Cree® XLamp® ML-E T8 Reference Design

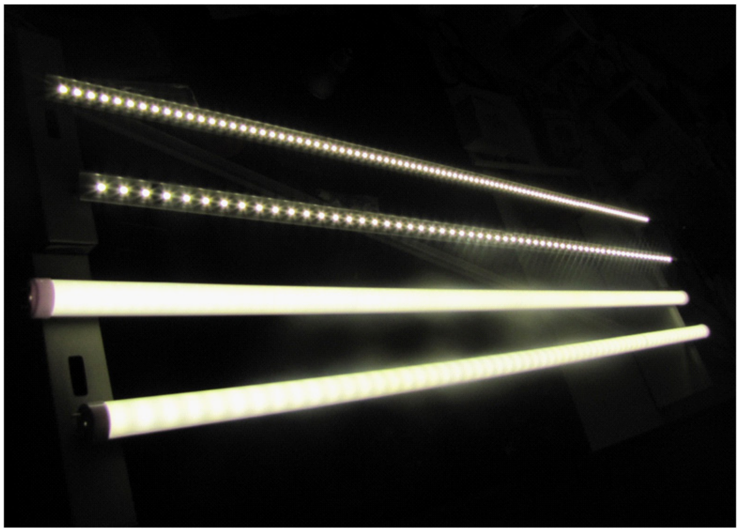

Figure 1: Prototype T8 lamps in Cree's Application Engineering lab with and without diffuser shield

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INTRODUCTION

Several Department of Energy (DOE) CALiPER program tests conducted in 2008-2010 evaluated a broad sample of market-available LED-based T8 lamps and concluded that they do not yet represent a viable option to the fluorescent lamp.

From the CALiPER Round 10 report:

> Rounds 5 and 9 of CALiPER testing included a series of SSL products that are marketed as replacements for linear fluorescent lamps. … Testing of SSL and benchmark fluorescent products in Rounds 5 and 9 all concluded that SSL linear replacement lamps are not yet suitable as one-for-one replacement for linear fluorescent lamps. SSL linear replacement lamps tested so far do not provide the light output and efficacy levels of the linear fluorescent lamps they aim to replace and have narrower light distribution requiring closer spacing of luminaires.[1]

1 DOE Solid-State Lighting CALiPER Program Summary of Results: Round 10 of Product Testing http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_round-10_summary.pdf

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From the CALiPER Round 11 report:

> Round 11 testing of linear replacement lamps shows clear progress, with recent SSL lamps achieving respectable efficacy, though not the light levels and distribution of fluorescent lamps. Using two SSL lamps to replace a single-lamp troffer, where lower light levels are needed or where other characteristics of SSL provide an advantage, may now be viable in some cases. The SSL lamps, however, will not likely be the most cost effective or reliable option at this time.[2]

The DOE CALiPER report[3] findings are summarized below. A check mark (√) indicates the lamp with the better performance characteristic.

Characteristic	LED T8 Replacements	Fluorescent Benchmarks
Initial lamp light output (lm)		√
Initial 2-lamp system efficacy (lm/W)		√
Initial 2-lamp fixture light output (lm)		√
Initial CRI		√
Fixture efficiency (%)	√	
Initial luminaire efficacy (lm/W)		√

Table 1: Summary of DOE CALiPER test results for 4-foot LED T8 replacements with fluorescent benchmarks.

This application note details a prototype T8 lamp design based on the Cree XLamp ML-E half-watt LED.

The purpose of this design exercise is to show that linear replacement lamps that meet or exceed specifications set forth by the DOE CALiPER report are now possible using this new LED lamp product. The XLamp ML-E package is a half watt LED designed specifically for close-pitch-spacing applications such as the T8 lamp.

The design goal is to produce a T8 lamp design with 2700-lm initial output, 50,000-hr lifetime, power consumption <32 W, having a smooth illumination profile and meeting all the DOE CALiPER recommendations as put forth in LED Performance Specification Series: T8 Replacement Lamps.[4]

There are specific challenges for an LED-based T8 lamp design. The market benchmark fluorescent luminaire is performing at 87 lm/W (or 64 lm/W with fixture). In general, light coming from the fluorescent lamp is linear and uniform. Incorporating LED point sources to match this performance requires careful optical and mechanical design.

2 DOE Solid-State Lighting CALiPER Program Summary of Results: Round 11 of Product Testing http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_round-11_summary.pdf
3 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
4 Op. cit.

DESIGN APPROACH/OBJECTIVES

In the Cree Application Note "LED Luminaire Design Guide,"[5] 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 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.

5 LED Luminaire Design Guide, Application Note APO000015, www.cree.com/products/pdf/LED_Luminaire_Design_Guide.pdf

THE 6-STEP METHODOLOGY

The goal for this project is to create a functionally competitive LED-based T8 lamp, without considering the electrical requirements of the T8 luminaire or fixture. Cree framed the project as a mechanical retrofit, so implementers have access to the large installed base of T8 fixtures.[6]

1. DEFINE LIGHTING REQUIREMENTS

The table below lists desirable characteristics to consider for the T8 lamp design.

