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TECHNICAL SPECIFICATION

colour inside

Flexible display devices –
Part 5-4: Measuring method of blur in flexible transparent displays

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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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 62715-5-4, which is a technical specification, has been prepared by IEC technical committee 110: Electronic displays.

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

Enquiry draft	Report on voting
110/1055/DTS	110/1084/RVTDS

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

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

A list of all 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 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- withdrawn,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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FLEXIBLE DISPLAY DEVICES –

Part 5-4: Measuring method of blur in flexible transparent displays

1 Scope

This part of IEC 62715 specifies the measuring conditions and measuring methods for determining the blur of objects when viewed through a flexible transparent display. This document mainly applies to flexible transparent display modules that have a constant radius curvature about a single axis. The display is measured in a static mechanical state.

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

IEC 62715-5-1, *Flexible display devices – Part 5-1: Measuring methods of optical performance*

3 Terms, definitions and abbreviated terms

For the purposes of this part of IEC 62715, the terms and definitions in IEC 62715-1-1 and the following 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 Terms and definitions

3.1.1
blur
unclear or indistinct outline of objects when they are viewed through a flexible transparent display

3.1.2
through-screen properties
image quality attributes when the intended information is behind the display panel and is viewed through it

3.1.3
pixel
smallest element of a picture that can be distinguished from its neighbouring elements

3.2 Abbreviated terms

DUT device under test

LMD light measuring device

PPI pixels per inch

4 Measuring conditions

4.1 Standard measuring environmental conditions

Measurements shall be carried out under the standard environmental conditions:

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

When different environmental conditions are used, they shall be noted in the test report.

4.2 Standard darkroom conditions

The luminance contribution from unwanted background illumination reflected off and/or transmitted through the DUT shall be less than 1/20 of the DUT'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 LMD is inadequate to measure at these low levels, then the lower limit of the LMD shall be noted in the test report.

4.3 Standard setup conditions

4.3.1 Display mounting

The fixture used to mount a curved display plays a critical role in obtaining accurate and reproducible results.[1][1] The display mount should be designed to accommodate the specific bendable characteristics of the flexible transparent display in its intended use configuration. The mount should be capable of maintaining the intended shape of the display and locate it in the required measurement position and viewing direction. The measuring methods specified in this document only apply for displays that have a constant radius of curvature about a single axis.

The origin of the coordinate system is positioned at the imaging surface of the DUT and centered on the screen. Unless otherwise specified, the optical axis of the LMD shall be aligned to within 1° of the DUT's surface normal at its centre. For spot-type LMDs, the retro-reflection of the LMD can be used to obtain this alignment. Otherwise, an alignment laser can be used to define the optical axis. The methods also assume that the rotation stages and mechanical mounting have sufficient accuracy and stability to maintain a tolerance of less than 1°.

4.3.2 Measuring configuration

Figure 1 illustrates the geometric configuration of the DUT, reference display device and LMD. The DUT is located in its intended use configuration using the display mounting fixture. It is positioned so that the optical axis of the LMD shall be aligned to within 1° of the DUT's surface normal at its centre. The purpose of the reference display device is to display a test pattern. A flat display can be used as a reference display device. It is positioned to be parallel to the DUT's surface normal at the centre. In Figure 1, the distance from the DUT to the reference display device is denoted as background distance. Background distance can be determined for convenience of measurement and based on the intended applications of the DUT. The LMD shall be focused on the test pattern.

