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INTERNATIONAL STANDARD

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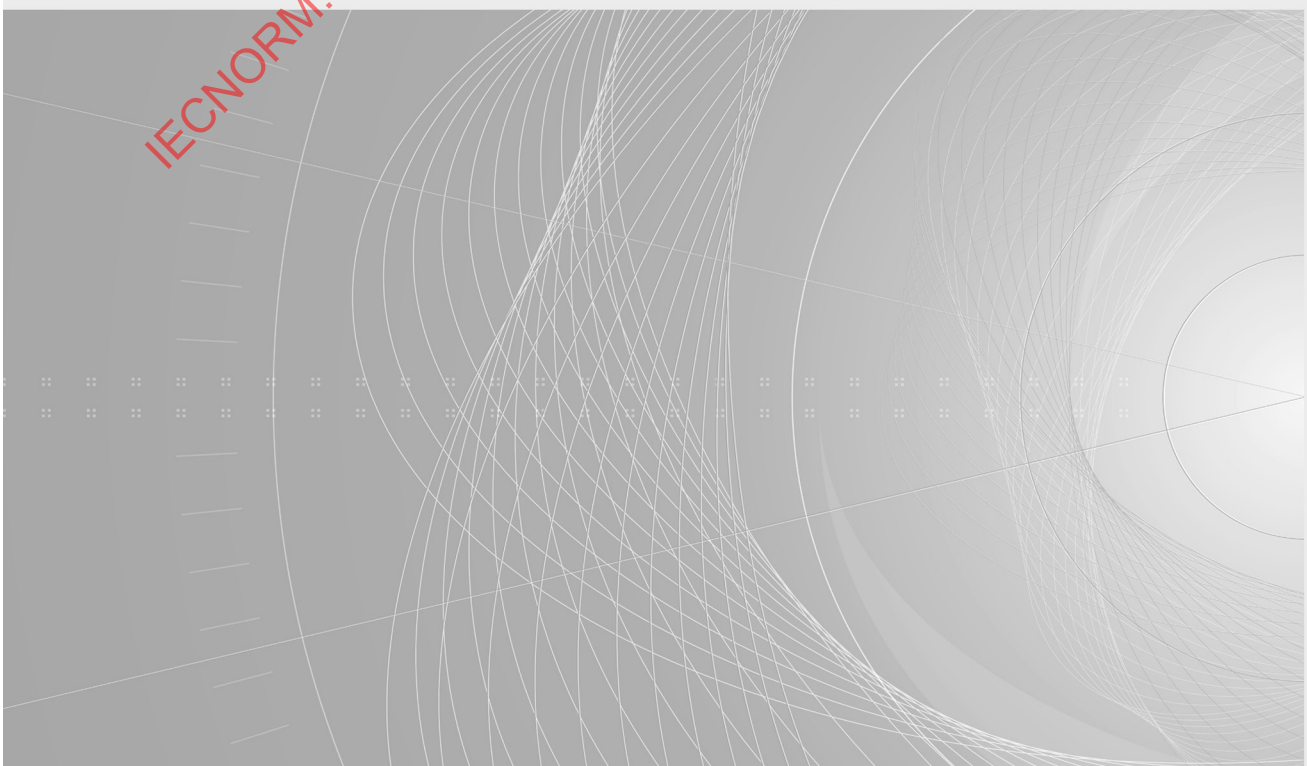
3D displays –
Part 52-1: Fundamental measurement methods of aerial display – Optical



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3D DISPLAYS –

Part 52-1: Fundamental measurement methods of aerial display – Optical

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IEC 62629-52-1 has been prepared by IEC technical committee 110: Electronic displays. It is an International Standard.

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

Draft	Report on voting
110/1593/FDIS	110/1616/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62629 series, published under the general title *3D displays*, 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 webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn, or
- revised.

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3D DISPLAYS –

Part 52-1: Fundamental measurement methods of aerial display – Optical

1 Scope

This part of IEC 62629 specifies the standard measurement methods and measurement conditions for determining the optical properties of aerial displays. This document excludes image quality of aerial displays, such as modulation transfer function (MTF) and resolution measurements.

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 62629-1-2:2021, *3D display devices – Part 1-2: Generic – Terminology and letter symbols*

ISO/CIE 19476, *Characterization of the performance of illuminance meters and luminance meters*

3 Terms, definitions, abbreviated terms and letter symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in 62629-1-2 and the following apply.

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

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

3.1.1
aerial display
display that forms a real image in mid-air by use of an incoherent light-source and a passive optical component to converge diverging light from the light-source

Note 1 to entry: Details of aerial display, including the principles and typical optical components to form a real image, are given in IEC TR 62629-51-1 [1].

[SOURCE: IEC 62629-1-2:2021, 3.1.20, modified – in the definition, the term "display" is removed from the light source description because the light source is not limited to display, and Note 1 has been expanded.]

3.1.2
aerial image area
two-dimensional area in mid-air where the aerial display exhibits information via electrically generated images

3.1.3
design viewing space
three-dimensional space within which the user places both eyes and can see the entire aerial image area

Note 1 to entry: Unlike the eye box of the eyewear display, the design viewing space of the aerial display usually has no upper limit in the viewing distance; the width and height are quite larger than the interpupillary distance. Both eyes of the viewer in the design viewing space will see the entire aerial image area meet a specified performance metric.

