Cree® XLamp® LEDs for Distributed Illumination Applications

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INTRODUCTION

In the first century of electric lighting, the now universal bulb-luminaire dichotomy gave rise to a variety of basic illumination (lamp or bulb) technologies, thousands of different styles and configurations of these lamps along with tens of thousands of luminaires. A large class of lighting systems, from cove lighting to in-ceiling troffers are implemented with single (or multiple) linear fluorescent lamps (LFL).

Many of the functional lighting requirements for distributed illumination can be met by using arrays of small-form-factor LEDs. Under-cabinet lighting, task lamps, outdoor pathway lights, and bollards, to name a few applications, can be inexpensively implemented with arrays of Cree XLamp LEDs. With this new generation of LED components, system efficacies of 50-90 lumens/watt are achievable with reasonable engineering and design practices.

This application note reviews the task-based illumination requirements for a broad set of applications and the Energy Star requirements for several specific implementations. We'll examine two of these applications in greater detail to review important design characteristics and production requirements to create attractive, (and where appropriate) Energy-Star-conforming luminaires and bulbs.

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GENERAL REQUIREMENTS FOR DISTRIBUTED ILLUMINATION

In the most generic definition, a distributed illumination source is one in which a glowing surface is used in illumination applications. When expressed in terms of linear illumination, these sources emit 5-50 lm/cm (12-125 lm/in). When expressed in terms of area, the sources generally emit 1.5–40 lm/cm2 (4-40 lm/in2). This definition is broad enough to encompass linear fluorescent lamps, compact fluorescent lamps (CFL), and small-form incandescent bulbs (such as a G5.3 base 12-V halogen bulb). When the illumination source is hidden, as in under-cabinet or wall-washing applications, the uniformity of the source illumination is not critical. When used in direct-view applications, there can be a strong aesthetic preference for smooth, uniform illumination surfaces.

Incumbent Illumination Sources: Fluorescent Tubes and Related Incandescent

In addition to the many area lighting applications created with LFLs, some applications use small incandescent bulbs that deliver warm white light but with poor efficacy, in the range of 15 lm/W. T8 LFLs set the performance bar in terms of lamp efficiency, well above 90 lm/W. Well-designed systems can achieve efficiencies of 70-90 lm/W. In distributed illumination applications, LFLs also set the standard for a smooth glowing look. Incandescent bulbs are most often used in distributed illumination applications in which the illumination sources are hidden, such as under-cabinet or cove lighting. F32T8 tubes can generate an initial 2460 "raw" lumens per linear meter (750 lumens/linear ft)1; F28T5 tubes can generate an initial 2130 lumens per linear meter (650 lm/ft). When used in a "typical" fluorescent luminaire, with optics and power supply, losses of up to 30% are typical and yield a "groomed" or in-situ output of 1720 lumens per linear meter (525 lm/ft) for a T8 tube and 1490 "groomed" lumens per linear meter (455 lm/ft) for a T5 tube. These high-efficiency bulbs are typically used in general overhead lighting, but they also represent high-efficiency, high-volume, low-priced lighting technology – a ready source of competitive benchmarking for all LED illumination sources.

Lighting Requirements (from ANSI/IESNA)

The Illuminating Engineering Society of North America (IESNA) has produced a comprehensive series of recommended practices across a variety of environments and tasks. Two of these documents, "Recommended Practice for Lighting Industrial Facilities" and "American National Standard Practice for Office Lighting," contain tables with task-based illuminance recommendations that are appropriate for linear- and area-lighting applications. The generalized framework for these recommendations is contained in the IESNA Lighting Handook, 9th Edition. These general categories and illumination requirements are summarized in Table 3 in the appendix. IESNA Recommended Practices (RP Series) lists illumination requirements for a more-detailed set of place-related tasks.

Performance Requirements (from Energy Star SSL)

The 2008 DOE/EPA document "ENERGY STAR® Program Requirements for Solid-State Lighting Luminaires"[2] calls out an initial set of performance requirements for a variety of lighting types and tasks. It marks the beginning of policy specifications for illumination systems above and beyond those of professional organizations in illumination systems and sets the initial benchmark for "quality lighting" applications. Lighting and luminaire manufacturers will use these requirements first as competitive differentiators and then as the minimum market standards. Cree uses these

1 Initial flux radiating circularly along the length of the tube. This does not take into account the losses associated with the lamp fixture, nor the nominal values after the lamps decline with service hours.

2 http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energystar_sslcriteria.pdf

requirements as minimal baseline standards in the recommendations we make.

Summary tables of the Energy Star criteria are reproduced in the Appendix.

EXAMPLES

T8 Emulation

T5 and T8 LFLs set the standard for a smooth-glow, high-efficiency and low-cost illumination source. Since 2008, dozens of LED-based T8 emulation products have been released to the market. Though none of them have achieved significant sales, there is ongoing market interest in T8 emulation products. Market potential is sufficiently large that market research analysts are studying the space and delivering formal reports on it.[3]

However, despite strong interest in LED-based replacement technology for LFLs, the US Deparment of Energy released two bulletins in spring 2010 strongly urging that LED linear replacement lamps are not useful commercial products and steering potential adopters of this technology away.[4,5] These are thorough documents showing a large sample of LED replacement lamps evaluated by the CALiPER program in Round 5 and Round 9 and concluding these products show substandard efficiency, efficacy and CRI, relative to incumbent T8 technology.

