

Cree® XLamp® MX-6 LED A19 Lamp Reference Design



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INTRODUCTION

Like all replacement bulbs, LED-based A-19 retrofit lamps pose many engineering challenges. Among these are delivering a light distribution and chromatic profile equivalent or superior to comparable incandescent lamps while dissipating the thermal load of LEDs delivering several hundred lumens.

This application note describes the design of a 40 W equivalent A19 retrofit lamp based on the Cree XLamp MX-6 family of LEDs. This lamp has been designed for the Asian market and associated emerging national standards. It is a cool white bulb with a lower Color Rendering Index (CRI) which also makes it a device not suitable for current European or American national standards. We created two versions of the lamp, one with the MX-6A package, having 4 LEDs connected in parallel, and one with the MX-6S package, having 4 LEDs connected in series, providing an opportunity to compare the performance of two physically identical but electrically different LED packages and associated drivers.

DESIGN APPROACH/OBJECTIVES

In the “LED Luminaire Design Guide”¹ 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

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

THE 6-STEP METHODOLOGY

The goal of this reference design is a 40-W-equivalent, A19 retrofit lamp. This design uses Cree XLamp MX-6 family LEDs combined with open-market tooling, optics and drivers and focuses on creating a snow-cone-type A19 retrofit lamp.

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	Luminous flux	Lumens (lm)
	Efficacy	Lumens per watt (lm/W)
	Illuminance distribution	Footcandles (fc)
	Color uniformity	
	Form factor	
Important	Price	\$
	Lifetime	Hours
	Operating temperatures	°C
	Operating humidity	% RH
	Correlated Color Temperature (CCT)	K
	CRI	100-point scale
	Manufacturability	
	Ease of installation	

Table 2: Ranked design criteria for a 40-W, A19 retrofit lamp

Because this reference design targets the Asian market, we benchmarked the Korean KSC7651² and Japanese JIS C 7501³ standards, excerpted in Table 3 and Table 4 below.

From the Korean standard:

CCT (K)	CCT Tolerance	CRI
6500	7040-6020	70
5700	6020-5310	70
5000	5310-4745	70
4500	4746-4260	70
4000	4260-3710	70
3500	3710-3220	70
3000	3220-2870	70
2700	2870-2580	70

Table 3: Korean KSC7651 standard excerpt

2 KSC7651 www.standard.go.kr/CODE02/USER/0B/03/SerKS_View.asp#

3 JIS C 7501 www.techstreet.com/cgi-bin/basket?action=add&item_id=3749386

From the Japanese standard:

Power	Luminous flux
25 W	230 lm
40 W	440 lm
50 W	600 lm
60 W	760 lm
75 W	1000 lm
100 W	1430 lm

Table 4: Japanese JIS C 7501 excerpt

2. DEFINE DESIGN GOALS

The design goals for this project:

Characteristic	Unit	Minimum Goal	Target Goal
Light output	lm	440	> 440
Power	W	< 10	8
Luminaire efficacy	lm/W	> 45	56
Lifetime	Hours	50,000	50,000
CCT	K	5000	5000
CRI		70	> 70
Power factor		0.55	> 0.7
Maximum ambient temperature	°C	30	40

Table 5: Design goals

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

LED Component Performance

This reference design is based on Cree’s MX-6 product family. The MX-6 LED has a variety of efficacies depending on color temperature, bin, and drive conditions. The non-directional light output of the MX-6 is ideal for an A19 lamp design; a snow-cone diffuser can further improve lighting uniformity and give the lamp an even lighting effect. Considering overall system efficiency and cost, we based designs on the MX-6A and MX-6S LEDs, highlighted in yellow in Figure 1. The difference in driver current and voltage showcase the strengths of each component and illustrate the importance of choosing a component designed for a specific application.

Color	CCT Range		Base Order Codes Min Luminous Flux (lm) @ 300 mA	
	Min.	Max.	Group	Flux (lm)
Cool White	5,000 K	8,300 K	Q5	107
			R2	114
			Q4	100
			Q5	107
80-CRI White	3,700K	4,300K	Q2	87.4
			Q3	93.9
	2,600K	3,700K	P4	80.6
			Q2	87.4
Warm White	3,700 K	4,300 K	Q3	93.9
			Q4	100
	2,600 K	3,700 K	Q2	87.4
			Q3	93.9

Color	CCT Range		Base Order Codes Min Luminous Flux (lm) @ 60 mA	
	Min.	Max.	Group	Flux (lm)
Cool White	5,000 K	8,300 K	R3	122
			R4	130
			R2	114
			R3	122
80-CRI White	2,600K	4,300K	Q4	100
			Q5	107
			Q3	93.9
			Q4	100
Warm White	3,700 K	4,300 K	Q5	107
			R2	114
	2,600 K	3,700 K	Q4	100
			Q5	107

