Cree® XLamp® XM-L EZW MR16 Reference Design

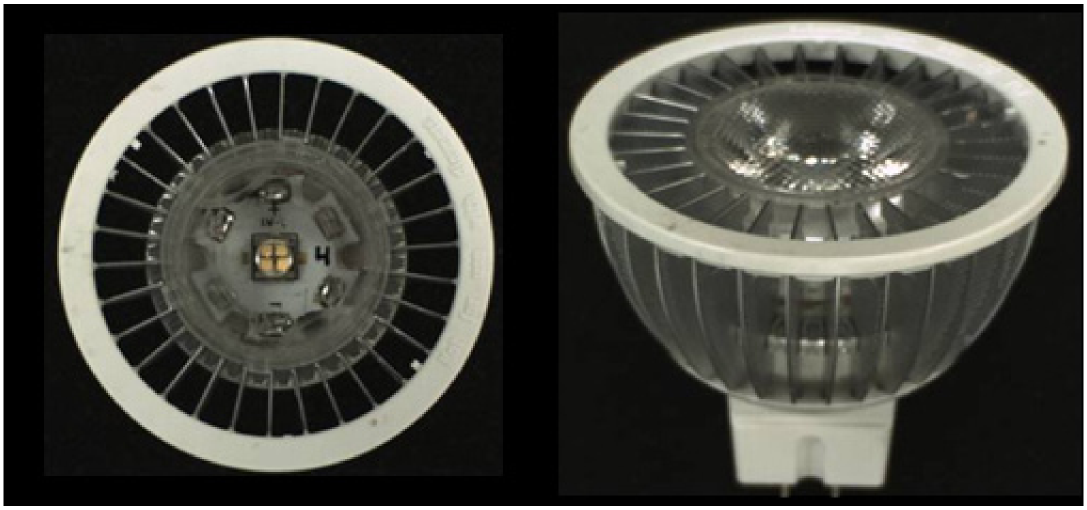

Figure 1: MR16 assembly

INTRODUCTION

The design presented here builds on the "Cree XLamp MT-G MR16 Reference Design"[1] to describe a design for a 20 W - 25 W MR16 replacement lamp. The XM-L EasyWhite LED has a smaller footprint than the MT-G and allows development of an MR16 replacement bulb for lower lumen density applications.

Though this application note focuses on the XM-L EZW LED, Cree offers a family of EasyWhite (EZW) products that can be applied to MR16 and related applications.

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

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DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide"[2] Cree advocates a six step framework for creating LED luminaires and lamps. We use this framework, with the design guide's summary table reproduced below.

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

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

THE 6-STEP METHODOLOGY

The main goal of this project was to demonstrate the ease of developing a replacement for halogen MR16 bulbs currently on the market, showing that an equivalent 20-W – 25-W MR16 bulb can be made available at a reasonable cost. The project was framed as a retrofit, so this project's MR16 bulb can be used in installed track lighting and fixtures.

1. DEFINE LIGHTING REQUIREMENTS

The table below lists important characteristics to consider for the design of the MR16 in this reference design.

Importance	Characteristics	Units
Critical	light intensity	CBCP (foot-candles)
	beam angle (FWHM)	degrees
	electrical power	watts (W)
	luminous flux	lumens (lm)
	form factor	per ANSI C78.21.2003
	bulb-to-bulb consistency	
Important	price	$
	lifetime (L_{70})	hours
	operating temperatures	°C
	operating humidity	% RH
	correlated color temperature (CCT)	°K
	color rendering index (CRI)	100-pt scale
	driver power factor	
	manufacturablilty	

Table 1: Target MR16 luminaire characteristics

Measurement of 20-W halogen MR16 lamps purchased from a home improvement store provides basic benchmark data.

