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Organic light emitting diode (OLED) displays –
Part 6-3: Measuring methods of image quality

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ORGANIC LIGHT EMITTING DIODE (OLED) DISPLAYS –

Part 6-3: Measuring methods of image quality

FOREWORD

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International Standard IEC 62341-6-3 has been prepared by IEC technical committee 110: Electronic display devices.

This second edition cancels and replaces the first edition published in 2012. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) the measuring method for viewing angle has been modified. Measurement of the half luminance angle, gamma distortion, and directional colour variation is added;
b) measurement method for colour characteristics is added;
c) additional explanation is added in static image resolution clause;
d) moving image resolution clause has been moved to Annex B.

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

FDIS	Report on voting
110/901/FDIS	110/923/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 the parts in the IEC 62341 series, under the general title *Organic light emitting diode (OLED) displays*, 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- withdrawn,
- replaced by a revised edition, or
- amended.

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

The contents of the corrigendum of October 2019 have been included in this copy.

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ORGANIC LIGHT EMITTING DIODE (OLED) DISPLAYS –

Part 6-3: Measuring methods of image quality

1 Scope

This part of IEC 62341 specifies the standard measurement conditions and measuring methods for determining the image quality of organic light emitting diode (OLED) display panels and modules.

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 62341-1-2:2014, *Organic light emitting diode (OLED) displays – Part 1-2: Terminology and letter symbols*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62341-1-2 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

3.1.1
average picture level
APL
average loading percentage of display sub-pixels based on input signal levels

3.1.2
static image resolution
maximum number of lines that can be adequately distinguished horizontally and vertically across the screen for static image signal inputs

Note 1 to entry: The unit of resolution is line, but pixel is also available as the unit of resolution.

3.1.3
colour fidelity
ability to reproduce the intended colour

3.1.4
colour desaturation
difference in chromaticity coordinates between solid colour and grilled pattern caused by image sharpening algorithm

3.1.5
directional gamma distortion
ratio of gamma differences between the perpendicular and other viewing direction

3.1.6
colour scale
range of luminance levels between maximum luminance and minimum luminance for the primary colour

3.2 Abbreviated terms

APL	average picture level
CCD	charge coupled device
CFF	critical flicker frequency
CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
CIELAB	CIE 1976 (L*a*b*) colour space
DUT	device under test
HVS	human visual system
LED	light emitting diode
LMD	light measuring device
MPPR	moving picture perceptual resolution
OLED	organic light emitting diode
PSF	point spread function
RGB	red, green, blue
SDF	stray light distribution function
SLSF	spectral line spread function

4 Standard measuring equipment and coordinate system

4.1 Light measuring device

The system configuration and/or operating conditions of the measuring equipment shall comply with the structure specified in each item.

To ensure reliable measurements, the following requirements apply to the light measuring equipment:

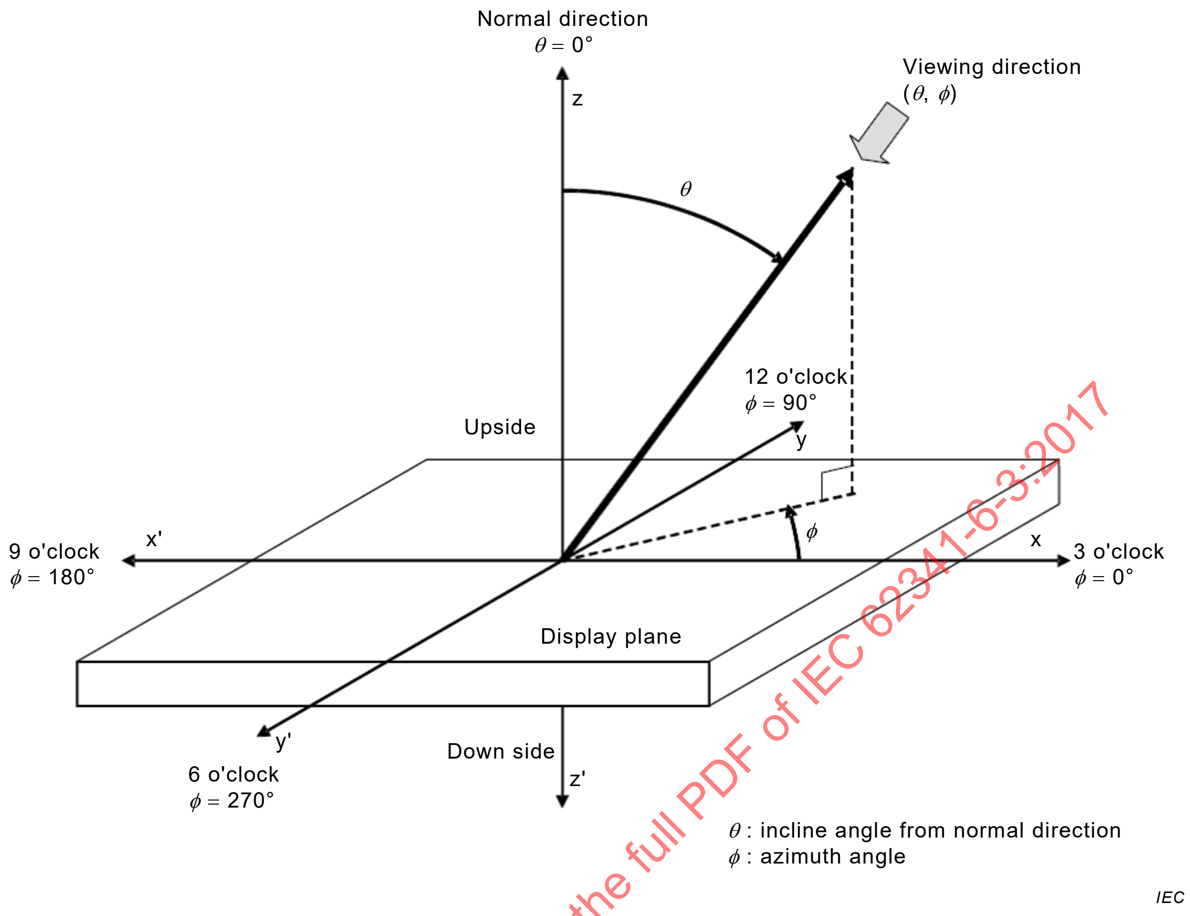
1) Luminance meter [1][1]: the instrument's spectral responsivity shall comply with the CIE photonic luminous efficiency function with a CIE-f1' value no greater than 3 % [2]; the relative luminance uncertainty of measured luminance (relative to CIE Illuminant A source) shall not be greater than 4 % for luminance values over 0,1 cd/m^2 and not greater than 10 % for luminance values 0,1 cd/m^2 and below.
2) Colorimeter: the detector's spectral responsivity shall comply with the colour matching functions for the CIE 1931 standard colorimetric observer with a colorimetric accuracy of 0,002 for the CIE chromaticity coordinates x and y (relative to CIE Illuminant A source) for luminance values over 1 cd/m^2. A correction factor can be used for the required accuracy by application of a standard source with similar spectral distribution as the display to be measured.

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

3) Spectroradiometer: the wavelength range shall be at least from 380 nm to 780 nm, and the wavelength scale accuracy shall be less than 1 nm. The relative luminance uncertainty of measured luminance (relative to CIE Illuminant A source) shall not be greater than 4 % for luminance values over 0,1 cd/m^2 and not greater than 10 % for luminance values 0,1 cd/m^2 and below. Note that errors from spectral stray light within a spectroradiometer can be significant and shall be corrected. A simple matrix method may be used to correct the stray light errors, by which stray light errors can be reduced by one to two orders of magnitudes. Details of this correction method are discussed in [3].
4) Goniophotometric mechanism: the DUT or LMD can be driven rotating around a horizontal axis and vertical axis; angle accuracy shall be better than 0,5°.
5) Fast-response photometer: the linearity shall be better than 0,5 % and the frequency response higher than 1 kHz.

4.2 Viewing direction coordinate system

The viewing direction is the direction in which the observer looks at the spot of interest on the DUT (see also IEC 62341-1-2:2014, Figure A.2). During the measurement, the LMD replaces the observer, looking from the same direction at a specified spot (i.e. measuring spot, measurement field) on the DUT. The viewing direction is conveniently defined by two angles: the angle of inclination θ (related to the surface normal of the DUT) and the angle of rotation ϕ (also called azimuth angle) as illustrated in Figure 1. The azimuth angle is related to the directions on a watch-dial as follows: ϕ = 0° is referred to as the 3-o'clock direction ("right"), ϕ = 90 ° as the 12-o'clock direction ("top"), ϕ = 180° as the 9-o'clock direction ("left") and ϕ = 270 ° as the 6-o'clock direction ("bottom").



Key

3 o'clock: right edge of the screen as seen from the perspective of the user

6 o'clock: bottom edge of the screen as seen from the perspective of the user

9 o'clock: left edge of the screen as seen from the perspective of the user

12 o'clock: top edge of the screen as seen from the perspective of the user

NOTE This coordination is defined by the angle of inclination and the angle of rotation (azimuth angle) in a polar coordinate system.

Figure 1 – Representation of the viewing direction

4.3 Standard measuring environmental conditions

Measurements shall be carried out under the standard environmental conditions:

- temperature: 25 °C ± 3 °C,
- relative humidity: 25 % RH to 85 % RH,
- atmospheric pressure: 86 kPa to 106 kPa.

When different environmental conditions are used, they shall be noted in the measurement report.

4.4 Power supply

The power supply for driving the DUT shall be adjusted to the rated voltage ± 0,5 %. In addition, the frequency of the power supply shall provide the rated frequency ± 0,2 %.

4.5 Warm-up time

Measurements shall be carried out after sufficient warm-up. Warm-up time is defined as the time elapsed from when the supply source is switched on, and a 100 % grey level of input signal is applied to the DUT, until repeated measurements of the display show a variation in luminance of no more than 2 % per minute and 5 % per hour.

