IEC TR 62595-1-3

Edition 1.0 2019-04

TECHNICAL REPORT

colour inside

Display lighting unit –
Part 1-3: Lighting units with arbitrary shapes

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IEC TR 62595-1-3:2019-04(en)

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DISPLAY LIGHTING UNIT –

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IEC TR 62595-1-3, which is a technical report, has been prepared by IEC technical committee 110: Electronic displays.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
110/1018/DTR	110/1064/RVDTR

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

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- withdrawn,
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INTRODUCTION

Recent developments in materials for flexible lighting sources (FLSs) with arbitrary shapes such as organic light emitting devices (OLEDs) have boosted their fabrication process as well as expanding their applications in various fields, for example electronic displays and wearable display devices. Since FLSs can emit light in a curved and deformed shape even under external stress, which is different from that of the devices with rigid substrates, these characteristics and performances require new evaluation and measurement methods. This document focuses on common issues of light emission from FLSs such as spatial uniformity of luminance and colour, and angular distribution of luminance and colour. This document delivers an archetype of a curved FLS's light emission and its measurement. The intent of this document is to provide guidance for the development of future measurement standards.

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DISPLAY LIGHTING UNIT –

Part 1-3: Lighting units with arbitrary shapes

1 Scope

This part of IEC 62595 focuses on common issues of light emission such as spatial uniformity of luminance and colour, and angular distribution of luminance and colour, from lighting units with arbitrary shapes like flexible lighting sources (FLSs). This document provides a model of light emission from a curved FLS and of light measurement on a curved FLS. Because the development of flexible liquid crystal panels is in progress (see the notes), the intent of this document is to provide guidance for the development of future measurement standards. This document is applicable to FLSs either as light sources, products or elements with arbitrary shapes of geometrical curvature having different spectral and spatial characteristics of light emission.

NOTE 1 Almost 20 years ago plastic LCDs were developed and used in a few applications.

NOTE 2 Flexible BLUs have been used for bendable LC panels in recent years.

NOTE 3 Recent transmissive and transflective flexible LCs require flexible BLUs.

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2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

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 Terms and definitions

3.1.1
plane FLS
light emission from a flat surface

3.1.2
convex FLS
light emission from a convex curved surface

3.1.3
concave FLS
light emission from a concave curved surface

3.1.4
transparent FLS
FLS with transparent substrate that emits light from both front and back surfaces, or otherwise from the inner or outer surfaces

3.1.5
foldable FLS
FLS bent over upon itself

3.1.6
bendable FLS
long or thin FLS forced from a straight form into a curved or angular one, or from a curved or angular form into some different form

3.1.7
rollable FLS
FLS capable of rolling or being rolled

3.1.8
stretchable FLS
FLS capable of being stretched, or fabricated on a stretchable or elastic substrate

3.1.9
single-curvature surface emission FLS
FLS that possesses a single radius of curvature, whether negative or positive, along its length, width or diagonal

3.1.10
white emission FLS
FLS with phosphor or any phosphor-like material converted white light emission

3.1.11
monochromatic emission FLS
FLS with a narrow band emission of light

3.1.12
chromatic emission FLS
FLS with polychromatic light emission

3.1.13
spatial characteristics
information on measurement point position, area, and size or images captured from spatial view-points at successive time intervals that are shown together on a single picture

3.2 Abbreviated terms

ALD angular luminance distribution
BLU backlight unit
DLU display lighting unit
DUT device under test
FLS flexible light source
LCD liguid crystal display
LED light emitting diode
LMD light measuring device
MF measurement field
OLED organic light emitting diode
VLU virtual luminance uniformity

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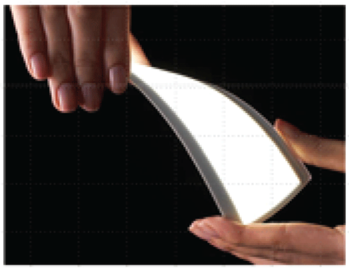
4 Flexible lighting units

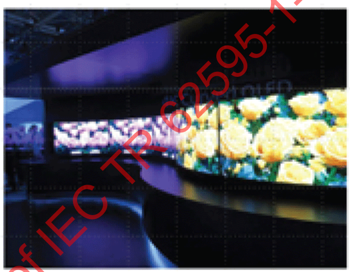
4.1 General

Recent developments in materials for flexible lighting sources (FLSs) such as organic light emitting devices (OLEDs) have expanded their applications in various fields, for example electronic displays and wearable display devices. Their exceptional characteristics, i.e., the flexibility of lighting units, have accelerated the usages of wearable devices.

