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INTERNATIONAL STANDARD

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Organic light emitting diode (OLED) displays –
Part 6-1: Measuring methods of optical and electro-optical parameters

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FOREWORD

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International Standard IEC 62341-6-1 has been prepared by IEC technical committee 110: Electronic display devices.

This second edition cancels and replaces the first edition published in 2009. This edition constitutes a technical revision.

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

a) extends the applicability of the measuring methods to include OLED displays that have multi-primary or red, green, blue and white sub-pixels;
b) adds a method to characterize how the luminance is affected by the amount of content on the screen;
c) adds a method to determine the dark room colour gamut volume in the CIELAB colour space.

The text of this standard is based on the following documents:

FDIS	Report on voting
110/816/FDIS	110/830/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- withdrawn,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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

ORGANIC LIGHT EMITTING DIODE (OLED) DISPLAYS –

Part 6-1: Measuring methods of optical and electro-optical parameters

1 Scope

This part of IEC 62341 specifies the standard measurement conditions and measuring methods for determining optical and electro-optical parameters of organic light-emitting diode (OLED) display modules and, where specified, OLED display panels. These methods are limited to flat displays measured in a dark room.

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 60050-845, *International Electrotechnical Vocabulary – Part 850: Lighting* (available at www.electropedia.org)

IEC 61966-2-1, *Multimedia systems and equipment – Colour measurement and management – Part 2-1: Colour management – Default RGB colour space – sRGB*

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

IEC 62341-6-2:2015, *Organic light emitting diode (OLED) displays – Part 6-2: Measuring methods of visual quality and ambient performance*

CIE 15:2004, *Colorimetry, 3rd edition*

CIE S 014-1, *Colorimetry – Part 1: CIE Standard Colorimetric Observers*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-845, 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
signal pixel
smallest encoded picture element in the input image

3.1.2
pre-gamma average picture level
average input level of all signal pixels relative to an equivalent white pixel driven by a digital RGB input

Note 1 to entry: Unless otherwise stated, the pre-gamma average picture level (APL) will simply be referred to as average picture level in this document.

Note 2 to entry: The APL will normally be expressed as a percentage, where a full white screen at maximum drive level would be 100 % APL.

3.2 Abbreviated terms

APL	average picture level
CCT	correlated colour temperature
CIE	Commission internationale de l'éclairage (International Commission on Illumination)
CIELAB	CIE 1976 ($L^*a^*b^*$) colour space
CMY	cyan, magenta, and yellow
DUT	device under test
LMD	light-measuring device
LUT	look-up table
PMOLED	passive matrix organic light-emitting diode
RGB	red, green, and blue
RGBCMY	red, green, blue, cyan, magenta, and yellow
sRGB	standard RGB colour space as defined in IEC 61966-2-1
UCS	uniform chromaticity scale
WRGB	white, red, green, and blue

4 Structure of measuring equipment

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

5 Standard measuring conditions

5.1 Standard environmental conditions for measurements

Measurements shall be carried out under standard environmental conditions at a temperature of 25 °C ± 3 °C, at a relative humidity of 25 % to 85 %, and at an air pressure of 86 kPa to 106 kPa. When different environmental conditions are used, they shall be noted in the report.

5.2 Standard dark room conditions for measurements

The luminance contribution from unwanted background illumination reflected off the test display shall be less than 1/20 of the display's black state luminance. If these conditions are not satisfied, then background subtraction is required and it shall be noted in the test report. In addition, if the sensitivity of the LMD is inadequate to measure 1/20 of the black level, then the lower limit of the LMD shall be noted in the test report.

5.3 Standard setup conditions

5.3.1 General

Standard setup conditions are given below. Any deviations from these conditions shall be recorded.

5.3.2 Adjustment of OLED display modules

The display shall be measured at its factory default settings. If other settings are used, they shall be noted in the test report. These settings shall be held constant for all measurements, unless stated otherwise. It is important, however, to make sure that not only the adjustments are kept constant, but also that the resulting physical quantities remain constant during the measurement. This is not automatically the case because of, for example, warm-up effects.

5.3.3 Starting conditions of measurements

Measurements shall be started after the OLED display and the measuring instruments achieve stability. It is recommended that, when the display is first turned on, it be operated for at least 30 min with a loop of colour patterns rendered on the screen. Sufficient warm-up time has been achieved when the luminance of the test feature to be measured varies by less than ±3 % over the entire measurement method for a given display image.

5.3.4 Measuring equipment requirements

5.3.4.1 General conditions

Light measurements shall generally be measured in terms of photometric or colorimetric units for a CIE 1931 standard colorimetric observer as defined in CIE S 014-1. Luminance can be measured by a photometer, and CIE tristimulus values (X, Y, Z) or CIE chromaticity coordinates by a colorimeter. A spectroradiometer can also obtain photometric and colorimetric values through a numerical conversion of the measured spectral radiance data (see for example [1][1]). Non-contact LMD, where the LMD is not in direct contact with the screen, shall be used without an illumination source. The following requirements are given for these instruments:

a) The LMD shall be a luminance meter, a colorimeter, or a spectroradiometer. The spectroradiometer shall be capable of measuring spectral radiance over at least the 380 nm to 780 nm spectral range, with a maximum bandwidth of 10 nm for smooth broadband spectra. For OLED primaries with bandwidth ≤ 25 nm, the maximum bandwidth shall be ≤ 5 nm. The spectral bandwidth of the spectroradiometer shall be an integer multiple of the sampling interval. For example, a 5 nm sampling interval can be used for a 5 nm or 10 nm bandwidth.

   Care shall be taken to ensure that the LMD has enough sensitivity and dynamic range to perform the required task. The measured LMD signal shall be at least ten times greater than the dark level (noise floor) of the LMD, and no greater than 85 % of the saturation level.

b) The LMD shall be focused on the image plane of the display and generally aligned perpendicular to the display surface at the centre of the measurement field, unless stated otherwise.

c) The relative uncertainty and repeatability of all the measuring devices shall be maintained by following the instrument supplier's recommended calibration schedule.

d) The LMD integration time shall be an integer number of frame periods, synchronized to the frame rate, or the integration time shall be greater than one hundred frame periods.

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

e) If LMD measurements are taken for displays with impulse driving or duty driving, the high peak luminance of these displays can cause detector saturation errors. The accuracy of these measurements can be checked by attenuating the light with a neutral-density filter. If the change in signal amplitude of the detector is proportional to the transmittance of the neutral-density filter, then there are no detector saturation errors. This method is for measuring the maximum time-averaged full-screen luminance.

When using LMDs, stray light within the LMD (e.g. lens flare, veiling glare) and non-uniformities of sensitivity across the detector area should be considered.

In addition to LMDs that form an average value for the measured quantity over the measurement field under consideration (i.e. spot photometers, Figure 1), there are imaging LMDs which give a value (or an array of values, e.g. R, G and B) for each individual area-element on the DUT. Such LMDs can replace a sequential mechanical scan of the surface of a display by an image of the entire active area of the DUT, and a subsequent evaluation of the data.

When imaging LMDs are used, a flat-field correction shall be applied to the LMD at the measuring distance.

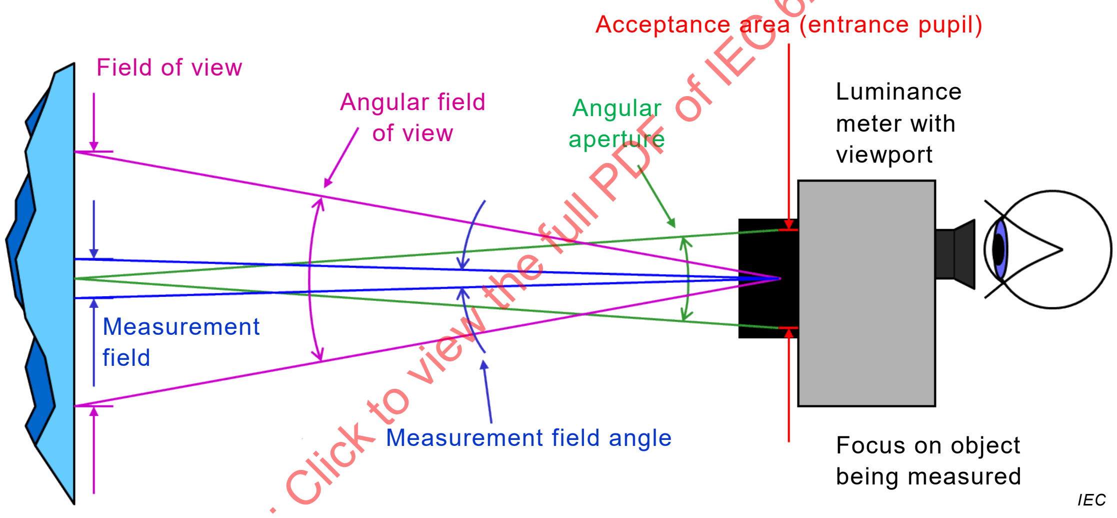


Figure 1 – Layout diagram of measurement setup

5.3.4.2 High pixel count matrix displays (≥ 320 × 240 pixels)

The following applies for high pixel count matrix displays.

a) When measuring matrix displays, the light-measuring devices should be set to a measurement field that includes more than 500 pixels. For LMDs with a circular measurement field, this would be equivalent to a disk with a diameter greater than 25 display pixels. If smaller measurement areas are necessary, photometric and colorimetric equivalence to 500 pixels shall be confirmed and noted in the test report.

b) For small displays, the recommended measuring distance is between 20 cm to 50 cm. For larger displays, the measurement area shall contain at least 500 pixels. The measuring distance shall be noted in the report.

c) The angular aperture shall be less than or equal to 5°, and the measurement field angle shall be less than or equal to 2° (see Figure 1).

d) The display shall be operated at its design field frequency. When using separate driving signal equipment to operate a panel, the drive conditions shall be noted in the report.

5.3.4.3 Low pixel count matrix displays (< 320 × 240 pixels) and segmented displays

The following applies for low pixel count matrix displays.

a) Low pixel count displays may contain fewer than 500 pixels. When the number of pixels in the measurement field is less than 500, it shall be noted in the report. The angular aperture shall be less than or equal to 5°, and the measurement field angle shall be less than or equal to 2°. The measurement conditions used shall be recorded.

b) For segment displays, the angular aperture shall be less than or equal to 5°, and the measurement field angle shall be less than or equal to 2°. All measurements shall be performed at the centre of a segment with the measurement field completely contained within the segment.

c) For small displays, the recommended measuring distance is between 20 cm to 50 cm. For larger displays, follow the manufacturer's recommended viewing distance. For larger displays, the measurement area shall contain at least 500 pixels. The measuring distance shall be noted in the report.

5.4 Standard locations of measurement field

Luminance, spectral distribution and/or tristimulus measurements may be taken at several specified positions on the display's surface. The standard measurement locations are identified by positions P_1 to P_9 in the active area, as illustrated in Figure 2. The active screen area is divided into nine equal-sized boxes, with the measurement area centred within each box and identified by the corresponding numbering shown in Figure 2. Each box is 1/3 of the width (W) and height (H) of the active area. Centre screen measurements are taken at position P_5. The display or detector shall be translated in the horizontal and vertical directions to perform measurements at the desired display positions, with all measurements taken normal to the screen. Any deviation from the standard positions above shall be recorded.

