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INTERNATIONAL STANDARD

colour inside

Flexible display devices –
Part 5-1: Measuring methods of optical performance

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CONTENTS

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FLEXIBLE DISPLAY DEVICES –

Part 5-1: Measuring methods of optical performance

FOREWORD

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International Standard IEC 62715-5-1 has been prepared by IEC technical committee 110: Electronic display devices.

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

FDIS	Report on voting
110/859/FDIS	110/870/RVD

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

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

A list of all parts of the IEC 62715 series, published under the general title *Flexible display devices,* 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- withdrawn,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.

INTRODUCTION

This part of IEC 62715 was designed for the standardization of measuring methods and detailed setup conditions that are used to characterize the optical performance of flexible display devices.

The surface conditions and shape of flexible displays can change depending on the application. For example, a smart watch may have a fixed convex display, a cell phone or TV a fixed concave display, and a bendable display may have either a concave or convex shape with a variable radius of curvature. Up to now, all of these displays would usually be characterized in their flat state. However, since it is possible that mechanical stress induced by bending the display can change its optical characteristics, the display should be measured in its designed bent state. This ensures that the display's optical performance is representative of its intended application. This document specifies the necessary conditions and methods to measure the optical performance of a display in a bent state.

FLEXIBLE DISPLAY DEVICES –

Part 5-1: Measuring methods of optical performance

1 Scope

This part of IEC 62715 specifies the standard measuring conditions and measuring methods for determining the optical performance of flexible displays in the dark or under ambient illumination. This document mainly applies to display modules that are bendable about one axis. The display is measured in a static mechanical state. The measuring methods apply to monochrome or colour displays with a single radius of curvature of 35 mm or greater.

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 845: Lighting* (available at <http://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 62715-1-1, *Flexible display devices – Part 1-1: 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*

IEC 62679-3-1:2014, *Electronic paper displays – Part 3-1: Optical measuring methods*

IEC TR 62728, *Display technologies – LCD, PDP and OLED – Overview and explanation of differences in terminology*

CIE 15:2004, *Colorimetry*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62715-1-1 and IEC TR 62728 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

3.2 Abbreviated terms

CCT	correlated colour temperature
CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
CIELAB	CIE 1976 (L*a*b*) colour space
DUT	device under test
ILU	integrated lighting unit (e.g. a front light in a reflective display)
LMD	light measuring device
PL	photoluminescence
RGB	red, green, blue
sRGB	standard RGB colour space as defined in IEC 61966-2-1

4 Structure of measuring equipment

4.1 Measuring configuration – Display mounting

4.1.1 General

The fixture used to mount a curved display plays a critical role in obtaining accurate and reproducible results.[1,2][1] The display mount should be designed to accommodate the specific bendable, foldable and/or curved characteristics of the flexible display in its intended use configuration. The mount should be capable of maintaining the intended shape of the display and locate it in the required measurement position and viewing direction. For curved displays, these measuring methods only apply for displays that have a constant radius of curvature about a single axis (e.g. cylindrical shape). Figure 1 illustrates the coordinate system for a convex display that is curved about the y-axis. The origin of the coordinate system is positioned at the imaging surface of the display and centred on the screen. The same coordinate system applies for a concave display with the image rendering surface facing the positive z-axis.

For flat displays, the image rendering plane is aligned in the x-y plane. A foldable display that contains flat areas connected by a narrow region with a short radius of curvature shall be measured in the flat areas, and treated as a flat display.

Unless otherwise specified, the optical axis of the LMD shall be aligned to within 1° of the display surface normal at the centre of the measurement field in order to minimize the alignment error introduced by the display curvature. For spot type LMDs, the retro-reflection of the LMD can be used to obtain this alignment. Otherwise, an alignment laser can be used to ensure that the LMD optical axis passes through a curved display's centre of curvature. The methods also assume that the rotation stages and mechanical mounting have sufficient accuracy and stability to maintain a $<$ 1° tolerance for any rotational or tilt motions.

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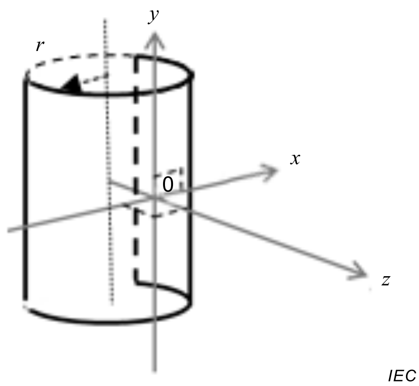
1 Numbers in square brackets refer to the Bibliography.

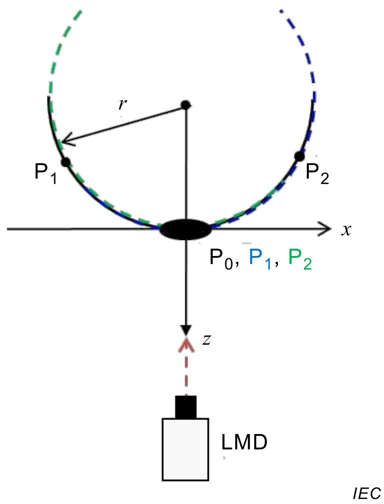


NOTE The origin is centred on the screen which is curved with a constant radius r at the surface of the imaging plane.

Figure 1 – Example of the coordinate system used for a convex display of a constant radius of curvature about the y-axis

4.1.2 Display mounting for uniformity measurements

For flat displays, the display uniformity is generally measured by translating the LMD parallel to the screen and measuring the display characteristics at different screen locations. However, for convex or concave displays, the display mounting shall allow the display to be rotated about its centre of curvature while ensuring that the imaging plane always passes through the y-axis at the origin. This is illustrated in Figure 2 for the case of a convex display. The same motion shall be used for concave displays. Figure 2 illustrates how lateral locations P_0, P_1, and P_2 can be rotated into the LMD measurement field. This display rotation allows the display uniformity to be measured at a constant viewing direction. Alternatively, the LMD can be mounted on a goniometer that rotates about the display's centre of curvature.

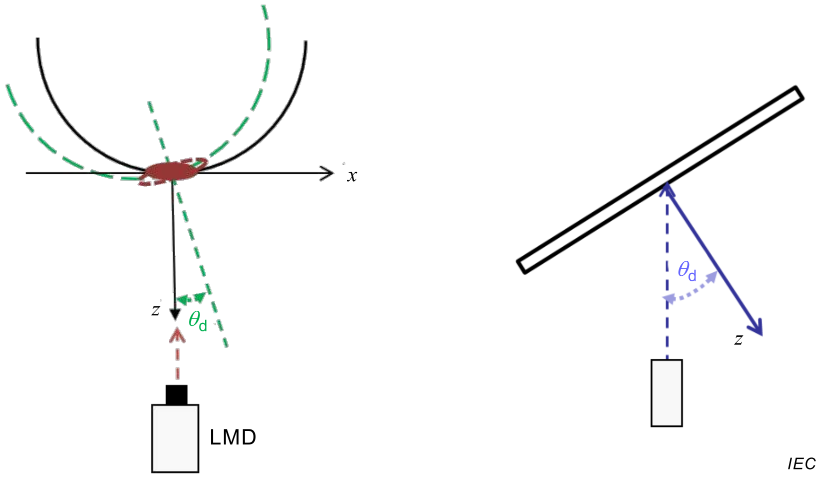


NOTE Figure 2 shows how a convex display which is curved with a constant radius r can be rotated about its centre of curvature to align different display locations in the x-z plane within the measurement field.

Figure 2 – Top view example of how a convex display can be rotated within the measurement field

4.1.3 Display mounting for viewing direction measurements

Viewing direction measurements on curved displays require the exact alignment of the LMD and the display.[1] The centre of the LMD measurement field is usually aligned perpendicular to the display surface. Alignment accuracy to within ±1° is recommended in order to minimize the alignment error introduced by the display curvature. It should be the same with the flat conditions. For the coordinate system defined in Figure 1, the LMD optical axis would pass through a curved display's centre of curvature. When measuring the viewing dependence of a curved display, the display mount would need to rotate about a point on the display surface at the centre of the measurement field in the x-z plane (as shown in Figure 3), or rotate in the y-z plane. The same motion would be required for a flat display. Alternatively, the LMD can be mounted on a goniometer that rotates about the same point on the display surface at the centre of the measurement field (the origin in the coordinate system defined in Figure 1).



NOTE These figures show how the display mount rotates about the surface of a convex or flat display for viewing direction measurements.

Figure 3 – Top view example of display mount that rotates in the x-z plane for viewing direction measurements

4.2 Light measuring device

It is generally assumed that the LMD will be a spot photometer, colorimeter, or spectroradiometer. The optical characteristics of these instruments are illustrated in Figure 4. The LMDs often have a selectable measurement-field angle (sometimes called the measurement aperture) that for a given measuring distance defines the measuring field on the display surface. The measurement-field angle shall be no greater than 2°. The measuring distance from the LMD to the display surface is nominally 0,5 m. This combination of measuring-field angle and distance usually satisfies the recommendation that the measurement field contain at least 500 pixels. However, for curved displays, if the measurement field becomes larger (or the radius of curvature becomes smaller), then the LMD samples light from the display surface over a larger range of inclination angles $\Delta\theta_d$. The range of inclination angles sampled by the LMD is given by:

$$\Delta\theta_d = \arcsin\left(\frac{c}{2r_c}\right) \qquad (1)$$

where c is the diameter of the measurement field and r_c is the display radius of curvature.

Figure 5 provides an example of how the range of inclination angles can vary for a given measurement field on displays with a 35 mm and 45 mm radius of curvature. In this example, the range of measurement fields that contain at least 500 pixels is identified by the shaded region under the curves. Figure 5 also includes an example of the measurement fields that can be obtained by a commercial spectroradiometer at a 0,5 m measurement distance as identified by its measurement-field angles (LMD aperture).

In general, it is desirable to minimize $\Delta\theta_d$ in order to avoid averaging over a large range of viewing directions during the measurement. For this reason, the range of inclination angles shall be $\Delta\theta_d < 5°$. In the example illustrated in Figure 5, the LMD with the 1° measurement-field angle would subtend a measurement field that has $\Delta\theta_d < 5°$ for the 45 mm radius of curvature display, but $\Delta\theta_d > 5°$ for the 35 mm radius of curvature display. However, if the LMD measurement distance is reduced to 0,4 m for the 35 mm radius of curvature display, then $\Delta\theta_d$ would also fall below 5°.

Another method to reduce the range of display inclination angles is to reduce the measurement-field angle of the LMD. But as the example in Figure 5 suggests, the smaller measurement-field angles produce measurement fields that may not sample the recommended > 500 display pixels. This may be mitigated for the 0,2° measurement-field angle example in Figure 5 by increasing the measuring distance. However, the combination of smaller measurement-field angle and longer measuring distance tends to produce noisier data, and could result in reproducibility problems. But if it can be demonstrated that the smaller measurement-field angles at shorter measuring distances give the same results as for LMD configurations that do contain at least 500 pixels, then the smaller measurement-field angles are acceptable.

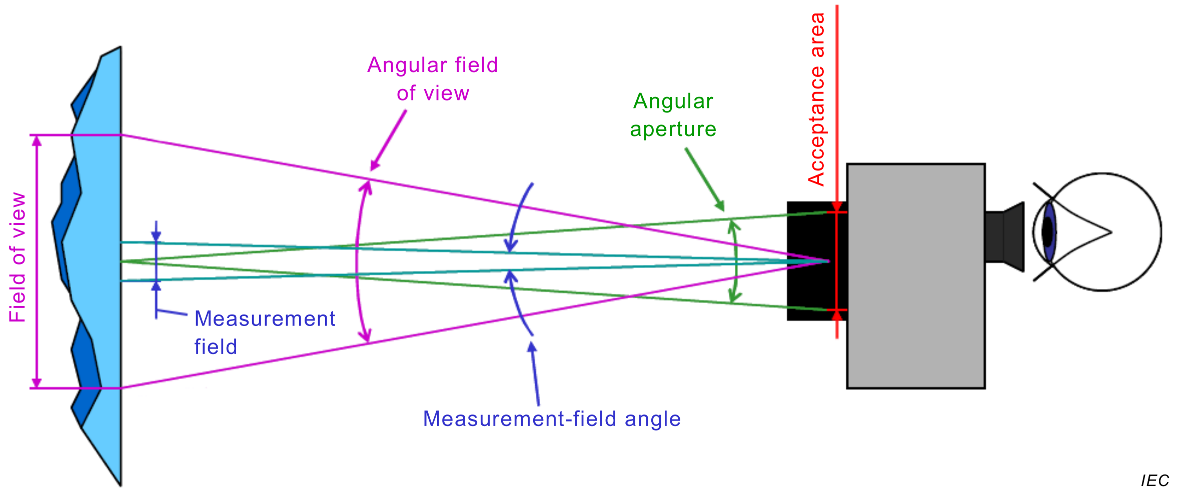
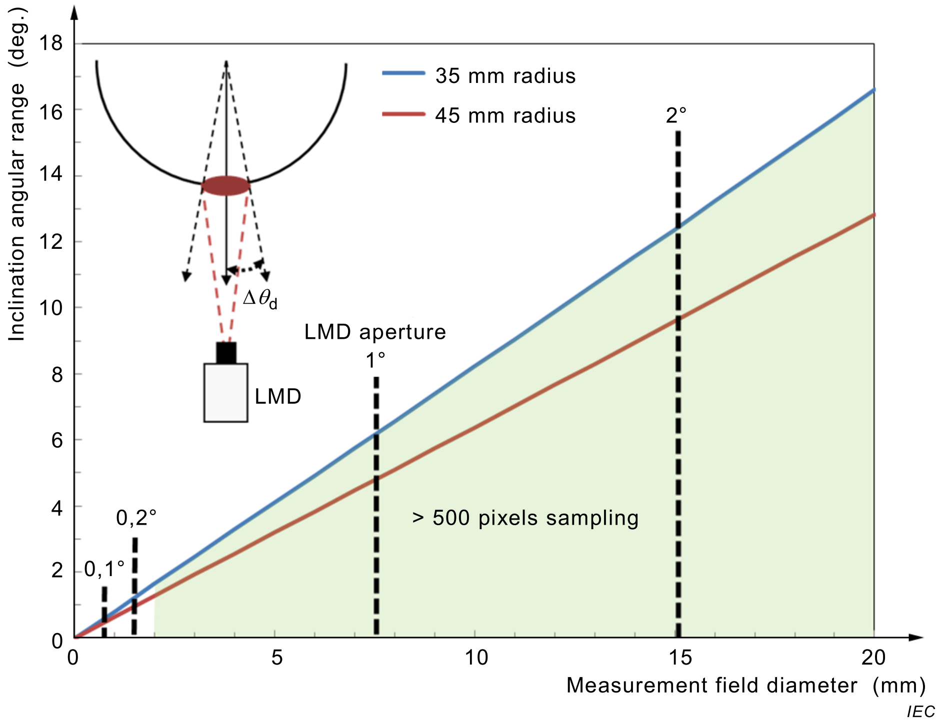


Figure 4 – Optical characteristics of a spot photometer, colorimeter, or spectroradiometer



NOTE 1 Figure 5 shows the relationship between the measurement field diameter and the range of inclinations angles captured within the measurement field for a given display radius of curvature.

