

INTERNATIONAL STANDARD



**Electronic displays –
Part 2-2: Measurements of optical characteristics – Ambient performance**

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**Electronic displays –
Part 2-2: Measurements of optical characteristics – Ambient performance**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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| | |
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| 110/1213/FDIS | 110/1232/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.

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

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INTRODUCTION

This document describes the common optical measurement methods applicable in the field of electronic display devices, which overlap with some of the parts of existing documents developed inside TC 110 (IEC 61747-6-2 [17]¹, IEC 62341-6-2 [18], IEC 61988-2-2 [19], IEC 62715-5-1 [20], IEC 62679-3-1 [21]), that describe the optical measurement methods of the individual technologies, such as LCD, OLED, PDP and others. This document on common optical measurement methods is intended to be used as the reference document in future documents and in revisions of existing documents (e.g. IEC 61747-6-2 [17], IEC 62341-6-2 [18], IEC 61988-2-2 [19], IEC 62715-5-1 [20], IEC 62679-3-1 [21]). The existing standards documents will be revised in their maintenance time and they will refer to this document to the largest extent.

All documents in IEC TC 110 that are concerned with the measurement of optical properties of electronic display devices under ambient illumination refer to a set of methods and procedures that are similar to each other, or sometimes even identical. This document is intended to identify these methods and to describe them, together with suitable precautions and diagnostics, as a reference for forthcoming documents to make the work of the involved experts more efficient and to avoid duplication of efforts.

Introduction of the common optical measurement methods (COMMs) is also related to a structure where each kind of optical measurement finds its unambiguous position for identification of similarities to other methods or for clarification of distinctions. This structural classification together with a general taxonomy is supposed to make the process of documents production easier, faster and thus more effective.

The above characteristics are summarized in Table 1. The display characteristics that are addressed in this part of IEC 62977 are indicated by a check mark ✓ in the table.

¹ Numbers in square brackets refer to the Bibliography.

Table 1 – Measurement structure from optical quantities to evaluation and to results (top down)

| Variables | Time | | Location | Direction | Test pattern, electrical driving, input signal | Illumination conditions | Temperature, humidity |
|-------------------------|---|---------------------------------|--------------------|------------------------|--|-----------------------------------|------------------------|
| | Fast | Slow | (<i>x, y</i>) | (<i>θ, φ</i>) | | | |
| Data sampling condition | Fast | Slow | Slow | Slow | Slow √ | | |
| Evaluation | | | | | | | |
| Results | Transitions from one optical state to another state (for example from test-pattern-1 to test-pattern-2) | Temporal stability (uniformity) | Lateral uniformity | Directional uniformity | Static pattern, √ Characteristic function (electro-optic transfer function, EOTF) Characteristic values (e.g. threshold, saturation) | Darkroom, √ Indoor, Outdoor | Standard environment √ |
| Evaluation 1st order | Turn-on, turn-off, delay (latency) time periods, temporal modulations | | | | Luminance, √ Contrast, √ chromaticity, √ Threshold, saturation values, steepness of transitions, etc. | | |
| Evaluation 2nd order | Flicker prediction, moving picture response time, etc. | | | | EOTF from which the exponent γ is evaluated Chromaticity/ colour gamut area, Colour gamut volume, √ | | |

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ELECTRONIC DISPLAYS –

Part 2-2: Measurements of optical characteristics – Ambient performance

1 Scope

This part of IEC 62977 specifies standard measurement conditions and measuring methods for determining the optical characteristics of electronic displays under indoor and outdoor illumination conditions. Standard illumination geometries are specified and the reflection properties of flat screens are determined under those conditions. Reference illumination levels and spectra are used to estimate the photometric and colorimetric characteristics of electronic displays under the same conditions. These methods apply to emissive, transmissive, and reflective displays, or combinations thereof, that render real 2D images on a flat screen.

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 (IEV) – Part 845: Lighting*

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

ISO/CIE 11664-1, *Colorimetry – Part 1: CIE standard colorimetric observers*

ISO/CIE 11664-4, *Colorimetry – Part 4: CIE 1976 L*a*b* colour space*

ISO 15076-1:2010, *Image technology colour management – Architecture, profile format and data structure – Part 1: Based on ICC.1:2010*

CIE 15, *Colorimetry*

CIE 168, *Criteria for the evaluation of extended-gamut colour encoding*

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-845 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1**signal pixel**

smallest encoded picture element in the input image

Note 1 to entry: Signal pixel is defined as the unit of signal resolution.

3.1.2**pre-gamma average picture level**

average input level of all signal pixels relative to an equivalent white pixel driven by a digital RGB input

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

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

Note 3 to entry: The pre-gamma APL is also called gamma-corrected APL in IEC 62087-2 [14]. In addition, it is noted that the tone rendering curve may not have a power law function with a well-defined exponent (gamma).

3.1.3**APL loading**

influence of average picture level on display performance, for example luminance

3.2 Abbreviated terms

| | |
|--------|---|
| APL | pre-gamma average picture level |
| CCT | correlated colour temperature |
| CIE | Commission Internationale de L'Éclairage (International Commission on Illumination) |
| CIELAB | CIE 1976 (L*a*b*) colour space |
| DUT | device under test |
| EOTF | electro-optic transfer function |
| FWHM | full-width-at-half-maximum |
| ILU | integrated lighting unit (e.g. an edge-lit front guide plate) |
| LCD | liquid crystal display |
| LED | light emitting diode |
| LMD | light measuring device |
| OLED | organic light emitting diode |
| RGB | red, green, and blue |
| SDR | standard dynamic range |
| sRGB | standard RGB colour space defined in IEC 61966-2-1 |

3.3 Symbols

A list of symbols used in this document is given in Table 2.

Table 2 – Summary of symbols

| Symbol | Units | Definition |
|---|--|---|
| E | lx | illuminance |
| $E(\lambda)$ | $W \cdot m^{-2} \cdot nm^{-1}$ | spectral irradiance |
| $E_{dir}(\lambda)$ | $W \cdot m^{-2} \cdot nm^{-1}$ | spectral irradiance from a directed light source at normal incidence |
| $E_{CIE,dir}(\lambda)$ | $W \cdot m^{-2} \cdot nm^{-1}$ | spectral irradiance of a CIE standard illuminant from a directed light source at normal incidence |
| $E_{hemi}(\lambda)$ | $W \cdot m^{-2} \cdot nm^{-1}$ | spectral irradiance from a hemispherical diffuse light source |
| $E_{CIE,hemi}(\lambda)$ | $W \cdot m^{-2} \cdot nm^{-1}$ | spectral irradiance of a CIE standard illuminant from a hemispherical diffuse light source |
| R_Q | | luminous reflectance factor for a rendered display colour Q |
| $R_Q(\lambda)$ | | spectral reflectance factor for a rendered display colour Q |
| ρ_Q | | luminous reflectance or diffuse reflectance for a rendered display colour Q |
| $\rho_Q(\lambda)$ | | spectral reflectance for a rendered display colour Q |
| L_Q | $cd \cdot m^{-2}$ | darkroom luminance for a rendered display colour Q |
| $L_Q(\lambda)$ | $W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$ | darkroom spectral radiance for a rendered display colour Q |
| $L_{Q,amb}(\lambda)$ | $W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$ | ambient spectral radiance, including reflected and darkroom emitted light, for a rendered display colour Q |
| $L_{Ref}(\lambda)$ | $W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$ | reflected spectral radiance when the reflection coefficients are independent of the rendered display colour Q |
| $X_Q, Y_Q,$ and Z_Q | $cd \cdot m^{-2}$ for Y_Q | CIE tristimulus values of the rendered display colour Q in a darkroom |
| $X_{Q,amb}, Y_{Q,amb},$ and $Z_{Q,amb}$ | $cd \cdot m^{-2}$ for $Y_{Q,amb}$ | equivalent CIE tristimulus values, including reflected and darkroom emitted light, for a rendered display colour Q |
| x_Q, y_Q | | CIE 1931 chromaticity coordinates of the rendered display colour Q in a darkroom |
| $x_{Q,amb}, y_{Q,amb}$ | | equivalent CIE 1931 chromaticity coordinates, including reflected and darkroom emitted light, for a rendered display colour Q |

4 Standard measuring conditions

4.1 Standard measuring environmental conditions

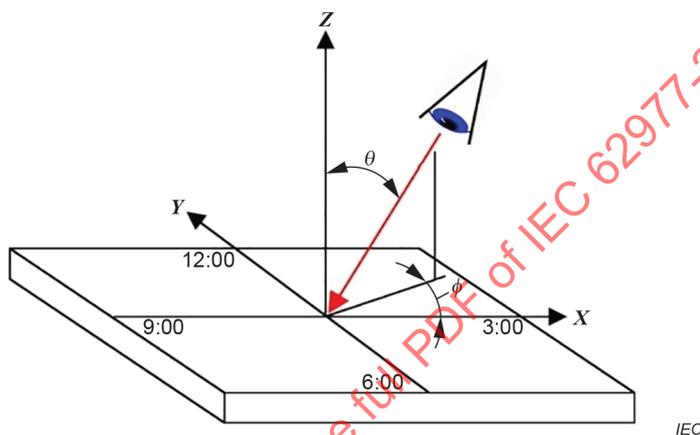
Measurements shall be carried out under the following standard environmental conditions:

- temperature: $25 \text{ }^\circ\text{C} \pm 3 \text{ }^\circ\text{C}$,
- relative humidity: 25 % to 85 %,
- atmospheric pressure: 86 kPa to 106 kPa.

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

4.2 Viewing direction and light source coordinate system

The viewing direction is the direction under which the observer looks at the point of interest on the display under test (DUT). During the measurement, the light measuring device (LMD) simulates the observer, by aiming the LMD at the point of interest on the DUT from the viewing direction. The viewing direction is defined by two angles: the angle of inclination θ (relative to the surface normal of the DUT) and the angle of rotation ϕ (also called azimuth angle) as illustrated in Figure 1. Although the azimuth angle is measured in the counter-clockwise direction, it is related to the directions on a clock face as follows: $\phi = 0^\circ$ is the 3-o'clock direction ("right"), $\phi = 90^\circ$ the 12-o'clock direction ("top"), $\phi = 180^\circ$ the 9-o'clock direction ("left") and $\phi = 270^\circ$ the 6-o'clock direction ("bottom"). The same coordinate system can be used to specify the positioning of the light sources used to represent the ambient lighting environment.



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

Figure 1 – Representation of the viewing direction (direction of measurement) and coordinate system used for light source configuration

4.3 Standard lighting conditions

4.3.1 General

A light source is chosen to provide as broad, stable, and smooth a spectrum as possible in order to reliably measure the spectral reflectance and reflection coefficients of the display surface specific to the geometry of the light source. This document then applies the reflection coefficients to simulate the display performance under the same geometric conditions using an illuminant, that is, a model or measured light source with an illumination level and/or spectrum that could be different from the light source used in the measurement.

An illuminant can be used to represent the use of a display that is viewed indoors (e.g. office), or in direct daylight (outdoors). These environments generally contain a combination of directed and uniform hemispherical diffuse light sources. The visual performance of the display can depend on the type of illumination and measurement geometry. Subclause 4.3 specifies the detailed conditions of the light sources for reflectance measurements under otherwise darkroom conditions.

A warm-up time can be necessary. The light source signal shall remain stable to within $\pm 0,5\%$ standard deviation within a single measurement, and $\pm 2\%$ for longer (>30 min) measurements.

4.3.2 Standard measuring darkroom conditions

The influence of unwanted background illumination shall be minimized, typically by illuminating the display in a darkroom. Unwanted background illumination is mainly a consideration for directed light sources, which is often solved by using light sources with spectral irradiance values that are substantially larger than the background. The darkroom spectral radiance contribution from the background illumination, that is, the measured spectral radiance reflected off the DUT, shall be not more than $1/10^{\text{th}}$ of the spectral radiance from the device black state with the illumination source on. If this condition is not satisfied, then background subtraction is required and it shall be noted in the report. In addition, if the sensitivity of the LMD is more than $1/100^{\text{th}}$ of the spectral radiance from the device black state, then the spectral radiance sensitivity limit of the LMD shall be noted in the report.

4.3.3 Standard ambient illumination

The following illumination conditions are specified for the optical measurements of displays under ambient illumination. The ambient illumination shall simulate indoor or outdoor illumination conditions. A combination of a hemispherical diffuse and directed source geometry is generally used to simulate either ambient indoor illumination or outdoor daylight illumination under a clear sky [1],[2]. Uniform hemispherical diffuse illumination will be used to simulate the background lighting in a room with the directed light source such as an occluded luminaire in a room, or the hemispherical skylight incident on the display, with the sun occluded. A directed light source in a darkroom will simulate the effect of directional illumination on a display by a luminaire in a room, or from direct sunlight.

The following reference illumination conditions shall be used to simulate indoor and outdoor display viewing environments. Additional conditions can also be used, depending on the use case.

a) Indoor room illumination conditions:

- Uniform hemispherical diffuse illumination – Use a light source closely approximating CIE Standard Illuminant A, CIE Standard Illuminant D65, or CIE Standard Illuminant D50 as defined in CIE 15. For spectral measurements, a spectrally smooth broadband light source (such as an approximation to CIE Standard Illuminant A) shall be used. A measurement of the spectral reflectance factor using a broad light source (such as Illuminant A) enables the indoor photopic and colour metrics to be calculated later for the desired reference spectra (for example CIE D65 Illuminant). The performance metrics shall be calculated using 300 lx for an indoor reading environment [3]. The actual hemispherical diffuse reflectance factor measurement can require higher illumination levels for better measurement accuracy. The results are then scaled down to the required illumination levels.
- Directional illumination – The same source spectra shall be used as with hemispherical diffuse illumination. The indoor room photopic and colour metrics shall be calculated using directional 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 can require higher illumination levels for better measurement accuracy. The results are then scaled down to the required illumination levels. The directed source shall be 45° above the surface normal ($\theta_s = 45^\circ$) and have an angular subtense of no more than 5° . The angular subtense is defined as the full angle span of the light source from the centre of the display's measurement area.
- Other illumination levels may be used in addition to those defined above for calculating the ambient contrast ratio under indoor illumination conditions. However, approximately 60 % of the total illuminance should be hemispherical diffuse, and 40 % directional illumination. Additional ratios of diffuse to directional illumination may also be measured.

b) Daylight illumination conditions:

- Uniform hemispherical diffuse illumination – Use a light source closely approximating skylight with the spectral distribution of CIE Illuminant D75 [4]. Additional CIE daylight illuminants (such as D65) may also be used, depending on the intended application. 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 metrics shall be calculated using 15 000 lx of hemispherical diffuse illumination (with specular included) incident on a display surface in a vertical orientation [4],[5]. 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.
- Directional illumination – The directional light source shall approximate CIE daylight Illuminant D50 [4]. 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 metrics can be calculated later with the D50 Illuminant spectra. The daylight contrast ratio or colour shall be calculated using 65 000 lx for a directed source at an inclination angle of $\theta_s = 45^\circ$ to the display surface, and the LMD shall be aligned normal to the display surface ($\theta_d = 0$) [4],[5]. 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 $0,5^\circ$.

