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INTERNATIONAL STANDARD

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

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DISPLAY LIGHTING UNIT –

Part 2-3: Electro-optical measuring methods for LED frontlight unit

FOREWORD

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International Standard IEC 62595-2-3 has been prepared by IEC technical committee TC 110: Electronic display devices.

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

CDV	Report on voting
110/891/CDV	110/933A/RVC

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.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

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- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

DISPLAY LIGHTING UNIT –

Part 2-3: Electro-optical measuring methods for LED frontlight unit

1 Scope

This part of IEC 62595 specifies the standard measurement conditions and measuring methods for determining electrical, optical, and electro-optical properties of LED frontlight units (FLUs) for reflective displays.

NOTE: See 3.1.1 for a definition of reflective display.

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 62595-1-2, *Display lighting unit – Part 1-2: Terminology and letter symbols*

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

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

3 Terms, definitions, abbreviated terms and letter symbols

For the purposes of this document, the terms, definitions, abbreviated terms and letter symbols given in IEC 62595-1-2 and the following 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
reflective display
display whose function is based on the light reflection of a reflective layer in its structure

EXAMPLE A reflective LCD, an electronic paper display, a micro electro-mechanical system (MEMS) and a micro electro-opto-mechanical system (MEOMS) display device. See IEC 62679-3-3.

3.1.2
normal state
normal-state FLU
state of an FLU in which the light emerges from its front surface that faces toward the reflective display

Note 1 to entry: For an example, see Annex A, Annex B, Figure A.1 and Figure B.1, [1] to [8][1].

3.1.3
inverted state
inverted-state FLU
FLU with an illuminating surface toward a viewer

Note 1 to entry: For an example, see Figure B.2.

3.1.4
optical trap
optical device that is used in FLU measurements for trapping or absorbing the emergent light from the opposite surface of the FLU under measurement device, whether the FLU is in a normal state or in inverted state

Note 1 to entry: For examples, see Figure 1.

3.1.5
optical absorbing sheet
optical absorbing plate
plane sheet or plate that is used beneath an FLU under measurement to absorb the emergent light

3.1.6
BRDF
bi-directional reflectance distribution function
variation of reflected luminance ($L_{vR}(\theta_r,\phi_{r;}\theta_i,\phi_i,\lambda_i)$) due to the change of non-polarized illumination ($E_v(\theta_i,\phi_i,\lambda_i)$) of an infinitesimal uniform area on an FLU

Note 1 to entry: See Annex C and Annex D. In case of an equal reflection factor of the FLU surface, the BRDF is a space invariant characteristic, and the eigen value of the FLU is expressed in solid angle (Ω) unit, i.e., in terms of steradian.

3.1.7
BTDF
bi-directional transmittance distribution function
variation of transmitted luminance ($L_{vT}(\theta_r,\phi_{r;}\theta_i,\phi_i,\lambda_i)$) due to non-polarized illuminating variation ($E_v(\theta_i,\phi_i,\lambda_i)$) of an infinitesimal area on an FLU

Note 1 to entry: See Annex C and Annex D. In case of an equal transmittance factor on each point of the FLU surface, the BTDF is a space invariant characteristic, and the eigen value of the BRDF of the FLU is expressed in solid angle (Ω) unit, i.e., in terms of steradian.

3.1.8
BPDF
bi-directional polarization distribution function
variation of luminance with polarization of the reflected light ($L_{vP}(\theta_r,\phi_{r;}\theta_i,\phi_i,\lambda_i)$) due to a change of non-polarized illumination ($E_v(\theta_i,\phi_i,\lambda_i)$) of an infinitesimal uniform area on an FLU

Note 1 to entry: See Annex C, Annex D and Annex E. In case of an equal reflection factor on each point of the FLU surface, the BPDF is a space invariant characteristic, and the eigen value of the BTDF of the FLU is expressed in solid angle (Ω) unit, i.e., in terms of steradian.

1 Numbers in square brackets refer to the Bibliography.

3.1.9
OTF
optical transfer function
contrast of transmitted line pairs through an FLU versus line pairs periodicities and orientations

Note 1 to entry: See Annex F.

3.1.10
optical transfer function evaluation chart
OTF evaluation chart
printed charts of straight black and white line pairs with different widths (line pairs per millimeter) and periodicities for use beneath a normal-state FLU to measure and plot the observed light intensity versus line pairs per millimeter

Note 1 to entry: An example of the resolution test chart can be obtained based on ISO 12233 [9].

Note 2 to entry: See Annex F.

3.1.11
optical signal-to-noise ratio
optical SNR
ratio of the luminance of the illuminating directed light, $L_{\text{v,signal}}(x_i,y_i, \theta_j,\phi_j)$, toward the reflective display in a predefined direction in the spherical coordinate system, (θ, ϕ), and the luminance of noise, $L_{\text{v,noise}}(x_i,y_i,\theta_j,\phi_j)$, i.e. besides the directed illuminating light, expressed as

$$SNR = \frac{L_{\text{v,signal}}\left(x_i, y_i, \theta_j, \phi_j\right)}{L_{\text{v,noise}}\left(x_i, y_i, \theta_j, \phi_j\right)} \quad (1)$$

3.1.12
aliasing interference fringe
moiré pattern
periodic interference pattern that appears between the spatial distribution of the sub-micro or micro-optical structures on the front surface (non-illuminating surface) of a normal-state FLU and the spatial pixel structure of the reflective display

Note 1 to entry: See [1] to [8].

3.1.13
visual inspection
act of checking defects such as distraction of the transparency caused by flaws in the LGP/LGF of the non-lit FLU or scratches on either side of an FLU that can been seen under high white illumination by turning over in various directions

3.1.14
perceptual visual quality
cosmetic quality
image fidelity performance of the lit FLU when the images of the reflective display are viewed through the FLU

Note 1 to entry: It is also the performance of a normal-state FLU in an integration or in combination with a reflective display that indicates the no-distraction of a displayed image.

Note 2 to entry: See 7.15.