Figure 1: Binning options for MX-6A (left) and MX-6S (right)

Thermal Requirements

Despite LED’s inherent efficacy advantage over conventional incandescent or fluorescent lighting, up to 75% of the input power is converted to heat. This heat must be dissipated (conducted) efficiently to ensure LED lumen maintenance and reliability. For a 40 W equivalent A19 retrofit lamp, we estimate the total power to be dissipated to be around 8 W. For this power level, there are many existing thermal solutions from which to choose. For this reference design, Cree chose an existing well-designed cast aluminum heat sink with good workmanship.⁴ Our simulation and actual test results confirmed this as a good choice for this retrofit lamp.



Figure 2: Aluminum heat sink

Cree’s thermal simulation⁵ of the MX-6A design with an input power of 8 W resulted in a solder point temperature estimate of ~60 °C. This is in reasonable agreement with the actual measurement of 68 °C from our thermocouple steady-state measurement. Figure 3 shows the thermal simulation of the solder point temperature. Figure 4 shows the thermal simulation of the airflow, in the form of convection currents, around the MX-6A A19 lamp. We did not simulate both versions since we do not expect a significant difference in thermal performance for the MX-6S LED implementation.

⁴ The heat sink is from a How Nice Optoelectronics A19 bulb, www.haolisi.com/en/3pro.asp

⁵ Cree used NIKA EFD Pro with Pro Engineering Wildfire
www.mentor.com/products/mechanical/products/floefd/
www.ptc.com/products/creo-elements-pro/

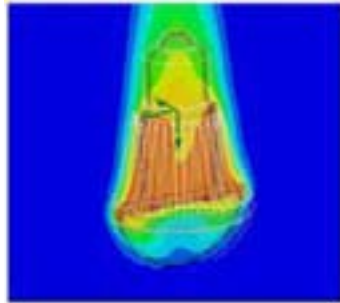


Figure 3: Thermal simulation of temperature of MX-6 A19

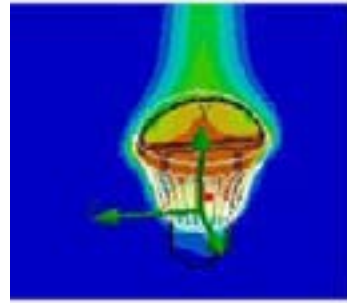


Figure 4: Thermal simulation of airflow around MX-6 A19

Drive Electronics

The choice of driver for an A19 retrofit lamp is constrained by the need for the driver to fit within the limited space of the A19 housing. We used two drivers for the A19 lamp designs, a low-voltage, high-current driver for the MX-6A lamp and a low-current, high-voltage driver for the MX-6S lamp. Because of the high-voltage nature of MX-6S LED, its driver is expected to have higher efficiency. For safety concerns, we limited our design to isolated power designs.

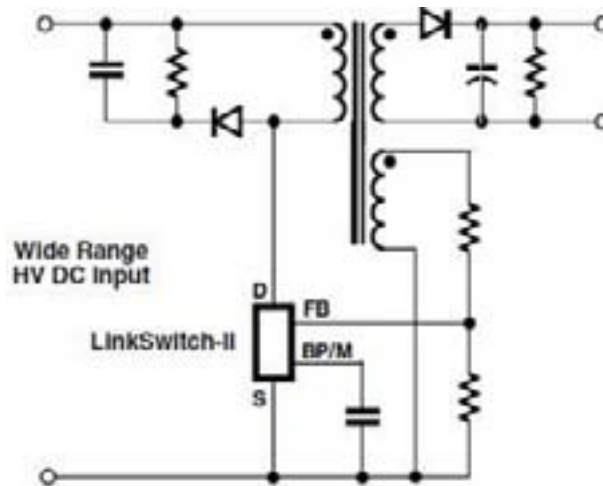


Figure 5: General circuit design for MX-6 driver

Both power supplies use a flyback design. The power factor for each of these drivers is above 0.5, and both were designed to fit in the form factor of an A19 lamp.

Figure 6 shows that the driver for the MX-6S lamp is appreciably smaller than the driver for the MX-6A lamp.

