Cree® XLamp® XM-L
High-Bay Reference Design

Figure 1: XM-L high-bay prototypes
(left: no optic design, right: Carclo Bubble optic)

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INTRODUCTION

There is a large market opportunity for LED-based high-bay luminaires. World-wide market estimates of low-bay and high-bay luminaires, both as replacements for existing fixtures and as initial installations in new construction, are in the hundreds of millions of units. High-bay luminaires incorporating the Cree XLamp XM-L LED offer numerous benefits compared to traditional high bay fixtures including energy efficiency, better illumination and the ability to integrate with building control systems.

Until the release of Cree's XLamp XM-L LED, several hundred LEDs were needed to match the luminous output of traditional high-bay lighting. The highly efficient XM-L LED makes using this LED in a high-bay luminaire a viable alternative to a metal-halide lamp.

This application note demonstrates how to incorporate the Cree XLamp XM-L LED into a high-bay luminaire.

An XM-L high-bay luminaire has multiple advantages over traditional metal-halide lamps.

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- No warm-up time
- No cool down needed before restart
- No humming or flickering
- No mercury
- Longer lifetime
- No re-lamping cost, which can be a significant expense in high-bay applications
- No risk of lamp breaking, sending glass fragments over a large area
- Dimmable, enabling the use of occupancy sensors for power savings

Figure 2: Typical high bay installations

Cree created these XM-L high-bay prototypes with help from several driver and optical partners to show several different approaches to an XM-L based high-bay luminaire design. These are only a few of the many possible implementations of the XM-L LED into a high-bay design.

DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide"[1] Cree advocates a six step framework for creating LED luminaires and lamps. We used this framework, with the design guide's summary table 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.

1 LED Luminaire Design Guide, Application Note AP15, www.cree.com/products/pdf/LED_Luminaire_Design_Guide.pdf

Step	Explanation
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.

Table 1: Cree 6-step framework

THE 6-STEP METHODOLOGY

The major goal for this project was to create an easy-to-implement, high-efficiency XM-L LED-based luminaire capable of replacing the traditional metal-halide high-bay fixtures on the market. Cree framed the project as a fixture replacement, so implementers can take full advantage of the XM-L LED's superior performance.

1. DEFINE LIGHTING REQUIREMENTS

Table 2 shows a ranked list of desirable characteristics for a high-bay luminaire.

Importance	Characteristics	Units
Critical	Illuminance distribution	Footcandles (fc)/lux
	Electrical power	Watts (W)
	Lifetime	Hours
	Payback	Months
	Luminous flux	Lumens (lm)
	Manufacturability	
Important	Operating temperatures	°C
	Operating humidity	% RH
	Correlated Color Temperature (CCT)	K
	Color Rendering Index (CRI)	100 point scale
	Ease of installation	

Table 2: Ranked design criteria for a high-bay luminaire

Figure 3 below shows measured intensity data for metal-halide luminaires purchased from an industrial store, normalized to show the light distribution for two types of luminaires.

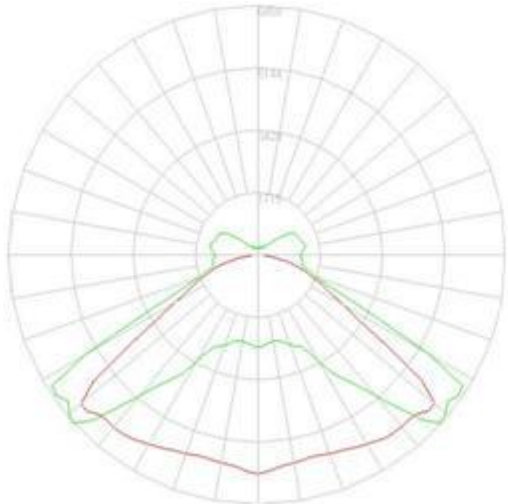

Figure 3: Goniometric intensity polar plot of metal-halide luminaires

Photometric testing and examination of existing high-intensity discharge (HID) metal-halide lamps provides comparison data, shown in Table 3.

Source	Luminaire Power (W)	Lamp Luminous Flux (lm)	Fixture Total Lumens	Fixture Efficiency	Usable Lumens*	Efficacy (lm/W)
HID aluminum reflector BT37 metal-halide lamp	436	29,013	20,924	54%	15,771	36.2
HID clear prismatic lens BT37 metal-halide lamp	436	29,013	26,790	61%	17,597	40.4

Table 3: Metal halide comparison data

* Usable lumens define the light in the 0-60° zonal lumens distribution. The rest of the light is considered to be wasted. The fixture efficiency, as defined in Cree's "LED Luminaire Design Guide,"[2] reflects the percentage of light that is useful.

2 Ibid., 6

Figure 4, Figure 5 and Figure 6 show the advantages of directional XLamp XM-L LEDs in this application. Omnidirectional metal-halide lamps do not transmit all their light toward the target to be illuminated, resulting in losses within the fixture. The directional XM-L LED transmits all its light toward the target, with minimal to no losses within the fixture. As a result of this difference, a lumens-for-lumens match between an XM-L LED and a metal-halide lamp is only partially relevant.

