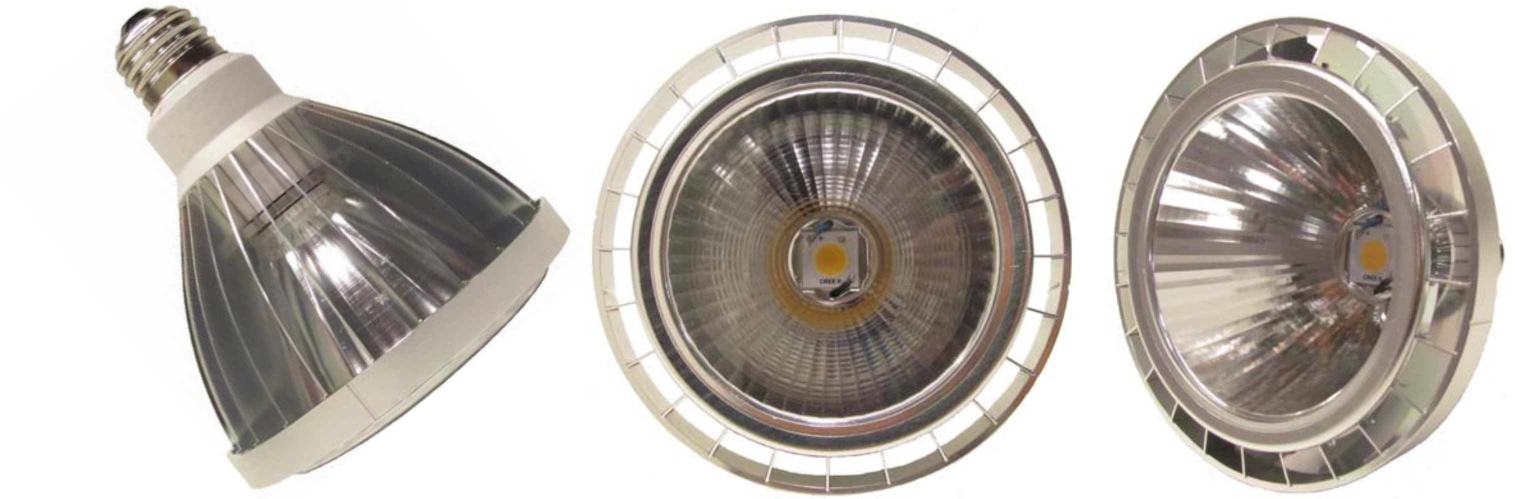
Cree® XLamp® CXA1507 LED PAR30 Reference Design



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INTRODUCTION

This application note details the design of a 75-watt equivalent PAR30 replacement lamp using Cree's XLamp CXA1507 LED. The CXA1507 LED provides the same easy handling as the original CXA2011, while occupying a 47% smaller footprint. Its single optical source replicates the look of traditional halogen designs.

The uniform emitting surface of the CXA1507 LED enables narrow-beam optical designs desired in commercial applications. This reference design shows that a single CXA1507 component enables true halogen performance in directional applications such as a PAR30 lamp.

The goal of this design is to enable an LED-based PAR30 replacement retrofit lamp with a narrow beam, delivering performance equivalent to a 75-watt halogen PAR30 lamp and conforming to ENERGY STAR requirements.

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DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide" application note, Cree advocates a 6-step framework for creating LED luminaires.[1] 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 efficiencies 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 major goal for this project is to demonstrate the ease of implementing a narrow-beam PAR30 lamp that could replace current halogen PAR30 lamps on the market, showing that a true 75-watt equivalent PAR30 LED lamp is possible using the Cree XLamp CXA1507 LED. Cree framed the project as a retrofit, so the PAR30 lamp designed in this application note could take advantage of the installed base of PAR30 fixtures.[2]

1. DEFINE LIGHTING REQUIREMENTS

Table 2 lists important characteristics to consider in the design of the PAR30 lamp in this reference design.