3.2 Abbreviated terms

ACU - angular colour uniformity

ALD - angular luminance distribution

BPDF - bi-directional polarization distribution function

BRDF - bi-directional reflectance distribution function

BTDF - bi-directional transmittance distribution function

CCD - charge coupled device

CMOS - complementary metal oxide semiconductor

DUT - device under test

FLU - frontlight unit

FOS - front-of-screen

LCD - liquid crystal display

LED - light emitting diode

lp - line pairs

LGF - light-guide film

LGP - light-guide plate

LMD - light measuring device

OTF - optical transfer function

SLG - stick-light guide

3.3 Letter symbols (quantity symbols / unit symbols)

The letter symbols for FLUs are shown in Table 1.

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

Arbitrary luminance of a point (x_i, y_i) on an FLU	L_{vi}	(cd/m^2)
Maximum luminance on an FLU	L_{vM}	(cd/m^2)
Minimum luminance on an FLU	L_{vm}	(cd/m^2)
Average luminance on an FLU	L_{va}	(cd/m^2)
Centre luminance on FLU	L_{vc}	(cd/m^2)
Spatial luminance uniformity	U	(%)
Spatial luminance non-uniformity	NU	(%)
Angular luminance in an arbitrary direction	$L_{\mathrm{v}}\ (x,\ y;\ \theta,\phi)$	(cd/m^2)
Solid angle	Ω	(sr)
Colour uniformity (chromaticity difference)	$\Delta u'v'$	
Spectral power distribution of a display lighting unit	$S_{\mathrm{FLU}}(\lambda)$	
Angular luminance distribution of transmitted light at an arbitrary point (x_i,y_i)	$L_{\mathrm{vT}}(x_i,y_i,\theta,\phi)$	(cd/m^2)
Angular luminance distribution of reflected light at an arbitrary point (x_i,y_i)	$L_{\mathrm{vR}}(x_i,y_i,\theta,\phi)$	(cd/m^2)
Angular luminance distribution of a polarized light at an arbitrary point (x_i,y_i)	$L_{\mathrm{vP}}(x_i,y_i,\theta,\phi)$	(cd/m^2)
Angular colour uniformity	$\Delta u'v'(\theta,\phi;x_i,y_i,)$	
BRDF	$L_{\mathrm{vR}}(\theta_r,\phi_r;\theta_i,\phi_i,\lambda_i)\ /\ E_{\mathrm{v}}(\theta_i,\phi_i,\lambda_i)$	(1/sr)
BTDF	$L_{\mathrm{vT}}(\theta_r,\phi_r;\theta_i,\phi_i,\lambda_i)\ /\ E_{\mathrm{v}}(\theta_i,\phi_i,\lambda_i)$	(1/sr)
BPDF	$L_{\mathrm{vP}}(\theta_r,\phi_r;\theta_i,\phi_i,\lambda_i)\ /\ E_{\mathrm{v}}(\theta_i,\phi_i,\lambda_i)$	(1/sr)
OTF	C_{R}	

4 Measuring devices

4.1 General

The following measuring devices shall be used in this document. The LMD shall be calibrated with the appropriate photometric or spectrometric standards.

4.2 Light measuring device (LMD)

4.2.1 Luminance meter

The luminance meter (a spot meter or an imaging meter) shall be equivalent to the human eye. The equipment shall be calibrated with the luminance standards, and should be carefully checked before measurement, considering the following elements:

– sensitivity of the measured quantity to measuring light;
– errors caused by veiling glare and lens flare (i.e., stray light in optical system);
– timing of data-acquisition, low-pass filtering and aliasing interference fringe effects;
– linearity of detection and data-conversion.

NOTE: ISO/CIE 19476 [10] is available asreference for the LMD evaluation procedures.

4.2.2 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 accuracy shall be 0,3 nm or less. The equipment shall be calibrated with the with the spectrometric standards. The performance should be carefully checked before measurement, considering the same elements as in 4.2.1.

4.2.3 Conoscopic system

The conoscopic system is the angular optical distribution measurement system with Fourier optics. The photometric values, such as luminance, which are obtained by the equipment without any photometric standard calibration shall not be used. The relative values, such as an angular optical distribution and colour uniformity, shall be applied.

4.2.4 Image sensor

The image sensor is constructed from a one-dimensional CCD (CMOS) line sensor or a two-dimensional CCD (CMOS). The image sensor shall be applied for measuring the OTF property of the DUT. The spatial resolution of the image sensor shall be at least twice as high as that of the DUT.

NOTE Sampling frequency or resolution is double or more that of the chart under measurement to prevent the aliasing interference fringe phenomenon or any countermeasure from eliminating aliasing interference fringe in the measurement.

4.3 Other devices

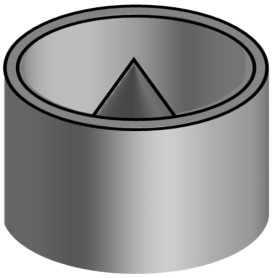
4.3.1 Sample stage

The orthogonal three axes stage should be used to adjust the measurement points of the DUT. The biaxial goniometer should be used to adjust the measurement direction (the zenith angle and azimuth angle) of the DUT. The positioning accuracy of these devices shall be enough to make the specified repeatability.

NOTE See Figure 2 and Figure 3.

4.3.2 Light absorber

The light absorber shall be an optical trap (Figure 1), an optical absorbing sheet or an optical absorbing plate. The reflection of the light absorber shall have a reflection factor as low as possible (less than 12 %) in all optical measurements including reflection, transmission and polarization. The light acceptance area of the light absorber shall be larger than the LMD's measurement spot whether the LMD is on the FLU's surface normal or at a slanted angle.



NOTE The optical trap comprises a black cone in black housing with an absorbing material that does not reflect any light ray incident on its surface.

Figure 1 – Example of light absorber (optical trap)

5 General measuring conditions

5.1 Standard conditions

Unless otherwise specified, all tests and measurements for a LED frontlight unit (Figure 2) shall be carried out after sufficient warm-up time for the illumination sources and DUT (see 5.3), under the standard environmental conditions as follows:

– temperature of 22 °C to 28 °C,
– relative humidity of 25 % to 85 %
– atmospheric pressure of 86 kPa to 106 kPa.