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

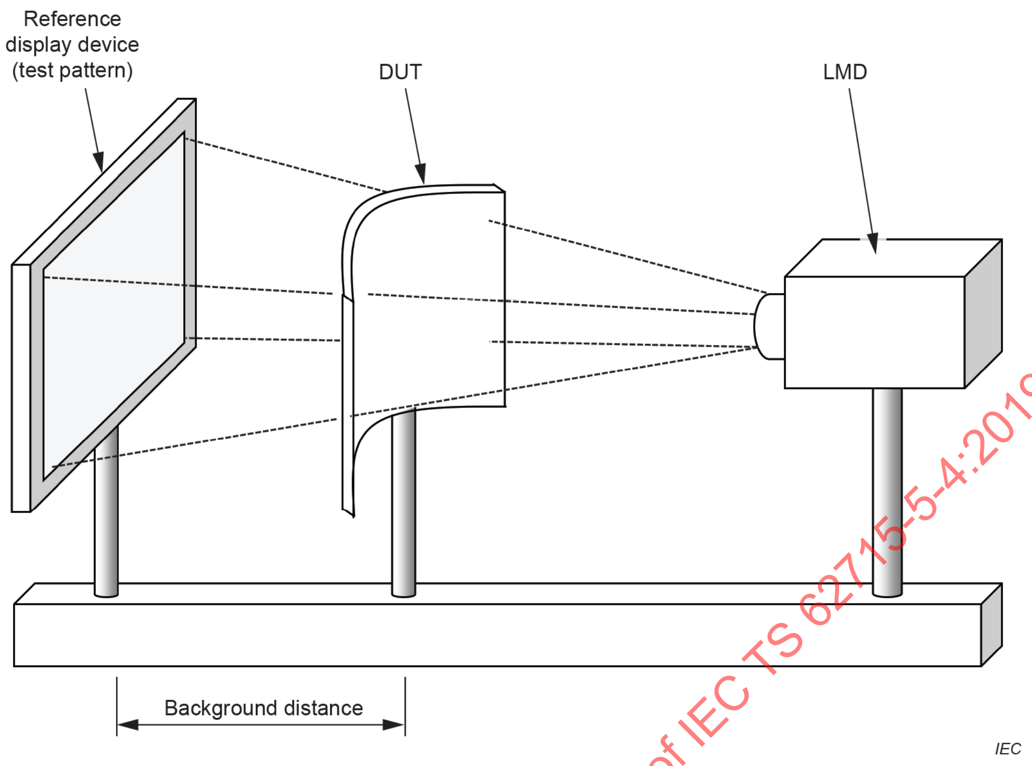


Figure 1 – Geometric configuration of measuring system

4.3.3 Starting conditions of measurements

Measurements shall be started after the DUT, reference display device and the LMD achieve stability. It is recommended that when the display is first turned on, it should be operated for at least 30 min. Sufficient warm-up time has to be allowed for both the DUT and reference display device to reach a luminance stability level of less than ± 3 % over the entire measurement.

4.3.4 Conditions of measuring equipment

The general conditions of the measuring equipment specified in IEC 62715-5-1 are adopted. Light measurements shall generally be measured in terms of photometric or colorimetric units for a CIE 1931 standard colorimetric observer [2]. Illuminance incident on the DUT can be measured by a photometer. The LMD shall be a luminance meter, colorimeter, or a spectroradiometer. An imaging LMD can be used for two-dimensional measurements of transmitted luminance to eliminate the need for translational motions. When a two-dimensional LMD is used for measurement, efforts shall be made so that the measurement results of the two-dimensional LMD are equal to those of the spot-type LMD. A moiré pattern from interference between the pixel patterns of the DUT and LMD can be prevented by focusing the LMD on the test target. If the test target is displayed on a reference display, a moiré pattern from interference between the pixel patterns of the reference display and the LMD can be prevented by using a reference display of high resolution (at least twice the resolution of the imaging LMD focused on the reference display, or by setting the spot LMD to a measurement field that includes more than 500 pixels of the reference display). When a two-dimensional LMD is not available, the measurement can be made by translating the spot-type LMD parallel to the surface of the reference display device and measuring the transmitted luminance along the line of measurement. When using a spot LMD and a translation scan, undesirable aliasing defects should be avoided by complying to the scanning theorem, for example choosing a sampling distance (the linear distance between consecutive spot measurements) not greater than 0,7 of the spot diameter.

The spectroradiometer shall be capable of measuring spectral radiance over at least the 380 nm to 780 nm wavelength range, with a maximum bandwidth of 10 nm for smooth broadband spectra. For light sources that have sharp spectral features, like LEDs and fluorescent lamps, the maximum bandwidth shall be ≤ 5 nm. The spectral bandwidth of the spectroradiometer shall be 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 shall be taken to ensure that the LMD has enough sensitivity and dynamic range to perform the required task. The measured LMD signal shall be at least ten times greater than the dark level (noise floor) of the LMD, and no greater than 85 % of the saturation level. If the LMD is not sensitive enough to measure a signal, and truncates the readout to zero, then the measurement is not acceptable and a more sensitive LMD is required.