NOTE 2 The shadowed area highlights the region where > 500 pixels are sampled for a given measurement field angle (dashed line).

Figure 5 – Example of the relationship between measurement field diameter and inclinations angles

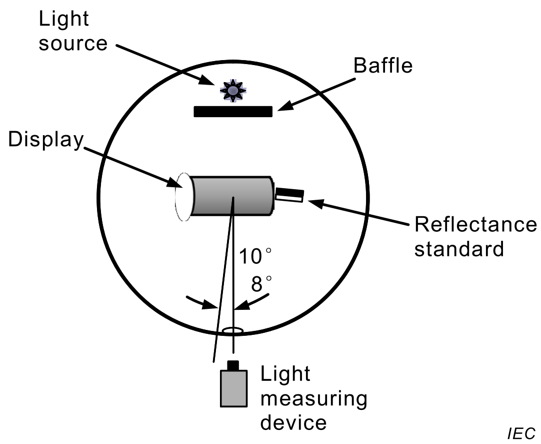
4.3 Light source configurations

4.3.1 General

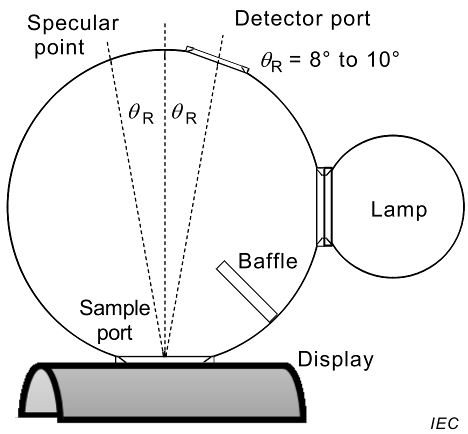
Light sources will be used to simulate the display performance under typical indoor or outdoor ambient lighting environments. These environments generally contain a combination of directed and uniform hemispherical diffuse light sources. Subclauses 4.3.2 and 4.3.3 define how these sources will be configured when evaluating the performance of curved displays under simulated indoor and outdoor illumination conditions. Flat displays will follow the same general configuration, without the need to consider the orientation of the display's bending axis.

4.3.2 Uniform hemispherical diffuse illumination

Uniform hemispherical diffuse illumination is generally realized by using an integrating sphere. For large displays, and displays with a large radius of curvature, the display may be placed against the sample port of a sampling sphere and the measurement area should be within the uniform illumination area of the display (see Figure 6, configuration B). However, if the display is too small to fill the sample port of a sampling sphere, or the curvature of a concave display is smaller than the curvature of the sampling sphere, then the display shall be placed in the centre of an integrating sphere (see Figure 6, configuration A). In either configuration, the long axis of the curved display (y-axis) shall be in the plane of incidence of the LMD and tilted 8° to 10° from the LMD optical axis. When using an integrating sphere, the reflection standard should be placed adjacent to the display and in the same plane as the display measurement area. Best practices for sphere design and measurements shall be followed. [3,4]



Configuration A (top view) – Integrating sphere



Configuration B (side view) – sampling sphere

Figure 6 – Example of reflection measurement geometries for spherical illumination

4.3.3 Directed source illumination

Directed source measurements are particularly sensitive to illumination area distortion and unintended beam focusing from curved displays. Therefore, display measurements with directed illumination shall use the configuration illustrated in Figure 7. The LMD and light source optical axis shall lie in the y-z plane centred through the origin. Alternatively, for a small convex display, a ring light centred above and/or below the measurement field can be used to illuminate the measurement field at a nominal 45° inclination angle (see Figure 8).[1,2] The LMD measurement area shall be centred and lie within the illumination area. The ring light illumination shown in Figure 8 fulfils two conditions: the ring light inclination is 45°, and the illuminance (or spectral irradiance) does not change with orientation along the circumference of the cylinder.

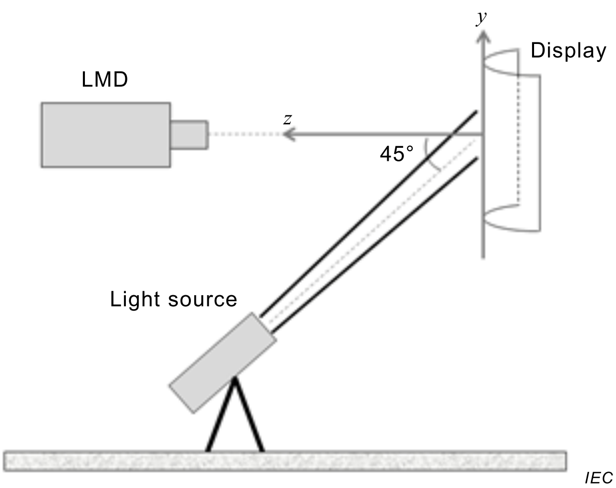


Figure 7 – Example of convex display illuminated by a directed light source

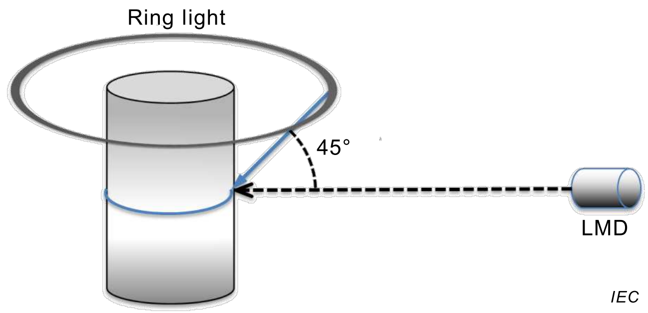


Figure 8 – Example of convex display illuminated by a ring light source

5 Standard measuring conditions

5.1 Standard measuring environmental conditions

Electro-optical measurements and visual inspection shall be carried out under the standard environmental conditions as follows:

– temperature of 25 C ± 3 °C,
– relative humidity of 25 % to 85 %,
– pressure of 86 kPa to 106 kPa.

When different environmental conditions are used, they shall be noted in the visual inspection or test report.

5.2 Standard lighting conditions

5.2.1 Dark room conditions

The luminance contribution from the background illumination reflected off the test display shall be $\leq$ 0,01 cd/m^2 or less than 1/20 of the display's black state luminance, whichever is lower. 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 at these low levels, then the lower limit of the LMD shall be noted in the test report.

Unless stated otherwise, the standard lighting conditions shall be the dark room conditions.

5.2.2 Standard ambient illumination spectra

The following illumination conditions are specified for the optical measurements of emissive and reflective displays under indoor or outdoor illumination conditions. A combination of two illumination geometries is generally used to simulate ambient indoor illumination, or outdoor daylight illumination under a clear sky.[4,5] Uniform hemispherical diffuse illumination will be used to simulate the background lighting in a room with the directed light source such as a luminaire in a room occluded, or the hemispherical skylight incident on the display, with the sun occluded. A directed light source in a dark room will simulate the effect of directed illumination on a display by a luminaire in a room, or from direct sunlight.

The following illumination conditions, which are consistent with OLED and electronic paper displays (IEC 62341-6-2 and IEC 62679-3-1) shall be used to simulate indoor and outdoor display viewing environments:

a) Indoor room illumination conditions:
   1) Uniform hemispherical diffuse illumination

      Use spectrally smooth broadband light source to photometrically approximate CIE Standard Illuminant A, CIE Standard Illuminant D65, or CIE Illuminant D50 as defined in CIE 15:2004. Better accuracy can be obtained by performing spectral measurements. For spectral measurements, if it can be demonstrated that the display does not exhibit significant photoluminescence (PL) (<1 % PL, see IEC 62341-6-2:2015, Annex A) for the selected reference source spectra, then a spectrally smooth broadband source (such as an approximation to CIE Standard Illuminant A) may be used to measure the spectral reflectance. A measurement of the spectral reflectance using a broad light source (such as Illuminant A) enables the indoor photopic and colour characteristics to be calculated later for the desired reference spectra (for example CIE Illuminant D65). The performance characteristics shall be calculated using 60 lx of uniform hemispherical illumination (with specular included) incident on the display surface for a typical TV viewing room, and 300 lx for an indoor reading environment.[6] The actual hemispherical diffuse reflectance measurement may require higher illumination levels for better measurement accuracy. The results are then scaled to the required illumination levels.

2) Directed illumination

The same source spectra shall be used as with hemispherical diffuse illumination. The indoor room photopic and colour display characteristics shall be calculated using directed illumination of 200 lx incident on the display surface for an indoor reading environment with the display in the vertical orientation. The actual reflectance factor measurement may require higher illumination levels for better measurement accuracy. The results are then scaled to the required illumination levels. The directed source shall be 45° above the surface normal (θ_s = 45°).

Other illumination levels may be used in addition to those defined above for calculating the display characteristics under indoor illumination conditions.

b) Outdoor daylight illumination conditions:

1) Uniform hemispherical diffuse illumination

Use spectrally smooth broadband light source to photometrically approximate skylight with the spectral distribution of CIE Illuminant D75.[7] Additional CIE daylight illuminants (such as D65) may also be used, depending on the intended application. Better accuracy can be obtained by performing spectral measurements. For spectral measurements, the spectral reflectance factor measurements can be made using a spectrally smooth broadband source (such as an approximation to CIE Standard Illuminant A). Skylight photopic and colour metrics can be calculated later for the CIE D75 Illuminant spectra. The skylight photopic and colour characteristics shall be calculated using 15 000 lx of hemispherical diffuse illumination (with specular included) incident on a display surface in a vertical orientation.[7,8] The actual hemispherical diffuse reflectance factor measurement may be taken at lower illumination levels. The results are then scaled up to the required illumination levels.

2) Directed illumination

The directed light source shall approximate CIE daylight Illuminant D50.[6] Additional CIE daylight illuminants (such as D65) may also be used, depending on the intended application. A spectrally smooth broadband source (such as an approximation to CIE Standard Illuminant A) may be used for the reflectance factor measurement. The sunlight photopic and colour characteristics can be calculated later with the D50 Illuminant spectra. The daylight photopic and colour characteristics shall be calculated using 65 000 lx for a directed source at an inclination angle of θ_s = 45° to the display surface, and the LMD shall be aligned normal to the display surface (θ_d = 0°).[7,8] The actual reflectance factor measurement may be taken at lower illumination levels. The results are then scaled up to the required illumination levels. The contrast ratio and colour are calculated for the scaled-up illuminance levels. The directed source shall have an angular subtense of approximately 0,5°.

For daylight photopic and colour calculations from spectral reflectance factor measurements, the relative spectral distributions of CIE Illuminants A, D50, D65 and D75 tabulated in CIE 15:2004 shall be used. Additional CIE daylight illuminants shall be determined using the appropriate eigenfunctions, as defined in CIE 15:2004.

The UV region (< 380 nm) of the light source shall be cut off by a UV blocking filter. When high light source illumination levels are used, an infrared-blocking filter is recommended to minimize device heating.

5.2.3 Standard illumination geometries

One or more of three types of illumination geometries shall be used for determining the performance of the DUT: directional illumination, ring light illumination, and hemispherical illumination. The standard configurations for implementing these illumination geometries are defined in IEC 62679-3-1:2014, 4.3.4. Additional illumination geometries may also be used. The details of the illumination geometry used for a given measurement shall be reported. Further guidance on the proper implementation of these illumination geometries is given in the SID Information Display Measurements Standard.[3]

5.2.4 Diffuse reflectance standard

Diffuse white reflectance standard samples can be obtained with a diffuse reflectance of 98 % or more. They are also available in different shades of grey. A luminance L_{std} measurement from such reflectance standards can be used to determine the illuminance E on the standard for defined detection geometry and illumination spectra and configuration:

$$E = \frac{\pi L_{\mathrm{std}}}{R_{\mathrm{std}}} \tag{2}$$

where R_{std} is the calibrated luminous reflectance factor for that measurement configuration.

When the illumination configuration is a uniform hemispherical illumination, then R_{std} is equivalent to luminous hemispherical reflectance ρ_{std}. The luminous reflectance value associated with the standard is only valid for the hemispherical illumination in which it was calibrated. If it is used with a directed source at any angle, there is no reason to expect that the luminous reflectance value will be the correct luminous reflectance factor value for that illumination configuration or spectrum.

