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TECHNICAL SPECIFICATION

colour inside

Electronic displays –
Part 3-1: Evaluation of optical performances – Colour difference based viewing direction dependence

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CONTENTS

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ELECTRONIC DISPLAYS –

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS IEC 62977-3-1, which is a technical specification, has been prepared by IEC technical committee 110: Electronic displays.

The text of this technical specification is based on the following documents:

Draft TS	Report on voting
110/1003/DTS	110/1065/RVDTS

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

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

A list of all the parts in the IEC 62977 series, under the general title *Electronic 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 standards 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 "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

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

INTRODUCTION

This document aims to provide a measurement method that determines the display angular dependence after colour and white reference adaptation and provides an evaluation of differences in a uniform colour space.

This document facilitates the cross-industry measurement of the viewing direction dependence of colour displays. Several studies [6 to 9][1] have indicated that the contrast ratio (CR > 10:1) is, from a visual quality point of view, not useful to determine the viewing direction range for matrix displays. When colour differences are included in a viewing direction metric, the correlation between the metric value and a visual assessment value is significantly increased [10]. A more recent study [11] revealed that a metric, combining viewing-direction related luminance degradation and colour deviation can accurately predict the relative change in the visual assessment value. This information is the basis for the determination of the viewing direction range, which has relevance from a visual quality point of view.

NOTE “Viewing direction range” is sometimes referred to as “viewing angle”. Although technically incorrect, for legacy reasons the terms is considered equivalent.

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

ELECTRONIC DISPLAYS –

Part 3-1: Evaluation of optical performances – Colour difference based viewing direction dependence

1 Scope

This part of IEC 62977 specifies the evaluation method of the viewing direction characteristics of electronic display devices under dark-room conditions. More specifically, this document focuses on the evaluation of the viewing direction characteristics based on colour difference.

This document applies to colour matrix displays, which are based on transmissive or emissive technologies.

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.

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

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

ISO/CIE 11664-6:2014, *Colorimetry – Part 6: CIEDE2000 Colour-difference formula*

CIE 159, *A colour appearance model for colour management systems: CIECAM02*

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

3 Terms, definitions and abbreviated terms

3.1 General

No terms and definitions are listed in this document.

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

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

3.2 Abbreviated terms

APL	average pixel loading
CIE	Commission Internationale de L'Eclairage (International Commission on Illumination)
CIEDE2000	CIE 2000 delta-E colour difference system
CIELAB	CIE 1976 (L*a*b*) colour space
CR	contrast ratio

DUT	device under test
FWHM	full-width-at-half-maximum
LMD	light measuring device
LCD	liquid crystal display
OLED	organic light emitting diode
PDP	plasma display panel

4 Standard measuring equipment and coordinate system

4.1 Light measuring device

The LMD shall be a luminance meter, colorimeter, or a spectroradiometer. For DUTs that have a sharp spectral peak FWHM (i. e. smaller than 20 nm), such as laser displays, LCDs with fluorescent lamp backlights, LEDs with narrow-peak phosphors, quantum-dot phosphors, or narrow-spectrum OLEDs, a spectroradiometer should be used. A filter colorimeter should generally not be used for light sources with sharp spectral peaks. If they are used, the colorimeter shall be calibrated with a narrow bandwidth spectroradiometer to give the same results for the specific spectrum. Report the spectroradiometer characteristics of the spectroradiometer which is used for calibration. For light sources with sharp spectral peaks, the maximum bandwidth of the spectroradiometer shall be ≤ 5 nm. The higher resolution spectrometer produces a more accurate colour measurement, especially for lasers sources. The spectroradiometer shall be capable of measuring spectral radiance over at least the 380 nm to 780 nm wavelength range, with a maximum bandwidth of 10 nm for smooth broadband spectra (i.e. broad spectrum with no sharp spikes)[1].

4.2 Viewing direction coordinate system

The viewing direction is the direction under which the observer looks at the point of interest on the device under test (DUT). During the measurement, the light-measuring device (LMD) simulates the observer, by aiming the LMD at the point of interest on the DUT from the viewing direction. The viewing direction is defined by two angles: the angle of inclination θ (relative to the surface normal of the DUT) and the angle of rotation φ (also called azimuth angle) as illustrated in Figure 1.

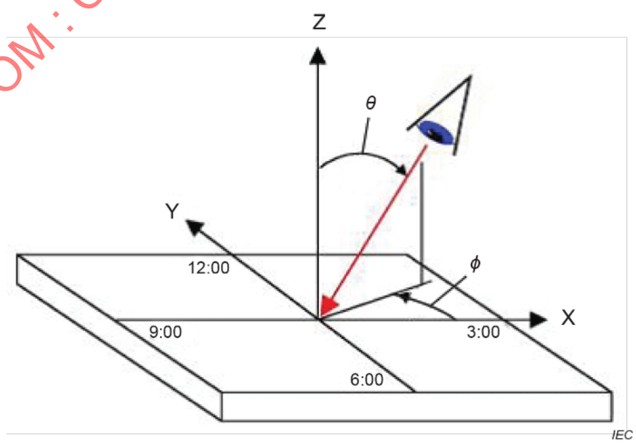


Figure 1 – Illustration of viewing directions θ and ϕ

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

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

5 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 Power supply

A driving power supply and driving signal equipment shall be used.

