Cree® XLamp® MP-L EasyWhite™ Pendant Luminaire Reference Design

This application note demonstrates a remarkably simple way to incorporate the Cree XLamp® MP-L EasyWhite™ LED into a pendant light, a popular hanging luminaire that has traditionally used A-form incandescent bulbs and more recently self-ballasted CFLs.

Pendant lights are not particularly efficient fixtures to begin with. When used with colored glass shades, large fractions of flux from the illumination source are absorbed by the shade. The fixtures offer a pleasing "glow" and "look" and so enjoy considerable popularity, even with the inherent loss of light. However, when used with a frosted white shade, an XLamp MP-L-based pendant can be an Energy Star-conformant SSL luminaire.

Luminaire design with the XLamp MP-L EasyWhite LED sets a new standard for ease of use in LED specification, design and implementation, giving an attractive, energy-efficient and compelling result.

In presenting this design, our team has sought to create a luminaire with a 50,000-hour lifetime, created through a low-power/high-efficacy instrumentation of the LED. We created these pendant prototypes without a great deal of thermal and electrical analysis at the beginning. Rather, we took educated guesses at many of the required parameters and performed our analysis after the fact. The XLamp MP-L EasyWhite pendant is so easy to work with that this approach produced dramatic results with just a few days of effort.

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DESIGN APPROACH/OBJECTIVES

In the "LED Luminaire Design Guide,"[1] Cree advocates a six-step framework for creating LED luminaires. 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.

THE 6-STEP METHODOLOGY

The major requirement and goal for this project was to create an easy-to-implement, high efficiency lamp that "looks" indistinguishable from a conventionally illuminated pendant. We framed the project as a retrofit, so implementers can take advantage of the substantial art-glass shades, mounting brackets, trim and wiring components currently used in production pendants and fixtures.[2]

1. Define Lighting Requirements

In a general requirements framework, a collection of desirable attributes or characteristics are ranked.

1 "LED Luminaire Design Guide," Application Note CLD-AP15, www.cree.com/products/pdf/LED_Luminaire_Design_Guide.pdf
2 Among the samples we created, we used a Portfolio brand Recessed Light Conversion Kit #0266578

Importance	Characteristics	Units
Critical	Luminaire Luminous flux	Lumens (lm)
	Illuminance distribution	Footcandles (fc)
	Electrical power	Watts (W)
	Aesthetics	
Important	Price	$
	Lifetime	Hours
	Operating temperatures	ºC
	Operating humidity	% RH
	Color temperature	K
	CRI	100-point scale
	Manufacturablilty	
	Ease of installation	
	Form factor	

Table 1: Some ranked design criteria for an LED luminaire project

In our case, photometric testing of an incandescent lamp pendant lamp gives us basic requirements data.

Source	Luminaire Power (W)	Luminous Flux (Lm)	Efficacy (Lm/W)	CCT
Incandescent, No Shade	60	669	11.2	2701
Incandescent + Red Art-Glass Shade	60	140	2.3	-
Incandescent + White Art-Glass Shade	60	460	9.1	2612

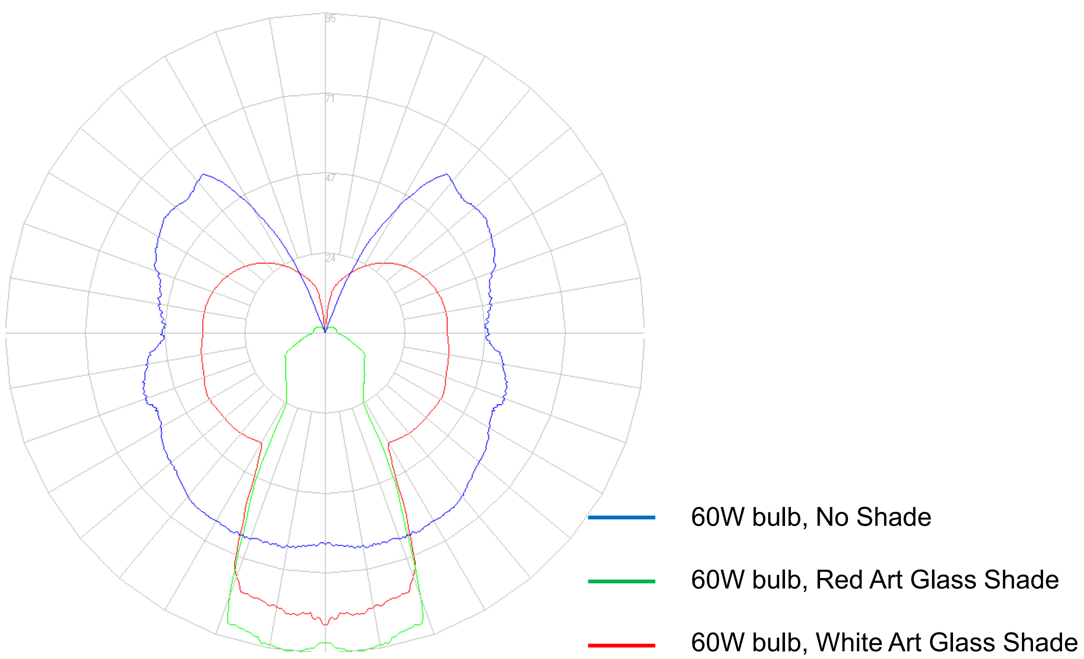


Figure 2: Goniometric intensity polar plot of incandescent pendant

Data from the Energy Star Program Requirements for Solid State Lighting Luminaires gives us additional performance requirements.[3]

