CLD-AP124 REV 0

Cree® XLamp® CXA2520 LED 6-Inch Downlight Reference Design

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INTRODUCTION

This application note details the design of a 6-inch downlight that exceeds the performance of typical 42-watt compact fluorescent lamp (CFL) products. The design uses Cree's XLamp CXA2520 LED, a multi-die, high-flux array optimized for high lumen output applications such as downlights, recessed fixtures and can lights. The CXA2520 offers lighting-class performance and reliability in a single, easy-to-use component.

Six-inch downlights are the industry standard indoors and outdoors in both residential and commercial applications such as soffits and ceilings, where a wide beam pattern is desirable. With a typical light output range from 1500 to 3600 lumens, the flexibility, high performance and ease of use offered by the XLamp CXA2520 LED makes it a strong candidate for use in a 6-inch downlight.

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Building on Cree's reference designs of 6-inch downlights using XLamp CXA2011 and XM-L LEDs, this design demonstrates the possibility of employing the XLamp CXA2520 LED as the light source of a 42-watt CFL equivalent downlight for use in indoor commercial and residential applications.[1]

DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide"[2] Cree advocates a 6-step framework for creating LED luminaires. All Cree reference designs use this framework, and the design guide's summary table is reproduced below in Table 1.

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 goal of the design is to show the ease of design and implementation of a 6-inch downlight using one Cree XLamp CXA2520 LED that betters the performance of typical 42-watt CFL downlights.

1. DEFINE LIGHTING REQUIREMENTS

Table 2 shows a ranked list of desirable characteristics for a 6-inch downlight.

1 Cree XLamp CXA2011 LED 6-Inch Downlight Reference Design, AP92, www.cree.com/XLamp_ref_des/CXA2011_6in_downlight
Cree XLamp XM-L LED 6-Inch Downlight Reference Design, AP93, www.cree.com/xlamp_ref_des/XML_6in_downlight

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

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Importance	Characteristics	Units
Critical	Luminous flux (steady-state)	lumens (lm)
	Efficacy	lumens per watt (lm/W)
	Luminous distribution	
	Color uniformity	
	Form factor	
Important	Price	$
	Manufacturability	
	Lifetime	hours
	Operating temperatures	degrees (°C)
	Operating humidity	% relative humidity
	Correlated color temperature (CCT)	K
	Color rendering index (CRI)	100-point scale
	Ease of installation	

Table 2: Some ranked design criteria for an LED downlight

Table 3 and Table 4 summarize the ENERGY STAR requirements for luminaires.[3]

Luminaire Type	Luminaire Efficacy (Initial)	ENERGY STAR REQUIREMENTS	
		Luminaire Minimum Light Output (Initial)	Luminaire Zonal Lumen Density Requirement
Downlights: • recessed • surface • pendant • SSL downlight retrofits	42 lm/W	≤ 4.5" aperture: 345 lumens > 4.5" aperture: 575 lumens	Luminaire shall deliver a minimum of 75% of total initial lumens within the 0-60° zone (axially symmetric about the nadir)

Table 3: ENERGY STAR luminous efficacy, output and zonal lumen density requirements

Characteristic	Requirements
Light source life requirements: all luminaires	The LED package(s) / LED module(s) / LED array(s), including those incorporated into LED light engines or GU24 based integrated LED lamps, shall meet the following L70 lumen maintenance life values (refer to Lumen Maintenance Requirements in the next section): • 25,000 hours for residential grade indoor luminaires • 35,000 hours for residential grade outdoor luminaires • 35,000 hours for commercial grade luminaires Lumen maintenance life projection claims in excess of the above requirements shall be substantiated with a TM-21 lumen maintenance life projection report.

