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California Energy Commission
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Prototype Luminaires Completion Report

Development of High Efficiency Porch Lamps Using Light-Emitting Diodes

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Prototype Luminaires Completion Report

Introduction

LBNL designed, built, and photometrically tested new designs of exterior luminaires with LEDs to replace existing inefficient fixtures that contain only incandescent bulbs. The new designs may easily augment existing fixtures to reduce the "on" time of these energy-consuming incandescent bulbs or they may be used as stand-alone fixtures that provide ambient lighting. The fixture that holds the LEDs will utilize lighting methods in which the light from the LEDs will be reflected across a diffuse reflective surface, inhibiting direct view of the light from passersby.

This phase of the effort, the prototyping of new designs, consisted of several different elements:

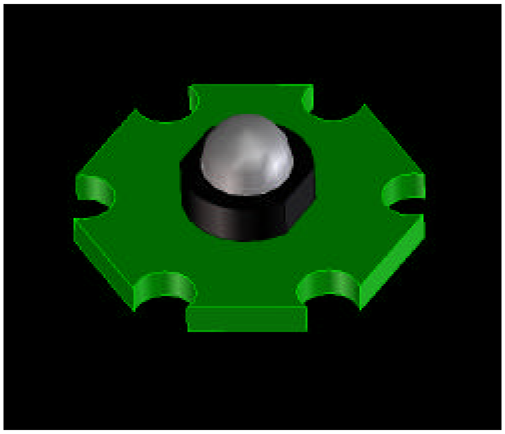
1) The testing of LED components has taken place and will continue throughout the project. This is necessary to keep pace with the current state of this rapidly evolving technology. Two high output LED components have been identified as the most immediately promising LEDs for the applications considered. They are the Luxeon product line from Lumileds and the Dragon product line from Osram. Each has advantages and disadvantages that are outlined below.
2) The optical configuration of the LED arrays was investigated and developed. Several approaches were attempted, and a preferred method identified.
3) The concepts outlined in the Matrix of New Concepts were physically built.

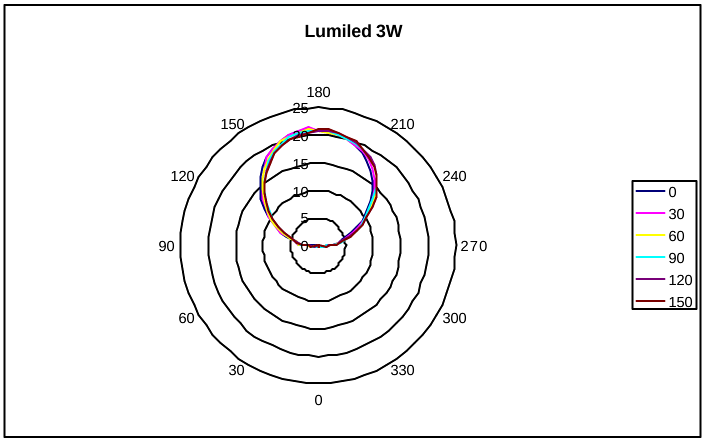
Identification of low cost efficient LEDs

LBNL purchased several different LEDs from varying manufacturers. Considerations included light output and its ratio against cost, and availability. After initial testing and evaluation, the Lumiled LEDs and Osram LEDs were chosen for further examination. The following are some LEDs along with their data:

Lumiled (stars)

- 30 lumens/watt
- Expensive ($5.19/pc)
- Round lens
- Hand assembly

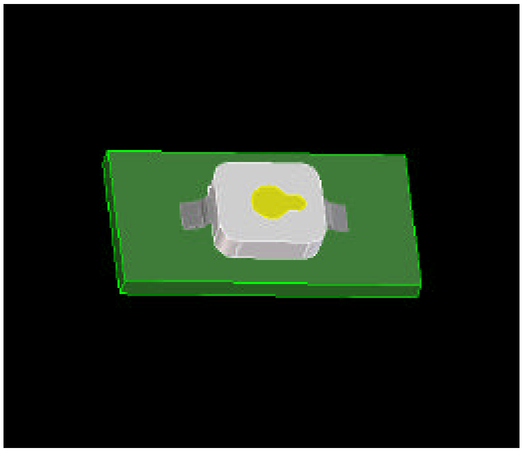


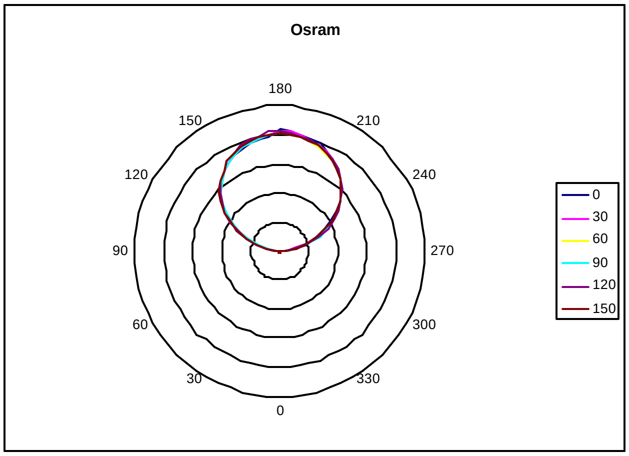


Lumileds LEDs have been found to give the highest lumen output per LED. LBNL tests have shown an LED performance of 20 lm/watt. Further, Lumileds has recently released in production quantities the Luxeon III, a 3-watt LED rated at 50K hrs. This LED is available in white, green, and blue (nitride series). The white Luxeon III sells for ~$7.50/pc in quantity and has a lumen output range from 60-80 lumens (dependent on drive current). This places the $/lm of these LEDs at ~ $.10/lm. At this output level, these LEDs make very promising choices for white light applications where a single LED can provide the ambient light level required. Of course, the LEDs can be combined in larger arrays with scaling increased outputs, which opens up the possibility of an LED-only fixture. These LEDs have the disadvantage of requiring hand or spot reflow soldering techniques.

Osram (Golden Dragon)

- 20 lumens/watt
- Inexpensive ($1.63/pc)
- Small package
- Automated assembly





Osram's high output LED series is called the "Dragon" series. These LEDs are 1-watt devices aimed at high output, automated production applications. Researchers have acquired and tested the yellow (590 nm) version, and are expecting samples of the white version very soon (the white Dragons are a newer line and are just being released).

These LEDs do not give outputs equal to the Lumileds devices, but have other advantages that make them attractive. They are built to withstand automated soldering techniques and can be used as standard electronic components in pick and place electronic fabrication, including wave and IR reflow soldering. They are also smaller than the Lumileds devices. In addition, they cost less than Lumileds LEDs, with a quantity price of under $1.63/device. This places the $/lm at ~$.08/lm. Osram has stated that they expect higher efficiency versions of both the yellow and white LEDs by the end of next year. This information is, of course, speculative.

