IEC 63145-20-10

Edition 1.0 2019-08

INTERNATIONAL STANDARD

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Eyewear display –
Part 20-10: Fundamental measurement methods – Optical properties

IEC 63145-20-10:2019-08(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 17.180.99; 31.120

ISBN 978-2-8322-7269-5

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FOREWORD

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International Standard IEC 63145-20-10 has been prepared by IEC technical committee TC 110: Electronic displays.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
110/1105/FDIS	110/1131/RVD

Full information on the voting for the approval of this International Standard 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 63145 series, published under the general title *Eyewear display*, 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- withdrawn,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
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EYEWEAR DISPLAY –

Part 20-10: Fundamental measurement methods – Optical properties

1 Scope

This part of IEC 63145 specifies the standard measurement conditions and measurement methods for determining the optical properties of eyewear displays. This document applies to non-see-through type (virtual reality "VR" goggles) and see-through type (augmented reality "AR" glasses) eyewear displays using virtual image optics.

Contact lens-type displays and retina direct projection displays are out of the scope of this document.

2 Normative references

There are no normative references in this document.

3 Terms, definitions, abbreviated terms and letter symbols

3.1 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

3.1.1
entrance pupil of the LMD
optical image of the physical aperture stop, as 'seen' through the front of the LMD lens system

Note 1 to entry: If there is no lens in front of the aperture, the entrance pupil's location and size are identical to that of the aperture stop.

3.1.2
eye-box
qualified viewing space
three-dimensional space within which users place their eye so as to be able to properly see the entire virtual image without moving the head or making any other adjustment (other than the natural rotation of the eye)

Note 1 to entry: "Able to properly see" means that the display image fulfils all the requirements indicated in the product specification.

3.1.3
eye point
design location at which the entrance pupil of the eye is placed to achieve the optimal performance when using an eyewear display and which serves as the origin location of the measurement

Note 1 to entry: An estimating example is shown in Annex A.

3.1.4
eye relief
distance from the cornea of the eye to the closest optical element of the virtual-image display

3.1.5
field of view
angular region subtending the proper active area of the virtual image as observed from the eye point of the eyewear display

Note 1 to entry: "Proper" means that the display image fulfils all the requirements indicated in the product specification, for example the limits of luminance, resolution, etc.

3.1.6
measurement direction
direction from which the eye point views the virtual image, as measured relative to the optical axis of the eyewear display using spherical coordinates

Note 1 to entry: See Figure 1.

3.1.7
pixel angular density
pixel number per unit degree

3.2 Abbreviated terms

AR augmented reality

CCD charge-coupled device detector

DUT device under test

FOV field of view

LMD light measuring device

VR virtual reality

3.3 Letter symbols (symbols for quantities and units)

The letter symbols for eyewear displays are shown in Table 1.

Table 1 – Letter symbols (symbols for quantities and units)

Quantities	Symbol	Unit
Measuring point (i = 0: centre)	P_i	
Arbitrary luminance of a position (x, y, z) and direction (α, Ψ) on the eyewear display	$L_v(x, y; z, \alpha, \Psi)$	cd/m^2
Maximum luminance	L_{vM}	cd/m^2
Minimum luminance	L_{vm}	cd/m^2
Average luminance (spatial)	L_{va}	cd/m^2
Centre luminance	L_{vC}	cd/m^2
Luminance uniformity	U	%
Luminance non-uniformity	NU	%
Angle of horizontal FOV	A_h	degree
Angle of vertical FOV	A_v	degree
Angle of diagonal FOV	A_d	degree
Width of eye-box	W_{box}	mm
Height of eye-box	H_{box}	mm
CIE 1976 chromaticity coordinates at P_i	u'_i, v'_i	
Chromaticity difference in CIE 1976 uniform-chromaticity-scale diagram	$\Delta u'v'$	
Contrast ratio	CR	
Pixel angular density	D_L	pixel per degree (ppd)
Solid angle of measurement field	Ω	sr

4 Standard measurement conditions

4.1 Standard environmental conditions

Unless otherwise specified, all tests and measurements for eyewear displays shall be carried out after sufficient warm-up time for the illumination sources and DUT (see 4.3), under the following standard environmental conditions:

– temperature 22 °C to 28 °C,
– relative humidity 25 % to 85 %, and
– atmospheric pressure 86 kPa to 106 kPa.

When different environmental conditions are used, they shall be reported in detail in the specification.

4.2 Power supply

In order to stabilize the performances of the DUT, the power supply for driving the DUT shall be adjusted according to the specification of the DUT.

NOTE When the DUT is driven by a battery, it is less susceptible to power supply fluctuations.

4.3 Warm-up time

The optical performances of DUT are affected by the transient temperature behavior of the device. It takes a certain time for the luminance output of the DUT to achieve a steady state.

If the luminance output is not within a ±3 % variation, it shall be reported. All measuring conditions shall be kept constant during the measurements.

NOTE If the measurement result does not become a steady state, it might be influenced by the output fluctuation of the DUT and/or the fluctuation of the LMD such as noise.

4.4 Dark room condition

The luminance contribution from the background in the test room reflected off the measurement space shall be less than 1/20 of the minimum luminance output from the DUT. If the condition is not satisfied, then background subtraction is required and it shall be noted in the report.

5 Measurement systems

5.1 Standard coordinate system

To indicate the spatial positions of virtual images, a spherical coordinate system of elevation (latitude) and azimuth (longitude) shall be used in the measurements; the polar axis is vertically oriented as shown in Figure 1. The angles measured in the vertical half plane of the data are elevation angles, denoted as α, and the horizontal angles to the half plane are azimuth angles, denoted as Ψ. The origin direction (α = 0, Ψ = 0) of the spherical coordinate system shall be coincident with the optical axis of the DUT.

NOTE 1 The spatial positions of the virtual image can be expressed in a geographic coordinate chart, as shown in Annex B.

A three-dimensional Cartesian coordinate system (x, y, z) is used to indicate the positional relationship among the eye-box, eye point, eye relief of the DUT, entrance pupil of the LMD and so on, as shown in Figure 2. Unless specified otherwise, the eye point of the DUT is placed at the centre of the entrance pupil of the eye, and defined as the origin of the coordinate system. The manufacturer or supplier of the DUT shall specify the eye point position or the eye relief.

The origins of both the spherical coordinate system and the Cartesian coordinate system shall be located at the eye point.