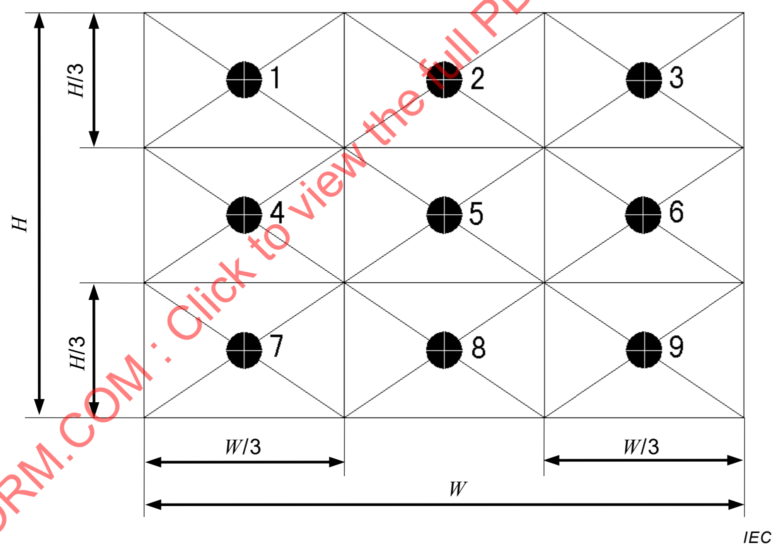


Figure 2 – Standard measurement positions in the active area of the display

5.5 Standard test patterns

The characterization of display luminance and colour can depend on the display test pattern. Therefore, several standard test patterns are given to help make the measurements more realistic to actual use cases (see Annex E). Additional test patterns may also be used (see Annex F). The standard test patterns use the scaling illustrated in Figure 3. The display is divided into a 3 × 3 array of rectangular areas, each of which has sides that are 1/3 of the dimension of the height and width of the screen's active area. Each of these nine rectangular areas can then be further subdivided into smaller rectangles, as demonstrated in the upper left-hand corner of Figure 3. The smallest subdivision would yield a rectangular box that has dimensions of 1/9 of those of the active area of each region of the 3 × 3 array.

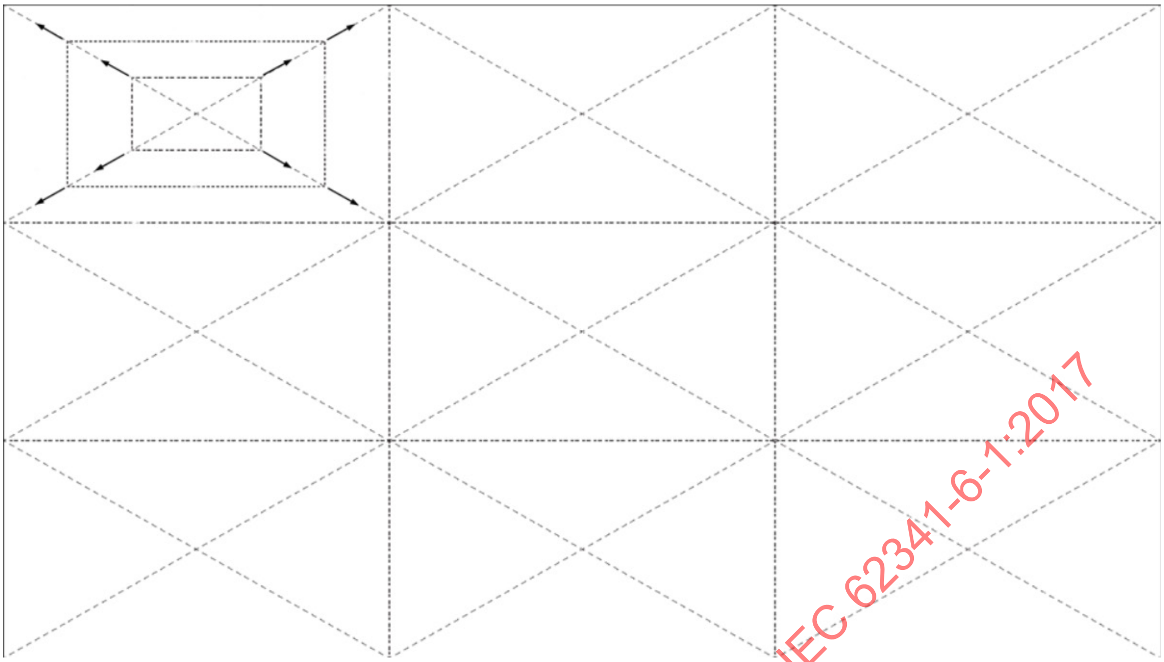


Figure 3 – Test pattern scaling used to define the area size of the coloured rectangles in the active area of the display

The standard test pattern for basic primary luminance and colour measurements shall use the low APL loading example of the colour tile test patterns illustrated in Figure 4. In this case, coloured rectangular boxes, with 1/9 of the dimensions of the active area, are centred on the nine standard active area locations on a black background. The red, green, and blue boxes are driven at the maximum input signal levels for the primary channels. For example, the red box is driven at the maximum input signal for the red channel, while the green and blue channels are at their minimum signal level. The white boxes are driven at their maximum red, green, and blue channel inputs. Each colour tile pattern is identified by the initials CT (colour tile) and the colour of the centre box. The patterns in Figure 4 are identified as CTR, CTG, CTW, and CTB when starting from the upper left-hand pattern and moving clockwise.

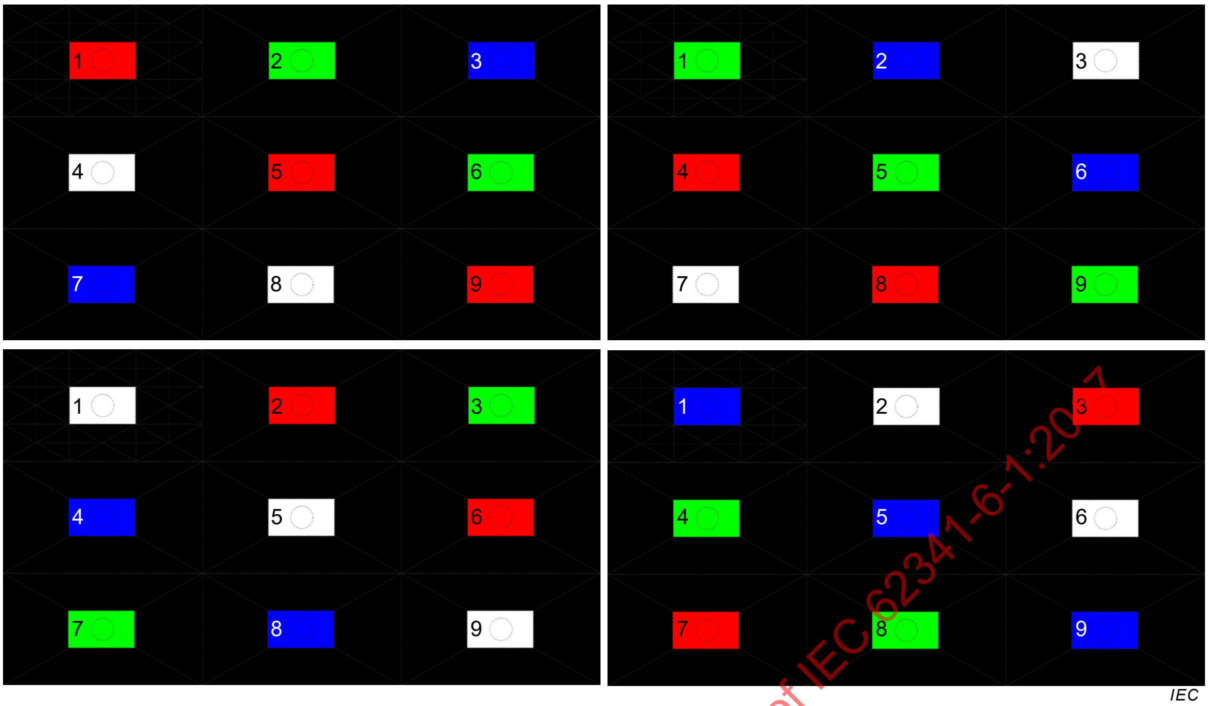


Figure 4 – Low APL loading series of red, green, blue, and white test patterns used for basic luminance, colour, and uniformity measurements

The area scaling of the coloured rectangles is adjusted to manipulate the APL loading on the display. The amount of APL loading is input-referred, assuming it is an RGB digital input. The percent APL is defined as:

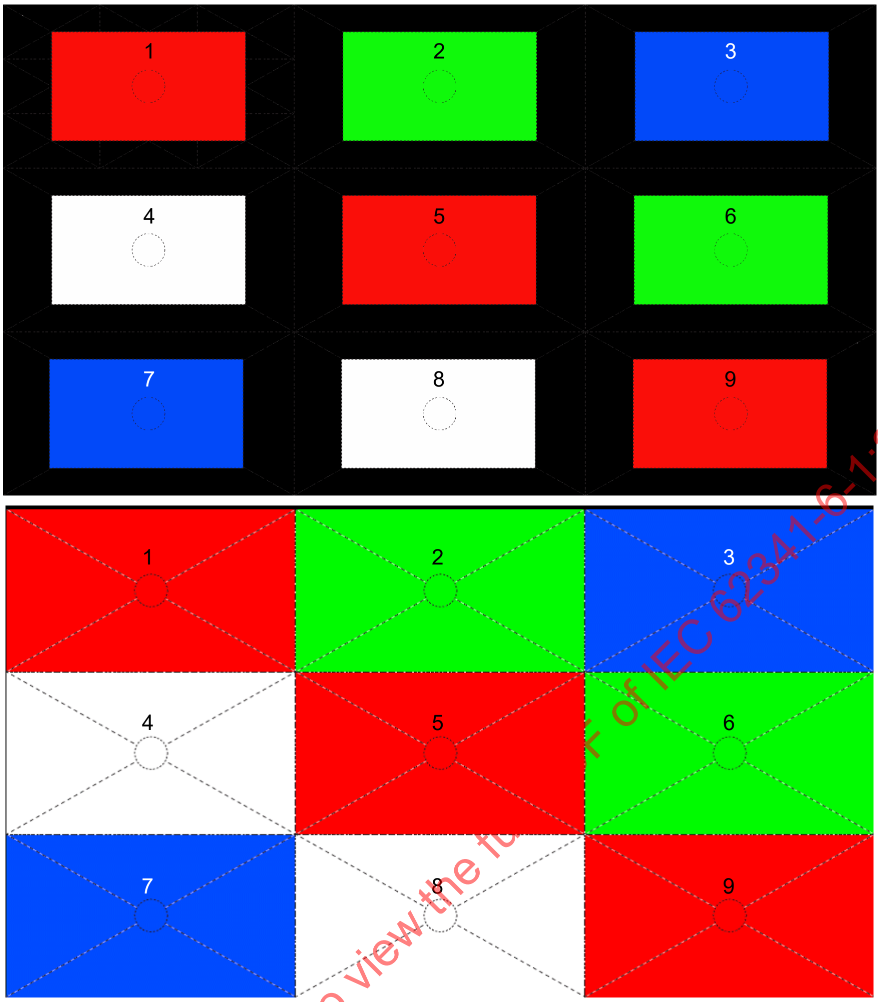
$$APL(\%) = 100 \times \frac{\sum_{i=1}^{N} PL\mathrm{i}}{N} \tag{1}$$

where the summation is over all pixels in the active area, PL_i is the normalized signal pixel level of the i-th pixel relative to maximum white level, and N is the total number of pixels. A 100 % APL would be represented by all pixels in the active area at maximum white level. This would be implemented by setting the levels for the red, green, and blue input channels to their maximum values. A single primary colour (e.g. red) rendered on a full screen would have 1/3 of the APL of a full white screen. If it is assumed that the red, green, and blue areas correspond to 1/3 of the APL of the white areas, then the APL for each pattern in Figure 4 is (starting at the upper left-hand corner and going clockwise) 5,3 %, 5,3 %, 6,2 %, and 5,3 %. The average APL for the four patterns in Figure 4 is 5,6 %. An example calculation of the top left pattern in Figure 4 is given by:

[(7 primary colours x 1/3 of white) + (2 white boxes x 3/3 of white)]

x [(1/9)^2 fractional area of boxes] = 5,3% APL

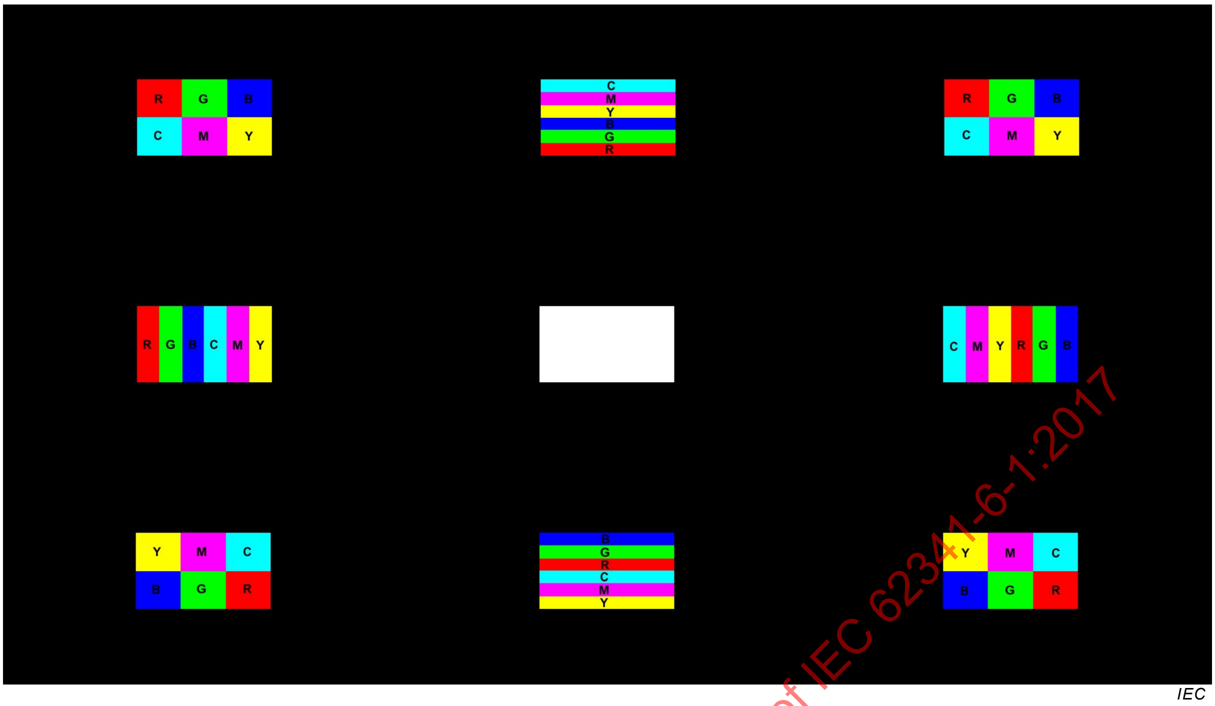
Higher loading versions of the colour tile pattern are illustrated in Figure 5. The sequence of four-colour tile patterns at the medium loading geometry would give an average APL equivalent of 22 %, whereas the high loading pattern would give an average APL equivalent of 50 %.



NOTE The corresponding CTG, CTB, and CTW patterns are of similar size but have green, blue, and white, respectively, in the centre box.

Figure 5 – Medium (top) and high (bottom) APL loading versions of CTR pattern

In cases where more than the white and RGB input primary colours are needed for luminance and colour measurements, the low APL loading RBGCMY box pattern illustrated in Figure 6 shall be used. This pattern is intended for centre luminance and colour measurements. Each coloured box is centred on the nine standard active area locations (see Figure 2) on a black background, with height and width corresponding to 1/9 of the dimensions of the active area. Each of the white, red, green, blue, cyan, magenta, and yellow colours are at their maximum input-referred signal setting as defined in Table 1. The centre rectangle can be changed to the desired colour to be measured. However, the colours of the surrounding eight rectangular patterns shall remain constant. If a maximum white colour is rendered in the centre box, the APL is 6,2 % for this low loading case. Additional higher-loading patterns may also be used. For example, a medium APL loading pattern with 2/9 of the dimensions of the active area that produces about 25 % APL is illustrated in Figure 7. A high-loading version, where each rectangle is 1/3 of the active area's dimensions, would have 56 % APL.

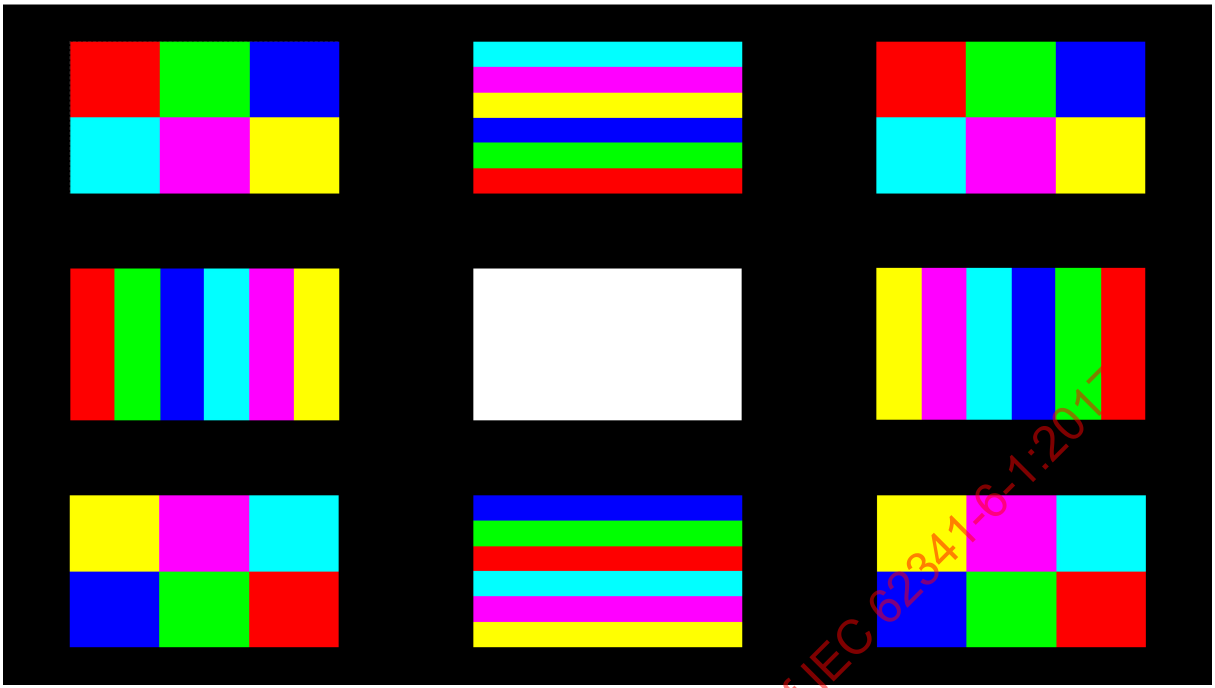


NOTE The centre rectangle can be changed to any desired colour, while the surrounding rectangles remain fixed. The notation identifies the colours used in the pattern and is not displayed when measurements are taken.

Figure 6 – Standard low APL RGBCMY test pattern used for centre luminance and colour measurements

Table 1 – Standard digital-equivalent input signals for rendering the white, primary and secondary colours in test patterns

Colour Q	Equivalent 8-bit digital signal level		
	Red channel	Green channel	Blue channel
K (Black)	0	0	0
R (Red)	255	0	0
G (Green)	0	255	0
B (Blue)	0	0	255
Y (Yellow)	255	255	0
M (Magenta)	255	0	255
C (Cyan)	0	255	255
W (White)	255	255	255



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NOTE The centre rectangle can be changed to any desired colour, while the surrounding rectangles remain fixed.

Figure 7 – Optional medium APL RGBCMY test pattern used for centre luminance and colour measurements

A more detailed evaluation of APL loading can be performed by starting with the low APL test pattern in Figure 6, but the size of all boxes increases gradually until the entire screen is filled. The colour pattern of each box location remains the same; only the size of each box changes.

6 Measuring methods for optical parameters

6.1 Primary luminance, colour, and uniformity of full-colour high-resolution modules

6.1.1 Purpose

The purpose of this method is to measure the display luminance, colour, and their uniformity at maximum RGB and white input signal levels rendered on full-colour high-resolution OLED display modules. The white field correlated colour temperature (CCT) is also measured. The standard low APL loading colour tile pattern defined in Figure 4 shall be used for these measurements. Additional higher-loading versions of this pattern may also be measured.

6.1.2 Measuring conditions

The following measuring conditions apply.

a) Apparatus: a light-measuring device that can measure luminance and colour, a driving power source, driving signal equipment, and a means to translate the LMD or the display.

b) Standard environmental measurement conditions, dark room conditions, and standard setup conditions.

c) Standard low APL loading sequence of colour tile patterns (see Figure 4).

6.1.3 Measuring method for high-resolution full-colour modules

Measure the maximum white and RGB luminance and colour at the nine standard screen locations using the following procedure.

a) Render the CTR colour tile pattern with a red centre box (see the upper left pattern in Figure 4) on the OLED display and allow the luminance to stabilize.

b) Align the optical axis of the LMD perpendicular to the display screen and centred on the standard position P_1 (see Figure 2) in the centre of the upper left-hand coloured box.

c) Measure the luminance and CIE 1931 chromaticity coordinates (x, y).

d) Translate the LMD (or display) to the other standard display positions (P_2 to P_9) in sequence and measure the luminance and colour at each position. When a white box is measured, also record the CCT value if available from the LMD.

e) Render the next colour tile pattern (Figure 4), and repeat steps b) to d) above.

f) Repeat luminance and colour measurements at all nine display positions for all coloured tile patterns as illustrated in Figure 8, for a total of 36 measurements.

g) Report the combined luminance and colour for each colour Q (where in this case Q = R, G, B or W) at the nine display positions as indicated in Table 2 and Table 3. For example, the white luminance and colour data is extracted from the measurements of all four colour tile patterns, which together uniquely provide a white box at each of the nine standard locations.

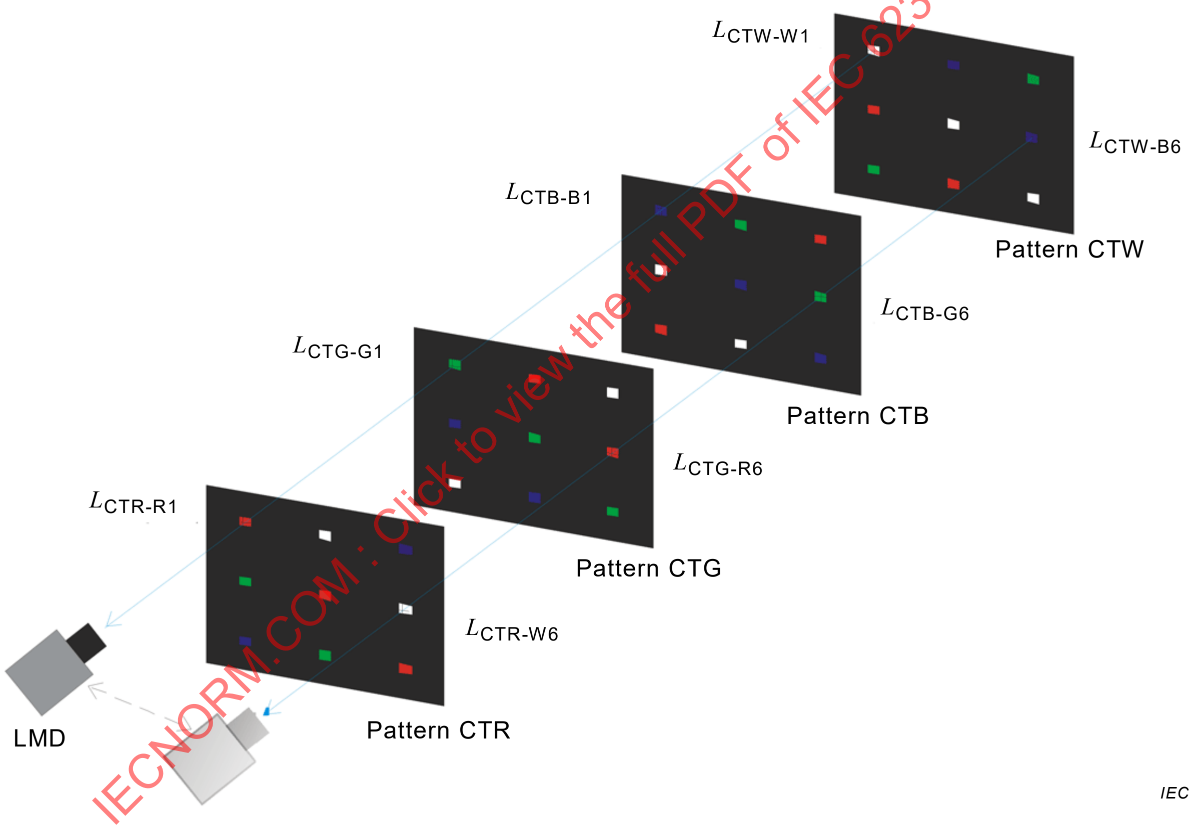


Figure 8 – Sequence for measuring luminance and colour at the nine standard display positions for all coloured tile patterns