Optical Configurations

Considerations

The low lumen output per LED, now at a maximum of 80 lm/LED (compared to ~1000 lumens from 60W incandescent), requires many LED systems to use multiple LEDs. Multiple light sources will then cast multiple shadows from any single illuminated edge. The effect that this creates is most apparent, and most troublesome, from moving elements within the light field, namely a hand or other body element that casts multiple and visually confusing shadows. The effect is most pronounced with linear, closely spaced multiple LED sources. While it remains to be seen what widespread public opinion will be on this issue, the general consensus from people interviewed at the lab has been slightly to moderately negative when queried about the multiple shadow effect.

The directional qualities of LED light sources can make them ideally suited for task lighting applications. Some LED systems approach a 180 degree beam spread, meaning that 100 percent of the flux falls within an angle of 180 degrees, while others have a much tighter beam pattern of 5 to10 degrees. Surface mount LEDs, including those used in this project, typically have wider beam angles, 120 degrees being a commonly found configuration. No LEDs have been found that emit light in an angle greater than 180 degrees, meaning that this unidirectional quality is well suited to send light flux in a particular direction to meet the requirements of a specific visual task. Researchers found that the typical 120-degree LED output was well suited for lighting a wall and ground, but the bare LEDs created glare problems.

Any fixture that allows direct viewing of the LED chip source will produce objectionable disability glare to the viewer. In an outdoor nighttime environment, this glare will impair a person’s dark adaptation. Another lesser-explored element of glare is a person’s inclination to stare at a ‘new technology’ out of curiosity. While not being a fair judge of a fixture’s true performance, the tendency of people to look directly at a bright light source can only harm their perception of something “new and exciting”. As LED efficiencies and outputs increase, so too will this problem of the need to mitigate the problem of direct glare.

Cutoff angles are also important when considering the reflector/diffuser design. Deep reflector designs can eliminate the possibility of glare, but also will be physically much larger than the LED dimensions themselves. Also, sharp cutoff angles will create heavy shading at the edge of the distribution.

Options

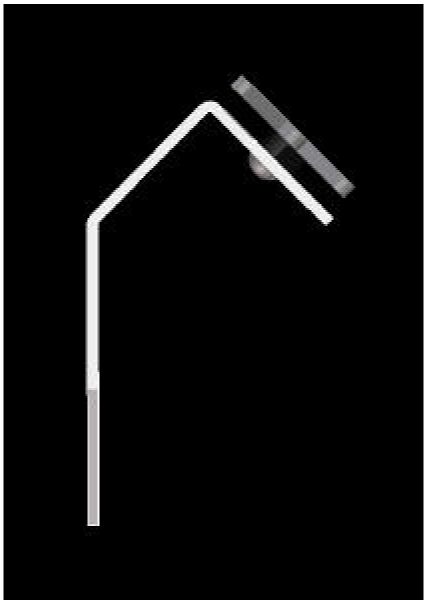
The options considered for decreasing direct LED glare, and distributing the light along the wall and ground were as follows:

1) **Diffusers.** Diffusers have transmittances in the range of 45 to 70 percent. Inter-reflections within the light cavity can increase the external transmission. Researchers experimented with the traditional diffusers of acrylic and frosted glass. Neither were able to produce fixture efficiencies over 75 percent in the experiments that were performed. The light distribution was, however, aesthetically acceptable. Holographic diffusers from Wavefront Technologies were also used in experiments. Holographic diffusers have microscopic patterns pressed into thin plastic sheets. The

light output distributions obtainable with these diffusers were good, but the experiments were unable to produce efficiencies greater than 80 percent.

2) **Prismatic lens arrays.** Acrylic prismatic lenses were able to mitigate the glare problem and give reasonable efficiencies. Most acrylic lenses allow transmissions higher than 90 percent. Some lens imaging occurred that would need to be addressed, but this should be possible with proper design. The experiments at the lab produced efficiencies closer to 85 percent. While the use of these lenses can produce acceptable results, other novel approaches evolved that appear more suitable.
3) **Specular reflectors.** Specular reflectors are easy to form and offer reflectivities in the 92 to 98 percent range. They do not address the issue of multiple shadows, and most designs using LEDs will need deep fixture geometries to avoid direct glare. No favorable specular reflector designs were generated.

4) **Diffuse reflectors.** Diffuse reflectors can be found with reflectivities in the 90 to 96 percent range. The type found to offer the most appealing output is a gloss white high reflection powder coat paint. Experiments were performed to determine the best configuration, and a preferred embodiment was identified.



This reflector aims the LED(s) back at the wall at an angle of 45 degrees to the horizontal. The reflector has one 90-degree angle and one 135-degree angle, and holes corresponding to the LED locations to allow light into the cavity. No front cover is used, and a portion of direct LED flux is allowed to reach the wall and floor beneath the fixture. Another portion of the flux is diffusely reflected down and away from the wall. Glare is mitigated, and multiple shadows are smoothed out from the diffuse light. The output has a wall component and a ground component, and the cutoff angle is very soft. Depending on the entire fixture geometry, there is small or no portion of the flux above the horizontal. The nature of the design makes this approach scalable to accommodate any number of LEDs in a linear row, and the diffuse reflection allows variations in reflector dimensions without greatly affecting the efficiency. The reflector is 1to 1.5 inches in depth, and most designs have efficiencies in the 90 to 94 percent range. Overall impressions of the output have thus far been very positive. Issues concerning the direct exposure of the LED lens are currently being investigated.

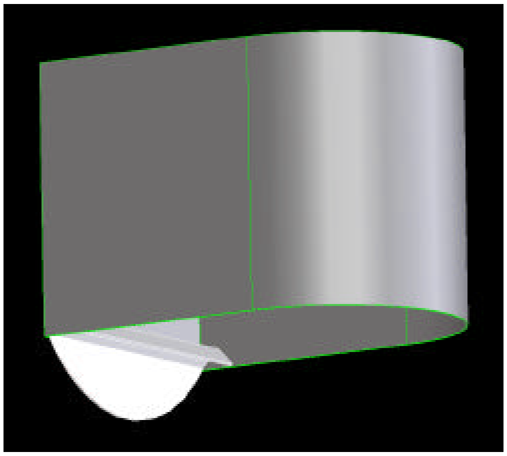
The diffuse reflector approach has shown the best results for efficiency and desired output. The design is both simple and inexpensive, and allows integration into any number of fixture geometries.

