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INTERNATIONAL STANDARD

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Laser displays –
Part 5-1: Measurement of optical performance for laser front projection

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC 62906-5-1 has been prepared by IEC technical committee 110: Electronic displays. It is an International Standard.

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

Draft	Report on voting
110/1351/FDIS	110/1367/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 62906 series, published under the general title *Laser displays*, can be found on the IEC website.

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under 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- withdrawn,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.

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LASER DISPLAYS –

Part 5-1: Measurement of optical performance for laser front projection

1 Scope

This part of IEC 62906 specifies the standard measurement conditions and measurement methods for front projection displays without screen which use lasers or laser hybrids as light sources. The hybrid light sources can use both lasers and spontaneous emission-based light sources. This document covers optical performance measurements for full-frame projection technologies such as digital micro-mirror devices (DMDs), liquid crystal on silicon (LCOS), and liquid crystal display (LCD) projectors. Other displays, such as raster-scanned (flying spot) projection displays, are not included.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content shall constitute 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 60825-1, *Safety of laser products – Part 1: Equipment classification and requirements*

IEC 61947-1:2002, *Electronic projection – Measurement and documentation of key performance criteria – Part 1: Fixed resolution projectors*

IEC 62471-5, *Photobiological safety of lamps and lamp systems- Part 5: Image projectors*

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

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

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

CIE 15, *Colorimetry*

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

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions 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

NOTE Most definitions and units are in accordance with the naming methods used in ISO 11145 and IEC 62906-1-2

3.1.1
chromaticity difference
geometric distance $\Delta u'v'$ between two colours in the CIE 1976 $u'v'$ chromaticity diagram

3.1.2
white light output (WLO) method
method that estimates total luminous flux measured from the average of nine points for a full white screen or for a sequence of white tiles that total the area of the full screen

3.1.3
colour-signal white (CSW) method
method that estimates total luminous flux from the sum of the input-referred red, green, and blue tile sequence

Note 1 to entry: The area of all colour tiles totals the area of the full screen.

3.2 Abbreviated terms

APL	average picture level
CAT	chromatic adaptation transform
CCT	correlated colour temperature
CGV	colour gamut volume
CIE	International Commission on Illumination
CIELAB	CIE 1976 (L*a*b*) colour space
CSW	colour signal white
CT	colour tile
DMD	digital micro-mirror device
DUT	device under test
EOTF	electro-optical transfer function
ISO	International Organization for Standardization
LCD	liquid crystal display
LCOS	liquid crystal on silicon
LDD	laser display device
LED	light emitting diode
LMD	light measuring device
RGB	red, green, blue
RGBCMY	red, green, blue, cyan, magenta, yellow
SDR	standard dynamic range
sRGB	standard RGB colour space as defined in IEC 61966-2-1
WLO	white light output

4 Standard measuring conditions

4.1 General

Unless stated otherwise, the following standard measuring conditions shall be used. When carrying out optical measurements of the laser projector, the measuring environment, equipment, and methods shall comply with IEC 60825-1 and IEC 62471-5 for human safety.

4.2 Standard measuring environmental conditions

All the tests and measurements shall be made under the following standard environmental conditions:

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

If other conditions are used, they shall be noted in the report.

NOTE For temperature sensitive cases, 25 °C ± 2 °C is used.

4.3 Standard dark room conditions

The laser projectors are intended to be measured under dark room conditions. The illuminance contribution from unwanted background illumination shall be less than 1 / 20 of the projector's lowest illuminance in a given test pattern. The room background illuminance can be estimated by using a projection mask (see section 15.1.4 in [1][1]). For the determination of the colorimetric values, the background tri-stimuli shall be applied.

When it is not possible to achieve the background illuminance conditions, then background subtraction by using the projection mask for the same test pattern shall be used in the measurement. If the luminance measurement with a reflectance standard is applied to determine the illuminance, the dimension of the projection mask has to take into account the measurement area of the reflectance standard instead of the measurement area of the illuminance meter.

In the case of direct illuminance measurement, a stray light elimination tube (see section 15.1.5 in [1]) can be used with the illuminance meters to minimize the contribution of the background illumination. A stray light elimination tube is required if for a given test pattern, the background illuminance measured with a projection mask is more than 67 % of the illuminance measured on the same location in the test pattern without the projection mask.

It should be noted that the reflections from the mask, projector shell, LMD and their frames in the front of the detection area can produce significant background illuminance, especially in the case of a luminance measurement. It is recommended to absorb the direct projection beam by applying light traps behind the virtual screen. Blackout curtains and black room surface (such as walls, ceiling, floor, etc.) with a reflectance less than 3 % are valuable for reducing the background illumination.

4.4 Standard conditions of measuring equipment

Standard equipment conditions are described in 4.5. Any deviations from these conditions shall be noted in the report.

Measurements shall be started after the laser projector, the light source, and measuring instruments achieve stability. The illuminance originating from the projector shall not vary by more than ±2 % over the entire measurement duration.

1 Numbers in square brackets refer to the Bibliography.

4.5 Conditions of measuring equipment

4.5.1 General conditions

The measuring equipment shall be as follows:

a) The laser projector is to be characterized by focusing a test pattern on a projected image plane at a defined distance from the projector. This image plane is the location where a projection screen would be placed. The image plane for projector measurements shall be set up in accordance with the angle, height, and distance specified in the manufacturer's set-up instructions (Figure 1). The projector's optical axis shall lie in the vertical plane perpendicular to the image plane and intersect the centre of the screen. The measurement configuration shall be reported.

b) Unless stated otherwise, the measurement area of the LMD shall be at the centre of the image area to be measured.

c) The measurement area at the image plane shall be at least 1 cm in diameter and contain at least 10 pixels × 10 pixels. It shall be confirmed that this number of pixels is sufficient by shifting the LMD over a lateral distance of 20 % of the measurement area diameter and by verifying that the illuminance changes by less than 2 % and the colour by less than 0,003 in (x, y) chromaticity values, for a full white screen as test pattern. A large enough measurement area is needed to average out speckle-induced non-uniformity.

d) Illuminance shall be determined by using direct illuminance measurement with an illuminance (or spectral irradiance) meter with a cosine-corrected transmission diffuser or an integrating sphere as LMD (Figure 1a), or the measurement be made using a reflectance standard and a luminance (or spectral radiance) meter as LMD (Figure 1b). The optical properties of these devices are generally dependent on the inclination angle of the light. The measurements shall compensate for any light incidence angle dependence of these items. This is especially important for short-focus (short-throw) projectors where the inclination angle can be large. In that case, the integrating sphere with a thin edge at the entrance port is preferred. Both the integrating sphere and reflectance standard method can be used but they will need to be calibrated for the illumination inclination angle used in the measurement. The image plane can be established through use of a virtual screen where the image is focused in the x–y coordinate plane. The virtual screen can be set up with the LMD (Figure 1a) or reflectance standard (Figure 1b). The front surface of the diffuser or reflectance standard, or the entrance port of the integrating sphere should be placed at the projector image plane. The measurement area shall lie within the plane of this virtual screen. The screen can be constructed with a black frame, with millimetre grids placed at the corners of the frame. The frame shall be sufficiently large so that the specified image area is contained within the four corner grids. The spacing between the corner grids shall be calibrated to an accuracy of ±0,2 % of the minimum vertical or horizontal dimension of the projected image. The millimetre grids need to be covered with matte black materials to avoid causing stray light when performing sensitive dark level measurements.

e) Spectrally integrated light measurements shall be measured in terms of calibrated photometric or colorimetric units traceable to a recognized national metrology institute, illuminance for an illuminance meter, or CIE 1931 tristimulus values (X, Y, Z) and chromaticity coordinates (x, y) for a colorimeter.

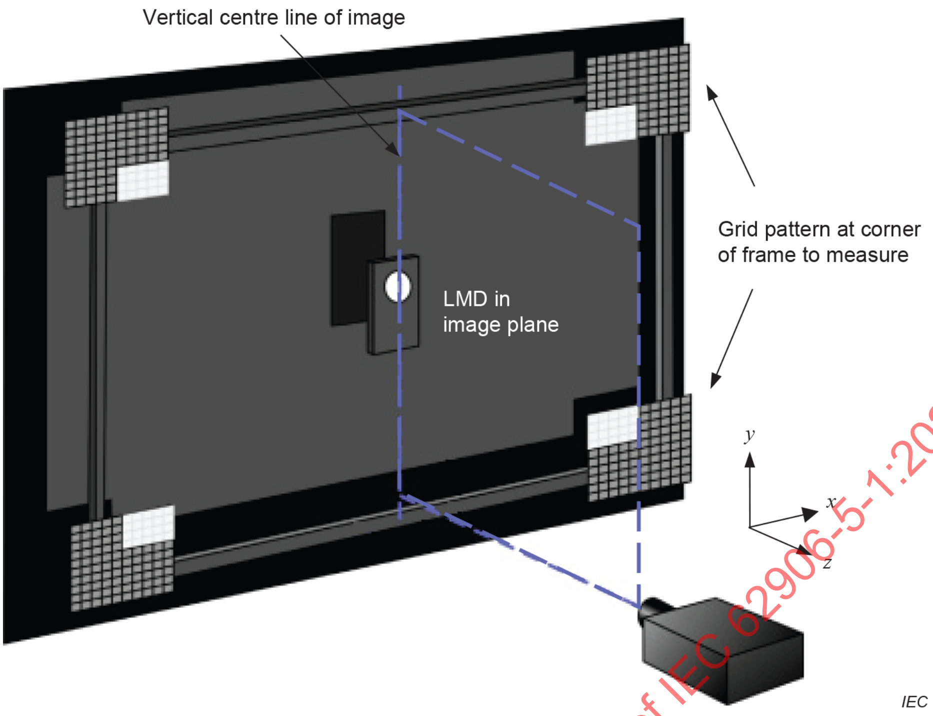
f) Photometric and colorimetric data shall be calculated for a CIE 2° standard colorimetric observer, as specified in CIE 15.

g) The light measuring device (LMD) shall have enough sensitivity and dynamic range to perform the required task. The measured LMD signal in the lowest illuminance measurement shall be at least ten times greater than the dark level (noise floor) of the LMD, and no greater than 85 % of the saturation level in the highest illuminance measurement. The LMDs are especially prone to saturation with laser sources, and calibrated neutral density filters are generally applied. Detector saturation can be diagnosed by using a calibrated neutral density filter in front of the projector.