1 LED Luminaire Design Guide, Application Note AP15, www.cree.com/xlamp_app_notes/luminaire_design_guide

2 Production and cost-optimized implementations are beyond the scope of this document.

Importance	Characteristics	Metric
Critical	Light intensity - center beam candle power (CBCP)	candelas (cd)
	Beam angle - full width half maximum (FWHM)	degrees (°)
	Electrical power	watts (W)
	Luminous flux	lumens (lm)
	Efficacy	lm/W
	Form factor	
Important	Price	$
	Lifetime	hours
	Operating temperatures	°C
	Correlated color temperature (CCT)	K
	Color rendering index (CRI)	100-point scale
	Lamp-to-lamp consistency	
	Power factor	
	Manufacturability	

Table 2: Ranked design criteria for PAR30 lamp

Table 3 summarizes the ENERGY STAR® requirements for all integral LED lamps.[3]

Characteristic	Requirements
CCT and Duv	Lamp must have one of the following designated CCTs (per ANSI C78.377-2008) consistent with the 7-step chromaticity quadrangles and Duv tolerances below. Nominal CCT / Target CCT (K) and Tolerance / Target Duv and Tolerance: 2700 K / 2725 ± 145 / 0.000 ± 0.006 3000 K / 3045 ± 175 / 0.000 ± 0.006 3500 K / 3465 ± 245 / 0.000 ± 0.006 4000 K / 3985 ± 275 / 0.001 ± 0.006
Color maintenance	The change of chromaticity over the minimum lumen maintenance test period (6,000 hours) shall be within 0.007 on the CIE 1976 (u′, v′) diagram.
CRI	Minimum CRI (R_a) of 80. R_9 value must be greater than 0.
Dimming	Lamps may be dimmable or nondimmable. Product packaging must clearly indicate whether the lamp is dimmable or not dimmable. Manufacturers qualifying dimmable products must maintain a Web page providing dimmer compatibility information. Minimum efficacy, light output, CCT, CRI, and power factor of dimmable lamps will be confirmed with the lamp operated at full power.
Warranty	A warranty must be provided for lamps, covering material repair or replacement for a minimum of three (3) years from the date of purchase.
Allowable lamp bases	Must be a lamp base listed by ANSI.
Power factor	Lamp power < 5 W and low voltage lamps: no minimum power factor is required Lamp power > 5 W: power factor must be ≥ 0.70 Note: Power factor must be measured at rated voltage.
Minimum operating temperature	-20 °C or below
LED operating frequency	≥ 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. Dimming operation shall meet the requirement at all light output levels.
Electromagnetic and radio frequency interference	Must meet appropriate FCC requirements for consumer use (FCC 47 CFR Part 15)

3 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

Characteristic	Requirements
Audible noise	Class A sound rating
Transient protection	Power supply shall comply with IEEE C62.41-1991, Class A operation. The line transient shall consist of seven strikes of a 100 kHz ring wave, 2.5 kV level, for both common mode and differential mode.
Operating voltage	Lamp shall operate at rated nominal voltage of 120, 240 or 277 VAC, or at 12 or 24 VAC or VDC.

Table 3: ENERGY STAR requirements for all integral LED lamps

Table 4 summarizes the ENERGY STAR requirements for replacement PAR lamps.[4]

Criteria Item	ENERGY STAR Requirements
Definition	Directional lamp means a lamp having at least 80% light output within a solid angle of ∏ sr (corresponding to a cone with angle of 120°)
Minimum luminous efficacy	Lamp diameter < 20/8 inch: 40 lm/W Lamp diameter > 20/8 inch: 45 lm/W
Color spatial uniformity	The variation of chromaticity within the beam angle shall be within 0.006 from the weighted average point on the CIE 1976 (u′, v′) diagram.
Maximum lamp diameter	Not to exceed target lamp diameter
Maximum overall length (MOL)	Not to exceed MOL for target lamp
Minimum center beam intensity PAR lamps	Link to online tool at www.energystar.gov/ia/products/lighting/iledl/IntLampCenterBeamTool.zip
Lumen maintenance	> 70% lumen maintenance (L_{70}) at 25,000 hours of operation
Rapid-cycle stress test	Cycle times must be 2 minutes on, 2 minutes off. Lamp will be cycled once for every 2 hours of L_{70} life.

Table 4: ENERGY STAR requirements for PAR lamps

Table 5 shows performance data for several market-available 75-W halogen PAR30 lamps.[5]

Source	Luminous Flux (lm)	Efficacy (lm/W)	Beam Angle (°)	CBCP (cd)	Lamp Power (W)	CCT	CRI	Lifetime (hrs)
Halogen lamp A	1130	15.1	9	15,400	75	2900	100	2500 hrs
Halogen lamp B	1100	14.7	10		75	2850		2500 hrs
Halogen lamp C	1000	13.3	10	12,300	75	2900		3000 hrs

Table 5: 75-W halogen PAR30 lamp performance data

2. DEFINE DESIGN GOALS

Table 6 shows the design goals for this project. We used the ENERGY STAR Center Beam Intensity Benchmark Tool to determine the CBCP required for a 75-W 10° beam angle lamp.[6]

