Cree/NXP Task Light Reference Design

Figure 1: NXP Cree task light

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INTRODUCTION

This application note demonstrates that an LED task light can readily outperform its linear fluorescent equivalent and incorporate dimming for mood setting and for additional energy savings. Cree, NXP Semiconductors and Bright View Technologies collaborated to design an under-cabinet SSL fixture that exceeds linear fluorescent performance while keeping cost low and meeting Energy Star performance specifications. This design is a simple approach to fluorescent lamp replacement and can easily be integrated into many linear lighting applications.

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DESIGN APPROACH/OBJECTIVES

In the Cree Application Note "LED Luminaire Design Guide,"[1] 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.

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.

THE 6-STEP METHODOLOGY

The major goal for this project was to demonstrate a straightforward task light design using Cree XLamp LEDs that meets or exceeds the performance of a comparison fluorescent fixture.

1. DEFINE LIGHTING REQUIREMENTS

A desirable task light is low in power consumption and efficiently illuminates the area where it is installed. Listed in Table 1 are specific metrics that can quantify luminaire performance.

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

Importance	Characteristics	Units
Critical	Luminous flux	Lumens (lm)
	Luminance/illuminance	candela/m2 or lux
	Electrical power	Watts (W)
	Meet safety standards	Agency listing/mark
	Price	$
	Lifetime	Hours
Important	Correlated Color Temperature (CCT)	Kelvin
	Color Rendering Index (CRI)	100 point scale
	Manufacturability	$
	Ease of installation	Time = $
	Comply w/Energy Star	Has label
	Compatible w/controls	Yes/No
	End-of-life disposition	Cost to recycle

Table 1: Design criteria

Table 2 summarizes general Energy Star® requirements to be met to be eligible to qualify for the Energy Star Program.[2]

Characteristic	Requirement
CCT	The luminaire must have one of the following designated CCTs and fall within the 7-step chromaticity quadrangles as defined in ANSI/NEMA/ANSLG C78.377-2008. • 2700 K • 3000 K • 3500 K • 4000 K
Color angular uniformity	The variation of chromaticity shall be within 0.004 from the weighted average point on the CIE 1976 (u′, v′) diagram.
Color maintenance	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.
CRI	Indoor luminaires shall have a minimum CRI of 80.
Off-state power	Luminaires shall not draw power in the off state.
Lumen maintenance requirement	L70 > 25,000 hours
Power factor (PF)	Total luminaire input power < 5 W: PF > 0.5 Total luminaire input power > 5 W: PF > 0.7
Warranty	3-year warranty
Operating frequency	> 120 Hz

Table 2: General Energy Star requirements

2 Energy Star Program Requirements Product Specification for Luminaires (Light Fixtures) - Eligibility Criteria - Version 1.0 www.energystar.gov/ia/partners/prod_development/new_specs/downloads/luminaires/ES_Luminaires_V1_Final_Specification.pdf

The under-cabinet shelf-mounted lighting requirements[3]:

Characteristic	Requirement
Minimum light output	125 lumens per lineal foot
Zonal lumen density	• Minimum of 60% of total lumens within 0-60° zone • Minimum of 12.5% of total lumens within 60-90° zone
Minimum luminaire efficacy	29 lm/W

Table 3: Under-cabinet shelf-mounted lighting requirements

2. DEFINE DESIGN GOALS

The design goals for this project:

Characteristic	Unit	Minimum Goal	Target Goal
Luminaire light output	Lm	200	300
Illuminance/luminance profile	Lux	Same	Better
System power	W	8	6
Luminaire efficacy	Lm/W	40	50
Lifetime	Hours	25,000	50,000
CCT	K	3,500	2,700
CRI		80	85
Maximum ambient temperature	°C		49

The guiding principle for this design was to meet Energy Star guidelines and provide an off-the-shelf design that can be used immediately or easily modified to meet specific requirements.

Since it is advantageous to be able to dim a task light, a main goal was to provide flicker-free dimming down to < 1% light output. Another goal was to ensure the task light can be switched on at very low dimmer levels.