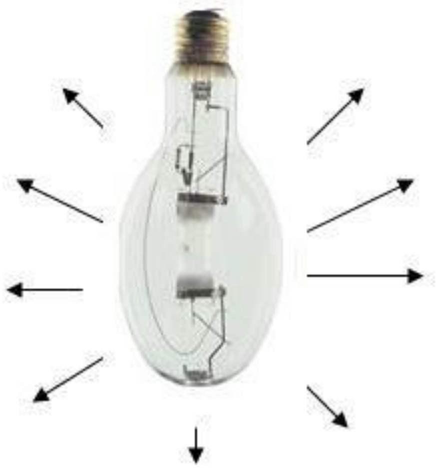

Figure 4: Typical metal-halide lamp light distribution

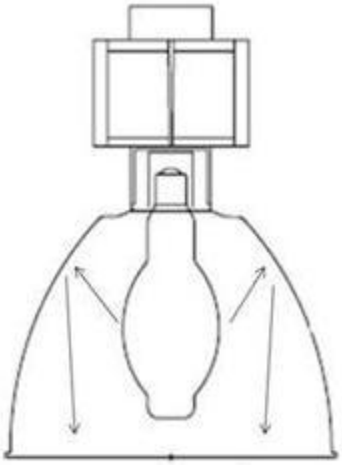

Figure 5: Typical high-bay luminaire light distribution

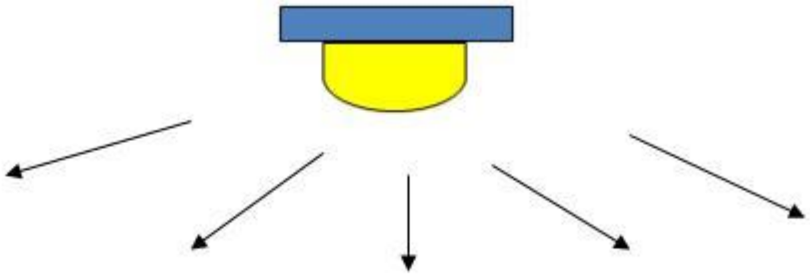

Figure 6: Typical high power LED light distribution

The Illuminating Engineering Society of North America (IESNA) gives performance requirements[3] for various situations.

Category	Fc	Lux	Description	Example
A	3	32.3	Public space	Wine cellar
B	5	53.8	Simple orientation	Toilets & washroom
C	10	107.6	Working space simple tasks	Auditorium, locker room
D	30	322.9	Visual tasks of high contrast and large size	Library, museum
E	50	538.2	Visual task of high contrast and small or low contrast and large size	Commercial kitchen, classroom
F	100	1076.4	Visual task of low contrast and small size	Basketball court
G	300	3229.2	Visual task near threshold	Autopsy table, surgical task

Table 4: IESNA requirements

The ENERGY STAR program provides general performance requirements.[4] There are currently no specific ENERGY STAR requirements for high-bay fixtures, however the following requirements apply to directional, commercial and indoor luminaires.

Characteristic	Requirement
CCT	The luminaire must have one of the following nominal CCTs and fall within the corresponding 7-step chromaticity quadrangles as defined in ANSI/NEMA/ANSLG C78.377-2008. 2700 K 3000 K 3500 K 4000 K 5000 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	Luminaire shall meet or exceed $R_a \geq 80$.
Off-state power	Luminaires shall not draw power in the off state.
Dimming	The luminaire and its components shall provide continuous dimming from 100% to 35% of total light output. Step dimming, if employed, shall provide at least two discrete light output levels ≥ 35% of total light output and not including 100% output.
Source start time	Light source shall remain continuously illuminated within one second of application of electrical power.

3 IESNA Lighting Handbook, 9th Edition
4 ENERGY STAR Program Requirements Product Specification for Luminaires (Light Fixtures) - Eligibility Criteria - Version 1.0 http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/luminaires/ES_Luminaires_V1_Final_Specification.pdf

Characteristic	Requirement
Source run-up time	Light source shall reach 90% of stabilized lumen output within one minute of application of electrical power.
Power Factor (PF)	Total luminaire input power ≤ 5 W: PF ≥ 0.5 Total luminaire input power > 5 W: PF ≥ 0.7 for residential PF ≥ 0.9 for commercial
Warranty	3-year warranty for luminaires with replaceable drivers. 5-year warranty for luminaires with non-replaceable drivers.
Driver case temperature	Measured temperature for the hottest location on the driver case shall not exceed the driver manufacturer’s maximum recommended temperature during in situ operation.
Minimum operating temperature	-18°C or below
Operating frequency	≥ 120 Hz Note: This performance characteristic addresses problems with visible flicker due to low frequency operation and applies to steady-state as well as dimmed operation. Dimming operation shall meet the requirement at all light output levels.
Luminaire efficacy	42 lm/W
Minimum light output	≤ 4.5 in. aperture: 345 lumens > 4.5 in. aperture: 575 lumens
Zonal lumen density	Minimum of 75% of total initial lumens within 0-60° zone (axially symmetric about the nadir)
Lumen maintenance requirement	L_{70} ≥ 35,000 hours for commercial luminaires

Table 5: ENERGY STAR requirements

The DesignLights Consortium provides requirements for a high-bay luminaire.[5]

Characteristic	Application	
	High-Bay and Low-Bay Fixtures for Commercial and Industrial Buildings	**High-Bay-Aisle Lighting**
Minimum light output	> 10,000 lm	> 10,000 lm
Zonal lumen density Nominal requirement, zone	≥ 30% 20–50°	≥ 50%, 20–50° ≥ 30%, 0–20°
Minimum luminaire efficacy	60 lm/W	60 lm/W

5 Technical Requirements Table v1.5 http://www.designlights.org/solidstate.manufacturer.requirements.php

Characteristic	Application	
	High-Bay and Low-Bay Fixtures for Commercial and Industrial Buildings	High-Bay-Aisle Lighting
Allowable CCTs	2700 K 3000 K 3500 K 4000 K 4500 K 5000 K 5700 K 6000 K	2700 K 3000 K 3500 K 4000 K 4500 K 5000 K 5700 K 6000 K
Minimum CRI	70	70
Minimum lumen maintenance requirement at 6000 hrs	94.1%	94.1%
Minimum luminaire warranty	3 years	3 years

Table 6: DesignLights Consortium high-bay luminaire requirements

2. DEFINE DESIGN GOALS

The design goals for this project:

Characteristic	Unit	Minimum Goal	Target Goal
Illuminance profile	Fc	same as 400 W metal halide lamp	same as 400 W metal halide lamp
Power	W	< 250	200
Luminaire efficacy	lm/W	> 70	80
Lifetime	hours	25,000	50,000
CCT	K	7000	7000
CRI		identical	better
Maximum ambient temperature	°C	30	40
Bill of materials (BOM) cost	$	400	400
Lumens (round output)	lm	17,000	17,000
Lumens (oval output)	lm	10,000	10,000

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

Optical Efficiency

The two main optical losses in an LED system are light loss within the fixture and secondary optic loss. To eliminate light loss within the fixture we designed the fixture so there is no light loss within it. This was done by spacing the LEDs far enough from the edge of the fixture and close enough to the output so no light hits the sides and has to be reflected out. Secondary optics can have light loss as high as 20% and as low as 7%.