NOTE The term luminous reflectance or luminous reflectance factor will simply be referred to as reflectance or reflectance factor in the remainder of this document.

5.3 Standard setup conditions

5.3.1 Adjustment of display modules

Depending on the intended application, the display shall be measured in a flat state, or held rigid with a smooth and constant radius of curvature over its entire active area. 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.

If it can be demonstrated that the optical characteristics of the display in its flat state are the same as for its curved state, then the display may be measured in the flat state. The bending state of the display used during the measurements shall be reported.

5.3.2 Starting conditions of measurements

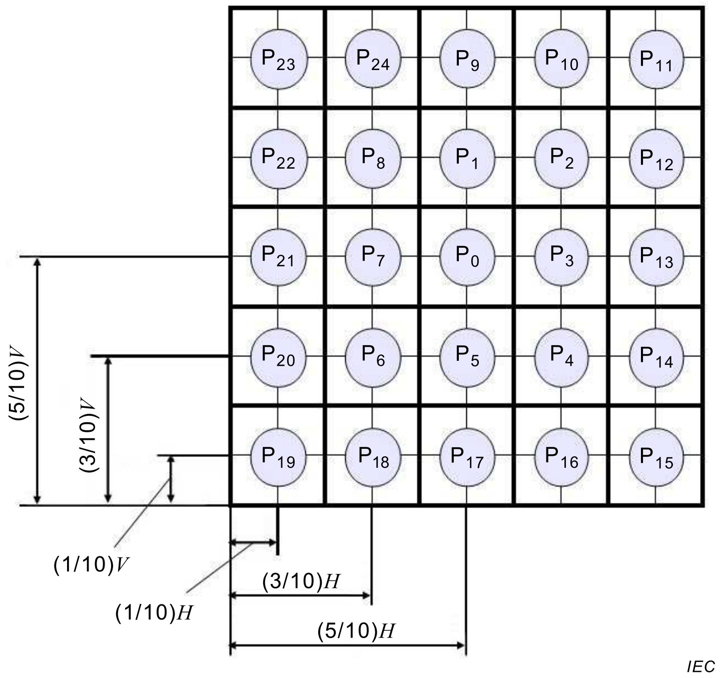
Measurements shall be started after the display modules and measuring instruments achieve stability. Sufficient warm-up time has to be allowed for the display modules to reach a luminance deviation level of less than ±5 % over the entire measurement for a given display image.

5.3.3 Conditions of measuring equipment

Conditions of measuring equipment are given IEC 62679-3-1:2014, 4.4.3. Any deviations from these conditions 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 DUT surface. To this end, the active area of the display is divided into 25 identical imaginary rectangles (see Figure 9). Unless otherwise specified, measurements are carried out in the centre of each rectangle. The rectangles are numbered starting from the centre, and progressing towards the edges in a clock-wise spiral fashion. Care shall be taken that the measuring fields on the display do not overlap. Positioning of the measuring field at the prescribed positions in the horizontal (H) and vertical (V) direction shall be to within 7 % of H and V, respectively. 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 above standard positions shall be reported.



NOTE Standard measurement positions are at the centres of all rectangles P_0 to P_{24}. The height and width of each rectangle are 20 % of display height and width respectively.

Figure 9 – Standard measurement positions

6 Optical measuring methods in dark room conditions

6.1 Luminance and its uniformity

6.1.1 General

The purpose of this method is to determine the luminance and the luminance uniformity in the display active area under dark room conditions. For reflective displays, this method only applies to displays that have an integrated lighting unit (ILU) and it is tested at the factory standard settings, unless specified otherwise. Additionally, ILU levels may also be tested, but the light level should be reported with the test results.

6.1.2 Measuring equipment

The apparatus shall be as follows:

- a luminance meter, colorimeter or spectroradiometer;
- a driving power source;
- driving signal equipment;
- a means to translate a flat display or LMD in the vertical and horizontal directions;
- a display mount that can rotate a curved display about its centre of curvature (see Figure 2) or LMD that can be mounted on a goniometer that rotates about the display's centre of curvature.

6.1.3 Screen centre luminance measuring method

The measuring method shall be as follows:

a) Mount the display in its flat or curved state in a fixture according to the guidance provided in 4.1.

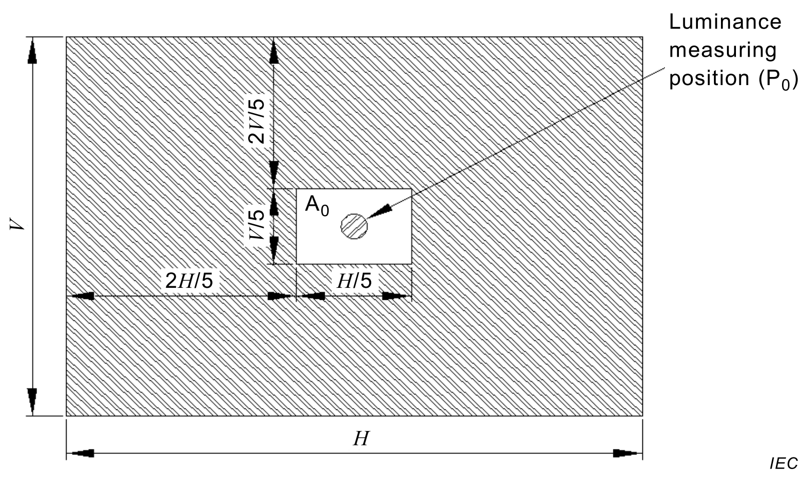
b) Place the LMD at the recommended distance from the display and align the optical axis to be normal to the centre of the display active area (position P_0).

c) Set the display to a 4 % area window (see Figure 10) at the desired colour Q at the highest luminance level. Allow the display to stabilize.

d) Measure the display luminance L_{Q0} for colour Q at position P_0.

e) Repeat for other display colours as needed.

f) Report the screen centre luminance L_{Q0} for colour Q in the test report.



NOTE A window of desired colour Q is positioned in the centre of the screen with a black background.

Figure 10 – Test pattern used for 4 % area window measurements

6.1.4 Luminance uniformity measuring method

The measuring method shall be as follows:

a) Mount the display in its flat or curved state in a fixture that will allow the LMD to remain at a fixed distance from the measurement field, and normal to the display surface at the centre of the measurement field.

b) Place the LMD at the recommended distance from the display and align the optical axis to be normal to the centre of the display active area (position P_0).

c) Set the display to a full screen at the desired colour Q at the highest luminance level. A full white screen is generally used. Additional colour may also be measured. Allow the display to stabilize.

d) Measure the display luminance L_{Q0} for colour Q at position P_0.

e) Move the display (see 4.1.2 for curved displays) or LMD and take sequential luminance measurements at the five (positions P_0, P_{11}, P_{15}, P_{19} and P_{23}) or nine (positions P_0, P_9, P_{11}, P_{13}, P_{15}, P_{17}, P_{19}, P_{21} and P_{23}) locations defined in Figure 9.

6.1.5 Luminance uniformity definition and evaluation

The percent luminance non-uniformity of the display at colour Q is given by:

$$NU_{\mathrm{Q}} = 100\% \frac{L_{\mathrm{Q,max}} - L_{\mathrm{Q,min}}}{L_{\mathrm{Q,max}}} \tag{3}$$

where $L_{\mathrm{Q,max}}$ and $L_{\mathrm{Q,min}}$ are the maximum and minimum luminance values, respectively, of the measured locations.

All the luminance values, the minimum and maximum luminance values, and the luminance non-uniformity value should be reported with a description of the measuring conditions.

6.2 Contrast ratio

6.2.1 General

The purpose of this method is to measure the display contrast ratio in the centre of the active area under dark room conditions. For reflective displays, this method only applies to displays that have an integrated lighting unit (ILU) and it is set to its maximum light level.

6.2.2 Measuring equipment

The apparatus shall be as follows:

– a luminance meter, colorimeter or spectroradiometer;

– a driving power source;

– driving signal equipment.

6.2.3 Measuring method

The measuring method shall be as follows:

a) Mount the display in its flat or curved state in a fixture according to the guidance provided in 4.1.

b) Place the LMD at the recommended distance from the display and align the optical axis to be normal to the centre of the display active area (position P_0).

c) Set the display to a 4 % area white window (see Figure 10) at the highest luminance level in the centre of the active area; the remaining background is black at the lowest luminance level. Allow the display to stabilize.

d) Measure the display peak white luminance L_{W0} at position P_0.

e) Set the display to a full black screen at the lowest luminance level. Allow the display to stabilize.

f) Measure the display black luminance L_{K0} at position P_0.

6.2.4 Definition and evaluation

The 4 % window dark room contrast ratio is given by:

$$DCR_{4\%} = \frac{L_{\mathrm{W0}}}{L_{\mathrm{K0}}} \tag{4}$$

where L_{K0} and L_{W0} are the black and peak white luminance values, respectively, measured at the centre of the screen.

The 4 % window dark room contrast ratio, in addition to the black and peak white luminance values, shall be reported with a description of the measuring conditions.

6.3 Chromaticity, colour uniformity, and colour gamut area

6.3.1 General

The purpose of this method is to measure the display chromaticity for a desired colour Q, the colour uniformity, and colour gamut area under dark room conditions. It is also possible to express the colour gamut area under ambient conditions using the ambient chromaticity coordinates obtained in 7.3. For reflective displays, this method only applies to displays that have an integrated lighting unit (ILU) and it is tested at the factory standard settings, unless specified otherwise. Additionally, ILU levels may also be tested, but the light level should be reported with the test results.

6.3.2 Measuring equipment

The apparatus shall be as follows:

– a colorimeter or spectroradiometer;
– a driving power source;
– driving signal equipment.

The display shall be mounted and aligned according to the guidance provided in 4.1.

6.3.3 Screen centre chromaticity measuring method

The measuring method shall be as follows:

a) Mount the display in its flat or curved state in a fixture according to the guidance provided in 4.1.
b) Place the LMD at the recommended distance from the display and align the optical axis to be normal to the centre of the display active area (position P_0).
c) Set the display to a 4 % area window (see Figure 10) at the desired colour Q at the highest luminance level. Allow the display to stabilize.
d) Measure the CIE 1931 chromaticity coordinates (x_{Q}, y_{Q}) for colour Q at position P_0.
e) The following transformation shall be used to calculate the CIE 1976 UCS chromaticity coordinates (u'_{Q}, v'_{Q}) for colour Q:

$$u'_{\mathrm{Q}} = \frac{4x_{\mathrm{Q}}}{3 - 2x_{\mathrm{Q}} + 12y_{\mathrm{Q}}}, v'_{\mathrm{Q}} = \frac{9y_{\mathrm{Q}}}{3 - 2x_{\mathrm{Q}} + 12y_{\mathrm{Q}}} \tag{5}$$

f) Repeat for other display colours as needed.
g) Report the CIE 1931 chromaticity coordinates, the display settings, and the measurement configuration.

6.3.4 Screen centre colour gamut and colour gamut area measuring method

The measuring method shall be as follows:

a) Use the measuring method in 6.3.3 to determine the CIE 1931 and CIE 1976 UCS chromaticity coordinates for white, red, green, and blue colours at the digital input signal levels specified in Table 1.

b) The colour gamut is generally 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 of measuring results is shown in Figure 11.

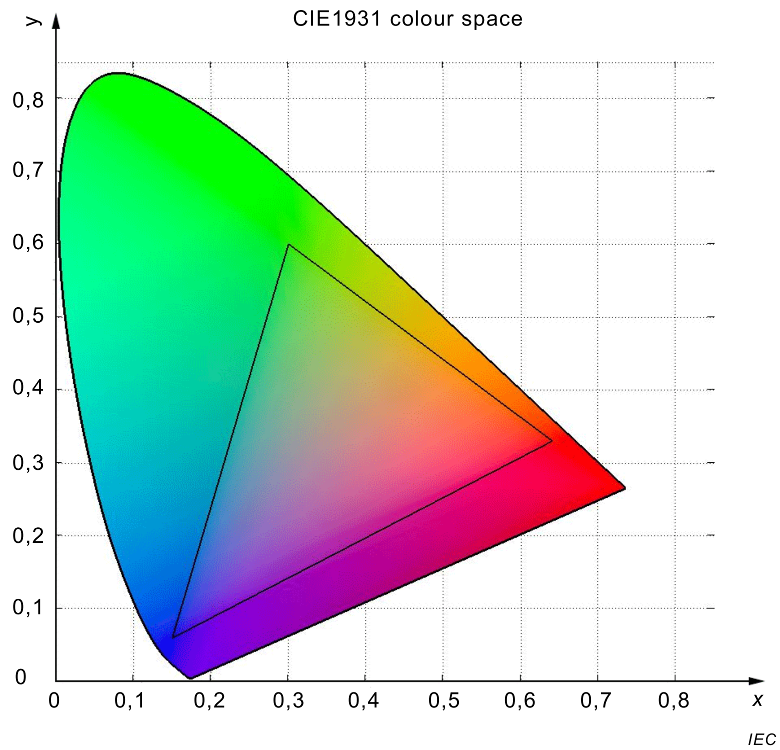
c) The colour gamut area is defined as the percent colour space area enclosed by the colour gamut relative to the entire spectrum locus in the CIE 1976 UCS chromaticity diagram (see Figure 11). For three-primary displays, this is calculated as:

$$A = 256{,}1 \times |(u'_R - u'_B)(v'_G - v'_B) - (u'_G - u'_B)(v'_R - v'_B)|, \tag{6}$$