FLSs are innovative elements with planar light emitting elements. FLSs have excellent surface emission characteristics with mechanical durability as shown in the lighting and display devices in Figure 1 [1][1]. Surface light emitting FLSs are applicable to the fields of display lightings in the wearable, internet of things (IoT), and healthcare industries, and are expected to be a large promising market [1 to 28].



a) White flexible FLS element for display illumination (back or front)



b) Curved display

Figure 1 – Examples of curved FLS and curved display

Nowadays the piecewise and roll-to-roll manufacturing approaches are being explored while addressing problems in FLS durability, efficiency and luminance homogeneity. In addition, the material research, plant construction, component technology and application are being studied for future elements and products [12 to 16].

Since the flexible planar lighting units are thin, light-weight, and have geometrical deformability, i.e., bending, rolling, folding, and stretching, these properties can benefit the automobile and aircraft industries. The robustness of these flexible devices appears in their relatively uniform light distribution, i.e., a weak directivity in bending, in optical invariant, and in light diffusion that results in dimmed shadow in bending.

In addition new industries are exploring the methods to integrate flat and flexible lighting units into automobiles, aircrafts and households. Since the FLSs can emit light in a curved and deformed shape even under external stress, which is different from that of the devices with rigid glass substrates, these characteristics and performances require new evaluation and measurement methods. In addition the measurement items in static and dynamic applications are indispensable for accelerating the new market of the planar FLS elements or products. Therefore, this document intends to focus on and to resolve the issues of curved FLSs such as optical quantities measurements from certain angles and to show the necessity for developing guidance for future standardization work.

The measurements of flat planar light sources as well as flat FLSs have been studied and their optical quantities measurements have been established. The existing measurement devices are mechanically and optically adapted to the flat planar light emitting devices or displays. However, the static FLSs with a single, double or even an arbitrary curvature have not yet been studied or established yet. Therefore, the measurements of the curved FLS

[1] Numbers in square brackets refer to the Bibliography.

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elements or products require a new evaluation of the measurement devices, which have adaptive characteristics.

4.2 FLSs possessing arbitrary curvature

The issues of curved TV sets and FLSs with large curvatures have been studied in recent years [17 to 19, 25 to 28]. In addition, the analyses given in [20] to [22] are based on an assumption that the projected cross section of a cone defined as the measurement field (MF) on a single curved surface is elliptical. However, the contour of an MF or the boundary of the field on the DUT is not an ellipse. The projection of a circle on a tilted plane surface is an ellipse. However, the projection of the MF on a curved surface is not an ellipse and should be calculated.

The issues of FLSs with a small curvature, i.e., the degree of flatness and the surface's geometric structure, hitherto have not been studied. In addition, the existing luminous flux or luminance measurement devices have been used for the optical quantities measurements of curved large size illuminating devices. In the conventional measurement the provisions of front luminance evaluation are based on flatness, i.e., an object with a radius of infinity. However, the new measurements require information on surface prior to measurement, and new luminance or luminous flux measuring devices (LMDs). In addition, new definitions are required for curved FLSs (see 3.1.1 to 3.1.12) because the depth of focus or the defocus of the measuring devices changes with respect to FLS curvature. The defocus of an LMD that is used for measuring a flat plane causes erroneous results. The measurement items are the luminance on the surface normal or slanted angles, luminance uniformity (whether with Lambertian or nearly Lambertian distribution) or virtual luminance uniformity, that is, to compare the luminance of different points on a curved surface, angular luminance distribution, angular chromaticity and its uniformity, and luminous flux measurement on an arbitrary point and area on the curving FLSs, as shown in Figure 2.

