

INTERNATIONAL STANDARD



**Display lighting unit –
Part 2-5: Measurement method for optical quantities of non-planar light sources**

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INTERNATIONAL STANDARD



Display lighting unit –

Part 2-5: Measurement method for optical quantities of non-planar light sources

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.120; 31.260

ISBN 978-2-8322-9771-1

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DISPLAY LIGHTING UNIT –

**Part 2-5: Measurement method for optical quantities
of non-planar light sources**

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The text of this International Standard is based on the following documents:

FDIS	Report on voting
110/1296/FDIS	110/1320/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62595 series, published under the general title *Display lighting unit*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
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INTRODUCTION

The recent introduction of curved OLED TVs, and the expected rapid spread of flexible displays in portable devices, highlights the necessity of new measurement methods. In recent years flexible displays have been integrated into products such as cellular phones and wearable devices [1] to [5]¹. Development and integration of flexible displays have increased the application of curved devices, for example distinct or curved-back large-size wall displays, foldable signage displays, and commercial wearable or handheld devices. The measurement of optical characteristics of displays with radii larger than 35 mm has been documented.

Recently flexible light sources (LSs) have been used for general lighting applications and as light source for flexible non-emissive displays. Since bending a planar lighting unit alters the optical properties of the unit, assessment of the optical performance of the lighting units in a curved state, i.e., concave or convex condition, is indispensable for manufacturing companies.

A light source can be a planar or non-planar (continuous multiple curvatures), i.e., convex (outer light emitting surface of a curvature), or concave light source (inner light emitting surface of a curvature). When a light source is bent the LS is under strain, i.e., tension or depression, the optical characteristics differ from that of a planar LS. A non-planar LS may have local curvatures on its surface with different surface normal from position to position. Such an LS can be a semiconductor light-emitting diode (LED, OLED, polymer LED (PLED)) or a phosphor excited type using a pump source. An LS can have a narrow-band radiation or more than one narrow band emission.

Issues concerning flexible light sources with surface curvatures, which are different from those issues concerning displays (e.g., resolution, contrast, lateral and directional characteristics or directions of viewing), hitherto have not been documented.

Since the characteristics of a non-planar light source (NPLS) change with the decreasing radius of the curvature, the optical characteristics of LS such as lateral and directional luminance and luminance variations, lateral and directional chromaticity distributions and their variations, luminous intensity distribution, and luminous flux, will be measured and evaluated.

This document establishes the measurement methods for cylindrical light sources that can be a base for the study of non-planar LS, which is assumed to be an integration of small areas. The fundamental element of such a surface can be a convex or a concave curvature with a first order of radius, i.e., a cylindrical shape, which is worth considering in this document.

In addition, a curved light source is used in a variety of conditions. Therefore, the optical measurements of an LS will be performed in a darkroom.

As in the measurement of planar LSs the following measurements are used for convex and concave LS measurements: 1) a lateral scanning measurement and 2) a directional scanning measurement. In the case of lateral scanning, the surface normal coincides with the optical axis of the light measurement device. In the case of directional scanning the local surface normal makes an angle with the optical axis of the measurement device.

Since the aperture of a light measurement device is not zero (non-zero aperture), there exist an optimized measurement distance and angle (i.e., 0,1°, 0,2°, 1°, and 2°) for the measurements. In the measurement of a cylindrical LS, a light measurement device which has sufficient depth-of-field or depth-of-focus is selected, because the measurement field on the LS has a three-dimensional geometry and is different from that of a plane.

¹ Numbers in square brackets refer to the Bibliography.

DISPLAY LIGHTING UNIT –

Part 2-5: Measurement method for optical quantities of non-planar light sources

1 Scope

This part of IEC 62595 specifies the measurement methods for measuring the optical characteristics of convex and concave cylindrical light sources. These non-planar light sources (NPLSSs) can have either a continuous, distinct, segmented or block-wised light radiating surface, for example OLED panels, integrated LEDs, integrated mini-LEDs, micro-LEDs, laser diodes, each being either monochromatic or polychromatic.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61747-6-2, *Liquid crystal display devices – Part 6-2: Measuring methods for liquid crystal display modules – Reflective type*

IEC 62595-2-1, *Display lighting unit – Part 2-1: Electro-optical measuring methods of LED backlight unit*

IEC 62595-2-3, *Display lighting unit – Part 2-3: Electro-optical measuring methods for LED frontlight unit*

IEC 62679-3-3, *Electronic paper displays – Part 3-3: Optical measuring methods for displays with integrated lighting units*

IEC 62922, *Organic light emitting diode (OLED) panels for general lighting – Performance requirements*

ISO/CIE 11664-3, *Colorimetry – Part 3: CIE tristimulus values*

ISO/CIE 19476, *Characterization of the performance of illuminance meters and luminance meters*

CIE S 017/E:2020, *International Lighting Vocabulary*

CIE 1931, *Colour space*

3 Terms, definitions, abbreviated terms and letter symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

planar light source

light source with a nearly infinite radius of curvature

3.1.2

non-planar light source

light source having continuous multiple curvatures

3.1.3

convex light source

light source defined by the outer light emitting surface of a curvature

3.1.4

concave light source

light source defined by the inner light emitting surface of a curvature

3.1.5

flexible light source

light source capable of bending or being bent or to endure strain without being destroyed

3.1.6

single-curvature surface emission light source

cylindrical light source

light source that possesses one radius of curvature whether negative (concave) or positive (convex), along its length, width or diagonal

3.1.7

multiple-curvature surface light source

light source that possesses multiple radii of curvatures whether negative (concave) or positive (convex), along any dimension such as length, width or diagonal

3.1.8

phosphor converted emission light source

light source with a pump source that is used to excite a phosphor or any phosphor-like material that radiates light of wavelengths longer than the pump source

3.2 Abbreviated terms

CCT	Correlated colour temperature
COC	Circle of confusion
DC	Direct current
DoF	Depth-of-field
dof	Depth-of-focus
DUT	Device under test

LED	Light emitting diode
LMD	Light measurement device
LS	Light source
MF	Masurement field
NPLS	Non-planar light source
OLED	Organic light emitting diode
PLS	Planar light source
SLMD	Spot-type light measuring device

NOTE The measurement field is an area on the DUT viewed through the LMD lens within a cone limited by the measurement field angle.

3.3 Letter symbols (quantity symbols/unit symbols)

The letter symbols for NPLS are shown in Table 1.

Table 1 – Letter symbols (quantity symbols/unit symbols)

Definition	Symbol	Unit
Luminance of an arbitrary area centred at point (x_i, y_i) on an NPLS	$L_{vi}(x_i, y_i, \theta_0, \phi_0)$	cd/m ²
Maximum luminance on an NPLS	L_{vm}	cd/m ²
Minimum luminance on an NPLS	L_{vm}	cd/m ²
Directional average luminance on an NPLS	L_{va}	cd/m ²
Centre luminance on NPLS (in case of definition for an NPLS)	L_{vc}	cd/m ²
Lateral luminance uniformity	U_{lat}	%
Directional luminance uniformity	U_{dir}	%
Directional luminance viewed from an arbitrary direction	$L_v(x, y, z, \theta, \phi)$	cd/m ²
Chromaticity difference (chromaticity difference, CIE 1976)	$\Delta u'v'$	
Directional chromaticity difference	$\Delta u'v'(\theta, \phi, x_i, y_i, z_i)$	
Uniformity in chromaticity	U_c	
Depth-of-field	ΔL	mm
Depth-of-focus	Δl	mm
Direct current	I_{DC}	mA
Peak value of an alternating current	I_{peak}	mA
RMS of an alternating current	I_{rms}	mA
Effective value of an alternating current	I_{eff}	mA
DC voltage	V_{DC}	V
Peak value of an alternating voltage	V_{peak}	V
RMS of an alternating voltage	V_{rms}	V
Effective value of an alternating voltage	V_{eff}	V
Correlated colour temperature for lateral measurement	CCT_{lat}	K
Correlated colour temperature for directional measurement	CCT_{dir}	K
Luminous flux of a standard LS	Φ_{vstd}	lm
Luminous flux of a DUT	Φ_{vDUT}	lm
Chromaticity coordinates	x_{ca}, y_{ca}	

NOTE Directional luminance distribution, $L_{\nu_i}(x_i, y_i, \theta, \phi)$, is measured for an area centred at point (x_i, y_i, z_i) , along the zenith angle (θ) and an intended azimuth angle (ϕ).

4 Measurement devices

4.1 General

In 4.1 to 4.5 a light measurement device, such as a spectrometer, an integrating sphere and a goniometer with LMD are used. In addition, three axial stages for fixing the device under test are used.

For an evaluation of the measurement results, the Cartesian and the spherical coordinate systems are used as shown in Figure 1.

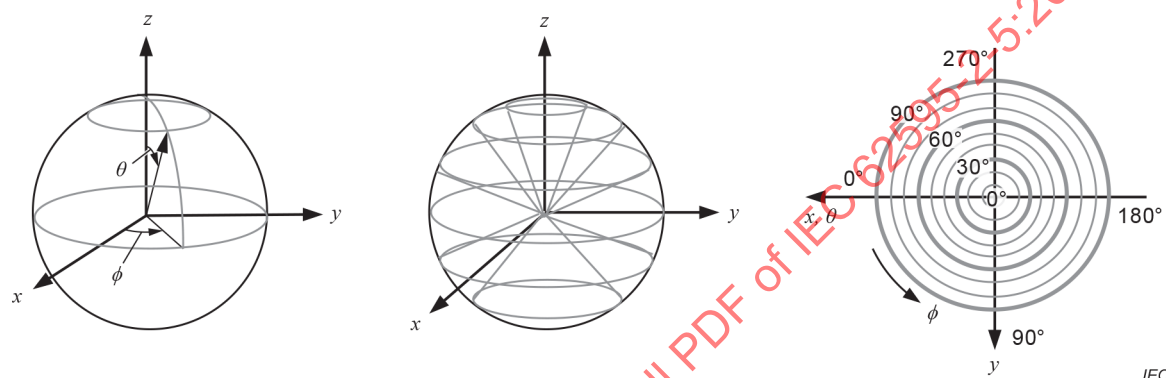


Figure 1 – Cartesian and spherical coordinate systems for NPLS measurement

4.2 Spot-type light measuring device

The spot LMD (SLMD) shall be equipped with a view finder (see Figure 2). The position of the entrance pupil (aperture) of the LMD shall be provided by the manufacturer or the supplier. The size of the entrance pupil of the LMD should be set between 2 mm and 5 mm, and shall be smaller than the output light field of the DUT [1] to [6].

NOTE 1 The terms used in Figure 2 correspond to ISO/CIE 19476.

The optics of an SLMD shall be equivalent to the spectral luminous efficiency function (CIE S 017/E:2020) $V(\lambda)$. The LMD to measure the optical characteristics such as luminance and chromaticity shall be calibrated with the appropriate photometric or spectrometric standards. When a filter-type LMD such as a luminance meter is used to ensure the luminance accuracy for the intended DUT light sources, its responsivity should comply with the spectral luminous efficiency for CIE photopic vision or it should be compared with a calibrated spectrometer. The spectral mismatch correction factor can be specified (see NOTE 2).

NOTE 2 ISO/CIE 19476 indicates the spectral mismatch factor between the spectral responsivity of the filter-type LMD and the CIE spectral luminous efficiency function. Details of the spectral mismatch correction factor are given in ISO/CIE 19476.