Source	Measured Power (W)	Luminous Flux (Lm)	Efficacy (Lm/W)	CBCP (cd)	Beam Angle (°)	CCT (K)
MR16 A	20.78	280	13.5	420	36	2900
MR16 B	21.17	254	12.0	455	30	2780
MR16 C	20.66	260	12.6	950	22	2780

Table 2: Benchmark halogen MR16 data

Measurement of these MR16 halogen lamps shows the inconsistency of the beam angles. The graphs in Figure 2 show the measured data, normalized to show the light distribution for the comparison halogen lamps. The data show variation in the peak intensity locations and beam shape. This application note shows that an XM-L EZW based MR16 significantly improves on these light distributions, creating a repeatable beam of the same intensity.

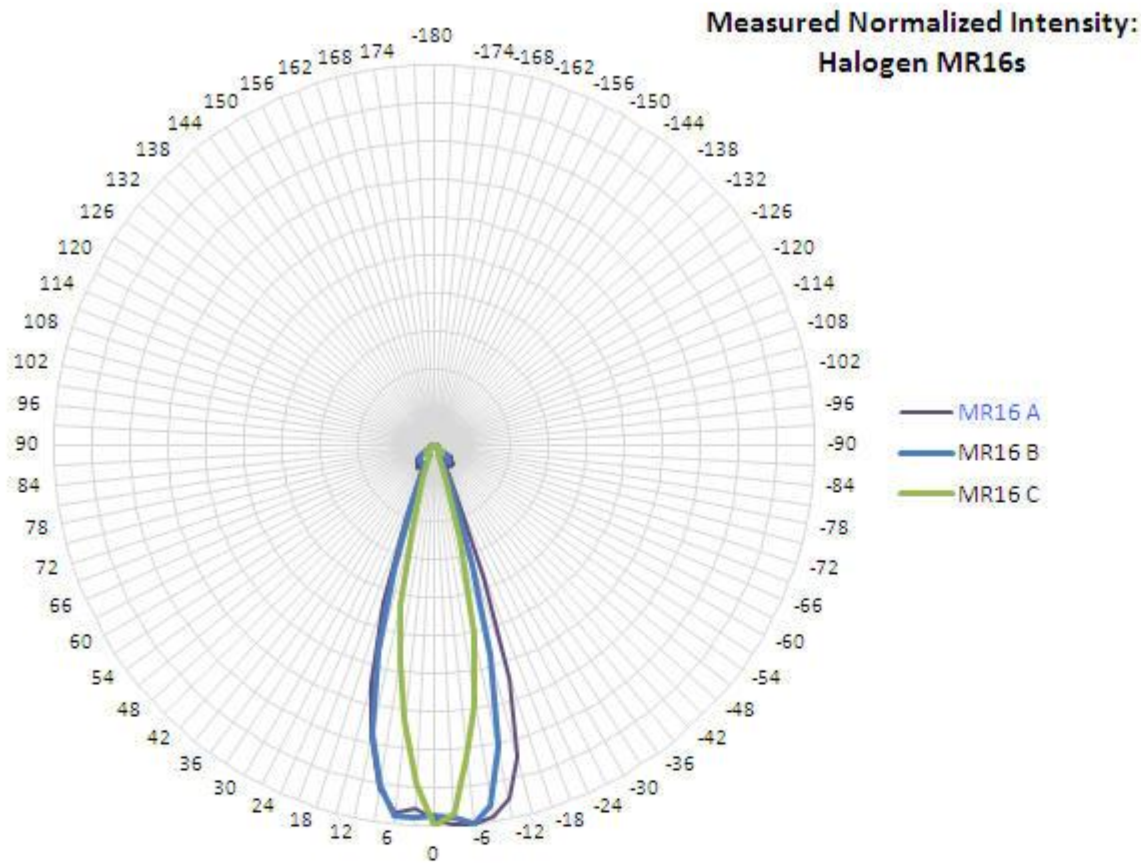

Figure 2: Measured goniometric intensity polar plot of halogen MR16

Data from the Energy Star *Program Requirements for Integral LED Lamps* gives us additional performance requirements.[3]