General Energy Star Luminaire Requirements[4]:	
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	CCT (K)
2700 K	2725 ± 145
3000 K	3045 ± 175
3500 K	3465 ± 245
Color Spatial Uniformity	The variation of chromaticity in different directions (i.e., with a change in viewing angle) shall be within 0.004 from the weighted average point on the CIE 1976 (u′,v′) diagram.
Color Maintenance	The change of chromaticity over the lifetime of the product shall be within 0.007 on the CIE 1976 (u′,v′) diagram.
Color Rendering Index (CRI)	Indoor luminaires shall have a minimum CRI of 75.
Off-state Power	Luminaires shall not draw power in the off state.
Warranty	A warranty must be provided for luminaires, covering repair or replacement of defective electrical parts (including light source and power supplies) for a minimum of three (3) years from the date of purchase. For residential products, the written warranty must be included with the luminaire packaging at the time of shipment.
Thermal Management	Luminaire manufacturers shall adhere to device manufacturer guidelines, certification programs, and test procedures for thermal management.

And pendant-specific data:

Application Requirements[5]	
Maximum Allowable Luminaire Aperture	Luminaire aperture must be less than or equal to 8 inches in diameter (if circular) or on any side (if rectangular).
Minimum Light Output	≤ 4.5″ Aperture: 345 lumens (initial) > 4.5″ Aperture: 575 lumens (initial)
Zonal Lumen Density Requirement	Luminaire shall deliver a minimum of 75% of total lumens (initial) within the 0-60° zone (bilaterally symmetrical).
Minimum Luminaire Efficacy	35 lm/W
Allowable CCTs	2700 K, 3000 K and 3500 K

With this information we can set some objective criteria: the XLamp MP-L EasyWhite pendant implementation must meet all the basic metrics above.

3 http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energystar_sslcriteria.pdf
4 Ibid., p3
5 Ibid., p8

2. Define Design Goals

The design goals for this project:

Characteristic	Unit	Minimum Goal	Target Goal
(Red Glass) Luminaire Light Output	Lm	140	140
(White Glass) Luminaire Light Output	Lm	460	500
Illuminance Profile	Fc	Identical	
Power	W	<<60	10
(Red Glass) Luminaire Efficacy	Lm/W	>>2.3	10
(White Glass) Luminaire Efficacy	Lm/W	35	50
Lifetime	Hours	25,000	50,000
CCT	K	3,000	2,700
CRI		75	85
Max ambient temperature	ºC	30	
BOM Cost	$	80	70

We arrived at the estimated BOM targets because we prototyped with pendants that are commonly available from home improvement warehouses. These units typically retail for $30 - $60 for a single pendant/socket configuration. Our goal is to add the LED, heat sink and driver for about $45 in low-volume configurations.

3. Estimate Efficiencies of the Optical, Thermal & Electrical Systems

Optical Efficiency

The MP-L EasyWhite pendant has a variety of efficacies depending on color temp. Based on the initial data, we chose to work with the EasyWhite at 2700K, highlighted below, to give the closest possible CCT to an incandescent bulb. These parts, running at 120 mA, delivers less total flux than a 60-W incandescent A-style bulb, but the directionality of the source, with a 125° beam spread, would direct more flux towards the pendant opening, as compared to the spherical illuminance profile of the incandescent bulb.

Color	CCT Range	Base Order Codes Min Luminous Flux (lm)		Order Code
		Group	Flux (lm)	
EasyWhite	4,000 K	C0	800	MP-LEZW-A1-0000-0000C040F
		D0	900	MP-LEZW-A1-0000-0000D040F
	3,500 K	B0	700	MP-LEZW-A1-0000-0000B035F
		C0	800	MP-LEZW-A1-0000-0000C035F
	3,000 K	B0	700	MP-LEZW-A1-0000-0000B030F
		C0	800	MP-LEZW-A1-0000-0000C030F
	2,700 K	B0	700	MP-LEZW-A1-0000-0000B027F

Figure 3: Order codes from MP-L EasyWhite data sheet

The MP-L EasyWhite pendant has three strings of LEDs. The basic electrical data and optical output is listed below.[6] By running the MP-L EasyWhite pendant at 150 mA, 70 VDC, we can match the flux of an incandescent bulb, consuming only 10.5 watts of power.

Compare: LED lm | LED lm/W | LED Vf | LED W

System: Target Lumens : 700 | Optical

LED 1

Model: Cree XLamp MPL 3S {EZW}

Flux: B0 [700] | 700.0

Price: $ - | Tj (ºC) | 25

LED Multiple: x1

Current (A)	LED lm	LED lm/W	LED Vf	LED W
0.100	569	79.4	71.73	7.17
0.110	585	73.4	72.44	7.97
0.120	601	68.5	73.12	8.77
0.130	617	64.3	73.77	9.59
0.140	633	60.7	74.4	10.42
0.150	649	57.7	75	11.25
0.160	665	55	75.57	12.09
0.170	681	52.6	76.12	12.94
0.180	697	50.5	76.64	13.8
0.190	714	48.7	77.13	14.65
0.200	730	47	77.59	15.52

Figure 4: Cree's Product Characterization Tool with XLamp MP-L flux data

After some experimentation we chose to drive the XLamp MP-L pendant at 120 mA and to drive the three strings in parallel. This choice was driven by our desire to use under 10 watts of power while delivering roughly the same luminous flux as the equivalent incandescent version.