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

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.

If there is fluorescent light with a radiance larger than 1/100 that of the DUT black state (including background reflected light) the spectral reflectance analysis should not be used. In this case, the spectrum of the light sources should match the spectrum of the CIE illuminants, and the photometric reflection coefficients shall be measured directly. These coefficients will then include the contribution from the fluorescence. The presence of fluorescence can be checked by turning the display off and shining a directional source (with a blue filter) on the display at a 45° inclination angle and determining if a glow from the illumination area can be observed.

4.3.4 Standard illumination geometries

4.3.4.1 General

The measurement geometry can have a significant effect on the measured reflection properties of a display [6]. Three types of illumination geometries shall be used for determining the performance of the display. Standard configurations for implementing these illumination geometries are defined in 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 [1].

4.3.4.2 Directional illumination

Directional illumination is obtained when a light source produces approximately parallel rays incident on the DUT. The maximum deviation of the rays from the optical axis depends on the diameter of both the source and measuring spot. The maximum angle of deviation from the optical axis is given by

$$\arctan\left(\frac{r_{ms} + r_s}{d}\right) < 5^\circ \quad (1)$$

where r_s is the source radius, d is the distance to the measuring spot, and r_{ms} is the measuring spot radius. The illumination across the cross-section of the beam shall be uniform to within 5 % ($[L_{max} - L_{min}] / L_{max}$). A source of light sufficiently distant from the DUT can provide directional illumination (e.g. sun and moon). When simulating outdoor directional ambient illumination like the sun and moon, the subtense of the source (as observed by the DUT) should be $\leq 0,5^\circ$.

Directional illumination can be realized with at least three different types of sources when the source dimensions are small enough compared to the distance between the source and the measuring spot on the sample. These geometries are depicted in Figure 2:

- flat Lambertian source, for example the exit port of an integrating sphere (top, with light source in grey),
- spherical isotropic source (e.g. incandescent bulb inside a diffusing glass-sphere) (middle, with light source in grey),
- projection system with lenses or mirrors (bottom, with lens on the right).

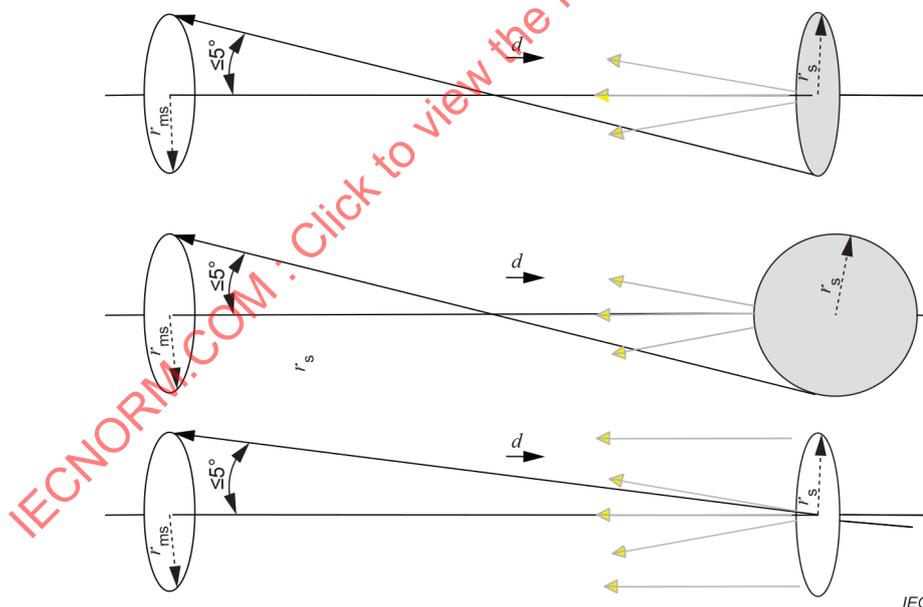


Figure 2 – Illustrated examples for directional illumination

Directional illumination is implemented by using a light source with a small diameter (compared to the distance to the measurement spot) aligned to form an inclination angle θ_S with respect to the surface normal of the DUT. This directed light source produces an illumination spot on the DUT. The LMD is placed at an inclination angle θ_R in the plane of the incident light, and its measurement field centred within the illumination spot. The light source and LMD can be adjusted over a range of inclination angles, but the LMD shall remain in the plane of incidence (i.e. $\phi_S = \phi_R + 180^\circ$). This configuration is shown in Figure 3 (left) with its representation in a polar coordinate system (right). The measurement field on the DUT is defined by the DUT area element that is imaged on the detector in the LMD.

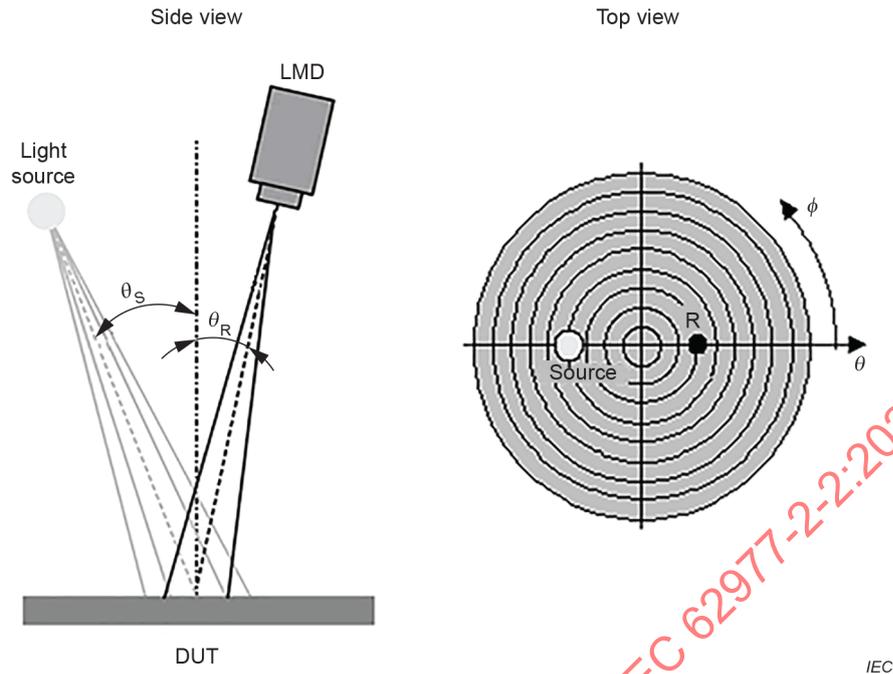


Figure 3 – Example of the measuring setup using directional illumination where $\theta_S = 40^\circ$ and $\theta_R = 30^\circ$

The standard conditions are $\theta_S = 45^\circ$ and $\theta_R = 0^\circ$. Alignment accuracy to within $\pm 0,4^\circ$ is recommended to keep alignment-related measurement error within $\pm 5\%$.

4.3.4.3 Ring light illumination

Ring light illumination can be considered a special case of directional illumination. It provides directional illumination with rotational symmetry about the display's surface normal and is centred on the measurement spot. Ring light illumination can be realized in the following ways:

- fiber-optic ring light,
- integrating sphere with a ring-shaped aperture (annulus),
- optical systems with lenses and mirrors, for example a concave ring mirror.

A ring-shaped light-source centred about the surface normal of the DUT illuminates the DUT from an angle of inclination $\theta_S \pm \Delta$ for all azimuthal angles $\phi_S = 0$ to 360° . The LMD is aligned to form an angle $\theta_R < \theta_S - \Delta$ with respect to the surface normal of the DUT. Figure 4 shows a side view of the measuring setup (left) and its representation in a polar coordinate system (right). A more detailed illustration of the ring light characteristics is given in Figure 5. The subtense of the ring light (2Δ in this case) shall be specified. The source and detector shall be aligned to the defined geometry to within $\pm 3^\circ$. The illumination of the measuring spot on the DUT shall be uniform within 5% . This setup is used with the light source fixed, and the LMD can be adjusted within the limits of the ring light opening. The standard conditions are $\theta_R = 0^\circ$ and a source inclination angle of $\theta_S \pm \Delta = 45^\circ \pm 3^\circ$.

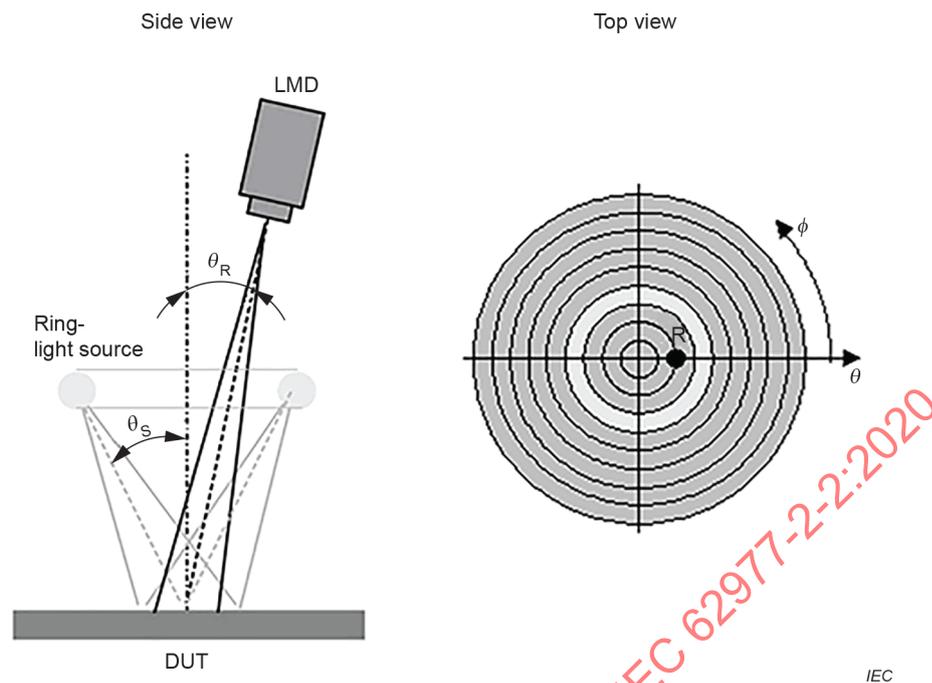
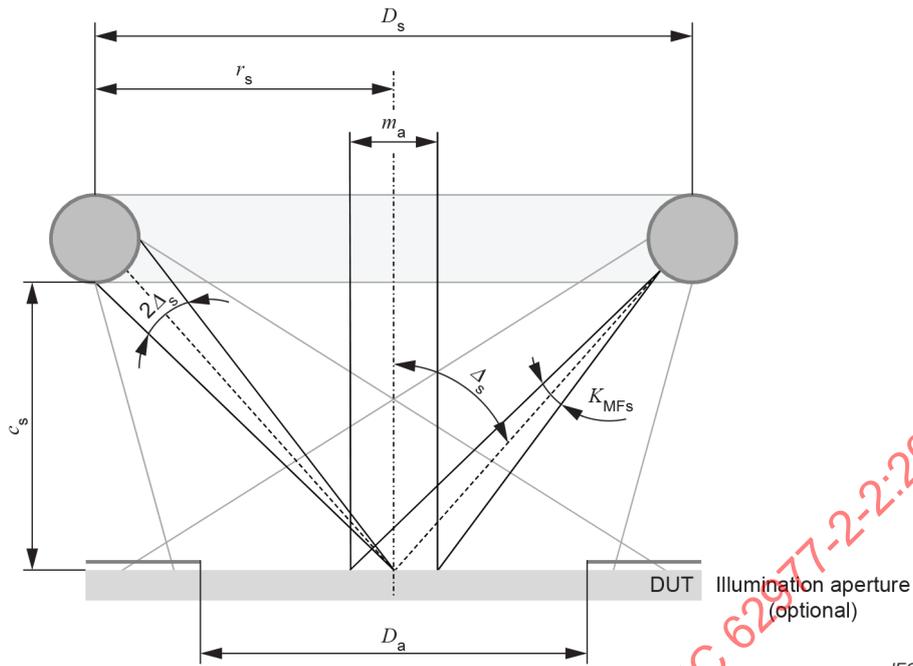


Figure 4 – Example of ring light illumination measuring setup where $\theta_S \pm \Delta = 35 \pm 5$ and $\theta_R = 20^\circ$

It is recommended that the ring light and LMD have an alignment accuracy of $\pm 0,7^\circ$ in order to keep the alignment-related measurement error within $\pm 5\%$. When simulating outdoor directional ambient illumination using the ring light, the subtense 2Δ of the source (as observed by the DUT) should be $\leq 0,5^\circ$. A fiber-optic ring light is recommended in this case.



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Key:

- Ring light subtense (2Δ_s, K_{MFs})
- Ring light inclination (Δ_s, Δ_r)
- Ring light distance (C_s)
- Light radius (r_s)
- Ring light width (D_s)
- Measurement field (m_a)
- Illumination field (aperture) (D_a)
- Measurement field illumination subtense (K_{MFs})

Figure 5 – Detailed schematic of ring light characteristics

The maximum angle of deviation from the optical axis is given by:

$$\arctan\left(\frac{c_s}{r_s}\right) - \arctan\left(\frac{c_s}{r_s - \frac{m_a}{2}}\right) < 5^\circ \tag{2}$$

Thus, the ring light diameter (D_s) should be at least six times larger than the measurement field diameter (m_a).