Table 2 – Example of luminance measured of the same colour at the nine standard screen positions and the resulting luminance non-uniformity

Measuring point	Luminance L_i for colour Q cd/m^2
P_1	210
P_2	205
P_3	208
P_4	199
P_5	195
P_6	211
P_7	215
P_8	204
P_9	207
L_{ave}= 206 cd/m^2; L_{max}= 215 cd/m^2; L_{min}= 195 cd/m^2; NU= 9,3 %	

Table 3 – Example of the same colour measured at the nine standard screen positions and the resulting chromaticity non-uniformity

Measuring point	x_{Qi}	y_{Qi}	u'_{Qi}	v'_{Qi}	$\Delta u'v'$ for any colour Q								
					P_1	**P_2**	**P_3**	**P_4**	**P_5**	**P_6**	**P_7**	**P_8**	**P_9**
P_1	0,311	0,325	0,198	0,466	0,000								
P_2	0,330	0,320	0,214	0,466	0,016	0,000							
P_3	0,307	0,323	0,196	0,464	0,003	0,018	0,000						
P_4	0,309	0,328	0,196	0,467	0,002	0,018	0,003	0,000					
P_5	0,310	0,326	0,197	0,466	0,001	0,017	0,002	0,001	0,000				
P_6	0,303	0,319	0,195	0,461	0,006	**0,020**	0,003	0,006	0,005	0,000			
P_7	0,311	0,324	0,199	0,465	0,001	0,015	0,003	0,004	0,002	0,006	0,000		
P_8	0,315	0,320	0,203	0,464	0,005	0,011	0,007	0,008	0,006	0,009	0,004	0,000	
P_9	0,314	0,327	0,199	0,467	0,001	0,015	0,004	0,003	0,002	0,007	0,002	0,005	0,000
$(x_Q, y_Q)_{ave}$=(0,312, 0,323); $(\Delta u'v')_{max}$= 0,020													

6.1.4 Maximum luminance of white and RGB primaries

The maximum luminance is calculated for white ($L_{W,ave}$) and the red ($L_{R,ave}$), green ($L_{G,ave}$) and blue ($L_{B,ave}$) primaries from the average of the luminance measurements at the nine standard positions (P_1 to P_9). The results shall be recorded as suggested in Table 2.

6.1.5 Average colour of white and RGB primaries

The average colour is determined at the maximum input signal level for each colour. Since the space in the CIE 1931 chromaticity diagram is not linear, the chromaticities of each colour (x_{Qi}, y_{Qi}) at screen position P_i shall first be converted to CIE tristimulus values using the following relations:

$$X_{Qi} = \frac{x_{Qi} L_{Qi}}{y_{Qi}} \tag{2}$$

$$Y_{Q_i} = L_{Q_i} \tag{3}$$

$$Z_{Q_i} = \frac{(1 - x_{Q_i} - y_{Q_i})L_{Q_i}}{y_{Q_i}} \tag{4}$$

where L_{Q_i} is the luminance of the window pattern at screen position Pi for the colour Q. The average CIE tristimulus values X_Q, Y_Q, Z_Q for each colour (Q = R, G, B or W) are then calculated from the measurements at the nine standard positions (P_1 to P_9). The average CIE 1931 chromaticity coordinates of each colour are obtained from the average tristimulus values by using the following formulae:

$$x_Q = \frac{X_Q}{X_Q + Y_Q + Z_Q} \tag{5}$$

$$y_Q = \frac{Y_Q}{X_Q + Y_Q + Z_Q} \tag{6}$$

The average CIE 1931 chromaticity coordinates (x_Q, y_Q) for white and the input-referred RGB primaries shall be recorded as suggested in Table 3. In the Table 3 example, the luminance values at each screen location in Table 2 are used in conjunction with the chromaticity coordinates at those positions to determine the average CIE 1931 chromaticity coordinates following Formulae (2) to (4).

6.1.6 Luminance uniformity of white and RGB primaries

The luminance uniformity of a given colour is characterized at the maximum input signal level for that colour. For each colour, determine the maximum and minimum luminance values from the measurements taken at the nine standard positions. The luminance non-uniformity of the display is characterized by the following formula:

$$NU(\%) = 100 \times \frac{L_{max} - L_{min}}{L_{max}} \tag{7}$$

The luminance uniformity (U) is 100-$NU(\%)$. Record the luminance non-uniformity results for each colour as suggested in Table 2.

6.1.7 Colour non-uniformity of white and RGB primaries

For each colour Q, convert the CIE 1931 chromaticity coordinates measured at the nine standard positions to the CIE 1976 UCS (uniform chromaticity scale) chromaticity coordinates (u'_Q, v'_Q) using the following formula:

$$u'_Q = \frac{4x_Q}{3 - 2x_Q + 12y_Q}, v'_Q = \frac{9y_Q}{3 - 2x_Q + 12y_Q} \tag{8}$$

Record the CIE 1976 UCS chromaticity coordinates for each colour and screen position as suggested in Table 3. For each location P_i of the same rendered colour, determine the CIE 1976 chromaticity difference between pairs of measured CIE 1976 UCS chromaticity coordinates (u', v') using the following formula:

$$\Delta u'v' = \sqrt{\left(u_i' - u_j'\right)^2 + \left(v_i' - v_j'\right)^2} \tag{9}$$

for i, j = 1 to 9, and $i \neq j$. The colour non-uniformity is defined as the largest chromaticity difference $(\Delta u'v')_{max}$ between any two screen positions. The largest colour difference can be narrowed down by plotting the nine (u', v') coordinates rather than calculating all (u', v') pairs. Record the CIE 1976 UCS chromaticity difference for each colour to no smaller uncertainty than ±0,001, as illustrated in Table 3.

6.1.8 Colour additivity of white and RGB primaries

The colour-signal white luminance (L_{CSW}) is the sum of the average luminance for the rendered red, green and blue input-referred primaries ($L_{R,ave} + L_{G,ave} + L_{B,ave}$). Any difference between the measured average white luminance ($L_{W,ave}$) and L_{CSW} indicates a lack of additivity of the colour signal primaries in the display colour management. If $L_{W,ave} \neq L_{CSW}$, then this discrepancy shall be described in the test report.

6.1.9 White correlated colour temperature

The correlated colour temperature of a white light source can be graphically extracted using a chromaticity diagram (see Figure 9). A white light source whose chromaticity is closest to a line perpendicular to the Planckian locus of a blackbody radiator at a specific temperature (a point on the Planckian locus) is defined as having a correlated colour temperature at this temperature (see Figure 9). This is strictly valid only for the deprecated CIE 1960 uniform chromaticity scale diagram. If white CCT values are measured directly by the LMD at the nine standard screen positions, record the average white CCT value. If the measurement instrument does not provide the CCT directly, there are some methods to obtain the CCT from chromaticity coordinates (see Annex D). The CCT is generally only valid for white colours, not individual primaries.

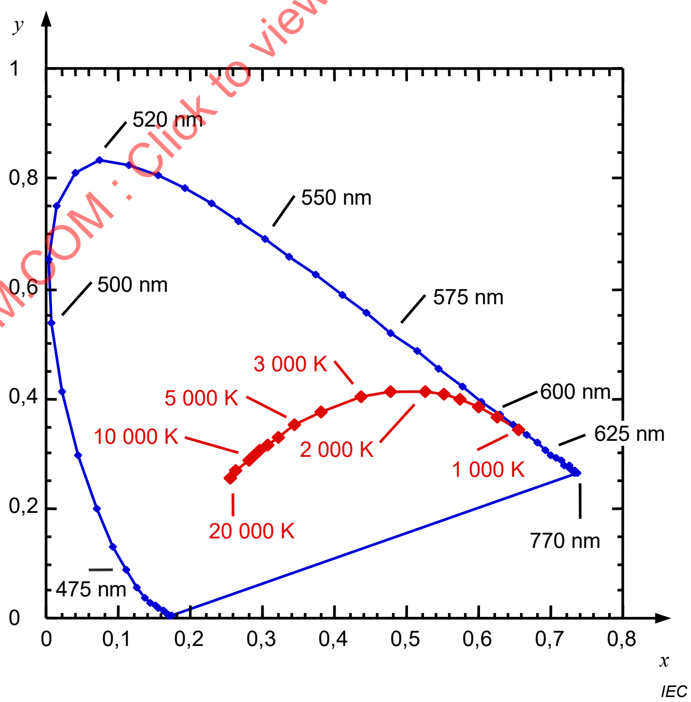


Figure 9 – Colour of blackbody source at various temperatures as represented on the CIE 1931 chromaticity diagram

6.2 Primary luminance, colour, and uniformity of low-resolution modules

6.2.1 Purpose

The purpose of this method is to measure the luminance, colour, and uniformity of low-resolution displays with pixel counts below 320 × 240 pixels and for segmented displays. If the low-resolution displays have full-colour capability, then the individual RGB primaries shall be measured, along with white, at their maximum signal level. Otherwise, the maximum luminance setting at the input signal channels will be used for each primary. If the display is capable of rendering a white field, the CCT will also be measured. A full-screen pattern will be used for low-resolution displays.

6.2.2 Measuring conditions

The following measuring conditions apply.

a) Apparatus: a light-measuring device that can measure luminance and colour, a driving power source, driving signal equipment, and a means to translate the LMD or the display.

b) Standard environmental measurement conditions, dark room conditions, standard setup conditions.

6.2.3 Measuring method for low-resolution modules and segmented displays

For full-colour displays, measure the maximum white and RGB luminance and colour at the nine standard screen locations (P_1 to P_9, see Figure 2). Render a full-screen pattern for each colour. The LMD is aligned normal to the screen and translated to the centre of each standard position. Record the measurements in a similar manner to Table 2 and Table 3. Calculate the average luminance, average chromaticity, luminance and colour non-uniformity, and white CCT following the analysis described in 6.1. Record the results in a similar manner to Table 2 and Table 3.

For monochrome displays, apply an input signal to make the full screen emit at the highest luminance level. Measure the maximum luminance and colour at the nine standard screen locations. Calculate the average luminance, average chromaticity, luminance and colour non-uniformity, and white CCT (if applicable) in line with the analysis described in 6.1. Record the results in a similar manner to Table 2 and Table 3.

For segmented displays, measure the luminance and colour inside each unique colour segment closest to the centre at its maximum signal level. The segment location measured shall be recorded. Record the measurement results.

6.3 Signal loading

6.3.1 Purpose

The purpose of this method is to measure the change in active matrix display luminance when increasing the APL.

6.3.2 Measuring conditions

The following measurement conditions apply.

a) Apparatus: a light-measuring device that can measure luminance, a driving power source, and driving signal equipment.

b) Standard environmental measurement conditions, dark room conditions, standard setup conditions.

6.3.3 Measuring methods

a) Set up the OLED display and the LMD under the standard measurement conditions.

b) Set up the measurement following the layout diagram shown in Figure 2, with the measurement field located at position P_5 in the centre of the screen.

c) Render the lowest APL pattern on the screen, with the white box in the centre (see Figure 6).

d) For a monochromatic display, apply a maximum input signal to make the box emit at the highest luminance level. The box shall have the same dimensional scaling as the equivalent white box area in the APL loading pattern.

e) Take a luminance measurement in the middle of the centre box.

f) Increase the size of each coloured box. Measure the luminance of increasingly larger boxes until the screen is filled. It is recommended that the box dimensions described in Table 4 be used. If other dimensions are used, they shall be noted.

g) Determine the signal loading for white. The display signal loading S_{load} is defined as:

$$S_{\text{load}} = 100 \times \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}}} \tag{10}$$

where L_{max} and L_{min} are the maximum and minimum luminance, respectively, measured for the centre boxes at the various sizes.

h) The centre box colour may be changed to any of the RGBCMY individual colours at their maximum signal level, and the signal loading procedure repeated for that colour.

i) Report all the measured luminance values and box dimensions, the maximum and minimum luminance for each colour, the percentage of signal loading for each colour, the OLED display settings, the test pattern used, and the measurement configuration.