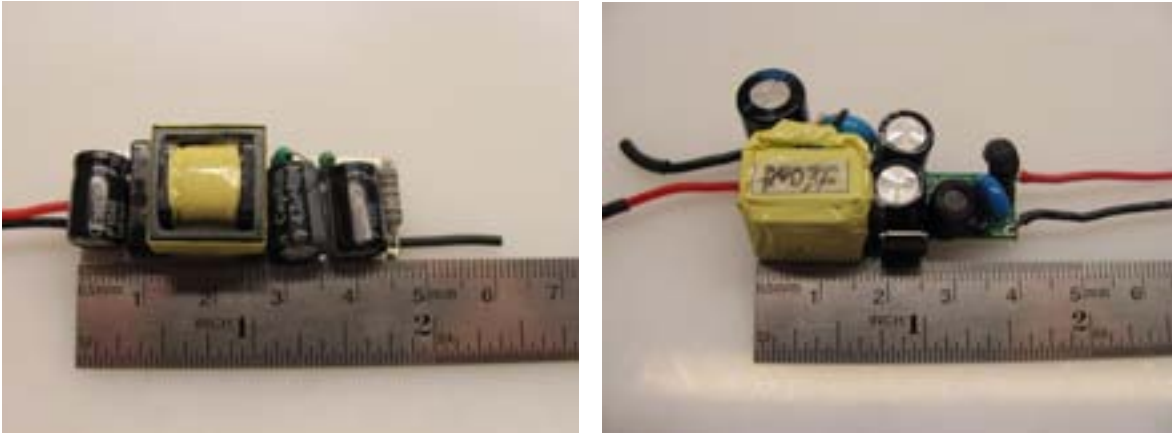


Figure 6: Drivers for MX-6A (left) and MX-6S (right)

Secondary Optics

Uniformly distributed lighting is a key requirement for an LED-based A19 retrofit lamp. The secondary optics must diffuse the light from the LED and distribute it evenly and uniformly, giving an effect of a diffuse source rather than a bright hot spot. Good secondary optics contribute to both brightness and color uniformity without a great sacrifice in optical efficiency. The three sample diffusing domes we evaluated all were 85% efficient. That is, there was a 15% loss of signal when using a diffusing dome. Figure 7 shows an example of a diffuser used in an LED lamp to achieve a uniform lighting effect.



Figure 7: Diffuser example

4. CALCULATE THE NUMBER OF LEDS

We used Cree’s Product Characterization Tool (PCT)⁶ to estimate the number of LEDs to be used, specifying parameters such as light output and limitations of driver and optical efficiency. Due to the different LED arrangements in the MX-6A and MX-6S packages, we paid special attention to the bin from which we selected the LEDs. We wanted to compare the two lamps and, because the binning conditions are different, the power levels are also different.

As shown in Figure 8 and Figure 9, we chose to use four MX-6A LEDs from the Q5 flux bin (order code MX6ASWT-A1-2B0-Q5) and four MX-6S LEDs from the R4 flux bin (order code MX6SWT-A1-3C0-R4) for the two A19 retrofit lamps.

System:		Target Lumens :			450			Optical Efficiency:			85%			Electrical Efficiency:			75%		
Current (A)	LED 1										LED 2				LED 3				
	Model Cree XLamp MX-6 {CW/WW}										Model Cree XLamp MX-6 {CW/WW}				Model (none)				
	Flux Q5 [107]					Tsp (°C) 70					Flux Q4 [100]		Tsp (°C) 70		Flux		Tj (°C) 25		
	Price \$ -										Price \$ -				Price \$ -				
	SYS #	LED	SYS lm tot	SYS W	LED Vf	SYS #	LED	SYS lm tot	SYS W	LED Vf									
0.100	16		462.3	5.92	2.78	17		459	6.29	2.78									
0.110	15		473.6	6.15	2.8	16		472.2	6.56	2.8									
0.120	14		479.3	6.31	2.82	15		479.9	6.76	2.82									
0.130	13		479.5	6.39	2.83	14		482.6	6.88	2.83									
0.140	12		474	6.39	2.85	13		479.9	6.92	2.85									
0.150	11		463.1	6.32	2.87	12		472.2	6.89	2.87									
0.160	11		491.6	6.78	2.89	11		459.5	6.78	2.89									
0.170	10		472.6	6.59	2.91	11		485.8	7.25	2.91									
0.180	10		498	7.03	2.93	10		465.4	7.03	2.93									
0.190	9		471.1	6.72	2.95	10		489.2	7.46	2.95									
0.200	9		493.7	7.11	2.96	9		461.4	7.11	2.96									
0.210	8		458.7	6.68	2.98	9		482.3	7.51	2.98									
0.220	8		478.5	7.04	3	9		503.1	7.92	3									
0.230	8		498.1	7.4	3.02	8		465.5	7.4	3.02									
0.240	7		453	6.8	3.03	8		483.8	7.77	3.03									
0.250	7		469.9	7.12	3.05	8		501.9	8.14	3.05									
0.260	7		486.7	7.45	3.07	7		454.8	7.45	3.07									
0.270	7		503.3	7.78	3.09	7		470.4	7.78	3.09									
0.280	7		519.8	8.11	3.1	7		485.8	8.11	3.1									
0.290	6		459.6	7.24	3.12	7		501.1	8.44	3.12									
0.300	6		473.7	7.52	3.14	7		516.5	8.78	3.14									
0.350	5		451.4	7.5	3.21	6		506.2	9	3.21									
0.400	5		505.8	8.77	3.29	5		472.7	8.77	3.29									
0.450	5		557.7	10.09	3.36	5		521.2	10.09	3.36									
0.500	4		486	9.15	3.43	4		454.2	9.15	3.43									
0.550	4		523.9	10.25	3.49	4		489.6	10.25	3.49									
0.600	4		559.9	11.37	3.55	4		523.3	11.37	3.55									
0.650	4		594.2	12.52	3.61	4		555.4	12.52	3.61									
0.700	3		469.9	10.25	3.66	4		585.6	13.67	3.66									