The following requirements are given for the LMD:

1) The LMD shall be focused on the image plane of the reference display device as illustrated in Figure 1. The centre of the LMD shall be aligned perpendicularly to the centre of the reference display device, unless stated otherwise.
2) The relative uncertainty and repeatability of all the measuring devices shall be maintained by following the instrument supplier's recommended calibration schedule.
3) The LMD integration time shall be an integer number of frame periods, synchronized to the frame rate, or the integration time shall be greater than 200 frame periods.
4) The angular aperture in Figure 2 shall be ≤ 5°, and the measurement field angle shall be ≤ 1°.
5) The display shall be operated at its design field frequency. When using separate driving signal equipment to operate a panel, the drive conditions shall be noted in the test report.

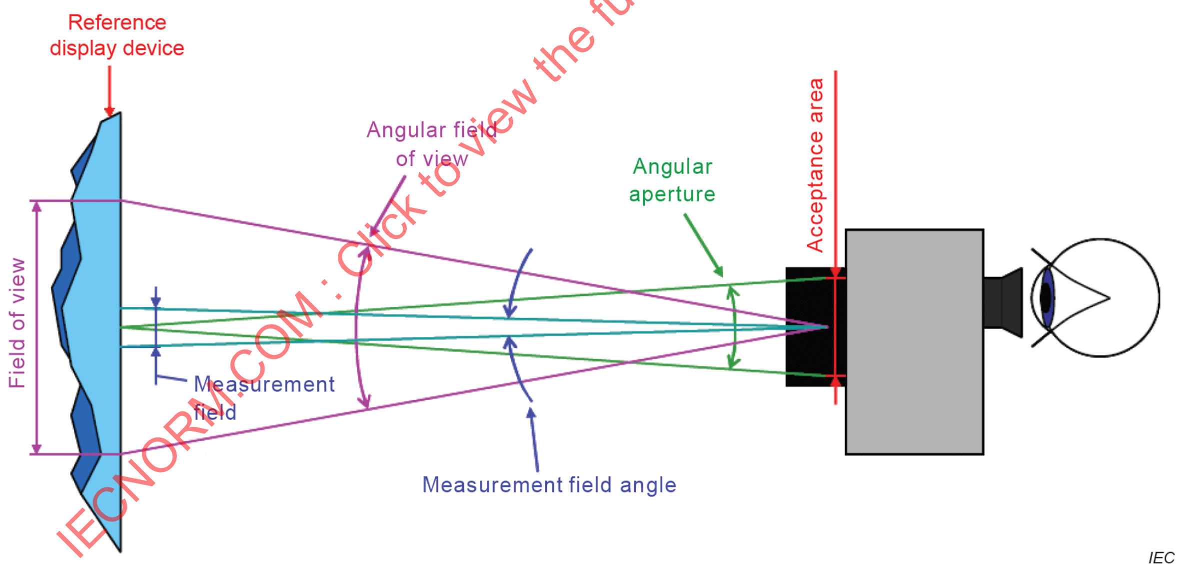


Figure 2 – Layout diagram of measurement setup

5 Blur caused by a flexible transparent display

5.1 Purpose

Figure 3a) illustrates an example of a black-to-white test pattern to be displayed in the reference display device. It mimics an object located behind the flexible transparent display. Figure 3b) illustrates an example of the transmitted image of the black-to-white test pattern in Figure 3a) when it is viewed through the flexible transparent display. The black-to-white test pattern in Figure 3a) is free of blur. However, the blur caused by the flexible transparent display can be noticed in Figure 3b). The purpose of this measurement method is to calculate the degree of blur caused by the flexible transparent display.

5.2 Measuring conditions

For this measurement, the following conditions shall be applied.

a) Apparatus:
   1) LMD that can measure luminance;
   2) reference display device to display the black-to-white test pattern behind the DUT;
   3) driving power source;
   4) driving signal equipment.