Table 4 – Scaling the size of the colour boxes in the APL loading pattern relative to the screen dimensions

Box dimensional scaling (relative to screen dimension)	Percentage of coloured screen area	Percent APL (equivalent white area)
1/9	11 %	6,2 %
1/8	14 %	7,8 %
1/7	18 %	10 %
1/6	25 %	14 %
1/5	36 %	20 %
1/4	56 %	31 %
1/3	100 %	56 %

6.4 Dark room contrast ratio

6.4.1 Purpose

The purpose of this method is to measure the dark room contrast ratio (DRCR) of the OLED display under test using the standard low APL colour tile pattern.

6.4.2 Measuring conditions

The following measuring conditions apply.

a) Apparatus: a light-measuring device that can measure luminance, a driving power source, driving signal equipment, and a means to translate the LMD or the display.

b) Standard environmental measurement conditions, dark room condition, standard setup conditions.

6.4.3 Measuring method

Measure the low APL loading dark room contrast ratio using the following procedure.

a) Follow the procedure in 6.1 to determine the average white luminance $L_{W,ave}$. Use 6.2 for low-resolution, monochrome or segmented displays.
b) Render a full black screen at the lowest input signal level.
c) Align the optical axis of the LMD perpendicular to the display screen and centred on the standard position P_1 (see Figure 2) and measure the luminance at that position.
d) Translate the LMD to the remaining eight standard positions and measure the luminance at each position.
e) Calculate the average black luminance $L_{K,ave}$ from the nine positions.
f) The low APL loading dark room contrast ratio $DRCR_{LL}$ is given by:

$$DRCR_{LL} = \frac{L_{W,ave}}{L_{K,ave}} \tag{11}$$

g) Record the average white and black luminance, the low APL loading dark room contrast ratio, the OLED display settings, the test pattern used, and the measurement configuration.
h) Additional contrast ratio measurements may be made using the average white luminance from the medium- and high-loading test patterns in Figure 5. These results shall be recorded with their test conditions.

6.5 Display colour gamut, colour gamut area, and colour gamut volume

6.5.1 Purpose

The range of colours that the display can render can be illustrated by its colour gamut, and quantitatively expressed in terms of an area in a two-dimensional colour space, or a volume in a three-dimensional colour space. The procedures for determining these attributes are described. The colour measurements are determined by using the standard low APL loading colour tile pattern given in Figure 6. This method applies only to full-colour displays.

6.5.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a light-measuring device that can measure luminance and colour, a driving power source, driving signal equipment, and a means to translate the LMD or the display.
b) Standard environmental measurement conditions, dark room conditions, standard setup conditions.

6.5.3 Measuring method

The specified colours are input-referred, and generally measured at their maximum signal level. The maximum input signal levels for the primary and secondary colours are given in Table 1. The chromaticity coordinates of the desired colour to be measured, Q, are obtained through the following procedure.

a) Render the low APL loading RGBCMY test pattern (Figure 6) with the desired colour Q in the centre box on the OLED display and allow the luminance to stabilize.
b) Align the optical axis of the LMD perpendicular to the display screen and centred on the standard position P_5 (see Figure 2) in the centre of the screen.
c) Measure the luminance and CIE 1931 chromaticity coordinates (x, y).
d) Record the luminance and chromaticity coordinates, and repeat measurements for other centre colours as needed. Additional APL loading versions of the RGBCMY pattern (Figure 6) may also be measured as needed to better represent the intended application.

6.5.4 Display colour gamut

The display colour gamut is obtained by measuring the CIE 1931 chromaticity coordinates of the RGB primaries at their maximum input-referred signal levels using the procedure specified in 6.5.3. For low-resolution displays, 6.2 may be used. The colour gamut can be represented by the triangle in the CIE 1931 chromaticity diagram formed by the red (x_R, y_R), green (x_G, y_G), and blue (x_B, y_B) colours as corner points. An example is shown in Figure 10.

6.5.5 Display colour gamut area in CIE 1976 chromaticity diagram

The colour gamut area is defined as the percentage colour space area enclosed by the colour gamut relative to the entire spectrum locus in the CIE 1976 UCS chromaticity diagram. As described in 6.5.4, the colour gamut is defined by the chromaticity coordinates rendered when a maximum signal is sequentially applied to the RGB signal inputs. Figure 10 illustrates an example where the same RGB primaries are plotted in the CIE 1931 (left) and CIE 1976 (right) chromaticity diagrams. Formula (8) was used to convert the chromaticity coordinates. The area enclosed by the RGB triangle in the CIE 1976 chromaticity diagram is calculated as

$$A_{u'v'} = 256{,}1 \times \left| (u'_R - u'_B)(v'_G - v'_B) - (u'_G - u'_B)(v'_R - v'_B) \right| \quad (12)$$

where the subscripts R, G and B refer to the red, green and blue primaries, respectively. The colour gamut area for the example of sRGB primaries (IEC 61966-2-1) in Figure 10 would be 33 %.

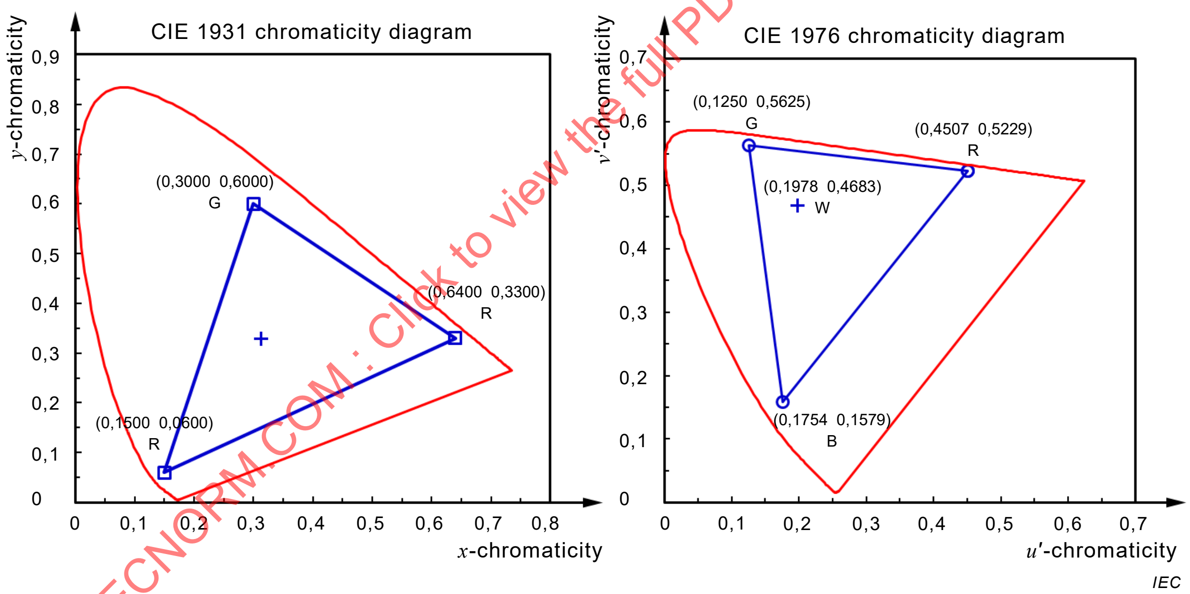


Figure 10 – Example representation of the same primary colours in the CIE 1931 (left) and CIE 1976 (right) chromaticity diagrams

6.5.6 Colour gamut volume

A more accurate representation of the colour range can be obtained by sampling the boundary colours of the display's gamut in a three-dimensional colour space. The CIELAB colour space will be used for this purpose (see publication CIE 15:2004). The purpose of this method is to measure the colour gamut volume of the colour gamut boundary of an OLED display module under dark room conditions. This colour gamut volume shall be compared to the IEC sRGB standard (IEC 61966-2-1) colour gamut volume with a D65 white point. The percentage of the sRGB colour gamut volume shall be obtained using the following procedure.

a) The low APL loading RGBCMY test pattern (Figure 6) shall be used to measure the desired central box colours. The colours will be measured according to the procedure in

6.5.3. Additional measurements on higher APL loading versions of the same test pattern may be made if needed for the intended application.

b) The colour gamut volume calculation requires that at least red, green, blue, cyan, yellow, magenta, black and white (see Table 1) be measured. Each of these colours (except black) is displayed at their maximum signal level. The measurement of additional colours helps to make the calculation more accurate.

c) The chromaticity coordinates of each colour shall be converted to tristimulus values using Formulae (2) to (4).

d) The tristimulus values shall be transformed into the three-dimensional CIELAB colour space specified by CIE 15:2004. Additional three-dimensional uniform colour spaces may also be used and identified in the test report. Each colour point can be plotted on the L^*, a^*, and b^* axes of the CIELAB colour space by referencing the peak white tristimulus values (X_W, Y_W and Z_W) and by using the following transformation formulae:

$$L^* = 116 \times f(Y_Q/Y_W) - 16 \quad (13)$$

$$a^* = 500 \times f(X_Q/X_W) - f(Y_Q/Y_W) \quad (14)$$

$$b^* = 200 \times f(Y_Q/Y_W) - f(Z_Q/Z_W) \quad (15)$$

where

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

An example of the colour data in the CIELAB uniform colour space is given in Figure 11.

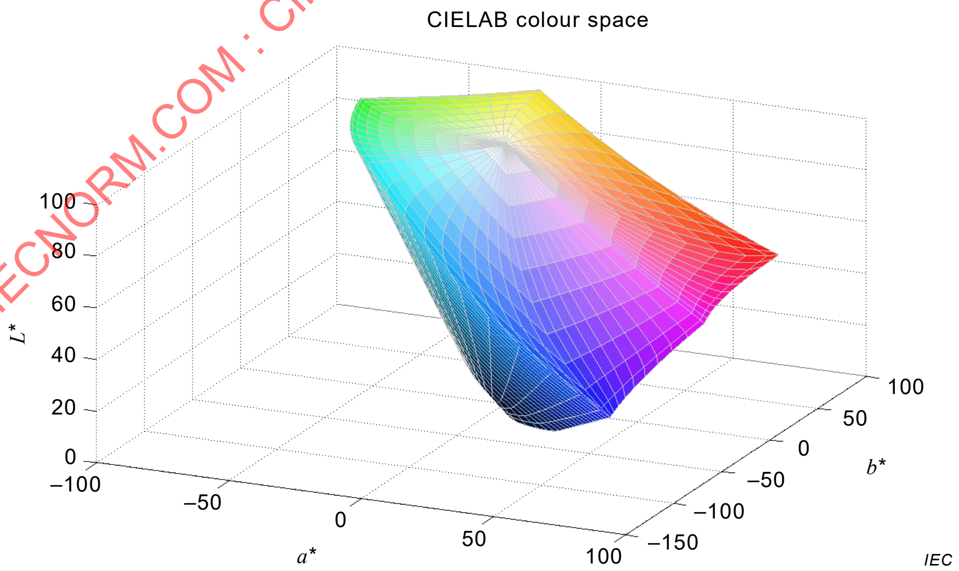


Figure 11 –Example of the range of colours produced by a given display as represented by the CIELAB colour space

e) Calculate the colour gamut volume corresponding to the possible range of display colours as represented in the CIELAB colour space. See IEC 62341-6-2:2015, Annex C, for a detailed description of the analysis recommended to calculate the colour gamut volume.

Other gamut calculation methods may be used, however, they shall yield the same results as the reference method described in IEC 62341-6-2.

f) Record the percentage of colour gamut volume relative to the IEC sRGB standard colour space (IEC 61966-2-1), the tristimulus values of each colour, the test pattern used, and the measurement conditions.

7 Measuring methods for power consumption

7.1 Purpose

The purpose of this method is to measure the power consumption of the OLED display module under defined APL loading conditions. The test pattern and APL loading conditions shall be dependent upon the intended application.