> LED linear replacement lamps available today do not compete with linear fluorescent lamps on the basis of light output, color quality, distribution, lumen maintenance, or cost-effectiveness. DOE does not recommend replacing linear fluorescent lamps with LED linear replacements.[6]

In the Performance Specification Series: T8 Replacement Lamps, DOE makes some recommendations of bulb performance for this class of product. These include:

Initial Minimum Light Output	Minimum Lamp Life, L_{70}	Minimum CRI
2700 lumens	35,000 hours	80

A review of the data from CALiPER testing shows systems that need to improve in flux and efficacy by a factor of 2-3.

The DOE recommendations can be achieved with arrays of XLamp ML-B and ML-E LEDs. Figure 1 shows some possible configurations, based on Cree's Product Characterization Tool (PCT), a software system that simulates electrical, thermal and flux behaviors of Cree's XLamp LEDs.[7]

3 Electronicast Consultants, Upper Lake, CA. "LED Linear Tube Lamps, Global Market Forecast and Analysis, 2009-2016," 2010.

4 US Department Of Energy, EERE, LED APPLICATION SERIES: LINEAR FLUORESCENT REPLACEMENT LAMPS, May 2010. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-t8-flourescent-replacement.pdf

5 US Department of Energy, EERE, LED PERFORMANCE SPECIFICATION SERIES:T8 REPLACEMENT LAMPS, April 2010. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/t8_replacement-lamps.pdf

6 DOE, Op. Cit.

7 http://pct.cree.com/register.asp

Figure 1 shows a basic set of assumptions, configured in the top part of the illustration. In the row of purple settings: a target CCT of 2700 K and assumptions the system can deliver 90% optical efficiency and 90% electrical efficiency.

Selecting a few representative flux bins from the ML-B and ML-E order codes shows a number of possible configurations delivering record levels of flux and efficacy from this T8-emulation application. Driving the parts conservatively, at 150 mA, will allow the creation of systems using between 70 and 110 ML-B LEDs, delivering 40 – 65 lm/W and consuming between 42 and 67 W/system. The pitch of the linear array of ML-B LEDs would be between 1.8 and 1.1 cm (0.7 and 0.4 in). Systems using between 60 and 80 ML-E LEDs can be created, delivering 60 - 80+ lm/W and consuming between 33 and 43 W/system. The pitch of the linear array of ML-E LEDs would be between 2.0 and 1.5 cm (0.8 and 0.6 in). These kinds of metrics indicate high-efficiency drivers and optics will allow products that achieve efficacy parity with LFLs.

Without high-efficiency drivers and optics, to achieve efficacy of greater than 90 lm/W would require very low driving current and additional ML-E LEDs with a pitch of about 0.8 cm (0.3 in). At this spacing, the XLamp ML-E LEDs can be effectively obscured with a variety of diffusers.

Compare: SYS # LE | LED Vf | SYS W | SYS lm/W — Current Display Range: Fine (0.1A - 0.7A)

System: Target Lumens : 2,700 — Optical Efficiency: 90% — Electrical Efficiency: 90%

	LED 1				LED 2				LED 3			
	Model	Cree XLamp ML-B (CW/WW)			Model	Cree XLamp ML-B (CW/WW)			Model	Cree XLamp ML-B (CW/WW)		
	Flux	TYP (5000K) [28.4]		28.4	Flux	H0 [18.1]		18.1	Flux	J0 [23.5]		23.5
	Price	$ -	Tsp (°C	50	Price	$ -	Tsp (°C	50	Price	$ -	Tsp (°C	50
	LED Multiple			x1	LED Multiple			x1	LED Multiple			x1
Current (A)	SYS # LED	LED Vf	SYS W	SYS lm/W	SYS # LED	LED Vf	SYS W	SYS lm/W	SYS # LED	LED Vf	SYS W	SYS lm/W
0.100	97	3.29	35.57	76.4	150	3.29	55	49.1	118	3.29	43.27	62.7
0.110	88	3.34	36.18	75.4	135	3.34	55.5	48.6	108	3.34	44.4	60.8
0.120	85	3.39	38.72	70.2	129	3.39	58.77	46.1	100	3.39	45.56	59.3
0.130	80	3.43	40	68	123	3.43	61.5	44	94	3.43	47	58
0.140	75	3.47	40.83	66.1	118	3.47	64.24	42.2	90	3.47	49	55.1
0.150	72	3.51	42.4	64.5	113	3.51	66.54	40.8	85	3.51	50.06	54.3
0.160	68	3.55	43.07	63.2	108	3.55	68.4	39.5	82	3.55	51.93	52.1
0.170	66	3.58	44.73	60.5	104	3.58	70.49	38.4	80	3.58	54.22	50.2

Compare: SYS # LE | LED Vf | SYS W | SYS lm/W — Current Display Range: Fine (0.1A - 0.7A)

