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Edition 1.0 2016-04

TECHNICAL SPECIFICATION

colour inside

Flexible display devices –
Part 5-2: Measuring methods of optical characteristics from the vantage point for curved displays

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

IEC TS 62715-5-2, which is a technical specification, has been prepared by IEC technical committee 110: Electronic display devices.

The text of this standard is based on the following documents:

Enquiry draft	Report on voting
110/715/DTS	110/739/RVC

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

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

A list of all parts in the IEC 62715 series, published under the general title *Flexible display devices*, can be found on the IEC website.

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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FLEXIBLE DISPLAY DEVICES –

Part 5-2: Measuring methods of optical characteristics from the vantage point for curved displays

1 Scope

This part of IEC 62715, which is a technical specification, specifies the general rules and the details of optical measuring methods from a fixed point (the so-called vantage point) for curved emissive and transmissive type displays such as OLED and LCD in dark room conditions. This document focuses on concave shape large screen displays (non-portable) around a horizontal and/or vertical axis with fixed or variable curvature radius.

The measuring method stipulated in this technical specification is applied to the curved display modules under the following states:

- vantage-point luminance variation by viewing angles
- vantage-point contrast ratio variation by viewing angles
- vantage-point chromaticity variation of white colour by viewing angles
- vantage-point colour gamut area variation by viewing angles
- vantage-point chromaticity variation of primary colours by viewing angles
- luminance uniformity and its uniformity variation by viewing angles
- chromaticity uniformity and its uniformity variation by viewing angles
- viewing angle of half-luminance
- viewing angle of half-contrast

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62715-1-1, *Flexible display devices – Part 1-1: Terminology and letter symbols*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62715-1-1 as well as the following apply.

3.1.1
curved display
display that has a single curvature radius along the screen horizontally and/or vertically

Note 1 to entry: The curvature radius of each screen position is fixed by the manufacturer or user controllable curvature radius.

Note 2 to entry: The direction of curvature might be concave or convex from the viewer's position.

Note 3 to entry: The curved screen display is also called curved display, as in curved TV and curved monitor.

3.1.2
vantage-point measurement
test configuration in which measurements are taken at various measuring points on the display screen through a common observation point in space in front of the screen

Note 1 to entry: The observer (at the viewing distance D) is at a fixed point, the so-called vantage point or viewing point, and then from that fixed vantage point, the angle of view from the screen centre to the corners is changed according to human viewing directions toward the screen.

Note 2 to entry: In this document, the vantage point for the measurement is located on the same horizontal plane as the display centre, and on a line between the display centre and the display's axis of rotation.

3.1.3
screen visual angle
maximum range of vantage-point viewing directions Θ_{VA} measured from the vantage point towards the edges of the display

Note 1 to entry: The horizontal screen visual angle is the range of vantage-point viewing directions between the left and right edges of the screen.

Note 2 to entry: The vertical screen visual angle is the range of vantage-point viewing directions between the top and bottom edges of the screen.

3.1.4
viewing angle
angle between the normal direction of the screen surface and the measurement or viewing direction

Note 1 to entry: If there is no indication about the screen position, the viewing angle is based on the screen centre.

Note 2 to entry: The horizontal viewing angle is the angle between the screen normal direction and the vantage point, both lying on the same horizontal plane.

Note 3 to entry: The vertical viewing angle is the angle between the screen normal direction and the vantage point, both lying on the same vertical plane.

3.1.5
luminance variation by viewing angle
percent difference of display white luminance, between normal incidence (at 0° viewing angle) and a specific viewing angle at each screen measuring point or averaged over the screen measuring points

3.1.6
contrast ratio variation by viewing angle
percent difference of contrast ratio between normal incidence (at 0° viewing angle) and a specific viewing angle at each screen measuring point or averaged over the screen measuring points

3.1.7
chromaticity variation by viewing angle
chromaticity difference between normal incidence (at 0° viewing angle) and a specific viewing angle at each screen measuring point or averaged over the screen measuring points

3.1.8
luminance uniformity variation by viewing angle
percent difference of display white luminance uniformity between normal incidence (at 0° viewing angle) and a specific viewing angle

3.1.9
chromaticity uniformity variation by viewing angle
difference of chromaticity uniformity at normal incidence (at 0° viewing angle) to the other viewing angle

3.1.10
half-luminance viewing angle
horizontal viewing angle that has the half value of the luminance at the normal direction

3.1.11
half-contrast viewing angle
horizontal viewing angle that has the half value of the contrast at the normal direction

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

APL	average picture level
CCT	correlated colour temperature
CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
CIELAB	CIE 1976 (L*a*b*) colour space
DUT	device under test
LMD	light measurement device

4 Standard measuring equipment

4.1 Video signal generator

An analogue video signal generator or a digital video signal generator is used. The signal characteristics shall match with the measured curved display module. Input signal, in this document, means pre-gamma signal and APL means post-gamma APL.

4.2 Non-contact LMD

For the purpose of vantage-point measurement, the non-contact LMD shall be used. When using a non-contact LMD, a spectroradiometer or a non-contact colorimeter is installed, as shown in Figure 1. The optical axis of the non-contact LMD should be normal in the case of measuring the centre of the display surface. In this document, for the purpose of vantage-point measurement, the measuring distance l_{M} from the LMD to the centre of the display screen shall be either the design viewing distance or $3V$ where V is the effective screen height of the display and H is the horizontally effective screen width of the display. The design viewing distance might be recommended based on the display resolution and curvature radius. The LMD colour measurements shall comply with the colour matching functions for the CIE 1976 standard colorimetric observer.

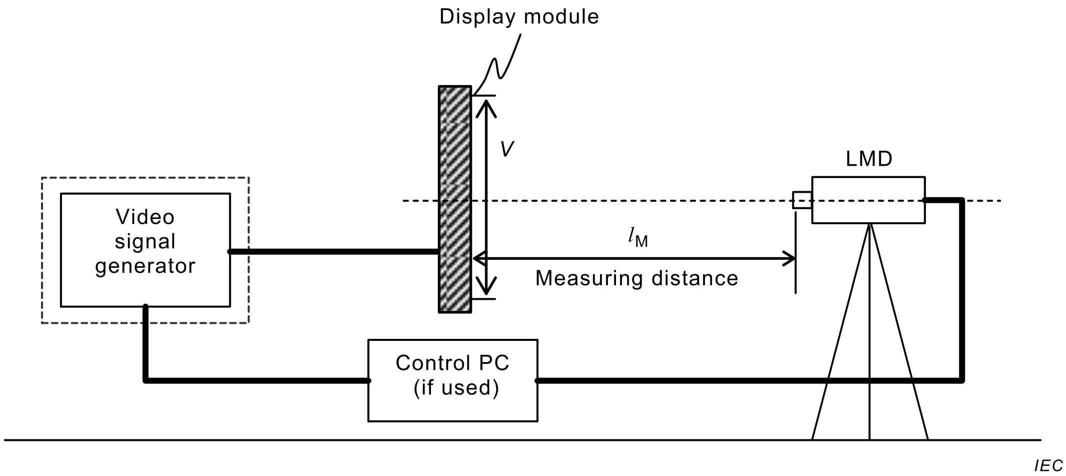

Figure 1 – Measuring layout for non-contact measurement

5 Standard measuring conditions

5.1 Standard measuring environmental conditions

Measurements shall be carried out under the standard environmental conditions. When different environmental conditions are used, they shall be noted in the report.

Temperature:	25 °C ± 3 °C
Relative humidity:	25 % RH to 85 % RH
Atmospheric pressure:	86 kPa to 106 kPa

5.2 Power supply

The power supply for driving the DUT shall be adjusted to the rated voltage ±5 %. In addition, the frequency of the power supply shall provide the rated frequency ±2 %.

5.3 Warm-up time

Measurements shall be started after the display modules and measuring instruments achieve stability. Sufficient warm-up time is defined as the time elapsed from when the supply source is switched on, and a 100 % gray level of input signal is applied to the DUT, until repeated measurements of the display show a variation in luminance of no more than 2 % per minute and 5 % per hour.

5.4 Standard measuring dark room conditions

The luminance contribution from the background illumination reflected off the test display shall be ≤ 0,01 cd/m^2. If this condition is not satisfied, then background subtraction is required and it shall be noted in the ambient performance report. In addition, if the sensitivity of the LMD is inadequate to measure at these low levels, then the lower limit of the LMD shall be noted in the ambient performance report. The clothes of the observer(s) and the wall of the room shall be dark in order to avoid the reflection of the light emitted from the display back onto the display. The measurement for all measuring points of the display screen and all measuring positions shall proceed in the same dark room.

5.5 Adjustment of display modules

Luminance, contrast and chromaticity of the white field and other relevant parameters of the displays have to be adjusted to nominal status in the detail specification and they shall be noted in the measurement report. When there is no level specified, the maximum contrast and/or luminance level shall be used. These adjustments shall be held constant for all measurements, unless noted otherwise in the measurement report. Additional conditions are specified separately for each measuring method.

