

Optical Design of LED module for Street Light Applications

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Abstract

In this paper, the optical properties of the 54[W] LED module have confirmed by changing the angles of LED modules for street light applications. The angle of LED module changed from the 0[°] to 60[°] varying by 20[°] as horizontal direction Θ_1 . Moreover, the angle of LED module changed from the 0[°] to 15[°] varying by 5[°] as vertical direction Θ_2 .

As a result of simulation, the average illumination was about 17[lux] and the overall illuminance uniformity was 0.29 for a 10.39[m] long and 6[m] wide illuminance area at height of 6[m], which is acceptable for street lighting illumination in the Illuminating Engineering Society(IES) standard.

Key Words : Light Distribution Pattern, Optical Modeling, Numerical Simulation, Light Emitting Diode,
Average Illumination

1. Introduction

Lighting can affect performance, mood, moral, safety, and decisions. Lighting plays an important role in general lighting applications, especially street lighting. Street lighting illuminates the street showing the driver changes in direction up ahead, obstacles in the way, and the street surface conditions. Street lighting also lights more than just the street; walkways and adjacent areas also

benefit[1-2]. The consideration of LEDs for high intensity lighting requirement applications, such as street lighting, is a new application nowadays[3]. LED technology for lighting applications has the potential for wide-scale use and large energy saving. One of the advantages to LED lighting is that LEDs require a relatively small amount of wattage to produce the same amount of light as an incandescent or halogen bulb. Because of this, LEDs are low-energy solutions for lights that may be on for more than a few hours each night. To use less electricity for environmental reasons, LEDs lighting will be the solution of this problem.

Moreover, LED sources will last longer than traditional sources, such as incandescent bulbs and halogen bulbs. These traditional sources will simply start to slowly dim, giving a consumer a

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heads-up that they need to change their bulbs. Compare with incandescent bulbs, which break inside when they burn out, and halogen bulbs, which blink irritatingly as they start to go, LEDs are manufactured as one solid piece, with no glass or filaments to break, these lights are resistant to shock, vibration, and impact[4-5].

In this paper, we have intended to design LED luminaire in street light application. To promote the wide applications of the street lighting, it is essential to conduct an analysis of the optical performance of LED luminaire.

2. Design Process

The target of this paper is over 12[lux] of average illuminance and illumination uniformity 0.25 at 6 meter height on 10.39×6[m²] of illuminance area. Because illumination levels shall meet those criteria set out by the Illuminating Engineering Society(IES) as summarized in the following table 1.

In the IES standard, we have used Collector as Road Classification and used Commercial as Area Classification.

We have designed luminaire with illumination design software, LightTools. We have made the experiment for input data of used LED modeling. And we have modeled the used LED in program. To get higher illumination, we need to use secondary optics for LED. So, we have modeled the secondary optics which has the 25[°], 30[°] and 40[°] of half beam angle, respectively to get the target illuminance. Lastly, we have simulated the changing of the two slope angles of the LED modules from the 0[°] to 60[°] varying by 20[°] and the other is the 0[°] to 15[°] varying by 5[°] to get the required target illuminance. We have made this luminaire design in optical simulation program as follow in Fig. 1.

Table 1. Illumination Levels of the IES

Road Classification	Area Classification	Average Maintained illuminance (Lux)	Illuminance Uniformity ratio Ave. to Min
Arterial	Commercial	17	3:1
	Intermediate	13	
	Residential	9	
Collector	Commercial	12	4:1
	Intermediate	9	
	Residential	5	
Local	Commercial	9	6:1
	Intermediate	7	
	Residential	4	

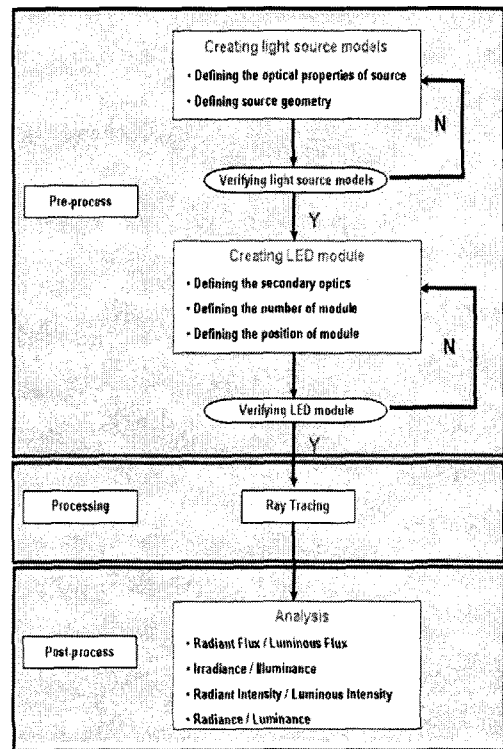


Fig. 1. Simulation process for street light luminaire

3. Optical simulation and Analysis of results

3.1 Source Selection for LED modeling

To design LED package, we have compared the various sources from different companies. Table 2 gives the summary of the optical properties of the compared LEDs.

