Cree® XLamp® XP-E MR16 Reference Design

INTRODUCTION

It is a challenge to design an efficient, high lumen, small form factor, solid-state luminaire at a reasonable cost. The limited space of an MR16 lamp means that designing the optical, thermal, and electrical components to achieve the desired requirements is not easy.

This application note details the design of an MR16 lamp using Cree's XLamp XP-E LED. The goal of this design is to develop a replacement 20 W MR16 lamp meeting the ENERGY STAR requirements. In this reference design we used simulation and prototype creation to build a replacement for the traditional 20 W MR16 halogen bulb. Building on Cree's reference designs of prototype MR16 replacement lamps using XLamp MT-G and XM-L EZW LEDs[1], this design provides another possibility to create an LED-based MR16 lamp that exceeds the performance of existing halogen MR16 bulbs.

TABLE OF CONTENTS

1 Cree XLamp MT-G MR16 Reference Design, Application Note AP62
http://www.cree.com/products/pdf/XLampMTG_MR16_Ref.pdf
Cree XLamp XM-L EZW MR16 Reference Design, Application Note AP71
http://www.cree.com/products/pdf/XLampXML_MR16_ref.pdf

Cree, Inc.
4600 Silicon Drive
Durham, NC 27703
USA Tel: +1.919.313.5300

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.

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 1: Cree 6-step framework

THE 6-STEP METHODOLOGY

The major goal for this project was to create a 20 W equivalent XLamp XP-E LED-based MR16 lamp. It is meant to be a plug-in replacement for any MR16 fixture and operate with the existing low voltage power supply.

1. DEFINE LIGHTING REQUIREMENTS

Table 2 shows a ranked list of desirable characteristics to address in an MR16 reference design.

Importance	Characteristic	Units
Critical	Light intensity	Center Beam Candle Power (CBCP) candelas (cd)
	Nominal beam angle	Angle (deg)
	Electrical power	Watts (W)
	Luminous flux	Lumens (lm)
	Form factor	
Important	Price	$
	Lifetime	Hours
	Operating temperatures	°C
	Operating humidity	% RH
	Correlated Color Temperature (CCT)	K
	Color Rendering Index (CRI)	100 point scale
	Manufacturability	
	Ease of installation	

Table 2: Ranked design criteria for MR16 replacement lamp

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

As a comparison, photometric testing of several halogen MR16 lamps provides basic benchmark data.[3]

Source	Luminaire Power (W)	Luminous Flux (lm)	CBCP (cd)	Efficacy (lm/W)	Beam Angle (°)	CCT (K)
MR16 A	20	2802	420	13.6	36	2900
MR16 B	20	254	455	12	30	2780
MR16 C	20	260	950	12.6	22	2780

Table 3: Halogen MR16 comparison data

The following table summarizes the ENERGY STAR requirements for all integral LED lamps.[4]

Characteristic	Requirement
CCT	Lamp must have one of the following designated CCTs (per ANSI C78.377-2008) consistent with the 7-step chromaticity quadrangles and Duv tolerances below. Nominal CCT (K) / Target CCT (K) and tolerance / Target Duv and tolerance 2700 / 2725 ± 145 / 0.000 ± 0.006 3000 / 3045 ± 175 / 0.000 ± 0.006 3500 / 3465 ± 245 / 0.000 ± 0.006 4000 / 3985 ± 275 / 0.001 ± 0.006
Color maintenance	The change of chromaticity over the minimum lumen maintenance test period (6,000 hours) shall be within 0.007 on the CIE 1976 (u’, v’) diagram.
CRI	Minimum CRI (R_a) of 80. R_9 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.
Warranty	3-year warranty
Allowable lamp bases	Must be a lamp base listed by ANSI.
Power factor (PF)	Lamp power ≤ 5 W and low voltage lamps: no minimum PF Lamp power > 5 W: PF ≥ 0.70
Minimum operating temperature	-20°C or below
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. Dimming operation shall meet the requirement at all light output levels.
Electromagnetic and radio frequency interference	Must meet appropriate FCC requirements for consumer use (FCC 47 CFR Part 15)
Audible noise	Class A sound rating
Transient protection	Power supply shall comply with IEEE C62.41-1991, 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.
Operating voltage	Lamp shall operate at rated nominal voltage of 120, 240 or 277 VAC, or at 12 or 24 VAC or VDC.

Table 4: ENERGY STAR requirements for integral LED lamps

3 Measured in an integrating sphere at Cree’s facility in Santa Barbara, California

4 ENERGY STAR Program Requirements for Integral Lamps, Eligibility Criteria, Version 1.2, Table 4
http://www.energystar.gov/ia/partners/product_specs/program_reqs/ILL_prog_reqs.pdf

The following table summarizes ENERGY STAR requirements for MR16 lamps.[5]

Characteristic	Requirement
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 spacial 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 as per ANSI C78.21-2003.
Maximum overall length (MOL)	Not to exceed MOL for target lamp as per ANSI C78.21-2003.
Minimum center beam intensity	473 cd - determined from the ENERGY STAR® Integral LED Lamp Center Beam Intensity Benchmark Tool (ed. 7/6/2010)
Lumen maintenance	$L_{70} \geq$ 25,000 hours
Rapid-cycle stress test	Cycle times must be 2 minutes on, 2 minutes off. Lamp will be cycled once for every 2 hours of required minimum L_{70} life.

