Lighting Technology Lab
Near-field goniometry

Light Technology Institute

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Group L09

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1. Introduction

Goniophotometry is a technique of measuring the angular distribution of light. In this lab, light measurements are performed in near field, i.e. with distance that according to the photometric law of distance does not allow to treat the light source as point source, but as extended light source.
The following report is about the characterisation of the different LEDs with the near-field goniometer. All steps from setting up the machine till the rayfile analysis are described.

1.1 Photometry

Photometry is the science of light metrology. These measurements are restricted to the visible range of the electromagnetic spectrum, the range that is perceived by the human eye (380 nm – 780 nm). The sensitivity of the human eye can be seen on the *figure 1*. The human eye is most sensitive at the wavelength of 555 nm in daylight (red curve on the *figure 1*) and most sensitive at the wavelength of 505 nm at night (black curve on the *figure 1*).

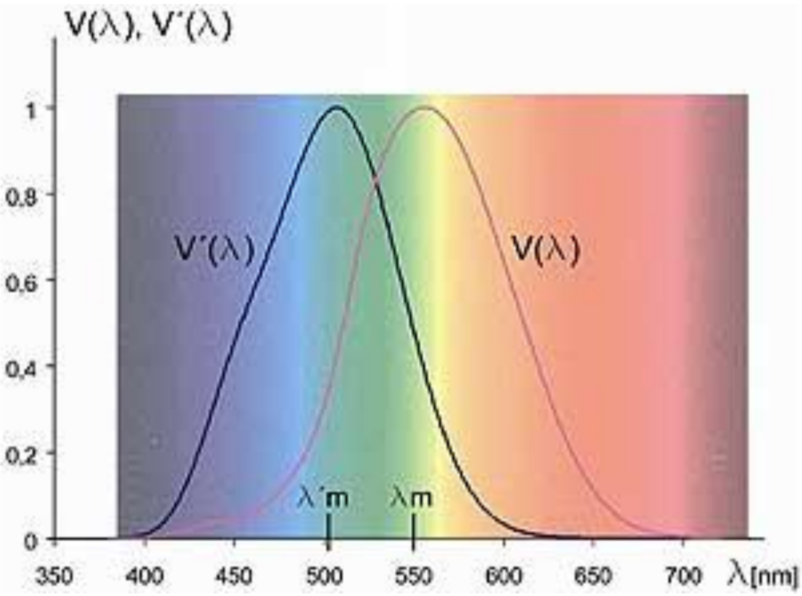

Figure 1 The sensitivity of the human eye. Red line: photopic curve. Black line: scotopic curve. [6]

Basic photometric quantities, that represents different kinds of light measurement, will be explained.
Luminous flux Φ describes how much light is emitted from a source. This quantity is a radiant power weighted with V(λ)- curve. The unit of Φ is lumen.
To evaluate the amount of light in a specified direction, we need the luminous intensity *I* which is luminous flux per solid angle Ω:

$$I = \frac{d\Phi}{d\Omega}$$

The unit of *I* is candela. [cd =$\frac{lm}{sr}$]

The third important photometric quantity is illuminance E, that describes the luminous flux incident on a surface A:

$$E = \frac{\mathrm{d}\Phi}{dA_{object} * \cos(\alpha)}$$

α is the angle at which a light ray hits the surface of a receiver. Its unit is lux. [lx $=\frac{lm}{m^2}$]

Luminance L describes luminous flux emitted or reflected from a surface in a direction.

$$L = \frac{d^2\Phi}{\cos(\alpha) * dA * d\Omega}$$

Luminance is measured in cd/m^2.

1.3 Near field goniophotometry

The main aspect that distinguishes the near field and far field goniophotometry is application of luminance camera for light measurement. The light source is no longer considered as a point source like in the far field goniometry, but its size and extension is taken into account. The goniophotometer RiGO801-300 (*fig.2*) that was used for the measurements can measure light sources with diameter of up to 30 cm. The device consists of a turning arm that is mounted to a rotating frame. Luminance camera is installed on the turning arm. Through rotation of the frame and turning of the arm, the camera can gather luminance values from each position around a lamp or luminaire.