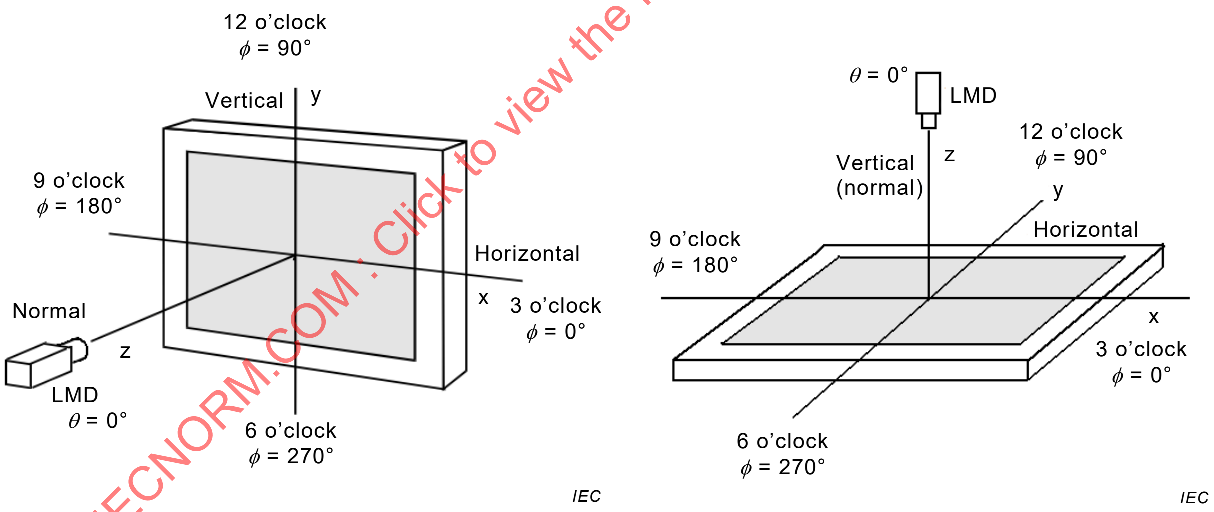
4.6 Standard measuring dark-room conditions

The luminance contribution from the background illumination reflected off the test display shall be < 0,01 cd/m^2. If these conditions are not satisfied, then background subtraction is required and it shall be noted in the measurement report. In addition, if the sensitivity of the LMD is inadequate to measure these low levels, then the lower limit of the LMD shall be noted in the measurement report.

4.7 Standard set-up conditions

By default, the display shall be installed in the vertical position (Figure 2a)), but the horizontal alternative (Figure 2b)) is also allowed. When the latter alternative is used, it shall be noted in the measurement report.

Luminance, contrast and chromaticity of the white field and other relevant parameters of the displays have to be adjusted to nominal status in the detailed specification and they shall be noted in the measurement report. When there is no level specified, the maximum contrast and/or luminance level shall be used. These adjustments shall be held constant for all measurements, unless noted otherwise in the measurement report. Additional conditions are specified separately for each measuring method.



a) **Primary installation** b) **Alternative installation**

Figure 2 – DUT installation conditions

5 Measuring methods

5.1 Measuring methods for spatial image quality

5.1.1 Viewing angle

5.1.1.1 Purpose

The purpose of this method is to measure the viewing angle of an OLED display module in the horizontal (ϕ = 0˚, ϕ = 180˚) and vertical (ϕ = 90˚, ϕ = 270) viewing direction.

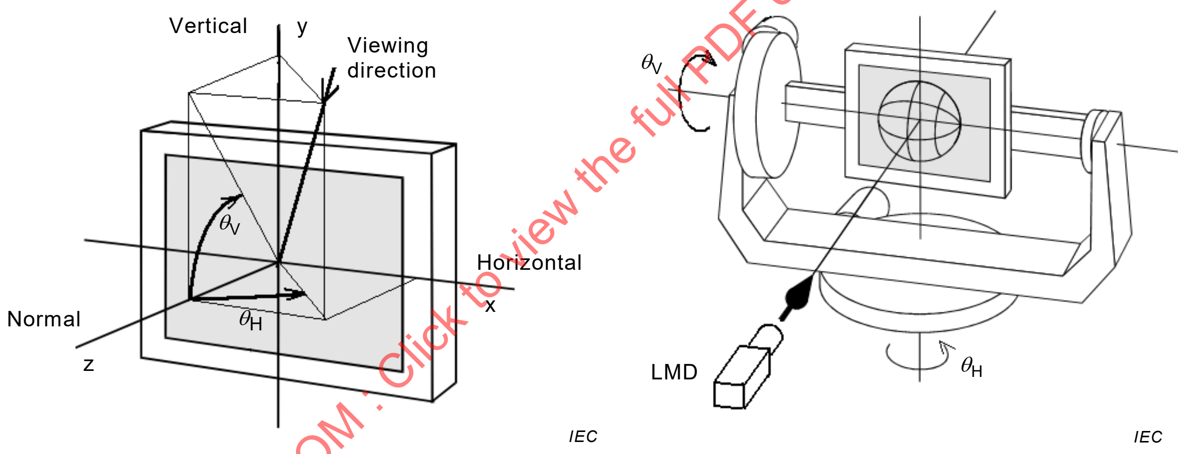
5.1.1.2 Measuring conditions

Standard measuring is implemented under standard dark-room and set-up conditions.

5.1.1.3 Set-up

For this measurement, the LMD and DUT shall be set up as follows:

1) Apparatus: an LMD to measure luminance and chromaticity of the DUT; a driving power source; a driving signal equipment; a geometric mechanism illustrated in Figure 3.
2) Mount the display and LMD in a mechanical system that allows the display to be measured along its vertical and horizontal planes, which lie normal to the display surface. Figure 3 illustrates the geometry to be used in this measurement. The angle relative to the display normal in the horizontal plane, the 3 o'clock and 9 o'clock direction, is expressed as θ_H, and the angle in the vertical plane, the 6 o'clock and 12 o'clock direction, by θ_V. Either the display can be tilted to scan both planes, or the LMD can be moved within these planes. During the measuring procedure, the LMD shall be directed at the same field of measurement for all angles of inclination. In either case, the centre of the measurement field shall remain at the same location on the DUT surface for all angles of inclination. The angular positioning of the display in the goniophotometric system shall be accurate to ±0,5°, and the measuring range shall be implemented from -90° to +90° both in the vertical and horizontal planes.



a) Geometric structure of display to be measured

b) Geometric system

Figure 3 – Conceptual geometry used for measuring the viewing angle range

3) Align the LMD perpendicular to the display surface (θ = 0, ϕ = 0), and position it to the centre of the display.

5.1.1.4 Measurement of the half luminance angle

The measurement shall be as follows:

1) Apply a 4 % window size white screen with a 100 % signal level (R = G = B = 255 for an 8-bit input signal) to the DUT as shown in Figure 4.
2) Measure the centre luminance (L_0) perpendicular to the display surface (θ = 0°, ϕ = 0°). The measurement area shall cover at least 500 pixels, or demonstrate equivalent results with fewer sampled pixels.
3) Take luminance ($L_{0,\phi}$) measurements as the LMD steps through the various angles in the horizontal (ϕ = 0°, ϕ = 180°) and vertical (ϕ = 90°, ϕ = 270°) viewing planes. The measurement area should not expand past the 4 % window at large viewing directions.

4) Record the change in luminance from the perpendicular direction. The luminance change is defined in terms of the luminance ratio:

$$LR_{\theta,\varphi} = \frac{L_{\theta,\varphi}}{L_0} \qquad (1)$$

The half luminance angle can be defined as an angle when the luminance ratio (LR), calculated using Formula (1), equals 50 %.

5) Determine the half luminance angles in each of the four viewing directions (ϕ = 0°, ϕ = 180°, ϕ = 90°, ϕ = 270°).

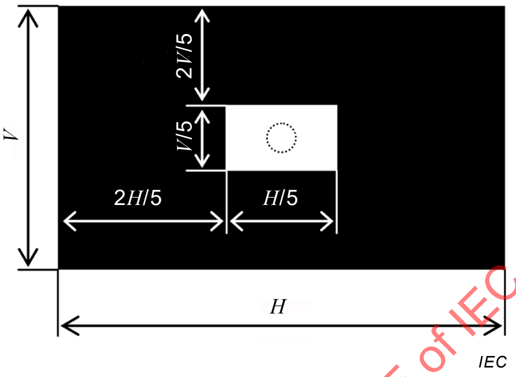


Figure 4 – 4 % window pattern for half luminance angle

NOTE Other measurement systems, such as conoscopic instruments, can also be used for the viewing angle range measurement, if equivalent results can be demonstrated.

5.1.1.5 Measurement of colour difference

The measurement method shall be as follows:

1) Apply a 4 % window size ‘white’, ‘red’, ‘green’, and ‘blue’ screen with a 100 % signal level (R = G = B = 255 for ‘white’; R = 255, G = B = 0 for ‘red’; G = 255, R = B = 0 for ‘green’; B = 255, R = G = 0 for ‘blue’) to the DUT.
2) Measure the centre CIE 1976 chromaticity coordinates (u'_0, v'_0) perpendicular to the display surface (θ = 0°, ϕ = 0°). The measurement area shall cover at least 500 pixels, or demonstrate equivalent results with fewer sampled pixels.
3) Take chromaticity coordinate values as the LMD steps through the various angles in the horizontal (ϕ = 0°, ϕ = 180°) and vertical (ϕ = 90, ϕ = 270°) viewing planes.
4) Record the change in chromaticity coordinates from the perpendicular direction. Colour shifts with viewing angle are to be determined by a value from the colour difference formula using the CIE 1976 uniform chromaticity scale. Furthermore any advanced colour difference model such as CIE 94 and CIE 2000 can be used for this measurement.

$$\Delta u'v'_{\theta,\varphi} = \sqrt{(u'_0 - u'_{\theta,\varphi})^2 + (v'_0 - v'_{\theta,\varphi})^2} \qquad (2)$$

$$\Delta E^*_{94} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*_{ab}}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*_{ab}}{k_H S_H}\right)^2} \qquad (3)$$

where

$$k_L = k_C = k_H = 1,\ \ S_L = 1,\ \ S_C = 1 + 0{,}045\sqrt{a_0^{*2} + b_0^{*2}},\ \ S_H = 1 + 0{,}015\sqrt{a_0^{*2} + b_0^{*2}}$$

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}$$

and where

$$k_L = k_C = k_H = 1,\ \ S_L = 1 + \frac{0{,}015((L_0^* + L_{\theta,\varphi}^*)/2 - 50)^2}{\sqrt{20 + ((L_0^* + L_{\theta,\varphi}^*)/2 - 50)^2}}$$

$$T = 1 - 0{,}17\cos(H' - 30^\circ) + 0{,}24\cos(2H') + 0{,}32\cos(3H' + 6^\circ) - 0{,}20\cos(4H' - 63^\circ)$$

$$R_T = -2\sqrt{\frac{C'^7}{C'^7 + 25^7}}\sin\left[60^\circ \cdot \exp\left(-\left[\frac{H' - 275^\circ}{25^\circ}\right]^2\right)\right] \tag{4}$$

5) Determine the viewing angles in each of the four viewing directions (ϕ= 0°, ϕ=180°, ϕ=90°, ϕ=270°) using specified chromaticity and colour difference values.