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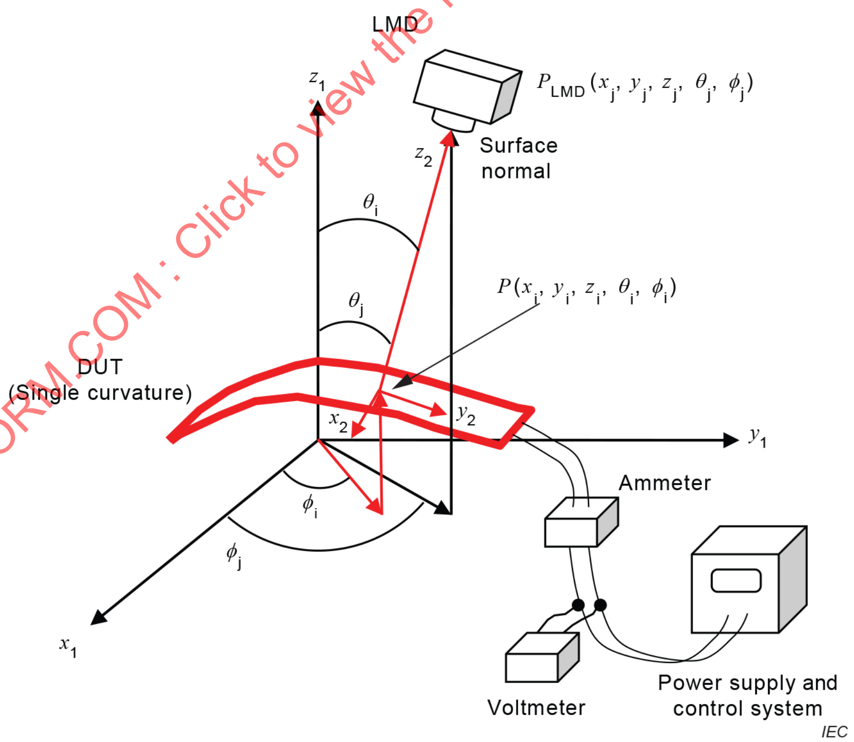
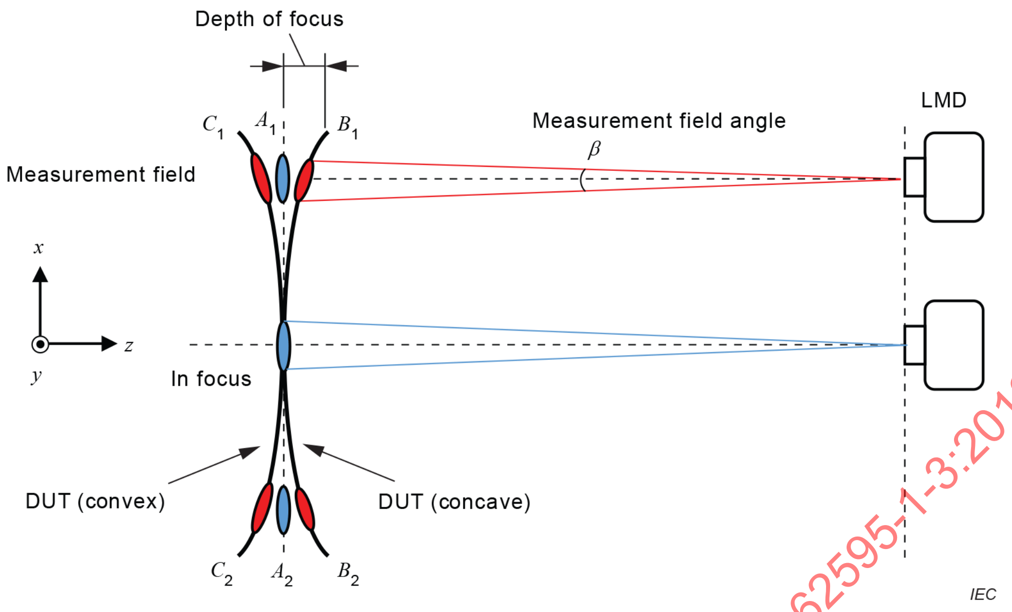


Figure 2 – FLS with an arbitrary curvature and measurement system

Since an FLS can be used in a freeform shape, the optical measurement requires analysis of the complicated curvature and as a result rigorous geometrical mathematics are needed [23, 24]. Hence, this document handles the first degree of curvature, i.e., a concave and convex FLS with a single curvature, as shown in Figure 3.



NOTE The measurement of curved surfaces results in erroneous results due to defocus or depth of focus of the light measuring devices.

Figure 3 – FLS element with curvature and change of measurement field contour due to curvature

5 Single-curvature FLS model

The geometries of a single-curvature (concave and convex) FLS are shown in Figure 4. The LMD is set at a distance D_{LMD} from the curved FLS. In case of a conventional flat plane DUT the radius is large enough with respect to the LMD's depth of focus. However, the radius is limited to D_{LMD} which results in a flat plane circular measurement field and by definition the diameter is written as:

$$U_0 = A_0 B_0 = 2 D_{\mathrm{LMD}} \cdot \tan \frac{\theta_0}{2} \tag{1}$$

where

θ_0 is the measurement angle of the LMD;

D_{LMD} is the distance between the LMD and the DUT;

$A_0 B_0$ ($= U_0$) is by definition the diameter of the circular cross section of the measurement field (viewed cone through the LMD).

However, the area is a cap of a sphere with a radius of D_{LMD} that results in the following measurement field with a chord of the arc (in actual case) as follows:

$$U_1 = A_1 B_1 = D_{\mathrm{LMD}} \cdot \theta_0 \tag{2}$$

where

$A_1 B_1$ ($= U_1$) is the chord of the arc (cross section of the cap).