Radiation pattern describes the relative strength of the light in various directions from the light source. The radiation patterns of the compared LEDs are lambertian because we have used this light source in street light applications. The chip of all four LEDs is InGaN blue LED. Nowadays the LED company distributes the white LED which is InGaN blue chip coated with Ce-doped YAG phosphor[6-8]. The power consumption of all compared LEDs was assumed 1 watt. According to experimental data, the radiation pattern of SUNNIX LED is sharper than others LEDs shown in Fig. 2. Moreover, it gives the high luminous flux at narrow angular distribution. So, we have chose SUNNIX LED for our designated luminaire.

Table 2. Optical properties of various LEDs

Product Name	Color	Luminous Flux [lm]	Beam Angle	CCT [K]
Z-power LED	pure white	52	120[°]	6,300
SUNNIX LED	cool white	73.8	55[°]	7,000 10,000
Luxeon Star/C	white	45	140[°]	4,500 10,000
CREE XR-E LED	cool white	73.9	90[°]	3,700 5,000

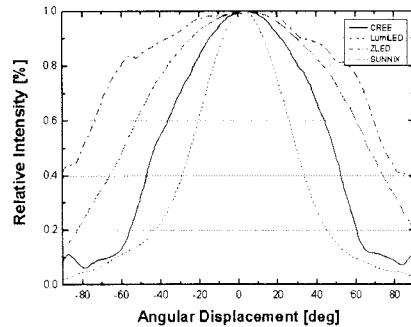


Fig. 2. Angular Distribution of various LEDs

3.2 LED device modeling

We made the SUNNIX LED modeling using the parameters of LightTools illumination software [9-10]. We put experimental data in the modeling LED for angular distribution and relative spectrum. Fig. 3 illustrates a solid representation of 1[W] SUNNIX LED model. The model has a total luminous flux of 73.8 lumens and an angular distribution of 55[°]. The housing material is assumed to be Aluminum. The optical characteristics of the housing material are important since the housing also acts as a reflector for the emitting die. The reflector geometry is a tapered circular that starts with an 8[mm] diameter and tapers to a diameter of approximately 5.6[mm] at the bottom where the die sits. The reflector cavity is encapsulated by silicone resin for highest luminous efficacy. This resin is assumed to have an index of refraction $n_{\text{silicone}}=1.65$. The die is positioned at the center of the reflector cavity and is immersed in the silicone resin.

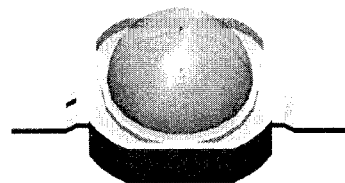


Fig. 3. Solid representation of the LED source model

3.3 Secondary lens modeling

Due to our target illuminance, we need to make more light distribution from LED. So we modeled and compared among the commercially available lens in program. All lens made up of Acrylic