The illuminated area diameter (D_a) should be at least 1,5 times larger than the measurement field diameter (m_a).

If the display consists of thick layers (>1 mm) above the reflective surface of the DUT's imaging plane, care should be taken to measure the ring light distance (c_s) from the farthest visible layer in the display, not the front surface of the display.

NOTE If the reflected light from the display exhibits an asymmetric scatter pattern (e.g. matrix scatter), then the ring light source is used for directional illumination measurements [7]. If a directional source is used with asymmetric scatter, it is possible that the results are not reproducible.

4.3.4.4 Hemispherical illumination

Hemispherical illumination is omni-directional light that is uniformly incident on a display surface. It can be used to simulate the diffuse background illumination of indoor environments or the diffuse illumination of outdoor skylight (with direct sunlight blocked). In the true hemispherical case, incident light rays of constant luminance are uniformly distributed over all angles of inclination at the measuring spot. Two possible examples of the measurement geometry are shown in Figure 6. A good approximation of ideal hemispherical illumination (i.e. constant luminance from all directions up to 90° inclination) can only be provided by integrating spheres where the diameter of the measurement port (Figure 6, configuration A) or the sample port (configuration B) is small compared to the diameter of the sphere. If an integrating sphere that is at least seven times the physical outer diagonal of the display is available, the display can be mounted in the centre of the sphere (Figure 6, configuration A). For large displays, a sampling sphere (Figure 6, configuration B) or a hemisphere would be more suitable, following the guidance in CIE 38. In all cases, the configuration shall follow the standard $d_i:8^\circ$ to $d_i:10^\circ$ illumination/detection geometry, where d_i is the standard notation for diffuse illumination with the specular component included. The following procedure shall be used when performing hemispherical illumination measurements:

- The display is placed in the centre of an integrating sphere/hemisphere, or against the sample port of a sampling sphere.
- Establish the required illumination at the measurement spot. The colour temperature and illumination spectra can be measured from the reflected light of a white diffuse reflectance standard near the display measurement area (Figure 6 configuration A) or the sampling sphere wall adjacent to the sample port (Figure 6, configuration B). The type of light source used, its spectrum, and CCT shall be noted in the test report.

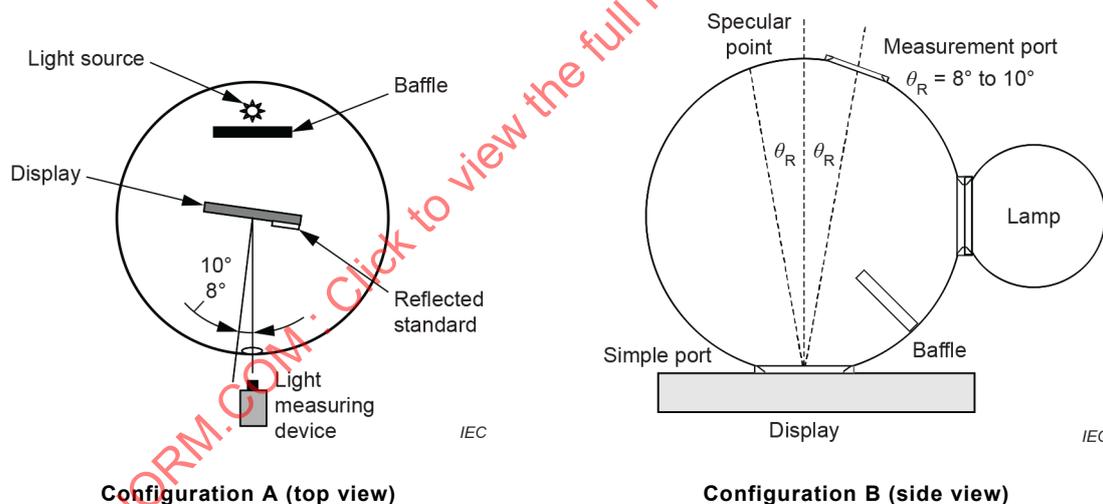


Figure 6 – Example of measurement geometries for hemispherical illumination using an integrating sphere (left) or sampling sphere (right)

- The LMD is aligned to view the centre of the display through a measurement port in the sphere wall at an inclination angle of $8^\circ \pm 2^\circ$ from the display normal. The required LMD angle of inclination can also be realised by tilting the display within the integrating sphere. The LMD is focused on the display's image plane.

- d) The measurement port diameter shall be 20 % to 30 % larger than the effective aperture of the LMD lens. Care needs to be taken to avoid any direct light from the sources, or any bright reflections off any surface (other than the screen itself), from hitting the lens of the LMD in order to minimize the veiling glare contamination of the reflected luminance measurement. The LMD shall be moved back from the measurement port so that the bright walls of the sphere are not visible to the LMD. In addition, the sample port diameter will typically need to be larger than 25 mm in order for the LMD's measurement field to be completely contained within the sample port.
- e) The measurement port shall be bevelled away from the lens. The small diameter of the bevel is toward the LMD, and the large diameter on the inside of the sphere.
- f) The spectral irradiance or illuminance on the display can be measured using a white diffuse reflectance standard with a known hemispherical diffuse spectral reflectance factor $\rho(\lambda)$, or the photopically-weighted (or luminous) hemispherical diffuse reflectance factor ρ . The white diffuse reflectance standard shall be calibrated under uniform hemispherical diffuse illumination in an integrating sphere. When an integrating sphere (configuration A) or hemisphere is used, the white diffuse reflectance standard shall be placed on the display surface. If t is the thickness of the white diffuse reflectance standard, then it shall be placed on the surface at a distance of $5 \times t$ to $7 \times t$ from the measurement area to avoid shadowing. The white reflectance standard can also be placed adjacent to and in the same plane as the display if the sphere illumination is uniform over that distance. For uniform illumination, the integrating sphere should be at least seven times larger than the physical outer diagonal of the display under test. In the case of the sampling sphere, the spectral irradiance can be determined by a measurement of the interior sphere wall adjacent to the sample port [8]. The hemispherical diffuse spectral reflectance factor, or the luminous hemispherical diffuse reflectance factor, of the interior sphere wall can be determined by comparing the spectral radiance (or luminance) of the wall with that of a calibrated white diffuse reflectance standard placed at the sample port (i.e. $\rho_{\text{wall}} = \rho_{\text{std}} \times (L_{\text{wall}} / L_{\text{std}})$).
- g) If a sampling sphere is used, the display measurement area shall contain more than 500 display pixels. It is recommended that the sampling sphere be at least six times larger than the sample port diameter. If there is a significant distance between the display emitting surface and the sample port entrance, then the size of the sample port may need to be increased [9].

The standard conditions are $\theta_R = 8^\circ$ and a source subtense of $2 \times \theta_{S-\text{max}} \geq 170^\circ$. The illumination of the measuring spot on the DUT shall be uniform to within 5 %.

4.4 Standard setup conditions

4.4.1 General

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

4.4.2 Adjustment of display

The display shall be measured at its factory settings. If other settings are used, they shall be noted in the test report. These settings shall be held constant for all measurements. It is important, however, to make sure that not only the adjustments are kept constant, but also that the nominally steady-state physical quantities remain constant during the measurement. This is not automatically the case because of, for example, warm-up effects or auto-dimming features. Any automatic luminance or gain control shall be turned off. Otherwise it should be noted in the report. This document does not intend to include the effect of the ambient light (or brightness) control, and this display function shall be turned off. If that is not possible, then it is recommended that it should be set to turn on no lower than 300 lx. If the ambient light control cannot be set, then a constant illumination source of at least 300 lx should be mounted on the ambient light sensor and should be optically shielded from the test room. The state of the auto-light control shall be reported. In addition, if the display has an auto-dimming feature which reduces the display luminance of a static image after a prolonged time, then in some cases it is effective to render a black frame for at least 8 s prior to rendering and

measuring the desired test pattern. The measurements shall be completed before the dimming feature is triggered. It is assumed that the reflection properties of the display screen are independent of the viewing mode. If that is not the case, then the viewing mode shall be defined by the test specification and be consistently used for all measurements. The display should be operated in a mode that does not have overscan.

This document assumes that the reflection properties of the display will be different for each screen colour or grey level, as is common with reflective displays and some LCDs. If the reflection properties of the display are independent of the image content, then the display reflection properties may be measured with a full black screen.

4.4.3 Starting conditions of measurements

Measurements shall be started after the displays and measuring instruments achieve stability. The DUT shall be turned on first and operated for at least 30 min prior to the measurement. Some display technologies may need a loop of colour patterns rendered on the screen during the warm-up period. Sufficient warm-up time has been achieved when the luminance of the test feature to be measured varies by less than $\pm 3\%$ over the entire measurement period (e.g. uniformity measurements) for a given display image.

Any automatic luminance or gain control shall be turned off. Otherwise it should be noted in the report. The ambient light (or brightness) control, which can reduce the luminance level with dim ambient illumination, shall be turned off. If that is not possible, it is recommended to set it to turn on no lower than 300 lx to minimize the influence of the brightness control. The state of the auto-light control shall be reported. In addition, if the display has an auto-dimming feature which reduces the display luminance of a static image after a prolonged time, then at least an 8 s black frame shall be rendered prior to rendering and measuring the desired test pattern. The measurements shall be completed before the dimming feature is triggered.

4.4.4 General conditions of measuring equipment

The light reflected from the display active area shall be measured in terms of photometric or colorimetric units using the CIE 1931 standard colorimetric two-degree observer, as defined in ISO/CIE 11664-1. Luminance can be measured by a photometer, and CIE tristimulus values (X , Y , Z) or CIE chromaticity coordinates by a colorimeter. A spectroradiometer can also obtain photometric and colorimetric values through a numerical conversion of the measured spectral radiance data (see for example [10]). Non-contact LMDs should be used without an integrated illumination source. The following requirements are given for these instruments:

The standard non-contact measurement equipment setup is shown in Figure 7. The LMD shall be a luminance meter, colorimeter, or spectroradiometer. For DUTs that have sharp spectral peak full-width-at-half-maximums (FWHMs) smaller than 20 nm, such as laser displays, LCDs with fluorescent lamp backlights or LEDs with narrow-peak phosphors, quantum-dot phosphors, or narrow-spectrum OLEDs, a spectroradiometer should be used. A filter colorimeter should generally not be used for light sources with sharp spectral peaks. If they are used, the colorimeter should be calibrated for the specific spectrum with a narrow bandwidth spectroradiometer [11]. However, the calibration methods generally assume that the display exhibits additive colour mixing. For light sources with sharp spectral peaks, the maximum bandwidth of the spectroradiometer shall be ≤ 5 nm. The higher resolution spectrometer produces a more accurate colour measurement, especially for laser sources. The spectroradiometer shall be capable of measuring spectral radiance over at least the 380 nm to 780 nm wavelength range, with a maximum bandwidth of 10 nm for smooth broadband spectra (i.e. broad spectrum with no sharp spikes).

Care shall be taken to ensure that the LMD has enough sensitivity and dynamic range to perform the required task. If the LMD measures a non-zero value, the measured LMD signal shall be at least ten times greater than the dark level (i.e. the noise floor with the lens cap on) of the LMD. If the LMD is not sensitive enough to measure a signal and truncates the readout to zero, then the measurement is not acceptable and a more sensitive LMD is required.

NOTE The measured LMD signal is no greater than 85 % of the saturation level.

The following additional best practices shall be followed:

- a) The LMD shall be focused on the image plane of the display and generally aligned perpendicularly to the display surface at the centre of the active display area, unless stated otherwise.
- b) The relative uncertainty and repeatability of all the measuring devices shall be maintained by following the instrument supplier's recommended calibration schedule.
- c) The start and duration of the LMD's temporal integration shall be synchronized with the optical modulation signal of the DUT. If such a signal is not available, the LMD shall be synchronized with the vertical synchronization of the input video signal. If the LMD is not capable of synchronizing, then the LMD integration time shall be at least 200 cycles of the fundamental Fourier Transform frequency of the modulated light in order to measure the luminance to better than 5 %.
- d) If LMD measurements are taken for displays with impulse-driving or pulse width modulation methods (including LCD backlights), the high peak luminance of these displays can cause detector saturation errors. The accuracy of these measurements can be checked by attenuating the light with a neutral density filter with known characteristics. If the change in signal amplitude of the detector is proportional to the transmittance of the neutral density filter, then there are no detector saturation errors. This method can be used for measuring the time-averaged screen luminance.

Additional general measurement best practices are given in detail in [1].

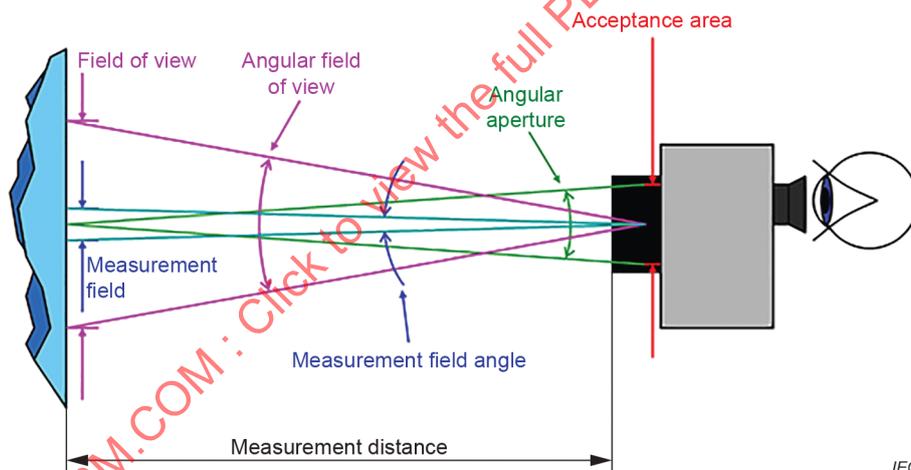


Figure 7 – Layout diagram of measurement setup

4.5 Reflection standards

4.5.1 General

Calibrated reflection standards can be used to determine the reflection properties of displays.