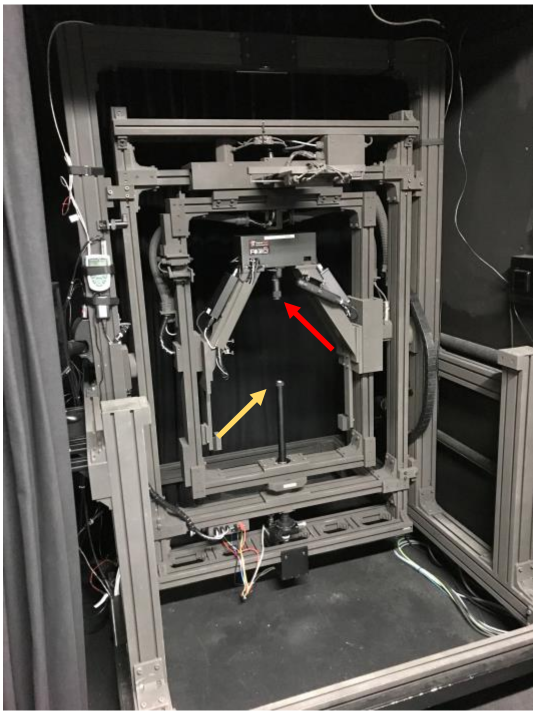

Figure 2 Near field goniophotometer RiGO801-300 with marked luminance camera (red arrow) and position of the light source (yellow arrow).

The main components of the camera, used in the goniophotometer, are CCD sensor, an objective lens and filters. One filter lies between the sensor and the lens (e.g. V(λ) filter) and the second one in front of the lens (e.g. neutral density filter).
Each point of the extended light source is imaged onto one pixel of the CCD-Sensor (*figure 3)*.

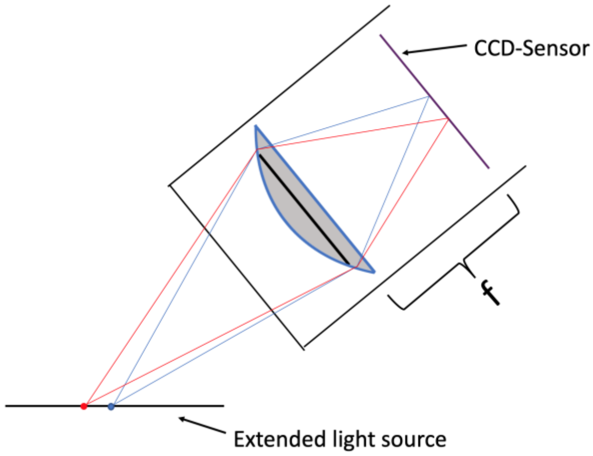

Figure 3 Schematic principle of the luminance camera

Additionally, the goniometer contains a photometer that moves together with the camera on the spherical surface around the measurement object. The detector can also record measurement data and does the photometric normalization of the camera data [1]. The photometer contains a stacked V(λ)-filter, unlike the photometer in a far-field goniometer that has a pattern of different colour filters over the whole photometer sensor.

1.2 Purpose of the experiment

The purpose of this measurements is determination of luminous intensity distribution (LID), luminance distribution, luminous flux and centre of light for two different LEDs.
With the near field goniophotometer, a red Single Chip LED and a RGB LED are characterized.

1.3 Data output

During the measurements of the LED a *.ttr* file is generated, it consists of up to 1 Billion light rays. Each light ray contains following information: *starting point* (in x, y, z) and *direction* of the ray as well as the *relative luminous flux,* that is theoretically calculated based on the luminance pixel values by multiplying with the solid angle of the pixel and the area element of the light source [1,2,3].
The final files can have a size of up to 100 MB. Reduction of the data amount is required for further compute issues.
After converting the *.ttr* into a *rayfile* it is possible to do further analysis of the light source. With the information of the *rayfile* it is possible to compute several quantities of the LED such as: luminous flux, photometric centre and luminous intensity distribution (LID).
In addition, the generated *rayfile* can be implemented in simulation programs in order to simulate optical systems.

2. Procedure

In the lab, two LEDs were investigated:

- as first measurement: 3-Chip RGB LED from Seoul
- as second measurement: 1-Chip SuperFlux LED from Philips

The preparation of the measurements involved selecting appropriate camera objective lens and filters and positioning the LED in the goniometer centre.

