

Determination of luminous intensity of light-emitting diodes with modified inverse-square law

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Abstract. We present a method that can be used for accurate analysis of luminous intensity measurements of LEDs. The method is based on the modified inverse-square law where information on the LED behavior is included in three parameters; luminous intensity, radius of the image of the source, and location of the image of the source. The method was studied with 17 different LEDs. The standard deviation of the fitting was typically less than 1%.

Introduction

LEDs are finding more and more applications in e.g. traffic lights, LCD-displays, banners, maritime signal lights, general illumination and automotive headlights. This sets new needs for measurement standards.

As compared to traditional photometry, LEDs have narrow beams and spectral features, low power levels and troublesome geometries. LEDs are usually equipped with built-in lenses which enable desired angular distributions for the LEDs. These lenses produce problems in LED measurements as they transfer the image of the light source away from its physical place. Also the size of the image is different.¹

To overcome the geometrical problems, CIE has recommended² that luminous intensities of LEDs should be measured at two defined geometrical conditions, CIE A and CIE B. We have built a setup for measuring these. An annoying feature in the measurements is that the two luminous intensities may vary quite a lot from each other which may cause difficulties when applying the measured LEDs in high-accuracy applications, e.g. as standard LEDs. We propose a new analysis based on the modified inverse square law that overcomes this limitation.

Studied methods

CIE 127 standard: The CIE 127 publication proposes to measure the luminous intensities of LEDs with a photometer having a circular aperture of 1 cm². Measurements are to be carried out at two distances, $d_A = 316$ mm and $d_B = 100$ mm. Measured illuminances are converted to luminous intensities using equation

$$I_{LED\ A/B} = E_v \cdot d_{A/B}^2 \quad (1)$$

The conditions A and B correspond to solid angles of 0.001 sr and 0.01 sr, respectively, and the measured quantity is called the averaged LED intensity. The distances $d_{A/B}$ should be measured from the aperture plane of the photometer to the front tip of the LED. The LEDs should be operated in constant-current mode and the temperature should be stabilized.

Modified inverse-square law: The proposed method is

based on the measurements of illuminances at various distances from the LED. The measured illuminance values E_v obey the modified inverse-square law

$$E_v = \frac{I_v}{(d + \Delta d)^2 + r_1^2 + r_2^2}, \quad (2)$$

where I_v is the luminous intensity of the LED, d is the distance between the reference planes of the LED and the photometer, Δd is the distance offset of the LED, r_1 is the radius of the emitting surface of the LED and r_2 is the radius of the aperture of the photometer. The modified inverse-square law takes into account the effects of transverse dimensions and distance offset of the LED light source and can be used to compensate for the effects of lenses.

Equation (2) is fitted to the measured illuminance values with the least-squares method by using parameters I_v , Δd and r_1 as free fitting parameters. The measurement distances are selected to cover the region where the measured LED is to be used. The signal should vary sufficiently and the resolution of the photometer must be adequate at each distance.³

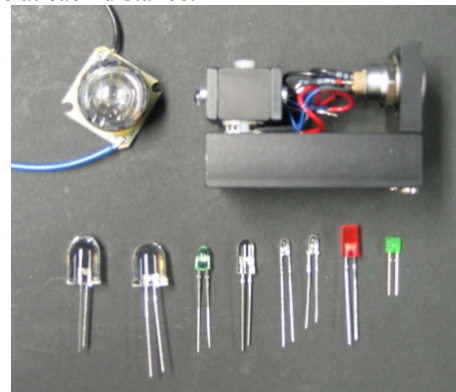


Figure 1. The studied LEDs. The high power LED and temperature-stabilized LED are shown on the top.

Measurement set-up

Photometer: In this work, we used a commercial LED standard photometer from LMT Lichtmesstechnik GmbH. This photometer is in accordance with the CIE 127. Behind the aperture there is a cosine-corrected diffuser, a temperature stabilized $V(\lambda)$ -filter and a Si-photodiode.

Optical rail: The measurements were made mainly on a 1-m optical rail with accurate magnetic length scale. The photometer was mounted on a rail carrier. The studied LEDs were fixed to the other end of the optical rail. The studied LEDs and the photometer were aligned to the same optical axis by using a two-beam alignment laser. The

distances d were measured from the aperture plane of the photometer to the front tip of the LED.

Studied LEDs: Methods were tested with 17 different LEDs with varying geometries, colors and power levels. LED types are presented in Figure 1. Four of the studied LEDs had temperature stabilization at the temperature of 25°C. Constant-current of 20 mA was used for low power LEDs and 330 mA for the high power LEDs.

