IEC TR 62977-2-5

Edition 1.0 2018-11

TECHNICAL REPORT

colour inside

Electronic display devices –
Part 2-5: Transparent displays – Measurements of optical characteristics

IEC TR 62977-2-5:2018-11(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 31.120; 31.260

ISBN 978-2-8322-6189-7

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 62977-2-5, which is a technical report, has been prepared by IEC technical committee 110: Electronic display devices.

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

Draft TR	Report on voting
110/919/DTR	110/935B/RVDTR

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

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

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

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

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- withdrawn,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

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

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ELECTRONIC DISPLAY DEVICES –

Part 2-5: Transparent displays – Measurements of optical characteristics

1 Scope

This part of IEC 62977 describes the conditions and measuring methods for determining the displayed properties (on-screen) and the through-screen properties of transparent direct-view-type liquid crystal displays (LCDs) and those of organic light emitting diode (OLED) displays.

2 Normative references

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

IEC 62341-6-4:2017, *Organic light emitting diode (OLED) displays – Part 6-4: Measuring methods of transparent properties*

IEC 62341-6-2, *Organic light emitting diode (OLED) displays – Part 6-2: Measuring methods of visual quality and ambient performance*

3 Terms and definitions

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

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

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

3.1
transparent display module
display module which can show the information on the screen and allow objects behind the display to be viewed through the screen

3.2
on-screen property
image quality attributes when the intended information is on the display panel

3.3
through-screen property
image quality attributes when the intended information is behind the display panel and is viewed through it

3.4
transmittance
ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions

3.5
transmitted haze
percent of transmitted light that is scattered more than 2,5° from the direction of the incident beam

3.6
clarity
measure based on luminance modulations from stripe patterns to represent the degree of clear distinction of see-through objects

3.7
purity
ratio of luminance which is measured in a 0,2° region to luminance of total transmitted light in a transparent display panel to represent the degree of clear distinction of see-through objects

3.8
colour shift
change in chromaticity of the reference object when viewed through a transparent display device

3.9
contrast ratio offset
change in contrast ratio of the reference object when viewed through a transparent display device

4 Measuring conditions

4.1 Standard measuring environmental conditions

Measurements are carried out under the standard environmental conditions:

– temperature: 25 °C ± 3 °C,
– relative humidity: 25 % to 85 %,
– atmospheric pressure: 86 kPa to 106 kPa.

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

4.2 Standard lighting conditions

4.2.1 Darkroom conditions

The luminance contribution from unwanted background illumination reflected off the test display shall be less than 1/20 of the display's black state luminance. If this condition is not satisfied, then background subtraction is required and it shall be noted in the test report. In addition, if the sensitivity of the light measuring device (LMD) is inadequate to measure at these low levels, then the lower limit of the LMD shall be noted in the test report.

4.2.2 Ambient illumination conditions

Ambient lighting conditions will make a large impact on the performance of a transparent display. For observers who watch a transparent display, various ambient conditions are suggested based on previous research. Table 1 shows the standard indoor and daylight ambient illumination conditions.

Uniform hemispherical diffuse illumination is used to simulate the background lighting in a room or the hemispherical skylight incident on the display, with sun occluded. The detailed information to simulate those ambient conditions is described in IEC 62341-6-2 [1][1] and in IDMS [2].

Table 1 – Standard ambient conditions

Design screen illuminance	Indoor and daylight illumination environment	Recommended illumination geometry
Up to 200 lx	(mostly) General building areas (ISO 9241-307 [3])	60 % hemispherical, 40 % directional at 45°
Up to 300 lx	(mostly) General machine work, rough assembly work, (general) museum (ISO 9241-307), office environment	60 % hemispherical, 40 % directional at 45°
Up to 500 lx	Medium assembly and decorative work, simple inspection, counters, libraries, (mostly) educational areas, control rooms (ISO 9241-307)	60 % hemispherical, 40 % directional at 45°
Up to 750 lx	Fine work, technical drawing (ISO 9241-307)	60 % hemispherical, 40 % directional at 45°
Up to 1 000 lx	Precision work, quality control, inspection, medical examination and treatment (ISO 9241-307)	60 % hemispherical, 40 % directional at 45°
Up to 1 500 lx	High-precision work (ISO 9241-307)	60 % hemispherical, 40 % directional at 45°
> 1 500 lx	Special workplaces in the medical area (ISO 9241-307)	60 % hemispherical, 40 % directional at 45°
80 000 lx	The daylight contrast ratio and colour is calculated using a combination of hemispherical diffuse illumination (with specular included) and directional illumination incident on a display surface in a vertical orientation	15 000 lx hemispherical, 65 000 lx directional at 45°

4.2.3 Ambient illumination spectra

The ambient performance of the display can be significantly impacted by the spectral distribution of the illumination source. Unless it is specified otherwise, the source illumination closely approximates CIE Illuminant D65 [4]. The source illumination used for measuring the display reflection and transmission properties has a spectrally smooth and broadband emission. Spectral reflection and transmission measurements can then be used to predict the ambient display performance for any desired illumination spectra.

When evaluating the display's ambient indoor performance, it is recommended to use the same spectral distribution for the hemispherical and directional source illumination. Light source spectra approximating CIE Illuminant A, Illuminant D50, and Illuminant D65 are recommended for indoor applications. In order to simulate outdoor applications, Illuminant D50 is recommended for the directional illumination, and Illuminant D75 is recommended for hemispherical illumination.

1 Numbers in square brackets refer to the Bibliography.

4.3 Standard setup conditions

4.3.1 Starting conditions of measurements

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

4.3.2 Standard measuring positions

Luminance, radiance distribution and/or tristimulus values may be measured at several specified positions on the DUT surface; see Figure 1. Unless otherwise specified, measurements are carried out in the centre of each circle. Care is taken that the measuring spots on the display do not overlap.

Any deviation from the above-described standard positions is added to the detail specification.

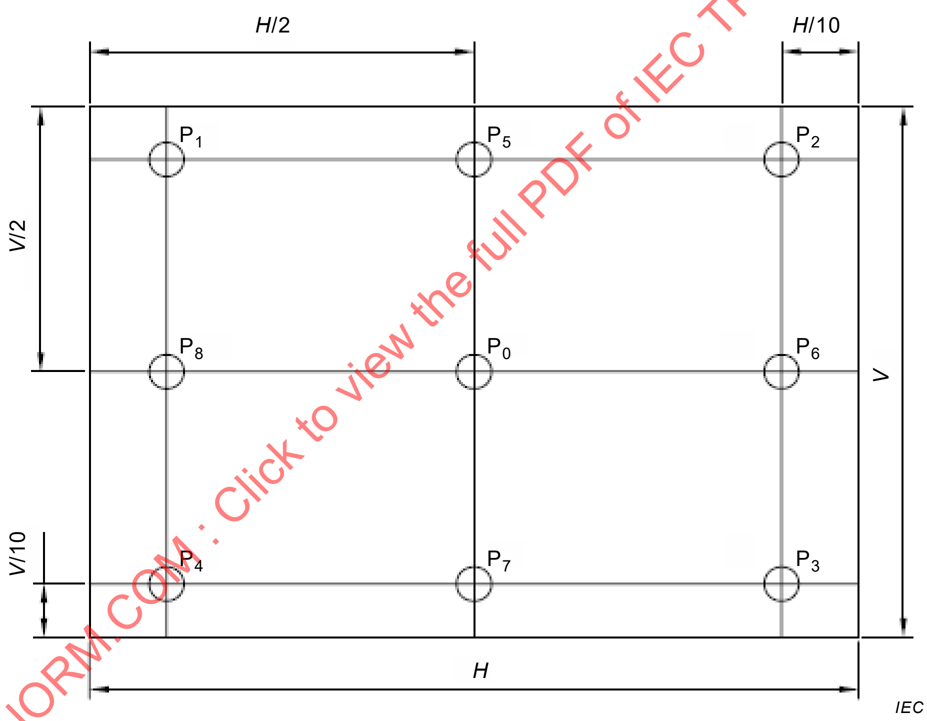


Figure 1 – Measurement points

4.3.3 Conditions of measuring equipment

General conditions of the measuring equipment specified in IEC 62341-6-2 are adopted. Three different LMDs may be applied to the measurements of the light transmitted and/or reflected by the DUT: a luminance meter, a colorimeter or a spectroradiometer. If measuring segmented displays, the measurement field area is located completely inside a single segment, and does not include any of its surroundings.

For DUT which is not equipped with its own source of illumination, an external light source which has the same size as that of the DUT is used. Assemble the back light source with the transparent display module to ensure that there is no light leakage.

Measure the following parameters of the light source in the plane of the DUT at P_0 and other relevant positions from P_1 to P_8 (Figure 1); measure and specify:

a) spectrum of emission;

b) luminance L;

c) temporal stability of the luminance $L(t)$.

The general conditions of the measurement are as follows:

1) The standard measurement setup is shown in Figure 2. The LMD is a luminance meter, colourimeter, or a spectroradiometer capable of measuring spectral radiance over at least the 380 nm to 780 nm wavelength range, with a maximum bandwidth of 10 nm for smooth broadband spectra. For light sources that have sharp spectral features, like LEDs and fluorescent lamps, the spectroradiometer's maximum bandwidth is less than 5 nm. The spectral bandwidth of the spectroradiometer is an integer multiple of the sampling interval. For example, a 5 nm sampling interval can be used for a 5 nm or 10 nm bandwidth. Care is taken to ensure that the device has enough sensitivity and dynamic range to perform the required task.