The objective lens, that gathered all relevant light, was selected. For both LEDs, it was an objective lens with focal length of 80 mm.
The measurement object was positioned in the goniometer centre by means of the X-Y-Z shifting and rotating unit and additionally by using the luminance camera. The light source was placed, so that its photometric centre overlapped approximately with the goniometer centre.
Positions of the camera in three axes (x, y and z) allowed to check the alignment of the luminaire what can be seen of the *figure 4* and *5*. The photometric centre for the RGB LED was placed in the middle of the surface and for the SuperFlux LED a little above the surface, because of the additional optics.

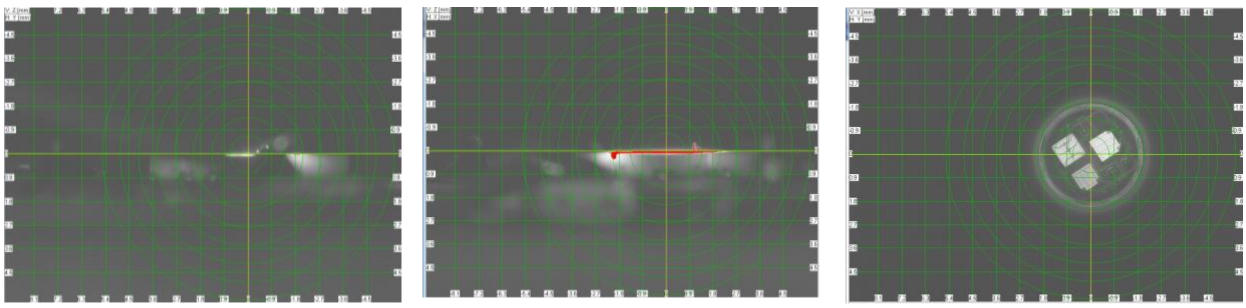

Figure 4 Positioning of the RGB LED. Left: in the x-axis direction, middle: in the y-axis direction, right: in the z-axis direction.

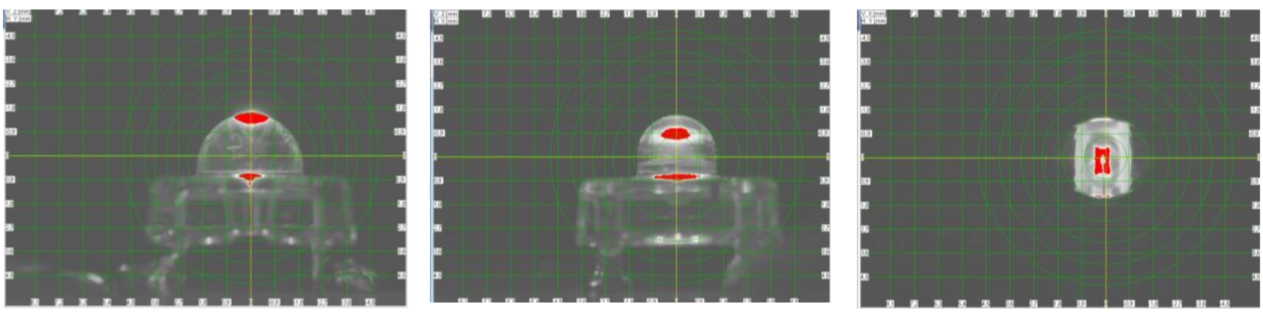

Figure 5 Positioning of the SuperFlux LED. Left: in the x-axis direction, middle: in the y-axis direction, right: in the z-axis direction.

The SuperFlux LED luminaire consisted of a dome unlike RGB LED as can be seen on the graph. Next, camera filters were selected.

The first filter between the CCD sensor and camera objective lens was V(λ)-filter for luminance adaptation. In order to limit high intensity light beams, the neutral density of OD 4 was placed in front of the objective lens. The most appropriate optical density of the filter and optimum integration time was found for the maximum luminance. In order to achieve an optimum signal-to-noise ratio and optimum exploitation of the measuring dynamic range, the dynamic range of the camera image was set above 80 % but less than 95 % to avoid an overflow. Any overdriven regions in the image were marked red. The maximum brightness was found by positioning the camera within angular range in different C-planes.

Calibration involved setting the optimum measuring range for the radiation direction with the maximum illuminance for the photometer. This also limited the risk of any overflow.

Before starting the measurements, the LEDs were burned-in in order to reach stable working point.