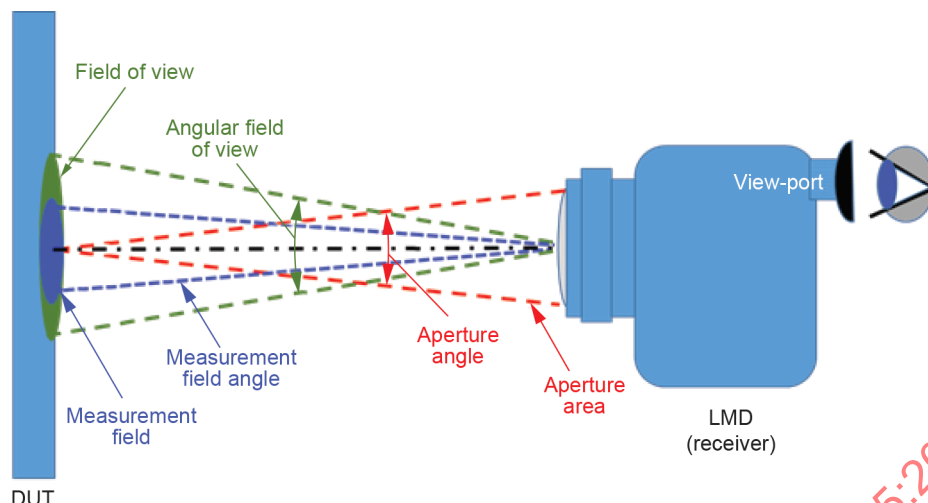


Figure 2 – Example of LMD with the viewing area surrounding the measurement field

To ensure accurate measurements, the following requirements shall be applied. Otherwise, the differences shall be noted in the report. More information on LMD evaluation can be found in ISO/CIE 19476.

The LMD should be carefully checked before measurements, considering the following points:

- sensitivity of the LMD to measuring light (i.e., to cover the spectrum of the DUT);
- errors caused by the veiling glare and lens flare (i.e. stray light in the optical system);
- timing of data-acquisition, low-pass filtering (noise reduction);
- linearity of detection and data conversion;
- measurement field size.

In addition, the LMD shall be calibrated in accordance with ISO/CIE 19476. All devices shall be checked for sufficient depth-of-field (DoF). Ensure that the LMD measures the DUT on the intended curvature area. The depth-of-focus in the LMD's optical detector, ($\Delta l_r + \Delta l_f$), is proportional to the depth-of-field. The depth-of-focus is explained in Annex A.

4.3 Spectroradiometer (spectral radiance-meter)

The wavelength range shall be at least 380 nm to 780 nm and the spectral bandwidth shall be 5 nm or less. The wavelength deviation shall be between -0,3 nm and +0,3 nm. The equipment shall be calibrated with the spectral radiance standard. The performance should be carefully checked before measurement, considering the same elements as in 4.2.

4.4 Electrical measurement devices

4.4.1 Current meter

In the measurement of a DUT, a DC drive or signal driving can be required. In case of direct current, an ammeter (current meter) shall be between points C and D (see IEC 62595-2-1 and IEC 62595-2-3), as shown in Figure 3.

In case of signal driving of the DUT, the peak value (I_{peak}) and effective current (I_{eff} , i.e., the I_{rms} value) should be recorded as in Figure 3.

4.4.2 Voltage meter

The measurement of input voltage should be performed under standard measurement conditions using the voltage meter (voltmeter) between points A and B in as shown in Figure 3 (see IEC 62595-2-1 and IEC 62595-2-3).

In case of DC driving of the DUT, the voltage (V_{DC}) should be recorded by using a voltmeter between A and B in Figure 3.

In case of signal driving of the DUT, the peak value (V_{peak}) and effective voltage (V_{eff} i.e., the V_{rms} value) should be recorded.

The measurement of input voltage should be performed under standard measurement conditions using the voltage meter (voltmeter) between points A and B as shown in Figure 3.

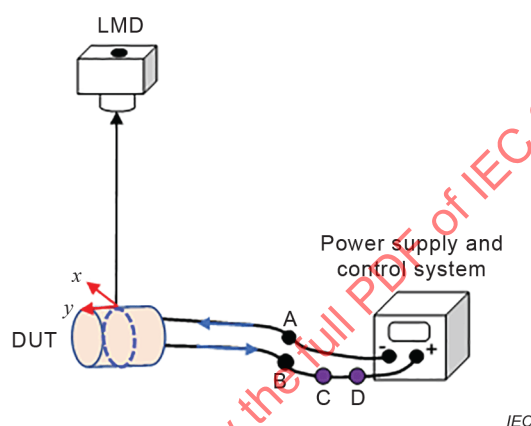


Figure 3 – Current and voltage measurements using an ammeter between points C and D and a voltage meter between points A and B

4.5 Luminous flux measurement devices

4.5.1 General

There are two typical methods of measuring luminous flux:

- 1) a spherical photometer method with an integrating sphere, and
- 2) a light distribution measurement method with a goniophotometer of any type for measurement of the luminous intensity from which the luminous flux is calculated.

4.5.2 Luminous flux

4.5.2.1 Integrating sphere method and installation position

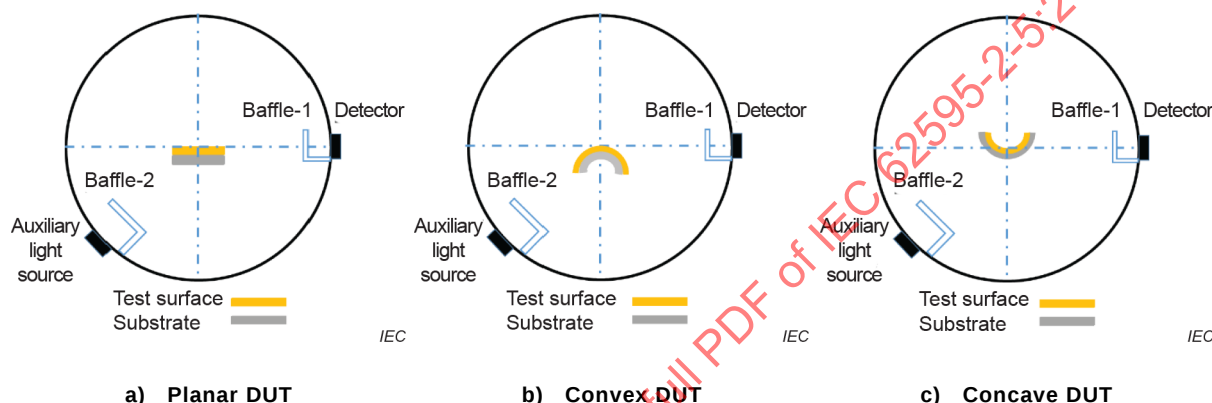
An integrating sphere can perform luminous flux measurement with reasonable accuracy. The size of an integrating sphere is important in the measurement of a DUT. The larger integrating sphere exhibits less throughput than the smaller spheres and thus higher optical attenuation, thereby eventually introducing a lower signal-to-noise ratio. One of the points that shall be considered is the effect of self-absorption and its correction. This means that the percentage of flux absorbed by installations and by the DUT itself inside the integrating sphere shall be taken into account. Therefore, prior to measurement, the self-absorption correction factor shall be measured (6.6.9.4).

This factor shall be used for correcting the real amount of the luminous flux that is emitted by the LS (removing the effect of the jigs and the DUT itself). In addition, a standard LS with a

spectrum covering the spectrum of the DUT shall be used to calibrate the integrating sphere as well.

An integrating sphere (4π geometry) setup can be used for DUT (convex/concave cylindrical LS) flux measurements. Such an LS shall be installed in a manner that light emitted from any sides is included in the measured value. Figure 4 shows an example of measurement setup. Regardless of the planar, convex or concave configurations of the sample, the centre of the light emitting surface of the sample shall be placed at the centre of the sphere, with the light-emitting area placed in the upper direction, in accordance with IEC 62922.

NOTE The direction of the light emitting surface in an integrating sphere is an important factor. The measurement results on “setting the direction of the front surface of the light source” were presented at a CIE meeting [9]. The direction of the light emitting surface, i.e. up, down, right, left, of a DUT in an integrating sphere affects the measurement results. Based on the results in the reference, the variations between the measured luminous fluxes are within 4 %.



NOTE The DUTs are positioned in the same place as the standard lamp, at the centre of the integrating sphere.

Figure 4 – Geometry of 4π -sphere measurement

4.5.2.2 Goniophotometric measurements

Goniophotometry sometimes with mirror is used for measurement of DUTs (convex/concave cylindrical LSS) of all sizes as an alternative to integrating sphere photometry. The emitted light from all directions of the DUT shall be included in the measurement.

In the absence of an integrating sphere of appropriate size relative to the DUT a goniophotometer shall be used.

In the case of a convex-type DUT, the measurement shall be conducted by aligning the rotation centre at the vertex of the DUT as shown in Figure 5a). For the concave DUT, the inner intended area is fixed upward as shown in Figure 5b). The positioning of the DUT in a mirror-type goniometer is shown in Figure 6. A laser marking device on the goniometer or a separate device on a tripod is used to align the intended area on the DUT in the horizontal and vertical directions. This alignment system is a horizontal alignment device, so that the xyz -stage can be used for adjustment of the DUT after being fixed on the stage.

NOTE For general guidance on the use of goniophotometers, see CIE 084:1989 [8], CIE S 025:2015 [9], and 4.5 and 6.2.

In a measurement of a concave cylindrical LS, the side surfaces of the DUT block the measurement resulting in a limited measurement field angle (zenith angle θ), so that a primary study of the measurement is required.

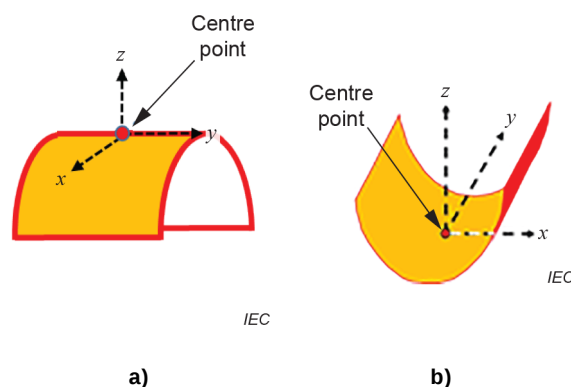


Figure 5 – Measuring points on convex and concave DUTs based on the setups of Figure 4

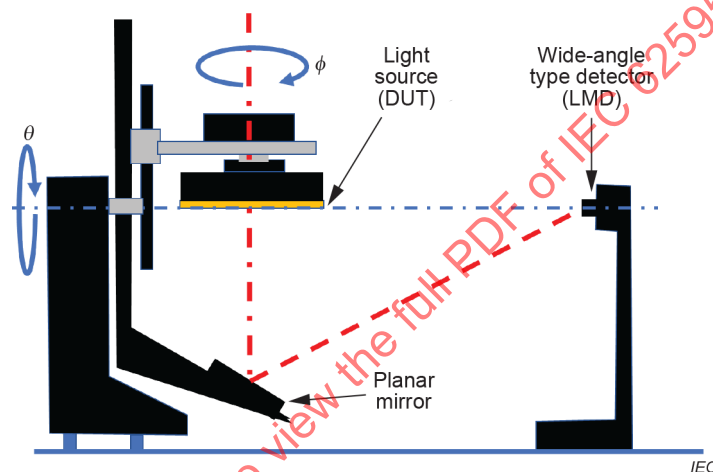


Figure 6 – Example of a mirror type goniometric system

4.5.3 Sample stage

An orthogonal three-axis stage should be used to adjust the measurement field location of the DUT (Figure 3). A biaxial goniometer should be used to adjust the DUT surface normal in the intended direction, i.e., aligning the zenith angle (θ) and azimuth angle (ϕ) for the DUT (requiring the axial stage). The positioning of these devices shall be sufficiently stable / repeatable to make the specified measurement repeatability.