To achieve as little secondary optic loss as possible, Carclo[6] and Ledil[7] optics were chosen having efficiencies as high as 93%.

Figure 7: Carclo Bubble optic

The Carclo optic produces a round distribution of light wider than that of a high-bay luminaire without an optic. Such a distribution is useful in illuminating a space such as a large retail store.

Figure 8: Ledil Strada optic

The Ledil optic produces an oval distribtion of light that is useful in illuminating spaces such as aisles in a warehouse.

Thermal Requirements

The XLamp XM-L LED operates at up to 10 watts of electrical power, depending on the drive current, and requires a heat sink to dissipate this thermal load. About 40% of that energy is converted to radiant flux and the rest to heat. Because we want to the fixture to operate at less than 200 W, the heat sink will have to support a thermal load of 120 W.

The heat sink has two functions in this high-bay design: primarily to dissipate the thermal load of the LED, but also to provide a frame for the fixture. This allows for as much surface area as possible to be exposed to ambient conditions and takes full advantage of designing the luminaire around the XM-L LED. Cree chose to work with machined aluminum to provide a series of large cooling fins. Machining of this prototype was done with the help of a local machine shop.

A STEP file for the heat sink and assembly mounting arm is available on the Cree website.[8]

6 Carclo Technical Plastics Ltd. website: http://www.carclo-optics.co.uk/
7 Ledil Oy website: http://www.ledil.com
8 http://www.cree.com/XLampModels/XLamp_ML_Highbay.zip

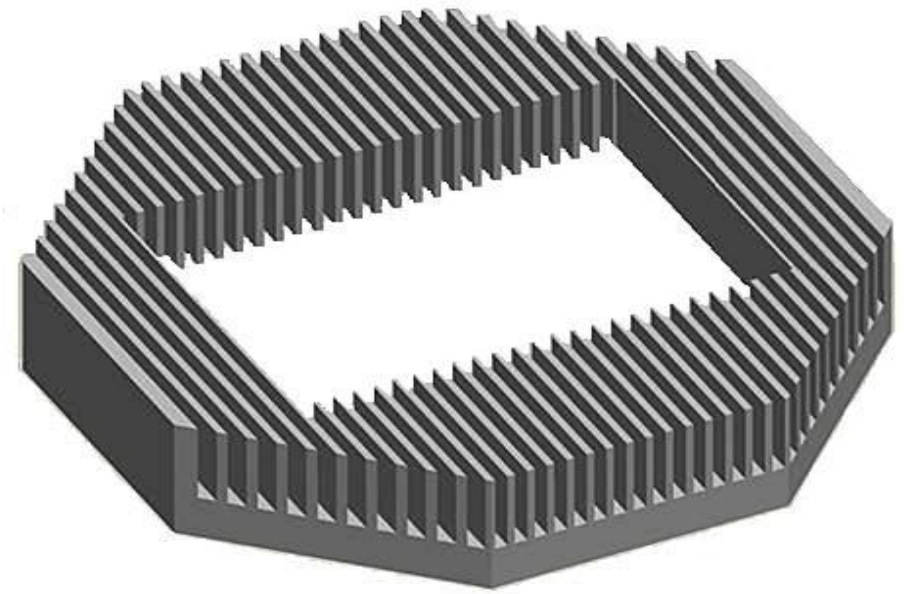

Figure 8: Machined aluminum heat sink

To verify the utility of this design, Cree performed thermal simulations using Ansys simulation software.[9] Shown below in Figure 9 is a simulation showing a cross section of the heat-sink housing with a 150-W thermal load at steady state in a 25°C-ambient operating environment. The highest temperature in the simulation is at the solder point; the LED/heat-sink boundary never goes above 76°C, or 51°C above ambient. The thermal resistance of the XM-L LED is 2.5°C/W, so the junction temperature will be ~89°C. With heat-sink thermal dissipation like this, the design will have no trouble achieving a 50,000-hour L_{70} lifetime.[10]

9 Cree used Ansys Design Space, http://www.ansys.com/products/structural-mechanics/products.asp

10 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.