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

NOTE: See IEC 61747-30-1, IEC 61747-6-2, and IEC 62679-3-3.

5.2 Measurement setup

The DUT, LMD, power source, driving and control devices for FLU light sources and electrical measuring devices should be arranged as shown in Figure 2. The luminance on an FLU shall be (in normal state or inverted state) measured using an LMD. To avoid reflected light from the other side (opposite the measuring surface of the FLU under measurement), a light absorber shall be used. The measured luminance includes the emergent light (in normal state or inverted state) and the reflected light on the inner back surface of the FLU.

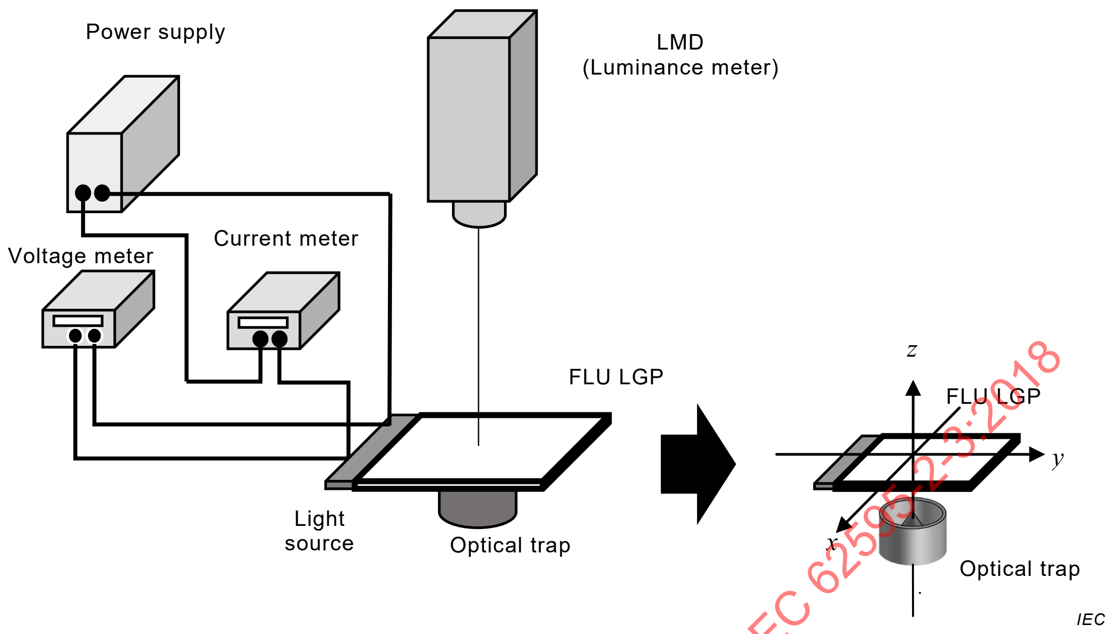


Figure 2 – Example of measurement setup for a LED FLU

5.3 Warm-up time

The measurement of the LED FLU shall be performed in the steady state of the LED's junction temperature as in IEC 62595-2-1.

6 Electrical measurement methods

6.1 Conditions

The FLU shall be placed in the measurement arrangement shown in Figure 2 and it shall be assured that the conditions given in Clause 5 (refer to IEC 62679-3-3 and IEC 61747-6-2) are fulfilled.

After applying the initial electrical driving conditions (i.e. analogue input voltage(s) or digital input signals) of the FLU and waiting during the warm-up time specified in 5.3 in order to reach the steady state, the electrical quantities of interest shall be measured.

6.2 Current

The measurement of input current should be performed under standard measurement conditions using the current meter shown in Figure 2.

6.3 Voltage

The measurement of input voltage should be performed under standard measurement conditions using the voltage meter shown in Figure 2.

6.4 Power consumption

The measurement of power consumption should be carried out under the standard measurement conditions given in Clause 5 (see IEC 62595-2-1), using a power meter.

7 Optical measurement methods

7.1 General

An FLU shall be evaluated as an illumination device as well as an imaging device. The illumination characteristic of the FLU as a transparent illumination device is partially similar to a BLU and as an imaging device similar to a reflective display device. Therefore under both the external (or bright room) and internal (or dark room) illuminations, measurement items are required for evaluation of the FLU. The reflection characteristic of the FLU under external illumination emerges from external surfaces and internal surfaces on and in the FLU in normal and inverted states. Since an FLU employs sub-micro or micro-features for reflecting the propagating light toward the reflective display, the imaging characteristic evaluation is also important when integrated with the reflective display.

7.2 Dark room conditions

7.2.1 General

The dark room conditions shall be compliant with IEC 61747-6-2 for liquid crystal display devices or IEC 62679-3-3 for electronic paper displays. In the case of other dark room conditions, these shall be reported.

7.2.2 Measurement items under the external lighting condition

The reflection from the front surface and back surface should be measured to clarify the amount of reflection that leads to optical noise in the FLU and image degradation in the integration with a reflective display. The evaluation should be performed by measuring the BRDF. In order to avoid reflection from an external object in the rear of the FLU, a light absorber should be used beneath the FLU to absorb external reflections.

Since the FLU device is transparent, the transmitted light is also of great concern. The BTDF on the back surface, in normal or inverted states, should be evaluated. The reflected light or the transmitted light may have been polarized under the bright room illumination. Therefore, the polarization characteristic (e.g. BRDF, or BTDF with polarization) should be measured in the same manner as for reflection and transmission. The bi-directional polarization distribution function (BPDF) is also required for evaluation of an external effect on the performance of the FLU.

7.2.3 Measurement items under the internal lighting condition

An FLU functions as an illuminating device when illuminated by the built-in light sources. The reflection or transmission of the FLU should be measured in a dark room on both sides of the FLU. The sub-micro or micro features have polarization characteristics that can affect a polarizer used as a reflective display. Therefore, the polarization characteristic of the FLU on both surfaces of the lit FLU should be evaluated. The BPDF should be measured on the normal and inverted states of the lit FLU.