General Energy Star Luminaire Requirements:		
Correlated Color Temperature (CCT)	The luminaire must have one of the following designated CCTs and fall within the 7-step chromaticity quadrangles as defined in the Appendix.	
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 of chromaticity over the minimum lumen maintenance test period (6000 hours) shall be within 0.007 on the CIE 1976 (u’,v’) diagram.	
Color Rendering Index (CRI)	Minimum CRI (Ra) of 80. In addition, the R9 value must be greater than 0.	
Dimming	Lamps may be dimmable or nondimmable. 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.	
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	Integral LED lamps must meet the appropriate FCC requirements for consumer use (FCC 47 CFR Part 15).	
Audible Noise	Integral lamp shall have a Class A sound rating.	
Transient Protection	Power supply shall comply with IEEE C.62.41-1991, 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.	

3 http://www.energystar.gov/ia/partners/product_specs/program_reqs/ILL_prog_reqs.pdf

2. DEFINE DESIGN GOALS

The design goals for this project:

Characteristic	Unit	Minimum Goal	Target Goal
Luminaire Light Output	Lm	250	280
Illuminance/Luminance Profile		Same	Better
Power	W	<5	<5
Beam Angle	°	36	36
Center Beam Candle Power (CBCP)	Cd	470	490
Lifetime	Hours	25,000	50,000
CCT	K	3,000	3,000
CRI		80	85
Bulb-to-bulb consistency		< 4-step McAdams Ellipse	< 2-step McAdams Ellipse

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

Component Efficiency

For the the 6-V and 12-V version of XM-L EZW LED, figure 3 shows their basic LED electrical data and optical output from Cree's Product Characterization Tool.[4]

Current (A)	LED 1				LED 2			
	Model: Cree XLamp XM-L 6V (EZW)				Model: Cree XLamp XM-L 12V (EZW)			
	Flux: T6 (280)		Tsp (°C): 65		Flux: T6 (280)		Tsp (°C): 65	
	Price: $ -				Price: $ -			
	LED lm	LED lm/W	LED Vf	LED W	LED lm	LED lm/W	LED Vf	LED W
0.100	50	94.3	5.34	0.53	95	87.2	10.88	1.09
0.150	73	90.1	5.39	0.81	137	82.5	11.07	1.66
0.200	95	87.2	5.44	1.09	178	79.1	11.25	2.25
0.250	116	84.7	5.49	1.37	217	75.9	11.42	2.86
0.300	137	82.5	5.54	1.66	254	73.2	11.57	3.47
0.350	158	81	5.58	1.95	289	70.5	11.72	4.1
0.400	178	79.1	5.62	2.25	322	67.9	11.85	4.74
0.450	198	77.6	5.67	2.55	353	65.5	11.98	5.39
0.500	217	75.9	5.71	2.86	382	63.1	12.09	6.05
0.550	235	74.4	5.75	3.16	410	61.2	12.19	6.7
0.600	254	73.2	5.79	3.47	436	59.2	12.29	7.37
0.650	271	71.7	5.82	3.78	459	57.1	12.37	8.04
0.700	289	70.5	5.86	4.1	482	55.3	12.44	8.71
0.750	305	69	5.89	4.42	502	53.5	12.5	9.38
0.800	322	67.9	5.93	4.74	521	51.9	12.55	10.04
0.850	337	66.5	5.96	5.07	538	50.3	12.59	10.7
0.900	353	65.5	5.99	5.39	553	48.6	12.63	11.37
0.950	368	64.3	6.02	5.72	567	47.2	12.65	12.02
1.000	382	63.1	6.05	6.05	580	45.8	12.66	12.66

Figure 3: Cree's Product Characterization Tool with XLamp XM-L EZW data

4 http://pct.cree.com

Thermal Requirements

An XLamp XM-L EZW LED operating at 5 or more watts of power, at steady state temperature, needs a heat sink to dissipate the thermal load. In an LED-based MR16 design, the heat sink must not only dissipate the heat generated by the LED, but also provide a mechanical frame for the LED, optic, driver and base and, to be an MR16 retrofit, fit into the ANSI-standard enclosure defined in ANSI C78.24-2001. To demonstrate the ease of creating a high quality XM-L EZW MR16 retrofit lamp, Cree chose an off-the-shelf heat sink from Neng Tyi Precision Industries Co., Ltd.[5] for this design.