5.6 Measuring geometry for vantage point

5.6.1 General

To measure in vantage-point directions, the display module should be installed on a rotatable and tiltable fixture to enable the changes in horizontal, vertical, and/or oblique measuring directions. In 5.6, it is assumed that the display module shall be generally installed in the vertical position to the ground. The curvature type of the examples is concave, but the convex type is also available for these applications. The measuring direction that is the same as the viewing direction is varied according to each vantage point and each viewing angle of the measuring position.

5.6.2 Measuring geometry in horizontal vantage point

Figure 2 shows the measuring geometry of the top view in the horizontal vantage point. The measuring distance l_M at the left or right measuring point of the screen may be unequal to that of the screen centre, which will require the LMD to be refocused at these points. The measuring distance is based on the standard viewing distance of the normal direction. It can be measured between the screen centre of the display module and the optical lens of the LMD.

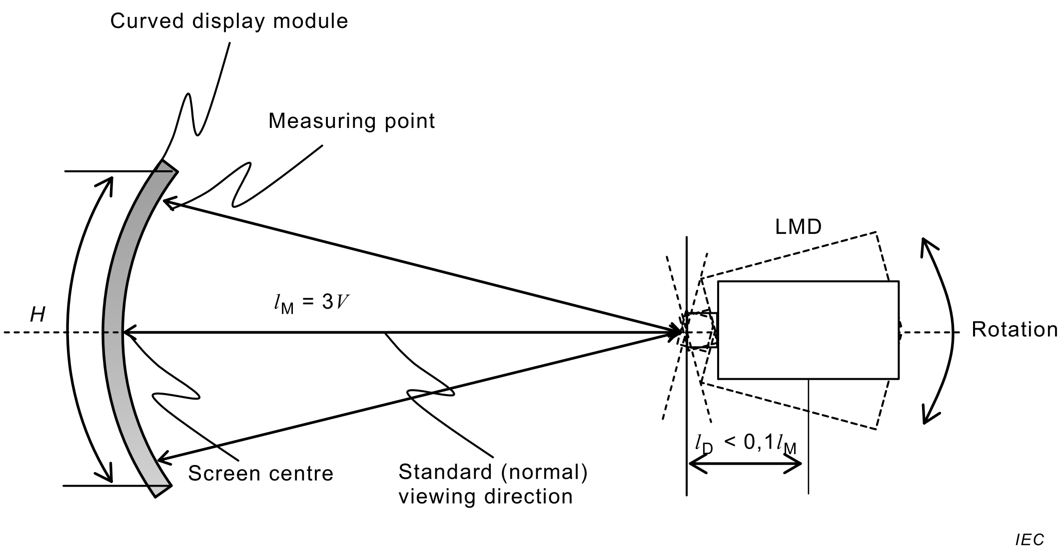

Figure 2 – Measuring geometry in horizontal vantage point (top view)

5.6.3 Measuring geometry in vertical vantage point

Figure 3 shows the measuring geometry of the top view in the vertical vantage point. The measuring distance l_M at the upper or lower measuring point of the screen may be unequal to that of the screen centre, which will require the LMD to be refocused at these points. When using a tripod mount for the LMD, the LMD might be rotated by the mount point. Because of the gap l_D between the LMD lens and the mount point, the viewing angle of the upper/lower and left/right measuring point of the screen becomes slightly small, but if $l_D < 0,1\ l_M$, it can be neglected.

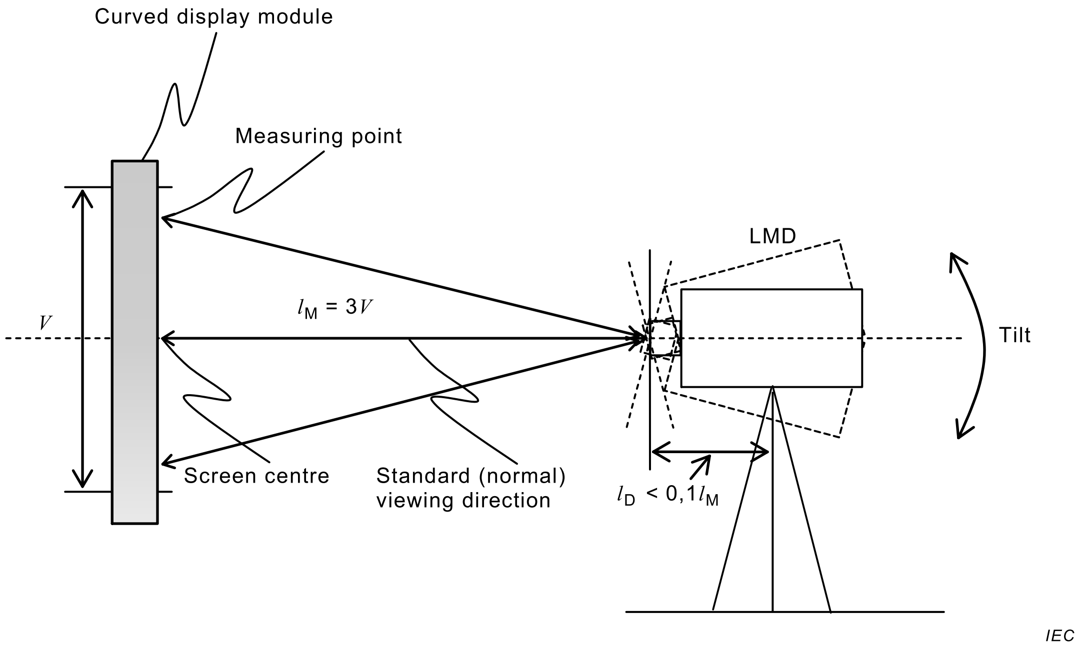

Figure 3 – Measuring geometry in vertical vantage point (side view)

5.7 Measuring layout for viewing position

5.7.1 General

When watching a display, according to the viewing position, a viewing angle shall be set up between the display's perpendicular direction and the viewing direction. In 5.7, for the measurement by the viewing angle with the actual watching conditions of customers, the range of the viewing position of normal to ±45° of the display which is possible in the actual usage shall be applied. The range of the viewing angle might be determined from over 90 % of actual usages of consumers when watching large screen displays.

For the measurement in the viewing angle, as the viewing angle is mainly changed in the horizontal direction, the LMD can be installed on a movable tripod around the display to enable to change the horizontal viewing angle. Alternatively, the display module may rotate horizontally to change the viewing angle when the LMD is fixed. Depending on the display size or the measurement room space, one of the alternatives shall be adopted.

5.7.2 Measuring layout by moving LMD

The viewing direction of the viewer becomes the viewing angle of the display. In this case, the measurement distance shall not change regardless of the viewing angles. The measuring geometry of 0° to 45° is shown in the figure. As the actual watching conditions, the viewing angle will be recommended to be 0°, 15°, 30° and 45° in Figure 4. In this case, the opposite sides of the viewing angles do not have to be measured because generally most of the curved displays are almost symmetrical horizontally in the optical variations between the left side and right side viewing angles. Figure 4 shows the measuring geometry of the top view by horizontal viewing angles from 0° to 45° of the right side.

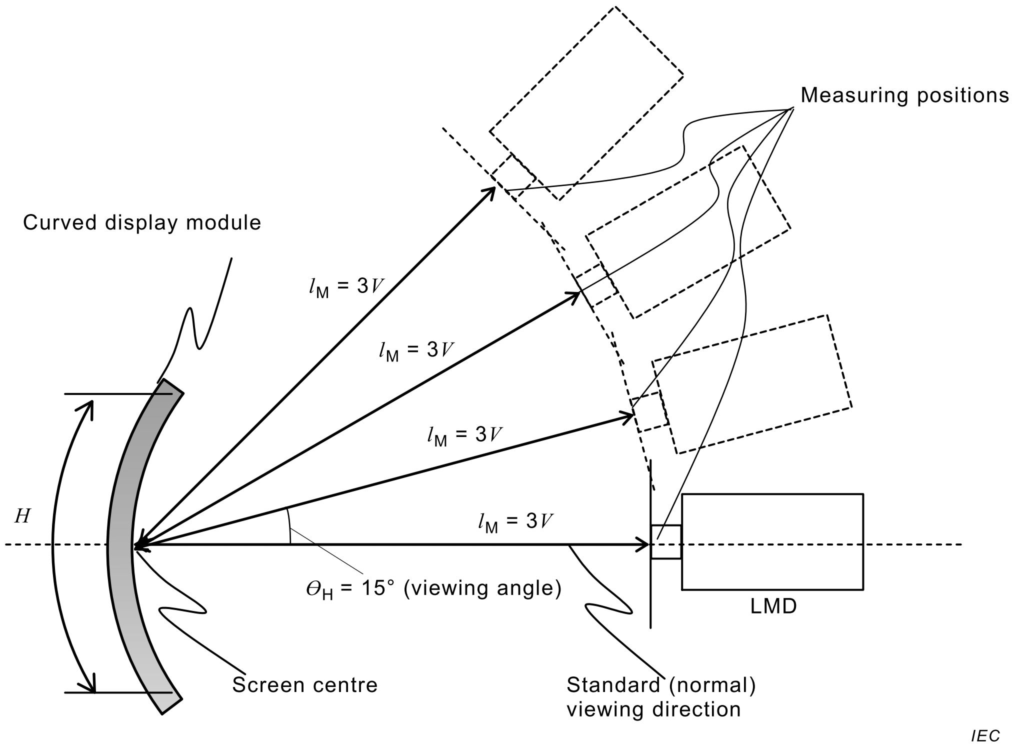

Figure 4 – Measuring geometry by horizontal viewing angles (top view)

In each viewing angle of the viewing position, the measuring direction is changed by the viewing angle at the same time. Figure 4 shows the measuring direction of the screen centre by the horizontal viewing angle (Θ_H) that is caused by the viewer's position. In any measuring position, the measurement distance l_M should not be changed. But because of the angle of the vantage point, the viewing angles and the measuring distances of the other points of the screen are different from those of screen centre.