5.3 Warm-up time

Measurements shall start 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 require 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.

5.4 Standard measuring dark-room 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 often be estimated by turning off the display. When the reflected background luminance and total (reflected plus black) luminance are greater than the sensitivity 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 and 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 (see ISO 9241-305 [17]) should be used to minimize the contribution of the background illumination [3]. This method can be used to estimate the reflected luminance from the black state luminance.

NOTE Blackout curtains can be used to reduce the reflection from the DUT.

5.5 Standard set-up conditions

5.5.1 General

Standard set-up conditions are given below. Any deviations from these conditions shall be reported.

5.5.2 Adjustment of display

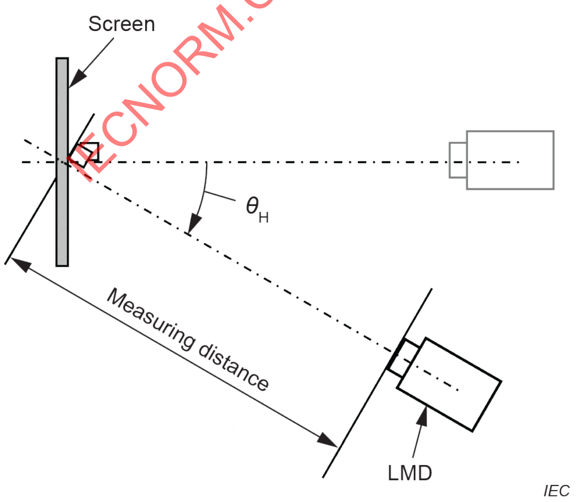
The display shall be configured to the specified settings, and the settings recorded in the test report. These settings shall be held constant for all measurements, unless stated otherwise. It is important, however, to make sure that not only the adjustments are kept constant, but also that the resulting physical quantities remain constant during the measurement. This is not automatically the case because of, for example, warm-up effects or auto-dimming features. Any automatic luminance or gain control shall be turned off. Otherwise it shall be noted in the report. The ambient light (or brightness) control shall be turned off. If that is not possible, it is recommended to set it to turn on no lower than 300 lx to minimize the influence of the brightness control. The state of the auto-light control shall be reported. In addition, if the display exhibits image sticking and/or 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 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.

6 Measurement methods

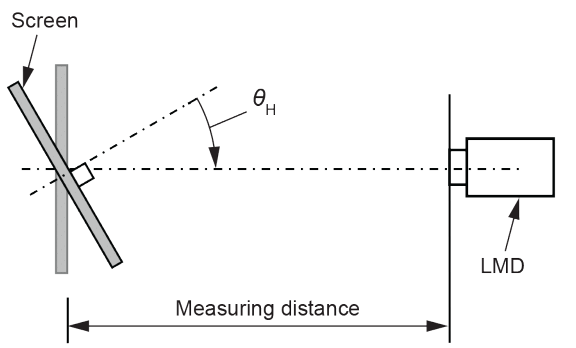
6.1 Measurement procedures

1) Render the specified test pattern with the required colour Q centred on the display screen. Allow the luminance to stabilize.
2) Align the optical axis of the LMD in the specified direction relative to the display screen and centred on the display screen.
3) Measure the tristimulus values X_Q, Y_Q, Z_Q at the screen centre.
4) Render the specified test pattern with the reference white pattern centred on the display screen. Allow the luminance to stabilize.
5) Measure the tristimulus values X_n, Y_n, Z_n at the screen centre.
6) Repeat the measurement for additional colours.
7) Report the set-up conditions, the test pattern, the colour, and tristimulus values X_Q, Y_Q, Z_Q, X_n, Y_n, Z_n at the specified colour Q, respectively.

To measure the viewing direction dependency, the centre of the screen is measured from the horizontal, vertical, or diagonal viewing directions defined in each measurement method or the relevant specification as shown in Figure 1. Instead of moving the LMD as indicated in Figure 2a) and Figure 3a), the DUT can be tilted vertically or turned horizontally to be measured as shown in Figure 2b) and Figure 3b). The recommended ranges of the direction (θ) are shown in Table 1 and Table 2 for TV in living rooms and for mobile devices, respectively. The horizontal and vertical measuring direction ranges shall be defined by the supplier in the relevant specification, and shall be noted in the report. If the customer/application requires additional direction ranges, they shall be applied and noted in the report.