4 Ibid., Table 7C
5 Source: Data sheets available on-line
6 www.energystar.gov/ia/products/lighting/iledl/IntLampCenterBeamTool.zip

Characteristic	Unit	Minimum Goal	Target Goal
Light output	lm	900	> 900
Efficacy	lm/W	50	> 55
Beam angle	degrees (°)	10	< 10
CBCP - 10° beam angle	cd	9561	> 9561
Power	W	28	< 16
CCT	K	3000	3000
CRI	100-point scale	80	80
Power factor		0.9	> 0.9

Table 6: CXA1507 PAR30 lamp design goals

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

We used Cree's Product Characterization Tool (PCT) tool to determine the drive current for the design.[7] For the 900-lm target, we estimated 89% optical efficiency and 88% driver efficiency. We also estimated a solder point temperature of 60 °C.

The PCT output highlighted in Figure 1 shows that, at 350 mA, one CXA1507 LED provides sufficient light output to meet the design goals.

	LED 1			
	Model	Cree XLamp CXA1507 {EZW}		
	Flux	F4 [730]		730.0
	Price	$ -	Tsp (ºC)	60
	ΔVf	0.000	Multiple	x1
Current (A)	SYS # LED	SYS lm tot	SYS W	SYS lm/W
0.230	2	1457.08	19.7	74
0.240	2	1501.45	20.646	72.7
0.250	2	1544.88	21.598	71.5
0.260	2	1586.82	22.554	70.4
0.270	2	1627.59	23.515	69.2
0.280	2	1667.22	24.481	68.1
0.290	2	1706.06	25.453	67
0.300	2	1743.49	26.429	66
0.350	1	957.47	15.694	61
0.400				

Figure 1: PCT output with CXA1507 flux data

Thermal Requirements

The heat sink in this PAR30 reference design must not only dissipate the heat generated by the XLamp CXA1507 LED, but also provide the mechanical frame for the LED, optic, driver, and base. Additionally, to be considered a true PAR30

7 PCT is available at: pct.cree.com

retrofit, the parabolic reflector footprint must fit into the ANSI standard envelope as defined in ANSI C78.24-2001.[8] We created a heat sink design[9] with Tai Sun Electric Limited, shown in Figure 2, that is similar to the design method and stamped fin process used in Cree's MT-G MR16, CXA2011 AR111, XB-D A19 and MT-G2 PAR38 reference designs.[10] The heat sink kit includes an optic holder, shown in Figure 3, and a plastic screw base, shown in Figure 4.

Figure 2: CXA1507 PAR30 heat sink

Figure 3: Optic holder

Figure 4: Plastic screw base

8 www.nema.org/stds/c78-24.cfm
9 Model PAR30-HS-CXA-W1, www.hztaisun.com/Default.aspx
10 Cree XLamp MT-G LED MR16 Reference Design, Application Note AP62, www.cree.com/xlamp_ref/mtg_mr16
Cree XLamp CXA2011 LED AR111 Reference Design, Application Note AP88, www.cree.com/xlamp_ref/mtg_ar111
Cree XLamp XB-D LED 75-watt Equivalent A19 Lamp Reference Design, Application Note AP110, www.cree.com/xlamp_ref/xbd_75w_A19
Cree XLamp MT-G2 EasyWhite LED PAR38 Reference Design, www.cree.com/xlamp_ref/mtg2_par38

We performed thermal simulation to verify this thermal design is sufficient. Shown in Figure 5 are the simulation results showing thermal images of the lamp assembly. The simulated solder point temperature (T_{SP}) was 62 °C.[11] The thermal resistance of the CXA1507 LED is 2.5 °C/W, so at 14 W the junction temperature (T_J) will be approximately 97 °C.

