IEC 62977-2-1

Edition 1.0 2021-01

INTERNATIONAL STANDARD

colour inside

Electronic displays –
Part 2-1: Measurements of optical characteristics – Fundamental measurements

IEC 62977-2-1:2021-01(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC online collection - oc.iec.ch
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 18 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC 62977-2-1

Edition 1.0 2021-01

INTERNATIONAL STANDARD

colour inside

Electronic displays –
Part 2-1: Measurements of optical characteristics – Fundamental measurements

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.120; 31.260

ISBN 978-2-8322-9225-9

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

ELECTRONIC DISPLAYS –

Part 2-1: Measurements of optical characteristics – Fundamental measurements

FOREWORD

International Standard IEC 62977-2-1 has been prepared by IEC technical committee 110: Electronic displays.

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

FDIS	Report on voting
110/1256/FDIS	110/1275/RVD

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

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

A list of all parts in the IEC 62977 series, published under the general title *Electronic displays*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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

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

INTRODUCTION

This document describes the common optical measurement methods applicable in the field of electronic display devices, which can overlap with some of the parts of existing documents developed within TC 110 (IEC 61747-30-1 [1] [1], IEC 62341-6-1, IEC 61988-2-1 [2], IEC 62715-5-1 [3]), 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 61747-30-1, IEC 62341-6-1, IEC 61988-2-1, IEC 62715-5-1). The existing documents will be revised in their maintenance time to refer to this document to the largest extent possible.

All documents in IEC TC 110 that are concerned with the measurement of optical properties of electronic displays 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 method (COMM) 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 document 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.

Table 1 – Summary of display characteristics

Variables	**Time**		**Location** (x, y)	**Direction** (θ, ϕ)	**Test pattern, electrical driving, input signal**	**Illumination conditions**	**Temperature, humidity**
Data sampling condition	**Fast**	**Slow**	**Slow** √	**Slow**	**Slow** √		
Evaluation							
Results	transitions from one optical state to another state	temporal stability (uniformity)	uniformity √	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 gamma is evaluated chromaticity/ colour gamut area, √ colour gamut volume, √		

1 Numbers in square brackets refer to the Bibliography.

ELECTRONIC DISPLAYS –

Part 2-1: Measurements of optical characteristics – Fundamental measurements

1 Scope

This part of IEC 62977 specifies standard measurement conditions and measuring methods for determining the optical characteristics of electronic display modules and systems. These methods apply to emissive and transmissive direct view displays that render real 2D images on a flat panel. This document evaluates the optical characteristics of these displays under darkroom conditions. This document applies to the testing of display performance in response to standard analogue or digital input signals that are not absolute luminance encoded. The input signal is relative RGB without metadata information that codes for real luminance, colour space or colour coordinates. These methods are limited to input signals with typical OETFs such as defined in IEC 61966-2-1, ITU BT. Rec. 601, ITU BT. Rec.709, and ITU BT. Rec.2020. The tests in this document are not approved for use with HDR input signals.

NOTE A flat panel or flat panel display is a display with a flat surface and minimal depth that emits visible light from the surface. The display is subdivided into an array of electronically driven pixels which can be light valves modulating a backlight, or self-luminous. Emissive/transmissive/reflective hybrid displays can be flat panel or flat panel displays.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

IEC 62341-6-1, *Organic light emitting diode (OLED) displays – Part 6-1: Measuring methods of optical and electro-optical parameters*

IEC TR 62977-2-3, *Electronic display devices – Part 2-3: Measurements of optical properties – Multi-colour test patterns*

ISO 9241-305, *Ergonomics of human-system interaction – Part 305: Optical laboratory test methods for electronic visual displays*

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

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*

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

CIE 168:2005, *Criteria for the evaluation of extended-gamut colour encodings*

CIE 233:2019, *Calibration, characterization and use or array spectroradiometers*

ITU-R BT.601, *Studio encoding parameters of digital television for standard 4:3 and wide screen 16:9 aspect ratios*

ITU-R BT.709, *Parameters values for the HDTV standards for production and international programme exchange*

ITU-R BT.2020, *Parameters values for ultra-high definition television systems for production and international programme exchange*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-845 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 [4]. 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

3.1.4
chromaticity difference
geometric distance between two colour coordinates in a CIE chromaticity diagram, usually the CIE 1976 chromaticity diagram

3.1.5
chromaticity gamut area
colour gamut area
maximum area of chromaticity reproducible by a display

Note 1 to entry: "Colour gamut area" has been used in textbooks, industry, and the market for a long time. However, the CIE (eilv.cie.co.at) indicates that the term "colour gamut" should be regarded as a volume in a colour space. Therefore, a two-dimensional representation should be described as a chromaticity gamut area.

3.1.6
direct view
non-projection display technology where the image rendering surface is viewed directly without any optical components between the viewer and the surface

3.2 Abbreviated terms

APL	average picture level
CAT	chromatic adaption transform
CCT	correlated colour temperature
CIE	Commission Internationale de L'Eclairage (International Commission on Illumination)
CIELAB	CIE 1976 (L*a*b*) colour space
CMY	cyan, magenta, and yellow
DUT	device under test
EOTF	electro-optic transfer function
HDR	high dynamic range
LCD	liquid crystal display
LED	light-emitting diode
LMD	light measuring device
OETF	opto-electronic transfer function
RGB	red, green, and blue
RGBCMY	red, green, blue, cyan, magenta, and yellow
SDR	standard dynamic range
sRGB	a standard RGB colour space defined in IEC 61966-2-1
SPD	spectral power distribution
UCS	uniform chromaticity scale

4 General

4.1 Measured basic quantities

The basic quantities for luminance and chromaticity can be measured directly, for example with photometers and colorimeters, or they can be obtained from measured spectra (i.e. the spectral power distribution (SPD)) by a spectroradiometer. Spectroradiometers are generally more accurate than photometers or colorimeters, and should be used when higher accuracy is needed. Photometers and colorimeters allow for fast data acquisition as required for evaluation of optical transitions (e.g. "switching times"). The acquisition of the spectral power distribution is usually restricted to steady optical states.

4.2 Electrical driving of the display (depending on the nature of the display)

The electrical driving conditions of the display are as follows:

– driving voltage (waveform), current, frequency, etc.;
– RGB input (analogue, digital);
– test pattern (independent of display electrical interface).

4.3 Data acquisition timing and display driving

4.3.1 Stationary measurements

After application of a new driving state (test pattern), a delay (wait) period is introduced for the optical response to settle to a steady state before the measurement is carried out.

4.3.2 Properties of display under test

The physics of the display itself or the signal processing measures can affect the optical response (image), for example via luminance loading (luminance dependence on APL). The display to be measured shall be checked for this effect and the test patterns used during the measurement procedure shall be chosen and applied accordingly.

5 Standard measuring conditions

5.1 Standard measuring environmental conditions

Measurements shall be carried out under the standard environmental conditions:

– temperature: 25 °C ± 3 °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.

5.2 Standard measuring darkroom conditions

The luminance contribution from unwanted background illumination reflected off the test display shall be less than 1/20 of the display's black state luminance. The reflected background luminance can be approximated by turning off the display. When the reflected background luminance and total (reflected plus black) luminance are greater than the sensitivity limit of the LMD, then it is possible to calculate the black luminance by subtracting the background luminance from the total luminance. If the reflected background luminance or total luminance are similar to the sensitivity limit of the LMD, this shall be reported. In cases where the display has a very low luminance black state, a stray light elimination tube (according to ISO 9241-305) should be used to minimize the contribution of the background illumination. This method can be used to estimate the reflected luminance from the black state luminance.

NOTE Blackout curtains are a solution for reducing the reflection from the DUT.

5.3 Standard setup conditions

5.3.1 General

Standard setup conditions are given in 5.3. Any deviations from these conditions shall be reported.

5.3.2 Adjustment of display

The display shall be configured to the specified settings, and the settings recorded 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 resulting 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. The ambient light (or brightness) control (ABC), which can reduce the display 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 ABC. The state of the ABC 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. When the display has the option to be set for different viewing modes, the viewing mode shall be defined by the test specification, and be used with consistency for all measurements. Additional viewing modes can also be measured. The viewing mode used during testing shall be reported. The display should be operated in a mode that does not have overscan.

5.3.3 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 ±3 % over the entire measurement period (e.g. uniformity measurements) for a given display image.

5.3.4 Conditions of measuring equipment

5.3.4.1 General conditions

Optical properties of displays shall generally be expressed in photometric or colorimetric units using the CIE 1931 standard colorimetric 2° observer (according to 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 [5]). The following requirements are given for these instruments.

The LMD shall be a luminance meter, colorimeter, or a spectroradiometer. For DUTs that have sharp spectral peak full-width-at-half-maximums (FWHMs) smaller than 20 nm, such as 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 a colorimeter is used, it shall be calibrated with the measured colorimetry values obtained from a narrow bandwidth spectroradiometer. Even with this procedure, the colorimeter will give lower accuracy results than the spectroradiometer. Report the characteristics of the spectroradiometer (as given in CIE 233) which is used for calibration. For light sources with sharp spectral peaks, the maximum bandwidth of the spectroradiometer shall be ≤ 5 nm. In those cases, the wavelength accuracy shall be within ±0,3 nm. 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 should be taken to ensure that the LMD has enough sensitivity and dynamic range to perform the required task. Before measuring the DUT, it is recommended to check the LMD specification.

The following additional best practices shall be followed:

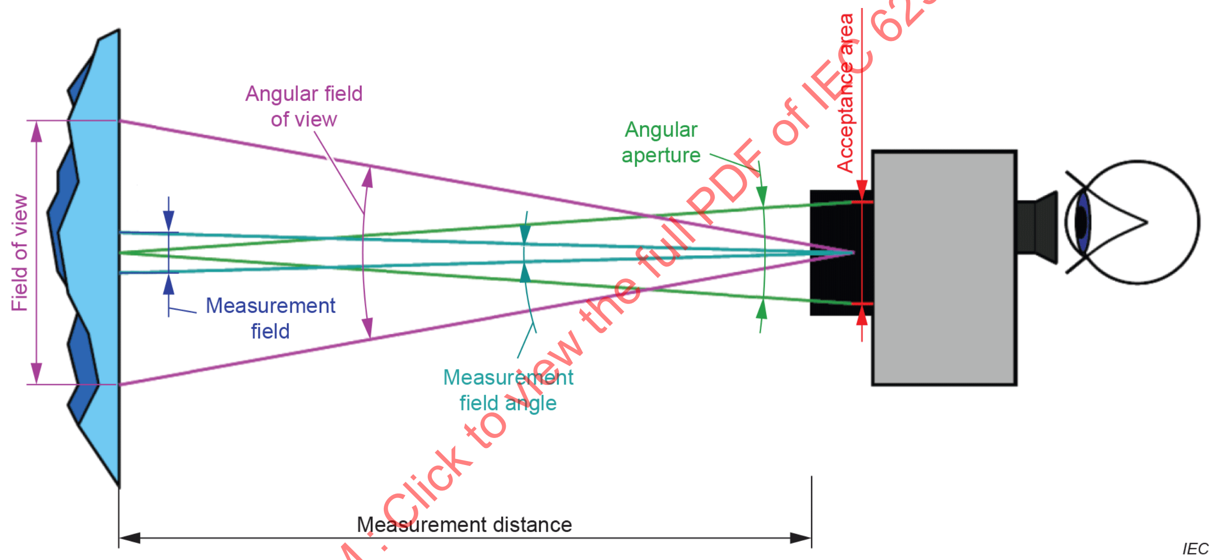
a) The LMD shall be focused on the image plane of the display and generally aligned perpendicularly to the display surface at the centre of the active display area, unless stated otherwise.
b) The relative uncertainty and repeatability of all the measuring devices shall be maintained by following the instrument supplier's recommended calibration schedule.
c) If the light level of the display is temporally modulated, then the LMD integration time shall be synchronized with the vertical frame synchronization 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 light of the modulated light in order to measure the luminance to better than 5 %. An initial assessment of the suitability of the LMD for temporally modulated signals can be made by a repeatability measurement with at least five measurements.

d) If LMD measurements are taken for displays with temporal light modulation (including LCD backlights), the temporal 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.

e) If the LMD is to measure a dim measurement area, the LMD field of view should avoid containing a bright background. If this is not possible, then a frustum or stray light elimination tube shall be used (according to ISO 9241-305).

Additional best practices for general measurement are given in detail in [6].

In addition to LMDs that give a spatially averaged value for the measured quantity over the measurement field under consideration (i.e. spot photometers, see Figure 1), there is the class of imaging LMDs which give an array of values (e.g. R, G and B) for each corresponding individual measurement area on the DUT. These imaging LMDs are not addressed in this document.



NOTE The measurement field angle and angular aperture are defined from/to the entrance pupil of the LMD. However, since the precise location of the LMD entrance pupil is often not specified by the manufacturer, the measurement distance is typically specified as the distance between the display under test and the front of the LMD optics.