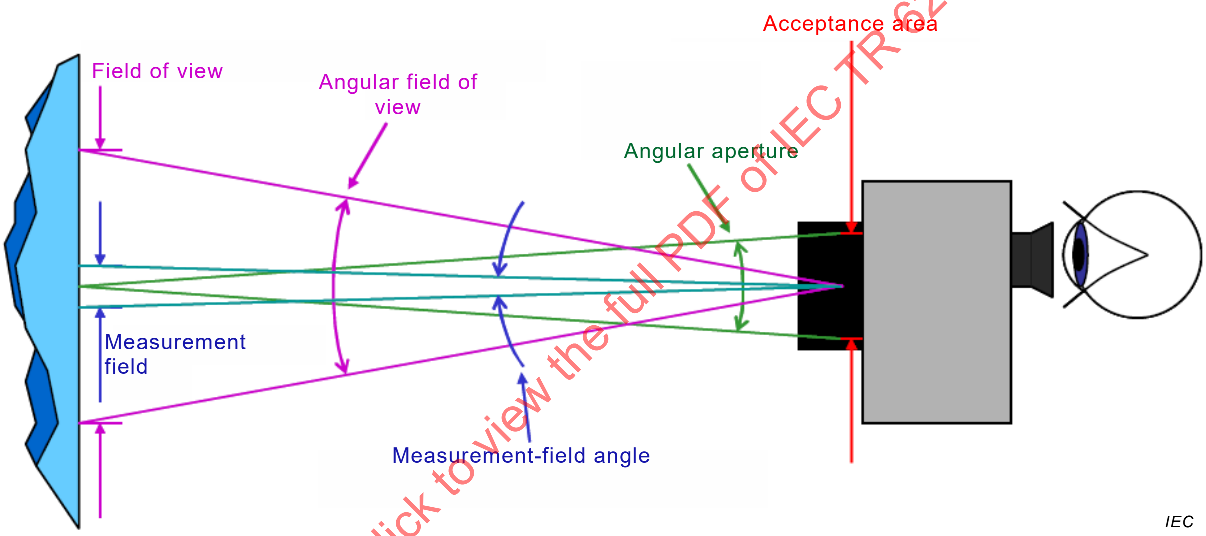


Figure 2 – Layout diagram of measurement setup

2) The LMD is focused on the image plane of the transparent display for on-screen performance and on the image plane of the background for transmission performance. The LMD is aligned perpendicularly to its surface, unless stated otherwise.

3) The relative uncertainty and repeatability of all the measuring devices is maintained by following the instrument supplier's recommended calibration schedule.

4) The LMD integration time is an integer number of frame periods, synchronized to the frame rate, or the integration time is greater than 200 frame periods.

5) When measuring matrix displays, the LMDs are set to a measurement field that includes more than 500 pixels. If smaller measurement areas are necessary, equivalence to 500 pixels is confirmed.

6) The angular aperture is less than or equal to 5°, and the measurement field angle is less than or equal to 2° (see Figure 2). The measuring distance and the aperture angle may be adjusted to achieve a measuring field greater than 500 pixels if setting the above aperture angle is difficult.

7) Display modules are operated at their design field frequency. When using separate driving signal equipment to operate a panel, the drive conditions are noted in the performance report.

Any deviations from these conditions are noted in the performance report.

5 Measuring methods of transparent properties

5.1 Hemispherical transmittance factor with specular included

5.1.1 Purpose

The purpose of this method is to measure the transmitted light, including the specular component, through a transparent display.

NOTE This method was originally specified for transparent OLED displays.

5.1.2 Measuring conditions

For this measurement, the following conditions are applied.

a) Apparatus:

1) light measuring device that can measure luminance or spectral radiance;
2) driving power source;
3) driving signal equipment;
4) integrating sphere with ports and a stabilized light source (see Figure 3), which is as follows:

i) The light source in the integrating sphere has a smooth broadband spectrum approximating CIE standard illuminant D65 [4]. The integrating sphere has a photopic optical detector which monitors the relative luminance level m inside the sphere. The monitor is fitted with baffles to prevent light from the light source or the sample port from falling on it directly. The spectral characteristics of the light source are kept constant during measurements on a transparent display. The measurement conditions are such that the transparent display temperature does not increase while measurements are made.

ii) The integrating sphere may be of any diameter as long as the total port area does not exceed 4,0 % of the internal area of the sphere. It is recommended that the diameter of the integrating sphere be not less than 150 mm so that specimens of a reasonable size can be used. When the diameter of the integrating sphere is 150 mm and the diameters of the sample, compensation and light trap ports are 30 mm, the ratio of the total port area to the internal area of the sphere is 3,0 %. For specular included measurements, a port plug or diffuse white standard with similar reflectance to the inner wall can be used to fill the port. A sphere geometry may also be used instead of the configuration illustrated in Figure 3 (see IEC 62341-6-4:2017, Annex A). If the integrating sphere does not have a compensation port, and placing the display at the sample port significantly changes the spectral distribution of the light in the sphere, the alternate sphere method in IEC 62341-6-4:2017, Annex A shall be used. In addition, if it is necessary to measure the hemispherical transmittance factor with the display on, then the alternate sphere method is used.

iii) It is recommended to use a sample port with a diameter of between 30 mm to 75 mm. If a compensation port is used, the sample and compensation ports of the integrating sphere are circular and of the same size. The compensation port is positioned at an angle of less than 1,57 rad (90°) from the sample port. The sample port, compensation port and light trap port will not lie on the great circle of the sphere. The ports are designed in such a way that samples placed at the port lie at nearly the same surface as the inner sphere wall.

iv) The surfaces of the interior of the integrating sphere and the baffles are of substantially equal luminous reflectance which is 90 % or more and does not vary by more than ±3 %. The sphere wall reflectance can be determined relative to a known reflection standard using the method described in IEC 62341-6-4:2017, Annex A.

v) Using this instrument, the repeatability standard deviation is 0,2 % or less. The within-laboratory reproducibility over long time intervals does not exceed the repeatability by a factor of 3.

vi) The flat sample is held against the sample port so that the normal of the sample is within 2° of the normal of the sample port. The sphere interior provides uniform illumination on the screen, with the screen receiving a constant luminance over its hemispherical inclination angles. This criterion is often satisfied when the sphere's internal light source dominates the illuminance inside the sphere compared to any sample contribution.

vii) The LMD is aligned normal to the centre of the sample port at an approximate distance of 0,5 m. The measurement field is focused on the sample port plane.

b) Standard measuring environmental conditions:

1) darkroom conditions;

2) standard setup conditions.

5.1.3 Measuring method

The method is similar to ASTM D1003 [5], and analogous to ISO 13468-1 [6]. This method assumes that the transmission properties of the transparent display are not affected by the illumination level on the display.

NOTE This method also assumes that the transmission properties are invariant to the rendered colour on the display, and allows the transmission properties to be measured with the DUT in the maximum transparent state.

a) If the integrating sphere has a light trap port, place a port plug or diffuse white standard at the port. Turn on the integrating sphere light source and allow the light source and LMD to stabilize. The measurement configuration in Figure 3 is set up in a dark room, and ingress of external light into the integrating sphere is prevented.

b) If the integrating sphere has a compensation port, place the back side of the transparent display against that port.

c) Measure the luminance L_{ref} or spectral radiance at the sample port, and record the monitor detector value m_{ref}.

d) Place the back side of the transparent display against the sample port. If the integrating sphere has a compensation port, place a light trap at that port. Measure the transmitted luminance (or spectral radiance) at the sample port $L_{\mathrm{di/0}}$, and record the monitor detector value $m_{\mathrm{di/0}}$.

e) Calculate the luminous hemispherical transmittance factor with specular included $T_{\mathrm{di/0}}$ using Formula (1):

$$T_{\mathrm{di/0}} = \frac{L_{\mathrm{di/0}}}{L_{\mathrm{ref}}} \cdot \frac{m_{\mathrm{ref}}}{m_{\mathrm{di/0}}} \qquad (1)$$

f) Repeat the readings for L_{ref}, m_{ref}, $L_{\mathrm{di/0}}$, and $m_{\mathrm{di/0}}$, making additional readings with the specimen in positions selected to determine uniformity.

g) Carry out the procedure three times, and use the average of the three calculated results as the luminous hemispherical transmittance factor value.

h) All details are required to be recorded for identification of the test specimens and the source of the specimens (type of light source used, information of transparent display).