7.2 Measuring conditions

The following measuring conditions apply.

a) Apparatus: a light-measuring device that can measure luminance, an ammeter, a voltmeter, a DC power source, an image signal generator.

b) Standard environmental measurement conditions, dark room conditions, standard setup conditions.

7.3 Measuring method

Proceed as follows.

a) Make all the electrical connections needed to operate the module under standard conditions. See the example setup in Figure 12.

b) Render the low, medium, or high APL loading version of the RGBCMY pattern with a white centre box (see for example Figure 6 and Figure 7) which most closely corresponds to the display's main intended use case. For TV and internet applications, the power consumption can alternatively be measured by the standard dynamic broadcast-content video or internet-content video, respectively, specified in IEC 62087-2. For PMOLED and low-resolution displays, the equivalent white rectangle for one of the versions of the low (6,2 %), medium (25 %), and high (56 %) APL loading RGBCMY patterns should be used. Set all power supplies to the standard voltage specification values. The test pattern or video content used shall be noted in the test report.

c) Measure the display luminance in the centre of the white box of the RGBCMY pattern. A luminance measurement is not taken for the video content. The rated luminance and the driving signal shall be specified in the report.

Record the luminance and all relevant power, voltage and current readings of all meters in Figure 12. See example in Table 5.

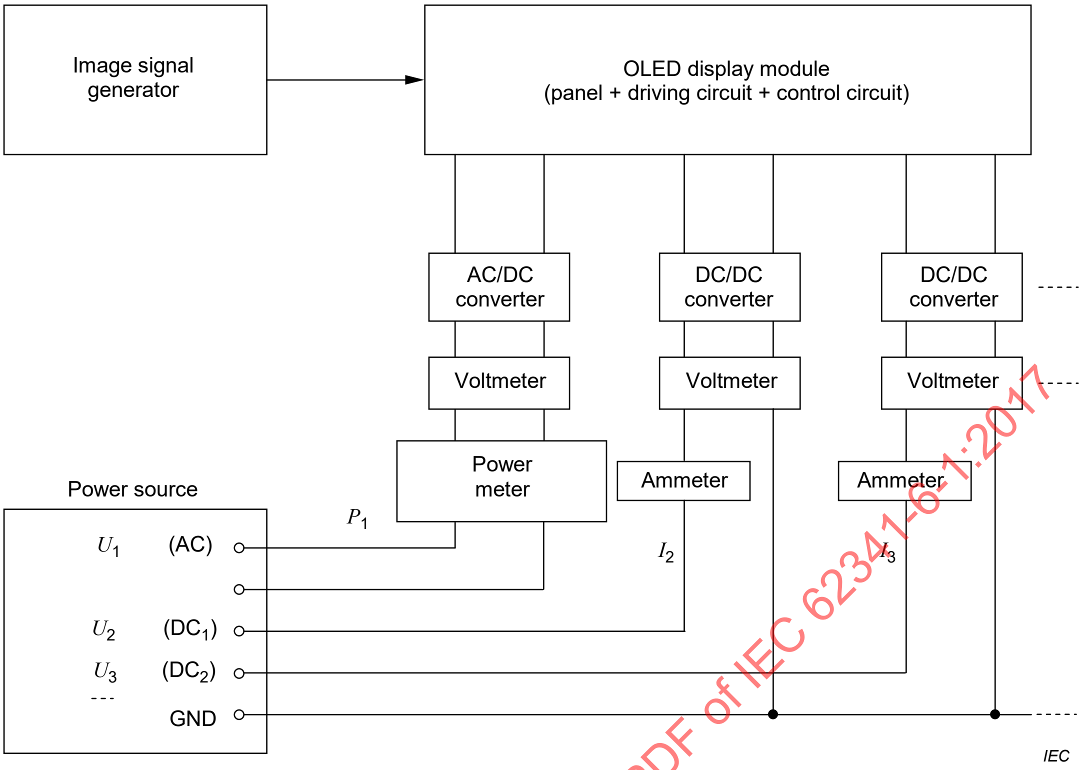


Figure 12 – Example of measurement setup of power consumption

Table 5 – Example of a summary sheet for module power consumption measurements

Source number	Power source	Voltage U	Current (mA)	Electrical power (mW)	Remarks
1	AC power source AC_1	U_1	–	P_1	
2	DC power source DC_1	U_2	I_2	$P_2 = U_2 \times I_2$	
3	DC power source DC_1	U_3	I_3	$P_3 = U_3 \times I_3$	
	⋮	⋮	⋮	⋮	
Total	Total power consumption			$P_{Tot} = P_1 + P_2 + P_3$	At 100 % white level

d) The total module power may also be measured at other white luminance levels and/or with a uniformly distributed pattern lighting a fraction of the total pixels. It could give significantly different results from the specified method depending on the efficiency versus luminance curve of the display. In this case, the luminance level and fraction shall be recorded.

Annex A
(normative)

Response time of passive matrix display panels

A.1 Purpose

The purpose of this method is to measure the response time of the passive matrix display panels.

A.2 Measuring conditions

The following measuring conditions apply.

a) Apparatus: drive signal equipment that can output an invertible plain field voltage signal (full screen white and black), an LMD that can produce a linear response to rapid changes in luminance and can transform the luminance signal into an electrical signal. The response time and sample time of the LMD shall be less than one-tenth of the response time of the passive matrix display panel.

NOTE A signal recorder having sufficient frequency bandwidth (typically > 10x) is needed to accurately record the driving signal.

b) Standard environmental measurement conditions, dark room conditions, standard setup conditions.

A.3 Measuring method

Proceed as follows.

a) Connect the voltage power source to the panel and ensure that only a certain area (e.g. 5 mm × 5 mm) in the centre of the display panel can be lit when the panel is in the ON state.

b) Operate the display at a steady OFF state, and then change the driving voltage to make the display skip to the ON state in an instant. Measure and record the luminance-time and driving voltage-time curves of the display by using the signal recorder, and obtain the turn-on time t_{on}.

c) Operate the display at a steady ON state, and then change the driving voltage to make the display panel skip to the OFF state in an instant. Measure and record the luminance-time and driving voltage-time curves of the display panel by using the signal recorder, and obtain the turn-off time t_{off}.

d) The lighted area, the response times of the LMD, the driving voltage source, the signal recorder, and the waveform of the driving voltage shall be recorded.

e) As an example, the relationship between the driving signal and the optical response times is shown in Figure A.1.

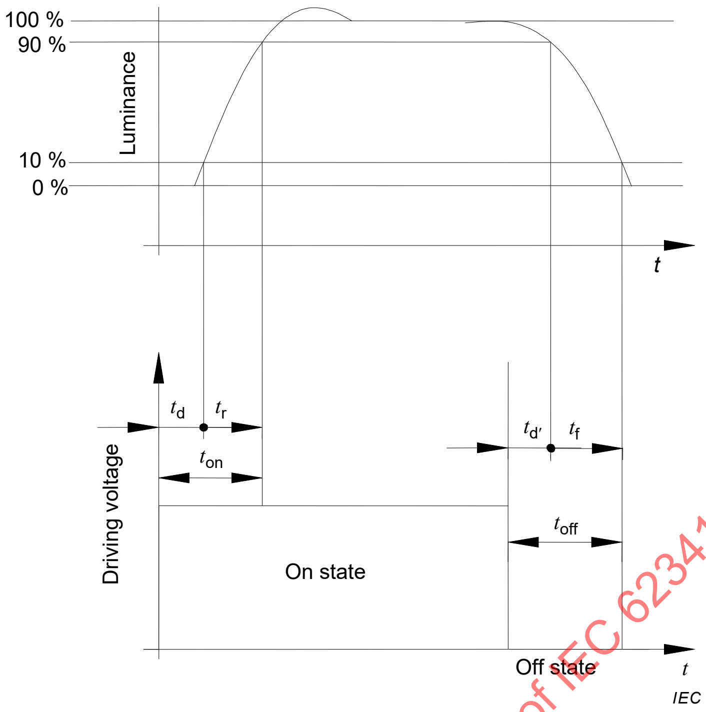


Figure A.1 – Relationship between the driving signal and the optical response times

The response time of the display panel includes the turn-on time t_{on} and the turn-off time t_{off}. The turn-on time includes the turn-on delay time t_d and the rise time t_r, and the turn-off time includes the turn-off delay time $t_{d'}$ and the fall time t_f.

The turn-on time t_{on} is defined as the time interval from the moment when the off-state voltage first skips to the on-state voltage (not including the skipping time) to the moment when the variational value of luminance reaches 90 % of the maximum variational value. The turn-on delay time t_d is defined as the time interval from the moment when the off-state voltage first skips to the on-state voltage (not including the skipping time) to the moment when the variational value of luminance reaches 10 % of the maximum variational value. The rise time t_r is defined as the time interval between 10 % and 90 % of the maximum variational value (as shown in Figure A.1).

The turn-off time t_{off} is defined as the time interval from the moment when the on-state voltage first skips to the off-state voltage (not including the skipping time) to the moment when the variational value of luminance reaches 90 % of the maximum variational value. Here, the turn-off delay time $t_{d'}$ is defined as the time interval from the moment when the on-state voltage first skips to the off-state voltage (not including the skipping time) to the moment when the variational value of luminance reaches 10 % of the maximum variable value, and the fall time t_f is defined as the time interval between 90 % and 10 % of the maximum variable value (as shown in Figure A.1).

Annex B
(normative)

Luminance current efficiency

B.1 Purpose

The purpose of this method is to measure the luminance efficiency of an OLED matrix display panel or equivalent test pixels, without row and column driving electronics.

B.2 Measuring conditions

The following measuring conditions apply.

a) Apparatus: a light-measuring device that can measure luminance, a ammeter and a DC power source.

b) Standard environmental measurement conditions, dark room conditions, standard setup conditions.

B.3 Measuring method

Proceed as follows.

a) An OLED display panel with drivers attached is generally not suitable for this measurement. Identify an OLED display panel where the total emitting diode current can be measured. This may require that all row contacts be shorted, and that column contacts be shorted. For a colour panel, the red, green, and blue sub-pixels shall be shorted independently of each other if possible. For passive matrix displays, high peak currents may preclude the simultaneous application of the pixel drive conditions over a sufficient display area. Where this is the case, test pixels with a structure as similar as possible to those on the display panel should be used.

b) Apply a current signal to the shorted contacts that simulates the pixel drive conditions in normal display operation. The drive signal for a given primary colour shall be equivalent to the primary colour current used to achieve a module white screen at 100 % grey level. For passive matrix displays, a pulsed current with the appropriate duty cycle will energize all sub-pixels of the same colour at the same time. If current loading is expected to severely impact the results, a smaller area of the display shall be energized. However, the emitting area shall include an adequate number of pixels ($>$ 500 pixels) in order to make an accurate luminance measurement.

c) Apply a 100 % red drive current to the red sub-pixels and measure the time-averaged current I_D used to energize the targeted area (A). The area (A) shall include the emitting sub-pixels and their surrounding dark area.

d) Measure the luminance (L) of the red emission from the emitting area of the OLED module following the diagram in Figure 1. If the emitting area is sufficiently large, an average luminance of five or nine spots (see 6.1.6) shall be used.

e) Apply a 100 % green drive current to the green sub-pixels and measure the time-averaged current I_D used to energize the targeted area (A). The area (A) shall include the emitting sub-pixels and their surrounding dark area.

f) Measure the luminance (L) of the green emission from the emitting area of the OLED module following the diagram in Figure 1.

g) Apply a 100 % blue drive current to the blue sub-pixels and measure the time-averaged current I_D used to energize the targeted area (A). The area (A) shall include the emitting sub-pixels and their surrounding dark area.

h) Measure the luminance (L) of blue emission from the emitting area of the OLED module as shown in the diagram in Figure 1.

i) The luminance current efficiency for each colour can be calculated by:

$$\eta C = \frac{LA}{I_D} \tag{B.1}$$

An example of a measurement configuration for measuring luminance current efficiency is shown in Figure B.1.

NOTE The driving signal, the test configuration, and the rated luminance are recorded.