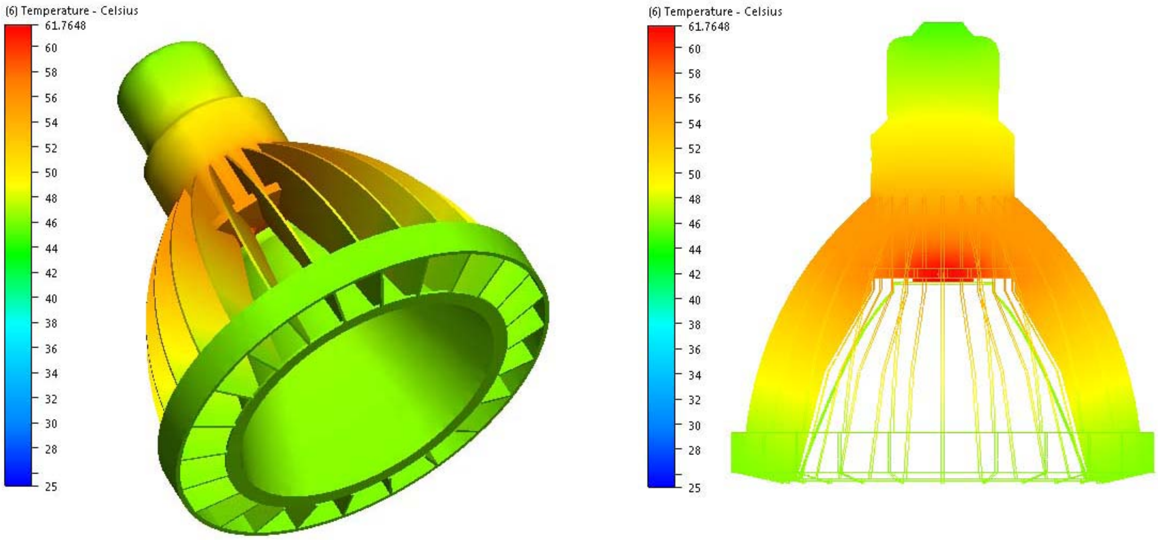


Figure 5: CXA1507 PAR30 lamp thermal simulation

Drive Electronics

One of the biggest challenges of this design was fitting the necessary high-power drive electronics into the relatively small area of the PAR30 base. Standard US PAR30 lamps run on 120-VAC line voltage directly to the lamps, so the internal driver must convert the 120 VAC from the Edison E26 socket to a 350-mA current source for the CXA1507 LED, running at approximately 40 V. Additionally, it was determined that, to better showcase the CXA1507 LED, a dimmable driver is necessary, as dimmability is often a market requirement for a PAR30 lamp.

Cree selected a dimmable, highly efficient driver from Power Integrations to meet the strict requirements needed to demonstrate a PAR30 75-W-equivalent LED lamp.[12] Power Integrations worked with Cree to design a driver specifically to fit in a plastic base created by Tai Sun for the PAR30 heat sink.

Figure 6: CXA1507 PAR30 driver

11 For additional information on thermal management, refer to the Thermal Management of Cree XLamp LEDs Application Note, AP05, www.cree.com/xlamp_app_notes/thermal_management

12 Part number LNK407EG, Power Integrations, www.powerint.com/sites/default/files/PDFFiles/der341.pdf, pages 40-52

The driver is approximately 91% efficient and output the current needed to operate the CXA1507 LED at 350 mA.

Secondary Optics

Another significant challenge was to tailor the secondary optic for the CXA1507 LED to fit within the standard PAR30 envelope and produce the desired narrow beam angle and CBCP. The optic had to fit within the PAR30 heat sink envelope and allow room for the driver and heat sink.

As shown in Figure 7, Cree used an off-the-shelf reflector from Illumination Machines, the MTG10, which is designed to produce a narrow, 10° beam from an XLamp MT-G LED.[13] The optical source sizes of the XLamp MT-G and CXA1507 LEDs are nearly equal, so we expect this reflector to work well with the CXA1507 LED. The Tai Sun heat sink is designed to accommodate this reflector, with a top optic holder that snaps into place to hold the reflector.

Figure 7: CXA1507 PAR30 reflector

Additionally, a plastic cover is used to seal the reflector and block access to the LED and the internal reflecting surface. Cree used an acrylic sheet,[14] cut into an 80-mm disc to fit on top of the reflector, as shown in Figure 8. The extremely high-quality acrylic causes less than 3% light loss.

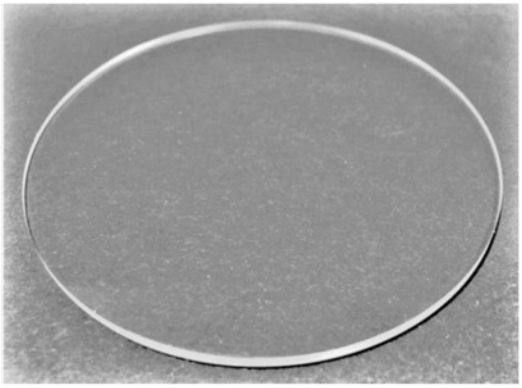


Figure 8: Acrylic plastic cover cut to fit on top of the CXA1507 PAR30 reflector

13 Illumination Machines MTG10, www.illuminationmachines.com/pdfs/CreeMTG10.pdf
14 Evonik Industries, ACRYLITE® Abrasion Resistant (AR) acrylic, www.acrylite.net/sites/dc/Downloadcenter/Evonik/Product/ACRYLITE/3489A%20Abrasion%20Resistant%20Sheet%20bro.pdf

4. CALCULATE THE NUMBER OF LEDS NEEDED

One.