Similar measurements as explained in 7.2.2 should be performed in dark room conditions. The lit FLU has a main illumination characteristic in the inverted-state. The spatial and angular illumination distribution characteristics should be measured on the surface of a lit FLU. However, the noise characteristic, the angular luminance or the spatial luminance and the uniformity characteristics should be measured in normal state on the FLU.

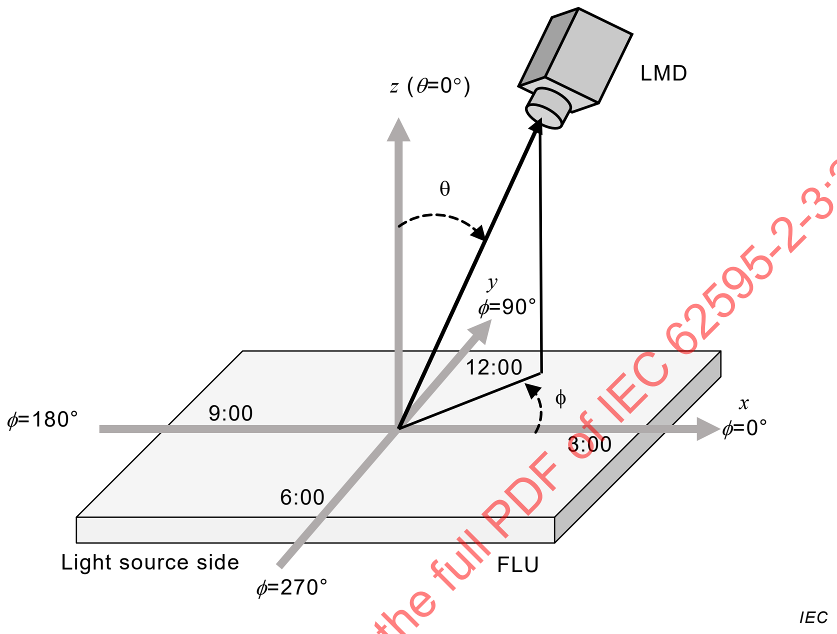
7.3 Conditions

The LED FLU to be measured should be placed in the measurement arrangement, and all the required conditions given in IEC 62595-2-1 shall be assured.

After applying the required initial electrical voltage and current as well as the driving conditions to the FLU, the transient state is measured. The device reaches the steady state after the required time specified in 5.3. The optical quantities such as $L_v(x_i, y_i, \phi_j, \theta_j)$, L_{vM},and L_{vm}, shall be measured at measurement points under the steady state.

To match the optical characteristics of the FLU (e.g. illumination cone) with the display panel, (e.g. reflective display accepting cone) the detailed measurements along the 3:00 to 9:00 axis (x-axis) and the 6:00 to 12:00 axis (y-axis) shall be measured. To evaluate more detailed characteristics of the FLU (see Figure 3), the measurements should be carried out at various angles between the DUT and LMD.

A polar coordinate system (θ, ϕ) with the zenith angle denoted by θ and the azimuth angle denoted by ϕ should be used for evaluation (see Figure 4).



NOTE The angular luminance uniformity measurement is performed along the x- and y-axes versus the zenith angle (θ) in a normal-state FLU or inverted-state FLU.

Figure 3 – Illustration of zenith angle θ and azimuth angle ϕ (normal-state FLU)

7.4 Luminance

7.4.1 General

The luminance shall be measured on the normal state and inverted state of the FLU.

7.4.2 Procedures

The luminance values, $L_v^{(B)}(x, y, \theta, \phi)$, on the illuminating surface, i.e., the inverted state, are for evaluating the uniformity. The luminance values, $L_v^{(F)}(x, y, \theta, \phi)$, on the non-illuminating surface should be evaluated as the optical noise. These values are used to evaluate the signal-to-noise ratio of the FLU. The rate of luminance values on both sides, $L_{vi}^{(B)}(x, y, 0, 0)/L_{vi}^{(F)}(x, y, 0, 0)$, denotes the optical signal-to-noise ratio (optical SNR) on the FLU in normal direction (see Figure 2 and Figure 3).

The procedure is as follows:

1) Set the DUT.
2) Adjust the LMD to the specified distance and viewing direction, according to angles θ and ϕ.
3) Supply the required current and voltage to the DUT.
4) Measure the DUT at position P_i to obtain the luminance $L_{vi}(x, y, \theta, \phi)$. In case of i = 0, the position implies the centre of the active area of the FLU.

5) Set the measurement position of the DUT (FLU in normal state or FLU in inverted state) on the light absorber.
6) Switch ON the DUT and measure the luminance at the point.
7) Shift the DUT to measure the next position and repeat steps 4) to 6).

NOTE 1 An LMD with a goniometric stage or a conoscopic system can be used.

NOTE 2 The applied optical trap can be a cylindrical type (Figure 1) that covers a signal measurement point or a black light absorber sheet.

NOTE 3 The measurement device can be used to measure the ALD, $L_V(x_i, y_i, \theta, \phi)$, luminance, $L_V(x_i, y_i, 0, 0)$, and the luminous flux, $\Phi_V(x_i, y_i)$.

NOTE 4 See Annex C.

7.5 Angular luminance distribution (ALD)

The ALD, L_{Vi} (x, y, θ, ϕ), should be measured at the predefined measuring points on the FLU. The ALD should be measured along ϕ = 0° to 180° and ϕ = 90° to 270°. The ALD can be measured along ϕ = (ϕ_c + 0°) to (ϕ_c + 180°) (ϕ_c = constant) for the purpose of evaluation. In case of Lambert distribution on the FLU, the invariant luminance cone should be granted at each point, since the cone variation modulates the viewing angle of the reflective display.

The ALD of a frontlight unit is evaluated in the polar coordinate system (Figure 4) where θ is the zenith angle (0°to 180°) and ϕ is the azimuth angle (0°to 360°).