5.7.3 Measuring layout by rotating the display module

Instead of moving the LMD, the display module itself can be rotated. The display module should be installed on a rotatable fixture to enable changes in the horizontal viewing angle based on the display screen centre. Figure 5 shows the measuring geometry of the top view by the horizontal display directions from 0° to 45°.

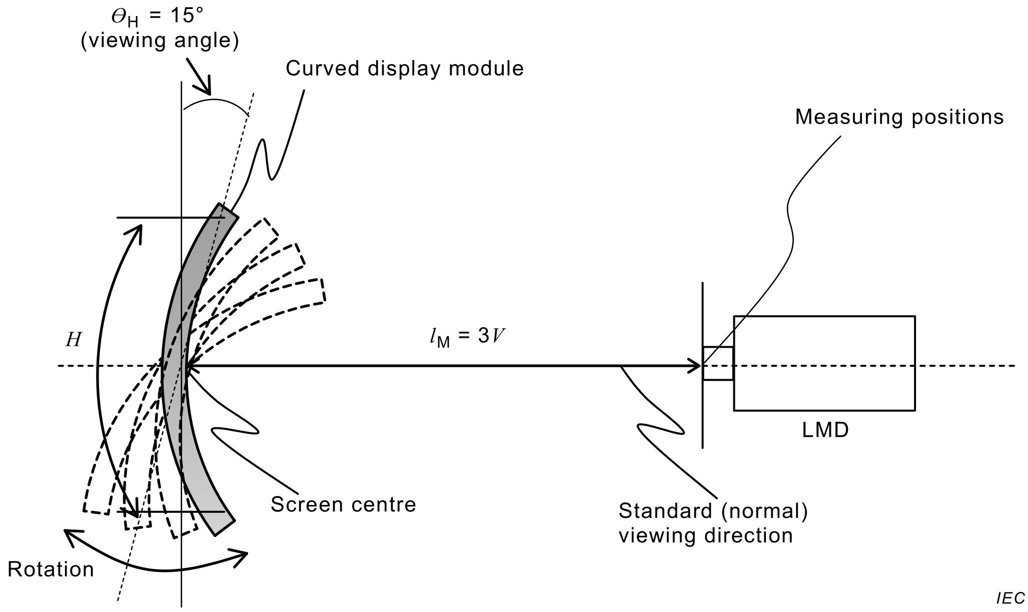

Figure 5 – Measuring geometry by horizontal display directions (top view)

As in 5.7.2, because of the angle of the vantage point, the viewing angles and the measuring distances of the other points of the screen are different from those of the screen centre.

5.8 Minimum curvature radius for the measurement

When the maximum viewing angle is 45° in this measurement, the curvature radius of the concave type display module should be bigger than $32V/9\pi$ for 16:9 aspect ratio displays as Figure 6 shows. Aspect ratio means the horizontal length versus the vertical length of the screen. In case of a smaller curvature radius than the minimum curvature radius, it will not be possible to measure the screen edge of the viewer's side or there will be an inaccurate measurement at 45° angle of viewing distance $3V$. Figure 6 shows the minimum curvature radius of a concave type curved display device in the top view. In Figure 6, if the curved display is smaller than the minimum curvature radius, the right side of the screen might be invisible and impossible to measure because the right side edge of the screen is 45°, that is, almost parallel to the measuring direction of right side measuring points.

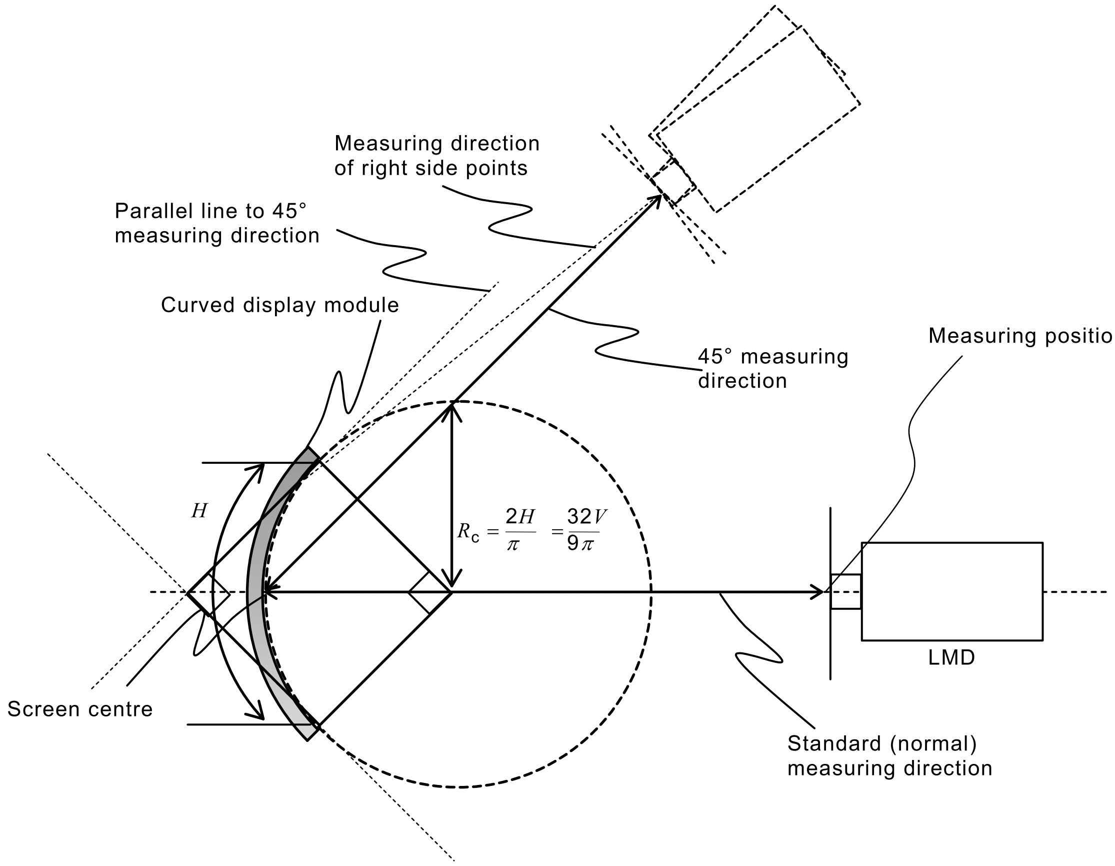

Figure 6 – Minimum concave type curvature radius for the measurement (top view)

5.9 Screen visual angle

5.9.1 Screen visual angle of a flat display module

When a complete flat display of a 16:9 aspect ratio displays a horizontal/vertical ratio k which is 1,778, for example, the screen visual angle at a $3V$ viewing distance is as follows:

$$\Theta_{\mathrm{VAF}} = 2\tan^{-1}\frac{\frac{k}{2}V}{3V} = 2\tan^{-1}\frac{\frac{16}{9\times 2}V}{3V} = 2\tan^{-1}\frac{16}{54} = 33{,}01(\text{degree}) \quad (1)$$

5.9.2 Screen visual angle of concave type display module

In case a concave type curved display of 16:9 aspect ratio displays a horizontal / vertical ratio k which is 1,67, when the curvature radius is $3V$, the horizontal screen visual angle at a $3V$ viewing distance that is the angle from the viewer to the left end and right end of the screen is as follows:

$$\Theta_{\mathrm{VACC}}/kV = 2\pi/2\pi \times 3V \tag{2}$$

$$\Theta_{\mathrm{VACC}} = \frac{kV \times 2\pi}{2\pi \times 3V} = \frac{\frac{16}{9}}{3} = \frac{16}{27}\,(\text{radian}) = 33{,}95\,(\text{degree}) \tag{3}$$

Figure 7 shows the screen visual angle of a concave type display device in the top view.