System: Target Lumens : 2,700 — Optical Efficiency: 90% — Electrical Efficiency: 90%

	LED 1				LED 2				LED 3			
	Model	Cree XLamp ML-E (CW/WW)			Model	Cree XLamp ML-E (CW/WW)			Model	Cree XLamp ML-E (CW/WW)		
	Flux	M3 [45.7]		45.7	Flux	M2 [39.8]		39.8	Flux	N2 [51.7]		51.7
	Price	$ -	Tsp (°C	50	Price	$ -	Tsp (°C	50	Price	$ -	Tsp (°C	50
	LED Multiple			x1	LED Multiple			x1	LED Multiple			x1
Current (A)	SYS # LED	LED Vf	SYS W	SYS lm/W	SYS # LED	LED Vf	SYS W	SYS lm/W	SYS # LED	LED Vf	SYS W	SYS lm/W
0.100	104	2.97	34.67	78	118	2.97	39.33	69	90	2.97	30	90
0.110	94	3	34.47	79.1	108	3	39.6	68.2	85	3	31.17	87.3
0.120	85	3.03	34	80	100	3.03	40	67.5	78	3.03	31.2	87.5
0.130	82	3.05	36.44	74.3	90	3.05	40	67.5	72	3.05	32	85.5
0.140	75	3.08	35.83	75.4	85	3.08	40.61	67	66	3.08	31.53	85.8
0.150	70	3.11	36.56	74.7	82	3.11	42.82	63.2	63	3.11	32.9	82.3
0.160	66	3.14	36.67	73.8	78	3.14	43.33	63	59	3.14	32.78	82.8
0.170	65	3.16	39	70	73	3.16	43.8	61.7	56	3.16	33.6	81.7

Figure 1: Cree's Product Characterization Tool showing system parameters for a 2700-lumen T8 application

To illustrate the new capabilities of the XLamp ML-E LED, we created several small circuit boards with LED pitches of 1 in, 0.5 in and 0.375 in (2.54, 1.27, 0.95 cm) and populated these boards with warm white ML-E LEDs.

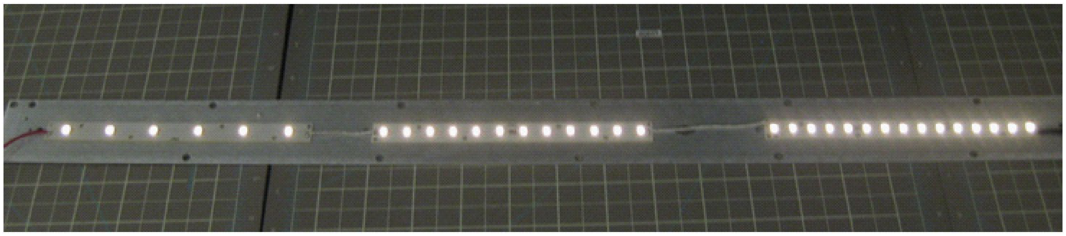


Figure 2: Three arrays of XLamp ML-E LEDs

Figure 3: XLamp ML-E LED arrays @ 150 mA, with diffuser

The covering diffuser is a 1-inch diameter 180 degree semi-cylinder from a commercially available T8 LED emulation product[8]. Though not easily apparent from the photograph, at 1 in pitch, XLamp ML-E LEDs are easily discernable in this configuration and, at 0.375 in pitch, the LEDs appear perfectly diffused. From Table 2 (page 7), we can see the addition of a diffusive element gives a 9.1% flux penalty, which is within the bounds of our 90% optical efficiency estimation.

Table 1 further elaborates on the results from the PCT (Figure 1 and related discussion, including a cumulative 19% system loss) and compares the total flux versus pitch that can be achieved using warm-white and cool-white LEDs from three Cree products, a previous-generation high brightness part, the CLA1A LED, and the new XLamp ML-B and ML-E LEDs. In the table, lumen values over 2000 are displayed with a green background, lumen values under 1600 are displayed with a red background and lumen values between 1600 and 2000 are displayed with a yellow background. While the CLA1A has been used in many distributed and linear applications, the higher efficiency XLamp ML-B and ML-E are natural successors.

8 Except as noted, we used this same diffuser in all the studies in the application note.

# LEDs	Spacing		Lumens					
	Pitch (cm)	Pitch (in)	CLA1A (WW)	CLA1A (CW)	ML-B (WW)	ML-B (CW)	ML-E (WW)	ML-E (CW)
384	0.318	0.125	1,954	3,322	5630	7309	12379	16081
256	0.470	0.185	1,304	2,216	3753	4873	8253	10721
192	0.635	0.250	977	1,661	2815	3655	6190	8040
128	0.953	0.375	651	1,107	1877	2436	4126	5360
96	1.270	0.500	489	831	1407	1827	3095	4020
78	1.745	0.687	391	664	1144	1485	2515	3266
64	1.905	0.750	326	554	938	1218	2063	2680
48	2.540	1.000	245	416	704	914	1547	2010

Table 1: Flux versus pitch of three small-form Cree LEDs in a four-foot LED T8 lamp

In addition to these efforts, the appendix contains a description of a dimmable T8 demonstration fixture that uses ML-E LEDs at 1 in (2.54 cm) pitch and 0.75 in pitch (1.9 cm) and a T8 demonstration fixture that uses ML-B LEDs at 0.5 in (1.3 cm) pitch and 0.375 in pitch (1 cm) .