NOTE 2 In the case of a binocular eyewear display, the left ocular can be used as the origin of the Cartesian coordinate system.

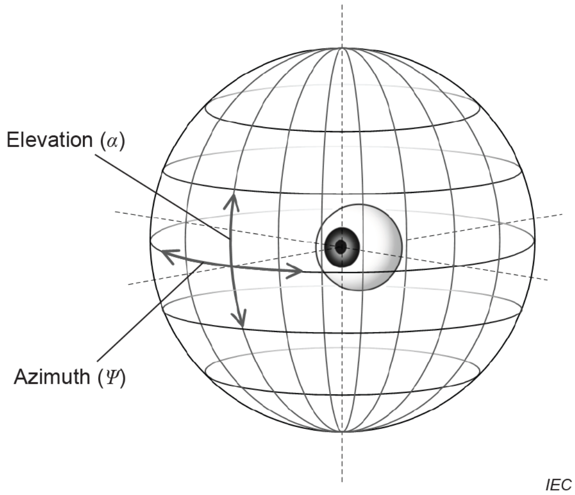
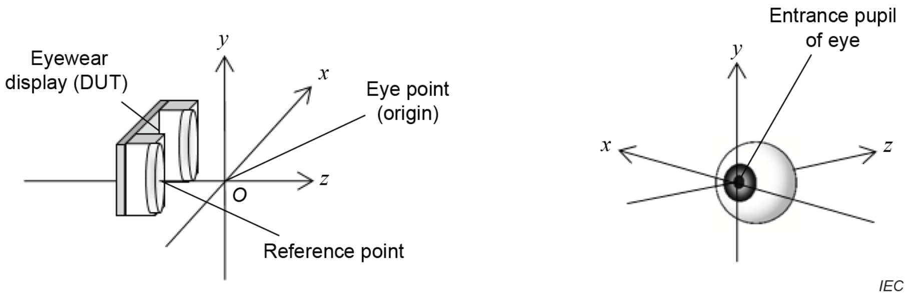


Figure 1 – Spherical coordinate system



NOTE This figure is an example of the entrance pupil of the eye located at the eye point of the DUT.

Figure 2 – Three-dimensional Cartesian coordinate system

5.2 Measurement equipment

5.2.1 Light measuring device (LMD)

5.2.1.1 General

The configurations and operating conditions of the equipment should comply with the structures specified in each item. To ensure accurate measurements, the following requirements shall be applied. Otherwise, the differences shall be noted in the report. ISO/CIE 19476 [8][1] describes the LMD evaluation procedures.

The optics of the LMD (a spot LMD or a 2D imaging LMD) shall be equivalent to the human eye, as shown in Figure 3. The LMD shall be equipped with a finder. The position of the entrance pupil (aperture) of the LMD shall be provided by the manufacturer or the supplier. The size of the entrance pupil of the LMD should be set between 2 mm and 5 mm, and shall be smaller than the output light field of the DUT. The LMD to measure the optical characteristics such as luminance and colour shall be calibrated with the appropriate photometric or spectrometric standards. The LMD should be carefully checked before measurements, considering the following points:

– sensitivity of the measured quantity to measuring light;
– errors caused by the veiling glare and lens flare (i.e., stray light in the optical system);
– timing of data-acquisition, low-pass filtering and aliasing-effects;
– linearity of detection and data conversion;
– measurement field size.

NOTE See IEC TR 63145-1-1:2018 [1], 6.2.

1 Numbers in square brackets refer to the Bibliography.

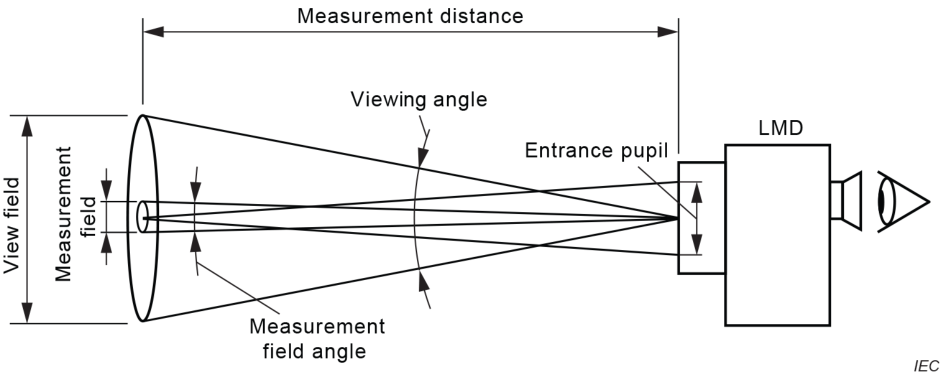


Figure 3 – Example of LMD structure

5.2.1.2 Spectrometer-type LMD

When a spectrometer-type LMD such as a spectroradiometer is used, the wavelength range shall be at least 380 nm to 780 nm, the spectral bandwidth shall be 5 nm or smaller, and the wavelength accuracy shall be 0,3 nm or smaller.

5.2.1.3 Filter-type LMD for measuring luminance

When a filter-type LMD such as a luminance meter is used to ensure the luminance accuracy for the intended DUT light sources, its spectral responsivity should comply with the spectral luminous efficiency for CIE photopic vision or it should be compared with a calibrated spectrometer. The spectral mismatch correction factor can be applied, if necessary.

NOTE CIE-f_1' indicates the spectral mismatch factor between the spectral responsivity of the filter-type LMD and the CIE photopic luminous efficiency function. Details of the spectral mismatch correction factor are given in ISO/CIE 19476 [8].

5.2.1.4 Filter-type LMD for measuring colour

When a filter-type LMD such as a colorimeter is used to ensure the colour accuracy for the intended DUT light sources, its spectral responsivity should comply with the CIE colour-matching functions for the CIE 1931 standard colorimetric observer (see ISO 11664-1 [7]) or it should be compared with a calibrated spectrometer. The colour correction factors can be applied, if necessary. The filter-type LMD shall not be used for absolute colour quantities, but for relative colour quantities such as colour uniformity.

5.2.1.5 2D imaging LMD

The 2D imaging LMD (using a two-dimensional sensor such as a CCD) is a kind of a filter-type LMD. The performances of the 2D imaging LMD shall comply with 5.2.1.3 and 5.2.1.4. The valid measurement field angle of the 2D imaging LMD shall be confirmed and the peripheral image of the 2D imaging LMD shall confirm the absence of vignetting. The number of pixels of the 2D imaging LMD should not be less than four times the virtual image sub-pixels number within the measurement field.