We selected a Warm White LED for this reference design, shown highlighted in yellow in Table 7. By choosing an LED from a mid-level flux bin, we ensure that the design uses an LED that is readily available.

Color	CCT Range	Base Order Codes Min. Luminous Flux @ 200 mA			2-Step Order Code		4-Step Order Code	
		Group	Flux (lm) @ 85 °C	Flux (lm) @ 25 °C*	Chromaticity Region		Chromaticity Region	
EasyWhite	3000K	F2	680	759	30H	CXA1507-0000-000N00F230H	30F	CXA1507-0000-000N00F230F
		F4	730	815		CXA1507-0000-000N00F430H		CXA1507-0000-000N00F430F

Table 7: CXA1507 LED order code

The dual purpose of this reference design is to show that a single LED package can deliver equivalent lighting utility and superior efficacy compared to existing halogen PAR30 lamps on the market and show that it is possible to produce a narrow-beam PAR30 lamp with an XLamp CXA1507 LED. The CXA1507 LED is a multi-chip LED package that can offer the required CBCP of a replacement lamp with new levels of LED-to-LED color consistency and efficiency. The easy-to-handle CXA1507 LED can enable superior LED lighting designs even more quickly.

5. CONSIDER ALL DESIGN POSSIBILITIES

There are many ways to design the necessary heat sink that can dissipate the heat of a retrofit LED-based PAR30 lamp and fit within the standard PAR30 ANSI-defined envelope. One such heat sink is from Tai Sun and is demonstrated in this reference design. There are also many ways to drive the LED and design the optics. Working with Power Integrations to create a reference design driver and with Illumination Machines to create and select appropriate optics provided the performance necessary for a true 75-W halogen PAR30 replacement lamp.

There are a number of desirable performance-related benefits in this design that are results of the XLamp CXA1507 LED package. Because the CXA1507 LED uses EasyWhite technology, LED-to-LED color consistency can be held to within two or four McAdam ellipses for any given CCT, depending on the order code. The CXA1507 LED is binned at 85 °C so the CCT will be as faithful as possible to the system operating environment. These features allow for new levels of specification accuracy.

However, the primary purpose of this reference design is to show how straightforward it is to design with Cree's XLamp CXA1507 LED. This application note is not intended to show the only way to do this, but rather demonstrate the ease of implementation in a difficult set of engineering constraints.

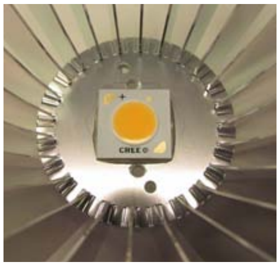
6. COMPLETE THE FINAL STEPS

This section illustrates the techniques used to create a working prototype PAR30 lamp using the XLamp CXA1507 LED and shows the results of the design.

Prototyping Details

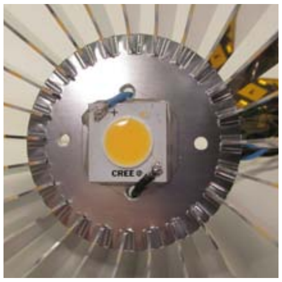
The essence of the design is to attach a Cree XLamp CXA1507 LED to a heat sink and assemble the necessary optics and driver around this to create a true 75-W halogen-equivalent PAR30 LED lamp. The assembly steps are detailed below.

1. We verified the component dimensions to ensure a correct fit.
2. We applied a thin layer of Arctic Silver thermally conductive adhesive to the back of the CXA1507 LED and placed it in the center of the heat sink.[15] The design needed no printed circuit board (PCB) or connector.



3. The reflector is designed for a hexagonal star PCB and the square CXA1507 LED does not fit the reflector opening, so we reshaped the reflector opening to accommodate the CXA1507 LED.

4. We fed the driver output wires through the holes in the heat sink and soldered the wires to the CXA1507 LED contact pads.