Under-Cabinet Luminaires

Incumbent under-cabinet fixtures are short (30-60 cm, 12-24 in) T5 and T8 fluorescent fixtures along with low-voltage incandescent fixtures, such as 12-V xenon and halogen bulbs. The incandescent fixtures deliver average efficacies of 15-16 lm/W. Because of the small size requirements and low-cost material selections in their high-volume constructions, most fluorescent fixtures do not fare much better, often delivering remarkably inefficient system results at 25-30 lm/W.

These fixtures deliver linear illumination of 656-853 lm/m (200-260 lm/ft). With the 45-60 cm (18-24 in) mounting heights that are common for these luminaires, they deliver illuminance values of 100-500 lux, contributing the majority of flux required for categories D, E and F in the IESNA Illumination Categories. This is lighting for the performance of visual tasks ranging from objects with high contrast and large size to the performance of visual tasks with objects of low contrast and small size.

To quantify the performance of this class of luminaire, we have made integrating-sphere measurements of a representative 18-in under-cabinet fixture along with a number of equivalent configurations using XLamp MX-6 and ML-E LEDs.

	Flux (lm)	CCT (K)	CRI	I (mA)	W	Power Factor	Lm/W
Utilitech F15T8	433.6	2819	85.2		16.8	0.53	25.81
Utilitech Retrofit (9 MX-6)	489.0	3324	77.9	0.350	12.03	0.93	40.65
Cree Prototype Fixture, 6-MX-6 Clear Lens	395.1	3468	76.9	0.350	7.05	0.94	56.04
Cree Prototype Fixture, 6-MX-6 Diffusive Lens	359.1	3448	77.1	0.350	7.00	0.93	51.30
Cree Prototype Fixture, 12-ML-E Clear Lens	405.3	2679	81.6	0.150	6.17	0.90	65.65
Cree Prototype Fixture, 12-ML-E Diffusive Lens	368.6	2661	81.3	0.150	6.17	0.90	59.71

Table 2: Comparative under-cabinet performance data

The use of LEDs allows for very thin luminaires. A recent commercial example is the Utilitech 29112, which is 5/8 in (1.5 cm) thick. This can be a significant benefit compared to current products with T8 and incandescent bulbs.

Figure 4: The Utilitech 29112

A common and often overlooked problem in under-cabinet lighting comes from multiple shadows cast by multiple illumination sources. Depending on the luminaire design, these multiple shadows can cause interference problems in many viewing tasks. Fluorescent tubes present the fewest problems with their single glowing illuminating surface. At the other end of the spectrum, many 45- and 60-cm (18- and 24-in) cabinets with a few equally spaced bulbs can pose interference from the multiple shadows generated by the multiple-point illumination sources.

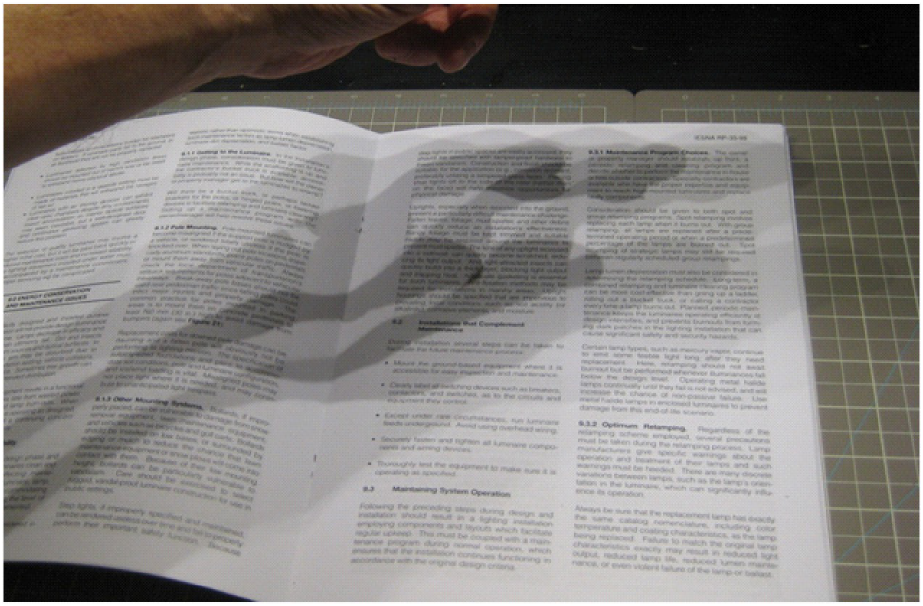


Figure 5: Shadows generated by five XLamp MX-6 LEDs at 3.5-in spacing

The addition of a closely spaced diffuser partially obscures the individual LEDs and the shadows they cast but does not remove the problem. In order to use widely spaced LEDs in this application, optical cavity and diffuser design is required.