NOTE Other measurement systems, such as conoscopic instruments, can also be used for the viewing angle range measurement, if equivalent results can be demonstrated.

5.1.1.6 Measurement of gamma distortion from viewing directions

The measurement method shall be as follows:

a) Apply the required input signal(s) using using either the 9- or 33-grey-level APL fixed pattern to the DUT as shown in Figure 5.

b) Measure the centre luminance (L_0) for specified grey levels perpendicular to the display surface (θ = 0°, ϕ = 0°). The measurement area shall cover at least 500 pixels, or demonstrate equivalent results with fewer sampled pixels.

c) Take luminance measurements ($L_{\theta,\phi}$) of each specified grey level, as the LMD steps through the various angles in the horizontal (ϕ = 0°, ϕ = 180°) and vertical (ϕ = 90°, ϕ = 270°) viewing planes.

d) Calculate each gamma values from the measured directions.

   1) For each luminance level j above black (j > 1) determine the net luminance as the luminance increase over black,

$$\Delta L_j = L_j - L_K,\quad j = 2,3,\ldots,M, \tag{5}$$

   where L_K = L_1 = black, and M = 9 or 33 depending on the APL fixed pattern used in Figure 5.

   2) For each level j > 1,

$$\Delta V_j = V_j - V_1, \quad j = 2,3,...,M, \tag{6}$$

where V_j is the grey level.

3) Calculate $\log(\Delta L_j)$ for each grey pattern (j > 1).

4) Calculate $\log(\Delta V_j)$ for each grey level (j > 1).

5) Create a log-log plot between the log of the net luminance and the log of the net grey level differences (or signal level differences).

6) Perform a linear regression of $\log(\Delta L_j)$ versus $\log(\Delta V_j)$ for j = 2,3,…,M, and record the correlation coefficient (see Figure 6).

e) Determine the gamma distortion values using Formula (7) for angles in the vertical and horizontal planes (ϕ = 0°, ϕ = 180°, ϕ = 90°, ϕ = 270°).

$$G_{DR}(\%) = \frac{|\gamma - \gamma_i|}{\gamma} \times 100(\%) \tag{7}$$

where γ is the reference gamma value which is the gamma value in the perpendicular direction and γ_i are the gamma values measured from the different directional angles. The directional gamma distortion ratio is the maximum of this set of values.

f) Report the measured data. Table 1 shows an example of the results.

a) 9-grey-level APL fixed pattern

b) 33-grey-level APL fixed pattern (33 grey levels: 0, 7, 15, 23, 31, 39, 47, 55, 63, 71, 79, 87, 95, 103, 111, 119, 127, 135, 143, 151, 159, 167, 175, 183, 191, 199, 207, 215, 223, 231, 239, 247, 255)

Figure 5 – Test pattern for gamma measurement

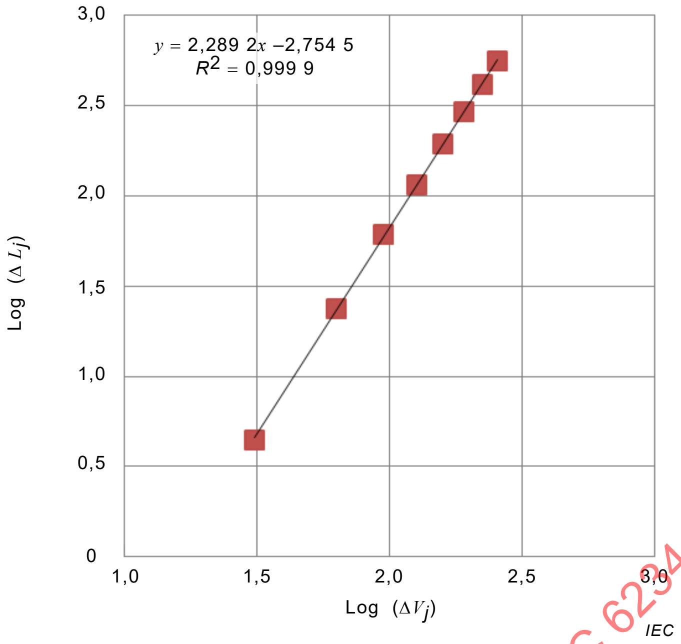


Figure 6 – Example of linear regression of log(ΔL_i) versus log(ΔV_j) at normal direction (0°)

Table 1 – Working example for gamma distortion from viewing direction

Reporting – Sample data						
Grey-scale luminance and gamma values at various angles						
Level designation	**Grey level,** V_j	**Luminance values from different angles** $L(\theta,\Phi)$				
		$L(0,0)$	L (-20, 180)	L (20, 0)	L (20, 90)	L (-20, 270)
White (9)	255	555,7	181,2	180,3	160,8	164,7
Level 8	223	415,5	131,9	133,8	117,6	125.3
Level 7	191	293,6	102,7	105,8	93,9	101,3
Level 6	159	194,9	78,3	82,2	73.6	80
Level 5	127	115,1	54,7	58,7	53,8	58,2
Level 4	95	60,83	37,24	40,23	38,12	40,83
Level 3	63	23,53	22,47	24,14	24	25,06
Level 2	31	4,488	8,75	9,535	9,918	10,03
Black (1)	0	0,031	0,058	0,056	0,073	0,067
Gammas:		2,29	1,4	1,36	1,28	1,30
g_i (%)			39,86	40,61	44,1	43,23
$g_{DR} = \max(g_i)$ (%)			43,2			

5.1.1.7 Measurement of directional gamut variation

The measurement method shall be as follows:

1) Apply a 4 % window size ‘red’, ‘green’, and ‘blue’ screen with a 100 % signal level (R = 255, G = B = 0 for ‘red’; G = 255, R = B = 0 for ‘green’; and B = 255, R = G = 0 for ‘blue’) to the DUT.

2) Measure the centre chromaticity coordinates (u'_0, v'_0) perpendicular to the display surface (θ = 0°, ϕ = 0°). The measurement area shall cover at least 500 pixels, or demonstrate equivalent results with fewer sampled pixels.
3) Take chromaticity coordinate values as the LMD steps through the various angles in the horizontal (ϕ = 0°, ϕ = 180°) and vertical (ϕ = 90°, ϕ = 270°) viewing planes.
4) Calculate the colour gamut area, A, using Formula (8):

$$A = \frac{\left|(u'_R - u'_B)(v'_G - v'_B) - (u'_G - u'_B)(v'_R - v'_B)\right|}{2} \quad (8)$$

5) Calculate the colour reproduction range, S, using Formula (9). The colour reproduction range is defined as the percentage of the colour gamut area to the reference area. Reference areas, A_{ref}, are presented in Table 2. The colour reproduction range is reported with the reference area.

$$S = \frac{A}{A_{ref}} \times 100 \quad (9)$$

Table 2 – Reference areas for the colour reproduction range

		u'	v'	$A_{ref}(u'v')$
NTSC	R	0,4769	0,5285	0,0744
	G	0,0757	0,5757	
	B	0,1522	0,1957	
ITU BT.709 (sRGB)	R	0,4507	0,5229	0,0649
	G	0,1250	0,5625	
	B	0,1754	0,1579	
Adobe RGB[2]	R	0,4414	0,5276	0,0740
	G	0,0757	0,5757	
	B	0,1754	0,1579	

6) Determine the inclination angles (θ) in each of the four viewing directions (ϕ = 0°, ϕ = 180°, ϕ = 90°, ϕ = 270°).
7) Calculate the colour gamut variation ratio, R, using Formula (10).

$$R_j = \frac{S_j}{S_{max}} \times 100 \quad (10)$$

where S_j is the colour reproduction range of the colour scale j and S_{max} is the colour reproduction range of the maximum colour scale.

NOTE Other measurement systems, such as conoscopic instruments, can also be used for the viewing angle range measurement, if equivalent results can be demonstrated.

2 Adobe RGB is the trade name of a product supplied by Adobe Systems Incorporated.

This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

5.1.2 Colour characteristics

5.1.2.1 Purpose

The purpose of this method is to measure the colour characteristics of an OLED display in the perpendicular viewing direction.

5.1.2.2 Measuring conditions

Standard measuring is implemented under standard dark-room and set-up conditions.

5.1.2.3 Basic set-up for colour performance

The DUT and LMD shall be set up as follows:

1) Apparatus: an LMD to measure luminance and chromaticity of the DUT; a driving power source; a driving signal equipment; a geometric mechanism illustrated in Figure 3.
2) Mount the display and LMD in a mechanical system that allows the display to be measured, normal to the display surface.
3) Input a signal to determine the CIE 1976 chromaticity coordinates (u', v'), and generate full 'red', 'green', and 'blue' screen with a 100 % signal level (R = 255, G = B = 0 for 'red'; G = 255, R = B = 0 for 'green'; and B = 255, R = G = 0 for 'blue') on the display.
4) Align the LMD perpendicular to the display surface (θ = 0, ϕ = 0), and position it to the centre of the display.

5.1.2.4 Measurement of colour fidelity

5.1.2.4.1 Purpose

The purpose of this method is to measure the colour fidelity for the primary and secondary colours of an OLED display. Generally, colour difference metrics are used for evaluation of the primary and secondary colours of a display. However, with recent standardization of a wide colour gamut, new display modules which have a wide colour gamut are being developed as well. Although a wide colour gamut display can produce vivid images, it would result in unnatural colours. Colour fidelity metrics based on hue difference can accurately predict the visual difference or unnatural feeling of images on a display module [22].

5.1.2.4.2 Set-up

For this measurement, the DUT shall be set up as follows:

a) Both a spectroradiometer and colorimeter can be used to measure the luminance and chromaticity of the DUT under the standard set-up conditions as shown in Figure 2a). The LMD shall be aligned perpendicularly to the centre of the DUT. A digital video signal generator is used to input the signal to be measured.
b) Input signal to the DUT:
    1) For the measurement, primary and secondary colours, that is, R, G, B, C, M, Y colour input signals are used. The signal level for each colour pattern is 255 for an 8-bit input signal.
    2) A 4 % sized single window pattern as shown in Figure 7 is used to measure the luminance and CIE chromaticity coordinates. The signal level for background is zero.