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

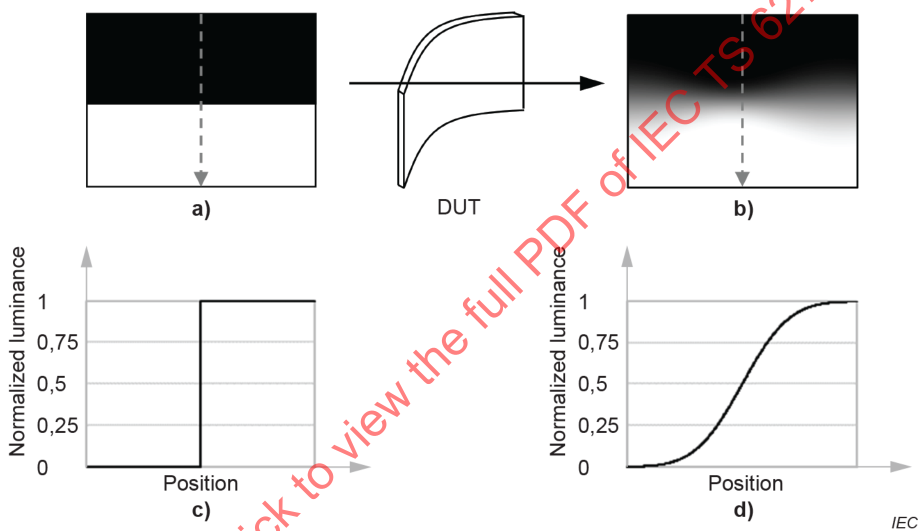


Figure 3 – Examples of test pattern with and without blur and luminance measurements

5.3 Measuring method

For this measurement, the following method shall be applied:

1) Allow sufficient time for the reference display device to reach thermal equilibrium. Then set a reference display device to display the black-to-white test pattern illustrated in Figure 3a). The test pattern in Figure 3a) has a black-to-white transition in the vertical direction. Alternatively, a test pattern with a black-to-white transition in the horizontal direction can also be used. The line of the measurement is illustrated as a dotted line in Figure 3a). The background distance along the line of measurement shall be the same because the blur of the see-through image depends on the background distance. The direction of the black-to-white transition of the test pattern shall be selected to maintain the same background distance along the line of measurement. The direction of the black-to-white transition shall be noted in the test report. In addition, the black and white patches within the test pattern can be placed in opposite positions. In addition to the direction of the black-to-white transition, the positions of the black and white patches within the test pattern shall be noted in the test report.

2) Allow sufficient time for the DUT to reach thermal equilibrium before making any measurements. Place the DUT in-between the reference display device and the LMD as illustrated in Figure 1. The DUT is positioned so that the optical axis of the LMD shall be aligned to within 1° of the DUT's surface normal at its centre. In addition, the reference display device is positioned to be parallel to the DUT's surface normal at its centre. During the measurement, the DUT is set to its maximum transparent state.
3) Coordinates of the measuring location in the line of measurement where the test pattern changes from black to white shall be determined by the method specified in IEC 62715-5-1. The measuring location shall be noted in the test report.
4) Perform a preliminary measurement of the transmitted luminance along the line of measurement using the LMD to estimate a width of blur that is defined as the width of the transition area from black to white (or white to black) (see Figure A.1). The estimated width of blur shall be noted in the test report.
5) Determine the diameter of a measurement field to measure the transmitted luminance, using the maximum diameters listed for different values of blur width in Table A.1. The values of the maximum diameters listed in Table A.1 represent the maximum diameters of a measurement field that prevent possible errors in the calculation of the value of a blur kernel. The selected diameter of a measurement field shall be noted in the test report.
6) When measuring the transmitted luminance, the LMDs should be set to a measurement field that includes more than 500 pixels in a reference display device. Table A.2 in Annex A lists the number of pixels within a measurement field for different combinations of the measurement field diameters and the PPI of a reference display device. The configuration of a reference display device shall be noted in the test report.
7) Determine a distance from the LMD to the reference display device so that the selected measurement field diameter is equivalent to a measurement field angle of 1°. Table A.4 in Annex A lists combinations of the measurement field diameter and corresponding distance from the LMD to the reference display device yielding a measurement field angle of 1°. Background distance, the distance from the DUT to the reference display device, can be determined for convenience of measurement and based on the intended applications of the DUT. The distance from the LMD to the reference display device as well as the selected background distance shall be noted in the test report.
8) Measure the transmitted luminance along the line of measurement using the LMD having a measurement field angle of 1°. The LMD measurement field should be contained completely within the target area defined by the 1° measurement field angle. A two-dimensional LMD can be used to obtain the transmitted luminance values along the line of measurement by a single measurement. When a two-dimensional LMD is not available, the measurement can be made by translating the spot type LMD parallel to the surface of the reference display device and measuring the transmitted luminance along the line of measurement. For example, values of Y from CIE 1931 XYZ can be measured by a spectroradiometer and used as the value of the transmitted luminance.
9) The LMD shall be focused on the image plane of the reference display device. The centre of the LMD shall be aligned perpendicularly to the centre of the reference display device surface, unless stated otherwise. The amount of transmitted luminance shall consist of more than 200 measurements along the line of measurement. Care shall be taken to ensure that most of the 200 measurements are located in the luminance transition area because the measurements taken in the area with saturated luminance (black or white) do not contain valuable information on blur caused by a flexible transparent display.
10) The measured values of the transmitted luminance are normalized so that the maximum value of the measurement is 1. For example, Figure 3c) and d) illustrate the graphs of the normalized luminance values along the lines of measurement. The horizontal axis in Figure 3c) and d) denotes measuring positions along the line of measurement marked as the dotted lines in Figure 3a) and b), respectively. The vertical axis in Figure 3c) and d) denotes the normalized values of the measured luminance. The staircase line in Figure 3c) represents an ideal luminance transition free of image blurring. However, the smooth luminance transition curve in Figure 3d) exhibits the blur in Figure 3b).
11) The blur caused by the DUT is represented by the Gaussian blur model in Formula (1).