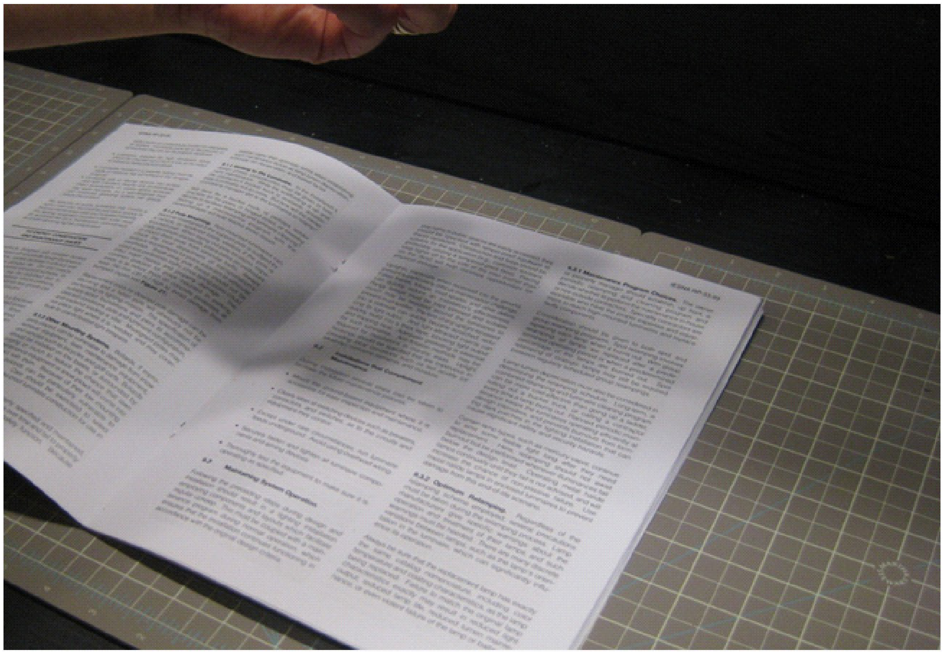


Figure 6: The same LED configuration with a closely spaced diffuser

An effective technique to reduce multiple shadows in under-cabinet lighting is to use larger numbers of lower-flux LEDs, such as the XLamp ML-B and ML-E LEDs. Using an increased number of higher efficacy, small-form-factor LEDs allows for a weaker diffuser, and/or closer LED-to-diffuser spacing and, therefore, improved optical performance. In this indirectly viewed task illumination, the level of diffusion needs to minimize multiple shadows, not achieve a perfectly uniform look in emulation of a linear fluorescent source.