Figure 8: Cree’s PCT with MX-6A data

6 Cree’s Product Characterization Tool. <http://pct.cree.com/>

System:		Target Lumens :			450			Optical Efficiency:			85%			Electrical Efficiency:			75%		
Current (A)	LED 1					LED 2					LED 3								
	Model Cree XLamp MX-6S {CW/WW}					Model Cree XLamp MX-6S {CW/WW}					Model (none)								
	Flux R4 [130] Tsp (°C) 70					Flux R3 [122] Tsp (°C) 70					Flux (none) Tj (°C) 25								
	Price \$ -					Price \$ -					Price \$ -								
	SYS #	LED	SYS lm tot	SYS W	LED Vf	SYS #	LED	SYS lm tot	SYS W	LED Vf									
0.020	13		467.7	5.85	16.86	14		472.7	6.3	16.86									
0.030	9		466.8	6.28	17.44	10		486.7	6.97	17.44									
0.040	7		469.7	6.71	17.98	8		503.8	7.67	17.98									
0.050	6		490	7.4	18.49	6		459.9	7.4	18.49									
0.060	5		477.9	7.59	18.98	6		538.2	9.11	18.98									
0.070	5		544.2	9.07	19.44	5		510.7	9.07	19.44									
0.080	4		485.7	8.47	19.86	4		455.8	8.47	19.86									
0.090	4		533.6	9.73	20.26	4		500.7	9.73	20.26									
0.100	4		578.7	11	20.63	4		543.1	11	20.63									
0.110	3		465.9	9.23	20.97	4		583	12.3	20.97									
0.120	3		496	10.21	21.28	3		465.5	10.21	21.28									
0.130	3		524.2	11.21	21.56	3		491.9	11.21	21.56									
0.140	3		550.5	12.22	21.82	3		516.7	12.22	21.82									
0.150	3		574.9	13.23	22.04	3		539.5	13.23	22.04									
0.160	3		597.6	14.23	22.24	3		560.8	14.23	22.24									
0.170	3		618.3	15.24	22.41	3		580.3	15.24	22.41									

Figure 9: Cree’s PCT with MX-6S data

Table 6 shows the characteristics of the MX-6 LEDs selected for this A19 reference design.

Component	Bin	Light Output	Test Current	Vf at Test Current	Power	Efficacy
MX-6A	Q5	107 lm	300 mA	3.3 V	0.99 W	108.7 lm/W
MX-6S	R4	130 lm	60 mA	20 V	1.2 W	108.3 lm/W

Table 6: MX-6A and MX-6S characteristics

With both designs having the same number of LEDs, efficacy and light emission pattern, this design effort is a good comparison of the two different driver-design efficiencies. The results can serve as a reference on MX-6A and MX-6S performance in overall luminaire designs.

5. CONSIDER ALL DESIGN POSSIBILITIES

Due to the vast quantity of A19 retrofit designs and parts available in the market, our team tried a number of combinations of available heat sinks, optics, and driver solutions. We finally chose to use an A19 kit from Shenzhen How Nice Optoelectronics Co., Ltd. that includes a heat sink, metal core printed circuit board (MCPCB), E27 screw base, and optical diffuser.⁷ The diffuser in this kit has a measured efficiency of 85%. Secondary-optics efficiency can reach 90%; however, since the primary function of this diffuser is to mix light and even out any hot spots, more internal mixing would cause a decrease in efficiency. We believe this optical efficiency is acceptable in this reference design. We believe that increased efficiency is possible in a custom design.

⁷ Kit model HLS-F60, website: www.haolisi.com/en/3pro.asp

We chose drivers from TXM Power Co. Ltd.⁸ and Gain High Ltd.⁹ The general specifications are shown in Table 7. The specifications were rather straightforward for the low-voltage design; the current is determined by the PCT calculation and the voltage is greater than the forward voltage of four LEDs connected in series. For the high-voltage design, we did not connect all four MX-6S LEDs in series; we made two strings of two LEDs connected in series then connected the two strings in parallel. The LED voltage of the MX-6S LEDs connected this way is about 40 V.