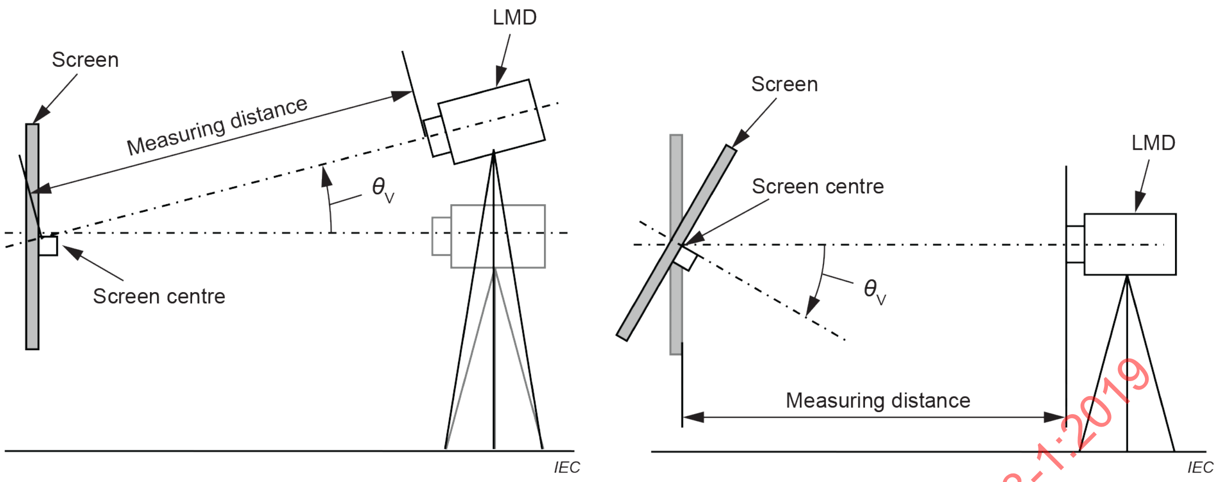


a) Motion of LMD (top view)



b) Rotation of display (top view)

Figure 2 – Measuring layout for horizontal viewing direction dependency



a) Motion of LMD (side view) b) Tilt of display (side view)

Figure 3 – Measuring layout for vertical viewing direction dependency

Table 1 – Measurement directions for TV in living rooms

	θ (degree)	*ϕ* (degree)
Horizontal	0, ±15, ±30, ±45, ±60	0
Vertical	0, ±15, ±30	90
Diagonal	45	0, 45, 90, 135, 180, 225, 270 and 315

Table 2 – Measurement directions for mobile displays

	θ (degree)	*ϕ* (degree)
Horizontal	0, ±15, ±30, ±40, ±50	0
Vertical	0, ±15, ±30, ±40, ±50	90
Diagonal	30	0, 45, 90, 135, 180, 225, 270 and 315

6.2 Test signals (test charts)

The test pattern of the input video signal supplied to the DUT is a 4 % window area centred on the screen with one of eleven test colours as described in Table 3The area outside the 4 % window area shall be driven to the black level. The minimum DUT luminance with a 100 % white input signal, i.e. $R = G = B = 255$ for an 8-bit signal, shall be 100 cd/m^2. The area outside the 4 % window area shall be driven to the black level. If the 4 % window contains fewer than 500 pixels, the window shall be chosen to contain at least 500 pixels. For reference, see Annex E. Optionally, any additional test colours 12 to 15 in Table 3 may be added.

NOTE The translation of the RGB input signal into output colours is described in Annex D.

Table 3 – Input signal of 4 % window for viewing direction measurements

	Colour Q	8-bit signal level (v) (BT2020 colour reference)		
		R	G	B
1	White	242	242	236
2	Grey	121	121	120
3	Black	52	51	51
4	R	146	70	64
5	G	105	144	62
6	B	63	65	143
7	Yellow	220	201	78
8	Magenta	160	97	144
9	Cyan	80	131	162
10	Dark skin	104	83	68
11	Light skin	180	154	133
	Other possible selections			
12	Blue sky	108	121	152
13	Yellow green	165	184	86
14	Dark grey	83	83	82
15	Light grey	201	200	199

7 Calculation of chromaticity and colour difference

First, it is necessary to adapt all measured tristimulus values to the common reference white point, D50 (according to CIE 168). The CAT02 chromatic adaptation transform (see CIE 159, using the Bradford coefficients) shall be used to perform the transformation.

Then, calculate the CIEDE2000 colour difference value between each direction and the perpendicular value of the colours Q (with their reference white measurement measured in the same direction as the chromaticity measurement) by first determining the CIELAB 1976 values for each of the measurement directions, according to Formulae (1), (2), (3) and (4), as described in ISO 11664-4.

For each colour Q:

$$L^*_{\mathrm{Q}} = 116 \times f\left(\frac{Y'_{\mathrm{Q}}}{Y'_{\mathrm{n}}}\right) - 16 \tag{1}$$

$$a^*_{\mathrm{Q}} = 500 \times \left[f\left(\frac{X'_{\mathrm{Q}}}{X'_{\mathrm{n}}}\right) - f\left(\frac{Y'_{\mathrm{Q}}}{Y'_{\mathrm{n}}}\right) \right] \tag{2}$$

$$b^*_{\mathrm{Q}} = 200 \times \left[f\left(\frac{Y'_{\mathrm{Q}}}{Y'_{\mathrm{n}}}\right) - f\left(\frac{Z'_{\mathrm{Q}}}{Z'_{\mathrm{n}}}\right) \right] \tag{3}$$

where X'_Q, Y'_Q, Z'_Q are the D50 adapted tristimulus values of the test colour stimulus based on the CIE 1931 standard colorimetric system defined in ISO 11664-1, and X'_n, Y'_n, Z'_n are the corresponding tristimulus values of the white stimulus. These are measured in the same direction as the viewing direction; for example, when the viewing direction is 30°, X_n, Y_n, Z_n are measured at 30°.