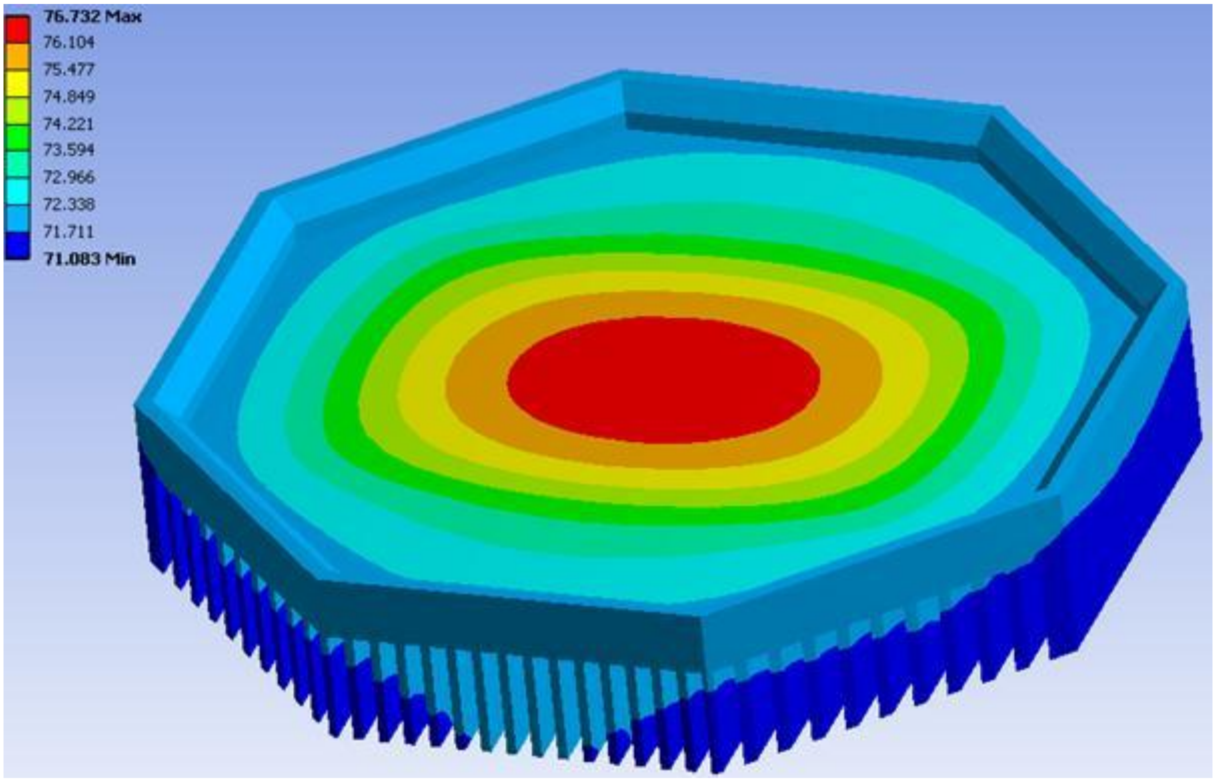

Figure 9: Ansys thermal simulation

Examining either the Cree Product Characterization Tool (PCT) or the relative flux vs. junction temperature graph in the XM-L data sheet,[11] an XM-L LED operating at a 89°C junction temperature will have a brightness of just less than 90% of the 85°C binning flux. Our measurements confirm this.

11 http://www.cree.com/products/pdf/XLampXM-L.pdf

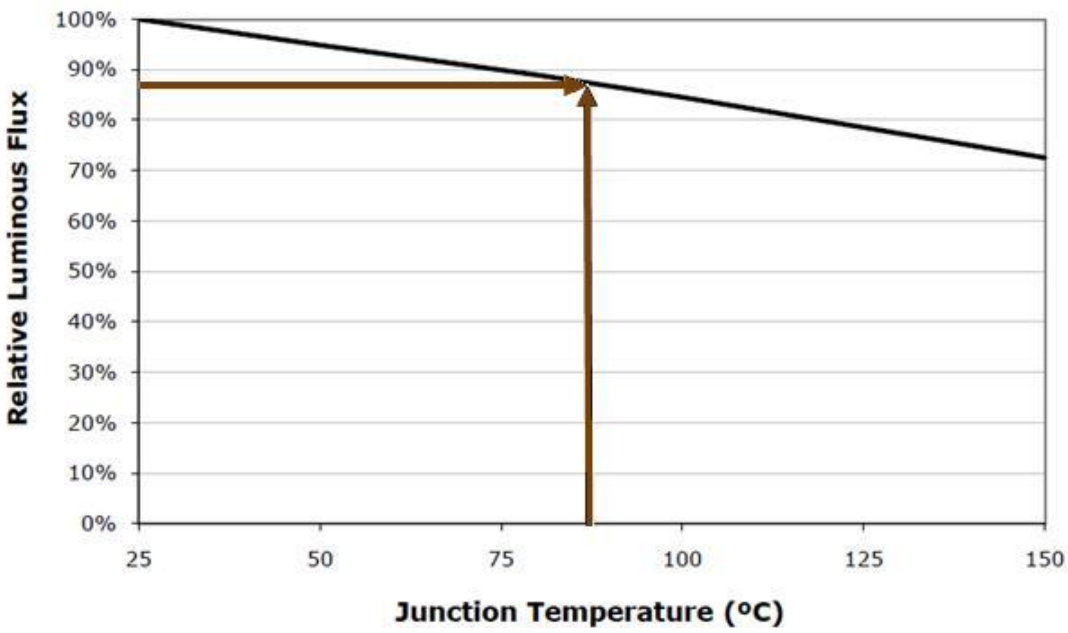

Figure 10: XLamp XM-L data sheet: Relative luminous flux vs. junction temperature

Drive Electronics

While there are many excellent suppliers of LED control electronics and many ways to deliver controlled DC power to the XLamp XM-L LED, Cree chose a readily available, full-range, off-the-shelf power supply from Thomas Research[12] and Mean Well[13] and a custom driver from NXP Semiconductors.[14] We chose the Thomas Research driver because it is already CE/UL certified, available from multiple distributors, has efficiencies as high as 91% and a power factor greater than 0.9. The NXP custom driver provides efficiency of ~95%, has four-channel output, a power factor above 0.9 and can be configured to have occupancy sensing dimming.

Figure 11: Power supplies (left: Thomas Research, right: NXP)

12 Thomas Research model TRC-120S175ST http://www.thomasresearchproducts.com/led_drivers.htm
13 Mean Well USA Inc. website: http://www.meanwellusa.com
14 NXP Semiconductors website: http://www.nxp.com/

Table 8 below summarizes the calculated efficiencies of the optical, thermal and electrical systems for this high-bay design.

System	Efficiency	Type
Optical	93%	Light
Thermal	88%	Light
Electrical	92%	Power

Table 8: Optical, thermal, electrical efficiencies

4. CALCULATE THE NUMBER OF LEDS

The design goal is to have a total of 17,000 lumens in a round beam and 10,000 lumens in an oval beam out of the prototype fixture, so the actual lumens needed out of the LEDs after all the system efficiencies are take into account is shown below.

Actual Lumens Needed = Target Lumens / (optical efficiency * thermal efficiency)

Round beam
Actual Lumens Needed = 17,000 / (93%*88%) Actual Lumens Needed = 20,772 lm
Oval beam
Actual Lumens Needed = 10,000 / (93%*88%) Actual Lumens Needed = 12,219

The XM-L LED delivers industry-leading flux and efficay. Based on the initial data, we chose to work with the Cool White, highlighted in yellow in Table 9 below, to give the closest possible CCT to a metal-halide lamp. These LEDs, running at 1.5 to 2 A, deliver less total flux than a 400-W metal-halide lamp, but the directionality of the XM-L LED source, with a 125° beam spread, direct more flux toward the fixture opening than the spherical illuminance profile of the metal-halide lamp.