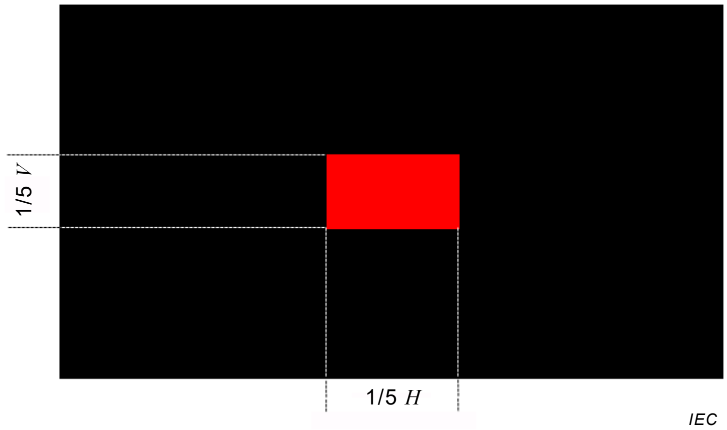


Figure 7 – 4 % window pattern for measuring the 'red' primary colour

Figure 8 – 4 % window pattern for each *G*, *B*, *C*, *M*, *Y* colour

5.1.2.4.3 Measurement method

For this measurement, the method shall be as follows:

1) Set the input signal to a maximum level for the red primary colour (R = 255).
2) Measure the luminance and CIE 1931 chromaticity value (CIE xyY) of the colour pattern and record the values.
3) Repeat 1), 2) for all primary and secondary colours G, B, C, M, and Y as shown in Figure 8.
4) A 4 % 'white' window is also displayed and measured for reference white tri-stimulus values X_n, Y_n, and Z_n.
5) All measured luminance and chromaticity values are used to convert to colour difference metrics for evaluation of the colour fidelity of the display.
6) Calculate using the following formulae.
   - The measurement data for the primary and secondary colour shall be transformed into the CIELAB colour coordinate as follows:

$$L^* = 116 \times f(Y/Y_n) - 16 \tag{11}$$

$$a^* = 500 \times [f(X/X_n) - f(Y/Y_n)] \tag{12}$$

$$b^* = 200 \times [f(Y/Y_n) - f(Z/Z_n)] \tag{13}$$

where

$$f(t) = \begin{cases} t^{1/3} & t > \left(\frac{6}{29}\right)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{16}{116} & \text{otherwise} \end{cases}$$

- The difference between two stimuli shall be quantified with the following colour difference formula:

$$\Delta E^*_{\mathrm{ab}} = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2} \tag{14}$$

where ΔL^*, Δa^*, and Δb^* are differences in L^*, a^*, and b^* values between the measured and the reference colour.

The conversion from CIE $L^*a^*b^*$ to chroma C^* and hue-angle h of $L^*C^*h_{\mathrm{ab}}$ colour space is given by:

$$C^* = \sqrt{\left(a^*\right)^2 + \left(b^*\right)^2} \tag{15}$$

$$h = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad \text{[degree]} \tag{16}$$

- The hue difference metric is calculated by the following rectangular hue difference, ΔH^*ab:

$$\Delta H^*_{\mathrm{ab}} = \sqrt{\left(\Delta E^*_{\mathrm{ab}}\right)^2 - \left(\Delta L^*\right)^2 - \left(\Delta C^*\right)^2} \tag{17}$$

where $\Delta L^* = L^*_{\mathrm{measured}} - L^*_{\mathrm{reference}}$, $\Delta C^* = C^*_{\mathrm{measured}} - C^*_{\mathrm{reference}}$

- The reference colour values, for example, 'red', 'green', 'blue', 'cyan', 'magenta', and 'yellow' values from ITU BT.709, can be chosen by the user of this document.

The colour fidelity of a display can be evaluated by hue difference.

5.1.2.4.4 Reporting

The calculation result using the hue difference metric for the primary and secondary colours shall be noted in the measurement report.

The measurement results shall include the following items:

a) values of target $L^*C^*h_{\mathrm{ab}}$

b) measured values of $L^*C^*h_{\mathrm{ab}}$

c) calculation results of ΔH^*_{ab}

Table 3 shows an example of the results.

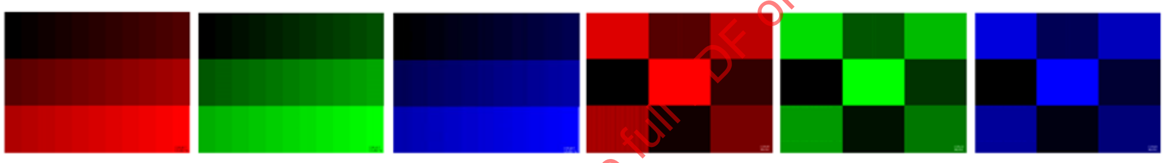
Table 3 – Example of measurement results for colour fidelity

Colour	Reference $L^*C^*h_{ab}$ (ITU BT.709)	Measured $L^*C^*h_{ab}$	ΔH^*_{ab}
R	(53,23, 104.,58, 0.0)	(51,66, 107,43, 4,5)	0,150
G	(87,74, 119,78, 96.0)	(89,71, 123,43, 92,1)	0,225
B	(32,30, 134,81, 266,3)	(30,24, 138,56, 260,8)	0,204
C	(91,12, 50,11, 156,4)	(93,76, 48,92, 159,15)	1,112
M	(60,32, 116,36, 288,2)	(65,84, 112,85, 283,9)	0,594
Y	(97,14, 96,92, 62,8)	(98,95, 95,34, 65,7)	3,421

5.1.2.5 Measurement of gamut change of the grey and colour scales

This measurement shall be performed as follows:

1) Input a signal to determine the CIE 1976 chromaticity coordinates (u', v') and generate a colour scale pattern for the ‘red’, ‘green’, and ‘blue’ colours on the display. Figure 9 shows constant picture level patterns that cycle the various colour levels at the centre.



IEC

Figure 9 – Test pattern for gamut change of the colour scale

2) Measure the colour coordinate values of each colour scale at a perpendicular angle to the display surface (θ = 0°, ϕ = 0°). The measurement area shall cover at least 500 pixels, or demonstrate equivalent results with fewer sampled pixels.
3) Separately measure the CIE 1976 chromaticity coordinates of the centre colour when the input signal is switched from ‘red’ (255, 0, 0), to ‘green’ (0, 255, 0), then ‘blue’ (0, 0, 255). Calculate the colour gamut area from the three primaries in the CIE 1976 chromaticity diagram following Equation (8).
4) Repeat the chromaticity measurements of the three primaries with lower input signal levels (e.g. with 8-bit equivalent levels of 31, 63, 95, 127, 159, 191, and 223). Calculate the colour gamut area for each signal level in the CIE 1976 chromaticity diagram following Equation (8).
5) Calculate the ratio of the CIE 1976 colour gamut areas of the lower signal levels to the maximum signal level, and express the result as a percent.
6) Report the colour gamut data at each colour scale. Table 4 and Figure 10 show an example of the results.

Table 4 – Example of measurement results for gamut change of colour scale

	31	63	95	127	159	191	223	255
Colour gamut (%)	36	81	93	97	98	99	100	100

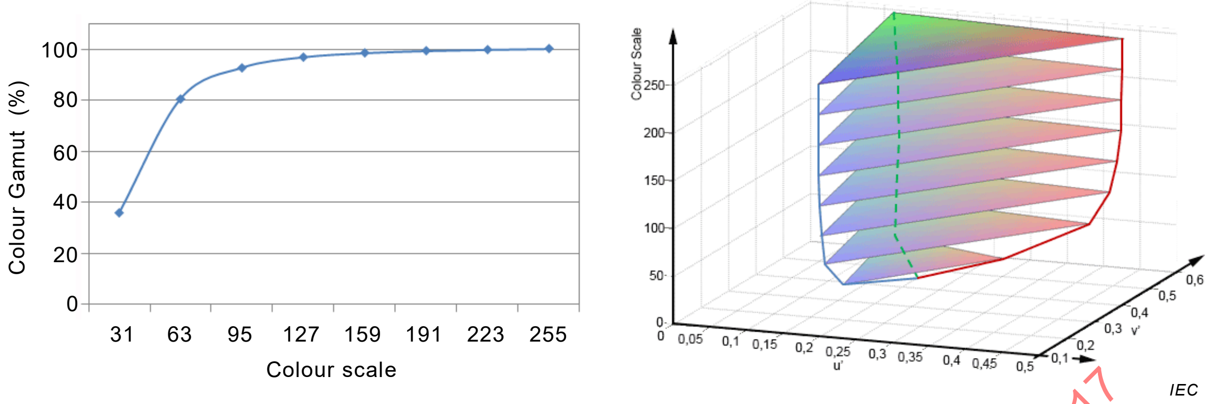


Figure 10 – Example of the measurement results

5.1.2.6 Measurement of colour desaturation

This measurement shall be performed as follows:

1) Measure the reference CIE 1976 chromaticity coordinates in the centre of the screen using a solid 127-digital-grey-level input (R = G = B =127). Also measure the reference chromaticity for each primary colour with the solid test patterns.
2) Measure the reference CIE 1976 chromaticity coordinates in the centre of the screen using a solid 191-digital-grey-level input (R = G = B = 191). Also measure the reference chromaticity for each primary colour with the solid test patterns.
3) Measure the colour coordinate values of a 1 x 1, 2 x 2, and 3 x 3 grilled test pattern consisting of alternating 255-grey-level primary colour and black (see Figure 11) as target colours.
4) Measure the colour coordinate values of a 2 x 1 grilled test pattern consisting of alternating 255-grey–level primary colour and black (see Figure 11) as target colours.

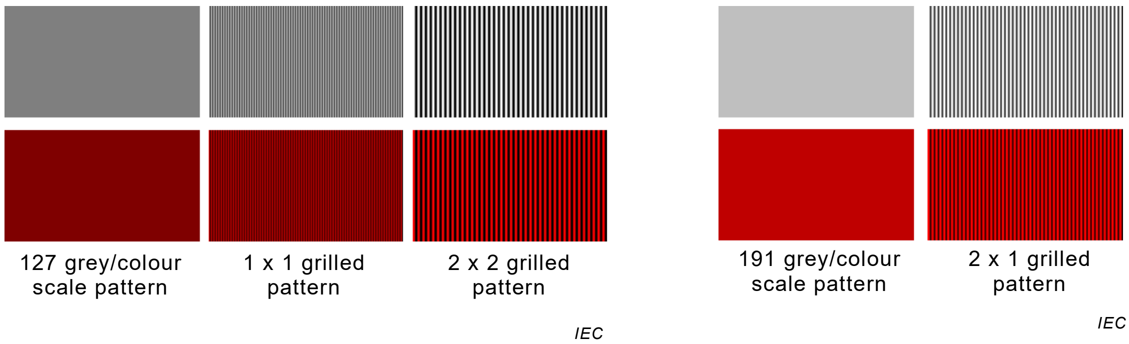
   Calculate the colour difference values between the reference and target coordinate values using Formula (18):

$$\Delta u'v' = \sqrt{(u'-u'_1)^2 + (v'-v'_1)^2} \qquad (18)$$

   where u' and v' mean the reference coordinate values while u_1' and v_1' are the target coordinate values.
5) Report the results for colour desaturation. Table 5 shows an example of the results.