Therefore:

$$f(t)=\begin{cases}\sqrt[3]{t} & \text{if} \quad t>(6/29)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t+\frac{4}{29} & \text{otherwise}\end{cases} \tag{4}$$

Thereafter, calculate CIE DE2000 according to Formulae (5) through (21), as described in ISO 11664-6:

Calculation of C'_i, h'_i

$$C^*_{i,ab}=\sqrt{\left(a^*_i\right)^2+\left(b^*_i\right)^2} \tag{5}$$

$$\bar{C}^*_{ab}=\left(C^*_{1,ab}+C^*_{2,ab}\right)/2 \tag{6}$$

$$G=0{,}5\left(1-\sqrt{\frac{\left(\bar{C}^*_{ab}\right)^7}{\left(\bar{C}^*_{ab}\right)^7+25^7}}\right) \tag{7}$$

$$a'_i=(1+G)a^*_i \tag{8}$$

$$C_i'=\sqrt{(a_i')^2+(b^*_i)^2} \tag{9}$$

$$h_i'=\begin{cases}0 & \text{if } b_i^*=a_i'=0 \\ \tan^{-1}(b_i^*,a_i') & \text{otherwise}\end{cases} \tag{10}$$

Calculation of $\Delta L', \Delta C', \Delta H'$:

$$\Delta L'=L^*_2-L^*_1 \tag{11}$$

$$\Delta C'=C'_2-C'_1 \tag{12}$$

$$\Delta h_i'=\begin{cases}0 & C_1'C_2'=0 & \\ h_2'-h_1' & C_1'C_2'\neq 0 & \left|h_2'-h_1'\right|\leq 180^\circ \\ \left(h_2'-h_1'\right)-360 & C_1'C_2'\neq 0 & \left(h_2'-h_1'\right)>180^\circ \\ \left(h_2'-h_1'\right)+360 & C_1'C_2'\neq 0 & \left(h_2'-h_1'\right)<-180^\circ\end{cases} \tag{13}$$

$$\Delta H' = 2\sqrt{C_1' C_2'} \sin\left(\frac{\Delta h'}{2}\right) \quad (14)$$

Calculation of the CIEDE2000 colour difference ΔE_{00}:

$$\bar{L}' = \left(L_2^* - L_1^*\right)/2 \quad (15)$$

$$\bar{C}' = \left(C_1' - C_2'\right)/2 \quad (16)$$

$$\bar{h}' = \begin{cases} \frac{h_1' + h_2'}{2} & |h_1' + h_2'| \leq 180^\circ \quad C_1'C_2' \neq 0 \quad C_1'C_2' \neq 0 \\ \frac{h_1' + h_2' + 360^\circ}{2} & |h_1' + h_2'| > 180^\circ \quad (h_1' + h_2') < 360^\circ \quad C_1'C_2' \neq 0 \\ \frac{h_1' + h_2' - 360^\circ}{2} & |h_1' + h_2'| > 180^\circ \quad (h_1' + h_2') \geq 360^\circ \quad C_1'C_2' \neq 0 \\ h_1' + h_2' & C_1'C_2' = 0 \end{cases} \quad (17)$$

$$T = 1 - 0{,}17\cos(\bar{h}' - 30^\circ) + 0{,}24\cos(2\bar{h}') + 0{,}32\cos(3\bar{h}' + 6^\circ) - 0{,}2\cos(4\bar{h}' - 63^\circ) \quad (18)$$

$$\Delta\theta = 30\exp\left\{-\left(\frac{\bar{h}' - 275^\circ}{25}\right)^2\right\} \quad (19)$$

$$R_C = 2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7 + 25^7}} \quad (20)$$

$$\Delta E_{00}^{1,2} = \Delta E_{00}(L_1^*, a_1^*, b_1^*; L_2^*, a_2^*, b_2^*)$$

$$= \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (21)$$

where S_L, S_C, S_H, R_T are the attenuation factors as shown in Table 4:

Table 4 – Attenuation factors

S_L	S_C	S_H	R_T
$1 + \frac{0{,}015\left(\bar{L}' - 50\right)^2}{\sqrt{20 + \left(\bar{L}' - 50\right)^2}}$	$1 + 0{,}045C'_{ab}$	$1 + 0{,}015C'_{ab}T$	$-\sin(2\Delta\theta)R_C$
NOTE Annex B includes examples of other attenuation factors. However, the attenuation factors listed in Table 4 are those used in this document.			

Determine the parametric factors for the measurement types k_{L}, k_{C} and k_{H} for the measurement desired, according to Table 5.

Table 5 – Parametric factors

Measurement type	k_{L}	k_{C}	k_{H}
Reference	1	1	1

Any colorimetric changes with the viewing direction can be summarized by the colour difference $\Delta E_{00}{}^{1,2}$. In this analysis, the $\Delta E_{00}{}^{1,2}$ values at each viewing direction are used to calculate the colour difference relative to the normal incidence (perpendicular) values. The average of $\Delta E_{00}{}^{1,2}$ of eleven colours Q shall be calculated.

NOTE 1 The perception of colour difference is described in Annex A.

NOTE 2 Other parameters are shown in Annex C.

NOTE 3 The CIEDE2000 formula is intended to be applied to objects with a sample colour-difference magnitude of 0 to 5 CIELAB units (ISO/CIE 11664-6:2014, Clause 4). Caution is therefore used if these values are exceeded.