Drive Electronics

For this reference design, Cree did not attempt to be compatible with all 12V transformers, instead choosing a commonly available electronic transformer, the Lightech[6] LET 60 LW, a low-wattage transformer compatible with both LED and incandescent MR16s.

The design for the MR16 driver used a design from Diodes, Inc.[7] based on their AL8806 controller. The driver efficiency was calculated to be 81.1%.

Secondary Optics

The baseline CBCP intensity was determined from the Energy Star Integral LED Lamp Center Beam Intensity Benchmark Tool (ed. 7/6/2010).

Cree's collaboration with Carclo Technical Plastics Ltd., a division of Carclo plc,[8] produced a 30-mm TIR lens compatible with the XM-L EZW LED that fit in the heat sink and was greater than 93% efficient.

4. CALCULATE THE NUMBER OF LEDS

One.

The purpose of this reference design was to show the ease of using a single XM-L EZW LED package to deliver equivalent illumination and better efficacy than halogen bulbs on the market. The XLamp XM-L EZW LED is a multi-chip LED package that can offer the CBCP required of an MR16 replacement bulb with improved LED-to-LED consistency and efficiency.

5 Neng Tyi website: http://www.nengtyi.com.tw
6 Lightech Electronic Industries, Ltd. website: http://lightechinc.com
7 Diodes, Incorporated's website: http://www.diodes.com/zetex/cree
8 Carlo website: http://www.carclo-optics.com

5. CONSIDER ALL DESIGN POSSIBILITIES

There are innumerable ways to design a retrofit MR16 bulb. Using Cree's MT-G MR16 reference design as a guide, Cree selected components that result in a 20 W - 25 W halogen MR16 replacement bulb, fulfilling the primary design goal—to show the ease of designing such a bulb with Cree's XLamp XM-L EZW LED.

The XM-L EZW LED brings a number of benefits to the design. Because of the XM-L LED's EasyWhite technology, LED-to-LED color consistency is guaranteed to within two or four MacAdam ellipses (for a given CCT and depending on the order codes). The XM-L EZW LED has a CRI minimum of 80, with higher CRI available, and is binned at 85° C, so the CCT will be as faithful as possible to the system environment. These features enable new levels of specification accuracy.

6. COMPLETE THE FINAL STEPS: IMPLEMENTATION AND ANALYSIS

Prototyping Details

The assembly of the XM-L EZW LED with the heat sink, optics and driver followed the steps detailed in Cree's MT-G reference design. The components are shown in Figure 4. The result is a 20 W - 25 W halogen MR16 replacement.