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

Figure 2 shows basic LED electrical data and optical output from Cree's Product Characterization Tool (PCT).[4] We chose a configuration using XP-E LEDs, and another using MX-6 LEDs. Equally efficient configurations could be created using XLamp ML-B, ML-E, MX-3 or XP-E HEW LEDs.

3 Ibid.
4 Available at pct.cree.com

Compare:	SYS # LE	SYS lm to	SYS lm/W	LED W	Current Display Range:	Medium (0.1A - 2.0A)	
System:	Target Lumens :	250	Optical Efficiency:	90%	Electrical Efficiency:	90%	

	LED 1	LED 2	LED 3
Model	Cree XLamp MX-6 {CW/WW}	Cree XLamp XP-E {CW/NW/WW}	Cree XLamp XP-E HEW {CW/NW/WW
Flux	N4 [62] 62.0	N4 [62] 62.0	P3 [73.9] 73.9
Price	$ -	$ -	$ -
Tj (°C)	25	25	25
LED Multiple	x1	x1	x1

Current (A)	LED 1 SYS # LED	LED 1 SYS lm tot	LED 1 SYS lm/W	LED 1 LED W	LED 2 SYS # LED	LED 2 SYS lm tot	LED 2 SYS lm/W	LED 2 LED W	LED 3 SYS # LED	LED 3 SYS lm tot	LED 3 SYS lm/W	LED 3 LED W
0.100	13	260	62.1	0.29	14	252	54	0.3	12	252	67.6	0.28
0.150	9	270	60	0.45	10	260	52	0.45	9	279	64.9	0.43
0.200	7	273	56.6	0.62	8	272	49.4	0.62	7	280	62.1	0.58
0.250	6	288	54	0.8	7	287	47.3	0.78	6	294	60.4	0.73
0.300	5	280	50.9	0.99	6	294	46.4	0.95	5	290	58.7	0.89
0.350	4	256	48.9	1.18	5	280	45	1.12	4	268	57.4	1.05
0.400	4	288	47	1.38	4	252	43.6	1.3	4	300	55.8	1.21
0.450	4	316	44.7	1.59	4	276	42.3	1.47	4	332	54.2	1.38
0.500	3	261	43.3	1.81	4	304	41.5	1.65	3	273	52.8	1.55
0.550	3	285	42.3	2.02	4	328	40.3	1.83	3	297	51.8	1.72
0.600	3	303	40.6	2.24	3	261	39	2.01	3	318	50.5	1.89
0.650	3	321	39	2.47	3	279	38.1	2.2	3	339	49.1	2.07
0.700	3	339	37.7	2.7	3	294	37.1	2.38	3	363	48.6	2.24

Figure 2: Cree Product Characterization Tool data

4. CALCULATE THE NUMBER OF LEDS NEEDED

An iterative process was used to determine the number of LEDs in the task lamp. The initial design used 6 LEDs at 1.25-in. pitch, but the light uniformity was not sufficient. Using five LEDs at 1.5-in. pitch, obscured by an precision engineered diffuser and driven at 350 mA, proved to provide optimum illumination. Other design choices with larger numbers of lower power LEDs would be equally plausible. For an extended discussion of LED pitch and various optical system tradeoffs, see Cree Application Note AP43, "Cree XLamp LEDS for Distributed Illumination Applications."[5]

5 www.cree.com/xlamp_app_notes/distributed_illumination

5. CONSIDER ALL DESIGN POSSIBILITIES AND CHOOSE THE BEST

Designing a solid-state lighting (SSL) linear fixture that exceeds linear fluorescent performance, is cost competitive, and exceeds Energy Star performance criteria requires a system-level design approach. All four system-level elements, LED selection, secondary optics, driver selection/performance and thermal management, must be considered.

LED Selection

A linear light fixture is expected to provide uniform light transmission, color temperature and, in the case of a dimmable LED-based fixture, maintain color temperature while dimming. This design shows that both the Cree XLamp XP-E and MX-6 LEDs exceed the targets for this application. The XP-E LED can be driven at a much higher current than the MX-6 LED, producing more light within the fixture, if requirements dictate.