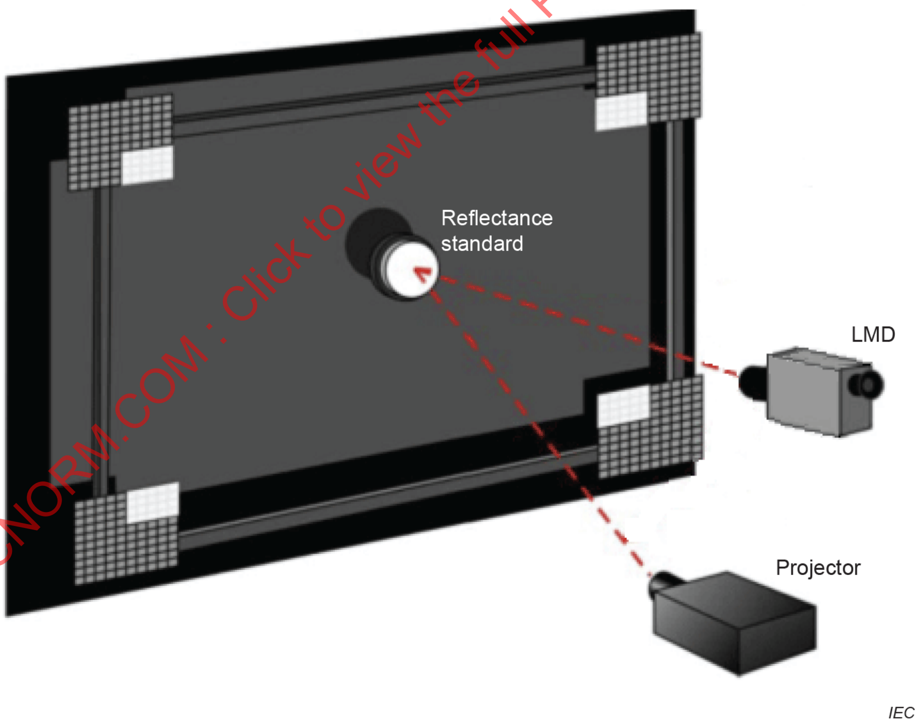
h) If the laser projector light is polarized, the polarization dependence of the LMD shall be less than 1 %.

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

j) If temporal synchronization with the projector or video source is possible, the LMD shall be synchronized with the frame synchronization signal, and the LMD integration time shall be an integer number of frame periods. If synchronization is not possible, the LMD integration time shall be larger than two hundred frame periods.



a) Virtual screen setup with the illuminance LMD



b) Virtual screen setup with the reflectance standard and luminance meter

Figure 1 – Virtual screen setup with (a) the illuminance LMD or (b) reflectance standard placed at the projector image plane for standard measurements

4.5.2 Measurement coordinate system

The measurement angular positioning is referred to by the coordinate system illustrated in Figure 2. The projected image is focused on the x-y plane of the coordinate system. The projector's optical axis can be described by two angles. The inclination angle θ increases relative to the surface normal of the image plane (z-axis). The angle of rotation, or azimuthal angle ϕ, increases from the x-axis in the x-y plane. This corresponds to the counter clockwise rotation of a clock dial, where ϕ = 0° when the dial is at 3 o'clock and ϕ = 90° when the dial is at 12 o'clock.

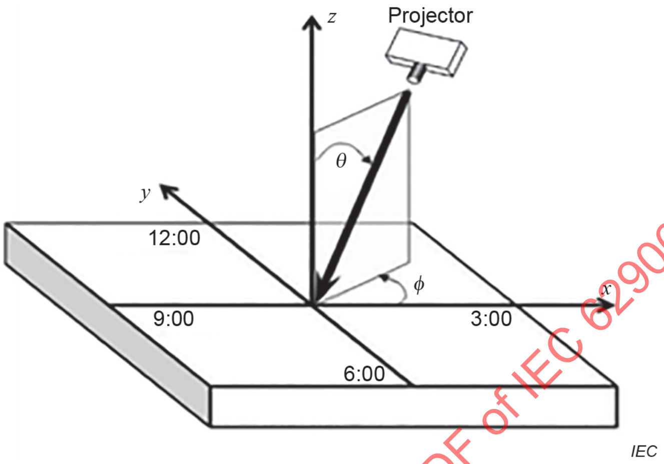


Figure 2 – Polar coordinate system used to describe the inclination and azimuthal angle of the projector

4.5.3 Diffuse reflectance standard

The illuminance or spectral irradiance can be measured directly, or by measuring the luminance or spectral radiance from a diffuse reflectance standard placed at the desired location in the image plane. Diffuse reflectance standards can be obtained with a diffuse reflectance of 98 % or more. A luminance L_{std} measurement from a spectrally flat diffuse reflectance standard can be used to determine the illuminance E,

$$E = \frac{\pi L_{std}}{R_{std}} \tag{1}$$

where

R_{std} is the calibrated luminous reflectance factor for that measurement configuration. The calibration of R_{std} shall be traceable to a national metrology institute.

The spectral irradiance $E(\lambda)$ can follow the same form as Formula (1), where L_{std} then denotes the spectral radiance $L_{std}(\lambda)$ and where R_{std} denotes the calibrated spectral reflectance factor $R_{std}(\lambda)$, which will have to be known and available in the visible wavelength range.

The white reflectance standard shall be calibrated for the same illumination and detection geometry as will be used in the measurement.

The LMD is generally positioned normal to the surface of the reflectance standard. If the projector placement interferes with this LMD position, then the LMD can be inclined away from the projector, but it shall still be aligned as close as possible to the normal axis of the reflectance standard. The value of R_{std} (or $R_{std}(\lambda)$) under this inclination angle shall not change more than 0,2 % from its value at normal incidence. If the variation is unacceptable, the correction factor shall be applied in this condition.

NOTE A white reflectance standard that is calibrated for spectral reflectance is preferred. If the white reflectance standard is calibrated for its photometric properties (i.e. luminous reflectance factor), then the white reflectance standard will only give valid results for light sources with the same relative spectral distribution that was used in the calibration.

4.5.4 Illuminance meter

Filtered illuminance meters are generally considered not to be accurate enough for laser projector measurements and are not recommended. Spectral measurement instruments are preferred for these narrow bandwidth light sources. If the filtered illuminance meter does not meet the required accuracy, it shall be calibrated with a spectral irradiance meter. However, it is noted that this calibration is valid only for a given spectral distribution of the light source (e.g. red, green, blue primaries, in addition to white and black), and the illuminance meter will need a unique calibration factor for every different spectral distribution. Several methods for performing a relative calibration of the illuminance meter are available in the literature [3], [4]. Many illuminance meters employ diffusers as a means to capture the incident illumination. These tend to also be valuable in scrambling projector polarization and smoothing speckle non-uniformity. If a light scrambling element (like a diffuser) is not employed in the illuminance meter, then its insensitivity to polarization and speckle shall be confirmed with a spectral irradiance meter that uses a diffusing element.

4.5.5 Colorimeter

Filtered colorimeters are generally not accurate enough for laser projector measurements, and are not recommended. Spectral measurement instruments are preferred for these light sources. If the filtered colorimeter does not meet the required accuracy, it shall be calibrated with a spectral irradiance meter. However, it is noted that this calibration is valid only for a given spectral distribution of the light source (e.g. red, green, blue primaries, in addition to white and black). Each of these spectral distributions will require its own unique calibration factor. Several methods for performing a relative calibration of the colorimeter are available in the literature [3], [4]. The colorimeter shall be insensitive to polarization and speckle non-uniformity. If a scrambling element (like a diffuser) is not employed in the colorimeter, then its insensitivity to polarization and speckle shall be confirmed with a spectral irradiance meter or spectroradiometer that uses a diffusing element.

4.5.6 Signal source of test patterns

If a digital video interface is available, it shall be used to display the test patterns. A video generator that uses the native resolution of the projector is recommended. If a computer's digital video output can also produce the same displayed images, it may also be used for displaying the required test patterns. If only an analogue video input is available on the projector, a pattern generator shall be used. The characteristics of this pattern generator are described in IEC 61947-1:2002, Annex B.

4.5.7 Integrating sphere

An integrating sphere can be used in conjunction with an LMD to measure illuminance and spectral irradiance. When using integrating spheres, the following guidelines shall be followed:

a) The sphere structure shall be designed with baffles to avoid direct light incident onto the LMD.

b) The inner surface of the integrating sphere shall be a white diffuse reflecting material with a spectral reflectance of > 90 % from 380 nm to 780 nm.

c) The light produced by the projector shall not cause the material in the integrating sphere to fluoresce.

d) When measuring light at large inclination angles (e.g. short-throw projectors), the integrating sphere shall have a thin edge at the entrance port.