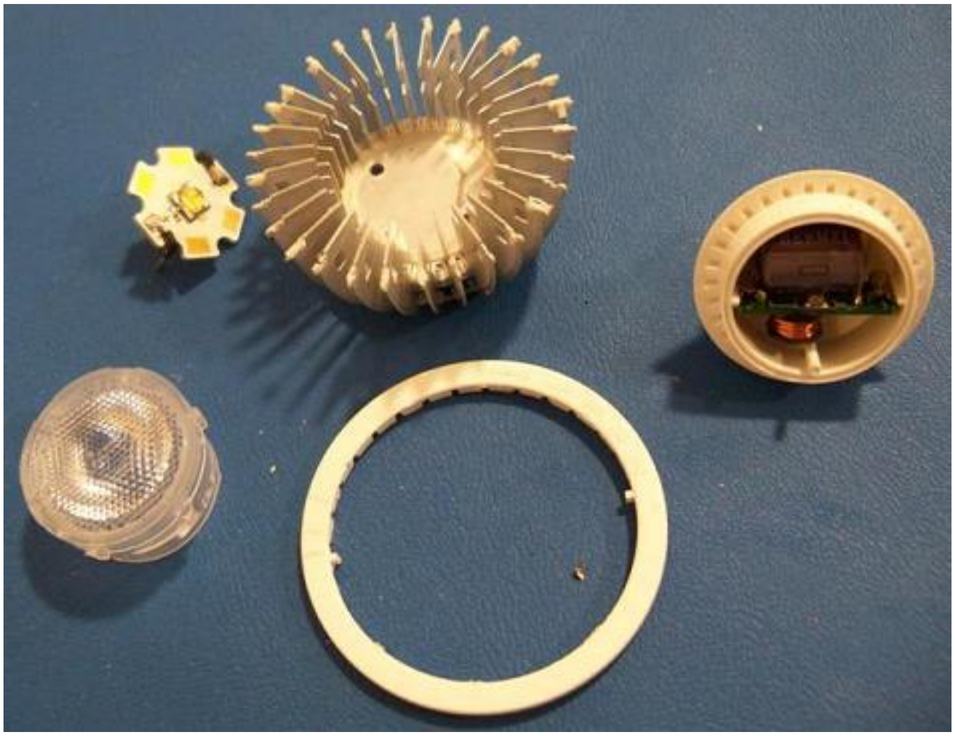

Figure 4: XM-L EZW MR16 components

Results

Thermal results:

Infrared images[9] indicate that the maximum surface temperature of the lamp is 54 –55° C.

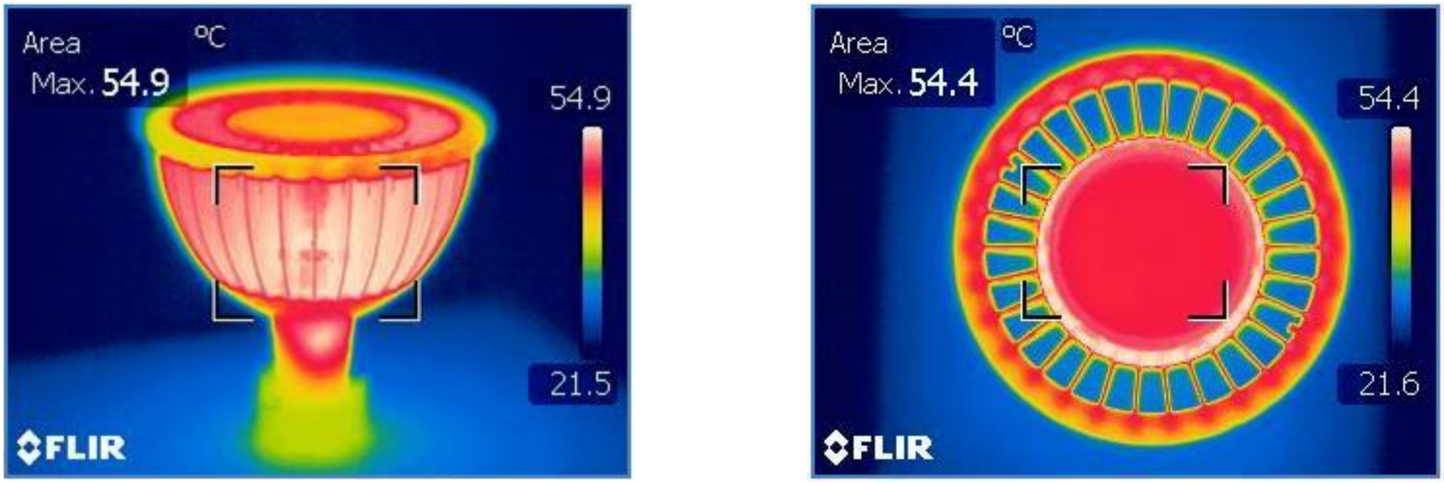

Figure 5: Thermal images

Figure 6 shows the measured solder point temperature (Tsp) and ambient temperature (Ta) over a 40-minute period. Based on the measured solder point temperature, the operating wattage of the LED and the typical thermal resistance of 2.5°C/W for the XML-EZW LED, the junction temperature (Tj) was calculated to be 76.8 °C.