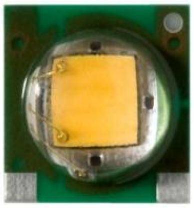


Figure 3: XP-E LED

Figure 4: ML-E LED

Figure 5: MX-6 LED

Figure 6: XP-E HEW LED

LED placement within the fixture is also critical. Linear fluorescent lamps have uniform light transmission and are omnidirectional. This gives a nice lighting profile when looking directly at the fixture, but also comes with a performance penalty in the constrained space of undercabinet design. Since SSL luminaires are point sources, careful consideration of LED placement within the fixture is vital.

Secondary Optics

The diffuser in the comparison linear fluorescent fixture traps as much as 50% of the light produced by the fluorescent tube. This has a huge negative impact on total efficacy of the fixture. Working with Bright View Technologies[6], a linear diffuser was designed and optimized for this application. This allowed for almost 85% of the light generated by the LEDs to be transmitted through the diffuser and onto the work surface.

	Luminous Flux	CCT	CRI
SSL without diffuser	307 lm	4051	85
SSL with diffuser	261 lm	4033	85

Table 4: Performance of LED task light vs. linear fluorescent

6 www.brightviewtechnologies.com

To eliminate shadowing and produce light uniformity, the LED-to-diffuser distance had to be tailored so the point-source LEDs are essentially invisible. The original design placed the LEDs 0.75 n. behind the diffuser. Though Bright View worked to optimize the diffuser, the distance between the LEDs and from the LEDs to the diffuser produced a suboptimal result, with the individual LEDs clearly visible and corresponding shadowing apparent. A second design placed the LEDs 1.75 in. behind the diffuser. The end result was a task light that has little to no shadowing from end-to-end of the fixture and hides the LEDs so the point sources are eliminated.

Driver Topology and Performance

It is highly likely that a user will come in contact with the fixture, so a safe topology that isolates the user from the AC mains is required. One of the great features of the SSL2101[7] is its ability to be configured for both buck (non-isolated) and flyback (isolated) configurations. We selected the flyback topology for this design, providing the maximum safety available in an SSL fixture.

Driver efficiency is critical, and this design achieves 80% efficiency at full load, as shown in Figure 7 and Figure 8. Figure 9 shows the power factor. The curves in these figures are for three drivers tested under identical conditions. Differences in the curves are due to variances in the driver performance based on manufacturing/component spreads in the driver assemblies.

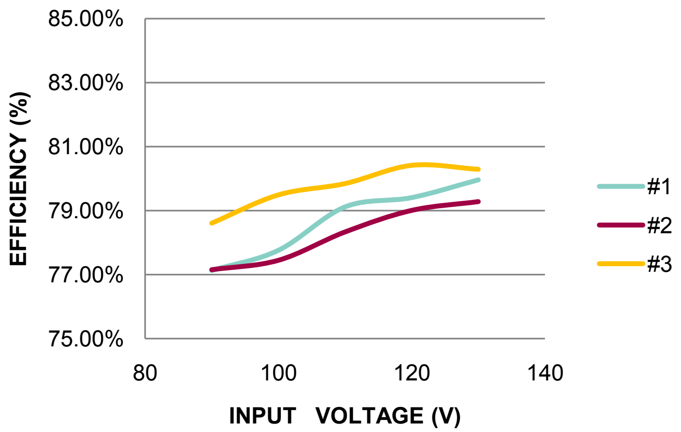


Figure 7: SSL2101 driver efficiency without triac dimmer in the circuit

7 www.nxp.com/#/pip/pip=[pip=SSL2101]|pp=[t=pip,i=SSL2101]

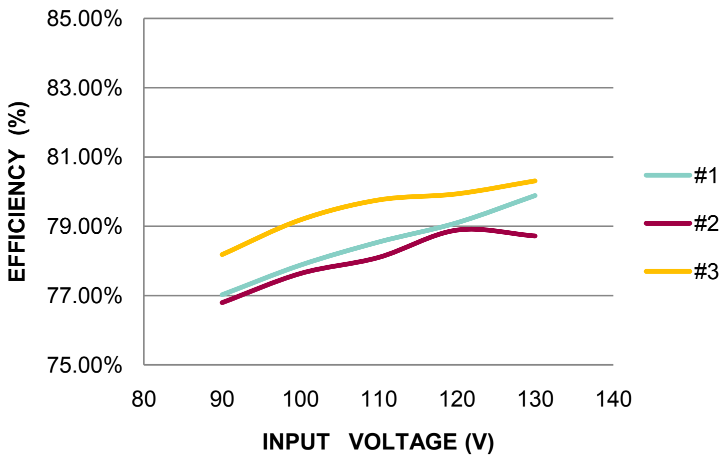


Figure 8: SSL2101 driver efficiency with triac dimmer in the circuit at maximum lumen output