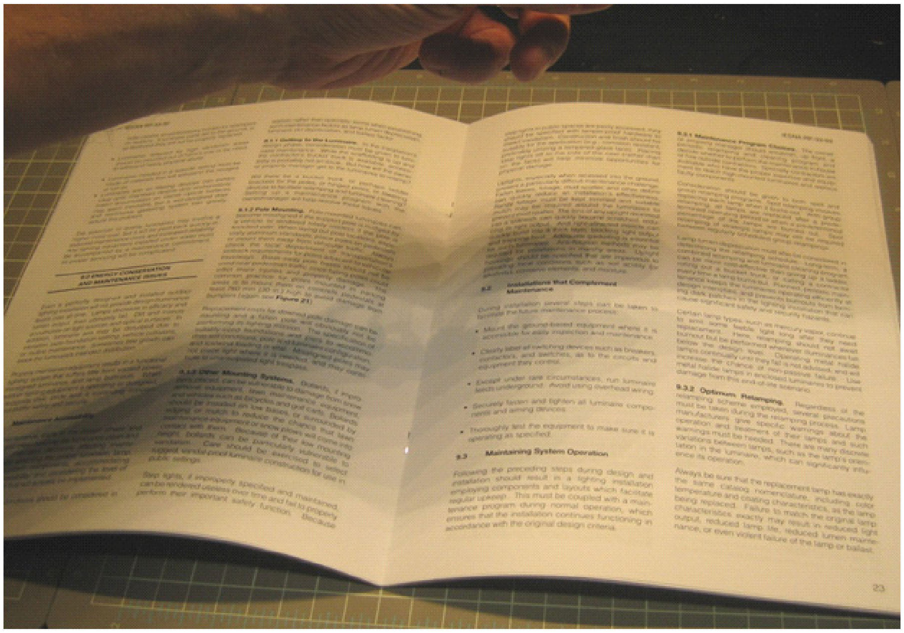


Figure 7: Twelve equally spaced XLamp ML-E LEDs reduce the impact of shadows

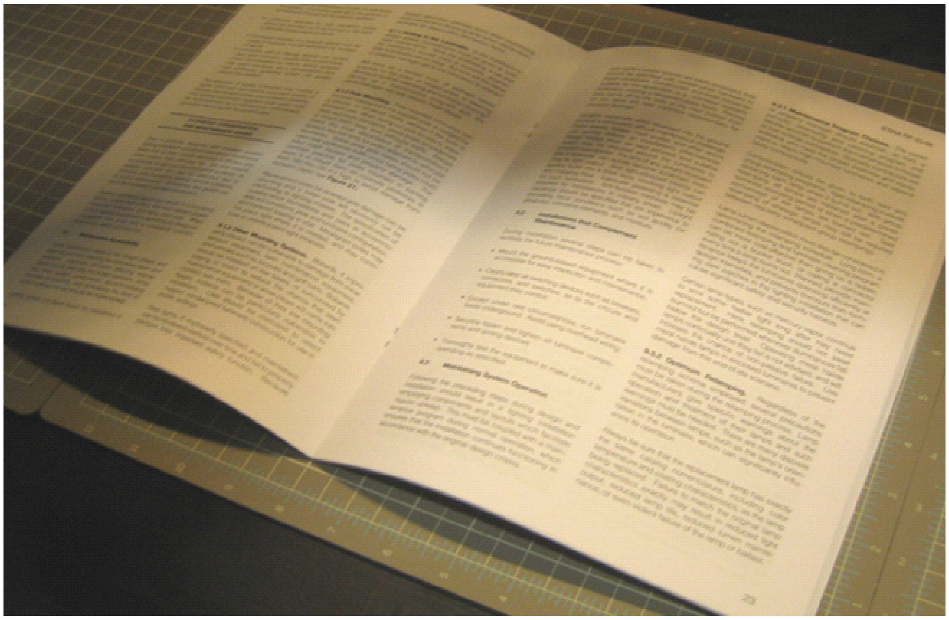


Figure 8: A closely spaced diffuser dispels the multiple shadows

There is no reason why well-designed LED-based luminaires can't become the dominant form of under-cabinet lighting. Uniquely slim designs, coupled with appropriate and smooth flux levels, will make for winning technical solutions. LEDs optimized for distributed and array-based lighting, such as the Cree XLamp MX-3, ML-B and ML-E are optimal for these tasks.

DISCUSSION AND CONCLUSIONS: SOLUTIONS USING ARRAYS OF XLAMP LEDS

LEDs that are optimal for distributed illumination applications have several common attributes.

- Uniform angular chromaticity – allows the delivery of uniform color over the illuminance profile of the luminaire or bulb with minimal secondary optics
- Superior device efficacy in a small package, delivering 40-100 lumens per part
- Best-in-class color stability and lumen maintenance
- Tight color binning to allow for predictable, repeatable arrays for high-volume production

The XLamp ML-B and ML-E are designed for distributed illumination. Our prototypes for under-cabinet and T8 illumination applications show we can create distributed-illumination products with warm-white system efficacies greater than 60 lm/W, which is in agreement with the PCT simulations in Figure 1. These illumination experiments have not been optimized at the systems level and, with proper design optimizations, efficacy improvement of 5-10% should be easily achievable.

DESIGN TECHNIQUES

Power Supplies for Larger Arrays

Distributed- and linear-illumination applications are often configured with large numbers of LEDs (10s to 100s). Organizing and powering this number of LEDs is an important consideration in system design. Many solutions are available, from multi-channel power supplies powering strings of series or parallel connected LEDs, to single-channel power supplies driving parallel groups of series-connected LEDs and solutions in between.

A list of LED power suppliers can be found on this page of the Cree website: www.cree.com/products/xlamp_drivers.asp

Circuit-Board Layout

Even though mid-flux LEDs do not dissipate much heat individually, when used in arrays there can still be thermal loads that require design consideration. FR-4 circuit boards, the most commonly used material for these kinds of design, may benefit from thermal vias, such as are described in Cree's Application Note AP-38, "Optimizing PCB Thermal Performance for Cree® XLamp® LEDs."[9] Alternately, small MC-PCBs can be attached to aluminum or other metal luminaire frames for generally sufficient thermal conduction.

Optical Cavities

Many distributed-illumination applications are used in space-constrained settings. Under-cabinet lighting is often constrained by the thickness of under-cabinet recesses; T8 replacement bulbs are most often constrained by the 1-in diameter of the 8/8 designs.

9 http://www.cree.com/products/pdf/XLamp_PCB_Thermal.pdf

For the best possible results, optical cavities should be lined with high-efficiency diffuse reflectors.[10] If diffusers are going to be used with linear or areal arrays, in a direct-illumination application, there are several techniques to present a smooth appearance, either by obscuring the array of LEDs with additional spatially periodic features or through diffusion.

- Recurring/geometric features in the luminaire – such as the louver networks commonly found in LFL troffers
- Recurring/geometric features in the secondary optics of the LED lamp or luminaire
- Point-source hiding with optical diffusers and optical-cavity optimization

A list of suppliers of diffusing films and other secondary optics can be found on the Cree website.[11] Among the many optics suppliers listed, Bright View Technologies, Fusion Optix and Luminit manufacture a variety of films for diffusion.

All these techniques can also be used to obscure subtle differences that occur when LED systems are created using arrays of LEDs from a variety of different chromaticity bins.

Taken together, these techniques and LEDs allow for the creation of low-cost, industry-leading, distributed-flux lighting applications.