Table 5: ENERGY STAR requirements for MR16 lamps

2. DEFINE DESIGN GOALS

The design goals for this project as derived from the information above:

Characteristic	Unit	Minimum Goal	Target Goal
Light output	Lm	210	> 210
Illuminance profile		Identical	
Power	W	<< 10	3.5
Beam angle	°	36	36
CBCP	Cd	473	> 473
Luminaire efficacy	lm/W	> 50	60
Lifetime	Hours	50,000	50,000
CCT	K	3000	3000
CRI		> 80	80
Maximum ambient temperature	°C	30	40

Table 6: Design goals

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

Component Efficiency

Considering efficiency, stability, cost, availability of secondary optics, color rendering and LM-80 availability, two LEDs from the XP family became candidates: the XLamp XP-E and XP-G, highlighted in yellow in Figure 2. The XP-E has a slight advantage due to its lower cost.

5 Ibid, Table 7C

Color	CCT Range		Base Order Codes Min Luminous Flux (lm) @ 350 mA		Order Code
	Min.	Max.	Group	Flux (lm)	
Cool White	5,000 K	10,000 K	Q4	100	XPEWHT-L1-0000-00C01
			Q5	107	XPEWHT-L1-0000-00D01
			R2	114	XPEWHT-L1-0000-00E01
			R3	122	XPEWHT-L1-0000-00F01
Outdoor White	4,000 K	5,300 K	Q3	93.9	XPEWHT-01-0000-00BC2
			Q4	100	XPEWHT-01-0000-00CC2
			Q5	107	XPEWHT-01-0000-00DC2
			R2	114	XPEWHT-01-0000-00EC2
Neutral White	3,700 K	5,000 K	Q3	93.9	XPEWHT-L1-0000-00BE4
			Q4	100	XPEWHT-L1-0000-00CE4
			Q5	107	XPEWHT-L1-0000-00DE4
80-CRI White	2,600 K	4,300 K	P4	80.6	XPEWHT-H1-0000-009E7
			Q2	87.4	XPEWHT-H1-0000-00AE7
			Q3	93.9	XPEWHT-H1-0000-00BE7
Warm White	2,600 K	3,700 K	P3	73.9	XPEWHT-L1-0000-008E7
			P4	80.6	XPEWHT-L1-0000-009E7
			Q2	87.4	XPEWHT-L1-0000-00AE7
			Q3	93.9	XPEWHT-L1-0000-00BE7

Color	CCT Range		Base Order Codes Min Luminous Flux @ 350 mA (lm)		Order Code
	Min.	Max.	Group	Flux (lm)	
Cool White	5,000 K	8,300 K	R2	114	XPGWHT-L1-0000-00E51
			R3	122	XPGWHT-L1-0000-00F51
			R4	130	XPGWHT-L1-0000-00G51
			R5	139	XPGWHT-L1-0000-00H51
Outdoor White	4,000 K	5,300 K	R2	114	XPGWHT-01-0000-00EC2
			R3	122	XPGWHT-01-0000-00FC2
			R4	130	XPGWHT-01-0000-00GC2
Neutral White	3,700 K	5,000 K	Q5	107	XPGWHT-L1-0000-00DE4
			R2	114	XPGWHT-L1-0000-00EE4
			R3	122	XPGWHT-L1-0000-00FE4
80-CRI White	2,600 K	4,300 K	Q3	93.9	XPGWHT-H1-0000-00BE7
			Q4	100	XPGWHT-H1-0000-00CE7
			Q5	107	XPGWHT-H1-0000-00DE7
Warm White	2,600 K	3,700 K	Q3	93.9	XPGWHT-L1-0000-00BE7
			Q4	100	XPGWHT-L1-0000-00CE7
			Q5	107	XPGWHT-L1-0000-00DE7

Figure 2: Binning comparison(left: XP-E, right: XP-G)

Cree chose to work with the XPEWHT-H1-0000-00AE7, highlighted in yellow in Figure 3, in this reference design.