4.5.2 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 a defined detection geometry and illumination spectra and configuration:

$$E = \frac{\pi L_{std}}{R_{std}} \quad (3)$$

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 reflectance ρ_{std} . The luminous reflectance value associated with the standard is only valid for the hemispherical illumination spectra 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 spectra.

The terms luminous reflectance and luminous reflectance factor shall be abbreviated to reflectance and reflectance factor, respectively.

4.6 Locations of measurement field

Luminance, spectral distribution and/or tristimulus measurements may be taken at several specified locations on the display surface. However, only the centre of the screen is recommended in this document.

5 Darkroom luminance and spectra

5.1 General

This method is used to measure the emitted spectra and luminance from a display in a darkroom rendering a desired colour Q . For a reflective display without an ILU, or ILU turned off, the spectra and luminance will be zero.

5.2 Test pattern

5.2.1 General

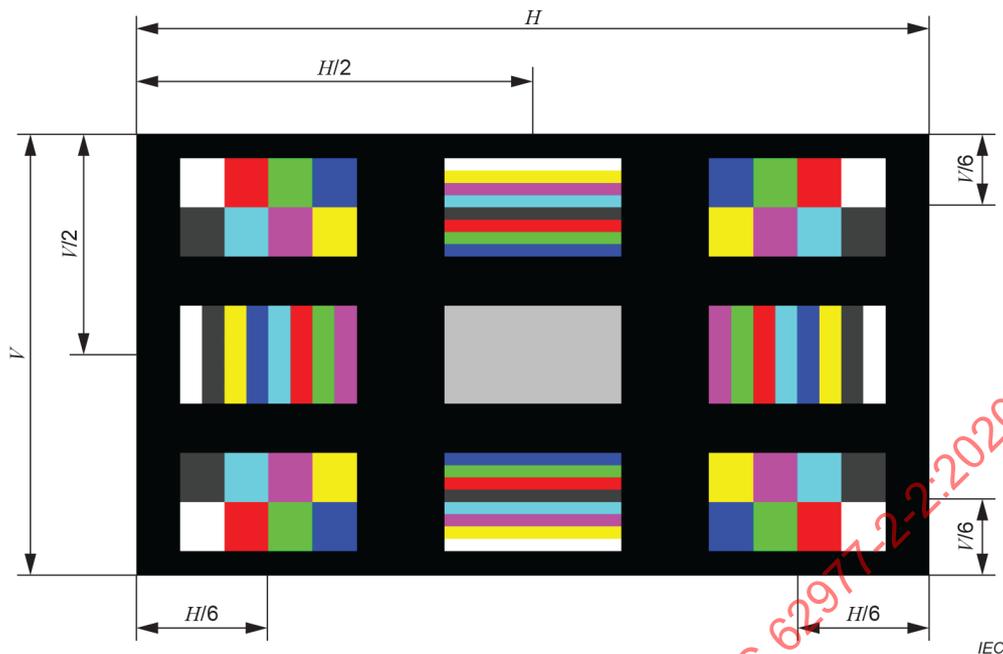
Two sets of fundamental test patterns are used in this document: the simple box set and a multi-colour pattern.

5.2.2 Simple box test patterns

The simple box set of test patterns is used to estimate the display performance. These patterns are mainly used for communication between manufacturers, in research and development, and in-line manufacturing testing for simple quality control.

The simplest test pattern is the full screen test pattern. This pattern uses the same colour of the desired colour Q for all addressable pixels.

An alternate box test pattern uses a black background with a relatively small colour area centred on the display screen. The centre rectangle can be changed to the desired colour Q to be measured. Two different area sizes are possible; a 4 % or a 10 % area box shall be used. These patterns are illustrated in Figure 8 for rectangular display areas. For rectangular active areas, the dimensions of the box are proportional to the dimensions of the active area. For example, the dimensions of the 4 % box would be 1/5 of the vertical and horizontal dimensions of the rectangular active area.



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

Figure 9 – Standard medium APL RGBCMYWx test pattern used for centre luminance and spectra measurements with 25 % APL

If the display active area is not rectangular, then the multi-colour test patterns may be adjusted to fit the format. However, the APL level and uniform proportion of colours shall be maintained.

5.2.4 Measuring conditions

The following measuring conditions apply:

- Apparatus: an LMD that can measure spectral radiance, a driving power supply, and driving signal equipment.
- Standard measuring environmental conditions; darkroom conditions; standard setup conditions.
- Simple box test patterns in Figure 8, or standard medium APL loading test patterns in Figure 9.

5.2.5 Measuring method

Measure the darkroom spectral radiance $L_Q(\lambda)$ and luminance L_Q of the desired colour Q in the centre of the active area using the following procedure:

- Render the test pattern in Figure 8 or Figure 9 with the desired colour Q in the centre of the active area. Allow the luminance to stabilize.
- Align the optical axis of the LMD perpendicularly to the display screen and centred on the centre of the display.
- Measure the spectral radiance $L_Q(\lambda)$ and luminance L_Q of the desired colour Q in the centre of the display.
- Repeat the measurement for other desired colours.

6 Reflection measurements

6.1 General

The purpose of this method is to measure the reflection properties of a display under defined illumination conditions. If a 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. If an emissive/transmissive-reflective hybrid display is to be measured, care shall be taken that only one mode of operation (emissive/transmissive or reflective) is used for all measurements. If that is not possible, and the mode can change with the illuminance, then the illuminance scaling method described in this document is not applicable. The reflectance of an illuminance-independent hybrid display shall be measured in the same way as for a reflective display but with the emissive/transmissive function turned off.

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.

6.2 Measuring conditions

The apparatus shall be as follows:

- a driving power source;
- a 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.

One of the simple box test patterns in Figure 8 shall be used. The pattern used shall be reported.

The illuminance condition shall be as follows:

- For the measurement of the display reflection coefficients, the illumination level of the test light source shall be appropriate to accurately perform the measurement.
- The standard directed, ring light, or hemispherical illumination conditions shall be used (see 4.3.4). 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 and spectrally corrected later in the analysis. The illumination/detection geometry used, its spectrum, and the light source CCT shall be reported.
- Except for the standard ambient illumination conditions, all other conditions are the standard conditions.

6.3 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 4.3.4.4. Turn ON the integrating sphere or sampling sphere's hemispherical diffuse illumination to the desired CCT. Allow the light source to stabilize.

NOTE 1 A change in sphere illuminance can be monitored by an illuminance detector attached to the sphere.

- b) Set the test input signal to the display to generate a 4 % or a 10 % window of colour Q at the highest luminance level, or reflectance level for a reflective display, with a black background (see Figure 8).
- 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 (darkroom conditions). Measure the spectral radiance $L_{Q,\text{hemi-ON}}(\lambda)$ or luminance $L_{Q,\text{hemi-ON}}$ at the centre of the coloured pattern with the hemispherical surround ON. For spectral measurements, the display luminance $L_{Q,\text{hemi-ON}}$ can be calculated using the following relation:

$$L = 683 \int_{\lambda} L(\lambda) V(\lambda) d\lambda \quad (5)$$

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

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

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

$$\rho_Q(\lambda) = \rho_{\text{std}}(\lambda) \frac{[L_{Q,\text{hemi-ON}}(\lambda) - L_{Q,\text{hemi-OFF}}(\lambda)]}{[S_{Q,\text{hemi-ON}}(\lambda) - S_{Q,\text{hemi-OFF}}(\lambda)]} \quad (6)$$

where $\rho_{\text{std}}(\lambda)$ 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 $L_{Q,\text{hemi-OFF}}(\lambda)$ and $S_{Q,\text{hemi-OFF}}(\lambda)$ 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:

$$\rho_Q = \frac{\int \rho_Q(\lambda) E_{CIE}(\lambda) V(\lambda) d\lambda}{\int_{\lambda} E_{CIE}(\lambda) V(\lambda) d\lambda} \quad (7)$$

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 shall be used. If additional daylight illuminants are desired, the following relation from CIE 15 shall be used:

$$E_{CIE}(\lambda) = E_0(\lambda) + M_1 E_1(\lambda) + M_2 E_2(\lambda) \quad (8)$$

where the E_0 , E_1 , and E_2 eigenfunctions are tabulated in CIE 15, and M_1 and M_2 are eigenvalues defined in the same document. For example, M_1 and M_2 are given in Table 3 for the case of D50, D65, and D75.

Table 3 – Eigenvalues M_1 and M_2 for CIE daylight Illuminants D50, D65, and D75

| Eigenvalues | Correlated colour temperature | | |
|-------------|-------------------------------|-----------|-----------|
| | 5 000 K | 6 500 K | 7 500 K |
| M_1 | -1,040 1 | -0,296 34 | 0,143 58 |
| M_2 | 0,366 66 | -0,688 32 | -0,759 93 |

For luminance measurements, the photometric equivalent of Formula (6) is used:

$$\rho_Q = \rho_{std} \frac{[L_{Q, \text{hemi-ON}} - L_{Q, \text{hemi-OFF}}]}{[S_{Q, \text{hemi-ON}} - S_{Q, \text{hemi-OFF}}]} \quad (9)$$

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 (9) 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. $L_{Q, \text{hemi-ON}}(\lambda) \gg L_{Q, \text{hemi-OFF}}(\lambda)$). The same applies for the photometric equivalents in Formula (9).

- 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.

6.4 Measuring the reflectance factor for a directed light source

The measuring method shall be as follows:

- a) Mount the display and directed light source according to the guidance provided in 4.3.4.2 or 4.3.4.3.
- b) Set the test input signal to the display to generate a 4 % or a 10 % window of colour Q at the highest luminance level, or reflectance level for a reflective display, with a black background (see Figure 8).

- c) Measure the spectral radiance $L_Q(\lambda)$, or luminance L_Q , at the centre of the colour pattern under darkroom conditions (and direct light source OFF). For spectral measurements, the display luminance L_Q can be calculated using Formula (5). Skip this step for reflective displays with no ILU or ILU off.
- d) Position the directed light source as specified in 4.3.4.2 or 4.3.4.3. In general, the discrete directed source geometry shall be used. If the display exhibits strong matrix (asymmetric) scatter, then a ring light is recommended [7]. 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. Confirm that no fluorescence is present.
- e) Measure the spectral radiance $L_{Q,dir}(\lambda)$ or the luminance $L_{Q,dir}$ from the centre of the display with the directed source illumination ON. For spectral measurements, the luminance $L_{Q,dir}$ from the display with directed illumination can be calculated using Formula (5).

To ensure measurement integrity, the display ambient spectral radiance with directed source ON shall be much greater than the display spectral radiance in a darkroom (i.e. $L_{Q,dir}(\lambda) \gg L_Q(\lambda)$). 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 $S_{dir}(\lambda)$ or luminance S_{dir} from the calibrated white diffuse reflectance standard. For spectral measurements, the spectral irradiance $E_{dir}(\lambda)$ on the white diffuse reflectance standard (and consequently the display) can be determined by using the following formula:

$$E(\lambda) = \frac{\pi L(\lambda)}{R(\lambda)} \quad (10)$$

with $E(\lambda) = E_{dir}(\lambda)$, $L(\lambda) = S_{dir}(\lambda)$, and where $R(\lambda) = R_{std}(\lambda)$ is the known spectral reflectance factor for the white diffuse reflectance standard in the same geometry.

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

$$E_V = 683 \int_{\lambda} E(\lambda) V(\lambda) d\lambda \quad (11)$$

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 (11) 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 the directed illumination for the measured illumination/detection geometry.

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

$$R_Q(\lambda) = \pi \frac{L_{Q,dir}(\lambda) - L_Q(\lambda)}{E_{dir}(\lambda)} = R_{std}(\lambda) \frac{L_{Q,dir}(\lambda) - L_Q(\lambda)}{S_{dir}(\lambda)} \quad (12)$$

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:

$$R_Q = \frac{\int_{\lambda} R_Q(\lambda) E_{\text{CIE}}(\lambda) V(\lambda) d\lambda}{\int_{\lambda} E_{\text{CIE}}(\lambda) V(\lambda) d\lambda} \quad (13)$$

where $E_{\text{CIE}}(\lambda)$ is the relative spectral distribution for the desired CIE illumination spectra. The CIE 15 tabulated data for CIE illuminants shall be used for $E_{\text{CIE}}(\lambda)$. If additional illuminants are desired, they shall use the expression given in Formula (7).

For photometric measurements, an analogous relation to Formula (12) is used:

$$R_Q = \pi \frac{L_{\text{Q,dir}} - L_Q}{E_{\text{dir}}} \quad (14)$$

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

The luminous reflectance factor in Formula (14) 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 Ambient optical performance

7.1 General

The optical characteristics of a display under indoor and outdoor illumination conditions are determined using the reflection coefficients from Clause 6 and the darkroom measurement methods from Clause 5.

7.2 Ambient contrast ratio

7.2.1 General

The purpose of this method is to determine the ambient contrast ratio of a display under defined indoor or daylight illumination conditions.

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 darkroom luminance measurements from Clause 5 and reflection measurements of the display under hemispherical diffuse and directed source illumination conditions. The measuring method for the hemispherical diffuse reflectance and directed reflectance factor of the display for the required illumination spectra is defined in Clause 4. These reflection parameters are used to calculate the combined (emitted and reflected) luminance of a display at the required illuminance levels. The screen

is set to the colours white ($Q = W$) then black ($Q = K$), and the emitted and reflected luminance components are measured for each screen colour W and K . The ambient contrast ratio is the ratio of the combined white luminance ($L_{W,amb}$) to the combined black screen luminance ($L_{K,amb}$).