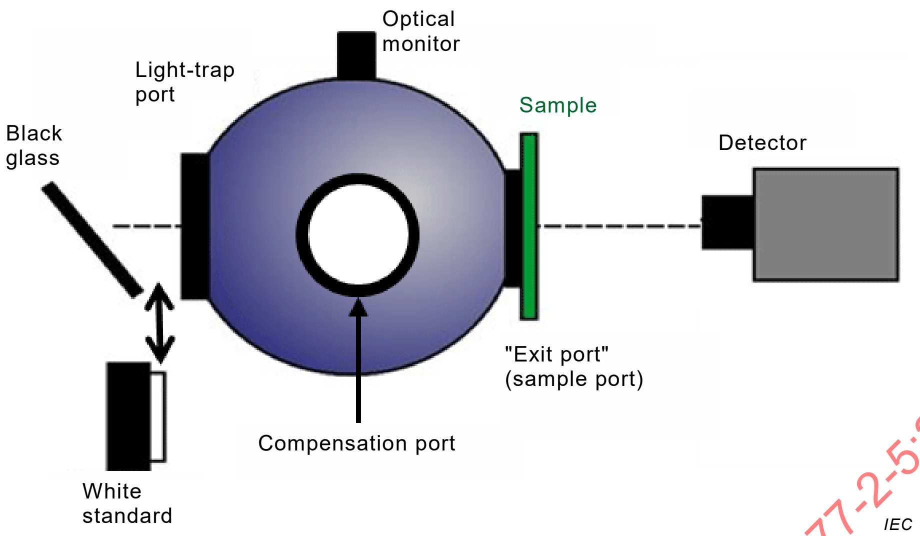


Figure 3 – Side view of measuring concept for the hemispherical transmittance factor measurement with specular included or excluded

5.2 Transmitted haze

5.2.1 General

Two different measuring methods are specified for transmitted haze. The measuring method for transmitted haze under hemispherical illumination is specified in 5.2.2. In addition, the measuring method for transmitted haze with directly incident light is specified in 5.2.3.

5.2.2 Transmitted haze under hemispherical illumination

5.2.2.1 Purpose

The purpose of this method is to measure the amount of haze transmitted to the viewer from a transparent display back-illuminated with hemispherical illumination.

NOTE This method was originally specified for transparent OLED displays.

5.2.2.2 Measuring conditions

For this measurement, the following conditions are applied.

a) Apparatus:

1) light measuring device that can measure luminance or spectral radiance;
2) driving power source;
3) driving signal equipment;
4) integrating sphere with ports and a stabilized light source (see Figure 3), which is as follows:

    i) The light source in the integrating sphere has a smooth broadband spectrum approximating CIE standard Illuminant D65 [4]. The integrating sphere has a photopic optical detector which monitors the relative luminance level m inside the sphere. The monitor is fitted with baffles to prevent light from the light source or the sample port from falling on it directly. The spectral characteristics of the light source are kept constant during measurements on a transparent display. The measurement conditions are such that the transparent display temperature does not increase while measurements are made.

ii) The total port area of the integrating sphere does not exceed 4,0 % of the internal area of the sphere. It is recommended that the diameter of the integrating sphere be not less than 150 mm so that specimens of a reasonable size can be used. When the diameter of the integrating sphere is 150 mm and the diameters of the sample, compensation and light trap ports are 30 mm, the ratio of the total port area to the internal area of the sphere is 3,0 %. If the integrating sphere does not have a compensation port, and placing the display at the sample port does not significantly change the spectral distribution of the light in the sphere, the monitor detector is used to compensate for change in the sphere illuminance due to the presence of the display at the sample port.

iii) The sample port and light trap port are centred on the same optical axis as the LMD. The diameter of the sphere z_s, and the light trap port diameter d_{LT} are sized such that the opening of the light trap port subtends θ_{LT} = 8° from the centre of the sample port. The LMD is positioned a distance z_{LMD} away from the sphere, producing a measurement field of diameter d_{mf} focused at the sample port, where $d_{mf} = z_d d_{pmf}/(z_{LMD} + z_s)$ and d_{pmf} is the projected measurement field diameter at the light trap port. The LMD and sphere are set up in such a way that the angular gap (annulus) $\xi = \theta_{LT}/2 - \arctan[d_{pmf}/(2\ z_s)]$ between the projected measurement field diameter d_{pmf} and the light trap port diameter gives ξ = 1,3°. When the above requirements are satisfied, the maximum angle ϕ that any measured light ray can have relative to the normal is less than 3°. Ensure that the LMD measurement field is contained within the image of the light trap port area.

A detailed illustration of the specular excluded and transmitted haze geometry is given in Figure 4.

b) Standard measuring environmental conditions:

1) darkroom conditions;

2) standard set-up conditions.

5.2.2.3 Measuring method

The method is similar to that of ASTM D1003 [5] and analogous to that of ISO 14782 [7].

This method assumes that the transmission properties of the transparent display are not affected by the illumination level on the display.

NOTE This method also assumes that the transmission properties are invariant to the rendered colour on the display, and allows the transmission properties to be measured with the DUT in the maximum transparent state.

a) Place a port plug or diffuse white standard at the light trap port. Turn on the integrating sphere light source and allow the light source and LMD to stabilize. The measurement configuration in Figure 3 is set up in a dark room, and ingress of external light into the integrating sphere is prevented.

b) If the integrating sphere has a compensation port, place the back side of the transparent display against that port.

c) Align the LMD normal to the sample port and focus the measurement field at the centre of the port. Measure the luminance L_1 at the centre of the sample port, and record the monitor detector value m_1.

d) Place the back side of the transparent display against the sample port. If the integrating sphere has a compensation port, place a light trap at that port.

e) Measure the transmitted luminance L_2 through the display at the centre of the sample port, and record the monitor detector value m_2.

f) Replace the port plug or diffuse white standard at the light trap port with a light trap. If the integrating sphere has a compensation port, place the port plug or the diffuse white standard at that port. Measure the transmitted luminance L_4 through the display at the centre of the sample port, and record the monitor detector value m_4.

g) Remove the transparent display from the sample port. Measure the luminance L_3 at the centre of the sample port, and record the monitor detector value m_3.

h) The luminous hemispherical transmittance factor with specular excluded $T_{\mathrm{Q,de/0}}$ is given as:

$$T_{\mathrm{Q,de/0}} = \frac{m_1}{L_1}\left[\frac{L_4}{m_4} - \frac{L_3 L_2 m_1}{L_1 m_3 m_2}\right] \quad (2)$$

where each variable is associated with the measurement configuration list in Table 2.

i) The percentage of luminous hemispherical transmitted haze $H_{\mathrm{de/0}}$ is determined by:

$$H_{\mathrm{de/0}} = 100\% \times \left[\frac{L_4 m_2}{L_2 m_4} - \frac{L_3 m_1}{L_1 m_3}\right] \quad (3)$$

Table 2 – Measuring conditions of the ports

Measured Luminance	Sample port	Light trap port	Compensation port
L_1		White reference	Display sample
L_2	Display sample	White reference	Light trap
L_3		Light trap	White reference
L_4	Display sample	Light trap	White reference

j) All details are required to be recorded for identification of the test specimens and the source of the specimens, such as type of light source used, information on transparent display.

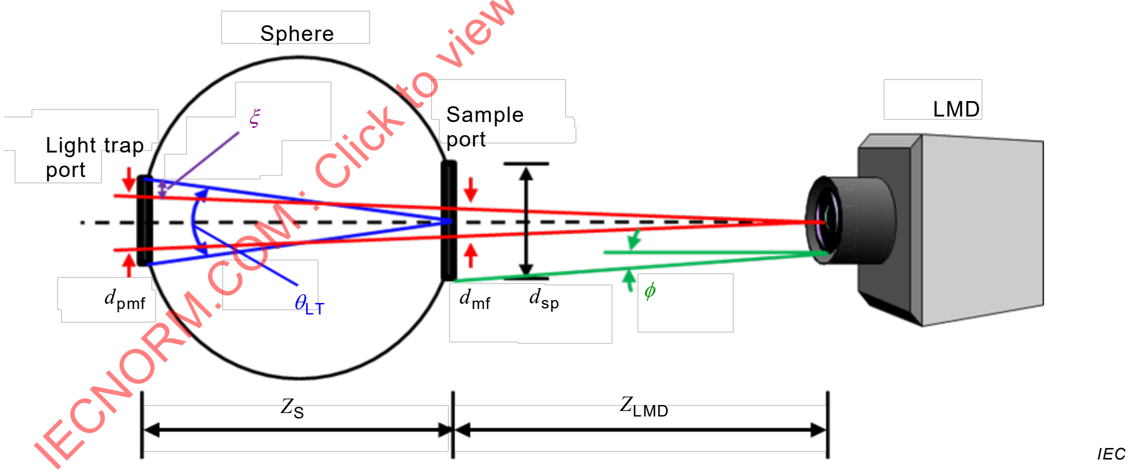


Figure 4 – Schematic arrangement of haze measurement

5.2.3 Transmitted haze with directly incident light

5.2.3.1 Purpose

The purpose of this method is to measure the transmitted haze with directly incident light for a transparent display module. This method is equivalent to that in 5.2.2 [5, 7].

NOTE This method was originally specified for transparent LCD displays.