NOTE 1 The measurement field of some 2D imaging LMDs is affected by the smaller entrance aperture.

NOTE 2 The 2D imaging LMD using a colour filter array might cause moiré.

5.2.2 Stage conditions

5.2.2.1 General

The stage shall be used to realize the coordinate system specified in 5.1. The stage should be constructed with the equivalent of a biaxial goniometer and an orthogonal three-axis translation stage.

5.2.2.2 Goniometer

A biaxial goniometer shall be assembled to be capable of measuring the azimuth (horizontal) and elevation (vertical) angles in the spherical coordinate system as shown in Figure 1. Examples of a five-axis stage are shown in Figure 4. The angular accuracy should be 0,1° or less. The goniometer can be pivoted at the centre of the entrance pupil of the LMD or 10 mm behind the entrance pupil.

5.2.2.3 Translation stage

An orthogonal three-axis translation stage is assembled with an adequate range to cover the measuring distance such as the eye-box volume, and, if necessary, to cover the interpupillary distance for binocular DUTs, as in the examples shown in Figure 4. The translation accuracy should be 0,05 mm or less.

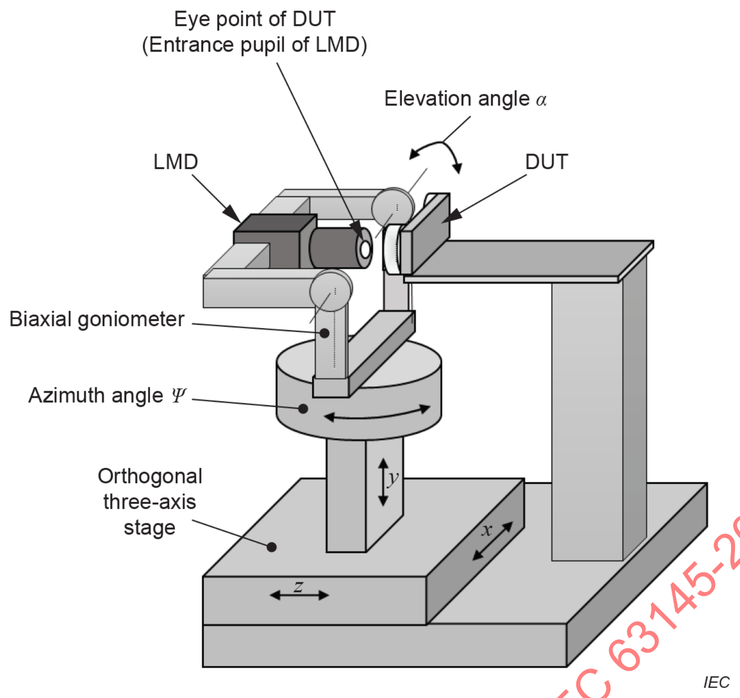
5.2.3 Setup conditions

The DUT shall be mounted on a stable platform to ensure image stability. The LMD position relative to the DUT shall be moved, and it can use a five-axis system (a biaxial goniometer and orthogonal three-axis translation stage). Examples of a measuring setup are shown in Figure 4. The eye point of the DUT shall match the origin of the biaxial goniometer. The optical axis of the DUT which is decided by the manufacturer or supplier shall be adjusted to the optical axis of the LMD and shall be aligned with the z-axis of the orthogonal three-axis translation stage. The aspect of the virtual image of DUT shall be adjusted to the x- and y-axes of the orthogonal three-axis translation stage.

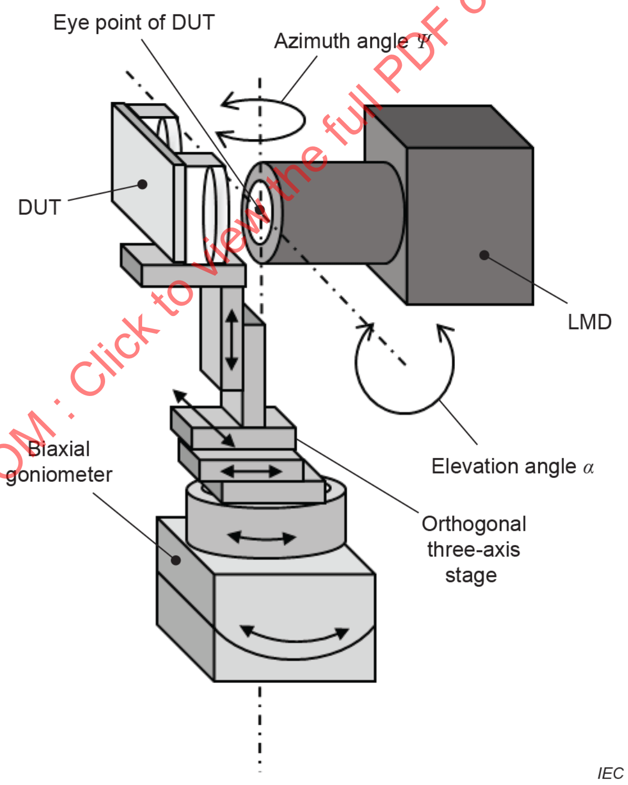
To measure the condition from an anterior view, when the DUT does not suppose a change of gaze angle (eye rotation), the origin of a biaxial goniometer shall be assumed as the entrance pupil of the eye (i.e. eye point of the DUT), not the rotation centre of the eyeball (eye movement). When the origin of the biaxial goniometer does not match the eye point of the DUT, the coordinate correction shall be required and shall be reported. When the DUT supposes a change of the gaze angle, the detailed information such as the position of the rotation centre shall be specified by the manufacturer or the supplier and shall be reported.

NOTE 1 The cornea position is about 3 mm in front of the iris position. Some optical designs are used based on the cornea position.

NOTE 2 The rotation centre of the eyeball is located about 10 mm behind the iris (entrance pupil of the eye).



a) LMD mounted on a biaxial goniometer and an orthogonal three-axis translation stage



b) DUT mounted on a biaxial goniometer and an orthogonal three-axis translation stage

NOTE 1 When the LMD is installed on the biaxial goniometer, the elevation stage is set on the azimuth stage.

NOTE 2 Some eyewear displays change their virtual image depending on their orientation.