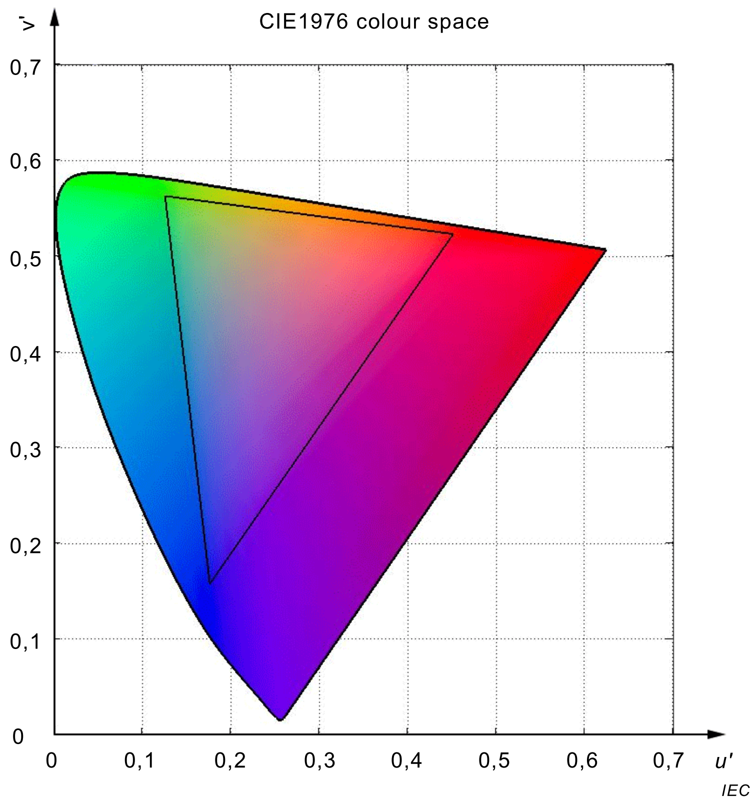
where the subscripts R, G and B refer to the red, green, and blue primaries, respectively. The colour gamut area for the sRGB primaries (IEC 61966-2-1) having the CIE 1931 (x, y) chromaticities red (0,64, 0,33), green (0,30, 0,60), and blue (0,15, 0,06) would be 33 %.

Table 1 – Input signals for CIELAB, CIE 1931 and CIE 1976 UCS colour gamut measurements

Colour Q	8-bit digital input signal level		
	R	G	B
Red	255	0	0
Green	0	255	0
Blue	0	0	255
Yellow	255	255	0
Magenta	255	0	255
Cyan	0	255	255
White	255	255	255



a) CIE 1931 chromaticity diagram



b) CIE 1976 UCS chromaticity diagram

Figure 11 – Examples of the colour gamut as represented in two common chromaticity diagrams

d) Report the CIE 1931 and CIE 1976 UCS chromaticity coordinates for white, RGB, the CIE 1976 UCS colour gamut area, the display settings, and the measurement configuration.

6.3.5 Colour uniformity measuring method

The measuring method shall be as follows:

a) Mount the display in its flat or curved state in a fixture that will allow the LMD to remain at a fixed distance from the measurement field, and normal to the display surface at the centre of the measurement field.

b) Place the LMD at the recommended distance from the display and align the optical axis to be normal to the centre of the display active area (position P_0).

c) Set the display to a full screen at the desired colour Q at the highest luminance level. A full white screen is generally used. Additional colour may also be measured. Allow the display to stabilize.

d) Measure the display CIE 1931 chromaticity coordinates (x_Q, y_Q) for colour Q at position P_0.

e) Move the display (see 4.1.2 for curved displays) or LMD and take sequential luminance measurements at the five (positions P_0, P_{11}, P_{15}, P_{19} and P_{23}) or nine (positions P_0, P_9, P_{11}, P_{13}, P_{15}, P_{17}, P_{19}, P_{21} and P_{23}) locations defined in Figure 9.

f) Use Formula (5) to obtain the CIE 1976 UCS chromaticity coordinates (u', v') from the CIE 1931 chromaticity coordinates (x, y).

g) Use the CIE 1976 UCS chromaticity coordinates (u', v') at each location P_i to determine the colour difference between pairs of sampled colours using the following chromaticity difference formula:

$$\Delta u'v' = \sqrt{\left(u_i' - u_j'\right)^2 + \left(v_i' - v_j'\right)^2} \tag{7}$$

for i, j = 0 to 4 or i, j = 0 to 8, and $i \neq j$. Colour non-uniformity is defined as the largest sampled chromaticity difference $(\Delta u'v')_{max}$ between any two points.

h) Determine the largest chromaticity difference. An example of a nine-point measurement is given in Table 2. The largest colour difference can be narrowed down by plotting the nine (u', v') coordinates rather than calculating all (u', v') pairs.

i) Report the largest CIE 1976 UCS chromaticity difference to no smaller uncertainty than ±0,001.

Table 2 – Example of CIE 1976 UCS chromaticity non-uniformity

Measuring point	x_i	y_i	u'_i	v'_i	$\Delta u'v'$								
					P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
P_0	0,311	0,325	0,198	0,466	0,000								
P_1	0,330	0,320	0,214	0,466	0,016	0,000							
P_2	0,307	0,323	0,196	0,464	0,003	0,018	0,000						
P_3	0,309	0,328	0,196	0,467	0,002	0,018	0,003	0,000					
P_4	0,310	0,326	0,197	0,466	0,001	0,017	0,002	0,001	0,000				
P_5	0,303	0,319	0,195	0,461	0,006	**0,020**	0,003	0,006	0,005	0,000			
P_6	0,311	0,324	0,199	0,465	0,001	0,015	0,003	0,004	0,002	0,006	0,000		
P_7	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_8	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
Max $\Delta u'v'$ = 0,020													

6.4 Peak white field correlated colour temperature

6.4.1 General

The purpose of this method is to measure the display peak white correlated colour temperature under dark room conditions. For reflective displays, this method only applies to displays that have an integrated lighting unit (ILU) and it is set to its maximum light level.

6.4.2 Measuring equipment

The apparatus shall be as follows:

– a colorimeter or spectroradiometer;
– a driving power source;
– driving signal equipment.

The display shall be mounted and aligned according to the guidance provided in 4.1.

6.4.3 Measuring method

The measuring method shall be as follows:

a) Mount the display in its flat or curved state in a fixture according to the guidance provided in 4.1.
b) Place the LMD at the recommended distance from the display and align the optical axis to be normal to the centre of the display active area (position P_0).
c) Set the display to a 4 % area white window (see Figure 10) at the highest luminance level. Allow the display to stabilize.
d) Measure the peak white CIE 1931 chromaticity coordinates (x_W, y_W) at position P_0.
e) Measure the CCT directly with the LMD. If the measurement instrument does not provide the CCT directly, the CCT can be approximated by McCamy's formula:

$$T_{CCT} = 437n^3 + 3601n^2 + 6861n + 5517 \tag{8}$$

where

$$n = (x_W - 0{,}3320)/(0{,}1858 - y_W) \tag{9}$$

The CCT is generally only valid for white colours, not individual primaries.
f) Report the CCT, the display settings, and the measurement configuration.

6.5 Viewing direction dependence

6.5.1 General

The purpose of this method is to measure the photometric and colorimetric properties of the display over a range of viewing directions under dark room conditions. For reflective displays, this method only applies to displays that have an integrated lighting unit (ILU) and it is set to its maximum light level.

6.5.2 Measuring equipment

The apparatus shall be as follows:

– a colorimeter or spectroradiometer;
– a driving power source;
– driving signal equipment;

– a means to pivot a flat or curved display about the surface of the image plane at the centre of the measurement area (see Figure 3);

– an LMD mounted on a goniometer that can pivot about the same measurement point.

The display shall be mounted and aligned according to the guidance provided in 4.1.3.

6.5.3 Measuring method

The measuring method shall be as follows:

1) Mount the display in its flat or curved state in a fixture according to the guidance provided in 4.1. The cylindrical axis of the display should be parallel to the vertical axis.
2) Place the LMD at the recommended distance from the display and align the optical axis to be normal to the centre of the display active area (position P_0).
3) Set the display to a full screen at the desired colour Q at the highest luminance level. A full white screen is generally used. Additional colour may also be measured. Allow the display to stabilize.
4) Measure the chromaticity and luminance $L_{\mathrm{Q},0°}$ of the display at normal incidence. Calculate the CIE tristimulus values X_Q, Y_Q, and Z_Q for the desired colour Q:

$$X_\mathrm{Q} = \frac{x_\mathrm{Q} L_\mathrm{Q}}{y_\mathrm{Q}} \tag{10}$$

$$Y_\mathrm{Q} = L_\mathrm{Q} \tag{11}$$

$$Z_\mathrm{Q} = \frac{(1 - x_\mathrm{Q} - y_\mathrm{Q}) L_\mathrm{Q}}{y_\mathrm{Q}} \tag{12}$$

5) While maintaining the distance between the detector and the display, pivot the display, or the detector, about the display surface in the horizontal plane to the next viewing direction. It is recommended that viewing direction measurements be taken at the following viewing directions: θ_d = 75° to – 75° in increments no greater than 15°.
6) At each viewing position, measure the chromaticity and luminance $L_{\mathrm{Q},\theta\mathrm{d}}$ of the display and calculate the CIE tristimulus values.
7) At each viewing direction, the CIELAB $L*$, $a*$, and $b*$ for that colour can be calculated using the following formulae:

$$L^*_{\mathrm{Q},\theta\mathrm{d}} = 116 \times f(Y_{\mathrm{Q},\theta\mathrm{d}} / Y_{\mathrm{n},0°}) - 16 \tag{13}$$

$$a^*_{\mathrm{Q},\theta\mathrm{d}} = 500 \times [f(X_{\mathrm{Q},\theta\mathrm{d}} / X_{\mathrm{n},0°}) - f(Y_{\mathrm{Q},\theta\mathrm{d}} / Y_{\mathrm{n},0°})] \tag{14}$$

$$b^*_{\mathrm{Q},\theta\mathrm{d}} = 200 \times [f(Y_{\mathrm{Q},\theta\mathrm{d}} / Y_{\mathrm{n},0°}) - f(Z_{\mathrm{Q},\theta\mathrm{d}} / Z_{\mathrm{n},0°})] \tag{15}$$

with

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

where $X_{n,0°}$, $Y_{n,0°}$, and $Z_{n,0°}$ represent the tristimulus values of the display's peak white point at normal incidence viewing direction, and $X_{Q,\theta d}$, $Y_{Q,\theta d}$, and $Z_{Q,\theta d}$ represent the colour Q measured at a viewing direction θ_d.

8) Report the luminance, chromaticity coordinates, and CIELAB $L^*a^*b^*$ values for all measurements in the horizontal plane.

6.5.4 Definition and evaluation

The photometric viewing direction dependence of the display can be characterized for a white screen (or any colour Q) by a viewing direction ratio that quantifies the change in the luminance $L_{W,\theta d}$ at angle θ_d relative to the value at normal incidence $L_{W,0°}$:

$$VDR_{W,\theta d} = \frac{L_{W,\theta d}}{L_{W,0°}} \tag{17}$$

or by the contrast ratio (white-to-black luminance values) as a function of viewing direction:

$$VDCR_{W,\theta d} = \frac{L_{W,\theta d}}{L_{K,\theta d}} \tag{18}$$

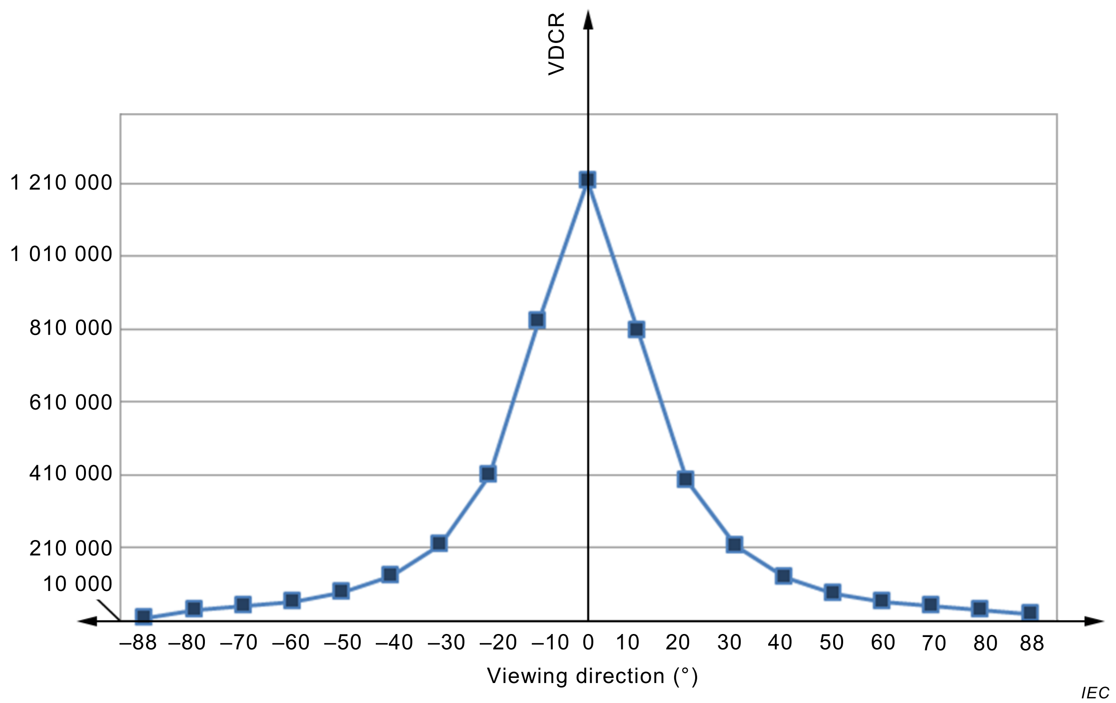


Figure 12 – Example of contrast ratio dependence on viewing direction

An example plot of the display contrast ratio dependence on the viewing direction is given in Figure 12. A similar plot can be made for the lightness difference ΔL^* relative to the value at normal incidence.