Group Code	Min. Luminous Flux @ 700 mA (lm)	Max. Luminous Flux @ 700 mA (lm)
S6	182	200
T2	200	220
T3	220	240
T4	240	260
T5	260	280
T6	280	300
U2	300	320

Table 9: Order codes from XM-L binning and labeling document

Basic XM-L LED electrical data and optical output from Cree's Product Characterization Tool (PCT)[15] is listed in Figure 12.

Current (A)	LED 1			
	Model	Cree XLamp XM-L {CW}		
	Flux	T6 [280]		280.0
	Price	$ -	Tj (ºC)	85
		LED Multiple		x1
	SYS # LED	SYS lm tot	SYS lm/W	SYS W
.700	76	17176	109.4	156.96
.750	71	17111	107.6	158.98
.800	67	17152	107.1	160.22
.850	63	17073	106.1	160.92
.900	60	17100	104.5	163.7
.950	57	17043	103.4	164.8
1.000	55	17215	102.1	168.59
1.100	50	17050	99.9	170.65
1.200	47	17296	97.9	176.76
1.300	44	17336	95.9	180.78
1.400	41	17179	94	182.72
1.500	39	17355	92.2	188.22
1.600	37	17353	90.5	191.84
1.700	35	17220	88.8	194.02
1.800	34	17510	87.1	201.04
1.900	32	17216	85.6	201.04
2.000	31	17329	84	206.22

Current (A)	LED 1			
	Model	Cree XLamp XM-L {CW}		
	Flux	T6 [280]		280.0
	Price	$ -	Tj (ºC)	85
		LED Multiple		x1
	SYS # LED	SYS lm tot	SYS lm/W	SYS W
0.700	73	17009	116.5	146
0.750	69	17181	114.8	149.62
0.800	65	17160	114	150.53
0.850	61	17019	112.8	150.89
0.900	58	17052	111.3	153.24
0.950	56	17304	110.4	156.8
1.000	53	17172	109.1	157.33
1.100	49	17248	106.5	161.96
1.200	45	17100	104.3	163.89
1.300	42	17094	102.3	167.12
1.400	40	17320	100.3	172.63
1.500	38	17442	98.2	177.6
1.600	36	17424	96.4	180.76
1.700	34	17272	94.6	182.53
1.800	32	17024	92.9	183.24
1.900	31	17205	91.2	188.61
2.000	30	17310	89.6	193.26

Figure 12: Cree's Product Characterization Tool with XLamp XM-L flux data
(left: with 92% optical efficiency and 90% driver efficiency, right: with no optical loss and 93% driver efficiency)

Depending on the drive current and the specific design goals to be achieved, the number of XM-L LEDs can vary greatly. The PCT data in Figure 13 above shows this. After some experimentation and basic calculations with the use of the PCT, we chose to drive 40 XLamp XM-L LEDs at 1.4 A for the no optic version. For the version with a wide-beam secondary optic we chose to drive 32 XM-L LEDs at 1.7 A, but as few as 31 and as many as 76 LEDs can be used. Both versions will be capable of meeting our 17,000 lumen output and less than 200 W power requirements. For the version with an oval-beam secondary optic, we chose to drive 24 XM-L LEDs at 1.4 A. This version will be capable of meeting our 10,000 lumen output and less than 200 W power requirements.

The purpose of this design exercise was to show that there are various ways to use XLamp XM-L LEDs achieve the light output required of an LED based high-bay luminaire. The number of LEDs in the design depends on critical design goals such as high efficiency and cost.

15 The analysis came from Cree's Product Characterization Tool. http://pct.cree.com/

Figure 13 shows a comparison photometric simulation using Dialux software. IES files for the high-bay simulation are available on the Cree website.[16]

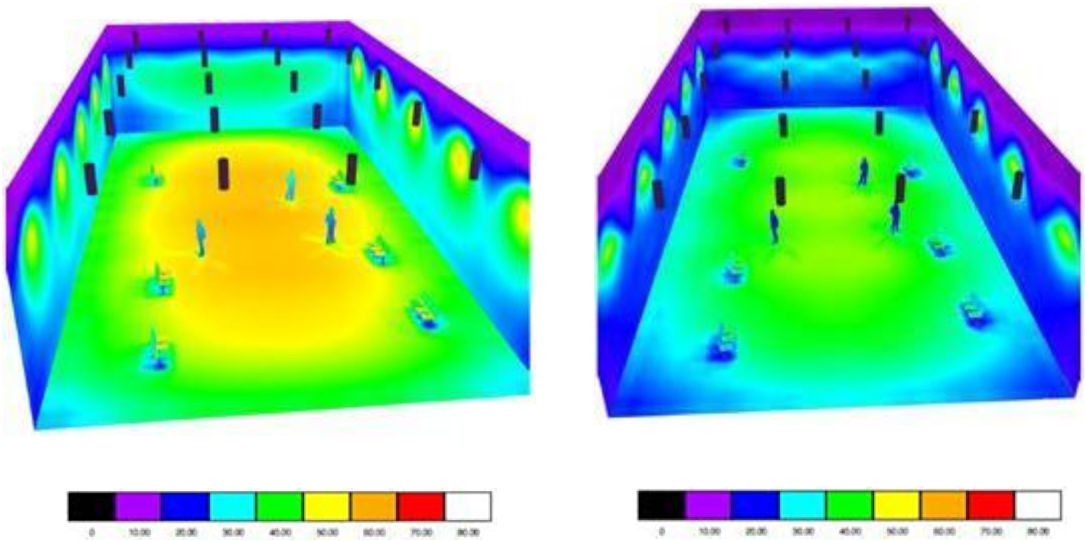

Figure 13: Photometric simulation (left 32-LED XM-L high-bay prototype, right: metal-halide)

5. CONSIDER ALL DESIGN POSSIBILITIES

The main decision for the design of an XM-L LED based high-bay luminaire is whether to design a retrofit lamp or design a fixture to replace a traditional bell-shaped fixture. Choosing to design a luminaire around the LEDs gives limitless possibilities. The luminaire can be lighter weight and smaller than a traditional fixture and can incorporate additional functions such as dimming and occupancy sensing.