Table 5 – Example of measurement results for 1 x 1 grilled colour desaturation

Colour desaturation		W		R		G		B	
		u'	v'	u'	v'	u'	v'	u'	v'
127 grey									
1 x 1 grilled	colour coordinate								
	$\Delta u'v'$								



(a) (b)

Figure 11 – Test pattern for colour desaturation

5.1.3 Crosstalk

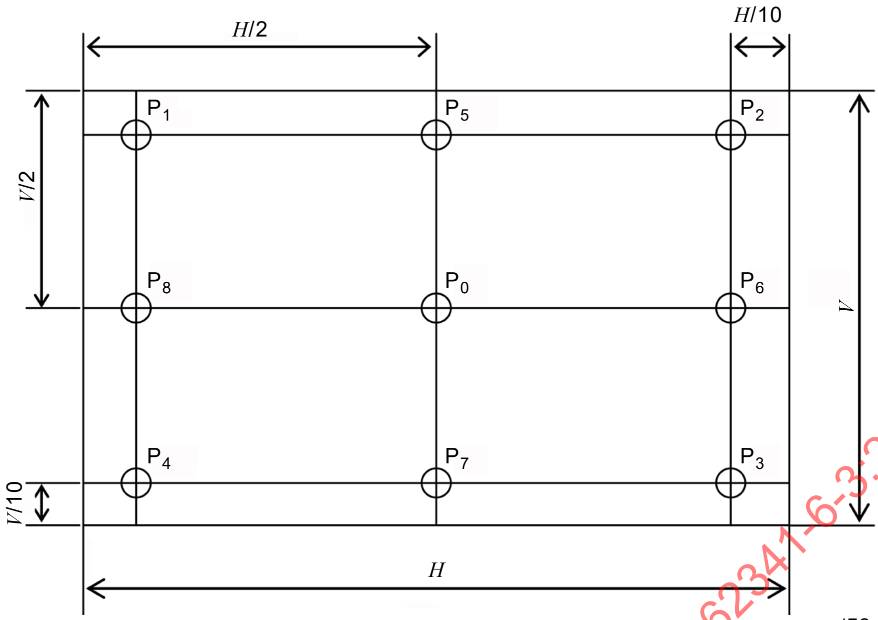
5.1.3.1 Purpose

The purpose of this method is to measure crosstalk, which is the cross-coupling of electrical signals between elements of an OLED display.

5.1.3.2 Measuring conditions

The following measuring conditions apply:

1) Apparatus:
   – an LMD that can measure luminance,
   – a driving power source, and
   – driving signal equipment.
2) Standard measuring environmental conditions:
   – dark-room conditions,
   – standard set-up conditions.
3) The LMD shall be aligned perpendicularly to position P_0 in Figure 12 to measure the luminance.



NOTE Positions indicated by P_0 to P_8, are located relative to the height (V) and display width (H) of active area.

Figure 12 – Standard measurement positions

5.1.3.3 Measurement and evaluation

Proceed as follows:

1) Measure the maximum white level window luminance, $L_{w,max}$, at the centre of the active area (position P_0 in Figure 12).

   The input signal is a 4 % white window pattern, with 100 % signal level, on a black background, with 0 % signal level, in the centre of the active area, as shown in Figure 13. The 4 % window has corresponding sides that are 1/5 of the vertical and horizontal dimensions of the active area. For a monochrome display, apply a signal at the highest grey level. For a colour display, apply a white signal level of 100 %.

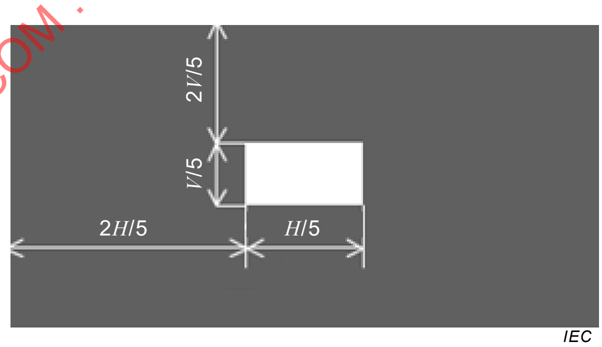


Figure 13 – Luminance measurement of 4 % window at P_0

2) Measure the 18 % level window luminance, $L_{w,18\ \%}$, at the centre of the active area (position P_0 in Figure 12).

   The input signal is a 4 % white window pattern, with 18 % signal level, on a black background, with 0 % signal level, in the centre of the active area, as shown in Figure 13. The 4 % window has corresponding sides that are 1/5 of the vertical and horizontal dimensions of the active area.

3) Measure the 18 % level full-screen luminance, $L_{FS,18\ \%}$, at the centre of the active area (position P_0 in Figure 12).

   Input signal is a full screen grey pattern, with 18 % signal level.

4) Measure the 18 % luminance signal L_{W_OFF} and L_{B_OFF} at the centre of the active area (position P_0 in Figure 12).

There are eight input patterns in total used in this step, which are indicated in Figure 14.

Figure 14 (left pattern) indicates the input signal pattern with the positions of the white segments A_{wi},(i = 1 to 4) which shall successively be activated to measure the luminance L_{wi},(i = 1 to 4) at P_0. The signal level of the white blocks is 100 % white, while background luminance level is 18 % white.

Figure 14 (right pattern) indicates the input signal pattern with the positions of the black segments A_{Bi},(i = 1 to 4) which shall successively be activated to measure the luminance L_{Bi},(i = 1 to 4) at P_0. The signal level of the black blocks is 0 % white, while background luminance level is 18 % white.

L_{W_OFF} and L_{B_OFF} are computed as follows:

$$L_{w\_OFF} = \frac{L_{w1} + L_{w2} + L_{w3} + L_{w4}}{4} \quad (19)$$

$$L_{B\_OFF} = \frac{L_{B1} + L_{B2} + L_{B3} + L_{B4}}{4} \quad (20)$$

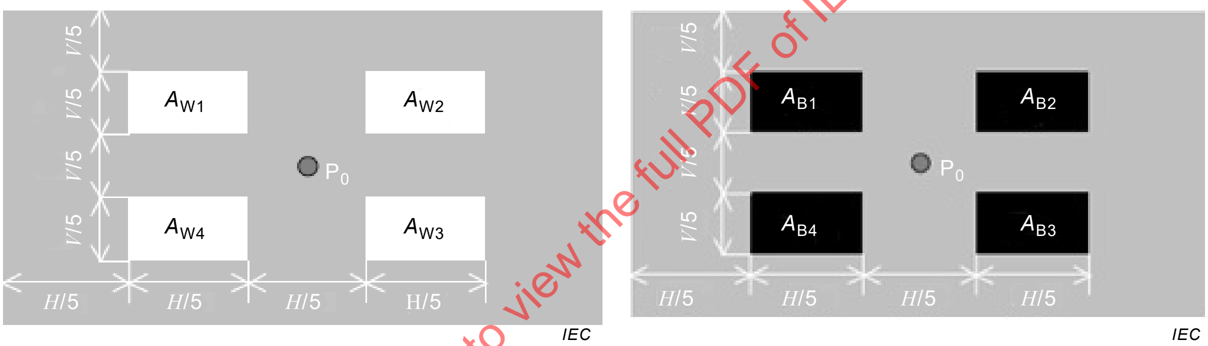


Figure 14 – Luminance measurement at P_0 with windows A_{W1}, A_{W2}, A_{B3}, and A_{B4}

5) Measure the 18 % luminance signal L_{Wi_ON} and L_{Bi_ON} at the centre of the active area (position P_0 in Figure 12).

There are also two input patterns with eight measuring points used in this step, which are indicated in Figure 15.

Figure 15 (left pattern) indicates the input signal pattern with the positions of the white segments A_{wi},(i = 5 to 8) which shall successively be activated to measure the luminance L_{wi_ON},(i = 5 to 8) at P_0. The signal level of the white blocks is 100 % white, while background luminance level is 18 % white.

Figure 15 (right pattern) indicates the input signal pattern with the positions of the black segments A_{Bi},(i = 5 to 8) which shall successively be activated to measure the luminance L_{Bi_ON},(i = 5 to 8) at P_0. The signal level of the black blocks is 0 % white, while background luminance level is 18 % white.

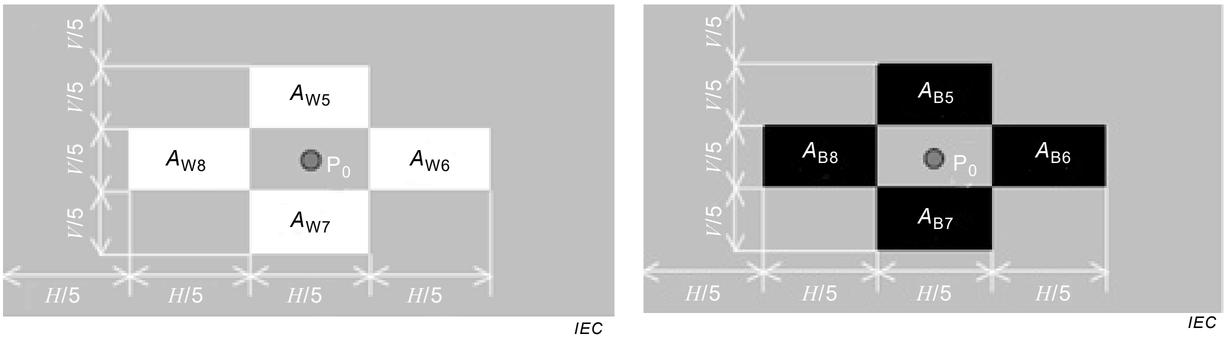


Figure 15 – Luminance measurement at P_0 with windows A_{W5}, A_{W8}, A_{B5} and A_{B8}

6) Calculate crosstalk

$$CT = \frac{|L_{Wi\_ON} - L_{W\_OFF}|}{L_{W\_OFF}} \times 100\% \quad (i = 5 \text{ to } 8) \tag{21}$$

for white windows A_{Wi} (i = 5 to 8), and

$$CT = \frac{|L_{Bi\_ON} - L_{B\_OFF}|}{L_{B\_OFF}} \times 100\% \quad (i = 5 \text{ to } 8) \tag{22}$$

for black windows A_{Bi} (i = 5 to 8).

The maximum crosstalk value shall be noted in the measurement report.

