Cree® LMH2 LED Module Spot Accent Luminaire Reference Design

TABLE OF CONTENTS

INTRODUCTION

This application note details the design of a track accent and a recessed accent luminaire that incorporate a spot accent reflector with Cree's LMH2 LED module. The goal of the design is to enable multiple spot accent luminaires that utilize one light source and one reflector in both track and recessed applications. This design enables a luminaire that delivers performance equivalent to 250-watt incandescent sources. The LMH2 LED module's ease of use makes it an attractive option for lighting designers who may be reluctant to employ individual LED components.

Spot accent luminaires incorporating Cree LED modules offer numerous benefits when compared to traditional accent lighting sources including higher energy efficiency, better illumination and the ability to integrate with building control systems.

Cree's LED modules, with full-spectrum 90+ color rendering index (CRI), enable accent lighting with

Reliance on any of the information provided in this Application Note is at the user's sole risk. Cree and its affiliates make no warranties or representations about, nor assume any liability with respect to, the information in this document or any LED-based lamp or luminaire made in accordance with this reference design, including without limitation that the lamps or luminaires will not infringe the intellectual property rights of Cree or a third party. Luminaire manufacturers who base product designs in whole or part on any Cree Application Note or Reference Design are solely responsible for the compliance of their products with all applicable laws and industry requirements.

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

Cree, Inc.
4600 Silicon Drive
Durham, NC 27703
USA Tel: +1.919.407.5300

both excellent color rendering and very high efficacy. The economic advantages of dimming, instant-on and superior efficacy, along with industry-leading CRI, make using the Cree LMH2 LED module an attractive alternative to spot accent lamps currently on the market, including ceramic metal-halide (CMH), compact fluorescent (CFL) and incandescent lamps.[1]

Figure 1: Example spot accent applications

Another source of track accent luminaires is LED parabolic aluminized reflector (PAR) lamp replacements. Those currently available on the market underperform compared to standard halogen lamps and several misrepresent their halogen equivalency on data sheets and packaging. The US Department of Energy's (DOE) Commercially Available LED Product Evaluation and Reporting (CALiPER) testing program corroborates this, most recently with the CALIPER Round 14 tests.[2]

The design in this application note demonstrates how Cree's highly efficient, high lumen-output LMH2 LED module, when designed with the proper heat sink, optics and driver, can enable a true 250-W incandescent PAR lamp replacement that delivers superior product repeatability, efficacy and longevity.

DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide", Cree advocates a 6-step framework for creating LED luminaires and lamps.[3] The design guide's summary table is reproduced in Appendix B. This reference design adapts this framework to the design of an LED-module-based luminaire.

1 See Appendix A for specific advantages.
2 CALiPER Application Summary Report 14: LED Downlight Retrofit Units, March, 2012, apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_14_summary.pdf
3 LED Luminaire Design Guide, Application Note AP15, www.cree.com/xlamp_app_notes/luminaire_design_guide

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

THE METHODOLOGY

The major goal for this design is to create an easy-to-implement, high-efficacy LED-module-based luminaire capable of replacing traditional incandescent, CFL and CMH accent luminaires on the market. Cree framed the design as a luminaire replacement, so implementers can take full advantage of Cree's LMH2 LED modules and their superior performance.

1. DEFINE LIGHTING REQUIREMENTS

Table 1 shows performance characteristics for several existing light sources.[4] We used this information as our benchmark for this reference design.

Lamp	Watts (W)	System Watts (W)	Lumens (lm)	Efficacy (lm/W)	CBCP (cd)	Lifetime (hrs)	Beam Angle (°)	CBCP/W
Incandescent	45	45	530	11.8	2000	3000	22	44.4
	75	75	960	12.8	3800	3000	22	50.7
	90	90	1350	15.0	4500	3000	22	50.0
	250	250	3100	12.4	8138	4000	25.8	32.6
CFL PAR	23	23	1300	56.5	284	8000	138	23.7
LED PAR	14	14	1079	77	4757	35,000	23.6	339.8
CMH	35	45.8	3300	72.1	7126	12,000	28.8	155.6

Table 1: Incumbent performance characteristics

2. DEFINE DESIGN GOALS

Based on the standards body requirements and benchmark data[5], we set the design goals for this project, shown in Table 2. Stately simply, our goal was to create an LMH2-module-based luminaire with performance surpassing that of existing technologies.

Characteristic	Unit	Minimum Goal	Stretch Goal
Beam angle	degrees (°)	20-30	20-30
CCT	K	3000	2700-4000
CBCP - 25° beam angle	cd	6000	7500
CRI	100-point scale	80	90
Lifetime	hours	25,000	50,000
Luminaire efficacy	lm/W	> 70	> 85
Luminaire light output	lm	> 2400	> 2700
Maximum ambient temperature	°C	35	40
Power	W	≤ 50	< 30

Table 2: Spot accent luminaire design goals

To demonstrate the flexibility of the LMH2 module, this reference design shows its use in three spot accent applications, a track luminaire and two adjustable recessed luminaires, one for use in North America and one for use in Europe.

4 Performance data was gathered from readily available catalog information and photometry found on the internet.
5 See Appendix C for ENERGY STAR® requirements and Appendix D for DesignLights™ Consortium requirements.