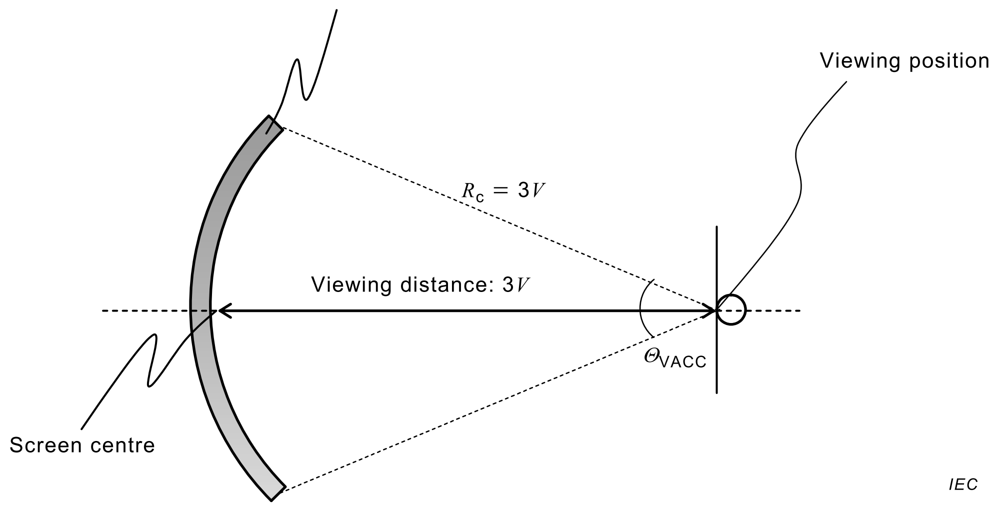

Figure 7 – Screen visual angle of concave type display device (top view)

6 Measuring methods of optical characteristics

6.1 General

6.1.1 Measuring items

The measuring items for curved display characteristics are as follows:

- luminance variation of white box by viewing angles
- contrast ratio variation of white box by viewing angles
- chromaticity variation of white box by viewing angles
- colour gamut area variation by viewing angles
- chromaticity variation of colour box by viewing angles
- luminance uniformity and uniformity variation by viewing angles
- chromaticity uniformity and uniformity variation by viewing angles
- viewing angle of half-luminance
- viewing angle of half-contrast

6.1.2 Measuring point locations

For the vantage-point measurement, the number of measurement points is generally 9. The locations of the 9 points are shown in Figure 8. The test pattern shall be specified depending on the measuring items, but the measuring position is always the same.

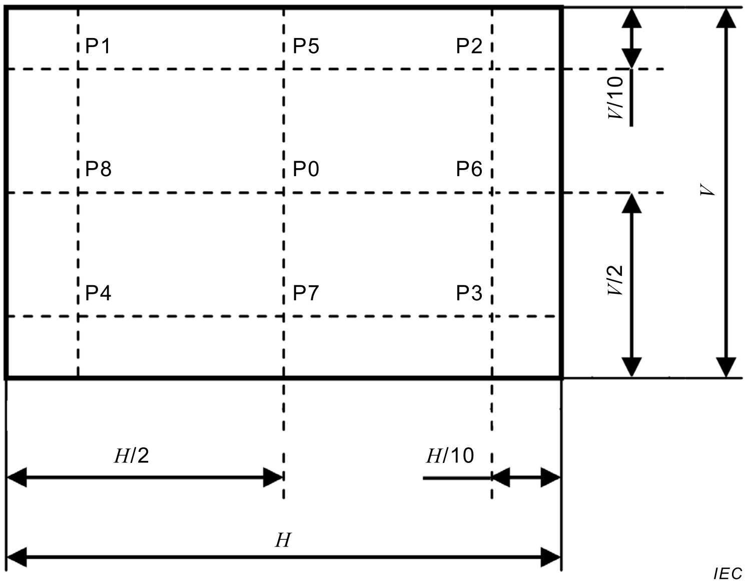

Figure 8 – 9-point locations for vantage-point measurement

6.1.3 Test pattern

The test pattern for white box measurements is showed in Figure 9. The pattern shall be displayed by 9 white rectangular boxes with black background. Each box is 1 % of the area of the screen that has a size of *H*/10 horizontally and of *V*/10 vertically. The total area of the boxes is 9 % of the screen area and the APL shall be 9 %. It might be suitable for the APL to get the maximum luminance of the self-emitting displays. The measuring points are the centre of each box and the measurement field of the LMD is suggested to contain 500 pixels or more.

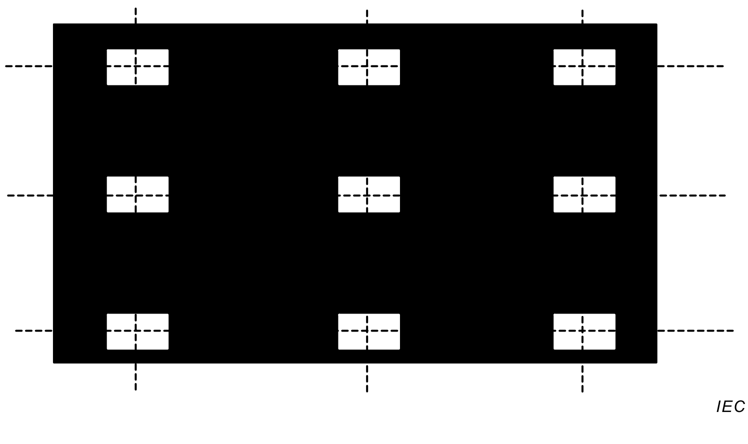

Figure 9 – Nine white boxes for vantage-point measurement

For the measurement of the contrast ratio, the black luminance can be measured at the 9 points of the cross dotted lines in Figure 10.

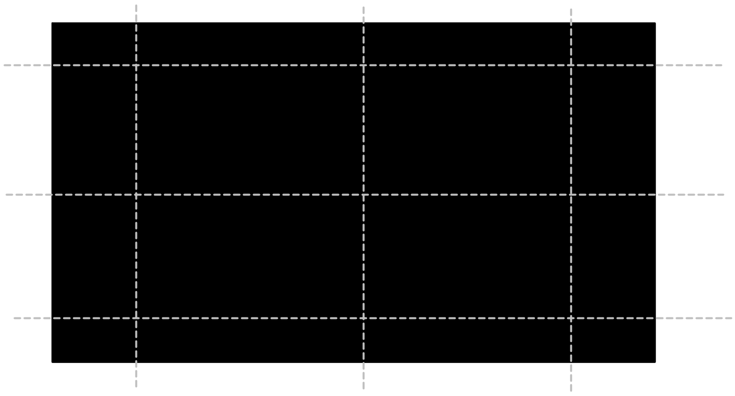

Figure 10 – Nine measuring points for vantage-point black measurement

The test patterns for colour box measurements are shown in Figure 11. They shall be displayed by 9 rectangular boxes of each R, G and B that are the same type as the white boxes. Depending on the CCT of the white balance of the WRGB type panel, the optical characteristics of the white box such as luminance, screen uniformity and APL may not add up to a just addition of the colour box characteristics.

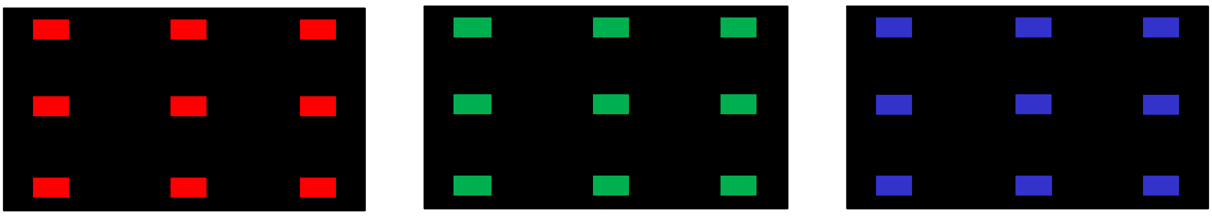

Figure 11 – Nine-colour boxes of R, G and B for vantage-point measurement

6.2 Measuring method

6.2.1 Measuring method at the screen centre position

The measuring direction shall be the vantage-point viewing direction to simulate the real condition of watching a display screen. Figure 12 shows the measuring direction of 9 vantage points at a viewing angle of 0°.

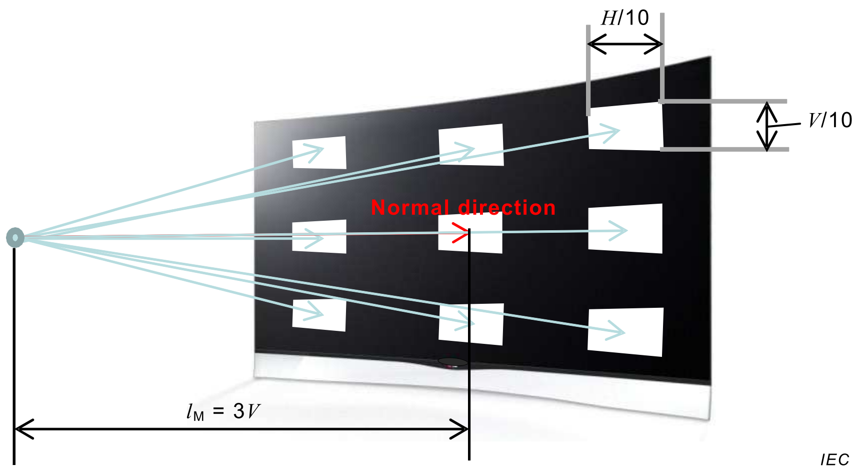

Figure 12 – Measuring directions of 9 vantage points

6.2.2 Measuring method at viewing angle position

At any measuring positions, the measuring points shall be the centre of 9 rectangular white boxes. According to the measuring positions, the viewing angles of the measurements shall be 0°, 15°, 30° and 45° from the perpendicular axis of the screen centre. In this case, the measuring distance is always the same, i.e. 3 V. In the viewing angle direction, the left-side or right-side direction of the perpendicular axis can be selected alternatively. Figure 13 shows the measuring directions from the 0° to the 45° viewing angle. The directions for 15° and 30° are not drawn fully and omitted except the direction of the centre box. The total number of measurements is 36 (= 4 × 9).