XLamp XP-E LED Standard Order Codes - 80-CRI White				
Minimum Luminous Flux (lm) @ 350 mA*		Chromaticity Regions	Order Code	CCT
Group	Flux (lm)			
80-CRI White (2600 K - 4300 K)				
P3	73.9	7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4, 8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4	XPEWHT-H1-0000-008F8	2900 K
		8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4, 8C1, 8C2, 8C3, 8C4, 8D1, 8D2, 8D3, 8D4	XPEWHT-H1-0000-008E8	2700 K
P4	80.6	5C1, 5C2, 5C3, 5C4, 5D1, 5D2, 5D3, 5D4, 6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4	XPEWHT-H1-0000-009F6	3700 K
		6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4, 6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4	XPEWHT-H1-0000-009E6	3500 K
		6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4, 7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4	XPEWHT-H1-0000-009F7	3200 K
		7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4, 7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4	XPEWHT-H1-0000-009E7	3000 K
		7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4, 8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4	XPEWHT-H1-0000-009F8	2900 K
		8A1, 8A2, 8A3, 8A4, 8B1, 8B2, 8B3, 8B4, 8C1, 8C2, 8C3, 8C4, 8D1, 8D2, 8D3, 8D4	XPEWHT-H1-0000-009E8	2700 K
Q2	87.4	5A1, 5A2, 5A3, 5A4, 5B1, 5B2, 5B3, 5B4, 5C1, 5C2, 5C3, 5C4, 5D1, 5D2, 5D3, 5D4	XPEWHT-H1-0000-00AE5	4000 K
		5C1, 5C2, 5C3, 5C4, 5D1, 5D2, 5D3, 5D4, 6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4	XPEWHT-H1-0000-00AF6	3700 K
		6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4, 6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4	XPEWHT-H1-0000-00AE6	3500 K
		6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4, 7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4	XPEWHT-H1-0000-00AF7	3200 K
		7A1, 7A2, 7A3, 7A4, 7B1, 7B2, 7B3, 7B4, 7C1, 7C2, 7C3, 7C4, 7D1, 7D2, 7D3, 7D4	XPEWHT-H1-0000-00AE7	3000 K
Q3	93.9	5A1, 5A2, 5A3, 5A4, 5B1, 5B2, 5B3, 5B4, 5C1, 5C2, 5C3, 5C4, 5D1, 5D2, 5D3, 5D4	XPEWHT-H1-0000-00BE5	4000 K
		5C1, 5C2, 5C3, 5C4, 5D1, 5D2, 5D3, 5D4, 6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4	XPEWHT-H1-0000-00BF6	3700 K
		6A1, 6A2, 6A3, 6A4, 6B1, 6B2, 6B3, 6B4, 6C1, 6C2, 6C3, 6C4, 6D1, 6D2, 6D3, 6D4	XPEWHT-H1-0000-00BE6	3500 K
Q4	100	5A1, 5A2, 5A3, 5A4, 5B1, 5B2, 5B3, 5B4, 5C1, 5C2, 5C3, 5C4, 5D1, 5D2, 5D3, 5D4	XPEWHT-H1-0000-00CE5	4000 K

Figure 3: XP-E color, bin and order code

The XLamp XP-E LED has completed LM-80 testing, fulfilling ENERGY STAR's requirement. The XP-E has been in volume production for over two years and has become the workhorse of many LED luminaires. It is a reliable choice for an MR16 retrofit lamp.

Thermal Requirements

Despite the XLamp XP-E LED's efficacy advantage over conventional incandescent and fluorescent lighting, as much as 80% of the input power is converted to heat. This heat needs to be dissipated efficiently to ensure LED and luminaire lumen maintenance and reliability. For a 4 W MR16 luminaire, there are many existing market thermal solutions from which to choose. For this reference design, Cree selected an existing well-designed machined aluminum heat sink with good workmanship. Our simulations and actual test results confirmed this as a good choice for this project.

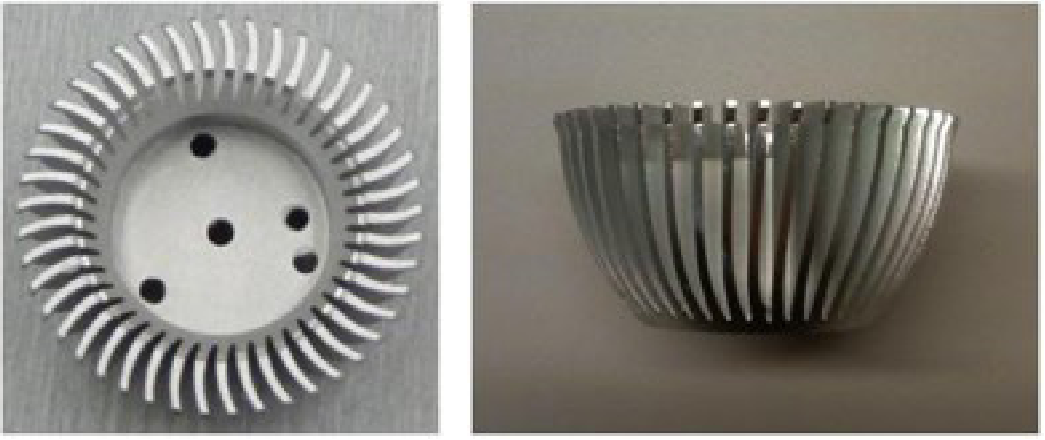


Figure 4: Machined aluminum heat sink

Cree performed thermal simulation[6] on the design with 3 XP-E LEDs running at both 350 mA and 700 mA and found the estimated solder point temperature to be 53°C. Figure 5 shows the thermal simulation of the solder point temperature. Figure 6 shows the thermal simulation of the airflow, in the form of convection currents, around the XP-E MR16 lamp.