3 ENERGY STAR® Program Requirements, Product Specification for Luminaires (Light Fixtures), Eligibility Criteria, Version 1.2, www.energystar.gov/ia/partners/product_specs/program_reqs/Final_Luminaires_V1_2.pdf?7b7d-2473

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Characteristic	Requirements
Lumen maintenance requirements: directional and non-directional luminaires	The LED package(s) / module(s) / array(s), including those incorporated into LED light engines or GU24 based integrated LED lamps, shall meet the following L_{70}(6k) rated lumen maintenance life values, in situ: • L_{70}(6k) ≥ 25,000 hours for residential indoor • L_{70}(6k) ≥ 35,000 hours for residential outdoor, or commercial Compliance with the above shall be documented with a TM-21 lumen maintenance life projection report as detailed in TM-21, section 7. The report shall be generated using data from the LM-80 test report for the employed LED package/module/array model ("device"), the forward drive current applied to each device, and the in situ TMP_{LED} temperature of the hottest LED in the luminaire. In addition to LM-80 reporting requirements, the following information shall be reported: • sampling method and sample size (per LM-80 section 4.3) • test results for each T_S and drive current combination • description of device including model number and whether device is an LED package, module or array (see Definitions) • ANSI target, and calculated CCT value(s) for each device in sample set • Δ u'v' chromaticity shift value on the CIE 1976 diagram for each device in sample set • a detailed rationale, with supporting data, for application of results to other devices (e.g. LED packages with other CCTs) Access to the TMP_{LED} for the hottest LED may be accomplished via a minimally sized hole in the luminaire housing, tightly resealed with a suitable sealant if created for purposes of testing. All thermocouple attachments and intrusions to luminaire housing shall be photographed.
CCT requirements: all indoor luminaires	The luminaire (directional luminaires), or replaceable LED light engine or GU24 based integrated LED lamp (non-directional luminaires) shall have one of the following nominal CCTs: • 2700 Kelvin • 3000 Kelvin • 3500 Kelvin • 4000 Kelvin • 5000 Kelvin (commercial only) The luminaire, LED light engine or GU24 based integrated LED lamp shall also fall within the corresponding 7-step chromaticity quadrangles as defined in ANSI/NEMA/ANSLG C78.377-2008.
Color rendering requirements: all indoor luminaires	The luminaire (directional luminaires), or replaceable LED light engine or GU24 based integrated LED lamp (non-directional luminaires) shall meet or exceed Ra ≥ 80.
Color angular uniformity requirements: directional solid state indoor luminaires	Throughout the zonal lumen density angles detailed above, and five degrees beyond, the variation of chromaticity shall be within 0.004 from the weighted average point on the CIE 1976 (u',v') diagram.
Color maintenance requirements: solid state indoor luminaires only	The change of chromaticity over the first 6,000 hours of luminaire operation shall be within 0.007 on the CIE 1976 (u',v') diagram, as demonstrated by either: • the IES LM-80 test report for the employed LED package/array/module model, or • as demonstrated by a comparison of luminaire chromaticity data in LM-79 reports at zero and 6,000 hours, or • as demonstrated by a comparison of LED light engine or GU24 based integrated LED lamp chromaticity data in LM-82 reports at zero and 6,000 hours.
Source start time requirement: directional and non-directional luminaires	Light source shall remain continuously illuminated within one second of application of electrical power.
Power factor requirements: directional and non-directional luminaires	Total luminaire input power less than or equal to 5 watts: PF ≥ 0.5 Total luminaire input power greater than 5 watts: Residential: PF ≥ 0.7 Commercial: PF ≥ 0.9
Transient protection requirements: all luminaires	Ballast or driver shall comply with ANSI/IEEE C62.41.1-2002 and ANSI/IEEE C62.41.2-2002, 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 frequency requirements: directional and non-directional luminaires	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.

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Characteristic	Requirements
Noise requirements: directional and non-directional luminaires	All ballasts & drivers used within the luminaire shall have a Class A sound rating. Ballasts and drivers are recommended to be installed in the luminaire in such a way that in operation, the luminaire will not emit sound exceeding a measured level of 24 BA.

Table 4: ENERGY STAR luminaire requirements

2. DEFINE DESIGN GOALS

Typical 42-W CFL downlights use a lamp that produces about 3100 lm, but luminaire light output is only about 2000 lm, giving a fixture efficiency of about 65%. We chose the design goals for this project, shown in Table 5, to better this performance using less energy over a longer lifetime. We chose a 50° cutoff angle as a good balance between maximizing direct illumination and minimizing glare. As shown in Figure 1, the cutoff angle is measured from the vertical axis of the luminaire outward to the point at which the brightness of the light source is no longer visible.