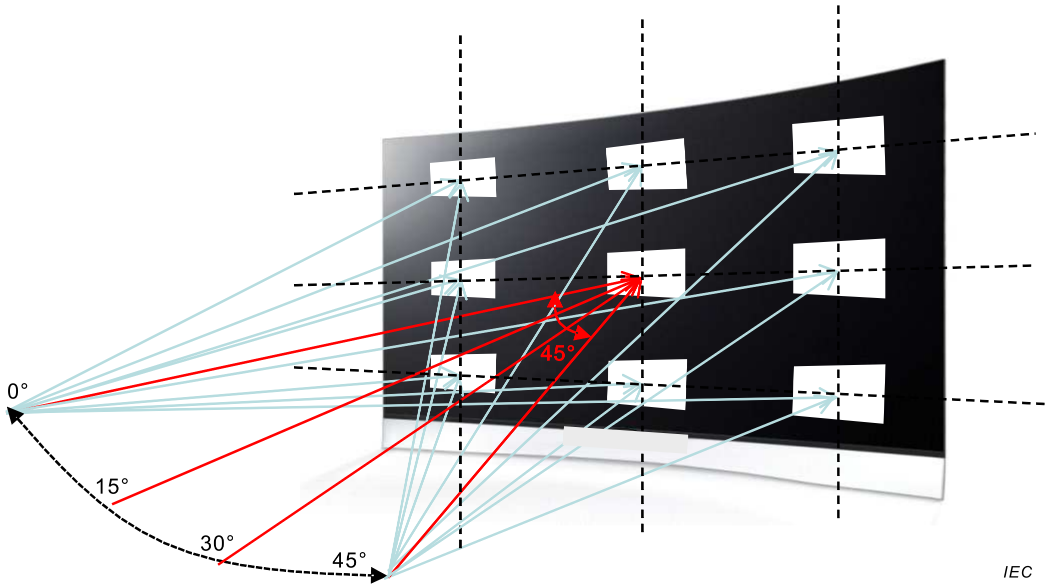

Figure 13 – Measuring directions (right side) by viewing angle 0°, 15°, 30° and 45°

Figure 14 shows the front upper view of Figure 13.

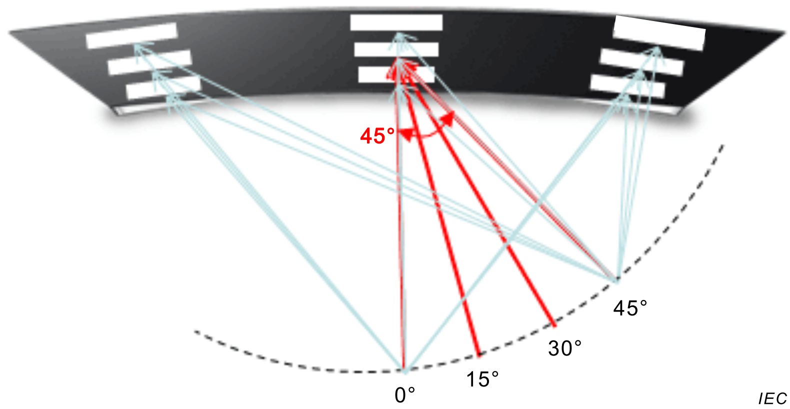

Figure 14 – Measuring directions (right side) by viewing angle 0°, 15°, 30° and 45° (front upper view)

6.3 Optical characteristics of white box by viewing angle

6.3.1 Luminance variation by viewing angle

L_{Θ}, which is the luminance at Θ° of the horizontal viewing angle, shall vary by viewing angle. The luminance variation of the measuring point p by the viewing angle is as follows:

$$LV_{\Theta\_p} = \frac{\left| L_{0\_p} - L_{\Theta\_p} \right|}{L_{0\_p}} \text{x100 (\%), where } \Theta = 15, 30, 45 \text{ (degree)} \tag{4}$$

where

L_{Θ_p}: luminance of white in cd/m² of point p at viewing angle Θ.

The average (mean) and standard deviations of the luminance variation of 9 points at viewing angle Θ are as follows:

$$LV_{\Theta} = \frac{1}{9}\sum_{p=0}^{8} LV_{\Theta\_p} \text{ (\%), where } \Theta = 15, 30, 45 \text{ (degree)} \tag{5}$$

$$SLV_{\Theta} = \sqrt{\frac{\sum_{p=0}^{8}(LV_{\Theta\_p} - LV_{\Theta})^2}{8}} \text{ (\%), where } \Theta = 15, 30, 45 \text{ (degree)} \tag{6}$$

Attention is drawn to the fact that Equation (5) is not a variation of the average luminance of 9 points by the viewing angle because the changes in luminance of each point might compensate each other. It is just the 9-point average of Equation (4) at each viewing angle.

6.3.2 Contrast ratio variation by viewing angle

CR_{Θ}, which is the contrast ratio at Θ° of the horizontal viewing angle, shall vary by the viewing angle. The contrast ratio variation of the measuring point p by the viewing angle is as follows:

$$CRV_{\Theta\_p} = \frac{\left| CR_{0\_p} - CR_{\Theta\_p} \right|}{CR_{0\_p}} \text{x}100 = \frac{\left| \frac{L_{0\_p}(W)}{L_{0\_p}(k)} - \frac{L_{\Theta\_p}(W)}{L_{\Theta\_p}(k)} \right|}{\frac{L_{0\_p}(W)}{L_{0\_p}(k)}} \text{x100 (\%), where } \Theta = 15, 30, 45 \text{ (degree)} \tag{7}$$

where

CR_{Θ_p}: contrast ratio of point p at viewing angle Θ

$L_{\Theta\_p}(k)$: luminance of black in cd/ m² of point p at viewing angle Θ

The average (mean) and standard deviations of the contrast ratio variations of 9 points at viewing angle Θ are as follows:

$$CRV_{\Theta} = \frac{1}{9}\sum_{p=0}^{8} CRV_{\Theta\_p} \text{ (\%), where } \Theta = 15, 30, 45 \text{ (degree)} \tag{8}$$

$$SCRV_{\Theta} = \sqrt{\frac{\sum_{p=0}^{8}(CRV_{\Theta\_p} - CRV_{\Theta})^2}{8}} \text{ (\%), where } \Theta = 15, 30, 45 \text{ (degree)} \tag{9}$$

Attention is drawn to the fact that Equation (8) is not a variation of the average contrast ratio of 9 points by viewing angle because the changes in contrast ratio of each point might compensate each other. It is simply the 9-point average of Equation (7) at each viewing angle.

6.3.3 Chromaticity variation by viewing angle

The chromaticity of the white boxes is also calculated in the $u'v'$ colour space by averaging the colour coordinates of the 9 points. u'_{Θ} and v'_{Θ} are the u' and v' colour coordinates of CIE 1976 at Θ° of the horizontal viewing angle.

The chromaticity of the white boxes shall vary by viewing angle. The chromaticity variation of the measuring point p by the viewing angle in the $u'v'$ colour coordinate is as follows:

$$\Delta C_{\mathrm{w\_\Theta\_p}} = \sqrt{(u'_{\mathrm{w\_\Theta\_p}} - u'_{\mathrm{w\_0\_p}})^2 + (v'_{\mathrm{w\_\Theta\_p}} - v'_{\mathrm{w\_0\_p}})^2}, \quad \text{where } \Theta = 15,\ 30,\ 45\ \text{(degree)} \tag{10}$$

where

$u'_{\mathrm{w\_\Theta\_p}}$: u' of the point p white box at viewing angle Θ

$v'_{\mathrm{w\_\Theta\_p}}$: v' of the point p white box at viewing angle Θ

The average (mean) and standard deviations of the chromaticity variation of the white box at viewing angle Θ are as follows:

$$\Delta C_{\mathrm{w\_\Theta}} = \frac{1}{9}\sum_{p=0}^{8} \Delta C_{\mathrm{w\_\Theta\_p}}, \quad \text{where } \Theta = 15,\ 30,\ 45\ \text{(degree)} \tag{11}$$

$$S\Delta C_{\mathrm{w\_\Theta}} = \sqrt{\frac{\sum_{p=0}^{8} (\Delta C_{\mathrm{w\_\Theta\_p}} - \Delta C_{\mathrm{w\_\Theta}})^2}{8}}, \quad \text{where } \Theta = 15,\ 30,\ 45\ \text{(degree)} \tag{12}$$