Importance	Characteristics	Units
Critical	Luminaire luminous flux	lumens (lm)
	Illuminance distribution	footcandles (fc)
	Electrical power	watts (W)
	Aesthetics	
Important	Price	$
	Lifetime	hours
	Operating temperatures	°C
	Operating humidity	% RH
	Color temperature	K
	CRI	100-pt scale
	Manufacturability	
	Ease of installation	
	Form factor	

Table 2: Some ranked design criteria for an LED luminaire project

DOE-recommended specifications for 4-foot LED linear replacement lamps are summarized below.[7,8]

Characteristic	Specification
Initial minimum lamp light output	2700 lumens
Minimum lamp life, L70	35,000 hours
CCT	ANSI C78.377
Minimum CRI	80

Table 3: Summarized DOE recommended specifications for 4-foot LED linear replacement lamps

6 As with many T8 designs, we did not design a power supply to match the LED tube to existing lamp ballasts, which would have to be removed for a practical installation.

7 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

8 ANSI_NEMA_ANSLG C78.377-2008 Specifications for the Chromaticity of Solid State Lighting Products

We tested two modern name-brand T8 lamps (3500 and 4100 K CCT) both in a standard troffer and without any fixture to have some initial benchmark data.[9]

Source	Luminaire Power (W)	Luminous Flux (Lm)	Efficacy (Lm/W)	CCT
T8 fluorescent lamp	34.8	2906	83.5	3328
T8 fluorescent lamp	34.8	2986	85.8	3934
T8 fluorescent lamp in troffer + lens shade	34.8	2288	65.8	3269
T8 fluorescent lamp in troffer + lens shade	34.8	2327	66.9	3900

Table 4: T8 fluorescent lamp benchmark data

2. DEFINE DESIGN GOALS

The performance requirements for this lamp are well defined by DOE.

The design goals for this project:

Characteristic	Unit	Minimum Goal	Target Goal
Neutral white T8 luminaire	Lm	2700	
Illuminance profile	Fc	Identical	
Power	W	< 32	28
Neutral white T8 luminaire efficacy	Lm/W	> 90	95
Warm white T8 luminaire efficacy	Lm/W		
Lifetime	Hours	50,000	50,000
CCT neutral white	K	4500	4500
CCT warm white	K	3500	3500
CRI		> 70	75
Maximum ambient temperature	°C	30	

Table 5: Project design goals

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

Optical Efficiency

Every LED delivers different efficacies depending on chromaticity, with cool-white temperatures being the most efficient and warm-white the least.[10] Based on our requirements we chose to work with neutral-white (Order Code MLEAWT-A1-0000-0004E4) to give a balance between high CRI, good efficacy and the closest possible CCT to a neutral-white T8 fluorescent tube.[11]

9 Data measured in a 2-meter, NIST-traceable integrating sphere at the Cree facility in Durham, NC.
10 See the ML Family Binning and Labeling document for a list of flux and chromaticity options for the ML-E http://www.cree.com/products/pdf/XLampML-E_BL.pdf
11 Basic performance data on the XLamp ML-E is available at http://www.cree.com/products/pdf/XLampML-E.pdf

Cree investigated two design options:

Design 1: Use LEDs in fine pitch to achieve a smooth-looking linear source with high efficacy.
Design 2: Use fewer LEDs in larger pitch as a cost-reduced design.

Design 1

The key to this retrofit T8 lamp design is to create a linear light source, in which the LEDs are arranged in a combination of parallel strings of LEDs, with the LEDs in each string connected in series. With a typical forward voltage (Vf) of 3.2 VDC at 150 mA, we decided to connect 8 LEDs in series, giving a per-string voltage of ~25 V, and connect multiple strings in parallel. Thus, the system voltage will be ~25V and we determined the number of strings with the help of Cree's Product Characterization Tool (PCT).[12]

Compare: SYS # LE | SYS W | SYS lm/W | SYS lm to — Current Display Range: Ex. Fine (0.02A - 0.35A

System: Target Lumens: 2,700 — Optical Efficiency: 90% — Electrical Efficiency: 85%

	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	N3 [56.8]		56.8	Flux	N2 [51.7]		51.7	Flux	N2 [51.7]		51.7
	Price	$ -	Tsp (°C	45	Price	$ -	Tsp (°C	45	Price	$ -	Tsp (°C	45
		LED Multiple		x8		LED Multiple		x8		LED Multiple		x1
Current (A)	SYS # LED	SYS W	SYS lm/W	SYS lm tot	SYS # LED	SYS W	SYS lm/W	SYS lm tot	SYS # LED	SYS W	SYS lm/W	SYS lm tot
0.020	360	23.29	117.9	2745	392	25.36	108.2	2744	386	27.25	99.2	2702
0.030	248	24.44	112.9	2759	272	26.8	102.8	2754	270	25.41	106.3	2700
0.040	192	25.41	108.6	2760	208	27.53	99.2	2730	193	24.98	108.2	2702
0.050	160	26.82	105.9	2840	168	28.16	96.9	2730	169	27.84	97.1	2704
0.060	136	27.6	103.5	2856	144	29.22	94.3	2754	143	28.6	95	2717
0.070	112	26.85	101.2	2716	128	30.68	91.8	2816	123	28.94	93.5	2706
0.080	104	28.75	99	2847	112	30.96	90	2786	108	30.49	88.6	2700
0.090	96	30.21	96.9	2928	104	32.73	88.2	2886	97	30.81	88.2	2716
0.100	88	31.06	94.9	2948	96	33.88	86.4	2928	88	31.06	87.8	2728
0.110	80	31.29	93.6	2930	88	34.42	85	2926	82	31.84	85	2706
0.120	72	31.02	91.7	2844	80	34.47	83.6	2880	75	32.65	82.7	2700
0.130	64	30.12	90	2712	72	33.88	82.1	2781	70	32.94	82.9	2730
0.140	64	32.66	88.9	2904	72	36.74	80.8	2970	66	33.39	81	2706
0.150	64	35.29	87.3	3080	64	35.29	79.3	2800	62	34.28	79.6	2728
0.160	56	33.19	86.1	2856	64	37.93	78.2	2968	59	34.71	78.2	2714
0.170	56	35.49	84.6	3003	56	35.49	77.1	2737	56	35.58	77.1	2744

Figure 2: Product Characterization Tool with Design 1 data

Looking at the possible solutions and comparing LED pitch, we chose to use 96 LEDs, resulting in 12.5 mm pitch spacing (just under 0.5 in). By driving the LEDs between 80 mA and 90 mA, the total system current is 0.96 A to 1.08 A @ 25.6 V with power consumption of ~30 W, achieving the design goal. Note that if we use LEDs of a lower flux bin, N2 rather than N3, the design must be adjusted to achieve the < 32 W goal.