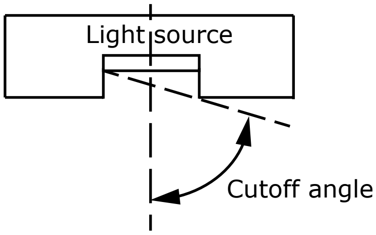

Figure 1: Cutoff angle

Characteristic	Unit	Minimum Goal	Target Goal
Light output	lm	2000	> 2000
Luminaire efficacy	lm/W	75	> 75
Cutoff angle	degrees	50	50
Lifetime	hours	35,000	50,000
CCT	K	3000	3000
CRI	100-point scale	80	> 80
Power	W	26	< 26
Power factor		0.9	> 0.9

Table 5: Design goals

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

We used Cree's Product Characterization Tool (PCT) tool, shown in Figure 2, to determine the drive current for the design.[4]

For the 2000-lumen target, we estimated 90% optical efficiency and 87% driver efficiency. We also estimated a solder point temperature (T_{SP}) of 45 °C.

4 PCT is available at: pct.cree.com

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Current (A)	LED 1			
	Model	Cree XLamp CXA2520 {EZW}		
	Flux	Q2 [2100]	Tsp (ºC)	45
	Price	$ -		
	SYS # LED	SYS lm tot	SYS W	SYS lm/W
0.520	2	3800.65	43.447	87.5
0.530	2	3856.12	44.35	86.9
0.540	2	3911.04	45.254	86.4
0.550	2	3965.44	46.16	85.9
0.600	1	2114.42	25.351	83.4
0.650	1	2239.96	27.637	81
0.700	1	2359.8	29.937	78.8

Figure 2: PCT view of the number of LEDs used and driving current

The PCT shows that, at 600 mA, one CXA2520 LED provides sufficient light output to meet the design goal.

Thermal Requirements

We used a commercially available heat sink/housing, shown in Figure 3, for the 6-inch downlight in this reference design.[5] The heat sink/housing is made of anodized forged aluminum. The heat sink/housing is part of a kit that includes a cover glass and front trim ring.

Figure 3: Top (left), side (center) and bottom (right) views of heat sink/housing

We performed thermal simulations to verify this thermal design is sufficient. Figure 4 shows the thermal simulation results for the design. The simulated T_{SP} is 46 °C.

5 Model ADC 10, Xing Yi Lighting, www.xingyilight.com/main.asp

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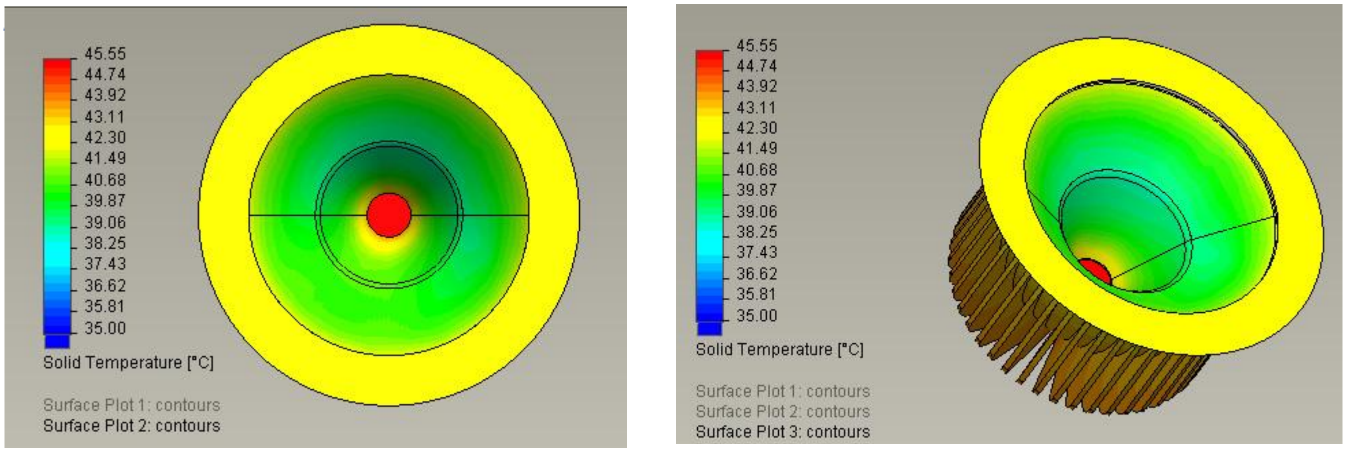