5. We attached the plastic base to the heat sink by positioning the driver in the driver housing and sliding the heat sink into grooves in the base. In a production environment, an adhesive might be used to secure this connection.
6. We soldered the driver AC input wires to the screw base end cap.

15 Arctic Silver, Inc., www.arcticsilver.com/

7. We placed the reflector in the heat sink such that the reflector opening fit around the LED.
8. We placed the acrylic plastic cover on top of the reflector.
9. We snapped the optic holder onto the heat sink to hold the reflector and acrylic plastic cover in place.
10. We performed final testing.

Results

Thermal Results

We measured the T_{SP} by attaching a thermocouple to an CXA1507 LED mounted to the PAR30 heat sink, as shown in Figure 9. The T_{SP} of the CXA1507 LED was 57 °C. This thermal performance is in line with the thermal simulation. We also took thermal photographs of the CXA1507 PAR30 lamp to evaluate its thermal dissipation, as shown in Figure 10. The photographs show no areas of concern.

Figure 9: CXA1507 PAR30 T_{SP} measurement with thermocouple

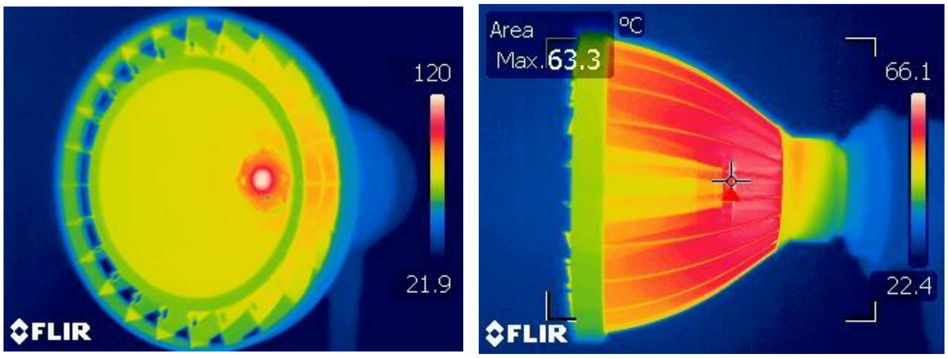


Figure 10: CXA1507 PAR30 thermal images

Based on the measured solder point temperature, the junction temperature (T_J) can be calculated as follows.

$T_J = T_{SP}$ + (LED power * LED thermal resistance)
T_J = 57 °C + (350 mA * 40 V * 2.5 °C/W)
T_J = 92 °C

Estimated LED Lifetime

Since the XLamp CXA1507 LED is a new component, based on our experience with similar LED systems, we expect the lumen maintenance performance of the CXA1507 LED to be at least as good as that of the XLamp CXA2011 LED.

We used the EPA TM-21 Calculator to determine the calculated and reported lifetimes for the XLamp CXA2011 LED at a 300-mA input current at an 85 °C solder point temperature.[16] The duration of Cree's CXA2011 LM-80 data set is 6,048 hours at the 300-mA drive current. The TM-21 methodology limits the projection to six times the duration of the LM-80 data set.

With a reported L70(6k) lifetime greater than 36,300 hours and a calculated L70(6k) lifetime of 41,000 hours for the CXA2011 LED at 300 mA, we expect the CXA1507 PAR30 lamp to easily meet the ENERGY STAR lumen maintenance requirement, > L70 at 25,000 hours.

Optical and Electrical Results

Table 8 shows steady-state results for the CXA1507 PAR30 lamp, obtained after a 60-minute stabilization time.[17] The table also shows performance data for the comparison 75-W halogen lamps and for several LED-based market-available replacement lamps. The CXA1507 PAR30 lamp exceeded the design goals, with a narrow beam angle and using 20% of the energy of the 75-W halogen lamps. The CXA1507 PAR30 lamp greatly surpassed the CBCP light output of the LED-based replacement lamps, with higher efficacy and a narrower beam angle.