Figure 4 – Examples of measurement setup

5.3 Test patterns

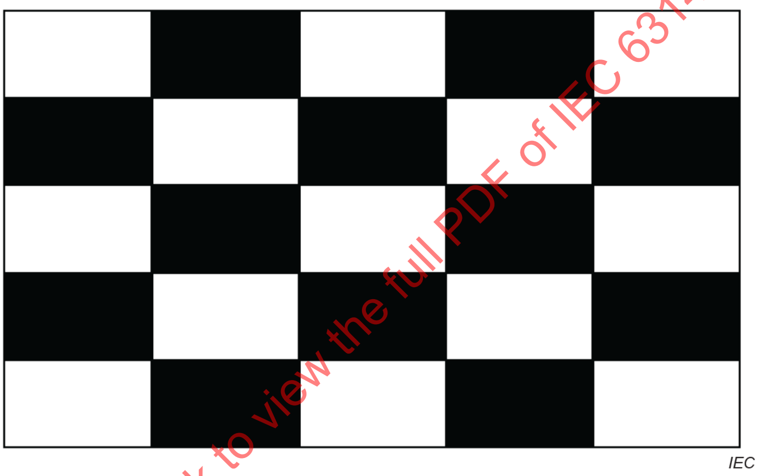
5.3.1 General

The following test patterns shall be specified by the manufacturer or the supplier, and the applied test pattern shall be noted in the report. When other test patterns are applied, they shall be noted in the report.

NOTE Unlike a conventional display, the boundary of the display area is not clear, and the choice of test pattern might affect the measurement results.

5.3.2 Checkerboard pattern

The checkerboard pattern as shown in Figure 5 should be used to measure the applicable properties and can be used for alignment of the DUT and LMD optics. The checkerboard pattern with crosses, whose example is specified in ISO 9241-305 [6], should also be used for alignment of the DUT and LMD optics. Both patterns of white and black at the centre can be used. Usually, a white and black checkerboard pattern is used, but a checkerboard pattern of another colour (red, green, blue and so on) and black can be used if necessary.



NOTE The 5 x 5 checkerboard pattern is helpful in navigating across the virtual image and focusing the LMD.

Figure 5 – Example of 5 x 5 checkerboard pattern

5.3.3 Solid colour patterns

The solid colour patterns can be used to measure the optical qualities. The colours should be defined in terms of the display primaries as white, black, red, green and blue. The pattern (full screen) is filled with a single colour.

5.4 Measuring points

The centre point (one point) or the multi-point (five points or nine points) measurements shall be applied, which are provided by the manufacturer or supplier. The measuring point(s) of one-point, five-point, and nine-point measurements are P_0, P_0 to P_4, and P_0 to P_8, respectively, as shown in Figure 6. When using other measuring points the manufacturer or the supplier should point out these positions. The applied measuring points are defined in each measuring item. If other measuring points are applied, this shall be defined in the relevant specification.

NOTE The centre point measurement is carried out to measure the typical characteristics of the DUT. The five-point and nine-point measurements are carried out to measure the deviations, averages, and uniformities.

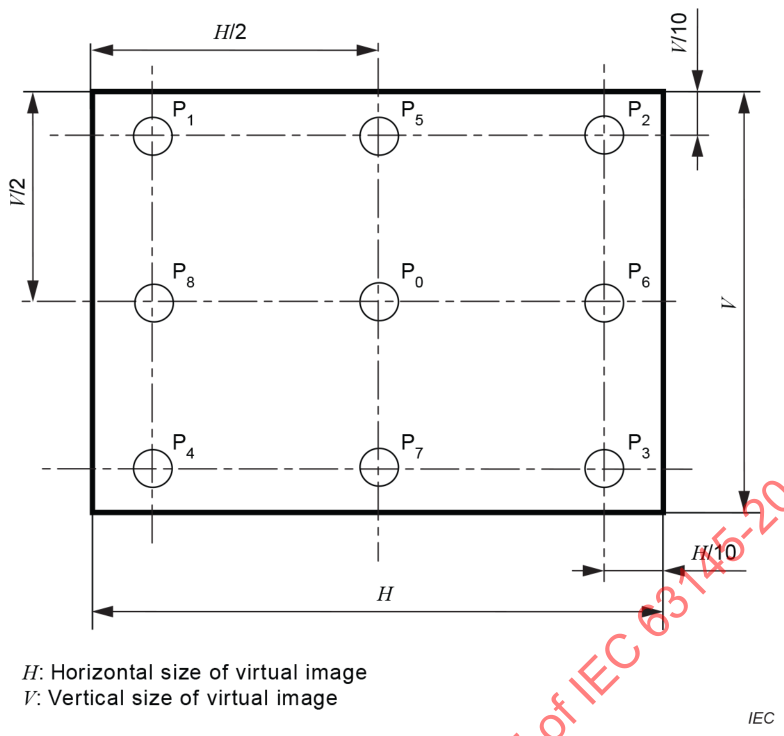


Figure 6 – Measuring points for the centre and multi-point measurement

6 Measurement methods for optical characteristics

6.1 General

In order to evaluate the optical characteristics of an eyewear display, the luminance, colour (chromaticity coordinates), contrast ratio, FOV, eye-box and pixel angular density shall be measured. The FOV and eye box are calculated based on the luminance and contrast ratio.

6.2 Preparation

The eyewear display to be measured (DUT) should be placed in the measurement arrangement specified in 5.2.3 using the chekerboard pattern specified in 5.3.2. The entrance pupil of the LMD and the eye point of the DUT shall match the origin position of the five-axis system ($x = 0$, $y = 0$, $z = 0$, $\alpha = 0$, $\Psi = 0$).

NOTE In case the pivoting point of the LMD is 10 mm behind the entrance pupil, this pivoting point can be used, instead of the entrance pupil, to match the origin position of the measurement.

The DUT-adjustable conditions which are related to the optical properties shall be specified by the manufacturer or supplier and reported. Some DUTs use image processing, and if a setting for the image processing is also adjustable, the default setting specified by the manufacturer or the supplier shall be applied and reported.

The focus of the LMD shall be adjusted through the image finder to become the clear virtual image. A raster pattern with a high resolution (the highest resolution is one-by-one line pair) which is appropriate for the DUT and provided by the manufacturer or the supplier, can be applied for adjustment of the virtual image focus.

The optical measurement capabilities of the LMD, such as luminance and spectral radiance, should be traceable to national metrology standards under the same conditions (for example entrance pupil size, measurement field angle and focus distance in some structures).

The optical quantities at different measuring points (directions) should be measured at the steady state after the required time specified in 4.3.