Driver Design	LED	Arrangement	Output Voltage	Output Current	Vendor
High current, low voltage	MX-6A	4 LEDs in series	13.7 V	450 mA	TXM Power Co. Ltd.
High voltage, low current	MX-6S	2 parallel strings of 2 LEDs in series	38.2 V	165 mA	Gain High Ltd.

Table 7: Driver specifications

6. COMPLETE THE FINAL STEPS: IMPLEMENTATION AND ANALYSIS

The methodology described above determined a suitable combination of MX-6 LEDs, components and drive conditions. This section describes how we assembled two A19 retrofit lamps and compares their performance with our targets for a 40 W equivalent A19 retrofit lamp for the Asian market. This section also includes a comparison of the driving schemes for the two reference designs.

Prototyping Details

1. We verified the component dimensions to insure a correct fit.
2. Following the recommendations for the XLamp MX family LEDs,¹⁰ we reflow soldered the LEDs onto the MCPCB with an appropriate solder paste and reflow profile. We cleaned the flux residue with isopropyl alcohol.
3. We applied a thin layer of thermal conductive compound to the back of MCPCB and secured it to the heat sink with the screws provided.
4. We inserted the driver into the lamp housing, fed the DC output wires through the thru-hole and soldered them to the corresponding terminal pads on the MCPCB.
5. We soldered the driver input wires to the E27 base wires' power connection. We tested the connection by applying power to the E27 base and checked that the LEDs were lit.
6. After the functional check, we assembled the lamp housing and the E27 base. This kit uses a snap-in design. Other kit designs may vary.
7. We screwed on the diffuser cap.
8. We performed final testing.

⁸ TXM Power Co. Ltd. <http://www.ledpower.com.cn>

⁹ Gain High Ltd. <http://www.gainhigh.com>

¹⁰ "Cree XLamp MX Family Soldering & Handling" http://www.cree.com/products/pdf/XLampMX_SolderingAndHandling.pdf

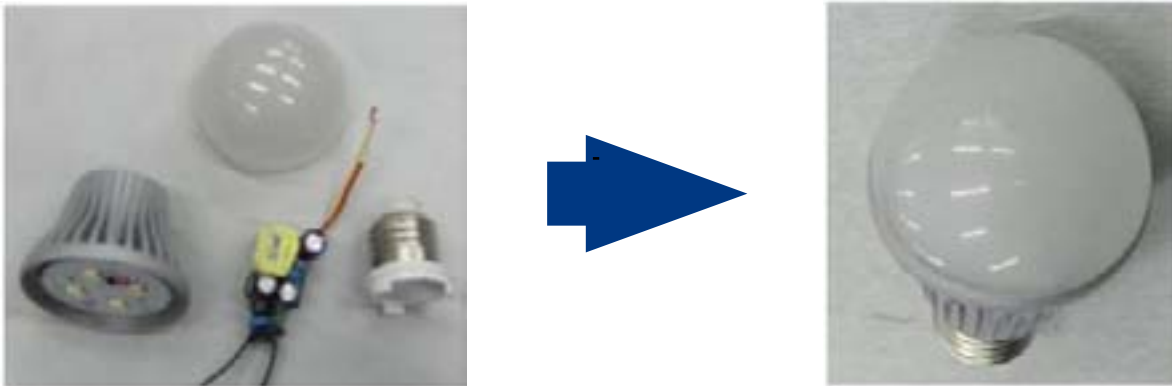


Figure 10: Assembly of components to become an A19 retrofit lamp

Results

Thermal Results

Cree verified that the thermal dissipation performance of the heat sink aligns with our simulation. As shown in Figure 11, a thermocouple was secured to an LED with Arctic Silver thermal epoxy to measure the solder point temperature. The steady-state solder point temperature of 68 °C shown in Figure 12 demonstrates that the thermal housing is sufficient for this design. An infrared thermal image of the lamp at steady state, shown in Figure 13, also verified the temperature is within our design estimate.



Figure 11: Thermocouple attached to MX-6 LED



Figure 12: MX-6 A19 solder-point temperature measurement



Figure 13: Steady-state infrared thermal image of MX-6 A19 lamp

Based on the measured solder-point temperature (T_{sp}), the operating wattage of the LED and the typical thermal resistance of 5 °C/W for the MX-6 LED, the resulting junction temperature (T_j) was calculated to be 78 °C.

