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Ergonomic requirements for work with visual displays based on flat panels —

Part 2: Ergonomic requirements for flat panel displays

Exigences ergonomiques pour travail sur écrans de visualisation à panneau plat —

Partie 2: Exigences ergonomiques des écrans à panneau plat

Reference number
ISO 13406-2:2001(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 13406 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 13406-2 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

ISO 13406 consists of the following parts, under the general title *Ergonomic requirements for work with visual displays based on flat panels*:

- *Part 1: Introduction*
- *Part 2: Ergonomic requirements for flat panel displays*

Annexes A, B and C of this part of ISO 13406 are for information only.

Introduction

ISO 13406 extends its companion standard ISO 9241 to account for the significant differences in ergonomic trade offs present when flat panels are used.

The rationale for this part of ISO 13406 is presented in ISO 13406-1.

This part of ISO 13406 presents the requirements for visual display units (VDUs) based on flat panels as defined in ISO 13406-1. It is intended for evaluators and users of this technology. Some document users will find part of the material complex. Notes, figures and examples are provided to lessen the problem. The legibility of flat panels is a principal concern. The requirements are primarily based on the visual ergonomic research used in ISO 9241-3 and on new research referenced in this part of ISO 13406. Here, as in ISO 9241-3, some requirements are based on visual comfort, muscular comfort and user acceptability. This part of ISO 13406 includes requirements and recommendations that are based on legibility, comfort and acceptability that arise when multicolour displays are used, based on the visual ergonomic research described in ISO 9241-8, but modified and extended to consider the unique trade offs of flat panels. Legibility in the presence of ambient room light and the acceptability of unwanted reflected images are addressed covering the flat panel aspects covered in ISO 9241-7 for cathode ray tube (CRT) technology.

Clause 3 Definitions presents or recalls those terms needed to specify requirements and measurements. Where possible, definitions taken from other publications are quoted verbatim. If some change has been made, the definition is followed by a note stating “Adopted from ISO xxxx:date,x.x”. Since this part of ISO 13406 often relies on mathematical models and physical measurements to ensure the fitness of purpose of flat panel VDUs, a clause 8 (Symbols) is presented as a convenient reference.

Guiding principles and performance requirements’ clauses modelled on ISO 9241-3 are presented to remind document users of the foundations of the work.

Design requirements and recommendations present the physical attributes that are to be strictly followed to conform (indicated by the word: shall) or preferred but not necessarily required (indicated by the word: should). The topics of design viewing distance, design viewing direction and design screen illumination depart somewhat from the precedents of ISO 9241-3. Two reasons exist:

a) an important type of flat panel has viewing characteristics that require more careful control and consideration of viewing direction than considered in ISO 9241-3;

b) there is no basis to assume that a flat panel VDU is tabletop mounted. These topics are presented as ergonomically constrained, supplier-specifications. This is not unprecedented, viewing distance was handled this way in ISO 9241-3. Once specified, these requirements become the conditions under which all other attributes are to be measured or decided.

A departure from ISO 9241-3 is the use of area-luminance. For CRT technology, the addressed locations are generally close together so that a *high-low-high-low-high-low*-pixel pattern will exhibit less contrast than a sparse pattern. Since the flat-panel pixel area is less than 100 % optically modulated (the fill factor is less than 1), the difference between sparse and dense pattern contrast is minor. The luminance determination has to be complicated by the need for viewing direction precision. The use of area-luminance simplification offsets that somewhat.

Some requirements are presented in categories. For example, some flat panels exhibit long image-formation times. For static images, such panels are ergonomically acceptable without reservation. Not all modern applications rely solely on such static images. Requirement categories are therefore established. If the supplied equipment has such a limitation, the supplier/evaluator is required to identify it. The system integrator, purchaser or user then can consider whether the category is consistent with intended applications.

Clause 8 covering measurements is intended for evaluators of flat panel VDUs. The panel surface is sampled for evaluation. Three evaluation sites are chosen and measured, and compliance decisions can be made from these measurements. Panels with large requirement margins do not require precision-evaluation equipment but panels with small margins can.

Clause 9 covering compliance is closely modelled on ISO 9241-3. The alternative test (Visual performance and comfort test) prepared as a normative annex in an amendment to ISO 9241-3, is cited as an alternative compliance route.

Annex A provides additional information on colour difference. Annex B extends the analytic flicker determination method of ISO 9241-3 to luminance-time modulation that is not CRT-like. Annex C informs the users of this International Standard of new work on an alternate modelling method for screens with reflection properties that cannot be adequately modelled with a simple combination of luminance coefficient (diffuse reflection) and luminance factor (specular or regular reflection) and standardized assumptions about the environment. This method develops the bidirectional reflection distribution function. When this work progresses further, it can possibly become a normative method and replace the method in clause 8. The bibliography cites references.

Ergonomic requirements for work with visual displays based on flat panels —

Part 2:
Ergonomic requirements for flat panel displays

1 Scope

This part of ISO 13406

- establishes ergonomic image-quality requirements for the design and evaluation of flat panel displays,
- defines terms needed to address image quality on flat panel displays,
- specifies methods of determining image quality on flat panel displays, and
- establishes ergonomic principles for guiding these requirements.

This part of ISO 13406 is applicable to

- flat panel display screens when used to perform office tasks,
- flat panel display screens that consist of a regular array of picture elements arranged in evenly spaced rows without built-in gaps,
- the presentation of fonts based on Latin-, Cyrillic- and Greek-origin alphabetic characters and Arabic numerals on flat panel display screens,
- the presentation of Asian characters, and
- flat panel display screens that are large enough to display at least 40 Latin-origin characters.

This part of ISO 13406 is not applicable to

- flat panel technology applied to a display that uses optics to form an image that is not the same size as the electro-optical transducer (projection applications of flat panel displays), or
- flat panel technology applied to a display limited to fixed-messages or segmented alphanumerics. [See 2.13 IEC SC 47C (Central Office) 3:1992].

NOTE Some of the measurement methods (e.g. contrast and luminance) in this part of ISO 13406 are not applicable for reflective flat panels. When technology has developed, appropriate measurement methods will be added to this part of ISO 13406.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 13406. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 13406 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

CIE Publication No. 15.2:1986, *Colorimetry*. (Central Bureau of the Commission International d'Éclairage CIE), Vienna, Austria.

ISO 9241-3:1992, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 3: Visual display requirements*.

ISO 9241-6, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 6: Guidance on the work environment.*

ISO 9241-7, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 7: Requirements for display with reflections*.

ISO 9241-8:1997, *Ergonomic requirements for office work with visual display terminals (VDTs) — Part 8: Requirements for displayed colours.*

3 Definitions

For the purposes of this part of ISO 13406, the following definitions apply.

NOTE The symbols used in certain definitions are explained in clause 4.

3.1 Photometry

3.1.1
area-luminance
luminance of an area of the screen that has a diameter of at least 10 pixels, such that the state of an individual pixel has less than 2 % effect

NOTE Area-luminance is expressed in candelas per square metre (cd/m^2).

3.1.2
background luminance
luminance of an area of the screen with no graphic images present

NOTE Background luminance is expressed in candelas per square metre (cd/m^2).

3.1.3
contrast
⟨in a perceptual sense⟩ assessment of the difference in appearance of two or more parts of a field seen simultaneously or successively (hence: brightness contrast, lightness contrast, colour contrast, etc.)

NOTE Adapted from IEC 60050 (845-02-47):1987.

3.1.4
EUT
Equipment Under Test

3.1.5
Lambert's (cosine) law

for a surface element whose radiance or luminance is the same in all directions of the hemisphere above the surface:

$$I(\theta) = I_n \cos(\theta) \tag{1}$$

Where $I(\theta)$ and I_n are the radiant or luminous intensities of the surface element in a direction at an angle θ from the normal to the surface and in the direction of that normal, respectively

[IEC 60050 (845-04-56):1987]

3.1.6
Lambertian surface

ideal surface for which the radiation coming from that surface is distributed angularly according to Lambert's cosine law

[IEC 60050 (845-04-57):1987]

For an ideal diffuse reflectance standard:

$$\rho_{\mathrm{STD}} = \pi \cdot q_{\mathrm{STD}} \tag{2}$$

3.1.7
luminance contrast

ratio between the higher, L_H and lower, L_L, luminances that define the feature to be detected, measured by contrast modulation (C_m) defined as:

$$C_\mathrm{m} = \frac{L_\mathrm{H} - L_\mathrm{L}}{L_\mathrm{H} + L_\mathrm{L}} \tag{3}$$

or contrast ratio (CR), defined as:

$$\mathrm{CR} = \frac{L_\mathrm{H}}{L_\mathrm{L}} \tag{4}$$

NOTE 1 For flat panels, area-luminance targets can be used to approximate the luminances that define the feature to be detected because pixels are discrete.

NOTE 2 Adapted from ISO 9241-3:1992, 2.22.

3.1.8
luminance coefficient (at a surface element, in a given direction, under specified conditions of illumination)

q_v, q

quotient of the luminance of the surface element in the given direction by the illuminance of the medium

NOTE 1 The luminance coefficient is expressed in reciprocal steradians.

NOTE 2 Adapted from IEC 60050 (845-04-71):1987.

$$q = \frac{L}{E} \tag{5}$$

3.1.9
luminance factor (at a surface element of a non-self-radiating medium, in a given direction, under specified conditions of illumination)

β_v, β

ratio of the luminance of the surface element in the given direction to that of a perfect reflecting or transmitting diffuser identically illuminated

$$\beta = \frac{L_{\text{sample}}}{L_{\text{perfect diffuser}}} \tag{6}$$

NOTE 1 The luminance factor is expressed as unit: 1

NOTE 2 Adapted from IEC 60050 (845-04-69):1987.

3.1.10
optically anisotropic surface

optical surface for which the radiation deviates from that of a Lambertian surface by more than 10 % at any inclination angle, $\theta < 45°$

3.2 Colorimetry

3.2.1
CIE 1976 $L^*u^*v^*$ colour space
CIELUV colour space

three-dimensional, approximately uniform colour space produced by plotting in rectangular coordinates L^*, u^*, v^* quantities defined by the three equations:

$$\left.\begin{array}{l} L^* = 116\,(Y/Y_n)^{\frac{1}{3}} - 16, \text{ when } Y/Y_n > 0{,}008\,856 \\ L^* = 903{,}3(Y/Y_n), \text{ when } Y/Y_n \leqslant 0{,}008\,856 \\ u^* = 13L^*(u' - u'_n) \\ v^* = 13L^*(v' - v'_n) \end{array}\right\} \tag{7}$$

Y, u', v' describe the colour stimulus considered and Y_n, u'_n, v'_n describe a specified white achromatic stimulus.

NOTE Approximate correlates of lightness, saturation, chroma and hue may be calculated as follows:

$$\text{CIE 1976 } u, v \textit{ saturation } s_{uv} = 13\left[\left(u' - u'_n\right)^2 + \left(v' - v'_n\right)^2\right]^2 \tag{8}$$

$$\text{CIE 1976 } u, v \textit{ chroma } C^*_{uv} = \left[u^{*2} + v^{*2}\right]^{\frac{1}{2}} = L^* s_{uv} \tag{9}$$

$$\text{CIE 1976 } u, v \textit{ hue-angle} \quad \begin{array}{c} h_{uv} = \arctan\left(\dfrac{v' - v'_n}{u' - u'_n}\right) = \arctan\left(\dfrac{v^*}{u^*}\right), \text{ such that} \\ 0° \leqslant h_{uv} < 90°, \ \textit{if} \ \ v^* \geqslant 0 \ \text{ and } u^* \geqslant 0 \\ 90° \leqslant h_{uv} < 180°, \ \textit{if} \ \ v^* \geqslant 0 \ \text{ and } u^* < 0 \\ 180° \leqslant h_{uv} < 270°, \ \textit{if} \ \ v^* < 0 \ \text{ and } u^* < 0 \\ 270° \leqslant h_{uv} < 360°, \ \textit{if} \ \ v^* < 0 \ \text{ and } u^* \geqslant 0 \end{array} \tag{10}$$

[IEC 60050 (845-03-54)]

3.2.2

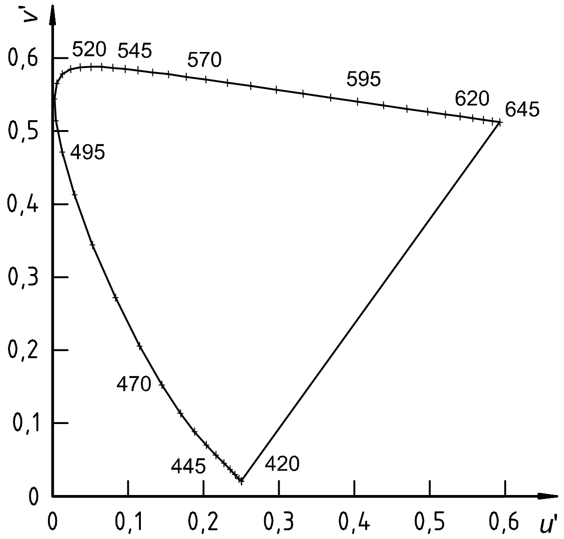
CIE 1976 uniform-chromaticity scale diagram

CIE 1976 UCS diagram

uniform-chromaticity-scale diagram produced by plotting in rectangular coordinates v' against u', quantities defined by the equations (11):

$$u' = \frac{4X}{X + 15Y + 3Z} = \frac{4x}{-2x + 12y + 3}$$
$$v' = \frac{9Y}{X + 15Y + 3Z} = \frac{9y}{-2x + 12y + 3} \qquad (11)$$

See Figure 1 and IEC 60050 (845-03-53).



NOTE The curve annotations are wavelengths in nanometers.

Figure 1 — CIE 1976 UCS Diagram

3.2.3

CIE 1976 $L^*u^*v^*$ colour difference

CIELUV colour difference

difference between two colour stimuli, defined as the Euclidean distance between the points representing them in the $L^*u^*v^*$ space and calculated as equation:

$$\Delta E^*_{uv} = \left[\left(\Delta L^*\right)^2 + \left(\Delta u^*\right)^2 + \left(\Delta v^*\right)^2 \right]^{\frac{1}{2}} \qquad (12)$$

The set X_n Y_n Z_n and corresponding u'_n v'_n define the colour of the nominally white object-colour stimulus.

(See CIE Publication No. 15.2.)

[IEC 60050 (845-03-55)]

3.2.4
chromaticity uniformity difference

distance on the CIE 1976 UCS diagram

$$\Delta u'v' = \sqrt{(u'_1 - u'_2)^2 + (v'_1 - v'_2)^2} \tag{13}$$

where

u'_1, v'_1 and u'_2, v'_2 are the coordinates of the same colour displayed at sites 1 and 2.

NOTE This is the appropriate measure of colour uniformity if luminance is not uniform or if the objects are not adjacent. (See 3.2.2.)

3.2.5
dominant wavelength of a colour stimulus, λ_d

wavelength of the monochromatic stimulus that, when additively mixed in suitable proportions with the specified achromatic stimulus, matches the colour stimulus considered

NOTE In the case of purple stimuli, the dominant wavelength is replaced by the complementary wavelength. See IEC 60050 (845-03-44).

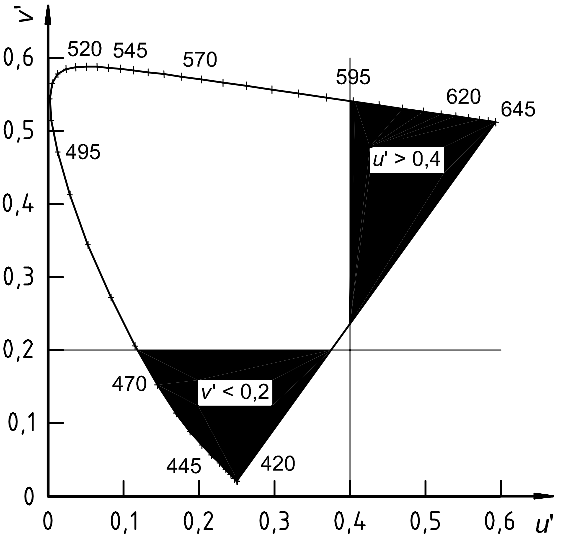
3.2.6
same dominant wavelength

two colours have the same dominant wavelength if the difference between the hue angles of each colour is small

3.2.7
spectrally extreme colours

spectrally extreme colours are extreme blue and extreme red

NOTE Extreme blue is any colour with $v' < 0{,}2$. Extreme red is any colour with $u' > 0{,}4$. The extreme regions are illustrated in Figure 2.



NOTE The curve annotations are wavelengths in nanometers.

Figure 2 — Extreme red and extreme blue

3.2.8
uniform colour space
colour space in which equal distances are intended to represent a threshold or suprathreshold perceived colour differences of equal size

[IEC 60050 (845-03-51):1987]

3.2.9
uniform-chromaticity-scale diagram
UCS diagram
two-dimensional diagram in which the coordinates are defined with the intention of making equal distances represent as nearly as possible equal steps of colour discrimination for colour stimuli of the same luminance throughout the diagram

[IEC 60050 (845-03-52):1987]

3.3 Geometry

3.3.1
active area
part of a display screen area delimited by picture elements [*2.1*, IEC SC 47C(Central Office) 3]

3.3.2
angular subtence
size of a visual target at a specified viewing distance, e.g. at the design viewing distance

$$\text{Angular subtence in degrees} = 2 \arctan \left(\frac{\text{target height}}{2 \times \text{viewing distance}} \right) \tag{14}$$

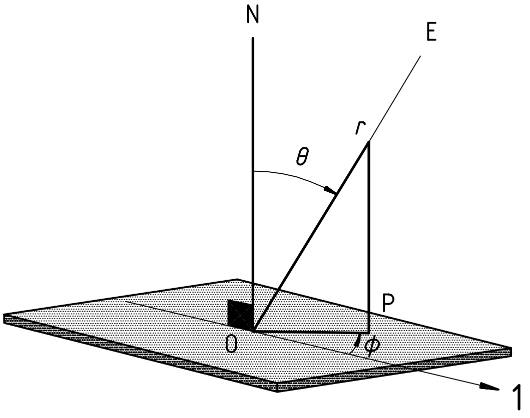
$$\begin{aligned} \text{Angular subtence in minutes of arc} &= 60 \times 2 \arctan \left(\frac{\text{target height}}{2 \times \text{viewing distance}} \right) \\ &\approx \frac{3\,438 \times \text{target height}}{\text{viewing distance}} \end{aligned} \tag{15}$$

NOTE The dimension for angular subtence is degrees (°), which is further divided into minutes of arc (′) and seconds of arc (″).

3.3.3
anisotropic display
display (usually a liquid crystal display) with emitted luminance and/or luminance coefficient that meets the criterion in 3.1.10

3.3.4
coordinate system
a normal spherical coordinate system (r, θ, ϕ)

See Figure 3.



Key

E Position of the entrance pupil of the luminance meter

OE = *r* Working distance

1 $\phi = 0°$ (3 o'clock)

NOTE 1 In some literature, the azimuth is specified by clock positions. 3 o'clock is defined as $\phi = 0°$.

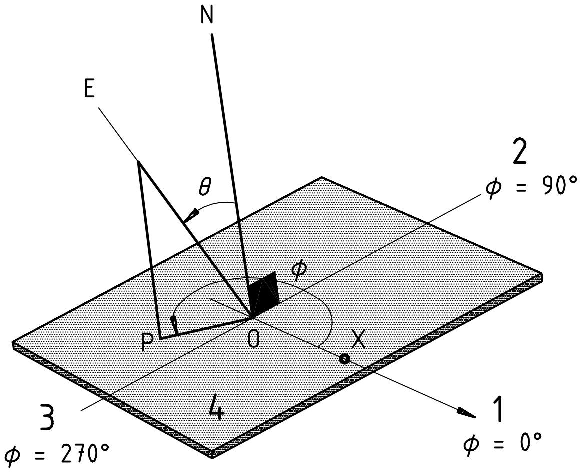
NOTE 2 Normally only positive values for θ are used. $(-\theta, \phi)$ is identical to the direction $(+\theta, \phi \pm 180°)$.

Figure 3 — Coordinate system

NOTE 1 The following is a detailed definition of the coordinate system. See Figure 4.

Let a point (pixel or centre of a visual target) be labelled O. Construct a line, from O to the entrance pupil of the measuring instrument, OE, and a line, ON normal to the image plane of the display. The angle from ON to OE in the ON - OE plane is the inclination angle, θ. The distance OE is the radius r.

Let P be any point on the line that is formed by the projection of OE on the image plane. Construct a line, OX in that plane to the right of and parallel to the line that bisects the active area horizontally. This is the X axis. The azimuth angle, ϕ, is the counterclockwise angle between OX and OP.



Key

1 3 o'clock; right edge of the screen as seen from the user

2 12 o'clock; top edge of the screen as seen from the user

3 6 o'clock; bottom edge of the screen as seen from the user

4 Image surface of the screen

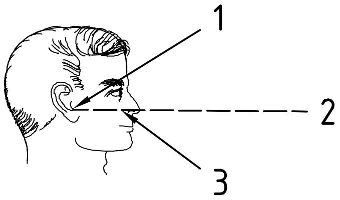
Figure 4 — Coordinate system - definition

NOTE 2 For more information on coordinates and viewing angles, see VESA Flat Panel Display Measurements Standards (1998), chapter 300-2.

3.3.5
Frankfort plane

is an imaginary plane through the head established by the lateral extensions of a line between the tragion and the lowest point of the orbit

See Figure 5.



Key

1 Tragion

2 Frankfort plane

3 Inferior ridge of the orbit

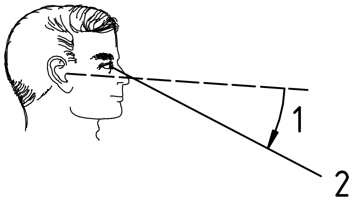
Orbit is the cavity in the skull that contains the eye. Tragion (or tragus) is the projection of cartilage in the pinna of the outer ear that extends back over the opening of the external auditory meatus.

Figure 5 — Frankfort plane

3.3.6
gaze angle

angle from the Frankfort plane to the plane formed by the pupils and the visual target

See Figure 6.



Key

1 Gaze angle

2 Line of sight

Figure 6 — Gaze angle

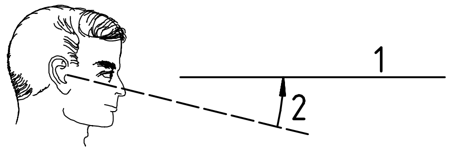
NOTE The comfortable range is about 0° to about 45°.

3.3.7
head tilt angle

angle from the Frankfort plane to the horizontal plane and due to tilt of the head

NOTE When the head is erect, the head tilt angle is about 4°

See Figure 7.



Key

1 Horizontal plane

2 Head tilt angle

Figure 7 — Head tilt angle

NOTE The comfortable range is about 0° to about 20°.

3.3.8
viewing angle range
conical space originating at a pixel that includes all viewing directions for which specifications are satisfied

[IEC SC 47C (Central Office) 3]

3.4 Display technology

3.4.1
fill factor
fraction (of the total area geometrically available to a pixel) that can be altered to display information

[ISO 9241-3:1992, 2.15]

3.4.2
emissive display
display that contains its own source(s) of light

NOTE 1 This light can be produced by the transducer itself or provided by one or more internal light source(s) modulated by the transducer.

NOTE 2 Adapted from 2.4, IEC/SC 47C (Central Office) 3.

3.4.3
gray scale
a display is said to have gray scale if it can display images demanding more than two luminance levels

[2.4, IEC/SC 47C (Central Office) 3]

3.4.4
image formation time
time for the relative luminance of a visual object to change from 0,1 to 0,9

NOTE 1 The relative luminance is

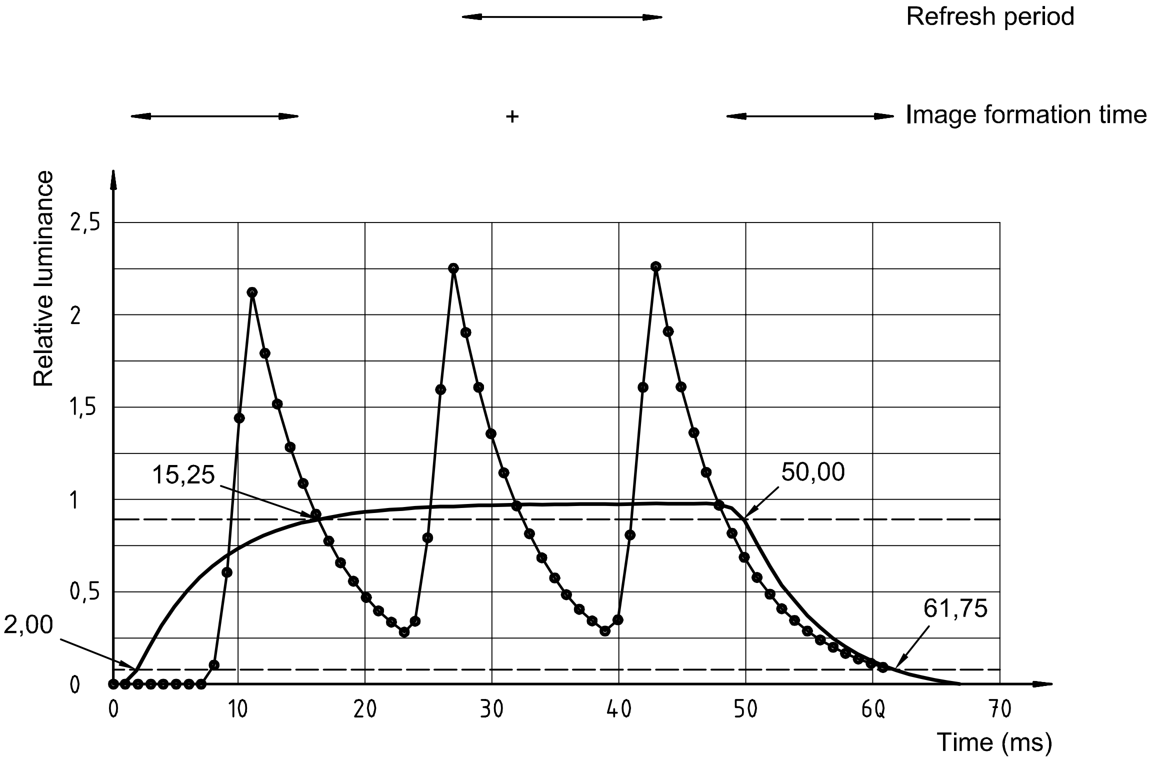
$(L - L_{\mathrm{MAX}})/(L_{\mathrm{MAX}} - L_{\mathrm{MIN}})$;

where

L_{MAX} and L_{MIN} are the time averaged highest and lowest luminance states, respectively;

L is the instantaneous luminance.

NOTE 2 The relative luminance is filtered to eliminate temporal variations that are not visually detectable. Image formation time is resolved to the ranges shown in Table 1 and is expressed in milliseconds.



NOTE 1 This illustrates a typical case.

NOTE 2 A constant-luminance back light is assumed (after prefiltering for 4kS/s sampling).

NOTE 3 Figure 8 illustrates the image formation time. The trace with the marks represents the unfiltered luminance time, normalized to a range of 1,0. The bold trace is the first trace filtered to include those frequencies that are psychophysically significant. The image formation time is judged on this trace. In this example, t_1 = 2,00 ms is the time recorded at 0,1 of the maximum luminance with the luminance increasing; t_2 = 15,25 ms is the time recorded at 0,9 of the maximum luminance with the contrast increasing; t_3 = 50,00 ms, is the time recorded at 0,9 of the maximum luminance with the luminance decreasing; and, t_4 = 61,75 ms is the time recorded at 0,1 of the maximum luminance with the luminance decreasing. Image formation time is $t_2 - t_1 + (t_4 - t_3)$ = 25 ms. The luminance time is sampled at 4 kS/s, so the precision is ± 0,5 ms.

NOTE 4 For flat panel displays with very fast electro-optic physics, the refresh period is the image formation time.

Figure 8 — Image formation time

Table 1 — Image formation time in milliseconds

Time range	Significance
$t \leqslant 10$	Motion artefacts become undetectable at image formation times less than 3 ms.
$10 < t \leqslant 55$	Contrast is stable for most applications. Motion artefacts can be distracting.
$55 < t \leqslant 200$	Applications using scrolling, animation and pointing devices lose detectable contrast. Blink coding from 0,33 Hz to 5 Hz is operable.
$t > 200$	Noticeable loss of contrast observed during key entry, scrolling, animation, and blink coding. Pointing devices with rapid cursor positioning can be used only with special techniques.

3.4.5
absolute luminance coding

information presented where the only dimension that is used for visual differentiation is difference in image luminances

3.4.6
relative luminance coding

information presented where either the coded images are touching or the luminance difference is secondary to a primary differentiation such as shape or colour

3.4.7
pixel

smallest element that is capable of generating the full functionality of the display

3.4.8
pixel pitch

the distance between corresponding points on adjacent pixels, both horizontally (H_{pitch}) and vertically (V_{pitch})

NOTE Pixel pitch is expressed in millimetres.

3.4.9
reflective display

display device that modulates light from an external source by reflection

[*2.12*, IEC 47 CO 2]

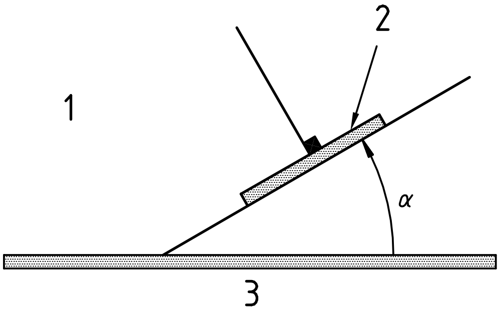
3.4.10
screen tilt angle

α

angle formed by the intersection of the plane tangent to the centre of the display and the horizontal plane

NOTE Screen tilt angle is expressed in degrees.

See Figure 9.



Key

1 Viewing side

2 Display

3 Horizontal surface (e.g. a table)

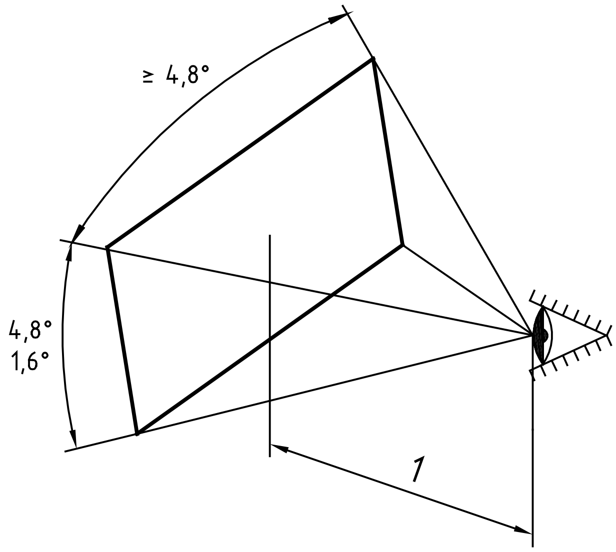
Figure 9 — Screen tilt angle, α

NOTE α is identical to the angle, A in 6.1.2 of ISO 9241-3:1992.

3.4.11
small-size panel

a flat panel with a viewing area with the smallest dimension in the range of 1,6° to 4,8° at the design viewing distance and with the largest dimension of at least 4,8° at the design viewing distance

See Figure 10.



Key

1 Design viewing distance

Figure 10 — Small-size panel

NOTE 1 Smaller panels will not hold more than 40 complying Latin characters and are outside the scope of the standard. The definition is used in screening and selecting measurement locations only. See *8.4.2* Standard measurement locations.

NOTE 2 For a viewing distance of 500 mm, 1,6° = 14 mm; 4,8° = 42 mm.

3.4.12
subpixel

a separately addressed internal structure in a pixel that extends the pixel function

NOTE Examples include primary colour subpixels used in some multicolour flat panels and multiple-size subpixels, used to create half-tone-like gray scale effects. Microstructure within primary subpixels is sometimes used to minimize anisotropy or to minimize fault visibility by adding redundancy in flat panels. Such microstructures are still called subpixels in this part of ISO 13406. Display engineering literature often uses the term “dot” which is not used in this part of ISO 13406.

3.4.13
pixel faults

local defects of types 1, 2 or 3

See Tables 2 and 3.

Table 2 — Pixel faults

Fault type	**Description**
Type 1 fault	Pixel in stuck high state (when system command = minimum luminance) ($L > 0{,}75\ L_X + 0{,}25\ L_N$)
Type 2 fault	Pixel in stuck low state (when system command = maximum luminance) ($L < 0{,}75\ L_N + 0{,}25\ L_X$)
Type 3 fault	Pixel or subpixel is abnormal, but not of type 1 or 2. For example, a stuck subpixel or intermittent fault.
Fault cluster	Two or more pixels or subpixels with faults within a 5 × 5 block of pixels.

L is the measured luminance of the pixel.

L_X is the average pixel response to a maximum luminance command (e.g. white).

L_N is the average pixel response to a minimum luminance command (e.g. black).

Table 3 — Definition of fault classes, $\text{Class}_{\text{Pixel}}$

Maximum number of faults per type per million pixels					
Class	**Type 1**	**Type 2**	**Type 3**	Cluster with more than one type 1 or type 2 faults	Cluster of type 3 faults
I	0,000	0,000	0,000	0,000	0,000
II	2,000	2,000	5,000	0,000	2,000
III	5,000	15,00	50,00	0,000	5,000
IV	50,00	150,0	500,0	5,000	50,00

3.4.14
transflective display
display device that modulates light from an external source by reflection and from another source by transmission through a semitransmissive reflector

[*2.15*, IEC/SC 47C (Central Office) 3]

3.4.15
transmissive display
display that modulates light from an external source by transmission

NOTE If the display has a built-in light source, this part of ISO 13406 treats the display as emissive, not transflective, and not transmissive.

[*2.16*, IEC SC 47C (Central Office) 3]

3.4.16
viewing area
active area plus any contiguous areas that display permanent visual information or display background

[*2.18*, IEC SC 47C (Central Office) 3]

3.5 Alphanumeric symbols

NOTE In keeping with the guiding principle that this part of ISO 13406 values consistency with ISO 9241-3, where appropriate, these definitions are identical to those contained in ISO 9241-3. If there is a departure from the original definition, the definition is followed by a note stating “Adapted from ISO 9241-3...”. Departures are based on the use of whole pixel spaces to judge object sizes. It is now common to have the capability to display more than one character font design. This change results in an acceptably small error, but allows many fonts to be evaluated without complex laboratory work.

3.5.1

anti-aliased font

alphanumeric characters in which a technique has been utilized to smooth character edges

[ISO 9241-3:1992, 2.2]

3.5.2

between-character space

distance between horizontally adjacent characters at their nearest points in whole pixel spaces

NOTE 1 Between-character space is expressed in pixels.

NOTE 2 Adapted from ISO 9241-3:1992, 2.3.

3.5.3

between-line spacing

distance between vertically adjacent characters at their nearest points in whole pixel spaces

NOTE 1 Between-line spacing is expressed in pixels.

NOTE 2 Adapted from ISO 9241-3:1992, 2.4.

3.5.4

between-word spacing

horizontal distance between adjacent words at their nearest points in whole pixel spaces

NOTE 1 Between-word spacing is expressed in pixels.

NOTE 2 Adapted from ISO 9241-3:1992, 2.5.

3.5.5

character format

number of horizontal and vertical elements (pixels) in the matrix used to form a single character

NOTE 1 Character format is expressed in pixels.

NOTE 2 Adapted from ISO 9241-3:1992, 2.7.

3.5.6

character height

ψ

distance, as the subtended angle, of the spaces in whole pixel between the top and bottom edges of a non-accented capital letter H

NOTE 1 Character height is expressed in degrees.

NOTE 2 Adapted from ISO 9241-3:1992, 2.8.

$$\psi = \frac{180 \times 60 \times V_{\text{pitch}} \times N_{\text{H,Height}}}{\pi \times D_{\text{view}}} \qquad (16)$$

$$\approx \frac{3\,438 \times V_{\text{pitch}} \times N_{\text{H,Height}}}{D_{\text{view}}} \qquad (17)$$

NOTE 3 The unit in equations (16) and (17) is ′ (minutes of arc). Minutes of arc is converted to degrees of arc by the factor (1°/60′). Degrees of arc is converted to radians by the factor (π/180°).

3.5.7
character width
horizontal distance between the edges at the widest part of an unaccented capital letter H (excluding serifs), measured in whole pixel spaces

NOTE 1 Character width is expressed in pixels.

NOTE 2 Adapted from ISO 9241-3:1992, 2.10.

3.5.8
character width-to-height ratio
ratio of character width to character height

NOTE Character width-to-height ratio is expressed in pixels.

[ISO 9241-3:1992, 2.11]

3.5.9
stroke width
average dimension of the horizontal and vertical edge-to-edge distance of a character stroke, judged by the number of whole, average pixel spaces in each

NOTE Stroke width is compressed in pixels.

3.5.10
legibility
ability for unambiguous identification of single characters or symbols that may be presented in a non-contextual format

3.5.11
readability
characteristics of a text presentation on a display that effect performance when groups of characters are to be easily discriminated, recognized and interpreted

3.5.12
character height number
$N_{\text{H,Height}}$
number of pixels in the height of an unaccented, uppercase character H

NOTE Character height number is expressed in pixels.

4 Symbols

Table 4 — Main symbols and units

See Tables 5 and 6 for more variable conventions.