For this design Cree chose to do the following.

- Maximize the coefficient of utilization.
- Use off-the-shelf optics.
- Design a heat sink that fits the design aesthetic and guarantees proper heat dissipation.
- Use an off-the-shelf driver for the simplest solution and a custom driver for a more efficient solution.
- Design a custom metal-core printed circuit board (MCPCB) that flexibly accommodates various numbers of LEDs placed on it.

6. COMPLETE THE FINAL STEPS: IMPLEMENTATION AND ANALYSIS

This section illustrates the techniques Cree used to create a prototype high-bay luminaire using the Cree XLamp XM-L LED and reviews the optical and electrical results.

16 http://www.cree.com/XLampModels/XLamp_ML_Highbay_IES.zip

Prototyping Details

The essence of this prototyping design is to assemble the XM-L LEDs onto a MCPCB, mount this PCB onto a heat sink and assemble these components with the necessary secondary optics and driver to create an LED-based luminaire comparable to existing 400-W metal-halide high-bay fixtures. The prototyping steps are detailed below.

1. MCPCB design

   a. The initial design of the PCB used an MTS rapid prototyping milling machine. This allowed the design to be adjusted before having the board made at a PCB company. Using the machine provided cost and time savings.

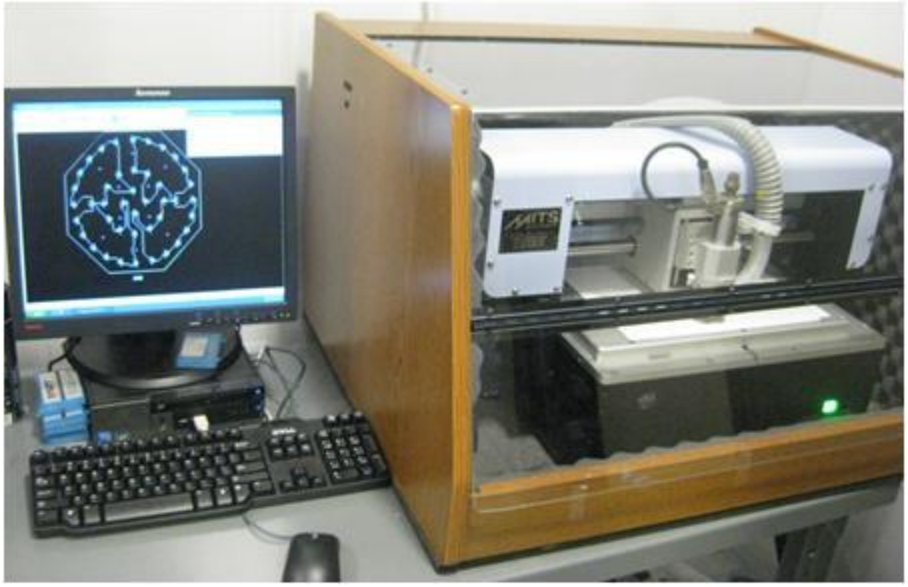

Figure 14: MTS rapid prototyping milling machine

   b. Once the PCB design was proven, it was drawn and compiled to Gerber files by Copper Wave, Inc.[17] and sent to Multilayer Prototypes, Inc.[18] for PCB fabrication. The result is shown in Figure 16 below. The Gerber files are available on the Cree website.[19]

17 Copper Wave, Inc. website: http://www.copperwavepcb.com/company.htm
18 Multilayer Prototypes, Inc. website: http://www.mpi-pcb.com/
19 http://www.cree.com/XLampModels/XLamp_ML_Highbay_MCPCB.zip

Figure 15: XM-L prototype high-bay PCB

2. Machining the heat-sink housing

   a. To prove the design of the heat-sink housing, a prototype was machined from the drawing and files used in the thermal simulations.

   b. The housing was machined and the mounting arm assembled by MCS Machine & Tool. The result is shown in Figure 16 below.

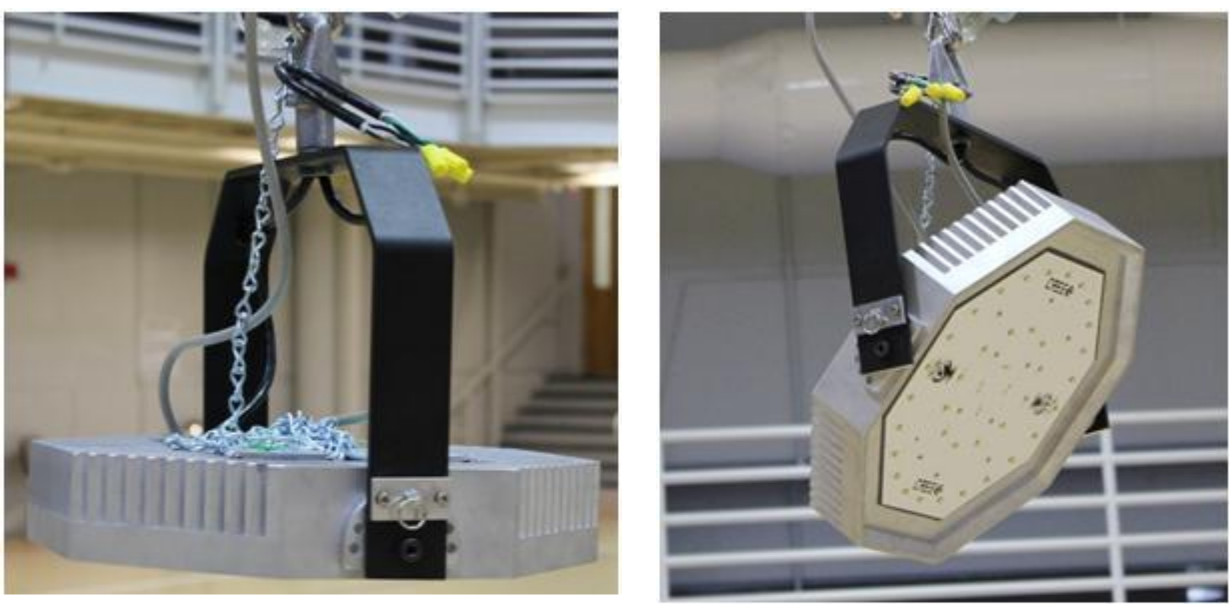

Figure 16: Machined housing

3. Assemble the drivers and PCB onto the housing

   a. The XM-L LEDs were soldered onto the PCB following Cree's Soldering and Handling Application Note for the XM-L LED.[20]
   b. The optic was attached to the PCB.
   c. The power supply was mounted to the back of the housing.
   d. The PCB was attached to the housing using screws with thermal grease between the back of the PCB and the housing.
   e. The PCB was connected to the power supply.