Figure 1 – Layout diagram of measurement setup with terminology

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

The following applies for high pixel count matrix displays:

a) When measuring matrix displays, the LMDs should be set to a measurement field that includes more than 500 pixels (according to IEC 62977-3-1:2019, Annex E [7]). A minimum of 500 pixels is recommended to minimize the influence of an unusually dim or bright pixel in the measurement area. If smaller measurement areas are necessary, photometric and colorimetric equivalence to 500 pixels shall be confirmed and noted in the test report.

b) For small displays (approximately ≤ 10 inch diagonal), the recommended measuring distance is between 20 cm to 50 cm. For contact-type and close-up-type LMDs, the measuring distance specified for the LMD should be used. The suitability of contact-type LMDs can be confirmed with non-contact LMDs. Caution should be taken that the luminance and colour of the display are not affected by the contact. For larger displays (approximately > 10 inch diagonal), follow the manufacturer-recommended viewing distance. If no recommendation is given, the recommended distance is 3 x V, where V is the height of the display's active area, or the shorter dimension of the active area. The measuring distance shall be noted in the report.

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

d) For LMDs that use a telecentric optical design, the angular aperture shall be less than or equal to 5°, but there is no measurement-field angle requirement, even if the measuring field is large.

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

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

The following applies for low pixel count matrix displays:

a) When the number of pixels in the measurement field is less than 500, it shall be noted in the report. The angular aperture shall be less than or equal to 5°, and the measurement-field angle shall be less than or equal to 2°. The measurement conditions used shall be reported.

b) For small displays, the recommended measuring distance is between 20 cm to 50 cm. For contact-type and close-up-type LMDs, the measuring distance specified for the LMD should be used. The suitability of contact-type LMD can be confirmed with non-contact LMD. Caution should be taken that the luminance and colour of the display are not affected by the contact. For larger displays, follow the manufacturer-recommended viewing distance. If no recommendation is given, the recommended distance is 3 x V, where V is the height of the display active area, or the shorter dimension of the active area. The measuring distance shall be noted in the report.

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

   For LMDs that use a telecentric optical design, the angular aperture shall be less than or equal to 5°, but there is no measurement-field angle requirement, even if the measuring field is large.

5.4 Location of measurement field

Luminance, spectral distribution and/or tristimulus measurements may be taken at several specified locations on the display surface. The common measurement locations are identified by locations P_0 to P_8 in the active area, as illustrated in Figure 2. The active screen area is divided into nine equal-sized boxes, with the measurement area centred within each box and identified by the corresponding numbering shown in Figure 2. Each box is 1/3 the horizontal size (H) and vertical size (V) of the active area. Centre-screen measurements are taken at location P_0. Any deviation from the above coordinate system shall be reported.

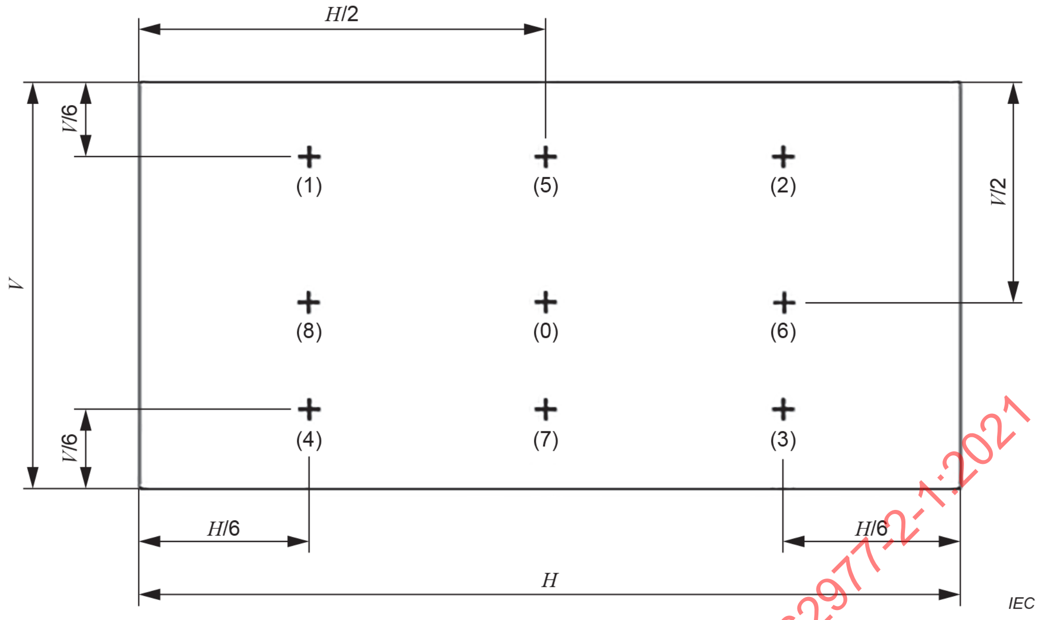


Figure 2 – Example of measurement locations with nine measurement locations equally spaced in the display active area

5.5 Standard test patterns

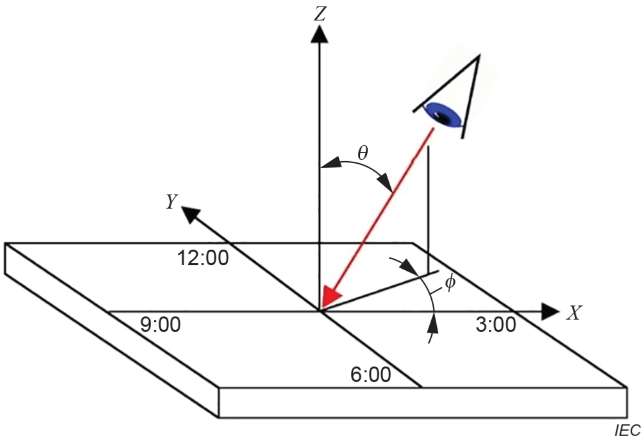
Two sets of fundamental test patterns are used in this document, the simple box set and the multi-colour set.

The simple box set of test patterns is used for the simple box measurement methods described in Clause 6. The basic box test pattern uses a single-colour rectangular box centred in the active area of the screen. The basic full screen test pattern is also used. These basic patterns may be used for communication between manufacturers. They may also be used for communication in research and development, quality control, and in-line manufacturing. These tests are described in 6.2.

The set of multi-colour test patterns is used for measurement methods in Clause 7, except for the uniformity measurements in 7.5 and 7.9. The test pattern shall follow the principle of multi-colour test patterns described in IEC TR 62977-2-3. As described in IEC TR 62977-2-3, the simple box test patterns may not adequately represent the display performance for natural images. Therefore, more general multi-colour test patterns are given for that purpose (see 7.2). The standard multi-colour test patterns are used for communication between manufacturers and end customers about the performance of final display products. These test patterns are not normally used for in-line production testing, except for special circumstances. However, the optical performance of the delivered product shall be measured using the multi-colour test patterns, except for 7.5 and 7.9.

5.6 Viewing direction 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 3. Although the azimuth angle is measured in the counter-clockwise direction, it is related to the directions on a clock face as follows: $\phi = 0°$ is the 3-o'clock direction ("right"), $\phi = 90°$ the 12-o'clock direction ("top"), $\phi = 180°$ the 9-o'clock direction ("left") and $\phi = 270°$ the 6-o'clock direction ("bottom").



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

Figure 3 – Representation of the viewing direction, or direction of measurement

6 Simple box optical measurement methods

6.1 General

The purpose of Clause 6 is to describe the basic optical measurement methods that are applicable for characterizing displays, including measurements of display panels and modules. The results from these methods can be used to communicate the product performance between manufacturers. The utility of these methods is given in Annex C.

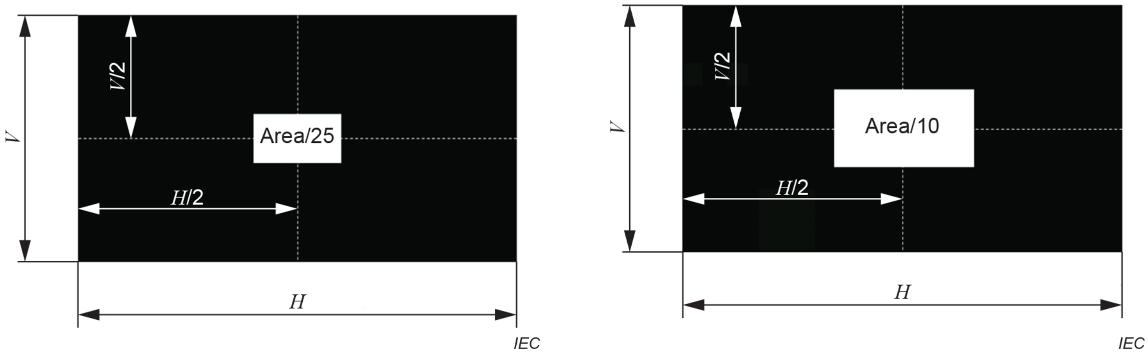
For each measurement method, if the measured white luminance in the centre of the full screen or box test pattern is different by more than 5 % from the centre colour-signal white (see Annex D) luminance $L_{\mathrm{CSW},\ 0}$ data using the multi-colour test patterns (Figure 10), then the simple box test results shall not be communicated to end customers. Under this condition, the methods in Clause 7 (excluding the full screen uniformity measurements 7.5 and 7.9) should be used for that purpose.

6.2 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 for all addressable pixels.

An alternative box test pattern uses a black background with a relatively small colour area centred on the display screen. Two different area sizes are possible; a 4 % or a 10 % area box shall be used. These patterns are illustrated in Figure 4 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.



a) 4 % area centre box b) 10 % area centre box

Figure 4 – Example of centre box test patterns using the standard 4 % and 10 % area boxes

6.3 Luminance

6.3.1 Purpose

This method determines the darkroom luminance of a specified full screen, 4 % area box, or 10 % area box of any specified colour Q in the centre of the active area of a display. The standard full screen, 4 % and 10 % centre box pattern are specified in 6.2.

6.3.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure luminance, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

6.3.3 Measuring method

Measure the centre luminance of the full screen, 4 % centre box, or 10 % centre box pattern using the following procedure:

a) Display the specified test pattern with the required colour Q centred in the measurement location P_0 (see Figure 2). Allow the luminance to stabilize within the specification of the LMD, and ensure the measurement is completed before the display power management acts to dim the display.

b) Align the optical axis of the LMD perpendicularly to the display screen and centred on the location P_0 (see Figure 2).

c) Measure the luminance at the screen centre.

d) Repeat the measurement for additional colours.

e) Report the setup conditions, the test pattern, the colour, and the luminance $L_{Q,FS}$, $L_{Q,4\,\%}$, or $L_{Q,10\,\%}$ for the full screen, 4 % centre box, or 10 % centre box pattern at the specified colour Q, respectively.

6.4 Darkroom contrast ratio

6.4.1 Purpose

This method determines the darkroom contrast ratio for a specified full white screen, 4 % area white box, or 10 % area white box in the centre of the active area of a display. The standard full screen, 4 % and 10 % centre box pattern are specified in 6.2.

6.4.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure luminance, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

6.4.3 Measuring method

Measure the contrast ratio of the full white screen, 4 % centre white box, or 10 % centre white box pattern using the following procedure:

a) Display the specified full white screen, 4 % area white box, or 10 % area white box pattern, with white at its maximum input signal level. Allow the luminance to stabilize within the specification of the LMD, and ensure the measurement is completed before the display power management acts to dim the display.

b) Align the optical axis of the LMD perpendicularly to the display screen and centred on the location P_0 (see Figure 2).

c) Measure the white luminance at screen centre. The measured white luminance is written as $L_{W,FS}$, $L_{W,4\ \%}$, or $L_{W,10\ \%}$, for the full white screen, 4 % area white box, or 10 % area white box pattern, respectively.

d) Render a black full screen test pattern, with black at the lowest grey level.

e) Measure the full screen black luminance $L_{K,FS}$.

f) Calculate the full screen or box darkroom contrast ratio:

Full screen darkroom contrast ratio: $$CR_{DR,FS} = \frac{L_{W,FS}}{L_{K,FS}} \quad (1)$$

4 % box darkroom contrast ratio: $$CR_{DR,4\%} = \frac{L_{W,4\%}}{L_{K,FS}} \quad (2)$$

10 % box darkroom contrast ratio: $$CR_{DR,10\%} = \frac{L_{W,10\%}}{L_{K,FS}} \quad (3)$$

g) Report the setup conditions, the test pattern, the full screen black luminance $L_{K,FS}$, the white luminance ($L_{W,FS}$, $L_{W,4\%}$, or $L_{W,10\%}$), and the full screen or box darkroom contrast ratio ($CR_{DR,FS}$, $CR_{DR,4\ \%}$, or $CR_{DR,10\ \%}$). The contrast ratio should be reported in the format CR:1, for example 1 000:1.

For displays that can achieve deep blacks, the black luminance can be measurement instrument limited. The sensitivity limit of the LMD should be investigated and reported in that case.

6.5 Luminance uniformity

6.5.1 Purpose

The purpose of this method is to spatially sample the luminance of a defined colour Q over the active area of the display. The luminance is measured with a full screen of a single colour at the nine measurement locations P_{U0} to P_{U8} (Figure 5). The luminance uniformity is measured for white and the input RGB primary colours. These colours are rendered at their maximum input command level.