Symbol	Name/Description	Units
AMP_n	$\frac{2 \times \lvert C_n \rvert}{C_0}$	1
c_0	Time-averaged dark-room luminance	cd/m^2
$\mathrm{Class}_{\mathrm{Pixel}}$	Pixel fault class, see *7.20 Pixel faults*	
$\mathrm{Class}_{\mathrm{Reflection}}$	Reflection class, see *7.17 Reflections*	
$\mathrm{Class}_{\mathrm{Viewing}}$	Viewing direction range class, see *7.2 Design viewing direction*	
C_m	Contrast modulation	1
c_n	The nth complex Fourier coefficient (at a multiple of the fundamental frequency)	cd/m^2
CR	Contrast ratio	1
D_{active}	The diagonal of the active area of the screen	mm
$D_{\mathrm{design\ view}}$	Design viewing distance (specified)	mm
D_{view}	The distance between the entrance pupil of the measurement instrument and the centre of the considered object on the screen. The distance between the bridge of the nose of the viewer and the centre of the screen	mm
E	Illuminance	lx
E_a	Screen illuminance from ambient lighting at a workplace	lx
E_{obs}	Observed retinal illuminance	td
E_{pred}	Retinal illuminance where flicker occurs (at a specific frequency)	td
E_s	Design screen illuminance	lx
FFT(v)	The Fast Fourier Transform of a vector of readings	1
f_n	n × the fundamental frequency	Hz
H_{pitch}	The horizontal pixel pitch	mm
h_{uv}	hue-angle	°
H_{view}	the height of the active area	mm
L^*	Lightness	1
L_1	First luminance [$L_{\mathrm{dark,HS(CL\text{-}0)}}$]	cd/m^2
L_2	Second luminance [$L_{\mathrm{dark,LS(CL\text{-}0)}}$]	cd/m^2
$L_{\mathrm{Ea,task\ area(TA\text{-}n)}}$	Area luminance of a task area (numbered n), with ambient lighting of the workplace	cd/m^2

Table 4 *(continued)*

Symbol	Name/Description	Units
$L_{\mathrm{FPA(t)}}$	Frame-period averaged luminance-time response function	
$L_{\mathrm{level,max}}$	The biggest luminance value of any test location in any test direction at the luminance code level	cd/m^2
$L_{\mathrm{level,min}}$	The smallest luminance value of any test location in any test direction at the luminance code level	cd/m^2
L_{max}	The biggest of a series of luminance values	cd/m^2
L_{min}	The smallest of a series of luminance values	cd/m^2
$L_{\mathrm{REFEXT\text{-}I}}$	Evaluation luminance level for extended specular source, class I and II	cd/m^2
$L_{\mathrm{REFEXT\text{-}III}}$	Evaluation luminance level for extended specular source, class III	cd/m^2
$L_{\mathrm{REFSML\text{-}I}}$	Evaluation luminance level for small specular source, class I and II	cd/m^2
$L_{\mathrm{REFSML\text{-}III}}$	Evaluation luminance level for small specular source, class III	cd/m^2
N_{H}	The number of columns of pixels on the screen	1
$N_{\mathrm{H,\ Width}}$	The number of pixels in the *width* of an unaccented uppercase character H	pixels
$N_{\mathrm{H,Height}}$	The number of pixels in the *height* of an unaccented uppercase character H	pixels
$N_{\mathrm{H,hz\_stroke}}$	The number of pixels in the *horizontal stroke* of an unaccented uppercase character H	pixels
$N_{\mathrm{H,vt\_stroke}}$	The number of pixels in the *vertical stroke* of an unaccented uppercase character H	pixels
N_{V}	The number of rows of pixels on the screen	1
q	Luminance coefficient	sr^{-1}
r	The radius of the exit port of the specular light source	mm
$S_{E\mathrm{s},E\mathrm{s}}(\lambda)$	The spectral distribution of the design screen illumination, E_{s}	1
T	Refresh period	ms
t_1	Time at $L_1 - 0{,}1(L_1 - L_2)$, state 1 → 2	ms
t_2	Time at $L_1 - 0{,}9(L_1 - L_2)$	ms
t_3	Time at $L_1 - 0{,}1(L_1 - L_2)$, state 2 → 1	ms
t_4	Time at $L_1 - 0{,}9(L_1 - L_2)$	ms
Tol	Tolerance	1

Table 4 *(continued)*

Symbol	Name/Description	Units
u' , v' u'_n , v'_n $u'_{E\mathrm{s},E\mathrm{s}}$, $v'_{E\mathrm{s},E\mathrm{s}}$	CIE 1976 UCS values, subscript n indicates “specified white achromatic stimulus” and Es,Es indicates design screen illumination	1
V_pitch	The vertical pixel pitch	mm
W_view	The width of the active area	mm
X, Y, Z X_n, Y_n, Z_n $X_{E\mathrm{s},E\mathrm{s}}$, $Y_{E\mathrm{s},E\mathrm{s}}$, $Z_{E\mathrm{s},E\mathrm{s}}$	Tristimulus values of a colour stimulus subscript n indicates “specified white achromatic stimulus” and Es,Es indicates design screen illumination	cd/m^2
x, y, z x_n, y_n, z_n $x_{E\mathrm{s},E\mathrm{s}}$, $y_{E\mathrm{s},E\mathrm{s}}$, $z_{E\mathrm{s},E\mathrm{s}}$	Chromaticity coordinates: The ratio of each of the tristimulus values to their sum, subscript n indicates “specified white achromatic stimulus” and Es,Es indicates design screen illumination	1
Y, Y_n	2°, 1931 tristimulus value, subscript n indicates “specified white achromatic stimulus”	cd/m^2
z	The distance from the exit port of the light source to the diffuse reflectance standard it is illuminating	mm
ΔE^*_{uv}	1976 CIE $L^*u^*v^*$ colour difference, CIELUV, 1 to 4 targets	—
$\Delta u'v'$	Colour uniformity difference between 2 targets. Widely separated 1° targets with luminance variation allowed	1
α	Screen tilt angle	°
β	The luminance factor (for regular reflection) NOTE Regular = specular, mirror-like	1
β_STD	Luminance factor of the specular reflectance standard of the test laboratory	1
ϕ	Azimuth angle	°
ϕ_D	Design azimuth angle (either 90° or 270°)	°
Ψ	The height of an unaccented upper case character H	°
ϕ_C	Critical azimuth angle	°
ρ_STD	Diffuse reflection factor of the diffuse reflectance standard of the test laboratory	1
θ	Inclination angle	°
θ_D	Design inclination angle	°
θ_range	Inclination-angle range	°
θ_rangemax	The maximum inclination angle range	°
θ_rangemin	The minimum inclination-angle range	°

Table 4 *(continued)*

Symbol	Name/Description	Units
′ (as a size)	The angular subtense of a visual target at a (specified) viewing distance See *3.3.2, angular substence*	′
° (as a size)	The angular subtense of a visual target at a (specified) viewing distance See *3.3.2, angular substence*	°

Table 5 — Arbitrary symbol: $A_{\mathrm{B,C(D)}}(E)$

Position	Explanation	Example	Explanation for the example
A	Physical quantity	Y	Luminance
B	Illumination condition	S-SML	Illuminated with the small specular source condition
C	Measured object	HS	Measuring the high state of the flat panel
D	Measurement location	CL-2	In the centre location, at measurement angle 2
E	Tristimulus curve or spectral wavelength	410	Wavelength λ = 410 nm
NOTE If the position E is omitted, then it is not applicable, or refers to the $V(\lambda)$-corrected value (=Y)			

Table 6 — List of symbols and subscripts

Position	Symbol	Explanation
A	Y	Intermediate luminance values
A	L	Final luminance values
A	R	Reflectometer value (See ISO 9241-7 for details)
A	S	Spectral value
A	q	Luminance coefficient
A	u'	Chromaticity coordinate in the CIE 1976 UCS diagram
A	v'	Chromaticity coordinate in the CIE 1976 UCS diagram
A	$\Delta u'v'$	Chromaticity uniformity difference in the CIE 1976 UCS diagram
A	β	Luminance factor
B	DIFF	Illumination with the diffuse light source of the test laboratory
B	S-SML	Illumination with the small specular light source of the test laboratory
B	S-EXT	Illumination with the extended specular light source of the test laboratory
B	dark	Dark-room conditions
B	E_{S}	Converted to design screen illumination E_{S} condition

Table 6 *(continued)*

Position	**Symbol**	**Explanation**
B	E_a	Screen illumination E_s at a workplace
B	REFEXT-I	Converted to large-glare source condition, class I and II
B	REFSML-I	Converted to small-glare source condition, class I and II
B	E_s+REFEXT-I	Converted to simulation of design screen illumination and large-glare source, class I and II
B	E_s+REFSML-I	Converted to simulation of design screen illumination and small-glare source, class I and II
B	REFSML-III	Converted to large-glare source condition, class III
B	REFEXT-III	Converted to small-glare source condition, class III
B	E_s+REFEXT-III	Converted to simulation of design screen illumination and large-glare source, class III
B	E_s+REFSML-III	Converted to simulation of design screen illumination and small-glare source, class III
B	E_a+AMBLUM	The combined light from ambient illuminance and the specular light sources at an actual workplace
C	HS	Flat panel in high state, photometer focus on the flat panel. In text presentation, HS and LS are the two colours used in the text, i.e. HS and LS can be colours other than black and white.
C	LS	Flat panel in low state, photometer focus on the flat panel. In text presentation, HS and LS are the two colours used in the text, i.e. HS and LS can be colours other than black and white.
C	HS-F_EXT	Flat panel in high state, photometer focus on the exit port of the extended light source
C	LS-F_EXT	Flat panel in low state, photometer focus on the exit port of the extended light source
C	HS-F_SML	Flat panel in high state, photometer focus on the exit port of the small light source
C	LS-F_SML	Flat panel in low state, photometer focus on the exit port of the small light source
C	HS-OFF	Flat panel in high state, backlight switched off. Only applicable to certain types of displays
C	LS-OFF	Flat panel in low state, backlight switched off. Only applicable to certain types of displays
C	OFF	Flat panel switched off
C	level	Flat panel in a specific absolute luminance coding level, numbered $1 \ldots n$
C	level-OFF	Flat panel in specific absolute luminance coding level, backlight switched off. Only applicable to certain types of displays.
C	DIFF	The diffuse light source of the test laboratory
C	S-SML	The small specular light source of the test laboratory
C	S-EXT	The extended specular light source of the test laboratory
C	HS-MIN	The required minimum luminance for the high luminance state

Table 6 *(continued)*

Position	Symbol	Explanation
C	Task area	A task area that is frequently viewed in sequence while using the display (document, covers, etc.)
C	dSTD	The diffuse reflectance standard of the test laboratory
C	sSTD	The specular reflectance standard of the test laboratory
C	aSTD	The alignment check standard of the test laboratory
C	colour-n	The flat panel in the colour n
C	Colour-n-OFF	Flat panel in specific colour n, backlight switched off. Only applicable to certain types of displays.
C	Es	Used with position A = X, Y or Z. Indicates that X, Y and Z stand for the tristimulus values of the design screen illumination.
D	HL-n	High measurement location, n = 0…7
D	LL-n	Low measurement location n = 0…7
D	CL-n	Centre measurement location, n = 0…7
D	CL-nS	Centre measurement location, n = 0…6 used in specular reflection measurements
D	CL-nD	Centre measurement location, n = 0…6, used in diffuse reflection measurements
D	dSTD-nSm	Location for calibration measurement of the diffuse reflectance standard, n = 0…6, m = 15, 30, 45
D	Lg	Location for measuring the luminance of the specular light sources.
D	TA-n	Task area location, n = min, max
D	T-n	Tolerance measurement location, n = 1...4
D	PL-n	Potential measurement locations, n = 11, 19, 91, 22, 33, 44, 55, 66, 77, 88, 99
D	m,n	Combination of two locations, used in uniformity calculations (e.g. CL1, CL2)
E	X	Weighted using the weighting function for CIE 1931 tristimulus coordinate X. Used in tristimulus analysis.
E	Y	Weighted using the weighting function for CIE 1931 tristimulus coordinate Y. This is equal to the weighting function for $V(\lambda)$.
E		If position E is omitted, then the weighting function $V(\lambda)$ is assumed
E	Z	Weighted using the weighting function for CIE 1931 tristimulus coordinate Z. Used in tristimulus analysis.
E	400, 410, … 700	The value at wavelength 400, 410, …, 700. Used in spectral analysis.

5 Guiding principles

The visual display work system is an integrated whole, which includes the flat panel display and other hardware (keyboards, pointing devices, etc.), environment, task structure, and other factors. The characteristics of a flat panel must be considered in relation to the other elements of the work system and not as a collection of isolated visual requirements.

Design elements often interact such that optimizing one degrades another. For example, in multicolour flat panel displays there are tradeoffs between the palette of available colours and the constancy of colour rendition with viewing direction. Tradeoffs should be made to achieve an acceptable balance.

For viewing efficiency in flat panel display environments, the image quality should be significantly above the threshold values for the individual stimuli. The recommendations of this part of ISO 13406 take this into account.

While many recommendations are based on performance data from the viewpoint of the above paragraph, some recommendations and requirements are based on user comfort.

Application elements, generally embodied in software, and the hardware elements cannot be judged separately. Coding and character formation require hardware capability and consistent application of that capability.

6 Performance requirements

The objective of this part of ISO 13406 is that the images presented on flat-panel-based VDUs be legible, readable and comfortable in use. See clause 9 for compliance with this part of ISO 13406 and clause 3 for definitions.

NOTE The terms **legibility** and **readability** are used as defined in ISO 9241-3. Some research uses the same terms for other purposes.

7 Design requirements and recommendations

7.1 Design viewing distance

Design viewing distance, $D_{\text{design view}}$ shall be not less than 400 mm, however, for certain applications (e.g., soft key labels of touch screens) the design viewing distance may be reduced to 300 mm.

For office work in the context of ISO 9241-3, the recommendations of 5.1 Design viewing distance, of ISO 9241-3:1992 should be followed.

Workstation requirements are the subject of ISO 9241-5. However, in the work place, the design should allow the display to be used with the design viewing distance. If the task requires a significant amount of reading, the design, the application and the work place should be consistent with display viewing at a distance where the character height, Ψ, of the character set meets the recommendations of *7.6: character height*, 20′ to 22′ (30′ to 35′ for Asian characters). This relationship is shown in Figure 11.

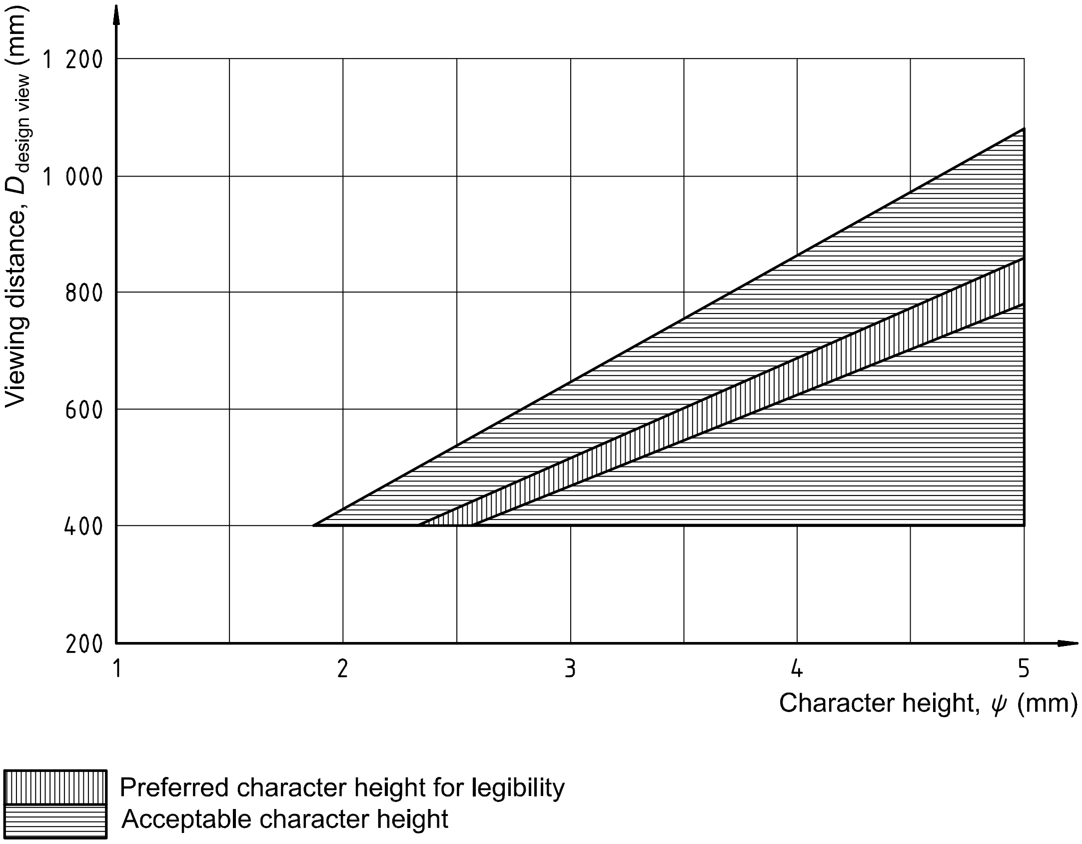


Figure 11 — Viewing distance — character size relationship

7.2 Design viewing direction

The display shall conform to all optical requirements over a relevant range of viewing directions. The supplier shall specify a design viewing direction (θ_D, ϕ_D) and an inclination angle range, θ_{range}.

The inclination angle range, θ_{range}, shall exceed a value consistent with the design viewing distance, $D_{\text{design view}}$ and a character height of $\Psi = 22'$. The design inclination angle, θ_D shall be larger than 0° (the case of a symmetric viewing cone) and shall be smaller than 40° – $\theta_{\text{range}}/2$ (to avoid measurements at angles outside the 80° viewing cone). See Figure 12.

NOTE 1 According to the definition of θ_D, θ_D can only be in the range 0°-90°. Viewing cone = θ_{range} is in the range 0°-180°.

The design azimuth angle, ϕ_D, is 90°, when the supplier intends that the top of the screen be closer to the users' eyes than the bottom, and 270° when the bottom is intended to be closer to the users' eyes and the top of the screen. See Figure 13.

Six directions are used for measurement. See *8.4.1 Test directions.*[1]

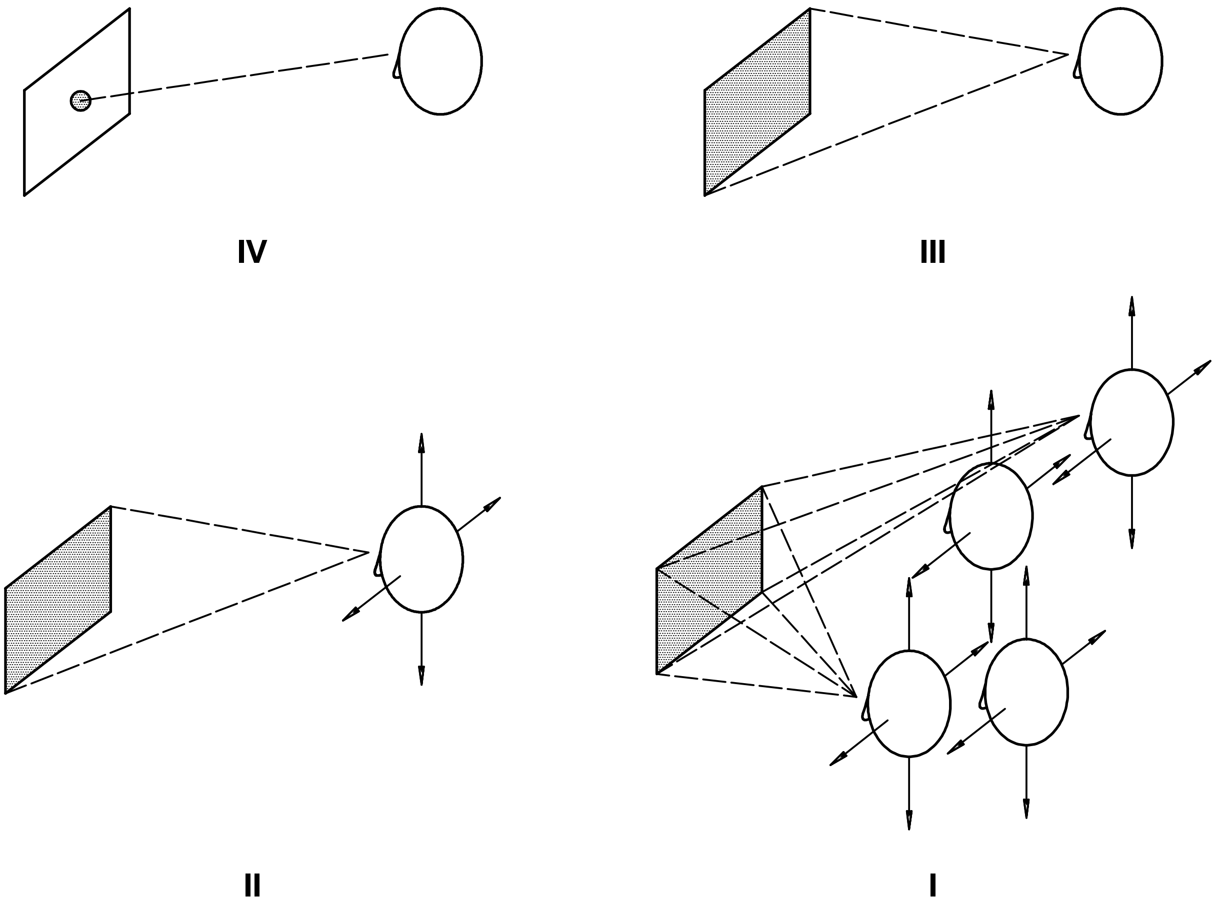
---

[1] At the time this part of ISO 13406 was written, the number of test directions was limited to six in order to make it economically possible to perform a test with the test equipment technology available at that time. Limiting the test to only six directions might not describe the entire performance of a flat panel. From an ergonomics point of view, it might be useful to extend flat panel evaluation to more than six test directions when subclauses *7.14 Display luminance, 7.15 Contrast, 7.17 Reflections, 7.19 Luminance uniformity, 7.25 Default colour set* and *7.27 Colour differences* are evaluated. The relevant azimuth angle range and inclination angle range to analyze depend on, for example, the task, the viewing distance, the screen size and the number of simultaneous users.

For ease of understanding, four performance classes for viewing direction range ($\text{Class}_{\text{Viewing}}$) are defined and referred to in the other requirements:

Table 7 — Viewing direction range classes, $\text{Class}_{\text{Viewing}}$

$\text{Class}_{\text{Viewing}}$	**Description**
I	Allows multiple users to view the whole area of the display at the design viewing distance from any viewing direction within an 80° viewing cone without reduced visual performance. Provides uniformity over the whole screen. Allows movement of the head. Not suitable for tasks where a narrow viewing cone is needed (e.g. privacy, low power consumption).
II	Allows a single user to view the whole area of the display at the design viewing distance from any location in front of the screen. Provides uniformity over the whole screen. Allows movement of the head. Not very well suited for tasks where a narrow viewing cone is needed (e.g. privacy, low power consumption).
III	Allows a single user to view the whole area of the display at the design viewing distance from one fixed location (the design viewing distance, design viewing direction in front of the centre of the screen). Provides uniformity over the whole screen. Does not allow movement of the head. Suitable for tasks where a narrow viewing cone is needed (e.g. privacy, low power consumption).
IV	Allows a single user to view the centre of the screen at the design viewing distance from one fixed location (the design viewing distance, design viewing direction in front of the centre of the screen). Requires user to tilt and rotate the display for uniform image appearance. Does not allow movement of the head. Very well suited for tasks where a narrow viewing cone is needed (e.g. privacy, low power consumption).
For some tasks, a narrow viewing direction range is desired. For example, if it is not wanted that co-travellers in a public transport vehicle can see the information on the screen. The selection of $\text{Class}_{\text{Viewing}}$ is usually an ergonomics task design trade-off decision.	

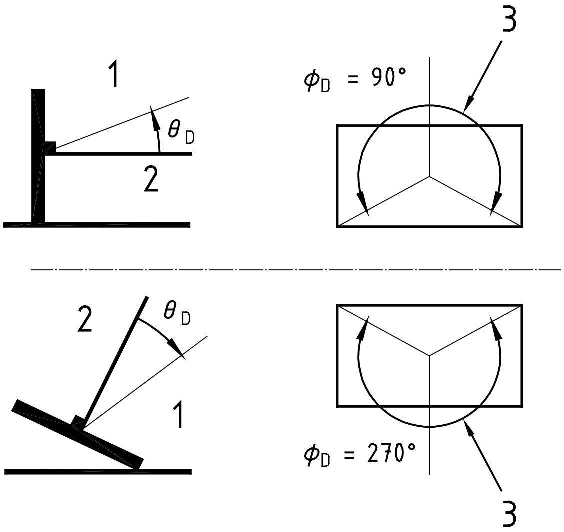


The arrows in the picture indicate the possibility of moving the head.

Four classes, $\text{Class}_{\text{Viewing}}$, are defined, I-IV. The relevant range of viewing directions depends on the task design, i.e. the size of the viewing area, the viewing distance and how much the user needs to move his head and still maintain acceptable legibility and viewing performance. This part of ISO 13406 defines different viewing-direction criteria for different parameters, such as contrast and chromaticity uniformity difference.

To enable ergonomic task design, the manufacturer shall report $\text{Class}_{\text{Viewing}}$ of the display in the user’s manual or in an equivalent way.

Figure 12 — Viewing direction range



Key

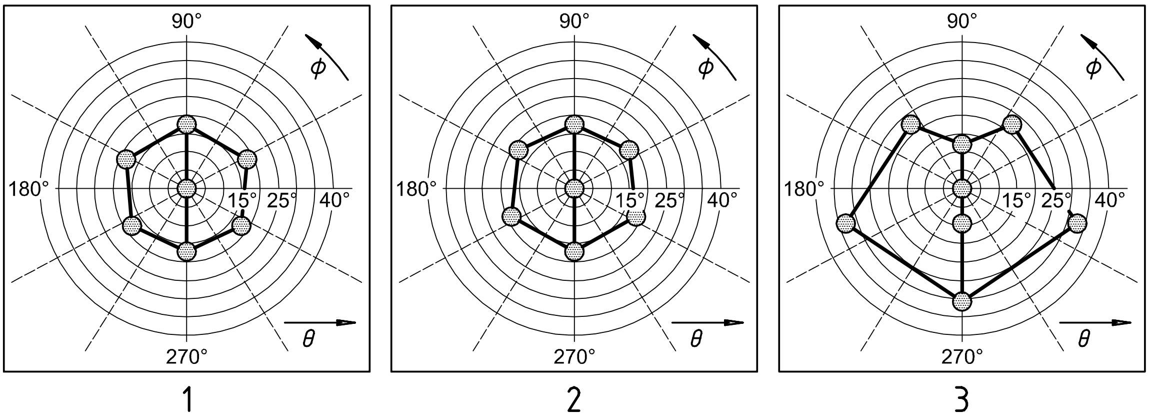
1 Line of sight

2 Normal

3 Relevant azimuth range

Figure 13 — Relevant azimuth range

Figure 14 is an illustration of test directions. The data used for the examples in Figure 14, Figure 30 and Tables 33 to 35 are identical.



Key

1 Landscape oriented, ϕ_D = 90°, θ_D = 0° and ϕ_C = 63,4° (Table 33)

2 Landscape oriented, ϕ_D = 270°, θ_D = 0° and ϕ_C = 63,4° (Table 34)

3 Portrait oriented, ϕ_D = 270°, θ_D = 10° and ϕ_C = 71,6° (Table 35)

Figure 14 — Examples of test directions

NOTE 2 The key factors affecting the user preference for design azimuth, ϕ_D, are glare, brightness and contrast. For isotropic emissive displays ϕ_D is usually 270° (because users try to avoid reflected glare caused by luminaires. For isotropic reflective displays ϕ_D is usually 90° (because users try to maximize the brightness). For anisotropic displays ϕ_D is an angle where contrast and brightness are sufficiently high but reflective glare is sufficiently low (thus ϕ_D depends highly on the display technology and the luminous environment).

NOTE 3 For single-viewer legibility, a value of θ_{range} greater than 80° will not add value. For all displays and printed material, as the inclination angle increases, the characters appear geometrically shorter. At 40°, a character appears about 25 % shorter.

For example, a 16' character, viewed at an inclination angle of 40°, is shortened to only 12'. It is unnecessary to require isotropy for larger inclination angles since even printed matter suffers from more severe off-angle viewing. Independence of parameters with viewing direction outside this 80° viewing cone may be useful when multiple viewers use a single display and character distortion is not a problem, but this situation is not addressed in this part of ISO 13406.

NOTE 4 The inclination angle range, θ_{range} was selected to allow acceptable display use without requiring head movement due to anisotropy. The minimum inclination angle range is based on reading comfort and depends on the size of the panel and the viewing distance. The maximum inclination angle range depends on legibility for a single viewer.

7.3 Design screen illuminance

The supplier shall specify the design screen illuminance, E_S. For emissive displays, E_S shall be from 250 lx to 750 lx. For transflective and reflective displays, the supplier shall indicate the minimum illuminance under which the display will meet the luminance requirements in *7.14 Display luminance.*

If a flat panel VDU is designed for use in an erect posture by a sitting user, the default screen illuminance, from ISO 9241-3, $E = [250 + (250 \cos \alpha)]$ lx, may be used where α is the screen tilt angle. (See 3.4.10 for the definition of screen tilt angle.)

If the application is using, or if the flat panel is designed to be used with, a default colour set, then the chromaticity coordinates u'_S, v'_S of the design screen illumination need to be defined in order to perform colour difference calculations.

NOTE 1 See *8.3.3.4 Luminance sources* for the spectro-radiometric distribution requirements needed for repeatable measurements.

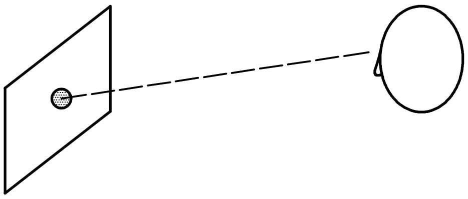
NOTE 2 Transflective or reflective displays with a minimum illuminance that exceeds 750 lx sometimes require a task light for office operation.

7.4 Gaze and head-tilt angles

The work place and flat panel VDU design should permit the user to view the screen in the design viewing direction (θ_D, ϕ_D) with a gaze angle from 0° to 45° and a head tilt angle from 0° to 20°.

7.5 Chromaticity uniformity difference (See Figure 15)

This requirement does not apply to monochrome displays.



IV

Any non-uniformity of the colour shall not create competing information content when evaluated at three locations on the screen for viewing direction range class, $\mathrm{Class}_{\mathrm{Viewing}}$ IV according to *7.2 Design viewing direction*. Depending on the task, $\mathrm{Class}_{\mathrm{Viewing}}$ I, II or III should be required.

Figure 15 — Chromaticity uniformity difference

The maximum chromaticity difference shall conform to the values in Table 8. The values required for the default colour set case in 7.25 are recommended for appearance in all applications.

Table 8 — Maximum chromaticity difference

$\frac{D_{\text{active}}}{D_{\text{design view}}}$ [a]	$\Delta u'v'$	
	Applications using colour per *7.25 Default colour set*	Any primary colour[b]
< 0,75	0,02	0,02
⩾ 0,75	0,03	0,03

[a] D_{active} is the diagonal of the active area of the screen, $D_{\text{design view}}$ is the design viewing distance.

[b] The primary colours are the unmixed colours from the flat panel, usually red, green and blue.

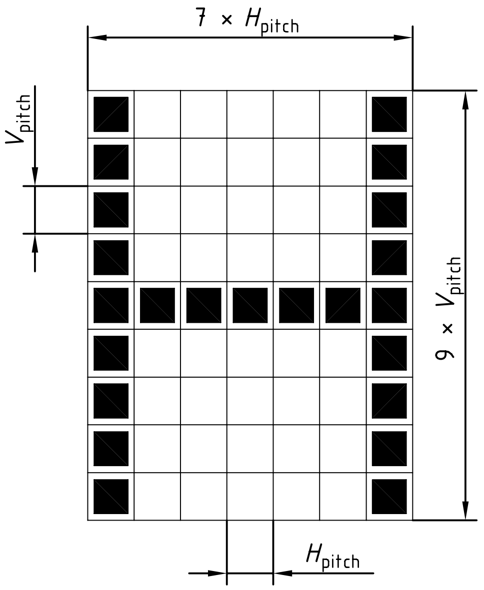
7.6 Character height

Flat panel displays shall be capable of presenting characters with a character height, Ψ according to Table 9. Character height is the number of pixels in an unaccented upper-case H, $N_{\text{H,Height}}$ times the vertical pitch, $V_{\text{pitch.}}$ See Figure 16 for an example.

Table 9 — Character heights, Ψ

	Minimum for legibility	**Preferred range for legibility**
Latin origin	16′	20′ to 22′
Asian	25′	30′ to 35′

For applications where legibility is incidental to the task, smaller characters may be used (e.g., for footnotes, superscripts, subscripts). The character height should exceed 10′ unless loss of legibility is acceptable (e.g., page layout appearance).



Character width = 7 × H_{pitch}, character height $\Psi = N_{H,Height} \times V_{pitch}$ and $N_{H,Height} = 9$.

Figure 16 — Example of character height

7.7 Stroke width

For a Latin-origin character, the number of pixels in a stroke shall be from 8 % to 20 % of $N_{H,Height}$.

NOTE Figure 16 illustrates a case of 9 pixels in an H, and a correct design of the stroke width. (1 pixel equals 11 %.)

7.8 Character width-to-height ratio

Table 10 — Character width-to-height ratio

	Required range	Preferred range for optimum legibility
Latin origin	0,5:1 to 1:1	0,6:1 to 0,9:1
Asian	0,8:1 to 1,2:1	
For Latin-origin characters, the ratio shall be judged on an unaccented upper-case character, H. See Figure 16.		

7.9 Fill factor

For flat panel displays having a pixel density of less than 30 pixels per degree at the design viewing distance, the fill factor shall exceed 0,3.

NOTE When displays are used in marginal illumination environments (uncontrollable glare or loss of contrast), user performance continues to improve for fill factors of up to 0,5.

7.10 Character format

Table 11 — Character format requirement for Latin, Cyrillic and Greek origin alphabetic characters and Arabic numerals.

Character matrix (width to height)		Remark
Minimum used for numeric and upper-case-only presentations	Minimum for reading for context or if legibility is important	
5 × 7	7 × 9	See below for restrictions and exceptions

The character matrix shall be increased upward by at least two pixels if diacritics are used. If lower case is used, the character matrix shall be increased downward by at least two pixels, to accommodate the descenders of the lower-case letters. Mixed-case alphabetics are more legible than upper-case-only alphabetics.

For higher density character matrices, the number of pixels used for diacritics should follow conventional designs for printed text. A 4 × 5 (width to height) character matrix shall be the minimum used for subscripts and superscripts, and for numerators and denominators of fractions displayed in a single character position. The 4 × 5 matrix may also be used for alphanumeric information not related to the operator's task, such as copyright information. (See ISO 9241-3:1992, 5.8)

Characters such as W can be wider than H. Characters such as I, j, l are narrower.

The matrix judgement is made on an unaccented upper-case H.

Table 12 — Character format requirement for Asian characters.

Character matrix (width to height)		Remark
Minimum used font size	Preferred font size	
15 × 16	24 × 24	Fixed sized font

7.11 Between-character spacing

For character fonts without serifs, the number of between-character pixels shall be a minimum of the stroke width count or one pixel. If characters have serifs, the between-character spacing shall be a minimum of one pixel between the serifs of adjacent characters. (ISO 9241-3:1992, 5.10)

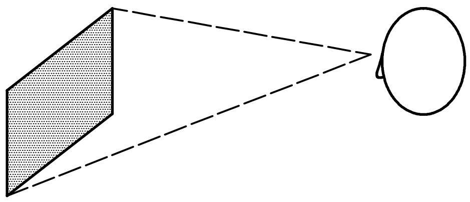
7.12 Between-word spacing

The minimum number of pixels between words shall be the number of pixels in the width of an unaccented upper-case H unless the character font is designed as a representation of designed print fonts or proportional spacing is used. When simulating a print font, the spacing used in the font design may be used. The number of pixels in the width of the character N is recommended as between-word spacing for proportionally spaced fonts.

7.13 Between-line spacing

A minimum of one pixel shall be used for spacing between lines of text. This area may not contain parts of characters or diacritics, but may contain underscores. (ISO 9241-3:1992, 5.12)

7.14 Display luminance



In ambient illumination, the luminance shall exceed the minimum value required for visual acuity when evaluated at three locations on the screen for viewing direction range class, $\text{Class}_{\text{Viewing}}$ III according to *7.2 Design viewing direction*. Depending on the task, $\text{Class}_{\text{Viewing}}$ II or I should be required.

Figure 17 — Display luminance

The luminance of information (either foreground or background) shall satisfy the following inequality, over all viewing directions according to *7.2 Design viewing direction*.

$$L_{\text{HS}} + L_{\text{D}} \geqslant 20\ \text{cd/m}^2 \qquad (18)$$

where

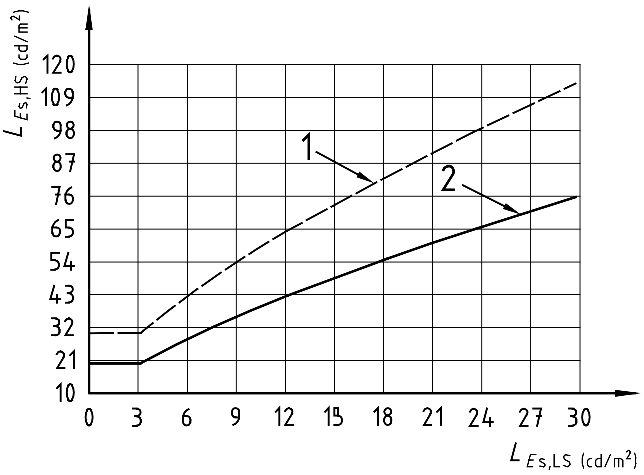
L_{HS} is the emitted luminance component in the high state;

L_{D} is the luminance component reflected from diffuse illumination.

Expanded

$$L_{E\text{s,HS}(n)} \geqslant 20\ \text{cd/m}^2,\ n = \text{CL}-1..\text{CL}-7,\text{HL}-1..\text{HL}-7,\text{LL}-1..\text{LL}-7 \qquad (19)$$

The luminance requirement is related to contrast [see *7.15 Contrast*, equation (22)]. In most cases the contrast requirement will mean that a higher luminance, e.g., 35 cd/m^2 is required. When the luminance is lower than 35 cd/m^2, contrast modulation will need to be higher than 0,5. Figure 18 is a graphical representation of equation (22).



Key

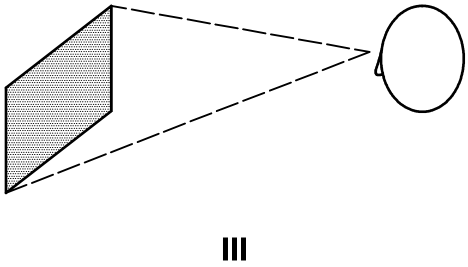
1 Flat panels with absolute luminance coding, the higher luminance level.

2 All flat panels. This includes panels with no absolute luminance coding.

Figure 18 — Graphical presentation of equation (22)

NOTE Users often prefer higher display luminance levels (e.g. 100 cd/m^2), particularly in conditions of high ambient illuminance.

7.15 **Contrast** (See Figure 19)



In ambient illumination, the contrast shall exceed the minimum value required for good visual performance when evaluated at three locations on the screen for viewing direction range class, Class$_{\mathrm{Viewing}}$ III according to *7.2 Design viewing direction*. Depending on the task, Class$_{\mathrm{Viewing}}$ II or I should be required.

Figure 19 — Contrast

The contrast of information shall satisfy the following inequality, over all viewing directions according to *7.2 Design viewing direction*.

$$\frac{L_{\mathrm{HS}} + L_{\mathrm{D}}}{L_{\mathrm{LS}} + L_{\mathrm{D}}} \geqslant 1 + 10 \times (L_{\mathrm{LS}} + L_{\mathrm{D}})^{-0{,}55} \tag{20}$$

where

L_{HS} is the emitted luminance component in the high state;

L_{LS} is the emitted luminance component in the low state;

L_{D} is the luminance component reflected from diffuse illumination.

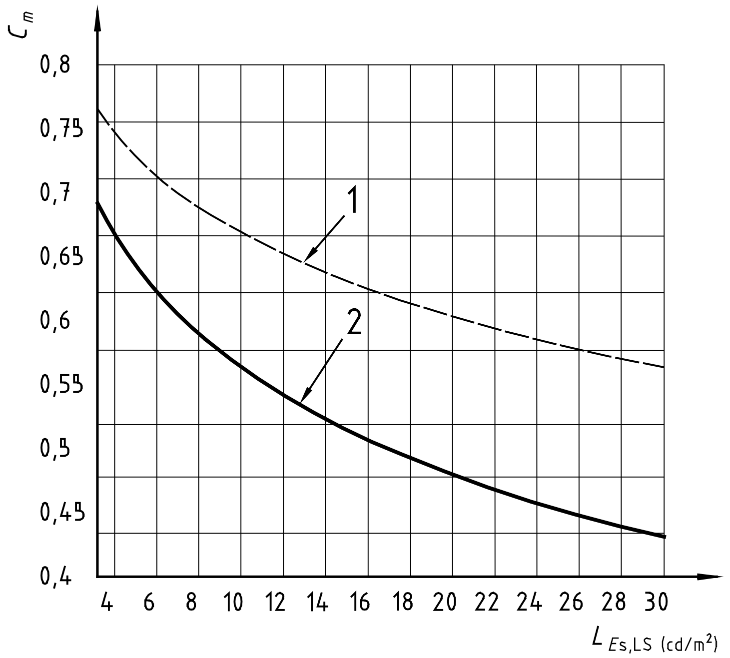
Expanded

$$C_{\mathrm{m}} = \frac{L_{E\mathrm{s,HS}(n)} - L_{E\mathrm{s,LS}(n)}}{L_{E\mathrm{s,HS}(n)} + L_{E\mathrm{s,LS}(n)}} \geqslant \frac{5 \times L_{E\mathrm{s,LS}(n)}^{-0{,}55}}{1 + 5 \times L_{E\mathrm{s,LS}(n)}^{-0{,}55}},\ n = \text{CL-1..CL-7, HL-1..HL-7, LL-1..LL-7} \tag{21}$$

Or the equivalent contrast ratio inequality:

$$CR = \frac{L_{E\mathrm{s,HS}(n)}}{L_{E\mathrm{s,LS}(n)}} \geqslant 1 + 10\, L_{E\mathrm{s,LS}(n)}^{-0{,}55},\ n = \text{CL-1..CL-7, HL-1..HL-7, LL-1..LL-7} \tag{22}$$

Figure 20 is a graphical representation of equation (21).



Key

1 Flat panels with absolute luminance coding, the higher luminance level.

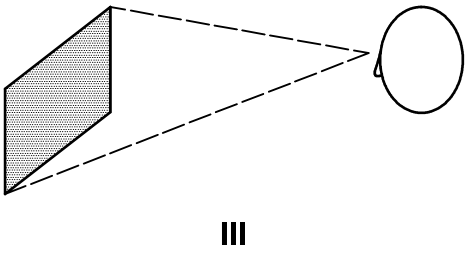
2 All flat panels. This includes panels with no absolute luminance coding.

Figure 20 — Graphical presentation of equation (21)

7.16 Luminance balance

The area-luminance of task areas that are frequently viewed in sequence while using the display (document, covers, etc.) should be between 0,1 $L_{E\text{a,HS(HL-7)}}$ and 10 $L_{E\text{a,HS(HL-7)}}$, where $L_{E\text{a,HS(HL-7)}}$ is the area-luminance of the highest luminance state used on the display in the application in the design viewing direction.

7.17 Reflections (See Figure 21)



In ambient illumination, the contrast of text shall, in the presence of reflections, exceed the minimum value required for good visual performance and the contrast of unwanted reflections shall not exceed the threshold for comfort; when evaluated at three locations on the screen for viewing-direction range class, $\text{Class}_{\text{Viewing}}$ III according to *7.2 Design viewing direction*. Depending on the task, viewing-direction range $\text{Class}_{\text{Viewing}}$ II or I should be required.

Figure 21 — Reflections

The supplier shall specify $\text{Class}_{\text{Reflection}}$ from Table 13 under which the flat panel display *meets 7.17.1 Contrast in the presence of reflections* and *7.17.2 Contrast of unwanted reflections*.

The requirements in this subclause are based on the research done during the development of ISO 9241-7.

Table 13 — Reference luminances for reflection classes, $\text{Class}_{\text{Reflection}}$

$\text{Class}_{\text{Reflection}}$	Luminance of the sources of specular reflection, cd/m^2	Environment[a]
I	Both $L_{\text{REFEXT-I}} = 200$ and $L_{\text{REFSML-I}} = 2\,000$	Suitable for general office use
II	Either $L_{\text{REFEXT-II}} = 200$ or $L_{\text{REFSML-II}} = 2\,000$	Suitable for most, but not all, office environments
III	Either $L_{\text{REFEXT-III}} = 125$ or $L_{\text{REFSML-III}} = 200$	Requiring a specially controlled luminous environment

NOTE 1 In $\text{Class}_{\text{Reflection}}$ II or III, either the 15° aperture or the 1° aperture source is evaluated, but not both. In $\text{Class}_{\text{Reflection}}$ I, both sources are evaluated.

NOTE 2 The reflection requirements and test methods are the same as in ISO 9241-7 except for the consideration of azimuth angles and display state. ISO 9241-7 tests at only one azimuth angle and one state, which is enough for proper characterization of CRT display performance. This part of ISO 13406 tests at six azimuth angles and two display states in order to give a proper characterization of the flat panel performance.

[a] For more information on environmental classification, see ISO 9241-7.

7.17.1 Contrast in the presence of reflections (See Figure 22)

To achieve good enough contrast, the following inequality shall be satisfied over all azimuth angles according to *7.2 Design viewing direction*:

$$\frac{(L_{\text{HS}} + L_{\text{D}} + L_{\text{S}})}{(L_{\text{LS}} + L_{\text{D}} + L_{\text{S}})} \geqslant 1 + 10 \times (L_{\text{LS}} + L_{\text{D}} + L_{\text{S}})^{-0,55} \qquad (23)$$

where

L_{HS} is the emitted luminance component in the high state;

L_{LS} is the emitted luminance component in the low state;

L_{D} is the luminance component reflected from diffuse illumination;

L_{S} is the luminance component reflected from specular illumination.

The objective is to maintain legibility in the presence of reflections. Contrast is used as a metric of legibility. The reflection class creates a relation between flat panel performance requirements and the lighting requirements of the work environment, defined in ISO 9241-6.

Figure 22 — Contrast in the presence of reflections

NOTE The contrast in this subclause is not precisely the same as the contrast in *7.15 Contrast* because measurement details differ (the reflectance component L_s and the measurement geometry).

7.17.2 Contrast of unwanted reflections

The contrast of unwanted reflected images shall satisfy one or both of the following inequalities, as defined by the flat panel manufacturer (see *7.18 Image polarity*), over all azimuth angles according to *7.2 Design viewing direction*.

For positive polarity screens or applications

$$\frac{L_\mathrm{HS} + L_\mathrm{D} + L_\mathrm{S}}{L_\mathrm{HS} + L_\mathrm{D}} \leqslant 1{,}25 \tag{24}$$

For negative polarity screens or applications

$$\frac{L_\mathrm{LS} + L_\mathrm{D} + L_\mathrm{S}}{L_\mathrm{LS} + L_\mathrm{D}} \leqslant 1{,}2 + \frac{1}{15} \times \frac{L_\mathrm{HS} + L_\mathrm{D}}{L_\mathrm{LS} + L_\mathrm{D}} \tag{25}$$

where

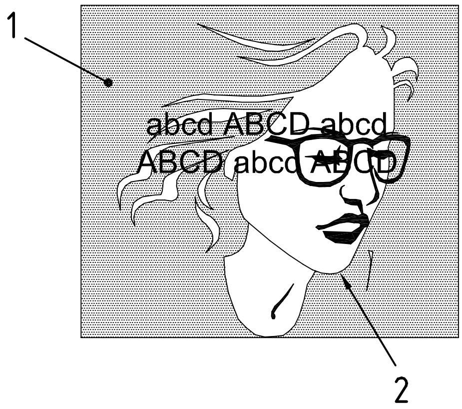
L_HS is the emitted luminance component in the high state;

L_LS is the emitted luminance component in the low state;

L_D is the luminance component reflected from diffuse illumination;

L_S is the luminance component reflected from specular illumination.

