

Cree® XLamp® MT-G LED AR111 Reference Design



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INTRODUCTION

This application note details the design of an AR111 lamp using Cree’s XLamp MT-G EasyWhite LED. The goal of the design is an LED-based AR111 replacement retrofit lamp that delivers performance comparable to a 50- to 75-watt halogen AR111 with much lower power consumption and a significantly longer lifetime.

As of late 2011, LED AR111 replacements currently available on the market significantly underperform when compared to standard halogen lamps and many misrepresent their halogen equivalency on their data sheets and packaging. The Department of Energy (DOE) Commercially Available Light-Emitting Diode Product Evaluation and Reporting (CALiPER) testing program verified these facts with their testing in Round 11 of their summary reports.¹

This reference design shows that a highly efficient, high lumen output multi-die LED array such as the XLamp MT-G, when designed with the proper heat sink, optic, and driver, can enable a true 50- to 75-watt AR111 lamp replacement, delivering superior product repeatability,

¹ apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_round-11_summary.pdf

efficacy and longevity. Using a single LED component reduces the component cost and increases the ease of assembly as well as providing a single point-source of illumination.

In this design, our team set out to create a lamp with true 50,000 hour L70 longevity, created through a low-power, high-efficacy application of the LED. Cree created these AR111 prototypes using a custom heat sink design and collaborated with multiple industry-leading driver and optic partners to create an integrated, optimized system with multiple combinations of components to function with the MT-G LED. This reference design shows only a few possible implementations of an AR111 lamp with the MT-G LED and is meant to demonstrate the increasing value of multi-disciplinary design to bring segment-leading products to market.

DESIGN APPROACH/OBJECTIVES

In the “LED Luminaire Design Guide”² 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	<ul style="list-style-type: none"> The design goals can be based either on an existing fixture or on the application’s lighting requirements.
2. Define design goals	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> 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 demonstrate an easy-to-implement, high-efficiency lamp that could replace the current halogen AR111 lamps on the market, showing that a true 50- to 75-watt equivalent AR111 LED lamp is possible at a reasonable cost.³ Cree framed the project as a retrofit, so the AR111 lamp designed in this application note could take advantage of the installed base of track lighting and fixtures.

2 LED Luminaire Design Guide, Application Note AP15, www.cree.com/products/pdf/LED_Luminaire_Design_Guide.pdf
 3 Production and cost-optimized implementations are beyond the scope of this document.

1. DEFINE LIGHTING REQUIREMENTS

Table 2 lists important characteristics to consider for the design of the AR111 lamp in this reference design.

Importance	Characteristics	Units
Critical	Light intensity - center beam candle power (CBCP)	candelas (cd)
	Beam angle - full width half maximum (FWHM)	°
	Electrical power	watts (W)
	Luminous flux	lumens (lm)
	Form factor	
Important	Price	\$
	Lifetime (L70)	hours
	Operating temperatures	°C
	Operating humidity	% RH
	Correlated color temperature (CCT)	K
	Color rendering index (CRI)	100-point scale
	Lamp-to-lamp consistency	
	Driver power factor	
	Manufacturability	

Table 2: Important characteristics of target AR111 lamp

Table 3 shows baseline performance data for several comparison halogen AR111 lamps. The table shows data specified on the product data sheets and measured from the lamps.⁴ The data show some dramatic differences in specified and measured performance in at least one characteristic of all the lamps. An n/a in the table denotes a value that is not specified in a lamp’s data sheet.

⁴ Measurements were taken at the Cree facilities in Durham, NC.

Characteristic	Unit	Source					
		Lamp A	Lamp B	Lamp C	Lamp D	Lamp E	Lamp F
Power (specified)	W	50	50	75	75	100	100
Power (measured)	W	48.5	47.7	75.1	75	99.6	99.8
Beam angle (specified)	°	24	25	24	25	25	25
Beam angle (measured)	°	16	22	19	23	18	14
Luminous flux (specified)	lm	950	n/a	1575	n/a	n/a	n/a
Luminous flux (measured)	lm	540	293	799	779	1123	1349
Efficacy (specified)	lm/W	19	n/a	21	n/a	n/a	n/a
Efficacy (measured)	lm/W	10.8	6.1	10.6	10.4	11.3	13.5
CBCP (specified)	cd	4000	3500	5300	5300	8500	8500
CBCP (measured)	cd	4313	1974	5709	4249	9253	13,169
CCT (specified)	K	3000	3000	3000	3000	3000	3000
CCT (measured)	K	2797	2776	2780	2802	2804	2863
CRI (specified)		n/a	n/a	n/a	n/a	n/a	n/a
CRI (measured)		99	100	100	99	99	99
Lifetime (specified)	hours	3000	3000	3000	3000	3000	3000

Table 3: Specified and measured baseline data

Although AR111 lamps are typically used in Europe and Asia, we used ENERGY STAR® requirements to assist in setting the design goals for this effort. Table 4 summarizes the ENERGY STAR® requirements for all integral LED lamps.⁵