Thermal Requirements

The XLamp MP-L EasyWhite pendant dissipates between 10-20 watts of electrical power, depending on drive current, and requires a heat sink to dissipate this thermal load.

In this pendant design, the heat sink has three functions, primarily to dissipate the thermal load of the LED, but also to provide a frame for, or to directly support, the pendant shade and deliver wiring support/stress relief for the LED. We chose to work with machined aluminum to provide a series of large-scale circular cooling fins and to have a male-threaded section that could work with a plastic flange to hold a the pendant shade securely.

6 The analysis came from Cree's Product Characterization Tool.

Figure 5: A picture of the machined aluminum heat sink

We designed the heat sink to its multi-functional requirements (thermal loading, pendant support and wiring-stress relief) and performed thermal analysis after first prototypes were machined from 4” segments of 2”-diameter round aluminum stock.

To verify the utility of this design, we performed thermal simulations in Ansys.[7] Shown below is a simulation showing a cross section the heatsink and pendant shade at 120, 150 and 250 mA at steady state in a 25 °C ambient operating environment. The highest temperature in the simulation is at the solder point, the LED/heat sink boundary and at 120 and 150 mA never goes above 72 °C. With heat sink thermal dissipation like this, the design will have no trouble achieving a 50,000-hour L70 lifetime.[8]

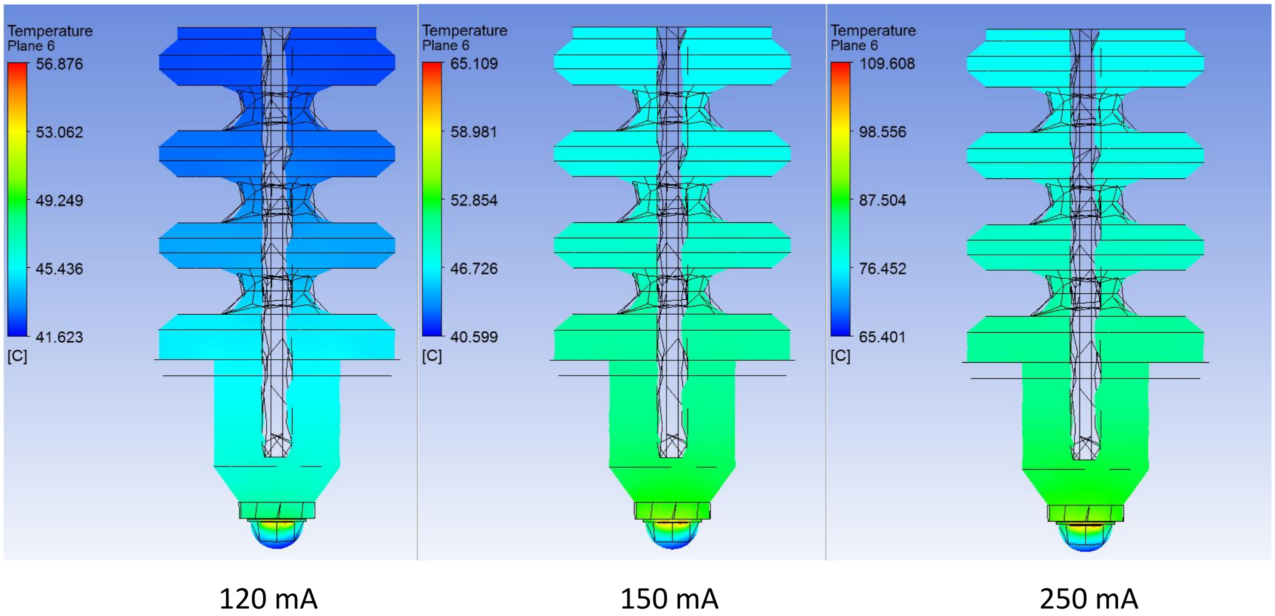


Figure 6: Ansys thermal simulations. Note the different temperature scales associated with each illustration

7 Cree used Ansys Design Space, http://www.ansys.com/products/structural-mechanics/products.asp

8 That is, after 50,000 hours of operation, in a well-designed system the LED will still deliver at least 70% of its initial luminous flux.

Data collected (below) from an MP-L heat-sink construction and driven at 120 mA show results and a gradient in line with the thermal simulations above.