The change of colour with viewing direction θ_d can be characterized as a colour shift, hue angle, or chroma. Any colorimetric changes with the viewing direction can be summarized by the colour difference $\Delta u'v'$ in the CIE 1976 UCS colour space or ΔE^*_{ab} in the CIELAB colour space. In this analysis, the CIELAB values at each viewing direction ($L^*_{Q,\theta d}$, $a^*_{Q,\theta d}$, and $b^*_{Q,\theta d}$) are used to calculate the CIELAB colour difference relative to the normal incidence values:

$$\Delta E^*_{\mathrm{ab}} = \sqrt{\left(L^*_{\mathrm{Q,\theta d}} - L^*_{\mathrm{Q,0^\circ}}\right)^2 + \left(a^*_{\mathrm{Q,\theta d}} - a^*_{\mathrm{Q,0^\circ}}\right)^2 + \left(b^*_{\mathrm{Q,\theta d}} - b^*_{\mathrm{Q,0^\circ}}\right)^2} \tag{19}$$

It may also be desirable to distinguish between the components of colour difference ΔE^*_{ab} in terms of correlates of chroma or hue. This can be achieved by using the CIE 1976 chroma C^* and CIE 1976 hue angle h, and expressing the colour differences in terms of CIE 1976 chroma difference ΔC^*, and CIE 1976 hue difference ΔH^*:

$$\Delta L^* = \left(L^*_{\mathrm{Q,\theta d}} - L^*_{\mathrm{Q,0^\circ}}\right) \tag{20}$$

$$\Delta C^*_{\mathrm{ab}} = \sqrt{\left(a^*_{\mathrm{Q,0^\circ}}\right)^2 + \left(b^*_{\mathrm{Q,0^\circ}}\right)^2} - \sqrt{\left(a^*_{\mathrm{Q,\theta d}}\right)^2 + \left(b^*_{\mathrm{Q,\theta d}}\right)^2} \tag{21}$$

$$\Delta H^*ab = \sqrt{\Delta E^{*\,2}_{\mathrm{ab}} - \Delta L^{*2} - \Delta C^{*\,2}_{\mathrm{ab}}} \tag{22}$$

The viewing direction dependence shall be summarized (over at least the θ_{d} = 0° to 75° range) for the desired performance characteristics in the format recommended in Table 3.

Table 3 – Example format used for reporting viewing direction performance

Parameter	Viewing direction					
	0°	15°	30°	45°	60°	75°
$L_{\mathrm{Q,\theta d}}$						
$VDCR$						
ΔE^*_{ab}						

6.6 Cross-talk with display in bent state

6.6.1 General

The purpose of this method is to determine the photometric cross-talk of a curved display in a dark room. The cross-talk may be caused by undesired capacitive, inductive, or conductive coupling from one circuit, part of a circuit, or channel, to another when the display is in a bent or curved state. For reflective displays, this method only applies to displays that have an integrated lighting unit (ILU) and it is set to its maximum light level.

6.6.2 Measuring equipment

The apparatus shall be as follows:

– a luminance meter, colorimeter or spectroradiometer;
– a driving power source; and
– driving signal equipment.

The display shall be mounted and aligned according to the guidance provided in 4.1.

6.6.3 Measuring method

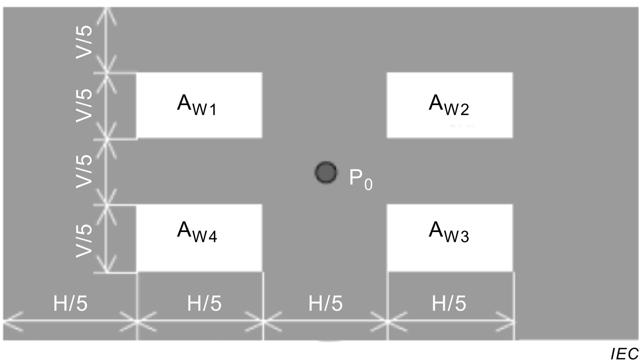
The measuring method shall be as follows:

1) Mount the display in its flat or curved state in a fixture according to the guidance provided in 4.1.
2) Place the LMD at the recommended distance from the display and align the optical axis to be normal to the centre of the display active area (position P_0 in Figure 13).
3) Establish the test pattern indicated on the display screen. The background is at 18 % grey level. Each of the 4 % white window boxes A_{wi} (i = 1 to 4) is set at 100 % grey, and turned on one at a time. Only one 4% white window is present at any time.
4) Measure the display luminance L_{Wi} (i = 1 to 4) at position P_0 as each 4 % white window A_{Wi} (i = 1 to 4) is presented one at a time.
5) Calculate the average luminance as follows:

$$L_{w\_bias} = \frac{L_{w1} + L_{w2} + L_{w3} + L_{w4}}{4} \tag{23}$$

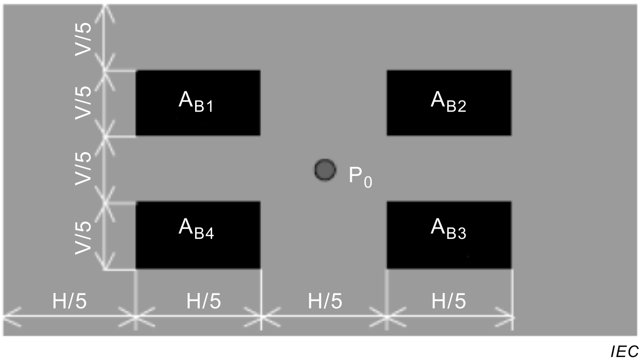
6) Establish the test pattern indicated in Figure 14 on the display screen. The background is at 18 % grey level. Each of the 4 % black window boxes A_{Bi} (i=1 to 4) are set at 0 % grey level and a turned on one at a time. Only one 4 % black window is present at any time.
7) Measure the display luminance L_{Bi} (i = 1 to 4) at position P_0 as each 4 % black window A_{bi} (i = 1 to 4) is presented one at a time.
8) Calculate the average luminance as follows:

$$L_{B\_bias} = \frac{L_{B1} + L_{B2} + L_{B3} + L_{B4}}{4} \tag{24}$$



NOTE The white boxes are diagonal to the luminance measurement position at P_0.

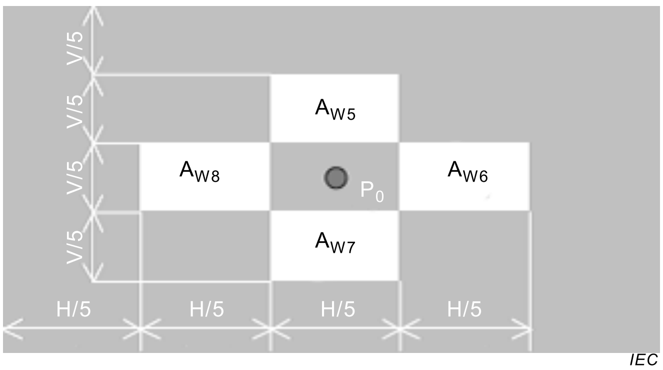
Figure 13 – Cross-talk pattern with diagonal 4 % white window boxes on grey background



NOTE The black boxes are diagonal to the luminance measurement position at P_0.

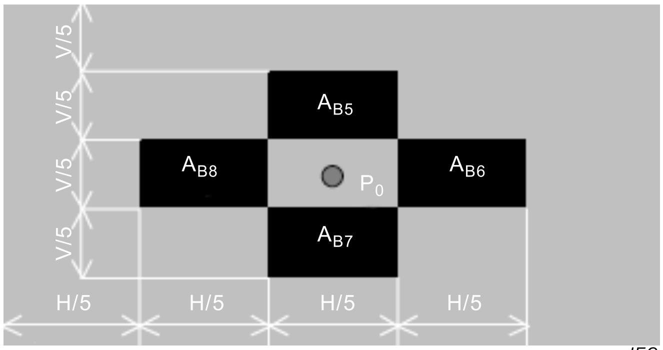
Figure 14 – Cross-talk pattern with diagonal 4 % black window boxes on grey background

9) Establish the test pattern indicated in Figure 15 on the display screen. The background is at 18 % grey level. Each of the 4 % white window boxes A_{Wi} (i = 5 to 8) is set at 100 % grey, and turned on one at a time. Only one 4 % white window is present at any time.
10) Measure the display luminance L_{Wi_CT}(i = 5 to 8) at position P_0 as each 4 % white window A_{Wi} (i = 5 to 8) is presented one at a time.
11) Establish the test pattern indicated in Figure 16 on the display screen. The background is at 18 % grey level. Each of the 4 % black window boxes A_{Bi} (i = 5 to 8) are set at 0 % grey level and a turned on one at a time. Only one 4 % black window is present at any time.
12) Measure the display luminance L_{Bi_CT}(i = 5 to 8) at position P_0 as each 4 % black window A_{Bi} (i = 5 to 8) is presented one at a time.



NOTE Aligned in the vertical and horizontal axis from the luminance measurement position at P_0.

Figure 15 – Cross-talk pattern with perpendicular 4 % white window boxes on grey background



NOTE Aligned in the vertical and horizontal axis from the luminance measurement position at P_0.

Figure 16 – Cross-talk pattern with perpendicular 4 % black window boxes on grey background

13) The percent white and black cross-talk from the display is given by:

$$CT_{\text{W}} = \max\left(100\% \frac{| L_{\text{Wi\_CT}} - L_{\text{W\_bias}} |}{L_{\text{W\_bias}}}\right), i = 5 \text{ to } 8 \tag{25}$$

$$CT_{\text{B}} = \max\left(100\% \frac{| L_{\text{Bi\_CT}} - L_{\text{B\_bias}} |}{L_{\text{B\_bias}}}\right), i = 5 \text{ to } 8 \tag{26}$$

The cross-talk values shall be reported with a description of the measuring conditions.

7 Optical measuring method under ambient illumination

7.1 Reflection measurements

7.1.1 General

The purpose of this method is to measure the reflection properties of a flexible display module under defined illumination conditions. The display shall be measured in its design or maximum bent state. If it can be demonstrated that the reflection properties do not change between the bent state and the flat state, then the reflection measurements can be performed with the display in its flat state.

This method applies to emissive/transmissive displays, as well as to reflective displays. If the reflective display is to be measured with the ILU on, then the ILU will be set to its maximum light level and the display will be treated as an emissive display.

The method specifies how to measure the display spectral reflectance factors and the luminous reflectance factors. It is recommended that the spectral reflectance factors be measured. If a luminance meter is used to obtain the luminous reflectance factors, then the measured luminous reflectance factors are only valid for the illumination spectra used during the measurement. These reflection factors should not be used for calculating the reflection properties from other spectral distributions.

7.1.2 Measuring conditions

7.1.2.1 General

The apparatus shall be as follows:

- a driving power source;
- driving signal equipment;
- an integrating sphere, sampling sphere, or hemisphere; and
- a directed light source.

For spectral measurements, a spectroradiometer that can measure luminance and spectral radiance is needed, as well as a white diffuse reflectance standard with a known hemispherical diffuse spectral reflectance factor and a directed spectral reflectance factor calibrated for the intended measurement geometry. For photometric measurements, a detector is required that can measure luminance, and a white diffuse reflectance standard is required with a known luminous hemispherical diffuse reflectance factor and a luminous directed reflectance factor calibrated for the intended measurement geometry and source spectra. The display shall be mounted and aligned according to the guidance provided in 4.1.

The illuminance condition shall be as follows:

- The standard directed, ring light, or hemispherical illumination conditions shall be used (see 5.2.3). The illumination spectra should approximate CIE Illuminant D50 or D65. Otherwise, a stable and spectrally smooth broadband visible light source (e.g. incandescent lamp) shall be used. The illumination/detection geometry used and the light source CCT shall be reported.
- Except for the standard ambient illumination conditions, all other conditions are the standard conditions.

7.1.2.2 Measuring the hemispherical diffuse reflectance

The measurement shall proceed as follows:

a) Place the display in an integrating sphere or against the sample port of a sampling sphere (see Figure 6 as indicated in 4.3.2. The long axis of the curved display (y-axis) shall be in the plane of incidence of the LMD. Turn ON the integrating sphere or sampling sphere hemispherical diffuse illumination to the desired CCT. Allow the light source to stabilize.

   NOTE 1 Any change in sphere illuminance can be monitored by a photopic detector attached to the sphere.

b) Set the test input signal to the display to generate a 4 % window of colour Q at the highest luminance level, or reflectance level for a reflective display, with a black background (see Figure 10).

c) Align the LMD through the measurement port, focused at the centre of the display, and at an 8° to 10° angle to the display surface normal. Turn room lights OFF. Measure the spectral radiance $L_{\mathrm{Q,hemi\text{-}ON}}(\lambda)$ or luminance $L_{\mathrm{Q,hemi\text{-}ON}}$ at the centre of the coloured pattern with the hemispherical surround ON. For spectral measurements, the display luminance $L_{\mathrm{Q,hemi\text{-}ON}}$ can be calculated using the following relation:

$$L = 683 \int_{\lambda} L(\lambda) V(\lambda) d\lambda \quad (27)$$

   where $V(\lambda)$ is the photopic luminous efficiency function as defined in CIE 15:2004.