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

$$T_j = 68 \text{ °C} + 2 \text{ W} * 5 \text{ °C/W}$$

$$T_j = 78 \text{ °C}$$

Based on Cree’s LM-80 testing of the MX-6 LED and using industry standard extrapolation methods, Cree expects this A19 lamp to achieve a lifetime of at least 50,000 hours.¹¹

Visual Performance

Figure 14 is a plot of the luminous distribution in the 0 to 150 degree zone for the MX-6 snow-cone retrofit lamp along with the distribution for a typical compact fluorescent lamp (CFL) and an incandescent lamp. By design, the snow-cone lamp is more “forward directing” than the omnidirectional CFL and incandescent lamps. The luminous distribution curve in Figure 14 also shows a smooth change over the viewing angle, giving an evenly lighted surface. The full width half medium (FWHM) of the distribution is about 140 degrees. We believe this is acceptable for a lamp that is mounted upside down in many ceiling fixture applications, in which lighting the ceiling is not a critical requirement. This design also gives an even color distribution, as shown in the CCT distribution plot in Figure 15 and the photograph in Figure 16. In summary, this design meets the optical requirement targets for this design.

¹¹ After 50,000 hours of operation, in a well designed system, the LED will still deliver at least 70% of its initial luminous flux.

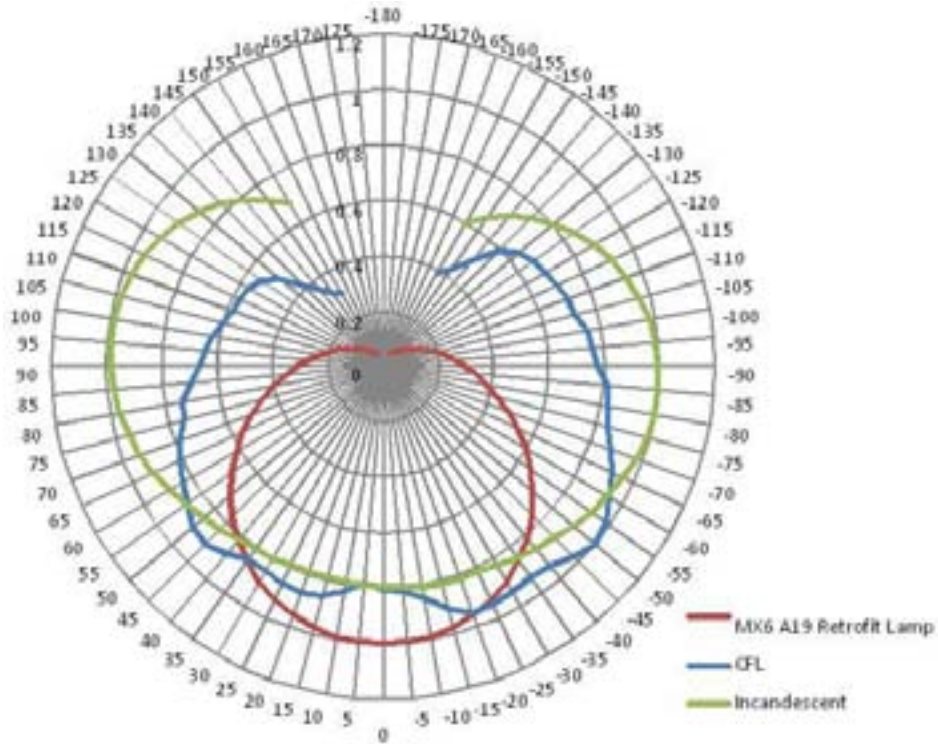


Figure 14: Normalized luminous distribution comparison

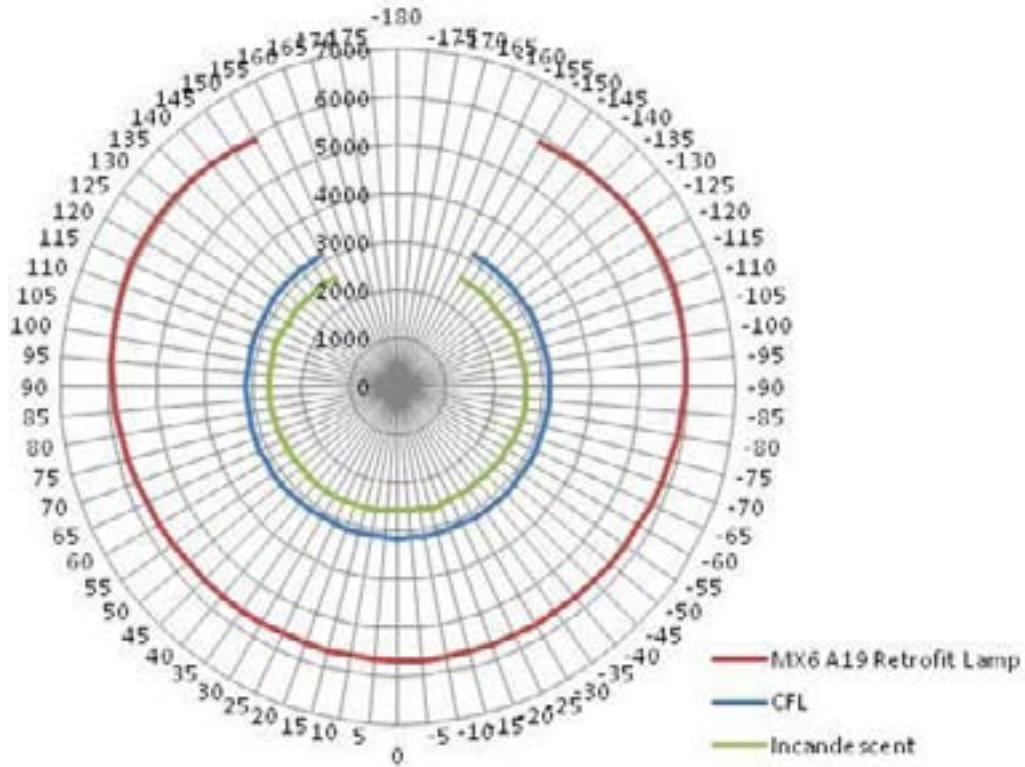


Figure 15: CCT uniformity comparison



Figure 16: Lighting effect of MX-6 A19 retrofit lamp on a white wall background

Optic results

Cree tested both designs for lumen output in a 500-mm integrating sphere.¹² We waited ten minutes to allow the lamps to reach steady-state before measurement. Table 8 summarizes the test results. We note that the light output from the MX-6A lamp is slightly below the 450-lm target, despite the unit producing 450 lm in an instant-on measurement. The thermal lumen depreciation at elevated temperatures can be improved by a better heat-sink design. Another solution is to increase the output current to 485 mA; however, due to the time required to incorporate a new driver, we did not pursue this option because the MX-6S design met the light output requirement. Another reason for the shortcoming is the actual diffuser efficiency is 85% rather than 90% in the PCT estimate.

¹² Measured in an integrating sphere at Cree’s facility in Santa Barbara, CA.