NOTE The concept is not complex. The left-hand side of each inequality is the contrast ratio of the specular image (for example, the face in Figure 23) against the background. For positive polarity, the acceptability of an unwanted reflected image is independent of the contrast of the wanted information (hence the right-hand side is simply a number). In the case of a negative polarity screen, the contrast of the wanted negative image competes with the unwanted image (hence the luminance ratio on the right-hand side).



Key

1 Background
2 Unwanted image (Specular reflection)

The display shows a text with two lines. The face of the user is unintentionally reflected in the display, creating an image that competes with the text. The objective is to keep the contrast of the reflected image low enough not to compete with the information on the display.

NOTE There are concerns for both large luminance sources, like the cheek, and small ones, like reflected edges, such as from the eyeglasses.

Figure 23 — Example of unwanted image from specular reflection

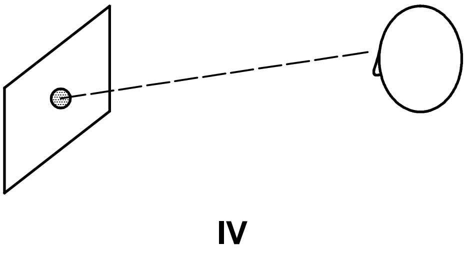
7.18 Image polarity

Either image polarity, dark characters on a brighter background (positive image polarity), or bright characters on a darker background (negative image polarity) is acceptable, *per se*, provided the flat panel VDU meets the requirements of this part of ISO 13406. Users vary in their preferences for image polarity. If a display provides both image polarities, it shall meet the requirements of this part of ISO 13406 in each image polarity.

NOTE There are advantages for each image polarity. For example,

- with positive polarity, specular reflections are less perceptible, edges appear sharper, and luminance balance is easier to obtain. Positive polarity is preferred for ordinary office tasks;
- with negative polarity, flicker is less perceptible, legibility is superior for individuals with anomalously low visual acuity, and characters can sometimes be perceived as larger than they are.

7.19 Luminance uniformity (See Figure 24 and Table 14)



For an intended uniform luminance, the luminance non-uniformity shall in ambient illumination, not exceed the threshold for reduced visual performance when evaluated at three locations on the screen for viewing-direction range class, Class$_{\text{Viewing}}$ IV according to *7.2 Design viewing direction*. Depending on the task, Class$_{\text{Viewing}}$ III, II or I should be required.

Figure 24 — Luminance uniformity

Table 14 — Luminance uniformity

Test object separation at the design viewing distance, perpendicular to the screen	Requirement Maximum luminance ratio
7° ⩽ angular separation	1,7
5° ⩽ angular separation < 7°	1,6
4° ⩽ angular separation < 5°	1,5
2° ⩽ angular separation < 4°	1,4
1,1° ⩽ angular separation < 2°	1,3
Depending on the angular separation of the targets, the non-uniformity ratio should not exceed the value in this table.	

NOTE The test procedure defined in *8.7.19 Luminance uniformity* intentionally does not measure all locations of the screen, but only three locations. The test procedure still covers the whole screen because *8.4.2.4 Additional locations* provides sufficient additional requirements on the selection of the three locations to cover the whole screen.

There should be no unintended luminance variation with image content. In the example shown in Figure 25, a white block is displayed as shown. The circles represent considered object locations, not an intended image. Ideally, the luminances at locations 91 and 55 are at one level and at 11, 19 and 99 at another level. On some panels, location 11 will exhibit a higher luminance than 19 or 99. The dark/bright areas can be reversed and similar problems can sometimes be seen. There are many variations of this problem. This is simply one example.

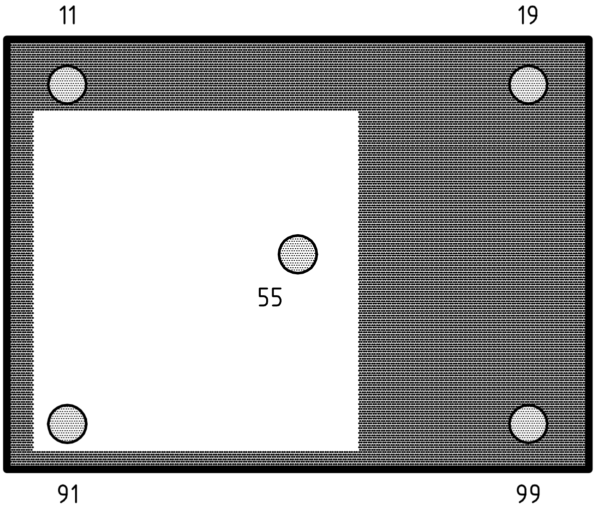


Figure 25 — Example of a pattern that can exhibit image-dependent luminance variation in some technologies

7.20 Pixel faults

Flat panel displays should be in fault class, $\text{Class}_{\text{Pixel}}$ I (refer to *3.4.13 pixels faults*). If not, the supplier shall specify $\text{Class}_{\text{Pixel}}$ of the display.

7.21 Image formation time

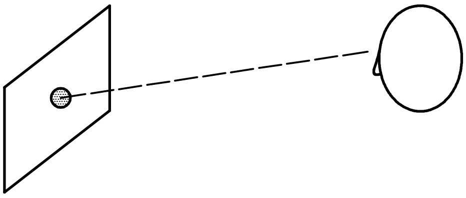
To avoid contrast loss during rapid image changes, flat panel display systems should provide a formation time of less than 55 ms, refer to *3.4.4 (image formation time)*. If not, the supplier shall specify the image-formation-time range of the display.

NOTE Certain LCDs exhibit long image formation times. The image may be electrically refreshed every 16 ms or less, but the formation of the optical effect (luminance, colour or reflectivity) can take more than 200 ms to form fully. These displays offer many desirable features, but contrast loss in applications that require motion effects including blinking or rapid cursor movements, so these must be specially managed. If not so managed, an application may be unusable.

7.22 Absolute luminance coding

This requirement applies only to applications employing absolute luminance coding only, as defined in *3.4.5 (absolute luminance coding)*.

In ambient illumination the contrast between different levels of luminance coding shall exceed the threshold for good visual performance for viewing-direction range class, $\text{Class}_{\text{Viewing}}$ IV according to 7.2 Design viewing direction. (See Figure 26). Depending on task $\text{Class}_{\text{Viewing}}$ III, II or I should be required.



IV

Figure 26 — Absolute luminance coding

The higher-to-lower ratio between area luminances, including reflected ambient light, of adjacent levels shall exceed 1,5.

7.23 Blink coding

Where blink coding is used solely to attract attention, a single blink frequency of 1 Hz to 5 Hz, with a duty cycle of 50 %, is recommended. Where readability is required during blinking, a single blink rate of 1/3 Hz to 1 Hz, with a duty cycle of 70 %, is recommended. It should be possible to switch off the blinking of the cursor. (ISO 9241-3:1992, 5.22).

If blink coding is used, flat panel displays shall provide an image formation time of less than 55 ms, refer to *3.4.4 (image formation time)*.

7.24 Temporal instability (flicker)

The image shall be free of flicker to at least 90 % of the user population. (ISO 9241-3:1992, 5.23).

For a decision method that is useful for flat panels see annex B.

NOTE The method of annex B will be informative only until further research is published.

7.25 Default colour set

When an application requires the user to discriminate or identify colours, it shall offer a default set of colours that meets the requirements of this part of ISO 13406. If colours can be altered by the user, the default set of colours shall be retrievable or restorable.

7.26 Multicolour object size

For characters and other small objects where legibility is the primary concern, see *7.15 Contrast*.

For isolated images where accurate colour identification is required, the image size should subtend 30′, preferably 45′.

The use of extreme blue ($v' < 0{,}2$) should be avoided for images subtending less than 2° (see *7.28 Spectrally extreme colours*).

7.27 Colour differences

Colour pairs in the default set shall have values of $\Delta E^{*}uv > 20$ Application that require accurate colour discrimination shall calculate $\Delta E^{*}uv$ for each colour pair in the set that is to be discriminated. Each colour pair should differ in dominant wavelength to minimize loss of discriminability due to the lightness of an achromatic surround. This is easily measured by the difference in hue angle, h_{uv} between all pairs. (See annex A for a discussion of limitations.)

In applications where performance is critical, it might be useful to evaluate the actual workplace and relate the colour difference to the colour uniformity. For instance, by requiring that the colour difference shall exceed 20 and exceed the colour non-uniformity (*7.5 Chromaticity uniformity difference*).

NOTE This requirement is only evaluated for viewing direction range class IV. Depending on the task, it might be useful to extend the analysis of the colour difference to class III, II or I.

7.28 Spectrally extreme colours

Table 15 provides recommendations concerning the use of extreme blue ($v' < 0{,}2$) and extreme red ($u' > 0{,}4$).

Table 15 — Spectrally extreme colours

Image background	Recommendation	Issue or reference
Positive polarity, achromatic	Preferred for most tasks.	ISO 9241-8
Positive polarity, chromatic	Avoid blue ($v' < 0{,}2$) on red.	Depth of field of the eye.
	See note 1 below.	False, unwanted stereopsis.
	Use black or dark gray foreground.	Colour identification.
Negative polarity, achromatic	Avoid blue ($v' < 0{,}2$).	Bad legibility. For text presentation: difficult to meet *7.15 Contrast.*
	Avoid red ($u' > 0{,}4$).	About 8 % of users have reduced red-green discrimination.
Negative polarity, chromatic	Avoid red ($u' > 0{,}4$) on blue ($v' < 0{,}2$).	Depth of field of the eye.
	See note 1 below.	False, unwanted stereopsis.

NOTE 1 Red ($u' > 0{,}4$) and blue ($v' < 0{,}2$) is the worst combination but any pair of colours can in principle evoke false stereopsis.

NOTE 2 These issues are discussed in ISO 9241-8: 1997 in *6.7 Spectrally extreme colours*, *6.7.1 Negative polarity*, *6.7.2 Positive polarity*, *6.7.3 Depth effects*, and *6.8 Background* and surrounding image effects. The ergonomic issues are the same for flat panels but the trade-offs are not. Therefore, only recommendations are included for flat panels. On flat panels, saturated red, green and blue and also the pair-wise combinations yellow, cyan and magenta exhibit the minimum anisotropy. This effect can be more important than the issues cited in Table 7. Of course, blue on black is not permitted unless the contrast provisions in *7.15 Contrast* are satisfied.

7.29 Number of colours

7.29.1 Simultaneous colour presentation

When *7.25 Default colour set* applies, the number of colours simultaneously presented on a display should be based on the performance requirements of the task. Especially on anisotropic flat panels, the number of colours presented simultaneously should be reduced. Similarly to ISO 9241-8, a maximum of 11 colours is recommended. In the presence of optical anisotropy and possibly greater compromises in colour uniformity, this number should be reduced.

7.29.2 Visual search for colour images

When a rapid visual search based on colour discrimination is required, no more than six colours should be used. For anisotropic displays, six can be too many. (*6.9.2 Visual search for colour images* of ISO 9241-8:1997)

7.29.3 Colour interpretation from memory

If the meaning of each colour of a set of colours is to be recalled from memory, no more than six colours should be used. Software applications that require the meaning of each colour of a set of more than six colours to be recalled shall make the associated meaning of each colour accessible. (*6.9.3 Colour interpretation from memory*, ISO 9241-8:1997)

8 Measurements

8.1 Introduction

These methods are provided to assist test laboratories (either a supplier's facility or a testing institute) in deciding whether a specific flat panel display conforms to this part of ISO 13406 insofar as such a decision can be made in a laboratory setting. Two requirements, *7.4 Gaze and head-tilt angles* and *7.16 Luminance balance* cannot be evaluated fully without measurement at the workplace. Many of the requirements are related to software and flat panel adjustments. This part of ISO 13406 does not define how to select flat-panel adjustment parameters or software to make a test representative of an intended actual use. That judgement has to be made by the test laboratory and described in the test report.

8.1.1 Measurement structure

The measurement requirements are structured into

- 8.1 Introduction
  - A brief overview is presented.
- 8.2 Supplier requirements
  - The supplier data that enter the evaluation decisions.
- 8.3 Test laboratory requirements
  - Facility, measurement tool requirements, and some calibration methods.
- 8.4 to 8.6 Common test elements
  - Definition of the geometries for the measurements.
  - Combined measurement procedures used in more than one requirement evaluation.

- 8.7 Requirement evaluations
  - Evaluation of requirements in *clause 7 Design requirements and recommendations.*

8.1.2 Measurement process

The general measurement process consists of the following steps:

a) Prepare the equipment-under-test.

b) Conduct site screening to select the three final measurement sites.

c) Measure the necessary parameters in a dark room.

d) Estimate the luminance coefficients, q.

e) Based on the uniformity of the available illumination apparatus, calculate the tolerance, Tol.

f) Correct each measurement to standardized illumination conditions.

g) Calculate the needed dependent parameters from the corrected measurements.

h) Conduct any needed design analysis.

i) Compare the results of steps g) and h) with the requirements in *7 Design requirements and recommendations*.

j) Report results.

8.2 Supplier requirements

8.2.1 Equipment for testing

The supplier provides the equipment incorporating a flat panel display, including sufficient local or remote processing equipment, hardware, software, firmware, data storage devices, controllers and/or data transmission and reception equipment to present at least one representative application of the product and the photometrics of the screen.

8.2.2 Equipment documentation

The equipment provided shall be documented. The following typify the required data. The principle is that the documents are just sufficient to identify the subject of the test and patterns measured uniquely.

a) Name of the supplier, address, etc.

b) An equipment list (display and other necessary equipment used to show compliance). The identification should include type numbers and relevant manufacturing data such as the version (if appropriate), manufacturing site (if appropriate), manufacturing date(s). The data should be sufficient to archive a unique identification of the equipment tested.

c) Identification of relevant BIOS, OS, etc. levels, if such details can be expected to affect the test outcome.

d) Identification of the software, including the version, supplier(s), etc. The data should be sufficient to archive a unique identification of the software tested.

e) Identification of the test-pattern software required to present visual test objects. The data should be sufficient to archive a unique identification of the test-pattern software used.

f) When applicable, drawings for determining fill factor [see 3.4.1 (fill factor) and 8.7.9 (Fill factor)].

g) Character font(s) for requirement analyses.

h) Default colour set and corresponding system commands [See *7.25 Default colour set.*]

i) Settings can include brightness, contrast, reference white and other technology specific settings. A single set of relevant settings is used throughout testing. The settings are required to represent actual settings expected in product use.

8.2.3 Supplier declared data

The following data shall be declared in the user's manual (or equivalent) and in detail product specifications:

a) Design viewing distance, $D_{\text{design view}}$ (See *7.1 Design viewing distance*).

b) Design inclination angle, θ_{D} (See *7.2 Design viewing direction* and *8.4.1 Test directions*).

c) Design azimuth angle, ϕ_{D} = 90° or 270° (See *7.2 Design viewing direction* and *8.4.1 Test directions*).

d) For reflective flat panels only, the angle between the EUT and the diffuse light source, θ_{dLg} (see *8.3.3.4 Luminance sources*).

e) Inclination angle range, θ_{range} for requirements:

  7.5 Chromaticity uniformity difference

  7.14 Display luminance

  7.15 Contrast

  7.17 Reflections

  7.19 Luminance uniformity

  7.22 Absolute luminance coding

  (See *7.2 Design viewing direction* and *8.4.1 Test directions*)

f) Viewing direction range class, $\text{Class}_{\text{viewing}}$, I-IV for requirements:

  7.5 Chromaticity uniformity difference

  7.14 Display luminance

  7.15 Contrast

  7.17 Reflections

  7.19 Luminance uniformity

  7.22 Absolute luminance coding

  (See *7.2 Design viewing direction* and *8.4.1 Test directions*)

g) Screen tilt angle, α (see *7.3 Design screen illuminance*).

h) Design screen illuminance (see *7.3 Design screen illuminance*):

1) illumination level, E_S;

2) colour: either specify an illuminant standardized by the CIE, or alternatively specify the colour coordinates, $x_{E\mathrm{s},E\mathrm{s}}$ $y_{E\mathrm{s},E\mathrm{s}}$ and the spectral distribution of the illuminance, $S_{E\mathrm{s},E\mathrm{s}}(\lambda)$.

i) Reflection class, $\text{Class}_\text{Reflection}$ I, II or III (see *7.17 Reflections*).

j) Image polarity, positive and/or negative (see *7.18 Image polarity*).

k) If the judgement of equation (110) should not be used:

— Reference white, Y_n, u'_n, v'_n [see 3.2.1 (CIE 1976 $L^*u^*v^*$ colour space; CIELUV colour space)].

l) If the display does not conform with pixel fault class I:

— pixel fault class, $\text{Class}_\text{Pixel}$ I, II, III or IV (see *7.20 Pixel faults*).

m) If the image formation time is longer than 55 ms:

— Image formation time, t (see *7.21 Image formation time*).

Reference white is usually one of the values in Table 16. See CIE 15.2:1986, sections 1.1 and 4.1 for relevant equations to calculate coordinates for other colour temperatures.

Table 16 — Typical reference white points

Colour Temperature	u'_n	v'_n
5 600K	0,204	0,479
6 500K	0,198	0,468
9 300K	0,189	0,446

NOTE A single set of settings or a multiple set of settings and the corresponding conditions of use may be specified. For example, several design screen illuminance levels could have corresponding brightness settings.

8.3 Test laboratory requirements

8.3.1 Test facility

Room conditions shall be consistent with Table 17.

Table 17 — Room conditions

Condition	Requirement	Remark
Dark-room screen illuminance	< 2 lx	At the screen centre
Room temperature	23 °C ± 4 °C	Near the panel
Relative humidity	10 % to 85 %	No condensation
Air pressure	70 kPa to 110 kPa	Test at < 3 000 m altitude

If parts of the equipment under test affect the screen illuminance (e.g. light being reflected from the keyboard of a portable computer) then those parts should be adequately covered by, for example, a black cloth.

8.3.2 Equipment under test

The flat panel display unit being tested shall be physically prepared for testing. When indicated by the manufacturer, it shall be warmed up for the specified time (not to exceed 1 h). Testing shall be conducted under normal user conditions for power supply. The bias settings (if any) of the display shall be set to those expected under typical use. Any reflection treatment or filter that is in place for the test specified in *8.7.17 Reflections* shall be in place for every test.

One adjustment setting shall be used for each complete test sequence. If multiple settings are provided, this implies multiple complete test sequences.

8.3.3 Test equipment

8.3.3.1 Test fixtures

The test fixtures shall be capable of accurately setting the meters to ± 3° in azimuth angle and ± 3° in inclination angle.

NOTE For good repeatability, a laboratory might want a higher accuracy.

8.3.3.2 Reflectance standards

Reflectance standards consistent with Table 18 shall be available.

Table 18 — Reflectance standards

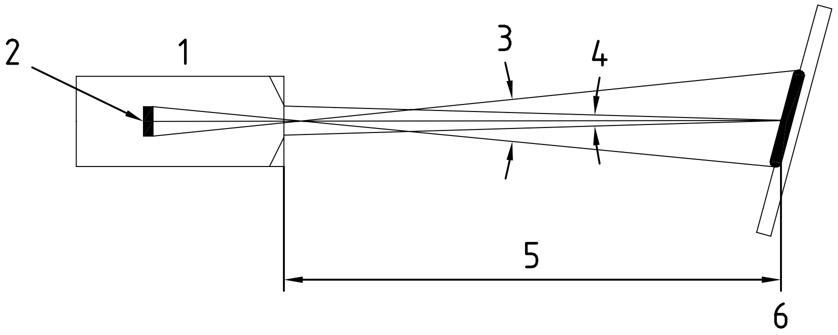
Standard	Recommended range	Units
Diffuse reflectance standard[a]	$\rho_{STD} > 0{,}90$	1
	$q_{STD} > 0{,}29$	sr^{-1}
Specular reflectance standard (Black glass)	β_{STD} from 0,03 to 0,06	1
Azimuth alignment check standard		

[a] For an ideal diffuse standard, see 3.1.5 and 3.1.6.

The azimuth alignment check standard is a surface with a specular reflectance factor that is constant for any azimuth angle, e.g. a piece of glass or a specular standard. No external calibration is required.

8.3.3.3 Meters

When applicable, meters or an equivalent photometric system shall be available, consistent with Table 19. See Figure 27 for the terms used.



Key

1 Photometer

2 Photo-sensitive element

3 FOV = Field of view = Angular extent of the considered object formed in the final image of the instrument

4 Acceptance cone. Angle formed by the entrance pupil of the instrument and the working distance

5 Working distance. Distance between the front lens of the meter and the considered object over which the meter can focus

6 EUT = Equipment under test

Figure 27 — Terms used in meter requirements

Table 19 — Required photometers and typical characteristics

Meter	Field of view	Remark	Where used
Spot photometer[a]	0,5° to 2°	Working distance: 100 mm to ∞	*8.6 Combined measurement for luminance, contrast and diffuse illumination* *8.7.14 Display luminance* *8.7.16 Luminance balance* *8.7.17 Reflections (large source)* *8.7.19 Luminance uniformity* *8.7.22 Absolute luminance coding*
Spot photometer	6′ to 20′	Working distance: 100 mm to ∞	*8.7.17 Reflections (small source)*
CCD photometer[b]	Resolution: $\leqslant$ 10 % of the vertical pitch	See clause 8.7.9.1 for detail requirements	*8.7.9.1 Fill factor: Panels that require microphotometric evaluation*
Fast response photometer	20′ (6′ preferred)	< 3 ms response time	*8.7.21 Image formation* *8.7.24 Temporal instability (Flicker)*
Spectroradiometer			*8.7.3 Design screen illuminance*
Colorimeter[c]	0,5° to 2°	x, y, Y (u', v', Y preferred)	*8.7.5 Chromaticity uniformity difference* *8.7.27 Colour differences*

Readout error from all sources of error shall not exceed 10 %.

The capability of the whole optical system (spot photometer and small light source) to accurately measure the haze reflectance peak of an EUT without specular reflectance, in a way that provides repeatability between laboratories, is critical in measurement *8.7.17 Reflections*. An evaluation criterion for the performance of the whole optical system is included in 8.7.17. A spot size of 2,2 mm or smaller, when focusing on the virtual image of the light source reflected in the screen of the EUT, shall be sufficient for measurement repeatability.

Meters shall be at least capable of a readout of three significant figures at a luminance level of 10 cd/m^2.

[a] The spot photometer, at a working distance of 500 mm shall have an acceptance cone of < 1°. The acceptance cone shall be specified.

[b] A slit photometer method is also acceptable.

[c] A tristimulus colorimeter might not measure all colours of all flat panel displays accurately (e.g. flat panel displays with a discontinuous emission spectrum). For such displays, only a spectroradiometer based colorimeter will be accurate.

8.3.3.4 Luminance sources

One extended source of approximately uniform luminance shall be available. The aperture of the source shall subtend at least 15° (30° preferred) from the centre of the screen of the device under test. Integrating spheres with aperture of at least 150 mm at a EUT-to-light-source distance of 500 mm are suitable. For colorimetric work, the spectral distribution needs to be characterized. Source luminance levels should be at least 2 000 cd/m^2. An auxiliary port cover with a 1° hole to simulate a small source is also required. Especially for measurements with the small source, considerably higher luminance, such as 10 000 cd/m^2 to 20 000 cd/m^2 may be needed to achieve good measurement accuracy and convenience with some types of displays. Thus it may be useful to use two different sources for the extended source, and the small source.

It is not sufficient to characterize the chromaticity of the source with the CIE parameters, u', v'. Use either a standard illuminant (D_{65} or F2 preferred) or characterize the source with a spectroradiometer.

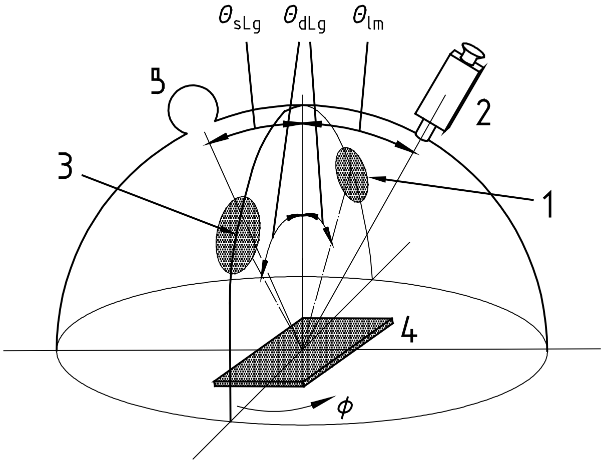
For further information on standard illuminants, see CIE No. 17; illuminant A, CIE 15.2; C, CIE 15.2; D_{50} and D_{75}, CIE 15.2; F1 to F12 (the fluorescent lamps), CIE 15.2. F7 and D_{65} are similar, technically. They are nearly the same daylight simulators. The "D" series are all daylight, but with correlated colour temperatures 100 times the subscript. C is a filtered A illuminant and its use has been discouraged since 1964.

Diffuse illuminance can be approximated with a large integrating sphere, a diffusing hemisphere or by using two luminance sources. The quality of the approximation in the third case shall be characterized with the tolerance, *Tol*.

For reflective panels, the manufacturer can specify that the flat panel is tested with only one of the two luminance sources. In this case, the size of the light source shall be 15° and the manufacturer shall specify the angle between the EUT and the diffuse light source, θ_{dLg}.

One size only was selected to provide metrological repeatability. 15° was selected based on the research done in the development of ISO 9241-7. The manufacturer shall specify the angle of incidence because different products can have different optimum angle (depending on intended task, environment etc.) and this part of ISO 13406 shall not limit future technical development.

Figure 28 shows the two diffuse illumination sources at 45°. LCD technology can sometimes be sensitive to this angle. If this type of panel fails a criterion with the 45° arrangement, the tests may be repeated with this angle set to 30°. If this election is made, it shall be noted in the compliance report.



Key

1 Diffuse illumination source 1
2 Spot photometer 0,5° to 2°
3 Diffuse illumination source 2
4 Diffuse reflectance standard
5 Luminance source for specular reflectance test

NOTE The photometer is in the plane that is orthogonal to the plane containing the centre lines of the diffuse illuminance sources. The luminance source for the specular reflectance test is in the same plane as the photometer.

Figure 28 — Perspective view of the test system with approximately diffuse illuminance apparatus

8.3.4 Special calibrations

8.3.4.1 Luminance meter

The luminance meter shall be calibrated with traceability to national standards and checked for repeatability over the required luminance range and checked for sensitivity to polarization of light.

The uncertainty of traceability to national standards can be up to 5 %. The uncertainty of repeatability over the required luminance range should be kept below 1 %, but can for some instruments be up to 4 %.

NOTE This calibration can be performed either at the test laboratory or at a calibration laboratory.

8.3.4.2 Specular light sources

The light sources shall be calibrated for:

- stability over the duration of the measurements;
- spatial uniformity over the exit port.

Make a test measurement in the laboratory, and base the uncertainty estimate of the output of the luminance sources on the measured values.

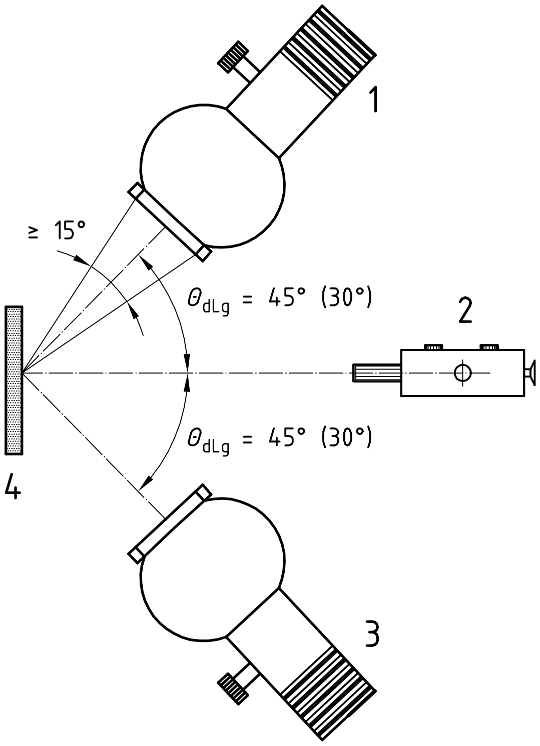
NOTE This calibration can be performed either at the test laboratory or at a calibration laboratory.

8.3.4.3 Diffuse illumination realized using two luminance sources

If the diffuse illumination is realized using two luminance sources, then some extra characterization shall be made.

8.3.4.3.1 Arrangement

Arrange the luminance sources and the spot photometer as shown in Figure 29. The spot photometer is constrained to the plane orthogonal to the plane defined by the centres of the apertures of the two sources and the considered object (a 1° field of view on the surface of the diffuse reflectance standard), as shown in Figure 29. This figure shows the two sources at 45°. Liquid-crystal-display (LCD) technology can sometimes be sensitive to this angle. If this type of panel fails a criterion with the 45° arrangement, the tests may be repeated with this angle set to 30°. If this choice is made, it shall be noted in the compliance report.



Key

1 Luminance source 1
2 Spot photometer 0,5° to 2°
3 Luminance source 2
4 Diffuse reflectance standard

This is the configuration to use when measuring the tolerance, Tol.

Figure 29 — Side view of approximately diffuse illuminance apparatus

8.3.4.3.2 Measurement of tolerance, Tol (see Table 20)

Measure the luminance at test directions Tol-1, Tol-2, Tol-3 and Tol-4 (see Table 32 on page 55).

Table 20 — Measurement of tolerance

n =	1	2	3	4	Illumination	Object	Focus
$L_{\text{DIFF,dSTD(Tol-n)}}$					DIFF	dSTD	dSTD

8.3.4.3.3 Calculation of tolerance, Tol

Calculate the tolerance, Tol:

$$\text{Tol} = \frac{2 \times \left(L_{\text{max}} - L_{\text{min}}\right)}{L_{\text{max}} + L_{\text{min}}} \tag{26}$$

where L_{max}, and L_{min} are the maximum and minimum luminances from the four measurements (Table 20), in candelas per square metre.

8.3.4.4 Diffuse reflectance standard

The diffuse reflectance standard shall be calibrated with the same geometry as used in the display evaluation measurements. For estimating the diffuse component in the specular measurement, calibration is needed for 15°/0° geometry.

8.3.4.4.1 When diffuse illumination is realized with a large integrating sphere or a hemisphere

No method of calibration is included in this part of ISO 13406. The method in 8.3.4.4.2 such that the average value of $q_{\text{S-SML,dSTD(dSTD-}n\text{S15)}}$, $q_{\text{S-SML,dSTD(dSTD-}n\text{S30)}}$ and $q_{\text{S-SML,dSTD(dSTD-}n\text{S45)}}$ is used as an estimate of q_{DIFF} and the standard deviation of the values is used as input and for an uncertainty analysis for q_{DIFF}.

8.3.4.4.2 When diffuse illumination is realized using two extended sources

Measure the ligth reflected in the diffuse reflectance standard. (See Table 21).

The measurement at 30° is needed only if the 30° geometry will be used in the measurements of the flat panel.

For a good measurement system and diffuse reflectance standard $Y_{\text{S-SML,dSTD}(n)}$ remains constant for all values of n and thus needs to be measured for one azimuth angle only e.g. dSTD-0S15, dSTD-0S30, and dSTD-0S45.

Table 21 — Measurement of the diffuse reflectance standard (tristimulus)

n =	0	1	2	3	4	5	6	7	Illumi-nation	Object	Focus[a]
$Y_{\text{S-SML,dSTD(dSTD-}n\text{S15)}}$									S-SML	dSTD	dSTD
$Y_{\text{S-SML,dSTD(dSTD-}n\text{S30)}}$									S-SML	dSTD	dSTD
$Y_{\text{S-SML,dSTD(dSTD-}n\text{S45)}}$									S-SML	dSTD	dSTD
$X_{\text{S-SML,dSTD(dSTD-}n\text{S45)}}$	not needed	not needed	not needed	not needed		not needed	not needed	not needed	S-SML	dSTD	dSTD
$Z_{\text{S-SML,dSTD(dSTD-}n\text{S45)}}$	not needed	not needed	not needed	not needed		not needed	not needed	not needed	S-SML	dSTD	dSTD

[a] Focus is at the diffuse reflectance standard.

Measure the spectral distribution of the light reflected in the diffuse reflectance standard. See Table 22.

Table 22 — Measurement of the diffuse reflectance standard (spectral)

$Y_{\text{S-SML,dSTD(dSTD-4S30)}}(\lambda)$ for λ =				Illumination	Object	Focus[a]
400	410	...	700	S-SML	dSTD	dSTD

[a] Focus is at the diffuse reflectance standard.

Measure the luminance of the light sources. See Table 23.

Table 23 — Measurement of the light source (tristimulus)

	L_g	**Illumination**	**Object**	**Focus**[a]
$X_{\text{S-SML,S-SML}(L\text{g})}$		S-SML	S-SML	S-SML
$Y_{\text{S-SML,S-SML}(L\text{g})}$		S-SML	S-SML	S-SML
$Z_{\text{S-SML,S-SML}(L\text{g})}$		S-SML	S-SML	S-SML

NOTE Greatest accuracy is achieved when selecting the measurement distance (luminance meter to light source) to be the same as the total distance in the specular measurements of the flat panel (luminance meter to flat panel + flat panel to light source).

[a] Focus is at the exit port of the light source.

Measure the spectral distribution of the light reflected in the diffuse reflectance standard. See Table 24.

Table 24 — Measurement of the light source (spectral)

$Y_{\text{S-SML,S-SML}(L_g)}(\lambda)$ for $\lambda =$				**Illumination**	**Object**	**Focus**[a]
400	410	...	700	S-SML	S-SML	S-SML

[a] Focus is at the diffuse reflectance standard.

From VESA Flat Panel Display Measurements Standard (1998), chapters A206, A210 and A214:

$$
\begin{aligned}
q_{\text{S-SML,dSTD(dSTD-}n\text{S15)}} &= \frac{Y_{\text{S-SML,dSTD(dSTD-}n\text{S15)}} \times (r^2 + z^2)}{\pi \times r^2 \times Y_{\text{S-SML,S-SML}(L\text{g})} \times \cos\theta_{\text{dSTD}}}, \quad n = 0...7 \\
q_{\text{S-SML,dSTD(dSTD-}n\text{S30)}} &= \frac{Y_{\text{S-SML,dSTD(dSTD-}n\text{S30)}} \times (r^2 + z^2)}{\pi \times r^2 \times Y_{\text{S-SML,S-SML}(L\text{g})} \times \cos\theta_{\text{dSTD}}}, \quad n = 0...7 \\
q_{\text{S-SML,dSTD(dSTD-}n\text{S45)}} &= \frac{Y_{\text{S-SML,dSTD(dSTD-}n\text{S45)}} \times (r^2 + z^2)}{\pi \times r^2 \times Y_{\text{S-SML,S-SML}(L\text{g})} \times \cos\theta_{\text{dSTD}}}, \quad n = 0...7
\end{aligned}
\tag{27}
$$

$$
\begin{aligned}
q_{S\text{-SML,dSTD(dSTD-4S30)}}(X) &= \frac{X_{\text{S-SML,dSTD(dSTD-4S45)}} \times (r^2 + z^2)}{\pi \times r^2 \times X_{\text{S-SML,S-SML}(L\text{g})} \times \cos\theta_{\text{dSTD}}} \\
q_{S\text{-SML,dSTD(dSTD-4S30)}}(Z) &= \frac{Z_{\text{S-SML,dSTD(dSTD-4S45)}} \times (r^2 + z^2)}{\pi \times r^2 \times Z_{\text{S-SML,S-SML}(L\text{g})} \times \cos\theta_{\text{dSTD}}}
\end{aligned}
\tag{28}
$$

$$
q_{S\text{-SML,dSTD(dSTD-4S45)}}(\lambda) = \frac{Y_{\text{S-SML,dSTD(dSTD-4S45)}} \times (r^2 + z^2)}{\pi \times r^2 \times Y_{\text{S-SML,S-SML}(L\text{g})}(\lambda)(\lambda) \times \cos\theta_{\text{dSTD}}}, \quad \lambda = 400,410,...700
\tag{29}
$$

where

r is the radius of the exit port of the light source;

z is the distance between the reflectance standard and the exit port of the light source;

$\theta_{L\text{g}}$ is the inclination angle between the light source and the reflectance standard (15°, 30°, 45°).

Calculate the luminance coefficients. See Table 25.

Table 25 — Luminance coefficients for the diffuse reflectance standard

n =	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Illumi-nation**	**Object**	**Focus**[a]
$q_{\text{S-SML,dSTD(dSTD-}n\text{S15)}}$									S-SML	dSTD	dSTD
$q_{\text{S-SML,dSTD(dSTD-}n\text{S30)}}$									S-SML	dSTD	dSTD
$q_{\text{S-SML,dSTD(dSTD-}n\text{S45)}}$									S-SML	dSTD	dSTD
$q_{\text{S-SML,dSTD(dSTD-}n\text{S45)}}(X)$	not needed	not needed	not needed	not needed		not needed	not needed	not needed	S-SML	dSTD	dSTD
$q_{\text{S-SML,dSTD(dSTD-}n\text{S45)}}(Z)$	not needed	not needed	not needed	not needed		not needed	not needed	not needed	S-SML	dSTD	dSTD
[a] Focus is at the diffuse reflectance standard.											

Table 26 — Calculation of the spectral distribution of the luminance coefficient

$q_{\text{S-SML,dSTD(dSTD-4S30)}}(\lambda)$ for λ =				**Illumination**	**Object**	**Focus**[a]
400	410	...	700	S-SML	dSTD	dSTD
Measure the spectral distribution of the light reflected in the diffuse reflectance standard.						
[a] Focus is at the diffuse reflectance standard.						

Estimate the uncertainty of the luminance coefficient, Δq, e.g. using the partial-derivative-based estimation of the total uncertainty of equation (27):

$$\Delta q = \left|\frac{\partial q}{\partial Y_{\text{S-SML}}}\right| \Delta Y_{\text{S-SML}} + \left|\frac{\partial q}{\partial Y_{\text{dSTD}}}\right| \Delta Y_{\text{dSTD}} + \left|\frac{\partial q}{\partial r}\right| \Delta r + \left|\frac{\partial q}{\partial z}\right| \Delta z + \left|\frac{\partial q}{\partial \theta}\right| \Delta \theta \qquad (30)$$

The uncertainty of the luminance coefficient can be very big and should always be properly calculated.

The example given in Table 27 illustrates only a part of the full calibration. All but one geometry is left out of the example. The tristimulus and spectral calibration is not included in the example.

Table 27 — Example of a calibration of a "diffuse white standard"

Variable	Value	Uncertainty
$Y_{\text{S-SML,dSTD(dSTD-}n\text{S30)}}$	0,64 cd/m^2	0,01 cd/m^2
$Y_{\text{S-SML,S-SML(}L\text{g)}}$	8 530 cd/m^2	100 cd/m^2
r	4,5 mm	0,1 mm
z	506 mm	7 mm
θ_{dSTD}	30°	2°
Calculated $q_{\text{S-SML,dSTD(dSTD-}n\text{S30)}}$	0,35 sr^{-1}	0,09 sr^{-1}
NOTE 1 The accuracy and performance of the luminance meter is the most critical factor in the calibration. It must have a very wide dynamic range and good linearity that have been verified through calibration. NOTE 2 The accuracy of the values of r and z are the second most important factors for good accuracy.		

NOTE This calibration can be performed either at the test laboratory or at a calibration laboratory. If performed at the test laboratory, special care must be given to achieving the required geometries with high accuracy. If performed at a calibration laboratory, it must be ensured that the calibration is performed using this specific lighting arrangement and geometry.

8.3.4.5 Specular reflectance standard

The specular reflectance standard shall be calibrated with the geometry used in the measurements. See Table 28.

Measure the luminance reflected in the specular reflectance standard.

Table 28 — Calibration of the specular reflectance standard

n =	CL-0S	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumi-nation	Object	Focus[a]
$Y_{\text{S-EXT,sSTD}(n)}$								S-EXT	sSTD	S-EXT
$Y_{\text{S-SML,sSTD}(n)}$								S-SML	sSTD	S-SML
For a good measurement system and specular reflectance standard, $Y_{\text{S-EXT,sSTD}(n)}$ remains constant for all values of n and thus needs to be measured for one azimuth angle only, e.g. CL-0S. If the specular reflectance standard has no haze component then $Y_{\text{S-EXT,sSTD}(n)} = Y_{\text{S-SML,sSTD}(n)}$ and the number of measurements can be reduced by half.										
[a] Focus is at the exit port of the light source.										

Measure the luminance L_g of the light sources. See Table 29.

Table 29 — Measurement of the light sources

	L_g	**Illumination**	**Object**	**Focus**[a]
$Y_{\text{S-EXT,S-EXT}(L\mathrm{g})}$		S-EXT	S-EXT	S-EXT
$Y_{\text{S-SML,S-SML}(L\mathrm{g})}$		S-SML	S-SML	S-SML
NOTE 1 Greatest accuracy is achieved when selecting the measurement distance (luminance meter to light source) to be the same as the total distance in the specular measurements of the flat panel (luminance meter to flat panel + flat panel to light source).				
[a] Focus is at the exit port of the light source.				

$$\beta_{\text{S-EXT,sSTD(CL-}n\text{S)}} = \frac{Y_{\text{S-EXT,sSTD(CL-}n\text{S)}}}{Y_{\text{S-EXT,S-EXT}(L\mathrm{g})}}, \quad n = 0...6$$
$$\beta_{\text{S-SML,sSTD(CL-}n\text{S)}} = \frac{Y_{\text{S-SML,sSTD(CL-}n\text{S)}}}{Y_{\text{S-SML,S-SML}(L\mathrm{g})}}, \quad n = 0...6 \qquad (31)$$

Calculate the luminance factors. See Table 30.

Table 30 — Calculation of the luminance factor of the specular reflectance standard

n =	**CL-0S**	**CL-1S**	**CL-2S**	**CL-3S**	**CL-4S**	**CL-5S**	**CL-6S**	**Illumination**	**Object**
$\beta_{\text{S-EXT,sSTD}(n)}$								S-EXT	sSTD
$\beta_{\text{S-SML,sSTD}(n)}$								S-SML	sSTD

NOTE 1 A specular reflectance standard will not be needed at all, if the luminance of the specular light sources can be measured directly.

NOTE 2 This calibration can be performed either at the test laboratory or at a calibration laboratory. A calibration at the test laboratory might give a slightly better result as the calibration will cover all aspects of measurement optics and alignment of the test system.

8.3.4.6 Alignment system

The ability of the alignment system to keep good enough alignment between the light source, flat panel and luminance meter is critical. This calibration provides a test of the alignment system. See Table 31.

This calibration must be performed with the actual test system.

Table 31 — Calibration of the specular reflectance standard

n =	**CL-0S**	**CL-1S**	**CL-2S**	**CL-3S**	**CL-4S**	**CL-5S**	**CL-6S**	**Illumi-nation**	**Object**	**Focus[a]**
$Y_{\text{S-SML,aSTD}(n)}$								S-SML	sSTD	S-SML

Measure the luminance reflected in the alignment-check standard.

If the alignment is good there should be no variation between the measured values.

NOTE The same procedure can be used to check the ability of the luminance meter to measure polarized light. Instead of the alignment check standard, use a calibrated polarizer. Verify that the variation of the measured values correlate with the calibrated characteristics of the polarizer.

[a] Focus is at the exit port of the light source.