6.4 Optical characteristics of colour box by viewing angle

6.4.1 Colour gamut area variation by viewing angle

The chromaticity of the display shall be measured at 9 points described in Figure 11 from each viewing direction. From the 3 primary colour coordinates of measuring point p, the colour gamut area S_{Θ_p} at viewing angle Θ is as follows:

$$S_{\Theta\_\mathrm{p}} = \frac{1}{2}[(u'_{\mathrm{r\_\Theta\_p}} - u'_{\mathrm{b\_\Theta\_p}})(v'_{\mathrm{g\_\Theta\_p}} - v'_{\mathrm{b\_\Theta\_p}}) - (u'_{\mathrm{g\_\Theta\_p}} - u'_{\mathrm{b\_\Theta\_p}})(v'_{\mathrm{r\_\Theta\_p}} - v'_{\mathrm{b\_\Theta\_p}})], \quad \text{where } \Theta = 0,\ 15,\ 30,\ 45\ \text{(degree)} \tag{13}$$

where

$u'_{\mathrm{r\_\Theta\_p}}$: u' of the point p red box at viewing angle Θ

$v'_{\mathrm{r\_\Theta\_p}}$: v' of the point p red box at viewing angle Θ

$u'_{\mathrm{g\_\Theta\_p}}$: u' of the point p green box at viewing angle Θ

$v'_{\mathrm{g\_\Theta\_p}}$: v' of the point p green box at viewing angle Θ

$u'_{\mathrm{b\_\Theta\_p}}$: u' of the point p blue box at viewing angle Θ

$v'_{\mathrm{b\_\Theta\_p}}$: v' of the point p blue box at viewing angle Θ

The colour gamut area shall vary by viewing angle. The colour gamut area variation by the viewing angle of the measuring point p can be calculated as follows:

$$SV_{\Theta\_p} = \frac{\left|S_{0\_p} - S_{\Theta\_p}\right|}{S_{0\_p}}, \quad \text{where } \Theta = 15, 30, 45 \text{ (degree)} \tag{14}$$

The average (mean) and standard deviations of the colour gamut area variation at viewing angle Θ are as follows:

$$SV_{\Theta} = \frac{1}{9}\sum_{p=0}^{8} SV_{\Theta\_p} \times 100\ (\%), \quad \text{where } \Theta = 15,\ 30,\ 45\ \text{(degree)} \tag{15}$$

$$SSV_{\Theta} = \sqrt{\frac{\sum_{p=0}^{8}(SV_{\Theta\_p} - SV_{\Theta})^2}{8}}\ (\%), \quad \text{where } \Theta = 15,\ 30,\ 45\ \text{(degree)} \tag{16}$$

6.4.2 Chromaticity variation and ΔE by viewing angle

As with the case of the white box, the chromaticity of the colour box also varies by viewing angle. In the red colour box, the chromaticity variation of the measuring point p by viewing angle in the $u'v'$ colour coordinate is as follows:

$$\Delta C_{r\_\Theta\_p} = \sqrt{(u'_{r\_\Theta\_p} - u'_{r\_0\_p})^2 + (v'_{r\_\Theta\_p} - v'_{r\_0\_p})^2}, \quad \text{where } \Theta = 15,\ 30,\ 45\ \text{(degree)} \tag{17}$$

In the same way, the chromaticity variation $\Delta C_{g\_\Theta\_p}$ for green and $\Delta C_{b\_\Theta\_p}$ for blue is calculated at each 9-point by the viewing angle.

In the red colour boxes, the average (mean) and standard deviations of the chromaticity variation at viewing angle Θ are as follows:

$$\Delta C_{r\_\Theta} = \frac{1}{9}\sum_{p=0}^{8} \Delta C_{r\_\Theta\_p}, \quad \text{where } \Theta = 15,\ 30,\ 45\ \text{(degree)} \tag{18}$$

$$S\Delta C_{r\_\Theta} = \sqrt{\frac{\sum_{p=0}^{8}(\Delta C_{r\_\Theta\_p} - \Delta C_{r\_\Theta})^2}{8}}, \quad \text{where } \Theta = 15,\ 30,\ 45\ \text{(degree)} \tag{19}$$

In the same way, for the green and blue colour boxes, the average and standard variation of $\Delta C_{g\_\Theta\_p}$ and $\Delta C_{b\_\Theta\_p}$ (ΔC_{g_Θ}, $S\Delta C_{g\_\Theta}$ and ΔC_{b_Θ}, $S\Delta C_{b\_\Theta}$) can be calculated.

For the evaluation of ΔE, the CIELAB colour coordinates are used. L^*, a^* and b^* are defined as follows:

$$L^*_{\mathrm{r}} = 116 f\left(\frac{Y_{\mathrm{r}}}{Y_w}\right) - 16, \qquad (20)$$

$$a^*_{\mathrm{r}} = 500\left[f\left(\frac{X_{\mathrm{r}}}{X_{\mathrm{w}}}\right) - f\left(\frac{Y_{\mathrm{r}}}{Y_{\mathrm{w}}}\right)\right],$$
$$b^*_{\mathrm{r}} = 200\left[f\left(\frac{Y_{\mathrm{r}}}{Y_{\mathrm{w}}}\right) - f\left(\frac{Z_{\mathrm{r}}}{Z_{\mathrm{w}}}\right)\right], \qquad (21)$$

$$f(s) = s^{1/3} \quad s > 0{,}008856$$
$$f(s) = 7{,}787s + 16/116 \quad s \le 0{,}008856 \qquad (22)$$

where

X_{r}, Y_{r}, Z_{r}: CIE X, Y, Z tri-stimulus value in red colour box

X_{w}, Y_{w}, Z_{w}: CIE X, Y, Z tri-stimulus value in white box

For an example of the red colour, ΔE of measuring point p at viewing angle Θ is defined based on the 0° viewing angle asfollows:

$$\Delta E_{\mathrm{r\_\Theta\_p}} = \sqrt{(L^*_{\mathrm{r\_0\_p}} - L^*_{\mathrm{r\_\Theta\_p}})^2 + (a^*_{\mathrm{r\_0\_p}} - a^*_{\mathrm{r\_\Theta\_p}})^2 + (b^*_{\mathrm{r\_0\_p}} - b^*_{\mathrm{r\_\Theta\_p}})^2}, \quad \text{where } \Theta = 15, 30, 45\,(\text{degree}) \qquad (23)$$

where

$L^*_{\mathrm{r\_0\_p}}$, $a^*_{\mathrm{r\_0\_p}}$, $b^*_{\mathrm{r\_0\_p}}$: L^*, a^* and $b^{*\,*}$ of the measuring point p at viewing angle 0°

$L^*_{\mathrm{r\_\Theta\_p}}$, $a^*_{\mathrm{r\_\Theta\_p}}$, $b^*_{\mathrm{r\_\Theta\_p}}$: L^*, a^* and b^* of the measuring point p at viewing angle Θ

In the same way, $\Delta E_{\mathrm{g\_\Theta\_p}}$ for green and $\Delta E_{\mathrm{b\_\Theta\_p}}$ for blue are calculated at each 9-point by viewing angle.

In the red colour boxes, the average (mean) and standard deviations of $\Delta E_{\mathrm{r\_\Theta\_p}}$ at viewing angle Θ are as follows:

$$\Delta E_{\mathrm{r\_\Theta}} = \frac{1}{9}\sum_{p=0}^{8} \Delta E_{\mathrm{r\_\Theta\_p}}, \quad \text{where } \Theta = 15, \ 30, \ 45 \ (\text{degree}) \qquad (24)$$

$$S\Delta E_{\mathrm{r\_\Theta}} = \sqrt{\frac{\sum_{p=0}^{8} (\Delta E_{\mathrm{r\_\Theta\_p}} - \Delta E_{\mathrm{r\_\Theta}})^2}{8}}, \quad \text{where } \Theta = 15, \ 30, \ 45 \ (\text{degree}) \qquad (25)$$

In the same way, for the green and blue colour boxes, the average and standard variation of $\Delta E_{\mathrm{g\_\Theta\_p}}$ and $\Delta E_{\mathrm{b\_\Theta\_p}}$ ($\Delta E_{\mathrm{g\_\Theta}}$, $S\Delta E_{\mathrm{g\_\Theta}}$ and $\Delta E_{\mathrm{b\_\Theta}}$, $S\Delta E_{\mathrm{b\_\Theta}}$) can be measured.

6.5 Uniformity and uniformity variation

6.5.1 General

Uniformity and uniformity variation for luminance and chromaticity shall be evaluated using the white box.

6.5.2 Luminance uniformity and uniformity variation by viewing angle

LU_{Θ} is the luminance uniformity at Θ° of viewing angle. Luminance uniformity variation at Θ° of viewing angle is obtained as follows:

$$LU_{\Theta} = \frac{\min(L_{\Theta\_0}, L_{\Theta\_1}, L_{\Theta\_2}, \ldots, L_{\Theta\_8})}{\max(L_{\Theta\_0}, L_{\Theta\_1}, L_{\Theta\_2}, \ldots, L_{\Theta\_8})} \times 100(\%) \ \text{where} \ \Theta = 15,30,45(\text{degree}) \quad (26)$$

$$LUV_{\Theta} = \frac{|LU_0 - LU_{\Theta}|}{LU_0} \times 100 \ \text{where} \ \Theta = 15,30,45(\text{degree}) \quad (27)$$

6.5.3 Chromaticity uniformity and uniformity variation by viewing angle

Chromaticity uniformity at viewing angle Θ can be calculated with the maximum $\Delta u'v'$ based on the colour coordinate of the centre white box. The chromaticity uniformity variation ΔCU_{Θ} at viewing angle Θ is obtained as follows:

$$CU_{\Theta} = \max\left(\sqrt{(u'_{\Theta\_1} - u'_{\Theta\_0})^2 + (v'_{\Theta\_1} - v'_{\Theta\_0})^2} \sim \sqrt{(u'_{\Theta\_8} - u'_{\Theta\_0})^2 + (v'_{\Theta\_8} - v'_{\Theta\_0})^2}\right)$$

where $\Theta = 15,30,45(\text{degree})$ (28)

$$\Delta CU_{\Theta} = |CU_0 - CU_{\Theta}|, \ \text{where} \ \Theta = 15,\ 30,\ 45\ (\text{degree}) \quad (29)$$

6.6 Half-luminance and half-contrast viewing angle

6.6.1 Half-luminance viewing angle range

Each luminance at the front, and left side and right side is calculated by averaging only 3 luminances of white boxes number 0, 6, 8 in a horizontal centre line, as in Figure 15.