Characteristic	Requirements															
CCT and Duv	Lamp must have one of the following designated CCTs per ANSI/NEMA/ANSI C78.377-2008 consistent with the 7-step chromaticity quadrangles and Duv tolerances listed below.															
	<table border="1"> <thead> <tr> <th>Nominal CCT</th> <th>Target CCT (K) and Tolerance</th> <th>Target Duv and Tolerance</th> </tr> </thead> <tbody> <tr> <td>2700 K</td> <td>2725 ± 145</td> <td>0.000 ± 0.006</td> </tr> <tr> <td>3000 K</td> <td>3045 ± 175</td> <td>0.000 ± 0.006</td> </tr> <tr> <td>3500 K</td> <td>3465 ± 245</td> <td>0.000 ± 0.006</td> </tr> <tr> <td>4000 K</td> <td>3985 ± 275</td> <td>0.001 ± 0.006</td> </tr> </tbody> </table>	Nominal CCT	Target CCT (K) and Tolerance	Target Duv and Tolerance	2700 K	2725 ± 145	0.000 ± 0.006	3000 K	3045 ± 175	0.000 ± 0.006	3500 K	3465 ± 245	0.000 ± 0.006	4000 K	3985 ± 275	0.001 ± 0.006
	Nominal CCT	Target CCT (K) and Tolerance	Target Duv and Tolerance													
	2700 K	2725 ± 145	0.000 ± 0.006													
	3000 K	3045 ± 175	0.000 ± 0.006													
3500 K	3465 ± 245	0.000 ± 0.006														
4000 K	3985 ± 275	0.001 ± 0.006														
Color maintenance	The change in chromaticity over the minimum lumen test period (6000 hours) shall be within 0.007 on the CIE (u', v') diagram.															
CRI	Minimum CRI (Ra) of 80. In addition, the R9 value must be greater than 0.															
Dimming	Lamps may be dimmable or non-dimmable. Product packaging must clearly indicate whether the lamp is dimmable or not dimmable. Manufacturers qualifying dimmable products must maintain a web page providing dimmer compatibility information. Minimum efficacy, light output, CCT, CRI and power factor of dimmable lamps will be confirmed with the lamp operated at full power.															
Warranty	A warranty must be provided for lamps, covering material repair or replacement for a minimum of three (3) years from the date of purchase.															
Allowable lamp bases	Must be a lamp base listed by ANSI.															
Power factor	For lamp power < 5 W and for low-voltage lamps, no minimum power factor is required. For lamp power > 5 W, power factor must be > 0.70. Note: Power factor must be measured at rated voltage.															
Minimum operating temperature	Integral lamp shall have a minimum operating temperature of 20 °C or below.															

⁵ ENERGY STAR® Program Requirements for Integral LED Lamps Eligibility Criteria – Version 1.4, Table 4 www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf

Characteristic	Requirements
LED 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.
Operating voltage	Lamp shall operate at rated nominal voltage of 120, 240 or 277 VAC or at 12 or 24 VAC or VDC.
Safety requirements	Integral LED lamps must meet the requirements of ANSI/UL 1993 – 2009

Table 4: ENERGY STAR requirements for integral LED lamps

Table 5 summarizes the ENERGY STAR requirements for non-standard lamps.⁶

Characteristic	Requirement
Minimum luminous efficacy	LED lamp power < 10 W: 50 lm/W LED lamp power > 10 W: 55 lm/W
Minimum light output	200 lumens
Luminous intensity distribution	No specific distribution is required. Must submit goniophotometry report showing luminous intensity distribution produced by the lamp.
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 L70 life.

Table 5: ENERGY STAR requirements for non-standard lamps

2. DEFINE DESIGN GOALS

Table 6 shows the design goals for this project.

Characteristic	Unit	Minimum Goal	Target Goal
Light output	lm	1000	1200
Illuminance profile		Identical to halogen	Better than halogen
LED power	W	<< 75	< 18
Beam angle	°	25-40	25-40
CBCP : 26° beam	cd	4000	> 5300
Lifetime	hours	25,000	50,000
CCT	K	3000	3000
CRI		80	85

Table 6: Design goals

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

Component Efficiency

The MT-G LED has a variety of efficacies depending on color temperature, bin and drive conditions. Based on data in the MT-G data sheet,⁷ Cree chose to work with the MTGEZW-00-0000-0N00H030F order code to give the closest possible CCT equivalent to a halogen lamp and the highest efficiency. We also chose to work with the MTGEZW-00-0000-0N00K050F order code to demonstrate a cool white (5000 K CCT) AR111 lamp. Both are highlighted in yellow in Figure 1

⁶ Ibid., Table 6

⁷ www.cree.com/products/pdf/XLampMTG-EZW.pdf

below. These components, when attached to a proper heat sink, fit with an appropriate secondary optic and driven under the correct conditions, will deliver sufficient CBCP to be considered a 50- to 75-W equivalent AR111 lamp.

Color	CCT Range	Base Order Codes Min. Luminous Flux (lm) (T _j =85 °C)		2-Step Order Code		4-Step Order Code	
		Group	Flux (lm)	Chromaticity Region		Chromaticity Region	
Standard CRI EasyWhite	5,000 K	H0	560	50H	MTGEZW-00-0000-0N00H050H	50F	MTGEZW-00-0000-0N00H050F
		J0	600		MTGEZW-00-0000-0N00J050H		MTGEZW-00-0000-0N00J050F
		K0	650		MTGEZW-00-0000-0N00K050H		MTGEZW-00-0000-0N00K050F
	4,000 K	G0	520	40H	MTGEZW-00-0000-0N00G040H	40F	MTGEZW-00-0000-0N00G040F
		H0	560		MTGEZW-00-0000-0N00H040H		MTGEZW-00-0000-0N00H040F
		J0	600		MTGEZW-00-0000-0N00J040H		MTGEZW-00-0000-0N00J040F
	3,500 K	F0	480	35H	MTGEZW-00-0000-0N00F035H	35F	MTGEZW-00-0000-0N00F035F
		G0	520		MTGEZW-00-0000-0N00G035H		MTGEZW-00-0000-0N00G035F
		H0	560		MTGEZW-00-0000-0N00H035H		MTGEZW-00-0000-0N00H035F
	3,000 K	F0	480	30H	MTGEZW-00-0000-0N00F030H	30F	MTGEZW-00-0000-0N00F030F
		G0	520		MTGEZW-00-0000-0N00G030H		MTGEZW-00-0000-0N00G030F
		H0	560		MTGEZW-00-0000-0N00H030H		MTGEZW-00-0000-0N00H030F
	2,700 K	E0	440	27H	MTGEZW-00-0000-0N00E027H	27F	MTGEZW-00-0000-0N00E027F
		F0	480		MTGEZW-00-0000-0N00F027H		MTGEZW-00-0000-0N00F027F
		G0	520		MTGEZW-00-0000-0N00G027H		MTGEZW-00-0000-0N00G027F

Figure 1: MT-G order codes

Basic electrical data and optical output from Cree’s Product Characterization Tool (PCT) is shown in Figure 2.⁸ The lumen target is 1200 and optical and electrical efficiencies were estimated to be 90%.