8.4 Test geometry

8.4.1 Test directions (See Table 32)

Table 32 — Definition of test directions

Test direction subscript name	**Inclination angles**			**Azimuth angle**	**Comment**
	EUT to luminance meter θ_{lm} =	**EUT to specular light source** θ_{sLg} =	**EUT to diffuse light sources** θ_{dLg} = [a]	**EUT** ϕ_{EUT} =	
LL-0	0°	no light	– 45°, + 45°	not relevant	
HL-0	0°	no light	– 45°, + 45°	not relevant	
LL-7	θ_D	no light	– 45°, + 45°	ϕ_D	
CL-7	θ_D	no light	– 45°, + 45°	ϕ_D	
HL-7	θ_D	no light	– 45°, + 45°	ϕ_D	
CL-0	0°	no light	– 45°, + 45°	not relevant	
CL-1 [b]	$\frac{1}{2}\theta_{\text{range}}$	no light	– 45°, + 45°	$\phi_D + 2\phi_C$	
CL-2 [b]	$\theta_D + \frac{1}{2}\theta_{\text{range}}$	no light	– 45°, + 45°	$\phi_D + \phi_C$	
CL-3 [b]	$\frac{1}{2}\theta_{\text{range}} - \theta_D$	no light	– 45°, + 45°	ϕ_D - 180°	
CL-4 [b]	$\theta_D + \frac{1}{2}\theta_{\text{range}}$	no light	– 45°, + 45°	ϕ_D	
CL-5 [b]	$\theta_D + \frac{1}{2}\theta_{\text{range}}$	no light	– 45°, + 45°	$\phi_D - \phi_C$	
CL-6 [b]	$\frac{1}{2}\theta_{\text{range}}$	no light	– 45°, + 45°	$\phi_D - 2\phi_C$	
L_g	0°	180°	no light	0°	
CL-0S	15°	15°	– 45°, + 45°	0°	
CL-1S	15°	15°	– 45°, + 45°	$\phi_D + 2\phi_C$	
CL-2S	15°	15°	– 45°, + 45°	$\phi_D + \phi_C$	
CL-3S	15°	15°	– 45°, + 45°	ϕ_D – 180°	

Table 32 *(continued)*

Test direction subscript name	**Inclination angles**			**Azimuth angle**	**Comment**
	EUT to luminance meter θ_{lm} =	**EUT to specular light source** θ_{sLg} =	**EUT to diffuse light sources** θ_{dLg} = [a]	**EUT** ϕ_{EUT} =	
CL-4S	15°	15°	– 45°, +45°	ϕ_D	
CL-5S	15°	15°	– 45°, +45°	$\phi_D - \phi_C$	
CL-6S	15°	15°	– 45°, +45°	$\phi_D - 2\phi_C$	
dSTD-0S15	0°	– 15°	no light	0°	
dSTD-1S15	0°	– 15°	no light	$\phi_D + 2\phi_C$	
dSTD-2S15	0°	– 15°	no light	$\phi_D + \phi_C$	
dSTD-3S15	0°	– 15°	no light	ϕ_D – 180°	
dSTD-4S15	0°	– 15°	no light	ϕ_D	
dSTD-5S15	0°	– 15°	no light	$\phi_D - \phi_C$	
dSTD-6S15	0°	– 15°	no light	$\phi_D - 2\phi_C$	
dSTD-0S30	0°	– 30°	no light	0°	
dSTD-1S30	0°	– 30°	no light	$\phi_D + 2\phi_C$	
dSTD-2S30	0°	– 30°	no light	$\phi_D + \phi_C$	
dSTD-3S30	0°	– 30°	no light	ϕ_D – 180°	
dSTD-4S30	0°	– 30°	no light	ϕ_D	
dSTD-5S30	0°	– 30°	no light	$\phi_D - \phi_C$	
dSTD-6S30	0°	– 30°	no light	$\phi_D - 2\phi_C$	
dSTD-0S45	0°	– 45°	no light	0°	
dSTD-1S45	0°	– 45°	no light	$\phi_D + 2\phi_C$	
dSTD-2S45	0°	– 45°	no light	$\phi_D + \phi_C$	
dSTD-3S45	0°	– 45°	no light	ϕ_D – 180°	
dSTD-4S45	0°	– 45°	no light	ϕ_D	
dSTD-5S45	0°	– 45°	no light	$\phi_D - \phi_C$	
dSTD-6S45	0°	– 45°	no light	$\phi_D - 2\phi_C$	
Tol-1 [b]	$\theta_D - ½\ \theta_{range}$	no light	– 45°, + 45°	0°	
Tol-2	θ_D	no light	– 45°, + 45°	0°	
Tol-3	15°	no light	– 45°, + 45°	0°	
Tol-4 [b]	$\theta_D + ½\theta_{range}$	no light	– 45°, + 45°	0°	
PL-11	0°	no light	no light	not relevant	

Table 32 *(continued)*

Test direction subscript name	Inclination angles			Azimuth angle	Comment
	EUT to luminance meter θ_{lm} =	EUT to specular light source θ_{sLg} =	EUT to diffuse light sources θ_{dLg} = [a]	EUT ϕ_{EUT} =	
PL-22	0°	no light	no light	not relevant	
PL-33	0°	no light	no light	not relevant	
PL-44	0°	no light	no light	not relevant	
PL-55	0°	no light	no light	not relevant	
PL-66	0°	no light	no light	not relevant	
PL-77	0°	no light	no light	not relevant	
PL-88	0°	no light	no light	not relevant	
PL-99	0°	no light	no light	not relevant	
PL-19	0°	no light	no light	not relevant	
PL-91	0°	no light	no light	not relevant	

Test directions CL-1, CL-2 and CL-3 are calculated based on the design azimuth angle θ_D and the design inclination angle θ_D in order to match the intended use of the flat panel. Test directions CL-4, CL-5 and CL-6 are calculated with inclination angle $\theta = 0°$ in order to always ensure good visual performance also with a viewing direction perpendicular to the screen.

θ_D, ϕ_D and θ_{range} are declared by the supplier. ϕ_C is calculated in *8.4.1.1 Calculation of the critical azimuth angle.* Constraints on these variables are calculated in *8.7.2 Design viewing direction.*

NOTE θ_{lm} and θ_{sSTD} are in the same plane, θ_{dSTD} in the second plane and ϕ_{EUT} in the third plane of an orthogonal coordinate system.

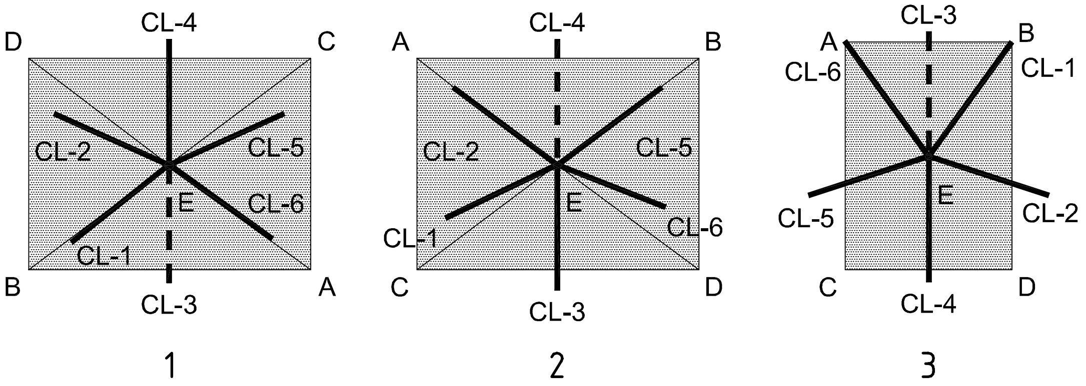
[a] LCD technology can sometimes be sensitive to this angle. If this type of technology fails a criterion with the + 45°/– 45° arrangement, the tests may be repeated with this angle set to +30°/–30°. If this election is made, it shall be noted in the compliance report.

[b] The supplier may choose to define one common value for θ_{range} or up to six different values (a different value for evaluation of each of the requirements specified in 7.5, 7.14, 7.15, 7.17, 7.19 and 7.22). This affects locations CL-1...6, Tol-1 and Tol-4.

See also *7.2 Design viewing direction*.

8.4.1.1 Calculation of the critical azimuth angle

Figure 30 shows examples of the test azimuths (directions). The data used for the examples in Figure 14, Figure 30 and Tables 33 and 35 are identical



Key

1 Landscape oriented, $\phi_D = 90°$, $\theta_D = 0°$ and $\phi_C = 63{,}4°$ (Table 33)

2 Landscape oriented, $\phi_D = 270°$, $\theta_D = 0°$ and $\phi_C = 63{,}4°$ (Table 34)

3 Portrait oriented, $\phi_D = 270°$, $\theta_D = 10°$ and $\phi_C = 71{,}6°$ (Table 35)

NOTE The three examples are not shown in scale.

Figure 30 — Examples of test azimuths

Five of the test azimuths are calculated from the design azimuth angle ϕ_D and the design inclination angle θ_D (an odd number, so that the region can have an orientation). The sixth azimuth angle is defined as $\phi_D - 180°$. Two more azimuth angles (– 0°, – 7°) are defined for some measurements; perpendicular to the screen and the design viewing direction. See Figure 30.

On a flat panel either the top or the bottom is intended to be more perpendicular to the user's eyes. If the top of the panel is intended, then the design azimuth angle, $\phi_D = 90°$, otherwise, 270°. If the design viewing direction $\theta_D = 0°$, then the design azimuth angle does not impact on measurements. See Figure 13 on page 27.

The region **ACDE**, which is closer to the user, is divided into four equal sectors (shown by the bold lines). The region **AEB** is divided into two sectors (shown by a dotted bold line). A critical angle, $\phi_C = (360° - \angle \mathbf{AEB})/4$ is calculated; $\angle \mathbf{AEB}/4 = (2 \times \angle \mathbf{CAD})/4 = [2 \times \arctan(\mathbf{CD}/\mathbf{AC})]/4 = [2 \times \arctan(W_{\text{view}}/H_{\text{view}})]/4 = ½ \times \arctan(W_{\text{view}}/H_{\text{view}})$. The needed azimuths for region **ACDE** are thus: ϕ_D, $\phi_D + \phi_C$, $\phi_D - \phi_C$, $\phi_D + 2\,\phi_C$, $\phi_D - 2\,\phi_C$.

$$\left.\begin{array}{ll} \phi_{\mathrm{c}} = \dfrac{360^\circ - 2 \times \arctan\left(\dfrac{W_{\text{view}}}{H_{\text{view}}}\right)}{4} & \text{, when } 2 \times \arctan\left(\dfrac{W_{\text{view}}}{H_{\text{view}}}\right) > \dfrac{360^\circ}{5} \\ \phi_{\mathrm{c}} = \dfrac{360^\circ}{5} & \text{, when } 2 \times \arctan\left(\dfrac{W_{\text{view}}}{H_{\text{view}}}\right) \leqslant \dfrac{360^\circ}{5} \end{array}\right\} \qquad (32)$$

$$\Leftrightarrow$$

$$\left.\begin{array}{ll} \phi_{\mathrm{c}} = 90^\circ - \frac{1}{2} \times \arctan\left(\dfrac{W_{\text{view}}}{H_{\text{view}}}\right) & \text{, when } \dfrac{W_{\text{view}}}{H_{\text{view}}} > 0{,}727 \\ \phi_{\mathrm{c}} = 72^\circ & \text{, when } \dfrac{W_{\text{view}}}{H_{\text{view}}} \leqslant 0{,}727 \end{array}\right\} \qquad (33)$$

Where

H_{view} is the height of the active area, in millimetres,

W_{view} is the width of the active area, in millimetres.

8.4.1.2 Example of test geometry calculations

The data in Tables 33 to 35 is illustrated in Figure 14 and Figure 30.

Table 33 — Example of a panel that cannot meet all requirements

Manufacturer declared data					Calculated data				
Variable	**Value**	**Unit**	**Pass/Fail**	**Clause**	**Variable**	**Value**	**Unit**	**Pass/Fail**	**Clause**
H_{view}	235	mm	n/a		D_{active}	391	mm	n/a	
W_{view}	313	mm	n/a			15,4	inch	n/a	
$D_{\text{designview}}$	600	mm	Pass	7.1	θ_{rangemin}	36,1	°	n/a	
θ_{D}	0	°	Pass	7.2	θ_{rangemax}	80	°	n/a	
θ_{range}	37	°	Pass	7.2	ϕ_{C}	63,4	°	n/a	
ϕ_{D}	90	°	n/a		H_{pitch}	0,490	mm/pixels	n/a	
N_{W}	640	pixels	n/a		V_{pitch}	0,489	mm/pixels	n/a	
N_{H}	480	pixels	n/a		16′	2,8	pixels	n/a	
						5,7	pixels	n/a	
					22′	3,8	mm	n/a	
						7,9	pixels	Fail	7.2 (7.10)
					20,2′	7,0	pixels	n/a	
					22,4′	8,0	pixels	n/a	
					7,5 req	0,02	$\Delta u'v'$	n/a	

Calculated test directions

CL-n, n =	0	1	2	3	4	5	6	7
θ	0,0°	18,5°	18,5°	18,5°	18,5°	18,5°	18,5°	0,0°
ϕ	n/a	216,9°	153,4°	270,0°	90,0°	26,6°	323,1°	90,0°

Table 34 — Example of a panel that can meet all requirements

Manufacturer declared data				
Variable	**Value**	**Unit**	**Pass/Fail**	**Clause**
H_{view}	235	mm	n/a	
W_{view}	313	mm	n/a	
$D_{\text{designview}}$	600	mm	Pass	7.1
θ_{D}	0	°	Pass	7.2
θ_{range}	37	°	Pass	7.2
ϕ_{D}	270	°	n/a	
N_{W}	800	pixels	n/a	
N_{H}	600	pixels	n/a	

Calculated data				
Variable	**Value**	**Unit**	**Pass/Fail**	**Clause**
D_{active}	391	mm	n/a	
	15,4	inch	n/a	
θ_{rangemin}	36,1	°	n/a	
θ_{rangemax}	80	°	n/a	
ϕ_{C}	63,4	°	n/a	
H_{pitch}	0,392	mm/pixels	n/a	
V_{pitch}	0,391	mm/pixels	n/a	
16′	2,8	pixels	n/a	
	7,1	pixels	n/a	
22′	3,8	mm	n/a	
	9,8	pixels	Pass	7.2 (7.10)
20,2′	9,0	pixels	n/a	
22,4′	10,0	pixels	n/a	
7,5 req	0,02	$\Delta u'v'$	n/a	

Calculated test directions								
CL-n, n =	0	1	2	3	4	5	6	7
θ	0,0°	18,5°	18,5°	18,5°	18,5°	18,5°	18,5°	0,0°
ϕ	n/a	36,9°	333,4°	90,0°	270,0°	206,6°	143,1°	270,0°

Table 35 — Second example of a panel that can meet all requirements

Manufacturer declared data				
Variable	**Value**	**Unit**	**Pass/Fail**	**Clause**
H_{view}	300	mm	n/a	
W_{view}	225	mm	n/a	
$D_{\text{designview}}$	500	mm	Pass	7.1
θ_{D}	10	°	Pass	7.2
θ_{range}	45	°	Pass	7.2
ϕ_{D}	270	°	n/a	
N_{W}	768	pixels	n/a	
N_{H}	1024	pixels	n/a	

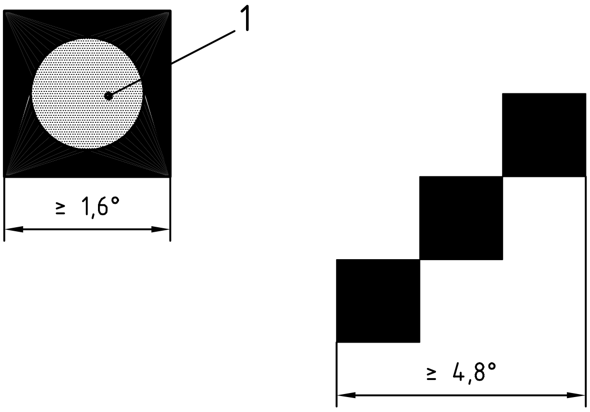
Calculated data				
Variable	**Value**	**Unit**	**Pass/Fail**	**Clause**
D_{active}	375	mm	n/a	
	14,8	inch	n/a	
θ_{rangemin}	41,1	°	n/a	
θ_{rangemax}	80	°	n/a	
ϕ_{C}	71,6	°	n/a	
H_{pitch}	0,293	mm/pixels	n/a	
V_{pitch}	0,293	mm/pixels	n/a	
16′	2,3	pixels	n/a	
	7,9	pixels	n/a	
22′	3,2	mm	n/a	
	10,9	pixels	Pass	7.2 (7.10)
20,2′	10,0	pixels	n/a	
22,4′	11,0	pixels	n/a	
7,5 req	0,03	$\Delta u'v'$	n/a	

Calculated test directions								
CL-n, n =	0	1	2	3	4	5	6	7
θ	0,0°	22,5°	32,5°	12,5°	32,5°	32,5	22,5°	10,0°
ϕ	n/a	53,1°	341,6°	90,0°	270,0°	198,4°	126,9°	270,0°

8.4.2 Standard measurement locations

8.4.2.1 Targets

Normal photometric practice is to use a target that is at least 60 % larger than the luminance meter image to guarantee that edge effects are eliminated. When possible, 85 % or more is preferred. With noted exceptions, all measurements shall be made with 1° targets imaged in the luminance meter focused in the centre of the target. See Figure 31.



Key

1 1° luminance meter image

Figure 31 — Photometric targets

8.4.2.2 Large flat panel displays

Large flat panels are displays with a minimum dimension of at least 4,8°.

A panel uses this section if its minimum dimension is at least 4,8° (subtended angle). The objective is to choose three final measurement sites from eleven initial sites. The eleven sites are shown in Figure 32. The centre-centre site, 55, is always selected. The other ten sites are screened for their dark room area-luminance (measured perpendicular to the screen, $\theta = 0°$), $L_{\text{dark,HS(PL-11...99, 91, 19)}}$ or their selected luminance coefficient, $q_{\text{DIFF,HS(1...11)}}$ for reflective flat panels. The site that has the lowest measured luminance (or luminance coefficient) is called LL, the highest is called HL and site 55 is called CL.

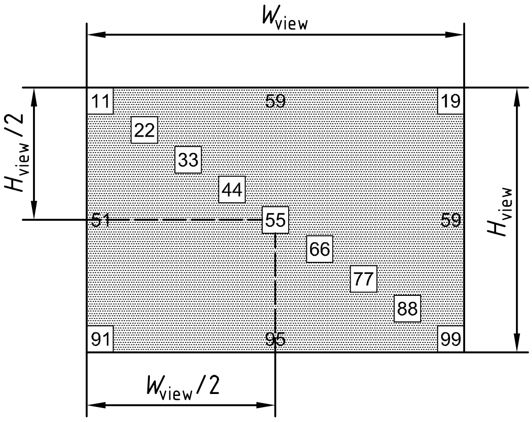


Figure 32 — Potential measurement locations

The initial sites should not overlap. If they must overlap (when the panel is smaller than typical computer-workstation displays), the initial sites shall not overlap site 55. In the minimum case, only five initial sites will exist. See Figure 32.

Figure 33 shows an example applied to a 640 by 480 pixel panel with no more than 44 pixels per degree. Each pixel patch is 53 pixels square. The number pair outside the target patch is the address of the upper left pixel, inside the lower right pixel. The pixel address numbering is assumed to be 0 0 for the leftmost, uppermost corner pixel to 639 479 for the rightmost, lowest pixel. Since the panel has even pixel counts, there is no centre-centre pixel. Site 55 therefore is centred on 319 239.

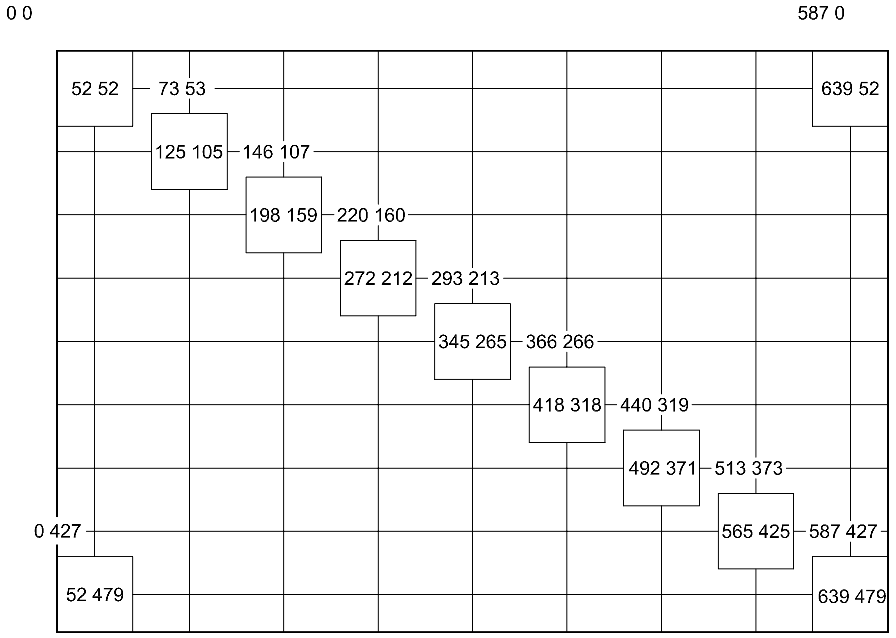


Figure 33 — Example of initial measurement sites for a 640 × 480 pixel flat panel display

8.4.2.3 Small flat panel displays

Small flat panels shall choose sites as in the larger panel case except that sites 19, and 91 are omitted. It is not necessary to overlap test sites more than 25 %, so sometimes the complete set of nine is not required. The process always yields the site that has the lowest measured luminance (or luminance coefficient), LL, the highest, HL and site 55, CL.

8.4.2.4 Additional locations

If there are locations on the screen, outside the assessed 11 sites, which in typical ambient-lighting user conditions are visibly worse than the LL location or HL location, then the measurements shall be performed in those locations in addition to the LL and HL locations.

The judgement of “visibly worse” shall be made in dark-room conditions and by a trained person.

NOTE 1 The “visibly worse” definition might sound unambiguous but it is not. The ambition is to find the locations that are visible by an average user in ambient lighting. When the judgement is made in dark-room conditions and by a trained person, the detection threshold is significantly lower than for the average user. Therefore the risk that an average user would detect a worst location that the test laboratory did not detect can be neglected.

NOTE 2 Most flat panels that currently meet the conditions of this part of ISO 13406 do not have such “visibly worse” locations.

NOTE 3 With an automatic test device, the visibly worst location can be found, for example, by scanning the whole screen in steps of 1° (subtended angle).

8.4.3 Measurement location and direction table

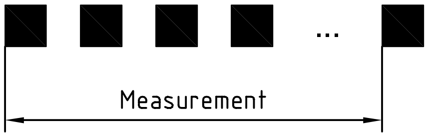
In the measurements that follow, some require a complete table of locations and directions for a set of parameters. Others are evaluated at a subset of locations and only in the design viewing direction.

The detailed requirement is defined separately for every measurement.

8.5 Combined measurement for character design analysis

For the definitions used in this subclause, consult the definitions in *3.5 Alphanumeric symbols*.

Measure the vertical pitch, V_{pitch} and the horizontal pitch, H_{pitch}. For accuracy, measure from the leading edge (or other convenient point) of one pixel to the same point many pixels away and divide by that number. See Figure 34. For example, if the panel had 480 lines of pixels, measure from the first pixel the same point on the last pixel (479 pixels away) and divide by 479.



$$H_{\text{pitch}} = \text{Measurement}/479$$

In this example the display has 480 columns of pixel. The distance from the leftmost to the rightmost column was measured and the value was divided by 479.

Figure 34 — Example of measuring pixel pitch

Character designs use these measurements and each specified character font and spacing design without additional measurement. Sometimes, the font specified is the result of a complex algorithm and a design document is not available. Then, the pixel arrangement may be observed on the screen, using a jeweller's loupe or equivalent.

Record the values given in Table 36.

Table 36 — Measured character design values

Symbol	Value	Description
$N_{\text{H,Height}}$		The number of pixels in the *height* of an unaccented uppercase character H.
$N_{\text{H, Width}}$		The number of pixels in the *width* of an unaccented uppercase character H.
$N_{\text{H,hz\_stroke}}$		The number of pixels in the *horizontal stroke* of an unaccented uppercase character H.
$N_{\text{H,vt\_stroke}}$		The number of pixels in the *vertical stroke* of an unaccented uppercase character H.

The character height (in minutes of arc, ′) is

$$\Psi = \frac{180 \times 60 \times V_{\text{pitch}} \times N_{\text{H,Height}}}{\pi \times D_{\text{view}}} \tag{34}$$

$$\approx \frac{3\,438 \times V_{\text{pitch}} \times N_{\text{H,Height}}}{D_{\text{view}}} \tag{35}$$

The character stroke width is the average of the horizontal and vertical stroke widths (pixel counts).

8.6 Combined measurement for luminance, contrast and diffuse illumination

The supplier may chose to define one common value for θ_{range} or up to six different values (a different value for evaluation of each of the requirements specified in 7.5, 7.14, 7.15, 7.17, 7.19 and 7.22). If different values have been defined, then this combined measurement will need to be repeated for every different value of θ_{range}.

8.6.1 Common measurements

The display luminance and contrast shall be verified for Tables 37 and 38 for anisotropic flat panels. For isotropic flat panels, only test direction CL-7 is required. In all cases, use measurement targets and photometric practice according to *8.4.2.1 Targets*. Intermediate results use Y for luminance in the material that follows.

Table 37 — Lateral measurements

n =	**CL-0**	**LL-0**	**HL-0**	**Illumination**	**Object**	**Focus**
$Y_{\text{dark,HS(n)}}$				dark	HS	HS
$Y_{\text{dark,LS(n)}}$				dark	LS	LS
Measure the emitted luminances in dark-room conditions.						

Table 38 — Goniometric measurements

n =	CL-1	CL-2	CL-3	CL-4	CL-5	CL-6	CL-7	Illumination	Object	Focus[a]
$Y_{\text{dark,HS(n)}}$								dark	HS	HS
$Y_{\text{dark,LS(n)}}$								dark	LS	LS
$Y_{\text{DIFF,dSTD(n)}}$								DIFF	dSTD	dSTD

Measure the values needed to characterize the flat panel as a function of

- state (high state, low state, switched off),
- viewing direction (CL-1…7).

To reduce the number of measurements, it has been assumed that $L_{(\text{CL-}n)} = k_1 \times L_{(\text{HL-}n)} = k_2 \times L_{(\text{LL-}n)}$, such that k_1 and k_2 remain constant for all azimuth angles and inclination angles (for all values of n). If this assumption is invalidated for a new technology, then equations (39) to (44) will not be valid and the 35 goniometric measurements of the flat panel in this table need to be repeated also for locations HL-1...7 and LL-1...7 (total of 91 measurements instead of 35).

For a uniform diffuse illumination (e.g. large integrating sphere) and a system insensitive to the azimuth angle between the equipment under test and a light meter (e.g. insensitive to polarization of light), all values in this table remain constant for all values of n and need be measured for one azimuth angle only, e.g. CL-0.

For a good measurement system and diffuse reflectance standard, regardless of the uniformity of the diffuse illumination, $Y_{\text{DIFF,dSTD}(n)}$ remains constant for all values of n, and thus $Y_{\text{DIFF,dSTD}(n)}$ needs to be measured for one azimuth angle only, e.g. CL-0.

[a] Focus is at the surface of the flat panel under test.

8.6.2 Reflectometer values.

8.6.2.1 Alternative 1 — Any display (see Tables 39 and 40)

Table 39 — Indirect measurement with diffuse light sources, Step 1, measure

n =	CL-1	CL-2	CL-3	CL-4	CL-5	CL-6	CL-7	Illumination	Object	Focus[a]
$Y_{\text{DIFF,HS}(n)}$								DIFF	HS	HS
$Y_{\text{DIFF,LS}(n)}$								DIFF	LS	LS

Measure the reflected non-specular luminance at 15°, with the flat panel switched on, in both LS and HS states.

To reduce the number of measurements it has been assumed that $L_{(\text{CL-}n)} = k_1 \times L_{(\text{HL-}n)} = k_2 \times L_{(\text{LL-}n)}$,, such that k_1 and k_2 remain constant for all azimuth angles and inclination angles (for all values of n). If this assumption is invalidated for a new technology, then equations will not be valid and the 14 goniometric measurements of the flat panel in this table need to be repeated also for locations HL-1...6 and LL-1...6 (total of 42 measurements instead of 14).

[a] Focus is at the surface of the flat panel under test.

$$\begin{aligned} Y_{\text{DIFF,HS-OFF(CL-}n)} &= Y_{\text{DIFF,HS(CL-}n)} - Y_{\text{dark,HS(CL-}n)}, \quad n = 1...7 \\ Y_{\text{DIFF,LS-OFF(CL-}n)} &= Y_{\text{DIFF,LS(CL-}n)} - Y_{\text{dark,LS(CL-}n)}, \quad n = 1...7 \end{aligned} \tag{36}$$

Table 40 — Indirect measurement with diffuse light sources, Step 2, calculate

n =	CL-1	CL-2	CL-3	CL-4	CL-5	CL-6	CL-7	Illumination	Object
$Y_{\text{DIFF,HS-OFF}(n)}$								DIFF	HS
$Y_{\text{DIFF,LS-OFF}(n)}$								DIFF	LS
Finally calculate the estimation of the reflected specular light using equation (36).									

8.6.2.2 Alternative 2 — Back-illuminated liquid crystal displays, where the illumination (e.g. backlight) can be switched off, but the state of the liquid crystals is still HS and LS (e.g. most notebook computers)

Table 41 — Direct measurement with diffuse light sources (not always possible)

n =	CL-1	CL-2	CL-3	CL-4	CL-5	CL-6	CL-7	Illumination	Object	Focus[a]
$Y_{\text{DIFF,HS-OFF}(n)}$								DIFF	HS	HS
$Y_{\text{DIFF,LS-OFF}(n)}$								DIFF	LS	LS
Measure the reflected non-specular luminance at 15°, with the flat panel switched on, in both LS and HS states, with the built-in illumination of the flat panel switched off. To reduce the number of measurements, it has been assumed that $L_{(\text{CL-}n)} = k_1 \times L_{(\text{HL-}n)} = k_2 \times L_{(\text{LL-}n)}$, such that k_1 and k_2 remains constant for all azimuth angles and inclination angles (for all values of n). If this assumption is invalidated for a new technology, then equations will not be valid and the 14 goniometric measurements of the flat panel in this table need to be repeated also for locations HL-1...6 and LL-1...6 (total of 42 measurements instead of 14).										
[a] Focus is at the surface of the flat panel under test.										

8.6.2.3 Calculate the diffuse reflectometer values

$$R_{\text{DIFF,HS-OFF(CL-}n)} = q_{\text{S-SML,dSTD(dSTD-}nS45)} \times \frac{Y_{\text{DIFF,HS-OFF(CL-}n)}}{Y_{\text{DIFF,dSTD(CL-}n)}}, \quad n = 1...7 \tag{37}$$

$$R_{\text{DIFF,LS-OFF(CL-}n)} = q_{\text{S-SML,dSTD(dSTD-}nS45)} \times \frac{Y_{\text{DIFF,LS-OFF(CL-}n)}}{Y_{\text{DIFF,dSTD(CL-}n)}}, \quad n = 1...7 \tag{38}$$

If the tests are performed with 30° diffuse illumination instead of 45°, then use $q_{\text{S-SML,dSTD(dSTD-}n30)}$ instead of $q_{\text{S-SML,dSTD(dSTD-}n30)}$ in equations (37) and (38).

Calculate the reflectometer values for diffuse reflection. (See Table 42).

Table 42 — Calculate diffuse reflectometer values

n =	1	2	3	4	5	6	7	Illumination	Object
$R_{\text{DIFF,HS-OFF(CL-}n)}$								Es	HS
$R_{\text{DIFF,LS-OFF(CL-}n)}$								Es	LS

$$L_{E\mathrm{s,HS(CL-}n)} = Y_{\mathrm{dark,HS(CL-}n)} + R_{\mathrm{DIFF,HS\text{-}OFF(CL-}n)} \times E_{\mathrm{s}},\ n = 1...7 \tag{39}$$

$$L_{E\mathrm{s,LS(CL-}n)} = Y_{\mathrm{dark,LS(CL-}n)} + R_{\mathrm{DIFF,LS\text{-}OFF(CL-}n)} \times E_{\mathrm{s}},\ n = 1...7 \tag{40}$$

$$L_{E\mathrm{s,HS(HL-}n)} = Y_{\mathrm{dark,HS(CL-}n)} \times \frac{Y_{\mathrm{dark,HS(HL-0)}}}{Y_{\mathrm{dark,HS(CL-0)}}} + R_{\mathrm{DIFF,HS\text{-}OFF(CL-}n)} \times E_{\mathrm{s}},\ n = 1...7 \tag{41}$$

$$L_{E\mathrm{s,LS(HL-}n)} = Y_{\mathrm{dark,LS(CL-}n)} \times \frac{Y_{\mathrm{dark,LS(HL-0)}}}{Y_{\mathrm{dark,LS(CL-0)}}} + R_{\mathrm{DIFF,LS\text{-}OFF(CL-}n)} \times E_{\mathrm{s}},\ n = 1...7 \tag{42}$$

$$L_{E\mathrm{s,HS(LL-}n)} = Y_{\mathrm{dark,HS(CL-}n)} \times \frac{Y_{\mathrm{dark,HS(LL-0)}}}{Y_{\mathrm{dark,HS(CL-0)}}} + R_{\mathrm{DIFF,HS\text{-}OFF(CL-}n)} \times E_{\mathrm{s}},\ n = 1...7 \tag{43}$$

$$L_{E\mathrm{s,LS(LL-}n)} = Y_{\mathrm{dark,LS(CL-}n)} \times \frac{Y_{\mathrm{dark,LS(LL-0)}}}{Y_{\mathrm{dark,LS(CL-0)}}} + R_{\mathrm{DIFF,LS\text{-}OFF(CL-}n)} \times E_{\mathrm{s}},\ n = 1...7 \tag{44}$$

Calculate the final values. See Table 43.

Table 43 — Calculate final values

n =	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Illumination**	**Object**
$L_{\mathrm{Es,HS(CL-}n)}$								E_{s}	HS
$L_{\mathrm{Es,LS(CL-}n)}$								E_{s}	LS
$L_{\mathrm{Es,HS(HL-}n)}$								E_{s}	HS
$L_{\mathrm{Es,LS(HL-}n)}$								E_{s}	LS
$L_{\mathrm{Es,HS(LL-}n)}$								E_{s}	HS
$L_{\mathrm{Es,LS(LL-}n)}$								E_{s}	LS

8.7 Requirement evaluations

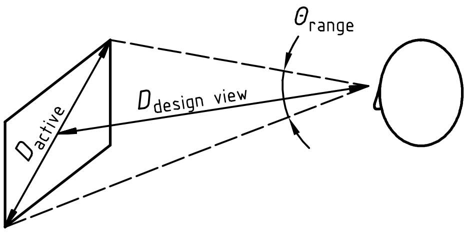
The equations and tables in this subclause have been written for emissive flat panel displays. When testing reflective flat panel displays, the measurements will be performed under laboratory illumination conditions and, by calculation, be converted to design screen illumination conditions. A procedure for providing illumination and converting to the design screen illumination has been provided in *8.7.27 Colour differences.*

8.7.1 Design viewing distance

Verify that the manufacturer's design viewing distance is greater than 400 mm or consistent with ISO 9241-3:1992, 6.1, as appropriate.

8.7.2 Design viewing direction

The minimum inclination-angle range is defined in Figure 35.



$$\theta_{\text{rangemax}} = 80° \tag{45}$$

$$\theta_{\text{rangemin}} = 2 \times \arctan\left(\frac{D_{\text{active}}}{2 \times D_{\text{design view}}}\right) \tag{46}$$

$$D_{\text{active}} = \sqrt{H_{\text{view}}^2 + W_{\text{view}}^2} \tag{47}$$

Figure 35 — Definition of θ_{rangemin}

8.7.2.1 Verify the design inclination angle

$$\theta_{\text{D}} \geqslant 0° \tag{48}$$

$$\theta_{\text{D}} \leqslant 40° - \tfrac{1}{2}\ \theta_{\text{range}} \tag{49}$$

8.7.2.2 Verify that the inclination-angle range is appropriate to the task and within the scope of this part of ISO 13406

$$\theta_{\text{range}} \geqslant \theta_{\text{rangemin}} \tag{50}$$

$$\theta_{\text{range}} \leqslant \theta_{\text{rangemax}} \tag{51}$$

8.7.2.3 Verify that the design viewing direction is compatible with the capability to display legible characters

$$\frac{2 \times D_{\text{designview}} \times \tan\left(\frac{22'}{2} \times \frac{1}{60'/°}\right)}{V_{\text{pitch}}} \geqslant 9 \text{ pixels} \tag{52}$$

8.7.2.4 Identify based on the measurement results from the other measurements the inclination-angle range classes and verify that the required class is met (see Tables 44 and 45)

Table 44 — Inclination-angle ranges for the viewing-direction range classes

$\text{Class}_{\text{viewing}}$	Criteria	Comment
I	$\theta_{\text{range}} \geqslant 80°$	At larger viewing angles than 40°, the geometric distortion of characters becomes the dominant legibility concern. Class I ensures good enough performance at inclination angles where character distortion is not a problem.
II	$\theta_{\text{range}} \geqslant 2 \times \theta_{\text{rangemin}}$	The simplified geometric model slightly overstates the requirement at all other locations except the four corners of the display.
III	$\theta_{\text{range}} \geqslant \theta_{\text{rangemin}}$	The simplified geometric model slightly overstates the requirement at all other locations except the four corners of the display.
IV	θ_{D}	Requirements are evaluated only in the design inclination angle.
NOTE The supplier may choose to define one common value for θ_{range} or up to six different values (a different value for evaluation of each of the requirements 7.5, 7.14, 7.15, 7.17, 7.19 and 7.22).		

Table 45 — Inclination-angle ranges for the viewing-direction range classes

Requirement	Required inclination-angle range class	Comment
7.5 Chromaticity uniformity difference	IV	
7.14 Display luminance	III	
7.15 Contrast	III	
7.17 Reflections	III	
7.19 Luminance uniformity	IV	
7.22 Absolute luminance coding	IV	This requirement needs to be evaluated only if absolute luminance coding is used.

8.7.2.5 Calculate data for the other measurements

For anisotropic flat panel displays, calculate the relevant range of test directions in accordance with 7.2 and 8.4.1 to be used in the other measurement clauses.

For isotropic flat panel displays, measurements shall be taken at $\theta = 0°$, except for the angles needed in 8.7.17 Reflections to characterize the reflection sensitivity of the flat panel display. Refer to 7.17 and 8.7.17 for details.

NOTE Azimuth angle, ϕ is not relevant to measurement results if $\theta = 0°$.

8.7.3 Design screen illuminance

Verify that the design screen illuminance is consistent with *7.3 Design screen illuminance*. If the evaluation source is not a CIE standard source, it shall be characterized spectro-radiometrically and the result noted on the compliance report.

8.7.4 Line-of-sight angle

This recommendation requires simultaneous evaluation of all the work-place components, including the user, for a decision to be made. The flat panel VDU and its application should be reviewed, but it is unlikely that a generalized decision can be made.

8.7.5 Chromaticity uniformity difference

Chromaticity uniformity difference is evaluated at the measurement locations under dark-room conditions with a colorimeter field of view appropriate for focusing as described in *8.4.2 Standard measurement locations.*

If a default colour set has been defined (see *7.25 Default colour set*) then the evaluations shall be made for both the primary colours and all colours of the default colour set; if not, then only for the primary colours.

If only design viewing-direction range class IV is evaluated, then locations CL-1…CL-6 are not needed.

According to *8.7.2 Design viewing direction*, locations CL-1 … CL-6 are not required for isotropic flat panels.

8.7.5.1 Measurements

Perform the measurements in Table 46. The number of required measurements depends on the type of display, the intended use of the display and the design viewing-direction class. (The colours m = 1…n, where n = the total number of colours to evaluate, usually 4 to 11).

Table 46 — Chromaticity uniformity difference measurements

			Isotropic displays Anisotropic displays, $\text{Class}_{\text{viewing}}$ IV										
			Anisotropic displays, $\text{Class}_{\text{viewing}}$ I, II, III										
		n =	CL-7	LL-7	HL-7	CL-1	CL-2	CL-3	CL-4	CL-5	CL-6	**Illumination**	**Object**
All flat panels	Flat panels for which a default colour set has been defined	$u'_{\text{dark,colour 1}}(n)$										dark	Colour 1, e.g. reference white
		$v'_{\text{dark,colour 1}}(n)$										dark	
		$u'_{\text{dark,colour 2}}(n)$										dark	Colour 2, e.g. red
		$v'_{\text{dark,colour 2}}(n)$										dark	
		$u'_{\text{dark,colour-3}}(n)$										dark	Colour 3, e.g. green
		$v'_{\text{dark,colour 3}}(n)$										dark	
		$u'_{\text{dark,colour-4}}(n)$										dark	Colour 4, e.g. blue
		$v'_{\text{dark,colour 4}}(n)$										dark	
		$u'_{\text{dark,colour 5}}(n)$										dark	Colour 5, e.g. 1st colour of the default colour set
		$v'_{\text{dark,colour 5}}(n)$										dark	
		$u'_{\text{dark,colour 6}}(n)$										dark	Colour 6, e.g. 2nd colour of the default colour set
		$v'_{\text{dark,colour 6}}(n)$										dark	
		...											
		$u'_{\text{dark,colour m}}(n)$										dark	Colour m, e.g. last colour of the default colour set
		$v'_{\text{dark,colour m}}(n)$										dark	

NOTE A default colour set would normally have 11 colours or less.

8.7.5.2 **Calculations** (See Table 47)

Calculate $\Delta u'v'$ between every pair of locations using the equation from *3.2.4 (chromaticity uniformity difference).*

$$\Delta u'v' = \sqrt{(u'_1 - u'_2)^2 + (v'_1 - v'_2)^2} \qquad (53)$$

Table 47 — Chromaticity uniformity difference calculations

			Isotropic displays																																			
			Anisotropic displays, Class$_{\text{viewing}}$ IV																																			
			Anisotropic displays, Class$_{\text{viewing}}$ I, II, III																																			
			Spatial			Spatial / goniometric																		Goniometric														
		$x =$ $y =$	HL-7, LL-7	HL-7, CL-7	LL-7, CL-7	HL-7, CL-1	HL-7, CL-2	HL-7, CL-3	HL-7, CL-4	HL-7, CL-5	HL-7, CL-6	LL-7, CL-1	LL-7, CL-2	LL-7, CL-3	LL-7, CL-4	LL-7, CL-5	LL-7, CL-6	CL-7, CL-1	CL-7, CL-2	CL-7, CL-3	CL-7, CL-4	CL-7, CL-5	CL-7, CL-6	CL-1, CL-2	CL-1, CL-3	CL-1, CL-4	CL-1, CL-5	CL-1, CL-6	CL-2, CL-3	CL-2, CL-4	CL-2, CL-5	CL-2, CL-6	CL-3, CL-4	CL-3, CL-5	CL-3, CL-6	CL-4, CL-5	CL-4, CL-6	CL-5, CL-6
All flat panels	Flat panels for which a default colour set has been defined	$u'v'_{\text{dark}}$, colour-1 (x, y)																																				
		$u'v'_{\text{dark}}$, colour-2 (x, y)																																				
		$u'v'_{\text{dark}}$, colour-3 (x, y)																																				
		$u'v'_{\text{dark}}$, colour-4 (x, y)																																				
		$u'v'_{\text{dark}}$, colour-5 (x, y)																																				
		…																																				
		$u'v'_{\text{dark}}$, colour-m (x, y)																																				

8.7.5.3 **Review of compliance**

Review for compliance with Table 8 — Maximum chromaticity difference in *7.5 Chromaticity uniformity difference*. Evaluate the relevant cells only (default colour set defined or not ; anisotropic or isotropic display; Class$_{\text{viewing}}$.