4.5.8 Spectral radiance/irradiance meters

The narrow spectral line widths of the projector laser sources usually require the use of a spectroradiometer with relatively small spectral bandwidths for accurate results. It is recommended to use a spectral stray light correction, such as in [23]). A spectroradiometer can be configured with an integrating sphere or cosine-corrected diffuser to measure the spectral irradiance of the projector directly. The following requirements are given for these instruments:

a) The spectroradiometer wavelength accuracy shall be within ±0,5 nm. The wavelength measuring range shall be at least 380 nm to 780 nm.

b) It is recommended to use a spectroradiometer with a spectral bandwidth of ≤ 5 nm (full-width-at-half-maximum).

c) The CIE 1931 x and y chromaticity accuracy shall be less than ±0,001 5 for a CIE Illuminant A light source. The illuminance or luminance accuracy shall be less than ±2% for a CIE Illuminant A light source.

d) The CIE 1931 x and y chromaticity repeatability shall be less than ±0,000 5 for a CIE Illuminant A light source. The illuminance or luminance repeatability shall be less than ±0,5 % for a CIE Illuminant A light source.

An alternative method of spectral irradiance can be implemented by using a spectral radiance meter with a diffuse reflectance standard.

If measurements are taken at large incident angles, such as in the case of short-focus projectors, it is recommended to use the spectral radiance meter with a reflectance standard or integrating sphere with a thin edge at the entrance port. The reflectance standard shall be corrected for the large inclination angle dependence.

5 Adjustment of the laser projector

5.1 Projector and image plane placement

The amount of flux exiting the lens of the projector can be affected by the focus and zoom of the projector lens. The zoom and preferred image size will dictate an optimum distance from the projector to the image plane where the flux is the greatest. The manufacturer shall specify the projector angle, height, zoom, image size and optimum distance. A lens-shift projector shall be positioned at its optimum optical path as specified by the manufacturer. If the manufacturer does not define the optimum setup, the projector zoom shall be set to the wide-angle position (largest angle, lowest throw ratio). The projector shall project an image at its native aspect ratio. The projector and image plane (virtual screen) configuration shall be documented in the report.

5.2 Focusing of the projector

A factory-provided alignment pattern, or a pattern as shown in Figure 3, can be used to focus the projector at the optimal projection distance. The projector focus shall be adjusted until the centre and edge features of the projected image at the image plane are the sharpest.

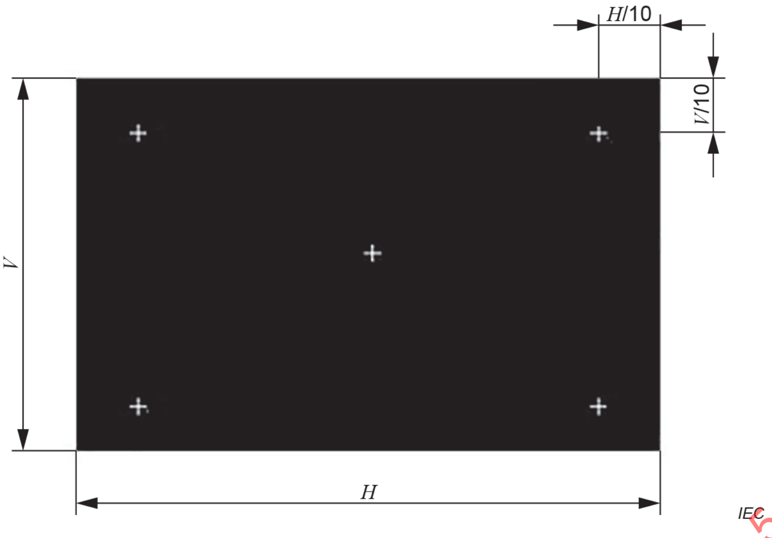


Figure 3 – Example image pattern with width H and height V used to focus the projector

5.3 Standard projector setup conditions

The projector settings shall be configured the same for all tests. Any pre-sets (such as viewing mode, iris or dynamic power control turned on/off) shall be reported, and any deviations from the factory default settings shall be reported. The projector shall be positioned and focused at the standard configuration (see 4.5.1). If the projector has a variable aperture (iris) or dynamic power control that is turned on, then it shall remain on for all tests. If the standard placement, settings, or configuration are not used, those details shall be reported.

The projector shall be operated with all covers in place, as in normal operation. The digital signal levels shall be specified in terms of the RGB component input channels.

5.4 Standard image measurement locations

Unless otherwise specified, all projector measurements shall be taken in the defined image plane at the locations indicated in Figure 4. The common measurement locations are identified by locations P_1 to P_9 in the active area, as illustrated in Figure 4. Locations P_{10} to P_{13} may be included for uniformity measurements when more information is desired in the corners. 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 4. 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_5. Any deviation from the above coordinate system shall be reported.

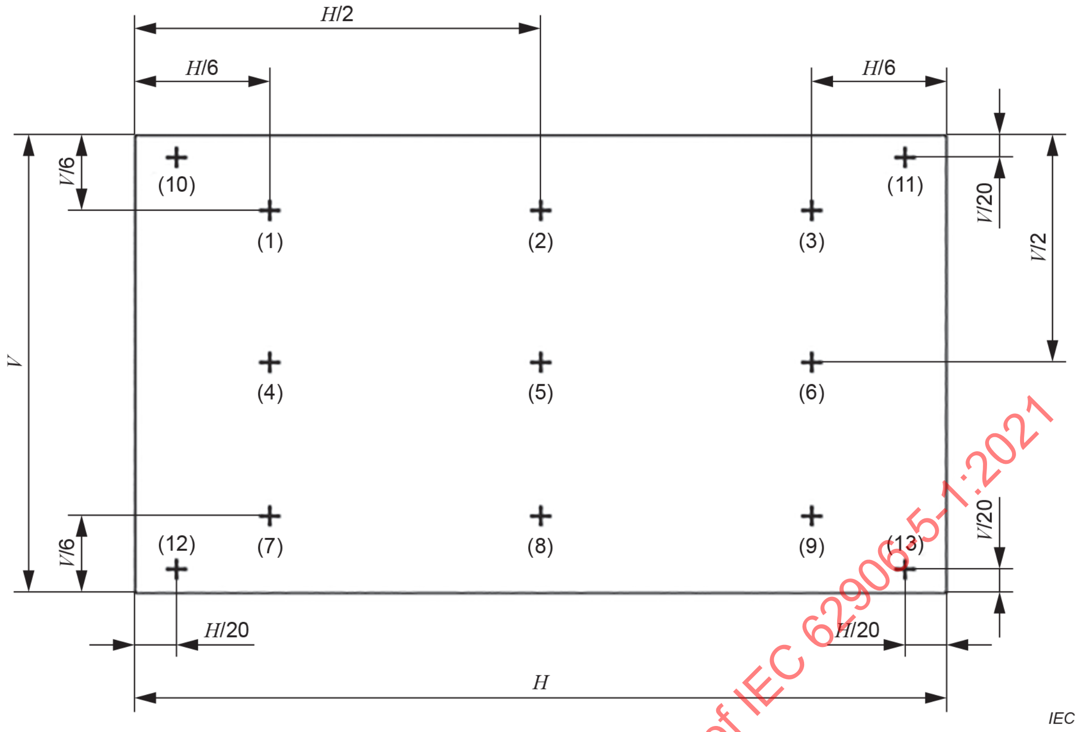


Figure 4 – Standard measuring locations on the projected image

5.5 Colour tile patterns

Prior research has demonstrated that some laser projector performance characteristics can be influenced by the test pattern used in the measurement as demonstrated in IEC TR 62977-2-3. Therefore, the following colour tile patterns shall be used to minimize this variation and provide realistic performance characteristics. These colour tile patterns are illustrated in Figure 5. Each pattern is identified as a colour tile (CT) with a given primary colour or white colour in the centre. For example, the CTB pattern is a colour tile with the maximum blue primary colour in the centre box. All colours in the colour pattern represent input-referred maximum white or maximum RGB primary colours. Therefore, a maximum blue colour would have an equivalent 8-bit digital (R,G,B) input value of (0, 0, 255), a maximum green would be (0, 255, 0), a maximum red would be (255, 0, 0), and a maximum white would be (255, 255, 255). An individual colour within a test pattern is identified by the pattern name, the colour of the box, and the centre position of the box as defined in 5.4. For example, the illuminance measured in the red centre box for pattern CTR would have the notation $E_{\text{CTR,R5}}$.

In some measurement methods, the colour tile patterns are rendered in sequence (as illustrated in Figure 5), and the measured colour for a given pattern and location is evaluated in conjunction with the other colours in the same location on other patterns.

