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Instruction Manual

for

LED Luminous Intensity Measurements

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Table of contents

1. Definition

1.1. Scope

This instruction manual describes operation and alignment procedures for luminous intensity measurements of standard light-emitting diodes (LEDs) constructed at the Metrology Research Institute of the Helsinki University of Technology (TKK).

1.2. Object and field of application

LED: Light sources used as luminous intensity standards.

Control unit: Controls the current and temperature of the LED.

LMT P11 SOT: Standard photometer used for illuminance measurements.

2. Equipment

2.1. Standard LEDs

The standard LEDs at TKK are 5 mm in diameter and have four colors: white, blue, green and red. The cathodes of the LEDs are directly coupled to aluminum bodies which are temperature-stabilized (25 °C) by Peltier element between the aluminum body and the LED holder (see Figure 1). The LEDs are operated by a constant DC-current of 20 mA.

The measured relative spectral power distributions of the standard LEDs are measured with a calibrated spectroradiometer. The measured spectra are presented in Figure 2.

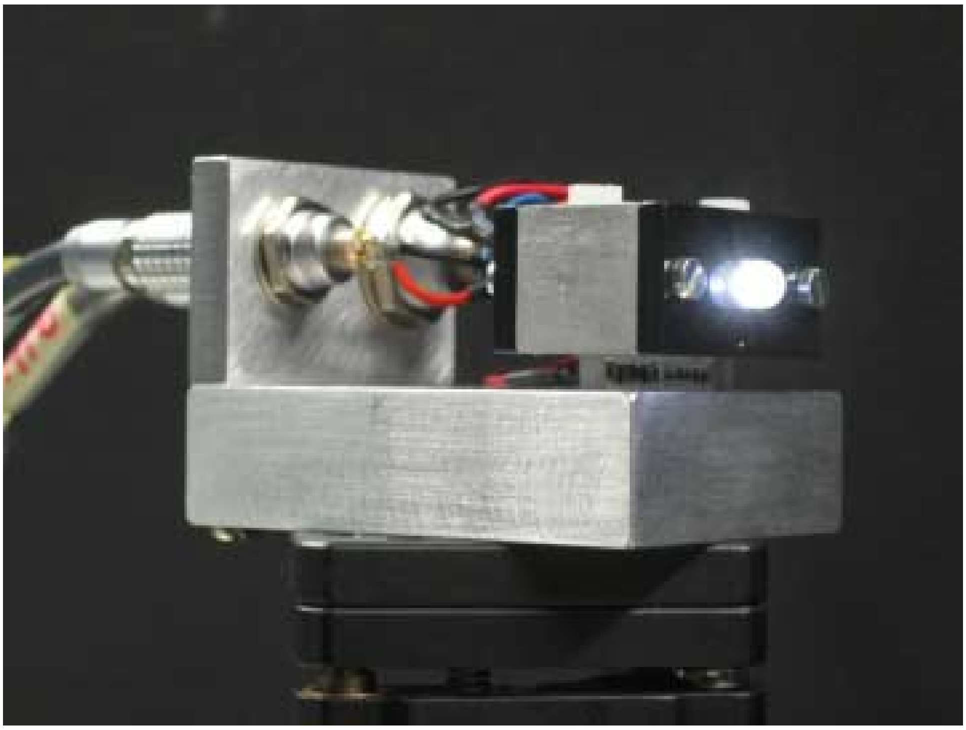

Figure 1. A white standard LED. The temperature of the LED is stabilized with a Peltier element.