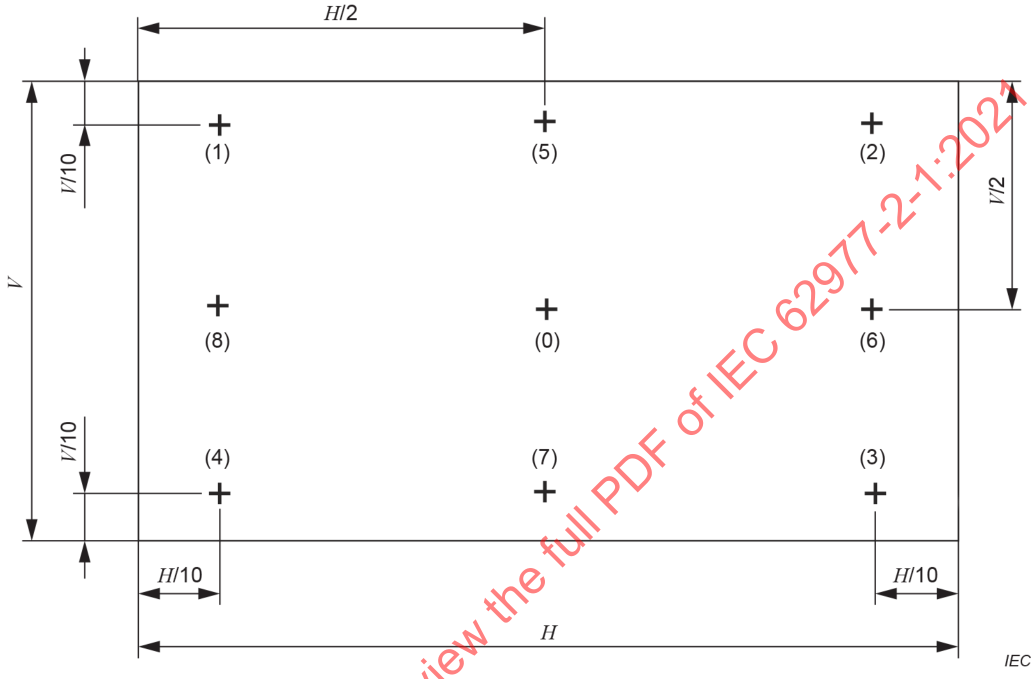


Figure 5 – Example of uniformity measurement locations with nine measurement locations

6.5.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure luminance, a driving power supply, driving signal equipment, and a means to translate the LMD or display with respect to each other.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) Use of a full screen of a single colour measured at the measurement locations shown in Figure 5.

6.5.3 Measuring method

Measure the sampled luminance uniformity of a defined colour Q over the active area using the following procedure:

a) Render a full screen test pattern of a defined colour Q. Allow the luminance to stabilize within the specification of the LMD, and ensure the measurement is completed before the display power management acts to dim the display.

b) Align the optical axis of the LMD perpendicularly to the display screen and centred on location P_{U0}.

c) Measure the luminance L_0 at location P_{UO}.

d) Translate the LMD (or display) to the other display locations (P_{U1} to P_{U8}) and measure the luminance at each location.

e) Report the results in a similar form to Table 2.

f) Calculate the percent luminance non-uniformity NU and uniformity U using the following formulae:

$$NU = 100\% \frac{L_{max} - L_{min}}{L_{max}} \tag{4}$$

$$U = 100\% - NU \tag{5}$$

where L_{max} is the maximum luminance value measured for the measured screen locations, and L_{min} is the minimum value.

g) Report the setup conditions, the percent luminance non-uniformity NU and uniformity U for each colour, and the individual measurements as illustrated in Table 2.

Table 2 – Example of luminance of white, red, green, and blue measured at nine screen locations and the resulting average luminance

Measuring point	Luminance L_w for white cd/m²	Luminance for red cd/m²	Luminance for green cd/m²	Luminance for blue cd/m²
P_{U0}	215	51	140	24
P_{U1}	211	49	135	27
P_{U2}	208	51	133	24
P_{U3}	207	48	135	25
P_{U4}	205	48	133	24
P_{U5}	210	48	137	25
P_{U6}	195	44	128	23
P_{U7}	204	47	133	24
P_{U8}	199	45	131	23
Average	206	48	134	24
Non-uniformity	9,3 %	13,7 %	8,6 %	14,8 %
Uniformity	90,7 %	86,3 %	91,4 %	85,2 %

6.6 Chromaticity

6.6.1 Purpose

This method determines darkroom chromaticity of a specified full screen, 4 % area box, or 10 % area box of a specified colour Q in the centre of the active area of a display. The standard full screen, 4 % and 10 % centre box pattern are specified in 6.2.

6.6.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a colour measuring device that can measure the CIE 1931 chromaticity coordinates, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

6.6.3 Measuring method

Measure the centre chromaticity of the full screen, 4 % centre box, or 10 % centre box pattern using the following procedure:

a) Render the specified test pattern with the specified colour Q centred in measurement location P_0 (see Figure 2). Allow the luminance to stabilize within the specification of the LMD, and ensure the measurement is completed before the display power management acts to dim the display.

b) Align the optical axis of the LMD perpendicularly to the display screen and centred on the location P_0 (see Figure 2).

c) Measure the chromaticity at the screen centre.

d) Repeat the measurement for additional specified colours.

e) Report the setup conditions, the test pattern, the colour, and the chromaticity $(x, y)_{Q,FS}$, $(x, y)_{Q,4\ \%}$, or $(x, y)_{Q,10\ \%}$ for the full screen, 4 % centre box, or 10 % centre box pattern at the specified colour Q, respectively.

6.7 White chromaticity and correlated colour temperature

6.7.1 Purpose

The purpose of this method is to measure the white chromaticity, and correlated colour temperature (CCT), at the maximum white input signal level. A specified white full screen, 4 % area box, or 10 % area box will be measured in the centre of the active area of a display. The standard full screen, 4 % and 10 % centre box pattern are specified in 6.2.

6.7.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a colour measuring device that can measure the CIE 1931 chromaticity coordinates for the CIE 1931 2° standard observer, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

6.7.3 Measuring method

Measure the white luminance at the maximum drive level in the centre of the active area using the full screen, 4 % centre box, or 10 % centre box pattern with the following procedure:

a) Render the white pattern and allow the chromaticity values to stabilize within the specification of the LMD, and ensure the measurement is completed before the display power management acts to dim the display. The white colour shall be rendered at the maximum grey level.

b) Align the optical axis of the LMD perpendicular to the display screen, and centred on location P_0 (see Figure 2) as well as on the white test pattern.

c) Measure the white CIE 1931 chromaticity coordinates (x, y) at the centre. If the LMD also supplies the CCT value, report this value as well. If the LMD does not measure CCT, then the CCT can be estimated using the methods described in CIE 15.

d) Report the setup conditions and test results in the test report.

6.8 Chromaticity non-uniformity

6.8.1 Purpose

The purpose of this method is to spatially sample the chromaticity of a specified colour Q over the active area of the display. The chromaticity is measured with a full screen of a single colour at the nine measurement locations P_{U0} to P_{U8} (Figure 5). The chromaticity uniformity is measured for white and the input RGB primary colours. These colours are rendered at their maximum input command level.

6.8.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a colour measuring device that can measure the CIE 1931 or CIE 1976 chromaticity coordinates, a driving power supply, driving signal equipment, and a means to translate the LMD or display with respect to each other.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) Use a full screen of a single colour measured at the measurement locations shown in Figure 5.

6.8.3 Measuring method

Spatially sample the chromaticity and calculate the uniformity for a defined colour Q over the active area using the following procedure:

a) Render a full screen test pattern of a defined colour Q. The display chromaticity values shall be stable (within the specification of the LMD) over the measurement period.

b) Align the optical axis of the LMD perpendicularly to the display screen and centred on location P_{U0} (see Figure 5).

c) Measure the CIE tristimulus values (X, Y, Z), or CIE 1931 chromaticity coordinates (x, y), at location P_{U0}.

d) Translate the LMD (or display) to the other display locations (P_{U1} to P_{U8}) and measure the chromaticity at each location.

e) The chromaticity values and summary data for each colour shall be recorded, as illustrated in Table 3. The CIE 1976 UCS (uniform chromaticity scale) chromaticity coordinates (u', v') specified in CIE 15 can be calculated from the CIE tristimulus values, or from the CIE 1931 chromaticity coordinates, measured at the nine locations using the following formulae:

$$u' = \frac{4X}{X + 15Y + 3Z} = \frac{4x}{3 - 2x + 12y} \tag{6}$$

$$v' = \frac{9Y}{X + 15Y + 3Z} = \frac{9y}{3 - 2x + 12y} \tag{7}$$

where X, Y, and Z represent the CIE tristimulus values, and x and y represent the CIE 1931 chromaticity coordinates.

f) For each measurement location P_{Ui} and P_{Uj}, determine the CIE 1976 chromaticity difference between pairs of measured CIE 1976 UCS chromaticity coordinates (u', v') using the following formula:

$$(\Delta u'v')_{ij} = \sqrt{\left(u'_i - u'_j\right)^2 + \left(v'_i - v'_j\right)^2} \tag{8}$$

for i, j = 0 to 8, and $i \neq j$. The chromaticity non-uniformity is defined as the largest chromaticity difference $(\Delta u'v')_{max}$ between any two measurement locations (i.e. the maximum value of Formula (8)). The largest colour difference can be narrowed down by plotting the nine (u', v') coordinates rather than calculating all (u', v') pairs.

g) Report the setup conditions and test results as illustrated in Table 3 in the test report.

Table 3 – Example of a white colour measured at nine screen locations and the resulting chromaticity non-uniformity

Measuring point	x_i	y_i	u'_i	v'_i	$\Delta u'v'$								
					P_{U0}	P_{U1}	P_{U2}	P_{U3}	P_{U4}	P_{U5}	P_{U6}	P_{U7}	P_{U8}
P_{U0}	0,311	0,325	0,198	0,466	0,000								
P_{U1}	0,330	0,320	0,214	0,466	0,016	0,000							
P_{U2}	0,307	0,323	0,196	0,464	0,003	0,018	0,000						
P_{U3}	0,309	0,328	0,196	0,467	0,002	0,018	0,003	0,000					
P_{U4}	0,310	0,326	0,197	0,466	0,001	0,017	0,002	0,001	0,000				
P_{U5}	0,303	0,319	0,195	0,461	0,006	**0,020**	0,003	0,006	0,005	0,000			
P_{U6}	0,311	0,324	0,199	0,465	0,001	0,015	0,003	0,004	0,002	0,006	0,000		
P_{U7}	0,315	0,320	0,203	0,464	0,005	0,011	0,007	0,008	0,006	0,009	0,004	0,000	
P_{U8}	0,314	0,327	0,199	0,467	0,001	0,015	0,004	0,003	0,002	0,007	0,002	0,005	0,000
Result: $(\Delta u'v')_{max}$ = 0,020													

6.9 Chromaticity/colour gamut area

6.9.1 Purpose

This method estimates the span of colours the display is capable of producing in a darkroom by representing the colours in a CIE 1931 and 1976 chromaticity diagram. The colours are measured for a specified full screen, 4 % area box, or 10 % area box in the centre of the active area of a display. The standard full screen, 4 % and 10 % centre box pattern are specified in 6.2.

6.9.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a colour measuring device that can measure the CIE 1931 or 1976 chromaticity coordinates, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

6.9.3 Measuring method

The measurement shall be as follows:

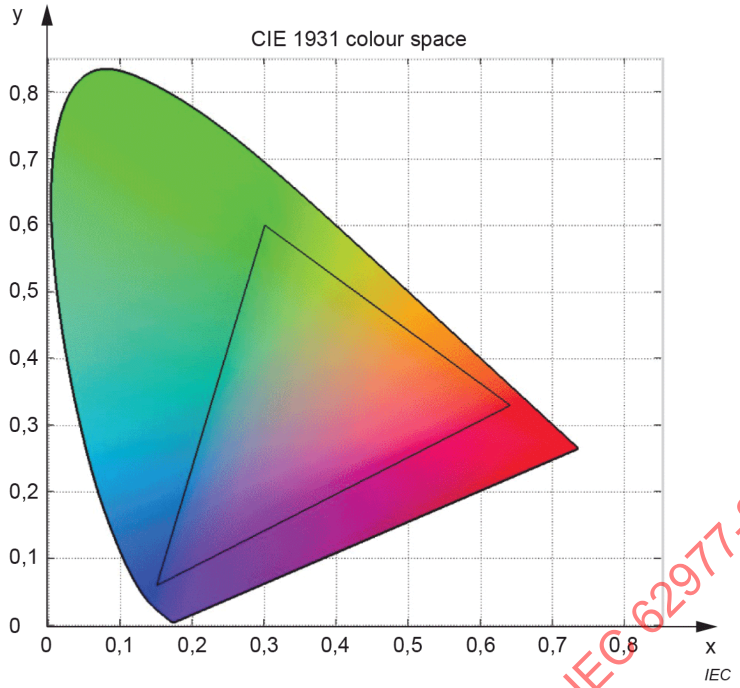
a) Follow the procedure in 6.6 for the specified test pattern to measure the CIE 1931 chromaticity coordinates (x, y) or CIE 1976 chromaticity coordinates (u', v') of the red primary in the centre of the screen with the digital input value as indicated in Table 4.

b) Repeat the chromaticity measurements for the green and blue primary colours as indicated in Table 4. The cyan, magenta, and yellow colours may also be measured if specified.