The darkroom black and white luminance (L_K and L_W) values are measured following the method described in Clause 5. For reflective displays with no ILU or ILU off, L_K and L_W will be zero. Calculate the indoor room (sometimes called brightroom) or daylight contrast ratio using the following formula:

$$ACR = \frac{L_{W,amb}}{L_{K,amb}} = \frac{\left(L_W + \frac{\rho_W E_{CIE,hemi}}{\pi} + \frac{R_W E_{CIE,dir} \cos \theta_s}{\pi} \right)}{\left(L_K + \frac{\rho_K E_{CIE,hemi}}{\pi} + \frac{R_K E_{CIE,dir} \cos \theta_s}{\pi} \right)} \quad (15)$$

where the reference parameters are $E_{CIE,hemi} = 60$ lx, $\theta_s = 45^\circ$, and $E_{CIE,dir} \cos(\theta_s) = 40$ lx for a TV viewing room; $E_{CIE,hemi} = 300$ lx, $\theta_s = 45^\circ$, and $E_{CIE,dir} \cos \theta_s = 200$ lx for an office; and $E_{CIE,hemi} = 15\,000$ lx, $\theta_s = 45^\circ$, 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 pattern, respectively, are calculated from Formula (7) 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 white or black pattern, respectively, are calculated from Formula (13) using the same CIE Standard Illuminant A, CIE Standard Illuminant D65, or CIE Standard Illuminant D65 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 display under defined indoor (sometimes called brightroom) or outdoor daylight illumination conditions.

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 darkroom 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 Clause 4. The method for measuring the darkroom spectral radiance $L_Q(\lambda)$ at the centre and perpendicular to the display for the desired colour state Q is described in Clause 5. For reflective displays with no ILU or ILU off, $L_Q(\lambda)$ will be zero. The total ambient spectral radiance $L_{Q,amb}(\lambda)$ measured by a detector perpendicular to the display, with reflections from the hemispherical diffuse and directed sources included, will be:

$$L_{Q,amb}(\lambda) = L_Q(\lambda) + \frac{\rho_Q(\lambda)E_{CIE,hemi}(\lambda)}{\pi} + \frac{R_Q(\lambda)E_{CIE,dir}(\lambda)\cos\theta_s}{\pi} \quad (16)$$

where $E_{CIE,hemi}(\lambda)$ and $E_{CIE,dir}(\lambda)$ are the irradiance spectra for the standard hemispherical diffuse and directed sources, respectively. The relative irradiance spectra of Standard Illuminant A, CIE Standard Illuminant D65, or CIE Illuminant D50 for indoor illumination are tabulated in CIE 15. The relative irradiance spectra of CIE Illuminants D75 and D50 are used for daylight illumination, where CIE Illuminant D75 is also tabulated in CE 15. $E_{CIE,hemi}(\lambda)$ and $E_{CIE,dir}(\lambda)$ are obtained by multiplying the relative spectra by an appropriate constant that would produce the reference illumination levels when integrated using Formula (13). The reference levels are $E_{CIE,hemi} = 60$ lx, $\theta_s = 45^\circ$, and $E_{CIE,dir}\cos\theta_s = 40$ lx for a TV viewing room; $E_{CIE,hemi} = 300$ lx, $\theta_s = 45^\circ$, and $E_{CIE,dir}\cos\theta_s = 200$ lx for an office; and $E_{CIE,hemi} = 15\,000$ lx, $\theta_s = 45^\circ$, and $E_{CIE,dir}\cos\theta_s = 65\,000$ 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:

$$X_{Q,amb} = 683 \int_{\lambda} L_{Q,amb}(\lambda) \bar{x}(\lambda) d\lambda \quad (17)$$

$$Y_{Q,amb} = 683 \int_{\lambda} L_{Q,amb}(\lambda) \bar{y}(\lambda) d\lambda \quad (18)$$

$$Z_{Q,amb} = 683 \int_{\lambda} L_{Q,amb}(\lambda) \bar{z}(\lambda) d\lambda \quad (19)$$

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

If the reflection coefficients are constant for all colours, then the ambient tristimulus values can be expressed as:

$$X_{Q,amb} = X_Q + 683 \int_{\lambda} L_{Refl}(\lambda) \bar{x}(\lambda) d\lambda \quad (20)$$

$$Y_{Q,amb} = Y_Q + 683 \int_{\lambda} L_{Refl}(\lambda) \bar{y}(\lambda) d\lambda \quad (21)$$

$$Z_{Q,amb} = Z_Q + 683 \int_{\lambda} L_{Refl}(\lambda) \bar{z}(\lambda) d\lambda \quad (22)$$

where X_Q , Y_Q , and Z_Q are the darkroom tristimulus values for a measured display colour Q , and $L_{\text{Refl}}(\lambda)$ is the display colour-independent reflected spectral radiance:

$$L_{\text{Refl}}(\lambda) = \frac{\rho(\lambda)E_{\text{CIE,hemi}}}{\pi} + \frac{R(\lambda)E_{\text{CIE,dif}}\cos\theta_S}{\pi}. \quad (23)$$

However, this simplification shall not be used for displays where surface reflection characteristics change with the displayed colour (e.g. reflective displays and some LCD displays).

The darkroom tristimulus values can be calculated from the measured darkroom luminance L_Q and CIE 1931 chromaticity coordinates (x_Q , y_Q) of each colour Q using the following formulae:

$$X_Q = \frac{x_Q L_Q}{y_Q} \quad (24)$$

$$Y_Q = L_Q \quad (25)$$

$$Z_Q = \frac{(1 - x_Q - y_Q)L_Q}{y_Q}. \quad (26)$$

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

$$x_{Q,\text{amb}} = \frac{X_{Q,\text{amb}}}{X_{Q,\text{amb}} + Y_{Q,\text{amb}} + Z_{Q,\text{amb}}} \quad (27)$$

$$y_{Q,\text{amb}} = \frac{Y_{Q,\text{amb}}}{X_{Q,\text{amb}} + Y_{Q,\text{amb}} + Z_{Q,\text{amb}}} \quad (28)$$

Report the effective tristimulus values and CIE 1931 chromaticity coordinates for the display colour Q , the CIE illuminants and illuminance values used in the calculations, and the measuring conditions. If additional geometries or illuminance levels are used, they shall be noted in the test report. All values used to calculate the ambient colour shall be recorded in the test report.

7.4 Ambient colour gamut volume

7.4.1 General

The purpose of this method is to measure the ambient colour gamut CIELAB volume of a display under defined ambient illumination conditions. The method uses the procedure described in 7.3 to obtain the ambient tristimulus values for the necessary colours under the standard indoor or outdoor illumination environment. This method applies to static images when the eye is adapted to the displayed images, where the background light is not considered. For the purposes of metrology, it is assumed that the observer is fully adapted to the display white. The white used with a particular pattern may not be the peak white.

CIELAB defines a homogeneous human perceptual colour space. It uses three axes, one that describes lightness, and two that together map hue and chroma. CIELAB colour volume is only one of many attributes of the total display colour performance. The human visual system adapts to the brightness and colour of the illuminant, as all colours are ratios in a tristimulus system. This adaptation affects the volume, as all colours are relative to the illuminant. To understand the volume of colour, the illuminant should be defined. To measure the display gamut volume with ambient reflections, the peak luminance with ambient reflections is assumed to be the illuminant, as all input plus reflected colours are ratios of that for any display in an ambient environment. Since the darkroom white of the display (in combination with the ambient reflections) affects the colour gamut volume value, it is necessary to perform a chromatic adaptation to a common white point in order to have a common basis for determining the gamut volume (see CIE 168).

This method is limited to input signals with typical OETFs such as IEC 61966-2-1, ITU-R BT.601-7 [22], ITU-R BT.709-6 [23], and ITU-R BT.2020-2 [24]. This method is limited to SDR signal inputs.

CIELAB volume can be measured in any display mode. However, even in the presence of an SDR input signal, if a display's output response is customized to enhance highlights ("HDR-like"), CIELAB colour gamut volume could be impacted. In that case, manufacturers may specify which modes will match the behaviour of the SDR input signal, provided that all other measurements are carried out in that mode. A new metric may be developed to cover display modes wherein the display output does not match the behaviour of the SDR input signal.

CIELAB colour gamut volume is not a visualization of colour gamut and does not define the coverage to a standard. Two displays with the same gamut volume can cover different regions of colour space and appear different.

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 measurement of the ambient colour gamut CIELAB volume at the centre of the active area under standard indoor or outdoor illumination conditions is determined by the following procedure:

- a) The RGBCMYWx test pattern (Figure 9) shall be used to measure the desired centre box colours. The tristimulus, or luminance and chromaticity, shall be measured following the procedure in 7.3.
- b) The colour gamut volume calculation requires that many colours be measured in order to accurately determine the CIELAB colour gamut volume. A greater number of sampled colours will result in a more accurate determination of the gamut volume. When colours are measured, it is recommended that these colours use sets of measured colours chosen based on equally spaced surface colours in the RGB colour space. For example, a set of 98 RGB surface colours representing a 5 × 5 grid of equally spaced surface colours (tabulated in Table A.1) can be used to calculate the CIELAB gamut volume and be reported as CIELAB Volume {98}. Depending on the complexity of the gamut surface, more accurate results can be obtained by interpolating to 602 points from 98 by curve fitting. It is recommended to use a set of 602 colours (reported as CIELAB Volume {602}), representing a 11 × 11 grid of equally spaced surface colours (see Table A.2), which is

estimated to be within 2 % of the true volume. The CIELAB gamut volume shall be reported with the corresponding number of measured colours. Additional colours sets can also be used depending on the required level of accuracy.

- c) If the display surface reflection changes with the rendered colours, then Formulae (17) to (19) shall be used. If the display surface reflections do no change with the rendered colour, then the simplified Formulae (20) to (22) can be used. In the latter case, the reflection coefficients only need to be measured once. Otherwise, the reflection coefficients need to be measured for every colour.
- d) Once all of the colours are measured, the ambient tristimulus values of the maximum luminance white colour ($X_{W, amb}$, $Y_{W, amb}$ and $Z_{W, amb}$) are identified. It is necessary to adapt all the measured tristimulus values to the common reference white point, D50 (according to CIE 168). The chromatic adaptation transform (following ISO 15076-1, using the Bradford coefficients in Annex B) is used to perform the transformation. The chromatic adaptation transform is determined from the measured tristimulus values ($X_{W, amb}$, $Y_{W, amb}$ and $Z_{W, amb}$) and is used to transform the rest of the measured colours, represented by (X_P , Y_P , Z_P). This method is consistent with the ICC colour management system.
- e) The chromatically adapted ambient tristimulus values shall be transformed into the three-dimensional CIELAB colour space (defined by ISO/CIE 11664-4). The CIELAB L^* , a^* , and b^* values for each colour P are calculated from the transformed ambient tristimulus values using the following formulae:

$$L^* = 116 \times f(Y_P / Y_{D50}) - 16 \quad (29)$$

$$a^* = 500 \times [f(X_P / X_{D50}) - f(Y_P / Y_{D50})] \quad (30)$$

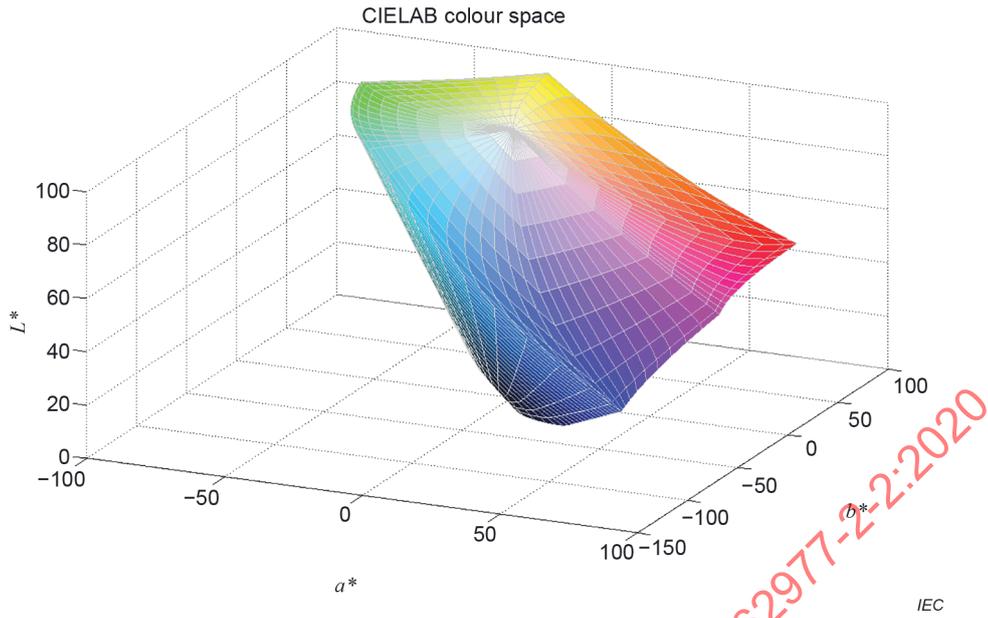
$$b^* = 200 \times [f(Y_P / Y_{D50}) - f(Z_P / Z_{D50})] \quad (31)$$

where

$$f(t) = \begin{cases} t^{1/3} & t > (6/29)^3 \\ \frac{1}{3} \left(\frac{29}{6}\right)^2 t + \frac{16}{116} & \text{otherwise} \end{cases} \quad (32)$$

- f) Each colour point can be plotted on the L^* , a^* , and b^* axis of the CIELAB colour space. An example of the colour data in the CIELAB uniform colour space is given in Figure 10.
- g) Calculate the colour gamut volume corresponding to the possible range of ambient display colours as represented in the CIELAB colour space. See Annex B for a detailed description of the analysis recommended for calculating the colour gamut volume. Other gamut calculation methods may be used in specific applications when the architecture of the display and the method results in a measurement that is within 2 % of the method described in Annex B. For example, a display that exhibits additivity and a known tone response curve could use the eight-point method with interpolation (see for example IEC 62341-6-1 [15]).
- h) Report the ambient colour gamut CIELAB volume, the number of boundary colours used, the test pattern used, and the measurement conditions. The colour gamut volume of an ideal sRGB display (IEC 61966-2-1) with D65 white point and zero black level is $8,32 \times 10^5$ (see the CIE 168 method using the Bradford chromatic adaptation transforms). CIE 168 also provides a method for calculating the amount of overlap between the measured colours and a specified colour space.

NOTE While not covered in this document, the Boolean intersection of two gamut volume hulls can be calculated. This intersected volume can be defined as the percentage of the measured gamut volume that is contained within a specified reference volume. An example calculation can be found in CIE 168, but uses an older chromatic adaptation transform and different colour sampling than recommended in this document.