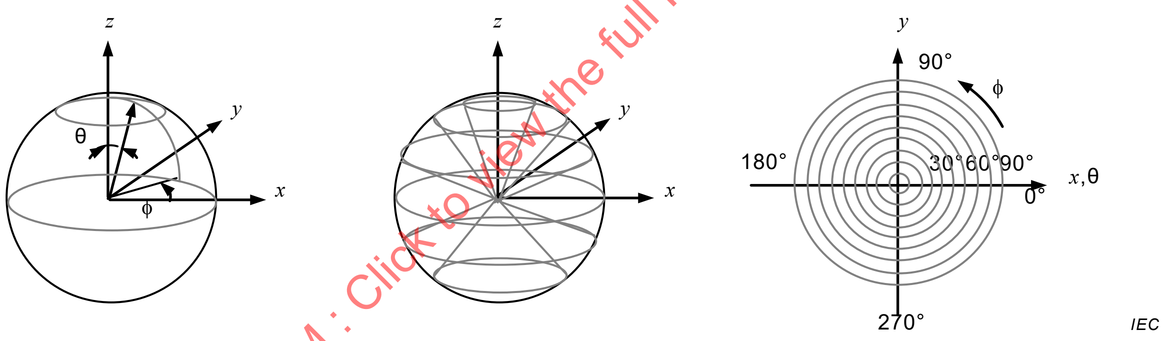


Figure 4 – Polar coordinate system for frontlight unit measurement

As explained above, the angular characteristics such as BTDF, BRDF, or BPDF should be measured and plotted in the polar coordinate system. A conoscopic system (an effective zenith angle range should be considered) or goniometric system with a manual correction factor of 1/cos(θ) shall be used for measurements. Instead of a goniometer, a built-in Fourier transform imaging optics conoscopic system with a built-in correction factor can be used for measurements.

7.6 Luminance uniformity or non-uniformity

Luminance uniformity, U, or luminance non-uniformity, NU, is a value that shows how uniform the luminance is over the surface of the active area of the normal-state FLU.

$$NU = 100 - U \tag{2}$$

The luminance uniformity or non-uniformity measurement is sensitive to the testing positions. Typical layouts of measurement points over the FLU surface are the same as in IEC 62595-2-1, IEC 61747-6-2 and IEC 62679-3-3.

A typical formula for calculating luminance non-uniformity, NU, and other formulae used widely in display industries can be found in IEC 62595-2-1.

7.7 Spectral power distribution

Spectral power distribution $S_{\mathrm{FLU}}(\lambda)$ shall be measured using a spectroradiometer or an equivalent optical instrument. The measuring procedures shall be in accordance with 7.3 and 7.4.

7.8 Chromaticity

CIE 1931 chromaticity coordinates (IEC 60050-845:1987, 845-03-28) x, y, z on the FLU surface shall be in accordance with IEC 62595-2-1 [11],[12].

7.9 Colour uniformity

Colour uniformity should be evaluated using CIE 1976 chromaticity (IEC 60050-845:1987, 845-03-53) differences ($\Delta u'v'$) between the centre and the other points on the FLU surface, using the formula defined in IEC 62595-2-1 [11],[12].

7.10 Angular luminance uniformity

The uniformity in the illumination cone of an FLU cone should be matched to the reflective characteristic of the display device in order to make a high quality display with a built-in FLU. The light cone should be directed to any direction depending on the reflective characteristic of the reflective display device.

Angular performance of the LED FLU directly affects the whole display performances. The luminance values at angles (θ, ϕ) = (0°, 0°), (θ, 0°), (θ, 90°), (θ, 180°) and (θ, 270°) in the polar coordinate system defined in 7.1 should be measured in the coordinate system of Figure 3. Measurement at additional angles shall be carried out if necessary. The above measurements can be carried out at each point of the inverted-state FLU shown in Figure 3 in order to obtain the angular luminance uniformity.

7.11 Angular colour uniformity

An angular colour uniformity (ACU) in the angular luminance distribution, i.e., $L_{\mathrm{vi}}(x, y, \theta, \phi, \Omega)$ of an FLU affects the display colour performance. The ACU is a criterion with which to evaluate the FLU. Arbitrary solid angles should be selected and evaluated in the same manner as the angular luminance uniformity given in 7.10. Colour uniformity should be in accordance with 7.9 to obtain the chromaticity differences within a predefined solid angle (Ω). In case of white (illuminated by pseudo-white LEDs) illumination of an FLU, the correlated colour temperature (CCT) in ACU should also be chosen as a criterion.

7.12 FLU polarization characteristic measurement

1) Set the FLU on a light absorber (optical trap) in a dark room (see Figure 2 and Figure 3).
2) Adjust the measuring point to the centre of the light absorber.
3) Switch on the FLU (internal illumination).
4) Set the FLU in normal or inverted state on the light absorber, below an angular optical measurement system shown in Annex C.
5) Measure the polarized optical intensity under three polarizers of 0°, 45°, and 90° at azimuth and zenith angles.
6) Using the measured polarized optical intensity of the three polarizers, calculate the degree of polarization at each zenith and azimuth angle (θ_{i}, ϕ_{i}) in a hemisphere centred at the FLU measurement point (see Annex E).

Figure 5 is an example of measured polarization on an FLU.