   NOTE 2 In this document, spectral measurements like spectral radiance will be specifically identified by the spectral radiance's wavelength dependence (e.g. $L_{\mathrm{Q,hemi\text{-}ON}}(\lambda)$), whereas its photometric equivalent luminance will have no explicit wavelength dependence (e.g. $L_{\mathrm{Q,hemi\text{-}ON}}$).

d) Align the LMD to the centre of the calibrated white diffuse reflectance standard and measure its spectral radiance $S_{\mathrm{Q,hemi\text{-}ON}}(\lambda)$ or luminance $S_{\mathrm{Q,hemi\text{-}ON}}$ with the hemispherical surround ON and the display in its colour state Q. For the sampling sphere case, $S_{\mathrm{Q,hemi\text{-}}}$

$_{ON}(\lambda)$ or $S_{Q,hemi-ON}$ is the spectral radiance and luminance, respectively, measured from the sphere wall adjacent to the sample port.

e) Turn OFF the integrating sphere or sampling sphere hemispherical diffuse illumination. This may be accomplished by turning off the light source. If the sphere light is input by a portable source (like an optical fibre bundle), then the light can be turned OFF by disconnecting at the light source end so that the interior conditions and performance of the sphere are not changed. Skip this step for reflective displays with no ILU or ILU off.

f) Measure the spectral radiance $S_{Q,hemi-OFF}(\lambda)$ or luminance $S_{Q,hemi-OFF}$ of the reflectance standard, or sampling sphere wall, with the surround OFF and the display in its colour state Q. Skip this step for reflective displays with no ILU or ILU off.

g) Align the LMD to the centre of the display. Measure the screen spectral radiance $L_{Q,hemi-OFF}(\lambda)$ or luminance $L_{Q,hemi-OFF}$ in the centre of the display with the diffuse surround OFF. Skip this step for reflective displays with no ILU or ILU off.

h) Calculate the hemispherical diffuse spectral reflectance $\rho_Q(\lambda)$, or luminous hemispherical diffuse reflectance ρ_Q, of the colour Q display pattern for the measured illumination/detection geometry.

For spectral measurements, the following relation is used:

$$\rho_Q(\lambda) = \rho_{std}(\lambda)\frac{\left[L_{Q,\,hemi\text{-}ON}(\lambda) - L_{Q,\,hemi\text{-}OFF}(\lambda)\right]}{\left[S_{Q,\,hemi\text{-}ON}(\lambda) - S_{Q,\,hemi\text{-}OFF}(\lambda)\right]} \tag{28}$$

where $\rho_{std}(\lambda)$ is the known hemispherical spectral reflectance for the white diffuse reflectance standard, or sampling sphere wall, in the same geometry. For reflective displays with no ILU or ILU off, the terms $L_{Q,hemi-OFF}(\lambda)$ and $S_{Q,hemi-OFF}(\lambda)$ will be zero. The luminous hemispherical diffuse reflectance ρ_Q of a display rendering colour Q under the desired hemispherical diffuse illumination spectra is determined using the spectral reflectance factor $\rho_Q(\lambda)$ in the following formula:

$$\rho_Q = \frac{\int_\lambda \rho_Q(\lambda) E_{CIE}(\lambda) V(\lambda) d\lambda}{\int_\lambda E_{CIE}(\lambda) V(\lambda) d\lambda} \tag{29}$$

where $E_{CIE}(\lambda)$ is the relative spectral distribution of the desired illumination. The spectral distributions of CIE Illuminants A, D65, D50 and D75 tabulated in CIE 15:2004 shall be used. If additional daylight illuminants are desired, the following relation from CIE 15:2004 shall be used:

$$E_{CIE}(\lambda) = E_0(\lambda) + M_1 E_1 V(\lambda) + M_2 E_2(\lambda) \tag{30}$$

where the E_0, E_1, and E_2 eigenfunctions are tabulated in CIE 15:2004, and M_1 and M_2 are eigenvalues defined in the same document. For example, M_1 and M_2 are given in Table 4 for the cases of D50 and D75.

Table 4 – Eigenvalues M_1 and M_2 for CIE daylight Illuminants D50 and D75

Eigenvalues	Correlated colour temperature	
	5 000 K	7 500 K
M_1	-1,040 1	0,1435 8
M_2	0,366 66	-0,759 93

For luminance measurements, the photometric equivalent of Formula (31) is used:

$$\rho_Q = \rho_{std} \frac{\left[L_{Q,\text{hemi-ON}} - L_{Q,\text{hemi-OFF}}\right]}{\left[S_{Q,\text{hemi-ON}} - S_{Q,\text{hemi-OFF}}\right]} \quad (31)$$

For reflective displays with no ILU or ILU off, the terms $L_{Q,\text{hemi-OFF}}$ and $S_{Q,\text{hemi-OFF}}$ will be zero. However, the hemispherical diffuse reflectance ρ_Q of the display with a screen colour Q, and the white diffuse reflectance standard ρ_{std}, shall only be used for hemispherical diffuse light sources with the same geometry and spectral distribution as that used in this measurement. Therefore, any ambient contrast ratio or colour calculation using the hemispherical diffuse reflectance ρ_Q that was determined by the photometric method in Formula (30) is only valid for light sources with similar spectra and geometry.

To ensure measurement integrity, the reflected component of the sphere illumination shall be much greater than the display emission (i.e. $L_{Q,\text{hemi-ON}}(\lambda)>>L_{Q,\text{hemi-OFF}}(\lambda)$). The same applies for the photometric equivalents in Formula (31).

i) Report the CCT of the display test illumination, ρ_Q, the detector parameters (incident angle, measurement field angle, and distance to sample) and illumination source geometry used in the measurements in the test report.

7.1.2.3 Measuring the reflectance factor for a directed light source

The measuring method shall be as follows:

a) Mount the display in its flat or curved state in a fixture according to the guidance provided in 4.1.

b) Set the test input signal to the display to generate a 4 % window of colour Q at the highest luminance level, or reflectance level for a reflective display, with a black background (see Figure 10).

c) Measure the spectral radiance $L_Q(\lambda)$, or luminance L_Q, at the centre of the colour pattern under dark room conditions. For spectral measurements, the display luminance L_Q can be calculated using Formula (26). Skip this step for reflective displays with no ILU or ILU off.

d) Position the directed light source as specified in 4.3.3. In general, the discrete directed source geometry shall be used. If the display exhibits strong matrix (asymmetric) scatter, then a ring light is recommended.[9] If it can been demonstrated that the reflection properties of the curved display under directed illumination are the same for the display in its flat state, then the ring light configuration may also be used. Turn ON the light source at the desired CCT, and wait for the light source to stabilize. Adjust the source intensity so that the light reflected off the display produces a strong signal at the LMD.

e) Measure the spectral radiance $L_{Q,\text{dir}}(\lambda)$ or the luminance $L_{Q,\text{dir}}$ from the centre of the display with the directed source illumination ON. For spectral measurements, the luminance $L_{Q,\text{dir}}$ from the display with directed illumination can be calculated using Formula (26).

To ensure measurement integrity, the display ambient spectral radiance with directed source ON shall be much greater than the display spectral radiance in a dark room (i.e. $L_{Q,\text{dir}}(\lambda) >> L_Q(\lambda)$). The same applies for the photometric equivalents.

f) Remove the display and place the white diffuse reflectance standard in the same measurement plane as the LMD.

g) Measure the spectral radiance $S_{\text{dir}}(\lambda)$ or luminance S_{dir} from the calibrated white diffuse reflectance standard. For spectral measurements, the spectral irradiance $E_{\text{dir}}(\lambda)$ on the white diffuse reflectance standard (and consequently the display) can be determined by using the following formula, with $E(\lambda)=E_{\text{dir}}(\lambda)$, $L(\lambda)=S_{\text{dir}}(\lambda)$, and where $R(\lambda)=R_{std}(\lambda)$ is the known spectral reflectance factor for the white diffuse reflectance standard in the same geometry:

$$E(\lambda) = \frac{\pi L(\lambda)}{R(\lambda)} \quad (32)$$

The illuminance E_V can be obtained from the spectral irradiance $E(\lambda)$ by:

$$E_V = 683\int_{\lambda} E(\lambda)V(\lambda)d\lambda \tag{33}$$

where for the directed source case, the display illuminance $E_V = E_{dir}$ is obtained from $E(\lambda) = E_{dir}(\lambda)$. For photometric measurements, an analogous relation to Formula (32) is used to calculate the illuminance E_{dir}.

h) Calculate the spectral reflectance factor $R_Q(\lambda)$, or luminous reflectance factor R_Q, of the colour display pattern with directed illumination for the measured illumination/detection geometry.

For spectral measurements, the spectral reflectance factor $R_Q(\lambda)$ is determined using the following formula:

$$R_Q(\lambda) = \pi\frac{L_{Q,dir}(\lambda) - L_Q(\lambda)}{E_{dir}(\lambda)} = R_{std}(\lambda)\frac{L_{Q,dir}(\lambda) - L_Q(\lambda)}{S_{dir}(\lambda)} \tag{34}$$

For reflective displays with no ILU or ILU off, $L_Q(\lambda)$ will be zero. The following formula shall be used to calculate the luminous reflectance factor R_Q for a colour Q display pattern under directed illumination having the desired spectral distribution:

$$R_Q = \frac{\int_{\lambda} R_Q(\lambda)E_{CIE}(\lambda)V(\lambda)d\lambda}{\int_{\lambda} E_{CIE}(\lambda)V(\lambda)d\lambda} \tag{35}$$

where $E_{CIE}(\lambda)$ is the relative spectral distribution for the desired CIE illumination spectra. For indoor contrast ratio measurements, the same source spectra shall be used in this calculation as for the hemispherical diffuse reflectance of Formula (29). When calculating the outdoor ambient contrast ratio, CIE Illuminant D50 shall be used for $E_{CIE}(\lambda)$ following the CIE 15:2004 tabulated data.

For photometric measurements, an analogous relation to Formula (36) is used:

$$R_Q = \pi\frac{L_{Q,dir} - L_Q}{E_{dir}} \tag{36}$$

For reflective displays with no ILU or ILU off, L_Q will be zero.

The luminous reflectance factor in formula (36) shall only be used to calculate the ambient contrast of the same source spectra and geometry as that used in the measurement.

i) Report the CCT of the test illumination, the detector parameters (incident angle, measurement field angle, distance to sample), illumination source parameters (incident angle, angular subtense, distance to sample, beam divergence) used in the measurements, and R_Q in the test report.

7.2 Ambient contrast ratio

7.2.1 General

The purpose of this method is to determine the ambient contrast ratio of a flexible display module under defined indoor or daylight illumination conditions. The method uses the basic characteristics of the display measured by the methods in other clauses/subclauses to estimate the performance under typical indoor or outdoor lighting environments.

NOTE If a display exhibits significant photoluminescence, then the ambient contrast ratio calculation is only valid for the same illumination spectra and geometry used to measure the reflection coefficients.

7.2.2 Measuring conditions

The illuminance conditions shall be as follows:

– The standard ambient illumination conditions for an indoor room and clear sky daylight shall be used. Additional illumination conditions may also be used, depending on the application.

– Except for the standard ambient illumination conditions, all other conditions are the standard conditions.

7.2.3 Measuring method

The ambient contrast ratio is determined from dark room measurements and reflection measurements of the display under hemispherical diffuse and directed source illumination conditions. The measuring method for hemispherical diffuse reflectance and directed reflectance factor of the display for the required illumination spectra is defined in 7.1. These reflection parameters are used to calculate the combined (emitted and reflected) luminance of a display with a 4 % black and white window pattern at the required illuminance levels. The ambient contrast ratio is the ratio of the combined white luminance to the combined black screen luminance.

The black luminance L_K is measured at the centre and perpendicular to the display at a 0 % grey level for a full black screen under dark room conditions (following 6.1). Set the display to a 4 % area white window (see Figure 14) at the highest luminance level in the centre of the active area, and the remaining background is black at the lowest luminance level. Measure the white luminance L_W at the centre and perpendicular to the display under dark room conditions. For reflective displays with no ILU or ILU off, L_K and L_W will be zero. Calculate the indoor room or daylight contrast ratio of a 4 % window, using the following formula:

$$ACR = \frac{\left(L_W + \dfrac{\rho_W E_{CIE,hemi}}{\pi} + \dfrac{R_W E_{CIE,dir}\cos\theta_S}{\pi}\right)}{\left(L_K + \dfrac{\rho_K E_{CIE,hemi}}{\pi} + \dfrac{R_K E_{CIE,dir}\cos\theta_S}{\pi}\right)} \qquad (37)$$

where the reference parameters are $E_{CIE,hemi}$ = 60 lx, θ_s = 45°, and $E_{CIE,dir}\cos(\theta_s)$ = 40 lx for a TV viewing room; $E_{CIE,hemi}$ = 300 lx, θ_s = 45°, and $E_{CIE,dir}\cos\theta_s$ = 200 lx for an office; and $E_{CIE,hemi}$ = 15 000 lx, θ_s = 45°, and $E_{CIE,dir}\cos\theta_s$ = 65 000 lx for the outdoor daylight contrast ratio.

The hemispherical diffuse reflectance coefficients ρ_W and ρ_K for the display with a white or black 4 % window pattern, respectively, are calculated from Formula (29) using CIE Standard Illuminant A, CIE Standard Illuminant D65, or CIE Illuminant D50 spectrum for indoor illumination, or the CIE Illuminant D75 spectrum for daylight illumination. The directed source reflectance factor coefficients R_W and R_K for the display with a full white or black screen, respectively, are calculated from Formula (35) using the same CIE Standard Illuminant A, CIE Standard Illuminant D65, or CIE Illuminant D50 spectrum for indoor illumination, and the CIE Illuminant D50 spectrum for daylight illumination. If additional geometries or illuminance levels are used, they shall be noted in the test report. All values used to calculate the ambient contrast ratio shall be recorded in the test report.