5 General measuring conditions

5.1 Standard conditions

Unless otherwise specified all tests and measurements for an NPLS (e.g. cylindrical LS) shall be carried out after sufficient warm-up time (see 5.4.5), under the standard environmental conditions as follows:

- temperature $25\text{ °C} \pm 3\text{ °C}$
- relative humidity 25 % to 85 %
- atmospheric pressure 86 kPa to 106 kPa

When different environmental conditions are used, these conditions shall be reported in detail in the specification.

NOTE See IEC 61747-3-1 [10], IEC 62679-3-3, and IEC 61747-6-2.

5.2 Darkroom conditions

The optical performance of a light source is initially measured under darkroom conditions. The illuminance contribution from the background illumination reflected off the room shall be less than 0,5 % of the minimum illuminance of the light source (when the light source is switched ON). If the condition is not satisfied, then background subtraction is required, and it shall be noted in the test report. In addition, if the sensitivity of the LMD is inadequate to measure at the low level, then the lower limit of the LMD shall be noted in the test report.

Unless stated otherwise the standard lighting conditions shall be the darkroom conditions.

5.3 Measurement setup

The DUT, LMD, power source, driving and control devices for the DUT, and the electrical measuring devices should be arranged as shown in Figure 3. The luminance of the DUT shall be measured using an SLMD.

5.4 Setting the electrical characteristics of measurement devices

5.4.1 Conditions

Electro-optical measurements and visual inspection shall be carried out under the standard environmental conditions given in 5.1. When different environmental conditions are used, they shall be noted in the visual inspection or test report.

5.4.2 Current

The measurement of input current should be performed under standard measurement conditions using the ammeter between points C and D in Figure 3. In case of DC driving of the DUT, the current (I_{DC}) should be recorded by using an ammeter between C and D in Figure 3.

In case of signal driving of the DUT, the peak value (I_{peak}) and effective current (I_{eff} , i.e., the value I_{rms}) should be recorded.

5.4.3 Voltage

The measurement of input voltage should be performed under standard measurement conditions using the voltage meter (voltmeter) between points A and B in Figure 3 (IEC 62595-2-1 and IEC 62595-2-3).

In case of DC driving of the DUT, the voltage (V_{DC}) should be recorded by using a voltmeter between points A and B in Figure 3.

In case of signal driving of the DUT, the peak value (V_{peak}) and effective voltage (V_{eff} i.e., the V_{rms} value) should be recorded.

The measurement of input voltage should be performed under standard measurement conditions using the voltmeter between points of A and B shown in Figure 3.

5.4.4 Power

The measurement of supplied power consumption should be carried out under the standard measurement conditions given in 5.4 (see IEC 62595-2-1), using a power meter in case of DC driving ($V_{DC} \times I_{DC}$). However, in case of signal driving, the supplied power should be calculated as $V_{eff} \times I_{eff}$ or $V_{rms} \times I_{rms}$. The measurement of power consumption should be carried out under

the standard measurement conditions given in 6.1 and 6.2 (IEC 62595-2-1), using a power meter.

5.4.5 Warm-up time

The measurement of a DUT shall be performed with the DUT in steady state. The warm-up time differs for various devices. For example, the warm-up time for an OLED without housing is in the range of 15 mins and the emitted flux is stable, i.e., the variation is within $\pm 3\%$.

In general, the measurements shall be carried out after sufficient warm-up time for the DUT. The warm-up time is defined as the time elapsed from when the supply source is switched on, until repeated measurements of the DUT show a variation in the luminance of no more than 3% for 5 min for at least 5 sampling points, but not less than 15 min.

6 Optical measurement methods

6.1 General

There are mainly two setups for measuring the optical properties of a DUT:

- 1) the lateral scanning setup shown in Figure 7, and
- 2) the directional scanning setup shown in Figure 8.

In case 1) the DUT moves around the curvature of the DUT parallel to the DUT curvature. The DUT surface normal is coincident with the optical axis of the LMD similar to that of the planar type in Figure 7a). In case 2), the optical characteristics are measured in the zenith and azimuth angles, where the LMD views the intended measurement point on the DUT.

6.2 Conditions

The conditions given in 6.1 apply.

6.3 Perceptual visual quality

6.3.1 General

An LS to be measured shall be free from any optical defect. Defects such as scratches, flaws, or non-desirable reflection should not be present on the front surface of the NPLS, since such defects affect the performance. The visual inspection should take place under an external illumination or a highly bright and omni-directional illumination.

6.3.2 Procedures

The luminance levels, $L_v(x_i, y_i, \theta, \phi)$, of the required locations on the cylindrical surface are measured in the following order:

- a) Set the DUT on an xyz-stage.
- b) Adjust the LMD to the specified or recommended distance, in a plane perpendicular to the light source including the surface normal (coincident with the optical axis of the LMD) of the intended locations, as shown in Figure 7b) or c).
- c) Supply the required current and voltage to the DUT.
- d) Set the measurement position of the DUT where the DUT's surface normal is coincident with the optical axis of the LMD (as seen through the lens of the LMD), similar to that of the planar type in Figure 7a).
- e) Switch ON the DUT and measure the luminance at the intended point.
- f) Shift the DUT or the LMD to measure the next position and repeat steps a) to e).

- g) Measure the DUT at an intended location to obtain the luminance (chromaticity or spectrum, luminous intensity) of the local surface normal.
- h) Shift the DUT or the LMD to measure the next position and repeat steps a) to h).

6.4 Lateral and directional scanning configuration

6.4.1 General

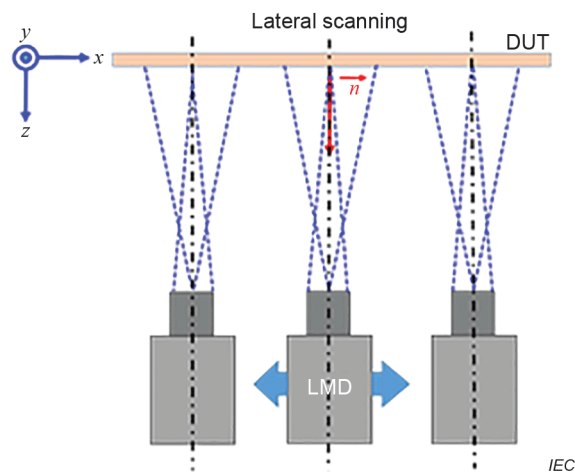
In contrast to planar LSs, the mounting of a curved LS is an important factor in how the LS is measured. The LS mount or fixture shall carefully control the shape of the LS, whether it is curved with various radii. In 6.4.2 and 6.4.3 two measurement configurations are explained.

6.4.2 Lateral scanning configuration

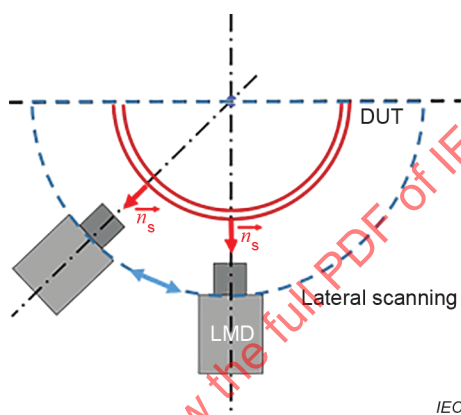
The LS mounting fixture should allow for the proper rotation of the LS about its centre axis (lateral scanning), or about its surface tangent line, i.e., y -axis (directional scanning). A Cartesian coordinate system (Figure 1) is used with its origin at the surface of the LS, usually at the vertical and horizontal mid-point of the LS (see Figure 7 cross section of cylindrical LS). This configuration can be scaled for LSs with various radii of curvature. The optical axis of the light measurement device is generally aligned with the z -axis, and the measurement area centred at the Cartesian origin on the cylindrical LS surface.

When performing a uniformity measurement, the DUT position is fixed, while the LMD is translated along the horizontal (cylindrical coordinate system) axis and rotated around the DUT (lateral scanning, Figure 7 a), c)). This maintains the LS surface normal to be coincident with the optical axis of the LMD [6] to [16].

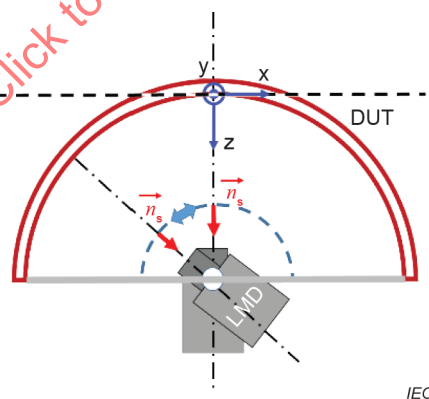
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a) Lateral optical characteristic of a PLS



b) Lateral optical characteristic of a convex cylindrical LS



c) Lateral optical characteristic of a concave cylindrical LS

NOTE 1 The vector, n , is the direction vector or optical axis of the LMD.

NOTE 2 The lateral scanning can also be performed along the long axis of the cylinder.

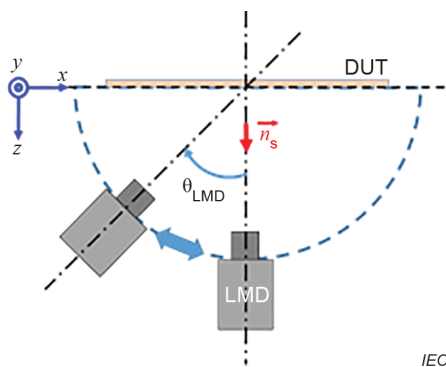
Figure 7 – Planar LS and cylindrical LS (NPLS) in lateral scanning measurement arrangements

6.4.3 Directional scanning configuration

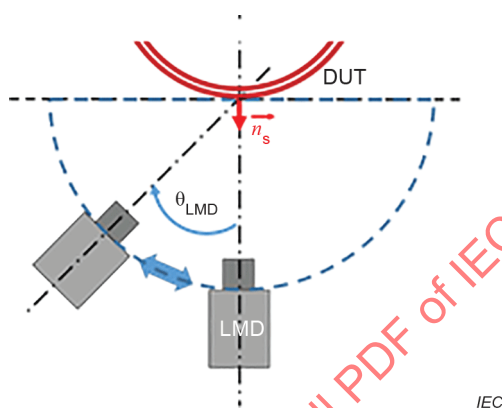
In comparison to the lateral scanning measurement, for the directional scanning measurement, the LMD can be mounted on a goniometer with its centre of rotation aligned with the intended LS's measurement area as in Figure 8. However, for direction dependence measurements, the LMD shall be pivoted in the area located in dashed lines (xz -plane) about y -axis. In other case the LMD can be fixed and the DUT shall be pivoted at the measurement point/area along the tangent axis on the surface of the DUT (along the length of the cylinder). Here the x -axis is to the right and the long axis of cylinder is the y -axis, perpendicular to this paper surface and z -axis is the surface normal in Figure 8a).

The position of the LMD and the DUT can be reversed, i.e., by fixing the LMD and by rotating the DUT.