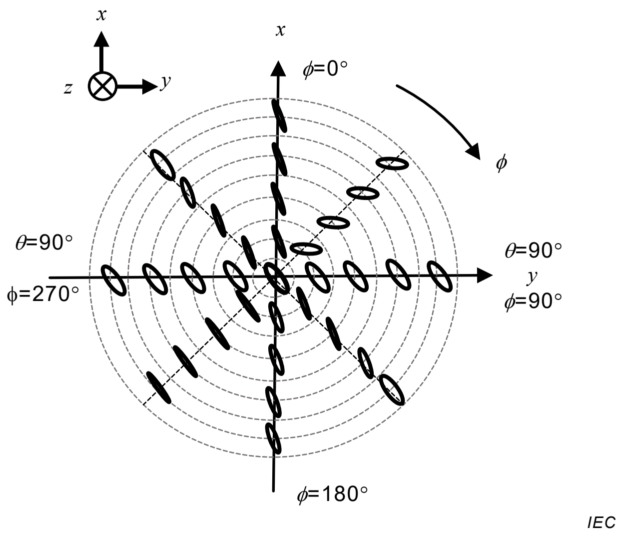


Figure 5 – Example of light polarizing characteristics of an FLU in inverted state

7.13 Normal- or inverted-state FLU characteristics

An FLU as a transparent medium has reflection properties on both surfaces. The measurement and evaluation of both surfaces of an FLU at OFF-state shall be performed in order to integrate with a reflective display. The characteristics of an FLU for illuminating a reflective display at ON-state shall be measured for coupling with the reflective display. The cosmetic quality, for example a flaw or scratch, and interference between the micro-reflectors and the reflective display, should be evaluated by using the optical transfer function evaluation chart (see Annex F).

7.14 Optical noise measuring

To measure the ALD of optical noise (undesired luminance), the luminance should be measured along the zenith angle in any azimuth angle. Since the noise is a 3D distribution, the measurement results shall be evaluated in any required direction. The signal measurement shall be performed in the same way. The signal-to-noise ratio can be defined in any solid angle (Ω).

NOTE See Annex G, Annex H and Annex I.

7.15 Cosmetic quality or perceptual visual quality

An FLU should be free from any optical defect. Defects such as scratches, flaws, or non-desirable reflection should not be present on either side or inside the LGP or FLU, since such defects affect the front-of-screen (FOS) performance. The visual inspection should be under an external illumination or a highly bright and omni-directional illumination.

The FLU with sub-micro or micro-structures shall be evaluated using the test-image charts. Since the FLU is not a display device, these charts should be printed on paper and used beneath a normal-state FLU. The white paper reflection factor (reflectance) should be more than 85 %. The black paper should have a reflectance of less than 12 %.

The contrast or optical transfer function (OTF) of the FLU should be evaluated using line pairs. In case of rotationally homogeneous illumination, black and white line pairs with different widths can be used in any azimuthal angle. However, if the FLU is a directional one, the OTF parallel and perpendicular to light source(s) is preferred. The following procedure is the measuring method for the OTF.

1) Set the FLU in normal state in contact with the lowest pitch (1 line pair/mm; lp/mm) chart shown in Figure F.1.
2) Switch ON the FLU.
3) Set the image sensor above the FLU.
4) Capture the electrical line signal of the black and white image transmitted through the FLU by the image sensor.
5) Measure the signal of the transmitted image in the perpendicular direction, i.e. the maximum (S_{max}) and the minimum (S_{min}) of the signal.
6) Use the maximum (S_{max}) and the minimum (S_{min}) in the following formula:

$$CR = \frac{S_{\text{max}} - S_{\text{min}}}{S_{\text{max}} + S_{\text{min}}} \tag{3}$$

7) Remove the chart.
8) Set the charts with higher spatial frequencies and calculate the OTF in the same manner.
9) Normalise the measured OTF of the charts (i.e. with black and white stripes) to the C_{R} value obtained by using only white and only black charts.

The measurement can be repeated at any rotation angle (ϕ) of the charts with respect to FLU positioning or housing.

NOTE 1 The OTF of the FLU's integrated reflective display is the product of the OTFs of the display and the FLU.

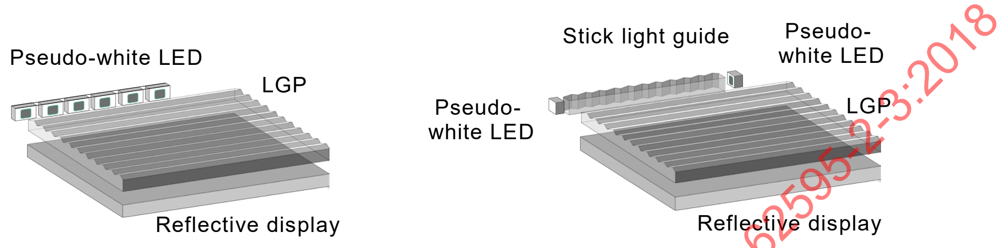
NOTE 2 An OTF similar to the graph shown in Figure F.2 is obtained.

NOTE 3 See Annex F.

Annex A
(informative)

Optical structure of an FLU

As shown in Figure A.1, light rays are inserted into the LGP from one of its side facets (face to LEDs). The rays are reflected on the inner surfaces of the micro-structures (on the front surface of the LGP) due to total internal reflection. The rays emerge from the illuminating surface (see Figure B.1). In case of indirect driving of the FLU, the LEDs illuminate a featured stick-light guide (SLG), and the SLG directs the rays toward the LGP/LGF.



(a) LEDs directly illuminate the micro-structured LGP

(b) LEDs illuminate the stick-light guide that couples light to the micro-structured LGP

Figure A.1 – Direct edge-lit FLU and indirect edge-lit FLU

Annex B
(informative)

Normal-state FLU and inverted-state FLU

A normal-state FLU is defined as an FLU with an illuminating surface toward a reflective display (see 3.1.2 and Figure B.1). An inverted-state FLU is defined as an FLU with an illuminating surface toward a viewer (see 3.1.3 and Figure B.2).

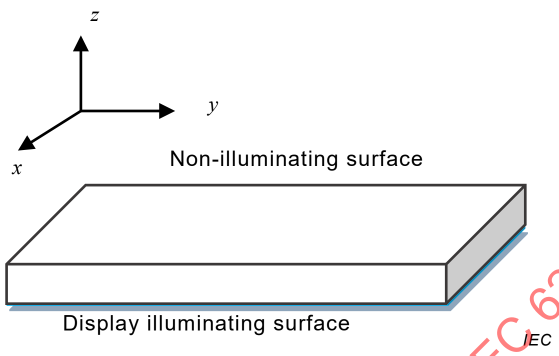


Figure B.1 – Normal-state FLU

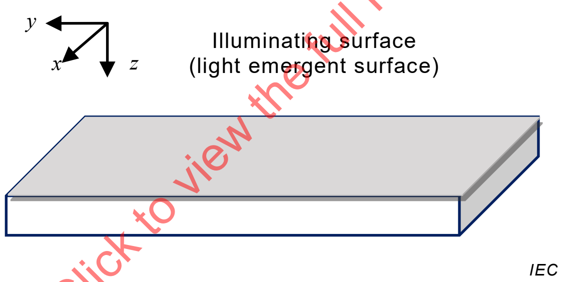


Figure B.2 – Inverted-state FLU

Annex C
(informative)

Angular measurement system

There are two kinds of optical systems for angular optical measurement. One is the goniometric system (Figure C.1) and the other is the Fourier optics (or conoscopic) system (Figure C.2).