7.3 Ambient display colour

7.3.1 General

The purpose of this method is to measure the ambient colour of a flexible display module under defined indoor or outdoor daylight illumination conditions. The method uses the basic characteristics of the display measured by the methods in other clause/subclauses to estimate the performance under typical indoor or outdoor lighting environments.

NOTE If a display exhibits significant photoluminescence, then the ambient display colour calculation is only valid for the same illumination spectra and geometry used to measure the reflection coefficients.

7.3.2 Measuring conditions

The illuminance conditions shall be as follows:

– The standard ambient illumination conditions for an indoor room and clear sky daylight shall be used. Additional illumination conditions may also be used, depending on the application.

– Except for the standard ambient illumination conditions, all other conditions are the standard conditions.

7.3.3 Measuring method

The chromaticity of a display under hemispherical diffuse and directed (including the ring type) illumination conditions is a combination of the display's intrinsic light emission and reflected ambient light. The ambient chromaticity of a display at a given colour state (e.g. white, black, red, green, or blue screen) under illumination conditions is determined by its equivalent display ambient tristimulus values. These values can be calculated from dark room measurements at the desired colour state, and reflection measurements of the display under hemispherical diffuse and directed source illumination conditions at that colour. The measuring methods for the hemispherical diffuse spectral reflectance and directed spectral reflectance factor of the display are described in 7.1.

Measure the spectral radiance $L_{\mathrm{Q}}(\lambda)$ at the centre and perpendicular to the display for the desired colour state Q (following 6.3.3) under dark room conditions. For reflective displays with no ILU or ILU off, $L_{\mathrm{Q}}(\lambda)$ will be zero. The total ambient spectral radiance $L_{\mathrm{Q,amb}}(\lambda)$ measured by a detector perpendicular to the display, with reflections from the hemispherical diffuse and directed sources included, will be:

$$L_{\mathrm{Q,amb}}(\lambda) = L_{\mathrm{Q}}(\lambda) + \frac{\rho_{\mathrm{Q}}(\lambda) E_{\mathrm{CIE,hemi}}}{\pi} + \frac{R_{\mathrm{Q}}(\lambda) E_{\mathrm{CIE,dir}} \cos\theta_{\mathrm{S}}}{\pi} \quad (38)$$

where $E_{\mathrm{CIE,hemi}}(\lambda)$ and $E_{\mathrm{CIE,dir}}(\lambda)$ are the irradiance spectra for the standard hemispherical diffuse and directed sources, respectively.

The relative irradiance spectra of Illuminant A, CIE Standard Illuminant D65, or CIE Illuminant D50 for indoor illumination are tabulated in CIE 15:2004. The relative irradiance spectra of CIE Illuminants D75 and D50 are used for daylight illumination, where CIE Illuminant D75 and D50 can be determined by Formula (29) and Table 4. $E_{\mathrm{CIE,hemi}}(\lambda)$ and $E_{\mathrm{CIE,dir}}(\lambda)$ are obtained by multiplying the relative spectra by an appropriate constant that would produce the reference illumination levels when integrated using Formula (35). The reference levels are $E_{\mathrm{CIE,hemi}}$ = 60 lx, θ_{s} = 45°, and $E_{\mathrm{CIE,dir}}\cos\theta_{\mathrm{s}}$ = 40 lx for a TV viewing room; $E_{\mathrm{CIE,hemi}}$ = 300 lx, θ_{s} = 45°, and $E_{\mathrm{CIE,dir}}\cos\theta_{\mathrm{s}}$ = 200 lx for an office; and $E_{\mathrm{CIE,hemi}}$ = 15 000 lx, θ_{s} = 45°, and $E_{\mathrm{CIE,dir}}\cos\theta_{\mathrm{s}}$ = 65 000 lx for outdoor daylight. If additional geometries, spectra, or illuminance levels are used, they shall be noted in the test report. The effective ambient tristimulus values for the display under these illumination conditions are:

$$X_{\mathrm{Q,amb}} = 683 \int_{\lambda} L_{\mathrm{Q,amb}}(\lambda)\bar{x}(\lambda)d\lambda \quad (39)$$

$$Y_{\mathrm{Q,amb}} = 683 \int_{\lambda} L_{\mathrm{Q,amb}}(\lambda)\bar{y}(\lambda)d\lambda \quad (40)$$

$$Z_{\mathrm{Q,amb}} = 683 \int_{\lambda} L_{\mathrm{Q,amb}}(\lambda)\bar{z}(\lambda) d\lambda \tag{41}$$

where $\bar{x}(\lambda)$, ***Error! Bookmark not defined.***$\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ are the colour matching functions (see CIE 15:2004).

The ambient 1931 CIE x and y chromaticity coordinates for the display at the desired colour state Q under the standard daylight illumination conditions are:

$$x_{\mathrm{Q,amb}} = \frac{X_{\mathrm{Q,amb}}}{X_{\mathrm{Q,amb}} + Y_{\mathrm{Q,amb}} + Z_{\mathrm{Q,amb}}} \tag{42}$$

$$y_{\mathrm{Q,amb}} = \frac{Y_{\mathrm{Q,amb}}}{X_{\mathrm{Q,amb}} + Y_{\mathrm{Q,amb}} + Z_{\mathrm{Q,amb}}} \tag{43}$$

Report the effective tristimulus values and CIE 1931 chromaticity coordinate for the rendered display colour Q, the CIE illuminants and illuminance values used in the calculations, and the measuring conditions.

7.4 Ambient colour gamut volume

7.4.1 General

The purpose of this method is to measure the ambient colour gamut volume of a flexible display module under defined ambient illumination conditions. The method uses the basic characteristics of the display measured by the methods in other clauses/subclauses to estimate the performance under typical indoor or outdoor lighting environments. The display chromaticity coordinates measured under dark room conditions may also be used to determine the dark room colour gamut volume. This colour gamut volume shall be compared to the IEC sRGB standard (IEC 61966-2-1) colour gamut volume with a D65 white point. This method is limited to display modules with RGB primaries.

NOTE If a display exhibits significant photoluminescence, then the ambient colour gamut volume calculation is only valid for the same illumination spectra and geometry used to measure the reflection coefficients.

7.4.2 Measuring conditions

The illuminance conditions shall be as follows:

– The standard ambient illumination conditions for an indoor room and clear sky daylight shall be used. Additional illumination conditions may also be used, depending on the application.
– Except for the standard ambient illumination conditions, all other conditions are the standard conditions.

7.4.3 Measuring method

The ambient colour gamut volume will be calculated from the effective ambient tristimulus values determined for each displayed colour following the procedures in 7.3. The measurements and calculations shall be consistently performed for a 4 % box window colour on a 0 % grey level background.

The ambient colour gamut volume with ambient illumination will be represented by the convex hull of display colours measured within the CIELAB colour space for the defined indoor and outdoor lighting conditions. The volume of that colour space under standard ambient display illumination is determined by the following procedure:

a) Apply a 4 % box window pattern, for at least eight defined colours. The colours shall uniformly sample the display's colour capability. For example, a three-primary display shall be measured for at least red, green, blue, cyan, yellow, magenta, black and 100 % grey level white (see Table 5). Each colour (except black) is displayed at its maximum signal level.

b) The effective ambient tristimulus values shall be determined following the procedure in 7.3. If it can be shown that the spectral reflection coefficients are invariant to the displayed colour at maximum signal level, then a common hemispherical diffuse spectral reflectance or directed spectral reflectance factor can be used for all the colours at maximum signal level.

Table 5 – An example of minimum colours required for gamut volume calculation of a 3-primary 8-bit display

Colour	8-bit Digital signal level
Red	Red = 255, Green = 0, Blue = 0
Green	Red = 0, Green = 255, Blue = 0
Blue	Red = 0, Green = 0, Blue = 255
Yellow	Red = 255, Green = 255, Blue = 0
Magenta	Red = 255, Green = 0, Blue = 255
Cyan	Red = 0, Green = 255, Blue = 255
White	Red = 255, Green = 255, Blue = 255
Black	Red = 0, Green = 0, Blue = 0

c) The ambient tristimulus values shall be transformed into the three-dimensional CIELAB colour space (see 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 daylight tristimulus values ($X_{\mathrm{W,day}}$, $Y_{\mathrm{W \cdot day}}$ and $Z_{\mathrm{W \cdot day}}$) and using the following transformation formulae:

$$L^* = 116 \times f(Y_{\mathrm{Q,day}} / Y_{\mathrm{W,day}}) - 16 \tag{44}$$

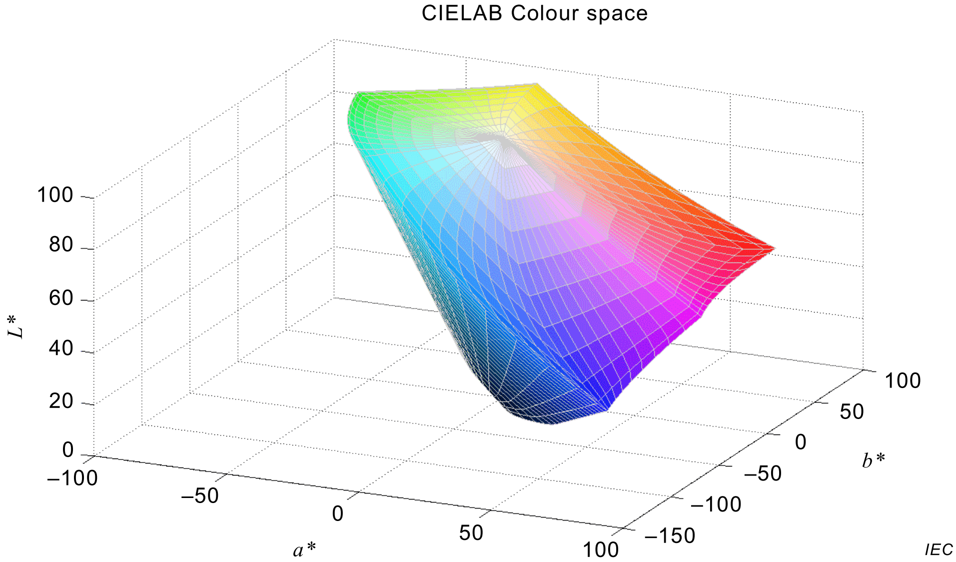
$$a^* = 500 \times \left[f(X_{\mathrm{Q,day}} / X_{\mathrm{W,day}}) - f(Y_{\mathrm{Q,day}} / Y_{\mathrm{W,day}}) \right] \tag{45}$$

$$b^* = 500 \times \left[f(Y_{\mathrm{Q,day}} / Y_{\mathrm{W,day}}) - f(Z_{\mathrm{Q,day}} / Z_{\mathrm{W,day}}) \right] \tag{46}$$

where

$$f(t) = \begin{cases} t^{1/3} & t > (6/29)^3 \\ \frac{1}{3}(\frac{29}{6})^2 t + \frac{16}{116} & \text{otherwise} \end{cases} \tag{47}$$

An example of the ambient colour gamut volume in the CIELAB uniform colour space is given in Figure 17.



NOTE Figure 17 shows an example of the range in colours produced by a display as represented by the CIELAB colour space.

Figure 17 – Example of the range in colours produced by a display

Calculate the colour gamut volume corresponding to the possible range of ambient display colours as represented in the CIELAB colour space. See Annex A for a detailed description of the analysis recommended to calculate the colour gamut volume. Other gamut calculation methods may be used if they yield the same results as the reference method described in Annex A.

NOTE This document evaluates a display ambient performance with the CIELAB model. More advanced colour appearance models are needed to evaluate a display appearance when the background is considered.

7.4.4 Reporting

The CIELAB colour gamut volume shall be reported in the test report along with the characteristics of the standard ambient illumination that were used. If additional colour spaces are used, they shall be reported as well. Report the spectral reflectance factors. The measured ambient tristimulus values shall all be reported as illustrated in Table 6. Table 6 shall indicate the original effective tristimulus values, i.e., the tristimulus values shall not be normalized to 100. For each ambient illumination condition a separate table is required. The CCT and white CIE 1931 chromaticity coordinates, in the dark room and ambient conditions, shall be reported in a form similar to Table 7. The percent of colour gamut volume relative to the IEC sRGB standard colour space (IEC 61966-2-1) with a D65 white point shall be reported in a form described by Table 8.

Table 6 – Measured tristimulus values for the minimum set of colours

Colour	$X_{\mathrm{Q,amb}}$	$Y_{\mathrm{Q,amb}}$	$Z_{\mathrm{Q,amb}}$
Red			
Green			
Blue			
Yellow			
Magenta			
Cyan			
White			
Black			
This is required for the gamut volume calculation under the specified ambient illumination condition (see Table 5).			

Table 7 – Calculated white point in the dark room and ambient illumination conditions

Colour	Surround	x	y	CCT
White	Dark room			
	Indoor or outdoor condition			

Table 8 – Colour gamut volume in the CIELAB colour space

Colour Gamut Volume	
Ambient illumination	Percent relative to sRGB ($8{,}21 \times 10^5$)
Dark room	%
Indoor or outdoor condition	%

Annex A
(informative)

Calculation method of ambient colour gamut volume

A.1 Purpose

The purpose of this method is to describe a procedure to calculate the colour gamut volume of scattered colour points in the three-dimensional CIELAB colour space.