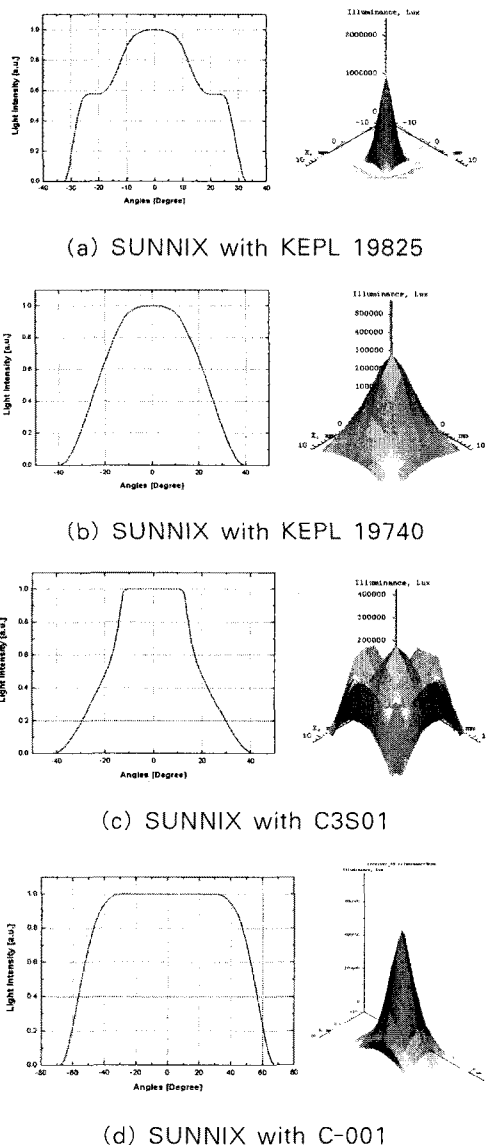


Fig. 4. Simulation results of light and illuminance distributions of SUNNIX LED with various secondary lenses

PMMA which has $n_d=1.491$ of the refractive index. The refractive index of air is 1.003 and that of LED's dome is 1.65. When the rays from the LED die pass through the silicone dome, these rays will more diverge than original rays. Continuously, these rays will more diverge when it pass through the secondary optics due to the ray from the high refractive index to the low refractive index. Moreover, we have controlled the half angle divergence of each modeled lens. If we have kept the dimension of lens, we can control the angular displacement. Fig. 4 illustrates the simulation results of light and illuminance distributions of 1[W] SUNNIX LED with various secondary lenses.

According to Fig. 4 results, the light distribution of 1[W] SUNNIX LED with C-001 lens gave lambertian cosine distribution and the shaper illuminance shape. Moreover, the simulation result gave the high illuminance value as 50.74[lux].

3.4 LED street light luminaire modeling

In this session, we have made two modeling processes which are LED module modeling and luminaire modeling[12]. The module containing 6 LEDs which were set up equal spacing within 204 mm on PCB in Fig. 5. We obtained the emitted rays by using Monte Carlo ray tracing from the LED module. One million rays were emitted from the LED module and the illuminance distribution was obtained.

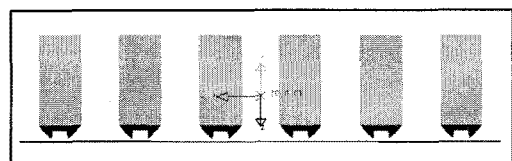


Fig. 5. LED module using 1(W) SUNNIX LED with C-001

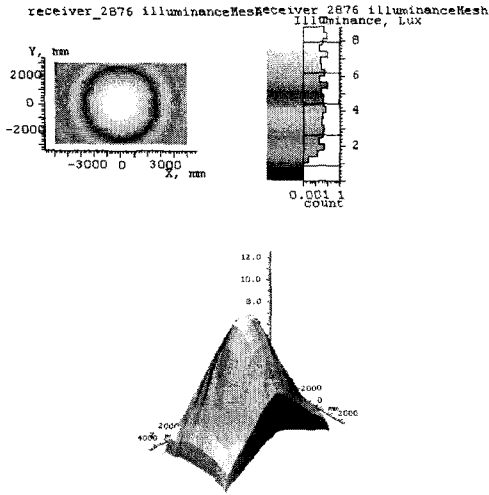


Fig. 6. Output illuminance distribution of LED module

Fig. 6 illustrates the illuminance distribution of LED module by receiver at 6 meter on $10.39 \times 6 [m^2]$. The histogram on the right side of the raster chart is the key to interpreting the colors as illuminance values. This simulation gave the total flux as 360.52 lumen and the illuminance as 6[lux] for LED module which has containing 6 LEDs.

The illuminance distribution of the LED module used in street light luminaire was measured in simulation program[13-14]. The simulation results are illustrated in Fig. 7. The center value of the light distribution is highest and the left values gradually decreased from the center to outer part.