⁸ The analysis came from Cree’s Product Characterization Tool. pct.cree.com

Current (A)	LED 1				LED 2			
	Model	Cree XLamp MT-G 36V {EZW}			Model	Cree XLamp MT-G 36V {EZW}		
	Flux	H0 [560]	Tsp (°C)	63	Flux	K0 [650]	Tsp (°C)	63
	Price	\$ -			Price	\$ -		
	LED lm	LED lm/W	LED Vf	LED W	LED lm	LED lm/W	LED Vf	LED W
0.100	332.8	100.9	33.04	3.3	386.3	117.1	33.04	3.3
0.150	482.9	95.8	33.6	5.04	560.5	111.2	33.6	5.04
0.200	623	91.3	34.11	6.82	723.1	106	34.11	6.82
0.250	752.7	87.1	34.55	8.64	873.7	101.1	34.55	8.64
0.300	872.6	83.3	34.95	10.48	1012.9	96.6	34.95	10.48
0.350	982.8	79.6	35.29	12.35	1140.8	92.4	35.29	12.35
0.400	1083.4	76.1	35.58	14.23	1257.6	88.4	35.58	14.23
0.450	1174.4	72.9	35.81	16.12	1363.1	84.6	35.81	16.12
0.500	1256.1	69.8	35.99	18	1458	81	35.99	18
0.550	1328.7	66.9	36.12	19.87	1542.2	77.6	36.12	19.87
0.600	1392.7	64.1	36.2	21.72	1616.5	74.4	36.2	21.72
0.650	1447.6	61.5	36.22	23.54	1680.3	71.4	36.22	23.54
0.700	1494.3	59	36.19	25.33	1734.5	68.5	36.19	25.33

Figure 2: Cree’s PCT with XLamp MT-G minimum flux data

After some basic calculations and use of the PCT, we determined to drive the 36-V MT-G at 0.5 A to generate the sufficient system luminous output and efficacy, highlighted in yellow in Figure 2. The choice was constrained by our desire to use less than 18 W of LED power while delivering more than the minimum required CBCP.

Thermal Requirements

The XLamp MT-G LED operates at approximately 18 W of power when running at the designated 0.5 A input current and requires a heat sink to dissipate this thermal load. In an LED-based AR111 design, the heat sink must not only dissipate the heat generated by the LED, but also provide the mechanical frame for the LED, optic, driver, and base. Additionally, to be considered an AR111 retrofit, the overall footprint must fit into an AR111 envelope of less than or equal to 111 mm in diameter and about 60 mm tall. Cree worked with Tai Sun Electric Limited to create a custom heat sink for this reference design, shown in Figure 3.⁹ We measured a thermal resistance of 2.0 °C/W heat sink to ambient (θ_{hs-a}) for the heat sink.

⁹ www.hztaisun.com, Part number Cree_MTG_refdesign_AR111_1



Figure 3: Tai Sun AR111 heat sink

We performed thermal simulations to verify heat sink performance.¹⁰ The simulation results in Figure 4 and Figure 5 show images of the assembly and a cross section of the heat sink running at 18 W input power to the LED as well as a small amount of heat generated by the driver, in a 25 °C ambient environment. The peak solder point temperature (T_{sp}) computed by the software was 64 °C, or 39 °C above ambient. The thermal resistance of the MT-G LED is 1.5 °C/W, so the junction temperature (T_j) was calculated to be 91 °C.

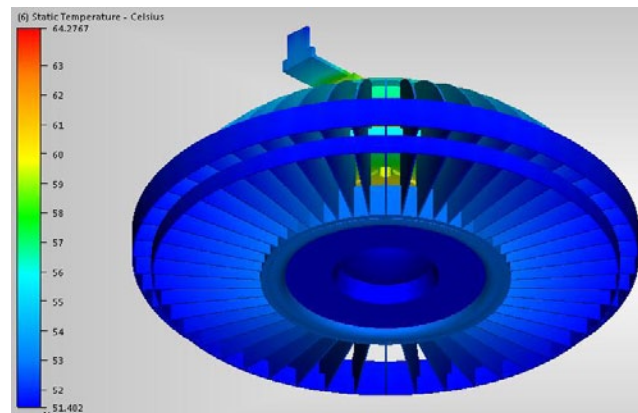


Figure 4: Thermal simulation of MT-G AR111 lamp

¹⁰ Cree used Autodesk Simulation CFD, www.autodesk.com/simulationcfd

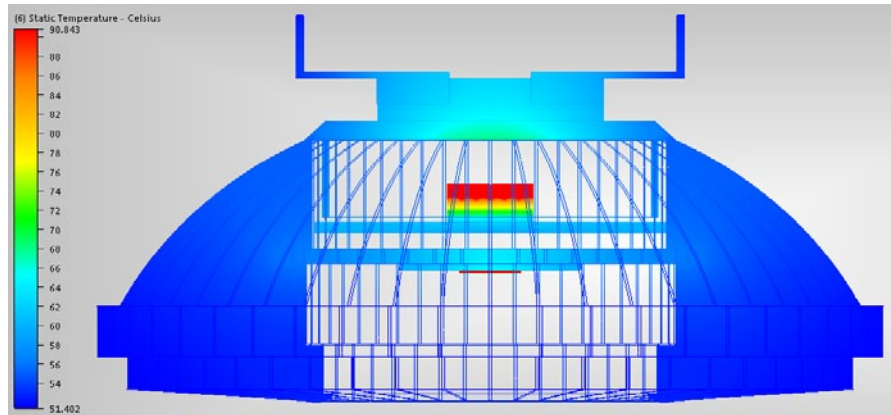


Figure 5: Thermal simulation of MT-G AR111 heat sink

Figure 6 shows a thermal simulation of the air flow between the MT-G AR111 heat sink fins.