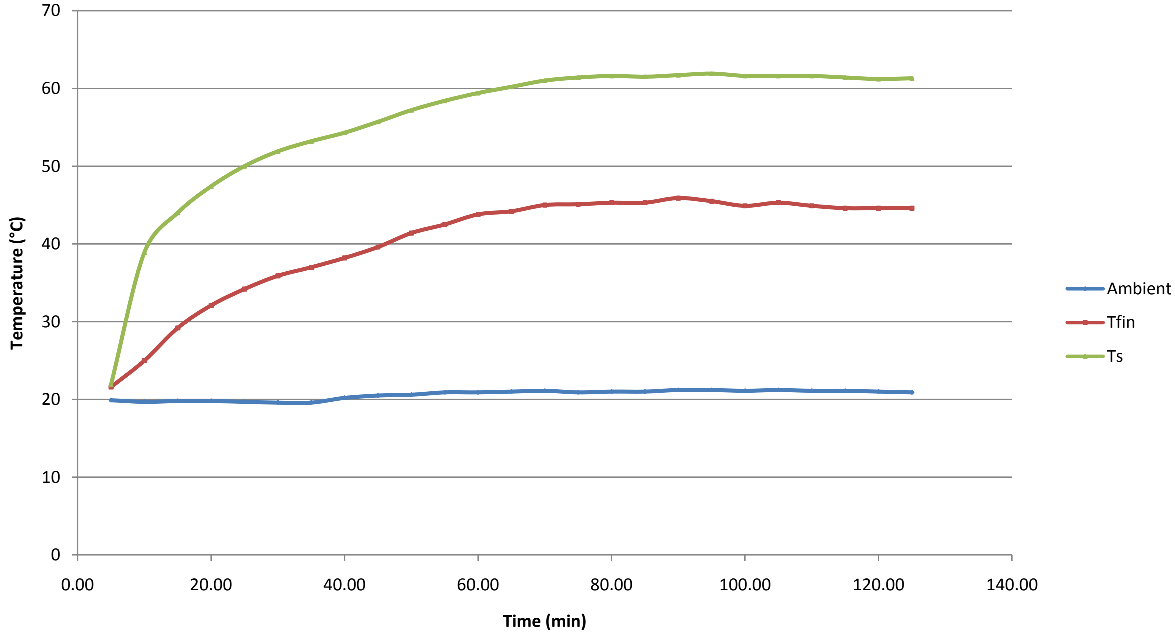


Figure 7: Thermal Performance of XLamp MP-L Pendant Lamp Driven at 120 mA

Drive Electronics

While there are many excellent suppliers of LED control electronics and many ways to deliver controlled DC power to the XLamp MP-L EasyWhite pendant, we chose a readily available, full-range, off-the-shelf, non-dimmable power supply from MagTech.9 We chose this part because it is already CE/UL-certified and available from multiple distributors. We measured several of these parts as being 82-90% efficient.

4. Calculate the Number of LEDs

One.

The purpose of this design exercise is to show that a single LED package can deliver equivalent lighting utility and superior efficacy. The XLamp MP-L EasyWhite LED is a multi-chip LED package that offers the light output of a light bulb and new levels of LED-to-LED color consistency.

9 Model LD-CU3536AF

5. Consider All Design Possibilities

The design possibilities for an LED pendant light are straightforward. The project is intended to be a minimal modification to an existing luminaire. The objective is to show how simple it is to start using the most sophisticated LEDs in luminaire design. Therefore

- Minimize the use of secondary optics (in this case none)
- Use a heat sink that fits in the design aesthetic and guarantees proper dissipation
- Use off-the-shelf drivers for the simplest possible wiring

The approach we document in the next section is one where we purchased off-the-shelf pendant luminaires and decorative glass shades from a major home improvement retailer. We removed the fittings associated with the 26-mm socket and replaced those with the fittings and heat sink required for the XLamp MP-L EasyWhite product. Finally, we placed the drive circuitry in the decorative metal trim that covers the ceiling bracket.

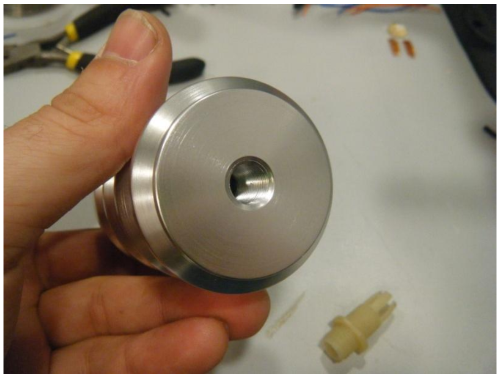
6. Complete the Final Steps: Implementation and Analysis

In this section we illustrate some of the techniques Cree used to create a variety of prototype pendants using the XLamp MP-L EasyWhite product and review the photometric results of the XLamp MP-L EasyWhite-based pendants in comparison to the original incandescent pendant.

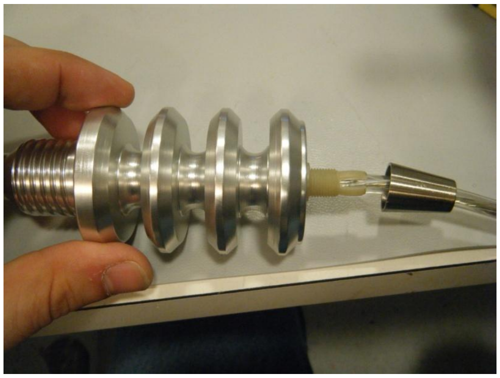
Prototyping Details

All of the design "finesse" comes in developing an appropriate wiring scheme for the XLamp MP-L EasyWhite pendant, coupling the LED effectively to the heat sink and integrating the heat-sink/LED assembly into the luminaire.

1. Mechanical considerations in the design of the heat sink:
   a. A through hole is the most convenient way to get the cable to run from the driver circuit to the LED.
   b. In addition to the through hole, we made a cavity to accommodate the LED wiring harness, described below.
   c. Strain relief, in the form of a compression fitting or equivalent on the top of the heat sink that will help to secure the heat sink and glass to the conductors/suspension cable. See pictures below:



Heat sink has been tapped for strain relief.



Heat sink shown with strain relief and compression cap.

Figure 8: Views of the heat sink

2. Once strain relief is mounted to heat sink, feed the cable through the strain relief and heat sink and remove some of the insulation to expose the conductors.
3. Because the MP-L LED has three strings of LED chips mounted in series, there are three pairs of conductors on the LED package. This design delivers equal power to each of the three circuits.
   a. So once the exposed cable has been drawn through the bottom end of the heat sink, we spliced three short segments onto each conductor. These six conductors will be attached to the cathode and anode pads, respectively.