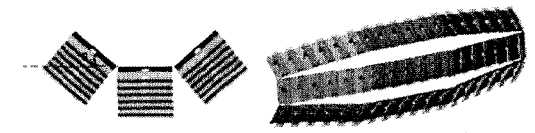
	-6.1	-36.4	-31.7	-21.0	-15.3	-7.6	0	7.6	15.3	21.0	31.7	36.4	6.1
-27.7	1.39	1.92	2.60	3.25	3.89	4.57	4.93	4.54	4.10	3.22	2.64	1.98	1.38
-23	1.64	2.32	2.92	3.89	4.93	5.44	5.62	5.55	4.63	3.84	2.93	2.35	1.54
-18.4	1.88	2.45	3.20	4.41	5.82	6.35	6.70	6.27	5.45	4.38	3.51	2.42	1.90
-13.8	1.89	2.65	3.97	5.04	6.09	7.19	7.50	7.26	6.31	5.11	3.78	2.69	1.95
-8.2	2.02	2.82	3.89	5.13	6.81	7.93	8.16	7.81	6.75	5.25	3.95	2.80	1.98
-4.6	2.10	3.02	4.15	5.75	7.09	8.26	8.66	8.21	7.17	5.64	4.17	3.05	2.10
0	2.01	3.10	4.17	5.61	7.47	8.61	8.87	8.46	7.37	5.63	4.17	3.04	2.06
4.6	2.10	3.01	4.22	5.69	7.22	8.45	8.71	8.42	7.20	5.39	4.24	2.82	2.10
8.2	2.06	2.97	4.00	5.30	6.58	7.85	8.31	7.83	6.79	5.56	4.08	2.91	2.08
13.8	1.94	2.87	3.86	4.91	6.37	7.20	7.42	7.15	6.18	4.83	3.58	2.64	1.96
18.4	1.75	2.46	3.38	4.50	5.60	6.27	6.56	6.46	5.67	4.50	3.39	2.54	1.63
23	1.57	2.12	3.02	4.04	4.58	5.42	5.86	5.40	4.83	3.71	3.11	2.17	1.64
27.7	1.62	2.00	2.61	3.51	4.07	4.50	4.76	4.60	4.08	3.48	2.65	2.09	1.55
	0-2	2-3	5-7	7-8	8-9								

Fig. 7. Illuminance distribution of the LED module

Now we can do further modeling for the whole LED luminaire by changing two slope angles of the LED modules from the $0[^\circ]$ to $60[^\circ]$ varying by $20[^\circ]$ and the other from the $0[^\circ]$ to $15[^\circ]$ varying by $5[^\circ]$ for the required target illuminance. We have intended 54[W] LED luminaire. So we have used 9 LED modules. One LED module has 6 LEDs which has 1 watt. We have arranged 3 segments. One segment contained 3 LED modules, as shown in Fig. 8 (a). We denoted that Θ_1 is the varying angles from the $0[^\circ]$ to $60[^\circ]$ varying by $20[^\circ]$ and Θ_2 is the varying angles from the $0[^\circ]$ to $15[^\circ]$ varying by $5[^\circ]$, as shown in Fig. 8 (b). First, we have done the Θ_2 is put $0[^\circ]$ and the Θ_1 is varied. We collected the data during this process. And then, we have made the Θ_2 is put $5[^\circ]$ and the Θ_1 is varied. Like as above process, we have continuously changed the Θ_2 until $15[^\circ]$ varying by $5[^\circ]$ during the Θ_1 is varying from $0[^\circ]$ to $60[^\circ]$ varying by $20[^\circ]$.



(a) The arrangement condition of the 9 LED modules



(b) The changing condition of the slope angles

Fig. 8. The conditions for LED module arrangement and slope angle changing of 54(W) LED luminaire

We confirmed data during simulation and compared the result data. We got the highest

illuminance and flux at θ_1 is 0° and θ_2 is 5° . We confirmed the simulation data when θ_1 and θ_2 continuously changed. At all conditions of θ_1 , θ_2 is 5° gave the highest values. But the more increasing θ_2 than 5° the lower value of the total flux and the illuminance shown in Fig. 9. Our main target is the 17[lux] of the illuminance of designated LED luminaire. So we have selected our designated lamp model set up θ_1 is 60° and θ_2 is 5° . Fig. 10 illustrates the uniformity of the whole lamp away from receiver which has 6 meter distance.