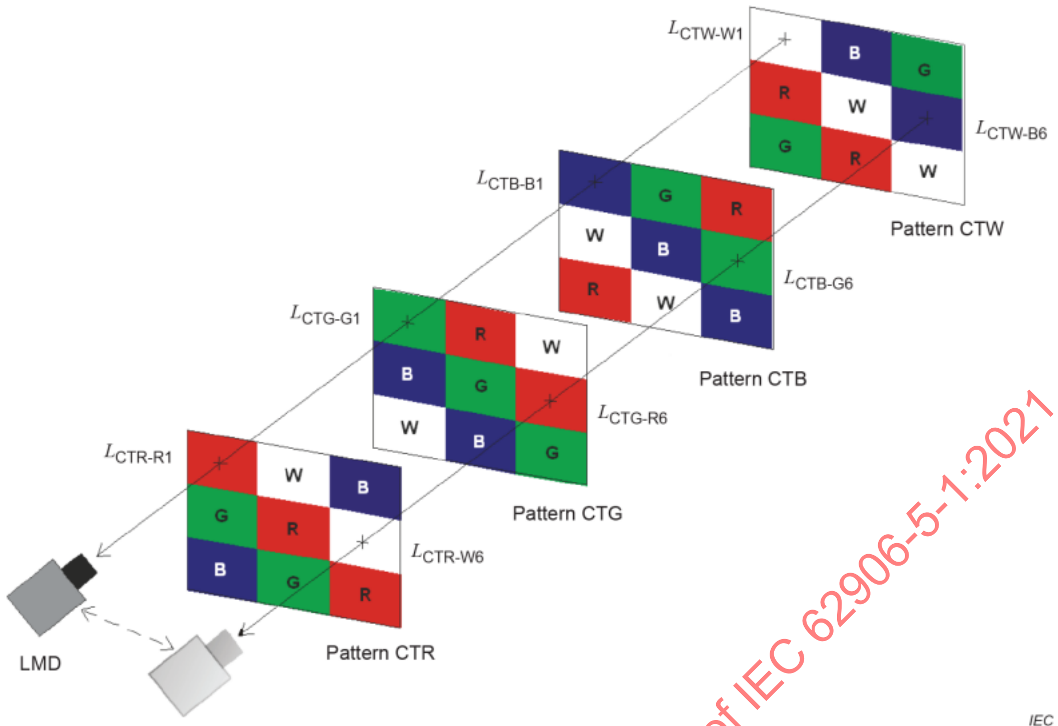


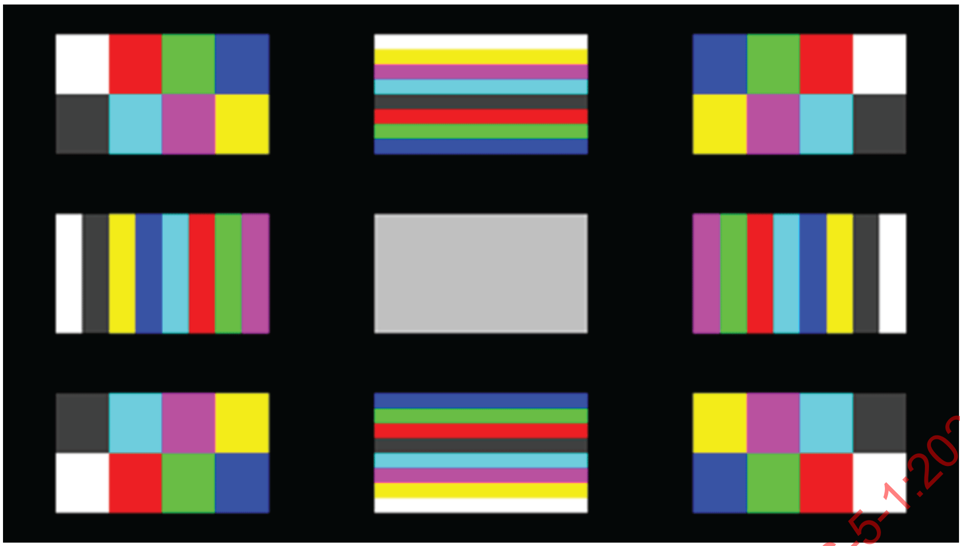
Figure 5 – Set of four colour tile test patterns used for projector characterization

5.6 RGBCMY colour pattern

The RGBCMY colour pattern is shown in Figure 6. Each of the large coloured boxes are centred on the nine standard projected image locations (see Figure 4) on a black background, with height and width corresponding to 2/9 of the dimensions of the projected image. The centre box can be changed to the desired colour to be measured. However, most of the colours in the surrounding eight box patterns shall remain constant at their maximum input-referred signal settings as defined in Table 3. The small dark boxes in the surrounding boxes are to compensate for the APL change in the pattern when the centre box changes, and the signal level of these eight dark boxes is equal to the complementary value of the signal for the centre box. The intent is to maintain the APL of the pattern at a value of 20/81, which is approximately 25 %, for all the centre colour measurements to eliminate any measurement influence such as luminance change due to APL loading. For the example shown in Figure 6, when the centre colour is set to an 8-bit signal value of (192, 192, 192), the surrounding grey boxes are set to its complementary value of (63, 63, 63). When a more saturated colour is measured in the centre (such as cyan with (0, 200, 200)), then the surrounding boxes would be set to its signal complementary colour (255, 55, 55). If the centre illuminance of a mid-grey colour varies by less than 3 % when the colour of the eight complementary colour blocks changes from black to peak white, then the colour of the complementary colour blocks can be kept to black (0, 0, 0) for all signal values of the centre colour, when using this test pattern.

NOTE 1 Unless otherwise stated, the pre-gamma average picture level (APL) will simply be referred to as average picture level in this document. The APL will normally be expressed as a percentage, where full white screen at maximum drive level would be 100 % APL.

NOTE 2 If the display is sensitive with more than 5 % luminance change when the APL varies, the complementary colour can be calculated in the linear domain.



NOTE The centre box can be changed to any desired colour, while all the surrounding boxes remain fixed except for the eight dark grey boxes that will be signalled with the complementary values of the signal for the centre tile.

Figure 6 – Standard medium APL RGBCMY test pattern used for centre illuminance and colour measurements with 25 % APL

5.7 Measuring the projected image area

The area measurement of the projected image is a critical input for determining some projector performance characteristics. Unless defined otherwise, it shall be made at the standard projector adjustment, focus, distance, and setup conditions. It is recommended that a virtual screen setup with millimetre grids at the corners be used to determine the projected image area. A full white screen pattern is recommended for the area measurement. The image shall be focused such that the outer edge of the image is sharp. If the projected image is rectangular, then the image area A is simply the product of the horizontal and vertical image dimensions as measured in the virtual screen. If the projected image is not rectangular, then the image area can be obtained from the image diagonal vectors p and q (see Figure 7):

$$A = \frac{1}{2}\left| p \times q \right| = \frac{1}{2}\left| p_x q_y - p_y q_x \right| \quad (2)$$

with

$$p_x = x_{UR} - x_{LL}, p_y = y_{UR} - y_{LL}$$
$$q_x = x_{UL} - x_{LR}, q_y = y_{UL} - y_{LR} \quad (3)$$

where the position coordinates for the lower left corner of the projected image are (x_{LL}, y_{LL}), for the lower right corner (x_{LR}, y_{LR}), upper left corner (x_{UL}, y_{UL}), and upper right corner (x_{UR}, y_{UR}).

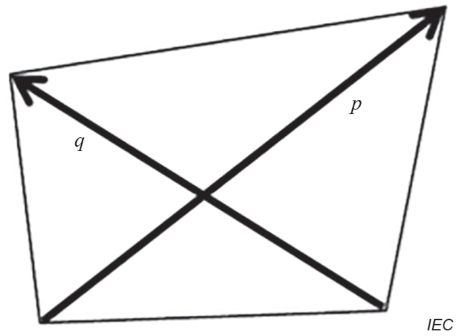


Figure 7 – Area of projected image

5.8 Maintaining the normal working conditions

The projector settings (such as brightness, contrast, viewing mode, automatic iris control or dynamic power control) shall be established at the beginning and be unchanged for all measurements. These settings shall be reported.

6 Measuring methods

6.1 Light output

The informative measurement methods of white light output (WLO) and colour-signal white (CSW), included in Annex D, provide two different approaches to evaluate the light output of front projection laser displays. The applicability of the measurement methods is not discussed in this document and, as these methods are informative, this document does not require the results of either method to be reported. There are scenarios when the two measurement methods show different results. It is beyond the scope of this document to interpret the meaning of such differences.

6.2 Spectroradiometric measurements

6.2.1 General

Spectral measurements can be performed to accurately determine the basic characteristics of the projector's RGB input-referred signal primary colours and the input-referred signal white colour. Since laser projectors can have one or more lines with narrow spectral bandwidth, spectral measurements are critical for accurate photometric and colorimetric results. Spectral measurements are preferred for all measurements.

NOTE When the spectral measurement of one primary colour (e.g., red) takes place on a multicolour pattern, the fraction from the other colours (in this example, green and blue) that hit the virtual screen next to the measurement area can be filtered in the measured spectra.

6.2.2 Measuring equipment

A spectral irradiance meter or a spectral radiance meter with a diffuse reflectance standard, and a signal generator shall be used.

6.2.3 Measuring method

The measurement shall be as follows:

a) The projector shall be positioned in the standard configuration, focused, and set to the standard setup conditions and specified viewing mode. If other conditions are used, they shall be reported in detail. The measurement area of the LMD shall be in the centre of the image (position 5, Figure 4) and in the image plane.

b) A set of four RGBW colour tile patterns (see Figure 5) are rendered in sequence at the image plane. Each image is allowed to stabilize, and the spectral irradiance is measured in the middle (position 5, Figure 4) of the centre rectangle in turn. If spectral radiance is measured using the diffuse reflectance standard at the image plane, it shall be converted to spectral irradiance as specified in 4.5.3.

c) Additional projector settings or viewing modes may be measured, as desired, by repeating the above procedures. Each measured data shall be reported with the projector settings and viewing modes.