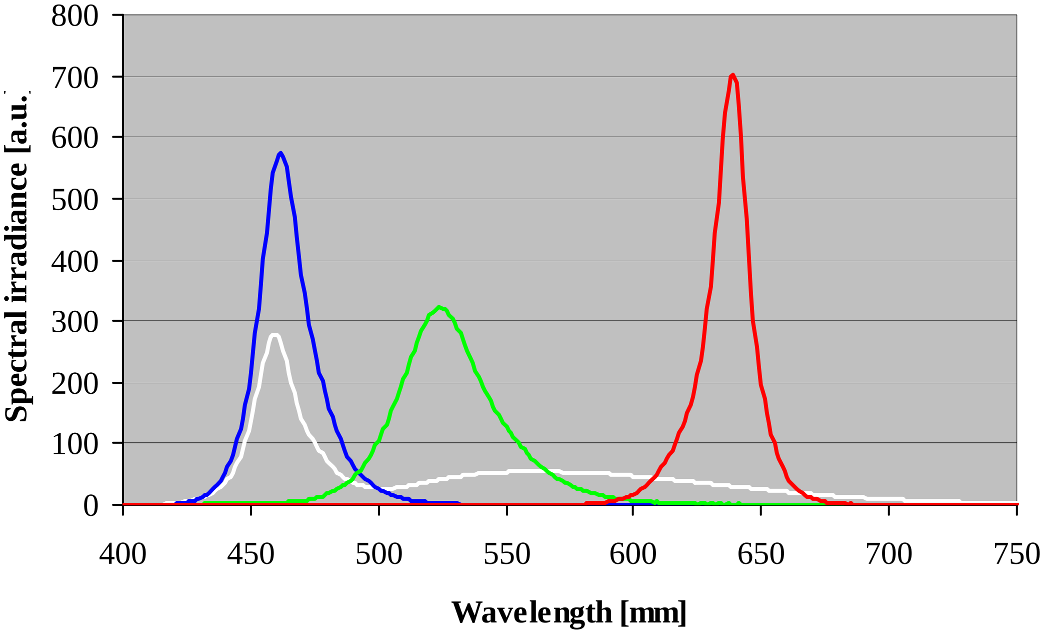

Figure 2. The relative spectral power distributions of the standard LEDs. The peak intensities are not to scale.

2.2. Control unit

The control unit is presented in Figure 3. The unit monitors the status of the LED (operating current, possible short-circuit or open connection) with a PIC micro-controller. The temperature is monitored by another controller inside the unit.

Figure 3. The LED control unit.

The PIC takes care of the soft start of the LED. The stabilization time for the LED was measured to be 5 minutes [1]. The average value of the LED current was 20.026 mA and standard deviation 3 µA (0.015 %).

The control unit is also capable of driving 1W Luxeon LEDs with operating current of 330 mA.

2.3. Standard photometer

The standard photometer used for the LED measurements, presented in Figure 4, is manufactured by LichtMessTechnik GmbH [2]. The photometer follows the requirements set by the CIE [3]. The $V(\lambda)$ filter inside the photometer is temperature-stabilized and the photometer has a good $V(\lambda)$ match. A planar diffuser is placed between the filter-detector package and the circular aperture. The aperture area is 100 mm^2 (diameter = 11.3 mm). The diffuser plane is the distance reference plane and it is situated 3.0 mm behind the front surface of the photometer.

A cable with 4-pin LEMO® connectors is connected between the photometer and the controller. The cable carries the photocurrent from the photometer to the controller and supplies the operating voltage of the temperature controller inside the photometer. The photocurrent is taken from the controller to a current-to-voltage converter (CVC).

The output voltage of the CVC is measured with a digital voltage meter (DVM) and recorded with a computer via GPIB bus.