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

Using the Cree LMH2 LED module as the basis for a spot accent luminaire allows a simple, straightforward development process.

- Select a lumen value

  Using the LMH2 LED module as the basis for the spot accent luminaire eliminates the need to determine which and how many individual LEDs to use to reach the desired light level and color temperature. Using the LMH2 LED module also eliminates the need to determine the arrangement of the LEDs on a printed circuit board (PCB) and the construction steps to connect the LEDs to each other and to the PCB. Rather, the only requirement is to determine the desired light level and color temperature. For example, Table 3 shows light output from several comparison CFL lamps and the LMH2 module that provides equivalent light output.

CFL Power (W) & Type	CFL Light Output (lm)	Light Output from Luminaire (lm)			Cree LMH2 Module (lm)	Module Power (W)
		Efficiency				
		55%	70%	90%		
13 Quad	900	495	630	585	850	10.0
18 Quad	1200	660	840	1125	1250	15.5
26 Quad	1800	990	1260	1125	1250	15.5
32 Trip	2400	1320	1680	1800	2000	25.5
42 Trip	3200	1760	2240	2700	3000	37.5
2026 (52) Quad	3600	1980	2520	2700	3000	37.5

Table 3: Example light output determination

  To show the maximum performance available from the LMH2 module, this reference design uses the 3000-lm flat lens model option of the LMH2 LED module. Other LMH2 model options offer 850, 1250 and 2000 lm. All LMH2 model are also available with a dome lens that provides a modified lambertian distribution.

- Select the optics

  As described in Appendix F, we collaborated with QRC Manufacturing, Inc.[6] to design a parabolic reflector for this reference design.

- Select a heat sink

  As shown in Appendix G, we selected the Cree-supplied heat sink[7] that is designed to work with the LMH2 LED module.

- Select a driver

  We shortened our development effort by selecting the Cree LMD300 driver[8] described in Appendix H.

6 www.qrcmfg.com
7 Cree part number LMH020-HS00-0000-0000001
8 Cree part number LMD300-0040-C900-7030000

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

- Create an enclosure for the luminaire.
  Appendix I describes how Cree produced simple housings for the prototype track and adjustable recessed luminaires in this reference design.

The reflector is the only component that was not designed and fabricated by Cree. The LMH2 module, driver and heat sink are currently available components. The housings and adaptor were designed and fabricated by Cree for this prototype reference design. Ideally, a luminaire manufacturer converting an existing luminaire to an LMH2-module-based luminaire could utilize the recessed housing from an existing incandescent, CFL or CMH luminaire line. This would require adapting the reflector, LMH2 module and LMD300 driver to the specific application.

3. COMPLETE THE FINAL STEPS

This section shows how to assemble the luminaires and shows the results of the design.

Prototyping Details

Track luminaire

The track luminaire includes the following components.

- LMH2 module
- Driver
- Heat sink
- Reflector
- Driver housing
- Reflector/LMH2 housing
- Track adaptor

Figure 2 shows how the LMH2 track luminaire was assembled.

Figure 2: LMH2 track luminaire assembly

Adjustable recessed luminaire

The adjustable recessed LMH2 module luminaire includes the following components.

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

- LMH2 module
- Driver
- Heat sink
- Reflector
- Recessed housing assembly

Figure 3 shows the assembled LMH2 adjustable recessed luminaires.

Figure 3: Cross-section view of assembled LMH2 adjustable recessed luminaires

Results

LMH2 LED Module Lifetime

As of this writing, Cree warrants that the LMH2 LED module will operate for five (5) years at the performance levels and conditions specified in the LMH2 LED module data sheet.[9]

Optical and Electrical Results

We obtained the results in Table 4 by testing the track accent luminaire in a 2-meter sphere after a 60-minute stabilization time.[10] As the table shows, the luminaire meets the project's design goals and exceeds the ENERGY STAR and DLC requirements. Because the adjustable recessed luminaire uses the same LMH2 module, driver and heat sink, Cree expects its performance to match that of the track accent luminaire.[11]

Characteristic	Unit	Minimum Goal	Stretch Goal	LMH2 Result
Beam angle	degrees (°)	20-30	20-30	25
CCT	K	3000	2700-4000	2700-4000
CBCP - 25° beam angle	cd	6000	7500	7596
CRI	100-point scale	80	90	> 90
Lifetime	hours	25,000	50,000	50,000
Luminaire efficacy	lm/W	> 70	> 85	73
Luminaire light output	lm	> 2400	> 2700	2498
Maximum ambient temperature	°C	35	40	35
Power	W	≤ 50	< 30	33.9

Table 4: LMH2 track accent luminaire results

Table 5 compares the LMH2 performance to the benchmark luminaires and shows that the LMH2 luminaire betters the performance of the benchmark luminaires while providing energy savings and increased longevity.