Figure 4: Thermal simulation of CXA2520 downlight

Driver

The driver for this downlight can be located above the ceiling, apart from the downlight, and there is no driver size limit. We used a universal input voltage constant-current driver, shown in Figure 5.[6] The driver is a slightly modified version of a commercially available driver model.

Figure 5: CXA2520 downlight driver

Secondary Optics

We used a custom reflector to achieve the desired 50° cutoff angle.[7] The reflector, shown in Figure 6, is about 90% optically efficient and fits within the heat sink/housing. The reflector may also be suitable for use in spotlights and track luminaires.

6 Model SP-22V2A PFC, Shenzhen SGQ Electronic Technology Co. Ltd, sgqsz.cn.gongchang.com
7 Model 5711-E, Nata Lighting Company Limited, www.nata.cn/

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Figure 6: CXA2520 downlight reflector

4. CALCULATE THE NUMBER OF LEDS

The purpose of this reference design is to show that a single XLamp CXA2520 LED can deliver equivalent lighting utility and superior performance compared to existing 42-W CFL downlights on the market. The CXA2520 LED is a multi-chip LED package that can offer the required lumens with new levels of LED-to-LED color consistency and efficiency. The new XLamp CXA2520 LED is 15% brighter than the original CXA2011,[8] which can enable superior LED lighting designs even more quickly.

We selected a Warm White LED for this reference design, shown highlighted in yellow in Table 6. By choosing an LED from a mid-level flux bin, we ensured that the design uses an LED that is readily available.

Color	CCT Range	Base Order Codes Min. Luminous Flux @ 550 mA			2-Step Order Code		4-Step Order Code	
		Group	Flux (lm) @ 85 °C	Flux (lm) @ 25 °C*	Chromaticity Region		Chromaticity Region	
EasyWhite	4000K	Q2	2100	2379	40H	CXA2520-0000-000N00Q240H	40F	CXA2520-0000-000N00Q240F
		Q4	2260	2560		CXA2520-0000-000N00Q440H		CXA2520-0000-000N00Q440F
		R2	2420	2741		CXA2520-0000-000N00R240H		CXA2520-0000-000N00R240F
	3500K	P4	1965	2226	35H	CXA2520-0000-000N00P435H	35F	CXA2520-0000-000N00P435F
		Q2	2100	2379		CXA2520-0000-000N00Q235H		CXA2520-0000-000N00Q235F
		Q4	2260	2560		CXA2520-0000-000N00Q435H		CXA2520-0000-000N00Q435F
	3000K	P4	1965	2226	30H	CXA2520-0000-000N00P430H	30F	CXA2520-0000-000N00P430F
		Q2	2100	2379		CXA2520-0000-000N00Q230H		CXA2520-0000-000N00Q230F
	2700K	P2	1830	2073	27H	CXA2520-0000-000N00P227H	27F	CXA2520-0000-000N00P227F
		P4	1965	2226		CXA2520-0000-000N00P427H		CXA2520-0000-000N00P427F
		Q2	2100	2379		CXA2520-0000-000N00Q227H		CXA2520-0000-000N00Q227F

Table 6: CXA2520 LED order codes

8 At 1 A, junction temperature (T_J) = 85 °C

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5. CONSIDER ALL DESIGN POSSIBILITIES

There is a multiplicity of ways to design an LED-based downlight. This reference design aims to show that a single easy-to-use CXA2520 LED enables a downlight offering superior performance.

This design presents a number of desirable performance-related benefits that are results of the XLamp CXA2520 LED package. Because the CXA2520 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 CXA2520 LED is binned at 85 °C, so the CCT will be as faithful as possible to the system operating environment. These component features allow for new levels of specification accuracy.