NOTE 4 Presently, there are no established parametric factors for display measurement. In the interim period, until more decisive experimental results are available, the choice of 1, 1, 1 is regarded as the best solution.

8 Reporting

The colour difference between the chromaticity of the normal direction and the chromaticity of the measured direction, CIEDE2000, shall be reported. An example of the reporting format is shown in Table 6. For possible selection of colour Q, refer to Table 3.

Since the CIEDE2000 colour difference will understate the actual luminance change with the viewing direction (since luminance normalization is done at the measurement direction) it is required to also report the luminance change with the viewing direction.

The raw tristimulus values X, Y and Z of each direction may also be reported.

Table 6 – Example of reporting format

Colour difference in horizontal direction

Horizontal θ / **Colour Q**	**-60**	**-45**	**-30**	**-15**	**0**	**+15**	**+30**	**+45**	**+60**
White	0	0	0	0	0	0	0	0	0
Grey					0				
Black					0				
R					0				
G					0				
B					0				
Yellow					0				
Magenta					0				
Cyan					0				
Dark skin					0				
Light skin					0				
Average					-				

Luminance change in horizontal direction

Horizontal θ / **Colour Q**	**-60**	**-45**	**-30**	**-15**	**0**	**+15**	**+30**	**+45**	**+60**
White					100 %				
Grey					100 %				
Black					100 %				
R					100 %				
G					100 %				
B					100 %				
Yellow					100 %				
Magenta					100 %				
Cyan					100 %				
Dark skin					100 %				
Light skin					100 %				
Average					100 %				

Colour difference in vertical direction

Vertical θ / Colour Q			-30	-15	0	+15	+30		
White			0	0	0	0	0		
Grey					0				
Black					0				
R					0				
G					0				
B					0				
Yellow					0				
Magenta					0				
Cyan					0				
Dark skin					0				
Light skin					0				
Average					-				

Luminance change in vertical direction

Vertical θ / Colour Q			-30	-15	0	+15	+30		
White					100 %				
Grey					100 %				
Black					100 %				
R					100 %				
G					100 %				
B					100 %				
Yellow					100 %				
Magenta					100 %				
Cyan					100 %				
Dark skin					100 %				
Light skin					100 %				
Average					100 %				

Colour difference in diagonal direction at θ = 45°

Diagonal φ / Colour *Q*	0	45						
White	0	0						
Grey	0							
Black	0							
R	0							
G	0							
B	0							
Yellow	0							
Magenta	0							
Cyan	0							
Dark skin	0							
Light skin	0							
Average	0							

Luminance change in diagonal direction at θ = 45°

Diagonal φ / Colour *Q*	0	45						
White	100 %							
Grey	100 %							
Black	100 %							
R	100 %							
G	100 %							
B	100 %							
Yellow	100 %							
Magenta	100 %							
Cyan	100 %							
Dark skin	100 %							
Light skin	100 %							
Average	100 %							

Records of the measurement shall be made to describe deviations from the standard measurement conditions and include the following information:

– selected standard measuring system and its related conditions,

– driving signals (waveforms, voltage and frequency).

Annex A
(informative)

Perception of colour difference

An example of the rating of the perception of colour difference is shown in Table A.1.

Table A.1 – Perception of colour difference

K	$\Delta E_{min}(k)$	$\Delta E_{max}(k)$	Perception of colour difference	Performance indicator
1	0,0	0,5	Hardly	5
2	0,5	1,5	Slight	$5-(\Delta\bar{E}-0,5)$
3	1,5	3,0	Noticeable	$4-(\Delta\bar{E}-1,5)/1,5$
4	3,0	6,0	Appreciable	$3-(\Delta\bar{E}-3)/3$
5	6,0	12,0	Much	$2-(\Delta\bar{E}-6)/6$
6	12,0	24,0	Very much	$1-(\Delta\bar{E}-12)/12$
7	24,0	∞	Strongly	0

NOTE Table A.1 provides an indication of the perceived colour difference for various ranges of ΔE_{76} and ΔE_{00}. It also provides a numerical "performance indicator" providing a subjective rating of the perceived difference from 0 ("strongly visible") to 5 ("hardly visible"). Since the ΔE_{00} values are (by design) similar to ΔE_{76}, the table is applicable to both.

Annex B
(informative)

Other attenuation factors

B.1 General

Regarding calculation of ΔE^*, other weighting factors have been proposed. In Annex B, these factors are listed, but in this document, only the unmodified CIE 2000 ΔE_{00} is used.

B.2 Attenuation factors proposed

Some examples of proposed attenuation factors are shown in Table B.1.

Table B.1 –- Attenuation factors

Measurement type	S_L	S_C	S_H	R_T
CIE	$1+\frac{0{,}015\left(\bar{L}'-50\right)^2}{\sqrt{20+\left(\bar{L}'-50\right)^2}}$	1 + 0,045 C'_{ab}	1 + 0,015 $C'_{ab}T$	-sin(2$\Delta\theta$)R_C
IDW paper [9]	0,42	1,55	1,03	-sin(2$\Delta\theta$)R_C

Formula (B.1), for an adjusted value for the S_c weighting function, is also referenced in [18].

$$\frac{1}{S_C}=\frac{A}{\sqrt{2\pi\sigma(C^*+x)}}\exp\left[-\frac{\left[\ln(c^*+x)-\mu\right]^2}{2\sigma^2}\right] \tag{B.1}$$

CIE proposes a set of attenuation factors that work well in side-by-side comparison. For “memory colour”, another set can be more appropriate. The user may choose one of the other parameters, but the parameter used will be reported.