12 Available at http://pct.cree.com

Design 2

Cree analyzed another option that minimizes the number of LEDs while still maintaining an acceptable level of illumination. We used an approach similar to Design 1, setting a maximum pitch and using the maximum rated current. The PCT yields the following.

Compare: SYS # LE | SYS W | SYS lm/W | SYS lm to — Current Display Range: Ex. Fine (0.02A - 0.35A)

System: Target Lumens: 2,700 — Optical Efficiency: 90% — Electrical Efficiency: 85%

	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: N3 [56.8]			56.8	Flux: N2 [51.7]			51.7	Flux: N2 [51.7]			51.7
	Price: $ -	Tsp (°C)		45	Price: $ -	Tsp (°C)		45	Price: $ -	Tsp (°C)		45
	LED Multiple			x5	LED Multiple			x5	LED Multiple			x1
Current (A)	SYS # LED	SYS W	SYS lm/W	SYS lm tot	SYS # LED	SYS W	SYS lm/W	SYS lm tot	SYS # LED	SYS W	SYS lm/W	SYS lm tot
0.020	350	23.06	118.4	2730	390	25.69	106.3	2730	386	27.25	99.2	2702
0.030	245	24.21	113.3	2744	270	26.68	101.2	2700	270	25.41	106.3	2700
0.040	190	25.04	109.3	2736	205	27.01	100.2	2706	193	24.98	108.2	2702
0.050	155	25.89	106.6	2759	170	28.4	97	2754	169	27.84	97.1	2704
0.060	130	26.61	102.6	2730	145	29.68	92.8	2755	143	28.6	95	2717
0.070	115	27.6	100.8	2783	125	30	91.7	2750	123	28.94	93.5	2706
0.080	100	27.76	98.7	2740	110	30.54	89.3	2728	108	30.49	88.6	2700
0.090	90	28.38	96.4	2736	100	31.53	88.2	2780	97	30.81	88.2	2716
0.100	85	30	94.6	2839	90	31.76	86.7	2754	88	31.06	87.8	2728
0.110	75	29.29	93.7	2745	85	33.2	85.5	2839	82	31.84	85	2706
0.120	70	30.14	92	2772	75	32.29	83.6	2700	75	32.65	82.7	2700
0.130	65	30.59	90.1	2756	70	32.94	82.5	2716	70	32.94	82.9	2730
0.140	60	30.64	88.9	2724	70	35.74	80.7	2884	66	33.39	81	2706
0.150	60	33.04	87.2	2880	65	35.79	79.5	2847	62	34.28	79.6	2728
0.160	55	32.61	86	2805	60	35.58	77.9	2772	59	34.71	78.2	2714
0.170	55	34.81	84.7	2948	60	37.98	77.1	2928	56	35.58	77.1	2744

Figure 3: Product Characterization Tool with Design 2 data

In this case, we chose to use 60 LEDs. In a 4-foot tube, this translates to a pitch of 20.5 mm (0.8 in). In terms of electrical behavior, with 12 parallel strings of 5 ML-Es in series (~16 V @ 150 mA), the total system current is 1.8 A @ 16 V with power consumption of ~ 30 W. This approach works for the N3 and above flux bins, but does not work with lower flux bins.

In both design approaches, a diffuser is required to achieve a smooth-looking light source. A diffuser for Design 1, having LEDs with 12.5 mm pitch, does not need to be as strong as the one for Design 2, having LEDs with 20.5 mm pitch.

Other design alternatives are suggested in step 5.

Thermal Requirements

To meet the design goal, the T8 lamp must dissipate about 32 W of electrical power. We utilized a finned heat sink along the length of the tube to achieve thermal cooling. We sourced a market-ready LED fixture component from the Internet[13] and used this as a quick demonstration. The heat sink looks similar to the pictures below.

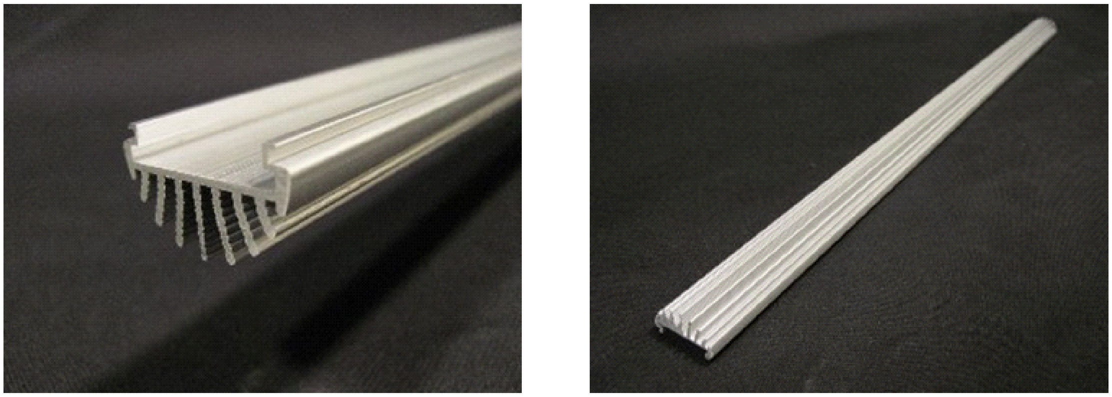

Figure 4: Extruded aluminum heat-sink housing

Strings of LEDs will be solder reflowed onto aluminum base metal core printed circuit boards (MCPCB) and attached to the heat sink with thermal conductive compound.