However, the primary purpose of this reference design is to show how simple and straightforward it is to design with Cree's XLamp CXA2520 LED. This application note is not intended to show the only way to do this, but instead demonstrate the ease of implementation with this set of engineering constraints. Certainly numerous other successful solutions are possible.

The performance range of the XLamp CXA2520 LED enables a wide variety of luminaires that all use a single CXA2520 LED. CCTs from 2700 K to 5000 K and lumen output up to 4500 lm[9] is available, providing the flexibility to offer a variety of luminaires that use a single LED light source and reflector. This flexibility is enhanced by the XLamp CXA2530 LED, which has the same physical dimensions and optical source size as the CXA2520 and offers even more design possibilities.

6. COMPLETE THE FINAL STEPS: IMPLEMENTATION AND ANALYSIS

Using the methodology described above, we determined a suitable combination of an LED, components and drive conditions. This section describes how Cree assembled the downlight and shows the results of the design.

Prototyping Details

1. We verified the component dimensions to ensure a correct fit.
2. We attached the CXA2520 LED to the heat sink with a small amount of thermally conductive epoxy.[10] Thermally conductive compound can also be used.[11]
3. After the thermal epoxy cured, we fed the driver output wires through the heat sink and soldered them to the LED, following the recommendations in Cree's Soldering and Handling Application Note for the CXA2520 LED.[12]
4. We tested the connection by applying power and verified the LED lit up.
5. We positioned the reflector on the LED, added the cover glass and secured both parts to the heat sink with the screw-on front trim ring.
6. We performed final testing.

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9 At 61 W, 85 °C
10 We used Silanex Technology ST0903. www.silanex.com/Product03.htm
11 Refer to Cree's Chemical Compatibility application note for compounds that are safe to use with Cree LEDs. Cree XLamp LED Chemical Compatibility Application Note, AP63, www.cree.com/products/pdf/XLamp_Chemical_Comp.pdf
12 Cree XLamp CXA Family LEDs Soldering and Handling, Application Note AP74, www.cree.com/xlamp_app_notes/CXA_SH

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Results

Thermal Results

Cree verified the board temperature with a thermocouple to confirm that the thermal dissipation performance of the heat sink aligns with our simulations. The measured solder point temperature was 41 °C.

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

$T_J = T_{SP}$ + (LED power * LED thermal resistance)

T_J = 41 °C + (26 W * 0.8 °C/W)

T_J = 62 °C

This thermal performance is in line with the thermal simulation.

Estimated LED Lifetime

Based on thousands of hours of long-term testing of the CXA2011 LED at higher temperatures than the measured 41 °C T_{SP} of the CXA2520 downlight, Cree expects an L70 lifetime significantly longer than 50,000 hours. 42-W CFL lamps typically have lifetimes ranging from 10,000 to 12,000 hours, so the 4 to 5 times longer lifetime of the CXA2520 downlight offers solid maintenance cost savings.

Optical and Electrical Results

We tested the downlight in a 1.5-meter sphere after a 60-minute stabilization time to obtain the results in Table 7.[13] As the table shows, the downlight meets the target goals for the design. The 2140-lm light output positions this downlight in the upper reaches of the light output of downlights currently on the market. The downlight also meets the ENERGY STAR light output, efficacy, power factor, CCT and CRI requirements.

Characteristic	Unit	Downlight
Luminous flux	lm	2140
Luminaire efficacy	lm/W	82
Cutoff angle	°	50
CCT	K	3046
CRI	100-point scale	80
Power	W	26.1
Power factor		0.95

Table 7: CXA2520 downlight steady-state results

We also tested the intensity distribution of the downlight. Figure 7 shows an even intensity distribution with a 56° beam angle. The figure also shows the 50° cutoff angle that was a goal of this effort.