10 Examples of these reflectors include
Furakawa MCPET, http://www.furukawaamerica.com/catDetail.php?catID=39
White Optics, http://whiteoptics.com/products.html
Mitsubishi Plastics Hishimetal EX-DR, http://www.mpi.co.jp/english/
Bayer Makrolon White, http://plastics.bayer.com, http://www.bayerbms.com

11 http://www.cree.com/products/xlamp_part.asp

APPENDIX

ILLUMINATION CATEGORIES FROM IESNA

Orientation and simple tasks These tasks are found in public spaces where reading and visual inspection are only occasionally performed. Higher levels are recommended for tasks where visual performance is occasionally important.		
A **B** **C**	Public Space Simple Orientation for Short Visits Working spaces where simple visual tasks are performed	30 lux 50 lux 100 lux
Common visual tasks These tasks are found in commercial, industrial and residential applications. Recommended illuminance levels differ because of the characteristics of the visual task being illuminated. Higher levels are recommended for visual tasks with critical elements of low contrast or small size.		
D **E** **F**	Performance of visual tasks of high contrast and large size Performance of visual tasks of high contrast and small size or low contrast and large size Performance of visual tasks of low contrast and small size	300 lux 500 lux 1,000 lux
Special visual tasks Visual performance is of critical importance. These tasks are very specialized, including those with very small and very low contrast critical elements. Recommended illuminance levels should be achieved with supplementary task lighting. Higher recommended levels are often achieved by moving the light source closer to the task.		
G	Performance of visual tasks near threshold	3,000 - 10,000 lux

Table 3: Determination of illumination categories, from *IESNA Lighting Handbook*[12]

ENERGY STAR REQUIREMENTS FOR SELECT INDOOR AND OUTDOOR LIGHTING APPLICATIONS[13]

	Kitchen Under-Cabinet	Portable Desk Task Light	Cove Lighting	Surface-Mounted, Directional Head
Minimum (Initial) Output	125 lm/ft	200 lm	200 lm/ft	200 lm
Zonal Density	0-60° - 60% 60-90° - 25%	0-60° - 85%	120-150° - 35%	0-90° - 85%
Minimum Efficacy	24 lm/W	29 lm/W	45 lm/W	35 lm/W
Allowable CCT	2700 K 3000 K 3500 K	2700 K 3000 K 3500 K 4000 K 4500 K 5000 K	2700 K 3000 K 3500 K	2700 K 3000 K 3500 K

Table 4: Energy Star requirement for select indoor-lighting applications

12 *IESNA Lighting Handbook, 9th Edition*

13 http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energystar_sslcriteria.pdf

	Wall-Mounted Porch Light	Step Lights	Pathway Lights	Pole-Mounted Decorative Luminaire
Minimum (Initial) Output	150 lm	50 lm	100 lm	300 lm
Zonal Density	0-90° - 85%	0-90° - 85%	0-90° - 85%	0-90° - 85% <110° - 0%
Minimum Efficacy	24 lm/W	20 lm/W	25 lm/W	35 lm/W

Table 5: Energy-Star requirement for select outdoor-lighting applications

	Under-Cabinet, Shelf-Mounted Task Lighting	Portable-Desk Task Light	Recessed-Surface & Pendant-Mounted Downlights	Wall-Wash Luminaire
Minimum (Initial) Output	125 lm/ft	200 lm	≤ 4.5 in 345 lm > 4.5 in 575 lm	575 lm
Zonal Density	0-60° - 60% 60-90° - 25%	0-60° - 85%	0-60° - 75%	20-40° - 50%
Minimum Efficacy	29 lm/W	29 lm/W	35 lm/W	40 lm/W
Allowable CCT	2700 K 3000 K 3500 K 4000 K 4500 K 5000 K	2700 K 3000 K 3500 K 4000 K 4500 K 5000 K	2700 K 3000 K 3500 K 4000 K 4500 K 5000 K	2700 K 3000 K 3500 K 4000 K 4500 K 5000 K

Table 6: Energy-Star requirement for select non-residential lighting applications

CREE DIMMABLE T8 DEMONSTRATION FIXTURE

The Cree T8 demonstration fixture[14] demonstrates a high quality, high efficacy implementation of distributed illumination in an 8/8 (8 x 1/8 in.) diameter tube.

Figure 9: Cree dimmable T8 demonstration fixture

WHAT'S THE STORY?