Wire has been stripped back and has been fed through the strain relief and the heat sink exposing the wires at the end of the fixture.

Three orange positive and three blue negative wires have been attached to the main power in cable to allow for MPL product to be utilized in this application. Always solder and shrink wrap connections to prevent shorting.

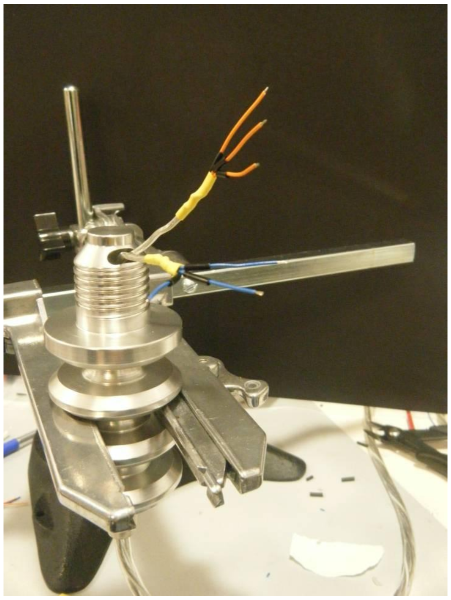
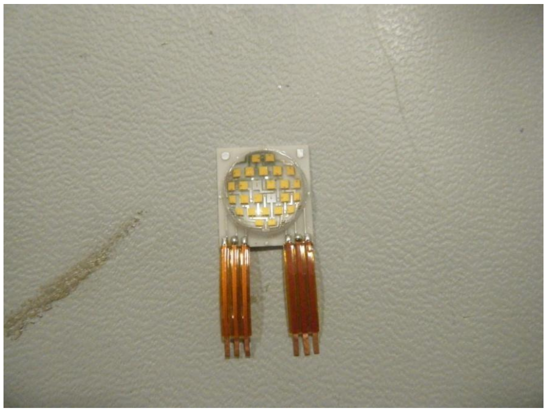


Figure 9: Wire management in the heat sink

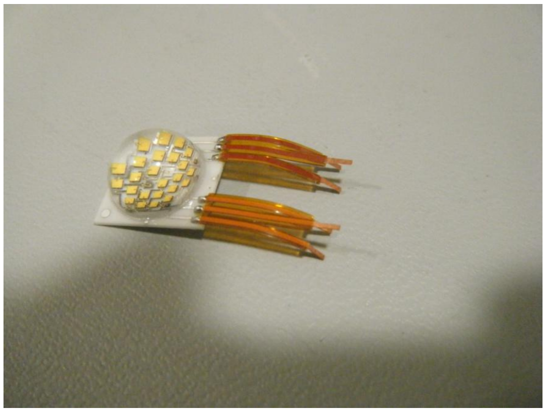
4. In order to make the wiring as simple as possible, we soldered 3-conductor ribbon cables to the cathode and anode pads.10 Once ribbon cable is soldered to the MP-L package you will need to split the legs on the ribbon cable to allow heat-shrink tubing to be placed over the power cable/ribbon cable joint.

    a. After the legs have been separated, we tinned the ends to allow for a good solder connection between the power and ribbon cables.

10 Cree looks forward to announcing a modular socket/interconnect part and supplier for the XLamp MP-L EasyWhite later this year.



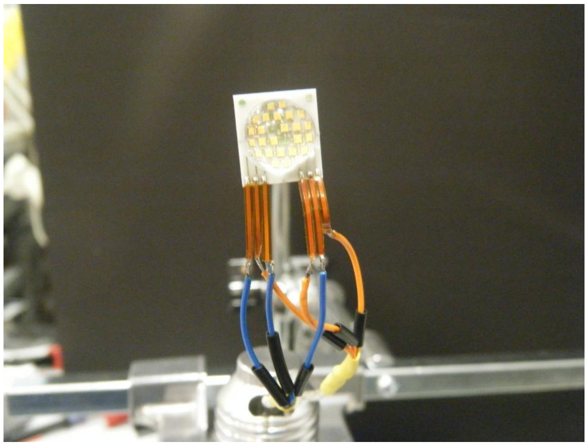
3-conductor ribbon cables soldered to the XLamp MP-L pads



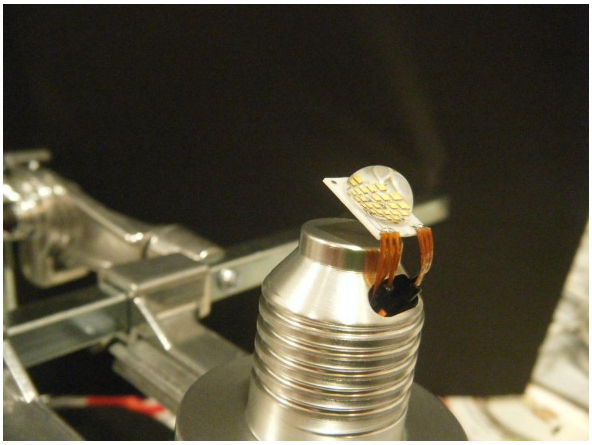
Ribbon cables with split legs

Figure 10: XLamp MP-L wiring "harness"

5. After electrical connection has been made and heat-shrink tubing to the XLamp MP-L LED, gently pull wires back through heat sink so that the XLamp MP-L LED will sit on the pedestal of the heat sink.