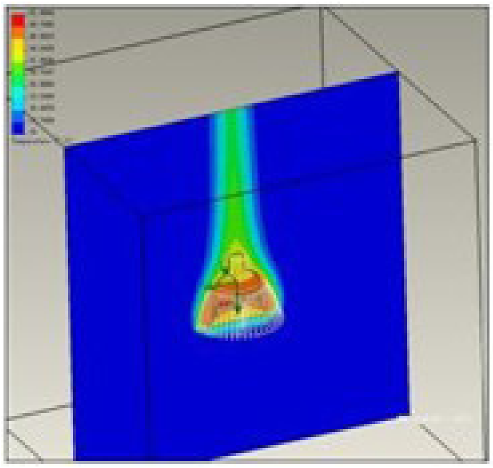


Figure 5: Thermal simulation of temperature of XP-E MR16

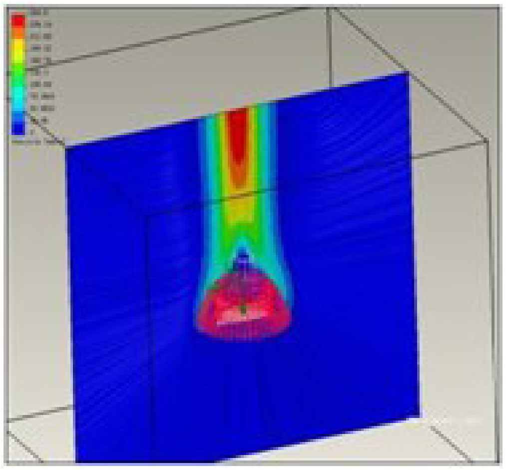


Figure 6: Thermal simulation of airflow around XP-E MR16

6 Cree used NIKA EFD Pro V8.2 with Pro E Wildfire
http://www.mentor.com/products/mechanical/products/floefd/
http://www.ptc.com/products/creo-elements-pro/

Figure 7 shows the thermocouple attached to the XP-E MR16 lamp to record the solder point temperature. Figure 8 shows the measurement in progress and the temperature reading. The steady-state measurement of 60°C is a reasonable match to the thermal simulation.

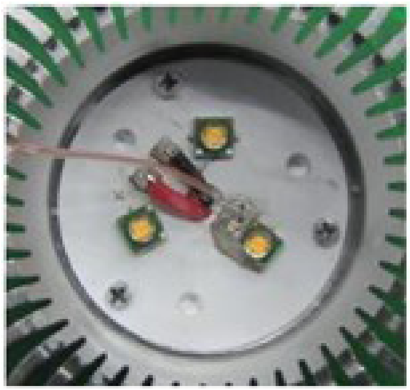
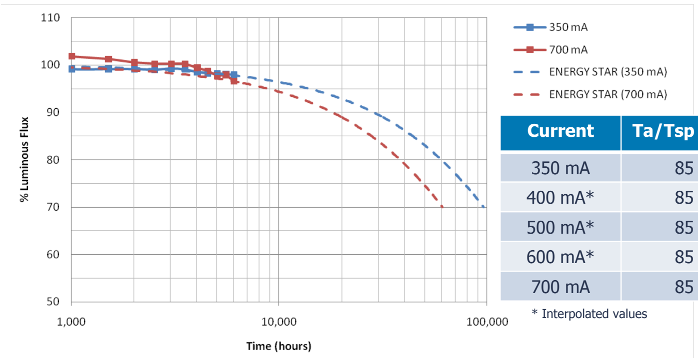


Figure 7: Thermocouple attached to XP-E LED

Figure 8:XP-E MR16 solder point temperature measurement

Based on Cree's experience with the XLamp XP-E LED and the L70 lifetime projection shown in Figure 9, we expect this design to attain both an ENERGY STAR compliant L70 rating of 25,000 hours and meet the target design goal of an L70 rating of 50,000 hours.



Current	Ta/Tsp (ºC)	L70 (hours)
350 mA	85	96,294
400 mA*	85	90,234*
500 mA*	85	79,234*
600 mA*	85	69,575*
700 mA	85	61,094

* Interpolated values

Figure 9: XP-E L70 lifetime estimate

Driver Electronics

Considering the traditional MR16 power requirement and for ease of retrofit, we chose to use a GU5.3 bi-pin connector with 12 VDC and 12 VAC power input. The LEDs were connected in series to achieve a higher overall Vf for better driver efficiency and to provide the constant drive current required by the LEDs to achieve consistent light output.

To meet the challenge of fitting a high-efficiency driver into the compact space of an MR16 lamp base, a non-dimmable driver with simple circuit design[7] was used, shown in Figure 10.