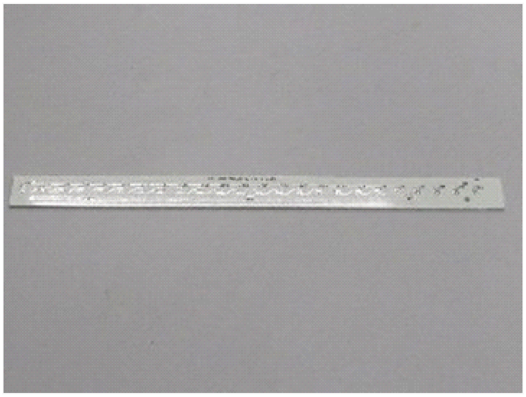

Figure 5: ML-E soldered on MCPCB

13 http://detail.china.alibaba.com/buyer/offerdetail/519683075.html

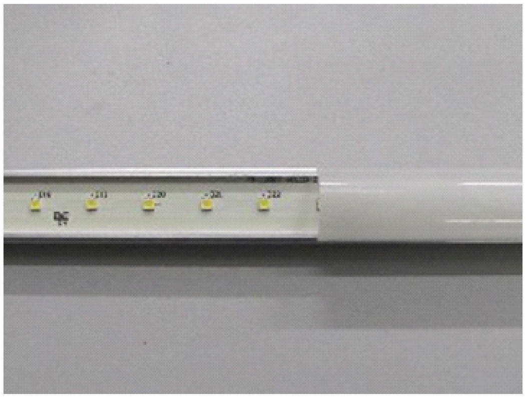

Figure 6: MCPCB mounted on heat sink/housing

Heat-sink and LED solder-point temperatures were predicted at a 25°C ambient temperature using thermal simulation software and confirmed with an infrared imaging camera. Predicted and actual temperatures matched within a few degrees C, around 51°C (T_{sp}) for 96 LEDs running at 90 mA each and around 60°C for 60 LEDs running at 150 mA. This temperature is well within the operating envelope for ML-Es. With heat sink thermal dissipation like this, the designs will have no trouble achieving a 50,000-hour L70 lifetime.[14]

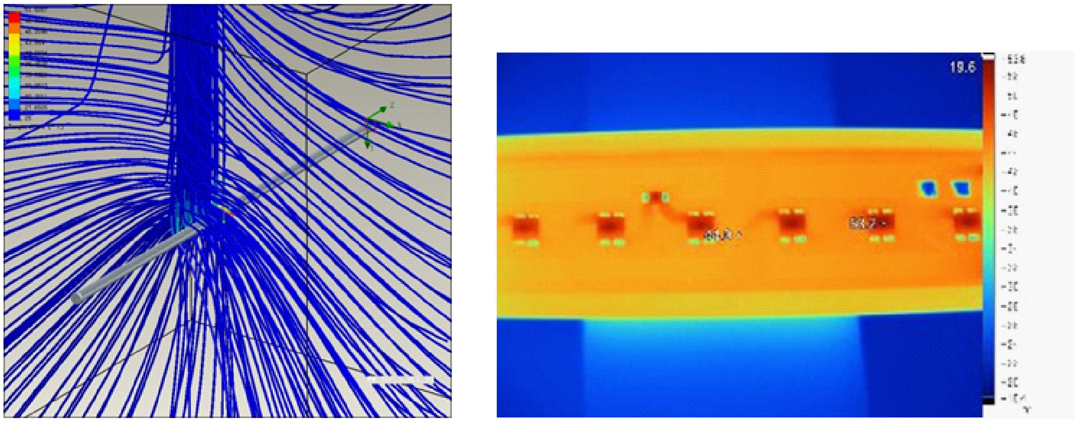

Figure 7: Thermal simulation and infrared image of 96 LED T8 lamp design showing Tsp ~51°C

14 That is, after 50,000 hours of operation, in a well-designed system, the LED will still deliver at least 70% of its initial luminous flux.

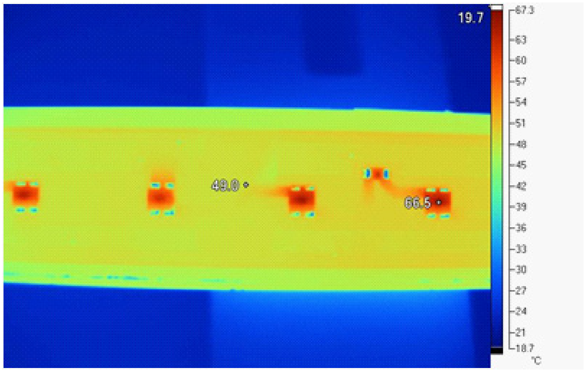

Figure 8: Infrared image of 60 LED T8 lamp design showing Tsp ~60°C

Drive Electronics

While there are many excellent suppliers of LED control electronics and many ways to deliver controlled DC power to the XLamp ML-E, we chose a readily available, constant-current, non-dimmable power supply from Autec Power Systems.[15] We chose this part because it has the right voltage and current range, is already UL-certified and is available from multiple distributors. Cree measured several of these parts as being ~85% efficient.