$$g(k,\sigma)=\frac{1}{\sqrt{2\pi\sigma^2}}\exp(-\frac{(k-M/2)^2}{2\sigma^2}) \qquad 1\leq k\leq M \tag{1}$$

In Formula (1), k represents the normalized luminance measured at the k^{th} measuring location. M denotes the number of measurements. As specified in step 9), M shall be greater than 200. In addition, σ in Formula (1) represents a standard deviation of the Gaussian model. For example, the blurred luminance transition curve as illustrated in the example in Figure 3d) can be obtained by the convolution of the step function representing the ideal response without blur (as in Figure 3c)) and the Gaussian blur kernel denoted in Formula (1). Figure 4b) graphically illustrates the process of convolution of the step function and the Gaussian blur kernel specified by the standard deviation. As schematically illustrated in Figure 4, the standard deviation specifying the Gaussian blur model is calculated by minimizing the mean squared error between the luminance transition data in Figure 4a) and the results of the convolution in Figure 4b).

12) Suppose that the measured luminance of the ideal luminance transition curve of a step function in Figure 4b) is denoted by a 1 x M vector $\mathbf{L}_{\text{ideal}}$, where M is the number of transmitted luminance measurements. The components in the first half of $\mathbf{L}_{\text{ideal}}$ are all 0s and those in the latter half are all 1s. Assume that the one-dimensional Gaussian kernel is expressed by Formula (1). Suppose that the Gaussian blur kernel in Formula (1) is also denoted by a 1 x M vector $\mathbf{G}_{\sigma} = [g(1, \sigma), g(2, \sigma), g(3, \sigma), \ldots, g(M, \sigma)]$. Then, the one-dimensional convolution of the ideal step response and the Gaussian blur kernel in Formula (1) can be represented in a vector form as Formula (2).