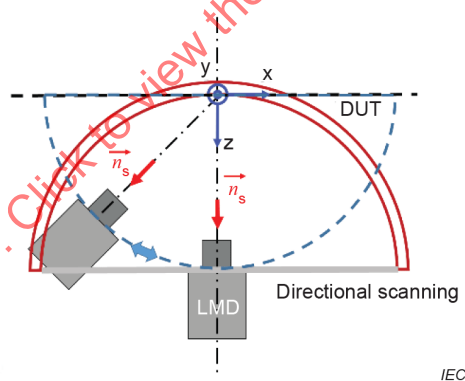
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a) Directional scanning measurement for acquiring the optical characteristic of a PLS



b) Directional scanning measurement for acquiring the optical characteristic of a convex cylindrical LS



c) Directional scanning measurement for acquiring the optical characteristic of a concave cylindrical LS

NOTE 1 These are the top views of how the LMD rotates about one position on the surface of a planar, convex or concave LS for directional measurements.

NOTE 2 The vector, $\vec{n}$, is the direction vector or the optical axis of the LMD.

Figure 8 – Planar LS and cylindrical LS (NPLS) in a directional scanning arrangement

6.5 Depth-of-field and depth-of-focus in measurement

6.5.1 General

One of the specifications of an LMD is the depth-of-field (DoF), i.e., the distance between the nearest and the farthest focus points ($\Delta L_r + \Delta L_f$) on a cylindrical DUT (see the fixation point in Figure 8 for a planar LS). The DUT shall be in acceptably sharp focus within the far and the near points as illustrated in Figure 9. Since there is a difference in measurement distance between the front surface of the DUT and the position of the inclined rays as shown in Figure 10, the measurement field on the cylindrical (located within the measurement field contour) LS shall be in focus. The difference in measurement distance (in the measurement field, the nearest and farthest points, to the LMD) is the depth-of-field. The depth-of-field can be calculated based on the focal length of the LMD's lens, the distance to the DUT, the acceptable circle of confusion size, and aperture of the LMD. The depth of focus in the LMD's optical detector, ($\Delta l_r + \Delta l_f$), is proportional to the depth-of-field.

NOTE The terms used in Figure 9 are adapted from camera optics.

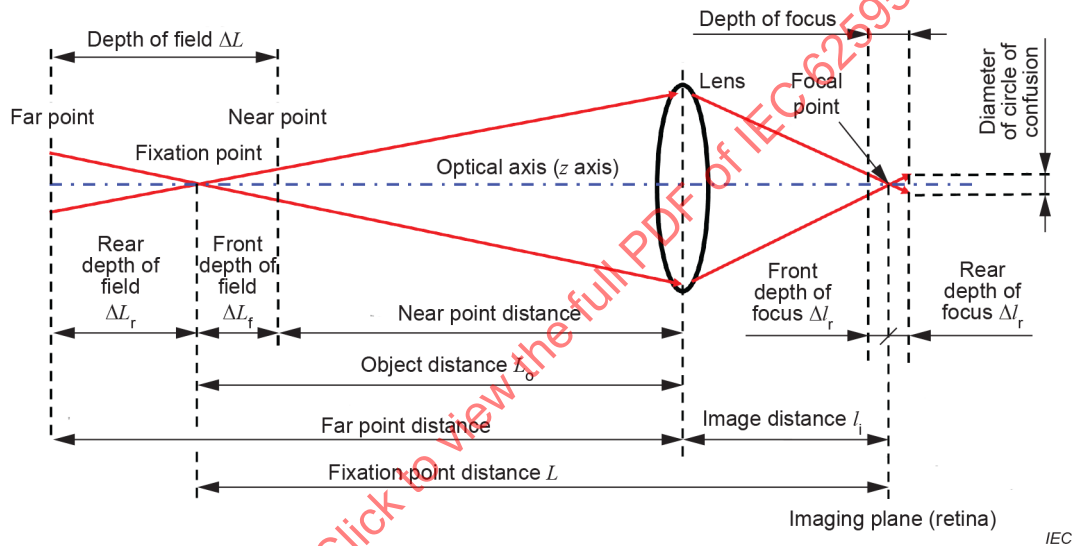
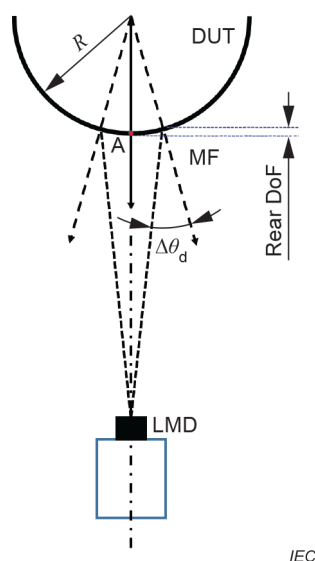


Figure 9 – Pictorial illustration of depth-of-field, depth-of-focus and circle of confusion for an LMD

6.5.2 Front and rear depth-of-field (DoF)

In the measurement of a cylindrical light source the front area and back area (located within the measurement field) or located within the contour of the measurement field shall be in focus in order to perform an acceptable measurement result. The closest and the farthest area element included in the measurement (i.e., within the field of measurement) should be within the range given by the near and far points as illustrated in Figure 9. The focus point is at A and the rear depth-of-field is shown in Figure 10. The focus point on the DUT can be set to a point between the nearest point to the LMD and the farthest point to the LMD, in order for the DoF to include a range (front DoF plus back DoF) with a sharp and resolvable image that is the focus in the LMD.



NOTE $\Delta\theta_d$ is the angle between the light ray (surface normal) at the circumference of the cylindrical LS and the contour of measurement field.

Figure 10 – Rear depth-of-field in the measurement setup of a cylindrical light source

6.5.3 Front and rear depth-of-focus (dof)

A depth-of-focus is the image-space complement of the depth-of-field and is related to how the quality of focus changes on the sensor side of the lens as the sensor is moved while the object remains in the same position. Depth-of-focus dictates how much tip and tilt can be tolerated between the image plane of the lens and the sensor plane itself. The lower the $f/\#$, the more the depth of focus is reduced and the more impact the tilt has on achieving a sharp image (best focus) across the sensor. A depth-of-focus exists in image-space with respect to depth-of-field (DoF) in object-space. The dof is defined by the COC of the LMD as shown in Figure 9.

6.6 Measurement procedures

6.6.1 General

The purpose of this method is to determine the luminance and the luminance variation in the light emitting area from the lateral and directional scanning measurements under darkroom conditions.

6.6.2 Cylindrical LS mounting for lateral measurements

The fixture used to mount a cylindrical LS plays a critical role in obtaining accurate and reproducible results [16]. The LS mount should be designed to accommodate the specific curvature or curved characteristics of the LS in its intended use configuration. The mount or fixture shall be capable of maintaining the intended shape of the LS and locate it in the required measurement position and illuminating direction. These measurement methods only apply to cylindrical LSs. Figure 7 illustrates the setups for a planar and convex/concave cylindrical LS that is curved about the cylinder's long axis (y -axis).

For planar LSs, the light emitting surface is aligned toward the LMD where the right side of the LS is along the x -axis, the y -axis is along the long axis of the cylinder and the z -axis is the surface normal direction toward the LMD.

Unless otherwise specified, the optical axis of the LMD shall be aligned to within 1° of the LS surfaces normal at the centre of the measurement field in order to minimize the alignment error introduced by the LS curvature. As it is mostly used in planar LS measurement for spot type LMDs, the retro-reflection of the LMD can be used to obtain this alignment. In the measurement of a planar LS, a mirror is set on the planar LS and the image of the LMD's aperture of lens is viewed through the LMD by adjusting the lens and getting the sharp image of the aperture. After adjusting the lens, the mirror is removed and the measurement is performed. Otherwise, an alignment laser can be used to define the optical axis (see IEC 62715-5-1 [6]). The methods also assume that the rotation stages and mechanical mounting have sufficient accuracy and stability to maintain less than 1° tolerance for any rotational or tilt motions.

6.6.3 Lateral luminance

The lateral luminance variation is measured in a setup shown in Figure 7b) and c). In this measurement an LMD is rotated in a plane perpendicular to the DUT's front surface tangent plane. In this setup the following devices are used: a luminance meter (see Annex B), spectroradiometer, a driving power source, a driving signal equipment, a means to translate a cylindrical LS or LMD in the vertical and horizontal directions, and an LS mount that can rotate a cylindrical LS about its centre of curvature (see Figure 7b), c) or LMD that can be mounted on a goniometer that rotates about the LS's intended area.

For the luminance measuring method:

- Mount the DUT (planar or cylindrical LS) in its planar or curved state in a fixture.
- Place the LMD at the recommended distance (e.g., 500 mm) from the cylindrical LS and align the LMD's optical axis to be coincide with the surface normal of the LS's emission area (front the point position) as shown in Figure 10.
- Measure the DUT (LS) luminance.
- Repeat the measurement for the other locations as required.
- Report the LS luminance in the intended locations and report the test results.

6.6.4 Lateral luminance uniformity

For planar LSs, the LS lateral luminance variation is measured by keeping coincident the LMD optical axis and LMD surface normal. As shown in Figure 7 and Figure 8, the LMD rotates in horizontal plane around its vertical axis (normal to optical axis) and the location of the measurement while ensuring that the DUT light emitting plane always passes through the y-axis as in Figure 10. Alternatively, the DUT can be mounted on a goniometer that rotates about a fixed LMD, where the measurement location is facing the LMD. The procedure is as follows.

- Mount the DUT (cylindrical LS) in a fixture that allows the LMD to remain at a fixed distance from the measurement field, where its optical axis coincides with the normal to the LS surface at the centre of the measurement field.
- Place the LMD at the recommended distance from the LS and align the optical axis to be normal to the centre of the LS emission area.
- Set the LS driving at the intended current and allow the LS to stabilize.
- Measure the LS luminance at the intended location.
- Move the LS or LMD and take sequential luminance measurements at the positions explained in IEC 62595-2-1 or any other areas' locations in IEC 62595-2-2 [17], or IEC 62595-2-3.

Luminance uniformity, U_{lat} , is a value that quantifies how uniform the luminance is over the surface of the active area of a cylindrical LS (see IEC 62595-2-1, IEC 62595-2-2 [17], or IEC 62595-2-3).

$$U_{lat} = 100 \times L_{vmin} / L_{vmax} (\%) \quad (1)$$

The luminance uniformity measurement (between the luminance of independent areas) is sensitive to the testing positions. Typical layouts of measurement areas over the cylindrical LS surface are the same as in IEC 62595-2-1, IEC 62679-3-3 and IEC 61747-6-2. The intended areas shall be measured along the surface normal and relative comparison should be performed between the intended locations. The uniformity shall be calculated using Formula (1) and the results should be reported.

NOTE Measurement fields and their contours on a planar and cylindrical LS are given in Annex C.

6.6.5 Lateral chromaticity and chromaticity variation

The measurement procedures shall be applied as follows.

- a) Obtain the spectrum or the CIE 1931 tristimulus values at the intended locations on the DUT (cylindrical LS) in a setup as in Figure 7b) or c).
- b) Calculate the CIE 1931 chromaticity coordinates (see ISO/CIE 11664-3) for the locations explained in 6.6.4 for each i -th spot (x_{ci}, y_{ci}) and calculate the average chromaticity coordinate of the LS for the required point (x_{ca}, y_{ca}) , using the following formula:

$$\begin{aligned} x_{ca} &= \frac{1}{N} \sum_{i=1}^N x_{ci} \\ y_{ca} &= \frac{1}{N} \sum_{i=1}^N y_{ci} \end{aligned} \quad (2)$$

where

N is the number of locations on the NPLS under measurement.