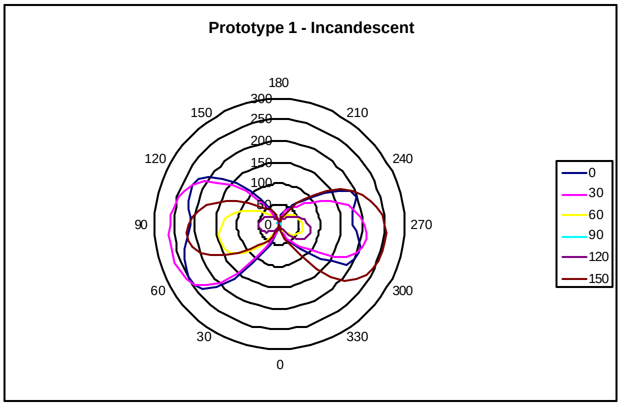
Prototypes

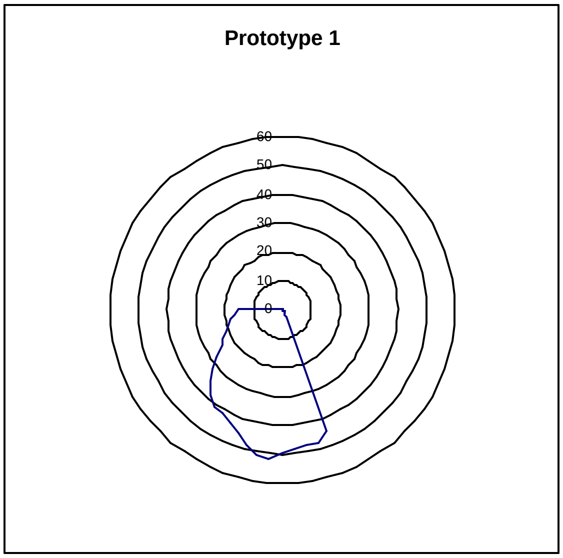
The following prototypes are currently the most promising for this project. Others that were developed are included in the appendix of this report. Three manufacturing partners have been identified: Shaper Lighting, The Watt Stopper, and Lithonia. The hybrid fixture prototypes utilize LED technology with incandescent; however, the fixtures may also use CFL lamps.

Prototype 1: Hybrid fixture – LED with incandescent

Wall pack fixture. 2 x 3 watt Luxeon III white.
LED power usage: 7W (one LED = 4 watt)
LED output: 122 lm
Fixture efficiency: 92%

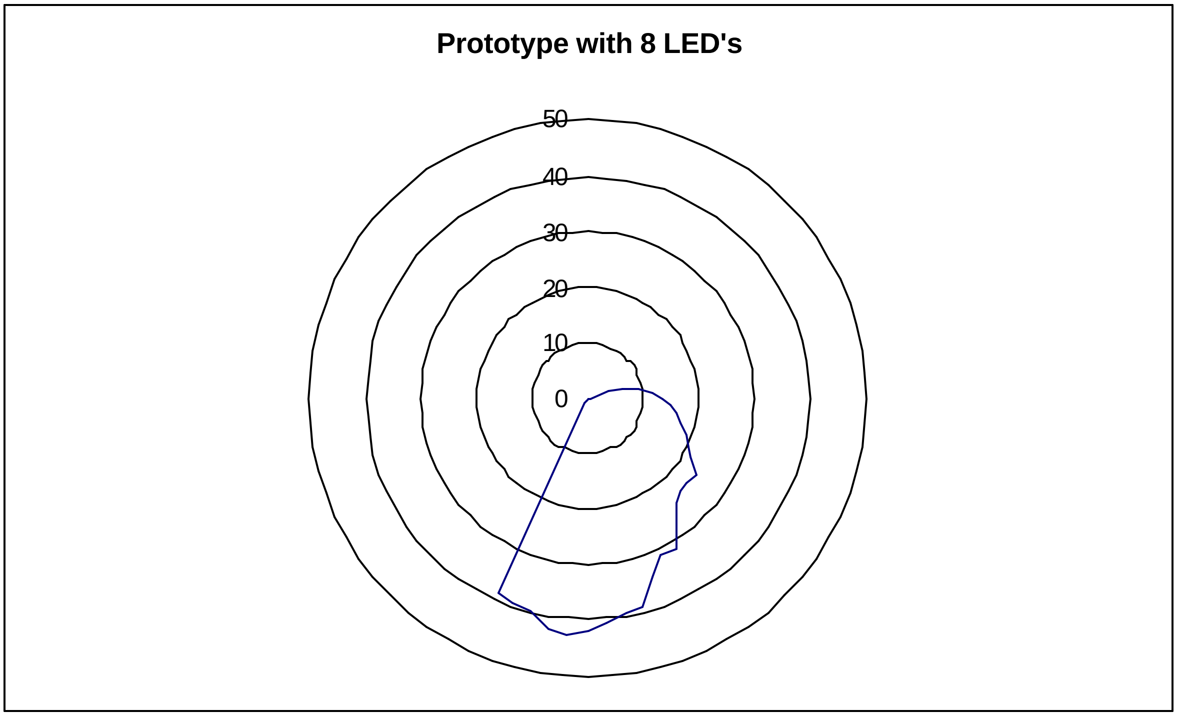






Goniometer Plot: The plot on the right is the LED light. The wall would be on the right hand side of the plot. The flux is directed back at the wall and down to the ground.

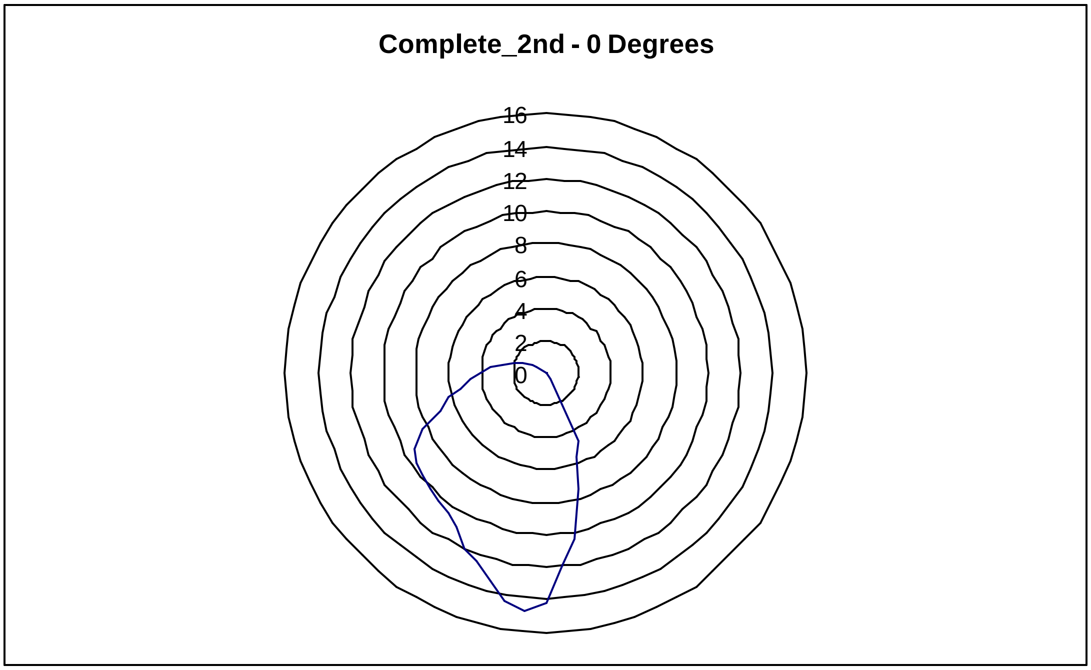
Prototype 2: Hybrid fixture – LED with incandescent
Wall pack fixture. 8 x 1 watt Osram Golden Dragon.
LED power usage: 8.6 W (could be 4.4 watt)
LED output: 101 lm
Fixture efficiency: 90%