Annex C
(informative)

Other parameters

C.1 Measurement of half luminance angle

The measurement of the half luminance angle can be performed as follows:

1) Apply a white screen with a 100 % signal level (R = G = B = 255 for an 8-bit input signal) to the DUT.
2) Measure the centre luminance (L_0) perpendicular to the display surface (θ = 0°, ϕ = 0°). The measurement area shall cover at least 500 pixels.
3) Take luminance ($L_{\theta,\phi}$) measurements as the LMD steps through the various directions in the horizontal (ϕ = 0°, ϕ = 180°) and vertical (ϕ = 90°, ϕ = 270) viewing planes.
4) Record the change in luminance from the perpendicular direction. The luminance change is defined in terms of the luminance ratio:

$$LR_{\theta,\varphi} = \frac{L_{\theta,\varphi}}{L_0} \tag{C.1}$$

The half luminance direction can be defined as the direction at which the luminance ratio (LR), calculated using Formula (C.1), equals 50%.

5) Determine the half luminance direction in each of the four viewing directions (ϕ = 0°, ϕ = 180°, ϕ = 90°, ϕ = 270).

C.2 Measurement of gamma distortion from the viewing directions

The measurement of gamma distortion from the viewing directions can be performed as follows:

a) Apply the required input signal(s) using an APL fixed pattern to the DUT. Examples of APL fixed pattern images are shown in Figure C.1.
b) Measure the centre luminance (L_0) for the specified grey levels perpendicular to the display surface (θ = 0°, ϕ = 0°). The measurement area shall cover at least 500 pixels.
c) Take luminance measurements ($L_{\theta,\phi}$) of each specified grey level, as the LMD steps through the various directions in the horizontal (ϕ = 0°, ϕ = 180°) and vertical (ϕ = 90°, ϕ = 270) viewing planes.
d) Calculate each gamma values from the measured directions.
   1) For each luminance level j above black (j > 1) determine the net luminance as the luminance increase over black

$$\Delta L_j = L_j - L_K,\ j = 2,3,\ldots,M, \tag{C.2}$$

   where L_k = L_1 = black

   2) For each level j > 1,

$$\Delta V_j = V_j - V_1,\ j = 2,3,\ldots,M, \tag{C.3}$$

   where V_j is the grey level.

   3) Calculate log($\triangle L_j$) for each grey pattern (j > 1).

4) Calculate log($\triangle V_j$) for each grey level (j > 1).

5) Create a log-log plot between the log of the net luminance and the log of the net grey level differences (or signal level differences).

6) Perform a linear regression of log($\triangle L_j$) versus log($\triangle V_j$) for j = 2,3,..., M, and record the correlation coefficient (see Figure C.2).

e) Determine the gamma distortion values as shown in Formula (C.4) in each of the four viewing directions (ϕ = 0°, ϕ = 180°, ϕ = 90°, ϕ = 270°).

$$G_{\mathrm{DR,i}}(\%) = \frac{|\gamma - \gamma_{\mathrm{i}}|}{\gamma} \times 100(\%) \tag{C.4}$$

Where γ is the reference gamma value and γ_{i} are the gamma values measured from the different directional angles. The directional gamma distortion ratio is the maximum of this set of values.

f) Report the measured data (see Table C.1 for an example).

NOTE Some EOTF distortions include a deviation from a power law and hence the exponent (gamma) cannot be defined.

a) 9-grey-level APL fixed pattern

b) 33-grey-level APL fixed pattern

Figure C.1 – Test pattern for gamma measurement

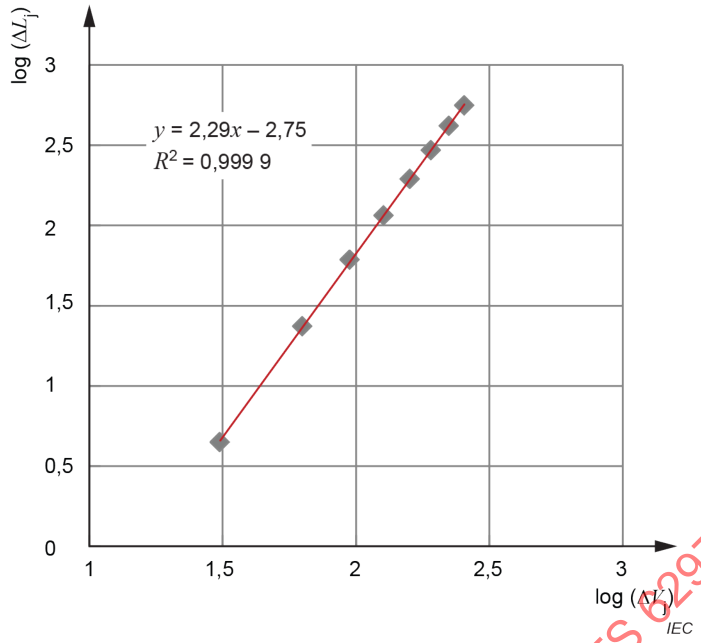


Figure C.2 – Example of linear regression of log(ΔL_j) versus log(ΔV_j) in normal direction (0°)