Lamp	Light Output (lm)	Efficacy (lm/W)	Beam Angle (°)	CBCP (cd)	Lamp Power (W)	CCT	CRI	Power Factor
CXA1507 PAR30	954	61.2	9	16,947	15.6	3004	80	0.989
Halogen lamp A	1130	15.1	9	15,400	75	2900	100	
Halogen lamp B	1100	14.7	10		75	2850		
Halogen lamp C	1000	13.3	10	12,300	75	2900		
Replacement lamp D	725	48.3	15	4101	15	3000	85	
Replacement lamp E	782	55.9	25	3450	14	2700	85	
Replacement lamp F	700	58.3	16	7000	12	4300	75	
Replacement lamp G	800	49.1	23	3800	16.3	3000	80	

Table 8: CXA1507 PAR30 lamp steady-state results and comparison data

We took the photographs in Figure 11 to compare the light distribution of the CXA1507 PAR30 lamp and one comparison 75-W halogen lamp. We positioned the lamps 1 m from the surface, which is ruled in 5-cm increments. Each lamp has a 9° beam angle. The CXA1507 PAR30 lamp has a bright, uniform, controlled light pattern. The CXA1507 PAR30 lamp is an exceptionally attractive, narrow-spot replacement lamp that would enhance the appearance of artwork in a museum or merchandise in a store.

16 ENERGY STAR TM-21 Calculator is available at www.energystar.gov/TM-21calculator

17 Testing was performed in a 2-meter sphere at Cree's Santa Barbara Technology Center and a Type C goniometer at Cree's Durham Technology Center. An IES file for the PAR30 lamp is available on the Cree website: www.cree.com/xlamp_app_notes/CXA1507_PAR30_ies

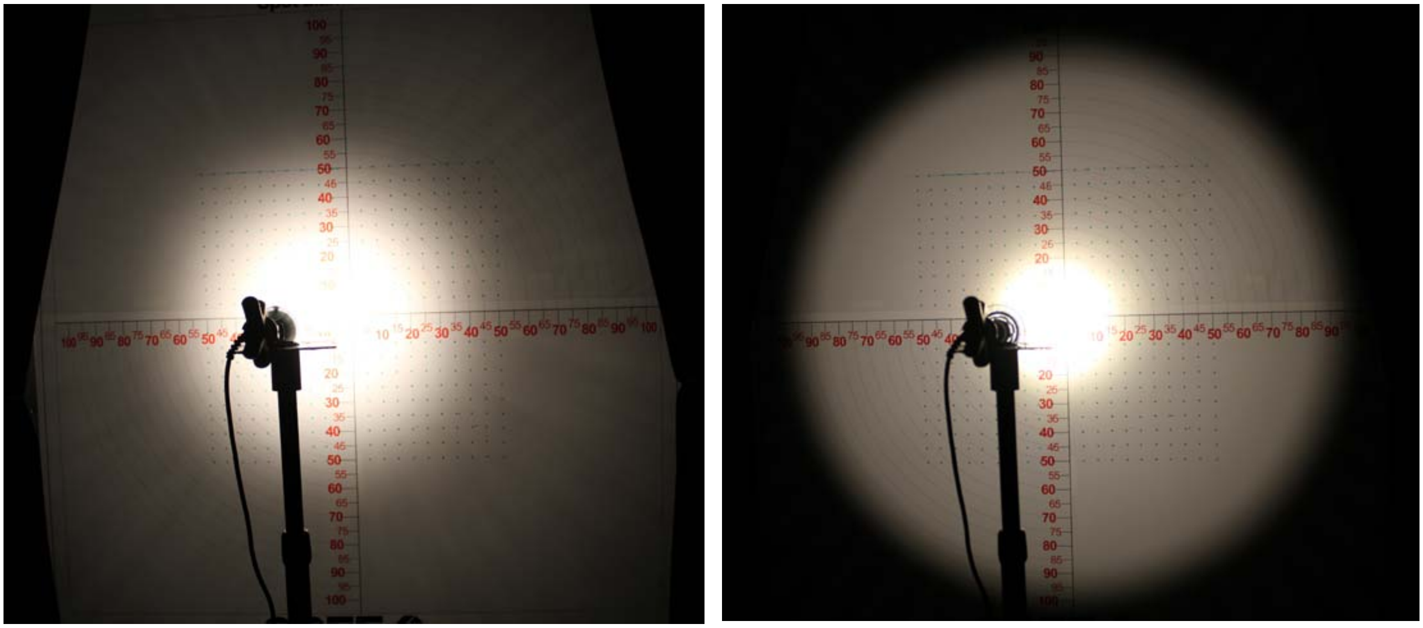


Figure 11: Light pattern comparison of 75-W halogen (left) to CXA1507 PAR30 (right)

We also tested the intensity distribution of the CXA1507 PAR30 lamp, shown in Figure 12. The lamp has an even intensity distribution for the narrow beam angle.