5.1.3.4 Reporting

The following information shall be noted in the measurement report:

1) Maximum crosstalk in percent with 100 % white window and black window.
2) Position of window that affects the maximum crosstalk at P_0.
3) Luminance at P_0 with the following conditions:
   – $L_{W,max}$
   – $L_{W,18\ \%}$
   – $L_{FS,18\ \%}$
   – L_{W_OFF} and L_{Wi_ON} in case of maximum crosstalk with white window,
   – L_{B_OFF} and L_{Bi_ON} in case of maximum crosstalk with black window.

5.1.4 Static image resolution

5.1.4.1 Purpose

The purpose of this method is to measure the effective resolution of an OLED display.

NOTE The measurement of the moving picture perceptual resolution of a display is described in Annex B.

5.1.4.2 Measuring conditions

The following measuring conditions apply:

1) Apparatus:
   – an LMD device;
   – a driving power source; and
   – driving signal equipment.
2) The integrated time of the measurement circuit shall be long enough so that the standard deviation of measured luminance is no greater than 2 % of the average value. For LMDs such as charged coupled devices (CCDs) or imaging photometers, the exposure time shall be a multiple of the frame time.
3) For an array detector, the number of pixels of the detector shall not be less than 4 for each display sub-pixel within the measurement field of view. For a spot meter, the diameter of the measurement field shall be less than 1/3 of the pixel area.
4) Standard measuring environmental conditions:
   – dark-room illumination;
   – standard set-up conditions;
   – measurement perpendicular to the display surface and in the centre of the display.
5) Test patterns:
   – horizontal lines for vertical resolution or vertical lines for horizontal resolution with n white or black lines as shown in Figure 16, where n = 1 to 4.
6) In case of a display product with signal processing such as a TV set, the display mode might be the default mode out of box.

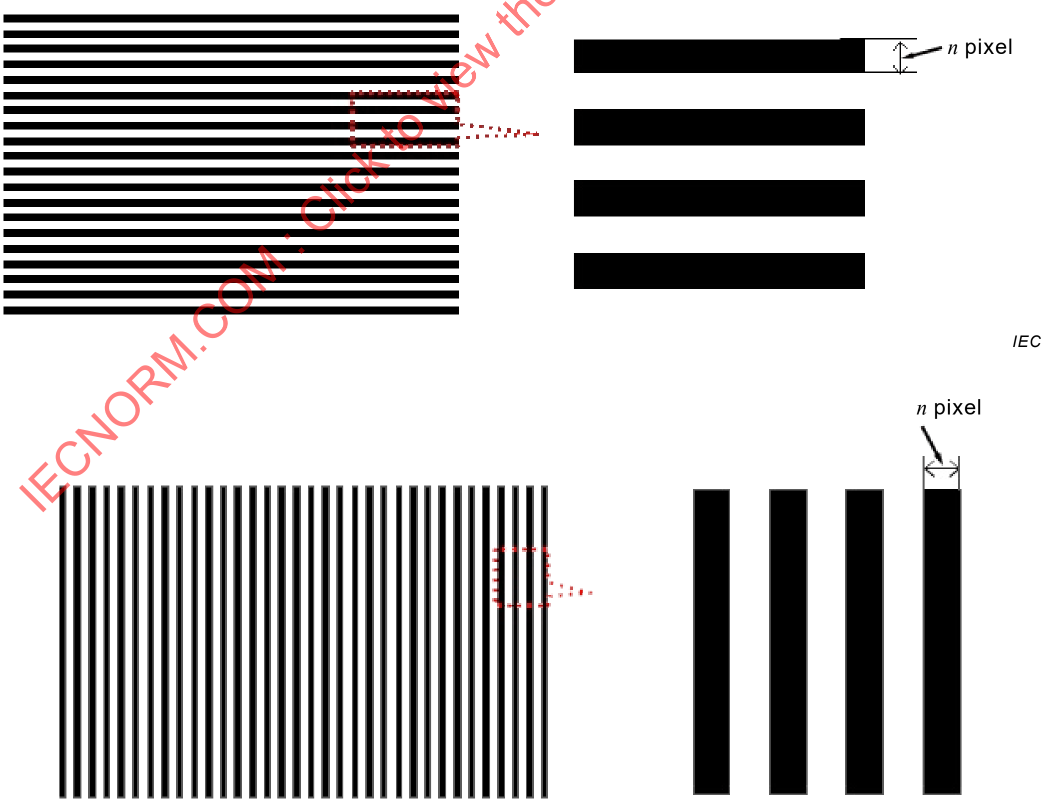


Figure 16 – Test pattern for effective resolution

5.1.4.3 Measuring method

Perform measurements of line profile and contrast for each pattern, for both the white and black lines. Perform measurements for at least two lines of window length both for black and white, and then calculate their average.

With an array or scanning spot LMD, obtain the luminance profile of the vertical line as a function of position. The direction of the array or scanning LMD is perpendicular to the vertical line. Besides conventional RGB stripe pixel, there might be various pixel types such as non-orthogonal pixel layout and non-rectangular pixel shape as well as non-RGB or non-fixed pixel displays with sub-pixel rendering technologies. An example of obtaining the luminance profile for horizontal resolution is provided in Figure 17a), where the window width for the luminance is decided by the black or white line width of the input signal as follows:

$$WS_{\mathrm{H}} = \frac{S_{\mathrm{w}}}{N_{\mathrm{H}}} \tag{23}$$

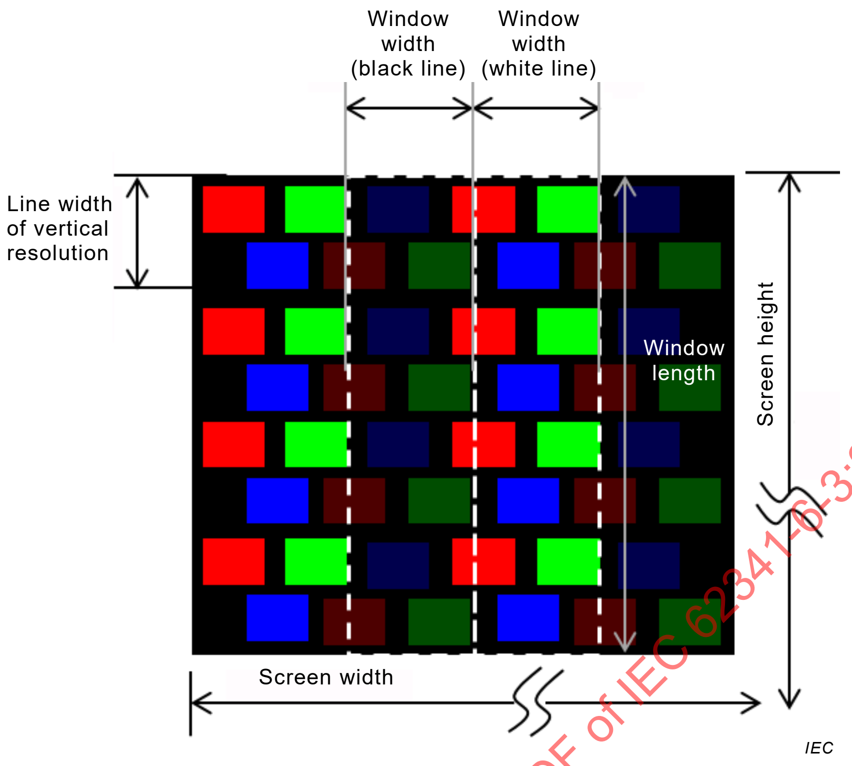
$$WS_{\mathrm{V}} = \frac{S_{\mathrm{h}}}{N_{\mathrm{V}}} \tag{24}$$

where WS_{H} and WH_{V} are window width size for horizontal and vertical resolution, S_{w} and S_{h} are screen width and height, and N_{H} and N_{V} are the number of black and white signal lines in the horizontal and vertical positions.

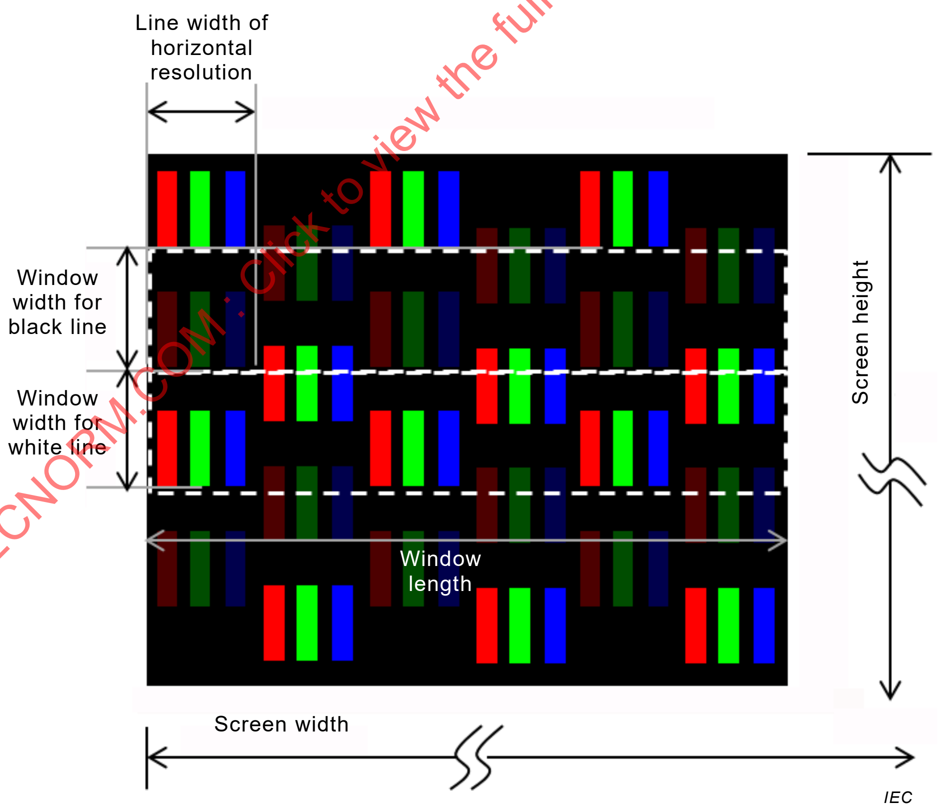
NOTE 1 The window width size, which can be obtained by using Formulae (23) and (24), is an efficient method for the digitally driven displays which shows constant window width for the fixed number of image data. For other types of displays that might show different window width from the signal pixel pitch, the moving-window average method in [22] is another efficient method.

The recommended window length for horizontal resolution is two or more rows and the recommended window length for vertical resolution is two or more columns. The position of the window shall be such as to make maximum line contrast while the windows of black and white line should be connected without gap or overlap.