Table C.1 – Worked-out example for gamma distortion from viewing direction

Reporting — Sample data						
Grey-scale luminance and gamma values at various angles						
Level designation	**Grey level, V_j**	**Grey scale from different angles (q) ***				
		Normal, L_j	**Left, q_L**	**Right, q_R**	**Up, q_U**	**Down, q_D**
		0°	-20°	20°	20°	-20°
White (9)	255	555,7	181,2	180,3	160,8	164,7
Level 8	224	415,5	131,9	133,8	117,6	125,3
Level 7	192	293,6	102,7	105,8	93,9	101,3
Level 6	160	194,9	78,3	82,2	73,6	80
Level 5	128	115,1	54,7	58,7	53,8	58,2
Level 4	96	60,83	37,24	40,23	38,12	40,83
Level 3	64	23,53	22,47	24,14	24	25,06
Level 2	32	4,488	8,75	9,535	9,918	10,03
Black (1)	0	0,031	0,058	0,056	0,073	0,067
Gammas:		2,29	1,4	1,36	1,28	1,30
$G_{DR,i}$ (%)			38,86	40,61	44,1	43,23
$G_{DR} = \max(G_{DR,i})$ (%)			44,1			

Annex D
(informative)

Translation of RGB input signal to output colours

Tables D.1, D.2, D.3 and D.4 show examples of test colours and can be used for the translation of test colours.

Table D.1 – Test colours

Index No.	Macbeth No.		X ±0,002	Y ± 0,002	Z ±0,002	x ± 0,002	y ± 0,002
10	#1	Dark skin	0,107 9	0,097 0	0,060 6	0,410 4	0,362 9
11	#2	Light skin	0,381 2	0,355 8	0,259 2	0,382 6	0,357 2
12	#3	Blue sky	0,178 6	0,190 8	0,345 2	0,249 9	0,267 0
	#4	Foliage	0,101 0	0,129 8	0,066 9	0,339 3	0,436 0
11	#8	Purplish blue	0,134 2	0,117 6	0,372 3	0,215 0	0,188 4
8	#9	Moderate red	0,284 5	0,192 2	0,137 5	0,463 2	0,312 9
10	#10	Purple	0086 8	0,065 2	0,146 9	0,290 4	0,218 1
13	#11	Yellow green	0,332 0	0,436 6	0,111 9	0,377 1	0,495 9
	#12	Orange yellow	0,461 7	0,431 2	0,084 0	0,472 6	0,441 4
6	#13	D blue	0,084 0	0,062 2	0,300 0	0,188 2	0,139 4
5	#14	D green	0,145 0	0,235 8	0,095 1	0,304 7	0,495 5
4	#15	D red	0,201 7	0,118 2	0,052 0	0,542 3	0,317 8
7	#16	D yellow	0,560 5	0,596 4	0,095 6	0,447 5	0,476 2
8	#17	Magenta	0,294 2	0,192 7	0,302 9	0,372 5	0,244 0
9	#18	D cyan	0,144 7	0,198 7	0,395 2	0,195 9	0,269 0
1	#19	White	0,839 8	0,887 6	0,923 5	0,316 8	0,334 8
15	#21	Grey36		0,362 0		0,310 0	0,316 0
2	#22	Grey19	0,193 1	0,203 1	0,221 6	0,312 6	0,328 7
14	#23	Grey10	0,087 8	0,092 6	0,102 4	0,310 4	0,327 4

Table D.2 – RGB translation values for 8-bit colour (BT.2020 colour reference)

Colour	*x*	*y*	*R*_linear(%)	*G*_linear(%)	*B*_linear(%)	8 bits			SMPTE-303M (D65)		
						R'	*G'*	*B'*	*X*	*Y*	*Z*
Dark skin	0,410 4	0,362 9	13,85	8,46	5,49	104	83	68	10,97	9,70	6,06
Light skin	0,382 6	0,357 2	46,22	32,51	23,57	180	154	133	38,12	35,58	25,92
Blue sky	0,249 9	0,267 0	15,13	19,48	32,02	108	121	152	17,86	19,08	34,52
Foliage	0,339 3	0,436 0	11,03	14,35	5,93	94	106	71	10,10	12,98	6,69
Blue flower	0,270 4	0,255 2	24,19	22,90	42,11	134	130	172	25,83	24,38	45,32
Bluish green	0,263 5	0,360 0	27,16	48,93	40,83	141	184	170	31,27	42,73	44,69
Orange	0,508 7	0,409 1	50,67	23,18	4,94	187	131	65	36,46	29,32	5,89
Purple blue	0,215 0	0,188 4	9,42	10,65	34,81	87	92	158	13,42	11,76	37,23
Moderate red	0,463 2	0,312 9	38,52	12,32	12,63	165	98	100	28,45	19,22	13,75
Purple	0,290 4	0,218 1	8,86	4,98	13,71	85	65	104	8,68	6,52	14,69
Yellow green	0,377 1	0,495 9	38,63	48,62	9,26	165	184	86	33,20	43,66	11,19
Orange yellow	0,472 6	0,441 4	61,79	39,05	6,88	205	166	76	46,17	43,12	8,40
Blue	0,188 2	0,139 4	4,61	4,93	28,15	63	65	143	8,40	6,22	30,00
Green	0,304 7	0,495 5	14,10	28,60	8,21	105	144	82	14,50	23,58	9,51
Red	0,542 3	0,317 8	29,10	5,74	4,75	146	70	64	20,17	11,82	5,20
Yellow	0,447 5	0,476 2	72,58	59,19	7,44	220	201	78	56,05	59,64	9,56
Magenta	0,372 5	0,244 0	35,98	12,01	28,23	160	97	144	29,42	19,27	30,29
Cyan	0,195 9	0,269 0	7,76	23,10	36,64	80	131	162	14,47	19,87	39,52
White	0,316 8	0,334 8	89,20	88,95	84,69	242	242	236	83,98	88,76	92,35
Neutral 8	0,314 6	0,331 4	59,06	58,90	57,70	201	200	199	55,88	58,87	62,87
Neutral 6.5	0,313 8	0,331 0	35,51	35,55	34,98	159	159	158	33,67	35,51	38,11
Neutral 5	0,313 2	0,330 3	19,27	19,33	19,12	121	121	120	18,3	19,3	20,83
Neutral 3.5	0,313 1	0,330 5	8,38	8,41	8,32	83	83	82	7,96	8,4	9,06
Black	0,314 4	0,327 8	2,99	2,93	2,96	52	51	51	2,83	2,95	3,22