5.2.3.2 Measuring conditions

For this measurement, the following conditions are applied.

a) Apparatus (see Figure 5):
   1) light measuring device that can measure luminance or spectral radiance;
   2) driving power source;
   3) driving signal equipment;
   4) integrating sphere with ports and a stabilized light source which is as follows:
      i) The light source and the photometer is used in conjunction with a filter to provide an output corresponding to the photopic standard luminous efficiency $V(\lambda)$ (as defined in IEC 60050-845 [8]). $V(\lambda)$ is identical to the colour-matching function $y(\lambda)$ specified in CIE S 014-1/E:2006 [9] under CIE standard illuminant D65 [4]. By measuring the spectral power distribution of the light source using the detector in advance, the measured spectral information is used to determine the equivalent result for a D65 light source. The output of the photodetector is proportional to the incident flux, to within 1 % of the incident flux, over the range used. The spectral and photometric characteristics of the light source and photometer are kept constant during measurements.
      ii) The light source and its associated optical system produce a parallel light beam, no ray of which makes an angle of more than 0,05 rad (3°) with the beam axis. This beam is not vignetted at either port of the integrating sphere.
      iii) The design of the instrument is such that the reading is zero in the absence of the light beam.
      iv) The integrating sphere used to collect the transmitted light may be of any diameter (but preferably no less than 150 mm in order to be able to accommodate large specimens), as long as the total port area does not exceed 3,0 % of the internal reflecting area of the sphere.
      v) The integrating sphere has an entrance port, an exit port, a compensation port and a photodetector port (see Figure 5). The entrance and exit ports are centred on the same great circle of the sphere, and there is an angle of (3,14 ± 0,03) rad (180° ± 2°) between the centres of the ports. The exit port subtends an angle of (0,140 ± 0,002) rad (8° ± 0,1°) at the centre of the entrance port. The exit and compensation ports have the same size. The entrance and compensation ports and the photodetector do not lie on the same great circle of the sphere. The compensation port is positioned at an angle of less than 1,57 rad (90°) from the entrance port. The compensation port is used to compensate for changes in the efficiency of the integrating sphere, which depends on the area of the inner surface, the number of ports and the way they are covered.
      vi) When the beam is unobstructed by a transparent display module, its cross-section at the exit port is approximately circular, sharply defined and concentric with the exit port, leaving round it an annulus which subtends an angle of (0,023 ± 0,002) rad (1,3° ± 0,1°) at the centre of the entrance port. It is important to verify whether the unobstructed-beam diameter and centring at the exit port are maintained, especially if the source aperture and focus are changed. The tolerance of ± 0,002 rad (± 0,1°) stated for the angle subtended by the annulus corresponds to an uncertainty of ± 0,6 % in a haze reading. This is relevant to the assessment of the precision of this test method.
      vii) The position of the photodetector on the integrating sphere is at an angle of (1,57 ± 0,26) rad (90° ± 15°) to the entrance port. The photodetector is fitted with baffles to prevent light from the specimen falling directly on it. Light traps is provided for the exit and compensation ports to absorb the beam completely when no specimen is present, or the instrument design obviates the need for light traps for the exit and compensation ports.

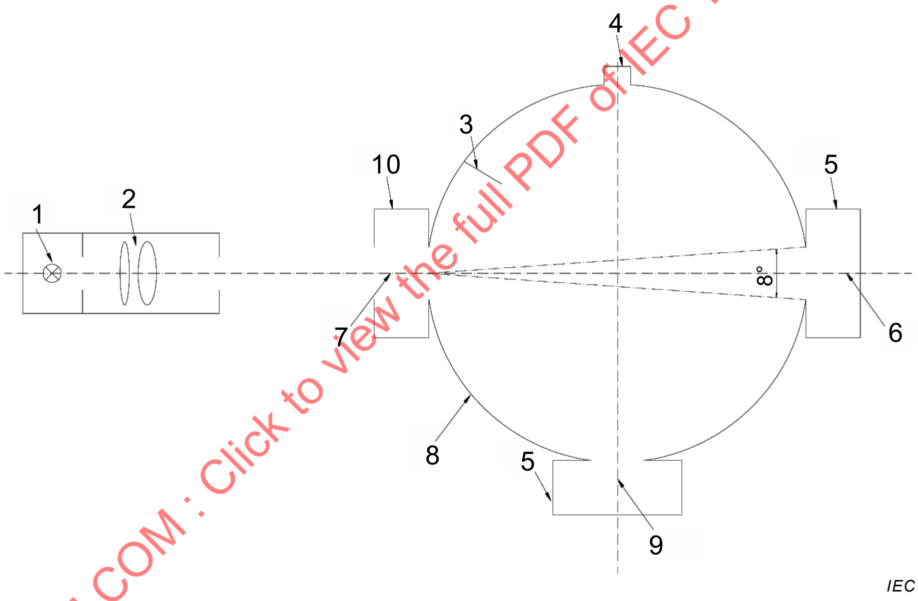
viii) The tristimulus value Y of the surfaces of the interior of the integrating sphere, the baffles and the white reference (a working reference normally provided by the instrument manufacturer) is 90 % or more and does not vary by more than ± 3 %. When direct measurement of the reflectance of the inner surface of the integrating sphere is difficult, the measurement may be made on a surface prepared from the same material in the same condition as the inner surface.

ix) The specimen holder is designed to hold the transparent display module rigidly in a plane perpendicular, to within ± 2°, to the light beam and as close as possible to the integrating sphere in order to ensure that all the light passing through the specimen, including scattered light, is collected. The holder is also designed so that flexible specimens such as film are kept flat. It is recommended that thin, flexible film be held round the edge in a double-ring clamp or stuck to the holder by means of double-sided adhesive tape. Double-sided adhesive tape can also be used for thicker specimens which does not fit in the double-ring clamp. The use of a vacuum pump and a vacuum plate to mount the specimen on the holder is also recommended.

b) Standard measuring environmental conditions:

1) darkroom conditions;

2) standard set-up conditions.



1	Lamp	6	Exit port
2	Lens	7	Entrance port
3	Baffle	8	Integrating sphere
4	Photo detector	9	Compensation port
5	Light trap	0	Specimen holder

Figure 5 – Schematic arrangement of the apparatus (TOP view)

5.2.3.3 Measuring method

For this measurement, the following method is applied.

a) Allow the apparatus sufficient time to reach thermal equilibrium before the measurements are made.

b) Mount a transparent display module in the sample holder.

c) Make the four measurements given in Table 3 at special points Pi in Figure 1 (where i is 0 to 4 or 0 to 8). Either 5 or 9 measurement points are used. For 5 points, use P_0 to P_4. For 9 points, use P_0 to P_8.

d) Carry out the procedure three times.

e) Calculate the haze, in percent, using the following Formula (4):

$$haze = \left(\frac{\tau_4}{\tau_2} - \frac{\tau_3}{\tau_1} \right) \times 100\ \% \tag{4}$$

where

τ_1 is the intensity of the incident light;

τ_2 is the intensity of all the light transmitted by the specimen;

τ_3 is the intensity of the light scattered by the instrument;

τ_4 is the intensity of the light scattered by the instrument and the specimen.

f) The following information is noted in the measurement report:

1) all details necessary for complete identification of the material or product tested;
2) the average thickness of a transparent display module;
3) the haze value, i.e. the average of the results for a transparent display module;
4) the type of light source used;
5) details of any incident likely to have affected the results;
6) the date of the test.

Table 3 – Measurements

	Entrance port	Exit port	Compensation port
τ_1		White reference	Light trap
τ_2	Transparent display module	White reference	Light trap
τ_3		Light trap	White reference
τ_4	Transparent display module	Light trap	White reference

5.3 Directional transmittance factor

5.3.1 Purpose

The purpose of this method is to measure the transmittance factor of a transparent display that is back-illuminated with a directional light source.

NOTE This method was originally specified for transparent OLED displays.

5.3.2 Measuring conditions

For this measurement, the following conditions are applied.

a) Apparatus:

1) light measuring device that can measure luminance or spectral radiance;
2) driving power source;
3) driving signal equipment;
4) white reflectance standard;
5) ring light with a stabilized light source, which is as follows:

i) Directional illumination is simulated by a ring light (Figure 6) centred about the display normal. A fibre optic ring light designed for a working distance that approximates 45° light inclination at the centre of the measurement position is recommended. The illumination within the measuring field area on the display is uniform. The uniformity is less than or equal to 5 %.

ii) For the ring light, the source has an emitter angular subtense of approximately 0,5°. The ring light emitting plane is co-planar with the display surface and centred about the measurement area. The central clear aperture of the ring light is at least 30 % larger than the effective aperture of the LMD lens.

iii) The ring light source has a smooth broadband spectrum approximating CIE standard illuminant D65 [4]. The spectral characteristics of the light source are kept constant during measurements on a transparent display. The measurement conditions are such that the transparent display temperature does not increase while measurements are made.

b) Standard measuring environmental conditions:

1) darkroom conditions;

2) Standard setup conditions.

5.3.3 Measuring method

The method is similar to the method specified in [10]. For this measurement, the following method is applied.

NOTE 1 This method assumes that the scatter properties of the transparent display are independent of the illumination level on the display.

NOTE 2 It is noted that it is not uncommon for the transmission properties to be largely invariant with the rendered colour.

NOTE 3 If it can be demonstrated that the transmission properties are largely invariant with the rendered colour, then they can be measured with the DUT in the maximum transparent state.

a) Place a white reflectance standard at the sample plane used for the display measurements. Unless the viewing distance is specified, position the LMD approximately 0,5 m from the sample plane and align the optical axis of the LMD centred and normal to the reflectance standard surface. Place the ring light facing the reflectance standard, centred on the optical axis, and positioned at a distance such that its light is incident at a 45° inclination angle to the centre of the measurement field.

b) Allow the ring light source to stabilize. Ensure that the LMD measurement field is centred within the uniform illumination of the ring light illumination on the reflectance standard. Measure the luminance L_{std} or spectral radiance $L_{\mathrm{std}}(\lambda)$ of the light reflected from the reflectance standard.

c) Calculate the illuminance E_{dir} (or spectral irradiance $E_{\mathrm{dir}}(\lambda)$) of the ring light at the sample plane using the known luminous reflectance factor R_{std} (or spectral reflectance factor $R_{\mathrm{std}}(\lambda)$) of the white standard for the same illumination/detector configuration:

$$E_{\mathrm{dir}} = \frac{\pi L_{\mathrm{std}}}{R_{\mathrm{std}}} \tag{5}$$

The calculation of the spectral irradiance has the same form.

d) Replace the reflectance standard with the transparent display positioned at the same sample plane, with the back surface of the display normal to the LMD optical axis. The desired measurement location on the display is centred about the measurement field of the LMD.

e) Move the LMD to the front of the transparent display, maintaining the same measurement distance, and align the LMD to the same optical axis and measurement field position as in the last measurement. A test pattern may be used to position the measurement field to the same location.

f) With the display rendering the desired colour Q, measure the luminance $L_{\mathrm{T},45/0}$ or spectral radiance $L_{\mathrm{T},45/0}(\lambda)$ of the transmitted light through the display

g) Turn off the ring light source and measure the darkroom emission from the display L_{em}.

h) The luminous directional transmittance factor $T_{45/0}$ for the 45° back illumination/normal detection configuration is given as:

$$T_{45/0} = \pi \frac{\left(L_{\mathrm{T},45/0} - L_{\mathrm{em}}\right)}{E_{\mathrm{dir}}} \tag{6}$$

The expression for the spectral directional transmittance factor $T_{45/0}(\lambda)$ has the same form.