Repeat these procedures for the horizontal line inputs to measure the vertical resolution. An example of obtaining the luminance profile for vertical resolution is provided in Figure 17b). The recommended window length is two or more horizontal lines.



a) Luminance window for horizontal resolution



b) Luminance window for vertical resolution

Figure 17 – Example of luminance window for one-line grilled input

NOTE 2 Stray light within an instrument, often called veiling glare, can cause serious measurement errors. Thus, it is critical to apply a correction for an instrument's stray light in order to obtain measurement results such as contrast modulations with acceptable uncertainties. For an array LMD, a simple matrix method for stray light correction can be used, by which stray light errors can be reduced by one order of magnitude (see [3]). Annex A provides a brief description of the matrix method. For a spot LMD, a replica mask or line mask can be used. Details of the replica method are discussed in [14].

5.1.4.4 Calculation and reporting

Proceed as follows:

1) Calculate the contrast modulation for each pattern

$$C_{\text{m}}(n) = \frac{L_{\text{w}}(n) - L_{\text{k}}(n)}{L_{\text{w}}(n) + L_{\text{k}}(n)} \quad (n = 1 \text{ to } 5) \tag{25}$$

where $L_{\text{w}}(n)$ and $L_{\text{k}}(n)$ are the average luminance of all the centres of the white and black lines, respectively.

2) Calculate the grille line width n_{r} (in pixels).

The calculated grille line width is estimated by linear interpolation to be equal to the contrast modulation threshold C_{T}.

$$n_{\text{r}} = n + \frac{C_{\text{T}} - C_{\text{m}}(n)}{C_{\text{m}}(n+1) - C_{\text{m}}(n)} \quad \text{for } C_{\text{m}}(n) < C_{\text{T}} < C_{\text{m}}(n+1) \tag{26}$$

The contrast modulation threshold C_{T}, which is 50 % for text resolution and 25 % for image resolution, depends on the display application. An example for n_{r} calculation is provided in Figure 18, where pixel 0 is switched on and the measured contrast modulation varies with the distance (in pixel) from pixel 0. If $C_{\text{m}}(1)$ is larger than C_{T}, then n_{r} is 1.

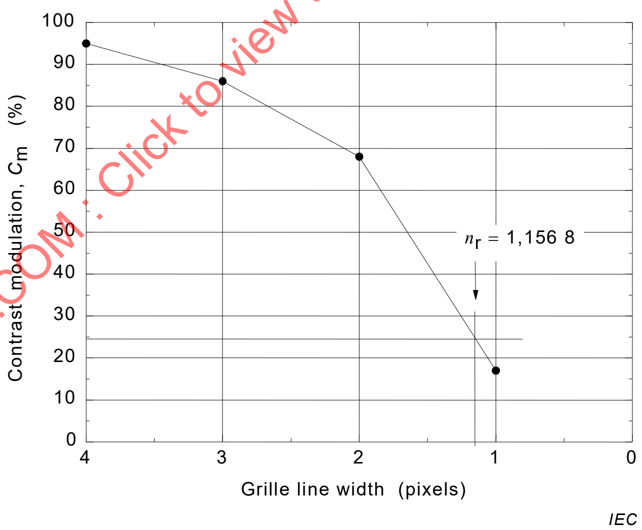


Figure 18 – Contrast modulation measurement

3) Calculate the resolution (in number of resolvable lines/pixels) for both horizontal (pixels) and vertical (lines) directions as follows:

$$ER = \frac{N_{\text{al}}}{n_{\text{r}}} \tag{27}$$

where ER is static image resolution and N_{al} is the number of addressable lines, respectively.

NOTE The term of pixel is used as the unit of static image resolution horizontally and vertically.

The number of addressable lines/pixels, contrast modulation threshold (C_T), calculated effective resolution, and contrast modulation plots in both horizontal and vertical directions shall be noted in the measurement report.

5.2 Measuring methods for temporal image quality

5.2.1 Flicker

5.2.1.1 Purpose

The purpose of this method is to measure the potential of an observable flicker from an OLED display module.

5.2.1.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a signal generator; a frequency analyzer; and an LMD with the following characteristics to record the luminance as a function of time:
   1) photopic vision response function with CIE-f1: no greater than 5 %,
   2) capable of producing a linear response to rapid changes in luminance,
   3) frequency response: greater than 120 Hz,
   4) an angular aperture that shall be less than 5°,
   5) dark field (zero) corrected.

b) Standard measuring environmental conditions:
   – dark-room illumination;
   – standard set-up conditions.

5.2.1.3 Set-up

5.2.1.3.1 Geometric arrangement

For this measurement, the LMD and DUT shall be set up as follows:

1) The optical axis of the LMD is in accordance with the central normal line of the DUT (see Figure 19).

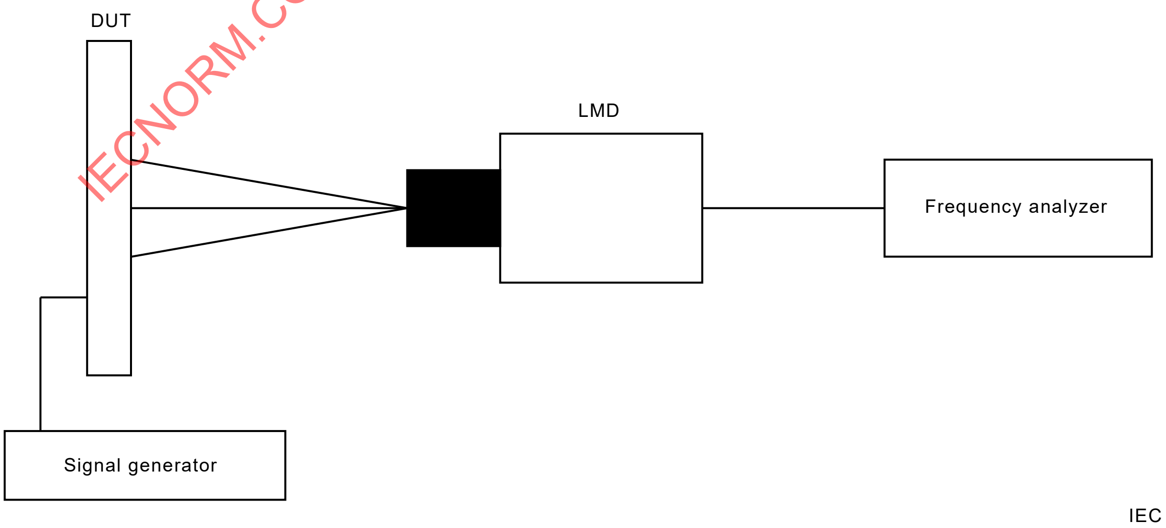


Figure 19 – Apparatus arrangement

2) Measurement region: larger than 500 pixels.
3) Measuring distance: twice the diagonal distance of DUT. The minimum distance shall be 500 mm.

5.2.1.3.2 Pattern

The nominal test pattern is constant full screen white at specified level L_W, which shall be noted in the measurement report. If other empirically or analytically derived worst-case test patterns are used, the changed colour, drive level, pattern, and/or viewing direction shall be noted in the measurement report.

5.2.1.4 Measuring procedure

Proceed as follows:

1) Set the DUT under the standard measuring conditions.
2) Display the selected test pattern, and wait until the test pattern is stable.
3) Measure the luminance as a function of time $L(t)$ with the LMD.

5.2.1.5 Measuring method

5.2.1.5.1 Flicker modulation amplitude

This measurement shall be performed as follows:

a) Analyze the luminance and perform a Fourier transform with the array of data $L(t)$, to acquire the power spectrum $P(F)$.
b) Weight the power spectrum $P(F)$ with a temporal contrast sensitivity function (see Figure 20 and Table 6), to obtain perceptive power spectrum $P'(F)$.
c) Transform $P'(F)$ into the luminance as a function of time $L'(t)$ with the inverse Fourier transform.

Table 6 – Temporal contrast sensitivity function

Frequency (Hz)	Contrast sensitivity	Frequency (Hz)	Contrast sensitivity
1	38,00	39	10,21
2	68,21	40	9,10
3	96,87	41	8,10
4	121,89	42	7,20
5	142,28	43	6,40
6	157,50	44	5,68
7	167,46	45	5,03
8	172,37	46	4,46
9	172,76	47	3,95
10	169,30	48	3,49
11	162,79	49	3,09
12	154,06	50	2,73
13	143,86	51	2,41
14	132,90	52	2,13
15	121,74	53	1,88
16	110,82	54	1,66
17	100,43	55	1,46
18	90,78	56	1,29
19	81,96	57	1,14
20	73,97	58	1,00

Frequency (Hz)	**Contrast sensitivity**	**Frequency** (Hz)	**Contrast sensitivity**
21	66,80	59	0,89
22	60,38	60	0,78
23	54,62	61	0,69
24	49,45	62	0,61
25	44,79	63	0,54
26	40,57	64	0,47
27	36,74	65	0,42
28	33,25	66	0,37
29	30,06	67	0,32
30	27,16	68	0,29
31	24,50	69	0,25
32	22,07	70	0,22
33	19,85	71	0,20
34	17,83	72	0,17
35	16,00	73	0,15
36	14,33	74	0,14
37	12,82	75	0,12
38	11,45		

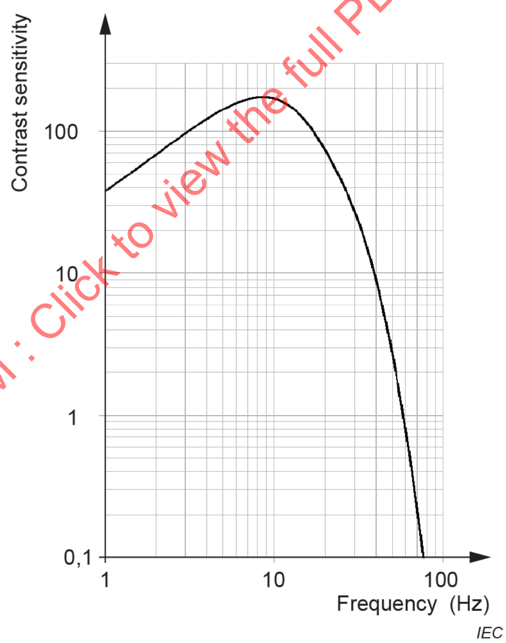


Figure 20 – Temporal contrast sensitivity function

d) Subsequently, calculate the flicker modulation amplitude (A_{FM}) as follows:

1) Determine the main flicker frequency f_m from the maximum of $P'(f)$.