6.2.4 Data analysis

The measured data shall be analysed as follows:

a) The spectral data shall be reported by plotting the spectral distributions measured from the centre of the four colour tile test patterns. The peak wavelength values shall also be reported. The tristimulus values for the color Q can be obtained by the following formulae:

$$X_Q = 683 \int_\lambda E_Q(\lambda) \bar{x}(\lambda) d\lambda \tag{4}$$

$$Y_Q = E_Q = 683 \int_\lambda E_Q(\lambda) \bar{y}(\lambda) d\lambda \tag{5}$$

$$Z_Q = 683 \int_\lambda E_Q(\lambda) \bar{z}(\lambda) d\lambda \tag{6}$$

where

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$	are the colour matching functions (see CIE 15);
$E_Q(\lambda)$	is the spectral irradiance for the colour Q;
λ	is the wavelength;
E_Q	is the illuminance for the colour Q.

b) Report all illuminance values of the red ($E_{CTR,R5}$), green ($E_{CTG,G5}$), blue ($E_{CTB,B5}$), and white ($E_{CTW,W5}$) centre box in each test pattern, and the projector setup conditions used to measure them.

6.3 Illuminance uniformity

6.3.1 General

The illuminance uniformity of a white screen is evaluated as the brightest and dimmest illuminance relative to the average illuminance.

6.3.2 Measuring equipment

An illuminance meter or illuminance colorimeter with the required accuracy for the measured light source, a spectral irradiance meter or spectral radiance meter with a calibrated diffuse spectral reflectance standard, and signal generator shall be used.

6.3.3 Measuring method

The measurement shall be as follows:

a) The projector shall be positioned in the standard configuration, focused, and set to the standard setup conditions and specified viewing mode.
b) Project a full white screen image at maximum grey level and allow the projector illuminance to stabilize.
c) Measure the white illuminance at each of the common (P_1 to P_9) nine positions as indicated in Figure 4. Alternatively, all thirteen positions (P_1 to P_{13}) may be measured.
d) Determine the maximum $E_{\mathrm{FS,Wmax}}$ and minimum $E_{\mathrm{FS,Wmin}}$ white illuminance between all nine or thirteen positions, and the average illuminance $E_{\mathrm{FS,W}}$ from the nine positions P_1 to P_9 only.
e) The percent deviation of the highest and lowest illuminance values relative to the average, U_{high} and U_{low} respectively, shall be calculated as follows:

$$U_{\mathrm{high}} = \left(\frac{E_{\mathrm{FS,Wmax}} - E_{\mathrm{FS,W}}}{E_{\mathrm{FS,W}}} \right) \times 100(\%)$$
$$U_{\mathrm{low}} = \left(\frac{E_{\mathrm{FS,Wmin}} - E_{\mathrm{FS,W}}}{E_{\mathrm{FS,W}}} \right) \times 100(\%) \tag{7}$$

f) Report the maximum $E_{\mathrm{FS,Wmax}}$ and minimum $E_{\mathrm{FS,Wmin}}$ white illuminance, the average illuminance $E_{\mathrm{FS,W}}$, the percent deviations U_{high} and U_{low}, and the number of measurement points (9 or 13) used.

6.4 Contrast ratio

6.4.1 General

The contrast ratio is the ratio of the maximum white illuminance to the black illuminance of the projected image. As explained in IEC TR 62977-2-3, the illuminance value can depend on the pattern used to measure it, so two methods are given for the evaluation of the contrast ratio.

6.4.2 Measuring equipment

An illuminance meter or illuminance colorimeter with the required accuracy for the measured light source, a spectral irradiance meter or spectral radiance meter with a calibrated diffuse spectral reflectance standard, and a signal generator shall be used.

6.4.3 Measuring method

6.4.3.1 Full screen contrast ratio

The full screen contrast ratio (CR_{FS}) method follows ISO/IEC 21118:2020 [8], B.2.3.

6.4.3.2 Colour pattern contrast ratio

The RGBCMY test pattern shown in Figure 6 shall be applied. The eight dark rectangles will be signalled with (255, 255, 255) when the centre colour tile is signalled (0, 0, 0) for determining E_{K}, and the eight dark rectangles will be signalled with (0, 0, 0) when the centre colour tile is signalled (255, 255, 255) for determining E_{W}.

The colour pattern contrast ratio measurement shall be as follows:

a) The projector shall be positioned in the standard configuration, focused, and set to the standard setup conditions and specified viewing mode. It is recommended to set up the measurement in a large room with matte black surfaces, to minimize the amount of stray light, and to use the background subtraction method when it is required, as described in 4.3.

b) Measure the white illuminance E_{W} in the centre of the image plane which is illuminated by the RGBCMY test pattern (see Figure 6) with a white box in the centre. The white box shall be rendered at its maximum signal level.

c) Render the colour test pattern in Figure 6 with a black centre box at the lowest grey level, and allow the projector illuminance to stabilize.

d) Measure the black illuminance E_{K} in the centre of the image plane which is illuminated by the RGBCMY test pattern (see Figure 6) with a black box in the centre. Stray light shall be minimized, and the background subtraction method should be used when it is required, as described in 4.3.

e) The colour pattern contrast ratio CR_{CP} is calculated as:

$$CR_{\mathrm{CP}} = \frac{E_{\mathrm{W}}}{E_{\mathrm{K}}} \quad (8)$$

where

E_{W} is the white illuminance as defined in step b).

f) Report the white illuminance E_{W}, the black illuminance E_{K}, the colour pattern contrast ratio CR_{CP}, the projector configuration, settings and viewing mode.

NOTE If the centre illuminance varies by less than 3 % when the colour of the eight complementary colour blocks changes from black to peak white, then the colour of the complementary colour blocks can be kept to black (0, 0, 0) for either signal value (black or white) of the centre colour, when using this test pattern.

6.5 Chromaticity coordinates

6.5.1 General

This method measures the CIE chromaticity coordinates of a colour patch projected on the image plane. The multi-colour test pattern in Figure 6 shall be used, following the general guidance of IEC TR 62977-2-3.

6.5.2 Measuring equipment

An illuminance colorimeter with the required accuracy for the measured light source, a spectral irradiance meter or spectral radiance meter with a calibrated diffuse spectral reflectance standard, and a signal generator shall be used. The measuring equipment shall meet the requirements of the measurement uncertainty. When stray light is a concern for measuring dim colours, then the background subtraction method on the tristimulus values (X, Y, Z), or a stray light elimination method can be used, as described in 4.3.

6.5.3 Measuring method

The measurement shall be as follows:

a) The projector shall be positioned in the standard configuration, focused, and set to the standard setup conditions and specified viewing mode.

b) Project the RGBCMY test pattern shown in Figure 6, with the desired colour Q to be measured in the centre box, on the image plane and allow the illuminance to stabilize.

c) The measurement area shall be in the centre of the image (position 5, Figure 4).

d) Measure the spectrum or tristimulus values, and then calculate CIE 1931 chromaticity coordinates of the desired colour Q at the centre of the image.

e) Repeat the measurement for other projector setup conditions and viewing modes, as needed.

NOTE For dim colours, and if the background subtraction method can be used following the instructions of 4.3, the tristimulus values are determined as well for the background illuminance with the projection mask, and the results can be subtracted from the measured values for the colour Q.

6.5.4 Data analysis

The measured data shall be analysed as follows:

a) If spectral data is measured, Formula (4) to Formula (6) shall be used to calculate the tristimulus values. The CIE 1931 chromaticity coordinates (x, y) can be calculated for the colour Q from the tristimulus values as follows:

$$x_{\mathrm{Q}} = \frac{X_{\mathrm{Q}}}{X_{\mathrm{Q}} + Y_{\mathrm{Q}} + Z_{\mathrm{Q}}} \tag{9}$$

$$y_{\mathrm{Q}} = \frac{Y_{\mathrm{Q}}}{X_{\mathrm{Q}} + Y_{\mathrm{Q}} + Z_{\mathrm{Q}}} \tag{10}$$

The (u', v') chromaticity coordinates for the CIE 1976 uniform chromaticity scale (CIE 1976 UCS) are given by:

$$u'_{\mathrm{Q}} = \frac{4X_{\mathrm{Q}}}{X_{\mathrm{Q}} + 15Y_{\mathrm{Q}} + 3Z_{\mathrm{Q}}} = \frac{4x_{\mathrm{Q}}}{-2x_{\mathrm{Q}} + 12y_{\mathrm{Q}} + 3} \tag{11}$$

$$v'_{\mathrm{Q}} = \frac{9Y_{\mathrm{Q}}}{X_{\mathrm{Q}} + 15Y_{\mathrm{Q}} + 3Z_{\mathrm{Q}}} = \frac{9y_{\mathrm{Q}}}{-2x_{\mathrm{Q}} + 12y_{\mathrm{Q}} + 3} \tag{12}$$

b) Report the tristimulus data, the CIE 1931 chromaticity coordinates, the CIE 1976 UCS chromaticity coordinates, the input RGB digital values used to create the desired colour Q, the projector configuration, settings and viewing mode.

6.6 White point chromaticity coordinates and correlated colour temperature

6.6.1 General

This method measures the CIE chromaticity coordinates of the maximum grey level (white) colour projected on the image plane, and its correlated colour temperature (CCT).

6.6.2 Measuring equipment

An illuminance colorimeter with the required accuracy for the measured light source, a spectral irradiance meter or spectral radiance meter with a calibrated diffuse spectral reflectance standard, and a signal generator shall be used. The measuring equipment shall meet the requirements of the measurement uncertainty.