In this manner the calculations are extended to DUTs with radii of R_2 and R_3 as shown in Figure 4. The following measurement fields, that is, the chords, are obtained:

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$$U_2 = A_2B_2 = R_2\theta_2 \tag{3}$$

$$U_3 = A_3B_3 = R_3\theta_3 \tag{4}$$

The angles θ_2 and θ_3 can be obtained by calculating the cross point of FLS-2 and FLS-3 with the up and down border lines of the viewing angle. The measurement fields are the circles with diameters of A_2B_2 (= U_2) and A_3B_3 (= U_3) corresponding to the chords of the segments with radii of R_2 and R_3. When these measurement fields are compared to that of the flat plane, the following differences (ΔU_1, ΔU_2, ΔU_3) are obtained:

$$\Delta U_1 = |U_0 - U_1| \tag{5}$$

$$\Delta U_2 = |U_0 - U_2| \tag{6}$$

$$\Delta U_3 = |U_0 - U_3| \tag{7}$$

The differences between the M_{FA} chords in the y-direction are calculated as follows:

$$M_{FA0} = 2D_{LMD} \cdot \tan\frac{\theta_0}{2} \tag{8}$$

$$M_{FA1} = 2D_{LMD} \cdot \sin\frac{\theta_0}{2} \tag{9}$$

$$M_{FA2} = 2R_2 \cdot \sin\frac{\theta_2}{2} \tag{10}$$

$$M_{FA3} = 2R_3 \cdot \sin\frac{\theta_3}{2} \tag{11}$$

The differences in the chords show the amount of depth of focus at the edge of the chords (D_{EF}, in the z-direction) as follows:

$$D_{EF0} = 0 \tag{12}$$

$$D_{EF1} = D_{LMD} - D_{LMD} \cdot \cos\frac{\theta_0}{2} \tag{13}$$

$$\begin{aligned} D_{EF2} &= \left(D_{LMD} + R_2\right) - R_2 \cdot \cos\frac{\theta_2}{2} - D_{LMD} \\ &= R_2 - R_2 \cdot \cos\frac{\theta_2}{2} \end{aligned} \tag{14}$$

$$D_{EF3} = \left(D_{LMD} - R_3\right) + R_3 \cdot \cos\frac{\theta_3}{2} \tag{15}$$

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The differences in the viewed area (defined by the chord or the arc) through the cone (measurement field) are given as follows:

$$\Delta M_{\text{FA1}} = \left| M_{\text{FA0}} - M_{\text{FA1}} \right| \tag{16}$$

$$\Delta M_{\text{FA2}} = \left| M_{\text{FA0}} - M_{\text{FA2}} \right| \tag{17}$$

$$\Delta M_{\text{FA3}} = \left| M_{\text{FA0}} - M_{\text{FA3}} \right| \tag{18}$$

The measurement results are affected by the directionality of the sources and relative positions of the LMD and DUT. Therefore, the analysis of the geometries shown in Figure 3 is performed as shown in Figure 4.

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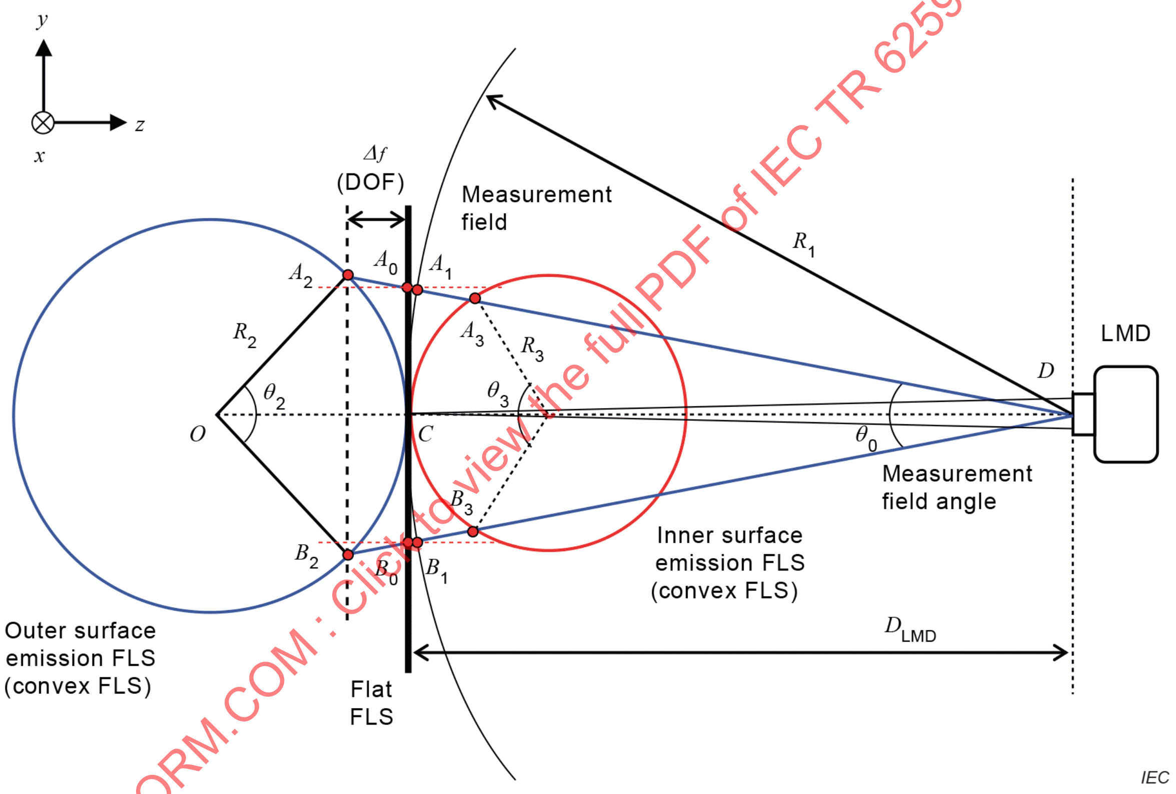
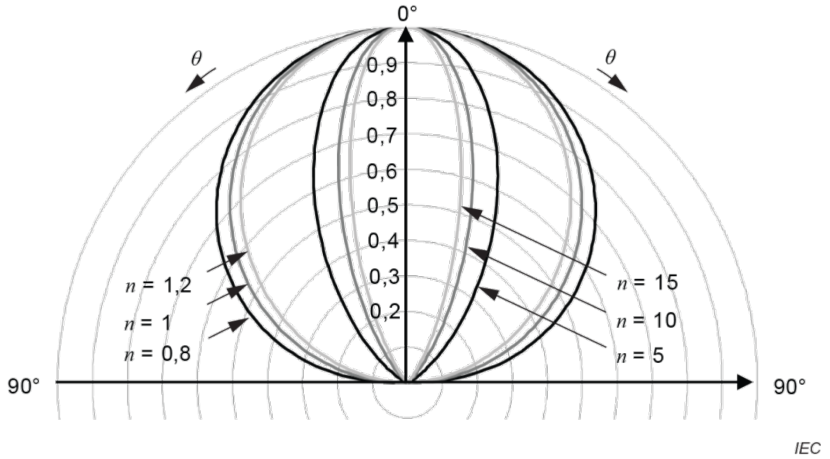