A.2 Procedure for calculating the colour gamut volume

The procedure shall be as follows (see Figure A.1):

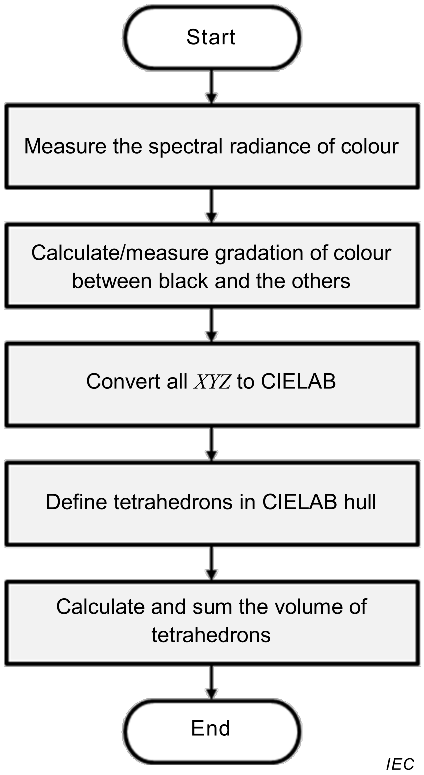


Figure A.1 – Analysis flow chart for calculating the colour gamut volume

1) Measure at least the red, green, blue, cyan, magenta, yellow, black and white colours of the display under the standard indoor or outdoor illumination conditions according to 7.4. Table A.1 provides an example using sRGB primaries under dark room illumination conditions and with the white luminance (Y) normalized to 100 %:

Table A.1 – Tristimulus values of the sRGB primary colours

Colour	x_Q	y_Q	$X_{Q,amb}$	$Y_{Q,amb}$	$Z_{Q,amb}$
Red	0,640	0,330	41,239	21,264	1,933
Green	0,300	0,600	35,758	71,517	11,919
Blue	0,150	0,060	18,048	7,219	95,053
Cyan	0,225	0,329	53,806	78,736	106,973
Magenta	0,321	0,154	59,287	28,483	96,986
Yellow	0,419	0,505	76,998	92,781	13,853
Black	0,000	0,000	0,000	0,000	0,000
White	0,313	0,329	95,046	100,000	108,906

2) Convert all colours points into the CIELAB colour space using Formulae (43) to (46). See Table A.2 and Figure A.2 for an example of the sRGB colour set in the CIELAB colour space.

Table A.2 – Example of sRGB colour set represented in the CIELAB colour space

Colour	$a*$	$b*$	$L*$
Red	80,105	67,223	53,233
Green	-86,188	83,186	87,737
Blue	79,194	-107,854	32,303
Cyan	-48,084	-14,128	91,117
Magenta	98,250	-60,833	60,320
Yellow	-21,561	94,488	97,138
Black	0	0	0
White	0	0	100

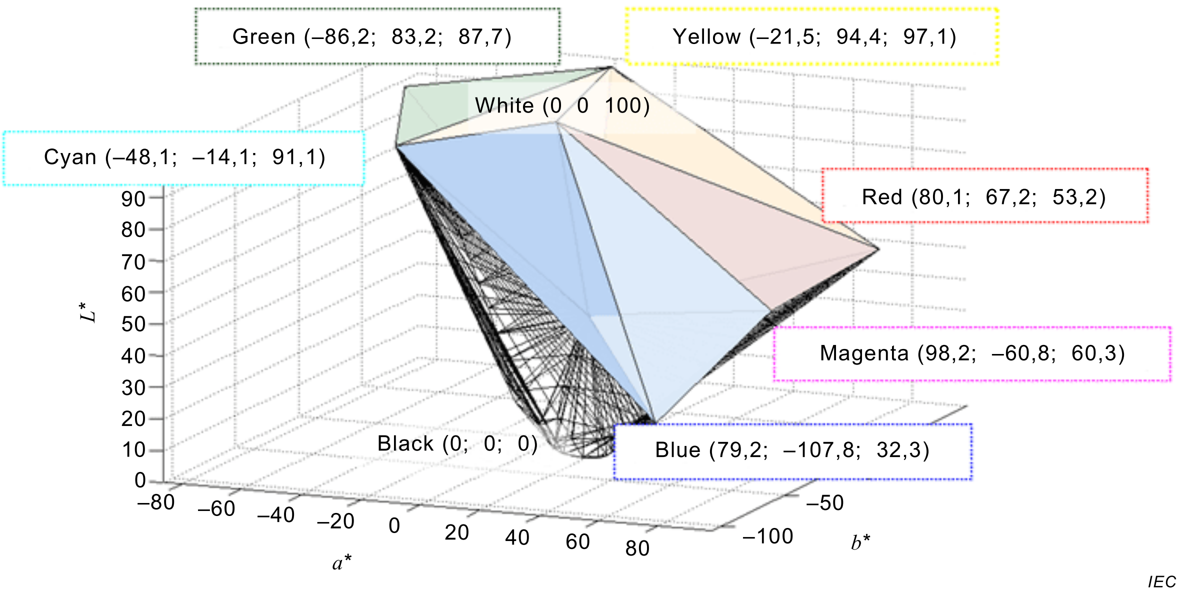


Figure A.2 – Graphical representation of the colour gamut volume for sRGB in the CIELAB colour space

3) Compute the colour gamut volume by adding up all the tetrahedrons contained within the displayed colour points and report as a percentage of the volume compared with the sRGB colour gamut volume. An example of a display in a dark room with the sRGB colour gamut volume calculated in the CIELAB colour space is provided in Table A.3.

Table A.3 – Example of sRGB colour gamut volume in the CIELAB colour space

Colour gamut volume	
Total	8,21 x 10^5
Percent relative to sRGB	100 %

A.3 Surface subdivision method for CIELAB gamut volume calculation

A.3.1 Purpose

This algorithm accepts an arbitrary set of gamut corner cases specified in CIE 1931 *XYZ* tri-stimulus values. The minimum set of colours would be red, green, blue, cyan, magenta, yellow, black and white. For devices that do not have a well-behaved convex hull shape in the CIELAB colour gamut volume profile, many more sampled colours will be needed to accurately determine the colour gamut volume value. The *XYZ* values are arranged in the rows of the input variable *P*, with a minimum of eight colour corner cases required. The output value is the calculated colour gamut volume.

A.3.2 Assumptions

It is assumed that the colour gamut in the CIE *XYZ* colour space will be defined as the convex hull of given corner cases. The colour gamut in the CIELAB colour space will be this convex hull, normalised in the CIE *XYZ* space by the corner case with the maximum luminance (taken as the white point), and translated into the CIELAB colour space where it will no longer be entirely convex.

A.3.3 Algorithm

a) Obtain the convex hull (see Note 1) of the colour corner points in P. Store the tessellation of the surface of this hull in *T*. Initialise a total volume *v* to 0.

b) Calculate the average of the points P to be used as a gamut mid-point and store in P_m.

c) For each triangular surface tile in *T*:

   1) Let *s* equal the number of edges that have extents (see Note 2) in L^*, a^*, b^* coordinates greater than 10.

   2) If $s = 0$ then calculate the volume defined between the vertices of the surface tile and P_m. Add this volume to *v*.

   3) If $s = 3$ then calculate the mid-points in the CIE *XYZ* space and subdivide the triangular tile into four sub-tiles defined by each corner vertex with the two nearest mid-points and the three mid-points. Repeat three times for each triangular sub-tile.

   4) If $s = 1$ or 2 then calculate the mid-point in the CIE *XYZ* space of the edge with the largest extents in CIELAB and subdivide the triangular tile into two sub-tiles along the line between the mid-point and opposite vertex. Repeat three times for each triangular sub-tile.

   NOTE 1 Where the corner points are the standard RGBCMYKW.

   NOTE 2 Extents are used rather than length as they are faster to calculate.

d) Return the total volume now contained in *v*.

A.3.4 Software example execution

In order to execute the Matlab[2] program below, the following command is executed with the corresponding sRGB data loaded into memory:

>> P = GetGamutCorners('sRGB')

Default D65 white is used

P =

0	0	0
0,412 4	0,212 6	0,019 3
0,770 0	0,927 8	0,138 5
0,357 6	0,715 2	0,119 2
0,538 1	0,787 4	1,069 7
0,180 5	0,072 2	0,950 5
0,592 9	0,284 8	0,969 9
0,950 5	1,000 0	1,089 1

where the data matrix corresponds to the following tristimulus coordinates as exemplified by Table A.1:

X_{K}	Y_{K}	Z_{K}
X_{R}	Y_{R}	Z_{R}
X_{Y}	Y_{Y}	Z_{Y}
X_{G}	Y_{G}	Z_{G}
X_{C}	Y_{C}	Z_{C}
X_{B}	Y_{B}	Z_{B}
X_{M}	Y_{M}	Z_{M}
X_{W}	Y_{W}	Z_{W}

The CIELAB colour gamut volume is obtained by executing the following command:

>> CIELabVol_subd(P)

ans =

8,21x10^5

---

2 Matlab is the trade name of a product supplied by MathWorks®. 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.

```
CIELabVol_subd.m

function [v] = CIELabVol_subd(P)
%Each row of P contains XYZ tri-stimulus values of gamut corner points.
%The 3D gamut is defined as the convex hull of these points in XYZ space.
%The surface is recursively subdivided down to a threshold scale in CIELAB
%and the volume made by each surface tile to a central point is summed

thresh=10; %CIELab subdivision threshold

%Get the hull defined by the points
T=convhulln(P);

%Get the white point (taken as the primary with the maximum Y)
[W,i]=max(P(:,2));
W=P(i,:);

%Normalise the gamut to the white point
Pn=P./(repmat(W,size(P,1),1));

%get the mid-point
Pm=mean(Pn);

%add-on the CIELab points
Pn=[Pn, XYZ2Lab(Pn)];
Pm=[Pm, XYZ2Lab(Pm)];

%calculate and sum the Lab volume of each surface tile to the mid-point
v=0;
for n=1:size(T,1),
    v=v+SubDLabVol(Pn(T(n,:),:),Pm,thresh);
end

%% sub-functions
% XYZ2Lab converts XYZ values arranged in columns to L* a* b*
    function [ t ] = XYZ2Lab( t )
    i=(t>0.008856);
    t(i)=t(i).^(1/3);
    t(~i)=7.787*t(~i)+16/116;
    t=[116*t(:,2)-16, 500*(t(:,1)-t(:,2)), 200*(t(:,2)-t(:,3))];
    end

%Recursive function to devide up the surface tile then return the volume
    function [ v ] = SubDLabVol( vp,c,th )
        %Get the max extent of each edge (quicker than length calculation)
        m=max(abs(vp-circshift(vp,1)),[],2);
        %Count how many edges have extents larger than the threshold
        s=sum(m>th);

        if (s==0), %no edges larger: return the volume
            v=abs(det(vp(:,4:6) - repmat(c(1,4:6),3,1))/6);

        elseif (s==3),%all edges larger: divide tile in four
            %get edge mid-points
            ip=(vp(:,1:3)+circshift(vp(:,1:3),1))/2;

      %calculate CIELab points of the mid-points
            ip=[ip,XYZ2Lab(ip)];
```

```
      %and call recursively for each sub-tile
            v=SubDLabVol([vp(1,:);ip(1:2,:)],c,th);
            v=v+SubDLabVol([vp(2,:);ip(2:3,:)],c,th);
            v=v+SubDLabVol([vp(3,:);ip(1:2:3,:)],c,th);
            v=v+SubDLabVol(ip,c,th);

        else %one or two edges larger: split the tile on the largest edge
            %shift the order so 1-2 has the largest extent
            [m,i]=max(m);
            vp=circshift(vp,2-i);

            %calculate the mid-point of 1-2 and the CIELab point
            ip=(vp(1,1:3)+vp(2,1:3))/2;
            ip=[ip,XYZ2Lab(ip)];

            %and call recursively for the two sub-tiles
            v=SubDLabVol([vp([1 3],:);ip],c,th);
            v=v+SubDLabVol([vp(2:3,:);ip],c,th);
        end
    end
end
```

```
GetGamutCorners.m

function [ P ] = GetGamutCorners( P ,wh)
%GET PRIM returns a set of colour corner points based on a standard gamut
%   input string must contain one of:
%       'sRGB', 'Rec709', 'EBU', 'NTSC'
%           optionally one of
%       'D50', 'D55', 'D65', 'D75', 'IllA', 'IllE'
    if ischar(P)
        if nargin<2
            wh=P;
        end
        if strfind(P,'sRGB') || strfind(P,'Rec709')
            prim=[0.64,0.33;0.3,0.6;0.15,0.06];
        elseif strfind(P,'EBU')
            prim=[0.64,0.33;0.29,0.6;0.15,0.06];
        elseif strfind(P,'NTSC')
            prim=[0.67,0.33;0.21,0.71;0.14,0.08];
        else
            error('non-valid colour primary specification');
        end
        P=prim;
    end
    if ischar(wh)
        if strfind(wh,'D50')
            wh=[0.3457,0.3585];
        elseif strfind(wh,'D55')
            wh=[0.3324,0.3474];
        elseif strfind(wh,'D65')
            wh=[0.3127,0.3290];
        elseif strfind(wh,'D75')
            wh=[0.2990,0.3149];
```

```
    elseif strfind(wh,'IllA')
            wh=[0.44757,0.40745];
        elseif strfind(wh,'IllE')
            wh=[0.3333,0.3333];
        else
            wh=[0.3127,0.3290];
            display('Default D65 white used');
        end
    end
    wh=[wh, 1-sum(wh)]/wh(2);
    P=[P, 1-sum(P,2)];
    P=P.*repmat((wh/P)',1,3);
    %P=[KRYGCBMW]'
    P=[0 0 0;P(1,:);sum(P(1:2,:));P(2,:);sum(P(2:3,:));...
        P(3,:);sum(P([1 3],:)); sum(P)];
end
```

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