All the relevant values in Table 47 shall meet the requirements in Table 8.

8.7.6 Character height

Use the values from *8.5 Combined measurement for character design analysis*.

Verify that Ψ meets the requirements in Table 9.

8.7.7 Stroke width

Use the values from *8.5 Combined measurement for character design analysis*.

Verify that

$$8\ \% \times N_{\text{H,Height}} \leqslant \frac{N_{\text{H,hz\_stroke}} + N_{\text{H,vt\_stroke}}}{2} \leqslant 20\ \% \times N_{\text{H,Height}} \tag{54}$$

8.7.8 Character width-to-height ratio

Use the values from *8.5 Combined measurement for character design analysis*.

Verify that the ratio $\frac{N_{\text{H,Width}}}{N_{\text{H,Height}}}$ meets the requirements in Table 10.

8.7.9 Fill factor

There are two means to satisfy this requirement, one is to exceed 30 pixels per degree, tested by the following inequality:

$$N_{\text{V}} > 60 \arctan\left(\frac{H_{\text{view}}}{2 \times D_{\text{design view}}}\right) \tag{55}$$

where

N_{v} is the number of lines of pixels in the height of the viewing area,

H_{view} is the height of the viewing area,

$D_{\text{design view}}$ is the design viewing distance.

The other is to determine the fill factor [see *3.4.1 (fill factor)*].

If it is necessary to determine the fill factor to meet the requirement, some flat panel technologies require microphotometric evaluation but most technologies are best evaluated by analysis of the pixel and subpixel design [3.4.7 (**pixel**) and 3.4.12 (**subpixel**)]. In all cases, panels with subpixels are evaluated by determining the fill factor of each subpixel and summing. It is immaterial that the blue subpixel exhibits lower luminance than the green.

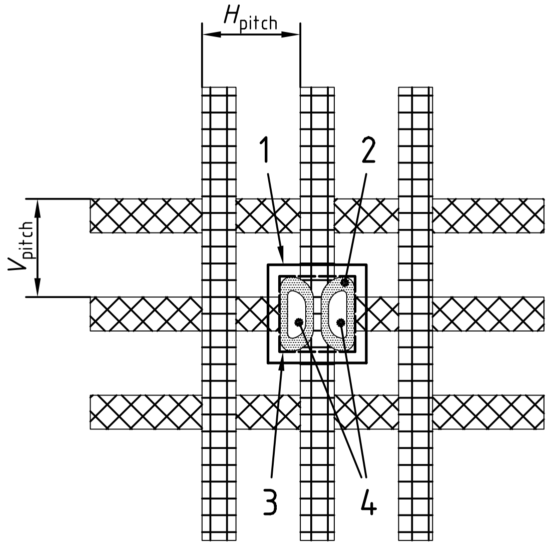
8.7.9.1 Panels that require microphotometric evaluation

The geometrically available area is judged by finding the peak luminance of a pixel under dark-room conditions with a slit luminance meter or micro-photometer with the ability to focus on 0,1 V_{pitch}. Then locating the vertical and horizontal points where the luminance has fallen as near as possible to 50 %. The fill factor is that area divided by $V_{\text{pitch}} \times H_{\text{pitch}}$.

For multi-colour flat panels the values, including the 50 % level, are measured separately for each primary colour.

Example illustrating a technology such as the double-substrate ac-plasma where the luminance at the pixel location is partly occluded by an opaque conductor.

NOTE The dashed box that circumscribes the 50 % luminance contour regions is used to judge the geometrically available area.



Key

1 Total pixel area

2 50 % contour

3 Available pixel area

4 Peak luminance

Figure 36 — Microphotometric case

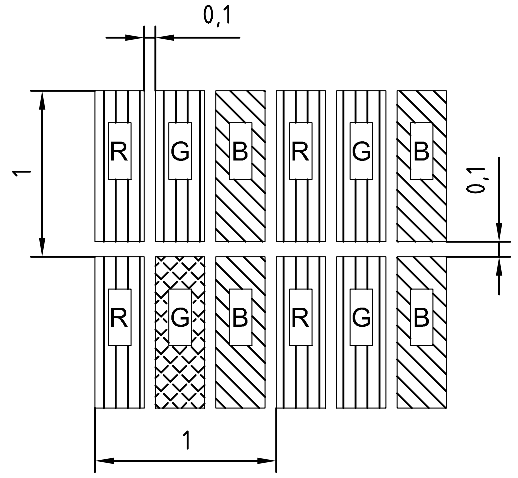
8.7.9.2 Panels that can be evaluated from artwork

Many flat panels are more conveniently and accurately represented by a design analysis of the electro-optical producing artwork. The actual luminance accurately follows the artwork.

Subpixel structures can be used to achieve multicolour, gray scale, minimize fault visibility or minimize anisotropy.

The manufacturer shall supply the required drawing. For multicolour flat panels, sum the red, green and blue apertures and divide by the pixel area.

Figure 37 shows an example of a typical multicolour panel.

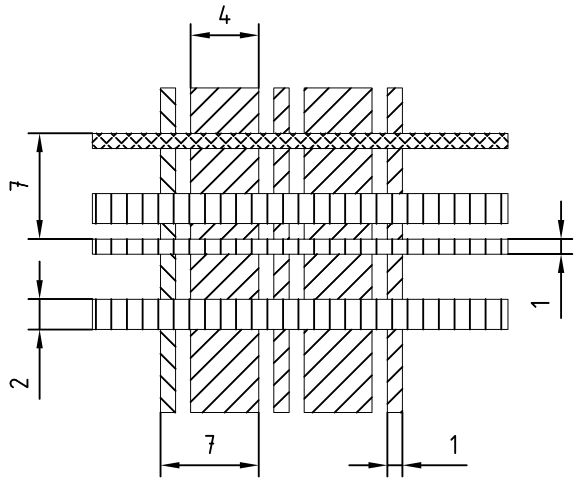


The black matrix areas have relative dimension, 0,1 and the pixel total area is 1 × 1. The total black matrix area is 3 × 0,9 × 0,1 + 1 × 0,1 = 0,37. So in this example, the fill factor is 1 – 0,37 = 0,63.

NOTE The figure shows four pixels.

Figure 37 — Multicolour pixels composed of R-Red, G-Green and B-Blue subpixels

Figure 38 shows an example of a possible electrode pattern on a display where a gray-level visual effect is produced by variable-width subpixels. The light output is proportional to the intersection of the horizontal and vertical electrode area.



The pixel area is 7 × 7 = 49 units. The intersecting areas are 1, 2, 4 and 8 that sum to 15. The fill factor is 15/49 = 0,31 just meeting the criterion.

NOTE The figure shows four pixels.

Figure 38 — Gray scale by binary weighted subpixels. The intersections produce 1, 2, 4 and 8 units producing 0 to 15 linear luminance levels

8.7.10 Character format

Use the values from *8.5 Combined measurement for character design analysis*.

Verify that $N_{\mathrm{H,Height}}$ and $N_{\mathrm{H,Width}}$ meet the requirements in Table 11.

Verify that the font meets the rest of the requirements in *7.10 Character format.*

8.7.11 Between-character spacing

For definitions, refer to *8.5 Combined measurement for character design analysis*.

Verify that the font and the application meet the requirements in *7.11 Between-character spacing*.

8.7.12 Between-word spacing

For definitions, refer to *8.5 Combined measurement for character design analysis.*

Verify that the font and the application meet the requirements in *7.12 Between-word spacing*.

8.7.13 Between-line spacing

For definitions, refer to *8.5 Combined measurement for character design analysis.*

Verify that the font and the application meet the requirements in *7.13 Between-line spacing.*

8.7.14 Display luminance

Use the values from *8.6 Combined measurement for luminance, contrast* and *diffuse illumination*, Table 43.

Verify that the 21 requirements

$$L_{\mathrm{Es,HS}(n)} \geqslant (1+\mathrm{Tol}) \times 20\ \mathrm{cd/m}^2,\ n = \mathrm{CL-1...CL\text{-}7,\ HL\text{-}1...HL\text{-}7,\ LL\text{-}1...LL\text{-}7} \tag{56}$$

are met.

8.7.15 Contrast

Use the values from *8.6 Combined measurement for luminance, contrast, and diffuse illumination*, Table 43.

Verify that the 21 requirements (contrast modulation)

$$C_{\mathrm{m}} = \frac{L_{E\mathrm{s,HS}(n)} - (1+\mathrm{Tol}) \times L_{E\mathrm{s,LS}(n)}}{L_{E\mathrm{s,HS}(n)} + (1+\mathrm{Tol}) \times L_{E\mathrm{s,LS}(n)}} \geqslant \frac{5 \times L_{E\mathrm{s,LS}(n)}^{-0{,}55}}{1+5 \times L_{E\mathrm{s,LS}(n)}^{-0{,}55}},\ n = \mathrm{CL\text{-}1...CL\text{-}7,\ HL\text{-}1...HL\text{-}7,\ LL\text{-}1...LL\text{-}7} \tag{57}$$

or equivalent 21 requirements (contrast ratio)

$$\frac{L_{E\mathrm{s,HS}(n)}}{L_{E\mathrm{s,LS}(n)}} \geqslant (1+\mathrm{Tol}) \times \left(1+10 \times L_{E\mathrm{s,LS}}{}^{-0{,}55}\right)\ n = \mathrm{CL\text{-}1...CL\text{-}7,\ HL\text{-}1...HL\text{-}7,\ LL\text{-}1...LL\text{-}7} \tag{58}$$

are met.

8.7.16 Luminance balance

Luminance balance can only be evaluated in full at the workplace:

8.7.16.1 Evaluation at the workplace

a) Measure $L_{E\text{a,HS(HL-7)}}$ of the flat panel, where $L_{E\text{a,HS(HL-7)}}$, is the area-luminance of the highest luminance state used on the display by the application in the design viewing direction, in the actual ambient lighting of the workplace.

b) Measure $L_{E\text{a,task area(TA-min)}}$ and $L_{E\text{a,task area(TA-max)}}$, where $L_{E\text{a,task area(TA-min)}}$ and $L_{E\text{a,task area(TA-max)}}$ are the lowest and highest area luminances of any task area that is frequently viewed in sequence while using the display (document, covers, etc.), in the actual ambient lighting at the workplace.

c) $L_{E\text{a,HS(HL-7)}}$, $L_{E\text{a,task area(TA-min)}}$ and $L_{E\text{a,task area(TA-max)}}$) should meet the following criteria:

$$0{,}1 \times L_{E\text{a,task area(TA-max)}} \leqslant L_{E\text{a,HS(HL-7)}} \leqslant 10 \times L_{E\text{a,task area(TA-min)}} \qquad (59)$$

8.7.16.2 Evaluation in a test laboratory

The luminance balance between the screen and other parts of the product (covers, keyboards, etc) can be evaluated in a laboratory using the specified design screen illumination:

a) Estimate $L_{E\text{s,HS(HL-7)}}$

  1) Evaluate the eighteen luminance values $L_{E\text{s,HS(CL-}n\text{)}}$, $L_{E\text{s,HS(HL-}n\text{)}}$ and $L_{E\text{s,HS(LL-}n\text{)}}$, where n = 1...6 from *8.6 Combined measurement for luminance*, *contrast and diffuse illumination*, Table 43.

  2) Select the smallest of these values as the estimate for $L_{E\text{s,HS(HL-7)}}$.

b) Estimate $L_{E\text{s,task area(TA-min)}}$ and $L_{E\text{s,task area(TA-max)}}$ (see Table 48)

  1) Measure $Y_{\text{DIFF,task area(TA-min)}}$ and $Y_{\text{DIFF,task area(TA-max)}}$, where $Y_{\text{DIFF,task area(TA-min)}}$ and $Y_{\text{DIFF,task area(TA-max)}}$ are, when illuminated with the diffuse light source of the laboratory, the lowest and highest area luminances of any task area of the product that is frequently viewed in sequence while using the display (covers, keyboards, etc.).

  2) Measure $Y_{\text{DIFF,dSTD(TA-min)}}$ and $Y_{\text{DIFF,dSTD(TA-max)}}$, where $Y_{\text{DIFF,dSTD(TA-min)}}$ and $Y_{\text{DIFF,dSTD(TA-max)}}$ are the measured luminances of the diffuse reflectance standard when placed at the locations TA-min and TA-max.

Table 48 — Task area and dSTD

Measure	n = min	n = max	Illumination	Object	Focus
$Y_{\text{DIFF,task area(TA-n)}}$			DIFF	task area	task area
$Y_{\text{DIFF,dSTD(TA-n)}}$			DIFF	dSTD	dSTD

  3) Calculate $L_{E\text{s,task area(TA-min)}}$ and $L_{E\text{s,task area(TA-max)}}$.

$$L_{E\text{s,task area(TA–}n\text{)}} = \frac{Y_{\text{DIFF,task area(TA–}n\text{)}} \times q_{S\text{–SML,dSTD(dSTD–}n\text{S45)}} \times E_{\text{s}}}{Y_{\text{DIFF,dSTD(TA–}n\text{)}}}, \; n = \text{min, max} \qquad (60)$$

c) $L_{E\text{s,HS(HL-7)}}$, $L_{E\text{s,task area(TA-min)}}$ and $L_{E\text{s,task area(TA-max)}}$) should meet the following criteria:

$$0{,}1 \times L_{E\text{s,task area(TA-max)}} \leqslant L_{E\text{s,HS(HL-7)}} \leqslant 10 \times L_{E\text{s,task area(TA-min)}} \tag{61}$$

NOTE The luminance balance characteristics of the product can in a laboratory be further analysed by measuring $L_{\text{DIFF,task area(TA-min)}}$ and $L_{\text{DIFF,task area(TA-max)}}$, for typical objects (standard office papers, magazine paper, etc.) used in offices.

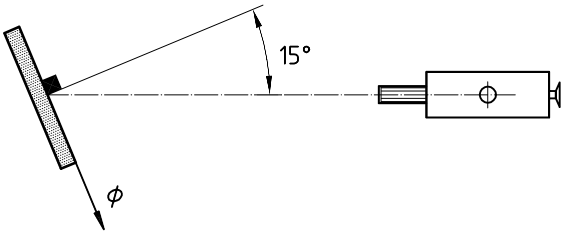
8.7.17 Reflections

8.7.17.1 Overview

Verify that the reflection resistance class has been specified from Table 13. Record whether the display testing is being done for positive polarity, negative polarity or both.

NOTE Class I requires that the luminance factor β be estimated for both a 15° and a 1° source.

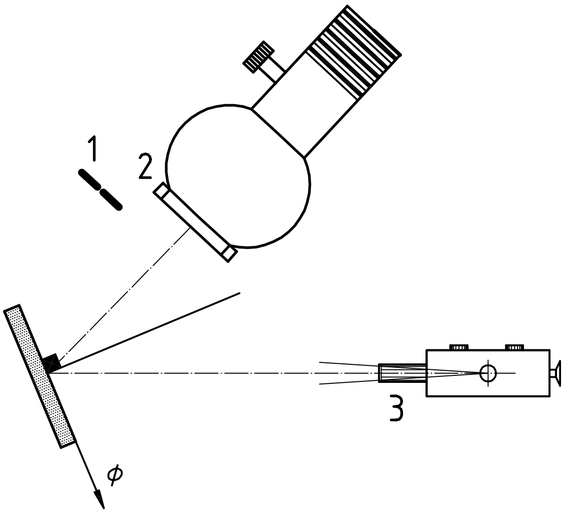
These measurements are taken at locations CL-nS, where n = 1...6. The working distance and aperture of the luminance meter must be such that the measuring field is less than 0,5 × the image of the small specular source, but large enough to include at least a 10-pixel circular field. All measurements for this evaluation shall be conducted with the luminance meter in the geometry of Figure 39.



Sideview of the measurement geometry. The meter is at (15°, ϕ).

Figure 39 — Measurement geometry for reflection evaluation

Depending on class selection, one or both of the configurations shown in Figure 40 may be needed.



Key

1 1° aperture to create small source

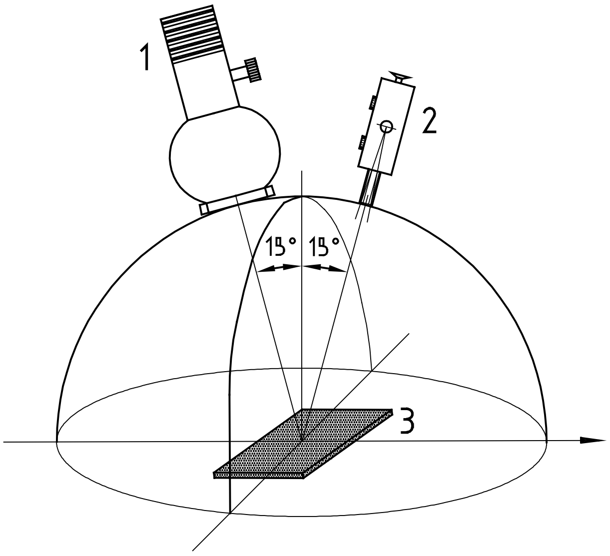
2 ⩾ 15° exit port to create extended source

3 1° to 2° aperture for extended source, ⩽ 0,3° for small source

Sideview of the measurement geometry. The luminance source is at (15°, ϕ + 180°) and the luminance meter at (+ 15°, ϕ).

Figure 40 — Configuration for estimating β, the luminance factor

Figure 41 shows a perspective view of the specular reflection apparatus.



Key

1 Luminance source (shown with the 15° aperture)

2 Spot photometer

3 Panel or reflectance standard

Perspective view of the measurement geometry. The luminance source is at (15°, ϕ + 180°) and the luminance meter at (+ 15°, ϕ).

Figure 41 — Perspective of the specular reflection apparatus

The following data from the diffuse and specular standards is needed (as usual, *Y* is used for the luminance of preliminary results).

The luminance meter shall be focused as defined in Tables 49 to 51. For the small-source specular reflection measurement, the angular alignment mechanism of the light source and the photometer shall have a resolution finer than 0,2° so that it is possible to determine the peak in reflected luminance.

8.7.17.2 Measurements

8.7.17.2.1 Light sources

8.7.17.2.1.1 Alternative 1, use no specular standard

Table 49 — Measurement of the light sources

	L_g	Illumination	Object	Focus
$Y_{\text{S-EXT,S-EXT}(L_g)}$		S-EXT	S-EXT	S-EXT[a]
$Y_{\text{S-SML,S-SML}(L_g)}$		S-SML	S-SML	S-SML[b]
Measure the luminance of the light sources. NOTE Greatest accuracy is achieved when selecting the measurement distance (light meter to light source) to be the same as the total distance in the specular measurements of the flat panel (light meter to flat panel + flat panel to light source).				
[a] Focus is at the exit port of the light source. [b] Focus is at the exit port of the light source.				

8.7.17.2.1.2 Alternative 2, use a specular standard

Table 50 — Measurement of reflectance standards

	CL-0S	Illumination	Object	Focus[a]
$Y_{\text{S-EXT,sSTD(CL-0S)}}$		S-EXT	sSTD	S-EXT
$Y_{\text{S-SML,sSTD(CL-0S)}}$		S-SML	sSTD	S-SML
Measure the values needed to calculate the luminances of the light sources.				
[a] Focus is at the exit port of the light source.				

$$Y_{\text{S-EXT,S-EXT}(L_g)} = \frac{Y_{\text{S-EXT,sSTD(CL-0S)}}}{\beta_{\text{S-EXT,STD(CL-0S)}}}$$
$$Y_{\text{S-SML,S-SML}(L_g)} = \frac{Y_{\text{S-SML,sSTD(CL-0S)}}}{\beta_{\text{S-SML,STD(CL-0S)}}} \tag{62}$$

Table 51 — Calculation of the light sources

	L_g	Illumination	Object
$Y_{\text{S-EXT,S-EXT}(L_g)}$		S-EXT	S-EXT
$Y_{\text{S-SML,S-SML}(L_g)}$		S-SML	S-EXT
Measure the luminance of the light sources. NOTE Greatest accuracy is achieved when selecting the measurement distance (light meter to light source) to be the same as the total distance in the specular measurements of the flat panel (light meter to flat panel + flat panel to light source).			

When using a specular standard, additional measurement uncertainty is introduced from

- the accuracy of calibration of the specular reflection standard,
- non-perfect alignment of the specular reflection standard, and
- possible azimuthal variation of the characteristics of the specular reflection standard.

Use the data from the calibration of the specular standard to define an increased uncertainty estimate for $Y_{\text{S-EXT,S-EXT}}(L_{\text{g}})$ and $Y_{\text{S-SML,S-SML}}(L_{\text{g}})$.

8.7.17.2.2 Diffuse reflectance standard

For a uniform diffuse illumination (e.g. large integrating sphere) and a system insensitive to the azimuth angle between equipment under test and light meter (e.g. insensitive to polarization of light) all the values in Table 52 remain constant for all values of n and need be measured for one azimuth angle only, e.g. CL-0.

Table 52 — Measurement of diffuse reflectance standard

n =	**CL-1S**	**CL-2S**	**CL-3S**	**CL-4S**	**CL-5S**	**CL-6S**	**Illumination**	**Object**	**Focus**[a]
$Y_{\text{DIFF,dSTD}}(n)$							DIFF	dSTD	dSTD

NOTE 1 If it has been verified through a calibration measurement that the reflectance characteristics of the diffuse reflection standard are independent of the azimuth angle, then the measurement of dSTD need to be performed for one azimuth angle only, e.g. CL-0S.

NOTE 2 If the measurement system is accurate and stabile, then the values for dSTD in this table should remain the same from measurement to measurement. Thus these values can be used as quality assurance values for the system.

[a] Focus is at the surface of the flat panel under test.

8.7.17.2.3 Emitted luminance from the flat panel at 15° (see Table 53)

Table 53 — Measurements in the dark and with diffuse illumination

n =	**CL-1S**	**CL-2S**	**CL-3S**	**CL-4S**	**CL-5S**	**CL-6S**	**Illumination**	**Object**	**Focus**[a]
$Y_{\text{dark,HS}}(n)$							dark	HS	HS
$Y_{\text{dark,LS}}(n)$							dark	LS	LS

Measure the values needed to characterize the flat panel as a function of

- state (high state, low state, switched off), and
- viewing direction (CL-1S…6S).

[a] Focus is at the surface of the flat panel under test.

8.7.17.2.4 Reflectometer values.

8.7.17.2.4.1 Alternative 1, any display (see Tables 54 to 58)

Table 54 — Indirect measurement with specular light sources, step 1

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumination	Object	Focus[a]
$Y_{\text{S-EXT,HS-F\_EXT}(n)}$							S-EXT	HS	S-EXT
$Y_{\text{S-EXT,LS-F\_EXT}(n)}$							S-EXT	LS	S-EXT
$Y_{\text{S-SML,HS-F\_SML}(n)}$							S-SML	HS	S-SML
$Y_{\text{S-SML,LS-F\_SML}(n)}$							S-SML	LS	S-SML
First measure the luminance at the exit port of the light source, with the flat panel switched on.									

[a] The focusing in these twelve measurements is at the exit port of the light source.

Table 55 — Indirect measurement with specular light sources, step 2

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumination	Object	Focus[a]
$Y_{\text{dark,HS-F\_EXT}(n)}$							dark	HS	S-EXT
$Y_{\text{dark,LS-F\_EXT}(n)}$							dark	LS	S-EXT
$Y_{\text{dark,HS-F\_SML}(n)}$							dark	HS	S-SML
$Y_{\text{dark,LS-F\_SML}(n)}$							dark	LS	S-SML
Then **very carefully** cover the light source and maintain all alignments **exactly identical** to the previous measurements. Measure the luminance of the light emission from the flat panel with the focus on the light source, with the light source dark. These values are needed for calculating the specular reflection component without contribution of emitted light from the flat panel. If the distance between EUT and the small source is identical to the distance between EUT and the extended source, then row 1 = row 3 and row 2 = row 4.									

[a] The focusing in these twelve measurements is intentionally unusual (on the exit port of the dark light source).

Table 56 — Indirect measurement with specular light sources, step 3, calculate

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumination	Object
$Y_{\text{S-EXT,HS-OFF}(n)}$							S-EXT	HS
$Y_{\text{S-EXT,LS-OFF}(n)}$							S-EXT	LS
$Y_{\text{S-SML,HS-OFF}(n)}$							S-SML	HS
$Y_{\text{S-SML,LS-OFF}(n)}$							S-SML	LS
Finally calculate the estimation of the reflected specular light using equation (63).								

$$
\begin{aligned}
Y_{\text{S-EXT,HS-OFF(CL-}n\text{S)}} &= Y_{\text{S-EXT,HS-F\_EXT(CL-}n\text{S)}} - Y_{\text{dark,HS-F\_EXT(CL-}n\text{S)}}, \quad n = 1...6\\
Y_{\text{S-EXT,LS-OFF(CL-}n\text{S)}} &= Y_{\text{S-EXT,LS-F\_EXT(CL-}n\text{S)}} - Y_{\text{dark,LS-F\_EXT(CL-}n\text{S)}}, \quad n = 1...6\\
Y_{\text{S-SML,HS-OFF(CL-}n\text{S)}} &= Y_{\text{S-SML,HS-F\_SML(CL-}n\text{S)}} - Y_{\text{dark,HS-F\_SML(CL-}n\text{S)}}, \quad n = 1...6\\
Y_{\text{S-SML,LS-OFF(CL-}n\text{S)}} &= Y_{\text{S-SML,LS-F\_SML(CL-}n\text{S)}} - Y_{\text{dark,LS-F\_SML(CL-}n\text{S)}}, \quad n = 1...6
\end{aligned}
\tag{63}
$$

Table 57 — Indirect measurement with diffuse light sources, step 1, measure

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumination	Object	Focus[a]
$Y_{\mathrm{DIFF,HS}(n)}$							DIFF	HS	HS
$Y_{\mathrm{DIFF,LS}(n)}$							DIFF	LS	LS
Measure the reflected non-specular luminance at 15°, with the flat panel switched on, in both LS and HS states. To reduce the number of measurements, it has been assumed that $L_{\mathrm{(CL\text{-}n)}} = k_1 \times L_{\mathrm{(HL\text{-}n)}} = k_2 \times L_{\mathrm{(LL\text{-}n)}}$, such that k_1 and k_2 remains constant for all azimuth angles and inclination angles (for all values of n). If this assumption is invalidated for a new technology, then the equations will not be valid and the 12 goniometric measurements of the flat panel in this table need to be repeated also for locations HL-1...6 and LL-1...6 (total of 36 measurements instead of 12).									
[a] Focus is at the surface of the flat panel under test.									

$$Y_{\mathrm{DIFF,HS–OFF(CL\text{-}}n\mathrm{S)}} = Y_{\mathrm{DIFF,HS(CL\text{-}}n\mathrm{S)}} - Y_{\mathrm{dark,HS(CL\text{-}}n\mathrm{S)}}, \quad n = 1...6$$
$$Y_{\mathrm{DIFF,LS–OFF(CL\text{-}}n\mathrm{S)}} = Y_{\mathrm{DIFF,LS(CL\text{-}}n\mathrm{S)}} - Y_{\mathrm{dark,LS(CL\text{-}}n\mathrm{S)}}, \quad n = 1...6 \qquad (64)$$

Table 58 — Indirect measurement with diffuse light sources, step 2, calculate

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumination	Object
$Y_{\mathrm{DIFF,HS\text{-}OFF}(n)}$							DIFF	HS
$Y_{\mathrm{DIFF,LS\text{-}OFF}(n)}$							DIFF	LS
Finally calculate the estimation of the reflected diffuse light using equation (64).								

8.7.17.2.4.2 Alternative 2, Back-illuminated liquid crystal displays, where the illumination (e.g. backlight) can be switched off, but the state of the liquid crystals is still HS and LS (e.g. most notebook computers) (see Tables 59 and 60).

Table 59 — Direct measurement with specular light sources (not always possible)

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumination	Object	Focus[a]
$Y_{\mathrm{S\text{-}EXT,HS\text{-}OFF}(n)}$							S-EXT	HS-OFF	S-EXT
$Y_{\mathrm{S\text{-}EXT,LS\text{-}OFF}(n)}$							S-EXT	LS-OFF	S-EXT
$Y_{\mathrm{S\text{-}SML,HS\text{-}OFF}(n)}$							S-SML	HS-OFF	S-SML
$Y_{\mathrm{S\text{-}SML,LS\text{-}OFF}(n)}$							S-SML	LS-OFF	S-SML
Measure the reflected specular luminance, with the flat panel switched on, in both LS and HS states, with the built-in illumination of the flat panel switched off.									
[a] The focusing in these 24 measurements is on the exit port of the light source.									

Table 60 — Direct measurement with diffuse light sources (not always possible)

n =	**CL-1S**	**CL-2S**	**CL-3S**	**CL-4S**	**CL-5S**	**CL-6S**	**Illumination**	**Object**	**Focus**[a]
$Y_{\text{DIFF,HS-OFF}(n)}$							DIFF	HS	HS
$Y_{\text{DIFF,LS-OFF}(n)}$							DIFF	LS	LS
Measure the reflected non-specular luminance at 15°, with the flat panel switched on, in both LS and HS states, with the built-in illumination of the flat panel switched off. To reduce the number of measurements, it has been assumed that $L_{(\text{CL-}n)} = k_1 \times L_{(\text{HL-}n)} = k_2 \times L_{(\text{LL-}n)}$, such that k_1 and k_2 remains constant for all azimuth angles and inclination angles (for all values of n). If this assumption is invalidated for a new technology, then equations will not be valid and the 12 goniometric measurements of the flat panel in this table need to be repeated also for locations HL-1...6 and LL-1...6 (total of 36 measurements instead of 12).									
[a] Focus is at the surface of the flat panel under test.									

8.7.17.2.4.3 The non-specular component in the specular measurement (See Table 61)

Table 61 — Measurement of non-specular component

n =	**CL-1S**	**CL-2S**	**CL-3S**	**CL-4S**	**CL-5S**	**CL-6S**	**Illumination**	**Object**	**Focus**[a]
$Y_{\text{S-EXT,dSTD}(n)}$							S-EXT	dSTD	S-EXT
$Y_{\text{S-SML,dSTD}(n)}$							S-SML	dSTD	S-SML
Measure the reflected specular luminance, with the flat panel switched on, in both LS and HS states, with the built-in illumination of the flat panel switched off. NOTE 1 If it has been verified, through a calibration measurement, that the reflectance characteristics of the diffuse reflection standard are independent of the azimuth angle, then the measurement needs to be performed for one azimuth angle only, e.g. CL-0S. NOTE 2 If the measurement system is accurate and stabile, then the values in this table should remain the same from measurement to measurement. Thus these values can be used as quality assurance values for the system.									
[a] The focusing in these twelve measurements is on the exit port of the light source.									

8.7.17.3 Summary of symbols used in calculations

In this part of ISO 13406 it is assumed that emitted luminance of flat panels is independent of the polarity. In ISO 9241-7 the emitted luminance is measured separately in each polarity because the luminance of CRT displays is dependent on the polarity (step 1, Table 62).

As the reflectance characteristics of anisotropic displays is dependent on azimuth, many measurements in this part of ISO 13406 are repeated for six different azimuth angles. If the flat panel is isotropic, then only one azimuth angle is necessary, e.g. CL-0S (steps 1,2 and 3, Table 62).

As the orientation of the liquid crystal affects the reflectance for LCDs, measurements are not made with the flat panel switched off, but in the states LS-OFF and HS-OFF instead. If the state of the flat panel does not affect the reflection characteristics then the measurement need only be performed in the off state (steps 1, 2, 3 and 4, Table 62).

Table 62 — Raw data needed in calculations

Step	ISO 9241-7	ISO 9241-7 with ISO 13406-2 symbols	ISO 13406-2
1	$L_{\mathrm{B(15°)}}$ positive polarity	$Y_{\mathrm{dark,HS\text{-}pospol(CL\text{-}0S)}}$	$Y_{\mathrm{dark,HS(CL\text{-}}n\mathrm{S)}}$, n = 1…6
	$L_{\mathrm{F(15°)}}$ negative polarity	$Y_{\mathrm{dark,HS\text{-}negpol(CL\text{-}0S)}}$	
	$L_{\mathrm{F(15°)}}$ positive polarity	$Y_{\mathrm{dark,LS\text{-}pospol(CL\text{-}0S)}}$	$Y_{\mathrm{dark,LS(CL\text{-}}n\mathrm{S)}}$, n = 1…6
	$L_{\mathrm{B(15°)}}$ negative polarity	$Y_{\mathrm{dark,LS\text{-}negpol(CL\text{-}0S)}}$	
2	$L_{\mathrm{DS(SML,15°)}}$	$Y_{\mathrm{S\text{-}SML,OFF(CL\text{-}0S)}}$	$Y_{\mathrm{S\text{-}SML,HS\text{-}OFF(CL\text{-}}n\mathrm{S)}}$, n = 1…6
			$Y_{\mathrm{S\text{-}SML,LS\text{-}OFF(CL\text{-}}n\mathrm{S)}}$, n = 1…6
	$L_{\mathrm{DS(STD,15°)}}$	$Y_{\mathrm{S\text{-}SML,dSTD(CL\text{-}0S)}}$	$Y_{\mathrm{S\text{-}SML,dSTD(CL\text{-}}n\mathrm{S)}}$, n = 1…6
3	$L_{\mathrm{DS(EXT,15°)}}$	$Y_{\mathrm{S\text{-}EXT,OFF(CL\text{-}0S)}}$	$Y_{\mathrm{S\text{-}EXT,HS\text{-}OFF(CL\text{-}}n\mathrm{S)}}$, n = 1…6
			$Y_{\mathrm{S\text{-}EXT,LS\text{-}OFF(CL\text{-}}n\mathrm{S)}}$, n = 1…6
	$L_{\mathrm{D(STD,15°)}}$	$Y_{\mathrm{S\text{-}EXT,dSTD(CL\text{-}0S)}}$	$Y_{\mathrm{S\text{-}EXT,dSTD(CL\text{-}}n\mathrm{S)}}$, n = 1…6
4	$L_{\mathrm{D(0°)}}$	$Y_{\mathrm{DIFF,OFF(CL\text{-}0)}}$	$Y_{\mathrm{DIFF,HS\text{-}OFF(CL\text{-}}n\mathrm{S)}}$, n = 1…6
			$Y_{\mathrm{DIFF,LS\text{-}OFF(CL\text{-}}n\mathrm{S)}}$, n = 1…6
	$L_{\mathrm{D(STD,0°)}}$	$Y_{\mathrm{DIFF,dSTD(CL\text{-}0)}}$	$Y_{\mathrm{DIFF,dSTD(CL\text{-}}n\mathrm{S)}}$, n = 1…6
5	$L_{\mathrm{A(SML)}}$	$Y_{\mathrm{S\text{-}SML,S\text{-}SML(}L_{\mathrm{g}}\mathrm{)}}$	$Y_{\mathrm{S\text{-}SML,S\text{-}SML((}L_{\mathrm{g}}\mathrm{)}}$
	$L_{\mathrm{A(EXT)}}$	$Y_{\mathrm{S\text{-}EXT,S\text{-}EXT(}L_{\mathrm{g}}\mathrm{)}}$	$Y_{\mathrm{S\text{-}EXT,S\text{-}EXT(}L_{\mathrm{g}}\mathrm{)}}$

8.7.17.4 Calculate reflectometer values

$$R_{\mathrm{DIFF,HS\text{-}OFF(CL\text{-}}n\mathrm{S)}} = q_{\mathrm{S\text{-}SML,dSTD(dSTD\text{-}}n\mathrm{45)}} \times \frac{Y_{\mathrm{DIFF,HS\text{-}OFF(CL\text{-}}n\mathrm{S)}}}{Y_{\mathrm{DIFF,dSTD(CL\text{-}}n\mathrm{S)}}},\quad n = 1...6 \tag{65}$$

$$R_{\mathrm{DIFF,LS\text{-}OFF(CL\text{-}}n\mathrm{S)}} = q_{\mathrm{S\text{-}SML,dSTD(dSTD\text{-}}n\mathrm{45)}} \times \frac{Y_{\mathrm{DIFF,LS\text{-}OFF(CL\text{-}}n\mathrm{S)}}}{Y_{\mathrm{DIFF,dSTD(CL\text{-}}n\mathrm{S)}}},\quad n = 1...6 \tag{66}$$

If the tests are performed with 30° diffuse illumination instead of 45°, then use $q_{\mathrm{S\text{-}SML,dSTD(dSTD\text{-}}n\mathrm{30)}}$ instead of $q_{\mathrm{S\text{-}SML,dSTD(dSTD\text{-}}n\mathrm{45)}}$ in equations (65) and (66).

Calculate the reflectometer values for diffuse reflection. See Table 63.

Table 63 — Calculate diffuse reflectometer values

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Object
$R_{\mathrm{DIFF,HS\text{-}OFF(}n\mathrm{)}}$							HS
$R_{\mathrm{DIFF,LS\text{-}OFF(}n\mathrm{)}}$							LS
NOTE This reflectometer value represents the combined diffuse and haze reflection with a 45°/0° geometry. It is not a complete representation of the non-specular reflections. The characterization of reflections is further discussed in annex C.							

$$R_{\text{S-EXT,HS-OFF(CL-}n\text{S)}} = \frac{Y_{\text{S-EXT,HS-OFF(CL-}n\text{S)}} - Y_{\text{S-EXT,dSTD(CL-}n\text{S)}} \times \dfrac{R_{\text{DIFF,HS-OFF(CL-}n\text{S)}}}{q_{\text{S-SML,dSTD(dSTD}-n\text{S15)}}}}{Y_{\text{S-EXT,S-EXT(}L_{\text{g}}\text{)}}}, \quad n = 1...6 \qquad (67)$$

$$R_{\text{S-EXT,LS-OFF(CL-}n\text{S)}} = \frac{Y_{\text{S-EXT,LS-OFF(CL-}n\text{S)}} - Y_{\text{S-EXT,dSTD(CL-}n\text{S)}} \times \dfrac{R_{\text{DIFF,LS-OFF(CL-}n\text{S)}}}{q_{\text{S-SML,dSTD(dSTD}-n\text{S15)}}}}{Y_{\text{S-EXT,S-EXT(}L_{\text{g}}\text{)}}}, \quad n = 1...6 \qquad (68)$$

$$R_{\text{S-SML,HS-OFF(CL-}n\text{S)}} = \frac{Y_{\text{S-SML,HS-OFF(CL-}n\text{S)}} - Y_{\text{S-SML,dSTD(CL-}n\text{S)}} \times \dfrac{R_{\text{DIFF,HS-OFF(CL-}n\text{S)}}}{q_{\text{S-SML,dSTD(dSTD-}n\text{S15)}}}}{Y_{\text{S-SML,S-SML(}L_{\text{g}}\text{)}}}, \quad n = 1...6 \qquad (69)$$

$$R_{\text{S-SML,LS-OFF(CL-}n\text{S)}} = \frac{Y_{\text{S-SML,HS-OFF(CL-}n\text{S)}} - Y_{\text{S-SML,dSTD(CL-}n\text{S)}} \times \dfrac{R_{\text{DIFF,LS-OFF(CL-}n\text{S)}}}{q_{\text{S-SML,dSTD(dSTD-}n\text{S15)}}}}{Y_{\text{S-SML,S-SML(}L_{\text{g}}\text{)}}}, \quad n = 1...6 \qquad (70)$$

NOTE The second term of equations (67) to (70) is an estimation of the reflected non-specular component (see ISO 9241-7). Especially with small source reflections, the term approaches zero for many displays.

Calculate the reflectometer values for extended source and small source specular reflection. See Table 64.

Table 64 — Calculate specular reflectometer values

n=	**CL-1S**	**CL-2S**	**CL-3S**	**CL-4S**	**CL-5S**	**CL-6S**	**Object**
$R_{\text{S-EXT,HS-OFF(}n\text{)}}$							HS
$R_{\text{S-EXT,LS-OFF(}n\text{)}}$							LS
$R_{\text{S-SML,HS-OFF(}n\text{)}}$							HS
$R_{\text{S-SML,LS-OFF(}n\text{)}}$							LS

Table 65 gives a summary of reflectometer values used in ISO 9241-7 and in this part of ISO 13406.

Table 65 — Summary of reflectometer values

ISO 9241-7	**ISO 9241-7 with this part of ISO 13406 symbols**	**This part of ISO 13406**
R_{D}	$R_{\text{DIFF,OFF(CL-0S)}}$	$R_{\text{DIFF,HS-OFF(CL-}n\text{S)}}$, n = 1…6
		$R_{\text{DIFF,LS-OFF(CL-}n\text{S)}}$, n = 1…6
$R_{\text{S-EXT}}$	$R_{\text{S-EXT,OFF(CL-0S)}}$	$R_{\text{S-EXT,HS-OFF(CL-}n\text{S)}}$, n = 1…6
		$R_{\text{S-EXT,LS-OFF(CL-}n\text{S)}}$, n = 1…6
$R_{\text{S-SML}}$	$R_{\text{S-SML,OFF(CL-0S)}}$	$R_{\text{S-SML,HS-OFF(CL-}n\text{S)}}$, n = 1…6
		$R_{\text{S-SML,LS-OFF(CL-}n\text{S)}}$, n = 1…6

8.7.17.5 Convert to standard ambient illumination conditions

$$L_{E\text{s,HS(CL-}n\text{S)}} = Y_{\text{dark,HS(CL-}n\text{S)}} + E_{\text{s}} \times R_{\text{DIFF,HS-OFF(CL-}n\text{D)}},\ n = 1...6 \tag{71}$$

$$L_{E\text{s,LS(CL-}n\text{S)}} = Y_{\text{dark,LS(CL-}n\text{S)}} + E_{\text{s}} \times R_{\text{DIFF,LS-OFF(CL-}n\text{D)}},\ n = 1...6 \tag{72}$$

Calculate the combined luminance emitted from the EUT and reflected from the EUT with the design screen illuminance (intermediate result). See Table 66

Table 66 — Calculate emitted luminance + standard diffuse illumination

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumination	Object
$L_{E\text{s,HS}(n)}$							E_{s}	HS
$L_{E\text{s,LS}(n)}$							E_{s}	LS

$$\begin{aligned}
L_{E\text{s+REFEXT–I,HS(CL-}n\text{S)}} &= L_{E\text{s,HS(CL-}n\text{S)}} + L_{\text{REFEXT–I}} \times R_{\text{S-EXT,HS-OFF(CL-}n\text{S)}},\ n=1...6\\
L_{E\text{s+REFEXT–I,LS(CL-}n\text{S)}} &= L_{E\text{s,LS(CL-}n\text{S)}} + L_{\text{REFEXT–I}} \times R_{\text{S-EXT,LS-OFF(CL-}n\text{S)}},\ n=1...6\\
L_{E\text{s+REFSML–I,HS(CL-}n\text{S)}} &= L_{E\text{s,HS(CL-}n\text{S)}} + L_{\text{REFSML–I}} \times R_{\text{S-SML,HS-OFF(CL-}n\text{S)}},\ n=1...6\\
L_{E\text{s+REFSML–I,LS(CL-}n\text{S)}} &= L_{E\text{s,LS(CL-}n\text{S)}} + L_{\text{REFSML–I}} \times R_{\text{S-SML,LS-OFF(CL-}n\text{S)}},\ n=1...6
\end{aligned} \tag{73}$$

$$\begin{aligned}
L_{E\text{s+REFEXT–I,HS(CL-}n\text{S)}} &= L_{E\text{s,HS(CL-}n\text{S)}} + L_{\text{REFEXT–III}} \times R_{\text{S-EXT,HS-OFF(CL-}n\text{S)}},\ n=1...6\\
L_{E\text{s+REFEXT–I,LS(CL-}n\text{S)}} &= L_{E\text{s,LS(CL-}n\text{S)}} + L_{\text{REFEXT–III}} \times R_{\text{S-EXT,LS-OFF(CL-}n\text{S)}},\ n=1...6\\
L_{E\text{s+REFSML–I,HS(CL-}n\text{S)}} &= L_{E\text{s,HS(CL-}n\text{S)}} + L_{\text{REFSML–III}} \times R_{\text{S-SML,HS-OFF(CL-}n\text{S)}},\ n=1...6\\
L_{E\text{s+REFSML–I,LS(CL-}n\text{S)}} &= L_{E\text{s,LS(CL-}n\text{S)}} + L_{\text{REFSML–III}} \times R_{\text{S-SML,LS-OFF(CL-}n\text{S)}},\ n=1...6
\end{aligned} \tag{74}$$

Add the intermediate values to get the total luminance values with standardized diffuse illumination and glare sources. See Table 67.