NOTE The chords defining the measurement fields are analytically obtained and compared with the chord (cone's circular cross section) on a flat plane (conventional A_0B_0).

Figure 4 – Curved FLS with convex and concave curvatures

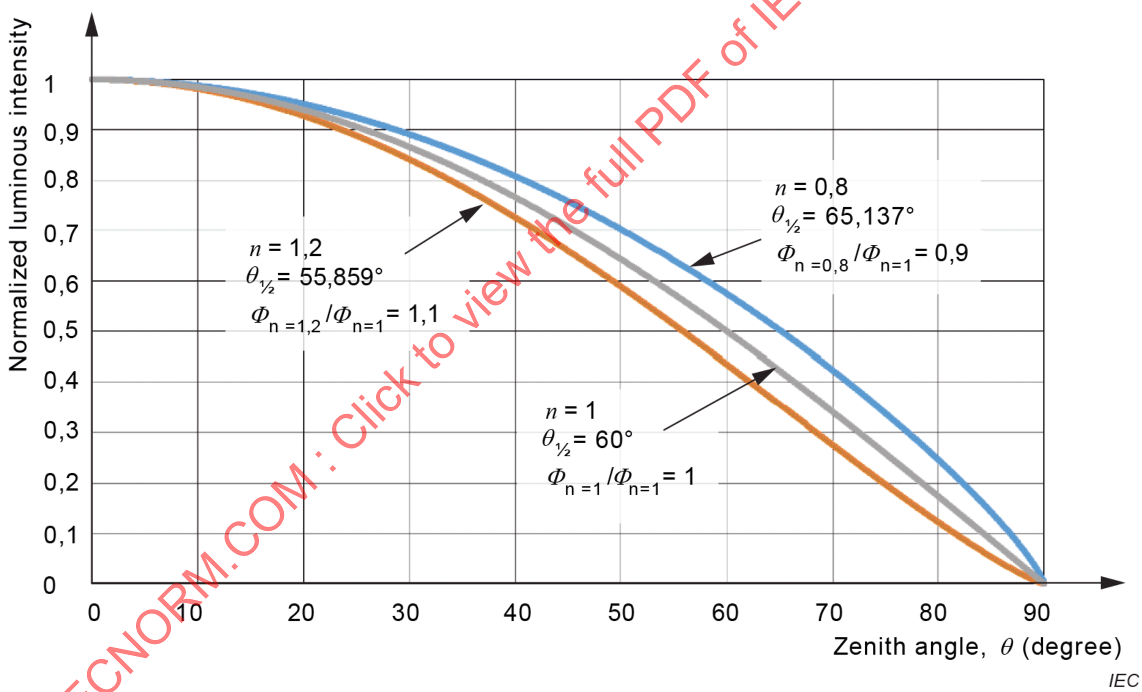
6 FLS light emission directionality

A curved FLS (source, product, and element) might have a reflective surface and an arbitrary luminous intensity distribution, i.e., $\cos^n(\theta)$. However, a secondary optics is used for shaping the emitted light. Figure 5 shows almost Lambertian distribution for n = 0,8 and n = 1,2. An example of directional distribution of n = 15 is plotted as reference in Figure 5. The nearly Lambertian sources can be treated as Lambertian with predefined approximation. Nevertheless, the directed FLS such as n = 15 leads to larger measurement errors, because the flux is directed into a narrow solid angle (light cone) as shown in Figure 6. The luminous flux concentrations are shown in Figure 7 in comparison with Lambertian distribution.