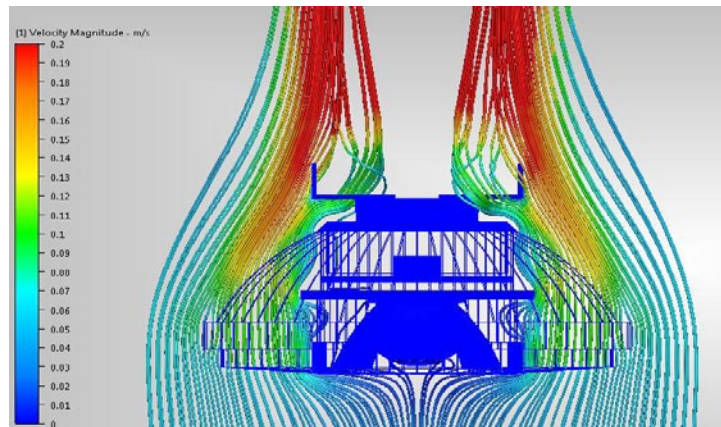


Figure 6: Thermal simulation of air flow between MT-G AR111 heat sink fins

Drive Electronics

Another challenge of this design was fitting the necessary drive electronics into the AR111 footprint. There are numerous types of transformers on the market, including magnetic and electronic. Full compatibility with all transformers depends significantly on driver design and is not in the scope of this document. For this reference design, Cree focused on the more common electronic transformers, such as the Lightech LET 60 LW, a low-wattage transformer compatible with both LED and halogen AR111s up to 60 W.¹¹ Standard AR111 track lighting transformers supply 12 VAC to the lamps, so the internal driver must convert the 12 VAC from the transformer to a 0.5 A current source for the MT-G component, running at approximately 36.0 V. One such fixture used in testing was the NTL-250 low-voltage track fixture from Nora Lighting.¹²

11 Lightech: lightechinc.com/let-60w-ac-120v-117v-class-2

12 Nora track light: www.noralighting.com/uploads/specs/ntl-250.pdf

We set a design goal of 80% driver efficiency to keep the LED power below 18 W and not generate excess heat. We worked with several driver partners and two solutions were identified and characterized for this reference design. Diodes Inc.¹³ and National Semiconductor¹⁴ fabricated drivers to fit the required form factor and deliver the necessary current for this specific design.

Schematics and reference designs of the specific drivers used can be found on each of the driver suppliers' websites. The driver from National Semiconductor is based on their LM3492 controller. The driver from Diodes Inc. is based on their ZXLD1370 controller. Both these drivers were ~85% efficient and had a power factor of ~0.8 - 0.9.

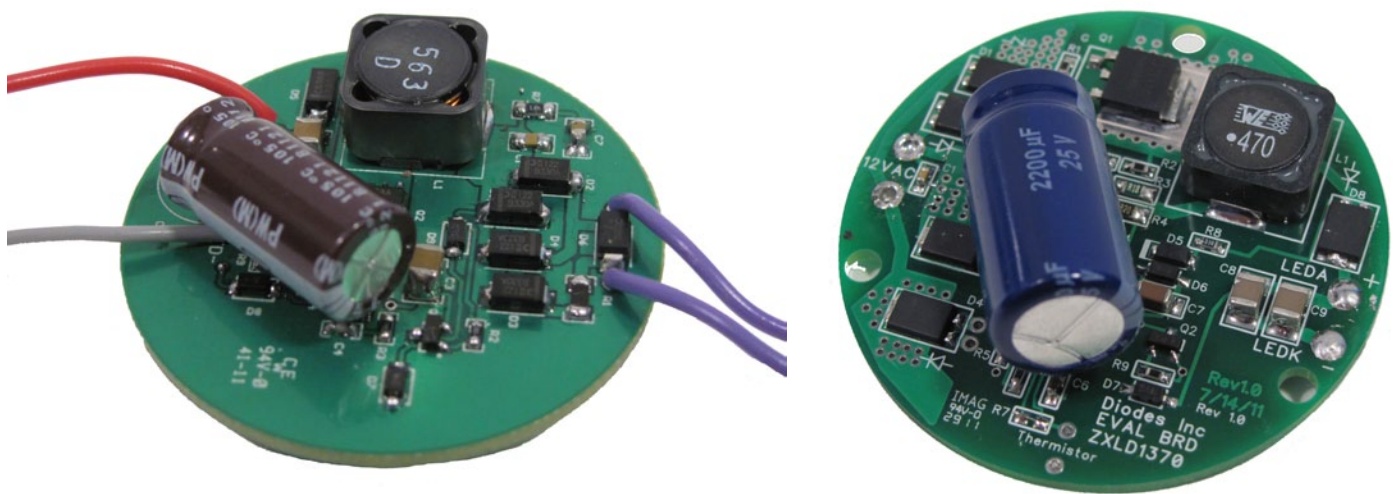


Figure 7: MT-G AR111 drivers (left: National Semiconductor, right: Diodes Inc.)

Secondary Optics

Another challenge was to tailor the secondary optic for the MT-G component to fit within the standard AR111 envelope and produce the desired beam angle and CBCP.

Cree collaborated with an optical partner to create a secondary optic for the XLamp MT-G LED that fit the form factor requirements and light intensity in the design goals. DBM Reflex created a total internal reflection (TIR) lens compatible with the XLamp MT-G component.¹⁵ Additionally, the Tai Sun heat sink was designed to fit and hold the optic. The heat sink has a screw-down optic holder to keep the optic in proper alignment. The photometric results for optic are shown below in the Results section.