Table 67 — Calculate total luminance values

n =	CL-1S	CL-2S	CL-3S	CL-4S	CL-5S	CL-6S	Illumination	Object
$L_{E\text{s+REFEXT–I,HS}(n)}$							E_{s}+REFEXT–I	HS
$L_{E\text{s+REFEXT–I,LS}(n)}$							E_{s}+REFEXT–I	LS
$L_{E\text{s+REFSML–I,HS}(n)}$							E_{s}+REFSML–I	HS
$L_{E\text{s+REFSML–I,LS}(n)}$							E_{s}+REFSML–I	LS
$L_{E\text{s+REFEXT–III,HS}(n)}$							E_{s}+REFEXT–III	HS
$L_{E\text{s+REFEXT–III,LS}(n)}$							E_{s}+REFEXT–III	LS
$L_{E\text{s+REFSML–III,HS}(n)}$							E_{s}+REFSML–III	HS
$L_{E\text{s+REFSML–III,LS}(n)}$							E_{s}+REFSML–III	LS

8.7.17.6 Evaluate conformance to 7.17.1 Contrast in the presence of reflections

For Class$_{\text{reflection}}$ I, evaluate for n = CL-1S…CL-6S:

$$\text{both}\ \frac{L_{E\text{s+ REFSML-I,HS}(n)}}{L_{E\text{s+ REFSML-I,LS}(n)}} \geqslant (1+\text{Tol})\times\left(1+10\times L_{E\text{s+ REFSML-I,LS}(n)}^{-0{,}55}\right) \tag{75}$$

$$\text{and}\ \frac{L_{E\text{s+ REFEXT-I,HS}(n)}}{L_{E\text{s+ REFEXT-I,LS}(n)}} \geqslant (1+\text{Tol})\times\left(1+10\times L_{E\text{s+ REFEXT-I,LS}(n)}^{-0{,}55}\right) \tag{76}$$

For Class$_{\text{reflection}}$ II, evaluate for n = CL-1S…CL-6S:

$$\text{either}\ \frac{L_{E\text{s+ REFSML-I,HS}(n)}}{L_{E\text{s+ REFSML-I,LS}(n)}} \geqslant (1+\text{Tol})\times\left(1+10\times L_{E\text{s+ REFSML-I,LS}(n)}^{-0{,}55}\right) \tag{77}$$

$$\text{or}\ \frac{L_{E\text{s+ REFEXT-I,HS}(n)}}{L_{E\text{s+ REFEXT-I,LS}(n)}} \geqslant (1+\text{Tol})\times\left(1+10\times L_{E\text{s+ REFEXT-I,LS}(n)}^{-0{,}55}\right) \tag{78}$$

For Class$_{\text{reflection}}$ III, evaluate for n = CL-1S…CL-6S:

$$\text{either}\ \frac{L_{E\text{s+ REFSML-III,HS}(n)}}{L_{E\text{s+ REFSML-III,LS}(n)}} \geqslant (1+\text{Tol})\times\left(1+10\times L_{E\text{s+ REFSML-III,LS}(n)}^{-0{,}55}\right) \tag{79}$$

$$\text{or}\ \frac{L_{E\text{s+ REFEXT-III,HS}(n)}}{L_{E\text{s+ REFEXT-III,LS}(n)}} \geqslant (1+\text{Tol})\times\left(1+10\times L_{E\text{s+ REFEXT-III,LS}(n)}^{-0{,}55}\right) \tag{80}$$

8.7.17.7 Evaluate conformance to 7.17.2 Contrast of unwanted reflections

For Class$_{\text{reflection}}$ I positive polarity, evaluate for n = CL-1S…CL-6S:

$$\text{both}\ \frac{L_{E\text{s+REFSML-I,HS}(n)}}{L_{E\text{s,HS}(n)}} \leqslant 1{,}25 \tag{81}$$

$$\text{and}\ \frac{L_{E\text{s+REFEXT-I,HS}(n)}}{L_{E\text{s,HS}(n)}} \leqslant 1{,}25 \tag{82}$$

For Class$_{\text{reflection}}$ I negative polarity, evaluate for n = CL-1S…CL-6S :

$$\text{both}\ \frac{L_{E\text{s+REFSML-I,LS}(n)}}{L_{E\text{s,LS}(n)}} \leqslant 1{,}2+\frac{1}{15}\times\frac{L_{E\text{s,HS}(n)}}{L_{E\text{s,LS}(n)}} \tag{83}$$

$$\text{and}\ \frac{L_{E\text{s+REFEXT-I,LS}(n)}}{L_{E\text{s,LS}(n)}} \leqslant 1{,}2+\frac{1}{15}\times\frac{L_{E\text{s,HS}(n)}}{L_{E\text{s,LS}(n)}} \tag{84}$$

For Class$_{\text{reflection}}$ II positive polarity, evaluate for n = CL-1S…CL-6S:

$$\text{either}\ \frac{L_{E\text{s+REFSML-I,HS}(n)}}{L_{E\text{s,HS}(n)}} \leqslant 1{,}25 \tag{85}$$

$$\text{or} \quad \frac{L_{E\text{s+REFEXT-I,HS}(n)}}{L_{E\text{s,HS}(n)}} \leqslant 1{,}25 \tag{86}$$

For Class$_{\text{reflection}}$ II negative polarity, evaluate for n = CL-1S…CL-6S:

$$\text{either} \quad \frac{L_{E\text{s+REFSML-I,LS}(n)}}{L_{E\text{s,LS}(n)}} \leqslant 1{,}2 + \frac{1}{15} \times \frac{L_{E\text{s,HS}(n)}}{L_{E\text{s,LS}(n)}} \tag{87}$$

$$\text{or} \quad \frac{L_{E\text{s+REFEXT-I,LS}(n)}}{L_{E\text{s,LS}(n)}} \leqslant 1{,}2 + \frac{1}{15} \times \frac{L_{E\text{s,HS}(n)}}{L_{E\text{s,LS}(n)}} \tag{88}$$

For Class$_{\text{reflection}}$ III positive polarity, evaluate for n = CL-1S…CL-6S:

$$\text{either} \quad \frac{L_{E\text{s+REFSML-III,HS}(n)}}{L_{E\text{s,HS}(n)}} \leqslant 1{,}25 \tag{89}$$

$$\text{or} \quad \frac{L_{E\text{s+REFEXT-III,HS}(n)}}{L_{E\text{s,HS}(n)}} \leqslant 1{,}25 \tag{90}$$

For Class$_{\text{reflection}}$ III negative polarity, evaluate for n = CL-1S…CL-6S:

$$\text{either} \quad \frac{L_{E\text{s+REFSML-III,LS}(n)}}{L_{E\text{s,LS}(n)}} \leqslant 1{,}2 + \frac{1}{15} \times \frac{L_{E\text{s,HS}(n)}}{L_{E\text{s,LS}(n)}} \tag{91}$$

$$\text{or} \quad \frac{L_{E\text{s+REFEXT-III,LS}(n)}}{L_{E\text{s,LS}(n)}} \leqslant 1{,}2 + \frac{1}{15} \times \frac{L_{E\text{s,HS}(n)}}{L_{E\text{s,LS}(n)}} \tag{92}$$

8.7.18 Image polarity

If the display is specified as being capable of both polarities (usually the case), verify that the requirements are satisfied in both polarities.

8.7.19 Luminance uniformity (see Table 68)

Use the values from *8.6 Combined measurement for luminance, contrast, and diffuse illumination*, Table 43.

If only the design viewing direction range class, Class$_{\text{viewing}}$ IV is evaluated, then locations CL-1…CL-6 are not needed.

Table 68 — Luminance uniformity values

n =	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Illumination**	**Object**
$L_{E\text{s,HS(CL-}n)}$								E_s	HS
$L_{E\text{s,HS(HL-n)}}$								E_s	HS
$L_{E\text{s,HS(LL-n)}}$								E_s	HS

To meet the requirements of *7.19 Luminance uniformity* under the provisions of *7.2 Design viewing direction*, the largest of the readings divided by the smallest shall be less than 1,7. For Class$_{\text{viewing}}$ IV, three readings are needed (CL-7, HL-7, LL-7). For Class$_{\text{viewing}}$ I, II and III, all twenty-one readings are needed. To evaluate the recommendations, calculate the angles between the sites and the corresponding ratios. The ratios should not exceed those recommended in Table 14 in *7.19 Luminance uniformity.*

8.7.20 Pixel faults

Pixel fault class, $\text{Class}_{\text{pixel}}$ is verified by direct observation.

a) Type 1

With the panel in the intended dark state, observe high-state pixels if any. If any clusters appear to be present, examine the area with a jeweller's loupe to see if the 5 × 5 criterion applies and record the result.

b) Type 2

With the panel in the intended dark state, scan the panel with a line of 30 pixels in the high state. In other words, set pixel 0 . . . 29 in the first scan line to the bright state, then turn pixel 30 high, 0 low then 31 high, 1 low, etc. At the end of the scan line it is best to turn in place and scan the next row of pixels from right to left so that the eye can stay with the line segment without having to flyback. In perfect areas, the line appears to move through the panel smoothly. A type 2 fault is easily observed when the line splits at the stuck pixel. Stuck pixels, if any, can be marked (physically or better in the software) and revisited to detect clustering.

c) Type 3

If a pixel or area of the panel seems abnormal to the person conducting the test, the pixel or area should be re-examined to see if the type 3 designation applies. This is unavoidably, judgmental.

8.7.21 Image formation time

Use test location CL-0. System commands shall be available to drive the target to the brightest state, $L_{\text{dark,HS(CL-0)}}$ and the lowest state, $L_{\text{dark,LS(CL-0)}}$. Use a fast response-time photometer, filtering out content below 500 Hz and above 1 000 Hz. In the examples that follow, the meter output is sampled at 4 kS/s. The 1 000 Hz filtering conservatively prevents aliasing error, 500 Hz conservatively encloses the maximum response time of the eye. In the method described here, a sampled system is used. It is recognized that a meter with adjustable analog filters can yield equivalent results.

a) Apply the first command to the device-under-test. Record the luminance-time response, $L(t)$ and calculate the frame-period averaged luminance-time response, $L_{\text{FPA}}(t)$.

In a sampled system,

$$L_{\text{FPA}}(t_i) = \frac{1}{T} \sum_{t_i - \frac{T}{2}}^{t_i + \frac{T}{2}} L(t) \tag{93}$$

where

T is the refresh period;

t_i is the sample time;

$L(t)$ is the low-passed filtered, luminance-time, sampled value.

This is called a running average, moving window average or sometimes a boxcar integration of the data.

b) After sufficient time, $L_{\text{FPA}}(t_i)$ reaches an approximately constant value, label this value L_1.

c) Apply a second command and record the luminance-time response, $L(t)$ and calculate the frame-period averaged luminance-time response, $L_{\mathrm{FPA}}(t)$.

d) After sufficient time, $L_{\mathrm{FPA}}(t_i)$ reaches an approximately constant value, label this value L_2.

e) Label the time when the luminance, $L_{\mathrm{FPA}}(t_i)$ reaches $L_1 - 0{,}1(L_1 - L_2)$ as t_1.

f) Label the time when the luminance, $L_{\mathrm{FPA}}(t_i)$ reaches $L_1 - 0{,}9(L_1 - L_2)$ as t_2.

g) Apply the first command and record the luminance-time response, $L(t)$ and calculate the frame-period averaged luminance-time response, $L_{\mathrm{FPA}}(t)$.

h) Label the time when the luminance, $L_{\mathrm{FPA}}(t_i)$ reaches $L_1 - 0{,}9(L_1 - L_2)$ as t_3.

i) Label the time when the luminance, $L_{\mathrm{FPA}}(t_i)$ reaches $L_1 - 0{,}1(L_1 - L_2)$ as t_4.

j) The image formation time is $(t_4 - t_3) + (t_2 - t_1)$.

NOTE $L_1 = L_{\mathrm{dark,HS(CL\text{-}0)}}$ and $L_2 = L_{\mathrm{dark,LS(CL\text{-}0)}}$.

The example in Figure 42 shows the luminance versus time characteristic. The unmarked trace is the unfiltered output. A high frequency electronic ballast is modulated by the transmissive LCD panel. The marked trace shows the effect of the filter with a pass band of 500 Hz to 1 000 Hz. In this trace the effect of refresh is observed.

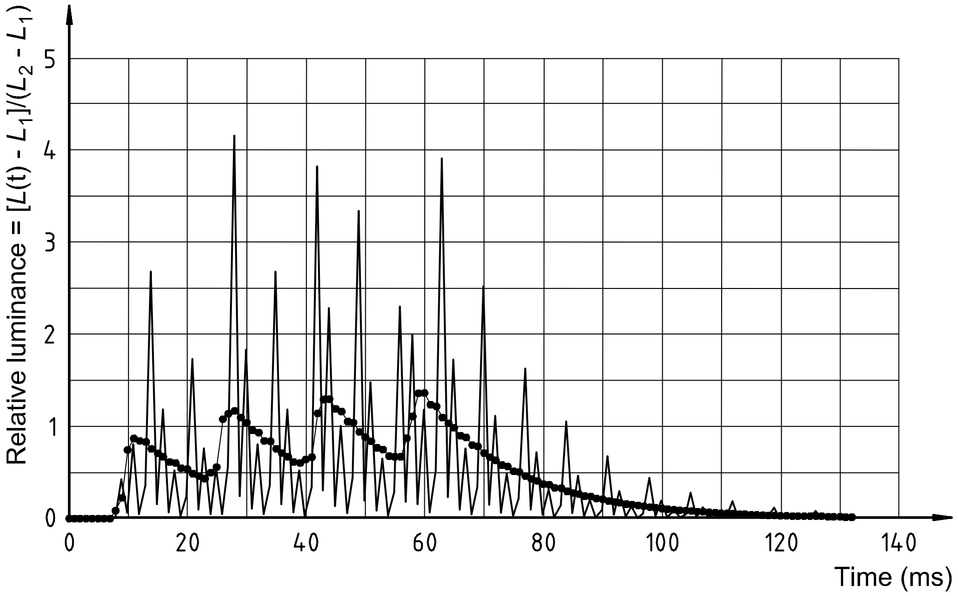


Figure 42 — Before and after initial filtering, 71 ms image formation time

In Figure 43, the filtered output from Figure 42 is repeated (the marked trace) and the frame-period averaged data is added (the solid trace). The needed times are: 2,50 ms; 38,50 ms; 66,75 ms and 102,00 ms for t_1, t_2, t_3 and t_4, respectively. The image formation time is (102,00 – 66,75) + (38,50 – 2,50) = 71 ms. Since this data was sampled at 4 kS/s, the precision is ± 0,5 ms (± 2 sample times). Also see Figure 8 in 3.4.4 for an example with shorter image formation time.

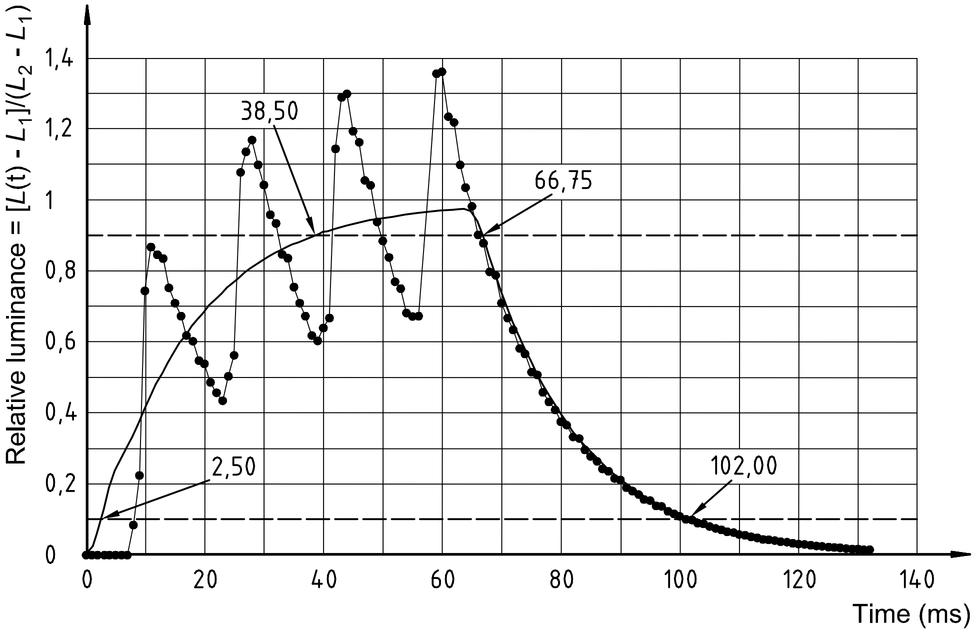


Figure 43 — Before and after frame period averaging, 71 ms case

NOTE There can be difficulties in making this measurement with asynchronously pulsed back lights. The supplier can arrange to measure image formation time in a representative unit with a steady (dc) blacklight or the photometer can be specially filtered and the photometer output specially analysed.

8.7.22 Absolute luminance coding

There are two means to satisfy this requirement:

- one is to use the flat panel only with applications that do not use absolute luminance coding, i.e. present information where the only dimension used for visual differentiation is the image luminances;
- the other is to meet the requirements in 8.7.22.1 and 8.7.22.2.

If only design viewing-direction range class IV is evaluated, then locations CL-1…CL-6 are not needed.

8.7.22.1 Measure and calculate every luminance code level

Repeat the measurements and calculations of Tables 69 to 73 for all levels (1…n, where usually level 1 is equal to LS and level n is equal to HS).

The display luminance shall be verified for the complete Tables 69 to 73 for anisotropic flat panels. For isotropic flat panels, the test directions -1…-6 can be neglected

Table 69 — Emitted luminance in dark

n =	CL-0	LL-0	HL-0	Illumination	Object	Focus
$Y_{\text{dark,level}(n)}$				dark	level	level
Measure the emitted luminances in dark-room conditions.						

Table 70 — Goniometric measurements

n =	CL-1	CL-2	CL-3	CL-4	CL-5	CL-6	CL-7	Illumination	Object	Focus[a]
$Y_{\text{DIFF,level}(n)}$								DIFF	level	level
$Y_{\text{dark,level}(n)}$								dark	level	level
$Y_{\text{DIFF,dSTD}(n)}$								DIFF	dSTD	dSTD

Measure the values needed to characterize the flat panel as a function of viewing direction for this level.

To reduce the number of measurements, it has been assumed that $L_{\text{(CL-n)}} = k_1 \times L_{(\text{HL-}n)} = k_2 \times L_{(\text{LL-}n)}$, such that k_1 and k_2 remains constant for all azimuth angles and inclination angles (for all values of n). If this assumption is invalidated for a new technology, then equations (95) to (97) will not be valid and the 14 goniometric measurements of the flat panel in this table need to be repeated also for locations HL-1...6 and LL-1...6 (totally 49 measurements instead of 21).

For a uniform diffuse illumination (e.g. large integrating sphere) and a system insensitive to the azimuth angle between equipment under test and light meter (e.g. insensitive to polarization of light) all values in the table remain constant for all values of n and need be measured for one azimuth angle only, e.g. CL-0.

For a good measurement system and diffuse reflectance standard, regardless of the uniformity of the diffuse illumination, $Y_{\text{DIFF,dSTD}(n)}$ remains constant for all values of n, and thus $Y_{\text{DIFF,dSTD}(n)}$ needs to be measured for one azimuth angle only, e.g. CL-0.

[a] Focus is at the surface of the flat panel under test.

$$R_{\text{DIFF,level-OFF(CL-}n)} = q_{\text{S-SML,dSTD(dSTD-}n\text{S45)}} \times \frac{Y_{\text{DIFF,level(CL-}n)} - Y_{\text{dark,level(CL-}n)}}{Y_{\text{DIFF,dSTD(CL-}n)}}, \quad n = 1...7 \tag{94}$$

Table 71 — Calculate reflectometer values

n =	1	2	3	4	5	6	7	Illumination	Object
$R_{\text{DIFF,level-OFF(CL-}n)}$								E_S	level

Calculate the reflectometer values for diffuse reflection

$$L_{E\text{s,level(CL-}n)} = Y_{\text{dark,level(CL-}n)} + R_{\text{DIFF,level-OFF(CL-}n)} \times E_\text{S}, n = 1...7 \tag{95}$$

$$L_{E\text{s,level(HL-}n)} = Y_{\text{dark,level(CL-}n)} \times \frac{Y_{\text{dark,level(HL-0)}}}{Y_{\text{dark,level(CL-0)}}} + R_{\text{DIFF,level-OFF(CL-}n)} \times E_\text{S}, n = 1...7 \tag{96}$$

$$L_{E\text{s,level(LL-}n)} = Y_{\text{dark,level(CL-}n)} \times \frac{Y_{\text{dark,level(LL-0)}}}{Y_{\text{dark,level(CL-0)}}} + R_{\text{DIFF,level-OFF(CL-}n)} \times E_\text{S}, n = 1...7 \tag{97}$$

Table 72 — Calculate total luminance values

n=	1	2	3	4	5	6	Illumination	Object
$L_{E\text{s,level(CL-}n)}$							E_S	level
$L_{E\text{s,level(HL-}n)}$							E_S	level
$L_{E\text{s,level(LL-}n)}$							E_S	level

Calculate the total luminance values.

Table 73 — Calculate L_{min} and L_{max}

	Value	Description	Illumination	Object
$L_{level,min}$		Smallest value from Table 72.	E_s	level
$L_{level,max}$		Biggest value from Table 72.	E_s	level
Find the maximum and minimum luminance values from Table 72.				

8.7.22.2 Evaluate the critical ratio requirement (see Table 74)

Table 74 — Evaluate critical ratios

Critical ratio	Calculated value	Requirement	Pass / Fail
$L_{1,max}$		$\geqslant$ 1,5	
$L_{2,min}/L_{1,max}$		$\geqslant$ 1,5	
$L_{3,min}/L_{2,max}$		$\geqslant$ 1,5	
$L_{3,min}/L_{2,max}$		$\geqslant$ 1,5	
…		$\geqslant$ 1,5	
$L_{n,min}/L_{n-1,max}$		$\geqslant$ 1,5	
Calculate the critical ratio values based on the values in Table 72 for each luminance code level. To pass the requirement, the critical ratio requirement must be met for every luminance code level used by the application.			

Note that the luminance values have been evaluated over the range of viewing directions for the luminance criterion.

8.7.23 Blink coding

Verify that the image formation is less than 55 ms, if blink coding is used.

8.7.24 Temporal instability (Flicker)

See informative annex B. There are no technology-independent psychophysical tests for flicker on flat panels. Temporal modulation can be dependent on gray level and/or viewing direction and/or image content.

8.7.25 Default colour set

There are two means to satisfy this requirement:

- one is to use the flat panel only with applications that do not require the user to discriminate or identify colours,
- the other is to meet the following requirements:
  a) Verify that a default set of colours has been defined.
  b) Verify that every colour of the default colour set, including reference white, meets all the requirements of this part of ISO 13406.

c) Verify that every colour of the default colour set has been included in the evaluation of requirements evaluated for conformance with

- *7.5 Chromaticity uniformity difference,*
- *7.27 Colour differences, and*
- *7.29 Number of colours.*

d) If colours can be altered by the user, verify that the default set of colours is retrievable and restorable.

8.7.26 Multicolour object size

To evaluate the recommendations, calculate the size, in millimetres, for 30′, 45′ and 2°, for the design viewing distance, and report the values in the test report.

For the evaluation of multicolour object size, the size is calculated from the diameter of the object. See Figure 44.

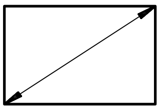


Figure 44 — Multicolour object size

8.7.27 Colour differences

This requirement applies only to flat panels for which a default character set has been defined in accordance with 7.25.

All measurements are performed in the test location CL-7, and via calculations converted to the design screen illumination.

The measurements and conversion calculations are made using wavelength *spectrums* (*8.7.27.1.1 Alternative 1 using spectral formulas*). Under special conditions, it is also allowed to perform the measurements and the calculations using the CIE 1931 tristimulus coordinates (*8.7.27.1.2 Alternative 2 using CIE 1931 tristimulus coordinates*). See annex A for further guidance.

The colour difference calculations use the CIE 1976 $L^*u^*v^*$ (CIELUV) colour difference formulas.

An overview of the measurements and calculations is given in annex A in matrix notation.

8.7.27.1 Measurements and conversions

8.7.27.1.1 Alternative 1 using spectral formulas

The formulas in this subclause has been written to apply without larger errors to any type of display. In most cases, different wavelength intervals, $\Delta\lambda$, than 5 nm and different wavelength ranges than 360 nm … 830 nm can be used. See annex A for further guidance.

8.7.27.1.1.1 **Measurements** (see Tables 75 to 77)

Table 75 — Measurements in dark-room conditions (EUT), $\mathrm{W}/(\mathrm{sr}\cdot\mathrm{m}^2\cdot\mathrm{nm})$

n =	$S_{\mathrm{dark,colour-}n\mathrm{(CL-7)}}(\lambda)$ for λ =				**Illumination**	**Object**
	360	365	…	830		
1					Dark	Colour 1, e.g. reference white
2					Dark	Colour 2, e.g. red
3					Dark	Colour 3, e.g. green
4					Dark	Colour 4, e.g. blue
5					Dark	Colour 5, e.g. 1st colour of the default colour set
6					Dark	Colour 6, e.g. 2nd colour of the default colour set
…						
m					Dark	Colour m, e.g. last colour of the default colour set

Measure the emitted spectrum from 360 nm to 830 nm in steps of 5 nm in dark-room conditions. This is the component emitted from the EUT.

Focus is at the surface of the flat panel under test.

NOTE $\mathrm{W}/(\mathrm{sr}\cdot\mathrm{m}^2\cdot\mathrm{nm})$ is the international standard unit for radiance as a function of wavelength. For more information see CIE Publication No. 15.2:1986, *Colorimetry*.

Table 76 — Measurements with diffuse illumination (EUT), $\mathrm{W}/(\mathrm{sr}\cdot\mathrm{m}^2\cdot\mathrm{nm})$

n =	$S_{\mathrm{DIFF,colour-}n\mathrm{(CL-7)}}(\lambda)$ for λ =				**Illumination**	**Object**
	360	365	…	830		
1					DIFF	Colour 1, e.g. reference white
2					DIFF	Colour 2, e.g. red
3					DIFF	Colour 3, e.g. green
4					DIFF	Colour 4, e.g. blue
5					DIFF	Colour 5, e.g. 1st colour of the default colour set
6					DIFF	Colour 6, e.g. 2nd colour of the default colour set
…						
m					DIFF	Colour m, e.g. last colour of the default colour set

Measure the emitted spectrum from 360 nm to 830 nm in steps of 5 nm in dark-room conditions. This is an intermediate value, including both the light emitted from the EUT and light reflected from the EUT.

Focus is at the surface of the flat panel under test.

NOTE 1 For every colour and wavelength, $S_{\mathrm{DIFF.colour-}n\mathrm{(CL-7)}}(\lambda) >> S_{\mathrm{dark.colour-}n\mathrm{(CL-7)}}(\lambda)$ in order to achieve good measurement accuracy with the photometer (high enough light level, high enough signal-to-noise ratio).

NOTE 2 $\mathrm{W}/(\mathrm{sr}\cdot\mathrm{m}^2\cdot\mathrm{nm})$ is the international standard unit for radiance as a function of wavelength. For more information see CIE Publication No. 15.2:1986, *Colorimetry*.

Table 77 — Measurements with diffuse illumination (dSTD), $W/\left(sr \cdot m^2 \cdot nm\right)$

$S_{DIFF,dSTD)}(\lambda)$ for λ =				Illumination	Object
360	365	…	830		
				DIFF	dSTD

Measure the reflected spectrum from 360 nm to 830 nm in steps of 5 nm in the laboratory diffuse illumination.

Focus is at the surface of the diffuse reflectance standard.

NOTE $W/\left(sr \cdot m^2 \cdot nm\right)$ is the international standard unit for radiance as a function of wavelength. For more information see CIE Publication No. 15.2:1986, *Colorimetry*.

8.7.27.1.1.2 Convert to spectral values under design screen illumination

$$S_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}(\lambda) = S_{\text{DIFF,colour-}n\text{(CL-7)}}(\lambda) - S_{\text{dark,colour-}n\text{(CL-7)}}(\lambda), \quad n = 1...m, \quad \lambda = 360...830 \tag{98}$$

For some displays, Table 78 can be measured directly, in which case Table 76 is not needed. For example, LCD displays where the display can be kept on with backlight or frontlight switched off.

Table 78 — Calculate the reflected component for illumination "DIFF", $W/\left(sr \cdot m^2 \cdot nm\right)$

n =	$S_{DIFF,colour-n-OFF(CL-7)}(\lambda)$ for λ =				Illumination	Object
	360	365	…	830		
1					DIFF	Colour 1, e.g. reference white
2					DIFF	Colour 2, e.g. red
3					DIFF	Colour 3, e.g. green
4					DIFF	Colour 4, e.g. blue
5					DIFF	Colour 5, e.g. 1st colour of the default colour set
6					DIFF	Colour 6, e.g. 2nd colour of the default colour set
…						
m					DIFF	Colour m, e.g. last colour of the default colour set

Calculate the reflected component in the laboratory diffuse illumination.

NOTE $W/\left(sr \cdot m^2 \cdot nm\right)$ is the international standard unit for radiance as a function of wavelength. For more information see CIE Publication No. 15.2:1986, *Colorimetry.*

$$R_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}(\lambda) = \frac{S_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}(\lambda) \cdot \pi \cdot q_{\text{S-SML,dSTD(dSTD-4S45)}}(\lambda)}{S_{\text{DIFF,dSTD(CL-7)}}(\lambda)}, \; n = 1...m, \; \lambda = 360...830 \tag{99}$$

Calculate the spectral reflectance factor for each colour. See Table 79.

Table 79 — Calculate the spectral reflectance factor for each colour, unit: unity

n =	$S_{\text{DIFF,colour-n-OFF(CL-7)}}(\lambda)$ for λ =				**Illumination**	**Object**
	360	365	…	830		
1					Dark	Colour 1, e.g. reference white
2					Dark	Colour 2, e.g. red
3					Dark	Colour 3, e.g. green
4					Dark	Colour 4, e.g. blue
5					Dark	Colour 5, e.g. 1st colour of the default colour set
6					Dark	Colour 6, e.g. 2nd colour of the default colour set
…						
m					Dark	Colour m, e.g. last colour of the default colour set
R·100 = The percentage reflection compared to the CIE ideal isotropic diffuser.						

$$\left.\begin{aligned}
X_{E\text{s,colour-}n\text{(CL-7)}} &= k_1 \cdot \int_{360}^{830} S_{\text{dark,colour-}n\text{(CL-7)}}(\lambda)\cdot \bar{x}(\lambda)\text{d}\lambda + k_2 \cdot \int_{360}^{830} S_{E\text{s},E\text{s}}(\lambda)\cdot R(\lambda)\cdot \bar{x}(\lambda)\text{d}\lambda \\
Y_{E\text{s,colour-}n\text{(CL-7)}} &= k_1 \cdot \int_{360}^{830} S_{\text{dark,colour-}n\text{(CL-7)}}(\lambda)\cdot \bar{y}(\lambda)\text{d}\lambda + k_2 \cdot \int_{360}^{830} S_{E\text{s},E\text{s}}(\lambda)\cdot R(\lambda)\cdot \bar{y}(\lambda)\text{d}\lambda \\
Z_{E\text{s,colour-}n\text{(CL-7)}} &= k_1 \cdot \int_{360}^{830} S_{\text{dark,colour-}n\text{(CL-7)}}(\lambda)\cdot \bar{z}(\lambda)\text{d}\lambda + k_2 \cdot \int_{360}^{830} S_{E\text{s},E\text{s}}(\lambda)\cdot R(\lambda)\cdot \bar{z}(\lambda)\text{d}\lambda
\end{aligned}\right\}, n = 1 \ldots m \qquad (100)$$

where

$$k_1 = 683\ lm/W \qquad (101)$$

$$k_2 = \frac{E_\text{s}}{\pi} \cdot \frac{1}{\int_{360}^{830} S_{E\text{s},E\text{s}}(\lambda)\cdot \bar{y}(\lambda)\text{d}\lambda} \qquad (102)$$

$S_{E\text{s},E\text{s}}(\lambda)$ is the spectral distribution of the design screen illumination, E_s;

$\bar{x}$, $\bar{y}$, $\bar{z}$ are the colour-matching functions of the CIE standard colorimetric observer;

the first term of equation (100) is the emitted component and the second term the reflected component.

Calculate the total CIE 1931 tristimulus values in the design screen illumination. See Table 80.

Table 80 — Calculate the total tristimulus value for illumination E_s, $W/(sr \cdot m^2 \cdot nm)$

n =	$X_{E\text{s,colour-}n\text{(CL-7)}}$	$Y_{E\text{s,colour-}n\text{(CL-7)}}$	$Z_{E\text{s,colour-}n\text{(CL-7)}}$	Illumination	Object
1				E_s	Colour 1, e.g. reference white
2				E_s	Colour 2, e.g. red
3				E_s	Colour 3, e.g. green
4				E_s	Colour 4, e.g. blue
5				E_s	Colour 5, e.g. 1st colour of the default colour set
6				E_s	Colour 6, e.g. 2nd colour of the default colour set
…					
m				E_s	Colour m, e.g. last colour of the default colour set

8.7.27.1.2 Alternative 2 using CIE 1931 tristimulus coordinates

8.7.27.1.2.1 **Measurements** (see Tables 81 to 83)

Table 81 — Measurements in dark-room conditions (EUT)

n =	$X_{\text{dark,colour-}n\text{(CL-7)}}$	$Y_{\text{dark,colour-}n\text{(CL-7)}}$	$Z_{\text{dark,colour-}n\text{(CL-7)}}$	Illumination	Object
1				Dark	Colour 1, e.g. reference white
2				Dark	Colour 2, e.g. red
3				Dark	Colour 3, e.g. green
4				Dark	Colour 4, e.g. blue
5				Dark	Colour 5, e.g. 1st colour of the default colour set
6				Dark	Colour 6, e.g. 2nd colour of the default colour set
…					
m				Dark	Colour m, e.g. last colour of the default colour set
Measure the CIE 1931 tristimulus coordinates in dark-room conditions. This is the component emitted from the EUT. Focus is at the surface of the flat panel under test.					

Table 82 — Measurements with diffuse illumination (EUT)

n =	$X_{\text{Diff,colour-}n\text{(CL-7)}}$	$Y_{\text{Diff,colour-}n\text{(CL-7)}}$	$Z_{\text{Diff,colour-}n\text{(CL-7)}}$	**Illumination**	**Object**
1				DIFF	Colour 1, e.g. reference white
2				DIFF	Colour 2, e.g. red
3				DIFF	Colour 3, e.g. green
4				DIFF	Colour 4, e.g. blue
5				DIFF	Colour 5, e.g. 1st colour of the default colour set
6				DIFF	Colour 6, e.g. 2nd colour of the default colour set
…					
m				DIFF	Colour m, e.g. last colour of the default colour set

Measure the CIE 1931 tristimulus coordinates in the laboratory diffuse illumination. This is an intermediate value, including both the light emitted from the EUT and light reflected from the EUT.

Focus is at the surface of the flat panel under test.

NOTE For every colour, $X,Y,Z_{\text{DIFF.colour-}n\text{(CL-7)}} >> X,Y,Z_{\text{dark.colour-}n\text{(CL-7)}}$ in order to achieve good measurement accuracy with the photometer (high enough light level and signal-to-noise ratio).

Table 83 —Measurements with diffuse illumination (dSTD)

$X_{\text{DIFF,dSTD(CL-7)}}$	$Y_{\text{DIFF,dSTD(CL-7)}}$	$Z_{\text{DIFF,dSTD(CL-7)}}$	**Illumination**	**Object**
			DIFF	dSTD

Measure the CIE 1931 tristimulus coordinates in the laboratory diffuse illumination.

Focus is at the surface of the diffuse reflectance standard.

8.7.27.1.2.2 Convert to tristimulus values under design screen illumination

$$\left.\begin{aligned}
X_{\text{DIFF,colour-}n\text{-OFF(CL-7)}} &= X_{\text{DIFF,colour-}n\text{(CL-7)}} - X_{\text{dark,colour-}n\text{(CL-7)}}\\
Y_{\text{DIFF,colour-}n\text{-OFF(CL-7)}} &= Y_{\text{DIFF,colour-}n\text{(CL-7)}} - Y_{\text{dark,colour-}n\text{(CL-7)}}\\
Z_{\text{DIFF,colour-}n\text{-OFF(CL-7)}} &= Z_{\text{DIFF,colour-}n\text{(CL-7)}} - Z_{\text{dark,colour-}n\text{(CL-7)}}
\end{aligned}\right\},\ n = 1 \ldots m \tag{103}$$

For some displays, Table 84 can be measured directly, in which case Table 83 is not needed. For example, LCD displays where the display can be kept on with backlight or frontlight switched off.

Table 84 — Calculate the reflected component for illumination "DIFF"

n =	$X_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}$	$Y_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}$	$Z_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}$	**Illumination**	**Object**
1				DIFF	Colour 1, e.g. reference white
2				DIFF	Colour 2, e.g. red
3				DIFF	Colour 3, e.g. green
4				DIFF	Colour 4, e.g. blue
5				DIFF	Colour 5, e.g. 1st colour of the default colour set
6				DIFF	Colour 6, e.g. 2nd colour of the default colour set
…					
m				DIFF	Colour m, e.g. last colour of the default colour set
Calculate the reflected component in the laboratory diffuse illumination.					

$$\left.\begin{aligned}
R_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}(X) &= \frac{X_{\text{DIFF,colour-}n\text{-OFF(CL-7)}} \cdot \pi \cdot q_{\text{S-SML,dSTD(dSTD-4S45)}}(X)}{X_{DIFF,dSTD(CL-7)}}\\
R_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}(Y) &= \frac{Y_{\text{DIFF,colour-}n\text{-OFF(CL-7)}} \cdot \pi \cdot q_{\text{S-SML,dSTD(dSTD-4S45)}}(Y)}{Y_{\text{DIFF,dSTD(CL-7)}}}\\
R_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}(Z) &= \frac{Z_{\text{DIFF,colour-}n\text{-OFF(CL-7)}} \cdot \pi \cdot q_{\text{S-SML,dSTD(dSTD-4S45)}}(Z)}{Z_{\text{DIFF,dSTD(CL-7)}}}
\end{aligned}\right\}, \quad n = 1...m \tag{104}$$

$$\left.\begin{aligned}
q_{\text{S-SML,dSTD(dSTD-4S45)}}(X) &= \frac{\int_{360}^{830} q_{\text{S-SML,dSTD(dSTD-4S45)}}(\lambda)\cdot \bar{x}(\lambda)\,\mathrm{d}\lambda}{\int_{360}^{830} \bar{y}(\lambda)\,\mathrm{d}\lambda}\\
q_{\text{S-SML,dSTD(dSTD-4S45)}}(Y) &= \frac{\int_{360}^{830} q_{\text{S-SML,dSTD(dSTD-4S45)}}(\lambda)\cdot \bar{y}(\lambda)\,\mathrm{d}\lambda}{\int_{360}^{830} \bar{y}(\lambda)\,\mathrm{d}\lambda}\\
q_{\text{S-SML,dSTD(dSTD-4S45)}}(Z) &= \frac{\int_{360}^{830} q_{\text{S-SML,dSTD(dSTD-4S45)}}(\lambda)\cdot \bar{z}(\lambda)\,\mathrm{d}\lambda}{\int_{360}^{830} \bar{y}(\lambda)\,\mathrm{d}\lambda}
\end{aligned}\right\} \tag{105}$$

Calculate the tristimulus reflectance factor for each colour.

Table 85 — Calculate the tristimulus reflectance factor for each colour

$R_{\text{DIFF,colour-}n\text{-OFF(CL-7)}}$				**Illumination**	**Object**
n =	(X)	(Y)	(Z)		
1				DIFF	Colour 1, e.g. reference white
2				DIFF	Colour 2, e.g. red
3				DIFF	Colour 3, e.g. green
4				DIFF	Colour 4, e.g. blue
5				DIFF	Colour 5, e.g. 1st colour of the default colour set
6				DIFF	Colour 6, e.g. 2nd colour of the default colour set
…					
m				DIFF	Colour m, e.g. last colour of the default colour set
X,Y,Z = the percentage reflection compared to the CIE ideal isotropic diffuser.					

$$\left.\begin{aligned} X_{E\text{s,colour-}n\text{(CL-7)}} &= X_{\text{dark,colour-}n\text{(CL-7)}} + \frac{X_{E\text{s},E\text{s}} \cdot R_{\text{DIFF,colour-}n\text{-off(CL-7)}}(X)}{\pi} \\ Y_{E\text{s,colour-}n\text{(CL-7)}} &= Y_{\text{dark,colour-}n\text{(CL-7)}} + \frac{Y_{E\text{s},E\text{s}} \cdot R_{\text{DIFF,colour-}n\text{-off(CL-7)}}(Y)}{\pi} \\ Z_{E\text{s,colour-}n\text{(CL-7)}} &= Z_{\text{dark,colour-}n\text{(CL-7)}} + \frac{Z_{E\text{s},E\text{s}} \cdot R_{\text{DIFF,colour-}n\text{-off(CL-7)}}(Z)}{\pi} \end{aligned}\right\},\quad n = 1 \ldots m \qquad (106)$$

where

$$\begin{aligned} X_{E\text{s},E\text{s}} &= \frac{x_{E\text{s}}}{y_{E\text{s}}} \cdot Y_{E\text{s},E\text{s}} \\ Y_{E\text{s},E\text{s}} &= E_{\text{s}} \qquad \text{(lx)} \\ Z_{E\text{s},E\text{s}} &= \frac{1 - x_{E\text{s}} - y_{E\text{s}}}{y_{E\text{s}}} \cdot Y_{E\text{s},E\text{s}} \end{aligned} \qquad (107)$$

i.e. equation (107) specifies the X,Y,Z tristimulus values of the design screen illumination.