4. CALCULATE THE NUMBER OF LEDS

As mentioned above, there are 2 designs: 96 and 60 LEDs.

5. CONSIDER ALL DESIGN POSSIBILITIES

The design possibilities for an LED T8 light are straightforward. This project is intended to be a minimal design to retrofit an existing application. The objective is to show how simple it is to use the most sophisticated LEDs in T8 fluorescent luminaire design. Therefore:

- Consider using a combination of LEDs of the N2 and lower flux bins. Although the number of LEDs to use and the pitch of the LEDs in such a configuration were not determined in this effort, a geometrically regular pattern of LEDs of adjacent flux bins would be able to deliver smooth-looking light at equivalent or better efficacy.
- Consider lighting effect vs. number of LEDs used vs. the flux bin of the LEDs.
- A suitable diffuser film may be needed, depending on LED spacing.
- Use a heat sink that fits the design aesthetic and guarantees proper heat dissipation.
- Use off-the-shelf drivers for the simplest possible wiring.
- Consider using the quarter-watt XLamp ML-B LED, which requires half the power of the ML-E LEDs and is able to deliver smooth-looking light.

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15 35W Constant Current LED Driver LEDWCx035. See: http://www.autec.com/pdf/LEDWCx035SxxxST.pdf. In addition to the Autec power supply, we sourced a lower-cost power supply from Changzhou Hongguang Electron Co. (http://www.HGPOWER.com).

6. COMPLETE THE FINAL STEPS: IMPLEMENTATION AND ANALYSIS

In this section, Cree illustrates some of the techniques used to create prototype T8 lamps with the ML-E package. Additionally, the photometric results of the prototype T8 lamps compared to a T8 fluorescent lamp available on the market are shown.

Prototyping Details

1. Mechanical considerations in creating the prototype T8 lamps:
   a. ML-E packages should be solder-reflowed on MCPCBs and residual flux should be cleaned off.
   b. The heat sink should be exposed to ambient air and should not be covered.
   c. MCPCBs should be mounted on the heat sink with thermal conductive compound.
2. Figure 10 shows the parts used to assemble the prototype T8 lamps.[16]

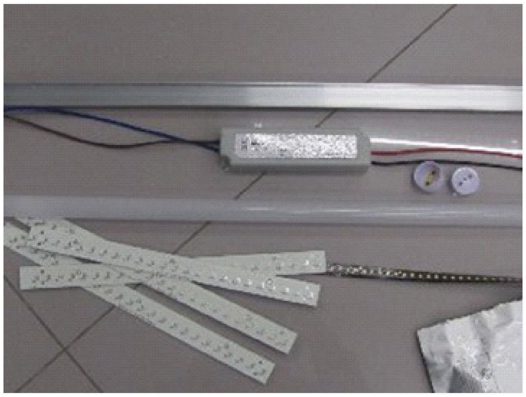

Figure 10: Parts used to assemble the prototype T8 lamp

3. ML-E packages were solder reflowed onto MCPCBs with the specific pitch.
   a. A circuit of 3 LED strings connected in parallel was constructed on an MCPCB. Each string consisted of 8 LEDs connected in series.
   b. 4 MCPCBs were connected in parallel and mounted on the heat sink housing.
   c. A silicone-based thermal compound typically used with CPU heat sinks was used between each MCPCB and the heat sink.

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Item	Supplier	Quantity
LEDs	Cree ML-E, MLEAWT-A1-4C0-N3-0-0001	96
	Cree ML-E, MLEAWT-A1-4C0-N3-0-0001	60
Metal-core printed circuit board	Custom-made Al MCPCB	4
External constant-current driver	US Autec Driver: LEDWCD035S105ST	1
	Changzhou Hongguang Electron Co	1
Al housing with diffuser set	http://hzsxn.cn.alibaba.com/	1
T8 tube end caps	http://hzsxn.cn.alibaba.com/	1