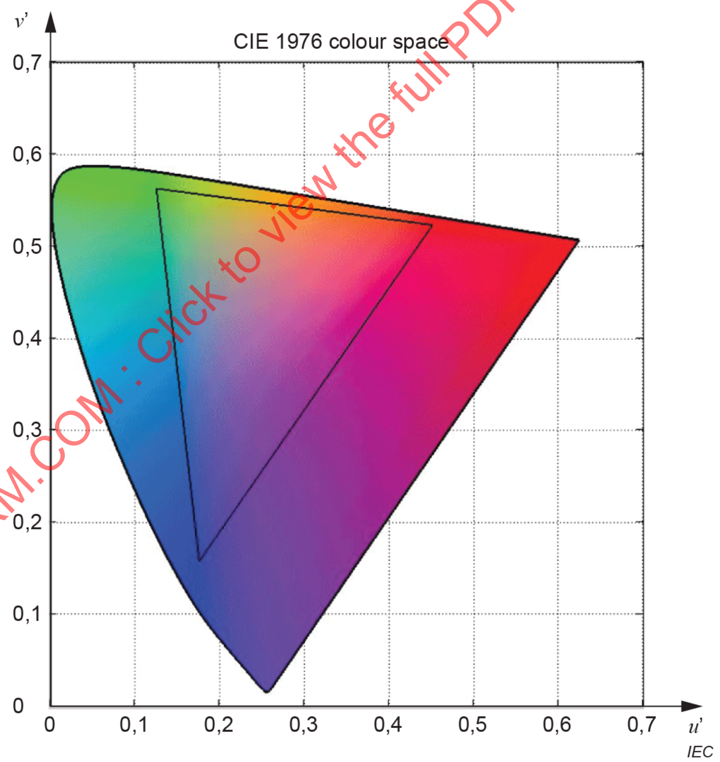
c) Report the CIE 1931 or CIE 1976 chromaticity coordinates for all the measured colours, graph the colours in a CIE 1931 or CIE 1976 chromaticity diagram (see Figure 6), and report the test pattern used and the display configuration.

Table 4 – Standard digital-equivalent input signals for rendering the white, primary and secondary colours in test patterns

Colour Q	Normalized digital signal level		
	Red input	Green input	Blue input
Red	1	0	0
Green	0	1	0
Blue	0	0	1
Yellow	1	1	0
Magenta	1	0	1
Cyan	0	1	1
White	1	1	1
Black	0	0	0



a) CIE 1931 chromaticity diagram



b) CIE 1976 UCS chromaticity diagram

Figure 6 – Examples of a display with colour boundaries represented by the black triangle in two common chromaticity diagrams

6.9.4 Chromaticity/colour gamut area in CIE 1931 and CIE 1976 chromaticity diagram

The chromaticity/colour gamut area is an approximation of a display's colour capability, which is more accurately quantified by the CIELAB colour gamut volume. The chromaticity/colour gamut area is expressed as the percent area enclosed by the measured colours relative to the entire spectrum locus in the CIE 1931 or CIE 1976 UCS chromaticity diagram. The CIE 1931 and 1976 gamut area metrics are applicable when the display is well-behaved (the signal primaries exhibit additive mixing) [5][8]. The gamut volume is needed when additive colour mixing cannot be assumed (such as when using 3D look-up tables or more than three unique temporal/spatial colour sub-pixels). The areal dimension in the $u'v'$ diagram is only perceptually uniform and valid when the luminance is constant. The gamut area in the CIE 1931 xy chromaticity diagram should be used since it is better correlated with the CIELAB colour gamut volume than the gamut area in the CIE 1976 $u'v'$ chromaticity diagram.

The chromaticity values measured at their maximum input signal level, as described in 6.9.3, shall be plotted in the CIE 1931 or CIE 1976 chromaticity diagrams (see Figure 6). The percentage of the area enclosed by the RGB triangle in the CIE 1931 chromaticity diagram relative to the entire spectrum locus is calculated as:

$$GA_{xy} = 149{,}6\left|\left(x_{\mathrm{R}} - x_{\mathrm{B}}\right)\left(y_{\mathrm{G}} - y_{\mathrm{B}}\right) - \left(x_{\mathrm{G}} - x_{\mathrm{B}}\right)\left(y_{\mathrm{R}} - y_{\mathrm{B}}\right)\right| \tag{9}$$

where the subscripts R, G and B refer to the red, green, and blue primaries, respectively. The CIE 1931 chromaticity/colour gamut area for the BT.2020 primaries (ITU Rec BT.2020) is 63 %. The CIE 1931 chromaticity/colour gamut area value for *sRGB* primaries specified by IEC 61966-2-1 would be 34 %. Report the measured chromaticity values for the *RGB* input colours, and the CIE 1931 chromaticity diagram gamut area.

Cyan, magenta, and yellow colours from Table 4 can also be included for the CIE 1931 chromaticity/colour gamut area calculation using the following formula:

$$GA_{xy} = 149{,}6 \times \left| \begin{aligned} &\left(x_{\mathrm{M}} - x_{\mathrm{B}}\right)\left(y_{\mathrm{M}} + y_{\mathrm{B}}\right) + \left(x_{\mathrm{B}} - x_{\mathrm{C}}\right)\left(y_{\mathrm{B}} + y_{\mathrm{C}}\right) \\ &+ \left(x_{\mathrm{C}} - x_{\mathrm{G}}\right)\left(y_{\mathrm{C}} + y_{\mathrm{G}}\right) + \left(x_{\mathrm{G}} - x_{\mathrm{Y}}\right)\left(y_{\mathrm{G}} + y_{\mathrm{Y}}\right) \\ &+ \left(x_{\mathrm{Y}} - x_{\mathrm{R}}\right)\left(y_{\mathrm{Y}} + y_{\mathrm{R}}\right) + \left(x_{\mathrm{R}} - x_{\mathrm{M}}\right)\left(y_{\mathrm{R}} + y_{\mathrm{M}}\right) \end{aligned} \right| \tag{10}$$

where the subscripts C, M and Y refer to the cyan, magenta, and yellow secondary colours, respectively.

The percentage of the area enclosed by the RGB triangle in the CIE 1976 chromaticity diagram relative to the entire spectrum locus is calculated as:

$$GA_{u'v'} = 256{,}1\left|\left(u'_{\mathrm{R}} - u'_{\mathrm{B}}\right)\left(v'_{\mathrm{G}} - v'_{\mathrm{B}}\right) - \left(u'_{\mathrm{G}} - u'_{\mathrm{B}}\right)\left(v'_{\mathrm{R}} - v'_{\mathrm{B}}\right)\right| \tag{11}$$

where the subscripts R, G and B refer to the red, green, and blue primaries, respectively. The CIE 1976 chromaticity/colour gamut area for the BT.2020 primaries (ITU Rec BT.2020) would be 57 %. The CIE 1976 chromaticity/colour gamut area value for *sRGB* primaries specified by IEC 61966-2-1 would be 33 %. Report the measured chromaticity values for the *RGB* input colours, and the CIE 1976 chromaticity diagram gamut area.

Cyan, magenta, and yellow colours from Table 4 can also be included for the CIE 1976 chromaticity/colour gamut area calculation using the following formula:

$$GA_{u'v'} = 256{,}1 \times \begin{vmatrix} (u'_{\mathrm{M}} - u'_{B})(v'_{\mathrm{M}} + v'_{\mathrm{B}}) + (u'_{\mathrm{B}} - u'_{\mathrm{C}})(v'_{\mathrm{B}} + v'_{\mathrm{C}}) \\ + (u'_{\mathrm{C}} - u'_{\mathrm{G}})(v'_{\mathrm{C}} + v'_{\mathrm{G}}) + (u'_{\mathrm{G}} - u'_{\mathrm{Y}})(v'_{\mathrm{G}} + v'_{\mathrm{Y}}) \\ + (u'_{\mathrm{Y}} - u'_{\mathrm{R}})(v'_{\mathrm{Y}} + v'_{\mathrm{R}}) + (u'_{\mathrm{R}} - u'_{\mathrm{M}})(v'_{\mathrm{R}} + v'_{\mathrm{M}}) \end{vmatrix} \quad (12)$$

where the subscripts C, M and Y refer to the cyan, magenta, and yellow secondary colours, respectively.

The number of measured colours used for the chromaticity/colour gamut area calculation shall be reported with the area value.

6.10 Luminance and colour variation with viewing direction

6.10.1 Purpose

The purpose of this method is to measure the variation in chromaticity and luminance of the display over a range of vertical and horizontal viewing directions. A specified full screen, 4 % area box, or 10 % area box of a defined colour Q will be measured in the centre of the active area of a display. The standard full screen, 4 % and 10 % centre box pattern are specified in 6.2. It is common to measure at least the white colour variation. Other colours and signal loading patterns are possible. The horizontal θ_{H} and vertical θ_{V} inclination angles shall be specified. Other azimuthal angles may also be specified.

6.10.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure luminance and CIE 1931 chromaticity coordinates, a driving power supply, driving signal equipment, and a means for rotating the LMD or display (see Figure 7 and Figure 8).

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

6.10.3 Measuring method

Measure the variation of the display's optical characteristics with the viewing direction using the following procedure for the display mounted in the vertical plane:

NOTE 1 A similar procedure can be used with the display mounted in the horizontal plane.

a) Render the specified full screen, 4 % area box, or 10 % area box test pattern with the specified colour Q (for example a white at a maximum grey level) in the centre of the screen and allow the luminance to stabilize within the specification of the LMD.

b) Align the optical axis of the LMD perpendicularly to the display screen and centred on the white box.

c) Measure the luminance and CIE 1931 chromaticity coordinates at $\theta_{\mathrm{H}} = \theta_{\mathrm{V}} = 0°$.

d) Rotate the display or LMD in the horizontal plane ($\phi = 0°$) at the specified angular increments (see Figure 7) and measure the luminance and CIE 1931 chromaticity coordinates at each specified horizontal inclination angle θ_{H}.

e) Rotate the display or LMD in the horizontal plane on the opposite side of the surface normal ($\phi = 180°$) at the specified angular increments (see Figure 7) and measure the luminance and CIE 1931 chromaticity coordinates at each specified horizontal inclination angle θ_H.

f) Rotate the display or LMD in the vertical plane (ϕ = 90°) at the specified angular increments (see Figure 8) and measure the luminance and CIE 1931 chromaticity coordinates at each specified horizontal inclination angle θ_V.

g) Rotate the display or LMD in the horizontal plane on the opposite side of the surface normal (ϕ = 270°) at the specified angular increments (see Figure 8) and measure the luminance and CIE 1931 chromaticity coordinates at each specified horizontal inclination angle θ_V.

h) Repeat chromaticity measurements at the same viewing directions for all specified colours to be measured using the full screen, 4 % area box, or 10 % area box test pattern with the specified colour in the centre. Additional azimuthal angles ϕ may also be measured and shall be included in the measurement report.

Report the setup conditions, the luminance and the CIE 1931 chromaticity coordinates at each of the measured inclination angles for all colours.

NOTE 2 It is noted that the measurement area will increase as the inverse of the cosine of the LMD inclination angle.