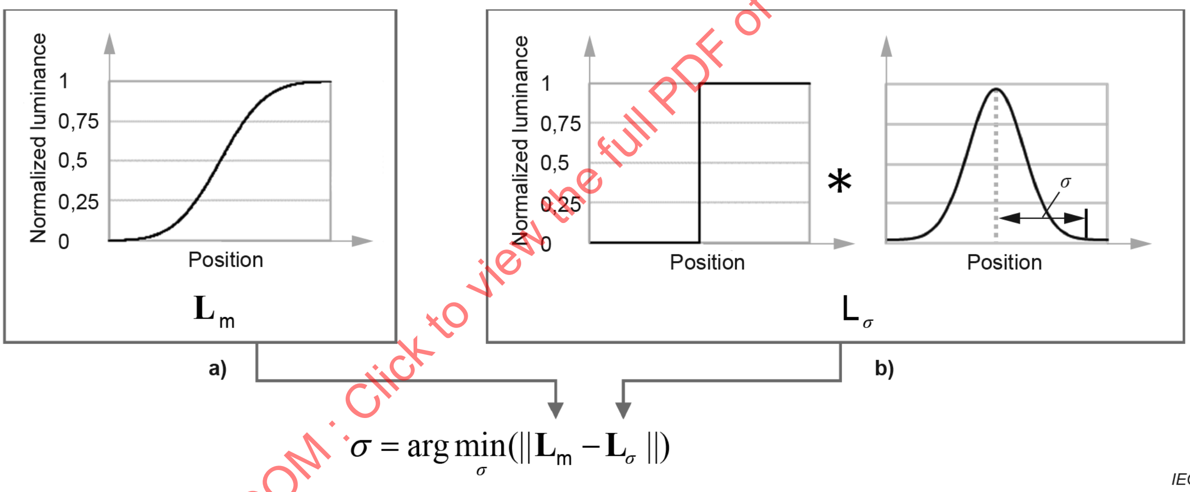


Figure 4 – Schematic diagram to illustrate the method of calculating the standard deviation specifying the Gaussian blur model

$$\mathbf{L}_{\sigma}{}^{t} = \mathbf{T}\mathbf{G}_{\sigma}{}^{t} \tag{2}$$

13) In Formula (2), t represents the transpose operation. $\mathbf{T}$ is a Toeplitz matrix of size M x M specified in the following Formula (3).

$$\mathbf{T}=\begin{bmatrix} 0 & 0 & 0 & \cdots & 0 & 0 & 1 \\ 0 & 0 & 0 & \cdots & 0 & 1 & 1 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 1 & 1 & \cdots & 1 & 1 & 1 \\ 1 & 1 & 1 & \cdots & 1 & 1 & 1 \end{bmatrix} \tag{3}$$

14) The standard deviation of the Gaussian blur kernel is determined by using the optimization criterion specified in Formula (4).

$$\sigma = \arg\min_{\sigma} \left(\| \mathbf{L}_{\mathrm{m}} - \mathbf{L}_{\sigma} \| \right) \tag{4}$$

In Formula (4), $\mathbf{L}_{\mathrm{m}}$ represents the normalized luminance measured along the line of measurement. $\mathbf{L}_{\sigma}$ represents the results of the convolution illustrated in Figure 4 b). In addition, $\|\cdot\|$ denotes the vector norm operation. The calculated value of the standard deviation based on the criterion in Formula (4) shall be noted in test report as the value of the blur measure.

15) Report the results of the measurements as shown in the examples in Table 1. The notation for the measuring location in the first column of Table 1 is specified in IEC 62715-5-1. Blur caused by a flexible transparent display may not be isotropic. It is recommended that two test patterns with opposite positions of black and white patches are used to calculate the blur measure for a given measuring location.

Table 1 – Example of test report for blur measure

Measuring location	Background distance	σ	Direction of black-to-white transition	Position of black and white patches
P_0	15cm	26,91	Vertical	Top-black, bottom-white
P_0	15cm	26,92	Vertical	Top-white, bottom-black
P_{13}	25cm	40,42	Vertical	Top-black, bottom-white
P_{21}	35cm	53,90	Vertical	Top-black, bottom-white
Width of blur in preliminary measurement (mm)			400	
Measurement field diameter (mm)			32	
Reference display device			65 in diagonal, 34 PPI	
Distance from LMD to reference display device (mm)			1 840	

Annex A
(informative)

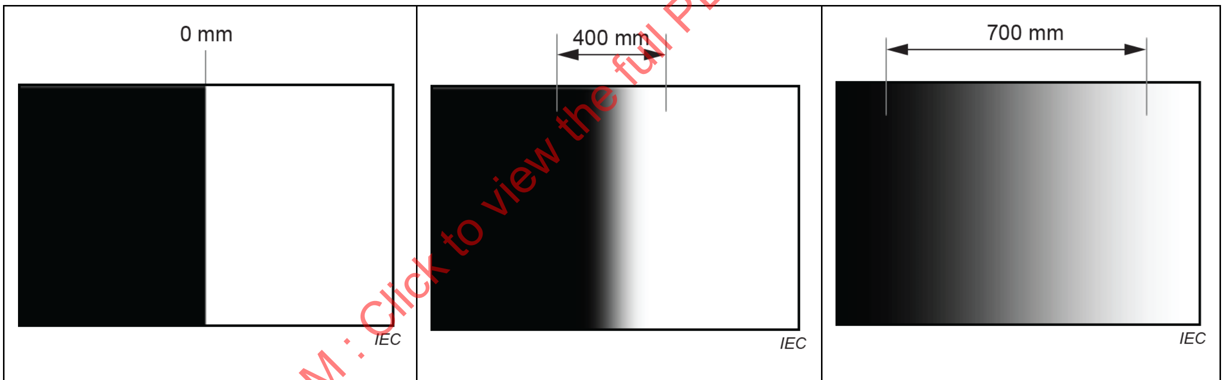
Example of blur measurement configuration