Ensure you have shrink wrap on each leg before soldering. Once wire have been soldered to ribbon cable, slide shrink wrap over connection and heat to shrink.



The XLamp MP-L LED should sit similar to this once wires have been pulled back through the heat sink.

Figure 11: Attaching the XLamp MP-L LED to the heat sink

6. The last step is to secure the XLamp MP-L LED to the heat sink pedestal. This can be done with thermally conductive epoxy or thermal tape. Cree recommends Arctic Silver[11] thermally conductive epoxy.

    a. A very small amount is needed to secure the XLamp MP-L LED to the heat sink

11 http://www.arcticsilver.com/arctic_silver_thermal_adhesive.htm

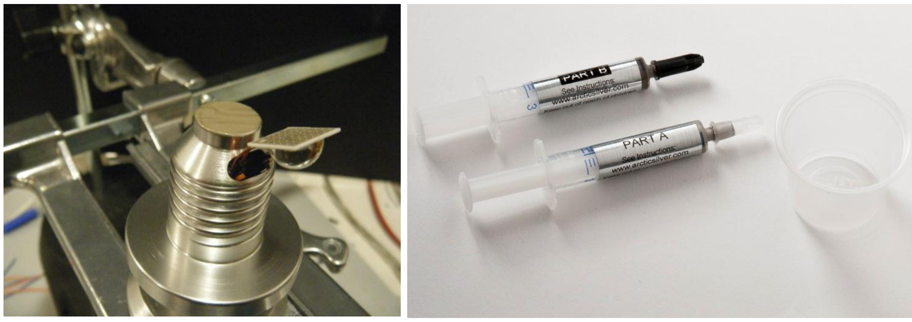


Figure 12: Use thermally conductive epoxy to secure the XLamp MP-L LED to the heat sink

7. Once the epoxy or tape has been applied, place the XLamp MP-L LED on the pedestal and secure the LED so the adhesive can cure. We used a segment of electrical tape with a protective shield over the dome of the LED.

8. After 15 minutes, the epoxy has set and the fixture is ready to be assembled, hung and powered up.

Figure 13: LED-drive electronics secured in ceiling receptacle cover

Figure 14: Powered up and ready to go

Figure 15: Finished XLamp MP-L EasyWhite pendant lamps

Results

We began this project with the observation that the XLamp MP-L LED was the first source that could replace a light bulb in a variety of applications. While we were building the first prototypes we sent incandescent pendant luminaires to an independent testing laboratory to establish performance benchmarks. At the end of the first prototyping cycle, we sent the XLamp MP-L Easywhite Pendant Luminaires to the same testing laboratory. The following data is from LM-79 reports from each of the configurations (bulb-only – no shade, red art-glass shade, white art-glass shade). The tabular data below, coupled with the candela plots that follow, show a compelling performance improvement for the XLamp MP-L-based luminaire.

Source	Luminaire Power (W)	Luminous Flux (lm)	Efficacy (lm/W)	CCT
Incandescent, No Shade	60.01	669	11.2	2701
Incandescent + Red Art-Glass Shade	60.02	140	2.3	
Incandescent + White Art-Glass Shade	58.47	460	9.1	2612
Cree MP-L EasyWhite, No Shade	9.75	494.5	50.8	2678
Cree MP-L EasyWhite+RedArt-Glass Shade	9.73	138.5	14.2	
Cree MP-L EasyWhite+White Art-Glass Shade	9.67	511.5	52.9	2691