9 Select the Documentation tab at www.cree.com/modules/lmh2
10 Testing was performed at Cree's Durham Technology Center (NVLAP lab code 500070-0 per IES LM-79-08).
11 The IES file for this design is available by selecting the Documentation tab at www.cree.com/modules/lmh2

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

Lamp	Watts (W)	System Watts (W)	Lumens (lm)	Efficacy (lm/W)	CBCP (cd)	Lifetime (hours)	Beam Angle (°)	CBCP/W
LMH2	33.9	33.9	2498	73	7500	50,000	24.7	221.2
Incandescent	45	45	530	11.8	2000	3000	22	44.4
	75	75	960	12.8	3800	3000	22	50.7
	90	90	1350	15.0	4500	3000	22	50.0
	250	250	3100	12.4	8138	4000	25.8	32.6
CFL PAR	23	23	1300	56.5	284	8000	138	23.7
LED PAR	14	14	1079	77	4757	35,000	23.6	339.8
CMH	35	45.8	3300	72.1	7126	12,000	28.8	155.6

Table 5: Comparison of LMH2 module luminaire to incumbents

Figure 4 shows a polar plot of the LMH2 track accent luminaire and incumbent luminaires.

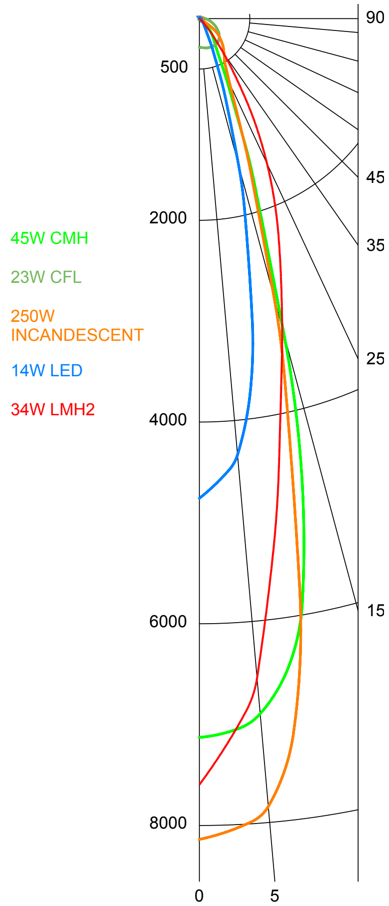


Figure 4: Polar plot of lumens in the 0-90° zone for LMH2 module luminaire and incumbents

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

Table 6 shows the illuminance of the LMH2 luminaire at various distances from the light source.

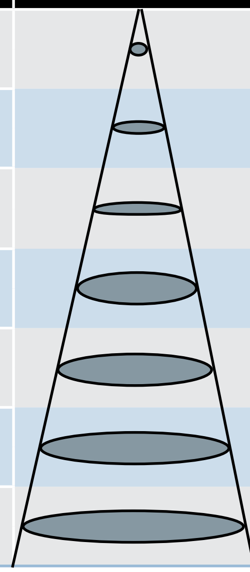
Height		Illuminance at a Distance					Beam Diameter	
		Illumination at Edge	Illumination at Center	Illumination at Edge	Illumination at Center			
0.3 m	1 ft	3,710 fc	7,596 fc	39,934 lx	81,763 lx		12.2 cm	0.4 ft
1.2 m	4 ft	232 fc	475 fc	2,497 lx	5,113 lx		53.3 cm	1.8 ft
2.1 m	7 ft	76 fc	155 fc	818 lx	1,668 lx		93.6 cm	3.1 ft
3.0 m	10 ft	37 fc	76 fc	398 lx	818 lx		133.8 cm	4.4 ft
4.0 m	13 ft	22 fc	45 fc	237 lx	484 lx		173.7 cm	5.7 ft
4.9 m	16 ft	14 fc	30 fc	151 lx	323 lx		214.0 cm	7.0 ft
5.8 m	19 ft	10 fc	21 fc	108 lx	226 lx		253.9 cm	8.3 ft

Table 6: LMH2 module luminaire illuminance – 25° beam angle

CONCLUSIONS

This reference design demonstrates the superior performance of two styles of Cree LMH2 LED-module-based spot accent luminaires. These luminaires can be used in spot accent applications that typically use non-LED-module light sources.

These luminaires use the 3000-lm flat lens model of the Cree LMH2 LED module. Other LMH2 models are available, with 850-, 1250- and 2000-lm light output. All LMH2 LED modules offer a wide range of CCTs (2700, 3000, 3500 and 4000K) and operate on 120, 220-240 and 277 V, so there is considerable flexibility in using an LMH2 LED module in a spot accent luminaire. Using the LMH2 LED module in conjunctions with the Cree-supplied heat sink and Cree LMD300 driver shortened the development process and provided assurance the components work well together. Regulatory approval of a luminaire using the Cree LMH2 LED module and LMD300 driver is enabled by such certifications as UL approval, CE conformity and RoHS compliance.[12]

With a CRI greater than 90, an LMH2-module-based luminaire maximizes the beauty of merchandise and its surroundings in such demanding markets as retail, museums, hospitality and restaurants. There is no infrared or ultraviolet radiation from an LMH2-module-based luminaire, so its light will not damage an illuminated product. With color-consistent dimming, i.e., there is no color shift when the luminaire is dimmed, an LMH2-module-based luminaire excels in applications where dimming is required. The overall performance of the Cree LMH2 LED module makes it an attractive design option for an LED-based spot accent luminaire.