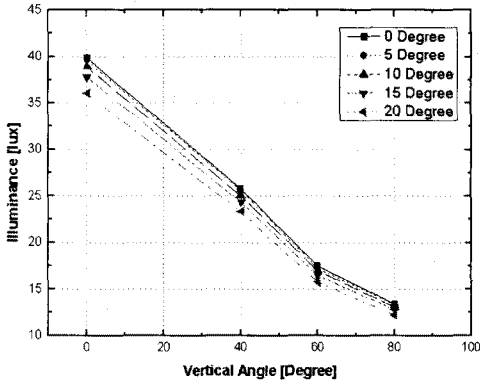


Fig. 9. Illuminance of LED Lamp by Changing the Slope Angles

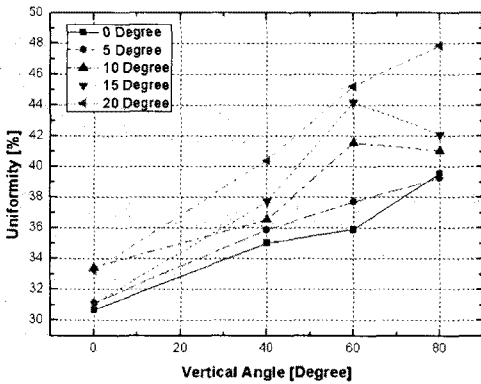
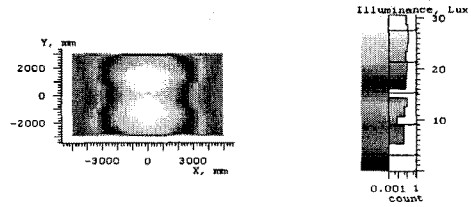
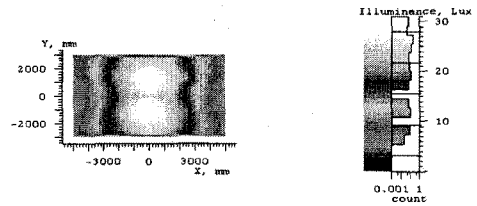


Fig. 10. Uniformity of LED Lamp by Changing the Slope Angles

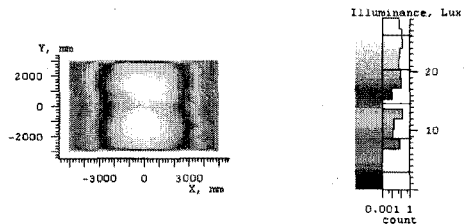
Fig. 11 illustrates the all conditions at $\theta_1=60^\circ$ of the illuminance distribution of the luminaire. The x and y axes correspond to the physical



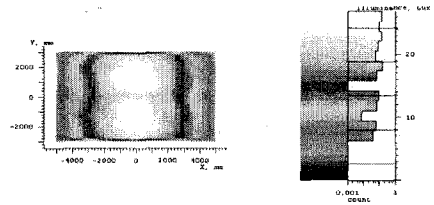
(a) $\theta_2=0^\circ$, $\theta_1=60^\circ$



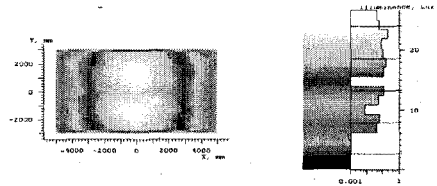
(b) $\theta_2=5^\circ$, $\theta_1=60^\circ$



(c) $\theta_2=10^\circ$, $\theta_1=60^\circ$



(d) $\theta_2=15^\circ$, $\theta_1=60^\circ$



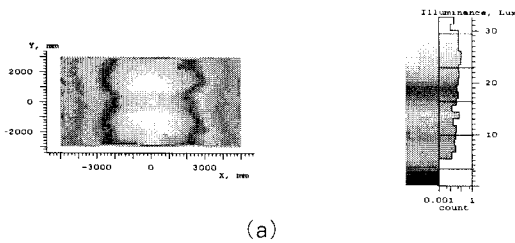
(e) $\theta_2=20^\circ$, $\theta_1=60^\circ$

Fig. 11. The illuminance distributions of luminaire in $\theta_1=60^\circ$ varying θ_2

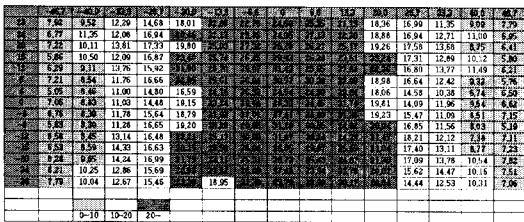
dimension of the receiver. The illuminance on this surface is given in the colorscale values. The slope changing Θ_2 has 5° and Θ_1 has 60° gave the our target illuminance.