A.1 Purpose

The accuracy of the blur measurement depends on the size of the measurement field. The size of a measurement field will be reduced to maintain the accuracy of the blur measurement. However, it will be large enough to obtain a consistent measurement of the transmitted luminance. When measuring the transmitted luminance, the LMDs should be set to a measurement field that includes more than 500 pixels in a reference display device. The purpose of Annex A is to provide examples of blur measurement configurations in order to select parameters for measurement of the transmitted luminance.

A.2 Examples of parameters in blur measurement

Figure A.1 illustrates different levels of blur. Figure A.1a) represents an ideal case without blur. A width of blur is defined as the width of the transition area from black to white (or white to black) as indicated by arrows in Figure A.1b) and c). The narrower a width of blur, the smaller a measurement field in order to achieve the desired accuracy of blur measurement. Therefore, the first task of determine a measurement field for blur measurement is to estimate a width of blur.



a) width of blur = 0 mm (ideal case) **b) width of blur = 400 mm** **c) width of blur = 700 mm**

Figure A.1 – Examples of different levels of blur

If a measurement field is smaller than a certain threshold value, the calculated measure of blur remains unchanged. However, if a size of a measurement field exceeds the threshold value, an error may be expected to occur in the calculation of a blur measure. Such a threshold can also be called as the maximum size of a measurement field. Table A.1 lists the maximum diameters of a measurement field without yielding an error in the calculation of a blur measure. They are determined experimentally. For example, when the width of blur = 100 mm, the value of the blur measure (value of the estimated standard deviation) will remain the same if the measurement field (in diameter) is less than 16 mm as specified in the second row of Table A.1.

When measuring the transmitted luminance, the LMDs should be set to a measurement field that includes more than 500 pixels in a reference display device. Table A.2 lists the number of pixels within a measurement field for different combinations of the measurement field diameters and PPI of a reference display device. Table A.3 lists a number of PPI values for possible configurations of the reference display devices.

Table A.1 – Examples of the maximum measurement field diameter for different values of blur width

Width of blur	Maximum diameter of a measurement field without change in the estimated value of blur kernel (diameter in mm, measurement locations = 200)
100 mm	16
200 mm	22
300 mm	27
400 mm	32
500 mm	34
600 mm	37
700 mm	39

Table A.2 – Examples of the maximum measurement field diameter for different values of blur width

Width of blur	Maximum diameter of a measurement field (mm)	Number of pixels within a measurement field		
		PPI of a reference display device		
		34 PPI	68 PPI	102 PPI
100 mm	16	468	1 870	4 260
200 mm	22	884	3 536	8 055
300 mm	27	1 332	5 326	12 132
400 mm	32	1 870	7 481	17 041
500 mm	34	2 111	8 446	19 238
600 mm	37	2 500	10 002	22 783
700 mm	39	2 778	11 112	25 312

Table A.3 – Examples of PPI for different configurations of a reference display device

Size of display (diagonal in inch)	PPI	
	Number of pixels (1 920 x 1 080)	Number of pixels (3 840 x 2 160)
43	51	102
55	40	80
65	34	68

The diameter of a measurement field is selected using Table A.1. It is a maximum value of the measurement field diameter without yielding an error in the calculation of a blur measurement. It is possible to calculate a distance from the LMD to the reference display device so that the selected measurement field diameter is equivalent to a measurement field angle of 1°. Table A.4 lists combinations of the measurement field diameter and corresponding distance from the LMD to the reference display device yielding a measurement field angle of 1°.

Literature on the blur measurement based on the Gaussian blur kernel can be found in [3]. In addition, an alternative method for edge blur evaluation can be found in [4].