NOTE Intensity distributions using $\cos^n(\theta)$ with different values of "n".

Figure 5 – Radiation pattern of FLSs with nearly Lambertian luminous intensities (n = 0,8, 1, 1,2) and collimated light intensities (n = 5, 10, 15) in a spherical coordinate system



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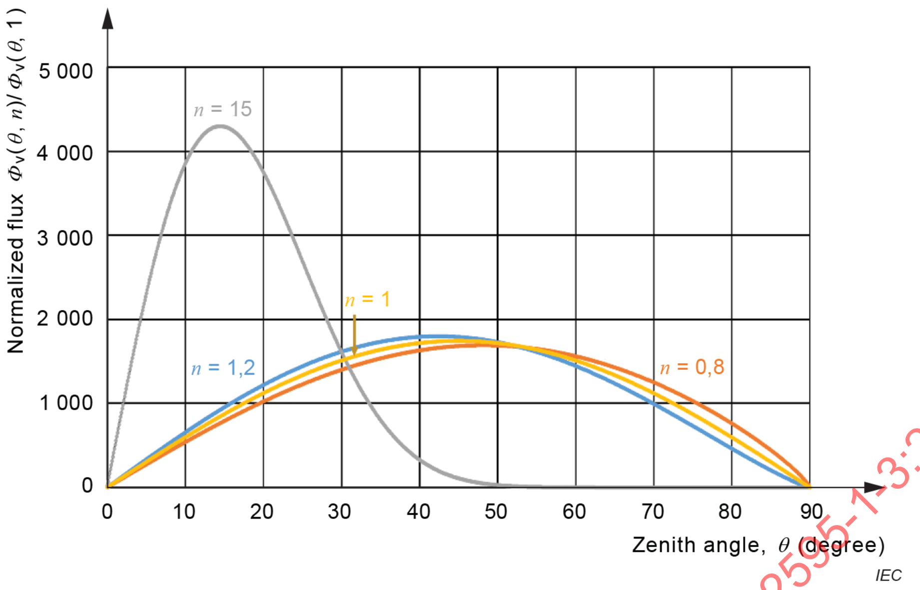
NOTE 1 These are the Lambertian and the nearly Lambertian radiance distributions of FLSs.

NOTE 2 Half-angles ($\theta_{1/2}$) and flux (Φ_n) ratios are shown in the graph.

Figure 6 – Radiation pattern profiles of FLSs with nearly Lambertian luminous intensities (n = 0,8, 1, 1,2)

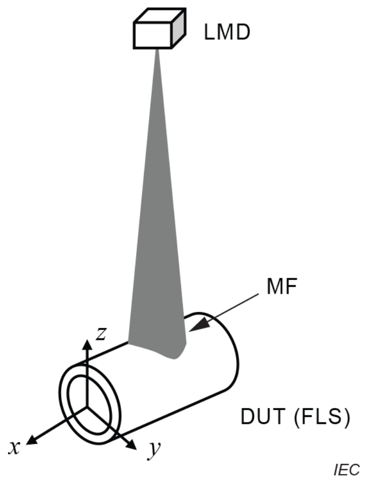


NOTE A concentration of flux in each FLS with a luminous intensity of n = 0,8, 1, 1,2 and n = 15 is used as reference.

Figure 7 – Confined flux in solid angles (θ = 0° to 90°) for intensity distributions with n = 0,8, 1, 1,2 and 15

7 Measurement field projection on a curved FLS

The projection of a round measurement field on a single-curvature FLS is important for precise evaluation. Figure 8 and Figure 9 show a projection of a round MF on an FLS with a radius of R. The projected area on the surface normal direction has a contour shown in Figure 10 and 11. The contour (MF's boundary) on a curved FLS and for an off-axis is shown in Figure 11 which is not an ellipse. Moreover, an off-axis, i.e., slanted, measurement is shown in Figure 12. In addition, the measurement of an inner surface emission FLS is divided into two parts, the upper part is expanded and the lower part is contracted as it varies with the angle between the optical axes of the LMD and the DUT, i.e., the δ-angle. The variation of the field area versus the $\delta\gamma$-angle is shown in Figure 13.