All the parameters during the measurements for both LEDs, such as ambient temperature, electrical parameters (current, voltage, power) size of the LEDs (height, diameter) or integration time can be found in the *Table 1*.

Table 1 Parameters during the measurements of RGB LED and SuperFlux LED.

Categories	Parameters	Seoul RGB LED	Philips SuperFlux LED
Dimension	Height	2.6 mm	6.55 mm
	Diameter	4.2 mm	7.5 mm
Temperature	Ambient temperature	24.6 °C	24.06 °C
Angle	$\theta_{min} - \theta_{max}$	90° – 270°	80° – 280°
	$\varphi_{min} - \varphi_{max}$	0° – 180°	0° – 180°
	Angular resolution θ	1.5°	1.5°
	Angular resolution φ	1.5°	1.5°
Time	Burn-in time	tmin: 10, tmax: 120 min	tmin: 10, tmax: 120 min
	Measurement time	20 min	22 min
	Integration time	1.75 ms	2 ms
Electrical parameters	Current	100 mA	70.05 mA
	Voltage	7.8 V	2.622 V
	Power	0.78 W	0.183 W
	Relative illuminance	0.4%	0.21%

Some values from the table need to be explained:

- $\theta_{min} – \theta_{max}$
  The RGB LED consists of three flat shining surfaces directed in the same way, therefore no light is supposed to go beyond a solid angle of ±90° relative to the surface normal, the measurements were performed only within a half sphere instead.
  In order to compare the measurements results with the datasheet, the range of θ_{min} – θ_{max} was 80° – 280° as reported by the manufacturer. [5]
- Relative illuminance
  Before and after measurements, illuminance in the beginning point was measured. The difference between these results should not be higher than 0.5% to accept measurements. This requirement was accomplished, what is visible in the table.

The luminance camera recorded luminance in steps of 1.5° for both polar angle θ (rotation of the goniometer frame) and the azimuth angle φ (turning of the goniometer arm). The photometer provides a reference luminous flux, since the camera is not reliable in terms of measuring absolute values. The time of RGB LED measurement was approximately 20 min and for the SuperFlux LED it was about 22 min, because of the enlarged angular range.

3. Evaluation

In this section the evaluation of the measurements is performed. To do so the measurements and the data provided by the manufacturer are compared.
Furthermore, the results obtained for the RGB LED will be used in the lab "Simulation of Optical Systems".

3.1 RGB LED

The measured luminous flux for the set electrical parameters *(*see *Table 1)* of the LED is 34 lm. The manufacturer quantifies the luminous flux equal to 105 lm for a forward current of 350 mA and a voltage of 10 V.
Due to the deviation in the electrical parameters, no adequate statement of the luminous flux can be provided. A second measurement with the correct electrical parameters would be necessary in order to compare the manufacturer's and the measured data reliably.

The measurement of the Seoul RGB LED shows the expected results in terms of the LID (*figure 6*). Since no further optics is used but just the pure chips, the LID of the LED has a lambertian characteristic.