- c) Calculate the chromaticity differences with respect to a specified reference (u'_a, v'_a) using the following formula:

$$\Delta u'v' = \sqrt{(u'_i - u'_a)^2 + (v'_i - v'_a)^2} \quad i = 1, 2, \dots, N \quad (3)$$

- d) Substitute the maximum value of $\Delta u'v'_i$ as the chromaticity difference and calculate the uniformity in chromaticity, U_c :

$$U_c = \max(\Delta u'v'_1, \Delta u'v'_2, \dots, \Delta u'v'_N) \quad (4)$$

Calculate (or measure) the correlated colour temperature (CCT) for the LS.

6.6.6 Directional luminance

Three setups are shown in Figure 8 for measuring the luminance variations of the planar, convex and concave LSS, in a directional scanning measurement. In this measurement the LMD is rotated around an intended location on the DUT. In these setups the following devices are used: A luminance meter, colorimeter or spectroradiometer, a driving power source, a driving signal equipment, a means to translate the LMD, by changing the angle, θ . Instead of the translation of the LMD, the DUT can be rotated and the LMD can be fixed, and a similar rotation is employed.

Directional scanning measurement of a cylindrical LS requires precise alignment of the LMD and the DUT. The optical axis of the LMD shall be coincident with the surface normal at $\theta = 0$.

This accuracy of the alignment shall be within $\pm 1^\circ$ in order to minimize the alignment error introduced by the cylindrical LS. It should be the same with the planar conditions (Figure 8a)).

For the luminance measuring method at $\theta = 0$:

- a) Mount the DUT (cylindrical LS) in a fixture (Figure 8b), c)).
- b) Place the LMD at the recommended distance (e.g., 500 mm) from the cylindrical LS and align the optical axis to be coincide with the DUT's surface normal.
- c) Measure the LS luminance.
- d) Rotate the LS around the y -axis (see Figure 7 and Figure 8).
- e) Repeat for other rotation angles as required.
- f) Report the LS luminance at $\theta = 0$ and the directional luminance variation of other locations for the rotated angles in the test report.

NOTE The upper and lower parts of the LMD lens view a cylindrical LS's different surface normal on the circumferences of the cylindrical LS resulting in measuring different light emission. Therefore, an optimized distance exists for each cylindrical LS (different R). See Annex D, Table D.1 and Figure D.2.

6.6.7 Directional luminance variations

For planar LSs, the LS uniformity is generally measured by translating the LMD parallel to the PLS and measuring the LS characteristics at different LS locations. However, for convex or concave LSs, the LS mounting shall allow the LS to be rotated about its front surface tangent axis (y -axis, Figure 8b), c)); the DUT's light emitting plane always passes through the y -axis at the origin. This is illustrated in Figure 8b) for the case of a convex cylindrical LS. The same motion shall be used for a concave cylindrical LS as in Figure 8c). Figure 8b) illustrates how directional luminance (rotation angle around the y -axis) on the LS can be scanned by rotating the LMD and adjusting perpendicularly the measurement field (for a zero-zenith angle). This LMD rotation allows the LS uniformity to be measured for each intended rotation angle. Alternatively, the DUT can be mounted on a goniometer that rotates about the LS's y -axis (center axis of rotation). The measurement procedure is as follows.

- a) Mount the cylindrical LS in a fixture that allows the LMD to remain at a fixed distance from the measurement field, and normal to the LS surface at the centre of the measurement field.
- b) Place the LMD at the recommended distance from the LS and align the optical axis to be normal to the centre of the LS light emission area (front surface point).
- c) Set the LS driving at the intended current and allow the LS to stabilize.
- d) Measure the LS luminance at the front point.
- e) Rotate the LS around the y -axis for the intended rotation angles and measure the luminance.
- f) Repeat the rotation of the LS or LMD and take sequential luminance measurements at the intended angles.

Directional luminance uniformity, U_{dir} , is a value that shows how uniform the luminance is over different source viewing angles of the single spot on an LS:

$$U_{\text{dir}} = 100 \times L_{\text{vmin}} / L_{\text{vmax}} \quad (5)$$

6.6.8 Directional chromaticity and chromaticity variation

The measurement procedures, similar to that for lateral luminance, shall be applied as follows.

- a) Obtain the spectrum or the CIE 1931 tristimulus values at the normal to the light emitting front surface as in above Figure 8 b) and c) (similar to that of directional luminance measurement in 6.6.7), turn the LS around the y -axis, and measure the chromaticity coordinates for each angle.

- b) Calculate the CIE 1931 chromaticity coordinates (see ISO 11664-3) for the angles for each intended i -th spot (x_{ci} , y_{ci}) and calculate the average chromaticity coordinate of the LS for the intended spot (x_{ca} , y_{ca}), using the following formulae:

$$\begin{aligned} x_{ca} &= \frac{1}{N} \sum_{i=1}^N x_{ci} \\ y_{ca} &= \frac{1}{N} \sum_{i=1}^N y_{ci} \end{aligned} \quad (6)$$

where

N is the number of rotated angles.

- c) Calculate the chromaticity differences with respect to a fixed intended angle using the following formula:

$$\Delta u'v' = \sqrt{(u'_i - u'_a)^2 + (v'_i - v'_a)^2} \quad i = 1, 2, \dots, N \quad (7)$$

- d) Substitute the maximum value of $\Delta u'v'_i$ as the chromaticity difference and calculate the uniformity in chromaticity, U_{cdir} :

$$U_{cdir} = \max(\Delta u'v'_1, \Delta u'v'_2, \dots, \Delta u'v'_N) \quad (8)$$

- e) Calculate the correlated colour temperature (CCT_{idir}) for the intended point on the LS.

NOTE A subscript can be used for x_{ca} and y_{ca} to distinguish the lateral chromaticity coordinates from those of the directional chromaticity coordinates.

6.6.9 Luminous flux

6.6.9.1 Integrating sphere

The initial luminous flux of a convex or concave cylindrical LS is measured using an integrating sphere. Additional measurement of the luminous flux is optional, in case the additional luminous flux data is provided by the manufacturer or a vendor in charge.

An integrating sphere (4π geometry) setup can be used for cylindrical LS (convex/concave) measurements. The LS (convex/concave) shall be installed in such a way that light emitted from any side is included in the measured value. Figure 4 shows an example of a measurement setup. Regardless of the configurations (planar, convex and concave) of the sample, the centre of the light emitting surface of the sample shall be placed at the centre of the sphere, with the light-emitting area facing upwards, in accordance with IEC 62922 (see [1] and 4.5.2.1).

6.6.9.2 Measuring equipment and connections

The following steps shall be performed for the luminous flux measurement.

- Use a stabilized DC power supply, where its output voltage fluctuation shall be within $\pm 0,1$ % of the specified voltage.
- Use a stabilized AC power supply, where its output voltage fluctuation shall be within $\pm 0,2$ % of the specified voltage.
- Frequency fluctuation shall be within $\pm 0,2$ % of the specified frequency.

- d) Meters used in alternating current shall be those that measure and display effective values.
- e) The impedance of the instrument connected in parallel to the DUT (LS) is the shunt current.
- f) The impedance shall be high enough that the current is less than 0,1 % of the DUT current.
- g) The impedance of the instrument connected in series with the DUT (LS) results in the voltage drop. It shall be low enough so that it is less than 1 % of the DUT voltage.

6.6.9.3 Integrating sphere performance

The following steps shall be considered for the measurement.

- a) The sphere shall have a high reflective surface, i.e., the spectral reflectance of the inner wall should be 90 % or more in the visible wavelength range.
- b) The intended lighting position of the DUT is the centre of the integrating sphere. Direct light from the DUT or reflection from jigs inside the integrating sphere shall not reach the detector.
- c) The electrical contact surface of the DUT has high reflection characteristic and relatively small absorption, so that the reflected light on the contact shall be sufficiently small to be reflected inside the integrating sphere.
- d) A stray light shall not be introduced into the integrating sphere.
- e) The baffle should have a structure in which the direct light from the light source does not strike the light receiver, and the size should be kept as small as possible.
- f) The size of the integrating sphere should be selected considering the temperature rise due to heat generated when the light source to be measured or the standard light source is turned on.
- g) The DUT for self-absorption measurement should have a structure in which direct light from the DUT does not strike the light receiver. The DUT should be in OFF-state.
- h) The size of the opening of the integrating sphere should be within 4 % of the inner wall area.
- i) For integrating spheres, the diameter of the integrating sphere should be large because baffles, apertures, jigs, etc., cause uncertainty in the measurement.
- j) The measurement accuracy is improved by reducing the ratio of the area of the light baffle to the area of the inner wall of the sphere.
- k) In case the size of the integrating sphere is increased, the output of the receiver decreases.
- l) The upper limit of the integrating sphere size is decided by the range of the signal-to-noise ratio, i.e., no effect on the measurement uncertainty.

6.6.9.4 Self-absorption correction factor

The measurement method is as follows.

- a) Set the standard light source (OFF-state) on the jig of the integrating sphere at the centre of the sphere (using a laser alignment device, see 6.6.9.5).
- b) Use an auxiliary (self-absorption lamp) light source (ON-state) to measure the output current of the sphere $i_{std,1}(\lambda)$.
- c) Remove the standard light source from the jig.
- d) Measure the output current of the sphere $i_{std,0}(\lambda)$ (auxiliary lamp is ON).
- e) Set the DUT (OFF-state) on the jig in the same position as above (the auxiliary light source is ON).
- f) Measure the output current of the sphere, $i_{dut,1}(\lambda)$.
- g) Remove the DUT from the jig of the sphere.
- h) Measure the output current of the sphere, $i_{dut,0}(\lambda)$.
- i) Calculate the following formula

$$\alpha(\lambda) = [i_{\text{std},1}(\lambda) / i_{\text{std},0}(\lambda)] / [i_{\text{dut},1}(\lambda) / i_{\text{dut},0}(\lambda)] \quad (9)$$

6.6.9.5 Measurement method

The measurement method is as follows.

Preconsideration:

- Use a laser beam scanning device which enables to make a laser line for aligning the centre of the integrating sphere (align the laser line to a mark on the door body of the sphere).
- Align the standard light source or the LS to be measured at the centre of the sphere (using the laser line).
- The laser device is set out of the sphere, having gyroscope and adjustable stands.
- Adjust the height of the stand bar (setting the stage of the light source) at the centre of the sphere using the laser line (scanning at the border of the upper and lower hemisphere of the integrating sphere).
- Thoroughly warm up the measuring equipment.
- Turn on the DUT for at least 30 min in the sphere, and measure the temperature in the sphere with the same temperature as the measurement conditions.
- The light distribution characteristics of the standard light source should be close to those of the light source to be measured.

Measurement:

- Set the standard light source at the centre of the integrating sphere (use a laser scanning alignment device to fix the LS at the centre of the sphere).
- Switch ON the standard light source for at least 30 min.
- Measure the output current of the sphere.
- Turn OFF the standard light source and remove the light source.
- Fix the DUT at the centre of the sphere in the same position as the standard light source and align the DUT to the same position as the standard light source a using laser alignment device and up-down fixture.
- Turn ON the DUT and wait for 30 min.
- Measure the output current of the sphere.
- Calculate the following formula.
- The total luminous flux of the DUT is given as follows:

$$\Phi_{\text{VDUT}} = \alpha \times k \times [i_{\text{DUT}} / i_{\text{std}}] \Phi_{\text{Vstd}} \quad (10)$$

where

Φ_{VDUT} is the luminous flux of the DUT;

Φ_{Vstd} is the luminous flux of the standard lamp;

α is the self-absorption correction factor of the DUT (see 6.6.9.4);

k is the colour correction factor;

i_{DUT} is the response of the detector (current or voltage output on the terminals on the outer side of the integrating sphere) when the DUT is ON;

i_{std} is the response of the detector (current or voltage output on the terminals on the outer side of the integrating sphere) when the standard lamp is ON.