Wall on left side

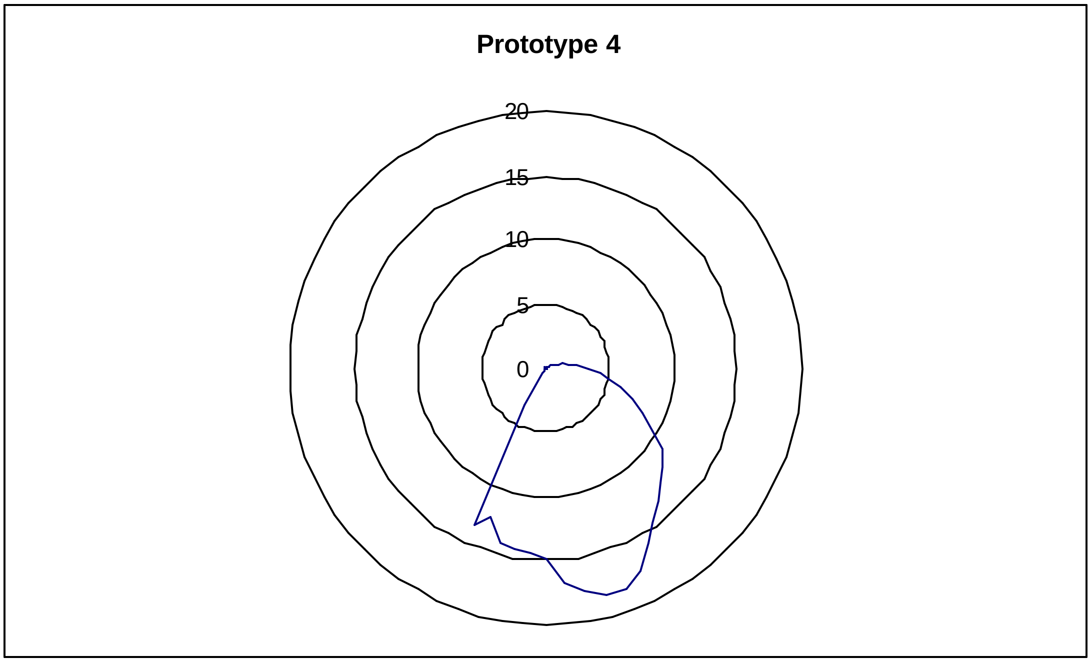
Prototype 3: Hybrid fixture – LED with incandescent

Par lamp security fixture. 4 x 1 watt Osram Golden Dragon.
LED power usage: 4.4 W
LED output: 101 lm
Fixture efficiency: 91%



Wall on right side

<u>Prototype 4: Hybrid fixture – LED with incandescent</u>
Porch light 'drop' unit. 1 Luxeon III white
LED power usage: 4.4 W
LED output: 61 lm
Fixture efficiency: 92%

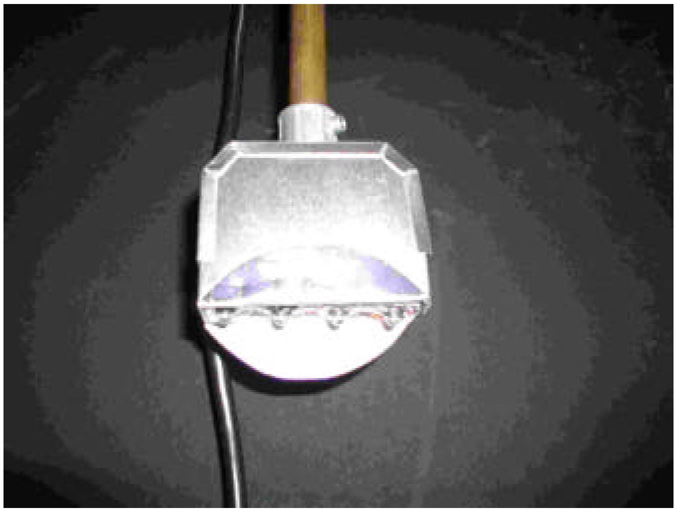


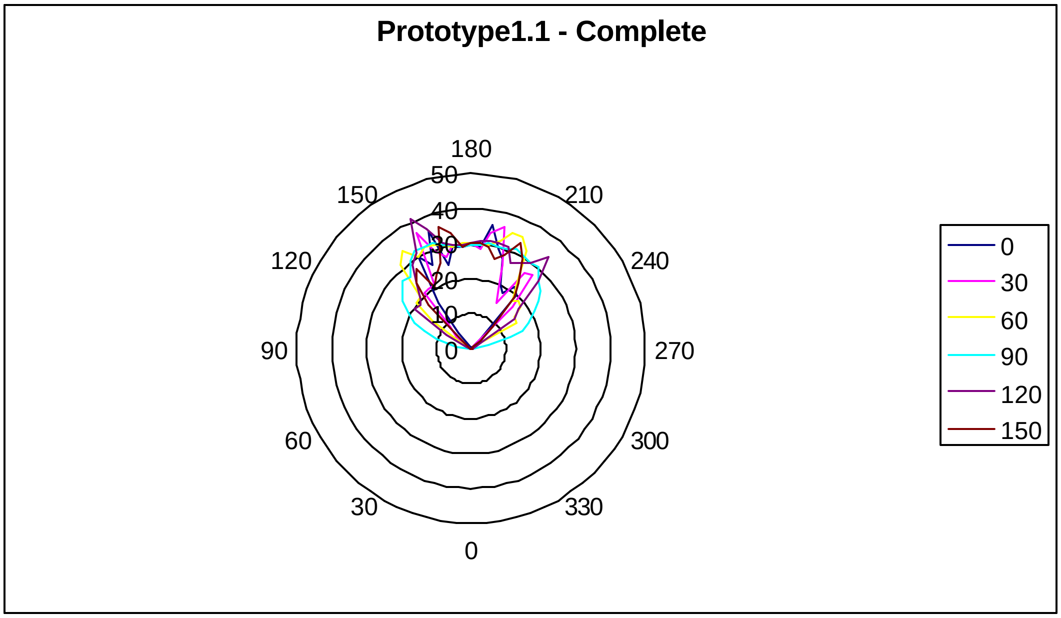
Appendix

This appendix includes miscellaneous data to illustrate aspects of the prototyping process. The prototypes listed are those that eventually led to the preferred embodiment of the reflector design.