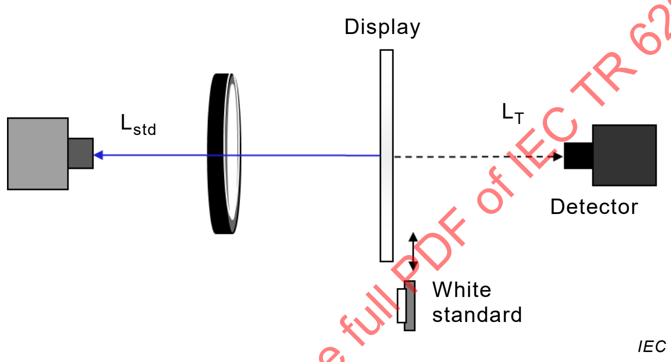


Figure 6 – Side view of measuring concept for the hemispherical transmittance factor measurement with specular included or excluded

5.4 Degree of clear distinction of see-through objects

5.4.1 General

Three different measuring methods are specified to measure the degree of clear distinction of objects when they are seen through a transparent display panel. The measuring method based on the ratio of luminance which is measured in a 0,2° region to luminance of total transmitted light in a transparent display panel is specified in 5.4.2. The measuring method based on the blur distance defined for a reference object is specified in 5.4.3. In addition, the measuring method based on the modulation transfer function is specified in 5.4.4.

5.4.2 Purity

5.4.2.1 Purpose

The purpose of this method is to measure the degree of distinct edges of objects when they are seen through a transparent display panel. It is measured based on the ratio of luminance which is measured in a 0,2° region to luminance of total transmitted light in a transparent display panel.

NOTE This method was originally specified for transparent OLED displays.

5.4.2.2 Measuring conditions

For this measurement, the following conditions are applied.

a) Apparatus:

1) light measuring device (LMD) that can measure luminance;
2) reference display device to display the test pattern behind the transparent display;
3) driving power source;
4) driving signal equipment.

b) Standard measuring environmental conditions:
1) darkroom conditions;
2) standard setup conditions.

5.4.2.3 Measuring method

For this measurement, the following method is applied.

a) Set a reference display device to display the test pattern (Figure 7 (a)) and allow the apparatus sufficient time to reach thermal equilibrium before making any measurements.
b) Measure the luminance of all the test patterns at the centre of the screen using an LMD having a measurement field of 0,2°.
c) When measuring matrix displays, the light measuring devices are set to a measurement field that includes more than 500 pixels. If smaller measurement areas are necessary, equivalence to 500 pixels is confirmed.
d) The angular aperture is less than or equal to 5°, and measurement field angle is less than or equal to 0,2°.
e) Calculate the purity reference value using Formula (7), and check the validity of the measurement using Formula (8). Unless Formula (8) is satisfied, adjust the alignment of setup and repeat the measurement. The 2 % in Formula (8) is the maximum luminance accuracy fluctuation of the LMD.

$$P_{\mathrm{ref}} = \frac{L_{\mathrm{CW,ref}} - L_{\mathrm{FK,ref}}}{L_{\mathrm{FW,ref}} - L_{\mathrm{FK,ref}}} \tag{7}$$

$$\frac{\left\| L_{\mathrm{FW,ref}} - L_{\mathrm{CW,ref}} \right| - \left| L_{\mathrm{FK,ref}} - L_{\mathrm{CK,ref}} \right\|}{\left| L_{\mathrm{FW,ref}} - L_{\mathrm{CW,ref}} \right|} \times 100 \leq 2\ \% \tag{8}$$

where

P_{ref} is the ratio of the luminance range with full screen patterns to the pattern of 0,2° measurement field restriction;

$L_{\mathrm{CW,ref}}$ is the reference luminance of the white 0,2° circle,

$L_{\mathrm{FK,ref}}$ is the reference luminance for the full black screen,

$L_{\mathrm{FW,ref}}$ is the reference luminance for the full white screen,

$L_{\mathrm{CK,ref}}$ is the reference luminance of the black 0,2° circle.

f) The transparent display is mounted between the measuring instrument and the reference display device, and display except the circle specified in Figure 7 (b) is covered so that light from reference display pass through the circle only (see Figure 7 (b)).
g) With the test pattern on the display fixed, measure the luminance of all the reference display test patterns in Figure 8 through the transparent display using an LMD having a measurement field of 0,2°. The LMD is still focused on the reference display.
h) Calculate the sample value using Formula (9), and check the validity of the measurement using Formula (10). Unless Formula (10) is satisfied, adjust the alignment of setup and repeat the measurement.

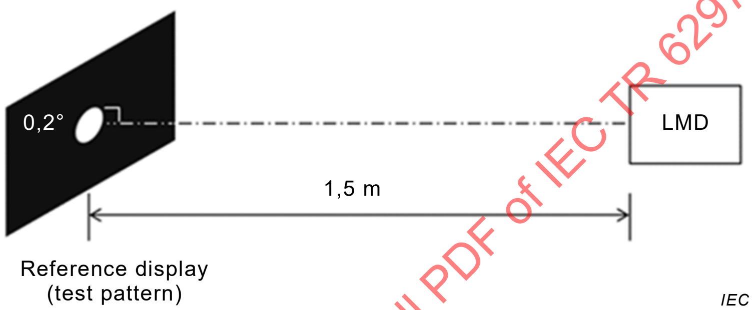
$$P_{\text{sample}} = \frac{L_{\text{CW,sample}} - L_{\text{FK,sample}}}{L_{\text{FW,sample}} - L_{\text{FK,sample}}} \tag{9}$$

$$\frac{\left\| L_{\text{FW,sample}} - L_{\text{CW,sample}} \right| - \left| L_{\text{FK,sample}} - L_{\text{CK,sample}} \right\|}{\left| L_{\text{FW,sample}} - L_{\text{CW,sample}} \right|} \times 100 \leq 2\ \% \tag{10}$$

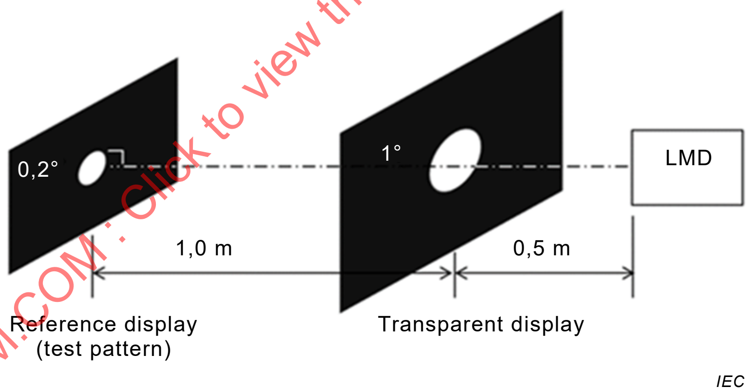
i) Calculate the purity of the transparent display using Formula (11):

$$P_{\text{ur}} = \frac{P_{\text{sample}}}{P_{\text{ref}}} \times 100 \tag{11}$$

j) Report the results of measurements as shown in the examples in Table 4.

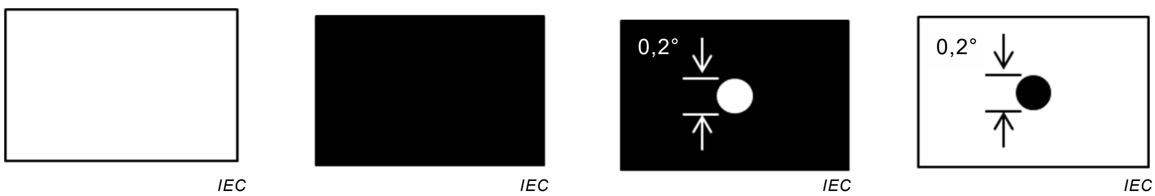


a) Configuration for direct test pattern measurement



b) Configuration for test pattern measurement through transparent display

Figure 7 – Measuring configuration for purity measurement



(a) Full white test pattern **(b) Full black test pattern** **(c) Circle of white (CW) test pattern** **(d) Circle of black (CK) test pattern**

Figure 8 – Test patterns for purity measurement

Table 4 – Measured example for purity

	L_{FW}	L_{FK}	L_{CW}	L_{CK}	*Validity*	P_{ur}
	cd/m^2					
Reference	49,50	0,14	48,99	-	-	99 %
Sample	20,03	0,06	16,46	3,65	0,64 %	82 %
Purity						83 %

5.4.3 Clarity (measurement method using a stripe pattern with a rigid width.)

5.4.3.1 Purpose

The purpose of this method is to measure the clarity using a stripe pattern with a rigid width.