Characteristic	Unit	MA-6A	MA-6S
Light output (10 min on time)	lm	410	451
Current	mA	462	165
Power	W	8.6	7.9
Efficacy	lm/W	47.7	57
CCT	K	5951	4922
Lifetime	hours	50,000	50,000
CRI		71.4	68.9

Table 8: MX-6 A19 retrofit lamp optical results

Compared to the MX-6A lamp, the MX-6S lamp offers advantages in light output, current and efficacy. In addition, the high-voltage MX-6S lamp can operate with smaller and higher efficiency drivers.

All the benefits of using the MX-6S LED are not reflected in PCT data. In an article in the February, 2011, issue of *LEDs Magazine*, Matthew Reynolds of National Semiconductor shows that using high-voltage LEDs results in lower operating temperatures of driver electronics, presenting the possibility of drivers that are more efficient and reliable.¹³ In the PCT analysis in Figure 17, a 6% increase in driver efficiency, from 80% to 85%, delivers an equivalent 6% improvement in efficacy.

Improvement Opportunities

We estimated the results of one potential improvement in the MX-6S A19 retrofit lamp. The PCT was configured to use the data measured for the MX-6S lamp: target lumens of 450, 85% optical efficiency, 80% electrical efficiency and T_{sp} of 68°C. Using the 8.6-W power level of the MX-6A lamp to utilize the “spare” power available to the MX-6S LED, we extrapolated an increase in the lumen output to 525, a 7% improvement while maintaining the CCT and A19 form factor.

Figure 17 is an estimate of the results of using warm-white MX-6S LEDs to achieve a warmer CCT than that of the cool-white LEDs used in the design. The figure presents data for warm-white LEDs from the Q5 and Q4 flux bins in comparison to data for the cool-white LED used in the design. The PCT was again configured to use the data measured for the MX-6S lamp: target lumens of 450, 85% optical efficiency and 80% electrical efficiency and T_{sp} of 68 °C. The data show that power greater than 10 W is required to achieve 450 lumens. The drive current must increase to 100 mA for the Q5 LED and to 110 mA for the Q4 LED. The higher T_{sp} for the warm white LEDs reflects one result of the higher power level. At this power level, the Q4 LED efficacy value drops to 40 lm/W, below the target for this design but possibly acceptable if color temperature is more important than efficacy.

¹³ Reynolds, Matthew, “High LED Drive Currents with Low Stack Voltages Create Efficiency Challenges,” *LEDs Magazine*, February, 2011, pp 53-59.