Prototype 1.1

The first lamp (hereon referred to as Prototype 1.1) is a simple implementation of four Lumiled LEDs. The LEDs are placed inside a rectangular enclosure with an opening on one end. Prototype 1.1 was designed to be attached flush against a wall, with or without an incandescent to supplement. Testing was done with various diffusers and metallic reflectors to determine the effectiveness of such additions on characteristics and efficiency of the light output. Use of metallic reflectors created undesired "ripples" of light (strong in several areas and dark in other areas) and created glare for passersby. To ameliorate this problem, diffusers were employed but these in turn decreased efficiency greatly.

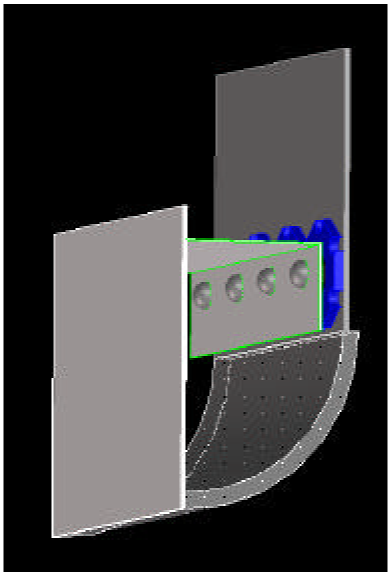


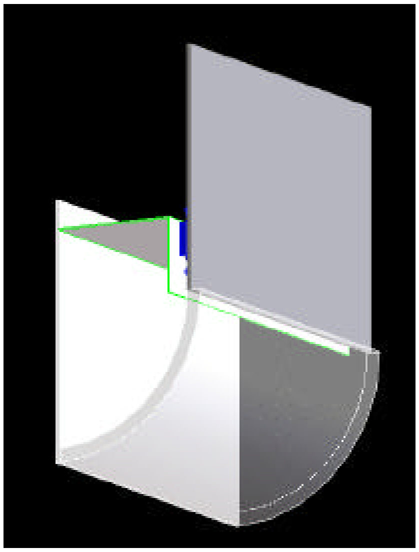


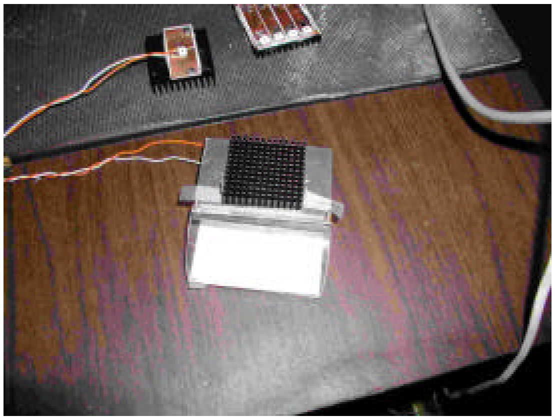
A modified version of Prototype 1.1 (hereon referred to as Prototype 1.2) consisted of using a white reflective, diffusive paint to reflect light. This paint created diffuse light while a small amount of light was lost which solved the problem from Prototype 1.1. Unlike Prototype 1.1, one of the semi-circular flaps is removed for better light distribution.

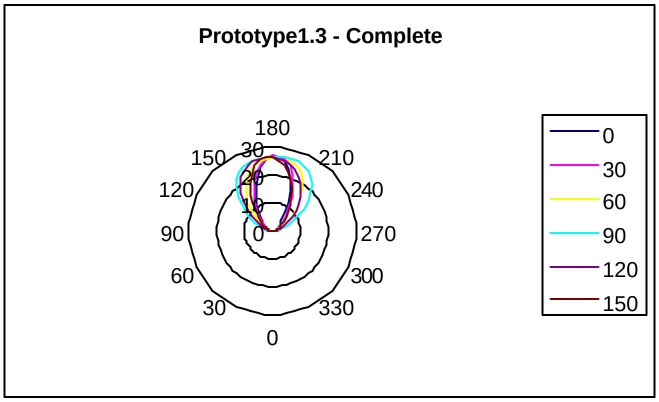
Prototype 1.3

The second design (hereon referred to as Prototype 1.3) is fundamentally different from the previous two prototypes. Prototype 1.3 once again employs the white reflective paint used in Prototype 1.2; however, unlike Prototype 1.2, Prototype 2 directs the LEDs to the paint and depends entirely on its reflective property; this was done to avoid any possibility of glare or direct-viewing of the light source.









Power Supply Notes

Scope:
This will bring the reader up to date on the progress of the LED/Porch Light project with an emphasis on the power supply question.

In April 2003, it became necessary to research the manner in which the LED segment of the LED/Porch Light project could be powered. To this end a variety of approaches were addressed:

1. Constant Current Power Supplies; Both “off the shelf” and “built in house” versions were investigated.

2. Constant Voltage Power Supplies; Again, both “off the shelf” and “in house” versions were looked at.

3. Associated supporting instrumentation; The instrumentation needed to fully research and test the various approaches taken.

1. Constant Current Power Supplies:

LEDs work best in a constant current mode wherein the current remains constant and the voltage associated with that current is allowed to “seek its’ own level”. This means that the voltage on a given circuit will fluctuate while maintaining the current at a constant level. The advantages to this approach are extended LED life, a light output that doesn’t vary in intensity, and simplicity of installation.

Being tasked with finding the best solution in this area necessitated research into what is available on the open market as well as the lab building its own version. Factors that were to be investigated included cost (per unit and quantity pricing), availability, and reliability. Testing both the “off the shelf” and “in house” units required the design and construction of supporting instrumentation to assist in development and testing.

A search of the marketplace showed there are very few vendors that actually have small, inexpensive constant current power supplies available. One of the vendors that meets the requirements is the Advanced Transformer “Xitanium” product line. These units were brought in house for research and testing. Other products (Optotronic, Supertex, Osram/Sylvania among others) were investigated and, at this point, fall short in one or more areas. They have not been disregarded entirely however, since the requirements may change as the project progresses.