Figure 17: Assembled XM-L prototype high-bay luminaire

Results

Thermal Results

Thermal measurements were taken according to Cree's Soldering and Handling Application Note for the XM-L LED.[21]

As Figure 18 shows, data collected from the XM-L LEDs in the prototype high-bay luminaire driven at 1.7 A demonstrate thermal results and gradient in line with the thermal simulations.

20 Cree XLamp XM-L LED Soldering and Handling, Application Note AP54 http://www.cree.com/products/pdf/XLampXM_SolderingandHandling.pdf

21 Ibid.

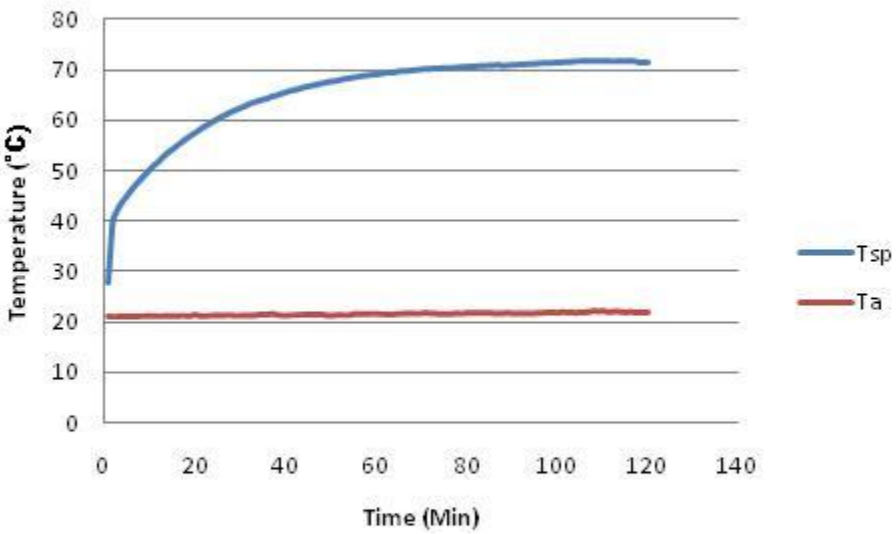

Figure 18: Thermal performance of 32-LED XLamp XM-L high-bay prototype driven at 1.7 A

Table 10 shows the solder point temperatures for the XM-L prototype high-bay luminaires.

Criteria	No Optic Result	Bubble Optic Result	Strada Optic Result
Tsp (°C)	65.8	71.6	62.5
Driver	NXP	Thomas Research	Meanwell
Optic	none	Carclo	Ledil
# LEDs	40	32	24

Table 10: Solder point temperature

Optical Results

Integrating sphere measurements[22] show photometric and chromaticity data that exceed the design goals.

Criteria	No Optic Result	Bubble Optic Result	Strada Optic Result
Radiant flux (W)	60.85	58.61	31.67
Total luminous flux (lm)	17,110	17,800	9844
Power factor	.998	.994	.563
Efficacy (lm/W)	108	92.9	98.2
Optical efficiency (%)	n/a	92	92
CCT (K)	6851	7060	6898
CRI (Ra)	69.7	70.4	69.3
Chromaticity (x-coord.)	0.3076	0.3052	0.3127
Chromaticity (y-coord.)	0.3222	0.3173	0.3266
Driver	NXP	Thomas Research	Meanwell
Optic	none	Carclo	Ledil
# LEDs	40	32	24

Table 11: Optical results

22 Measurements taken at Luminaire Testing Laboratory, Inc., website: http://www.luminairetesting.com/

Electrical testing[23] shows the XM-L prototype high-bay luminaire achieves an efficacy that greatly exceeds that of the comparison metal-halide fixtures.

Criteria	No Optic Result	Bubble Optic Result	Strada Optic Result
Power (W)	158	191.6	100.2
Power factor	.998	.994	.563
Efficacy (lm/W)	108	92.9	98.2
Driver	NXP	Thomas Research	Meanwell
Optic	none	Carclo	Ledil
# LEDs	40	32	24

Table 12: Electrical results

Goniometric measurements[24] show a consistent beam shape and light distribution for both XM-L prototype high-bay luminaires.