NOTE Some eyewear displays have eye-tracking capabilities for optimizing the image. The gaze direction of the LMD might not agree with the gaze direction as detected by the DUT for a true eye.

6.3 Luminance and luminance uniformity (non-uniformity)

6.3.1 General

The purpose of this method is to measure the luminance and luminance uniformity of the DUT, by positioning the entrance pupil of the LMD at the eye point. The LMD will pivot at the entrance pupil to point to the desired virtual image measurement position.

NOTE 1 In case the pivoting point of the LMD is 10 mm behind the entrance pupil, this pivoting point can be used, instead of the entrance pupil, to match the eye point of the DUT.

The standard measurement conditions (Clause 4), standard coordinate system (5.1), measurement equipment (5.2) and checkerboard pattern (5.3.2) shall be applied.

NOTE 2 For wide-field-of-view DUTs, the checkerboard pattern might not be accurate enough. In that case, the manufacturer or supplier will specify the pattern.

6.3.2 Measurement procedure

The luminance values, $L_{\text{v}}(0, 0, 0, \alpha, \Psi)$, of the nine points on the virtual image are measured using the as following procedure:

a) Position the DUT.

b) Display the checkerboard pattern with the white centre.

c) Adjust the LMD to match the entrance pupil at the eye point of the DUT and focus at a specified virtual image distance.

d) Adjust the measurement direction of the LMD to align to position P_i (i = 0 to 8).

e) Measure the luminance $L_{\text{v}i}$ $(0, 0, 0, \alpha_i, \Psi_i)$ of the DUT at position P_i.

f) Repeat for the other ocular, if applicable.

6.3.3 Calculation

Luminance non-uniformity, NU, is calculated by using the following formula:

$$NU = \frac{L_{\text{vM}} - L_{\text{va}}}{L_{\text{va}}} \text{ x } 100\ \% \qquad (1)$$

where

L_{vM} is the maximum luminance value of the measurement points;

L_{va} is the average luminance value, which is calculated by the following formula:

$$L_{\text{va}} = \frac{1}{9}\sum_{i=0}^{8} L_{\text{v}i} \qquad (2)$$

where

$L_{\text{v}i}$ is the luminance value of the measurement at position P_i.

For some applications, luminance uniformity, U, is applied and is calculated by the following formula:

$$U = 100 - NU\% \tag{3}$$

6.3.4 Report

The following items should be reported:

- luminance $L_{vi}(0, 0, 0, \alpha_i, \Psi_i)$ of each position P_i, with the elevation angle α_i and the azimuth angle Ψ_i;
- luminance non-uniformity (or luminance uniformity);
- eye point (eye relief);
- pivot rotation;
- type of LMD and aperture size;
- accuracy of sample stage; and
- correction methods for the measurement, if possible.

NOTE Some eyewear displays are designed as non-uniform displays to give priority to other features such as a large FOV.

6.4 Chromaticity and colour gamut

6.4.1 General

The purpose of this method is to evaluate the chromaticity area and colour gamut of the DUT as viewed from the eye point. In case of multi-primary displays, the gamut shall be measured by the white and primary colours at the maximum input of the RGB channels in sequence, and may also include a measurement of the secondary colours.

The standard measurement conditions (Clause 4), the standard coordinate system (5.1), the measurement equipment (5.2) and the solid colour patterns (5.3.3) shall be applied. An LMD that can measure colour quantities shall be used.

6.4.2 Measurement procedure

Measure the chromaticity of the DUT using the following procedure:

a) Move the entrance pupil of LMD at the eye point and adjust the optical axis of the LMD so that it is orientated toward the DUT centre.
b) Display the full-screen pattern (white, red, green or blue) on the DUT. Allow the luminance to stabilize.
c) Measure the chromaticity coordinates (x_p, y_p) for solid colour (p = W, R, G, B).
d) Repeat from b) to measure each displayed pattern.
e) Repeat for the other ocular, if applicable.

6.4.3 Calculation

a) The CIE 1976 UCS chromaticity coordinates (u', v') for each primary pattern (R, G, B) are calculated from the CIE 1931 chromaticity coordinates (x, y) as follows:

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

b) The colour gamut area metric is defined as the percent colour space area enclosed by the colour gamut relative to the entire spectrum locus in the CIE 1976 UCS. It is calculated as follows:

$$GA_{u'v'} = 256{,}1\left|(u'_R - u'_B)(v'_G - v'_B) - (u'_G - u'_B)(v'_R - v'_B)\right| \tag{5}$$

6.4.4 Report

The following items should be reported:

– CIE 1976 UCS chromaticity coordinates (u'_0, v'_0) of white;

– CIE 1976 UCS chromaticity coordinates (u'_p, v'_p) of each primary colour;

– colour gamut area;

– eye point (eye relief);

– type of LMD and aperture size;

– accuracy of sample stage; and

– correction methods for the measurement, if possible.

6.5 Chromaticity uniformity

6.5.1 General

The purpose of this method is to evaluate the chromaticity uniformity of the DUT as applied to the black and white checkerboard pattern, by positioning the entrance pupil of the LMD at the eye point. The LMD will pivot at the entrance pupil to point to the desired virtual image measurement position.

NOTE In case the pivoting point of the LMD is 10 mm behind the entrance pupil, this pivoting point can be used, instead of the entrance pupil, to match the eye point of the DUT.

The standard measurement conditions (Clause 4), the standard coordinate system (5.1), the measurement equipment (5.2) and the black and white checkerboard pattern (5.3.2) shall be applied. An LMD that can measure colour quantities shall be used.

6.5.2 Measurement procedure

Use the same procedures as for luminous uniformity specified in 6.3.2 to measure the chromaticity coordinates x_i and y_i at the multi-positions P_i instead of the luminance.

6.5.3 Calculation

a) The CIE 1976 UCS chromaticity coordinates (u'_i, v'_i) are calculated from the CIE 1931 chromaticity coordinates (x_i, y_i) using Formula (4).

b) Use the CIE 1976 chromaticity coordinates u'_i, v'_i at each location to determine the chromaticity distance between pairs of sampled colours using the following formula:

$$\Delta u'v' = \sqrt{\left(u'_j - u'_i\right)^2 + \left(v'_j - v'_i\right)^2} \qquad (6)$$

where i, j = 0 to 8, and $i \neq j$. Chromaticity non-uniformity is defined as the largest sampled chromaticity distance $(\Delta u'v')_{max}$ between any two points.

c) Repeat for the other ocular, if applicable.