Translation to 8-bit RGB input signals can be taken from Table D.2 but the translation can leave more room for error (e.g. gamma correction). It is preferred to verify the target colour by measurement.

In Table D.3 and Table D.4, the corresponding values for 10-bit BT.2020 and 10-bit BT.709 can be found.

Table D.3 – RGB translation values for 10-bit colour (BT.2020 colour reference)

Colour	x	y	R_linear(%)	G_linear(%)	B_linear(%)	Gamma corrected (γ = 2,2, 10 bits)			SMPTE-303M (D65)		
						R'	G'	B'	X	Y	Z
Dark skin	0,410 4	0,362 9	13,85	8,46	5,49	416	333	273	10,97	9,70	6,06
Light skin	0,382 6	0,357 2	46,22	32,51	23,57	720	614	530	38,12	35,58	25,92
Blue sky	0,249 9	0,267 0	15,13	19,48	32,02	434	486	610	17,86	19,08	34,52
Foliage	0,339 3	0,436 0	11,03	14,35	5,93	376	423	283	10,10	12,98	6,69
Blue flower	0,270 4	0,255 2	24,19	22,90	42,11	537	524	690	25,83	24,38	45,32
Bluish green	0,263 5	0,360 0	27,16	48,93	40,83	566	739	681	31,27	42,73	44,69
Orange	0,508 7	0,409 1	50,67	23,18	4,94	751	526	261	36,46	29,32	5,89
Purple blue	0,215 0	0,188 4	9,42	10,65	34,81	350	370	633	13,42	11,76	37,23
Moderate red	0,463 2	0,312 9	38,52	12,32	12,63	663	395	399	28,45	19,22	13,75
Purple	0,290 4	0,218 1	8,86	4,98	13,71	340	262	415	8,68	6,52	14,69
Yellow green	0,377 1	0,495 9	38,63	48,62	9,26	664	737	347	33,20	43,66	11,19
Orange yellow	0,472 6	0,441 4	61,79	39,05	6,88	822	667	303	46,17	43,12	8,40
Blue	0,188 2	0,139 4	4,61	4,93	28,15	253	260	575	8,40	6,22	30,00
Green	0,304 7	0,495 5	14,10	28,60	8,21	420	579	328	14,50	23,58	9,51
Red	0,542 3	0,317 8	29,10	5,74	4,75	584	279	256	20,17	11,82	5,20
Yellow	0,447 5	0,476 2	72,58	59,19	7,44	884	806	314	56,05	59,64	9,56
Magenta	0,372 5	0,244 0	35,98	12,01	28,23	643	390	576	29,42	19,27	30,29
Cyan	0,195 9	0,269 0	7,76	23,10	36,64	320	525	648	14,47	19,87	39,52
White	0,316 8	0,334 8	89,20	88,95	84,69	971	970	949	83,98	88,76	92,35
Neutral 8	0,314 6	0,331 4	59,06	58,90	57,70	805	804	797	55,88	58,87	62,87
Neutral 6.5	0,313 8	0,331 0	35,51	35,55	34,98	639	639	635	33,67	35,51	38,11
Neutral 5	0,313 2	0,330 3	19,27	19,33	19,12	484	485	482	18,3	19,3	20,83
Neutral 3.5	0,313 1	0,330 5	8,38	8,41	8,32	331	332	330	7,96	8,4	9,06
Black	0,314 4	0,327 8	2,99	2,93	2,96	208	206	206	2,83	2,95	3,22

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [M] \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$, where

$[M]$ RGB (BT.2020) → XYZ		
0,636 958	0,144 617	0,168 881
0,262 700	0,677 998	0,059 302
0,000 000	0,028 073	1,060 985

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = [M]^{-1} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$, where

$[M]^{-1}$ XYZ → RGB (BT.2020)		
1,716 651	-0,355 671	-0,253 366
-0,666 684	1,616 481	0,015 769
0,017 640	-0,042 771	0,942 103