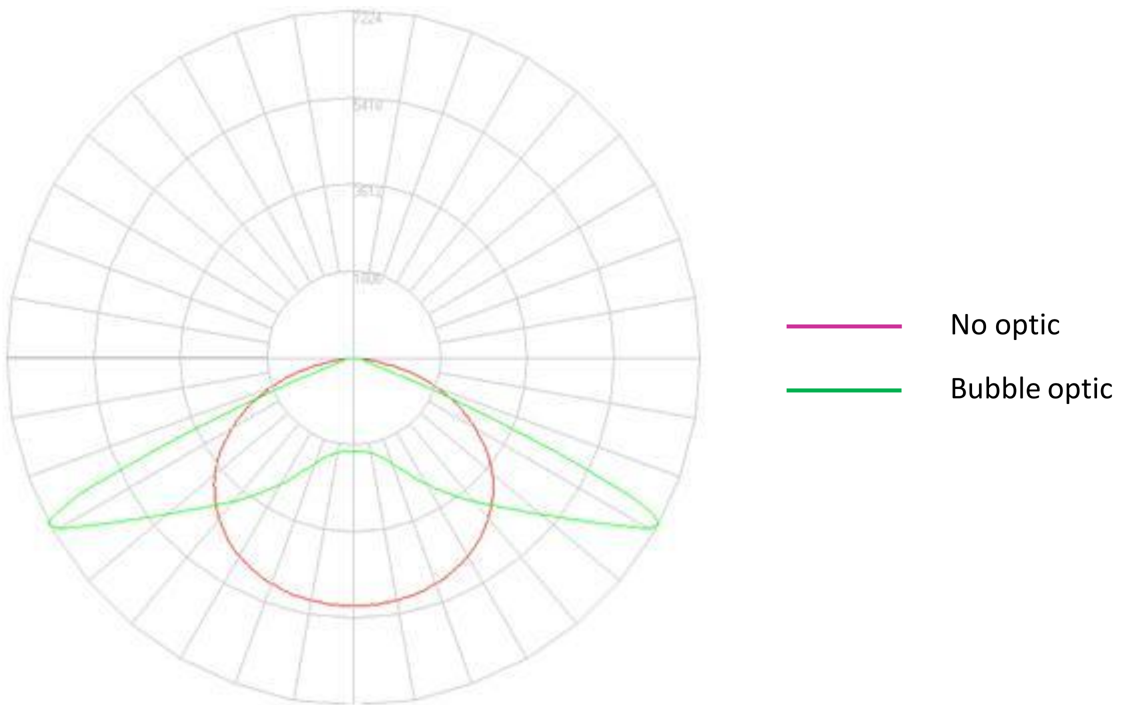

Figure 19: Goniometric intensity polar plot of XM-L prototype high-bay luminaire

The light intensity and distribution data[25] in Table 13 and Table 14 show the XM-L prototype high-bay luminaire effectively illuminates the area in which it is installed.

23 Ibid.
24 Ibid.
25 Ibid.

Mounting Height (ft/m)	Footcandles/Lux at Nadir		Diameter (ft/m)	
	Aluminum Reflector	Clear Prismativc	Aluminum Reflector	Clear Prismativc
6/1.8	167.1/1798.6	70.4/757.8	9.4/2.9	17.2/5.2
8/2.4	94.0/1011.8	39.6/426.3	12.5/3.81	22.9/7.0
10/3.0	60.2/648.0	25.4/273.4	15.7/4.8	28.7/8.7
12/3.7	41.8/450.0	17.6/189.4	18.8/5.7	34.4/11.4
14/4.3	30.7/330.45	12.9/138.9	21.9/6.7	40.1/12.2
16/4.9	23.5/253.0	9.9/106.6	25.17.7	45.8/14

Table 13: Metal halide light intensity and distribution

Mounting Height (ft/m)	Footcandles/Lux at Nadir			Diameter (ft/m)		
	No Optic	Bubble Optic	Strada Optic	No Optic	Bubble Optic	Strada Optic
4/1.12	323/3476.7	122/1313.2	62.9/677.0	5.5/1.7	12.7/3.9	11.9/3.6
6/1.8	143/1539.2	54.3/584.5	28.0/301.4	8.25/2.5	19.1/5.8	17.8/5.4
8/2.4	80.7/868.6	30.5/328.3	15.7/169.0	11/3.4	25.5/7.8	23.7/7.2
10/3.0	51.6/555.4	19.5/209.9	10.0/107.6	13.8/4.2	31.8/9.7	29.6/9.0
12/3.7	35.8/385.3	13.6/146.4	6.99/75.2	16.5/5.0	38.2/11.6	35.6/10.9
14/4.3	26.3/283.7	9.97/107.3	5.14/55.3	19.3/5.9	44.5/13.69	41.5/12.6
16/4.9	20.2/217.4	7.63/82.1	3.93/42.3	22/6.7	50.9/15.5	47.4/14.4

Table 14: XM-L high bay light intensity and distribution

Cost of Ownership

The cost of the XM-L LEDs, heat sink and driver in this prototype high-bay design met the $400 BOM target. A single HID metal-halide fixture typically retails for $180 – $250. Our BOM goal was not a primary factor for this design. Rather, high efficacy and effective light distribution were major considerations. This high-bay design is a prototype without any manufacturing or component optimizations. Initial fixture cost aside, the following calculations show the savings an XLamp XM-L LED high-bay luminaire can deliver.

For the cost of ownership calculations that follow:

- Assume that electricity costs $0.10 per kWh.
- The calculations don't include the initial or replacement costs of the fixtures or the labor costs to replace a metal-halide lamp.

Table 15 compares the cost of ownership of the comparison HID metal-halide fixtures to that of the XM-L prototype high-bay luminaires over the 50,000-hour lifetime of the XM-L LEDs. The metal-halide fixtures not only use significantly more energy but also require three metal-halide lamps.

High Bay Fixture	Lamp Wattage	Rated Lamp Lifetime	Replacement-Lamp Cost	Cost of Ownership
Metal halide	436	20,000 hrs	$11	$2207.50
XM-L no optic	158	50,000 hrs	-	$790.00
XM-L Bubble optic	191.6	50,000 hrs	-	$958.00
XM-L Strada Optic	100.2	50,000 hrs	-	$501.00

Table 15: Cost of ownership calculations

Table 16 shows the payback expected from the XM-L prototype high-bay luminaires as opposed to the comparison HID metal halide fixtures after 3 years of use in several situations.

Usage	Payback Total		
	XM-L No Optic	XM-L Bubble Optic	XM-L Strada Optic
24 hours/day	$741.58	$653.28	$893.48
12 hours/day	$376.29	$332.14	$452.24
8 hours/day	$243.53	$214.09	$294.16

Table 16: Payback after 3 years

CONCLUSIONS

This high-bay reference design demonstrates the integration of the Cree XLamp XM-L LED into a high-bay luminaire to replace a traditional high-bay fixture with great results. The design utilized proper heat sinking, optical control where needed, and multiple driver options to efficiently and effectively hit the design targets and outperform comparison metal-halide fixtures. Cree designed the heat sink and chose a driver to achieve a minimum L70 50,000-hr designation. This design shows the level of performance that can be achieved but should not be interpreted as the only way that a good high-bay luminaire can be designed.

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- Multilayer Prototypes, Inc.
- NXP Semiconductors
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