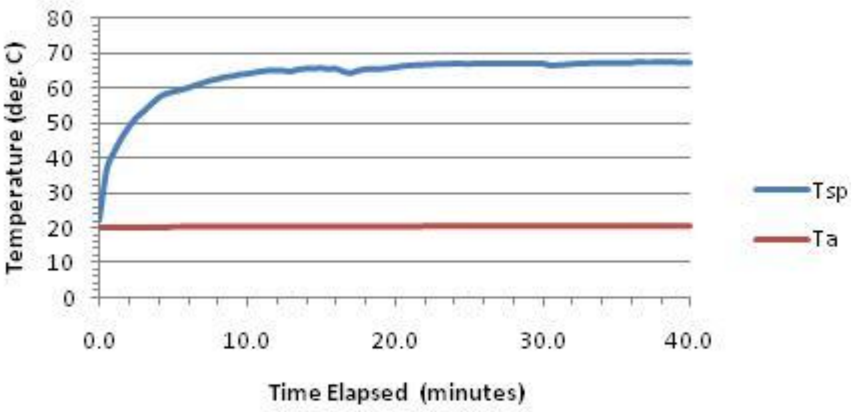

Figure 6: Solder point and ambient temperature of XM-L EZW MR16

Optic Results:

The optic results for the XM-L EZW MR16 show a beam angle of 36° and an optic efficiency of 93.4%. The graph in

9 Photographs were taken using a FLIR T300 at Cree's facility in Durham, NC.

Figure 7 shows the measured intensity data, normalized to show the light distribution for the XM-L EZW MR16 lamp. The data show consistent beam shape and light distribution, with the same intensity as comparison halogen lamps.

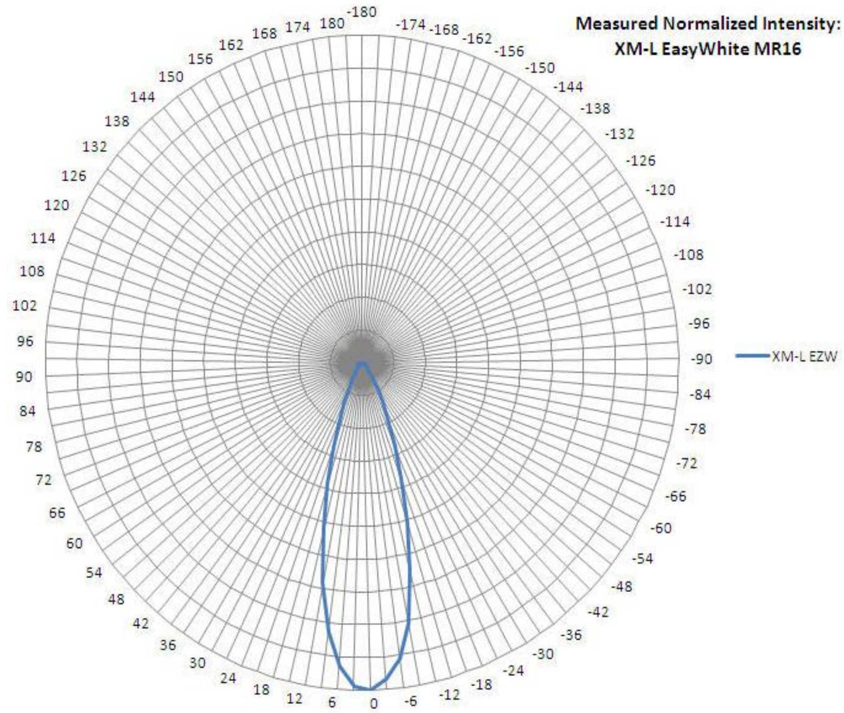

Figure 7: Measured goniometric intensity polar plot of XLamp XM-L EZW MR16

The data in Table 3 demonstrate that a 20 W MR16 halogen replacement that meets Energy Start requirements is possible with a single XM-L EZW LED.