7 Driver from Shen Zhen IPOWER Electronic Technology Co., Ltd.

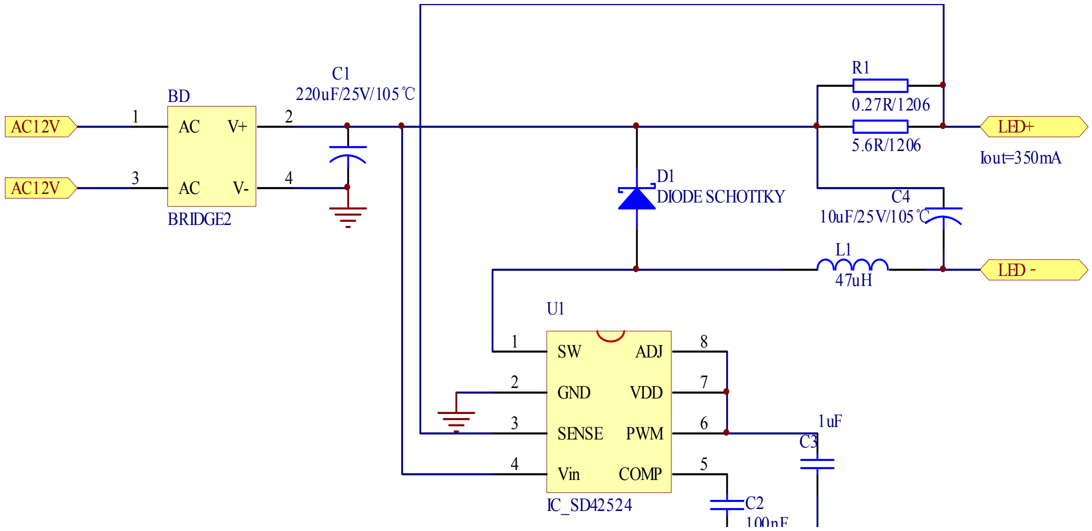


Figure 10: XP-E MR16 driver circuit design

Figure 11 shows the XP-E MR16 driver and GU5.3 connector.

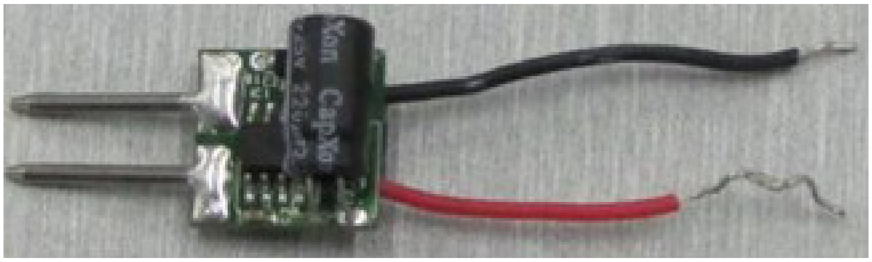


Figure 11: XPE-MR16 driver and GU5.3 connector

Secondary Optics

Cree's XLamp XP-E LED has been in volume production since 2009 and many market-ready optics designs are available. Considering efficiency, beam angle, size and repeatability, Cree chose to use Total Internal Refraction (TIR) optics for this application.

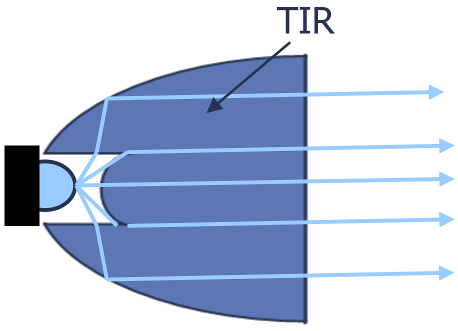


Figure 12: Example TIR optics

http://www.ipower-tek.com/en/products_01.asp?Cid=55

A well-designed TIR optic provides high optical efficiency, a narrow beam angle and good color mixing. As shown in Figure 13, some designs use surface texture or “mini-pillows” on the lens surface for color mixing to improve the color uniformity of the light beam.

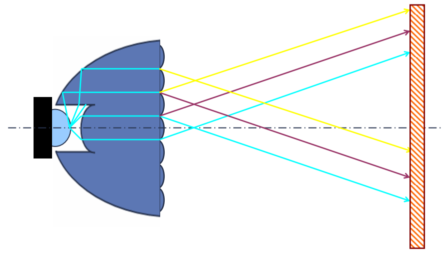


Figure 13: Example “mini-pillow” TIR optic

Figure 14 shows the secondary optics for the XP-E MR16.

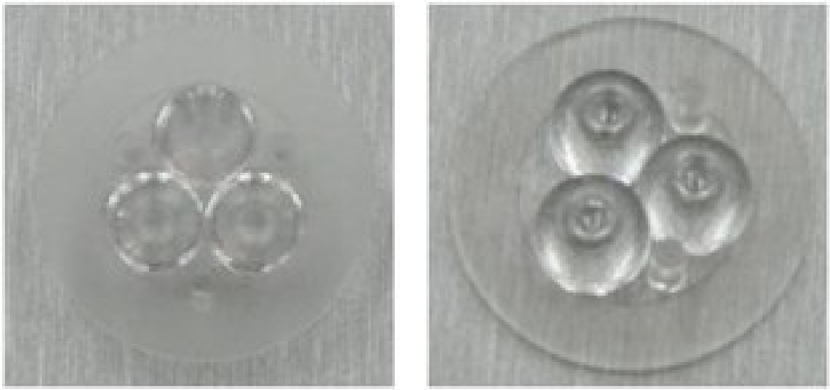


Figure 14: Secondary TIR optics for XP-E MR16

4. CALCULATE THE NUMBDER OF LEDS

The XLamp XP-E LED offers various efficacies depending on color temperature, bin and drive conditions. Based on the electrical data and optical output from Cree’s Product Characterization Tool (PCT),[8] we chose to work with the Q2 flux bin at 3000K CCT, highlighted in yellow in Figure 15 below, to give a close color point to a halogen bulb. The PCT data indicate that an MR16 lamp containing 3 XP-E LEDs is capable of meeting the design goals.