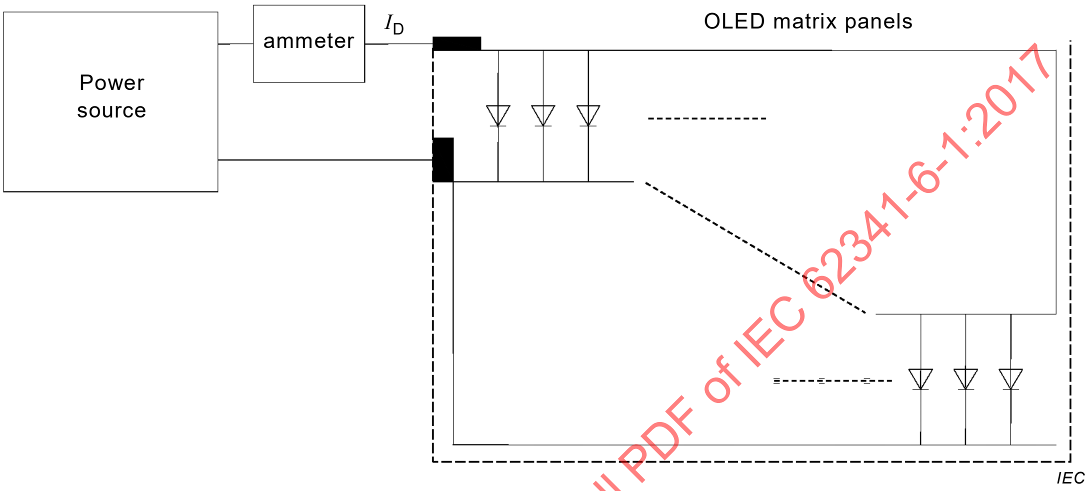


Figure B.1 – Example of a measurement configuration for measuring luminance current efficiency

Annex C
(informative)

Veiling glare frustum

When making optical measurements of black regions, stray light from adjacent bright regions of the displays can introduce significant errors. This is especially true for contrast measurements. Stray light can be significantly reduced by using a frustum. The frustum, or truncated cone, has an apex angle of 90°. It can be constructed from ~0,25 mm black vinyl plastic with a gloss surface on both sides, using the procedure described in Figure C.1.

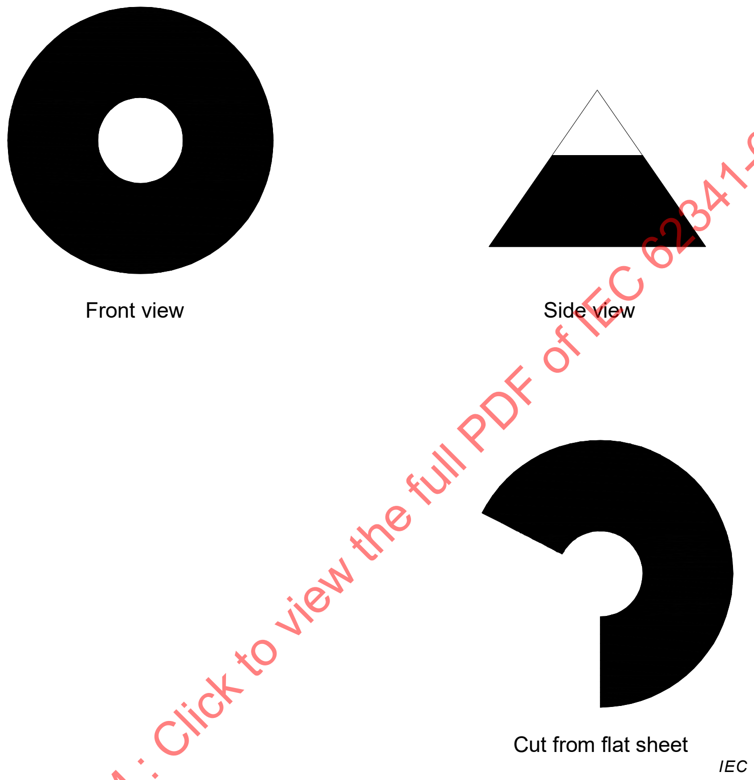


Figure C.1 – Pattern for veiling glare frustum

The equations relating to the frustum apex angle and inner/outer diameters can be found in [2]. A flat surface can be easily cut using mechanical compasses with a sharpened edge for cutting the plastic. Place one point at the centre and rotate around the centre with the cutter until the material becomes separated. Also, back and forth bending along a partial cut with a little stress can separate the material. Be sure to cut out the outer diameter first, otherwise the centre reference is lost.

When performing an optical measurement with the frustum, position the narrow end of the frustum above the measurement area of interest on the display without blocking the measuring instrument's aperture.

Annex D
(informative)

Methods to obtain the correlated colour temperature (CCT) from chromaticity coordinates

D.1 Method 1: using McCamy's approximate formula

A display's white field correlated colour temperature (T_{CCT}) may be calculated by using McCamy's approximate formula [4]:

$$T_{CCT} = 437n^3 + 3\,601n^2 + 6\,863n + 5\,517 \qquad \text{(D.1)}$$

where

$$n = (x - 0{,}332\,0) / (0{,}185\,8 - y) \qquad \text{(D.2)}$$

and x, y are the CIE 1931 chromaticity coordinates. This approximation is accurate between 2 000 K and 10 000 K. The measured colour of the source has to be relatively close ($\Delta u'v' < 0{,}01$) to that of the Planckian locus in order for the CCT to be valid [5].

D.2 Method 2: using Javier Hernandez-Andres's approximate formula

The white field correlated colour temperature (T_{CCT}) may be calculated by using Javier Hernandez-Andres's approximate formula [6]:

$$T_{CCT} = A_0 + A_1\exp(-n / t_1) + A_2\exp(-n / t_2) + A_3\exp(-n / t_3) \qquad \text{(D.3)}$$

where

$$n = (x - x_e) / (y - y_e) \qquad \text{(D.4)}$$

x, y are the CIE 1931 chromaticity coordinates and A_i, t_i are constants. These constants are listed in Table D.1. This approximation is accurate between 3 000 K and 8 × 10^6 K.

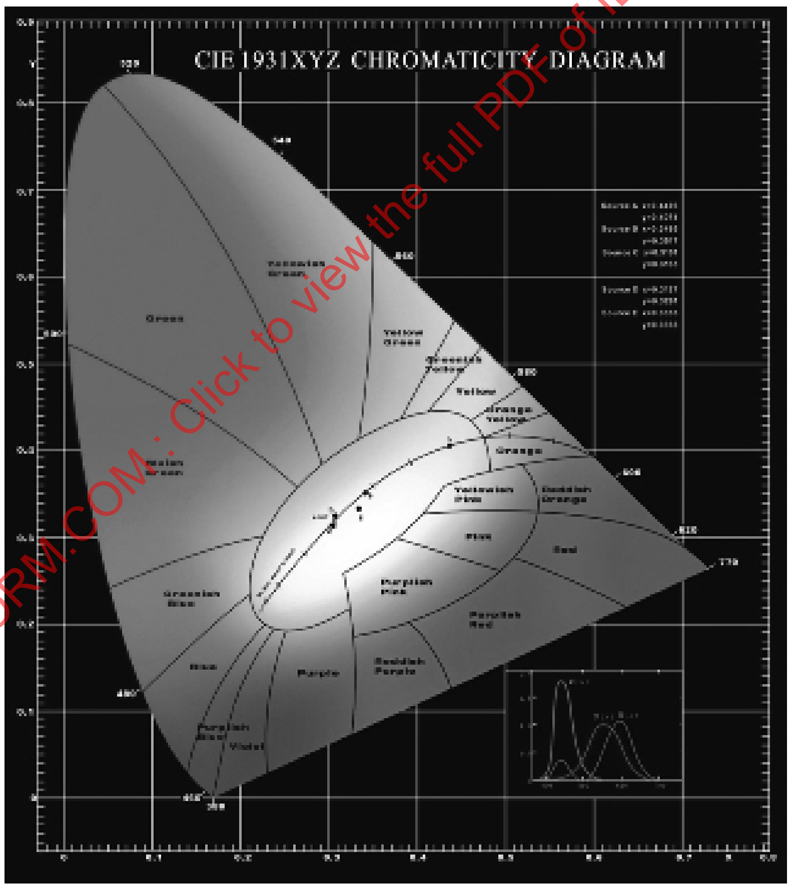
Table D.1 – x_e, y_e, A_i and t_i for Formula (D.3) and Formula (D.4)

Constants	Valid T_{CCT} range (K)	
	3 000 ~ 50 000	50 000 ~ 8 × 10^5
X_e	0,336 6	0,335 6
Y_e	0,173 5	0,169 1
A_0	–949,863 15	36 284,489 53
A_1	6 253,803 38	0,002 28
t_1	0,921 59	0,078 61
A_2	28,705 99	5,453 5 × 10^{-36}
t_2	0,200 39	0,015 43
A_3	0,000 04	/
t_3	0,071 25	/
NOTE Formula (D.3) has only two exponential terms in the higher CCT range.		

D.3 Method 3: graphical determination of correlated colour temperature

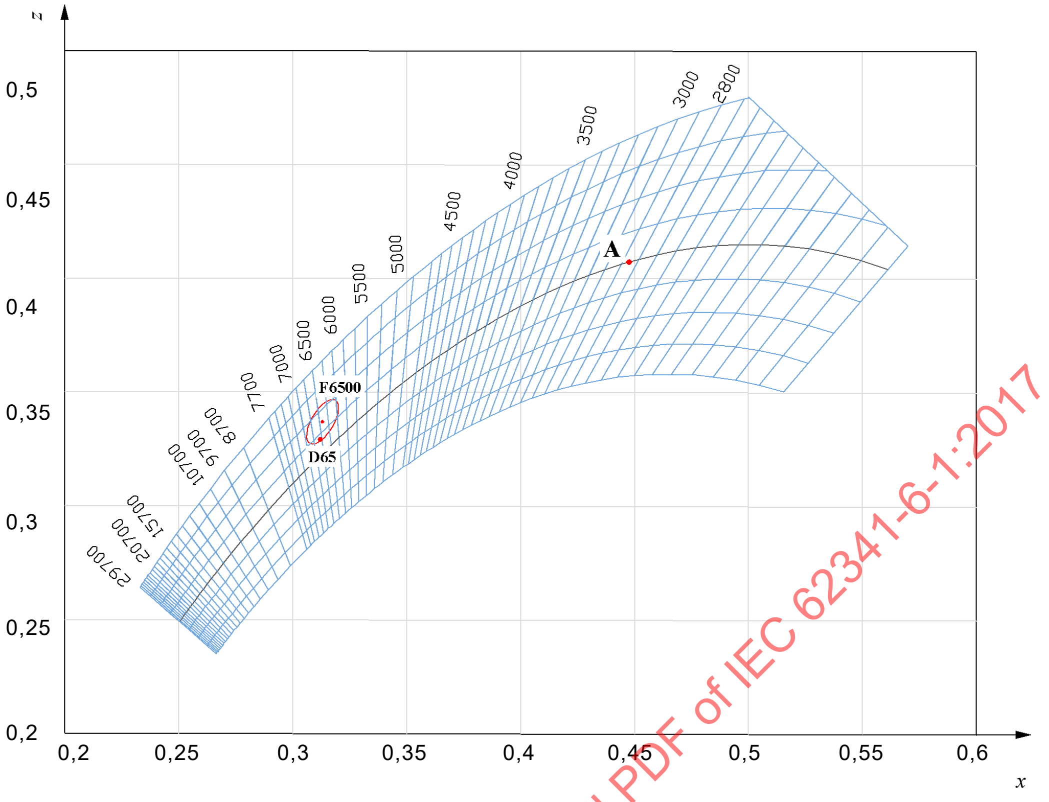
Correlated colour temperature (CCT) can be calculated from the chromaticity diagram shown in Figure D.1. By converting the CIE 1931 chromaticity coordinates (x, y) to CIE 1960 UCS chromaticity coordinates (u, v), the isotemperature lines are perpendicular to the Planckian locus on the CIE 1960 UCS diagram. The chromaticity point (u, v) is matched to the closest point on the Planckian locus. The temperature of the blackbody at this point is calculated as the CCT of the measured display, as illustrated in Figure D.2.