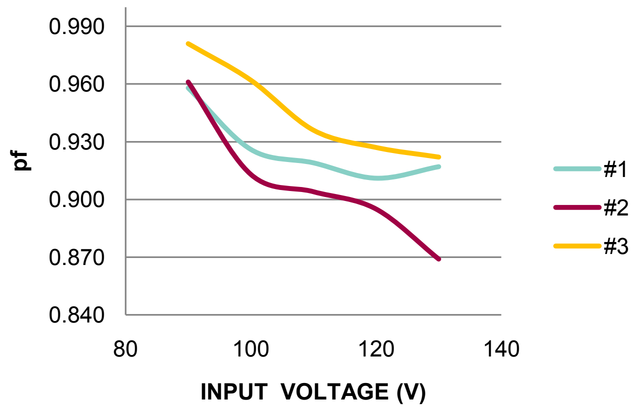


Figure 9: Power factor without triac dimmer in the circuit

Using the SSL2101 enabled a sought-after feature, triac dimming, to be provided. One of the main design goals was to be able to dim the task light down to < 1% light output without flickering. Since the NXP SSL drivers are specifically designed with this in mind, the goal was achieved with a straightforward design.

Figure 10: SSL2101

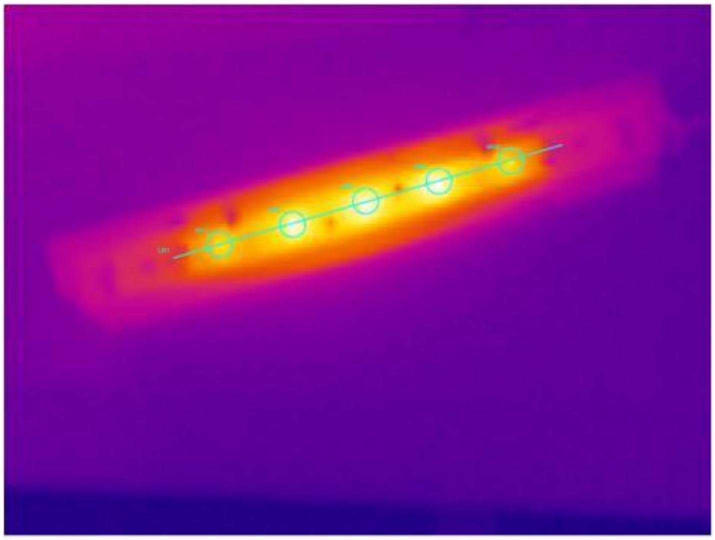
Another goal was to ensure a user can switch on the task light at very low dimmer levels. The low voltage startup of the SSL2101 made this achievable.

Thermal Management

Thermal management is critical in SSL luminaires. Ensuring the recommended maximum LED junction temperature is not exceeded is critical to long life and color point stability of the LEDs. We designed an aluminum housing, increasing the housing cost by 30% over a sheet metal version. This increased cost was offset by improved thermal performance without the necessity of an additional heat sink. An aluminum housing allows the LED assembly to be produced with standard FR-4 PCB material.

Thermal images of the LED board show that the system is well below the recommended maximum operating temperatures of the components in the design.