13 Diodes Inc.: www.diodes.com/zetex/cree.html

14 National Semiconductor: www.national.com/analog/partner/cree

15 DBM Reflex: www.dbmlighting.com. IES files for the optic are available at: www.cree.com/xlampmodels/mtg/mtg_ar111_ies.ies



Figure 8: DBM Reflex optic holder (left) and optic (right)

4. CALCULATE THE NUMBER OF LEDS

One.

The purpose of this reference design is to show that a single LED package can deliver equivalent lighting output and superior efficacy compared to existing lamps on the market. The XLamp MT-G LED is a multi-chip LED package that can offer the required CBCP of an AR111 replacement lamp with new levels of LED-to-LED color consistency and efficiency.

5. CONSIDER ALL DESIGN POSSIBILITIES

The design possibilities for a retrofit LED AR111 lamp are endless. There are countless ways to design a sufficient heat sink that can dissipate the heat and fit within the standard AR111 envelope. There are also many ways to drive the LED and design the optics. Working with driver companies and optics companies resulted in components that provide the performance necessary for a true 50-W to 75-W AR111 halogen replacement lamp.

However, this reference design is intended to show how straightforward it is to design with Cree’s XLamp MT-G LED. This application note is not intended to show the only way to do this, but rather to demonstrate the ease of implementation of an LED-based AR111 replacement lamp. With a dedicated design team and appropriate resources, many solutions are possible.

6. COMPLETE THE FINAL STEPS: IMPLEMENTATION AND ANALYSIS

This section illustrates some of the techniques used to create a working prototype AR111 lamp using the XLamp MT-G LED.

Prototyping Details

The essence of the design is to attach a Cree XLamp MT-G component to a heat sink and assemble the necessary optics and driver around this to create a true 50- to 75-W halogen AR111 replacement. The assembly steps are detailed below.

1. Per the details in the MT-G data sheet, we soldered a single MT-G LED to a custom metal core printed circuit board (MCPCB) designed for the MT-G component¹⁶ and the AR111 heat sink.
2. Once the LED was soldered to the star board, we soldered wire connectors to the MCPCB for contact with the driver.
3. We applied thermal interface material to the back of the MCPCB to attach it to the heat sink. We used Timtronics Silver Ice 710NS thermal grease in this reference design.¹⁷
4. We placed the MCPCB onto the heat sink with the leads placed through the thru-holes of the heat sink base plate. We used two M3x4 screws to affix the MCPCB to the heat sink.
5. We soldered the wires from the MCPCB to the driver output.
6. We inserted the driver board into the plastic base from LEDLink¹⁸ and soldered the wires from the base to the driver input.
7. We attached the plastic base to the heat sink with Dow Corning SE-9184 RTV silicone.¹⁹
8. We placed the optic over the MCPCB with the pins aligned to the holes in the MCPCB.
9. We screwed the optic holder into place to hold the optic snug.
10. The finished assembly was now ready to be powered by 12 VAC.

Results

Thermal Results

Figure 9 shows measured thermal data for an MT-G LED mounted to the AR111 heat sink, running at 18 W, exhibiting thermal performance in line with the thermal simulations.

16 MCPCB Gerber file available at: www.cree.com/xlampmodels/mtg/mtg_ar111_gerber.zip

17 Timtronics Silver Ice data sheet: [www.timtronics.com/PDF/electroconductive/Silver Ice 710NS.pdf](http://www.timtronics.com/PDF/electroconductive/Silver%20Ice%20710NS.pdf)

18 LEDLink: www.ledlink-optics.com/productsmodule.aspx part number: LL11A00MDFA2

19 Dow Corning SE-9184: www2.dowcorning.com/DataFiles/090007c88021bb11.pdf

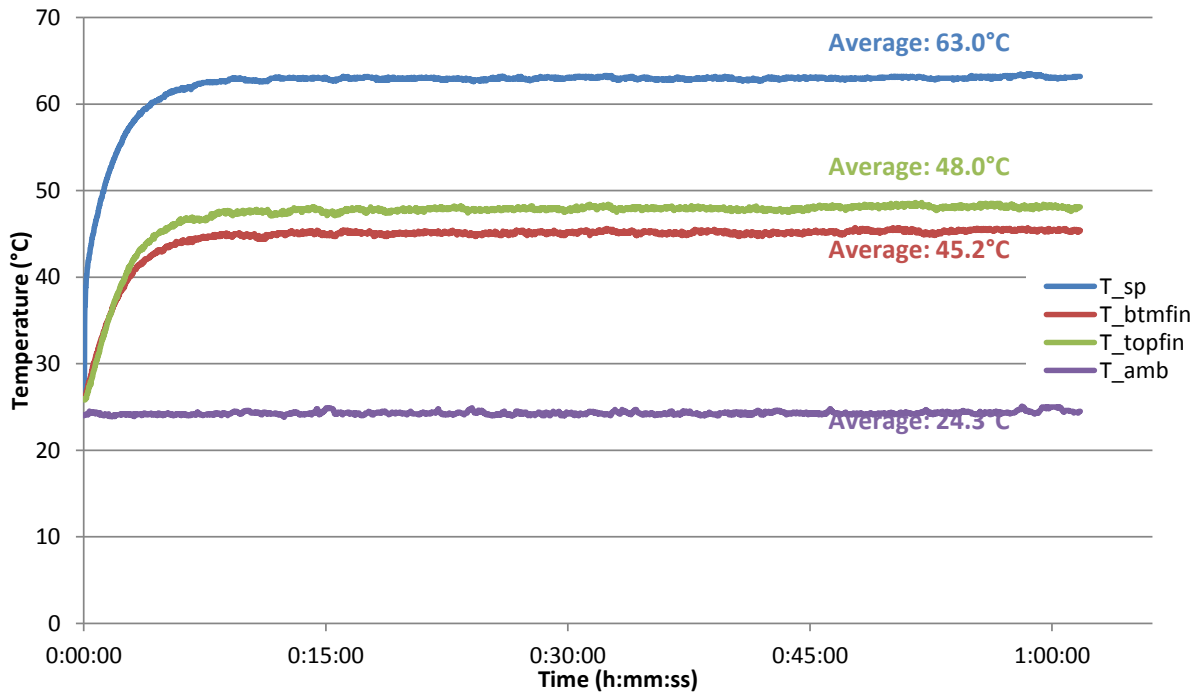


Figure 9: Measured solder-point and heat-sink temperatures for MT-G AR111 lamp at 18-W input power