6.6.3 Measuring method

The measurement shall be as follows:

a) The projector shall be positioned in the standard configuration, focused, and set to the standard setup conditions and specified viewing mode.

b) Follow the procedure in 6.5 to measure the CIE 1931 chromaticity coordinates (x, y) for the test pattern shown in Figure 6 at the peak white grey level projected on the image plane. The CCT value should be recorded.

c) Repeat the measurement for other projector setup conditions and viewing modes, as needed.

6.6.4 Data calculation

a) If the LMD does not provide the CCT value, the CCT can be calculated from the CIE 1931 chromaticity coordinates (x, y) by following CIE 15.

b) Report the maximum white CIE 1931 and the CCT values, the projector configuration, settings and viewing mode. If the colour difference $\Delta C = [(u'_W - u'_P)^2 + 4/9\ (v'_W - v'_P)^2]^{1/2}$ of the measured white in CIE 1976 chromaticity coordinates is more than 0,05 from the Planckian radiator curve, then expressing the white point in terms of CCT is no longer appropriate (see CIE 15).

6.7 Greyscale illuminance and chromaticity coordinates

6.7.1 General

This method measures the illuminance and CIE chromaticity coordinates of the projector's greyscale as projected on the image plane.

6.7.2 Measuring equipment

An illuminance colorimeter with the required accuracy for the measured light source, a spectral irradiance meter or spectral radiance meter with a calibrated diffuse spectral reflectance standard, and a signal generator shall be used. The measuring equipment shall meet the requirements of the measurement uncertainty.

6.7.3 Measuring method

The measurement shall follow the following steps:

a) The projector shall be positioned in the standard configuration, focused, and set to the standard setup conditions and specified viewing mode.

b) Project the test pattern shown in Figure 6 to measure the maximum white colour, with the input red, green, and blue channels at their maximum levels, and allow the projector illuminance to stabilize.

c) The measurement area shall be in the centre of the image plane (position 5, Figure 4). If a diffuse reflectance standard is used with a spectroradiometer, the diffuse reflectance standard shall be in the image plane and the LMD aligned normal to its surface.

d) Measure the illuminance and CIE 1931 chromaticity coordinates (x, y) for the peak white grey level projected on the image plane.

e) Repeat the illuminance and chromaticity measurements for other grey levels, such as those recommended in Table 1 .

f) Stray light shall be minimized or accounted for at the darkest grey levels as in 4.3.

g) Repeat the greyscale measurement for other projector setup conditions and viewing modes, as needed.

h) Report the illuminance and CIE 1931 and CIE 1976 chromaticity coordinates of all measured grey levels in a similar format to Table 1 , the projector configuration, settings and viewing mode. The number of grey levels is defined by the specification sheet.

Table 1 – Recommended format for greyscale results

Input grey level (8-bit example) (R = G = B)	Illuminance (lx)	CIE 1931 x-chromaticity	CIE 1931 y-chromaticity	CIE 1976 u'-chromaticity	CIE 1976 v'-chromaticity
0					
36					
72					
109					
145					
182					
218					
255					

6.8 Colour uniformity

6.8.1 General

This method evaluates the colour variation over a full screen pattern for a defined colour.

6.8.2 Measuring equipment

An illuminance colorimeter with the required accuracy for the measured light source, a spectral irradiance meter or spectral radiance meter with a calibrated diffuse spectral reflectance standard, and a signal generator shall be used. The measuring equipment shall meet the requirements of the measurement uncertainty.

6.8.3 Measuring method

The measurement shall be as follows:

a) The projector shall be positioned in the standard configuration, focused, and set to the standard setup conditions and specified viewing mode.

b) Project a full white screen image at maximum grey level on the image plane and allow the illuminance to stabilize.

c) The measurement area of the LMD shall be in the image plane. If a diffuse reflectance standard is used with a spectral radiance meter, the diffuse reflectance standard shall be in the image plane and the LMD aligned normal to its surface.

d) Measure the CIE 1976 UCS chromaticity coordinates (u', v') at each of the common nine positions P_i (where i =1 to 9) as indicated in Figure 4. Alternatively, all thirteen positions (P_1 to P_{13}) may be measured when specified. If the LMD does not measure the CIE 1976 UCS chromaticity coordinates directly, they can be determined using the analysis described in 6.5.4.

e) It is recommended that the colour uniformity be measured also for full-screen red, green, and blue primary colour inputs at their respective maximum signal level.

f) Repeat the colour uniformity measurement for other projector setup conditions and viewing modes, as needed.

6.8.4 Data analysis

The measured data shall be analysed as follows:

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

$$\Delta u'v' = \sqrt{\left(u'_i - u'_j\right)^2 + \left(v'_i - v'_j\right)^2} \tag{13}$$

for i, j = 1 to 9 or 13, and $i \neq j$. If thirteen locations are measured, then all thirteen shall be used in the calculation. The colour non-uniformity is defined as the largest sampled chromaticity difference $(\Delta u'v')_{max}$ between any two points.

b) Table 2 gives an example of how to determine the largest chromaticity difference between the nine measurement points. If thirteen measurement points are used, the table shall be expanded to include the additional points. The largest chromaticity difference can be narrowed down by plotting the nine or thirteen (u', v') coordinates rather than calculating all (u', v') pairs.

c) Report the CIE 1976 UCS chromaticity coordinates (u', v') at each of the nine or thirteen positions and the maximum chromaticity difference $(\Delta u'v')_{max}$ for each of the measured colours, the projector configuration, settings and viewing mode.

Table 2 – Example of colour uniformity analysis

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

6.9 Colour gamut

6.9.1 General

The following measuring methods are defined to evaluate the projector's colour gamut characteristics: chromaticity diagram, chromaticity gamut area, and CIELAB gamut volume, if appropriate. The measuring methods used shall be noted in the test report.

6.9.2 Chromaticity gamut area

6.9.2.1 General

This method estimates the span of colours the projector is capable of producing by representing the colours in the CIE 1931 chromaticity diagram.

6.9.2.2 Measuring equipment

An illuminance colorimeter with the required accuracy for the measured light source, a spectral irradiance meter or spectral radiance meter with a calibrated diffuse spectral reflectance standard, and a signal generator shall be used. The measuring equipment shall meet the requirements of the measurement uncertainty.

6.9.2.3 Measuring method

The measurement shall be as follows:

a) The projector shall be positioned in the standard configuration, focused, and set to the standard setup conditions and specified viewing mode.

b) Project the test pattern shown in Figure 6 for measuring the red primary with equivalent digital RGB 8-bit input values of (255, 0, 0), and allow the projector illuminance to stabilize.

c) The measurement area of the LMD shall be in the centre of the image plane (position 5, Figure 4). If a diffuse reflectance standard is used with a spectroradiometer, the diffuse reflectance standard shall be in the image plane and the LMD aligned normal to its surface.

d) Measure the illuminance and CIE 1931 chromaticity coordinates (x, y) for the red primary projected on the image plane.

e) Repeat the illuminance and chromaticity measurements for the other (green and blue) primary colours as indicated in Table 3 .

f) Report the illuminance and CIE 1931 chromaticity coordinates for all the measured colours, graph the colours in a CIE 1931 chromaticity diagram (see Figure 8), and report the projector configuration, settings and viewing mode.

Table 3 – Equivalent 8-bit RGB input signals used for colour gamut area measurements

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

6.9.2.4 Chromaticity gamut area calculation

The chromaticity gamut area is expressed as the percent colour space area enclosed by the measured gamut relative to the entire spectrum locus in the CIE 1931 chromaticity diagram. The chromaticity gamut area in the CIE 1931 chromaticity diagram should be used since it is better correlated with CIELAB gamut volume than the gamut area in the CIE 1976 UCS chromaticity diagram. Gamut volume (see 6.9.3) is needed when the display response does not correlate with additive mixing of the colour signal, for the colours shown in Table 3.

The percentage of area enclosed by the RGB triangle in the CIE 1931 chromaticity diagram relative to the entire spectrum locus is calculated as:

$$A_{xy} = 149{,}6\left|(x_R - x_B)(y_G - y_B) - (x_G - x_B)(y_R - y_B)\right| \tag{14}$$

where

the subscripts R, G and B are the red, green and blue primaries respectively.

The CIE 1931 chromaticity gamut area for the example of BT.2020 primaries (ITU-R BT.2020-2 [24]) in Figure 8 would be 63 %. The CIE 1931 chromaticity gamut area value for sRGB primaries (IEC 61966-2-1 [20]) would be 34 %. Report the measured chromaticity values for the RGB input colours, and CIE 1931 chromaticity diagram gamut area.

If it is desired to also include the cyan, magenta, and yellow colours from Table 3 for the CIE 1931 chromaticity gamut area calculation, the following formula can be used:

$$A_{xy} = 149{,}6\begin{bmatrix} \left|(x_Y - x_C)(y_G - y_C) - (x_G - x_C)(y_Y - y_C)\right| \\ + \left|(x_M - x_B)(y_C - y_B) - (x_C - x_B)(y_M - y_B)\right| \\ + \left|(x_R - x_M)(y_Y - y_M) - (x_Y - x_M)(y_R - y_M)\right| \\ + \left|(x_Y - x_C)(y_M - y_C) - (x_M - x_C)(y_Y - y_C)\right| \end{bmatrix} \tag{15}$$

where

the subscripts C, M and Y are the cyan, magenta, and yellow secondary colours, respectively.