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

	LED 1				LED 2			
	Model	Cree XLamp XP-E {CW/NW/WW}			Model	Cree XLamp XP-G {CW/NW/WW}		
	Flux	Q2 [87.4]		87.4	Flux	Q2 [87.4]		87.4
	Price	$ -	Tsp (ºC)	55	Price	$ -	Tsp (ºC)	55
		LED Multiple		x1		LED Multiple		x1
Current (A)	SYS # LED	SYS lm tot	SYS W	SYS lm/W	SYS # LED	SYS lm tot	SYS W	SYS lm/W
0.100	10	233	3.09	75.4	10	215	2.87	74.9
0.150	7	236.6	3.28	72.1	7	225.4	3.05	73.9
0.200	5	218.5	3.14	69.6	5	213	2.98	71.5
0.250	4	213.2	3.19	66.8	4	210.8	3.02	69.8
0.300	4	250	3.87	64.6	4	250.4	3.66	68.4
0.350	3	213.9	3.41	62.7	3	216.6	3.26	66.4
0.400	3	239.1	3.96	60.4	3	244.5	3.77	64.9
0.450	3	263.1	4.5	58.5	3	271.8	4.28	63.5
0.500	3	285.6	5.04	56.7	3	298.5	4.82	61.9
0.550	3	307.2	5.59	55	2	216.2	3.55	60.9
0.600	2	218.6	4.09	53.4	2	233	3.94	59.1
0.650	2	231.4	4.45	52	2	249.2	4.3	58
0.700	2	243.6	4.83	50.4	2	265	4.66	56.9
0.750	2	254.8	5.19	49.1	2	280	5.04	55.6
0.800	2	265.6	5.55	47.9	2	294.8	5.4	54.6
0.850	2	275.6	5.91	46.6	2	308.8	5.81	53.1
0.900	2	284.8	6.28	45.4	2	322.8	6.19	52.1
0.950	2	293.2	6.64	44.2	2	335.8	6.57	51.1
1.000	2	301.2	6.98	43.2	2	348.6	6.96	50.1

Figure 15: Cree's Product Characterization Tool with XLamp XP data

5. CONSIDER ALL DESIGN POSSIBILITIES

Due to the vast quantity of LED-based MR16 designs and parts available in the market, our team tried a number of combinations of heat sinks, optics, and driver solutions and finally chose to use an MR16 kit from Shenzhen Zhongke Lianhe Super-Conduction Technology Co. An optic, metal core printed circuit board (MCPCB), heat sink and GU5.3 plug are included in this kit.

6. COMPLETE THE FINAL STEPS: IMPLEMENTATION AND ANALYSIS

With the methodology above, we determined a suitable combination of XLamp XP-E LEDs, components and drive conditions. This section illustrates the techniques Cree used to create an MR16 replacement based on the design and compares the results with our goal, to create a 20 W XP-E MR16 replacement lamp.

Prototyping Details

1. We verified the component dimensions to ensure a correct fit.

Figure 16: XP-E MR16 components

2. Following the XLamp XP-family recommendations[9], we reflow soldered the XP-E LEDs onto the MCPCB with an appropriate solder paste and reflow profile and cleaned the flux residue with isopropyl alcohol.
3. We applied a thin layer of thermal conductive compound to the back of the MCPCB and secured the MCPCB to the heat sink with screws.
4. We inserted the driver into the GU5.3 plug end and soldered the DC output wires to the corresponding terminals on the MCPCB.
5. We connected the GU5.3 plug end to the heat sink and secured it with screws. We verified that the MCPCB and plug end were secure.
6. We inserted the TIR optics, ensuring proper alignment to the LEDs. Depending on the type of TIR optics and their design, various securing options can be used including self locking, additional locking ring, or adhesive.
7. We tested the completed assembly with 12 VDC.

Results

Optical Results

Optical testing of the XLamp XP-E MR16 shows this reference design meets the target specifications. Contour plots of color and luminance distribution of the reference design[10] are shown below in Figure 17 and Figure 18. These demonstrate that the TIR optics evenly distribute the light from the 3 XP-E LEDs and produce smooth light without hotspots.

9 "Cree XLamp XP Family Soldering & Handling" http://www.cree.com/products/pdf/XLampXP_SolderingandHandling.pdf