Based on a measured solder point temperature of 63 °C, the junction temperature can be calculated as follows.

$$T_j = T_{sp} + (\text{LED power} * \text{LED thermal resistance})$$

$$T_j = 63 \text{ °C} + (18 \text{ W} * 1.5 \text{ °C/W})$$

$$T_j = 90 \text{ °C}$$

Using the XLamp MT-G data sheet, the estimated performance can be calculated as shown below.²⁰ Keeping in mind that the XLamp MT-G is binned at 85 °C, Figure 10 shows that, for a junction temperature of 90 °C, the relative luminous flux will be 99% of the binned data. Figure 11 shows that an MT-G operating at 500 mA will output 225% luminous flux as compared to the binned data at 185 mA. Combining these two calculations nets a 222% increase in lumens versus the value for the luminous flux bin. This is confirmed by our measurements.

20 MT-G data sheet available at www.cree.com/products/pdf/XLampMTG-EZW.pdf

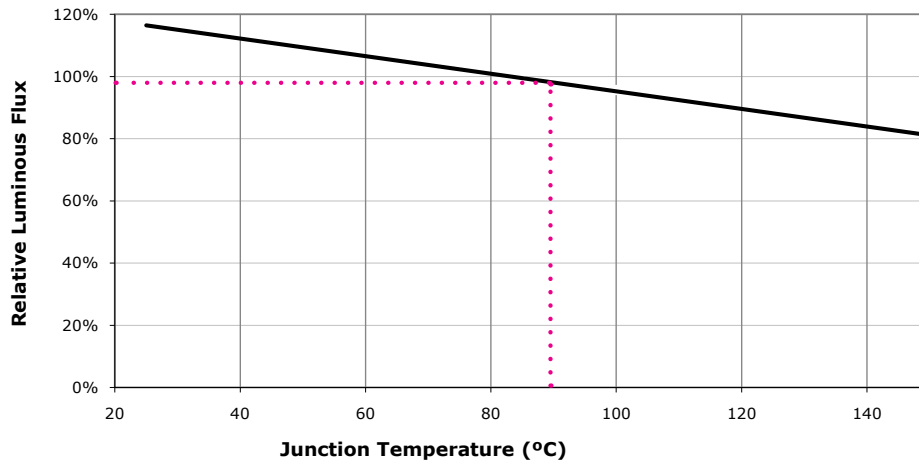


Figure 10: Relative luminous flux of MT-G LED vs. junction temperature

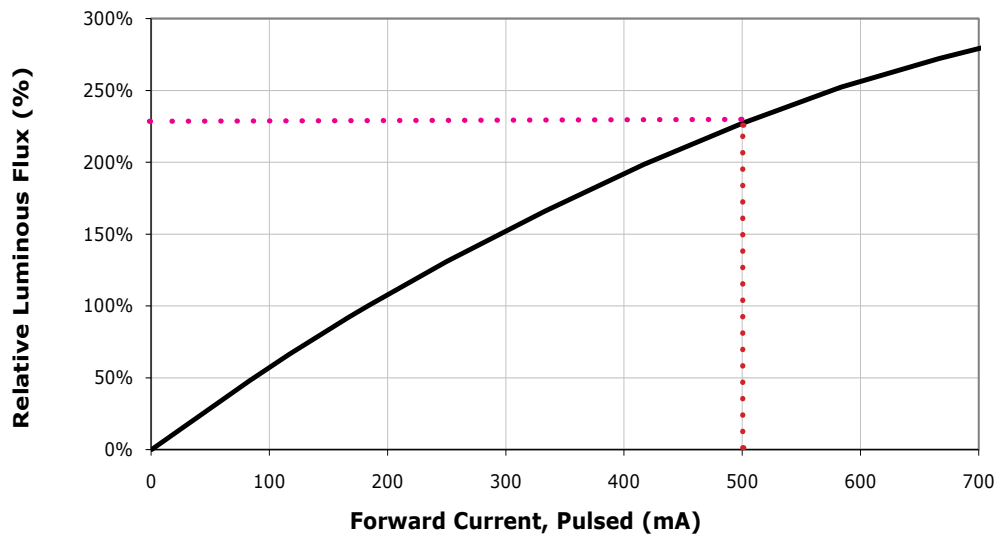


Figure 11: Relative luminous flux of MT-G LED vs. forward current

Using the TM-21 projection algorithm based on over 6,000 hours of testing, we project a calculated $L_{70}(6k)$ lifetime of 80,300 hours for the MT-G LED used in this lamp.