NOTE This method was originally specified for transparent LCD displays.

5.4.3.2 Measuring conditions

For this measurement, the following conditions are applied.

a) Apparatus (see Figure 9):

1) The apparatus consists of a standard light source, an integrating sphere with two ports, a two-dimensional LMD such as a CCD image colorimeter, reference object, a driving power supply and a driving signal generator which is used to light the transparent display modules (see Figure 9). The position of the integrating sphere and measuring device remain unchanged during the test.

NOTE A two-dimensional LMD can measure the map of luminance over the measurement area of the screen. The specification of the LMD used is noted in the report as in the example shown in Table 5.

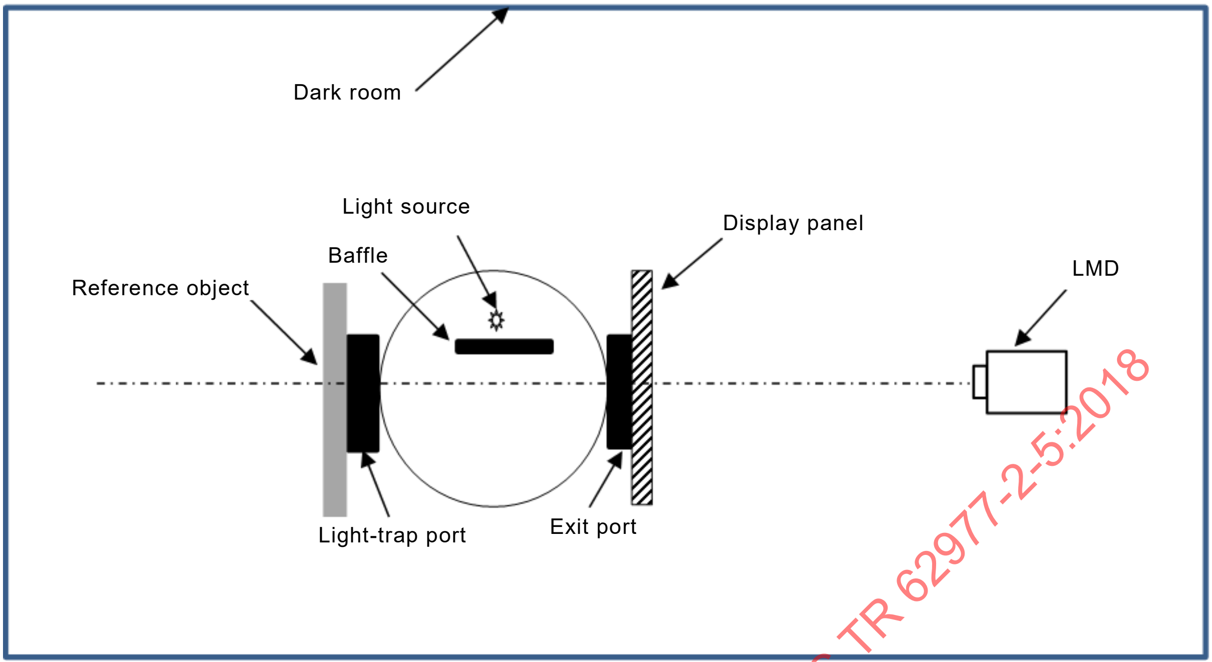
Table 5 – Example of reported specification of two dimensional LMD

CCD resolution	4 096 × 2 048	
CCD A/D dynamic range	More than 12 bits = 4 096 grey scale levels	
Wavelength range	380 nm to 780 nm	
System accuracy	Luminance stability	± 3 %

2) The reference object used in this test is in the shape of black and white stripes. The direction of the stripes is different according to different pixel structure, Figure 10 shows an example. The stripe width D is chosen from the list given below according to the size and application of the transparent display modules.

5 mm, 10 mm, 15 mm, 20 mm, etc.

3) The distance between light measuring device and the transparent display modules is consistent during the test, for example set as 50 cm, keep the reference object on the light trap port and the transparent display modules on the exit port in the test.



Keep the illumination of reference object surface constant during test (e.g. 2 000 lx ± 5 %).

NOTE The spectrum of the light source can have a significant impact on the results of the measurement. The spectral power distribution of the light source is measured by the detector and used to determine the equivalent result for a D65 light source.

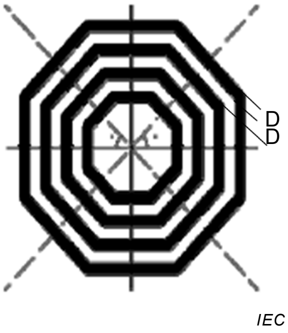
Figure 9 – Measuring system and its configuration

b) Standard measuring environmental conditions:
   1) darkroom conditions;
   2) standard setup conditions.

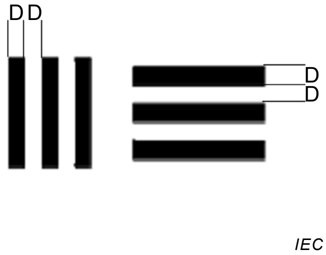
5.4.3.3 Measuring method

For this measurement, the following method is applied.

a) Allow the apparatus sufficient time to reach thermal equilibrium before the measurements are made.
b) Mount the reference object on the light-trap port, measure the luminance of the reference object when there is no transparent display module. Get a luminance curve of the reference object.
c) Mount a transparent display module on the exit port and apply a white signal level of 100 % over the entire screen.
d) Measure the luminance of the reference object through the transparent display module. Get another luminance curve of the reference object.
e) Compare the two brightness curves of the reference object.



(a) Configuration a



(b) Configuration b

Figure 10 – Example reference object and its configuration

f) Theoretically, the luminance curve of reference object is square wave and changes into sinusoidal wave through the transparent display module (see Figure 11).

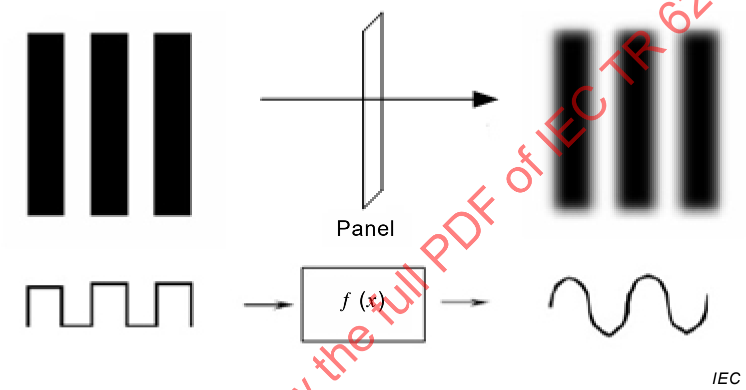


Figure 11 – Luminance curve of reference object

g) Calculate K and clarity using the following Formulae (12) and (13):

$$K = \left(\frac{\sum_{i=1}^{n} DP_{\mathrm{i}}}{2n} \right) \times \frac{1}{D} \tag{12}$$

$$Clarity = \frac{\sum_{i=1}^{n} \left(\frac{DW_{\mathrm{i}}}{K} + \frac{DB_{\mathrm{i}}}{K} \right)}{2n} \times \frac{1}{D} \times 100(\%) \tag{13}$$

where

n is the number of pairs in black and white stripe;

D is the original width of a single black or white stripe without transparent display module;

DW_{i} is the measured width of white stripes with transparent display module; which is measured at the point where the brightness is 90 % of 100 % grey-scale;

DB_{i} is the measured width of black stripes with transparent display module; which is measured at the point where the brightness is 10 % of 100 % grey-scale;

DP_{i} is the measured width of black and white stripes without transparent display module;

K is the affect factor of luminance meter.

Figure 12 shows the definition of above parameters.

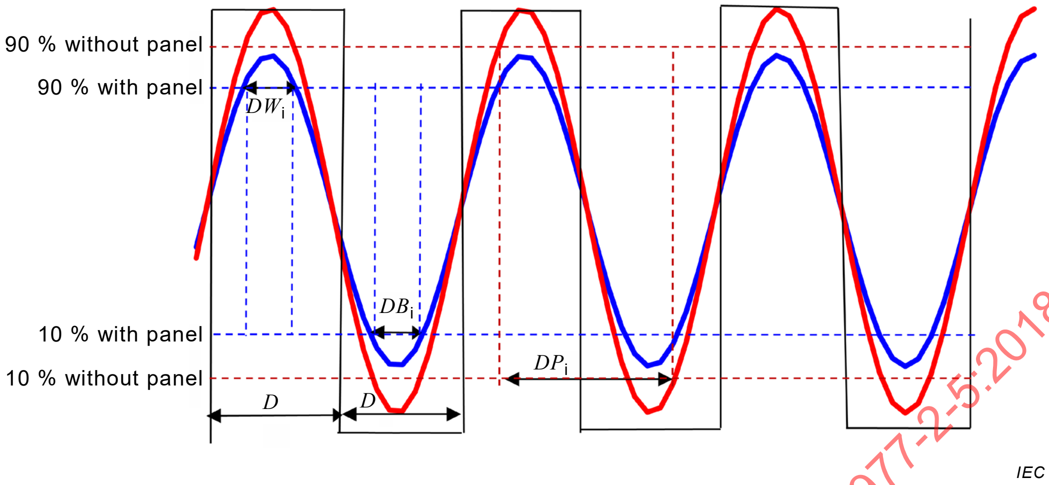


Figure 12 – Definition of test parameters

h) The following information is noted in the measurement report:
   1) the type of light source used;
   2) the size and detail information of a transparent display module;
   3) measuring distance between reference object and display modules under test;
   4) the stripe width of reference object;
   5) the clarity value of a transparent display module;
   6) detail of any incident likely to have influence to the results.(e.g. the illumination of reference object surface);
   7) the date of the test.