13 Testing was performed at the Cree's Shenzhen Technology Center. An IES file for the downlight is available at: www.cree.com/xlamp_app_notes/CXA2520_downlight_ies

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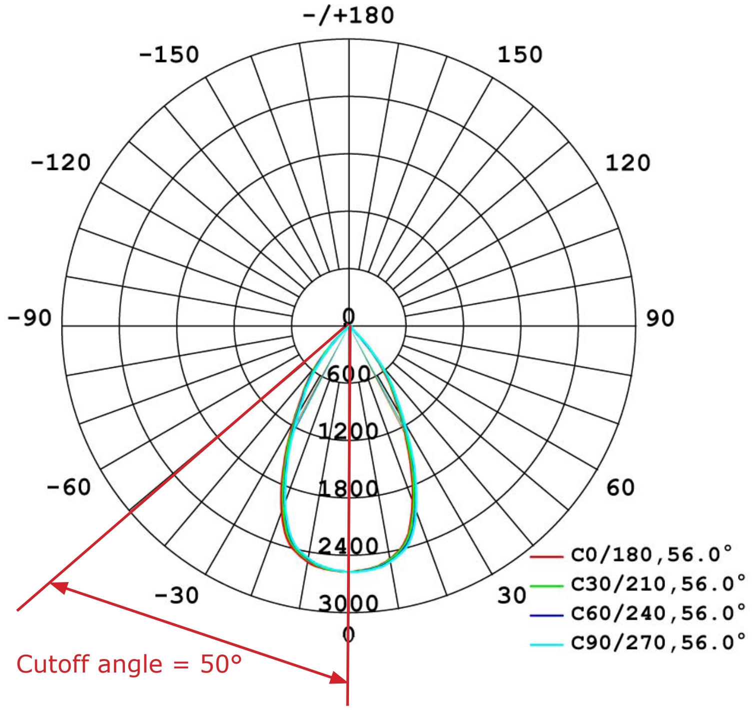


Figure 7: Angular luminous intensity distribution of CXA2520 downlight

Table 8 shows the center beam illuminance of the CXA2520 downlight at various distances from the light source.

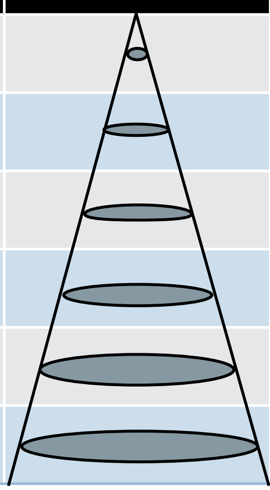
Height		Center Beam Illuminance			Beam Width	
0.5 m	1.7 ft	926 fc	9,970 lx		0.6 m	1.8 ft
1.0 m	3.3 ft	231 fc	2,492 lx		1.1 m	3.5 ft
1.5 m	5.0 ft	103 fc	1,107 lx		1.6 m	5.3 ft
2.0 m	6.6 ft	58 fc	623 lx		2.2 m	7.1 ft
2.5 m	8.3 ft	37 fc	399 lx		2.7 m	8.9 ft
3.0 m	9.9 ft	26 fc	279 lx		3.2 m	10.6 ft

Table 8: CXA2520 downlight illuminance – 56° beam angle

CONCLUSION

This reference design illustrates the ease of developing a very capable 6-inch downlight based on the Cree XLamp CXA2520 LED. The small number of steps to assemble the downlight illustrates the simple construction the CXA2520

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LED enables, lowering system cost. Simplicity of use and lighting-class performance make the Cree XLamp CXA2520 LED an attractive design option for an LED-based 6-inch downlight.

SPECIAL THANKS

Cree would like to acknowledge and thank the following partner companies for collaborating in the successful prototyping of this downlight.

- Shenzhen SGQ Electronic Technology Co. Ltd.
- Nata Lighting Company Limited - www.nata.cn

BILL OF MATERIALS

Component	Order Code/Model Number	Company	Web Link
Driver	SP-22V2A PFC	Shenzhen SGQ Electronic Technology Co. Ltd.	sgqsz.cn.gongchang.com
Heat sink/housing, cover glass, front trim ring kit	ADC 10	Xing Yi Lighting	www.xingyilight.com/main.asp
LED	CXA2520-0000-000N00Q230H	Cree, Inc.	www.cree.com/cxa2520
Reflector	5711-E	Nata Lighting Company Limited	www.nata.cn
Thermal epoxy	ST0903	Silanex Technology Pte Ltd.	www.silanex.com/Product03.htm

Table 9: Bill of materials for CXA2520 6-inch downlight

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