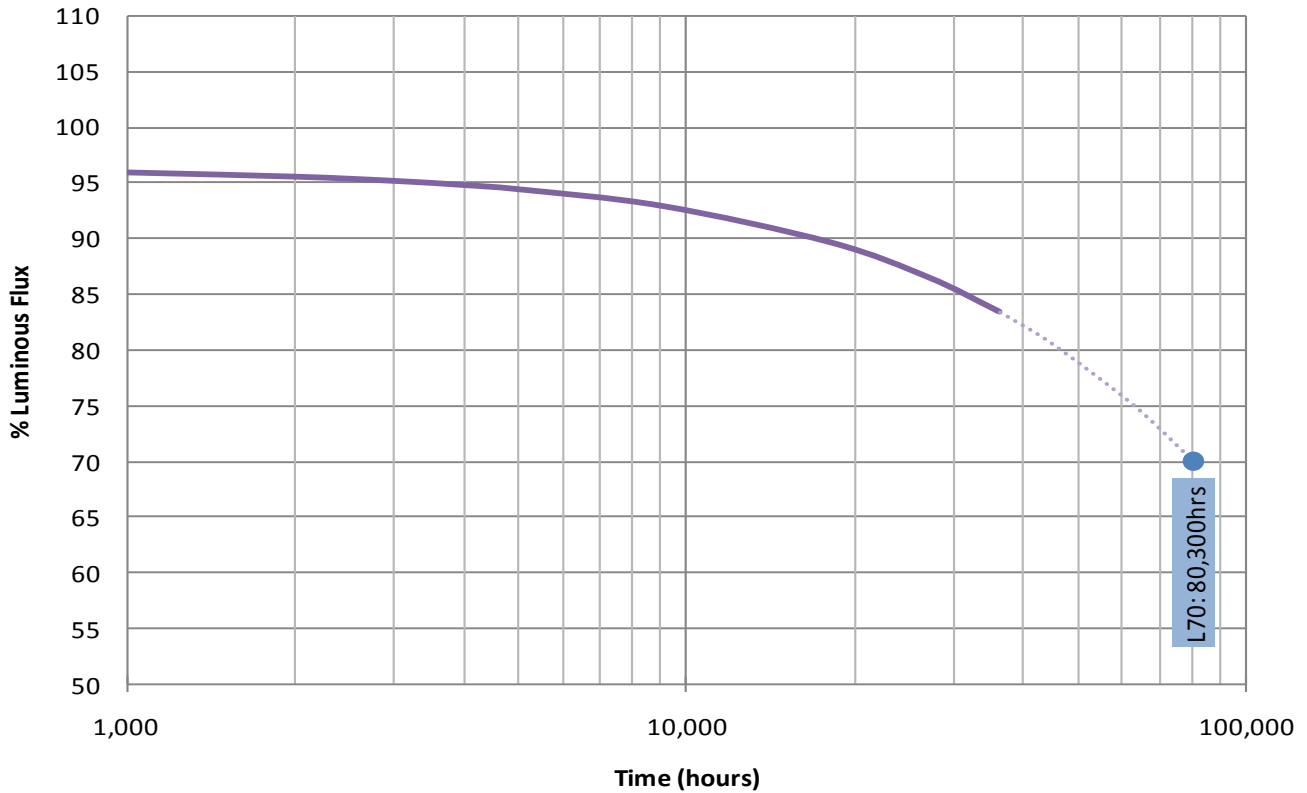


Figure 12: MT-G TM-21 data at 500 mA

Optical Results

Table 7 shows the optical results for the MT-G AR111 lamp.

Optic	Optic Type	Beam Angle	Cd/Lm	Efficiency
DBM Reflex CR-001	TIR	27°	3.5	91%

Table 7: Optical test data

The results that follow are average values for the 2 lamps we made for each driver and color temperature combination.

Table 8 shows steady-state test data for the XLamp MT-G AR111 lamps.²¹ The equivalence approximations are based on the measured CBCP values for the comparison halogen lamps, taking the narrower beam angles of the halogen lamps into account. The MT-G lamps produce CBCP light output equivalent to the comparison 50- and 75-W halogen lamps with 5-6 times better efficacy and use 50% to 66% less power. Furthermore, the MT-G lamps’ lumen output matches that of the 100-W halogen lamps. Comparison of light output intensity is difficult because the beam angles of the halogen lamps vary from 10% to nearly 50% narrower than their specified values.

²¹ CCT and CRI measurements were taken at the Cree facility in Santa Barbara, CA. Other measurements were taken at the Cree facility in Durham, NC.

Characteristic	Unit	Source			
		3000 K, Diodes Inc. Driver	3000 K, National Semiconductor Driver	5000 K, Diodes Inc. Driver	5000 K, National Semiconductor Driver
Power	W	21.1	21.2	21.2	21.1
Beam angle	°	27	27	27	27
Luminous flux	lm	1174	1126	1378	1280
Efficacy	lm/W	55.7	53.2	65.1	60.7
CBCP	cd	4130	3988	4920	4678
CCT		3049	2902	5060	5005
CRI		81	80	81	81
T _{sp}		67 °C	63 °C	67 °C	63 °C
Approximate equivalence		50 W	50 W	75 W	75 W

Table 8: Steady-state results for MT-G AR111 lamp

Figure 12 shows a goniometric intensity polar plot for the MT-G AR111 lamps and the comparison halogen lamps. In the diagram, DI denotes MT-G AR111 lamps with the Diodes, Inc. driver; NSC denotes MT-G AR111 lamps with the National Semiconductor driver. The data show consistent beam shape and light distribution, with the MT-G AR111 lamps having the same intensity as the comparison halogen lamps.