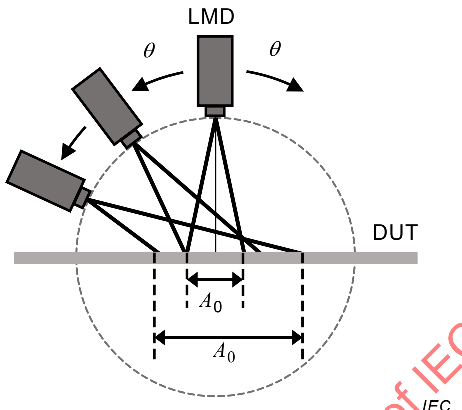


Figure C.1 –Standard goniometric system

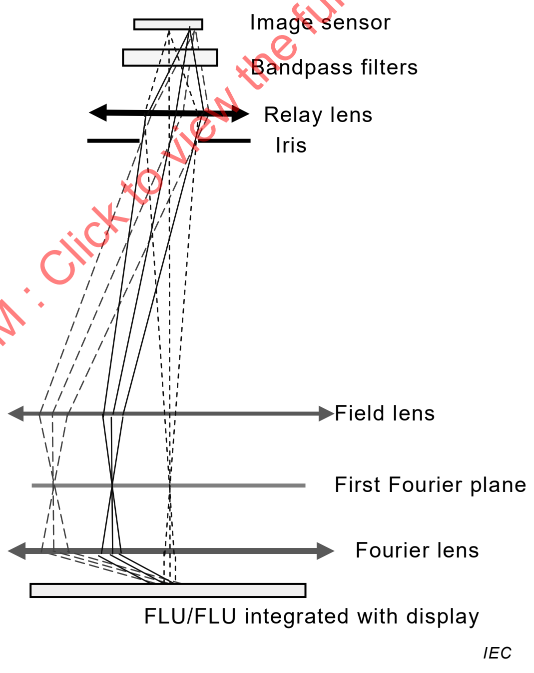


Figure C.2 – Conoscopic system

Annex D
(informative)

Measurement parameters for BRDF and BTDF

D.1 BRDF

An optical measurement system for the BRDF is shown in Figure D.1. The reflected light on the FLU in case of low and high reflectance is shown in Figure D.2.

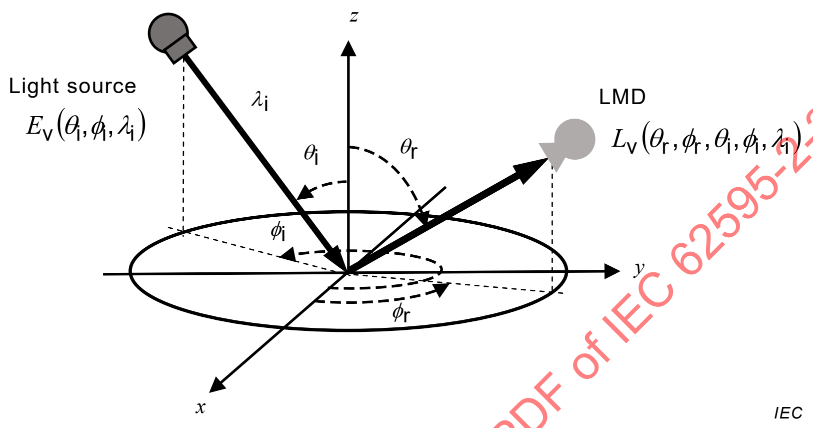
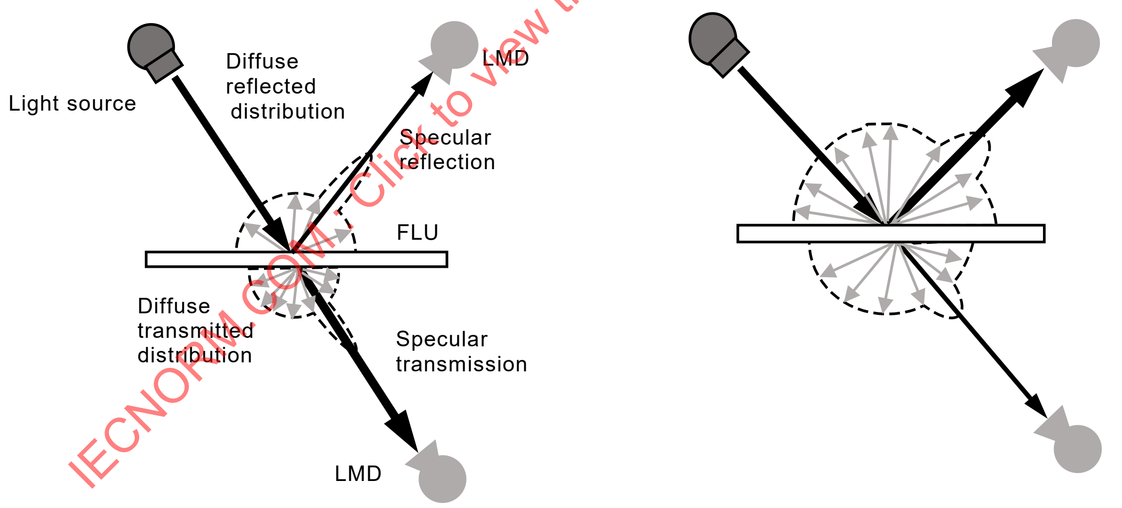