12 See the Cree LMH2 LED Module Design Guide, DG04, for details. www.cree.com/modules_guides/lmh2

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

SPECIAL THANKS

Cree would like to acknowledge and thank QRC Manufacturing, Inc.[13] for collaborating in the successful prototyping of this luminaire.

13 www.qrcmfg.com

Reliance on any of the information provided in this Application Note is at the user's sole risk. Cree and its affiliates make no warranties or representations about, nor assume any liability with respect to, the information in this document or any LED-based lamp or luminaire made in accordance with this reference design, including without limitation that the lamps or luminaires will not infringe the intellectual property rights of Cree or a third party. Luminaire manufacturers who base product designs in whole or part on any Cree Application Note or Reference Design are solely responsible for the compliance of their products with all applicable laws and industry requirements.

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

APPENDIX A – LMH2 LED MODULE ADVANTAGES

An LMH2-module-based luminaire has multiple advantages over traditional metal-halide, fluorescent and incandescent light sources.

- Instant-on - no warm-up time to reach its color point and CRI
    - CMH luminaires require up to five minutes to reach their full lumen level when initially energized
    - CFL luminaires with amalgam technology require up to two minutes to stabilize color when initially energized
- Instant re-strike - no cool down needed before restarting
    - CMH luminaires require up to ten minutes to re-strike after a momentary power outage
- Class A sound-rated drivers - no humming or flickering
    - Core and coil drivers in CMH applications can cause unacceptable humming
- Environmentally safe - no mercury
    - CMH and CFL lamps contain mercury
- Longer lifetime – current L70(6k) is 50,000 hours
    - Up to 2 times longer life than CMH, up to 3 times longer life than CFL and up to 12 times longer life than incandescent luminaires
- Reduced maintenance cost - no re-lamping expense
    - CMH and CFL lamps range from 10 to 40 USD each to re-lamp
- Safe for customers and end users - no risk of lamp shattering at its end of life
    - CMH lamps can break during operation and release 1,000 °C glass shards
- Repeatedly dimmable and switchable - enabling the use of occupancy sensors for energy savings
    - Short on-cycle times can decrease CFL lifetime to < 2,000 hours
- Consistent color for its operating lifetime
    - CFL and CMH lamps drift to unacceptable correlated color temperature (CCT) and CRI levels, often before the lamp’s end of life

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

APPENDIX B – CREE 6-STEP FRAMEWORK

Cree's 6-step framework for creating LED luminaires and lamps is shown in Table 7.

Step	Explanation
1. Define lighting requirements	• The design goals can be based either on an existing fixture or on the application's lighting requirements.
2. Define design goals	• Specify design goals, which will be based on the application's lighting requirements. • Specify any other goals that will influence the design, such as special optical or environmental requirements.
3. Estimate efficiencies of the optical, thermal & electrical systems	• Design goals will place constraints on the optical, thermal and electrical systems. • Good estimations of efficiencies of each system can be made based on these constraints. • The combination of lighting goals and system efficiencies will drive the number of LEDs needed in the luminaire.
4. Calculate the number of LEDs needed	• Based on the design goals and estimated losses, the designer can calculate the number of LEDs to meet the design goals.
5. Consider all design possibilities and choose the best	• With any design, there are many ways to achieve the goals. • LED lighting is a new field; assumptions that work for conventional lighting sources may not apply.
6. Complete final steps	• Complete circuit board layout. • Test design choices by building a prototype luminaire. • Make sure the design achieves all the design goals. • Use the prototype to further refine the luminaire design. • Record observations and ideas for improvement.

Table 7: Cree 6-step framework

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

APPENDIX C – ENERGY STAR REQUIREMENTS

Table 8 and Table 9 summarize the ENERGY STAR requirements for luminaires.[1]

Luminaire Type	Luminaire Efficacy (Initial)	ENERGY STAR REQUIREMENTS	
		Luminaire Minimum Light Output (Initial)	**Luminaire Zonal Lumen Density Requirement**
Downlights: • recessed • surface • pendant • SSL downlight retrofits	42 lm/W	≤ 4.5″ aperture: 345 lumens > 4.5″ aperture: 575 lumens	Luminaire shall deliver a minimum of 75% of total initial lumens within the 0-60° zone (axially symmetric about the nadir)
Accent Lights • includes line voltage track heads • includes directional ceiling fan light kits	35 lm/W	Luminaire shall deliver a minimum of 200 lumens per head.	Luminaire shall deliver a minimum of 80% within the 0-40° zone (axially symmetric about the center of the beam).