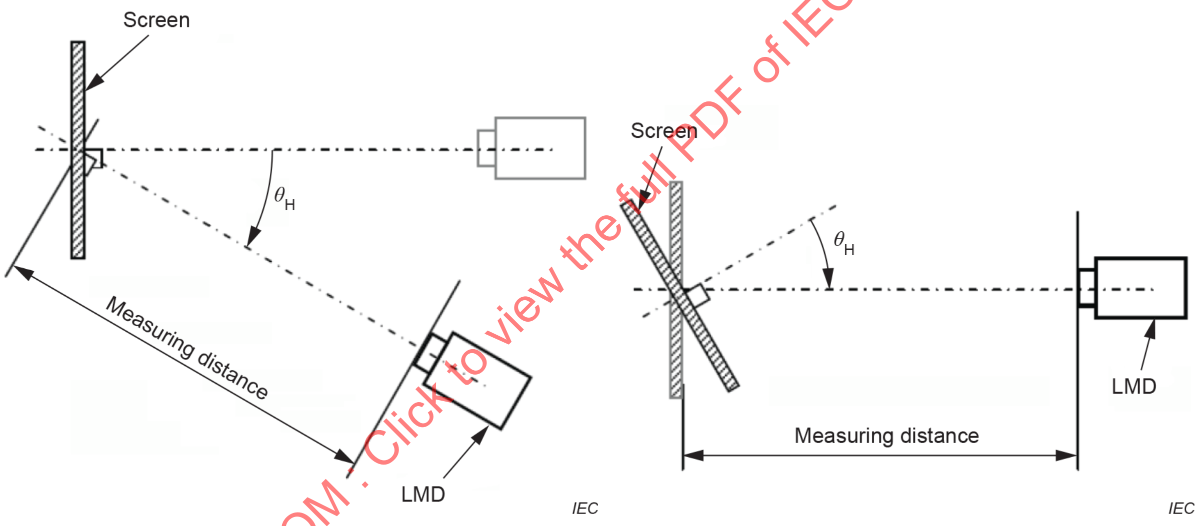


Figure 7 – Top view example of configurations for measuring luminance and colour in the horizontal viewing direction

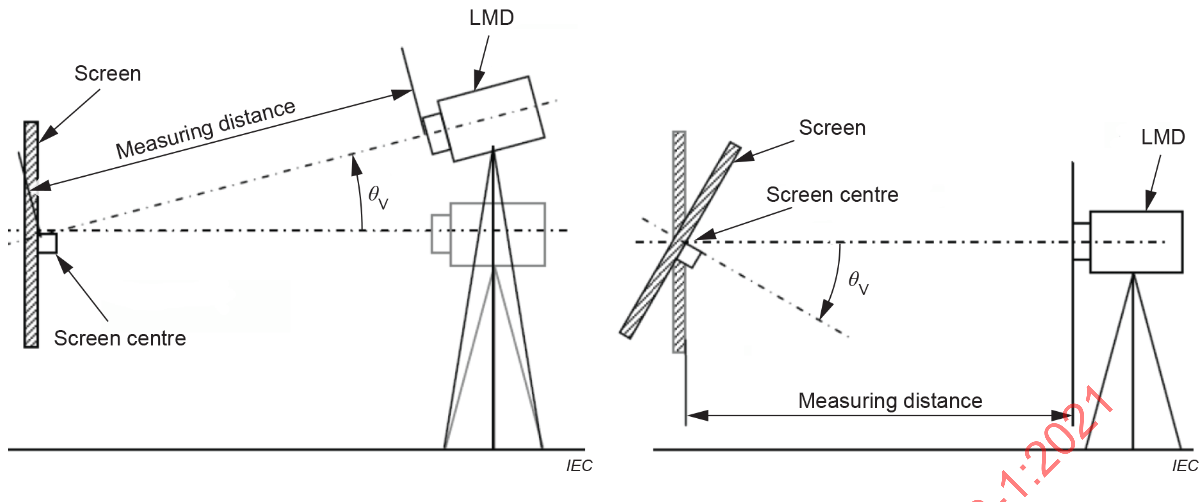


Figure 8 – Side view example of configurations for measuring luminance and colour in the vertical viewing direction

7 Display multi-colour optical measuring methods

7.1 General

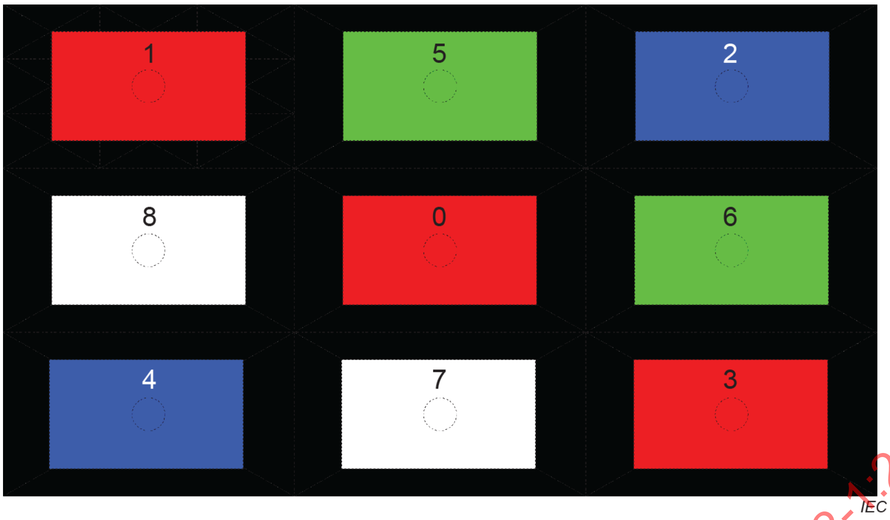
The purpose of Clause 7 is to describe the optical methods that shall be used to measure the display performance of prototypes and final display products (excluding display panels and modules). The measured results from these methods are used to communicate the display performance to customers.

For each measurement method, if the measured white luminance in the centre of the full screen or box test pattern used from Clause 6 is within 5 % from the centre colour-signal white (see Annex D) luminance $L_{\mathrm{CSW},0}$ data using the multi-colour test patterns (Figure 10), then the display test methods in Clause 6 can also be used for final display products. In addition, production line tests can use the basic test patterns in Clause 6 by correlating these test methods for a given product to the results obtained by using the equivalent test methods in Clause 7.

7.2 Test patterns

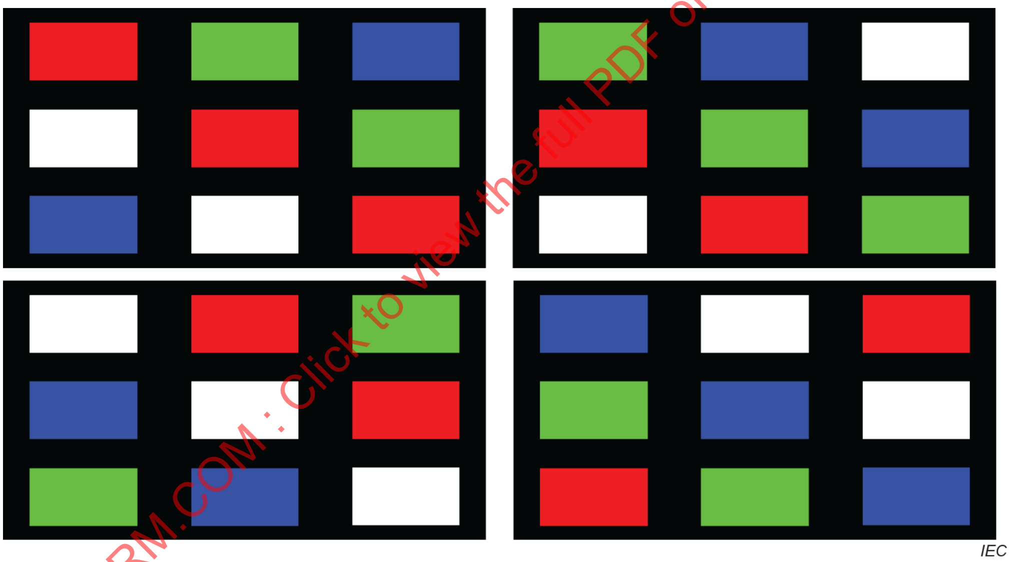
The principle of multi-colour test patterns described in IEC TR 62977-2-3 shall be used to better represent the performance for typical colour images. The multi-colour test pattern for luminance and colour measurements shall use the medium APL loading example of the colour tile test pattern illustrated in Figure 9. Coloured rectangular boxes, with 2/9 of the dimensions of the active area, are centred on the nine active area locations (see Figure 2) on a black background. The red, green, and blue boxes are driven at the maximum input signal levels for the primary RGB signal inputs. For example, the red box is driven at its maximum input signal for the red input, while the green and blue channels are at their minimum signal level. The white boxes are driven at their maximum signal red, green, and blue inputs.

In practice, many measurements in this document will need to measure a sequence of colour test patterns, as shown by the example in Figure 10. Each colour tile pattern is identified by the initials CT (colour tile) and the colour of the centre box. The patterns in Figure 10 are identified as CTR, CTG, CTB, and CTW when starting from the upper left-hand pattern and viewing each pattern in sequence in a clockwise direction. For example, CTB has a blue centre box, as shown in the lower right pattern. As the display renders each of the four test patterns in sequence, each of the nine standard measurement locations in Figure 2 contain all of the red, green, blue, and white colours to be measured.



The numbering and circles are only provided for descriptive purposes and should not be included in the actual pattern for measurements.

Figure 9 – Standard medium APL loading version of the colour tile test pattern with red, green, blue, and white boxes used for luminance and colour measurements



The CTR, CTG, CTB, and CTW patterns contain boxes of the same size but have red, green, blue, and white, respectively, in the centre box.

Figure 10 – Medium APL loading version of colour tile patterns illustrating the sequence of test patterns used for luminance and colour measurements

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

$$\mathrm{APL}(\%) = 100 \times \frac{\sum_{i=1}^{N} PL_i}{N} \tag{13}$$

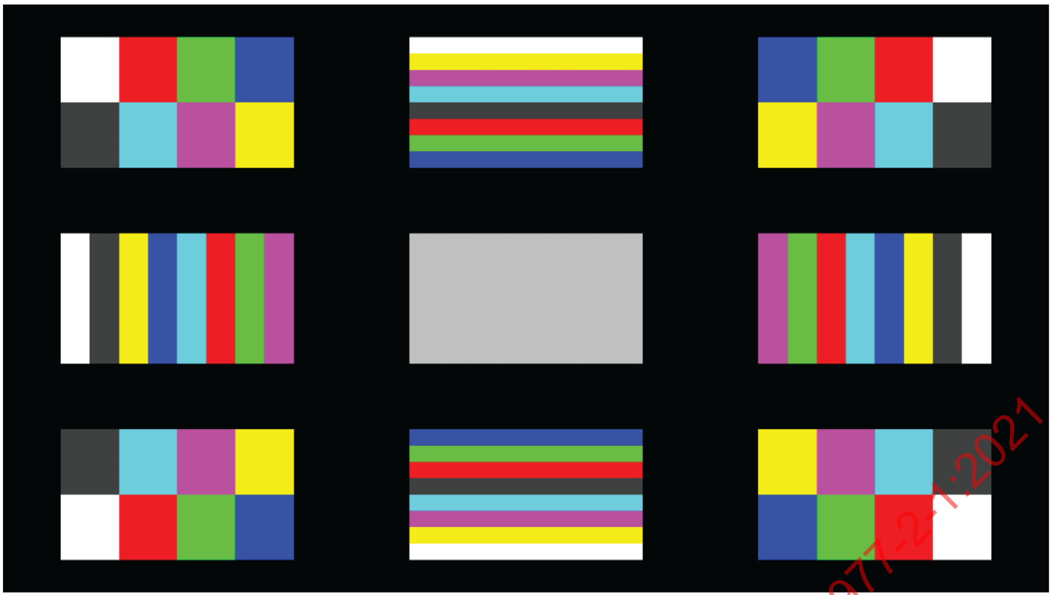
where the summation is over all pixels in the active area, PL_i is the normalized signal pixel level of the i-th pixel relative to the maximum white level, and N is the total number of pixels. A 100 % APL would be represented by all pixels in the active area at maximum white level. This would be implemented by setting the red, green, and blue inputs to their maximum values. A single primary colour (e.g. red) rendered on a full screen would have 1/3 of the APL of a full white screen. It is assumed that the red, green, and blue areas correspond to 1/3 of the APL of the white areas, so the APL for each pattern in Figure 10 is (starting at the upper left-hand corner and going clockwise) 21,4 %, 21,4 %, 21,4 %, and 24,7 %. The average APL for the four patterns in Figure 10 is 22,2 %. The slightly larger APL value for the centre white box pattern is 3,3 % larger than the other three patterns. An example of calculation of the top left pattern in Figure 10 is given by:

$$[(7 \text{ primary colours x } 1/3 \text{ of white}) + (2 \text{ white boxes x } 3 / 3 \text{ of white})]$$

$$\text{x } [(2/9)^2 \text{ fractional area of boxes}] = 21{,}4\ \%\ \text{APL}$$

In cases where more than the white and RGB input primary colours are needed for luminance and colour measurements, the medium APL loading RGBCMY box pattern illustrated in Figure 11 shall be used. This pattern is intended for centre luminance and colour measurements under constant APL loading. Each of the large coloured boxes in the test pattern are centred on the nine standard active area locations (see Figure 2) on a black background, with height and width corresponding to 2/9 of the dimensions of the active area. The centre rectangle is be changed to the desired colour to be measured. However, most of the colours in the surrounding eight rectangular patterns shall remain constant at their maximum input-referred signal setting as defined in Table 4. The small dark grey rectangles in the surrounding boxes are used to compensate for the APL change in the pattern (if needed) when the centre box colour is changed. The intent is to maintain the APL at approximately 25 % for all the centre colour measurements to eliminate any measurement influence due to APL loading. If the input RGB signal code values of the centre colour are (r, g, b), then the colour of the small grey rectangles in the surrounding boxes should be changed to (255 – r, 255 – g, 255 – b) when using 8-bit encoding. For the example shown in Figure 11, when the centre colour is set to an 8-bit signal value of (192, 192, 192), the small compensating rectangles are set to its complementary colour value of (63, 63, 63). When a more saturated colour is measured in the centre (such as cyan with (0, 200, 200)), then the small compensating rectangles would be set to its signal complementary colour value of (255, 55, 55). If the display is not sensitive to a few percent change in the APL value, then the small compensating rectangles can remain at black for all centre colours.