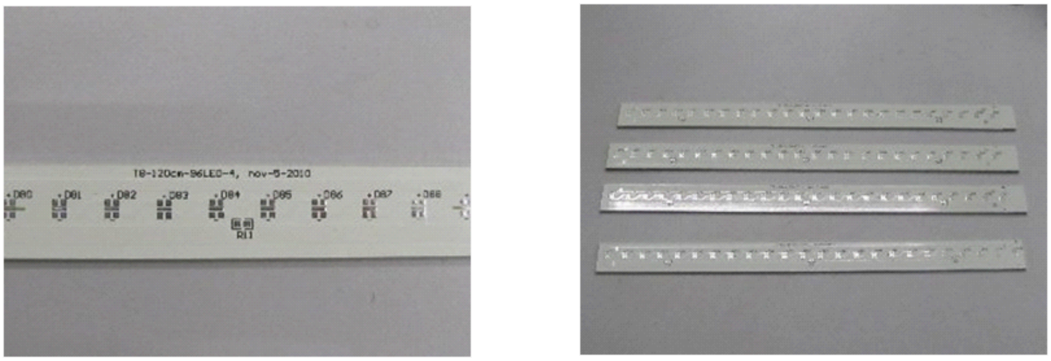


Figure 11: Each 96-LED T8 lamp has 4 MCPCBs connected in parallel

4. A simple Internet search identified a diffuser shield[17] to mix and distribute the light evenly.

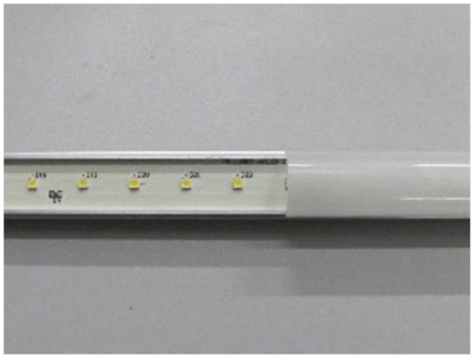


Figure 12: ML-E on MCPCB with diffuser shield

5. End caps were used to secure the T8 lamp.

Figure 13: Tube end caps used to secure the assembly

17 From the same source as the heat sink, op. cit.

6. An external constant current power supply was used to power the prototype T8 lamp.

Figure 14: External constant current power supply used to power the T8 lamp

RESULTS

Optical tests were performed on the prototype LED T8 lamps to verify they meet the specifications set forth by the DOE CALiPER report. A 2-meter sphere was used to test the lamps[18]. A steady-state light-up time of 1 hour was used to stabilize the lamps before testing. Test data in the table below shows that using the 96-LED T8 lamp at lower operating current can meet the DOE CALiPER suggested specification.

Source	Luminaire Power (W)	Luminous Flux (lm)	Efficacy (lm/W)	CCT
Cree ML-E (96 LEDs), no Fixture	32.6	2654	81.4	4261
Cree ML-E (96 LEDs), fixture + lens	32.6	2263	69.4	4200
Cree ML-E (60 LEDs), no fixture	35.8	2577	71.9	4379

Table 6: Test data

18 Measurements were taken in Cree's Shenzhen Technology Center.

The Far Field Pattern (FFP) of the prototype 96-LED T8 lamp is displayed below, showing a 110-degree full width at half maximum (FWHM) near the c

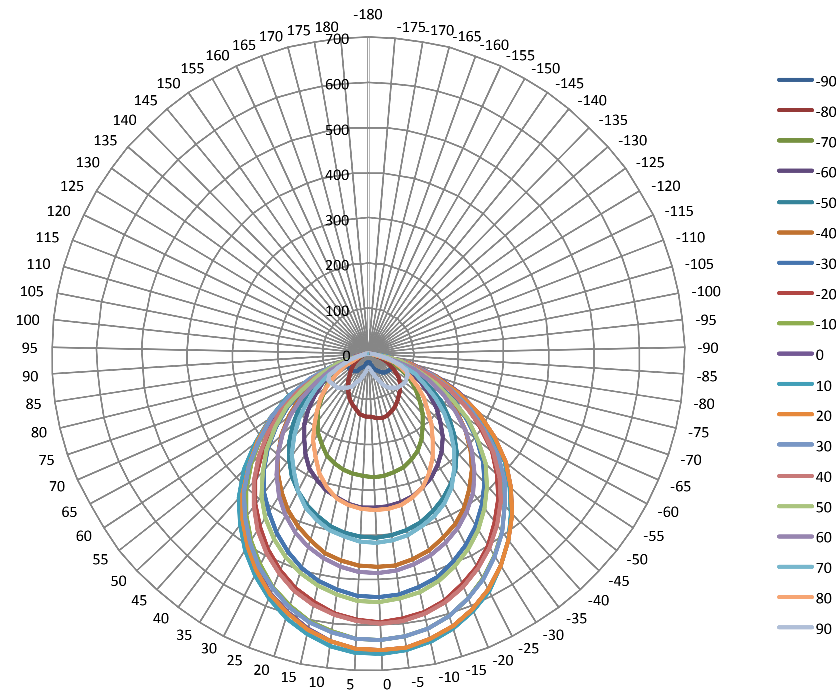
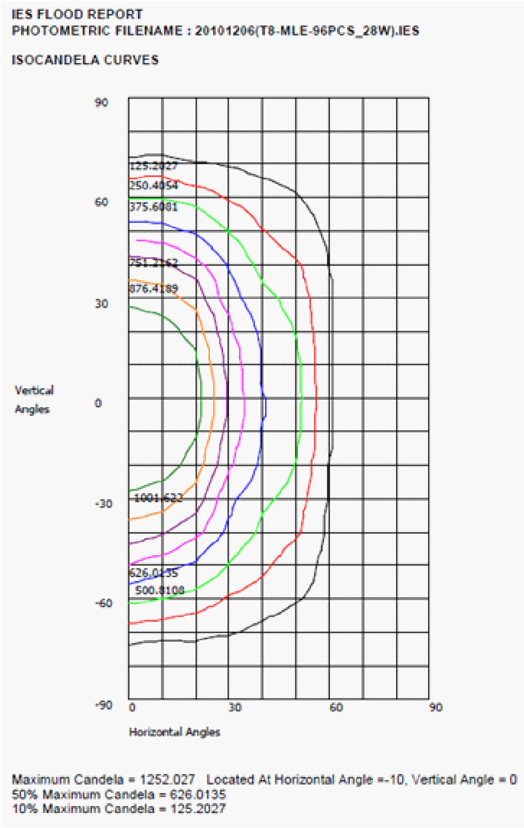


Figure 14: FFP of 96-LED T8 lamp

19 FFP measured with a goniophotometer in the Cree Shanghai Tech Center, China.

Further, the following diagrams compare spacial distribution (FFP) of the prototype 96-LED T8 lamp and a fluorescent lamp, each in a lighting fixture.