Figure D.1 – System for measuring the BRDF



(a) FLU with low front surface reflection (partially matte surface)

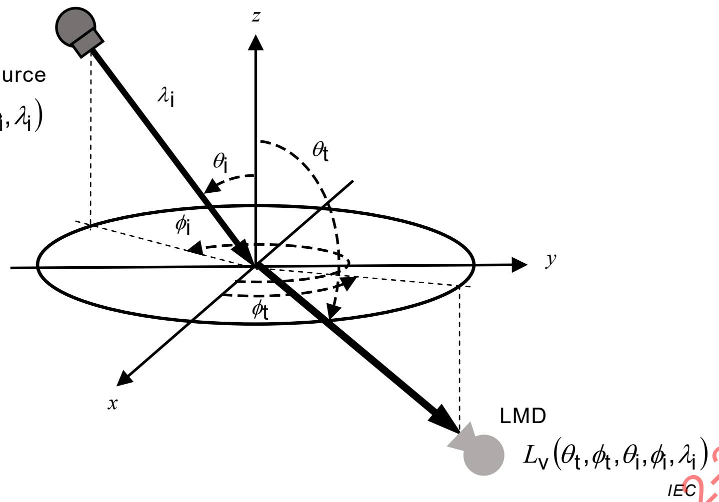
(b) FLU with high front surface reflection (glossy surface)

IEC

Figure D.2 – Measuring the BRDF of an LGP for an FLU

D.2 BTDF

An optical measurement system for the BTDF is shown in Figure D.3. The transmitted light through the FLU in case of low and high transmittance is shown in Figure D.2.



NOTE The geometrical shape of an LGP for an FLU can be a slab shape, a wedge shape, or an arbitrary shape.

Figure D.3 – System for measuring the BTDF

Annex E
(informative)

Determining the polarization state of reflected light on the front surface of an FLU or transmitted light through the FLU

Three polarizing filters (0, π/4, π/2) are used to measure I_0, $I_{\pi/4}$, $I_{\pi/2}$ to calculate the polarization ellipse at the given point (measuring point, P_i) for the given zenith (θ_i) and azimuth (ϕ_i) angles.

The measured values of I_0, $I_{\pi/4}$, $I_{\pi/2}$ using three polarizers give the polarization state at the given point for the given zenith and azimuth angles (see Figure E.1). The manual calculation or built-in calculator can give the polarization state.

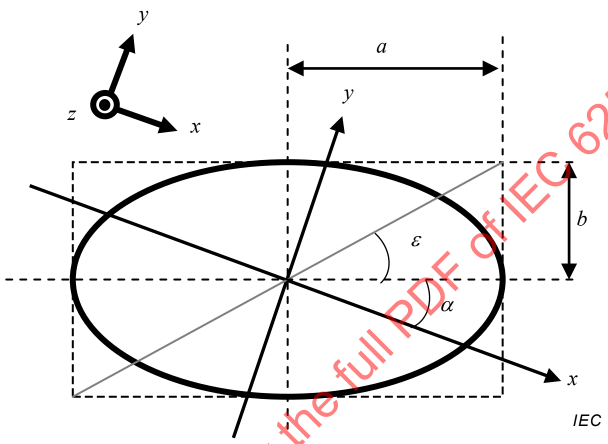


Figure E.1 – Geometry of a reflected or transmitted polarized light

$$I_0 = A_0 \frac{1+\cos 2\varepsilon \times \cos 2\alpha}{2} \tag{E.1}$$

$$I_{\pi/4} = A_0 \frac{1+\cos 2\varepsilon \times \sin 2\alpha}{2} \tag{E.2}$$

$$I_{\pi/2} = A_0 \frac{1-\cos 2\varepsilon \times \cos 2\alpha}{2} \tag{E.3}$$

$$\alpha = \frac{1}{2}\tan^{-1}\left(\frac{2I_{\pi/4} - I_0 - I_{\pi/2}}{I_0 - I_{\pi/2}}\right)$$
$$-\frac{\pi}{2} \le \alpha \le \frac{\pi}{2} \tag{E.4}$$

$$\varepsilon = \frac{1}{2}\cos^{-1}\left(\frac{I_0 - I_{\pi/2}}{\cos 2\alpha \times \left(I_0 + I_{\pi/2}\right)}\right)$$
$$0 \le \varepsilon \le \frac{\pi}{4} \tag{E.5}$$
$$\tan\varepsilon = \frac{b}{a}$$

Annex F
(informative)

Optical transfer function (OTF) of an FLU

F.1 Optical transfer function evaluation chart

Black and white line pairs (see Figure F.1) with different periodicities printed on photographic paper are used beneath the FLU instead of the reflective display shown in Figure A.1 to measure the transmitted light intensity versus the spatial frequencies (f_s = 1/P) or the inverse of the pitch of the line pairs [9]. The intensity versus the spatial frequency is the optical transfer function of the FLU that shows the image transmission of the FLU.

NOTE Printed charts are used instead of reflective displays in the x-direction (parallel to light sources) and y-direction (perpendicular to light sources) as in Figure A.1. The black and white pair-lines have a width of W for each and P as pitch of the line-pairs (P = 2W).

Figure F.1 – Printed charts on photographic paper for measuring the OTF of the FLU

F.2 Example of optical transfer function

The maximum and minimum signal measured by the LMD (image sensor) for each chart is used to calculate the OTF of that chart of spatial frequency. The measured results are normalised to that of the white and black chart levels (i.e. taken as zero spatial frequency). The resulting normalised values are plotted in a graph as shown in Figure F.2. The detected signal level approaches zero and as a result the OTF falls to zero at fifty line pairs per millimeter (e.g. in this document, line pairs are fifty line pairs per millimeter and black and white line widths are 10 µm). The size of a single micro-structure on the FLU is assumed to be 25 µm (spatial frequency of forty line pairs per millimeter) that can be compared with the chart-line width and its effect on the FLU resolution. The measuring device covers the measured spatial frequency, i.e., at least two pixels per line width (refer to 4.2.4).