Table 8: ENERGY STAR luminous efficacy, output and zonal lumen-density requirements

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

1 ENERGY STAR® Program Requirements, Product Specification for Luminaires (Light Fixtures), Eligibility Criteria, Version 1.1, www.energystar.gov/ia/partners/prod_development/new_specs/downloads/luminaires/Final_Luminaires_Program_Requirements.pdf

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

Characteristic	Requirements
Lumen maintenance requirements: directional and non-directional luminaires	Option 1 The LED package(s) / module(s) / array(s), including those incorporated into LED light engines or GU24 based integrated LED lamps, shall meet the following • L70(6k) rated lumen maintenance life values, in situ: • L70(6k) ≥ 25,000 hours for residential indoor • L70(6k) ≥ 35,000 hours for residential outdoor, or commercial Compliance with the above shall be documented with a TM-21 lumen maintenance life projection report as detailed in TM-21, section 7. The report shall be generated using data from the LM-80 test report for the employed LED package/module/array model ("device"), the forward drive current applied to each device, and the in situ TMP_{LED} temperature of the hottest LED in the luminaire. In addition to LM-80 reporting requirements, the following information shall be reported: • sampling method and sample size (per LM-80 section 4.3) • test results for each T_S and drive current combination • description of device including model number and whether device is an LED package, module or array (see Definitions) • ANSI target, and calculated CCT value(s) for each device in sample set • Δ u'v' chromaticity shift value on the CIE 1976 diagram for each device in sample set • a detailed rationale, with supporting data, for application of results to other devices (e.g. LED packages with other CCTs) Access to the TMP_{LED} for the hottest LED may be accomplished via a minimally sized hole in the luminaire housing, tightly resealed with a suitable sealant if created for purposes of testing. All thermocouple attachments and intrusions to luminaire housing shall be photographed. Option 2 Directional luminaires: using data collected at zero and 6,000 hours, the luminaire shall deliver at 6,000 hours the fraction of initial lumens specified below: Non-directional luminaires: using data collected at zero and 6,000 hours, each LED light engine or GU24 based integrated LED lamp shall deliver at 6,000 hours the fraction of initial lumens specified below: • indoor luminaires: ≥ 91.8% • outdoor luminaires: ≥ 94.1% • commercial luminaires: ≥ 94.1% These percentages are based on exponential decay functions for 25,000 hours and 35,000 hours to determine the 6,000 hour lumen maintenance necessary to achieve those rated lumen maintenance life values.
CCT requirements: all indoor luminaires	The luminaire (directional luminaires), or replaceable LED light engine or GU24 based integrated LED lamp (non-directional luminaires) shall have one of the following nominal CCTs: • 2700 Kelvin • 3000 Kelvin • 3500 Kelvin • 4000 Kelvin • 5000 Kelvin (commercial only) The luminaire, LED light engine or GU24 based integrated LED lamp shall also fall within the corresponding 7-step chromaticity quadrangles as defined in ANSI/NEMA/ANSLG C78.377-2008.
Color rendering requirements: all indoor luminaires	The luminaire (directional luminaires), or replaceable LED light engine or GU24 based integrated LED lamp (non-directional luminaires) shall meet or exceed Ra ≥ 80.
Color angular uniformity requirements: directional solid state indoor luminaires	Throughout the zonal lumen density angles detailed above, and five degrees beyond, the variation of chromaticity shall be within 0.004 from the weighted average point on the CIE 1976 (u',v') diagram.
Color maintenance requirements: solid state indoor luminaires only	The change of chromaticity over the first 6,000 hours of luminaire operation shall be within 0.007 on the CIE 1976 (u',v') diagram, as demonstrated by either: • the IES LM-80 test report for the employed LED package/array/module model, or • as demonstrated by a comparison of luminaire chromaticity data in LM-79 reports at zero and 6,000 hours, or • as demonstrated by a comparison of LED light engine or GU24 based integrated LED lamp chromaticity data in LM-82 reports at zero and 6,000 hours.
Source start time requirement: directional and non-directional luminaires	Light source shall remain continuously illuminated within one second of application of electrical power.
Source run-up time requirements: directional and non-directional luminaires	Light source shall reach 90% of stabilized lumen output within one minute of application of electrical power.

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

Characteristic	Requirements
Power factor requirements: directional and non-directional luminaires	Total luminaire input power less than or equal to 5 watts: PF ≥ 0.5 Total luminaire input power greater than 5 watts: Residential: PF ≥ 0.7 Commercial: PF ≥ 0.9
Transient protection requirements: all luminaires	Ballast or driver shall comply with ANSI/IEEE C62.41.1-2002 and ANSI/IEEE C62.41.2-2002, Class A operation. The line transient shall consist of seven strikes of a 100 kHz ring wave, 2.5 kV level, for both common mode and differential mode.
Off-state power consumption requirements: directional and non-directional luminaires	Luminaires incorporating an integral method of switching shall not draw power in the off state. Exception: Luminaires with integral motion sensors, photosensors or individually addressable luminaires with external control and intelligence shall consume no more than 1 watt in the off state. Exception: Power supplies connected to multiple luminaires may draw up to 1.5 watts in the off state. Exception: External power supplies (EPS) employed to power luminaires shall meet the level V performance requirements under the International Efficiency Marking Protocol and include the level V marking on the EPS.
Operating frequency requirements: directional and non-directional luminaires	Frequency ≥ 120 Hz Note: This performance characteristic addresses problems with visible flicker due to low frequency operation and applies to steady-state as well as dimmed operation. Dimming operation shall meet the requirement at all light output levels.
Noise requirements: directional and non-directional luminaires	All ballasts & drivers used within the luminaire shall have a Class A sound rating. Ballasts and drivers are recommended to be installed in the luminaire in such a way that in operation, the luminaire will not emit sound exceeding a measured level of 24 BA.
Electromagnetic and radio frequency interference requirements: directional and non-directional luminaires	Power supplies and/or drivers shall meet FCC requirements: • Class A for power supplies or drivers that are marketed for use in a commercial, industrial or business environment, exclusive of a device which is marketed for use by the general public or is intended to be used in the home. • Class B for power supplies or drivers that are marketed for use in a residential environment notwithstanding use in commercial, business and industrial environments.