First the spectral power distribution (SPD) of a Planckian radiator is calculated with the temperature as an input parameter. Then use CIE 1931 $\bar{x}$, $\bar{y}$, $\bar{z}$ colour matching functions to calculate the chromaticity coordinates for this SPD. The blackbody CIE 1960 chromaticity is compared to the white field chromaticity of the measured display. The CIE 1960 chromaticity difference $\Delta(u, v)$ between the blackbody and display is calculated analogously to Equation (4), where $u = u'$ and $v = 2v'/3$. The temperature (and chromaticity) of the Planckian radiator is modified to determine the minimum $\Delta(u, v)$ between the measured display and Planckian radiator. In determining the minimum $\Delta(u, v)$, it is advisable to start with a Planckian temperature below the temperature of the display u, v value and increment to a Planckian temperature above this value. This incremental calculation can terminate at a predetermined minimum change in $\Delta(u, v)$.



IEC

Figure D.1 – CIE 1931 XYZ chromaticity diagram



IEC

Figure D.2 – Blackbody locus (Planckian locus) and isotemperature lines in CIE 1931 chromaticity diagram

Annex E
(informative)

Measuring the performance of modern colour-managed displays and panels

E.1 Legacy displays

Early displays had driven electronics that were well-behaved. As illustrated in Figure E.1, the independent drive electronics in these legacy displays resulted in a direct correlation between the input signal and the primary colour emitters. This ensured that the display had colorimetric additive mixing. However, as colour display technology has advanced over the years, so has the colour management for these devices. Not only have display designers introduced multi-primary pixel formats, they have also applied real-time image processing to dynamically change how the image is rendered. This has reached the point where, in many cases, the input signal is not directly linked to the optical output.

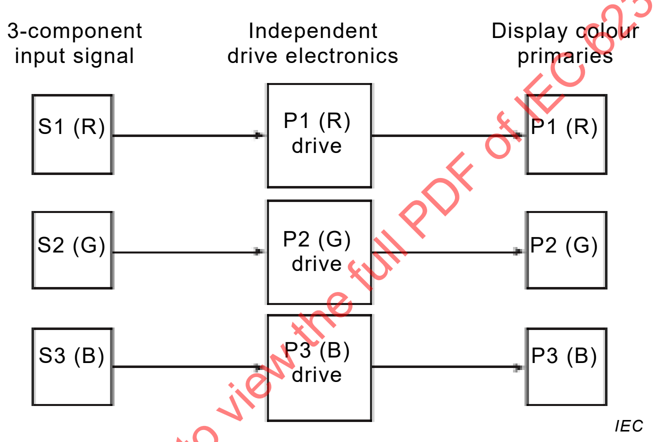


Figure E.1 – Legacy model where the independent drive electronics provide a direct correlation between the input RGB signals and the display's colour primaries

E.2 Modern displays

In the legacy RGB displays, the direct link between input signal to pixel output meant that there was only one unique combination of R, G, and B that would give the desired colour. However, as colour management advanced, display electronics included look-up tables (LUTs) as a programmable conversion interface between the input signal and pixel output (see top schematic in Figure E.2). The use of LUTs allowed the physical primary colours to be abstracted to conceptual primary colorants, where these colorants could be tailored to achieve the desired colour gamut. But the colorimetry of these systems would not necessarily follow colorimetric additive mixing. In addition, as the processing power of the electronics increased, the image processing could also analyse the upcoming image frame and dynamically change the LUT for the desired appearance.

The use of LUTs also enabled an input signal from only one RGB component to activate more than one primary emitter (see for example the bottom schematic in Figure E.2). For multi-primary displays, there may be several combinations of primary emitters that could produce the desired colour. The calibration of the LUT defines how the input signal will be rendered, which will not necessarily result in the expected colorimetric additive mixing based on the input signals. This lack of additivity can have an impact on how accurately the intended image content is rendered. In addition, the lack of additivity also means that the colour gamut area may not be accurately represented by just measuring the response of the R, G, and B inputs in turn. The colour gamut area may no longer be bounded by the triangle connecting the RGB chromaticity coordinates.

Given this ambiguity, it is important to test how well the display renders colours relative to the intent of the input content. If the content is intended for viewing on sRGB displays (IEC 61966-2-1), then the colour management should be tested to verify that the colours are rendered correctly. In addition, if the display also employs dynamic colour management, then the performance of the display can depend on the type of test pattern used. A set of colour test patterns have been developed to address these issues, and serve as the recommended patterns used in this document. These patterns are a best effort attempt to create a technology-neutral input signal that uniformly samples the colour gamut and queries in a fair manner the colour-managed response of the display. The value of these colour test patterns is illustrated by comparing them to traditional single-colour box patterns.

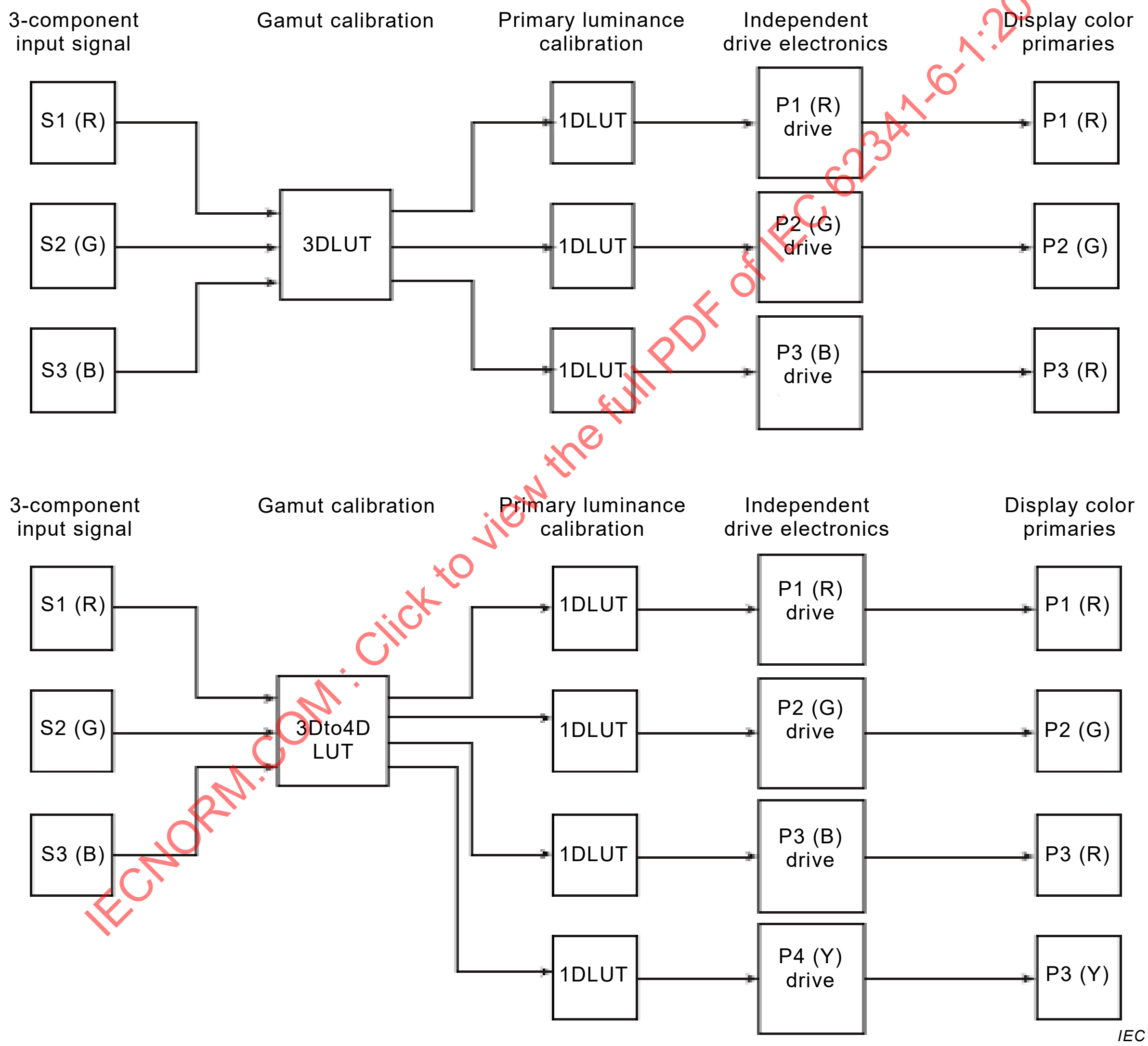


Figure E.2 – Example of modern drive models utilizing multi-dimensional LUTs for RGB (top) and multi-primary (bottom) displays

Prior research on multi-primary projectors demonstrated that some colour-managed systems adapted to the rendered test pattern. In some cases, the colour management system in some displays would preferentially boost the white luminance output on white images. However, this white luminance could never be achieved in more realistic colour images [3]. Therefore, the luminance of the white pattern would not equal the sum of the luminance values for the R, G, and B patterns. This lack of colour additivity can suggest a potential problem in the colour management. The benefit of the RGB checkerboard, or colour-signal white, pattern has been recognized by the display industry, and has been included as an important measurement in an industry standard [2]. The colour-signal white method for OLED displays has been adapted in this document by also considering the influence of luminance loading. Figure 4 illustrates a low APL loading implementation of the colour-signal white method. The 5 % to 6 % APL loading level is a practical lower limit, where the OLED is presumed to have achieved its highest luminance levels by minimizing the resistive loading effects. The amount of APL loading is only based on the input signal, and corresponds to the pre-gamma average picture level that is being input to the display. A 100 % APL would correspond to a maximum white signal input for all pixels in the active area. The inclusion of the white box with the RGB boxes allows the white luminance to be compared to the RGB luminance values under the same loading conditions.

E.3 Results

Table E.1 shows an example of measured luminance data for a commercial RGB and WRGB OLED display using the colour tile pattern in Figure 4, following the procedure in clause 6.1. In this example, the difference in percentage between the colour-signal white luminance ($L_{\mathrm{CSW}} = L_{\mathrm{R,ave}} + L_{\mathrm{G,ave}} + L_{\mathrm{B,ave}}$) and the average luminance of the white box $L_{\mathrm{W,ave}}$ was actually higher for the RGB display. This suggests that the colour management was better for this WRGB display than for the RGB display.

Table E.1 – Example of luminance data for an RGB and WRGB OLED display

Display technology	Average luminance (cd/m^2)				$L_{\mathrm{W,ave}}$ -L_{CSW}
	Red	Green	Blue	White	(%)
WRGB OLED display	78,4	268,2	38,2	393,9	2
RGB OLED display	88,7	218,7	28,6	380,4	13

The response of the OLED display to the input signal can be investigated further by measuring the APL loading behaviour of the display. Figure E.3 illustrates the different loading behaviour between the traditional single white centre box compared to the multi-colour pattern shown in Figure E.4. The APL loading of each test pattern is increased by enlarging the size of the individual boxes. The loading behaviour is observed to be different for the commercial RGB versus the WRGB OLED display. As one would expect, the APL loading response of the RGB display does not seem to depend on the presence of colour content. However, the presence of colour does impact the loading behaviour of the WRGB OLED, especially at the higher load levels. Therefore, since realistic images will typically contain a variety of colours, the sampling of red, green, blue, cyan, magenta, yellow, and white boxes used in Figure E.4 would be a more appropriate test pattern.

When evaluating the APL loading response of the display, the shape of the loading profile is not as important as how consistently the display can maintain that shape for all colours. This issue is illustrated in Figure E.5. In this evaluation, the luminance and colour in the pattern (Figure E.4) are measured at increasing levels of loading. The loading measurements are repeated in turn for the red, green, blue, cyan, magenta, and yellow boxes in the pattern. The top graph in Figure E.5 shows that each of the colours measured on the WRGB display has virtually the same loading profile. This means that the luminance ratio between the colours is also maintained. Since the luminance ratio between colours determines what colour is rendered by the display, a consistent luminance ratio means that the colour gamut will be stable through the range of loading levels. This is demonstrated by the relatively flat (brown) colour gamut area line shown in the top graph. In contrast, the bottom graph in Figure E.5 shows some variation in the APL loading profiles for each of the colours measured on the RGB display. This variation induced the larger change in the colour gamut area for the RGB display with APL loading.