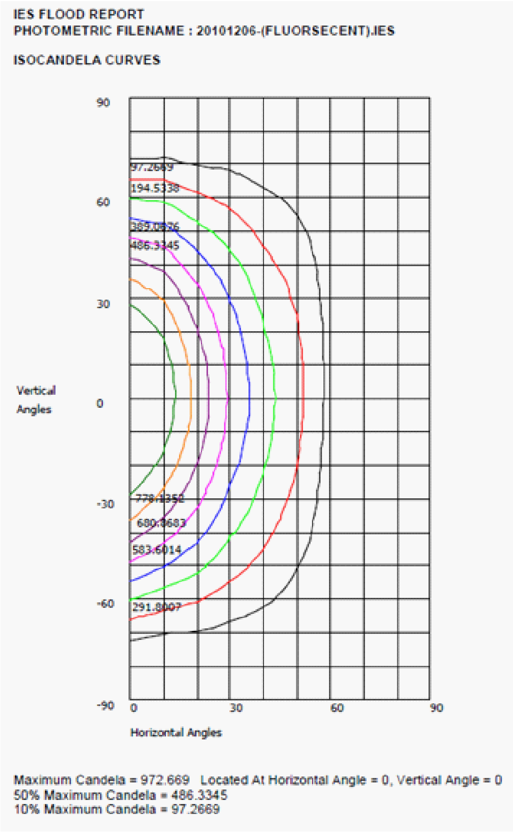


Figure 15: Iso-candela plot of 96-LED T8 lamp (left) compared to fluorescent lamp (right), each in a light fixture

Visual Results

Samples of both designs were tested for visual effect by hanging them in an office work space. The following pictures were taken with a digital camera without a flash, with other area lighting turned off during the photography.

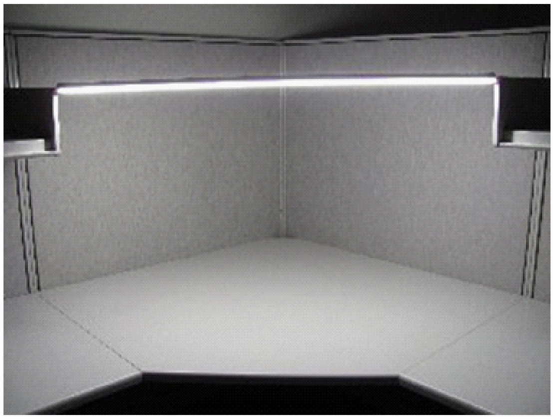
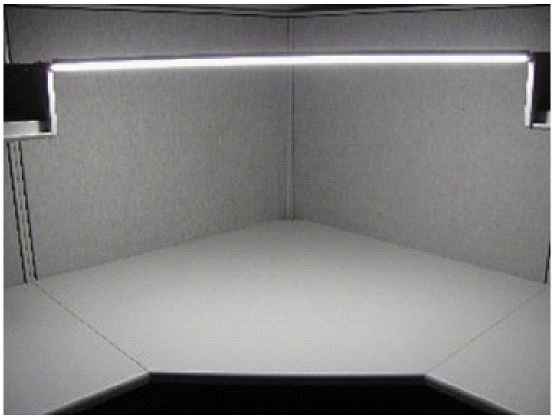



Figure 16: Visual performance of prototype T8 lamps in typical office cubicle work area (left: 96-LED T8 lamp, right: 60-LED T8 lamp)

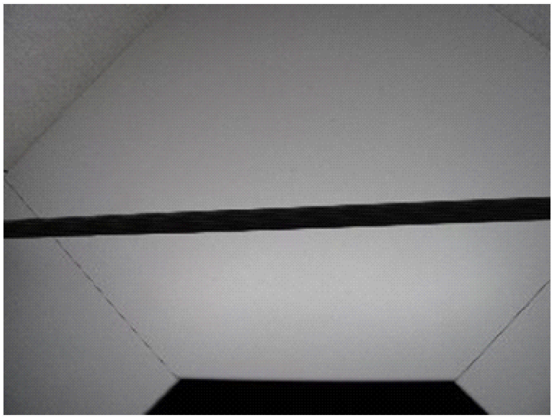
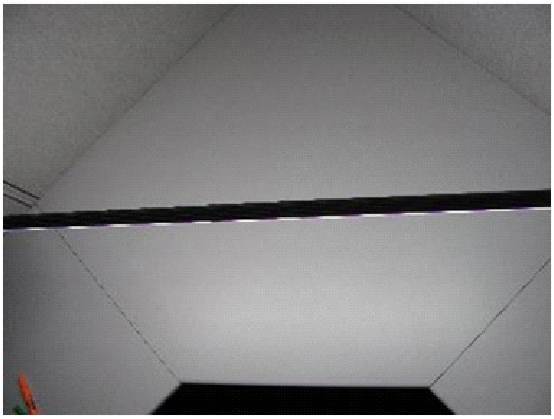



Figure 17: Visual performance of prototype T8 lamps in typical office cubicle work area, viewed from above (left: 96-LED T8 lamp, right: 60-LED T8 lamp)