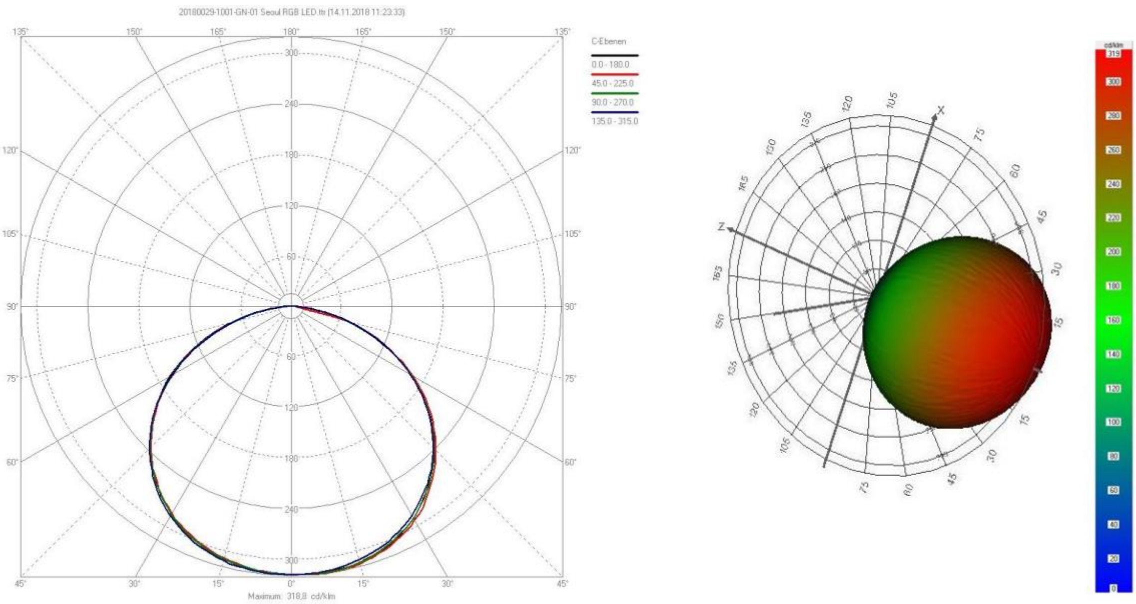

Figure 6 LID of the RGB LED according to the measurements in 2D (left) and 3D (right).

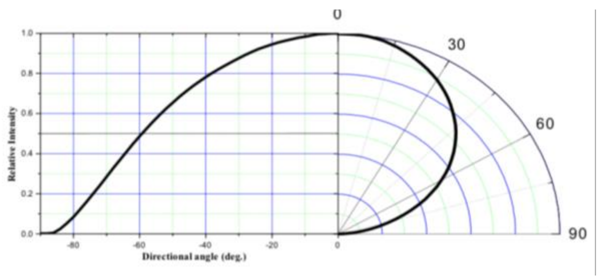

Figure 7 LID of the RGB LED according to the manufacturer [4].

The luminous intensity distribution of the RGB LED for the measurement (see *figure 6*) and the one of the producer (see *figure 7*) match each other.

Further analysis has to be done for each single colour chip red, green and blue. The goal is to find the centre of light and luminous flux for each chip. The generated data can be used for simulation purposes.

First of all, it is necessary to convert the generated rayfile into a ".dis" format. By doing so, million rays are compressed to just a few thousand. This is necessary to reduce the data base for further compute issues.
The compression is a statistical process. In order to take all light rays into account during the compression, a shape and size of an enveloping geometry has to be assumed. For RGB LED the sphere of radius of 3 mm is chosen. For a compression from 3 million to 100 thousand rays and the assumed enveloping geometry, 99,8 % of all light rays are taken into account.

Further analysis is based on the generated ".dis" file. For analysis, it is necessary to separate the single chips of the LED.
For this, the light rays are projected onto the xy-plane of the computed photometric centre. By doing so, more light rays appear from the shining surfaces. Thus, it is easily possible to separate each colour chip and generate an independent rayfile (see *figure 8*).

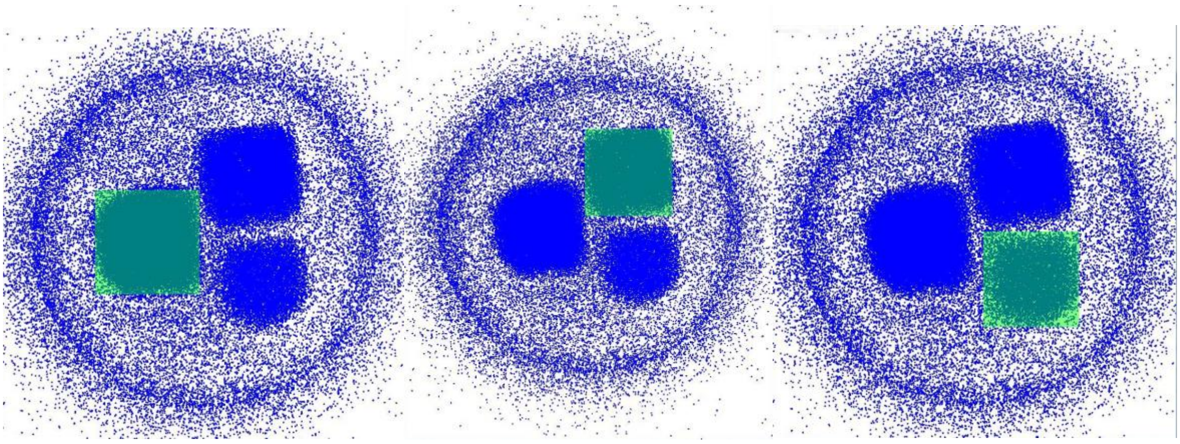

Figure 8 Separation of single colour chips: each blue point represents a single light ray. Left: marked green chip. Middle: marked blue chip. Right: marked red chip.