The Xitanium units were investigated with respect to current output under varying LED loads, short circuit performance, high load life testing, and physical characteristics. These units seem to meet the technical requirements placed upon them, and may be the selected power supply used in the LED/Porch Light project. Testing is continuing on this approach.

At the same time, research into building a constant current power supply in house was being carried out. Attempts ranged from simple half wave rectified, low component count circuitry to completely transformered, fully rectified, high component count circuitry. It was found that the cost of building one in-house was comparable to the store bought variety if development costs were not considered. Also, the cheapest approach to constant current involved circuit heating that was deemed unacceptable in the environment in which it will be placed. This approach, while still available, is not considered viable under present conditions.

2. Constant Voltage Power Supplies:

While LEDs do work best in a constant current mode, constant voltage had to be considered. The primary reason for this consideration is cost since these supplies are in wider usage and are available through more vendors. The supplies are also available in a wider variety of packages, affording us more flexibility in the design of the power supply packaging. Again, "off the shelf" and "in house" versions were investigated.

First, designs included generating the required voltage at the source and extending that voltage to the "satellite" module. Once there, a ballast resistor would be added to the circuitry to develop the required current. It was determined that the efficiency of this approach was not what was hoped. This was especially true when adding more modules to the circuit (each module would require its' own ballast resistor). Adding more modules also became problematic because the addition of modules would require a different voltage setting for the power supply depending on the number of modules in the chain. The heat generated by the ballast resistor was also a detriment.

The next iteration used a "central" power supply to generate an AC voltage (~12VAC) so each module would receive the same power. The module itself would then convert this power into what is required by the LED array. This scenario also includes a ballast resistor. Unfortunately this approach requires a higher parts count in each module which translates to higher costs. Also, because of the use of a ballast resistor, efficiency suffered in this attempt as well.

The possibility of simply running line voltage to each individual module was also discussed. And while this might be viable in new construction, it was decided that in a retrofit situation this was not a wise approach primarily due to code requirements concerning running line voltage on the exterior of a building.

In summary, the constant voltage aspect of this project has shortcomings that would seem to make this approach less than ideal. This is not to say that the constant voltage aspect has been scrapped, but unless these problems can be overcome economically (especially with respect to efficiency), this does not look promising.

3. Associated Supporting Circuitry:

In the process of developing and testing these various approaches, a variety of ancillary equipment and instrumentation had to be devised for use in these applications. This included design and testing of the instrumentation itself before it could be used to test what needed to be tested.

In order to demonstrate the ability of the project to detect motion, research into the IR component of this detection was required. An IR receiver had to be designed, tested, and incorporated into the overall design. It was hoped that a standard TV remote could be used to simulate an IR source to trigger the receiver. Initial research found that TV remotes generate a pulsed code and decrypting this code in the receiver would involve more time and effort than expected, so an IR generator had to be designed, built, and tested. This was done from “scratch” since a search for “off the shelf” items was fruitless.

An important aspect of the project is the aesthetics. Much thought was given to the overall look of the project always keeping in mind form, fit, and functionality. The modules have evolved over a period of time into something that takes into consideration the needs of the physical mounting of the LEDs, dissipation of heat, and the requirements of electrical safety. The “box” has gone through many changes with particular attention to compatibility with standard porch lights and electrical boxes. The mobile module concept allows placement of the module in virtually any location. In order to allow placement in a variety of locations, a study of cabling was needed.

Cables from a variety of vendors (Alpha, Belden, 3M, etc.) were researched with respect to size, current carrying capabilities, color, price, flexibility, and availability. Originally noise rejection was factored in but was found to be superfluous and was disregarded. With the wide variety of cables and cable manufacturers available today, a cable was finally selected. Although this selection is subject to change depending on circumstances. One aspect of the “connecterization” scheme that is still under study is exactly how to terminate the cabling required by the project. The review of this aspect is ongoing.

LED driver to supply 350mA @ ~8VDC. Requires a constant current supply.

Available from outside:

Xitanium LED Driver #120A0350C33F 350mA output @ 12W
LED Driver #120A0700C24F 700mA output @ 17W
May be too high E (~34V per E=P/I). Need to check.
#120A0350C33F “In stock” 10 @ $20.00 ea., 1000 @ $16.50 ea.
#120A0700C24F “In stock” 10 @ $20.00 ea., 1000 @ $16.50 ea.

Advanced Power Solutions 12VDC Power Supply (PC mount)
Mod #APS10AM-S-120083 110VAC in/12VDC@830mA out
1000 @ $16.50 ea. Lead Time/1000 = 12 weeks

Options:

A. Buy complete driver unit outside.
The main advantage is the lower per unit cost due to incurring no development costs. Also, no effort is expended trying to find a vendor to handle the product, and since the

product already exists in distributorship, lead times are negligible (as compared to building one).

The main disadvantage is that researchers have to design (physically and electronically) around what is available. Electronically this is really not a hardship; however, the physical packaging of the unit will affect the design of the final product at least to some extent.

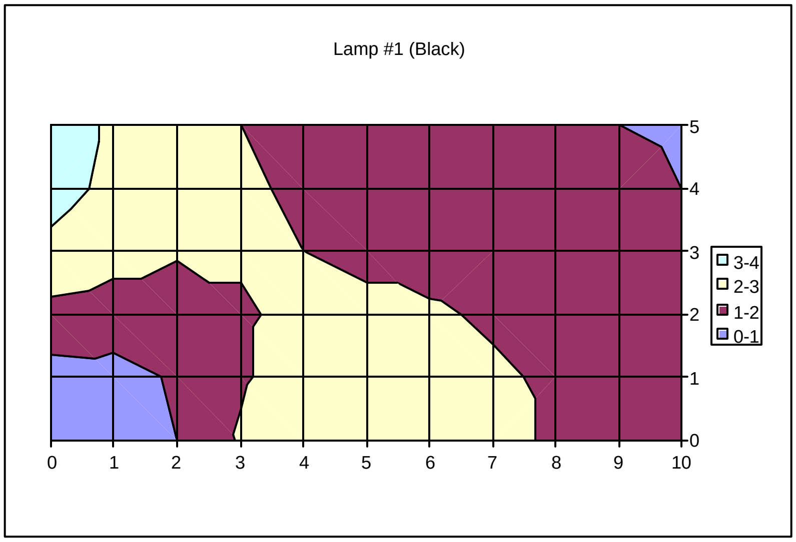
B. Buy a power supply outside and design a driver to use it.
The constant current power supply is essentially made up of two sections. The first is a power supply that converts the line input (120VAC) into a useable DC voltage. That is fed into the regulator portion of the overall supply where the DC output from the primary supply is regulated and fed to the load (LEDs). The AC/DC power supply is readily available from various vendors in a PC board mountable version and, at least in one instance, seems to be small enough to fit the current needs. The main advantage is that researchers can design the regulator stage to more accurately fit the needs for the final product. The cost of these AC/DC power supplies is comparable to the cost of the complete driver units now under consideration. However, LBNL must, in addition, design, test, and produce the regulator side of the overall power supply, thus increasing the cost of the total package.