NOTE Figure 10 shows an example of the range in colours produced by a display as represented by the CIELAB colour space.

Figure 10 – Example of the range in colours produced by a display

Annex A (normative)

RGB boundary colours for CIELAB gamut volume measurements

A.1 General

The CIELAB colour gamut volume for a given display is determined by measuring the range of colours that the display is capable of producing. Since full colour displays can commonly produce millions of colours, it is necessary to increase the test efficiency by sampling the colour range through a careful selection of colours that will accurately reflect the shape of the CIELAB gamut volume. A good way to do that is to mainly consider the colours at the outer boundaries of that gamut volume. Once the colour gamut is well defined, then the internal volume can be accurately calculated.

Colours shall be specified in the input-referred RGB colour space. The axes of the RGB colour space correspond to the digital levels at the RGB inputs of the display. It shall be assumed that colours on the surface of the RGB cube map to colours on the CIELAB colour gamut surface. It is expected that a higher sampling of these RGB colours will yield a better estimation of the CIELAB gamut.

The spacing of the inputs values in Table A.1 and Table A.2 are optimized for conventional standard dynamic range (SDR) tone curves. They will function well for display electro-optic transfer functions (EOTFs) approximating anything from a linear response to gamma 4,0. Displays with extreme EOTFs would require a different sampling of colours to fairly present the tone curve.

A.2 Equally-spaced 98 boundary colours on the RGB cube

An estimate of the CIELAB colour gamut volume for a given display can be made by using a set of 98 RGB boundary colours. The 98 colours are derived from the uniform grid of 5×5 points on each outer face of the RGB colour cube. These colours are specified as 8-bit equivalent digital RGB input levels as shown in Table A.1. The equally spaced 8-bit code values are obtained using

$$0, \text{Int}[255 / 4], \text{Int}[255 / 2], \text{Int}[255 \times (3 / 4)], \text{and } 255 \quad (\text{A.1})$$

where the $\text{Int}[\]$ function retains the truncated integer value.

Colour coding with higher bit depths can also be done by using uniform spacing with the 5×5 grid of boundary colours. For example, equally spaced 12-bit code values are obtained using

$$0, \text{Int}[4\ 095 / 4], \text{Int}[4\ 095 / 2], \text{Int}[4\ 095 \times (3 / 4)], \text{and } 4\ 095 \quad (\text{A.2})$$

An example CIELAB gamut volume calculation method is given in Annex B.

Table A.1 – Equally-spaced 98 RGB boundary colours used for CIELAB gamut volume measurements

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 63 |
| 3 | 0 | 0 | 127 |
| 4 | 0 | 0 | 191 |
| 5 | 0 | 0 | 255 |
| 6 | 0 | 63 | 0 |
| 7 | 0 | 63 | 63 |
| 8 | 0 | 63 | 127 |
| 9 | 0 | 63 | 191 |
| 10 | 0 | 63 | 255 |
| 11 | 0 | 127 | 0 |
| 12 | 0 | 127 | 63 |
| 13 | 0 | 127 | 127 |
| 14 | 0 | 127 | 191 |
| 15 | 0 | 127 | 255 |
| 16 | 0 | 191 | 0 |
| 17 | 0 | 191 | 63 |
| 18 | 0 | 191 | 127 |
| 19 | 0 | 191 | 191 |
| 20 | 0 | 191 | 255 |
| 21 | 0 | 255 | 0 |
| 22 | 0 | 255 | 63 |
| 23 | 0 | 255 | 127 |
| 24 | 0 | 255 | 191 |
| 25 | 0 | 255 | 255 |
| 26 | 63 | 0 | 0 |
| 27 | 63 | 0 | 63 |
| 28 | 63 | 0 | 127 |
| 29 | 63 | 0 | 191 |
| 30 | 63 | 0 | 255 |
| 31 | 63 | 63 | 0 |
| 32 | 63 | 63 | 255 |
| 33 | 63 | 127 | 0 |
| 34 | 63 | 127 | 255 |
| 35 | 63 | 191 | 0 |
| 36 | 63 | 191 | 255 |
| 37 | 63 | 255 | 0 |
| 38 | 63 | 255 | 63 |
| 39 | 63 | 255 | 127 |
| 40 | 63 | 255 | 191 |
| 41 | 63 | 255 | 255 |

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 42 | 127 | 0 | 0 |
| 43 | 127 | 0 | 63 |
| 44 | 127 | 0 | 127 |
| 45 | 127 | 0 | 191 |
| 46 | 127 | 0 | 255 |
| 47 | 127 | 63 | 0 |
| 48 | 127 | 63 | 255 |
| 49 | 127 | 127 | 0 |
| 50 | 127 | 127 | 255 |
| 51 | 127 | 191 | 0 |
| 52 | 127 | 191 | 255 |
| 53 | 127 | 255 | 0 |
| 54 | 127 | 255 | 63 |
| 55 | 127 | 255 | 127 |
| 56 | 127 | 255 | 191 |
| 57 | 127 | 255 | 255 |
| 58 | 191 | 0 | 0 |
| 59 | 191 | 0 | 63 |
| 60 | 191 | 0 | 127 |
| 61 | 191 | 0 | 191 |
| 62 | 191 | 0 | 255 |
| 63 | 191 | 63 | 0 |
| 64 | 191 | 63 | 255 |
| 65 | 191 | 127 | 0 |
| 66 | 191 | 127 | 255 |
| 67 | 191 | 191 | 0 |
| 68 | 191 | 191 | 255 |
| 69 | 191 | 255 | 0 |
| 70 | 191 | 255 | 63 |
| 71 | 191 | 255 | 127 |
| 72 | 191 | 255 | 191 |
| 73 | 191 | 255 | 255 |
| 74 | 255 | 0 | 0 |
| 75 | 255 | 0 | 63 |
| 76 | 255 | 0 | 127 |
| 77 | 255 | 0 | 191 |
| 78 | 255 | 0 | 255 |
| 79 | 255 | 63 | 0 |
| 80 | 255 | 63 | 63 |
| 81 | 255 | 63 | 127 |
| 82 | 255 | 63 | 191 |
| 83 | 255 | 63 | 255 |
| 84 | 255 | 127 | 0 |

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 85 | 255 | 127 | 63 |
| 86 | 255 | 127 | 127 |
| 87 | 255 | 127 | 191 |
| 88 | 255 | 127 | 255 |
| 89 | 255 | 191 | 0 |
| 90 | 255 | 191 | 63 |
| 91 | 255 | 191 | 127 |
| 92 | 255 | 191 | 191 |
| 93 | 255 | 191 | 255 |
| 94 | 255 | 255 | 0 |
| 95 | 255 | 255 | 63 |
| 96 | 255 | 255 | 127 |
| 97 | 255 | 255 | 191 |
| 98 | 255 | 255 | 255 |

A.3 Recommended 602 boundary colours on the RGB cube

It is recommended that a set of 602 RGB boundary colours be used to get an accurate estimate of the CIELAB colour gamut volume of a given display. The 602 colours are derived from the uniform grid of 11×11 points on each face of the RGB colour cube. The colours are specified as 8-bit equivalent digital RGB input levels as shown in Table A.2. The equally spaced 8-bit code values are obtained using

$$\begin{aligned}
 &0, \text{Int}[255 / 10], \text{Int}[255 \times (2 / 10)], \text{Int}[255 \times (3 / 10)], \\
 &\text{Int}[255 \times (4 / 10)], \text{Int}[255 \times (5 / 10)], \text{Int}[255 \times (6 / 10)], \text{Int}[255 \times (7 / 10)], \quad (\text{A.3}) \\
 &\text{Int}[255 \times (8 / 10)], \text{Int}[255 \times (9 / 10)], \text{and } 255,
 \end{aligned}$$

where the $\text{Int}[\]$ function retains the truncated integer value.

Colour coding with higher bit depths can also be done using uniform spacing with the 11×11 grid of boundary colours. An example CIELAB gamut volume calculation method is given in Annex B.

Table A.2 – Recommended RGB boundary colours used for CIELAB colour gamut volume measurements

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 25 |
| 3 | 0 | 0 | 51 |
| 4 | 0 | 0 | 76 |
| 5 | 0 | 0 | 102 |
| 6 | 0 | 0 | 127 |
| 7 | 0 | 0 | 153 |
| 8 | 0 | 0 | 178 |
| 9 | 0 | 0 | 204 |
| 10 | 0 | 0 | 229 |
| 11 | 0 | 0 | 255 |
| 12 | 0 | 25 | 0 |
| 13 | 0 | 25 | 25 |
| 14 | 0 | 25 | 51 |
| 15 | 0 | 25 | 76 |
| 16 | 0 | 25 | 102 |
| 17 | 0 | 25 | 127 |
| 18 | 0 | 25 | 153 |
| 19 | 0 | 25 | 178 |
| 20 | 0 | 25 | 204 |
| 21 | 0 | 25 | 229 |
| 22 | 0 | 25 | 255 |
| 23 | 0 | 51 | 0 |
| 24 | 0 | 51 | 25 |
| 25 | 0 | 51 | 51 |
| 26 | 0 | 51 | 76 |
| 27 | 0 | 51 | 102 |
| 28 | 0 | 51 | 127 |
| 29 | 0 | 51 | 153 |
| 30 | 0 | 51 | 178 |
| 31 | 0 | 51 | 204 |
| 32 | 0 | 51 | 229 |
| 33 | 0 | 51 | 255 |
| 34 | 0 | 76 | 0 |
| 35 | 0 | 76 | 25 |
| 36 | 0 | 76 | 51 |
| 37 | 0 | 76 | 76 |
| 38 | 0 | 76 | 102 |
| 39 | 0 | 76 | 127 |
| 40 | 0 | 76 | 153 |
| 41 | 0 | 76 | 178 |
| 42 | 0 | 76 | 204 |
| 43 | 0 | 76 | 229 |
| 44 | 0 | 76 | 255 |
| 45 | 0 | 102 | 0 |
| 46 | 0 | 102 | 25 |
| 47 | 0 | 102 | 51 |

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 48 | 0 | 102 | 76 |
| 49 | 0 | 102 | 102 |
| 50 | 0 | 102 | 127 |
| 51 | 0 | 102 | 153 |
| 52 | 0 | 102 | 178 |
| 53 | 0 | 102 | 204 |
| 54 | 0 | 102 | 229 |
| 55 | 0 | 102 | 255 |
| 56 | 0 | 127 | 0 |
| 57 | 0 | 127 | 25 |
| 58 | 0 | 127 | 51 |
| 59 | 0 | 127 | 76 |
| 60 | 0 | 127 | 102 |
| 61 | 0 | 127 | 127 |
| 62 | 0 | 127 | 153 |
| 63 | 0 | 127 | 178 |
| 64 | 0 | 127 | 204 |
| 65 | 0 | 127 | 229 |
| 66 | 0 | 127 | 255 |
| 67 | 0 | 153 | 0 |
| 68 | 0 | 153 | 25 |
| 69 | 0 | 153 | 51 |
| 70 | 0 | 153 | 76 |
| 71 | 0 | 153 | 102 |
| 72 | 0 | 153 | 127 |
| 73 | 0 | 153 | 153 |
| 74 | 0 | 153 | 178 |
| 75 | 0 | 153 | 204 |
| 76 | 0 | 153 | 229 |
| 77 | 0 | 153 | 255 |
| 78 | 0 | 178 | 0 |
| 79 | 0 | 178 | 25 |
| 80 | 0 | 178 | 51 |
| 81 | 0 | 178 | 76 |
| 82 | 0 | 178 | 102 |
| 83 | 0 | 178 | 127 |
| 84 | 0 | 178 | 153 |
| 85 | 0 | 178 | 178 |
| 86 | 0 | 178 | 204 |
| 87 | 0 | 178 | 229 |
| 88 | 0 | 178 | 255 |
| 89 | 0 | 204 | 0 |
| 90 | 0 | 204 | 25 |
| 91 | 0 | 204 | 51 |
| 92 | 0 | 204 | 76 |
| 93 | 0 | 204 | 102 |
| 94 | 0 | 204 | 127 |
| 95 | 0 | 204 | 153 |
| 96 | 0 | 204 | 178 |

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| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 97 | 0 | 204 | 204 |
| 98 | 0 | 204 | 229 |
| 99 | 0 | 204 | 255 |
| 100 | 0 | 229 | 0 |
| 101 | 0 | 229 | 25 |
| 102 | 0 | 229 | 51 |
| 103 | 0 | 229 | 76 |
| 104 | 0 | 229 | 102 |
| 105 | 0 | 229 | 127 |
| 106 | 0 | 229 | 153 |
| 107 | 0 | 229 | 178 |
| 108 | 0 | 229 | 204 |
| 109 | 0 | 229 | 229 |
| 110 | 0 | 229 | 255 |
| 111 | 0 | 255 | 0 |
| 112 | 0 | 255 | 25 |
| 113 | 0 | 255 | 51 |
| 114 | 0 | 255 | 76 |
| 115 | 0 | 255 | 102 |
| 116 | 0 | 255 | 127 |
| 117 | 0 | 255 | 153 |
| 118 | 0 | 255 | 178 |
| 119 | 0 | 255 | 204 |
| 120 | 0 | 255 | 229 |
| 121 | 0 | 255 | 255 |
| 122 | 25 | 0 | 0 |
| 123 | 25 | 0 | 25 |
| 124 | 25 | 0 | 51 |
| 125 | 25 | 0 | 76 |
| 126 | 25 | 0 | 102 |
| 127 | 25 | 0 | 127 |
| 128 | 25 | 0 | 153 |
| 129 | 25 | 0 | 178 |
| 130 | 25 | 0 | 204 |
| 131 | 25 | 0 | 229 |
| 132 | 25 | 0 | 255 |
| 133 | 51 | 0 | 0 |
| 134 | 51 | 0 | 25 |
| 135 | 51 | 0 | 51 |
| 136 | 51 | 0 | 76 |
| 137 | 51 | 0 | 102 |
| 138 | 51 | 0 | 127 |
| 139 | 51 | 0 | 153 |
| 140 | 51 | 0 | 178 |
| 141 | 51 | 0 | 204 |
| 142 | 51 | 0 | 229 |
| 143 | 51 | 0 | 255 |
| 144 | 76 | 0 | 0 |
| 145 | 76 | 0 | 25 |