Calculate the final CIE 1931 tristimulus values in the design screen illumination. See Table 86.

Table 86 — Calculate the total value for illumination "E_s"

n =	$X_{E\mathrm{s,colour}\text{-}n\mathrm{(CL\text{-}7)}}$	$Y_{E\mathrm{s,colour}\text{-}n\mathrm{(CL\text{-}7)}}$	$Z_{E\mathrm{s,colour}\text{-}n\mathrm{(CL\text{-}7)}}$	**Illumination**	**Object**
1				E_s	Colour 1, e.g. reference white
2				E_s	Colour 2, e.g. red
3				E_s	Colour 3, e.g. green
4				E_s	Colour 4, e.g. blue
5				E_s	Colour 5, e.g. 1st colour of the default colour set
6				E_s	Colour 6, e.g. 2nd colour of the default colour set
…					
m				E_s	Colour m, e.g. last colour of the default colour set
NOTE The best accuracy is achieved when the chromaticity coordinates (u',v') and the spectral distribution of the laboratory diffuse illumination (DIFF) and the design screen illumination (E_s) are as close to each other as possible.					

8.7.27.2 Calculate CIELUV colour space coordinates (see Tables 87 and 88)

$$u' = \frac{4X}{X + 15Y + 3Z} = \frac{4x}{-2x + 12y + 3}$$
$$v' = \frac{9Y}{X + 15Y + 3Z} = \frac{9y}{-2x + 12y + 3} \qquad (108)$$

Table 87 — Calculate CIE 1976 UCS diagram coordinates

n =	$u'_{E\mathrm{s,colour}\text{-}n\mathrm{(CL\text{-}7)}}$	$v'_{E\mathrm{s,colour}\text{-}n\mathrm{(CL\text{-}7)}}$	**Illumination**	**Object**
1			E_s	Colour 1, e.g. white
2			E_s	Colour 2, e.g. red
3			E_s	Colour 3, e.g. green
4			E_s	Colour 4, e.g. blue
5			E_s	Colour 5, e.g. 1st colour of the default colour set
6			E_s	Colour 6, e.g. 2nd colour of the default colour set
…				
m			E_s	Colour m, e.g. last colour of the default colour set

$$\left.\begin{aligned} L^* &= 116(Y/Y_n)^{\frac{1}{3}} - 16 && \text{, when } Y/Y_n > 0{,}008\,856 \\ L^* &= 903{,}3(Y/Y_n) && \text{, when } Y/Y_n \leqslant 0{,}008\,856 \\ u^* &= 13L^*(u' - u'_n) \\ v^* &= 13L^*(v' - v'_n) \end{aligned}\right\} \qquad (109)$$

Reference white (Y_n, u'_n, v'_n) is the achromatic white colour that the user adapts to.

Usually reference white can be determined by:

$$\left.\begin{aligned} &\left.\begin{aligned} Y_n &= \frac{E_\text{s}}{\pi} \\ u'_n &= u'_s \\ v'_n &= v'_s \end{aligned}\right\} \quad \text{when } \frac{E_\text{s}}{\pi} > Y_{E\text{s,white(CL-7)}} \\ &\left.\begin{aligned} Y_n &= Y_{E\text{s,white(CL-7)}} \\ u'_n &= u'_{E\text{s,white(CL-7)}} \\ v'_n &= v'_{E\text{s,white(CL-7)}} \end{aligned}\right\} \quad \text{when } \frac{E_\text{s}}{\pi} \leqslant Y_{E\text{s,white(CL-7)}} \end{aligned}\right\} \qquad (110)$$

where E_s, u'_s, and v'_s describe the design screen illumination.

This means that the evaluation is made with the highest luminance white, which is likely to be in the viewing field of the user; either the white of the flat panel, or the white of a white object on the work table, depending on which has the higher luminance. The former case is typical for emissive LCDs, the latter for reflective LCDs.

If it is likely that, in the intended use, the adaptive white will be something else than described by equation (110), then the Y, u', v' values of that white should be used in the calculations.

Table 88 — Calculate CIE 1976 CIELUV coordinates "E_s"

n =	$L^*_{E\text{s,colour-}n\text{(CL-7)}}$	$u^*_{E\text{s,colour-}n\text{(CL-7)}}$	$v^*_{E\text{s,colour-}n\text{(CL-7)}}$	**Illumination**	**Object**
1				E_s	Colour 1, e.g. reference white
2				E_s	Colour 2, e.g. red
3				E_s	Colour 3, e.g. green
4				E_s	Colour 4, e.g. blue
5				E_s	Colour 5, e.g. 1st colour of the default colour set
6				E_s	Colour 6, e.g. 2nd colour of the default colour set
…					
m				E_s	Colour m, e.g. last colour of the default colour set

8.7.27.3 Calculate the conformance assessment values

$$\Delta E_{uv}^{*} = \left[\left(\Delta L^{*} \right)^{2} + \left(\Delta u^{*} \right)^{2} + \left(\Delta v^{*} \right)^{2} \right]^{\frac{1}{2}} \tag{111}$$

Calculate the Euclidean distance in the CIELUV colour space for all colour pairs. See Table 89.

Table 89 — Calculate ΔE_{uv}^{*} for all colour pairs

1							…		
2							…		
3							…		
4							…		
5							…		
6							…		
…	…	…	…	…	…	…	…	…	…
m^{-1}							…		
m							…		
n =	1	2	3	4	5	6	…	m^{-1}	m

$$h_{uv} = \arctan\left(\frac{v' - v'_n}{u' - u'_n} \right) = \arctan\left(\frac{v^{*}}{u^{*}} \right), \text{ such that}$$

$$\begin{array}{lll} 0° \leqslant h_{uv} < 90° & \text{if } v^{*} \geqslant 0 & \text{and } u^{*} \geqslant 0 \\ 90° \leqslant h_{uv} < 180° & \text{if } v^{*} \geqslant 0 & \text{and } u^{*} < 0 \\ 180° \leqslant h_{uv} < 270° & \text{if } v^{*} < 0 & \text{and } u^{*} < 0 \\ 270° \leqslant h_{uv} < 360° & \text{if } v^{*} < 0 & \text{and } u^{*} \geqslant 0 \end{array} \tag{112}$$

Calculate the hue-angle for all colours. See Table 90.

Table 90 — Calculate the hue-angle

n =	h_{uv} Es,colour-n(CL-7)	Illumination	Object
1		E_S	Colour 1, e.g. reference white
2		E_S	Colour 2, e.g. red
3		E_S	Colour 3, e.g. green
4		E_S	Colour 4, e.g. blue
5		E_S	Colour 5, e.g. 1st colour of the default colour set
6		E_S	Colour 6, e.g. 2nd colour of the default colour set
…			
m		E_S	Colour m, e.g. last colour of the default colour set
Use the same reference white as in *8.7.27.2 Calculate CIELUV colour space coordinates*.			

8.7.27.4 Compliance

All values in Table 89 shall meet the requirement $\Delta E^*_{uv} > 20$.

All values in Table 90 should differ in value.

If *8.7.27.1.2 Alternative 2 using CIE 1931 tristimulus coordinates* was used, then include individual uncertainty estimates for all values of Table 89 and Table 90. Typically colours from the lower end of the visible spectrum (e.g. blue) will have higher uncertainty estimates. See annex A for further guidance.

NOTE For limitations of ΔE^*_{uv} see annex A.

8.7.28 Spectrally extreme colours

The appropriate use of these colours is an application issues and can be evaluated by reviewing the intended applications.

NOTE The chromaticity coordinates (u', v') of the default colour set have been measured in 8.7.5, Tables 46 and 47.

8.7.29 Number of colours

This requirement applies only to flat panels for which a default character set has been defined in accordance with 7.25.

The appropriate use of colours is an application issue and can be evaluated by reviewing the intended applications.

8.7.29.1 Simultaneous colour presentation

Count the number of colours simultaneously presented on the display.

The number of colours should be $\leqslant$ 11 for isotropic displays and possibly even less for anisotropic displays.

8.7.29.2 Visual search for colour images

Count the number of colours used in any search based on colour discrimination.

The number of colours should be $\leqslant$ 6 for isotropic displays and possibly even less for anisotropic displays.

8.7.29.3 Colour interpretation from memory

Count the number of colours whose meaning needs to be recalled from memory.

The number of colours should be $\leqslant$ 6.

If more than 6 colours are used, then an on-screen or an off-screen reference shall be available.

9 Compliance

Compliance with this part of ISO 13406 can be achieved either

by

a) meeting all mandatory requirements of *7 Design requirements and recommendations* using the methods of *8 Measurements*, or

b) by a positive result using the test method and associate mandatory requirements specified in an Amendment 1 to ISO 9241-3,

and including the information listed in clause 8.2.3 Supplier declared data in the user's manual (or equivalent) and in any detailed product specification available to the public.

NOTE 1 The test method according to Amendment 1 to ISO 9241-3 is appropriate for compliance route b) above.

NOTE 2 The test method is intended for VDTs for which *7 Design requirements and recommendations* cannot be applied completely.

Mandatory requirements are identified by the presence of the word "shall."

Compliance shall be determined using the default parameters, e.g., character set(s), colour(s), configuration(s), system options and operator settings.

Compliance with this part of ISO 13406 may depend on hardware, software and workstation elements and, although each such element shall be shown by its supplier to comply individually, the parties using any given combination of such elements shall be responsible for the compliance of that configuration.

The compliance report shall include the following information:

1) supplier's details (name and address, type numbers, etc.);

2) details of equipment relevant to the test, its settings and configuration, fixed and software-driven characteristics, test conditions and test results;

3) conditions of use;

4) special requirements;

5) if compliance route b) is used, full details of the criteria used for the selection of the test subjects and their relevant characteristics.

Annex A
(informative)

Colour difference calculation

A.1 Overview of 8.7.27 Colour differences using vector notation

The notation in 8.7.27 proved difficult to follow for some readers. Since what we are dealing with are vectors, these can alternatively be expressed using the following vector notation:

Any given vector V_i is defined as $\{X_V, Y_V, Z_V\}$, where X, Y, and Z are the tristimulus values, and

$X = (x/y)Y$

$Y = E$ or L (can be luminance, illuminance, or flux)

$Z = [(1-x-y)/y]Y$

Alternatively, V_i can be defined as $S_V(\lambda)$, the relative spectral power distributions over the range of wavelengths λ = 360 nm to 830 nm.

Table A.1 lists the tables covering the procedures specified in 8.7.27.

Table A.1

Procedure	Tables in 8.7.27	
	Alternative 1 – Spectral	Alternative 2 – Tristimulus
1) Measure the screen in dark-room conditions, D_i.	75	81
2) Measure the screen with diffuse illumination, I_i.	76	82
3) Obtain a measurement of the diffuse illumination by measuring the luminance, E_i, of the reflectance standard with diffuse illumination.	77	83
4) Calculate the reflective component of the screen with diffuse illumination, $R_i = I_i - D_i$.	78	84
5) Calculate the screen luminance factor, $U_{ii} = (R_i \pi q_i / E_i)$.	79	85
6) Assume a design screen illumination (obtained from CIE 15.2:1986 Table 1.1 or Table 1.4), S_i.		
7) If using the spectral power distribution method, convert T_i into tristimulus values using the method outlined in CIE 15.2:1986, section 3.1.	80	
8) If using the tristimulus method, calculate the screen under the design screen illumination, $T_i = D_i + S_i U_{ii}$.		86
9) Calculate the CIELUV colour space coordinates.	88	88
10) Calculate the conformance assessment values.	89, 90	89, 90

A.2 Guidance on flat panel display colorimetry

Measurements of some flat panel display technologies (e.g. LCD) are much more complicated and difficult than most other colour measurements because the display is anisotropic and it produces polarized light. Since many other measurement areas do not need to consider the effects of anisotropy and polarization, this means that many commercially available measurement devices and measurement methods cannot be used with such flat panel displays without causing unpredictable measurement errors. For example, a device for which the manufacturer states “low polarization error” is good enough in many other fields of measurement but might not be usable for LCD display measurements.

CIE 53-1982, *Methods of characterizing the performance of radiometers and photometers* can be used as guidance when analysing the suitability of a particular measurement device.

For *8.7.27 Colour differences*, it was decided to primarily use spectral measurements and calculations in order to obtain more accurate results and uncertainty predictions. The main reasons were the problems of non-continuous spectrums of flat panels and some laboratory light sources as well as problems arising from differences in spectrum between the design screen illumination and the laboratory light sources. These problems do not disappear with spectral measurements, but they are easier to predict than for tristimulus measurements. Furthermore, tristimulus methods can produce errors if the matching with the $\bar{x}$, $\bar{y}$, $\bar{z}$ functions is not good enough over the whole visible spectrum. Spectral devices can have weaknesses too.

The key issue is to make an in-depth validation of the measurement device and the laboratory light sources, together with test samples, including uncertainty calculations, before starting to issue test reports.

If an in-depth uncertainty study has been made, then it is also allowed to perform the measurements and the calculations using the CIE 1931 tristimulus coordinates. Note that the uncertainty will be a function of colour, design screen illumination spectrum and laboratory light source spectrum.

X, Y and Z are approximations only. The more complex the calculations are, the more this approximation will differ from results obtained through spectral calculations. This is not so critical with emissive flat panel monitors, but the importance increases for reflective and transflective displays.

For the spectral measurements and calculations, the bandwidth must be small and the wavelength range wide if measurement is to be accurate for any colour, type of display, design screen illumination and laboratory light source. In most cases, different wavelength intervals, $\Delta\lambda$, than 5 nm and different wavelength ranges than 360 nm … 830 nm can be used. $\Delta\lambda$ 5 nm at 380 nm … 780 nm is enough for most practical purposes and even narrower wavelength intervals might produce satisfactory results. Using a narrow wavelength interval will produce errors for the colours which include light from the ends of the visible spectrum (e.g. blue and red). See CIE 15.2 *Colorimetry* for more guidance.

A.3 Limitations of the CIE colorimetry

The CIE objective was to provide a “ . . . colour-difference formula for predicting the magnitude of the perceived colour difference between two given colour stimuli . . . ”. The experimental conditions were the following.

- Size of the colour difference: 1 to 10 units.
- Field size: 4 .
- Nature of the surround: uniform.
- Luminance of the surround: 100 $\mathrm{cd/m^2}$ to 1 000 $\mathrm{cd/m^2}$.
- Chromaticity of the surround: CIE D from 5 500 K to 7 500 K.
- Luminance of the sample: 5 % to 500 % of surround luminance.

- Dividing line (between sample and reference): approaching zero width.
- Observers: perceptibility judges, without acceptability bias.
- CIELUV, ΔE^{*}_{uv} has a number of limitations when applied to visual displays.
- Visual targets vary in size from 10' to 5° or more. For small targets, $\Delta u'$ is much more important (up to 5 times) than $\Delta v'$.
- There is no obvious interpretation of the white-point requirement. For example, Y_n is often user adjustable and influenced by the magnitude and colour temperature of the screen illumination plus the screen reflection properties that can vary with viewing direction.
- All VDT technologies have low spatial frequency luminance nonuniformity. ISO 9241-3 allows 1,7:1. In the presence of luminance nonuniformity, the accuracy of CIELUV is reduced.
- CIELUV does not incorporate all salient variables.
- It is not valid for flashing or briefly presented targets.

Annex B
(informative)

Flicker determination

B.1 Introduction

Flicker on flat panel displays is difficult to quantify. The method proposed here, extends the method in annex A of ISO 9241-3:1992. Several flat panel technologies present issues that make psychophysical methods of determining flicker problematic. By extending this method to cover new issues, these problems can be avoided. The extensions presented here take advantage of the linearity of the Fourier transform. The sum of added luminance-time functions can be treated one at a time, and the results added. This allows the luminance-time function to be measured, rather than calculated from phosphor time constants. With these exceptions, there are no departures from the original work.

NOTE The actual perception of flicker is known to vary between individual observers and within an individual observer. Some of these variations are systematic. Flicker sensitivity decreases with age (between individuals) and with fatigue (for the individual). The precision of any flicker method is subject to the characteristics of the subjects used in the underlying research. In addition, the conversion of display luminance to retinal illumination requires an assumption about the luminance that drives pupil response. In positive polarity displays, average display luminance and “adapting” luminance can be assumed to be the same. There is some evidence that this is not true for negative polarity displays. Due to cross-coupling of photo receptors in the eye, the correct value probably lies between the average and peak luminance. The average luminance is the worst case and is used in this annex.

B.2 Analytic model

B.2.1 Principle

It can be predicted whether people will detect a homogeneously illuminated display appears to flicker or not by the amount of energy in the temporal frequencies of the display (DeLange, 1961; Kelly, 1961, 1962, 1964; Farrell 1986, 1987). The first step in the method therefore, is to find out the amount of energy in the temporal frequencies, $E_{\text{obs}\ n}$. These numbers are then compared to the amounts of energies that people will detect as flicker, the predicted flicker threshold, $E_{\text{pred}\ n}$. The departure from annex A of ISO 9241-3:1992 is that flat panels exhibit more diverse luminance-time functions than progressively scanned cathode ray tubes, so significant energy may exist at several different frequencies. The index, n is carried from 1, at the fundamental repetition frequency of the display (generally, 0,5 times the refreshment rate is necessary on LCD panels), in integer steps until the frequency exceeds 120 Hz. The observed energies may be calculated or measured. The energy at various frequencies is learned by examining the Fourier transform of the luminance-time function.

If $E_{\text{obs}} < E_{\text{pred}}$ at every frequency then it is likely that people will not see flicker.

If $E_{\text{obs}} \geqslant E_{\text{pred}}$ at any frequency then it is likely that people will see flicker.

B.2.2 Fourier coefficients

The average luminance of a luminance-time function, $f(t)$ is:

$$c_0 = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} f(t)\,\mathrm{d}t \qquad (113)$$

where

- c_0, the zero Fourier coefficient, is the dark-room luminance averaged over time;

- T is the repetition period of the luminance-time function. For progressively scanned cathode ray tubes, the refreshment rate is $1/T$. See B.5 for notes on the Fourier transform.

NOTE When measuring $f(t)$ and using a fast Fourier transform, FFT, it is sometimes not appropriate to use FFT$(v)_0$ for c_0 since this could lead to errors depending on the specific form of FFT used.

FFT$(v)_0$ is the 0 term of the fast Fourier transform of v.

v is the list of measured samples of $f(t)$. The number of items in the list must be a power of 2 and an integer number of repetition times must be sampled.

The average luminance, c_0 is calculated from dark-room measurements. $L_R = qE_s$. In this model, the "adapting" luminance, L_t used in converting cd/m^2 to trolands is $c_0 + L_R$.

The general coefficients are:

$$c_n = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} f(t) e^{\frac{-2ni\pi t}{T}} \mathrm{d}t \qquad (114)$$

where

c_n is the nth Fourier coefficient,

$i = \sqrt{-1}$

T is the repetition time of $f(t)$.

In the case where $f(t)$ is the sum of components, for example, red, green and blue, the coefficients can be obtained one at a time and added.

$$c_0 = \sum_{j=1}^{m} c_0 j = L_t - L_r \qquad (115)$$

$$c_n = \sum_{j=1}^{m} c_n j \qquad (116)$$

$$\mathrm{AMP}_n = \frac{2 \times |c_n|}{c_0} \qquad (117)$$

If there are m components, then:

$$|c_n| = \sqrt{[\mathrm{Re}(c_n)]^2 + [\mathrm{Im}(c_n)]^2} \qquad (118)$$

where AMP is a value between 0 and 2 that is identical to the term in ISO 9241-3.

The frequency associated with AMP_n, f_n is:

$$f_n = \frac{n}{T} \text{ for } n = 1, 2\ldots \tag{119}$$

while f_n <120 Hz

$$\mathrm{AMP}_n = \frac{2 \times \left|\mathrm{FFT}(v)_n\right|}{\mathrm{FFT}(v)_0} \tag{120}$$

When using the fast Fourier transform, the set of observations, v_p for $p = 0 \ldots 2^z - 1$ is sampled at frequency, f_s and processed with FFT, where z is 6, 7 . . . The value AMP_n has a corresponding frequency $n \times f_\mathrm{s}/z$. The sampling frequency is $k \times 2^z/T$, where $k = 1, 2, \ldots$ The period of $f(t)$ must be determined. Generally, $k = 1$ yields the best result.

B.2.3 Pupil

The pupil area must be known to convert the luminance to trolands. The expression in annex A of ISO 9241-3:1992 for pupil area can be simplified:

$$A = b_0 L_\mathrm{t}^{b_1} \tag{121}$$

where

$b_0 = 12{,}451\ 84$

$b_1 = -0{,}160\ 32$

L_t is the adaptation luminance = $L_\text{H-dark}\ (\theta_\mathrm{D}, \phi_\mathrm{D}) + q_\mathrm{H}\ (\theta_\mathrm{D}, \phi_\mathrm{D})\ E_\mathrm{s}$.

B.2.4 DC component

To calculate the amount of energy in the temporal frequencies of interest.

a) Convert the screen luminance into units of retinal illuminance (trolands).

b) Calculate the pupil area, A from the formula (121).

c) The DC component is:

$$DC = A \times c_0$$

B.2.5 Decision criteria

Energy at each frequency is:

$$E_{\mathrm{obs}\ n} = \mathrm{DC} \times \mathrm{AMP}_n \tag{122}$$

The criteria are that the energy at every frequency satisfies:

$$E_{\text{obs}\,n} \leqslant E_{\text{pred}\,n} \tag{123}$$

where

$$E_{\text{pred}\,n} = ae^{\frac{nb}{T}}$$

where a and b are as given in Table B.1.

Table B.1 — Values of predicted energy and special coefficients

Row	Screen diagonal	Predicted energy coefficients		Special case coefficients	
	arc degrees	a	b	D	E
1	< 20	0,127 6	0,191 9	36,44	13,83
2	20 to 40	0,191 9	0,120 1	39,81	16,40
3	40 to 65	0,507 6	0,100 4	37,93	19,62
4	65	0,530 0	0,099 2	37,96	19,86

B.2.6 Simpler special case

Some technologies [e.g., EL, dc plasma, light-emitting diode (LED)], have luminance persistence that is much less than 1 ms. For such technologies, AMP = 2 for refresh rates less than 100 Hz.

Conditions:

a) Reflected luminance of 5 to 15 cd/m^2.

b) Average dark-room luminance L_{dark} is from 10 cd/m^2 to 340 cd/m^2.

Then, the display meets the requirement if the refresh rate is greater than

$$D + E \log_{10}(L_{\text{dark}})$$

where D and E are given in the two right-hand columns of Table B.1.

B.3 Protocol for data taking

The actual AC component of display luminance at a given frequency is determined from the time-resolved luminance of an approximately 1° area of the screen. This method is image dependent.

a) Test image

   1) Positive polarity or displays that support both polarities: Use an array of pixels at their brightest state or empirically determined worst gray level state. Use “white” for multicolour displays, or all primaries in their brightest state for limited-gamut multicolour displays.

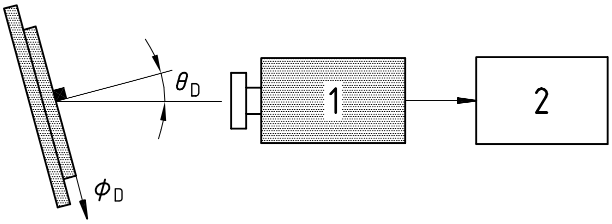
   2) Negative only polarity: Use an array of dense alphanumerics, randomly selected from the default character set. Use the brightest state or empirically determined worst gray level state. Use “white” for multicolour displays, or all primaries in their brightest state for line gamut displays.

b) Test image size and placement

   1) The test image is the same as in *8.4.2.1 Targets.*

   2) Place the image near location 55, *8.4.2 Standard measurement locations*.

   3) Use the design viewing direction, θ_D, ϕ_D *8.4.1 Test directions*.



Key

1 Luminance meter
2 Processing

Figure B.1 — Flicker measurement apparatus

c) Using the apparatus in Figure B.1, obtain the Fourier coefficients at frequencies from $1/T$ up to 120 Hz.

   At each frequency, n/T (n = 1, 2 ... n_{max}), compare the values of E_{obs} and E_{pred}. This is conveniently accomplished by plotting the values on Figure B.2.

where

T is the maximum repetition time of $f(t)$;

n_{max} is the maximum integer such that n_{max}/T < 120 Hz.

d) If each value of E_{obs} is less than E_{pred}, then the display is declared to be flicker free.

NOTE 1 The sampling must span the maximum repetition time accurately. If the repetition time were 25 ms and 64 samples were wanted, f_s should be approximately 2 560 Hz (64/0,025).

NOTE 2 There may be flicker modes not directly related to the refreshment of the display. If frequencies below 20 Hz are present, the predictions would be outside the original data and unreliable.

NOTE 3 LCD flat panels modulate light at one-half the refreshment rate at a magnitude that depends on the balance between the positive and negative half cycles. This balance depends on bias, but is also image dependent because of unwanted lateral coupling within the panel. No guidance for selecting reasonable test images is available. The bias cannot be adjusted to minimize modulation after displaying the test image.

The luminance meter resolves time varying luminances, $f(t)$ that vary at 360 Hz or more.

The first processing element is a low pass filter, with a pass band of 0 to 150 Hz (3 db). The filter should be at –60 db or less at the sampling frequency. With the filtered output, the maximum repetition time must be found. It is possible to do this automatically.

a) Sample for 100 ms at the maximum sampling frequency.

$$\Re = \sum_{w=0}^{0{,}05 f_s} \left| f(t)_w - f(t)_{w+q} \right| \tag{124}$$

b) Find q to minimize $\Re$,

c) Then $T = q/f_s$

d) Reset f_s such that $f_s = 2^m/T$, where m = 6, 7, ...

e) Sample the filtered $f(t)$ and calculate the FFT of the samples.

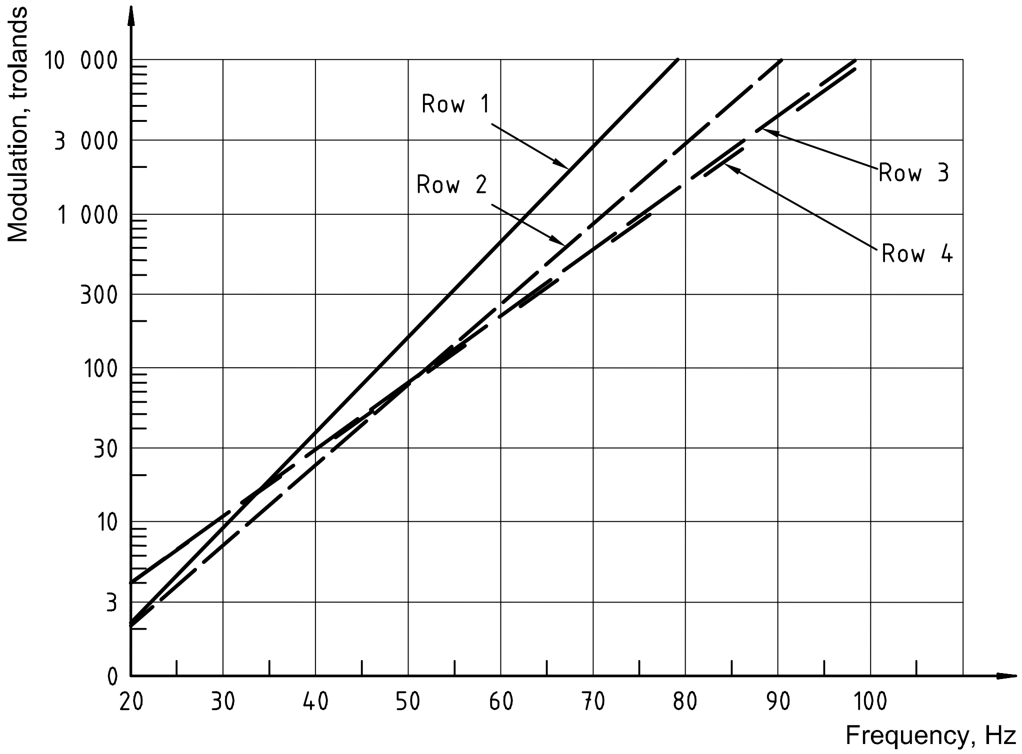


Figure B.2 — Maximum E_{obs} Row 1: < 20° , Row 2: 20° to 40°, Row 3: 40° to 65° and Row 4: > 65°

B.4 Worked example (see Tables B.2 and B.3)

A plasma flat panel operating in on-off mode is psychophysically flicker-free since the pulsation rate exceeds 80 000 Hz. However, to introduce gray scale, the panel can be driven with periodic waveforms. The brightest state is the flicker-free one, but each state that is intermediate between brightest and off achieves that level by time slices. In this example, the brightest state is 100 cd/m^2 in a dark room. The base repetition time, T, is 25 ms. It is necessary to examine 40 Hz, 80 Hz, and 120 Hz. The size of the panel is found in Row 2, between 20 and 40 in the diagonal. The reflected luminance referred to 250 lx illumination is 10 cd/m^2. The gray scale method is illustrated in Figure B.3.

The Fourier coefficients can be easily calculated. Two cases can be considered. Case 1 assumes that the entire panel can be in any state. Case 2 assumes that characters are presented in a negative image and that, on average, 6 % of pixels are in any brightness state.

While both cases fail, a design change can obviously save the second example. The alternative of two 6,25 ms pulses for the 50 % level will resolve the problem since AMP at 40 Hz becomes 0, and AMP at 80 Hz becomes 1,273. To make Case 1 pass, one must decrease a combination of T and the maximum luminance besides this change. For example, 17 ms and 65 cd/ m^2 passes.

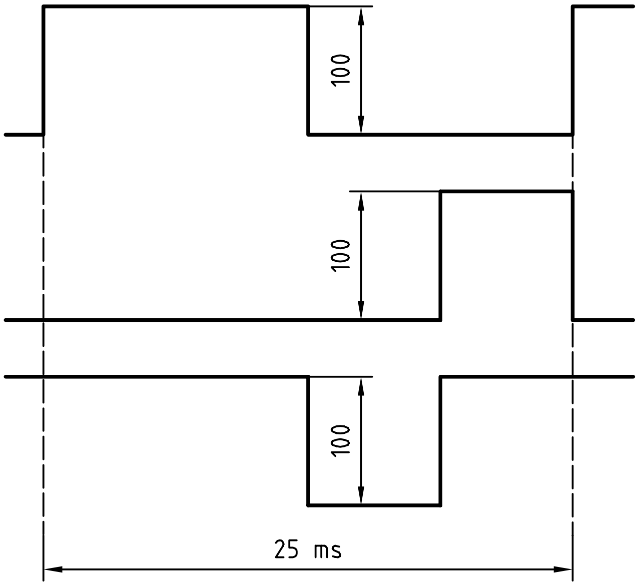


Figure B.3 — The top waveform produces 50 % luminance, the middle, 25 % and the bottom, 75 %

Table B.2 — Worked example, Case 1

	L_t cd/m^2		35,000	60,000	85,000	110,000
	A mm^2		7,042	6,459	6,109	5,861
	DC		176,061	322,972	458,147	586,128
AMP	at 40 Hz		1,801	1,273	0,600	0,000
	at 80 Hz		1,273	0,000	0,424	0,000
	at 120 Hz		0,600	0,424	0,200	0,000
E_{obs}	at 40 Hz		317,086	411,144	274,888	0,000
	at 80 Hz		224,126	0,000	194,254	0,000
	at 120 Hz		105,637	136,940	91,629	0,000
From Row 1, Table B.1			**Results**			
E_{pred}	at 40 Hz	23,41	Fail	Fail	Fail	Pass
	at 80 Hz	2856,12	Pass	Pass	Pass	Pass
	at 120 Hz	348 439,23	Pass	Pass	Pass	Pass

Tableau B.3 — Worked example, Case 2

	L_t, cd/m^2		11,500	13,000	14,500	16,000
	A, mm^2		8,418	8,254	8,111	7,984
	DC		12,627	24,763	36,500	47,904
AMP	at 40 Hz		1,801	1,273	0,600	0,000
	at 80 Hz		1,273	0,000	0,424	0,000
	at 120 Hz		0,600	0,424	0,200	0,000
E_{obs}	at 40 Hz		22,742	31,523	21,900	0,000
	at 80 Hz		16,074	0,000	15,476	0,000
	at 120 Hz		7,576	10,499	7,300	0,000
From Row 1, Table B.1			**Results**			
E_{pred}	at 40 Hz	23,41	Pass	Fail	Pass	Pass
	at 80 Hz	2 856,12	Pass	Pass	Pass	Pass
	at 120 Hz	348 439,23	Pass	Pass	Pass	Pass

B.5 Notes on Fourier Transform

There are several versions of the Fourier transform and several versions of the fast Fourier transform algorithm. Care must be exercised to be certain that the methods and formulas are consistent. The differences consist of whether the transform or inverse transform carry a coefficient (or both) and the summation range of the inverse transform. There can be a factor of 2 difference and also the sign of the imaginary terms can change. The second difference will not modify results, but the first will.

The transform and inverse transform version assumed here, analytic $f(t)$ is:

$$c_n = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} f(t) e^{\frac{-2 n i \pi t}{T}} \mathrm{d}t$$

$$f(t) = \sum_{n=-\infty}^{n=\infty} c_n \mathrm{e}^{\frac{2\pi i n t}{T}} \tag{125}$$

where

$n = 0, 1, \ldots \infty$

$i = \sqrt{-1}$

$f(t) = f(t + nT)$ for $n = 1, 2 \ldots$

The corresponding fast Fourier algorithms are of the form:

$$c_v = \frac{1}{N} \sum_{j=0}^{N-1} v_j \mathrm{e}^{\frac{-j 2 \pi i}{N}} \tag{126}$$

$$v_j = \sum_{v=0}^{N-1} c_v \mathrm{e}^{\frac{v j 2 \pi i}{N}} \tag{127}$$

where

c_v is the vth Fourier coefficient;

$i = \sqrt{-1}$

v_j is the set of N samples;

N is the number of samples (a power of 2).

In some FFT algorithms, c_0 is not the average of the sampled values. The sign of the exponent in the forward and reverse transforms is always different, but either can be positive. This does not affect the calculations in this annex. The formula for AMP$_\mathrm{i}$ is robust under any consistent formula that uses $1/N$ or $1/\sqrt{N}$ as a normalizing term. Since this is not always true, use the example in this annex to make certain. Introduce, v_j = if (j < 48, 100,0) with N = 64) into the algorithm, the values in Table B.4 should result. If the values that result are 2 times these values, do not use the factor 2 as shown. If the 0th term is not 75, do not use the algorithm for c_0.

Table B.4 — Calculated values

v	$\frac{2\lvert \mathrm{FTT}(v)_v \rvert}{\mathrm{FTT}(v)_0}$
1	0,600
2	0,425
3	0,201

Annex C
(informative)

Bidirectional Reflectance Distribution Function (BRDF)

C.1 Introduction

This annex introduces an alternative procedure for the determination of the amount and the angular distribution of optical scatter from a display device by measuring the bidirectional reflectance distribution function (BRDF).

Research is underway to learn if a practical method based on BRDF measurements can be used as a means of normative evaluation. The objective is a method that is both technically and practically superior to the methods of clause 8. What follows is a status of the ongoing research for the information of reviewers of this part of ISO 13406.

C.1.1 Significance and Use

Optical scatter from a visual display originates from the surface topography (due to antiglare treatments) and from microstructures below the surface (technology dependent). In the most general case, neglecting any wavelength dependence and polarization dependence, the BRD is a function of two directions, the direction of the light incidence (θ_i, ϕ_i) and the receiver (eye or photometer) direction (θ_r, ϕ_r). The BRDF is a four-dimensional function that relates how the incident illuminance dE_i from direction (θ_i, ϕ_i) contributes a quantity of luminance dL_r to the observed or measured reflected luminance

$$\mathrm{d}L_r = B\,(\theta_r,\phi_r,\theta_i,\phi_i)\ \phi_i\ (\theta_i,\phi_i) \tag{128}$$

where $B\,(\theta_r,\phi_r,\theta_i,\phi_i)$ is the BRDF.

For display purposes, it is anticipated that all the angular information for a complete BRDF will not be needed, and the data requirements can be minimized to information in one to three planes. The luminance observed from the reflection angle is given by the integral over all the directions of incident illuminance

$$L_r(\theta_r,\phi_r) = \int_0^{2\pi}\int_0^{\pi/2} B(\theta_r\ \phi_r,\theta_i\ \phi_i)\ \mathrm{d}E_i(\theta_i\ \phi_i) \tag{129}$$

Suppose we have a distribution of luminance sources in the ambient that give rise to the incident illuminance distribution dE_i. For each element of solid angle dΩ = sin(θ_i)dθ_i,dϕ_i measured from the screen, there is an associated source luminance in the room $L_s(\theta_i,\phi_i)$. The illuminance arising from that source is then L_s cos(ϕ_i) dΩ, where the cosine term accounts for the light being spread out more at larger angles from the normal. In terms of luminance sources in the surround of the display, then the observed reflected luminance becomes

$$L_r(\theta_r,\phi_r) = \int_0^{2\pi}\int_0^{\pi/2} B(\theta_r,\phi_r,\theta_i\ \phi_i)\times L_s(\theta_i\ \phi_i)\cos(\theta_i)\mathrm{d}\Omega \tag{130}$$

Specular reflection is characterized by $L = \beta L_s$ where L_s is the luminance of the source. However, diffuse (Lambertian) and specular reflections alone are not adequate to characterize the reflective properties of typical display devices.

There is a third type of reflection, predominantly in the specular direction, that we will call “haze”. The haze component is responsible for many measurement inconsistencies when the reflection is treated with the diffuse (Lambertian) and the specular models only.

All components need not exist simultaneously. At least one component exists, to have light reflected from the sample. There are displays that have entirely diffuse (Lambertian) surface treatments (a sheet of writing paper, for example). There are displays that do not have a specular component (you cannot see distinct reflected images of any light sources) and sometimes displays have only a haze component with a negligible diffuse component. There are displays that do not have a substantial haze component and only exhibit specular and diffuse reflections (this situation is assumed in ISO 9241-7.)

The BRDF can be expressed in terms of three additive components (Diffuse, D, Specular, S and Haze, H):

$$B = D + S + H \tag{131}$$

where

$$D = q = \rho / \pi \tag{132}$$

$$S = 2\beta\, \delta\left[\sin^2\theta_r - \sin^2\theta_i\right]\delta\left[\phi_r - \phi_i \pm \pi\right] \tag{133}$$

$$H = H\left(\theta_r, \phi_r, \theta_i, \phi_{i,}\right) \mathrm{d}E_i\left(\theta_i, \phi_i\right) \tag{134}$$

The specular component characterizes the distinctness of image. The delta functions ensure that the specular contribution only comes from whatever source is located in the specular direction of reflection. When this three-component BRDF is integrated over all incident illumination directions, the more familiar result is:

$$L_r\left(\theta_r, \phi_r\right) = qE_i + \beta L_s\left(-\theta_r, \phi_r\right) + \int_0^{2\pi} \int_0^{\pi/2} H\left(\theta_r, \phi_r, \theta_i, \phi_i\right) \times L_i\left(\theta_i, \phi_i\right) \cos\left(\theta_i\right) \mathrm{d}\Omega \tag{135}$$

The first two terms are the diffuse (Lambertian) and the specular contributions in their familiar form. The ($\phi_r \pm \pi$) term in the specular component simply selects the light from the direction reflected about the normal, that is, the usual specular configuration. The last term is the haze contribution.

The haze function is peaked about the specular direction. Sometimes the function can cover three or four orders of magnitude (very matte-black screens). To see substantial width of the function in such a case, it is necessary to use a logarithmic scale.

When this work is complete, it is anticipated that a parametric form of this function will be available that will adequately characterize the haze for use in calculations of display reflections. We anticipate that the haze height h, its full-width at half maximum w (perhaps 5 % or 10 % width), and some shape factor f is possibly required to specify the haze function. It is to be hoped that the shape factor will not be required. This would yield a complete characterization of the reflection with four or five parameters, q, β, h, w, and possibly f. With such a formalism, we should be able to calculate how a display will perform in any specified luminance surround without having to create that luminance distribution in the laboratory and measure the reflected luminance.

Clause C2 presents measurement techniques that are currently under investigation. They are modelled after several standardized reflection-measurement methods employed outside the display industry.

C.2 Measurement of the BRDF

The Bidirectional Reflectance Distribution Function BRDF [2/1, 2/2] relates the differential illuminance of an object $\mathrm{d}E_\mathrm{i}$ with the reflected differential luminance $\mathrm{d}L_\mathrm{r}$ and thus it is a function of *two directions*: the direction of light incidence ($\theta_\mathrm{i},\phi_\mathrm{i}$) and receiver direction ($\theta_\mathrm{r},\phi_\mathrm{r}$) as shown in Figure C.1:

$$\mathrm{BRDF}=\frac{\mathrm{d}L_\mathrm{r}}{\mathrm{d}E_\mathrm{i}}=\frac{\mathrm{d}P_\mathrm{r}}{\mathrm{d}\Omega_\mathrm{r}\times p_\mathrm{i}\cos\theta_\mathrm{r}}\left[sr^{-1}\right] \tag{136}$$

where

$\mathrm{d}L_\mathrm{r}$ is the sample differential luminance;

$\mathrm{d}E_\mathrm{i}$ is the sample differential illuminance;

P_i is the power of the incident beam;

$\mathrm{d}P_\mathrm{r}$ is the differential power of the scattered beam;

$\mathrm{d}\Omega_\mathrm{r}$ is the differential solid angle of receiver aperture;

θ_r is the angle of receiver inclination.

With the BRDF being a function of both source and receiver orientation, three basic categories of BRD-Functions can be distinguished:

A Fixed source, variable receiver (standard arrangement, see [1, 2]);

B Variable source, fixed receiver (alternative for evaluation of visual performance);

C Variable source and variable receiver (alternative useful measuring approach).

Case A represents the standard BRDF realization for characterization of an arbitrary opaque specimen. Case B can be a useful alternative for evaluation of the ergonomic performance of display screens, since it simulates a realistic workplace situation. In a real workplace, the observer direction remains fixed with respect to the display while several ambient light sources are illuminating the display from various different directions. This approach, B, has been chosen by Kelley *et al.* for modelling of display reflectance under illumination of a variety of ambient light sources [3].