C. Design and build the driver from the ground up.
This scenario affords the greatest amount of flexibility in the design of the driver. LBNL can tailor the output to match precisely the needs. This approach also allows the researchers to design the physical package to fit the needs. The primary drawback is cost. The development costs will be high when compared to Scenarios A and B since researchers would be designing a complete power supply/regulator. These costs would include parts research, breadboarding, testing, documentation, PC board development, and other more minor costs.

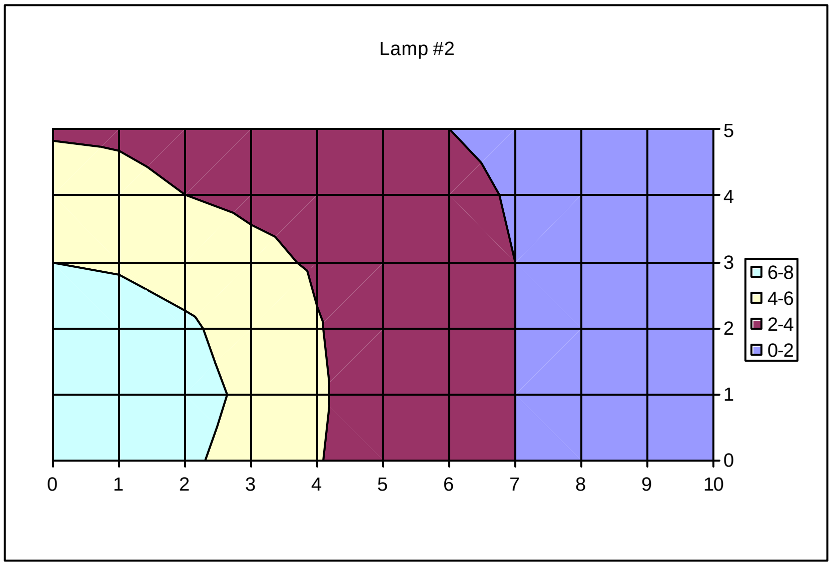
In sum, it would seem that the Scenario A would be the most logical (and least costly) approach. However, it would be prudent to follow a parallel path as a “back up” in the event that the primary effort doesn’t succeed. Scenario B looks to be the next best option both in development time and cost as a course to follow.

Additional data

LBNL purchased several relevant products to examine the statistics (e.g. total light output, efficacy, light distribution on a flat surface, etc.). The end product shall be more efficient than substantial samples of current products, yet the final product shall perform its main functions including lighting the target area (e.g. the porch area, stairs and walkway, etc.) with similar characteristics and functions concerning the light output. The following are some data on current products using incandescent bulbs:



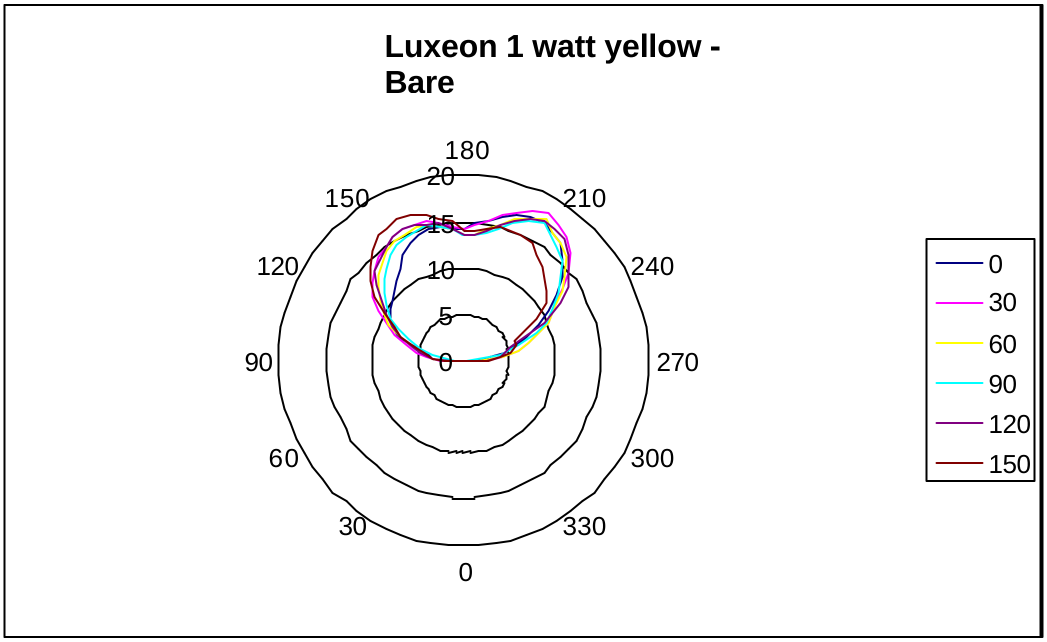
Porch Lamp (lamp up)



Porch Lamp (lamp down)

These graphs show the light distribution on the ground when the fixtures are placed at a height of seven feet.