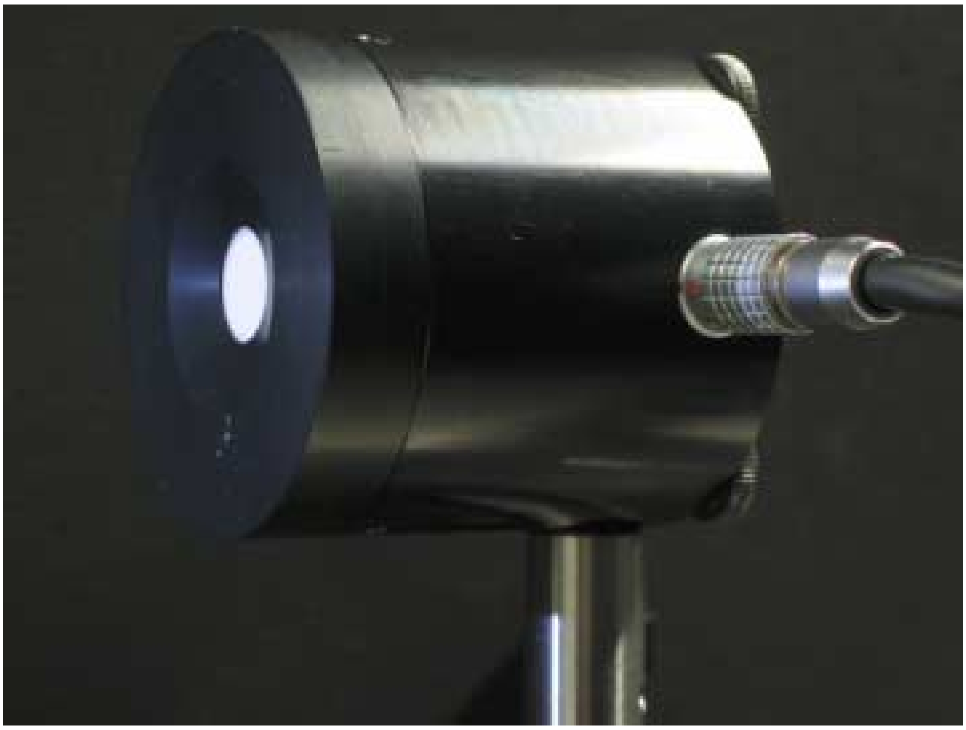

Figure 4. The standard photometer LMT P11 SOT.

2.4. Optical rail

A 1-m optical rail is used for setting the measurement distance. The rail has an accurate magnetic length scale. A sensor within a rail carrier supporting the photometer enables accurate measurement of distances between the standard LED and the photometer. The resolution of the length scale is 0.1 mm. To ensure stable operation, the rail has two aluminum footings which attach the rail to an optical table with M6 screws.

2.5. Maintenance of the equipment

The spectral power distributions of the LEDs are expected to remain stable, therefore they are not measured in regular intervals. The standard photometer is calibrated for illuminance responsivity once a year. Calibration is performed by measuring illuminance from a standard lamp against a reference photometer [4]. The spectral responsivity of the photometer is calibrated with a reference spectrophotometer [5] and recalibrated every 5 years. The rest of the measuring equipment (CVC, DVM) are calibrated according to Ref. [4].

2.6. Traceability

The illuminance responsivity of the photometer is traceable to the national standard of luminous intensity. Calibrations of the CVC and the DVM are traceable to the national standards of electricity.

3. Measurement methods and procedures

3.1. Inverse-square law

The luminous intensity I_v of a light source and the measured illuminance E_v follow the inverse-square law

$$I_v = E_v \cdot d^2 , \tag{1}$$

where d is the measurement distance. It works fine for point sources and relatively long measurement distances. However, with LEDs the size of the emitting surface may cause problems.

3.1.1. Averaged LED intensity by CIE

The CIE has developed a standard for LED measurements [3]. The standard sets the requirements for the photometer, the LED and the measurement procedure. A new term *averaged intensity* was developed to define specific conditions for LED measurements. The standard defines two measurement conditions $\boldsymbol{I_{LED\,A}}$ and $\boldsymbol{I_{LED\,B}}$.

Quote from Ref. [3]:

“Both conditions involve the use of a detector with a circular entrance aperture having an area of 100 mm^2 (corresponding to a diameter of 11,3 mm). The LED should be positioned facing the detector and aligned so that the mechanical axis of the LED passes through the centre of the detector aperture. It is the distance between LED and detector that constitutes the difference between conditions A and B. The distances are:

for CIE Standard Condition A: 316 mm,

and for CIE Standard Condition B: 100 mm.

In both cases the distance is measured from the front tip of the LED to the plane of the entrance aperture of the detector.”

The averaged LED intensity I_{LED} is calculated as

$$I_{LED} = \frac{I_{LED\,A} + I_{LED\,B}}{2} , \tag{2}$$

where luminous intensities $I_{LED\ A}$ and $I_{LED\ B}$ are defined according to CIE conditions A and B, respectively. In practice, luminous intensities are obtained as

$$I_{LED\ A/B} = F \cdot d^2 \cdot \frac{y}{s_{LED\ A/B}}, \quad (3)$$

where F is the spectral mismatch correction factor [6] for the LED, d is the measurement distance (either 316 mm or 100 mm) and y is the signal from the photometer. Illuminance responsivities $s_{LED\ A/B}$ are measured using CIE standard illuminant A and measurement distances of 316 mm and 100 mm.