5.4.4 Clarity (Measuring method using a stripe pattern with gradually changed width)

5.4.4.1 Purpose

The purpose of this method is to measure the degree of clear distinction of objects when they are seen through a transparent display panel. In addition, this method can be utilized to measure the matrix diffraction of the transparent display panel.

NOTE This method was originally specified for transparent LCD displays.

5.4.4.2 Measuring conditions

The measuring conditions specified in 5.4.3.2 are adopted in this method.

5.4.4.3 Measuring method

For this measurement, the following method is applied.

a) The reference object used in this test is in the shape of black and white stripes with gradually changed width. The relationship between strip width D and spatial frequency V is shown in Formula (14). The stripe width should be chosen based on what level of detail needs to be viewed on the object; Figure 13 shows an example.

$$D = \frac{1}{2V} \tag{14}$$

Figure 13 – Reference object and its configuration

b) Allow the apparatus sufficient time to reach thermal equilibrium before the measurements are made

c) Measure the luminance profile of the reference object when there is no transparent display module

d) Mount a transparent display module on the exit port and apply a white signal level of 100 % over the entire screen

e) The distance between light measuring device and the transparent display modules will be consistent during the test, for example set as 50 cm, keep the reference object on the light trap pot and the transparent display modules on the exit port during the test

f) Measure the luminance profile of the reference object through transparent display module.

g) Calculate the Michelson contrast ratio using the following formulae:

$$M(n) = \frac{L_{\text{max}}(n) - L_{\text{min}}(n)}{L_{\text{max}}(n) + L_{\text{min}}(n)} \tag{15}$$

$$M(n)' = \frac{L'_{\text{max}}(n) - L'_{\text{min}}(n)}{L'_{\text{max}}(n) + L'_{\text{min}}(n)} \tag{16}$$

$$MTF = \frac{M(n)'}{M(n)} \text{ Michelson contrast ratio} = M(n)'/M(n) \tag{17}$$

where:

$L_{\text{max}}(n)$ the maximum luminance of the n^{th} black and white stripe measured without transparent display module;

$L_{\text{min}}(n)$ the minimum luminance of the n^{th} black and white stripe measured without transparent display module;

$M(n)$ the modulation contrast of the n^{th} black and white stripe measured without transparent display module;

$L'_{\text{max}}(n)$ the maximum luminance of the n^{th} black and white stripe measured through a transparent display module;

$L'_{\text{min}}(n)$ the minimum luminance of the n^{th} black and white stripe measured through a transparent display module;

$M'(n)$ the modulation contrast of the n^{th} black and white stripe measured through a transparent display module.

h) The value of Michelson contrast ratio varies when the width of black and white stripes gradually changes. The number of black and white stripe pairs is defined within a unit length as stripe frequency, the higher the stripe frequency, the smaller the Michelson contrast ratio. Figure 14 shows an example of the relationship between stripe frequency and Michelson contrast ratio.

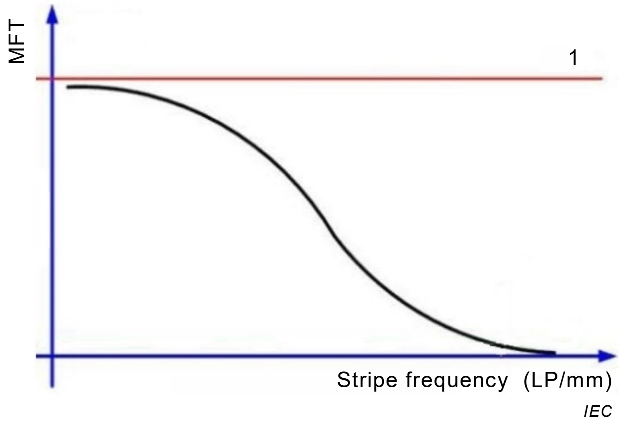


Figure 14 – The relationship between stripe frequency and Michelson contrast ratio

i) The following information is noted in the measurement report:
   1) the measurement result and calculated data;
   2) the size and detail information of a transparent display module;
   3) measuring distance between LMD and display modules under test;
   4) detail of any incident likely to have influence to the results. (e.g. the illumination of reference object surface);
   5) the date of the test.

5.5 Colour variation caused by a transparent display

5.5.1 Purpose

The purpose of this method is to measure the colour variation caused by a transparent display.

NOTE This method was originally specified for transparent OLED displays.

5.5.2 Measuring conditions

For this measurement, apply the following conditions.

a) Apparatus:
   1) spectroradiometer or equivalent light measuring device that can measure chromaticity of transparent display device;
   2) light source which closely approximates the CIE Standard Illuminant A, or a reference display device to display the test pattern behind the transparent display.

   NOTE This reference display can be used for evaluation of colour variation; driving power source; and driving signal equipment.

b) Standard measuring environmental conditions:
   1) darkroom condition;
   2) standard setup conditions.

5.5.3 Measuring method

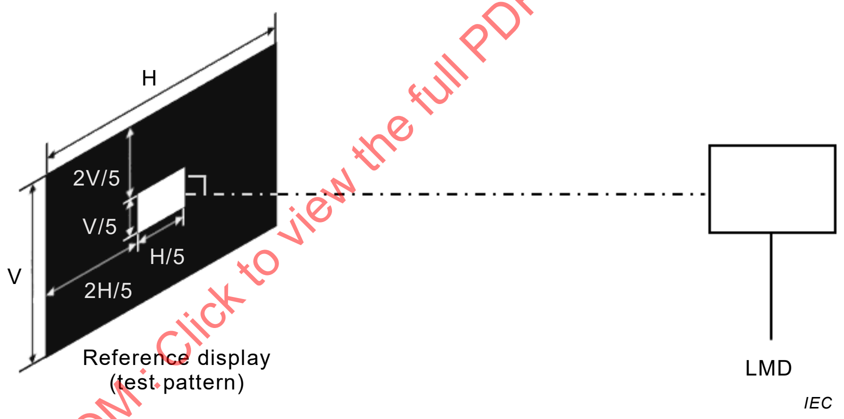
For this measurement, the following method is applied.

1) Set a light source which closely approximates the CIE Standard Illuminant A or reference display device. If light source which closely approximates the CIE Standard Illuminant A is chosen as light source, measure the CIE 1931 chromaticity coordinates (x, y) of the illuminant and proceed from 10) on.
2) Turn on the full screen white and 4 % window sized signal at a 100 % grey level.

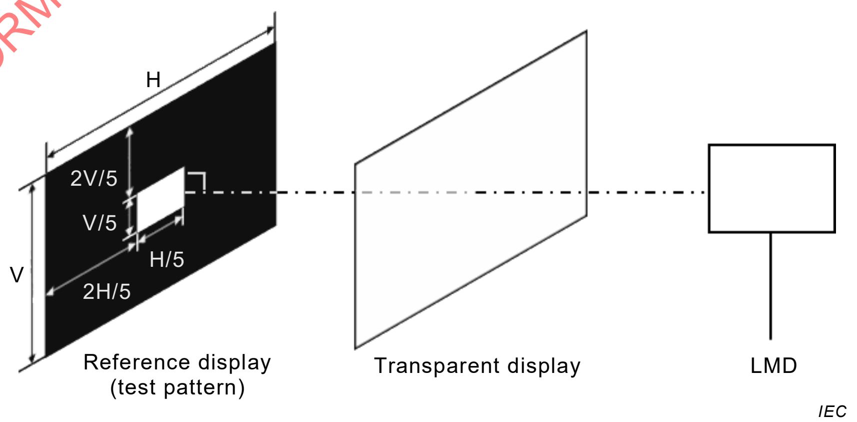
3) Measure the CIE 1931 chromaticity coordinates W(x, y) at the centre of the screen of the reference display (see Figure 15(a)).
4) Turn on the full screen red and 4 % window sized red signal.
5) Measure the CIE 1931 chromaticity coordinates R(x, y) at the centre of the screen of the reference display.
6) Turn on the full screen green and 4 % window sized green signal.
7) Measure the CIE 1931 chromaticity coordinates G(x, y) at the centre of the screen of the reference display.
8) Turn on the full screen blue and 4 % window sized blue signal.
9) Measure the CIE 1931 chromaticity coordinates B(x, y) at the centre of the screen of the reference display.
10) Calculate u', and v' from the measured x, y values using Formula (18).

$$u' = \frac{4x}{3-2x+12y} \,, \quad v' = \frac{9y}{3-2x+12y} \tag{18}$$

11) Set the transparent display in the designated place between the reference display and the measuring instrument. The transparent display is in the maximum transparent state (see Figure 15(b)).
12) Measure the chromaticity values for white, red, green, and blue colour pattern on the same location with the transparent display.



a) **Configuration for direct test pattern measurement**



b) **Configuration for test pattern measurement through transparent display**

Figure 15 – Measuring configuration

13) Calculate the colour variation with and without the transparent display for white and primary colours. Formula (19) is used for this calculation.

$$\Delta u'v' = \sqrt{\left(u_i' - u_j'\right)^2 + \left(v_i' - v_j'\right)^2} \qquad (19)$$

14) Report the values for the colour difference for each test pattern (white, red, green, and blue). Table 6 shows the example of the results.