The rayfiles for individual chip give the opportunity to calculate the photometric centre for every single colour chip: red, green and blue.

Table 2 Light centre position of different RGB LED colour chips.

Axes	Green	Blue	Red
x	-0.63	0.54	0.66
y	-0.09	0.67	-0.54
z	0.11	0.07	0.11
Luminous flux [lm]	12.63	7.96	3.73

The coordinates of light centre and the luminous flux for each LED chip can be found in the table (*Table 2*). Based on the sum of the luminous fluxes of the individual chips and the whole luminous flux of the LED (34 lm), it can be assumed that the stray light is equal to 9.62 lm (28%). Indeed, this value is not perfectly reliable. Stray light is each light ray which comes not directly from the chips area. This depends also on how well the area of each chip is defined while the separating process (see *figure 8*).

It is doubtful that the blue chip has a higher luminous flux than the red chip, also comparing to the manufactures data sheet.
This leads to the conclusion that the top-down perspective was set incorrectly before the file converting process. It seems the y values of the light rays are mirrored at the x-plane and the calculated photometric centre is in the wrong z-direction.
Comparing the data set (see *table 2*) with the real LED, the values of the red are those of the blue one and vice versa.

3.2 Single-chip SuperFlux LED

As mentioned before, the light centre was initially configured manually, in three axes with screws. It was assumed, that the light centre was in the middle of the epoxy lens (see *figure 4*).

After the measurements, computer calculation is made. The enveloping geometry is assumed to be a sphere with radius of 7mm. 100% of chosen 100 thousand rays are taken into account. Using this data, photometric centre coordinates can be counted. What is observable, the deviation relative to the initial configuration at axes x and y is not very big, as opposed to axis z (see *Table 3*).

Table 3 Photometric centre position of the SuperFlux LED

Axes	Coordinates
x	0.0693
y	0.0291
z	1.2044

Similarly, to the RGB measurement also this data set is inversed in z direction. The photometric centre should be below the LED's surface, since the used optics on the LED is a collimating one. According to the datasheet viewing angle is 25° x 68°. It is confirmed in measurements, that the visible angle in the C-plane of the widest distribution (C90°-270°, marked with green curve) is about 68° (*figure 9* and *10*) and in the narrowest distribution (C0°-180°, marked with black curve) is about 25° The highest luminous intensity is in the direction 6° from the centre in the C-plane 0° - 180°. This is confirmed with the Illuminance calibration.

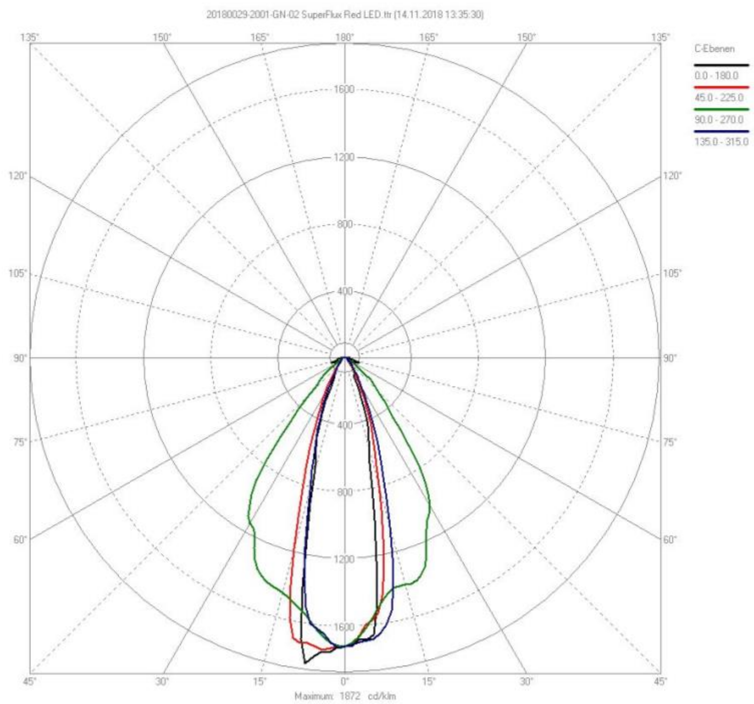

Figure 9 2D LID of the SuperFlux LED.