The number of measured colours used for the chromaticity gamut area calculation shall be reported with the area value. The gamut area overlap between the measured gamut and a reference gamut may also be reported if specified. An example method is given in Annex C.

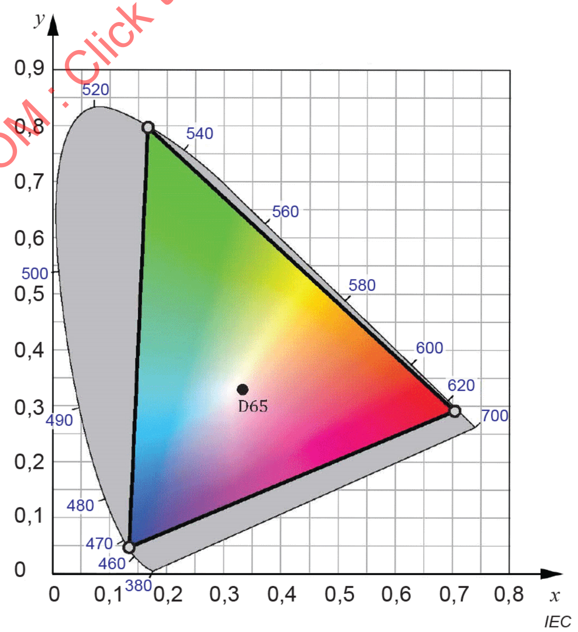


Figure 8 – Example representation of the chromaticity gamut area in the CIE 1931 chromaticity diagrams

6.9.3 CIELAB gamut volume

6.9.3.1 General

The purpose of this method is to measure the CIELAB colour gamut volume (CGV) of a laser projection display to determine its perceived colour capability as a whole volume under dark room conditions. The colours are measured with the standard medium APL RGBCMY test pattern shown in Figure 6. The various specified test colours are interchanged in the centre box.

In this method, the standard Bradford chromatic adaptation transform (ISO 15076-1) is used to convert the measured colours to the CIE D50 white point reference.

Manufacturers can choose any mode for the measurement of CGV. As specified in 5.3, all reported measurements shall be made in the same mode with the same setup configuration.

The CGV method requires accurate colorimetry from the LMD in all regions of the projector's colour space. Careful consideration of LMD colour accuracy and repeatability is crucial. Refer to 4.5 for details on LMD colour accuracy when measuring narrow bandwidth sources.

NOTE 1 Details of the input signal can be reported and the manufacturer can recommend the mode of measurement considering the input signal.

NOTE 2 Modes with custom highlight enhancement can impact CIELAB colour gamut volume.

6.9.3.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure the illuminance and CIE 1931 chromaticity coordinates (or tristimulus values directly), a driving power supply, and driving signal equipment.
b) Standard measuring environmental conditions; dark room conditions; standard setup conditions.
c) Standard medium APL loading RGBCMY test pattern (see Figure 6).

6.9.3.3 Measuring method

An accurate representation of the display's colour capability 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. The CIELAB colour space used for this purpose is required as the recommendation in CIE 168. This method measures the colour gamut volume of the colour gamut boundary of a display under dark room conditions. This colour gamut volume shall be determined using the following procedure:

a) The medium APL RGBCMY test pattern (Figure 6) shall be used to measure the desired centre box colours. The tristimulus values, or illuminance and chromaticity, shall be measured following the procedure in 6.5.
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 represents a 5 × 5 grid of equally spaced surface colours (tabulated in Annex A, Table A.1) which can be used to calculate the CIELAB gamut volume and be reported as CIELAB Volume {98}. It is recommended to use a set of 602 colours (reported at CIELAB Volume {602}), representing an 11 × 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 gamut volume shall be reported with the corresponding number of measured colours. Additional colour sets 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 illuminance and CIE 1931 chromaticity coordinates of each colour using Formula (16) to Formula (18):

$$X_Q = \frac{x_Q E_Q}{y_Q} \tag{16}$$

$$Y_Q = E_Q \tag{17}$$

$$Z_Q = \frac{(1 \cdot x_Q - y_Q) E_Q}{y_Q} \tag{18}$$

where

E_Q is the illuminance of the colour Q.

d) Once all colours are measured, it is necessary to adapt all the measured tristimulus values to the reference white point, D50 (according to CIE 168). The chromatic adaptation transforms (see ISO 15076-1), using the Bradford coefficients in Annex B are 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 transforms. All resulting colours are defined as (X_P, Y_P, Z_P). This method is consistent with the ICC colour management system.

e) 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 negative, then these adapted tristimulus values are truncated at the zero boundary and a caution statement will be given to that effect.

f) After chromatic adaptation, the tristimulus values shall be 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:

$$L^* = 116 \times f(Y_P / Y_{D50}) - 16 \tag{19}$$

$$a^* = 500 \times \left[f(X_P / X_{D50}) - f(Y_P / Y_{D50}) \right] \tag{20}$$

$$b^* = 200 \times \left[f(Y_P / Y_{D50}) - f(Z_P / Z_{D50}) \right] \tag{21}$$

where

$$f(t) = \begin{cases} t^{1/3} & t > (6/29)^3 \\ \left(\frac{841}{108}\right)t + \frac{4}{29} & \text{otherwise} \end{cases} \quad (22)$$

g) 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 9.

h) 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).

i) Report the colour gamut volume with the number of boundary colours used (see the example in Table 4), the test pattern used, and the measurement conditions. The colour gamut volume of an ideal sRGB display with zero black level is 8,32 × 10^5 ΔE^3 (see the CIE 168 method using the Bradford chromatic adaptation transforms). The recommended calculation method in Annex B, using a 11 × 11 equally-spaced grid of sampled colours, gives a value for sRGB of CIELAB Volume {602} = 8,31 × 10^5 ΔE^3.

NOTE CIE 168 also provides a method for calculating the amount of overlap between the measured colours and a specified colour space.

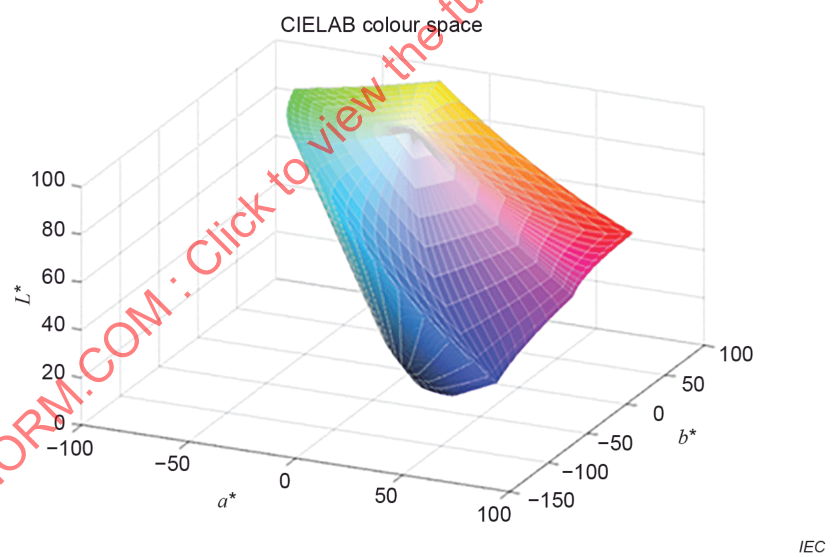


Figure 9 – Example of range in colours produced by a given display as represented by the CIELAB colour space

Table 4 – Example of report format for CIELAB gamut volume

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

Annex A
(normative)

RGB boundary colours for CIELAB gamut volume measurements

A.1 General

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

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

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

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

An estimate of the CIELAB colour gamut volume for a given display can be made by using a set of 98 RGB boundary colours. The 98 colours are derived from the uniform grid of 5 × 5 points on each outer face of the RGB colour cube. These colours are specified as 8-bit equivalent digital RGB input levels as shown in Table A.1. The equally spaced 8-bit code values are obtained using 0, Int[255 / 4], Int[255 / 2], Int[255 × (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 × 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 × (3 / 4)], and 4 095. An example CIELAB gamut volume calculation method is given in Annex B.

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

Colour number	Digital 8-bit equivalent RGB input signal level		
	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

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

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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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 projector. The 602 colours are derived from the uniform grid of 11 × 11 points on each face of the RGB colour cube. The colours are specified as 8-bit equivalent digital RGB input levels as shown in Table A.2. The equally spaced 8-bit code values are obtained using 0, Int[255 / 10], Int[255 × (2 / 10)], Int[255 × (3 / 10)], Int[255 × (4 / 10)], Int[255 × (5 / 10)], Int[255 × (6 / 10)], Int[255 × (7 / 10)], Int[255 × (8 / 10)], Int[255 × (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 × 11 grid of boundary colours. An example CIELAB gamut volume calculation method is given in Annex B.