2) Determine the flicker modulation amplitude A_{FM} in percent from $L'(t)$ as follows:

3) Obtain the average luminance, L'_{ave}, the maximum luminance L'_{max}, and the minimum luminance L'_{min} of $L'(t)$ (see Figure 21).

e) Calculate A_{FM} as follows:

$$A_{FM} = \left(\frac{L'_{max} - L'_{min}}{L'_{ave}} \right) \times 100\% \qquad (28)$$

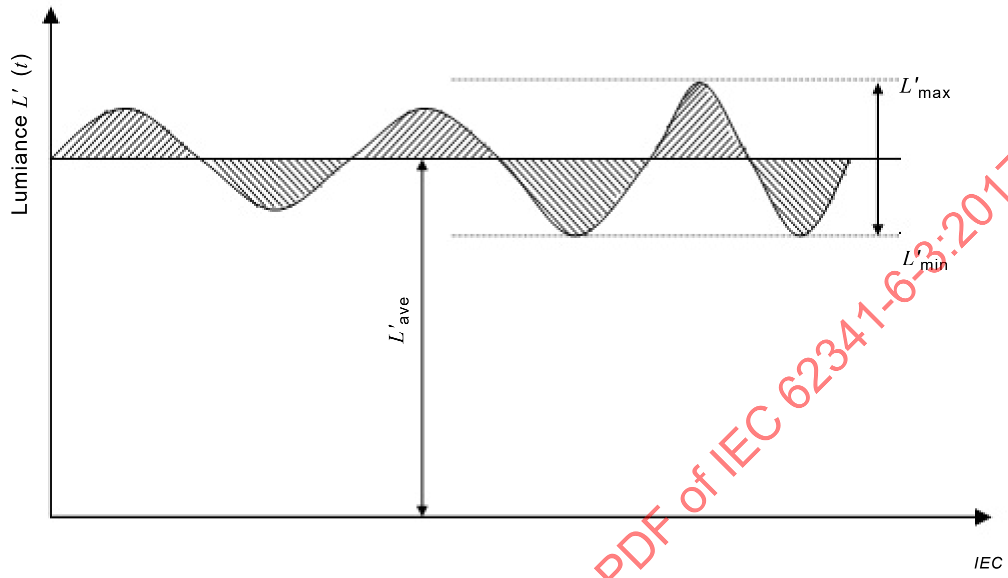


Figure 21 – Example of flicker modulation waveform

5.2.1.5.2 Critical flicker frequency (CFF)

From the acquired temporal luminance data [$L(t)$], in order to predict whether flicker will be observed, the model already described by Farrell [12] can be successfully used (see [13]). The calculated critical flicker frequency (CFF) value represents the lowest refresh rate to render a display flicker-free. If the refresh rate of a display is higher than the CFF, it is predicted that the observer will not perceive flicker. If the refresh rate is lower than the CFF, visible flicker is predicted.

$$CFF = m + n\{\ln[E_{ret} \times M(f)]\} \quad \text{(Hz)} \qquad (29)$$

$$\begin{cases} E_{ret} = L_{av} \times A_{pupil} & \text{(td)} \\ A_{pupil} = \pi \times (d/2)^2 & (\text{mm}^2) \\ d = 5 - 3 \times \tanh[0{,}4 \times \log(L_{av} \times 3{,}183)] & \text{(mm)} \end{cases} \qquad (30)$$

where

$$m = -\ln(a/b)$$

$$n = 1/b$$

and where E_{ret} is the retinal illumination, which depends on the average display luminance entering the eye (L_{av}) and the pupil area (A_{pupil}), which in turn depends on the pupil diameter d. $M(f)$ represents the normalized modulation amplitude of the fundamental frequency, derived from the recorded time varying screen luminance [$L(t)$], and a and b are constants, which depend only on the display size (for the applicable values, see [12]).

5.2.1.6 Reporting

In the case where the flicker modulation amplitude has been calculated, the following information shall be noted in the measurement report:

– the test pattern that was used to produce the luminance variations;
– the temporal CSF that was used for filtering the recorded luminance;
– the minimum luminance (L'_{min}), maximum luminance (L'_{max}), and the average luminance (L'_{av}) of the filtered temporal luminance [$L'(t)$] () (see Figure 21);
– the flicker modulation amplitude (A_{FM}), and its main modulation frequency f_M.

In the case where the critical flicker frequency has been calculated, the following information shall be noted in the measurement report:

- the test pattern that was used to produce the luminance variations;
- the values for parameters m and n, used in Formula (29);
- the average display luminance (L_{av});
- the calculated CFF value (in Hz), as well as the fundamental frequency (f) of the modulation amplitude [$M(f)$].

5.2.2 Grey-to-grey response time

5.2.2.1 Purpose

The purpose of this method is to measure response time performance of OLED panels and modules.

5.2.2.2 Measuring conditions

Standard measuring is implemented under standard dark-room and set-up conditions.

5.2.2.3 Measuring methods

The measuring methods shall be as follows:

1) Change the test pattern from grey V_i to grey level V_j. One example of equal lightness steps are the grey levels V = {0, 31, 63, 95, 127, 159,191, 223, 255}.
2) Acquire the time-varying relative luminance of the DUT by using a fast-response meter and a data acquisition device such as an oscilloscope or data acquisition card-equipped computer as shown in Figure 22.
3) Acquire the step response time values from each selected grey-to-grey level.
4) Report the measured grey-to-grey response time data using the report form as shown in Table 7.

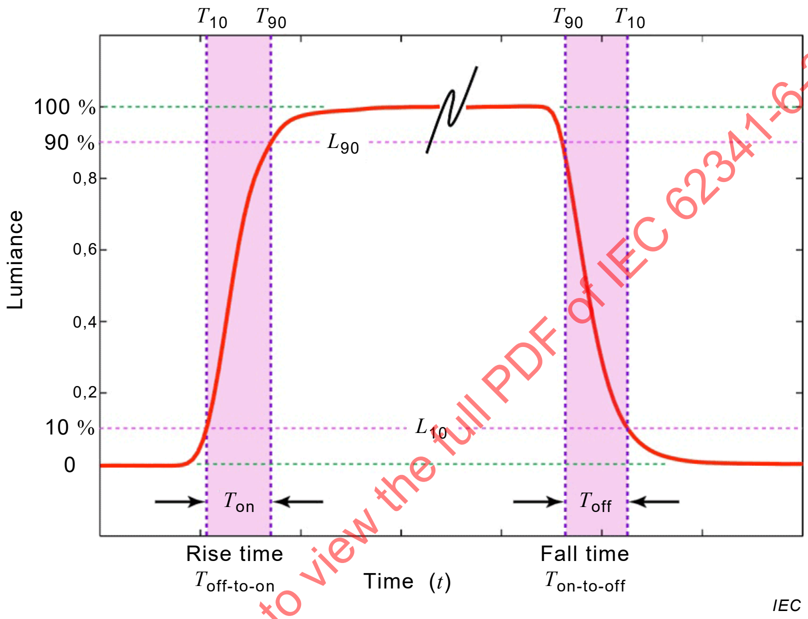


Figure 22 – Example of response time waveform

Table 7 – Example of reporting form of grey-to-grey response time

	End grey level									
Start grey level		0	31	63	95	127	159	191	223	255
	0	0	6,5	6,2	6,3	6,2	6,5	6,1	6,5	6,5
	31	6,6	0	6,4	6,2	6,2	6,1	6,6	6,4	6,2
	63	6,6	6,5	0	6,7	6,2	6,3	6,1	6,2	6,1
	95	6,2	6,2	6,1	0	6,5	6,4	6,4	6,3	6,3
	127	6,3	6,3	6,2	6,1	0	6,2	6,3	6,3	6,2
	159	6,2	6,3	6,1	6,2	6,1	0	6,2	6,1	6,2
	191	6,1	6,2	6,3	6,2	6,5	6,1	0	6,2	6,1
	223	6,2	6,3	6,2	6,3	6,4	6,1	6,2	0	6,3
	255	6,5	6,2	6,1	6,4	6,3	6,2	6,5	6,4	0
Max. (ms)	6,6									
Min. (ms)	6,1									
Average (ms)	6,3									

Annex A
(informative)

Simple matrix method for correcting the stray light of imaging instruments

A.1 Purpose

Improperly imaged, or scattered, optical radiation, commonly referred to as stray light, within an instrument is often the dominant source of measurement error. Stray light, spectral or spatial, can originate from the spectral components of a “point” source, which can be described by a spectroradiometer’s SLSF [19], and from the spatial elements of an extended source which can be described by an imaging instrument’s point spread function (PSF).

A.2 Measuring method

For spatial stray light correction, an imaging instrument is first characterized by a set of PSFs covering the imaging instrument’s field-of-view. A PSF is a two-dimensional relative spatial response of an imaging instrument when it is used to measure a point source (or a small pin-hole source). Each PSF is used to derive a stray light distribution function (SDF), i.e. the ratio of the stray light signal to the total signal within the resolving power of the imaging instrument.

By using the set of derived SDFs and interpolating between these SDFs, all SDFs are obtained. Each of the obtained two-dimensional SDF is transformed into a one-dimensional column vector. By using all column vector SDFs, an SDF matrix is obtained. As with the spectral stray light correction [20], the SDF matrix is then used to derive the spatial stray light correction matrix, and the instrument’s response to stray light is corrected by

$$Y_{\mathrm{IR}} = C_{\mathrm{spat}} Y_{\mathrm{meas}} \quad \text{(A.1)}$$

where

C_{spat} is the spatial stray light correction matrix,

Y_{meas} is the column vector of the measured raw signals obtained by transforming a two-dimensional imaging signal, and

Y_{IR} is the column vector of the spatial stray light corrected signals.

NOTE The development of matrix C_{spat} is done only once, unless the imaging characteristics of the instrument change.

Using Formula (A.1), the spatial stray light correction becomes a single matrix multiplication.

NOTE The measured PSFs also include other types of unwanted responses from the imaging instrument (e.g., CCD smearing); thus, the stray light correction eliminates other types of errors as well.

As an example of spatial stray light correction, a spatial stray light corrected CCD imaging photometer was used to measure luminance on the port of an integrating sphere source. A black spot (a small piece of black aluminum foil) was placed at the centre of the port of the integrating sphere source. The size of the sphere port was adjusted to be smaller than the field-of-view of the imaging photometer, so that the spatial stray light's signals arising from the source outside the field-of-view of the imaging photometer were zero; thus the stray light corrected signals on the black spot were theoretically zero.

The result of the correction is shown in Figure A.1, which is a plot of one-dimensional signals along a centre line across the sphere port. The maximum signal (not plotted) is normalised to one. Figure A.1 shows that the level of spatial stray light of the imaging photometer is