6.5.4 Report

The following items should be reported:

– chromaticity non-uniformity $(\Delta u'v')_{max}$;

– CIE 1976 UCS chromaticity coordinates (u'_i, v'_i) of each position P_i, with the elevation angle α_i and the azimuth angle Ψ_i;

– eye point (eye relief);

– type of LMD and aperture size;
– accuracy of sample stage; and
– correction methods for the measurement, if possible.

6.6 Contrast ratio

6.6.1 General

The standard measurement conditions (Clause 4) the standard coordinate system (5.1) and the measurement equipment (5.2) shall be applied. The 5 x 5 checkerboard pattern (5.3.2) with white centre (corners) and with black centre (corners), respectively, shall be applied.

6.6.2 Measurement procedure

a) Measure the luminance values, $L_{\mathrm{W}i}$ $(0, 0, 0, \alpha_i, \Psi_i)$ at the position P_i (i = 0 to 8) on the virtual image of the white centre chekerboard pattern, as indicated in 6.3.2.

b) Measure the luminance values, $L_{\mathrm{K}i}$ $(0, 0, 0, \alpha_i, \Psi_i)$ at the position P_i (i = 0 to 8) on the virtual image of the black centre chekerboard pattern, as indicated in 6.3.2.

c) Repeat for the other ocular, if applicable.

6.6.3 Calculation

The contrast ratio at the position P_i (i = 0 to 8) is calculated as follows:

$$CR_i = \frac{L_{\mathrm{W}i}}{L_{\mathrm{K}i}} \tag{7}$$

The averaged contrast ratio is calculated as follows:

$$CR_{\mathrm{a}} = \frac{1}{9}\sum_{i=0}^{8} CR_i \tag{8}$$

The contrast non-uniformity is calculated as follows:

$$NU_{\mathrm{CR}} = \frac{CR_{\mathrm{max}} - CR_{\mathrm{min}}}{CR_{\mathrm{a}}} \tag{9}$$

where

$L_{\mathrm{W}i}$ is the luminance value of white at position P_i;

$L_{\mathrm{K}i}$ is the luminance value of black at position P_i;

CR_i is the contrast ratio at position P_i;

CR_{a} is the average contrast ratio;

CR_{max} is the maximum contrast ratio among the nine positions;

CR_{min} is the minimum contrast ratio among the nine positions;

NU_{CR} is the contrast non-uniformity.

6.6.4 Report

The following items should be reported:

– luminance L_{Wi} of white, luminance L_{Ki} of black and contrast ratio CR_i at each position P_i, with the elevation angle α_i and the azimuth angle Ψ_i;
– average contrast ratio CR_a;
– contrast ratio non-uniformity NU_{CR};
– eye point (eye relief);
– type of LMD and aperture size;
– accuracy of sample stage; and
– correction methods for the measurement, if possible.

6.7 Field of view (FOV)

6.7.1 General

The purpose of this method is to evaluate the FOV performance of the DUT for the criteria based on luminance, chromaticity and contrast ratio. These criteria limits shall be specified by the manufacturer or the supplier. The FOVs are measured from the eye point location of the LMD. In the FOV measurement, the position and rotation of the LMD shall follow the information provided by the supplier or manufacturer of the DUT. The measurement is achieved by rotating around the entrance pupil of the LMD, or around the rotation centre of the eye. The rotation centre shall be specified by the supplier or manufacturer, and reported. In a human eye, the distance between the rotation centre and the iris is about 10 mm, and therefore the rotation centre can be approximately 10 mm behind the entrance pupil along the DUT's optical axis.

The standard measuring conditions (Clause 4), the standard coordinate system (5.1) and the measurement equipment (5.2) shall be applied. The solid white pattern (5.3.3) for luminance and chromaticity, and the checkerboard pattern (5.3.2) for the contrast ratio shall be applied. In case of non-rectangular FOV, the test patterns should be provided by the manufacturer or the supplier.

NOTE 1 For some DUTs, the FOVs are measured through a location which is 10 mm behind the entrance pupil (eye rotation), and the pivoting point of the LMD can be 10 mm behind the entrance pupil; this pivoting point can be used, instead of the entrance pupil, to match the eye point of the DUT in the procedures indicated in 6.7.2.

NOTE 2 The other criteria such as resolution and distortion can be used to evaluate the FOV.

6.7.2 Measurement procedure

a) Adjust the DUT to match the eye point with the entrance pupil of the LMD.
b) Display the full-screen white pattern.
c) Adjust the entrance pupil of the LMD at the centre of rotation of the biaxial goniometer, align the measurement direction at the centre of the virtual image, and then measure the luminance of the centre.
d) Search for the “corner”. The corner search is iterative. A “blind” luminance search of the kind described for finding the horizontal and vertical edges is complicated but could be iterated using a Euclidean type search taking half steps.
e) An example using the goniometer is as follows:
   1) Slew the LMD in the azimuth from the centre toward the left or right end horizontally (keep the elevation angle, $\alpha = 0$) until the luminance reading reduces to the criteria limit, for example to 50 % of the value at the centre point. Record the horizontal angles of both ends, Ψ_L and Ψ_R.
   2) Turn the LMD in the elevation from the centre toward the top or bottom vertically (keep the azimuth angle, $\Psi = 0$) until the luminance reading reduces to the criteria limit, for example to 50 % of the value at the centre point. Record the vertical angles of both ends, α_T and α_B.

3) Turn the LMD both in the azimuth and elevation from the centre toward the top-left corner, bottom-right corner, top-right corner or bottom-left corner in the diagonal direction, such as the 45° tilted angles (the diagonal angle is related to the aspect ratio), until the luminance reading reduces to the criteria limit, for example to 50 % of the value at the centre point. Record the horizontal and vertical angles at the corner for each direction, (Ψ_{TL}, α_{TL}) and (Ψ_{BR}, α_{BR}), as well as (Ψ_{TR}, α_{TR}) and (Ψ_{BL}, α_{BL}).

f) Repeat a) to e) to measure the chromaticity at the centre, and search for the "edge" and "corner" with the chromaticity criteria, instead of the luminance.

g) Display the checkerboard patterns, respectively.

h) Repeat a) to e) to measure the contrast ratio at the centre, and then search for the "edge" and "corner" with the contrast ratio criteria, instead of the luminance.