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

Colour number	Digital 8-bit equivalent RGB input signal level		
	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
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

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

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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	***G***	***B***
113	0	255	51
114	0	255	76
115	0	255	102
116	0	255	127
117	0	255	153
118	0	255	178
119	0	255	204
120	0	255	229
121	0	255	255
122	25	0	0
123	25	0	25
124	25	0	51
125	25	0	76
126	25	0	102
127	25	0	127
128	25	0	153
129	25	0	178
130	25	0	204
131	25	0	229
132	25	0	255
133	51	0	0
134	51	0	25
135	51	0	51
136	51	0	76
137	51	0	102
138	51	0	127
139	51	0	153
140	51	0	178
141	51	0	204
142	51	0	229
143	51	0	255
144	76	0	0
145	76	0	25
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
156	102	0	25
157	102	0	51
158	102	0	76
159	102	0	102
160	102	0	127
161	102	0	153
162	102	0	178
163	102	0	204
164	102	0	229
165	102	0	255
166	127	0	0
167	127	0	25
168	127	0	51
169	127	0	76
170	127	0	102
171	127	0	127
172	127	0	153
173	127	0	178
174	127	0	204
175	127	0	229
176	127	0	255
177	153	0	0
178	153	0	25
179	153	0	51
180	153	0	76
181	153	0	102
182	153	0	127
183	153	0	153
184	153	0	178
185	153	0	204
186	153	0	229
187	153	0	255
188	178	0	0
189	178	0	25
190	178	0	51
191	178	0	76
192	178	0	102
193	178	0	127
194	178	0	153
195	178	0	178
196	178	0	204
197	178	0	229
198	178	0	255

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

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

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

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

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

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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
457	76	255	153
458	76	255	178
459	76	255	204
460	76	255	229
461	76	255	255
462	102	255	25
463	102	255	51
464	102	255	76
465	102	255	102
466	102	255	127
467	102	255	153
468	102	255	178
469	102	255	204
470	102	255	229
471	102	255	255
472	127	255	25
473	127	255	51
474	127	255	76
475	127	255	102
476	127	255	127
477	127	255	153
478	127	255	178
479	127	255	204
480	127	255	229
481	127	255	255
482	153	255	25
483	153	255	51
484	153	255	76
485	153	255	102
486	153	255	127
487	153	255	153
488	153	255	178
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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
500	178	255	229
501	178	255	255
502	204	255	25
503	204	255	51
504	204	255	76
505	204	255	102
506	204	255	127
507	204	255	153
508	204	255	178
509	204	255	204
510	204	255	229
511	204	255	255
512	229	255	25
513	229	255	51
514	229	255	76
515	229	255	102
516	229	255	127
517	229	255	153
518	229	255	178
519	229	255	204
520	229	255	229
521	229	255	255
522	25	25	255
523	25	51	255
524	25	76	255
525	25	102	255
526	25	127	255
527	25	153	255
528	25	178	255
529	25	204	255
530	25	229	255
531	51	25	255
532	51	51	255
533	51	76	255
534	51	102	255
535	51	127	255
536	51	153	255
537	51	178	255
538	51	204	255
539	51	229	255
540	76	25	255
541	76	51	255
542	76	76	255

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

Colour number	Digital 8-bit equivalent RGB input signal level		
	R	*G*	*B*
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 laser projector 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 projector can produce for given setup conditions. Since the shape of the CIELAB volume can be complex, it is easier to define the colours to be sampled by specifying them in the input-referred RGB colour space. Once the colours are specified on the RGB cube, then a tessellation of those points is used to determine their corresponding CIELAB values. These triangles on the CIELAB gamut boundary are the base of the volume elements, which are then summed up to calculate the total volume.

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

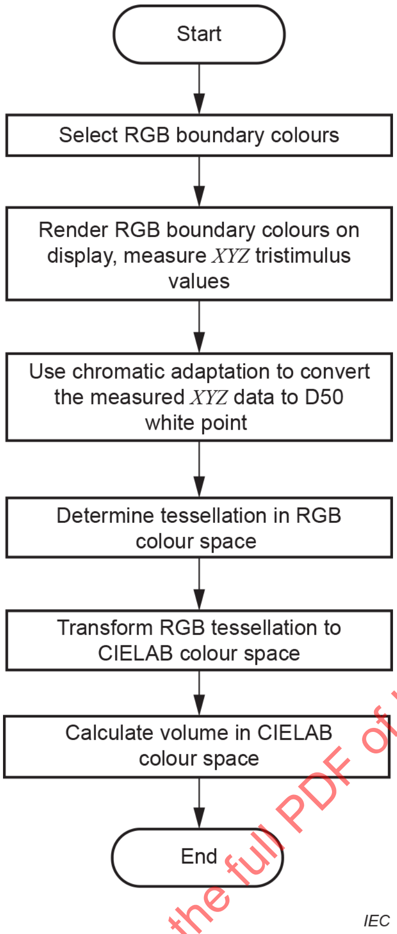


Figure B.1 – Analysis flowchart for calculating the CIELAB gamut volume

B.3 Number of sampled colours

The quality of the CIELAB gamut volume calculation will depend strongly on the number of sampled colours, and the complexity of the surface shape. An irregular-shaped CIELAB gamut will require a higher number of sampled colours. Since the gamut shape is not always known a priori, a conservative approach is to use the recommended 602 RGB boundary colours specified in Annex A. If the gamut surfaces are smooth, then a reasonable estimate of the CIELAB gamut volume can be obtained by fewer sampled points. For example, a laser projector 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 gamut volume calculation

B.4.1 General

There are several possible algorithms that can be used to calculate the CIELAB gamut volume. One algorithm that is recommended is described in B.4.3. This algorithm uses equally-spaced RGB colours on the surface of the cube in the RGB colour space.

B.4.2 Assumption

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

B.4.3 Uniform RGB grid algorithm

This algorithm accepts a uniform grid of RGB colour space coordinates that lie on each face of the RGB cube and their corresponding measured tristimulus values. The measured tristimulus values are chromatically adapted to a D50 white point. A triangular tessellation is determined on the RGB coordinates, and their corresponding measured CIELAB values are derived and converted to cylindrical coordinates using chroma (C^*) and hue angle (h^*), where $C^* = (a^{*2} + b^{*2})$ ^ 0,5 and h^* = atan2(b^*, a^*) with atan2 representing the two-argument arctangent math function spanning the range $-\pi <$ atan2 $(b^*, a^*) \leq \pi$, where b^*, a^* can be any real number. The volume of the tessellated CIELAB gamut is computed via numerical integration in the cylindrical coordinates of lightness (L^*), chroma (C^*), and hue 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. [19]

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}):

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

where

M_{adapt} is determined by:

$$\begin{bmatrix} M_{adapt} \end{bmatrix} = \begin{bmatrix} M_{BFD} \end{bmatrix}^{-1} \begin{bmatrix} \frac{\rho_P}{\rho} & 0 & 0 \\ 0 & \frac{\gamma_P}{\gamma} & 0 \\ 0 & 0 & \frac{\beta_P}{\beta} \end{bmatrix} \begin{bmatrix} M_{BFD} \end{bmatrix} \quad (B.2)$$

with the Bradford matrix given by:

$$\begin{bmatrix} M_{BFD} \end{bmatrix} = \begin{bmatrix} 0{,}895\ 1 & 0{,}266\ 4 & -0{,}161\ 4 \\ -0{,}750\ 2 & 1{,}713\ 5 & 0{,}036\ 7 \\ 0{,}038\ 9 & -0{,}068\ 5 & 1{,}029\ 6 \end{bmatrix} \quad (B.3)$$

and the cone response coefficients determined by:

$$\begin{bmatrix}\rho\\ \gamma\\ \beta\end{bmatrix} = \begin{bmatrix}M_{BFD}\end{bmatrix}\begin{bmatrix}X_W\\ Y_W\\ Z_W\end{bmatrix} \quad \text{(B.4)}$$

$$\begin{bmatrix}\rho_P\\ \gamma_P\\ \beta_p\end{bmatrix} = \begin{bmatrix}M_{BFD}\end{bmatrix}\begin{bmatrix}X_{D50}\\ Y_{D50}\\ Z_{D50}\end{bmatrix} \quad \text{(B.5)}$$

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 properly ordered tessellation of the final 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.

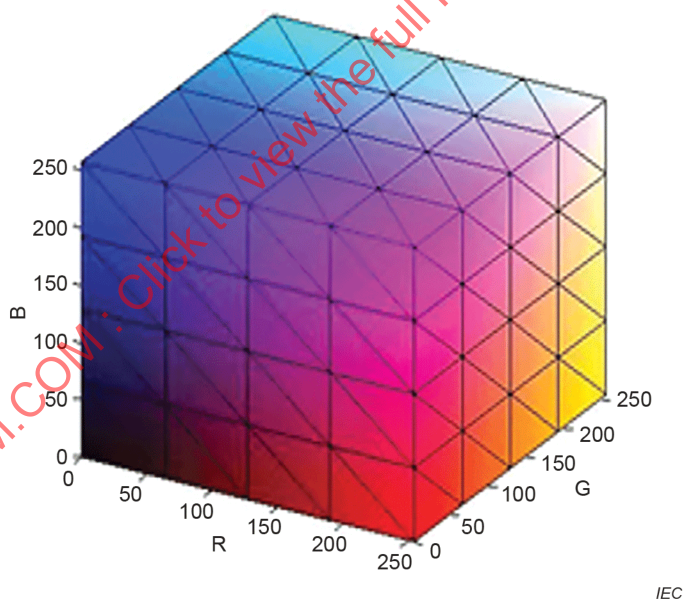


Figure B.2 – Example of tessellation using a 5 × 5 grid of surface colours on the RGB cube

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 $dL^*= 1$ and L^*=0,5, 1,5, 2,5, ..., 99,5.

g) For each vector, use the Möller-Trumbore ray-triangle intersection algorithm 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 $n = 1 \cdots N$ intersection. [19] Each vector may have 0 or more intersections.

h) The gamut volume, $V(L^*, h^*)$, 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 then 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".

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 × 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 × 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.

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.