System:		Target Lumens : 450				Optical Efficiency: 85%				Electrical Efficiency: 80%					
Current (A)	LED 1					LED 2					LED 3				
	Model	Cree XLamp MX-6S {CW/WW} x2				Model	Cree XLamp MX-6S {CW/WW} x2				Model	Cree XLamp MX-6S {CW/WW} x2			
	Flux	R4 [130]	Tsp (°C)	68	Flux	Q5 [107]	Tsp (°C)	80	Flux	Q4 [100]	Tsp (°C)	85			
Price	\$ -				Price	\$ -				Price	\$ -				
	SYS # LED	SYS lm tot	SYS W	SYS lm/W	SYS # LED	SYS lm tot	SYS W	SYS lm/W	SYS # LED	SYS lm tot	SYS W	SYS lm/W			
0.020	14	506.7	5.92	85.6	16	459.5	6.67	68.9	18	475.6	7.45	63.8			
0.030	10	521.8	6.55	79.6	12	496.7	7.76	64	12	457	7.71	59.3			
0.040	8	540.1	7.21	74.9	10	535.5	8.89	60.2	10	492.6	8.84	55.7			
0.050	6	493	6.95	70.9	8	521.4	9.15	57	8	479.6	9.1	52.7			
0.060	6	577	8.56	67.4	6	457.6	8.45	54.2	8	561.3	11.21	50.1			
0.070	6	657	10.22	64.3	6	521	10.1	51.6	6	479.2	10.05	47.7			
0.080	4	488.7	7.96	61.4	6	581.2	11.8	49.3	6	534.5	11.74	45.5			
0.090	4	536.9	9.14	58.8	6	638.4	13.54	47.1	6	587.1	13.47	43.6			
0.100	4	582.3	10.33	56.3	4	461.5	10.21	45.2	6	636.6	15.25	41.8			
0.110	4	625.1	11.55	54.1	4	495.4	11.42	43.4	4	455.5	11.37	40.1			
0.120	4	665.5	12.79	52	4	527.3	12.65	41.7	4	484.8	12.59	38.5			
0.130	4	703.3	14.04	50.1	4	557.2	13.89	40.1	4	512.3	13.82	37.1			
0.140	4	738.7	15.3	48.3	4	585.1	15.13	38.7	4	537.9	15.06	35.7			
0.150	4	771.4	16.56	46.6	4	610.9	16.38	37.3	4	561.6	16.31	34.4			
0.160	4	801.9	17.82	45	4	635	17.63	36	4	583.7	17.55	33.3			
0.170	4	829.7	19.08	43.5	4	656.9	18.88	34.8	4	603.8	18.79	32.1			

Figure 17: PCT data for warm white MX-6S LEDs

Driver-Circuit Comparison

We employed two driver circuit designs for the MX-6 LEDs in this reference design. Table 9 is a summary of the results. They are both primary feedback flyback designs and current accuracy and inherent loss are very similar. The power required to run the MX-6S driver is about 9% less than that for the MX-6A driver, as shown in the efficiency difference. There are two main losses in the MX-6A driver design compared to the MX-6S design: a large voltage drop and a high current loss. The large voltage differential can be viewed as similar to transformer conversion efficiency: the larger the differential, the larger the loss. For the high current loss, the output power loss can be stated simply as:

$$P_{\text{loss}} = I^2 \times R$$

where R = total internal resistance
 I = output current

When the output current increases, power loss also increases. This is a simple explanation of the efficiency difference and the reason for creating a high-voltage version of the MX-6 component, thereby presenting an opportunity to optimize other system components to increase overall system efficiency.

Characteristic	4 MX-6A LEDs in Series	4 MX-6S LEDs in 2 Parallel Strings of 2 LEDs in Series
Input voltage	220 VAC	220 VAC
Input power	8.6 W	7.9 W
Output current	462 mA	165 mA
Output voltage	13.7 V	38.2 V
Power factor	0.58	0.55
Efficiency	73.6%	79.8%
Current ripple	38%	12%

Table 9: MX-6A and MX-6S LED-driver results comparison

CONCLUSIONS

In this reference design, we accomplished the goal to design a 40-W equivalent, A19 retrofit lamp for the Asian market using the Cree XLamp MX-6A and MX-6S high-power LEDs. Using four MX-6A and MX-6S LEDs, the snow-cone lamps are comparable to a traditional A19 incandescent lamp but use 80% less power and offer a lifetime of more than 50,000 hours.

Our tests showed that the components used in this design satisfied most of our requirements and provide reasonable performance for a reference design. Improvement in every aspect of the design can be made by applying resources to optimize each of the optical, thermal and electrical components. Moreover, comparing the MX-6A and MX-6S A19 lamps reveals that the MX-6S LED offers the possibility of reducing other system-component limitations to further increase system efficiency. This is an example of a design that presents opportunities for enhancement to reach higher performance levels.