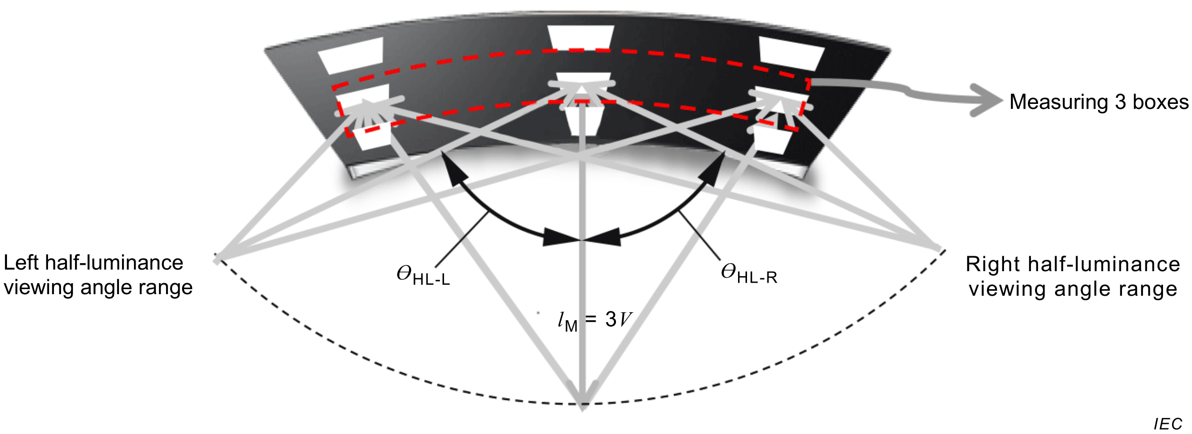

Figure 15 – Measuring method for half-luminance viewing angle

$$L_{\Theta_{HL-L}} = \frac{1}{2}(L_{0\_0} + L_{0\_6} + L_{0\_8}) = L_{\Theta_{HL-L}\_0} + L_{\Theta_{HL-L}\_6} + L_{\Theta_{HL-L}\_8} \quad (30)$$

where

$L_{\Theta\ HL-L}$: luminance at viewing angle Θ_{HL-L}

$$L_{\Theta_{\text{HL-R}}} = \frac{1}{2}(L_{0\_0} + L_{0\_6} + L_{0\_8}) = L_{\Theta_{\text{HL-R}}\_0} + L_{\Theta_{\text{HL-R}}\_6} + L_{\Theta_{\text{HL-R}}\_8} \quad (31)$$

where

$L_{\Theta\ \text{HL-R}}$: luminance at viewing angle $\Theta_{\text{HL-R}}$

$\Theta_{\text{HL-LR}}$ is the viewing angle range of the half-luminance compared to the front luminance. It is calculated by adding the left-side and right-side half-luminance viewing angles.

$$\Theta_{\text{HL-LR}} = \Theta_{\text{HL-L}} + \Theta_{\text{HL-R}} \quad (32)$$

where

$\Theta_{\text{HL-L}}$: left-side half-luminance viewing angle

$\Theta_{\text{HL-R}}$: right-side half-luminance viewing angle

6.6.2 Half-contrast viewing angle range

In the same way as for the half-luminance viewing angle range, $\Theta_{\text{HCR-LR}}$ is the viewing angle range of the half-contrast ratio compared to the front contrast ratio. It is obtained by measuring the black and white luminance at measuring points 0, 6 and 8.

$$CR_{\Theta_{\text{HCR-L}}} = \frac{1}{2}(CR_{0\_0} + CR_{0\_6} + CR_{0\_8}) = CR_{\Theta_{\text{HCR-L}}\_0} + CR_{\Theta_{\text{HCR-L}}\_6} + CR_{\Theta_{\text{HCR-L}}\_8} \quad (33)$$

where

$CR_{\Theta\ \text{HCR-L}}$: contrast ratio at viewing angle $\Theta_{\text{HCR-L}}$

$$CR_{\Theta_{\text{HCR-R}}} = \frac{1}{2}(CR_{0\_0} + CR_{0\_6} + CR_{0\_8}) = CR_{\Theta_{\text{HCR-R}}\_0} + CR_{\Theta_{\text{HCR-R}}\_6} + CR_{\Theta_{\text{HCR-R}}\_8} \quad (34)$$

where

$CR_{\Theta\ \text{HCR-R}}$: contrast ratio at viewing angle $\Theta_{\text{HCR-R}}$

$\Theta_{\text{HCR-LR}}$ is calculated by adding the left-side and right-side half-contrast viewing angles.

$$\Theta_{\text{HCR-LR}} = \Theta_{\text{HCR-L}} + \Theta_{\text{HCR-R}} \quad (35)$$

where

$\Theta_{\text{HCR-L}}$: left-side half-contrast viewing angle

$\Theta_{\text{HCR-R}}$: right-side half-contrast viewing angle

7 Reporting

7.1 Requirements of reporting

The report shall include the following items:

a) date and time of the visual inspection
b) identification of display module
   – product name, type and lot number
   – date of production
   – company name of production

- curvature type (concave or convex)
- curvature radius or curvature radii for variable curvature
- measuring viewing angle direction (right or left)
- measuring distance l_{M} (if not specified, $3V$ is assumed)

c) optical setting conditions of the display module such as contrast, brightness, etc.

d) measurement results of optical characteristics

7.2 Recommendations of measurement results reporting

The measurement results should include the following items:

a) luminance of white, black and colour boxes

b) chromaticity of white box

c) luminance of white box at the half-luminance viewing angle

Table 1 is an example of measurement results for the optical characteristics.

Table 1 – Example of measurement results for the optical characteristics

Items	**point number** / **viewing angle**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Difference** (max. – min.)
White (L_{Θ_p}(W)) (cd/m^2)	0°	387	371	366	365	362	366	369	360	359	28
	15°	380	372	361	367	357	360	359	361	370	23
	30°	345	342	341	330	337	338	337	341	346	16
	45°	300	302	299	301	305	308	305	301	293	15
u' of white ($u'_{w\_\Theta\_p}$)	0°	0,197 1	0,197 0	0,196 3	0,197 6	0,196 7	0,197 0	0,197 1	0,196 5	0,196 6	0,001 3
	15°	0,196 8	0,196 9	0,197 0	0,197 8	0,197 8	0,197 2	0,197 1	0,197 8	0,197 7	0,001 0
	30°	0,199 0	0,196 0	0,196 2	0,198 8	0,198 1	0,198 9	0,199 0	0,197 8	0,198 0	0,0030
	45°	0,199 1	0,198 9	0,198 0	0,199 1	0,198 7	0,199 2	0,198 9	0,199 2	0,199 9	0,001 9
v' of white ($v'_{w\_\Theta\_p}$)	0°	0,467 1	0,464 5	0,467 5	0,464 3	0,466 2	0,466 3	0,467 1	0,467 3	0,466 0	0,003 2
	15°	0,469 3	0,469 8	0,468 8	0,468 9	0,465 3	0,464 3	0,465 6	0,464 7	0,468 0	0,005 5
	30°	0,478 3	0,477 8	0,468 9	0,470 9	0,470 3	0,470 6	0,470 2	0,478 0	0,478 8	0,009 9
	45°	0,483 0	0,478 6	0,487 0	0,480 3	0,480 0	0,480 2	0,483 1	0,482 3	0,483 1	0,008 4
Black (L_{Θ_p}(k)) (cd/m^2)	0°	0,001	0,002	0,002	0,002	0,002	0,002	0,002	0,001	0,002	0,001
	15°	0,001	0,002	0,001	0,001	0,001	0,002	0,002	0,001	0,002	0,001
	30°	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,003	0,001
	45°	0,002	0,002	0,002	0,002	0,002	0,003	0,002	0,003	0,003	0,001
u' of red ($u'_{r\_\Theta\_p}$)	0°	0,454 9	0,455 5	0,455 7	0,454 4	0,455 3	0,455 0	0,454 9	0,454 6	0,455 4	0,001 3
	15°	0,454 1	0,455 1	0,455 0	0,454 2	0,454 2	0,454 8	0,454 9	0,454 5	0,454 3	0,001 0
	30°	0,453 0	0,453 1	0,453 8	0,453 2	0,453 9	0,453 1	0,453 0	0,453 9	0,454 0	0,001 0
	45°	0,452 5	0,452 9	0,452 0	0,452 9	0,453 3	0,452 8	0,453 1	0,452 8	0,453 5	0,001 5
v' of red ($v'_{r\_\Theta\_p}$)	0°	0,537 2	0,539 8	0,538 9	0,540 0	0,538 1	0,538 0	0,537 2	0,537 0	0,538 3	0,003 0
	15°	0,535 0	0,534 5	0,535 5	0,535 4	0,539 0	0,540 0	0,538 7	0,539 6	0,536 3	0,005 5
	30°	0,52 60	0,526 5	0,535 4	0,533 4	0,534 0	0,533 7	0,534 1	0,526 3	0,525 5	0,009 9