NOTE The small compensatory eight grey blocks will maintain the pre-gamma APL, but it may not maintain a constant luminance.



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

Figure 11 – Standard medium APL RGBCMY test pattern used for centre luminance and colour 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 (as illustrated in Figure 8 to Figure 11) shall be maintained.

7.3 Luminance

7.3.1 Purpose

The luminance measured from a display can be affected by the content being rendered. Therefore, the concept of APL loading described in IEC TR 62977-2-3 shall be used to control the impact of image content on the measurement. To estimate the luminance that a delivered display product would give for typical images, a medium APL multi-colour test pattern is used. The purpose of this method is to measure the individual and average luminance of white and the primary RGB colours in the active area of a display. The luminance is measured with the standard medium APL loading patterns (Figure 10) at the nine measurement locations (Figure 2). The colours are rendered at their maximum input command level. The luminance of additional colours beyond W, R, G, and B can be obtained by measuring only the centre box of the test pattern shown in Figure 11, using the desired colour in the centre.

7.3.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure luminance, a driving power supply, driving signal equipment, and a means to translate the LMD or display with respect to each other.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) Standard medium APL loading test patterns in Figure 10, and common measurement locations. The luminance shall be measured at the nine display locations for all four of the test patterns in sequence.

7.3.3 Measuring method

Measure the average luminance of white and RGB at their maximum drive input level over the active area using the following procedure:

a) Render the test pattern with the red box centred in measurement location P_0 (see Figure 2). Allow the luminance to stabilize within the specification of the LMD.

b) Align the optical axis of the LMD perpendicularly to the display screen and centred on the location P_0 in the centre of the display.

c) Measure the luminance L_0 at location P_0.

d) Translate the LMD (or display) to the other display locations (P_1 to P_8) and measure the luminance at each location.

e) Render the next colour tile pattern with a green centre box (CTG), and repeat steps b) to d) above.

f) Repeat luminance measurements at all nine display positions for all coloured tile patterns as illustrated in Figure 12 for a total of 36 measurements. The luminance values and summary data shall be recorded, as illustrated in Table 2.

g) Report the setup conditions, individual luminance values, and the average luminance $L_{W,ave}$, $L_{R,ave}$, $L_{G,ave}$, and $L_{B,ave}$, for white, red, green, and blue, respectively, in the test report. The luminance of colour-signal white, described in Annex D, can provide additional information about the brightness of typical colour images [11].

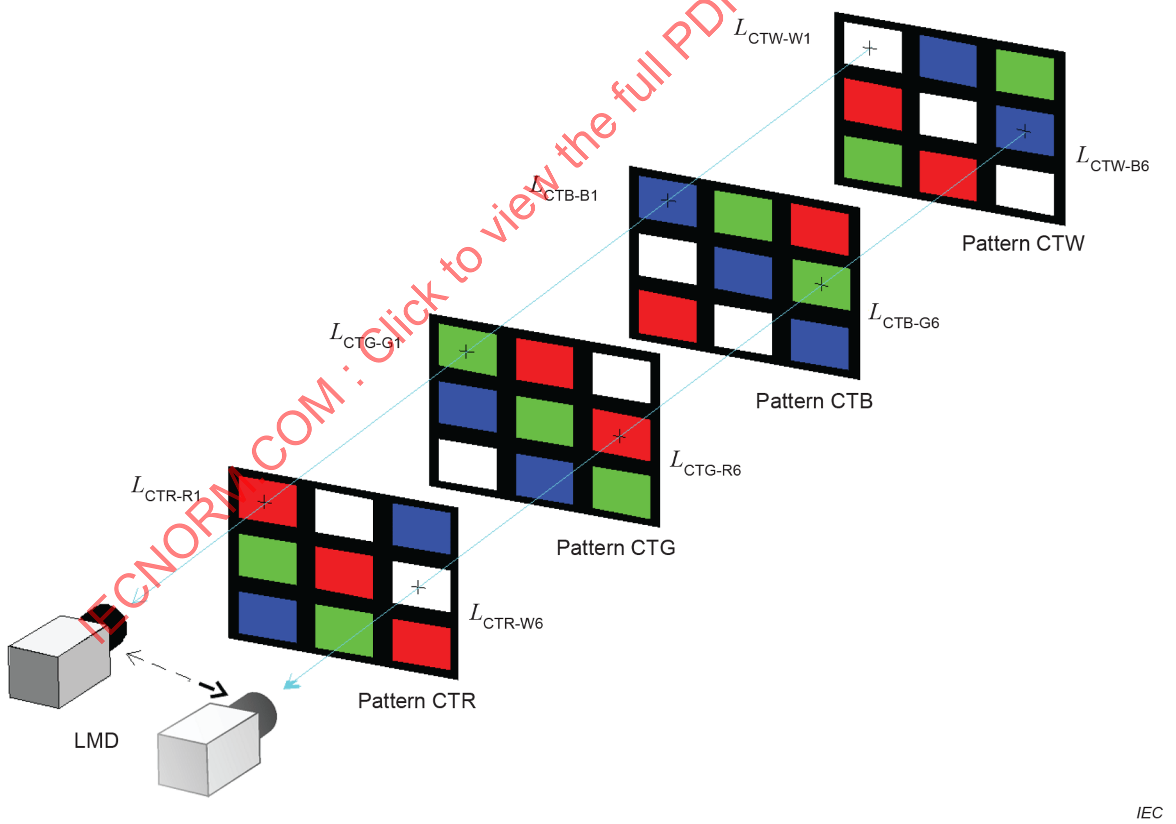


Figure 12 – Sequence for measuring luminance at the nine display locations for all coloured tile patterns

7.4 Darkroom contrast ratio

7.4.1 Purpose

The purpose of this method is to measure the darkroom contrast ratio in the centre of the display. The darkroom contrast ratio can be affected by the content being rendered. Therefore, to estimate the contrast ratio that a delivered display product would give for typical images, a medium APL RGBCMY test pattern (Figure 11) is used with a white and black centre box.

7.4.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure luminance, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) Standard medium APL RGBCMY test pattern (Figure 11) measured in the centre.

7.4.3 Measuring method

Measure the centre darkroom contrast ratio using the following procedure:

a) Measure the white luminance L_{W0} at the centre of the display with a centre white box (see Figure 11). The white box shall be rendered at the maximum grey level.

b) Render the colour test pattern following Figure 11 with a black centre box at the lowest grey level. Measure the black luminance L_{K0} at the centre of the active area (location $\mathrm{P_0}$). If the black luminance value is limited by the sensitivity of the LMD, it shall be reported as such.

c) Calculate the darkroom contrast ratio in the centre location ($\mathrm{P_0}$) using the following formula:

$$CR_{\mathrm{DR}} = \frac{L_{\mathrm{W0}}}{L_{\mathrm{K0}}} \qquad (14)$$

d) Report the setup conditions and test results in the test report.

For displays that can achieve deep blacks, the black luminance can be measurement instrument limited. The sensitivity limit of the LMD would be investigated and reported in that case.

7.5 Luminance uniformity

The spatially sampled luminance uniformity of a defined colour Q is defined in 6.5.

7.6 Chromaticity, tristimulus values, and spectra

7.6.1 Purpose

The purpose of this method is to measure the chromaticity or tristimulus values of a specified colour Q and spectral radiance (if required). The specified colour is input-referred, and colour is measured in the centre of the active area of a display. The colour is measured with the medium APL loading test pattern shown in Figure 11. This method applies to displays with RGB inputs.

7.6.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a colour measuring device that can measure the CIE 1931 chromaticity, tristimulus values, and spectra (if required), a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) Use the medium APL loading RGBCMY test pattern (see Figure 11).

7.6.3 Measuring method

Measure the specified colour at the centre of the active area using the following procedure:

a) Render the medium APL loading RGBCMY pattern (see Figure 11) with the specified colour Q at the centre of the active area and allow the luminance to stabilize within the specification of the LMD. The outer box colours are held constant at the values specified in Table 4.

b) Align the optical axis of the LMD perpendicular to the display screen and centre it on location P_0 (see Figure 2).

c) Measure the CIE 1931 chromaticity (x, y) or tristimulus values, and spectral radiance at the screen centre. If stray light is affecting the measurement of very dim colours, a frustum or stray light elimination tube shall be used (according to ISO 9241-305).

d) If other signal levels or colours are to be measured, render the desired signal level or colour in the centre box (while maintaining the colours for the outer boxes) and measure the centre chromaticity, tristimulus values, and spectral radiance (if required) using the same measurement procedure.

e) Report the setup conditions, CIE 1931 chromaticity coordinates (x, y) or tristimulus values, and spectral radiance (if required) in the test report.

7.7 White chromaticity and correlated colour temperature

7.7.1 Purpose

The purpose of this method is to measure the white chromaticity, and correlated colour temperature (CCT), at the maximum white input signal level in the centre of the active area of a display. The colour is measured with the standard medium APL loading RGBCMY pattern shown in Figure 11.

7.7.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a colour measuring device that can measure the CIE 1931 chromaticity coordinates for the CIE 1931 2° standard observer, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) Standard medium APL loading RGBCMY pattern (see Figure 11).

7.7.3 Measuring method

Measure the white luminance at the maximum drive level in the centre of the active area using the following procedure:

a) Render the standard medium APL RGBCMY pattern with the white box in the centre on the display and allow the luminance to stabilize within the specification of the LMD. The white box shall be rendered at the maximum grey level.

b) Align the optical axis of the LMD perpendicular to the display screen, and centred on location P_0 (see Figure 2) as well as on the white box.

c) Measure the white CIE 1931 chromaticity coordinates (x, y) at the centre of the white box. If the LMD also supplies the CCT value, report this value as well. If the LMD does not measure CCT, then the CCT shall be estimated using the methods specified in CIE 15.

d) Report the setup conditions and test results in the test report.

7.8 Chromaticity/colour gamut area

7.8.1 Purpose

The purpose of this method is to measure the colours produced by the individual RGB inputs in the centre of the display's active area, and to use these colours to approximate the display's colour rendering capability via the chromaticity diagram. The colours are measured with the standard medium APL loading RGBCMY test pattern shown in Figure 11. All colours are measured at their maximum signal levels. When $L_{\mathrm{W,ave}}$ is not within 5 % of L_{CSW} (Annex D), the colour capability is better represented by the colour gamut volume method in Clause 8.

7.8.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a colour measuring device that can measure the CIE 1931 or 1976 chromaticity coordinates, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) Standard medium APL loading RGBCMY test pattern (see Figure 11).

7.8.3 Measuring method

Measure the chromaticity/colour gamut at the centre of the active area using the following procedure:

a) Follow the test procedure in 7.6 using a red centre box for the test pattern in Figure 11 to measure the CIE 1931 chromaticity coordinates (x, y) or CIE 1976 chromaticity coordinates (u', v') at a maximum red input signal (see Table 4).

b) Repeat the chromaticity measurements for the green and blue primary colours as indicated in Table 4.

c) Report the CIE 1931 or CIE 1976 chromaticity coordinates for all the measured colours, graph the colours in a CIE 1931 or CIE 1976 chromaticity diagram (see Figure 6), and report the test pattern used and the display configuration.

7.8.4 Chromaticity/colour gamut area in CIE 1931 and CIE 1976 chromaticity diagram

The chromaticity/colour gamut area is an approximation of a display's colour capability, which is more accurately quantified by the CIELAB colour gamut volume. The chromaticity/colour gamut area is expressed as the percent area enclosed by the measured colour gamut relative to the entire spectrum locus in the CIE 1931 or CIE 1976 UCS chromaticity diagram. The CIE 1931 and 1976 gamut area metrics are applicable when the display is well-behaved (the signal primaries exhibit additive mixing) [5][8]. The gamut volume is needed when additive colour mixing cannot be assumed (such as when using 3D look-up tables or more than three unique temporal/spatial colour sub-pixels). The areal dimension in the $u'v'$ diagram is only perceptually uniform and valid when the luminance is constant. The chromaticity/colour gamut area in the CIE 1931 xy chromaticity diagram should be used since it is better correlated with the CIELAB colour gamut volume than the gamut area in the CIE 1976 $u'v'$ chromaticity diagram.

As described in 7.8.3, the colour gamut is defined by the chromaticity coordinates rendered when a maximum signal is sequentially applied to the RGB signal inputs. Figure 6 illustrates an example where the same RGB primaries are plotted in the CIE 1931 and CIE 1976 chromaticity diagrams. The percent of area $A_{u'v'}$ enclosed by the RGB triangle in the CIE 1976 chromaticity diagram relative to the entire spectrum locus is calculated using Formula (9). If it is desired to also include the cyan, magenta, and yellow colours from Table 4 for the CIE 1976 chromaticity/colour gamut area $A_{u'v'}$ calculation, Formula (10) can be used.

The percent of area A_{xy} enclosed by the RGB triangle in the CIE 1931 chromaticity diagram relative to the entire spectrum locus is calculated using Formula (11). If it is desired to also include the cyan, magenta, and yellow colours from Table 4 for the CIE 1931 chromaticity/colour gamut area A_{xy} calculation, Formula (12) can be used.