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 146 | 76 | 0 | 51 |
| 147 | 76 | 0 | 76 |
| 148 | 76 | 0 | 102 |
| 149 | 76 | 0 | 127 |
| 150 | 76 | 0 | 153 |
| 151 | 76 | 0 | 178 |
| 152 | 76 | 0 | 204 |
| 153 | 76 | 0 | 229 |
| 154 | 76 | 0 | 255 |
| 155 | 102 | 0 | 0 |
| 156 | 102 | 0 | 25 |
| 157 | 102 | 0 | 51 |
| 158 | 102 | 0 | 76 |
| 159 | 102 | 0 | 102 |
| 160 | 102 | 0 | 127 |
| 161 | 102 | 0 | 153 |
| 162 | 102 | 0 | 178 |
| 163 | 102 | 0 | 204 |
| 164 | 102 | 0 | 229 |
| 165 | 102 | 0 | 255 |
| 166 | 127 | 0 | 0 |
| 167 | 127 | 0 | 25 |
| 168 | 127 | 0 | 51 |
| 169 | 127 | 0 | 76 |
| 170 | 127 | 0 | 102 |
| 171 | 127 | 0 | 127 |
| 172 | 127 | 0 | 153 |
| 173 | 127 | 0 | 178 |
| 174 | 127 | 0 | 204 |
| 175 | 127 | 0 | 229 |
| 176 | 127 | 0 | 255 |
| 177 | 153 | 0 | 0 |
| 178 | 153 | 0 | 25 |
| 179 | 153 | 0 | 51 |
| 180 | 153 | 0 | 76 |
| 181 | 153 | 0 | 102 |
| 182 | 153 | 0 | 127 |
| 183 | 153 | 0 | 153 |
| 184 | 153 | 0 | 178 |
| 185 | 153 | 0 | 204 |
| 186 | 153 | 0 | 229 |
| 187 | 153 | 0 | 255 |
| 188 | 178 | 0 | 0 |
| 189 | 178 | 0 | 25 |
| 190 | 178 | 0 | 51 |
| 191 | 178 | 0 | 76 |
| 192 | 178 | 0 | 102 |
| 193 | 178 | 0 | 127 |
| 194 | 178 | 0 | 153 |

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| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 195 | 178 | 0 | 178 |
| 196 | 178 | 0 | 204 |
| 197 | 178 | 0 | 229 |
| 198 | 178 | 0 | 255 |
| 199 | 204 | 0 | 0 |
| 200 | 204 | 0 | 25 |
| 201 | 204 | 0 | 51 |
| 202 | 204 | 0 | 76 |
| 203 | 204 | 0 | 102 |
| 204 | 204 | 0 | 127 |
| 205 | 204 | 0 | 153 |
| 206 | 204 | 0 | 178 |
| 207 | 204 | 0 | 204 |
| 208 | 204 | 0 | 229 |
| 209 | 204 | 0 | 255 |
| 210 | 229 | 0 | 0 |
| 211 | 229 | 0 | 25 |
| 212 | 229 | 0 | 51 |
| 213 | 229 | 0 | 76 |
| 214 | 229 | 0 | 102 |
| 215 | 229 | 0 | 127 |
| 216 | 229 | 0 | 153 |
| 217 | 229 | 0 | 178 |
| 218 | 229 | 0 | 204 |
| 219 | 229 | 0 | 229 |
| 220 | 229 | 0 | 255 |
| 221 | 255 | 0 | 0 |
| 222 | 255 | 0 | 25 |
| 223 | 255 | 0 | 51 |
| 224 | 255 | 0 | 76 |
| 225 | 255 | 0 | 102 |
| 226 | 255 | 0 | 127 |
| 227 | 255 | 0 | 153 |
| 228 | 255 | 0 | 178 |
| 229 | 255 | 0 | 204 |
| 230 | 255 | 0 | 229 |
| 231 | 255 | 0 | 255 |
| 232 | 25 | 25 | 0 |
| 233 | 25 | 51 | 0 |
| 234 | 25 | 76 | 0 |
| 235 | 25 | 102 | 0 |
| 236 | 25 | 127 | 0 |
| 237 | 25 | 153 | 0 |
| 238 | 25 | 178 | 0 |
| 239 | 25 | 204 | 0 |
| 240 | 25 | 229 | 0 |
| 241 | 25 | 255 | 0 |
| 242 | 51 | 25 | 0 |
| 243 | 51 | 51 | 0 |

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 244 | 51 | 76 | 0 |
| 245 | 51 | 102 | 0 |
| 246 | 51 | 127 | 0 |
| 247 | 51 | 153 | 0 |
| 248 | 51 | 178 | 0 |
| 249 | 51 | 204 | 0 |
| 250 | 51 | 229 | 0 |
| 251 | 51 | 255 | 0 |
| 252 | 76 | 25 | 0 |
| 253 | 76 | 51 | 0 |
| 254 | 76 | 76 | 0 |
| 255 | 76 | 102 | 0 |
| 256 | 76 | 127 | 0 |
| 257 | 76 | 153 | 0 |
| 258 | 76 | 178 | 0 |
| 259 | 76 | 204 | 0 |
| 260 | 76 | 229 | 0 |
| 261 | 76 | 255 | 0 |
| 262 | 102 | 25 | 0 |
| 263 | 102 | 51 | 0 |
| 264 | 102 | 76 | 0 |
| 265 | 102 | 102 | 0 |
| 266 | 102 | 127 | 0 |
| 267 | 102 | 153 | 0 |
| 268 | 102 | 178 | 0 |
| 269 | 102 | 204 | 0 |
| 270 | 102 | 229 | 0 |
| 271 | 102 | 255 | 0 |
| 272 | 127 | 25 | 0 |
| 273 | 127 | 51 | 0 |
| 274 | 127 | 76 | 0 |
| 275 | 127 | 102 | 0 |
| 276 | 127 | 127 | 0 |
| 277 | 127 | 153 | 0 |
| 278 | 127 | 178 | 0 |
| 279 | 127 | 204 | 0 |
| 280 | 127 | 229 | 0 |
| 281 | 127 | 255 | 0 |
| 282 | 153 | 25 | 0 |
| 283 | 153 | 51 | 0 |
| 284 | 153 | 76 | 0 |
| 285 | 153 | 102 | 0 |
| 286 | 153 | 127 | 0 |
| 287 | 153 | 153 | 0 |
| 288 | 153 | 178 | 0 |
| 289 | 153 | 204 | 0 |
| 290 | 153 | 229 | 0 |
| 291 | 153 | 255 | 0 |
| 292 | 178 | 25 | 0 |

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| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 293 | 178 | 51 | 0 |
| 294 | 178 | 76 | 0 |
| 295 | 178 | 102 | 0 |
| 296 | 178 | 127 | 0 |
| 297 | 178 | 153 | 0 |
| 298 | 178 | 178 | 0 |
| 299 | 178 | 204 | 0 |
| 300 | 178 | 229 | 0 |
| 301 | 178 | 255 | 0 |
| 302 | 204 | 25 | 0 |
| 303 | 204 | 51 | 0 |
| 304 | 204 | 76 | 0 |
| 305 | 204 | 102 | 0 |
| 306 | 204 | 127 | 0 |
| 307 | 204 | 153 | 0 |
| 308 | 204 | 178 | 0 |
| 309 | 204 | 204 | 0 |
| 310 | 204 | 229 | 0 |
| 311 | 204 | 255 | 0 |
| 312 | 229 | 25 | 0 |
| 313 | 229 | 51 | 0 |
| 314 | 229 | 76 | 0 |
| 315 | 229 | 102 | 0 |
| 316 | 229 | 127 | 0 |
| 317 | 229 | 153 | 0 |
| 318 | 229 | 178 | 0 |
| 319 | 229 | 204 | 0 |
| 320 | 229 | 229 | 0 |
| 321 | 229 | 255 | 0 |
| 322 | 255 | 25 | 0 |
| 323 | 255 | 51 | 0 |
| 324 | 255 | 76 | 0 |
| 325 | 255 | 102 | 0 |
| 326 | 255 | 127 | 0 |
| 327 | 255 | 153 | 0 |
| 328 | 255 | 178 | 0 |
| 329 | 255 | 204 | 0 |
| 330 | 255 | 229 | 0 |
| 331 | 255 | 255 | 0 |
| 332 | 255 | 25 | 25 |
| 333 | 255 | 25 | 51 |
| 334 | 255 | 25 | 76 |
| 335 | 255 | 25 | 102 |
| 336 | 255 | 25 | 127 |
| 337 | 255 | 25 | 153 |
| 338 | 255 | 25 | 178 |
| 339 | 255 | 25 | 204 |
| 340 | 255 | 25 | 229 |
| 341 | 255 | 25 | 255 |

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 342 | 255 | 51 | 25 |
| 343 | 255 | 51 | 51 |
| 344 | 255 | 51 | 76 |
| 345 | 255 | 51 | 102 |
| 346 | 255 | 51 | 127 |
| 347 | 255 | 51 | 153 |
| 348 | 255 | 51 | 178 |
| 349 | 255 | 51 | 204 |
| 350 | 255 | 51 | 229 |
| 351 | 255 | 51 | 255 |
| 352 | 255 | 76 | 25 |
| 353 | 255 | 76 | 51 |
| 354 | 255 | 76 | 76 |
| 355 | 255 | 76 | 102 |
| 356 | 255 | 76 | 127 |
| 357 | 255 | 76 | 153 |
| 358 | 255 | 76 | 178 |
| 359 | 255 | 76 | 204 |
| 360 | 255 | 76 | 229 |
| 361 | 255 | 76 | 255 |
| 362 | 255 | 102 | 25 |
| 363 | 255 | 102 | 51 |
| 364 | 255 | 102 | 76 |
| 365 | 255 | 102 | 102 |
| 366 | 255 | 102 | 127 |
| 367 | 255 | 102 | 153 |
| 368 | 255 | 102 | 178 |
| 369 | 255 | 102 | 204 |
| 370 | 255 | 102 | 229 |
| 371 | 255 | 102 | 255 |
| 372 | 255 | 127 | 25 |
| 373 | 255 | 127 | 51 |
| 374 | 255 | 127 | 76 |
| 375 | 255 | 127 | 102 |
| 376 | 255 | 127 | 127 |
| 377 | 255 | 127 | 153 |
| 378 | 255 | 127 | 178 |
| 379 | 255 | 127 | 204 |
| 380 | 255 | 127 | 229 |
| 381 | 255 | 127 | 255 |
| 382 | 255 | 153 | 25 |
| 383 | 255 | 153 | 51 |
| 384 | 255 | 153 | 76 |
| 385 | 255 | 153 | 102 |
| 386 | 255 | 153 | 127 |
| 387 | 255 | 153 | 153 |
| 388 | 255 | 153 | 178 |
| 389 | 255 | 153 | 204 |
| 390 | 255 | 153 | 229 |

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| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 391 | 255 | 153 | 255 |
| 392 | 255 | 178 | 25 |
| 393 | 255 | 178 | 51 |
| 394 | 255 | 178 | 76 |
| 395 | 255 | 178 | 102 |
| 396 | 255 | 178 | 127 |
| 397 | 255 | 178 | 153 |
| 398 | 255 | 178 | 178 |
| 399 | 255 | 178 | 204 |
| 400 | 255 | 178 | 229 |
| 401 | 255 | 178 | 255 |
| 402 | 255 | 204 | 25 |
| 403 | 255 | 204 | 51 |
| 404 | 255 | 204 | 76 |
| 405 | 255 | 204 | 102 |
| 406 | 255 | 204 | 127 |
| 407 | 255 | 204 | 153 |
| 408 | 255 | 204 | 178 |
| 409 | 255 | 204 | 204 |
| 410 | 255 | 204 | 229 |
| 411 | 255 | 204 | 255 |
| 412 | 255 | 229 | 25 |
| 413 | 255 | 229 | 51 |
| 414 | 255 | 229 | 76 |
| 415 | 255 | 229 | 102 |
| 416 | 255 | 229 | 127 |
| 417 | 255 | 229 | 153 |
| 418 | 255 | 229 | 178 |
| 419 | 255 | 229 | 204 |
| 420 | 255 | 229 | 229 |
| 421 | 255 | 229 | 255 |
| 422 | 255 | 255 | 25 |
| 423 | 255 | 255 | 51 |
| 424 | 255 | 255 | 76 |
| 425 | 255 | 255 | 102 |
| 426 | 255 | 255 | 127 |
| 427 | 255 | 255 | 153 |
| 428 | 255 | 255 | 178 |
| 429 | 255 | 255 | 204 |
| 430 | 255 | 255 | 229 |
| 431 | 255 | 255 | 255 |
| 432 | 25 | 255 | 25 |
| 433 | 25 | 255 | 51 |
| 434 | 25 | 255 | 76 |
| 435 | 25 | 255 | 102 |
| 436 | 25 | 255 | 127 |
| 437 | 25 | 255 | 153 |
| 438 | 25 | 255 | 178 |
| 439 | 25 | 255 | 204 |