The light source (standard lamp or DUT) requires a time until the light output is sufficiently stabilized.

The lighting conditions of the standard light source (lighting method, environmental temperature, stabilization time, etc.) should be matched with the conditions for standard light source calibration.

The relative spectral response of the receiver used for obtaining the colour correction coefficient (k) should be included in the characteristics of the integrating sphere.

6.6.9.6 Gonioradiometric measurement

Gonioradiometry is used for measurement of an LS with a convex/concave shape of all sizes. This is an alternative to integrating sphere radiometry. The range of the required measurement wavelength shall be at least 380 nm to 780 nm. The emitted light from all directions of the DUT shall be included in the measurement.

In the absence of an integrating sphere of appropriate size relative to the LS (cylindrically convex/concave) to be measured, a gonioradiometer (or goniophotometer) shall be used.

In the case of a convex cylindrical LS, the measurement shall be conducted by aligning the rotation centre on the LS surface as shown in Figure 4.

The conditions, size of the DUT, curvature radius, configuration, luminous flux and spectrum shall be reported.

NOTE For general guidance on the use of goniophotometers, see CIE 084:1989 [8], CIE S 025:2015 [9], and 4.5 and 6.2.

7 Precautions

7.1 Remarks

Prior information on the curvature of a cylindrical light source leads to correct measurement of the optical quantities. For example, a cylindrical light source possesses a single radius, and an optimum measurement distance exists for such a radius (Annex C), since the measurement of cylindrical NPLSS is more sensitive to the following parameters:

- a) the radius of the DUT, R ,
- b) the measuring distance, D_{LMD} ,
- c) the LMDs' aperture size (aperture field angle),
- d) the DUT's emission directionality,
- e) the emission directionality,
- f) the LMD's measurement field angle,
- g) the measurement position on the DUT (LS),
- h) the MF shape on the cylindrical LS (NPLS), i.e., the MF area on the DUT.

The above parameters should be carefully handled to avoid uncertainties in the measurement.

Lateral luminance distribution is defined as the movement of the LMD in parallel to the light source surface, i.e., in the perpendicular surface to the light source. Directional luminance distribution is defined as the movement of the LMD in non-parallel to light source. These two methods are explained in reference [17].

Prior investigations [1] to [5] and [11] to [16] indicate that the measurement results are influenced by (a) to (h).

7.2 Further remarks

7.2.1 General

- a) When a cylindrical LS (convex/concave) is scanned with the LMD the dependency of the D_{LMD} on the radius of the cylindrical LS shall be considered.
- b) The LMD's measurement field angle shall be set as small as possible, i.e., to have smaller MF with respect to the radius of the LS.
- c) The above remarks are important to make the measurement results less susceptible to the measurement conditions, and to reduce the measurement variation to 1 %.
- d) When the LMD's measurement field angle is larger than 1° , D_{LMD} shall be reported clearly since the measurement result is sensitive to D_{LMD} for a large measurement field angle and the DUT's radius.
- e) In cases where the LMD is far from the curved NPLS (D_{LMD} is large), compensation for D_{LMD} tolerances is required, for example by using a small viewing angle ($0,1^\circ$ or $0,2^\circ$).
- f) Further, for the sake of reproducibility of the results, a wide measurement field angle or different D_{LMD} is used in the measurement; these conditions shall be reported.
- g) In the measurement of a cylindrical LS, the optical axis or the centre axis of the viewing (cone) solid angle alignment is most important part of the process and shall be carefully handled in order to obtain reproducible results.
- h) The luminance as well as the luminous flux of the local area on the NPLS are important for evaluation of the products such as display lighting or special lighting. The total flux of an NPLS or local flux should be measured as explained in this document.
- i) Since the measurement method and measurement conditions affect the measurement results of a cylindrical LS, this document is focused on cylindrical LSs to assist the manufacturers' metrology on curved NPLS products.

NOTE Refer to CIE 198-SP1.2:2011 [18].

7.2.2 Report

The necessary information shall include the following items and shall be reported:

- a) description of the device under test, i.e., DUT,
- b) specification of the light measuring device, i.e. LMD,
- c) measurement results:
 - average chromaticity coordinates (x_a, y_a) and (u'_a, v'_a),
 - chromaticity coordinates of the required points on the NPLS (u'_i, v'_i),
 - chromaticity differences between the intended spot (point) as the reference spot (point) or the other measured points $\Delta u'v'_i$,
 - correlated colour temperatures of the measurement points, (i.e., CCTs),
 - lateral luminance or directional luminance distribution,
 - lateral and directional luminance uniformity.

Annex A (informative)

Measurement field on the curved light source

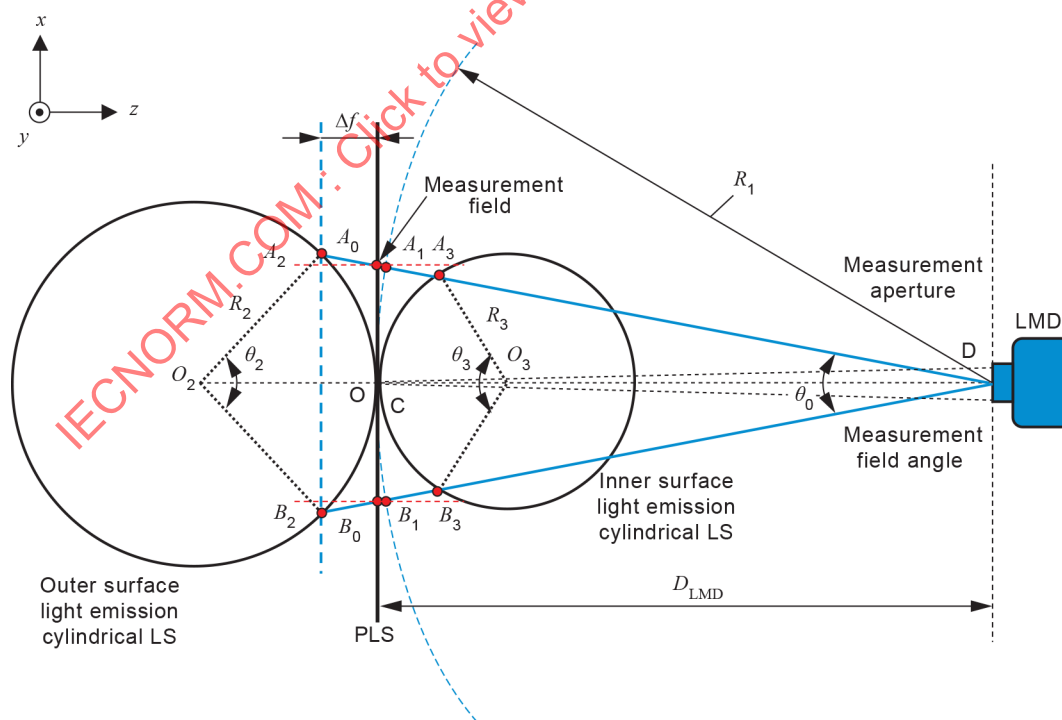
A.1 General

Annex A specifies detailed pictorial explanations on the issues that should be considered in NPLS measurement.

A.2 NPLS curvature and measurement field

As shown in Figure A.1, the cross sections of a planar LS, convex cylindrical LS and a concave cylindrical LS are shown. The cross sections of the measurement areas on each LS, that is, the measurement fields (MFs), are shown on the planar light source with the light emitting surface (A_0B_0), a convex cylindrical LS with an outer light emitting surface (A_2B_2) and a cylindrical concave LS with inner light emitting surface (A_3B_3). In general, the MF on the planar light source (LS) is A_0B_0 . However, more precisely the LMD measurement field angle includes the emission in the surface normal directions of A_1B_1 which is a virtual light source with an ideal emission confined in solid angle limited in the measurement field. This is different from that of a planar LS.

The cross section size of the MF is different on each LS. In order to acquire light from all points within the MF, the LMD shall have enough depth-of-field (DoF) in the object position and clear image of the object on the sensor position, that is, having a depth-of-focus (dof, in the LMD) especially when the radius of the light source decreases.



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NOTE Measurement field sizes on each LS in the x - and z -directions are obtained and compared with the measurement field (MF) on a planar light source A_0B_0 in Clause A.3.

Figure A.1 – Schematic diagram of the optical characteristics measurement of planar, convex and concave cylindrical light source

A.3 MFs on planar, convex and concave cylindrical LSs

Measurement fields (on the plane and arcs of curvatures)

$$U_0 = A_0B_0 = 2 \times D_{\text{LMD}} \times \tan (\theta_0 / 2) \quad (\text{A.1})$$

$$U_1 = A_1B_1 = D_{\text{LMD}} \times \theta_0 \text{ (real case)}$$

$$U_2 = A_2B_2 = R_2 \times \theta_2 \quad (\text{A.2})$$

$$U_3 = A_3B_3 = R_3 \times \theta_3$$

Differences in the measurement field cross sections:

$$\Delta U_1 = |U_0 - U_1|$$

$$\Delta U_2 = |U_0 - U_2| \quad (\text{A.3})$$

$$\Delta U_3 = |U_0 - U_3|$$

Differences in the depth-of-fields (in z-direction):

$$DEF_0 = 0$$

$$DEF_1 = D_{\text{LMD}} - D_{\text{LMD}} \times \cos(\theta_0 / 2)$$

$$DEF_2 = (D_{\text{LMD}} + R_2) - R_2 \times \cos (\theta_2 / 2) - D_{\text{LMD}} = R_2 - R_2 \times \cos (\theta_2 / 2) \quad (\text{A.4})$$

$$DEF_3 = R_3 - R_3 \times \cos (\theta_3 / 2)$$

Measurement fields (chords of the arcs, in the x-direction):

$$MFA_0 = 2 \times D_{\text{LMD}} \times \tan (\theta_0 / 2)$$

$$MFA_1 = 2 \times D_{\text{LMD}} \times \sin (\theta_0 / 2)$$

$$MFA_2 = 2 \times R_2 \times \sin (\theta_2 / 2) \quad (\text{A.5})$$

$$MFA_3 = 2 \times R_3 \times \sin (\theta_3 / 2)$$

Differences in measurement fields (chords of the arcs) due to the cylindrical radius:

$$\Delta MFA_1 = MFA_0 - MFA_1$$

$$\Delta MFA_2 = MFA_0 - MFA_2 \quad (A.6)$$

$$\Delta MFA_3 = MFA_0 - MFA_3$$

The angle θ_2 or θ_3 can be obtained by solving the following formulae

$$\begin{aligned} (z - D_{LMD} - R_2)^2 + x^2 &= R_2^2 \\ x &= z \times \tan(\theta_0 / 2) \end{aligned} \quad (A.7)$$

By obtaining z and y for A_3 , one can obtain the $\theta_2 = \sin^{-1}(x_{A2} / R_2)$.