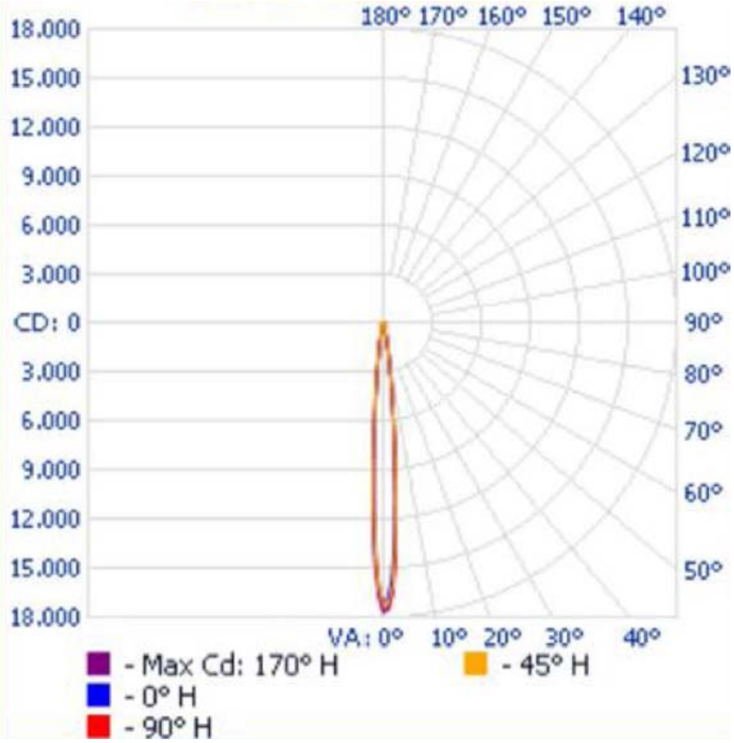


Figure 12: Goniometric intensity polar plot of XLamp CXA1507 PAR30 lamp (9° beam angle)

Table 9 shows the center beam illuminance of the CXA1507 PAR30 lamp at various distances from the light source.

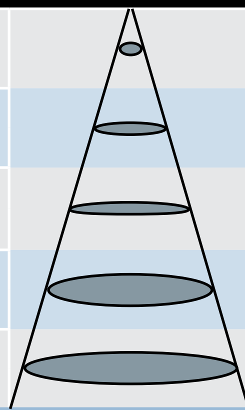
Height		Center Beam Illuminance			Beam Width	
0.6 m	2.0 ft	4,276 fc	46,026 lx		9.1 cm	0.3 ft
1.2 m	4.0 ft	1069 fc	11,507 lx		18.3 cm	0.6 ft
1.8 m	6.0 ft	475 fc	5,113 lx		27.4 cm	0.9 ft
2.4 m	8.0 ft	267 fc	2,874 lx		36.6 cm	1.2 ft
3.0 m	10.0 ft	171 fc	1,841 lx		45.7 cm	1.5 ft

Table 9: CXA1507 PAR30 center beam illuminance – 9° beam angle

CONCLUSIONS

This reference design demonstrates the ease of integration of the Cree XLamp CXA1507 LED into a conventional PAR30-sized housing with excellent results. The design utilized one CXA1507 component and proper heat sinking, optical control and driver design to efficiently and effectively hit the targets outlined by ENERGY STAR for 75-W equivalent narrow-beam PAR30 lamps. We chose drive currents and a heat sink to easily achieve a minimum L70 25,000-hour lifetime. This document is meant to show that this level of performance is attainable with a single CXA1507 LED component, but is not meant to be interpreted as the only way that a good LED PAR30 lamp can be designed.

The relatively large optical source size of a chip-on-board (COB) LED such as the XLamp CXA1507 typically presents a difficult challenge to achieve a narrow-beam PAR30 spotlight. The 9° beam angle of the PAR30 lamp in this reference design shows that such spotlights based on the CXA1507 LED are possible. Using other secondary optics can enable PAR30 lamps offering other beam angles.

SPECIAL THANKS

Cree would like to acknowledge and thank Evonik, Illumination Machines, Power Integrations and Tai Sun Electric Limited for their vision and collaboration on this reference design. The XLamp CXA1507 LED used in this design was an engineering prototype. Similarly, some of these partner companies have contributed advanced design prototypes that may be further optimized for improved manufacturability and performance. Please contact them directly for an update on these and other thermal, driver, and optical products.

- Evonik - corporate.evonik.com/
- Illumination Machines - www.illuminationmachines.com/
- Power Integrations - www.powerint.com/
- Tai Sun Electric Limited - www.hztaisun.com/