10 Plots were taken with Radiant Imaging's imaging photometer. http://www.radiantimaging.com

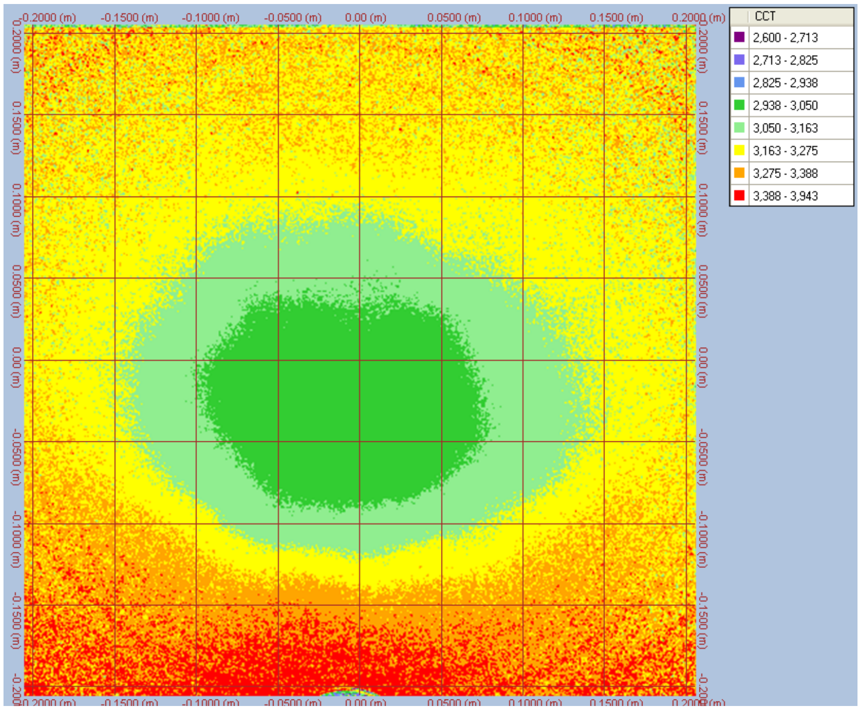


Figure 17: Contour plot of CCT color distribution (oval shape is a result of off-axis camera placement)

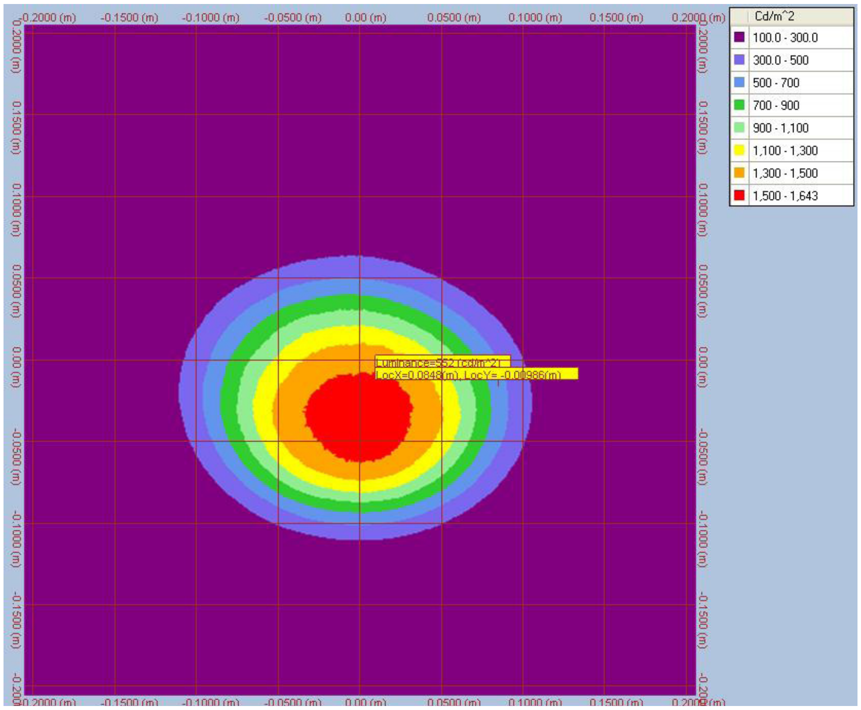


Figure 18: Contour plot of luminance distribution (oval shape is a result of off-axis camera placement)

As shown in Figure 19 and Figure 20, the XLamp XP-E MR16 lamp far field distribution pattern betters that of two halogen MR16 bulbs.

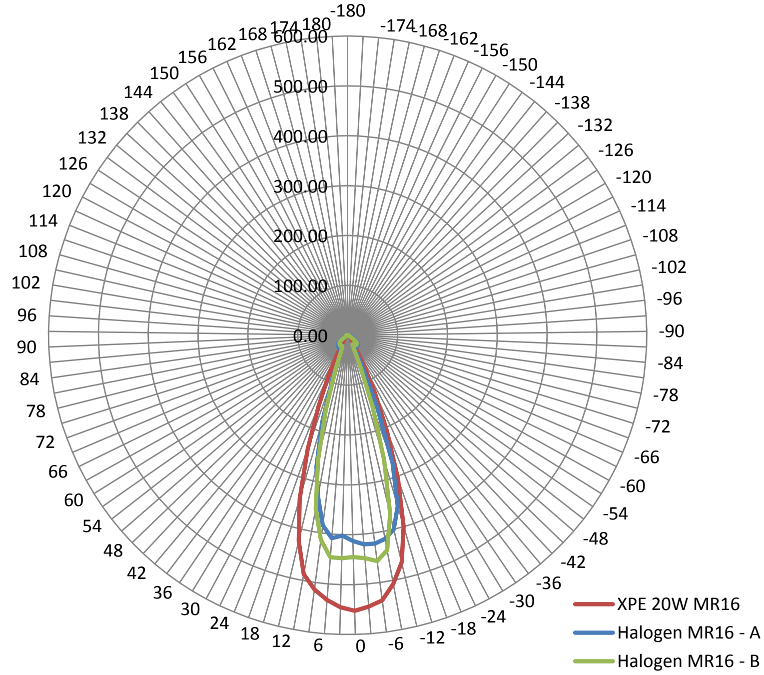


Figure 19: Goniometric intensity polar plot comparison of 20 W equivalent XP-E MR16