Items	point number / viewing angle	0	1	2	3	4	5	6	7	8	Difference (max. – min.)
	45°	0,521 3	0,525 7	0,529 0	0,528 8	0,524 3	0,524 1	0,522 9	0,522 0	0,530 1	0,008 8
u' of green ($u'_{g\_\Theta\_p}$)	0°	0,124 9	0,124 8	0,124 1	0,125 4	0,124 5	0,124 8	0,124 9	0,124 3	0,124 4	0,001 3
	15°	0,124 6	0,124 0	0,124 8	0,125 7	0,125 6	0,125 0	0,125 9	0,125 4	0,125 6	0,001 9
	30°	0,126 8	0,123 8	0,124 0	0,126 6	0,125 9	0,126 7	0,126 8	0,125 6	0,126 3	0,003 0
	45°	0,126 9	0,126 2	0,125 8	0,125 9	0,126 1	0,126 5	0,126 7	0,127 0	0,126 6	0,001 2
v' of green ($v'_{g\_\Theta\_p}$)	0°	0,552 7	0,555 3	0,552 3	0,555 5	0,553 6	0,553 5	0,552 7	0,552 5	0,553 8	0,003 2
	15°	0,550 5	0,554 5	0,551 0	0,551 9	0,554 5	0,554 3	0,554 2	0,543 3	0,551 9	0,011 2
	30°	0,541 5	0,542 0	0,550 9	0,548 9	0,549 5	0,549 2	0,549 6	0,541 8	0,541 0	0,009 9
	45°	0,54 60	0,541 2	0,543 8	0,539 5	0,539 8	0,539 6	0,543 9	0,546 0	0,546 6	0,007 1
u' of blue ($u'_{b\_\Theta\_p}$)	0°	0,177 5	0,177 4	0,176 7	0,178 0	0,177 1	0,177 4	0,177 5	0,176 9	0,177 0	0,001 3
	15°	0,177 2	0,177 3	0,177 4	0,178 2	0,178 2	0,177 6	0,177 5	0,178 2	0,178 1	0,001 0
	30°	0,178 0	0,176 4	0,177 6	0,179 2	0,178 5	0,177 8	0,177 9	0,17 82	0,177 5	0,002 8
	45°	0,178 5	0,177 6	0,178 4	0,179 5	0,177 9	0,177 4	0,177 8	0,178 9	0,177 9	0,002 1
v' of blue ($v'_{b\_\Theta\_p}$)	0°	0,154 8	0,152 2	0,155 2	0,152 0	0,153 9	0,154 0	0,154 8	0,155 0	0,153 7	0,003 2
	15°	0,157 0	0,156 5	0,156 1	0,155 0	0,153 0	0,152 0	0,153 3	0,152 4	0,155 7	0,005 0
	30°	0,158 8	0,158 6	0,156 6	0,158 6	0,158 0	0,158 3	0,157 9	0,158 9	0,160 1	0,003 5
	45°	0,159 5	0,162 2	0,159 7	0,159 3	0,160 1	0,159 8	0,158 9	0,164 2	0,158 1	0,006 1
Half-luminance (left,cd/m^2)	79°	190,0	–	–	–	–	–	184,0	–	185,0	–
	80°	188,0	–	–	–	–	–	179,0	–	181,0	–
Half-luminance (right,cd/m^2)	80°	188,0	–	–	–	–	–	181,0	–	181,0	–
	81°	187,0	–	–	–	–	–	186,0	–	182,0	–

From the white luminance average value of Table 1 at viewing angle 0°, the half-luminance becomes 183,6 cd/m^2. By selecting the nearest value to the half-luminance, the half–luminance viewing angles are known to be 80° for the left side and 80° as well for the right side.

From the measurement data of Table 1, the calculation results shall include the following items:

a) luminance characteristics
b) chromaticity characteristics
c) half-luminance viewing angle

Table 2 shows the calculation results from the data of Table 1. In Table 2, the colour gamut variation and uniformity related results are left out because they are not necessary for typical formats.

Table 2 – Calculation results from the measurement data of Table 1

Items	point number / viewing angle	0	1	2	3	4	5	6	7	8	Average	Standard deviation
LV_{Θ_p} (%)	15°	1,81	0,27	1,37	0,55	1,38	1,64	2,71	0,28	3,06	1,5 (LV_{15})	0,996 9
	30°	10,85	7,82	6,83	9,59	6,91	7,65	8,67	5,28	3,62	7,5 (LV_{30})	2,175 9
	45°	22,48	18,60	18,31	17,53	15,75	15,85	17,34	16,39	18,38	17,8 (LV_{45})	2,044 1
CR_{Θ_p} (x1 000:1)	0°	387	186	183	183	181	183	185	360	180	225,1 (CR_0)	84,417 0
	15°	380	186	361	367	357	180	180	361	185	284,1 (CR_{15})	96,458 0
	30°	173	171	171	165	169	169	169	171	115	163,4 (CR_{30})	18,158 1
	45°	150	151	150	151	153	103	153	100	98	134,1 (CR_{45})	25,439 3
CRV_{Θ_p} (%)	15°	1,8	0,3	97,3	101,1	97,2	1,6	2,7	0,3	3,1	33,9 (CRV_{15})	48,474 4
	30°	55,4	7,8	6,8	9,6	6,9	7,7	8,7	52,6	35,7	21,3 (CRV_{30})	20,726 5
	45°	61,2	18,6	18,3	17,5	15,7	43,9	17,3	72,1	45,6	34,5 (CRV_{45})	21,769 6

Items	point number / viewing angle	0	1	2	3	4	5	6	7	8	Average	Standard deviation
$\Delta C_{W\_\Theta\_p}$	15°	0,002 2	0,005 3	0,001 5	0,004 6	0,001 4	0,002 0	0,001 5	0,002 9	0,002 3	0,0026 (ΔC_{w_15})	0,001 4
	30°	0,011 4	0,013 3	0,001 4	0,006 7	0,004 3	0,004 7	0,003 6	0,010 8	0,012 9	0,007 7 (ΔC_{w_30})	0,004 5
	45°	0,016 0	0,014 2	0,0196	0,016 1	0,013 9	0,014 1	0,016 1	0,015 2	0,017 4	0,015 9 (ΔC_{w_45})	0,001 8
$\Delta C_{r\_\Theta\_p}$	15°	0,002 3	0,005 3	0,0035	0,004 6	0,001 4	0,002 0	0,001 5	0,002 6	0,002 3	0,002 8 (ΔC_{r_15})	0,001 4
	30°	0,011 4	0,013 5	0,0040	0,006 7	0,004 3	0,004 7	0,003 6	0,010 7	0,012 9	0,008 0 (ΔC_{r_30})	0,004 1
	45°	0,016 1	0,014 3	0,0106	0,011 3	0,013 9	0,014 1	0,014 4	0,015 1	0,008 4	0,013 1 (ΔC_{r_45})	0,002 5
$\Delta C_{g\_\Theta\_p}$	15°	0,002 2	0,001 1	0,0015	0,003 6	0,001 4	0,000 8	0,001 8	0,009 3	0,002 2	0,002 7 (ΔC_{g_15})	0,002 6
	30°	0,011 4	0,013 3	0,0014	0,006 7	0,004 3	0,004 7	0,003 6	0,010 8	0,012 9	0,007 7 (ΔC_{g_30})	0,004 5
	45°	0,007 0	0,014 2	0,0087	0,016 0	0,013 9	0,014 0	0,009 0	0,007 0	0,007 5	0,010 8 (ΔC_{g_45})	0,00 36
$\Delta C_{b\_\Theta\_p}$	15°	0,002 2	0,004 3	0,0011	0,003 0	0,001 4	0,002 0	0,001 5	0,002 9	0,002 3	0,002 3 (ΔC_{b_15})	0,001 0
	30°	0,004 0	0,006 5	0,0017	0,006 7	0,004 3	0,004 3	0,003 1	0,004 1	0,006 4	0,004 6 (ΔC_{b_30})	0,001 7
	45°	0,004 8	0,010 0	0,0048	0,007 5	0,006 3	0,005 8	0,004 1	0,009 4	0,004 5	0,006 3 (ΔC_{b_45})	0,002 2

Half-luminance angle	Left	80°	Right	80°	Sum	160°	–
Half-contrast angle	Left	70°	Right	70°	Sum	140°	

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