NOTE Measurement field (MF) cone's cross section projected on a cylindrical FLS with nearly comparable diameter.

Figure 8 – LMD's cone cross section nearly equal to that of the FLS's diameter

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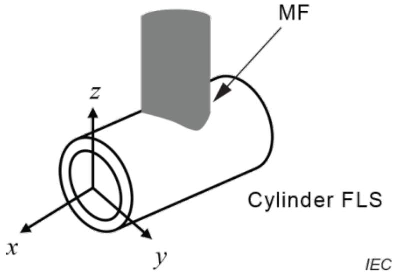
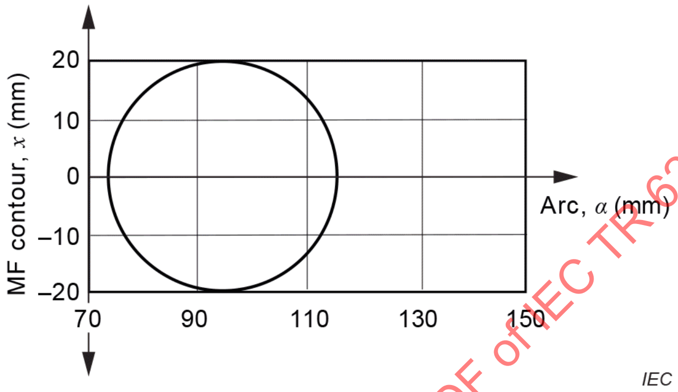
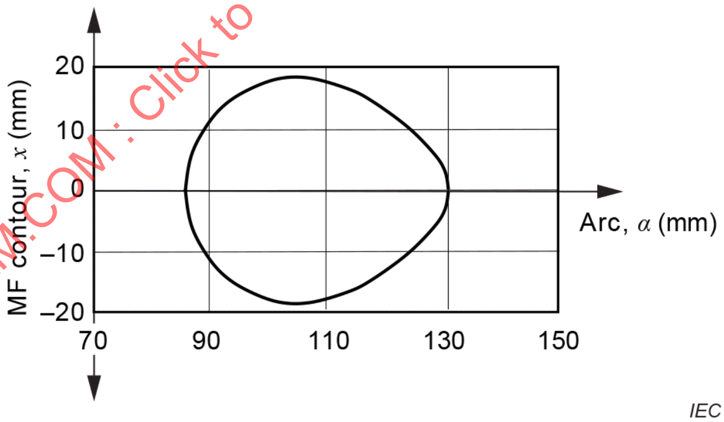


Figure 9 – Contour of projected measurement field's cone cross section on a cylindrical FLS



NOTE Viewing angle β =2°, R_{FLS} = ∞ (flat), MF's cross-section diameter, R_{MF} = 17,76 mm, measurement distance D_{LMD} = 1 000 mm (refer to Figure 8).

Figure 10 – Contour of a cone's cross section of the measurement field on a large radius cylindrical FLS R_{FLS} = ∞ (flat)



NOTE Viewing angle β = 2°, R_{FLS} = 30 mm, MF's cross-section diameter, R_{MF} = 17,76 mm, Y_{OFF} = 10 mm, measurement distance D_{LMD} = 1 000 mm (refer to Figure 8).

Figure 11 – Off-axis measurement and cone's cross section contour on the DUT (right half expanded and left half contracted)