NOTE 1 In the case of a diagonal direction, the criteria limit might be 25%.

NOTE 2 When the data aimed at the eye point are collected from the above eight tilted angles, it is often useful to generate FOV plots to determine the various fields of view shown in Annex A, such as the monocular FOV, total FOV, and overlapping binocular FOV.

Figure 7 shows an example of a FOV boundary.

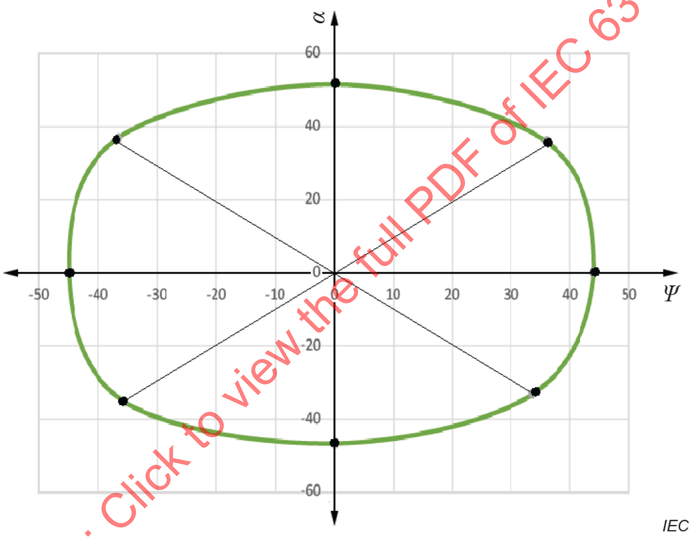


Figure 7 – Example of FOV boundary

6.7.3 Calculation

a) Calculate the angle of the horizontal FOV (A_h) using the following formula:

$$A_h = \psi_L + \psi_R \tag{10}$$

where

A_h is the angle of the horizontal FOV;

Ψ_L is the azimuth angle of the left edge;

Ψ_R is the azimuth angle of the right edge.

b) Calculate the angle of the vertical FOV (A_v) using the following formula:

$$A_v = \alpha_T + \alpha_B \tag{11}$$

where

A_v is the angle of the vertical FOV;

α_T is the elevation angle of the top edge;

α_B is the elevation angle of the bottom edge.

c) Calculate the angle of the diagonal FOV from top-left to bottom-right (A_{d1}) using the following formula:

$$A_{d1} = \sqrt{\psi_{TL}^2 + \alpha_{TL}^2} + \sqrt{\psi_{BR}^2 + \alpha_{BR}^2} \tag{12}$$

where

A_{d1} is the angle of the diagonal FOV from top-left to bottom-right;

Ψ_{TL} is the azimuth angle of the top-left corner;

α_{TL} is the elevation angle of the top-left corner;

Ψ_{BR} is the azimuth angle of the bottom-right corner;

α_{BR} is the elevation angle of the bottom-right corner.

d) Calculate the angle of the diagonal FOV from top-right to bottom-left (A_{d2}) using the following formula:

$$A_{d2} = \sqrt{\psi_{TR}^2 + \alpha_{TR}^2} + \sqrt{\psi_{BL}^2 + \alpha_{BL}^2} \tag{13}$$

where

A_{d2} is the angle of the diagonal FOV from top-right to bottom-left;

Ψ_{TR} is the azimuth angle of the top-right corner;

α_{TR} is the elevation angle of the top-right corner;

Ψ_{BL} is the azimuth angle of the bottom-left corner;

α_{BL} is the elevation angle of the bottom-left corner.

e) Calculate the averaged angle of the diagonal FOV (A_d) using the following formula.

$$A_d = \frac{A_{d1} + A_{d2}}{2} \tag{14}$$

where

A_d is the averaged angle of the diagonal FOV.

6.7.4 Report

The following items should be reported:

– angle of the horizontal FOV A_h and the vertical FOV A_v;
– averaged angle of the diagonal FOV A_d;
– angle of the diagonal FOV A_{d1} and A_{d2}:
– direction of the four corners (Ψ_{TL}, α_{TL}), (Ψ_{BR}, α_{BR}), (Ψ_{TR}, α_{TR}) and (Ψ_{BL}, α_{BL});
– direction of the four edges (Ψ_L, α_L), (Ψ_R, α_R), (Ψ_T, α_T) and (Ψ_B, α_B);
– type of criteria (luminance, chromaticity or contrast ratio) and criteria limit;
– eye point (eye relief), position of z-axis;

– type of LMD and aperture size;
– accuracy of sample stage; and
– correction methods for the measurement, if possible.

6.8 Eye-box based on luminance

6.8.1 General

The size of the eye-box is directly related to the FOV of the DUT. For the given FOV, the size of the eye-box shall be determined by moving the LMD around the eye point of the DUT according to the criteria limit value relatively to the centre of the virtual image.

In case that the DUT vendor has specified a minimum monocular FOV which is quantified at the eye point, the luminance of the DUT at the specified FOV shall be taken at each point of the three-dimensional eye-box ($W \times H \times D$) using the translation stage. Otherwise, the FOV shall be measured first as in 6.7.

The standard measurement conditions (Clause 4), the standard coordinate system (5.1), the measurement equipment (5.2) and the solid white pattern (5.3.3) shall be applied. The criteria limits shall be specified by the manufacturer or the supplier.

6.8.2 Measurement procedure

The measurement method is as follows:

a) Match the entrance pupil of the imaging LMD and the eye point of the DUT with the origin position of the motion stage (x = 0, y = 0, z = 0, α = 0, Ψ = 0).
b) Display the test pattern on the DUT.
c) Adjust the direction of the LMD toward the centre of the virtual image according to the result of the FOV (6.7) using the biaxial goniometer.
d) Measure the luminance to calculate the criteria.
e) Adjust the direction of the LMD toward one edge (i.e. top edge) of the virtual image.
f) Move the position of the LMD from the origin toward the top side on the plane which passes the origin and is perpendicular to the optical axis of the DUT using the three-axis translation stage by an appropriate step (rough step near the origin and finer step near the edge); the LMD keeps the alignment point at this edge on the virtual image with the help of the biaxial goniometer. Measure the luminance, until the luminance value becomes the criteria limit value (as 50 % of the luminance at the centre of the image).
g) Record the motion distance (Δy_{i1}) from the origin at the criteria limit value for the top side.
h) Repeat step f) for the remaining other sides (bottom, left and right), and record the motion distance values (Δy_{i2}, Δx_{i1}, Δx_{i2}) from the origin at the criteria limit value for other sides.
i) Adjust the direction of the LMD toward the other edges and/or corners of the virtual image.
j) Repeat steps f) to h), and record the motion distance values (Δy_{i2}, Δx_{i1}, Δx_{i2}) (i = 2 to 8).
k) Calculate the size of the eye-box at the plane of the eye point as follows:

$$W_{\text{BOX}} = \min\left(\Delta x_{i1}\right) + \min\left(\Delta x_{i2}\right) \ (i = 1 \text{ to } 8) \quad (15)$$

$$H_{\text{BOX}} = \min\left(\Delta y_{i1}\right) + \min\left(\Delta y_{i2}\right) \ (i = 1 \text{ to } 8) \quad (16)$$

l) Repeat for the other ocular, if applicable.