The third class of possible reflectance distribution functions, C, has instrumentation advantages. The sample is illuminated by a fixed diffuse small aperture or point-source and the angular distribution of reflected light intensity is evaluated by analysis of the reflected image of the light source with a two-dimensional detector array (i.e., human eye, CCD-camera). This approach has been proposed by Kelley for reflectance evaluation of flat display surfaces [4] and recently extended to curved surfaces (e.g., CRT-screens) [5].

There are three basic choices for the geometry of source emission in arrangements for BRDF evaluation:

- a source that delivers a collimated or a slightly converging beam with either small or large diameter;
- a point source (e.g., bare bulb of a flashlight); or
- a (small aperture) diffuse source.

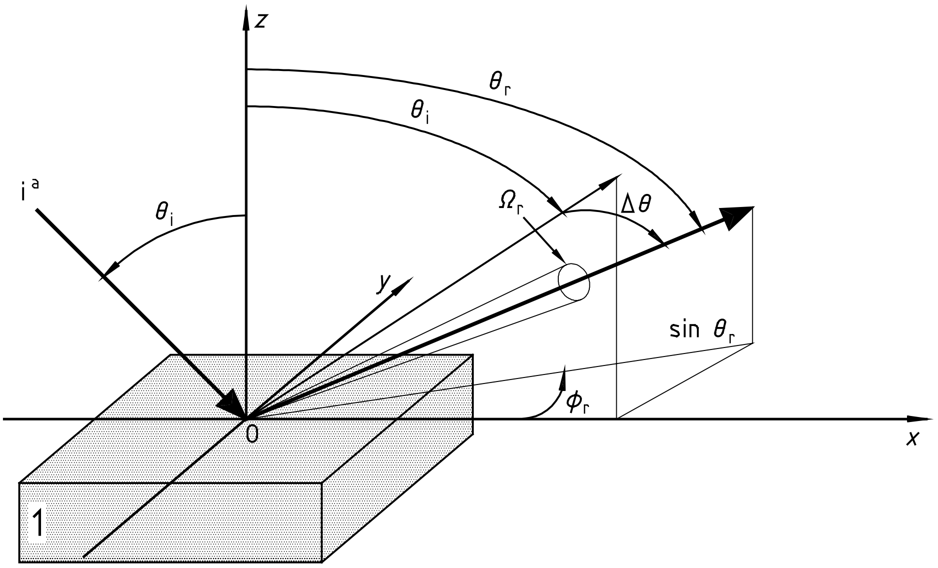
For the receiver, there are two possible settings with respect to focus:

- focused on the sample; or
- on the light source;

depending on the objective of evaluation: visual performance or physical sample characterization. In standard BRDF arrangements, the receiver is focused on the sample and the field of view (FOV) encloses the illuminated spot completely.

So far, BRDF measurements have been used for characterization of opaque materials like paints, enamels and other coatings that might as well be characterized in terms of *gloss*, *haze* and *distinctness-of-image gloss* [2/6, 2/7]. BRDF measurements may also be used for characterization of the microscopic surface structures that cause scattering of light [2].

In Figure C.1, the incident beam, i, characterized by (θ_i,ϕ_i) is shown in the xz-plane. The direction of the receiver is given by (θ_r,ϕ_r).



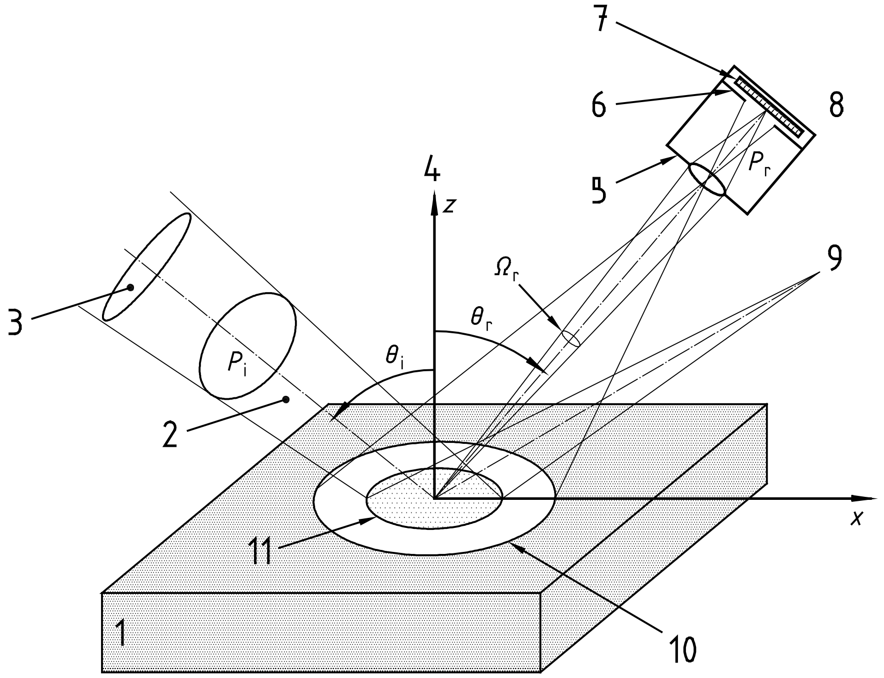
Key

a Incident

1 Sample

Figure C.1 — Coordinate system and angular conventions

The incident beam is set to converge in the plane of the receiver aperture. Standard BRDF condition: the illuminated spot A on the sample is smaller than the receiver FOV for all angles of receiver inclination θ_r.



Key

1	Sample
2	Incident beam
3	Final focusing or collimating element
4	Sample normal
5	Aperture stop
6	Field stop
7	Detector element
8	Receiver
9	Specular beam
10	FOV of receiver
11	Illuminated spot A

Figure C.2 — Source and receiver geometry

C.2.1 Conventional approach

Instruments for measuring the angular distribution of scattered light are either based on conventional mechanical scanning or an optical transform technique. In both cases, the instruments comprise a light source, a receiver for the reflected light and means for orienting source and receiver with respect to the sample under test.

C.2.1.1 Source

The source assembly comprises the light source itself (i.e., laser, incandescent bulb, discharge tube, etc.) and an optical system to produce an irradiance, E_i on the sample over a specified area, A, within a specified solid angle. The spectrum of source emission has to be specified in detail for chromatic or achromatic illumination; integral scalar characteristics like the “correlated colour temperature”, etc. are not sufficient. Collimated or slightly converging light beams (as shown in Figure C.2) are commonly used for measuring the BRDF.

The polarization state of the incident light shall be controlled and specified; unpolarized or circularly polarized light is preferred. Intensity and spectrum of the illuminating source shall be kept constant for the duration of the measurement to ensure significant results.

C.2.1.2 Receiver

The receiver comprises a detector element (opto-electric converter) and an optical system with specified Field-of-View and aperture angle (the FOV defines the measuring spot on the sample and the acceptance cone of the receiver, Ω_r, can be characterized by the aperture angle). The receiver shall be insensitive to the polarization state of incoming light and its overall spectral response shall be photopic unless otherwise noted; in some special cases, spectral analysis of the reflected light is required.

In order to measure the luminance of a sample object, the receiver optics shall be focused on the surface of the sample. For evaluation of the specular reflectance it is sometimes more appropriate to focus on the light source or its image instead.

When a photometer is incorrectly focused to a plane behind the actual object of measurement, the luminance readings will be higher than they would be under correct focusing conditions.

The axis of receiver inclination has to be adjusted to make sure that the same spot on the sample (i.e., FOV) is measured for all angles of receiver inclination and rotation. With constant aperture angle of the receiver, an initially circular measuring spot (FOV) becomes elliptical and asymmetrical (with respect to the axis of receiver inclination) for oblique receiver directions.

C.2.1.3 Positioning mechanism

The mechanical arrangement must provide means for orienting the source with respect to the sample in order to adjust the direction of light incidence, (θ_i,ϕ_i). When the sample exhibits azimuthal asymmetries (i.e., directionality) the capability to rotate the sample about its surface normal in the centre of the illuminated area, A, and to perform several measurements for different rotation angles is also required. Both axes of inclination and rotation of the light source, θ_i and ϕ_i respectively, shall intersect in the centre of the measuring spot. Both axes of inclination and rotation of the receiver, θ_r and ϕ_r respectively, shall intersect in the spot that is given by the intersection of axes of source-rotation and inclination.

Many adjustments and alignments have to be made carefully for each individual sample to ensure that the above listed geometrical conditions are realized. Even slight deviations can severely affect the measured results.

C.2.1.4 Source-receiver signature

Standard practices for goniophotometry of objects and materials [8] distinguish two alternative optical configurations with either a parallel and or a converging beam geometry, both of them featuring certain specific advantages and drawbacks with respect to for example, vignetting, angular resolution, etc.

In the converging beam configuration, for example, the image of the light source is projected into the entrance pupil of the receiver assembly to make sure that the complete flux is collected when no sample is present. In standard BRDF arrangements the receiver optics is focused on the plane of the sample.

When light source and receiver, without a sample, are initially aligned in a transmissive in-line configuration with their optical axes coinciding (i.e., the receiver “looks” directly into the source), the variation of receiver electrical output with angle of inclination is a peaked curve that drops off with increasing angular distance between the optical axes of source and receiver. The detailed shape of this curve is given by the angular characteristics of both source emission and receiver sensitivity. Since its shape is characteristic for the specific couple of source and receiver, the curve is called source-receiver signature. This signature can be obtained mathematically by convolution of the source emission versus angle of light propagation with the directional variation of receiver sensitivity.

An ideal light source will deliver a perfectly collimated beam (no divergence) with constant intensity across the beam and the ideal collimating receiver will accept only perfectly collimated beams with a constant sensitivity across its entrance aperture. Both source emission and receiver sensitivity versus distance from the beam center can then be represented as top-hat profiles (across-beam uniformity). When ideal source emission and ideal receiver sensitivity are plotted versus the direction of light propagation, we obtain a Dirac pulse for the case of a perfectly collimated beam (no angular spread) and a perfectly collimating receiver. The signature of a pair of ideal source and receiver is also a Dirac pulse.

In practical realizations, however, neither the source beam is perfectly collimated, nor are receiver sensitivity and source beam intensity constant over the beam diameter. The gradual decrease of both single quantities toward the edge of the beam results in a gradual drop-off of the source-receiver signature.

The source-receiver signature defines the limits of the angular resolution of any BRDF measuring equipment and arrangement and thus, it shall be kept as small as possible. There will, however, always be a competition between a high angular resolution (narrow signature) and the signal-to-noise ratio of the instrument. The lowest practical signatures are usually above 0,01° [2].

In an apparatus for measuring reflective samples, the above mentioned transmissive in-line configuration for evaluation of the source-receiver signature can be replaced by a specular arrangement (i.e., angle of light incidence equals angle of receiver inclination) with a specular, non-scattering mirror. High-quality front surface metallic mirrors, or preferably, plane polished black glass is used for this purpose.

C.2.1.5 Reduced geometry, in-plane BRDF

One way to reduce the complexity of the method and of the equipment is the restriction to measuring the reflected light in the plane of incidence only. Either the receiver or the source is moved while both are in the same plane (i.e., plane of incidence, PLIN, defined by the surface normal of the sample z and the central ray of the incident flux, see Figures C.1 and C.2). This special case is called In-Plane BRDF (IP-BRDF): IP-BRDF evaluation is applicable to characterize optical scatter of such samples that feature sufficient rotational symmetry about the surface normal.

C.2.1.6 Multiple reflections

In standard BRDF arrangements, the receiver FOV as determined by its field-stop must be sufficiently large to include the entire illuminated area, A. The cos(θ) term in the denominator of Formula (136) compensates for the drop of luminous (or radiant) intensity $\mathrm{d}P_\mathrm{r}$ / $\mathrm{d}\Omega_\mathrm{r}$ experienced by the receiver with increasing inclination θ_r and thus decreasing effective area, A_eff, of the illuminated spot.

BRDF measurements are generally restricted to opaque samples; thus only the upper surface layer contributes to the reflection of light [1].

Since the visual display devices under consideration here are composed of several transparent layers, the reflected light also comprises several individual parallel beams which originate from different optical interfaces. Their spatial separation increases with increasing angle of light incidence and with thickness of the layers. In order to collect all of these partial beams simultaneously with a sufficiently small receiver aperture, we modify the standard BRDF approach in such a way that the sample is illuminated with a uniform spot that is larger than the FOV. The receiver FOV must then be small enough and centred in the illuminated spot area that is does not exceed its limits even under maximum angle of inclination (i.e. FOV and illuminated spot as shown in Figure C.2 are interchanged). It is also required that the sample properties are uniform over the area from which partial beams will be collected. The measured quantity in this case is the luminance L_r and the corresponding BRDF is

$$\mathrm{BRDF} = \frac{C_1}{P_\mathrm{i}} \times L_\mathrm{r} \left[sr^{-1} \right] \tag{137}$$

Since in this configuration even a perfect mirror does not completely reflect the incident flux into the receiver assembly, the constant C_1 is obtained by calibration with suitable calibrated diffuse reflectance standards (see C.4.3.1). In the terminology of the ASTM, this is called “relative BRDF” due to calibration with and reference to a calibrated standard [1].

Comparison of BRDF curves of opaque samples (e.g. diffuse reflectance standard, paper, etc.) measured under both illumination conditions showed an excellent match of the results (after the required correction for cos θ_r). In a further step, comparison of the BRDF of glass plates with two partial reflected beams (10 mm PMMA, 3 mm float-glass), one from each glass-air interface, with the respective results of calculations, confirm the applicability of the modified illumination approach.

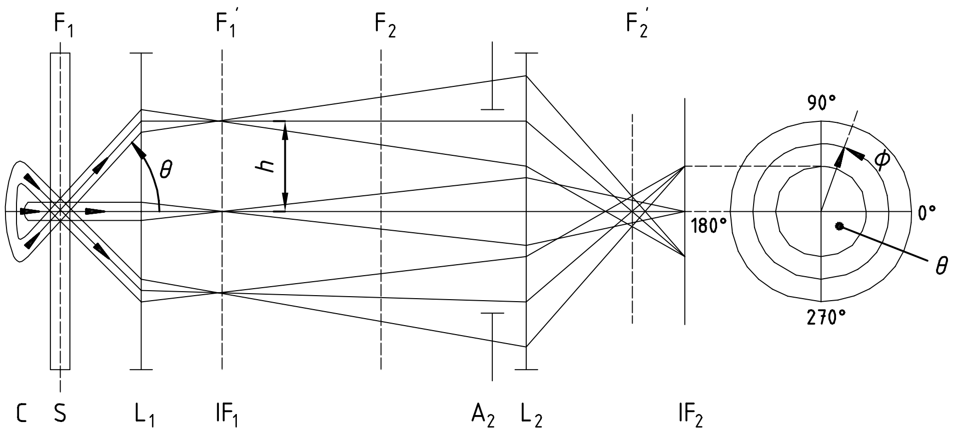
C.2.2 Alternative approach

A novel instrument has recently been realized for measuring the complete 2-dimensional BRDF without mechanical angular scanning by combining a conoscopic receiver with an illumination technique called “Focal Plane Illumination”.

C.2.2.1 Conoscopic receiver

The apparatus is based on the well-known conoscopic method where a cone of elementary collimated light beams C originating from the measuring spot on the transmissive sample S (located in the front focal plane of the transform lens L_1) is collected simultaneously over a large solid angle by the lens L_1 as sketched in Figure C.3. A pattern IF_1 is generated in the rear focal plane F'_1 of the lens L_1 with the intensity of each area element corresponding to the intensity of one elementary parallel beam with a specific direction of light propagation. The light propagating parallel to the optical axis of the conoscopic receiver forms the centre of that circular pattern (a typical example of a transform pattern is shown on the right side of Figure C.3) and beams with constant angle of inclination θ form concentric circles around the center with the radius of the circles h being proportional to the inclination θ. In the pattern IF_1, the angular intensity distribution of the cone of elementary parallel light beams C is transformed into a two-dimensional intensity distribution with each location in the pattern corresponding to one direction of light propagation [6].

A second optical system L_2 projects the transform pattern IF_1 in reduced size onto a two-dimensional detector array (e.g. CCD-array) for evaluation of the spatial intensity distribution which corresponds to the angular intensity distribution of the light emerging from the measuring spot on the sample.



Key

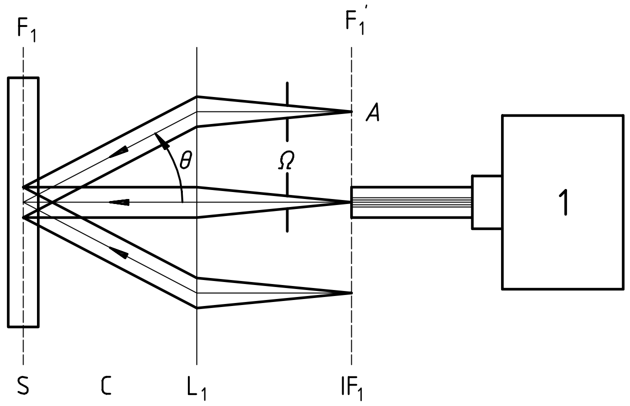
C	Cone of converging elementary parallel beams illuminating the transmissive sample S
F_1, F'_1, F_2, F'_2	Front and rear focal plane of lenses L_1 and L_2, respectively
IF	Transform pattern
A_2	Variable aperture
L_2	Relay lens for projection of IF_1 to detector array in the plane of IF_2

Figure C.3 — Concept of a conoscopic receiver

C.2.2.2 Focal plane illumination

If the sample is non-transmissive or for evaluation of the reflective properties of a sample, it is possible to provide a well defined illumination through the lens L_1 as sketched in Figure C.4. An elementary source of light with area A, emitting a cone of light Ω with the central ray parallel to the optical axis of the lens L_1, produces a collimated beam with its diameter given by the cone diameter at L_1 and the angular divergence determined by the area A. In order to obtain a well collimated beam (i.e. with minimum angular divergence) the source element A has to be as small as possible. In the other extreme case, an isotropic diffuse illumination for the sample can be generated by a collimated light beam completely covering the diameter of the lens L_1

Combination of a conoscopic receiver with the concept of “focal plane illumination” allows measurement and simultaneous observation of the angular distribution of light reflected by a sample [7].



Key

1 Light source

C Cone of converging elementary parallel beams illuminating the reflective sample S

F_1, F_1' Front and rear focal plane of transform lens L_1

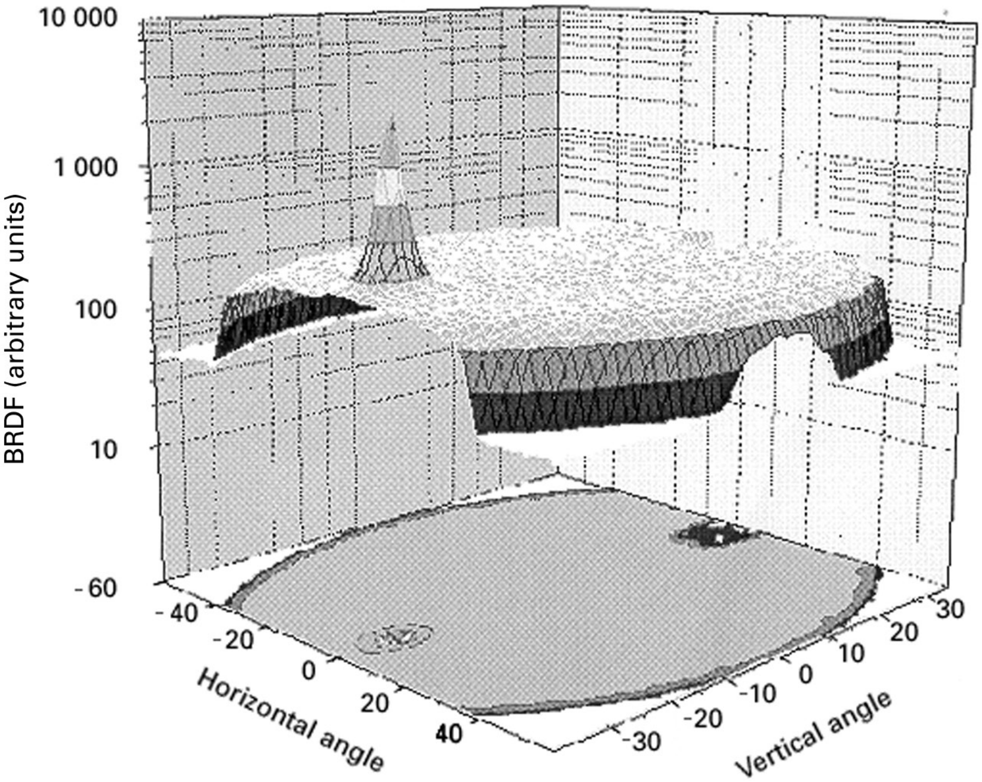
Figure C.4 — The concept of focal plane illumination

As an alternative to mechanical angular scanning, the conoscopic method offers some advantages with respect to the time required for “scanning” the solid angle of interest and the dimensions of the apparatus. Recent realizations of conoscopic receivers offer aperture angles up to ± 80°.

C.3 Typical BRDF results

C.3.1 Two-dimensional BRDF

A good example for illustration of the basic BRDF components is obtained from white glossy paper (i.e., magazine paper) as shown in Figure C.5. The sample is illuminated with a collimated beam of white light, the beam diameter is 1,1 mm and angle of light incidence is fixed at 35°. The aperture angle of the conoscopic optics used for the experiments throughout this paper is ± 60°.

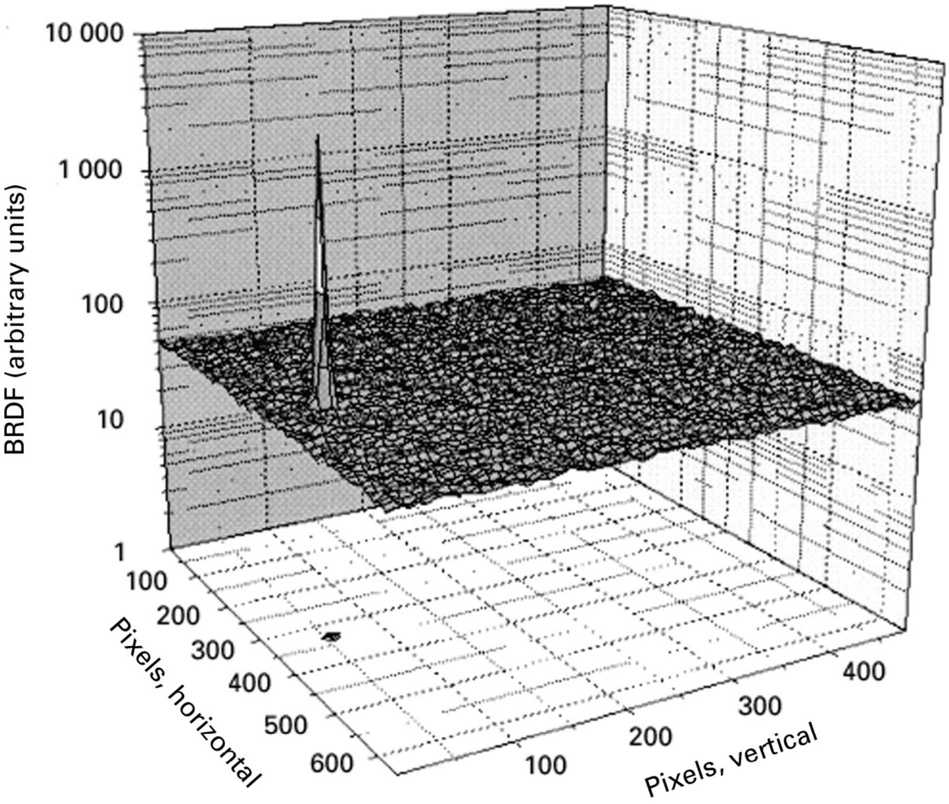


Exposure time t_e = 15 ms

Peak value = 2 914 counts

Figure C.5 — Two-dimensional BRDF of glossy white magazine paper

In the corners of Figure C.5 (i.e. in those detector areas that are not exposed to light), we see a base-level which is the noise-floor of the conoscopic receiver; the average noise level in Figure C.5 is 54 intensity units (A/D-converter counts). For most of the receiver directions around normal and up to approximately 50°, the reflected light intensity remains constant and forms a plateau with an average level of 217 intensity units; this is the Lambertian component of reflectance. On top of this plateau, located around the specular direction we see a bell-shaped peak which is the specular component spread-out by the haze. The amount of reflection haze can be characterized by the difference between the bell-shaped peak and the narrow source-receiver signature of the conoscopic system (measured with a polished black glass mirror) shown in Figure C.6. The width of the needle-shaped peak at 1 % of its maximum is 2,6°.

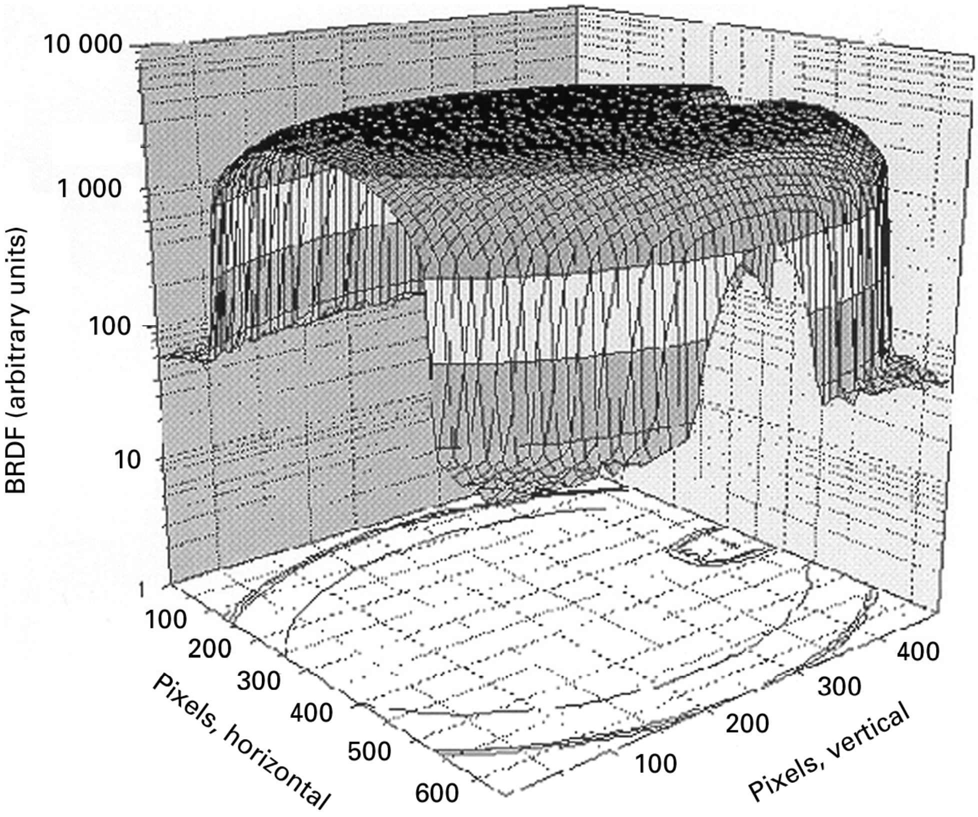


Exposure time t_e = 1 ms

Peak value = 3 500 counts

Figure C.6 — Two-dimensional BRDF of a specular mirror (polished plane black glass, NG9, Schott), representing the source-receiver signature, exposure time

The BRDF of a calibrated diffuse reflectance standard is shown in Figure C.7; here the reflected luminous intensity remains constant for all receiver directions, except for a drop-off at the rim of the Lambertian plateau, which is given by the gradual decrease of the receiver sensitivity toward larger inclinations. No increase of intensity can be found here at the specular direction, indicating a perfect scattering of the incident collimated light beam.



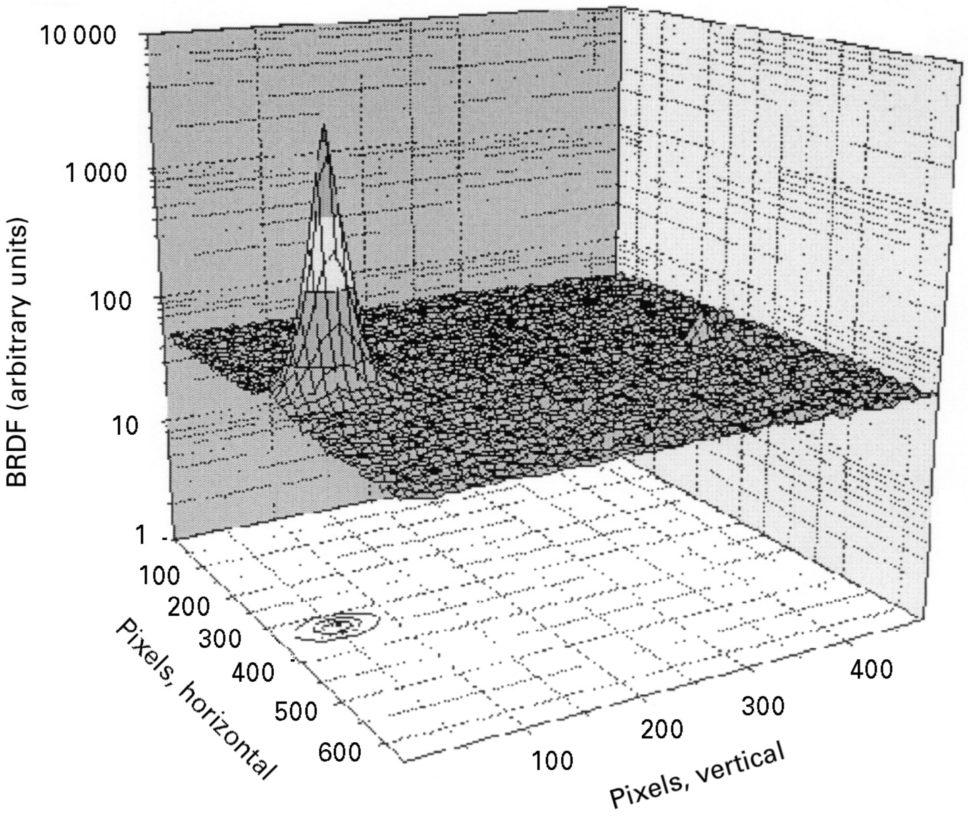
Reflectance r = 99,1%

Exposure time t_e = 250 ms

Plateau value = 3 600 counts

Figure C.7 — Two-dimensional BRDF of an ideal diffuse reflectance standard

The dip in the plateau opposite to the specular direction is caused by shadowing of the device used to feed light into the rear focal plane of the conoscopic lens system.



Exposure time t_e = 7 ms

Peak value = 3 990 counts

Figure C.8 — Two-dimensional BRDF of a 26,4 cm (10,4") colour STN-LCD-screen with anti-glare polarizer

The 2-dimensional BRDF obtained from a 26,4 cm (10,4") colour STN-LCD-screen is shown in Figure C.8; here, the bell-shaped haze peak rises directly from the noise floor and no substantial Lambertian plateau can be found even with much closer examination as shown in C.3.2.

C.3.2 In-plane BRDF

We also have carried out measurements with a conventional mechanical scanning BRDF apparatus, comprising a collimated beam white-light source (beam divergence ± 2°, circular polarization, 35° inclination) and a directional receiver (focused on the sample) with an aperture of slightly less than ± 2.

The IP-BRDF curve obtained from the 10,4" colour STN-LCD-screen of Figure C.8 is shown in Figure C.9. The effect of scattering due to structures and particles inside the LCD and on top of the front polarizer (e.g. anti-glare coating) is obvious as a broadening of the source-receiver signature measured here with a black glass mirror. Even for large angles of receiver inclination however (i.e. ± 35° from specular), no Lambertian plateau can be found. In order to cover the dynamic range of more than four orders of magnitude with a 12-bit receiver resolution, we have overlaid separate measurements with increased sensitivity away from the specular direction as shown in Figure C.9.

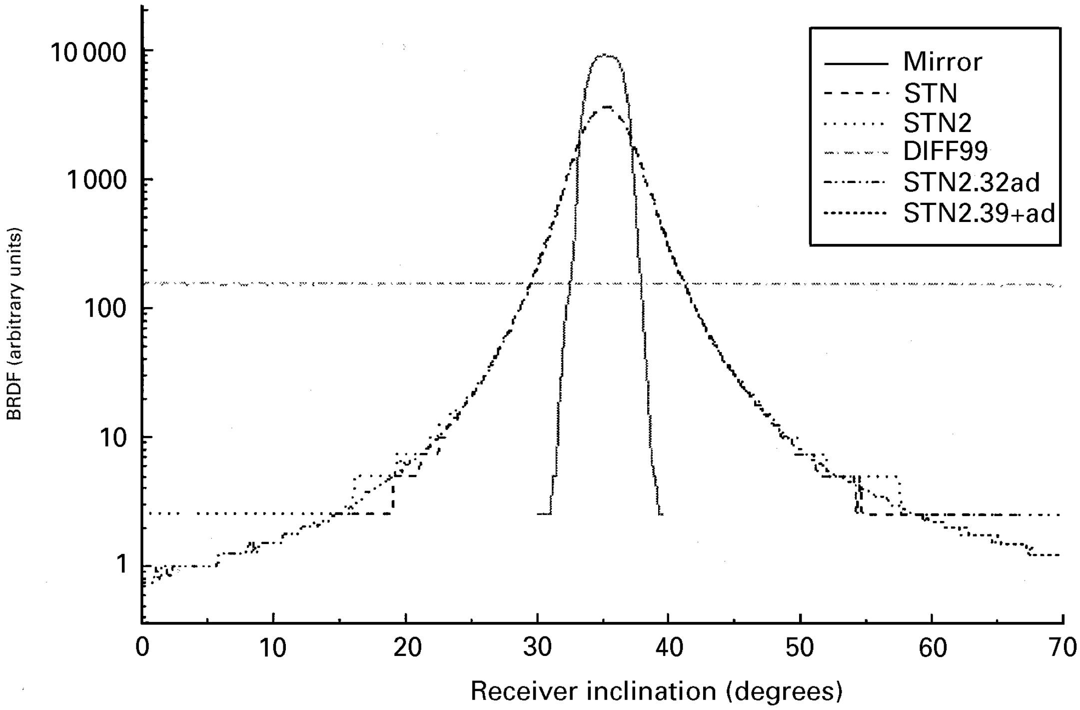


Figure C.9 — IP-BRDF curve of the color STN-LCD-screen, specular mirror (R_S = 0,044 4) and diffuse reflectance standard (r = 99,1 %) with a collimated beam white light source (beam divergence < ± 2°, circular polarization).

C.4 Evaluation and interpretation of BRDF Data

In some cases, we can easily distinguish the basic components (specular, haze and Lambertian) in the BRDF-curves as shown above (see, for example, Figure C.5).

The specular peak that forms the top of a haze-hill can be evaluated to yield either suitable specular gloss values (i.e. the "relative luminous reflectance factor in the mirror direction" if compared to calibrated gloss standards, made from, for example, polished and etched black glass [8]) or other specular reflectance characteristics depending on the geometry of the setup and the evaluation [8, 9, 10, 11].

C.4.1 Separation of specular and non-specular components

Separation of specular components from non-specular ones basically follows the physical process of measuring diffusely reflected components with an integrating sphere where the specular (i.e. regular) beam is excluded from the directional integration by a suitable light trap centred around the regular direction. All components reflected in non-specular directions are collected by the integrating sphere and their integral flux is measured. This approach is used, for example, for determination of an integral value of haze in transmission and reflection, where the haze-factor is given by the non-specular flux divided by the total flux [12, 13, 14] and it thus combines both haze and Lambertian components in one integral value. A complication is caused by appropriate selection of the size of the specular trap. Whenever haze is included in the reflection, the size of the specular port critically determines the amount of haze that is included in the non-specular component. Moreover, exact alignment of the specular direction into the centre of the light trap is essential. This problem can be avoided completely when the specular component is extracted mathematically from the BRDF data.

C.4.2 Haze-spread ratio

Ideally, the shape of the 2-dimensional distribution of reflected light should be described by mathematical formulas, with a limited number of parameters finally characterizing the complete angular distribution. Due to the variety of different BRDF-shapes, however, it is not easy to find suitable target functions for numerical fitting [3].

To make things easier during the first step, we propose the haze-induced spreading of the source-receiver signature for characterization of reflection haze. This spreading is defined as the ratio of the width of the BRDF curve of the sample object at 10 % maximum of the specular peak intensity compared to the width of the source-receiver signature at the same 10 % maximum level, and named S_{10}.

Assuming that no absorption is involved in the reflection process and idealizing the haze-hill into a cone, we obtain the following simple relation between the specular reflectance factor R_s and the haze-spread ratio S_{10}

$$S_{10}^2 \times R_\mathrm{s} = A\,constant \tag{138}$$

This formula shows that the specular reflectance decreases inversely proportional to the square of the haze-spread ratio S_{10}, i.e., a small increase of haze-spread effects a considerable decrease of the specular reflectance.

Since the haze-spread ratio varies with the source-receiver signature of the measuring instrument, this quantity has to be specified to make evaluations comparable.

C.4.3 Hemispherical reflectance

The ratio of the total flux reflected into the hemisphere around the centre of the target spot to the incident flux is given by the hemispherical reflectance R_H, also called total integrated scatter, TIS. Accordingly, the ratio of the specularly reflected power to the incident power defines the specular reflectance, and the ratio of the diffusely reflected power to the incident power defines the diffuse (i.e. non-specular) reflectance.

The hemispherical reflectance R_H is obtained by integrating the flux of scattered light over the hemisphere around the target spot centre.

$$R_\mathrm{H} = \frac{1}{P_i} \times \int_0^{\pi/2} \int_0^{2\pi} \frac{\mathrm{d}P_\mathrm{r}}{\mathrm{d}\Omega_\mathrm{r}} \times \sin\theta_\mathrm{r}\ \mathrm{d}\phi_\mathrm{r}\ \mathrm{d}\theta_\mathrm{r}$$

$$R_\mathrm{H} = \int_0^{\pi/2} \int_0^{2\pi} \mathrm{BRDF} \times \mathrm{cost}\theta_\mathrm{r} \times \sin\theta_\mathrm{r} \mathrm{d}\phi_\mathrm{r} d\theta_\mathrm{r} \tag{139}$$

The limits for integration are ideally 0° to 90° for receiver inclination θ_r and 0° to 360° for the azimuth ϕ_r. Either the limits have to be chosen during the measurement so that the results are significant (sometimes limited by the mechanical capabilities of the mechanism) or adequate numerical methods for extrapolation may be used to extend the amount of available data.

C.4.3.1 Diffuse Samples

Diffuse opaque samples scatter all of the non-absorbed incident light into the hemisphere around the centre of the target spot on the sample. If the scattered flux per solid angle unit decreases with cos θ_r and thus the BRDF is constant and does not depend on the inclination of the receiver, the sample reflectance is called Lambertian. The luminous intensity of light scattered by Lambertian samples is proportional to cos θ_r and thus proportional to the apparent size of the illuminated spot.

$$\mathrm{BRDF}_{Lambertian} = \frac{\mathrm{d}P_\mathrm{r}}{\mathrm{d}\Omega_\mathrm{r}} \times \frac{1}{P_i \cos\theta_\mathrm{r}} = A\,constant \tag{140}$$

After inserting $dP_r / d\Omega_r$ from equation (140) into (139) and integrating we obtain for the BRDF of the Lambertian sample with a hemispherical reflectance R_H

$$BRDF_{Lambertian} = \frac{R_H}{\pi} = \frac{\rho}{\pi} \tag{141}$$

The hemispherical reflectance R_H of a Lambertian diffuse reflector is also known as the diffuse reflectance ρ.

C.4.3.2 Specular samples

The BRDF curve of a mirror without scattering is sharply peaked around the specular direction and drops off steeply with both receiver inclination θ_r and azimuth ϕ_r. The amplitude of this curve is determined by the specular reflectance of the mirror, while its shape is given by convolution of the angular spread of the illuminating beam and the angular sensitivity of the receiver optics (i.e. source-receiver signature).

C.4.4 Numerical evaluation of BRDF data

C.4.4.1 General

The raw BRDF data first has to be corrected for the noise-floor and for the different receiver sensitivities used during the measurements (i.e. exposure times in the case of CCD-cameras, high-voltage settings in the case of PMTs).

Two standards are usually included in our BRDF measurement for reference and calibration: a specular standard made from polished black glass (here: refractive index of 1,51 at 550 m, specular reflectance factor R_S approx. 4,44 % at an inclination of 35°) and an ideal diffuse reflector (made from, for example, $BaSO_4$, MgO, etc.) and calibrated for the diffuse reflectance ρ. The BRDF data obtained from the diffuse standard is a straight line parallel to the X-axis or a Lambertian plateau in the 2-dimensional representation. The fact that an ideal diffusing standard must result in such a plateau can be used for checking the validity of a measurement and a specific setup.

C.4.4.2 IP-BRDF Data

Comparison of the peak-value of the sample BRDF curve of Figure C.9 with the peak value of the reference mirror yields a sample specular reflectance factor R_S = 1,76 % and by comparison of the width at 10 % of the peak intensity, we obtain a haze-spread ratio of S_{10} = 2,04.

C.4.4.3 Two-dimensional BRDF Data

After correction of the raw data for background noise and different receiver sensitivities, any obvious Lambertian plateau shall be identified, its level determined by comparison with the data of the calibrated diffuse reflectance standard, and then it shall be subtracted from the sample data to give the specular peak height and the haze-spread.

Taking the 2-dimensional BRDF data from the glossy white paper of Figure C.5 as an example, we obtain the three reflectance characteristics by comparison with the source-receiver signature shown in Figure C.6 and the calibrated diffuse reflectance standard shown in Figure C.7. See Table C.1.

Table C.1 — Evaluation of the reflectance characteristics of glossy white paper via comparison with a calibrated specular mirror and a diffuse reflectance standard

Sample	Paper	Mirror standard	Diffuse reflectance standards
Reference value	—	R_S = 4,44 %	ρ = 99,1 %
Exposure time	15 ms	1 ms	250 ms
Plateau value	217 counts	—	3 600 counts
Peak value	2 914 counts	3 503 counts	—
Noise floor	54 counts	52 counts	60 counts
10 % peak width	36 pixels	16 pixels	—

For the diffuse reflectance of the paper we obtain ρ = 76 %, for the specular reflectance factor R_S = 0,233 % and for the haze-spread ratio S_{10} = 2,25. Evaluation of the reflectance of printed black areas to the non-printed background of glossy paper yields a diffuse contrast ratio of 21 with a contrast of 0,78 (!) in the specular direction. This indicates inverse contrast, i.e., the black areas have a higher specular reflectance than the white areas, a well-known and visually disturbing phenomenon for white magazine paper.

Evaluation of the 2-dimensional BRDF of the colour STN-LCD-screen as shown in Figure C.8, compared to the reference mirror of Figure C.6 yields a specular reflectance factor of R_S = 0,7 % and a haze-spread ratio of S_{10} = 2,5. There is no obvious Lambertian plateau.

The differences between the evaluation of the IP-BRDF data and the 2-dimensional BRDF data presented here arise from the differences in the source-receiver signatures of both arrangements with the 10 % signature of the conoscopic instrument being ± 1,5° and that of the IP-BRDF arrangement being ± 2,2°.

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