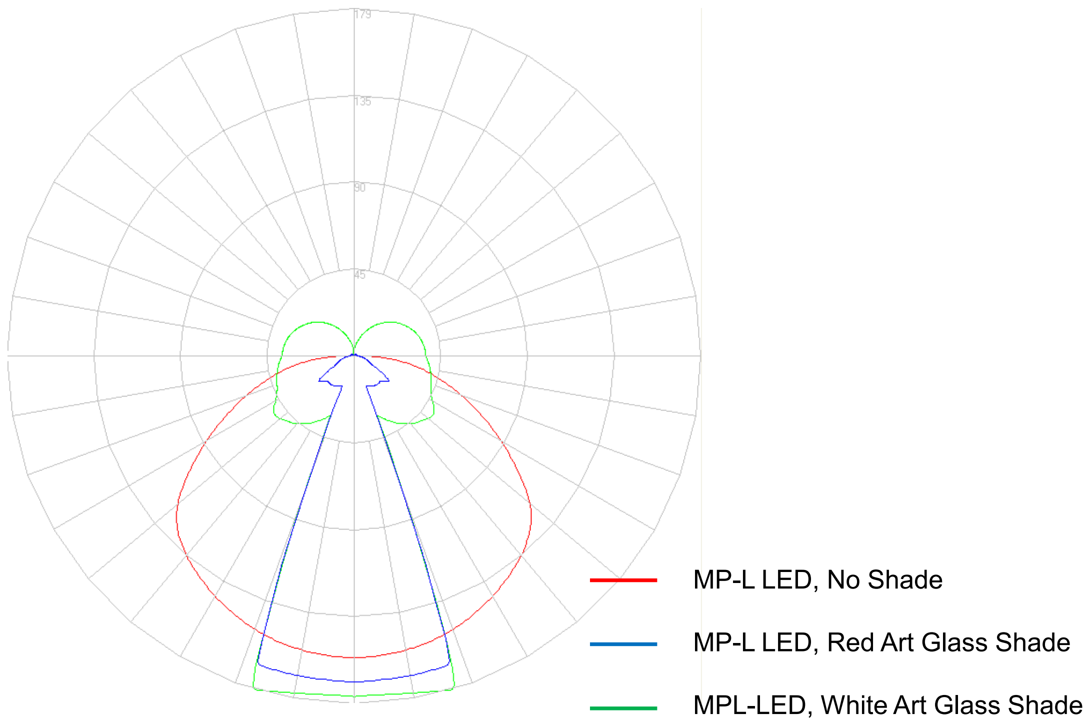


Figure 16: Goniometric intensity polar plot of XLamp MP-L EasyWhite pendant

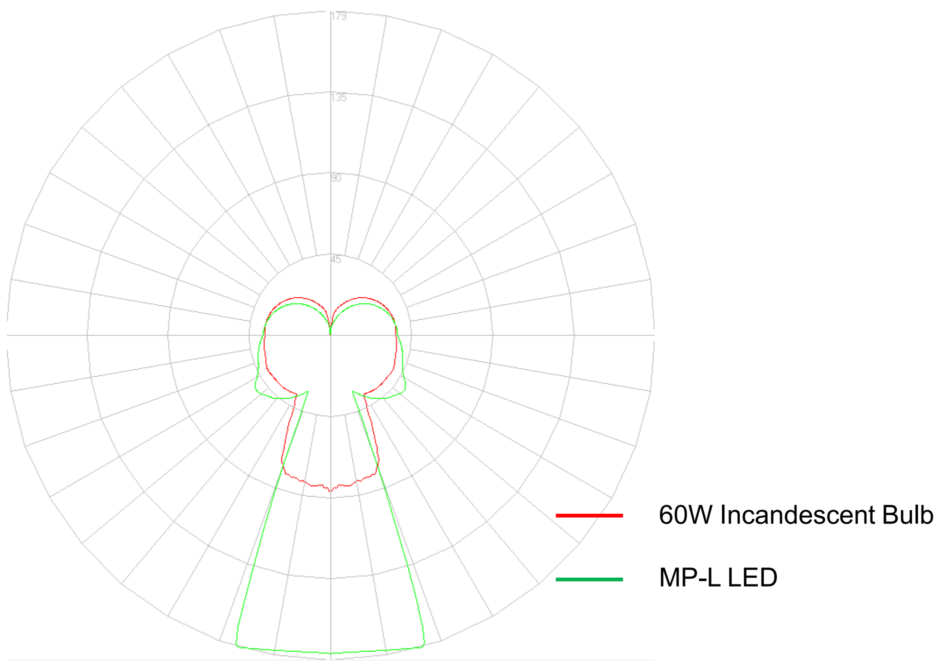


Figure 17: Goniometric intensity polar plot of MP-L EasyWhite LED vs incandescent bulb with white art-glass shade

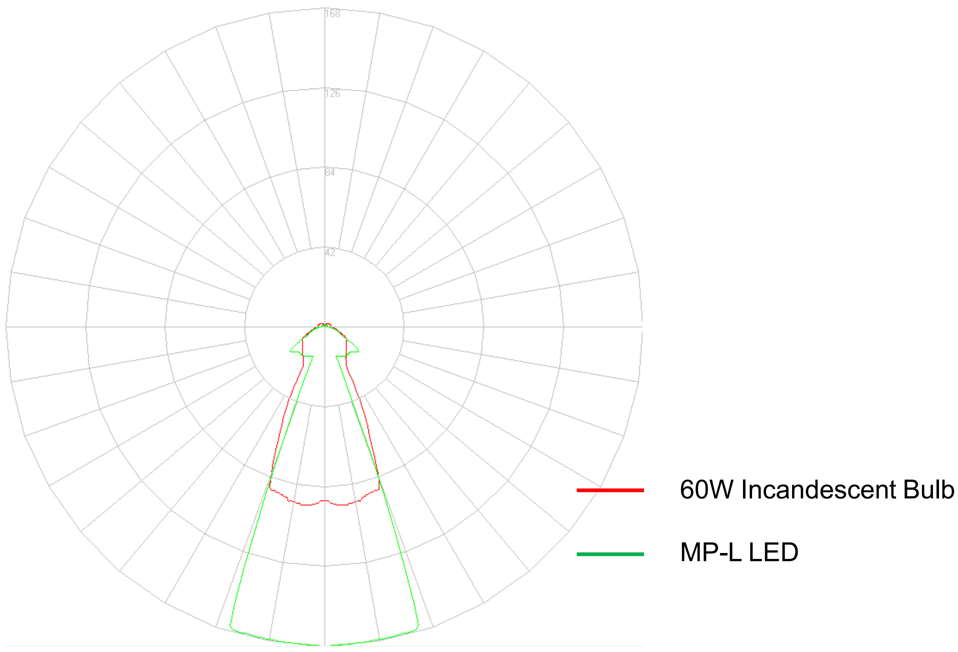


Figure 18: Intensity Polar Plot of MP-L EasyWhite LED vs Incandescent Bulb With Red Art-Glass Shade

CONCLUSIONS

This pendant design demonstrates a new level of ease of integration into a conventional illumination application with an attractive, high-efficacy result. We chose a driving current and heat sink design that guarantees low junction temperatures and, therefore, will deliver an extremely long luminaire life. This construction delivers the necessary operating environment to achieve the L70 50,000 hour designation.