LED	Light Output (lm)	Power (W)	Efficacy (lm/W)	Beam Angle (°)	CBCP (cd)	CCT	CRI	Tsp (°C)
6-V XM-L EZW	275	4.76	57.6	36	620	2990	82	67.1

Table 3: System test data, steady state

This design was able to achieve 20 W MR16 halogen equivalency based on the Energy Star requirements. The measured CBCP was 620 cd, above the minimum 496 cd required for a 36° beam. The lumen output was 275 lumens at steady state. Figure 8 shows the beam profile and intensity distribution.

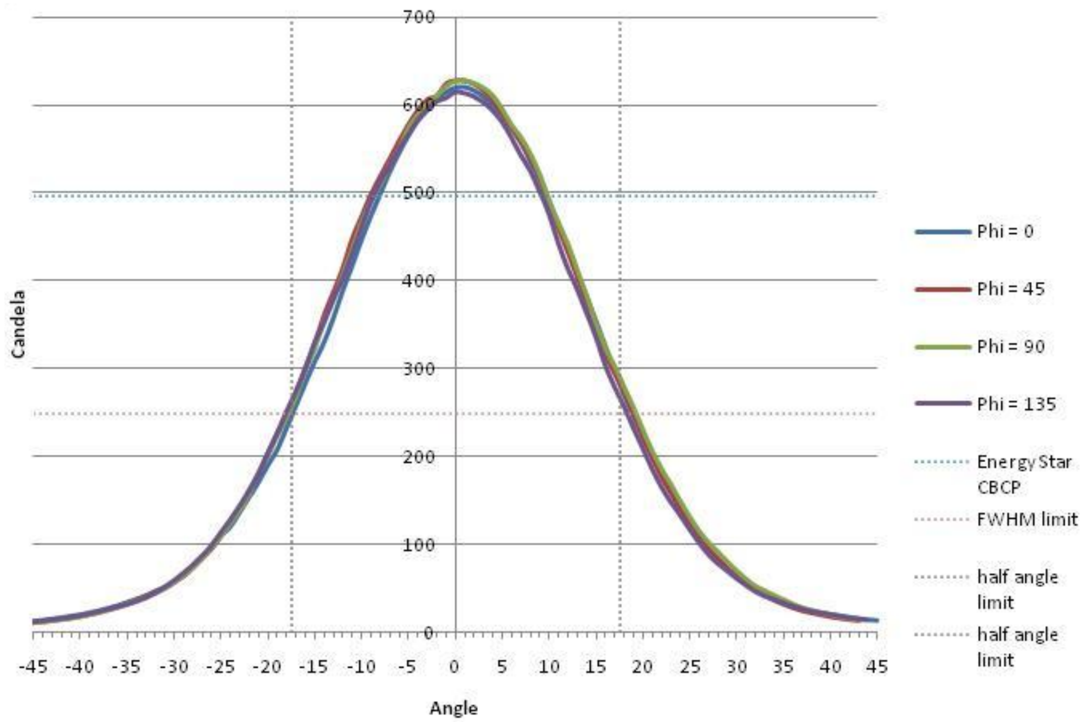

Figure 8: Measured intensity distribution of 20 W equivalent XM-L EZW MR16

CONCLUSIONS

The goal of the design was to enable an LED-based MR16 replacement retrofit bulb that delivers performance equivalent to 20-W – 25-W halogen MR16s and conforms to Energy Star requirements. This reference design demonstrates the ease of incorporating a Cree XLamp XM-L EZW LED into a conventional MR16 housing and meets the Energy Star requirements for a 20-W – 25W MR16 replacement. This document shows that this level of performance can be achieved with a single XM-L EZW LED but should not be interpreted as the only way that a good MR16 replacement can be designed.