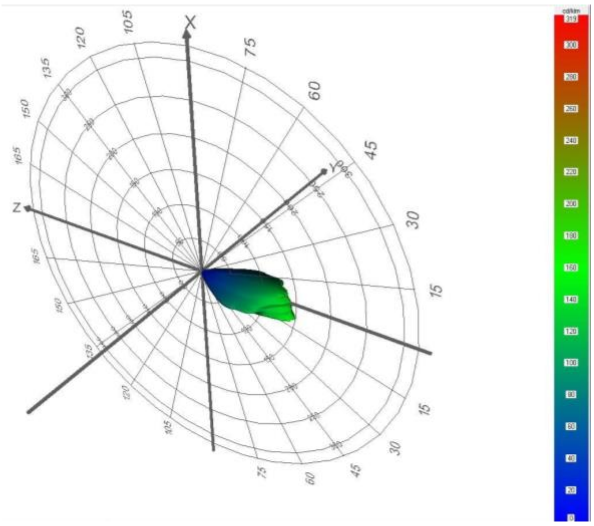

Figure 10 3D LID of the SuperFlux LED.

Comparing the measured LID with the datasheet provided by manufacturer (see *figure 11*), there is an asymmetry. The peak intensity in C0°-180° plane (see *figure 9*, marked with black curve) is supposed to be symmetrical. Based on the assumption that the measurement was done correctly, the LED is defective.

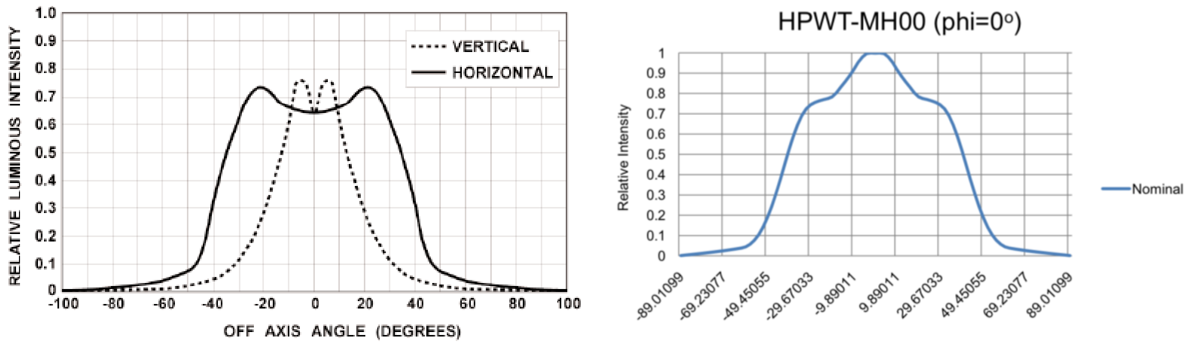

Figure 11 Relative luminous intensity according to manufacturer

The total luminous flux is 2.76 lm. The value is acceptable while the minimum for this type is 1.25 lm according to the datasheet.

This kind of LEDs are used in many lighting applications like vehicles, when dashboard lighting should be visible for the driver, but not necessary for passenger.

4. Conclusion

Near-field goniometer is an advanced machine, to use it in correct way high skills are necessary. It is easy to make measurements mistakes and receive falsified data. Each measurement required a lot of complex steps in right order. Moreover, software required a lot of information that needed to be added manually, what can result in further errors.
Near-field goniometer is an adequate machine to measure:

- Luminance distribution
- Luminous Intensity Distribution
- Luminous flux

The outcome of the measurements is represented by rayfiles.
In this lab, two LEDs were analysed: RGB LED and Single-chip LED. Photometric centre was found by means of rayfiles for both LEDs. Additionally, the same procedure was performed for single chips of RGB LED. The results for Single-chip LED matched the datasheet information. RGB LED, however, could not be compared with datasheet, due to application of different electrical parameters.

References

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[2] SoftwareManual-Rigo801

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[4] SEOUL Semiconductor – Technical Data Sheet, F503560, 05.2008

[5] Philips Lumileds - Technical Datasheet DS05

[6] https://light-measurement.com/spectral-sensitivity-of-eye