Table 9: ENERGY STAR luminaire requirements

Table 10 summarizes the ENERGY STAR requirements for replacement PAR lamps.[2]

Criteria Item	ENERGY STAR Requirements
Definition	Directional lamp means a lamp having at least 80% light output within a solid angle of ∏ sr (corresponding to a cone with angle of 120°)
Minimum luminous efficacy	Lamp diameter < 20/8 inch: 40 lm/W Lamp diameter > 20/8 inch: 45 lm/W
Color spatial uniformity	The variation of chromaticity within the beam angle shall be within 0.006 from the weighted average point on the CIE 1976 (u’, v’) diagram.
Maximum lamp diameter	Not to exceed target lamp diameter
Maximum overall length (MOL)	Not to exceed MOL for target lamp
Minimum center beam intensity PAR and MR16 lamps	
PAR lamps	Link to online tool at www.energystar.gov/ia/products/lighting/iledl/IntLampCenterBeamTool.zip
Lumen maintenance	> 70% lumen maintenance (L_{70}) at 25,000 hours of operation
Rapid-cycle stress test	Cycle times must be 2 minutes on, 2 minutes off. Lamp will be cycled once for every 2 hours of L_{70} life.

Table 10: ENERGY STAR requirements for PAR lamps

2 ENERGY STAR® Program Requirements for Integral LED Lamps Eligibility Criteria – Version 1.4, Table 7C, www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

As shown in Figure 5, we used the ENERGY STAR Center Beam Intensity Benchmark Tool[3] to determine that a 250-W equivalent PAR38 lamp with a 25° beam angle needs to provide CBCP of 7,892 cd.

ENERGY STAR® Integral LED Lamp Center Beam Intensity Benchmark Tool

PAR Lamps

Target Incandescent/Halogen Lamp Parameters

Enter PAR type/value:	38	lamp diameter in ⅛ of inch
Enter Nominal Lamp Wattage:	250	watts
Enter Nominal Beam Angle*:	25	degrees
Minimum Center Beam Intensity:	7892	cd

Term	Coefficient	PAR Type	Nominal Wattage	Beam Angle		Predicted Log CBCP	Log CBCP Two-sigma Lower Bound		Predicted CBCP	CBCP Two-sigma Lower Bound
Intercept	5.5102112	38	250	25		9.276	8.974		10678	7892
PAR	0.1395448									
Watts	0.0448725									
Beam Angle	-0.088493									
PAR*Watts	-0.000521									
PAR*Beam Angle	-0.000719									
PAR^2	-0.001192									
$Watts^2$	-0.00005981									
Beam $Angle^2$	0.0008786									
Root Mean Square Error	0.151113									

Figure 5: ENERGY STAR Center Beam Intensity Benchmark Tool output for 250-W equivalent PAR38 lamp with 25° beam angle

3 www.energystar.gov/ia/products/lighting/iledl/IntLampCenterBeamTool.zip

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

APPENDIX D – DESIGNLIGHTS CONSORTIUM REQUIREMENTS

The DesignLights Consortium provides requirements for track or mono-point directional lighting fixtures, summarized in Table 11.[1]

Characteristic	Unit	Value
Minimum light output	lm	250
Zonal lumen density		85%: 0°-90°
Minimum luminaire efficacy	lm/W	40
Allowable CCTs (ANSI C78.377-2008)	K	$\leq$ 5000
Minimum CRI		80
L70 lumen maintenance	hours	50,000
Minimum luminaire warranty	years	5

Table 11: DLC track lighting requirements

APPENDIX E – BENCHMARK PERFORMANCE DATA

Table 12 shows a ranked list of desirable characteristics to address in a spot accent luminaire design.

Importance	Characteristics	Metric
Critical	Illuminance distribution	footcandles (fc) / lux (lx)
	Electrical power	watts (W)
	Payback	months
	Luminous flux	lumens (lm)
	Light intensity - center beam candle power (CBCP)	candelas (cd)
	Beam angle - full width half maximum (FWHM)	degrees (°)
	Form factor	
Important	Operating temperatures	°C
	Operating humidity	% relative humidity
	Correlated color temperature (CCT)	K
	CRI	100-point scale
	Ease of installation	
	Price	$
	Efficacy	lumens per watt (lm/W)
	Lifetime	hours
	Manufacturability	

Table 12: Ranked design criteria for spot accent luminaire

1 Technical Requirements Table v1.7, DesignLights Consortium Qualified Products List - Non-Residential Applications, www.designlights.org/solidstate.manufacturer.requirements.php

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

APPENDIX F – ESTIMATE EFFICIENCIES OF THE OPTICAL, THERMAL & ELECTRICAL SYSTEMS

Many factors affect the quantity and quality of light that a luminaire produces. The three factors of greatest impact here are thermal, optical and electrical losses. Thermal losses occur when LEDs are operated in their upper acceptable temperature range. Thermal losses can be minimized or greatly reduced by lowering the LEDs' operating temperature. Optical losses occur as light interacts with and is absorbed by the reflector and refractor components of the luminaire. Highly reflective surfaces and optically clear materials minimize this impact, however reflector and refractor cost may not justify the expense. Electrical losses are determined by the LED driver's ability to efficiently convert the AC supply to DC. This added load is included in the efficacy calculation.