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 440 | 25 | 255 | 229 |
| 441 | 25 | 255 | 255 |
| 442 | 51 | 255 | 25 |
| 443 | 51 | 255 | 51 |
| 444 | 51 | 255 | 76 |
| 445 | 51 | 255 | 102 |
| 446 | 51 | 255 | 127 |
| 447 | 51 | 255 | 153 |
| 448 | 51 | 255 | 178 |
| 449 | 51 | 255 | 204 |
| 450 | 51 | 255 | 229 |
| 451 | 51 | 255 | 255 |
| 452 | 76 | 255 | 25 |
| 453 | 76 | 255 | 51 |
| 454 | 76 | 255 | 76 |
| 455 | 76 | 255 | 102 |
| 456 | 76 | 255 | 127 |
| 457 | 76 | 255 | 153 |
| 458 | 76 | 255 | 178 |
| 459 | 76 | 255 | 204 |
| 460 | 76 | 255 | 229 |
| 461 | 76 | 255 | 255 |
| 462 | 102 | 255 | 25 |
| 463 | 102 | 255 | 51 |
| 464 | 102 | 255 | 76 |
| 465 | 102 | 255 | 102 |
| 466 | 102 | 255 | 127 |
| 467 | 102 | 255 | 153 |
| 468 | 102 | 255 | 178 |
| 469 | 102 | 255 | 204 |
| 470 | 102 | 255 | 229 |
| 471 | 102 | 255 | 255 |
| 472 | 127 | 255 | 25 |
| 473 | 127 | 255 | 51 |
| 474 | 127 | 255 | 76 |
| 475 | 127 | 255 | 102 |
| 476 | 127 | 255 | 127 |
| 477 | 127 | 255 | 153 |
| 478 | 127 | 255 | 178 |
| 479 | 127 | 255 | 204 |
| 480 | 127 | 255 | 229 |
| 481 | 127 | 255 | 255 |
| 482 | 153 | 255 | 25 |
| 483 | 153 | 255 | 51 |
| 484 | 153 | 255 | 76 |
| 485 | 153 | 255 | 102 |
| 486 | 153 | 255 | 127 |
| 487 | 153 | 255 | 153 |
| 488 | 153 | 255 | 178 |

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| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 489 | 153 | 255 | 204 |
| 490 | 153 | 255 | 229 |
| 491 | 153 | 255 | 255 |
| 492 | 178 | 255 | 25 |
| 493 | 178 | 255 | 51 |
| 494 | 178 | 255 | 76 |
| 495 | 178 | 255 | 102 |
| 496 | 178 | 255 | 127 |
| 497 | 178 | 255 | 153 |
| 498 | 178 | 255 | 178 |
| 499 | 178 | 255 | 204 |
| 500 | 178 | 255 | 229 |
| 501 | 178 | 255 | 255 |
| 502 | 204 | 255 | 25 |
| 503 | 204 | 255 | 51 |
| 504 | 204 | 255 | 76 |
| 505 | 204 | 255 | 102 |
| 506 | 204 | 255 | 127 |
| 507 | 204 | 255 | 153 |
| 508 | 204 | 255 | 178 |
| 509 | 204 | 255 | 204 |
| 510 | 204 | 255 | 229 |
| 511 | 204 | 255 | 255 |
| 512 | 229 | 255 | 25 |
| 513 | 229 | 255 | 51 |
| 514 | 229 | 255 | 76 |
| 515 | 229 | 255 | 102 |
| 516 | 229 | 255 | 127 |
| 517 | 229 | 255 | 153 |
| 518 | 229 | 255 | 178 |
| 519 | 229 | 255 | 204 |
| 520 | 229 | 255 | 229 |
| 521 | 229 | 255 | 255 |
| 522 | 25 | 25 | 255 |
| 523 | 25 | 51 | 255 |
| 524 | 25 | 76 | 255 |
| 525 | 25 | 102 | 255 |
| 526 | 25 | 127 | 255 |
| 527 | 25 | 153 | 255 |
| 528 | 25 | 178 | 255 |
| 529 | 25 | 204 | 255 |
| 530 | 25 | 229 | 255 |
| 531 | 51 | 25 | 255 |
| 532 | 51 | 51 | 255 |
| 533 | 51 | 76 | 255 |
| 534 | 51 | 102 | 255 |
| 535 | 51 | 127 | 255 |
| 536 | 51 | 153 | 255 |
| 537 | 51 | 178 | 255 |

| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 538 | 51 | 204 | 255 |
| 539 | 51 | 229 | 255 |
| 540 | 76 | 25 | 255 |
| 541 | 76 | 51 | 255 |
| 542 | 76 | 76 | 255 |
| 543 | 76 | 102 | 255 |
| 544 | 76 | 127 | 255 |
| 545 | 76 | 153 | 255 |
| 546 | 76 | 178 | 255 |
| 547 | 76 | 204 | 255 |
| 548 | 76 | 229 | 255 |
| 549 | 102 | 25 | 255 |
| 550 | 102 | 51 | 255 |
| 551 | 102 | 76 | 255 |
| 552 | 102 | 102 | 255 |
| 553 | 102 | 127 | 255 |
| 554 | 102 | 153 | 255 |
| 555 | 102 | 178 | 255 |
| 556 | 102 | 204 | 255 |
| 557 | 102 | 229 | 255 |
| 558 | 127 | 25 | 255 |
| 559 | 127 | 51 | 255 |
| 560 | 127 | 76 | 255 |
| 561 | 127 | 102 | 255 |
| 562 | 127 | 127 | 255 |
| 563 | 127 | 153 | 255 |
| 564 | 127 | 178 | 255 |
| 565 | 127 | 204 | 255 |
| 566 | 127 | 229 | 255 |
| 567 | 153 | 25 | 255 |
| 568 | 153 | 51 | 255 |
| 569 | 153 | 76 | 255 |
| 570 | 153 | 102 | 255 |
| 571 | 153 | 127 | 255 |
| 572 | 153 | 153 | 255 |
| 573 | 153 | 178 | 255 |
| 574 | 153 | 204 | 255 |
| 575 | 153 | 229 | 255 |
| 576 | 178 | 25 | 255 |
| 577 | 178 | 51 | 255 |
| 578 | 178 | 76 | 255 |
| 579 | 178 | 102 | 255 |
| 580 | 178 | 127 | 255 |
| 581 | 178 | 153 | 255 |
| 582 | 178 | 178 | 255 |
| 583 | 178 | 204 | 255 |
| 584 | 178 | 229 | 255 |
| 585 | 204 | 25 | 255 |
| 586 | 204 | 51 | 255 |

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| Colour number | Digital 8-bit equivalent RGB input signal level | | |
|---------------|---|----------|----------|
| | <i>R</i> | <i>G</i> | <i>B</i> |
| 587 | 204 | 76 | 255 |
| 588 | 204 | 102 | 255 |
| 589 | 204 | 127 | 255 |
| 590 | 204 | 153 | 255 |
| 591 | 204 | 178 | 255 |
| 592 | 204 | 204 | 255 |
| 593 | 204 | 229 | 255 |
| 594 | 229 | 25 | 255 |
| 595 | 229 | 51 | 255 |
| 596 | 229 | 76 | 255 |
| 597 | 229 | 102 | 255 |
| 598 | 229 | 127 | 255 |
| 599 | 229 | 153 | 255 |
| 600 | 229 | 178 | 255 |
| 601 | 229 | 204 | 255 |
| 602 | 229 | 229 | 255 |

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Annex B (informative)

Calculation method for CIELAB gamut volume

B.1 Purpose

The purpose of this method is to describe a procedure to calculate the colour gamut volume of measured colours from a display in the three-dimensional CIELAB colour space.

B.2 Procedure for calculating the colour gamut volume

The calculation of the CIELAB colour gamut volume is implemented by measuring a large number of colours on the gamut boundary defining the range of colours that a display can produce for given setup conditions. Since the shape of the CIELAB volume can be complex, it is easier to define the colours to be sampled by specifying them in the input-referred RGB colour space. Once the colours are specified on the RGB cube, then a tessellation of those points is used to determine their corresponding CIELAB values. These triangles on the CIELAB gamut boundary are the base of the volume elements, which are then summed up to calculate the total volume.

Although this procedure is robust, it typically requires a very large number of colour measurements in order to accurately determine the CIELAB volume (see for example CIE 168). The number of sampled colours can be substantially reduced by choosing only the RGB boundary colours, as explained in Annex A. An example of flowchart for this process is given in Figure B.1.

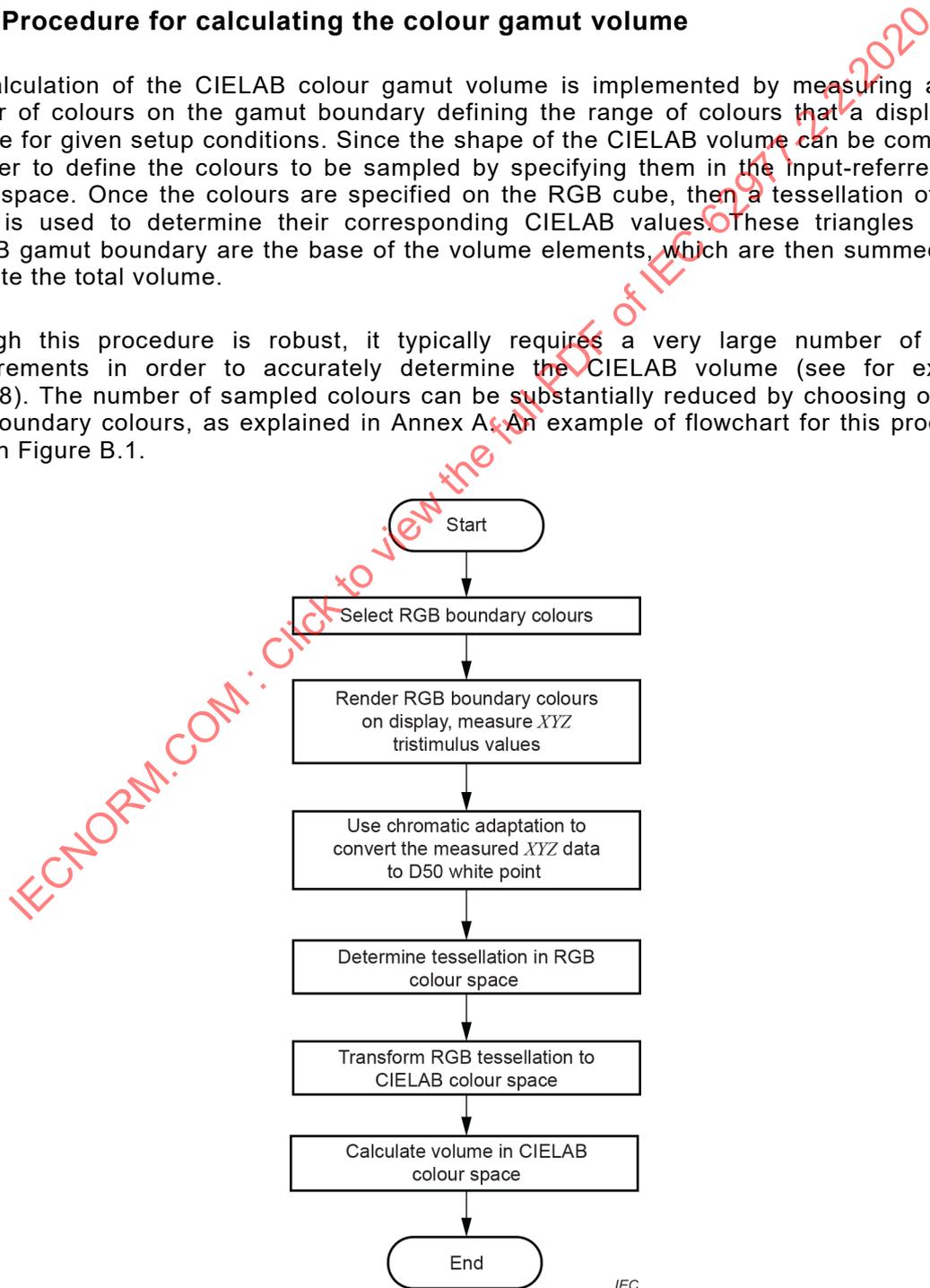


Figure B.1 – Analysis flow chart for calculating the CIELAB gamut volume

B.3 Number of sampled colours

The quality of the CIELAB gamut volume calculation will depend strongly on the number of sampled colours, and the complexity of the surface shape. An irregular-shaped CIELAB gamut will require a higher number of sampled colours. Since the gamut shape is not always known a priori, a conservative approach is to use the recommended 602 RGB boundary colours specified in Annex A. If the gamut surfaces are smooth, then a reasonable estimate of the CIELAB gamut volume can be obtained by fewer sampled points. For example, a display that exhibits additivity and a known tone response curve could use the eight-point method with interpolation (see for example IEC 62341-6-1 [15]).

B.4 RGB cube surface subdivision method for CIELAB gamut volume calculation

B.4.1 General

There are several possible algorithms that can be used to calculate the CIELAB gamut volume. One such algorithm that is recommended is described in Clause B.4. This algorithm uses equally-spaced RGB colours on the surface of the cube in the RGB colour space.

B.4.2 Assumption

It is assumed that colours on the surface of the RGB cube map to colours on the CIELAB colour gamut surface.

B.4.3 Uniform RGB grid algorithm

This algorithm accepts a uniform grid of RGB colour space coordinates that lie on each face of the RGB cube and their corresponding measured tristimulus values. The measured tristimulus values are chromatically adapted to a D50 white point. A triangular tessellation is determined on the RGB coordinates, and their corresponding measured CIELAB values are derived and converted to cylindrical coordinates using chroma (C^*) and hue angle (h^*), where $C^* = (a^{*2} + b^{*2})^{0.5}$ and $h^* = \text{atan2}(b^*, a^*)$ with atan2 representing the two-argument arctangent math function spanning the range $-\pi < \text{atan2}(b^*, a^*) \leq \pi$, where b^*/a^* can be any real number. The volume of the tessellated CIELAB gamut is computed via numerical integration in the cylindrical coordinates of lightness (L^*), chroma (C^*), and hue (h^*).

The calculation algorithm is as follows:

- 1) The specified sampled colours and measured tristimulus values are read from a data text file in the CGAT,17 format [12].
- 2) The measured XYZ tristimulus values for signal white ($R_{\max}, G_{\max}, B_{\max}$) are found in the data. If the measured white point is not equal to D50, the program computes a chromatic adaptation transform (CAT) from the measured white to CIE Illuminant D50. This computed CAT is then applied to all of the tristimulus values in the measured dataset. ISO 15076-1:2010, Annex E, describes the CAT02 chromatic adaptation transform using the Bradford coefficients. The chromatic adaptation is implemented as a linear transformation of the measured tristimulus values (X, Y, Z) in the adapted colour (X_P, Y_P, Z_P) using a matrix M_{adapt} that depends on the measured white (X_W, Y_W, Z_W) and the reference D50 white ($X_{D50}, Y_{D50}, Z_{D50}$):

$$\begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix} = \begin{bmatrix} M_{\text{adapt}} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (\text{B.1})$$