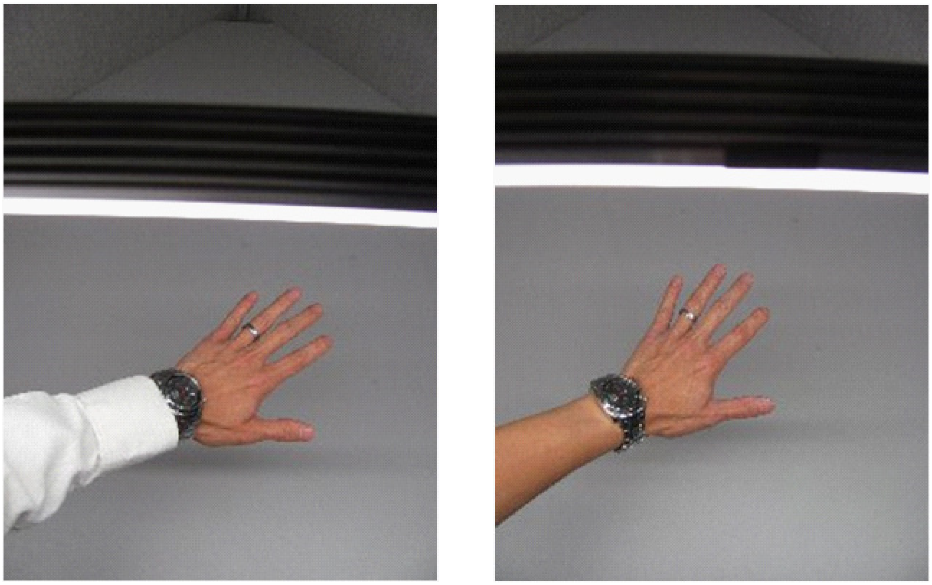


Figure 18: Shadowing effect of prototype T8 lamps
(left: 96-LED T8 lamp, right: 60-LED T8 lamp)

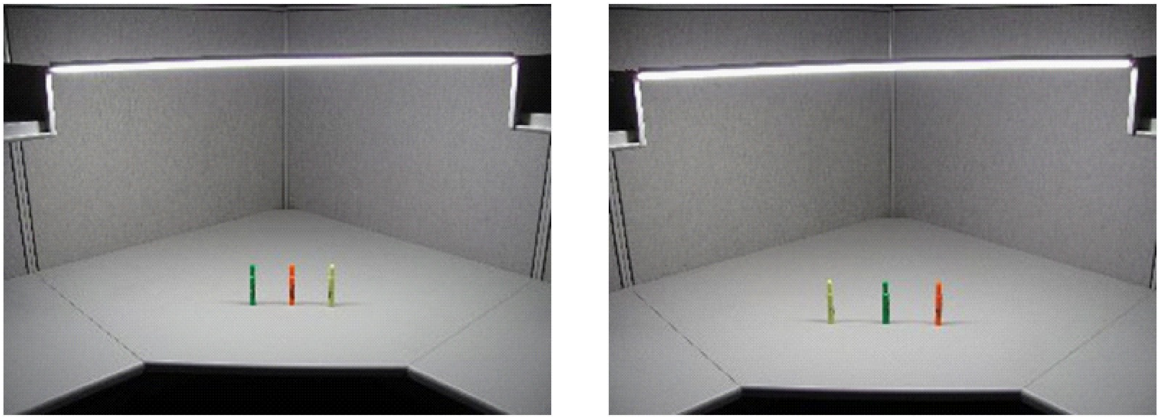


Figure 19: Visual performance of prototype T8 lamps in typical office cubicle work area with objects
(left: 96-LED T8 lamp, right: 60-LED T8 lamp)

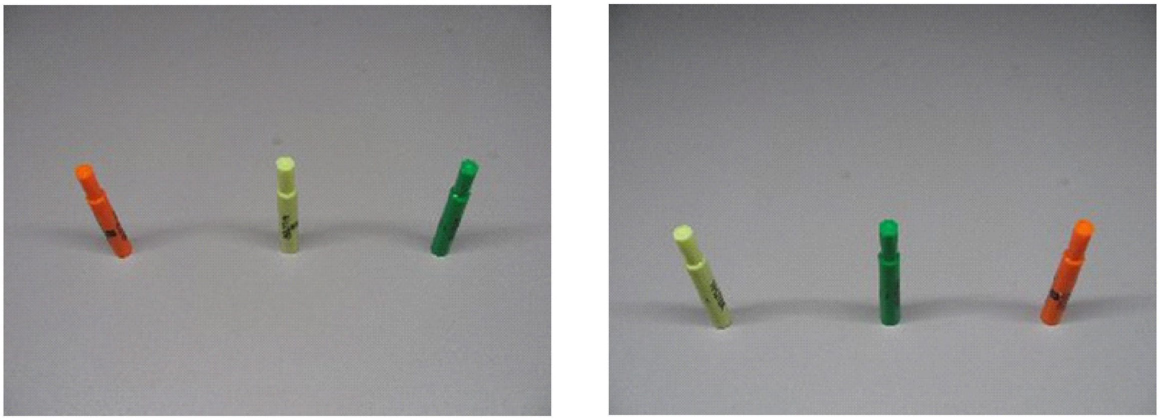


Figure 20: Shadowing effect of prototype T8 lamps in typical office cubicle work area with objects (left: 96-LED T8 lamp, right: 60-LED T8 lamp)

CONCLUSIONS

This prototype T8 lamp design demonstrates the possibility of retrofitting a T8 fluorescent lamp with Cree XLamp ML-E LEDs. With the two design possibilities presented herein, the stringent DOE CALiPER specification can be met. These prototype designs deliver the necessary light in a normal operating environment to achieve the L70 50,000 hour designation. Some visual consideration may be needed for the wider spaced design; with proper use of readily available diffuser films, "hot spots" and multiple shadowing issues can be solved and an ML-E T8 lamp can give an appealing light for users. This document shows that a good XLamp ML-E T8 lamp can be designed, but should not be interpreted as the only ways that this can be accomplished.