Figure 11 shows a thermal view of the LED area of the LED task light. The temperature/time chart plots the maximum temperature in the LED area versus time



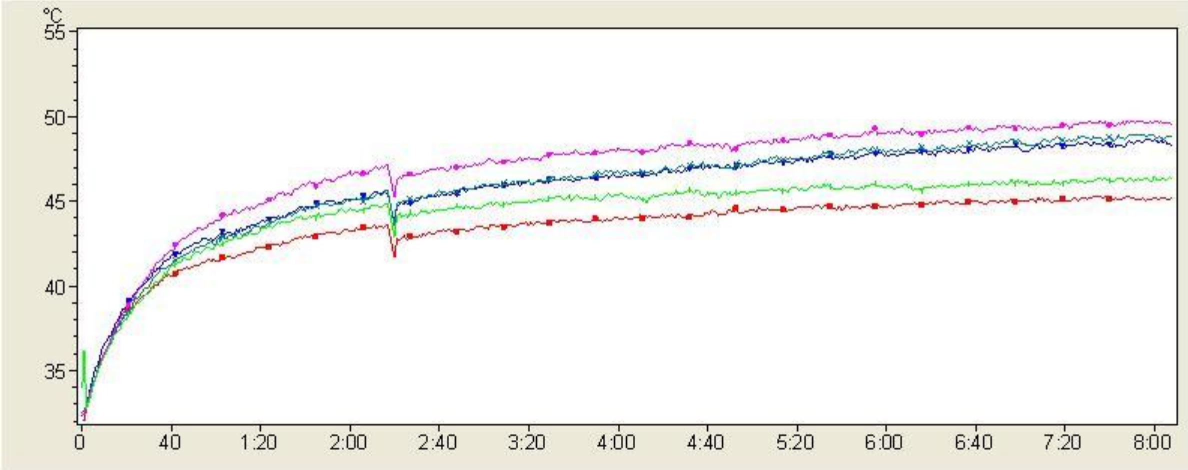


Figure 11: Thermal view of LED task light

Task Light Design

The LED task light utilizes five Cree XP-E or MX-6 LEDs driven by the NXP SSL2101 driver. The LEDs are a great fit in linear applications and feature an electrically isolated thermal path, enabling heat removal through low-cost PCBs, and excellent color point stability, all with industry-leading lumen maintenance.

The design utilizes NXP's SSL210x triac dimmable driver family to achieve excellent deep dimming, isolated flyback design, ease of mechanical design and excellent efficiency, approximately 79%, all with a PF > 0.9. This, in conjunction with Cree's superb lighting class XP-E or MX-6 LEDs, offers lighting designers a new standard in LED lighting.

The output is set at 6 W and delivers approximately 307 lumens without the diffuser. With the Bright View diffuser, the task light produces approximately 261 lumens. The equivalent fluorescent light had a lumen output through the diffuser of 201 lumens for 8 W of power.

6. COMPLETE FINAL STEPS

Performance Summary

Table 5 compares the performance the LED task light to a linear fluorescent. The LED task light produces 25% more lumens for 25% less power (6 W vs. 8 W) and has a significantly better CRI than the fluorescent. These tremendous results are achieved using state of the art Cree XP-E or MX-6 LEDs coupled with NXP's triac dimmable SSL2101 driver, capable of dimming the LED fixture down to < 1% of light output completely flicker free.

	Luminous Flux	CCT	CRI
LED task light	261 lm	4033	85
Fluorescent task light	201 lm	4068	62

Table 5: Performance summary of LED task light vs. linear fluorescent

The LED task light boasts triac dimming capabilities that the comparison fluorescent fixture lacked. The dimming is smooth and flicker free down to < 1% of light output and the unit can be switched on at very low light output levels. The unit is compatible with a wide range of off-the-shelf triac dimmers from popular manufacturers including Lutron, Leviton and Cooper.

Figure 12: Various triac dimmers

The basic design of this 6-W LED task light can be adapted quite easily for any type of 5-12 W LED fixture.

CONCLUSIONS

This LED task light readily outperforms a fluorescent equivalent. With good design practice we have shown how thermal performance can be managed for a long lifetime design. The completely flicker-free deep triac dimming brings another dimension to the fixture compared to fluorescent equivalents.

Using industry-leading Cree lighting class LEDs and NXP's driver, the flexible design can be applied as is or modified to different mechanical formats for multiple applications, such as an LED downlight or a wall-washing fixture. If more light is required, the power level of the design can be easily modified up to 15 W using the SSL2101 driver and up to 25 W using the SSL2102. This flexibility, coupled with brighter or more Cree LEDs, can accommodate most applications.