By solving the following for A_3 , one can obtain the position coordinates for (z_3, x_3) .

$$\begin{aligned} (z - D_{LMD} + R_3)^2 + x^2 &= R_3^2 \\ x &= z \times \tan(\theta_0 / 2) \end{aligned} \quad (A.8)$$

By obtaining z and x for A_3 , one can obtain $\theta_3 = \sin^{-1}(x_{A3} / R_3)$.

Annex B (informative)

Planar light source measurement

B.1 General

To compare the measurement conditions with those of the curved light sources, the following information which is used in standard measurement using a luminance meter is given as auxiliary information in Clause B.2.

B.2 Luminance meter and measurement field

For an example (see Table B.1), a measurement condition using a conventional luminance meter is given as follows:

- objective lens $f = 80$ mm, $f / 2,5$
- spectroradiometer CIE 1931
- receiver Si photodiode $\times 3$ (X, Y, Z)
- measurement field angle 2° , 1° , $0,2^\circ$, $0,1^\circ$
- measurement field angle (degree), spot size (mm), and measurement distance (m)

Table B.1 – Example of a measurement result

Measurement field angle (degree)	Measurement distance (m)				
	0,35	0,50	1,00	5,00	10,00
	MF diameter (mm)				
2,0	10,0	15,4	32,8	169	341
1,0	5,0	7,7	16,4	85	170
0,2	1,0	1,5	3,3	17	34
0,1	0,5	0,8	1,6	8	17

Contours of light measurement fields on planar, cylindrical convex, and concave light sources

The measurement field on a planar LS is a circle when the optical axis of the LMD coincides with the DLU's surface normal. The measurement field angles are 0,1°, 0,2°, 1°, 2°. The cross section of a measurement field angle cone with a planar LS is a circle. The line that connects the centre of the circle to the vertex of the solid angle is the centre axis of the cone (perpendicular to the planar LS). However, in case of a cylindrical LS the cross section or the contour of the measurement field is neither a circle nor an ellipse. The shape of the MF's contour as well as the depth-of-field change when the DUT has a non-planar shape. The depth-of-field of an LMD shall be confirmed in order to achieve a sharp image of the object (DUT).

The simulation results are shown in Figure C.1 and Figure C.2. The parameters are:

- the height of the cone: $h = \sqrt{3}$ mm,
- the half vertex angle of the cone: $\beta / 2 = 30^\circ$,
- the radius a of the cross section of the cone: $a = 1$ mm,
- the tilt angles of the planar DUT with respect to the x -axis, $\alpha = 90^\circ, 60^\circ, 45^\circ$ (examples).

The circumferences, expanded plane of the cone and the contour shapes on a tilt plane are shown in Figure C.1, Figure C.2 and Figure C.3 for tilt angles of $\alpha = 90^\circ$, 60° , 45° , respectively.

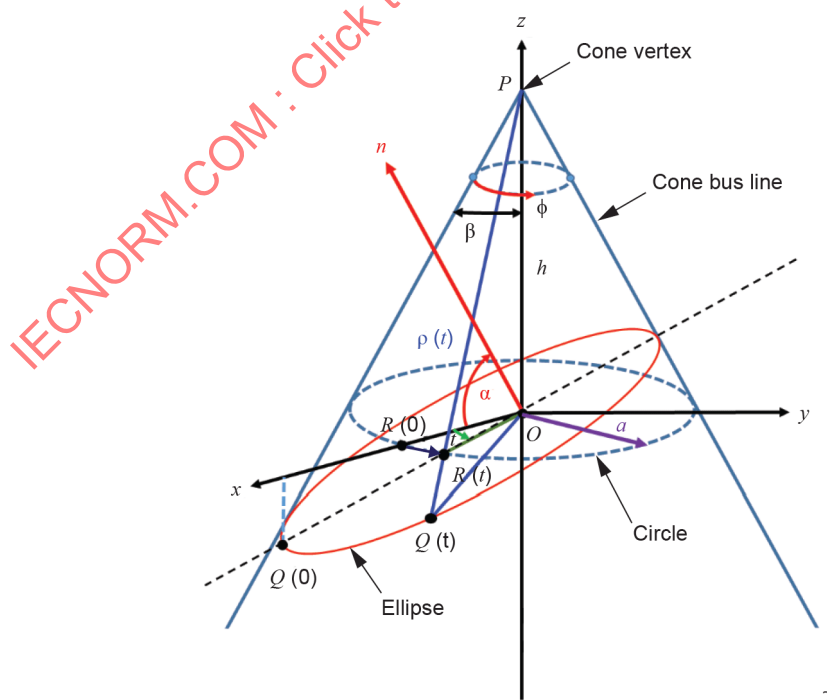


Figure C.1 – Geometry of intersections of a cone and a plane in non-tilt and tilt conditions

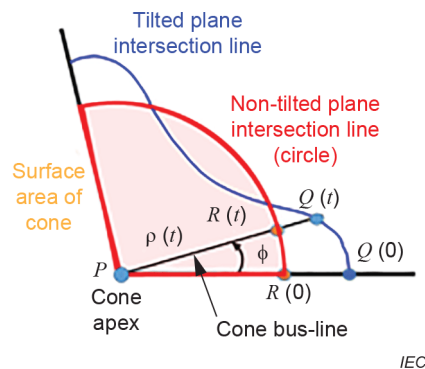
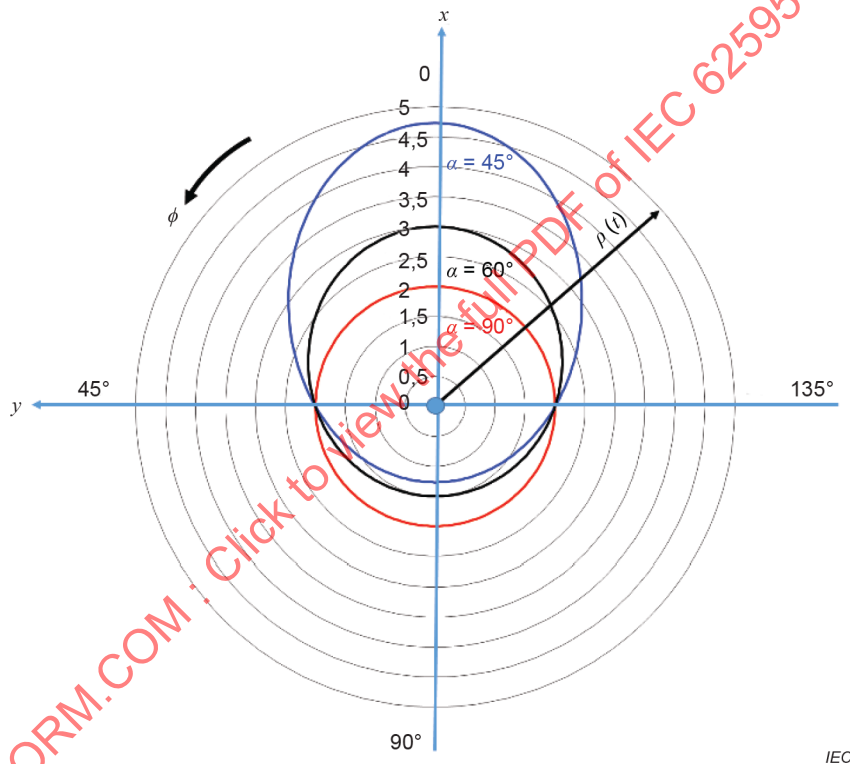


Figure C.2 – Expanded plane of a cone and intersection lines with tilt and non-tilt planes (see Figure C.1)



NOTE In this example the variation angle of the bus-line (PQ) around the vertex is limited to $0 \leq \phi \leq 180^\circ$.

Figure C.3 – Simulated intersections of three planar light sources with a cone (measurement field angle, i.e., a solid angle)

C.3 Projection of an MF contour on the outer surface of a cylindrical DUT

Examples of intersections shown in Figure C.4 and Figure C.5:

- viewing angle: $2\beta = 2^\circ$ (see Figure C.1)
- measurement distance: $D_{\text{LMD}} = 1\,000\text{ mm}$ (see Figure C.4)
- radius of the cylindrical LS: $R = 17,455\text{ mm}$
- radius on the tangent surface of a cylindrical LS: $r = 17,455\text{ mm}$
- azimuth angle (around the LS): $\phi = 0 - 2\pi$

– the outer and inner intersection contours are shown in the Figure C.5

Figure C.6 shows the measurement of a convex cylindrical LS and the possible cases as well as an illustration of the effect of the measurement field angle cone and the angle of inclination of the measurement direction.

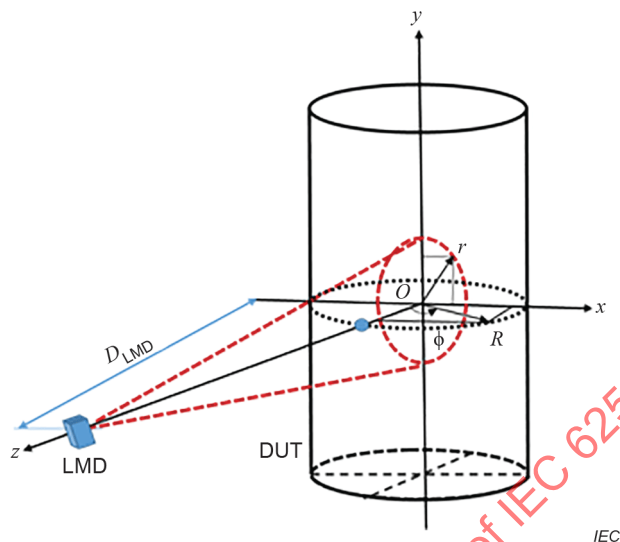
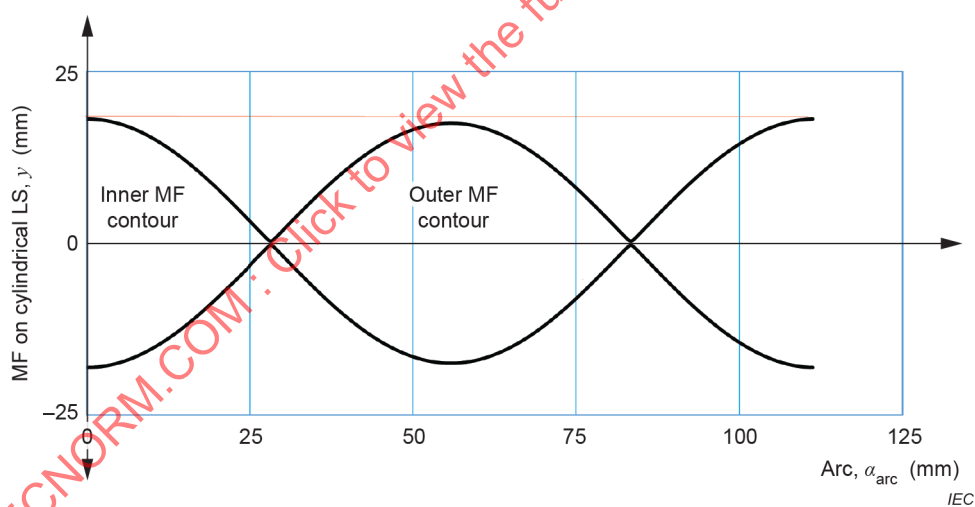


Figure C.4 – Geometry for calculating the intersection of a cone (measurement field angle; solid angle) and a cylinder (light source)

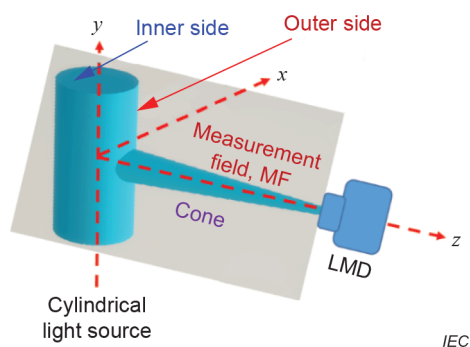


NOTE 1 Conditions for the simulation: viewing angle = 2; $D_{LMD} = 1\,000$ mm; radius of measurement cone, $r = 17,455$ mm; and radius of the cylindrical light source, $R = 17,455$ mm.