Measurement results

Illuminances were measured at various distances d between 100 mm and 1000 mm depending on the power level of the studied LED. The measurement distance selections also included the CIE recommended distances 316 mm and 100 mm for all LEDs.

Modified inverse-square law fitting for the green temperature-stabilized LED is presented in Figure 2 as an example of typical results.

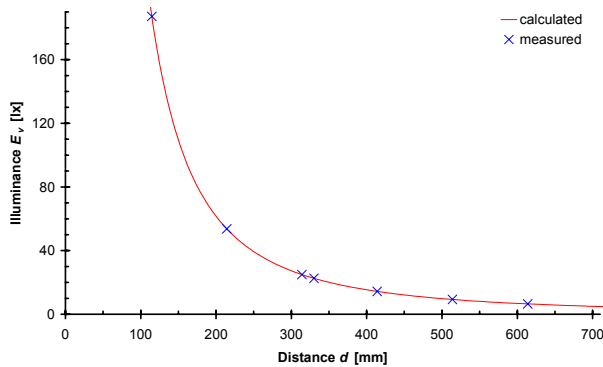


Figure 2. Inverse-square law for the green temperature stabilized LED.

The analysis was done at various fitting ranges due to different power levels. For the high power LEDs with and without a lens, illuminance values were fitted at the regions 100–3000 mm and 100–1600 mm, respectively. For the low power indicator LEDs, the distance measurements were done by steps of 50 mm between 100 mm and 316 mm. Other studied LEDs were analyzed using the region of 100–700 mm.

The results are presented in Table 1. It can be seen that most of the LEDs follow the modified inverse square law with standard deviation smaller than 1 %, biggest standard deviation being 2.1 %. Over more limited regions (e.g. excluding the 100-mm distance) agreement is typically better than 0.1 %. For most LEDs the size of the source can be assumed to be zero. For the LEDs containing powerful lenses this assumption can not be made, but an agreement can be found using r_1 as a free parameter. CIE luminous intensities typically vary quite a lot from each other for each of the studied LEDs.

It should be noted that the obtained values for Δd and r_1 are far from the physical dimensions. They should be considered merely as parameters in a two-aperture approximation of the optical system instead of true physical dimensions.

Table 1. Measurement results of the studied LEDs. The first column gives diameter and color of the LEDs. L is the length of the LED housing.

studied LED	Modified inverse-square law				$I_{LED A} / I_{LED B}$	L [mm]
	I_v [cd]	Δd [mm]	r_1 [mm]	standard deviation		
3 mm w	3.6	0.2	0.0	0.85 %	0.989	6.0
3 mm r	1.4	4.8	0.0	0.60 %	1.081	4.6
3 mm g	3.6	5.2	0.0	0.11 %	1.071	4.8
5 mm w	1.9	7.2	0.0	1.23 %	1.089	8.6
5 mm b	0.8	9.5	36.7	0.23 %	1.247	8.7
5 mm g	2.5	13.7	14.4	0.03 %	1.206	8.7
5 mm r	3.4	12.0	0.0	0.48 %	1.179	8.7
5 mm g	1.9	6.2	0.0	0.96 %	1.094	7.0
5 mm g	15.7	7.8	102.7	1.03 %	1.907	9.8
5 mm b/g	6.9	-44.1	85.1	0.18 %	1.278	10.7
10 mm o	69	-23.4	215.8	0.62 %	3.958	15.1
10 mm r	6.5	1.6	65.6	1.28 %	1.378	13.5
1W w	285	-11.0	45.6	0.17 %	1.057	14.1
1W g	403	31.6	0.0	2.09 %	1.337	14.1
1W g	5.5	2.3	0.0	0.14 %	1.029	3.0
sideview g	0.004	5.7	0.0	0.21 %	0.700	5.7
square r	0.026	-0.4	0.0	0.89 %	0.250	5x5

Conclusions

Applicability of the modified inverse-square law for the luminous intensity measurements of the LEDs has been studied with seventeen LEDs. Many of the studied LEDs contain a lens which complicates the distance measurements. The analysis removes the effect of the lens by moving the image of the source and allowing its size to vary. The essential information of the LEDs can be included in three parameters, luminous intensity I_v , radius of the image of the source r_1 , and location of the image of the source Δd .

Fitting made by the proposed method gives notably more consistent results than the CIE standard, and the solution includes the standardized parameters $I_{LED A}$ and $I_{LED B}$. The method is therefore useful in applications where more consistency is needed.

References

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