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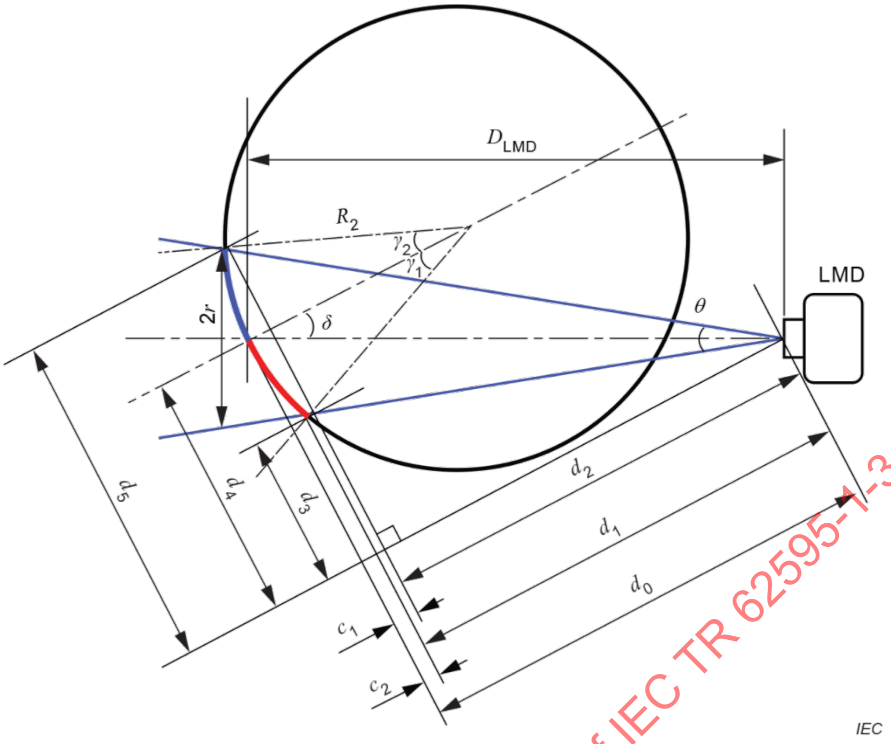
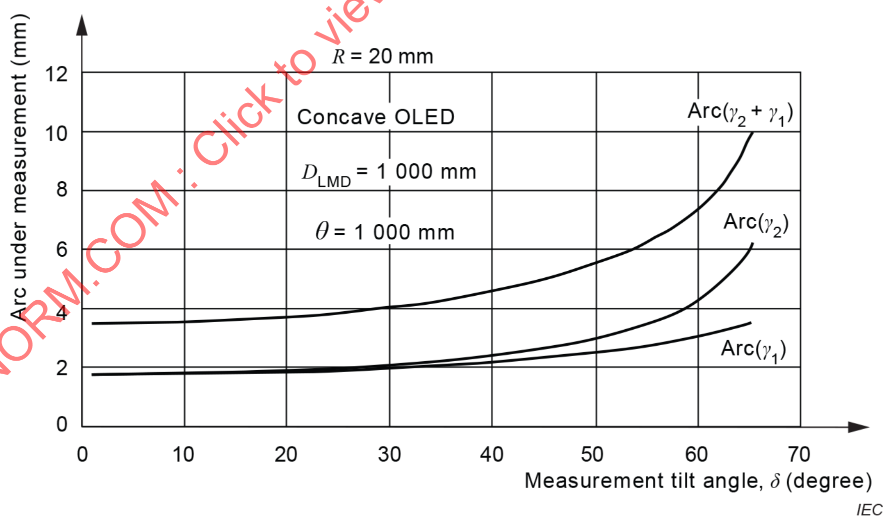


NOTE 1 Off-axis measuring field's cone cross section projected on the inner surface emission FLS. The upper part is expanded and the lower part is contracted.

NOTE 2 Half expanded and half declined projected MF with circular cross section (a view of the cross section).

Figure 12 – Measurement field cone's cross section contour on a cylindrical FLS versus the angle between the LMD and DUT axes (δ)



NOTE Measurement field cross section on a convex slanted FLS; expanded upper part and contracted lower part due to the slanted angle.

Figure 13 – Cross section of the measurement field (cone's cross section) with the angle (δ) between the LMD and DUT axes, on a concave cylindrical FLS

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8 Discussion and conclusions

Curved displays have been integrated into products such as TVs, cell phones, and wearable devices. The development and integration of the flexible displays boost the applications of the indoor and outdoor devices, for example distinct or wall-decorated large size curved or foldable signage displays, as well as commercial wearable and handheld devices. Since bending the display can alter its optical properties, it is necessary to evaluate the optical performance of the display's lighting units under the curved state, i.e., the stretched or contracted conditions. In contrast to a flat lighting unit of a display, the display's light source curvature introduces new measurement challenges. The optical characteristics such as spatial and angular luminance, spatial and angular luminance uniformity or virtual luminance uniformity, spatial and angular chromaticity distribution, spatial and angular colour uniformity, luminous intensity distribution, local luminous flux and change in the optical invariant on the flexible light source with a decreasing radius of curvature shall be evaluated to ensure the integration of the lighting unit with the flexible display.

Optical flux measurement on a curved FLS requires attachment to the integrated sphere. The existing LMDs and novel interfaces should be developed to meet the needs for measurement of the emerging curved FLSs.

In an FLS element in combination with secondary optics for light extraction and shaping, the secondary optics inserts new optical characteristics on the FLS. In case of Lambertian or nearly Lambertian light emissions novel light measuring methods are required, however, the FLSs with directional characteristics can require more analysis and complicated measurement methods.

Optical quantities measurement of an FLS with an arbitrary curvature is the main issue. An arbitrary curvature of an FLS can be analysed using a single curvature, and as a concept the single curvature is studied for the first time in this document. The measurement of a curved FLS, the depth of focus of the measurement devices and the defocus are the main issues. An FLS can be a monochromatic, polychromatic (multicolour) or white (phosphor and quantum dot or quantum rods converted white) element.

In this document the curved FLSs and the required standardization limited to a single curvature as a model, which can be extended to FLSs with arbitrary curvatures, have been reviewed. TC 110 DLU should urgently handle the FLSs (defined in 3.1.2 to 3.1.12) for stretchable or conformable displays.

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