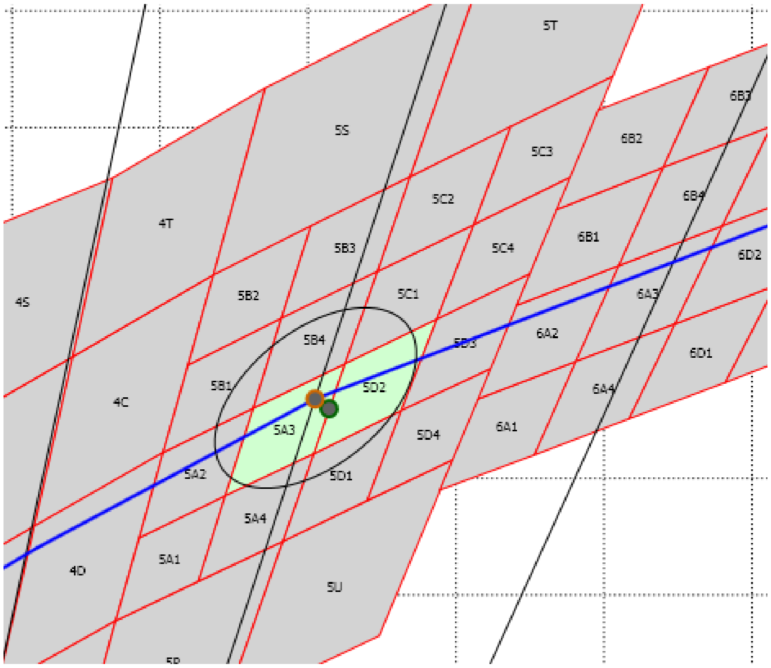
The purpose of this demonstration is to show our customers and prospects Cree distributed lighting LEDs can be used to build a variety of great-looking, high-efficacy fixtures.

- At full brightness, the "smooth look" section of the fixture delivers 630 lm/ft, with a system efficacy of about 90 lm/W.
- The "pillow look" section of the fixture delivers about 470 lm/ft.
- A wide variety of looks and system efficiencies are available, depending on flux, chromaticity, diffusion and system engineering.
- Cree stands ready to assist our customers as they prepare for the market.

There are several other points to make about this application-specific demonstration unit.

14 Part # SSLDEMO-LMP-T1

The LEDs



This is a demonstration of smooth, distributed illumination using the Cree ML-E. The LEDs in this demonstration are from the E5 group and M3 (45.2 lm) flux bin. In particular, these units were built using alternating 4000K LEDs from two adjacent chromaticity bins, 5A3 and 5D2. The results from the demonstration fixture are indistinguishable from those of an LFL mixed from these two bins, which fall within a 4-step MacAdam ellipse.

2 Different Pitches and 2 Different Approaches to Diffusion

1. The demonstration unit has 6 in of LEDs at 1 in (2.54 cm) pitch (center-to-center) and 6 in of LEDs at 0.75 in pitch (1.9 cm), for a total of fourteen LEDs, arrayed in series (150 mA @ 44 VDC).
2. When the LEDs are spaced an inch or more apart, it is extremely difficult to produce light with a perfectly smooth look. It is difficult for a diffuser and a small, T8-constrained optical cavity in a luminaire to completely obscure the LEDs. For this pitch of LED we chose to use a patterned diffuser that has a look that is almost "pillow-like."[15]
3. For the 0.75 in spaced LEDs we used a traditional circularly symmetric diffuser.[16]

The Power Supply

DC current is delivered through a 1.9 A, 24 V constant voltage power supply.

The driving circuit is based on a National Semiconductor LM3429, a single-channel, buck-boost circuit. 0-100% dimming is achieved with a pulse-width modulation circuit running at 120 Hz. The efficiency of the driver is 87%.

The CM Who Did the Work

The demonstration T8 tube is the result of collaboration between Cree and Marktech Optoelectronics.

15 Bright View K0-1001P007, a custom diffuser created for this application.

16 From Bright View Technologies (C1-85)

Cree ML-B Demonstration Fixture

This fixture demonstrates shows the use of XLamp ML-B LEDs in T8 replacement lamps. The fixture uses a total of 28 XLamp ML-B LEDs, 12 ML-B LEDs at 0.5 in (1.3 cm) pitch and 16 at 0.375 in (1 cm) pitch. The construction of the assembly is identical to the ML-E fixture, including aluminum base, transparent cover and a diffusive film under the cover. At the pitches used in this fixture, the diffuser effectively obscures the individual LEDs.

The data in the following tables show that an ML-B or ML-E based T8 replacement can efficiently deliver impressive results. The Cree XLamp ML-B and ML-E LEDs are viable alternatives on which to base a T8 replacement lamp.

LED	Flux (lm)	Efficacy (lm/W)	CCT (K)	CRI
ML-B, no cover or diffuser	617	64.3	4001	80
ML-E, no cover or diffuser	700	76.1	4720	71
ML-B, cover and diffuser	520	54.6	3977	80
ML-E, cover and diffuser	580	63.1	4635	71

Table 7: Demonstration-fixture results

LED	Cover	Cover + Diffuser
ML-B	93%	83%
ML-E	96%	85%

Table 8: Demonstration-fixture optical efficiency

The following table summarizes the results at the various pitches used in the two T8 demonstration fixtures and projects the lumens that could be produced from a 4-foot T8 replacement using LEDs at these pitches.

Number of LEDs		Spacing		Results	
		Pitch (cm)	Pitch (in.)	Lm/ft.	Lm from 4' T8
6	ML-E	2.54	1.0	940	3760
8	ML-E	1.90	0.75	1260	5040
12	ML-B	1.27	0.50	1040	4160
16	ML-B	0.95	0.375	1160	4640

Table 9: T8 Demonstration-fixture summary