Optical Requirements

Because current Illuminating Engineering Society of North America (IESNA) testing standards do not allow testing for luminaire efficiency, our benchmark optical characteristic is the industry standard, efficacy, measured in lumens per watt.

Secondary Optics

Reshaping the lambertian distribution of the Cree LMH2 module requires a reflector. Although many reflector shapes are available that offer valid solutions, this design uses a parabolic reflector. Cree created these prototype luminaires using tooling and optical designs from QRC Manufacturing, Inc.[1] Aesthetics, tooling costs and payback are the ultimate factors in deciding on the reflector technology and reflector shape a luminaire manufacturer uses.

The TrueWhite™ technology in the LMH2 LED module uses a patented mixture of unsaturated yellow and saturated red LEDs to produce white light. This extremely efficient combination requires attention to the separation of light color. A simple parabolic shape gathers and concentrates light from any of the individual sources in the module. This can cause red and/or yellow hues to be visible on a white surface.

There are several ways to mix the individual wavelengths of light and reduce separation. Diffusing the surface of the reflector, adding additional diffusion to the emitting surface of the LMH2 LED module and adding facets to the reflector are options. The addition of facets allows for the highest efficiency reflector and helps to meet the goal of this reference design to minimize optical losses. The shape developed is very similar to Figure 6.

1 www.qrcmfg.com

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

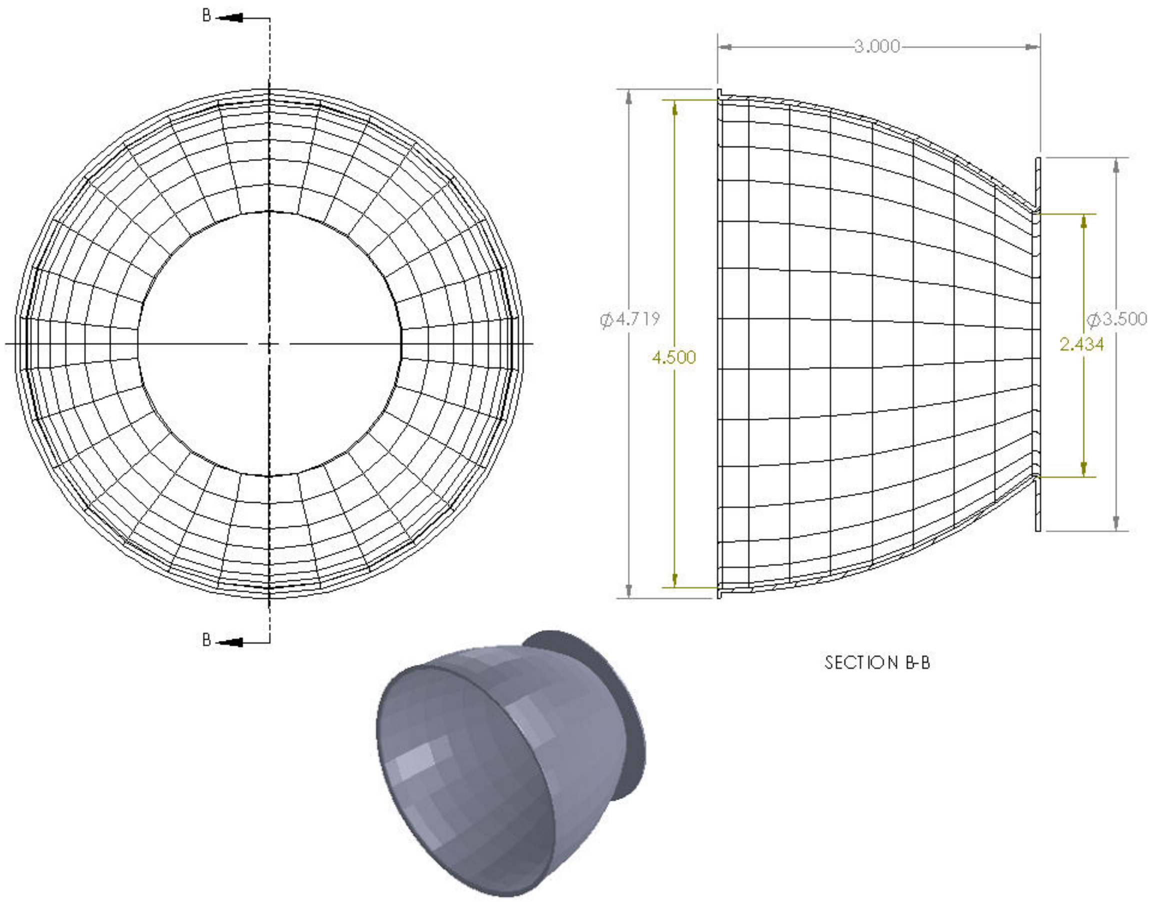


Figure 6: Faceted reflector

Some of the materials that can be utilized for the reflector include, but are not limited to, acrylic, vacuum-metalized acrylic or polycarbonate, polished aluminum and diffuse aluminum. For this reference design, the size of the reflector makes an acrylic version difficult to mold, diffused aluminum is inefficient and tooling for a plastic part is cost prohibitive. Injection molding holds a specific advantage over aluminum spinning and could be considered under the appropriate economic conditions. For this reference design we used polished aluminum and a spinning operation to make the reflector for this low-volume production.