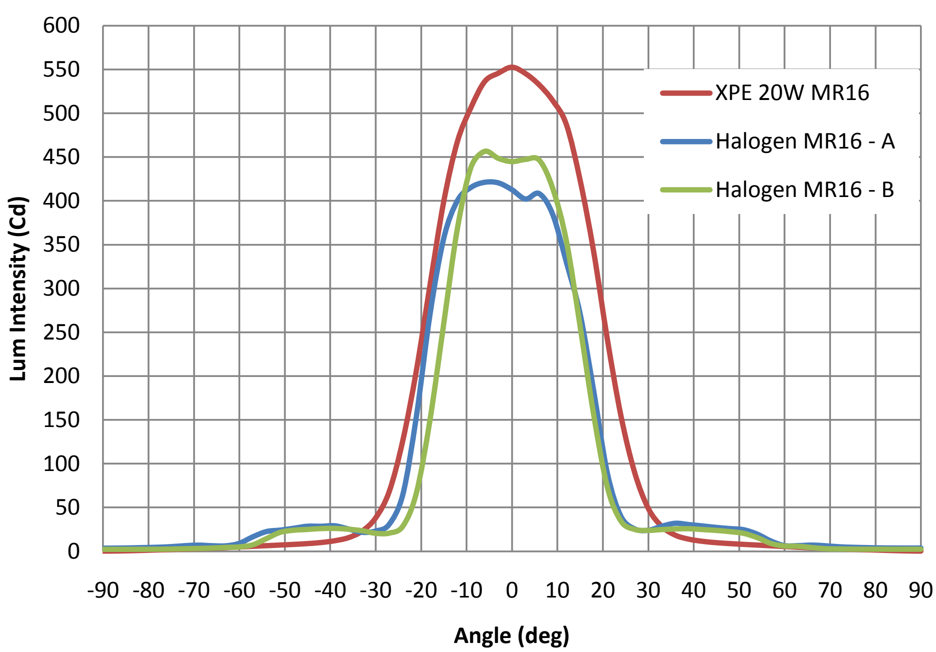


Figure 20: Measured luminous intensity comparison of 20 W equivalent XP-E MR16

Figure 21 shows the illuminance of the XLamp XP-E MR16 lamp at various distances from the light source. The beam angle is 35 degrees.

Height		Illuminance		Diameter	
1 m	3.2 ft	47.3 fc	508.6 lx	63.1 cm	2.1 ft
2 m	6.6 ft	11.8 fc	127.2 lx	126.1 cm	4.1 ft
3 m	9.8 ft	5.2 fc	56.5 lx	189.2 cm	6.2 ft
4.m	13.1 ft	3.0 fc	31.8 lx	252.2 cm	8.3 ft
5 m	16.4 ft	1.9 fc	20.4 lx	315.3 cm	10.3 ft
6 m	19.7 ft	1.3 fc	14.1 lx	378.4 cm	12.4 ft
7 m	23.0 ft	.9 fc	10.3 lx	441.4 cm	14.5 ft
8 m	26.2 ft	.7 fc	8.0 lx	504.5 cm	16.6 ft
9 m	29.5 ft	.6 fc	6.3 lx	567.5 cm	18.6 ft
10 m	32.8 ft	.5 fc	5.1 lx	630.6 cm	20.7 ft

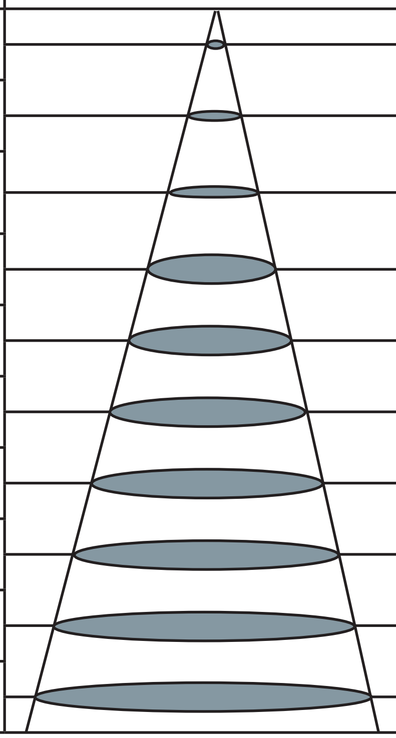


Figure 21: XP-E MR16 illuminance

Table 7 summarizes the results and shows that the XP-E MR16 lamp generally meets the design goals and betters the performance of comparison halogen fixtures.

Characteristic	Unit	Result	Target Goal
Light output (10 min. on time)	lm	209	> 210
Power	W	3.6	3.5
Beam angle	Deg	36	36
CBCP	Cd	508	> 473
Efficacy	lm/W	58	60
Lifetime	Hours	50,000	50,000
CCT	K	3000	3000
CRI		> 80	80
Maximum ambient temperature	°C	30	40

Table 7: XLamp XP-E MR16 test results

CONCLUSIONS

The intent of this design is to demonstrate that Cree's high-power XLamp XP-E LED can be easily incorporated into a MR16 retrofit lamp meeting the ENERGY STAR requirements. Testing of the prototype shows that this goal has been met. Despite the "plug and play" nature of this design, there are many improvements a committed design team with appropriate resources can make, such as a simpler and cheaper heat sink and a dimmable power supply. This design shows the level of performance that can be achieved with the Cree XLamp XP-E LED but should not be interpreted as the only way that a good XP-E LED-based MR16 lamp can be designed.