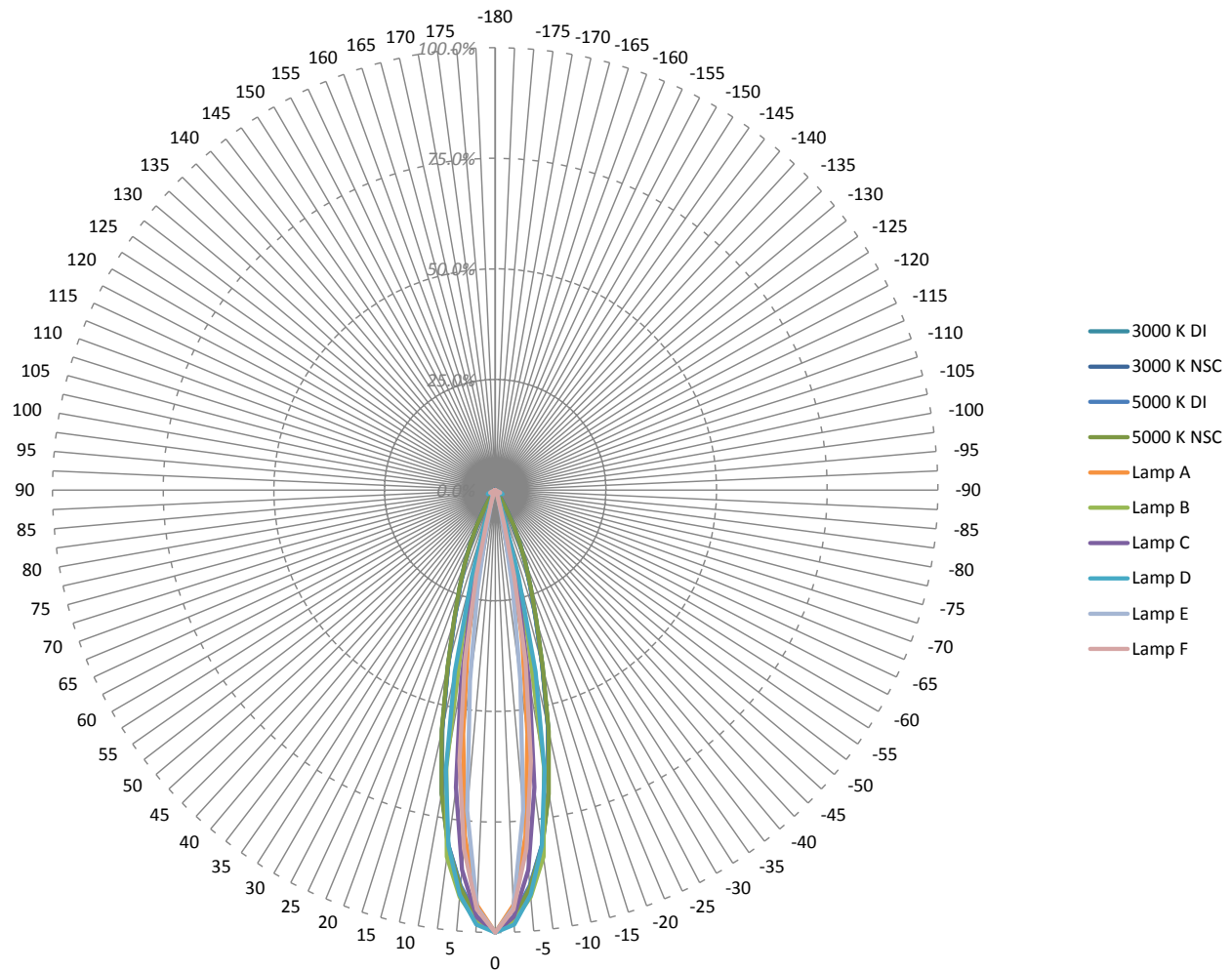


Figure 12: Goniometric intensity polar plot of XLamp MT-G AR111 and comparison halogen lamps

Although this reference design uses a 500-mA driver, operating the MT-G at full power at 700 mA would produce even more light and still be thermally viable. We were unable to obtain a driver that outputs 700 mA in time for this publication, so Table 9 shows the results obtained by operating the MT-G AR111 lamp on direct DC input at 700 mA and simulating the performance and light output based on driver and thermal losses comparable to those measured on the existing 500 mA drivers. The equivalence approximations are based on the measured CBCP values for the comparison halogen lamps, taking the narrower beam angles of the halogen lamps into account. The results show that, with a 700 mA driver, the MT-G AR111 lamp handily matches the performance of the comparison 50- to 75-watt halogen lamps. In addition, the MT-G AR111 lamp uses 75% less power to produce lumen output equivalent to the comparison 100 W halogen lamps with 5-6 times better efficacy. Based on thousands of hours of long-term testing of the MT-G LED at higher temperatures than the measured 77 °C T_{sp} , Cree expects an L70 lifetime significantly longer than the 50,000-hour goal for this design.

Characteristic	Unit	Source			
		3000 K, Diodes Inc. Driver	3000 K, National Semiconductor Driver	5000 K, Diodes Inc. Driver	5000 K, National Semiconductor Driver
Power	W	26.8	27.3	26.8	27.3
Beam angle	°	27	27	27	27
Luminous flux	lm	1339	1284	1563	1451
Efficacy	lm/W	50.0	47.0	58.3	53.2
CBCP	cd	4747	4584	5541	5268
CCT		3000	3000	5000	5000
CRI		81	80	81	80
T _{SP}		81 °C	77 °C	81 °C	77 °C
Approximate equivalence		75 W	75 W	75 W	75 W

Table 9: Simulated results for 700 mA MT-G AR111 lamp

CONCLUSIONS

Not just an interesting systems development exercise, this reference design presents a multi-vendor, multi-disciplinary approach to addressing the AR111 lamp constraints. The successful result required collaborative design and innovation in LED packaging and power supply, optics and heat sink development to bring a series of industry-leading practices to bear to achieve the desired performance. We believe this kind of collaboration will become increasingly common in the solid-state lighting arena. Just as traditional lamp and ballast manufacturers have engaged in symbiotic development, so too must companies working on LED illumination components work together to solve problems to their mutual benefit.

This reference design demonstrates the ease of integrating a Cree XLamp MT-G LED into a conventional AR111 housing footprint with great results. The design utilized proper heat sinking, optical control and driver design to efficiently and effectively hit the targets of a true 50- to 75-W equivalent AR111 lamp. The chosen driver current and heat sink provides the environment necessary to achieve an L70 50,000-hour designation. This design shows that this level of performance is attainable with a single MT-G component, but is not meant to be interpreted as the only way that a good LED-based AR111 lamp can be designed.

SPECIAL THANKS

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