The number of measured colours used for the chromaticity/colour gamut area calculation shall be reported with the area value.

7.9 Chromaticity non-uniformity

The spatially sampled chromaticity non-uniformity of a defined colour Q is defined in 6.8.

7.10 Luminance and colour variation with viewing direction

7.10.1 Purpose

The purpose of this method is to measure the variation in chromaticity and luminance of the display over a range of vertical and horizontal viewing directions. In general, the display is measured in the centre using the medium APL loading RGBCMY test pattern in Figure 11 with a white box in the centre. Other colours and signal loading patterns are possible. The horizontal θ_H and vertical θ_V inclination angles shall be specified. Other azimuthal angles may also be specified.

7.10.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure luminance and CIE 1931 chromaticity coordinates, a driving power supply, driving signal equipment, and a means for rotating the LMD or display (see Figure 7 and Figure 8).

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

7.10.3 Measuring method

Measure the variation of the display's optical characteristics with the viewing direction using the following procedure for the display mounted in the vertical plane:

NOTE A similar procedure can be used with the display mounted in the horizontal plane.

a) Render the medium APL RGBCMY test pattern in Figure 11 with the white box at a maximum grey level in the centre of the screen and allow the luminance to stabilize within the specification of the LMD.

b) Align the optical axis of the LMD perpendicularly to the display screen and centred on the white box.

c) Measure the luminance and CIE 1931 chromaticity coordinates at $\theta_H = \theta_V = 0°$.

d) Rotate the display or LMD in the horizontal plane ($\phi = 0°$) at the specified angular increments (see Figure 7) and measure the luminance and CIE 1931 chromaticity coordinates at each specified horizontal inclination angle θ_H.

e) Rotate the display or LMD in the horizontal plane on the opposite side of the surface normal (ϕ = 180°) at the specified angular increments (see Figure 7) and measure the luminance and CIE 1931 chromaticity coordinates at each specified horizontal inclination angle θ_H.

f) Rotate the display or LMD in the vertical plane (ϕ = 90°) at the specified angular increments (see Figure 8) and measure the luminance and CIE 1931 chromaticity coordinates at each specified horizontal inclination angle θ_V.

g) Rotate the display or LMD in the horizontal plane on the opposite side of the surface normal (ϕ = 270°) at the specified angular increments (see Figure 8) and measure the luminance and CIE 1931 chromaticity coordinates at each specified horizontal inclination angle θ_V.

h) Repeat chromaticity measurements at the same viewing directions for all specified colour to be measured using the medium APL test pattern in Figure 11 with the specified colour in the centre. Additional azimuthal angles ϕ may also be measured and shall be included in the measurement report.

i) Report the setup conditions, the luminance and the CIE 1931 chromaticity coordinates at each of the measured inclination angles for all colours.

8 CIELAB colour gamut volume

8.1 Purpose

The purpose of this method is to measure the CIELAB colour gamut volume of a display in the centre of its active area to determine its perceived colour capability under darkroom conditions. The measured results from these methods are used to communicate the display performance to customers. The colours are measured with the standard medium APL loading RGBCMY test pattern shown in Figure 11, with the various specified colours interchanged in the centre box. In addition to the normal direction, the colour gamut volume may also be measured in other viewing directions. This method is not intended to be used for every display on the production line, but rather on a sampled basis to represent the colour capability of the delivered product. In order to determine the CIELAB colour gamut volume, CIE 168 recommends that the colour data be chromatically adapted to a common D50 white point. The standard Bradford chromatic adaptation transform (ISO 15076-1) is commonly used to convert the measured colours to the common D50 white point reference. For the purposes of metrology, it shall be 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 gamut volume is only one of many attributes of total display colour performance. The human visual system adapts to the brightness of the illuminant as all colours are ratios in a tristimulus system. To understand the volume of colour, the illuminant shall be defined.

CIELAB colour gamut 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. Manufacturers may specify which modes will match the behaviour of the SDR input signal. 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. The colour gamut rings method in Annex E describes a valuable visualization of the display colour capability. The gamut rings are a 2D area projection that is directly correlated to the gamut volume.

This method is limited to input signals with typical OETFs such as IEC 61966-2-1, ITU BT. Rec.601, ITU BT. Rec.709, and ITU BT. Rec.2020. This method is limited to SDR signal inputs.

8.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure the luminance and CIE 1931 chromaticity coordinates (or tristimulus values directly), a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) Standard medium APL loading RGBCMY test pattern (see Figure 11 and its explanation for the small compensating rectangles in 7.2).

8.3 Measuring method

An accurate representation of the display's colour range or size can be obtained by sampling the boundary colours of the display, and measuring the volume of the gamut in a perceptually uniform three-dimensional colour space. Colour volume combined with the location of the colour gamut (see Annex E) describes the full colour capability. CIE 168 recommends that the CIELAB colour space be used for this purpose. This method measures the colour gamut volume of the colour gamut boundary of a display under darkroom conditions. This colour gamut volume shall be determined using the following procedure:

a) The medium APL RGBCMY test pattern (Figure 11) shall be used to measure the desired centre box colours. The tristimulus, or luminance and chromaticity, shall be measured following the procedure in 7.6. If it can be demonstrated that a full screen or centre box pattern (see 6.2) gives a CIELAB colour gamut volume that agrees within 2 % of the value using the pattern in Figure 11, then the full screen and box pattern may be used for the same display product.

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 represent a 5 x 5 grid of equally spaced surface colours (tabulated in Annex A, Table A.1) can be used to calculate the CIELAB colour gamut volume and be reported as CIELAB Volume{98}. Depending on the complexity of the gamut surface, a more accurate result can be obtained by interpolating to 602 points from 98 by curve fitting. It is recommended to use a set of 602 colours (reported at CIELAB Volume{602}), representing a 11 x 11 grid of equally spaced surface colours (in Annex A, Table A.2), which is estimated to be within 2 % of the true volume. The CIELAB colour gamut volume shall be reported with the corresponding number of measured colours. Additional colours set depend on the required level of accuracy.

c) If the tristimulus values of the colours are not measured directly, they can be determined from the measured luminance and CIE 1931 chromaticity coordinates of each colour using Formulae (15) to (17):

$$X_{\mathrm{Q}} = \frac{x_{\mathrm{Q}} L_{\mathrm{Q}}}{y_{\mathrm{Q}}} \tag{15}$$

$$Y_{\mathrm{Q}} = L_{\mathrm{Q}} \tag{16}$$

$$Z_{\mathrm{Q}} = \frac{(1 - x_{\mathrm{Q}} - y_{\mathrm{Q}}) L_{\mathrm{Q}}}{y_{\mathrm{Q}}} \tag{17}$$

where L_Q is the luminance of the colour Q.

d) Once all of the colours are measured, 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 (see ISO 15076-1, using the Bradford coefficients in Annex B) is used to perform the transformation. To perform this transform, the measured tristimulus values (X_W, Y_W, Z_W) are obtained from the signal levels 255, 255, 255 (for 8-bit encoding), the source white point of the chromatic adaptation transform. All of the resulting colours are defined as (X_P, Y_P, Z_P). This method is consistent with the ICC colour management system.

It is theoretically possible to use tristimulus values that would produce large negative tristimulus values after chromatic adaptation. However, such measured values would be unlikely for real displays. In any case, if the values of (X_p/X_{D50}), (Y_p/Y_{D50}), or (Z_p/Z_{D50}) are more negative than $-(24 / 116)^3$, then the L*a*b* calculation will not be valid. The example code in Annex B traps this exception.

e) After chromatic adaptation, the tristimulus values are transformed into the three-dimensional CIELAB colour space (according to ISO/CIE 11664-4). The CIELAB L^*, a^*, and b^* values for each colour P are calculated from the transformed tristimulus values using the following formulae:

$$L^* = 116 \times f\left(Y_P / Y_{D50}\right) - 16 \quad (18)$$

$$a^* = 500 \times \left[f\left(X_P / X_{D50}\right) - f\left(Y_P / Y_{D50}\right) \right] \quad (19)$$

$$b^* = 200 \times \left[f\left(Y_P / Y_{D50}\right) - f\left(Z_P / Z_{D50}\right) \right] \quad (20)$$

where

$$f(t) = \begin{cases} t^{1/3} & t > (6/29)^3 \\ \left(\frac{841}{108}\right)t + \frac{4}{29} & \text{otherwise} \end{cases} \quad (21)$$

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 13.

g) Calculate the colour gamut volume corresponding to the possible range of 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 8 point method with interpolation (see for example IEC 62341-6-1).

h) Report the colour gamut volume with the number of boundary colours used (see the example in Table 5), the test pattern used, and the measurement conditions. The colour gamut volume of an ideal sRGB display with zero black level is 8,32 x 10^5 ΔE^3 (see the CIE 168 method using Bradford chromatic adaptation transforms). The recommended calculation method in Annex B, using an 11 x 11 equally-spaced grid of sampled colours, gives a value for sRGB of CIELAB Volume{602} = 8,31 x 10^5 ΔE^3.

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.

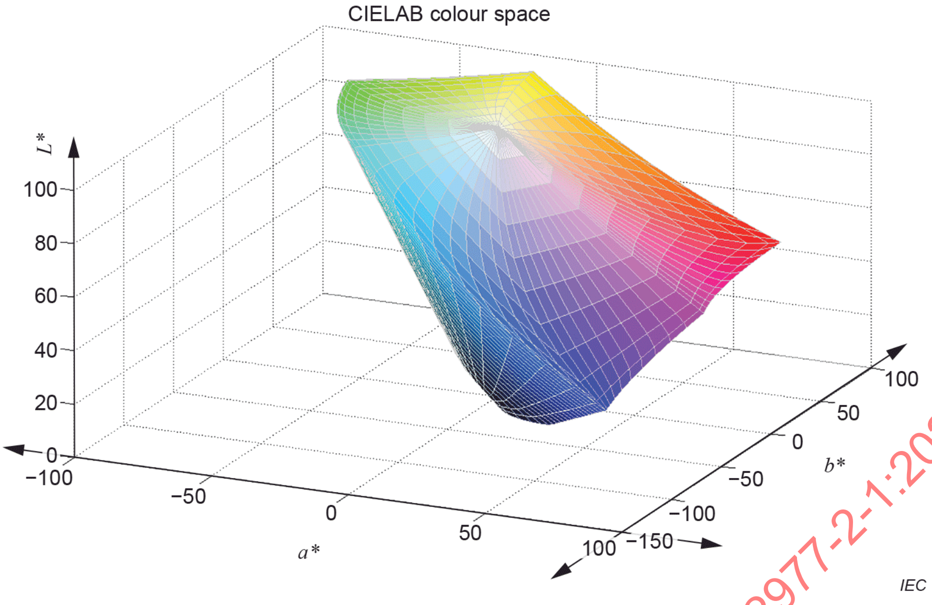


Figure 13 – Example of range in colours produced by a given display as represented by the CIELAB colour space

Table 5 – Example of report format for CIELAB gamut volume

Measurement parameter	CIELAB colour gamut volume (ΔE^3)
CIELAB gamut volume{602}	831 000

Annex A
(normative)

RGB boundary colours for CIELAB colour 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. For example, sRGB and Rec 709 would be completely compatible with this range. 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 x 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, Int[255 / 4], Int[255 / 2], Int[255 x (3 / 4)], and 255, where the Int[] function retains the truncated integer value. Colour coding with higher bit depths can also be done by using uniform spacing with the 5 x 5 grid of boundary colours. For example, equally spaced 12-bit code values are obtained using 0, Int[4 095 / 4], Int[4 095 / 2], Int[4 095 x (3 / 4)], and 4 095. An example CIELAB colour gamut volume calculation method is given in Annex B.

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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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		
	R	*G*	*B*
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		
	R	*G*	*B*
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 x 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 0, Int[255 / 10], Int[255 x (2 / 10)], Int[255 x (3 / 10)], Int[255 x (4 / 10)], Int[255 x (5 / 10)], Int[255 x (6 / 10)], Int[255 x (7 / 10)], Int[255 x (8 / 10)], Int[255 x (9 / 10)], and 255, where the Int[] function retains the truncated integer value. Colour coding with higher bit depths can also be done using uniform spacing with the 11 x 11 grid of boundary colours. An example CIELAB colour 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		
	R	*G*	*B*
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
97	0	204	204
98	0	204	229
99	0	204	255

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
143	51	0	255
144	76	0	0
145	76	0	25
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
440	25	255	229
441	25	255	255
442	51	255	25
443	51	255	51

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
487	153	255	153
488	153	255	178
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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
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

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 that adequately sample the entire range of colours that a display can produce for given setup conditions. Since the shape of the CIELAB colour gamut 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 colour gamut volume. 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.