When used with light-colored art-glass shades, implementers can also be confident the resulting luminaire will be both extremely attractive and Energy Star SSL-compliant.

APPENDIX

Since the original Pendant Luminaire Reference Design was published in Spring 2010, Tyco Electronics released their Solderless LED Socket, Type CM.[1, 2] This socket offers a number of simplifying solutions to product development with the XLamp MP-L. We add this appendix to show a number of design and assembly refinements to the original pendant luminaire.

By using the Solderless LED Socket, Type CM, along with a standard 2.5mm DC power jack and plug, we have been able to remove a number of the more painstaking steps in threading and connecting the original wiring harness, relative to our original implementation. In this appendix we document the new, simplified assembly procedure.

Figure 19: The revised pendant luminaire heat-sink assembly

Modified Heat-Sink Design and Assembly

In order to accommodate the simplified LED attachment mechanism of the Tyco Electronics product, we created a two-part version of the pendant heat sink.

1 Tyco Electronics (TE) Application Specification Solderless LED Socket, 114—13281, www.tycoelectronics.com

2 The TE Solderless LED Socket, Type CM provides an integrated electrical and optical solution for the Cree XLAMP MP-L LEDs. The socket enables power to be brought to the LED using either a LED-to-board solution or a LED-to-wire solution. The socket also has features to mount the TYRA Series of reflectors from LEDIL. The TE Solderless LED Socket is mounted using three No. 4 or M3 screws.

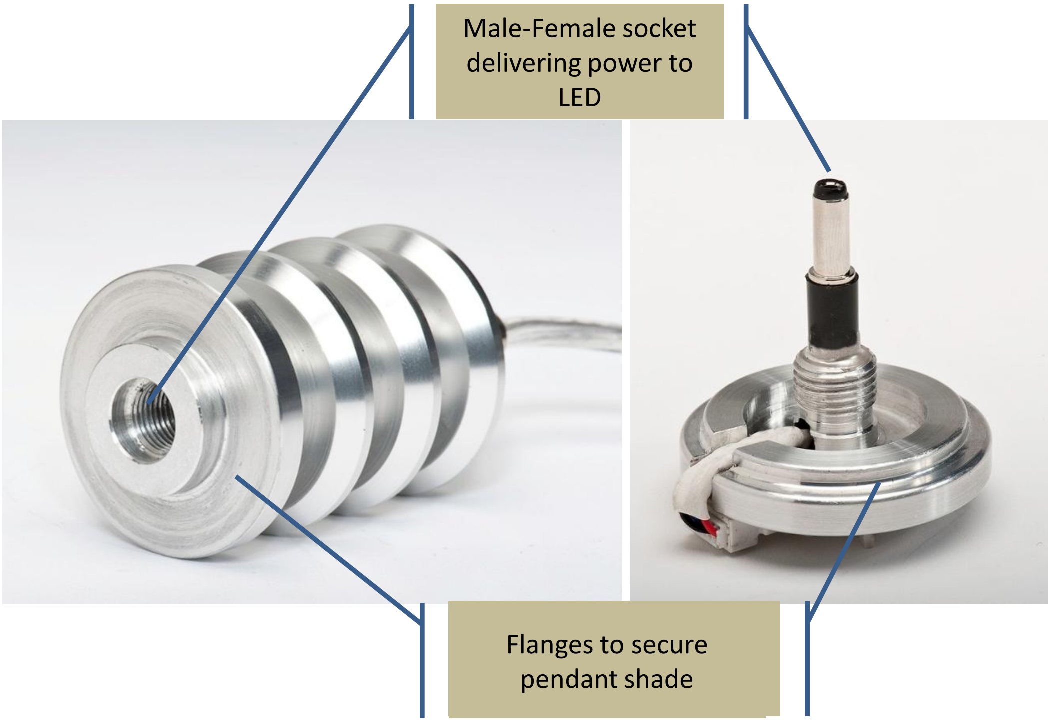


Figure 20: Revised Two-piece, Threaded Pendant Heat Sink Assembly

Power is delivered to the XLamp MP-L via the bayonet plug and jack. The original stress-relieved conductors terminate in a female socket located behind the female-threads of the heat sink body. The two parts are connected by threading the two pieces together. Threading the two halves of the heat sink delivers power to the XLamp MP-L and secures the glass pendant shade.

Figure 21: Threaded Heat Sink Assembly

The XLamp MP-L is precisely attached and held by the Tyco Electronics connector, shown below.

Figure 22: Tyco Electronics Solderless LED Socket, Type CM attached to the pendant heat sink

Power is delivered from the bayonet assembly to the LED by an AMP MiniCT connector, a commonly used wiring interconnect. Consult Tyco Electronics documentation for mechanical and electrical details of the Type CM Solderless LED Socket.

Final assembly is performed by placing the LED-containing portion of the heat sink inside the pendant shade and threading/tightening this piece to the other half of the heat sink assembly. Note the sizing of the two flanges, constructed so as to prevent over-compression of the heat sink against the glass shade.

Use of this solderless connector combined with the two piece threaded heat-sink assembly makes final assembly of the MP-L EasyWhite Pendant Luminaire a simple task and has reduced assembly time by an order of magnitude.

Figure 23: Final Assembly, First Stage

Figure 24: Final Assembly, Second Stage

The Cree Application Engineering team would like to give a special thanks to Mike Appel of MCS (919-596-3033) for the recommendations, construction and multiple quick turns of the heat sinks used for this application note.

Tyco Electronics and AMP are trademarks of Tyco Electronics.