15) Report the type of illuminant (the reference display device or light source approximating the CIE Standard Illuminant A). When the reference display device is utilized, its spectrums are reported in the test report.

16) Various colours can be selected and measured for this measurement method, such as the Munsell[2] colour reference.

Table 6 – Working example for colour variation index

Colour variation index		**Test pattern**			
		White	**Red**	**Green**	**Blue**
Without transparent display	u'	0,187 2	0,458 5	0,122 6	0,179 7
	v'	0,437 9	0,524 6	0,567 1	0,148 9
With transparent display	u'	0,190 2	0,460 0	0,124 3	0,177 2
	v'	0,454 1	0,524 3	0,562 3	0,154 8
Colour variation	$\Delta u'v'$	0,016 5	0,001 5	0,005 1	0,006 4

6 Measuring methods of on-screen properties

6.1 Ambient contrast ratio

6.1.1 Purpose

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

NOTE 1 This method was originally specified for transparent OLED displays.

NOTE 2 If the transparent display exhibits significant photo-luminescence, then the on-screen ambient contrast ratio calculation is only valid for the same illumination spectra and geometry used to measure the transmission and reflection coefficients.

6.1.2 Measuring conditions

For this measurement, the following conditions are applied:

a) Apparatus:

   1) light measuring device that can measure luminance or spectral radiance;
   2) driving power source;
   3) driving signal equipment;
   4) directional light source;
   5) integrating sphere or sampling sphere with a stabilized light source.

b) Illuminance condition:

2 The Munsell colour system is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

1) the standard ambient illumination conditions for an indoor room or clear sky daylight is used, as specified in Clause 4;
2) additional illumination conditions may also be used, depending on the application.

c) Standard measuring environmental conditions:
1) darkroom conditions;
2) standard setup conditions.

6.1.3 Measuring method

The method is similar to the method specified in [10]. For this measurement, the following method is applied:

NOTE 1 The ambient contrast ratio is determined from the transmission and reflection measurements of the display under hemispherical diffuse and directed source illumination conditions.

NOTE 2 The resulting transmission and reflection coefficients are used to calculate the combined (emitted, transmitted, and reflected) luminance of a display with a black screen and white screen at the required illuminance levels.

NOTE 3 The ambient contrast ratio is the ratio of the combined white screen luminance to the combined black screen luminance.

1) Measure the black luminance L_{min} at the centre and perpendicular to the display at a 0 % grey level for a full black screen.
2) Set the test input signal to the display to generate a 100 % grey level over the full screen or 4 % window located in the centre of the display, depending on the intended application.
3) Measure the white luminance L_{max} at the centre and perpendicular to the white display pattern under dark room conditions.
4) Calculate the ambient contrast ratio as specified for the intended application using the following formula:

$$ACR_{\text{j}} = \frac{L_{\text{max}} + L_{\text{max,amb}}}{L_{\text{min}} + L_{\text{min,amb}}} \tag{20}$$

and

$$L_{Q,\text{amb}} = \frac{\rho_{Q,\text{di/0}} \times E_{\text{F,hemi}}}{\pi} + \frac{\rho_{Q,45/0} \times E_{\text{F,dir}} \times \cos\theta_{\text{F,s}}}{\pi} + \frac{T_{Q,\text{di/0}} \times E_{\text{B,hemi}}}{\pi} + \frac{T_{Q,45/0} \times E_{\text{B,dir}} \times \cos\theta_{\text{B,s}}}{\pi} \tag{21}$$

where

Q	is the measured values with the display in the white state (maximum) or black state (minimum),
$\rho_{Q,\text{di/0}}$	is the front reflectance for uniform hemispherical illumination with specular included,
$E_{\text{F,hemi}}$	is the front illuminance for uniform hemispherical illumination of the spectral source to be evaluated,
$\rho_{Q,45/0}$	is the front spectral reflectance factor for a directional light source at an inclination angle $\theta_{\text{F,s}} = 45°$,
$E_{\text{F,dir}}\cos\theta_{\text{F,s}}$	is the front illuminance at an inclination angle $\theta_{\text{F,s}}$ for the directional source to be evaluated,
$T_{Q,\text{di/0}}$	is the transmittance factor for uniform hemispherical illumination on the back of screen,
$E_{\text{B,hemi}}$	is the back illuminance for uniform hemispherical illumination of the spectral source to be evaluated,

$T_{Q,45/0}$ is the transmittance factor for a directional light source at an inclination angle $\theta_{B,s}$ = 45° on the back of the screen, and

$E_{B,dir}\cos\theta_{B,s}$ is the back illuminance at an inclination angle $\theta_{B,s}$ for the directional source to be evaluated.

5) If the reflection and transmission coefficients of the transparent display are not dependent on the rendered colour, then $L_{max,amb} = L_{min,amb}$. The spectral radiance version of Formula (20) has the same form.

6) The actual values to be used to calculate the ambient contrast ratio are specified based on the intended application. Recommended values are given in Table 1.

7) All values used to calculate the ambient contrast ratio are recorded in the test report.

6.2 Display ambient colour measurement

6.2.1 Purpose

The purpose of this method is to determine the on-screen ambient colour of a transparent display module under defined indoor or daylight illumination conditions.

NOTE 1 This method was originally specified for transparent OLED displays.

NOTE 2 If the transparent display exhibits significant photo-luminescence, then the ambient contrast ratio calculation is only valid for the same illumination spectra and geometry used to measure the transmission and reflection coefficients.

6.2.2 Measuring conditions

For this measurement, the following conditions are applied.

a) Apparatus:
   1) spectroradiometer that can measure spectral radiance;
   2) driving power source;
   3) driving signal equipment;
   4) directional light source;
   5) integrating sphere or sampling sphere with a stabilized light source.
b) Illuminance condition:
   1) standard ambient illumination conditions for an indoor room or clear sky daylight is used, as specified in Clause 4.
   2) additional illumination conditions may also be used, depending on the application.
c) Except for the standard ambient illumination conditions, all other conditions are the standard conditions.

6.2.3 Measuring method

6.2.3.1 General

For this measurement, the following method is applied. The chromaticity of a display under hemispherical diffuse and directional illumination conditions is a combination of the display's intrinsic light emission, transmitted and reflected ambient light.

- The ambient chromaticity of a display at a given colour state Q (e.g. white, black, red, green, or blue screen) under illumination conditions is determined by its equivalent display ambient tristimulus values.
- These values can be obtained from darkroom measurements at the desired colour state, combined with transmission and reflection measurements of the display under hemispherical diffuse and directional source illumination conditions at that colour.
- The measuring methods used to characterize the transmission and reflection coefficients for the display under hemispherical and directional illumination are specified in [10].

6.2.3.2 Measurement and calculations

For this measurement, the following measurement and calculations are applied.

a) The total ambient spectral radiance $L_{Q,\text{tot}}(\lambda)$ with transmission and reflection contributions included is:

$$L_{Q,\text{tot}}(\lambda) = L_Q(\lambda) + L_{Q,\text{amb}}(\lambda) \tag{22}$$

where

$L_Q(\lambda)$ is the darkroom spectral radiance of the transparent display measured at the centre and perpendicular to the display for the desired colour state Q,

$L_{Q,\text{amb}}(\lambda)$ is defined in Formula (21).

b) The actual values to be used to calculate the total ambient spectral radiance for a given rendered display colour are specified based on the intended application. Recommend values are given in Table 1.

c) All values used to calculate the total ambient spectral radiance are recorded in the test report.

d) The effective display daylight tristimulus values of the display under these illumination conditions are:

$$X_{Q,\text{tot}} = 683\int_{\lambda} L_{Q,\text{tot}}(\lambda)\bar{x}(\lambda)d\lambda \tag{23}$$

$$Y_{Q,\text{tot}} = 683\int_{\lambda} L_{Q,\text{tot}}(\lambda)\bar{y}(\lambda)d\lambda \tag{24}$$

$$Z_{Q,\text{tot}} = 683\int_{\lambda} L_{Q,\text{tot}}(\lambda)\bar{z}(\lambda)d\lambda \tag{25}$$

where

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ are the colour matching functions (see CIE 15-2004 [4]).

e) The ambient 1931 CIE x and y and 1976 CIE u' and v' chromaticity coordinates of the emitting display at the desired colour state Q under the specified illumination conditions:

$$x_Q = \frac{X_{Q,\text{tot}}}{X_{Q,\text{tot}} + Y_{Q,\text{tot}} + Z_{Q,\text{tot}}}, \quad u' = \frac{4x_Q}{3 - 2x_Q + 12y_Q} \tag{26}$$

$$y_Q = \frac{Y_{Q,\text{tot}}}{X_{Q,\text{tot}} + Y_{Q,\text{tot}} + Z_{Q,\text{tot}}}, \quad v' = \frac{9y_Q}{3 - 2x_Q + 12y_Q} \tag{27}$$

6.3 Contrast ratio and colour coordinate with the incident illumination originating from objects behind the screen

6.3.1 Purpose

The purpose of this method is to measure the contrast ratio and colour coordinate with the incident illumination originating from objects behind the transparent display module. In 6.1, the contrast ratio method is shown, and in 6.2, that of colour reproducibility. In 6.3, the simple measuring method is shown.