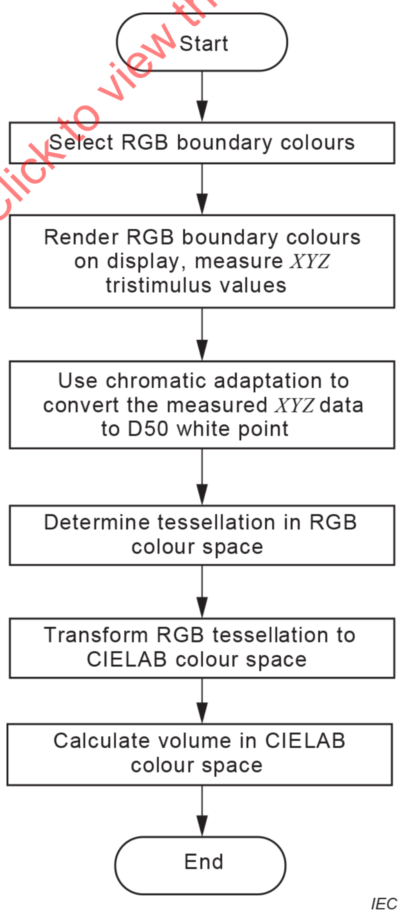


Figure B.1 – Analysis flow chart for calculating the CIELAB gamut volume

B.3 Number of sampled colours

The quality of the CIELAB colour gamut volume calculation will depend strongly on the number of sampled colours, and the complexity of the surface shape. An irregular-shaped CIELAB colour gamut volume 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 colour 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 8-point method with interpolation (see for example IEC 62341-6-1).

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

B.4.1 General

There are several possible algorithms that can be used to calculate the CIELAB colour gamut volume. One algorithm that is recommended is described in Clause B.4. This algorithm uses equally-spaced RGB colours on the surface of the cube in 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 2-argument arctangent math function spanning the range $-\pi \leq \text{atan2}(b^*,a^*) \leq \pi$, where a^* and b^* 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 angle (h^*).

The calculation algorithm is as follows:

a) The specified sampled colours and measured tristimulus values are read from a data text file in the CGAT,17 format. [9]

b) 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}):

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

where M_{adapt} is determined by:

$$\left[M_{\text{adapt}}\right]=\left[M_{\text{BFD}}\right]^{-1}\begin{bmatrix}\frac{\rho_{\text{P}}}{\rho} & 0 & 0\\ 0 & \frac{\gamma_{\text{P}}}{\gamma} & 0\\ 0 & 0 & \frac{\beta_{\text{P}}}{\beta}\end{bmatrix}\left[M_{\text{BFD}}\right] \tag{B.2}$$

with the Bradford matrix given by:

$$\left[M_{\text{BFD}}\right]=\begin{bmatrix}0{,}895\ 1 & 0{,}266\ 4 & -0{,}161\ 4\\ -0{,}750\ 2 & 1{,}713\ 5 & 0{,}036\ 7\\ 0{,}038\ 9 & -0{,}068\ 5 & 1{,}029\ 6\end{bmatrix} \tag{B.3}$$

and the cone response coefficients determined by:

$$\begin{bmatrix}\rho\\ \gamma\\ \beta\end{bmatrix}=\left[M_{\text{BFD}}\right]\begin{bmatrix}X_{\text{W}}\\ Y_{\text{W}}\\ Z_{\text{W}}\end{bmatrix} \tag{B.4}$$

$$\begin{bmatrix}\rho_{\text{P}}\\ \gamma_{\text{P}}\\ \beta_{\text{p}}\end{bmatrix}=\left[M_{\text{BFD}}\right]\begin{bmatrix}X_{\text{D50}}\\ Y_{\text{D50}}\\ Z_{\text{D50}}\end{bmatrix} \tag{B.5}$$

c) The D50 relative tristimulus data is then transformed into the CIE L*a*b* 1976 colour space following ISO/CIE 11664-4.

d) Tessellation in the RGB colour space:

   Each input signal sample value exists in a linear grid on the surface plane of each face of the RGB cube (see Figure B.2). The tessellation analysis however is assisted in this implementation by the uniform colour sampling of the RGB input signal colour space. This allows the proper tessellation ordering of the measured samples to be known. The tessellated triangles in the CIELAB colour space are identified through their correspondence to the input RGB code values. This eliminates any need for complex error-prone algorithms to determine the surface boundary and tessellate the result.

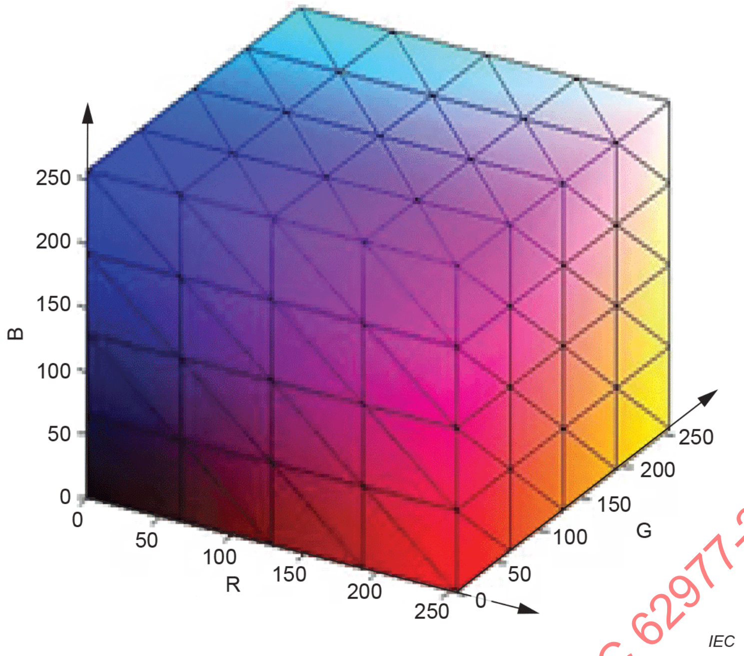


Figure B.2 – Example of tessellation using a 5 x 5 grid of surface colours on the RGB cube

e) Identify the corresponding tessellated triangles in the CIELAB colour space. Plot the CIELAB gamut.

f) For the gamut volume calculation, an intermediary form of the gamut is built by considering the cylindrical coordinates of lightness L^*, hue h^*, and chroma C^*. Determine a grid of vectors, uniformly spaced in lightness L^* and hue h^*, emanating from the L^* axis at constant L^* into the direction of h^*. The aim is to calculate the numerical integration of the volume in slices from L^* = 0 to L^* = 100 typically in steps of dL^* = 1. It is recommended to use at least 100 steps in L^* and 360 steps in h^*. To that end the vectors should be defined at the mid-points of these slices, so for dL^*=1 and L^*= 0,5, 1,5, 2,5, … 99,5.

g) For each vector, use the Möller–Trumbore ray-triangle intersection algorithm [10] to determine with which N surface triangles this vector will intersect and estimate the chroma $C^*(L^*, h^*, n)$ and orientation $d(L^*, h^*, n)$ (inward or outward facing) of each $n = 1 \ldots N$ intersection. Each vector can have 0 or more intersections.

h) The gamut volume contribution, $V(L^*, h^*)$, for each vector is computed by summing the volume contribution from each calculated intersection. Every intersection where the surface orientation is outward adds to the volume and every intersection where it is inward subtracts. For the case of no intersections, the contributed volume is 0.

i) The total numerically integrated gamut volume is calculated by summing all of $V(L^*, h^*)$.

This algorithm is implemented using the example Matlab[2] and Octave program below. The main program is called "Gamut_Volume_D50".

2 Matlab is the trade name of a product supplied by MathWorks®. Octave is free software licensed under the GNU General Public License.

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

B.4.4 Software example execution

This example uses a smaller number of measured colours to demonstrate how to run the program. In practice, measuring a small number of colours has the potential for larger errors.

A simple text file with a 3 x 3 grid of sampled coordinates on the RGB cube faces is used to demonstrate the execution of the Matlab program (see Table B.1). The text file is called "sRGB 3 x 3.txt", and can reside in the same folder as the main program. The main program "Gamut_Volume_D50" automatically imports the RGB data which defines the input colour, together with the corresponding measured *XYZ* tristimulus values.

Table B.1 – Example data format used for CIELAB colour gamut volume measurements

```
CGATS.17
FORMAT_VERSION 1.0

[ignore any additional header lines or lines after "end data"]

KEYWORD   SampleID
NUMBER_OF_FIELDS    7

BEGIN_DATA_FORMAT
SampleID  RGB_R     RGB_G     RGB_B     XYZ_X     XYZ_Y     XYZ_Z
END_DATA_FORMAT


BEGIN_DATA
1     0     0     0          0              0              0
2     0     0     128        0.047197412    0.018878965    0.248573037
3     0     0     255        0.1805         0.0722         0.950633333
4     0     128   0          0.093505787    0.187011574    0.031168596
5     0     128   128        0.140703199    0.205890539    0.279741632
6     0     128   255        0.274005787    0.259211574    0.981801929
7     0     255   0          0.3576         0.7152         0.1192
8     0     255   128        0.404797412    0.734078965    0.367773037
9     0     255   255        0.5381         0.7874         1.069833333
10    128   0     0          0.107812787    0.055590968    0.005053724
11    128   0     128        0.155010199    0.074469933    0.253626761
12    128   0     255        0.288312787    0.127790968    0.955687058
13    128   128   0          0.201318574    0.242602542    0.03622232
14    128   128   255        0.381818574    0.314802542    0.986855653
15    128   255   0          0.465412787    0.770790968    0.124253724
16    128   255   128        0.512610199    0.789669933    0.372826761
17    128   255   255        0.645912787    0.842990968    1.074887058
18    255   0     0          0.412315152    0.2126         0.019327273
19    255   0     128        0.459512564    0.231478965    0.267900309
20    255   0     255        0.592815152    0.2848         0.969960606
21    255   128   0          0.505820938    0.399611574    0.050495868
22    255   128   128        0.55301835     0.418490539    0.299068905
23    255   128   255        0.686320938    0.471811574    1.001129202
24    255   255   0          0.769915152    0.9278         0.138527273
25    255   255   128        0.817112564    0.946678965    0.387100309
26    255   255   255        0.950415152    1              1.089160606
END_DATA
```

During the execution of the program, the RGB data is tessellated (see Figure B.3).

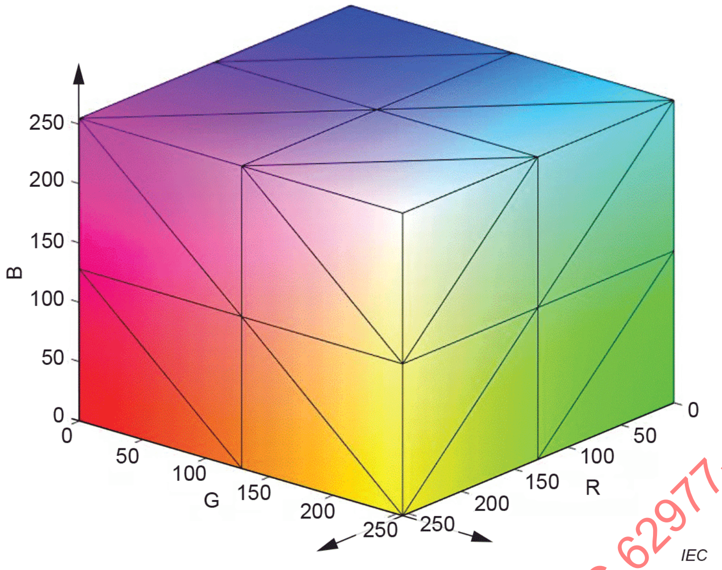


Figure B.3 – Example of tessellation for the RGB cube using a 3 x 3 grid

The transformation of the RGB cube tessellation into the CIELAB colour space for the tristimulus colours given in the data file is shown in Figure B.4.

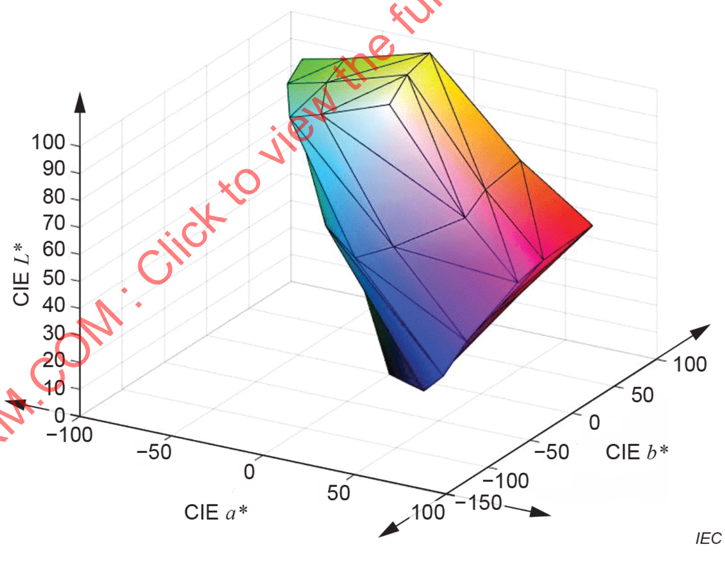


Figure B.4 – Example of tessellation for the CIELAB gamut volume using a 3 x 3 grid

The program results in the value 7,79 x 10^5 for the data given in the example of data shown in Table B.1.