Table 3. Illuminance distribution and uniformity of LED luminaire in $\Theta_1=60^\circ$ varying Θ_2

LED module position	Max. Illuminance ([lux])	Avg. Illuminance ([lux])	Total Light Output ([lm])
0~60°	30.67	17.46	1047.36
5~60°	31.00	17.28	1036.55
10~60°	29.06	16.96	1017.56
15~60°	26.94	16.46	987.88
20~60°	26.59	15.78	947.08



(a)



(b)

Fig. 12. The simulated (a) overall and (b) average illuminance distribution of LED Luminaire in $\Theta_1=60^\circ$ and $\Theta_2=5^\circ$ on a target area 10.39×6 (m²)

Table 3 gives the maximum and average output illuminances and the total light output. Due to our desired illuminance value, we can use the LED module position which are $\Theta_1=60^\circ$ with $\Theta_2=5^\circ$. Fig. 12 illustrates the overall and average simulated illuminance distribution of our designated LED

Luminaire in $\Theta_1=60^\circ$ and $\Theta_2=5^\circ$ on a target area 10.39×6 [m²], 6[m] away from LED Luminaire. We got the our target illuminance as 17 [lux] at this position.

4. Conclusion

In this paper, optical design of LED modules for 54[W] LED Luminaire was conduct with 9 LED Module.

We have selected the proper light source for our designated luminaire. SUNNIX LED gave the high luminous flux at narrow angular distribution. Moreover, we have modeled the secondary optics for LED which is used in this luminaire design to get more light distribution. SUNNIX LED with C-001 flat lens illustrates the shaper illuminance shape among four LEDs.

For the required illuminance value, we have changed the angles of the slope, Θ_1 , between the LED modules from the 0° to 60° varying by 20° and the one, Θ_2 , from the 0° to 15° varying by 5° . We have found the highest illuminance by changing the different conditions of the varying slope angles. The simulation results gave the highest illuminance of the 17 [lux] and the total flux of 1036.55 lumen at $\Theta_1=60^\circ$ and $\Theta_2=5^\circ$ position. When we have used C-001 flat lens which has 30° of half beam angle, we got our target illuminance.

We have analyzed the optical properties of our designated LED Luminaire by confirming the illuminance distribution and light uniformity, which are the main factors in street light applications. Therefore, we have expected our designated LED luminaire using in street light applications.

Acknowledgement

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References

- [1] National Lighting Product Information Program, "Parking Lot and Area Luminaires", specifier Reports, Volume 9, Number 1, pp. 12-17, 2004.
- [2] David E. Weigand, "Advanced Lighting Guidelines", from New Building Institute, pp. 76-116, 2003.
- [3] "LED Luminaire Design Guide", Application Note from CREE LED, 2007.
- [4] Jeff Y. Tsao, "Solid State Lighting-Lamps, Chips, and Materials for Tomorrow", IEEE circuit and Devices Magazine, Vol 20, pp.28-37, 2004.
- [5] N. Narendran, "LED Technology", Lighting Research Center, 2002.
- [6] M. George Craford, "High Power LEDs for Solid State Lighting: Status, Trends, and Challenges", Proceeding of First International Conference on White LEDs and Solid State Lighting, pp 5-9, November, 2007.
- [7] "High-Brightness LEDs", Nanophotonics: Assessment of Technology and Market Opportunities, January, 2005.
- [8] Insiya Shakir and Nadarajah Narendran, "White LEDs in Landscape Lighting Application", Proceedings of SPIE, 2002.
- [9] Art Davis, "Light Emitting Diode Source Modeling for Optical Design", Reflexite Display Optics, October 20, 2004.
- [10] Ivan Moreno and Ching-Cherng Sun, "Modeling the radiation pattern of LEDs," Opt. Express 1808, Vol. 16, No.3, Optical Society of America, 2008.
- [11] L. Svilainis, V. Dumbrava, "LED Far Field Pattern Approximation Performance Study," Proceedings of the ITI, pp 645-649, June 25-28, 2007.
- [12] Yimin Gu and Nadarajah Narendran, "Design and Evaluation of an LED-based Light Fixture", Proceedings of SPIE 5187: pp. 318-329, 2004.
- [13] Kai Wang, Xiaobing Luo, Zongyuan Liu, Bo Zhou, Zhiyin Gan, Sheng Liu, "Optical analysis of an 80-W light-emitting-diode street lamp", Optical Engineering 47(1) 013002, January, 2008.
- [14] John F. Van Derlofske, "Computer modeling of LED light pipe systems for uniform display illumination", Solid State Lighting and Displays, Proceedings of SPIE, Vol. 4445, pp. 119-129, International Society for Optical Engineering, 2001.

Biography

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