To measure the volume of the eye-box, the following procedures can be applied.

1) Move the LMD forward and backward along the z-axis using the three-axis translation stage.
2) Repeat e) to k) at every z-axis position.

NOTE 1 The lateral and vertical dimensions of the eye-box represent the total movement of a monocular viewing with a 5 mm entrance pupil.

NOTE 2 The longitudinal eye-box dimension represents the total fore-aft movement.

NOTE 3 In the case of a finite image distance, the centre luminance might be changed due to the LMD translation.

6.8.3 Report

The following items should be reported:

– eye-box region W_{box} and H_{box} at the eye point;

– eye-box volume W_{box} and H_{box} at each z-axis position;

– criteria limits;

– eye point (eye relief), position of z-axis;

– type of LMD and aperture size;

– accuracy of sample stage; and

– correction methods for the measurement, if possible.

6.9 Pixel angular density

6.9.1 General

The standard measurement conditions (Clause 4), the standard coordinate system (5.1), setup conditions (5.2.3) and the solid pattern (5.3.3) shall be applied. A 2D imaging LMD that can capture at least a 5° measurement field shall be used.

6.9.2 Measurement procedure

To measure the pixel angular density the following procedures shall be used:

a) Position the DUT.

b) Display the solid pattern, such as the full-screen white.

c) Adjust the LMD to match the entrance pupil at the eye point of the DUT and focus at a specified virtual image distance.

d) Capture the pixel image using the LMD at the centre of the virtual image, as shown in Figure 8.

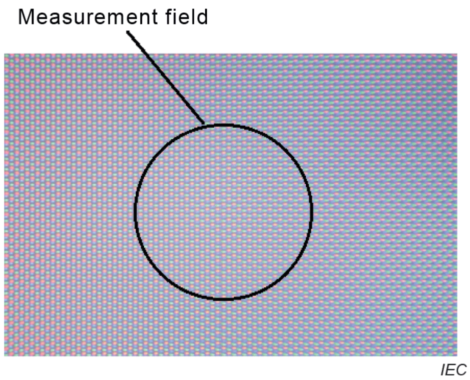


Figure 8 – Example of pixel angular density measurement

e) Count the pixel numbers, N, within the measurement field, such as the circular field (5°), as shown in Figure 8.

f) Calculate the monocular pixel angular density using the following formula:

$$D_L = \frac{\pi}{180}\sqrt{\frac{N}{\Omega}} \qquad (17)$$

where

D_L is the pixel angular density (unit: pixel per degree (ppd));

Ω is the solid angle of the measurement field (unit: sr).

Alternative method: in case a fixed number of pixels in the circular white pattern is displayed, the pixel angular density shall be calculated using Formula (17), by applying the number of pixels and measured solid angle of the viewing cone.

NOTE In the case of a regular arrangement of the pixels orthogonally, the pixel angular density can be determined by the formula $D_L = n / \theta$, where n is the number of pixels in the measurement angle θ (unit: degree).

6.9.3 Report

The following items should be reported:

– pixel angular density;

– measurement field angle of the LMD;

– eye point (eye relief), position of z-axis;

– type of LMD and aperture size; and

– correction methods for the measurement, if possible.

Annex A
(informative)

Estimating the eye point

A.1 General

The eye point is the designed location at which the entrance pupil of the eye is placed to achieve the optimal performance and serves as the origin location of the measurement. There are many characteristics which affect the location of the eye point, and the manufacturer or supplier specifies the eye point considering these many characteristics as well as ergonomic aspects. Therefore, it is difficult to find it without any information from the manufacturer or supplier. However, if the manufacturer or supplier does not specify the eye point position, it will need to be experimentally estimated in order to characterize an AR or VR device. There are several criteria by which the eye point could be determined [2], [3]. Two methods exist for determining the eye point.

It is noted that the position determined by these methods might not always be the same as the eye point specified by the manufacturer or supplier. But if no specified information is provided by the manufacturer or supplier, these methods would be effective.

A.2 Eye point based on full field luminance method

A.2.1 General

The eye point is generally designed to be located in a position where the pupil can observe the entire, or maximum, virtual visual field. The visual field will typically be defined in terms of the luminance profile across the visual field. This method estimates the eye point as the centre lateral location in the x-y plane of the eye-box in which the size of the luminance profile of the virtual image is largely maintained.

A.2.2 Measurement procedure

This method requires a 2D imaging LMD with a photopic response.

a) Render a cross-hair virtual image on the DUT.

b) Position the entrance pupil of the LMD roughly laterally in the eye box, 3 mm behind the eye relief distance. If the eye relief of the DUT is not known, then it is recommended to position the entrance pupil of the LMD 25 mm behind the last mechanical element of the DUT along its optical axis.

c) Focus the LMD on the virtual image of the cross-hair.

d) Tilt the LMD (or DUT) at the entrance pupil position of the LMD to centre the optical axis of the LMD on the centre of the cross-hair with the help of the biaxial goniometer.

e) Render a full screen white virtual image on the DUT, at maximum input code value. Capture the virtual image with the 2D imaging LMD. The luminance image size is defined as the area of the full screen virtual image in which the luminance is greater than 50 % of the peak luminance. Confirm that the size of the captured full screen image is at maximum size by laterally translating the LMD (or DUT) vertically and horizontally with the eye-box. The maximum image size is used as a reference for evaluating the relative reduction of the image.

f) Translate the LMD (or DUT) horizontally in the positive x-axis direction measuring any reduction in the area size of the virtual luminance image (see Figure A.1). Report the $+x$ position where the image area is reduced to 95 % of its maximum size.