Graphs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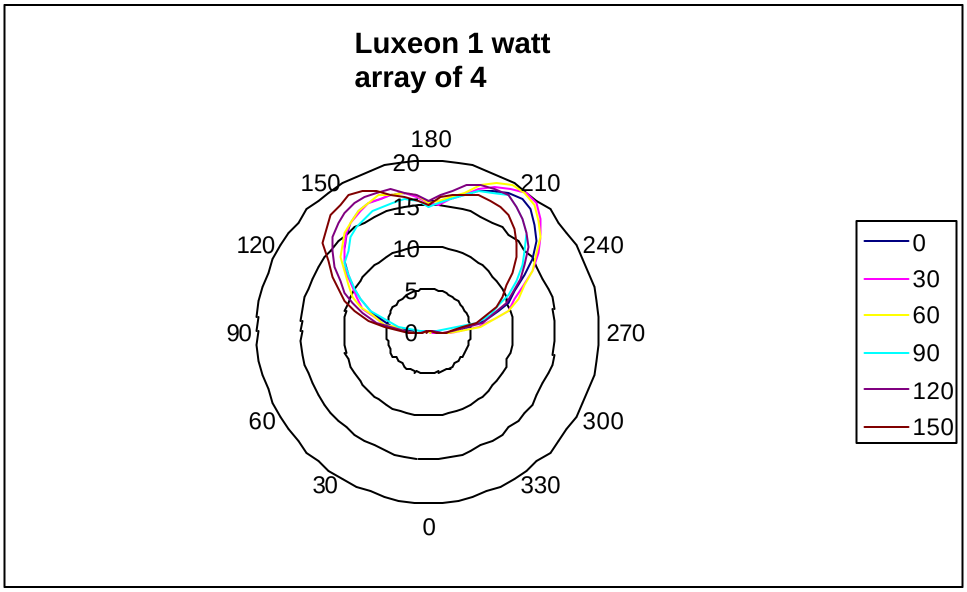
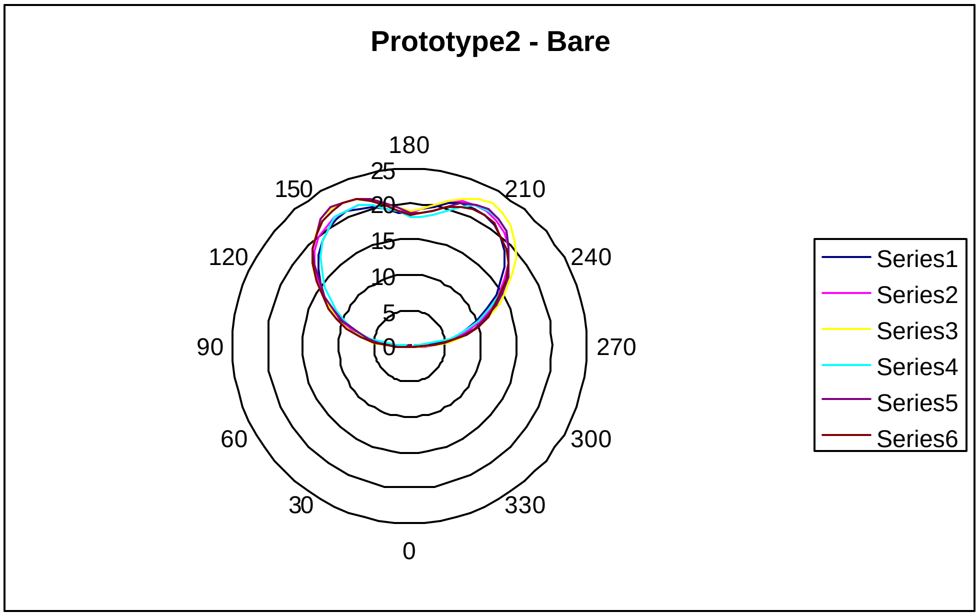

Luxeon 1 watt array of 4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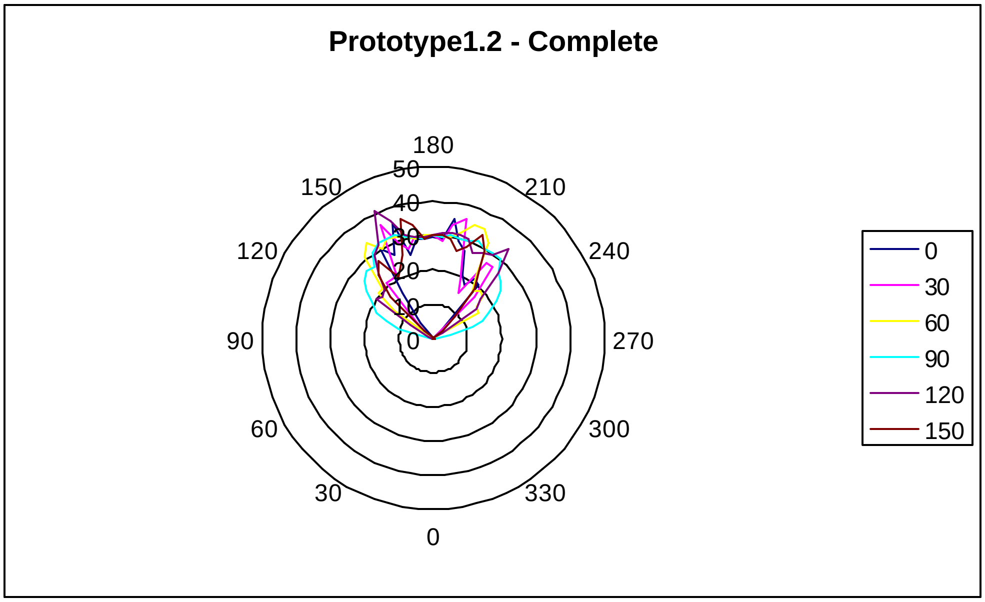
Series2
Series3
Series4
Series5
Series6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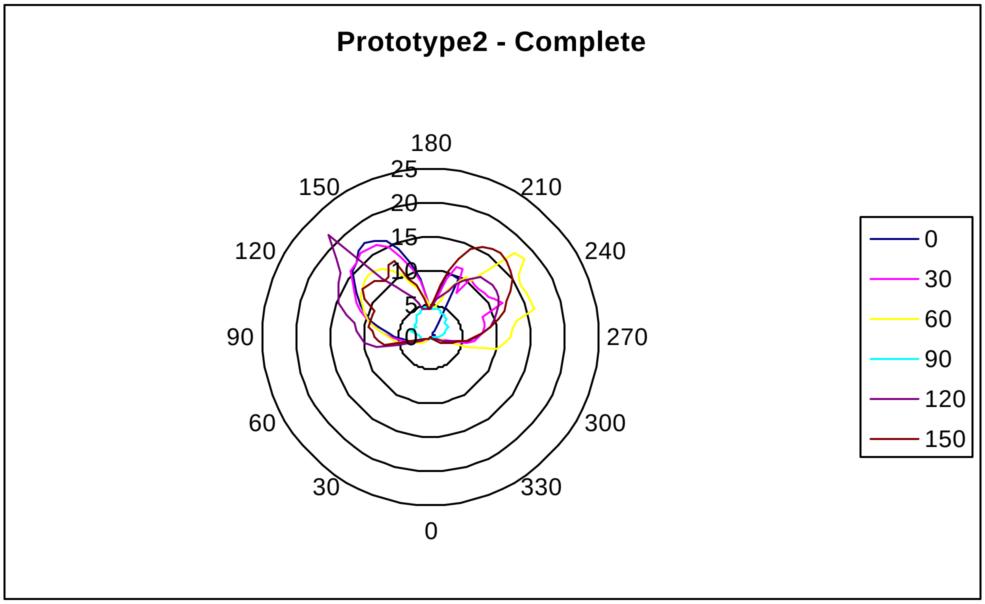
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180
210
240
270
300
330
0
30
60
90
120
150
25
20
15
10
5
0
0
30
60
90
120
150