3.1.2. Extended LED intensity by TKK

The measurement procedure at TKK takes advantage of the modified inverse-square law, where also the size of the LED source and the aperture area of the photometer are taken into account. In addition, the LED can be better considered as a point source if it is mathematically shifted to a location for which the inverse-square law holds. The modified inverse-square law is expressed as

$$E_v = \frac{I_v}{F \cdot ((d + d_0)^2 + r_1^{\ 2} + r_2^{\ 2})}, \quad (4)$$

where d_0 is the LED shift, r_1 is the radius of the photometer aperture and r_2 is the radius of the LED source. Illuminance is measured at distances d of 100, 200, 300, 316, 400, 500 and 600 mm from the front tip of the LED. The luminous intensity values are calculated for each distance. Using least-squares fitting and minimizing the deviations in the luminous intensity values, the parameters d_0, r_2 and the average of I_v are obtained. The standard deviation of the luminous intensity values should be less than 0.2 %. The CIE averaged LED intensity can be calculated also.

For 5-mm LEDs the parameter r_2 is usually zero, but for larger LEDs its significance increases.

3.2. Alignment procedures and resetting the distance

- The optical rail is attached to the optical table
- A two-beam alignment laser (OmTec) is mounted on the optical rail and aligned parallel to the rail.
- The standard LED source and the photometer are mounted on the opposite sides of the laser. The standard LED can be either on a rail carrier or attached directly to the optical table.
- A short metal bar with a hole in the middle (like Thorlabs 25-mm post) is placed so that the LED is inside the hole. A mirror is pushed against the other end of the

metal bar. LED holder is aligned so that the reflection from the mirror goes back to the laser output and the laser beam hits the center of the LED.

- A mirror is placed against the front surface of the photometer. The photometer is aligned when the laser beam goes back to the laser output and the laser beam is in the middle of the round aperture.

- When both the LED source and the photometer are aligned, the photometer is taken towards the standard LED. Using a suitable thin piece of plastic, the distance between the front tip of the LED and the photometer aperture can be determined. The display unit of the distance measurement system is then reset. This initial distance is taken into account in the luminous intensity measurements.

3.3. Luminous intensity measurement

The photometer is taken to the first measurement distance of 100 mm (taking into account the initial distance). The standard LED and the photometer are turned on and allowed to stabilize for 1 hour before the measurements. Baffle is placed between the standard LED and the photometer to reduce stray light.

Illuminances are measured at given distances by taking 20 samples from the photocurrent. The dark current (10 samples) is measured before each illuminance measurement by blocking the light from the LED. Dark currents are subtracted from the photocurrents during the data analysis.

4. Safety and handling precautions

- Even though LEDs are quite durable, the standard LEDs should be handled like normal incandescent lamps.

- Photometer is a delicate instrument, difficult and expensive to repair. Therefore, extreme caution should be taken when carrying and handling the photometer.

- All devices should be kept in a safe place when not in use.

5. Laboratory accommodation and environment

The LED luminous intensity measurements are performed either in the Optical Power Laboratory (room I136) or in the Sphere Laboratory (room I134b), located in the basement of the Department of Electrical and Communications Engineering. These laboratories are clean rooms. Instructions for using the clean rooms have been given in [7].

During the calibrations:

- The Clean Zone -aggregate should be on to prevent dust.

- Temperature should be monitored.
- Humidity should be monitored.

Humidity and temperature values during the measurements are written down.

6. References

[1] Pasi Manninen, *Loistediodien fotometriset mittaukset* (Master's Thesis, TKK, 2004).

[2] LMT Lichtmesstechnik GmbH Berlin, Helmholtzstrasse 9, D-10587 Berlin, Germany.

[3] Measurement of LEDs, CIE127 (Commission Internationale de l'Eclairage, Vienna, Austria, 1997).

[4] Jari Hovila, *Quality Manual of Luminous Intensity Laboratory*.

[5] F. Manoochehri, P. Kärhä, L. Palva, P. Toivanen, A. Haapalinna, E. Ikonen, "Characterisation of optical detectors using high-accuracy instruments," *Anal. Chim. Acta* **380**, 327-337 (1999).

[6] P. Toivanen, P. Kärhä, F. Manoochehri, E. Ikonen, "Realization of the unit of luminous intensity at the HUT," *Metrologia* **37**, 131-140 (2000).

[7] Clean room instructions / Puhdastilaohjeet.