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

APPENDIX G – THERMAL REQUIREMENTS

The LMH2 LED module operates at up to 38 watts, depending on the module specified. A thermal path is required to dissipate this thermal energy. About 25% of the input power is converted to radiant flux and the remainder is converted to heat. At the maximum wattage, the module produces approximately 28 watts of heat. To allow the heat sink to be used with all LMH2 models, we treated this maximum value as a design requirement.

The heat sink has two functions in the track luminaire: primarily to dissipate heat, secondarily to add an aesthetic feature to the design. In the adjustable recessed luminaire, the heat sink serves only to dissipate heat. To minimize tooling expense, we used the same heat sink in both applications.

LMH2 modules operate at power levels between 10 and 38 watts. Ultimately the in-situ conditions of the luminaire determine whether a heat sink is required. The Cree LMH2 heat sink is effective in most situations and we used it for this reference design. The heat sink is a forged design and has a 30-W capacity.

A STEP file for the heat sink is available on the Cree website.[1] Figure 7 shows the Cree LMH2 heat sink and conceptual renderings of other, unrealized variations.

Cree-supplied heat sink

Conceptual heat sink variations

Figure 7: Heat sink

1 Select the Documentation tab at www.cree.com/modules/lmh2.

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

APPENDIX H – DRIVER

There are many excellent suppliers of LED control electronics and many ways to deliver controlled DC power to the Cree LMH2 LED module. To shorten the development time for this reference design and because its performance is well known to us, we chose to utilize the Cree LMD300 driver, shown in Figure 8. This driver features 0/1 - 10-V dimming and operates at 120 - 277 V with a power factor of 0.98.

Figure 8: Cree-supplied LMD300 driver

APPENDIX I – DRIVER HOUSING

Track luminaire

In a track luminaire, the driver housing must be adjacent to the light source and be attractive. In this reference design, a simple sheet metal box houses the driver next to the light source of the track luminaire. The dimensions of the box (approximately 5⅝ in x 3¾ in x 1¾ in) allow all but one of the available Cree drivers to be used, enabling the track luminaire's use in North America, Europe and Asia.[1]

In a production track luminaire, the driver housing would likely use an extrusion with stamped end plates and be sized so it accommodates one driver model and the required mechanical connecting components.

The track adaptor must fit the specific track in which the luminaire is to be installed.

Adjustable recessed luminaire

The housing of the adjustable recessed luminaire is dimensioned so that the housing does not impede adjustment of the luminaire.

1 The Cree LMD300 220- to 240-V drivers require a larger driver housing.

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.

APPENDIX J – THERMAL RESULTS

For reference, module bench rise temperatures when the Cree heat sink is attached to the LMH2 module are shown in Table 13.

LMH2 Module	Input Power	Temperature
850 lm	10.5 W	39.9 °C
1250 lm	15 W	44.4 °C
2000 lm	28 W	56.8 °C
3000 lm	37.5 W	69.5 °C

Table 13: Module bench rise temperature after thermal stabilization in 25 °C environment

Figure 9 shows an image of the LMH2 module and heat sink taken with an infrared (IR) camera. Thermal analysis of the Cree heat sink shows that the LMH2 module's L70 lifetime described in the LMH2 design guide is delivered in a 25 °C ambient temperature environment.[1] Operation in an elevated ambient environment requires a heat sink other than the component available from Cree.

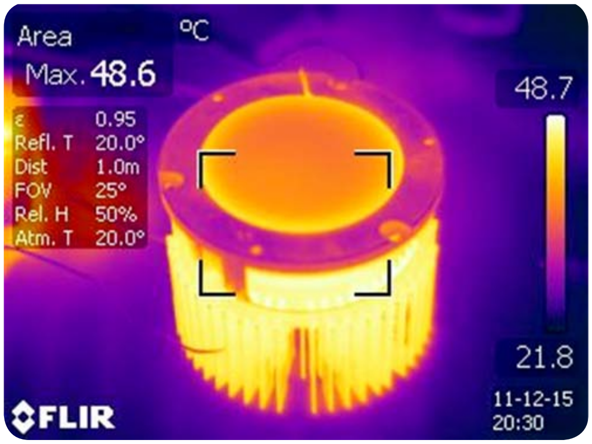


Figure 9: IR image of LMH2 module and heat sink

1 Cree LMH2 LED Module Design Guide, DG4, www.cree.com/modules_guides/lmh2

Copyright © 2012 Cree, Inc. All rights reserved. The information in this document is subject to change without notice. Cree®, the Cree logo and TrueWhite® are registered trademarks and Cree TrueWhite™ is a trademark of Cree, Inc. For product specifications, please see the data sheets available at www.cree.com. For warranty information, please contact Cree Sales at sales@cree.com.