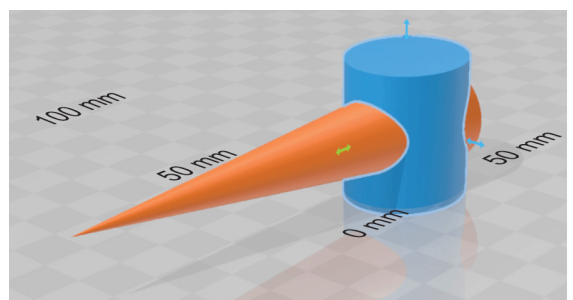
NOTE 2 The centre contour (outer MF contour, on the LS: ≈ 30 mm to ≈ 85 mm) is the outer surface intersection and the left and right sides are the inner surface, on the inner side of the LS (back, against the LMD: inner MF contour: < 30 mm and > 85 mm)) intersection.

Figure C.5 – Intersection of a cone and a cylindrical DUT

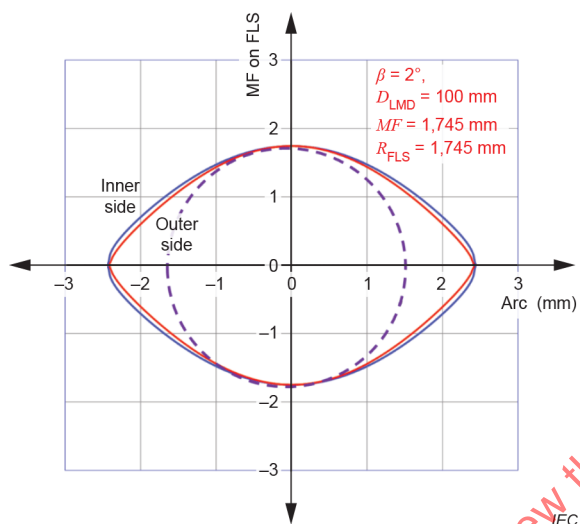
The shape of the MF contour on the cylindrical light source is shown pictorially in Figure C.4.



a) Measurement setup

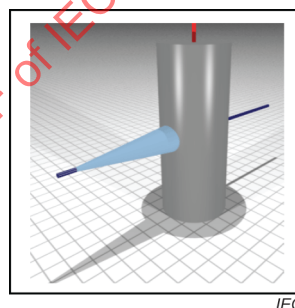


b) Intersection of a cone (measurement field solid angle (cone)) and a cylindrical light source

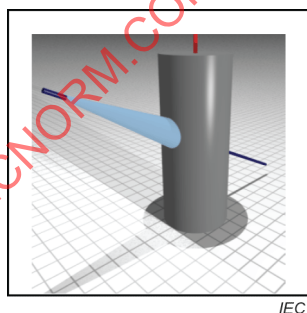


NOTE Outer and inner cross sections, solid lines in colour.

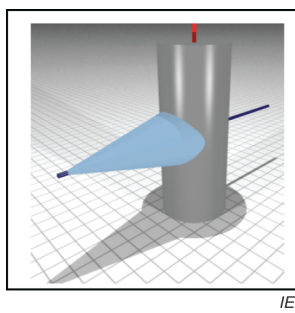
c) Intersection of a cone with a planar (dotted line) and a cylindrical light source (FLS: Cylindrical LS)



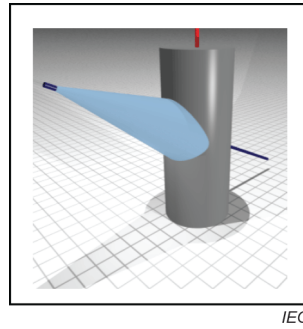
d) Perpendicular measurement direction (small measurement field solid angle (cone))



e) Oblique measurement direction (small measurement field solid angle (cone))



f) Measurement direction (large measurement field angle cone)



g) Oblique measurement direction with large measurement field solid angle (cone)

Figure C.6 – Measurement of a convex cylindrical LS and the possible cases, and illustration of the effect of the measurement field angle cone and the angle of inclination of the measurement direction

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Annex D (informative)

LMD aperture and inclination angle on a cylindrical light source

D.1 General

In a measurement of planar light sources, the upper and lower edges of a LMD aperture area sees different light rays emerging from the light source. When a light source is bent to make a curved one, the difference between the ray angles increase, i.e., the upper and lower edge areas of the LMD aperture, sees rather different inclination angles of the emergent light rays.

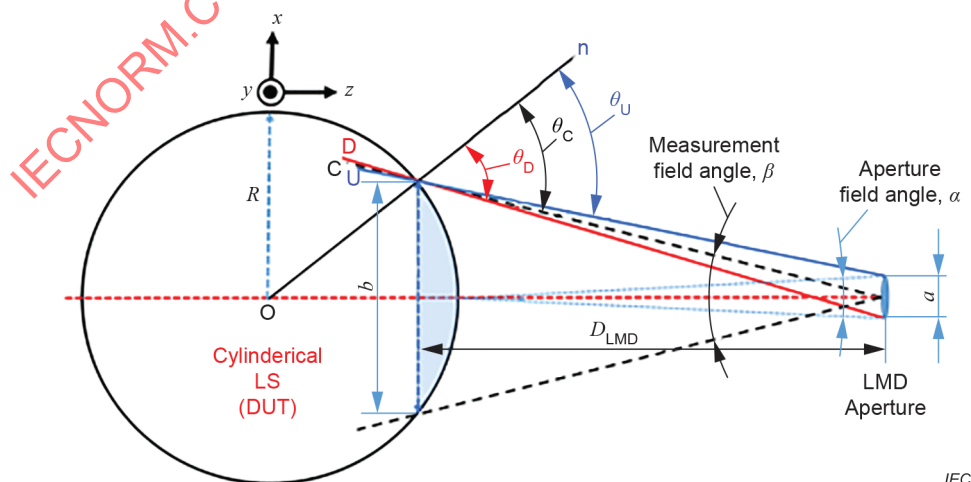
D.2 Inclination angle

In Annex C the effect of non-zero aperture (a) and a fixed measurement field (b) are calculated with the measurement distance as shown in detail in Figure D.1 [14].

In addition, the inclination angles (centre angle: θ_C , i.e., the zero aperture case, up-angle: θ_U , down-angle θ_D) can be calculated for different measurement distances (D_{LMD}). Since the inclination angle varies with the radius of the curved light source, the inclination angle for the lower edge of the LMD's aperture is calculated using Formula (D.1), as shown the calculation results in Table D.1.

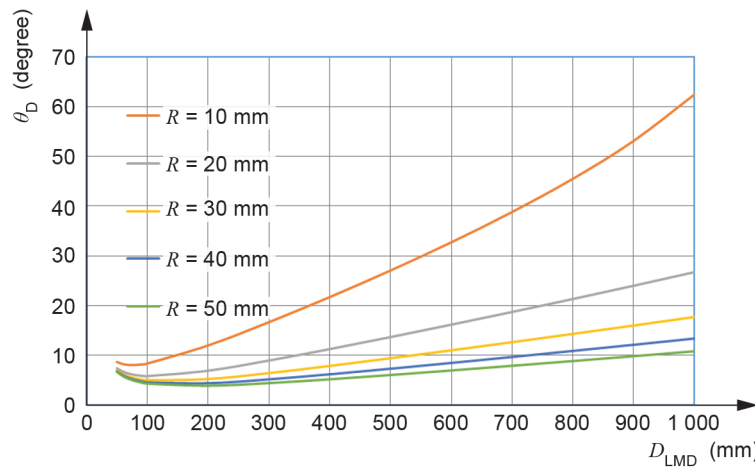
$$\theta_i = \arcsin \left\{ \sin \left(\arctan \left(\frac{a+b}{2 \times D_{LMD}} \right) \right) \times \left(1 + \frac{D_{LMD}}{R} - \frac{a \times D_{LMD}}{(a+b) \times R} \right) \right\} \quad (D.1)$$

By decreasing the measurement field angle from 2° to $0,1^\circ$, the MF size on the DUT decreases resulting in a lessening of the angle between the DUT surface normal and the centre and lower edge areas of the LMD's aperture field angle. There are minima for the measurement field angles, where for each LS of radius R there exists an optimum measurement distance, as shown in Figure D.2.

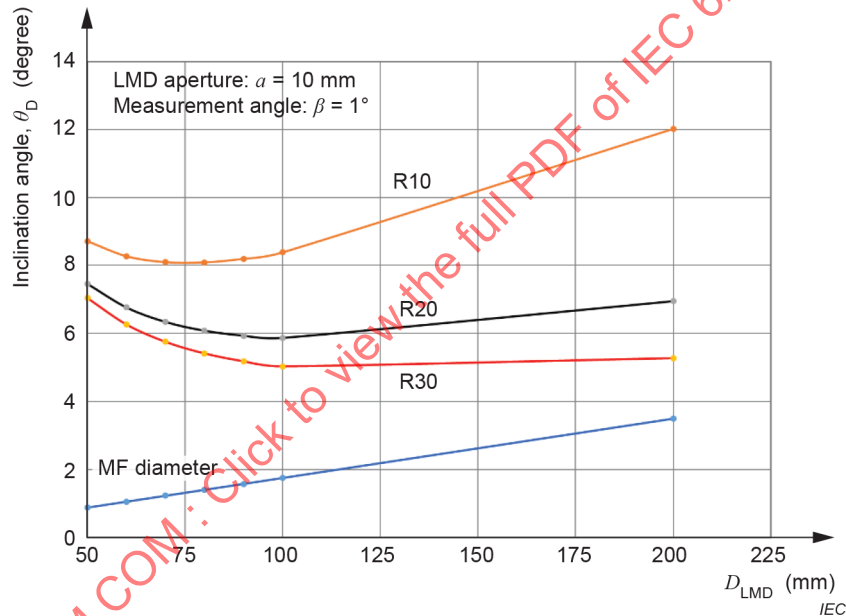


Inclination angles: θ_C , θ_U , θ_D ; fixed MF: b (DUT aperture); non-zero aperture size: a ; aperture angle: α ; measurement field angle: β ; measurement distance: D_{LMD} ; cylindrical light source radius: R .

Figure D.1 – Measurement of a cylindrical light source for a non-zero aperture LMD and fixed measurement field (b)



a) θ_D versus D_{LMD} for $D_{LMD} = 50$ mm to 1 000 mm ($\beta = 1^\circ$)



b) Inclination angle versus $D_{LMD} = 50$ mm to 225 mm

NOTE An optimum measurement distance exists for each cylindrical light source with radius R .

Figure D.2 – Variation of inclination angle, θ_D , with D_{LMD} for each cylindrical LS of radius R

D.3 Inclination angle variation

By choosing a measurement field angle, β , the light on the DUT or the light on the circumferences of the measurement field is selected. This means that the inclined rays on the contour of the measurement field are included in the measurement results. Table D.1 shows the variation of θ_U , θ_C , and θ_D with the variation of the measurement field, $b/2$ (refer to Annex B).