3.1.4
design viewing position
design location at which the midpoint of both eyes is placed to achieve the optimal performance when using an aerial display

Note 1 to entry: The design viewing position is not limited to the front centre of the aerial image area.

3.1.5
hardware reference point
design location on the aerial display hardware that is used for the origin of the coordinates

Note 1 to entry: The hardware reference point serves as the origin location of the measurement.

Note 2 to entry: The design viewing position is located along the line from the hardware reference point to the centre of the aerial image area.

3.1.6
floating distance
distance from the centre of the aerial image area to the hardware reference point

3.1.7
design viewing distance
<aerial display> distance from the design viewing position to the centre of the aerial image area

Note 1 to entry: The summation of the design viewing distance and the floating distance becomes the distance between the hardware reference point and the design viewing position.

3.2 Abbreviated terms

AIA aerial image area
CCD charge-coupled device
DUT device under test
DVP design viewing position
DVS design viewing space
HRP hardware reference point
LMD light measuring device
MTF modulation transfer function

3.3 Letter symbols (quantity symbols and units)

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

Table 1 – Letter symbols (quantity symbols and units)

Quantities	Symbols	Units
Measuring point (i = 0: centre)	P_i	
Luminance	L_v	cd/m^2
Maximum luminance	L_{max}	cd/m^2
Minimum luminance	L_{min}	cd/m^2
Average luminance (spatial)	L_{va}	cd/m^2
Luminance non-uniformity	NU	
Contrast ratio	CR	

4 Standard measurement conditions

4.1 Standard environmental conditions

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

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

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

4.2 Power supply

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

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

4.3 Warm-up time

The optical performances of the DUT can be affected by the temperature. It takes a certain time for the luminance output of the DUT to achieve a steady state. If the luminance output is not within ±3 % variation, it shall be reported. All measuring conditions shall be kept constant during the measurements.

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

4.4 Darkroom condition

The luminance contribution from the background in the test room reflected off the measurement space shall be less than 1/20 of 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 Measurement equipment

5.1.1 Goniometer

A biaxial goniometer shall be assembled to be capable of measuring the azimuth (horizontal) and elevation (vertical) angles. The angular accuracy should be 0,1° or less. A translation stage can be applied to move the position of the biaxial goniometer.

5.1.2 Light measuring device (LMD)

The configurations and operating conditions of the equipment should comply with the structures specified in each item. To ensure the accurate measurements, the following requirements shall be applied. Otherwise, the differences shall be noted in the report. ISO/CIE 19476 is available for reference to the LMD evaluation procedures.

The optics of the LMD (a spot LMD or a 2D imaging LMD) shall be equivalent to the human eye. The LMD shall be equipped with the finder. The position of the entrance pupil (aperture) of the LMD shall be provided by the manufacturer or the supplier. The entrance pupil size of the LMD should be set between 2 mm and 5 mm. 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 veiling glare and lens flare (i.e., scatters in the LMD optical system);
– timing of data-acquisition, low-pass filtering and aliasing-effects;
– linearity of detection and data-conversion;
– measurement field size (number of the image pixels).

The LMD shall be located on the goniometer. The goniometer rotation centre shall be located at the centre of the LMD entrance pupil.

NOTE 1 If the eye box is small and the influence of the eye-ball rotation is taking place, the rotation centre of the goniometer is located 10 mm behind the LMD entrance pupil, along the LMD optical axis to simulate the eye-ball rotation centre location. Unlike the eye box of eyewear display, however, the design viewing space of the aerial display is usually larger than the interpupillary distance. Thus, the influence of eye-ball rotation does not take place.

The 2D imaging LMD (using a two-dimensional sensor such as CCD) can be used for the measurements. However, 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 free of vignetting. When the 2D imaging LMD is applied, the measurement results such as luminance and chromaticity should correspond to those of the spot LMD. The specification of the LMD used shall be noted in the measurement report.

NOTE 2 The fields of view of some 2D imaging LMDs are affected by the smaller entrance aperture.

NOTE 3 The 2D imaging LMD can cause moiré because it is composed of a pixel array.

When a spectroradiometric type LMD such as a spectral radiance meter 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 less than or equal to 0,3 nm.

NOTE 4 CIE 250 [2] [1] and CIE 233 [3] provide detailed use and measurement uncertainty information for measurements with spectroradiometers.

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

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 5 CIE-*f*1' indicates the spectral mismatch factor between the spectral responsivity of the filter type LMD and the CIE photopic luminous efficiency function with CIE Illuminant A as the reference spectral power distribution. The detail of spectral mismatch correction factor is given in ISO/CIE19476.

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/CIE 11664-1 [4]) 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 the absolute colour quantities but for the relative colour quantities such as colour uniformity.

5.2 Test patterns

5.2.1 General

The following test patterns shall be applied, 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 The test pattern will be clearly visible within the design viewing space.

5.2.2 Geometrical test pattern

The geometrical test pattern with vertical, horizontal and diagonal lines is shown in Figure 1. This test pattern shall be used in the measurement methods in the position and size of the aerial image area (AIA). The standard nine locations of this test pattern are the image centre, the corners and the midpoints of each edge. The centre location is denoted by B_0. The eight locations on the boundary of the AIA are numbered from 1 to 8 and denoted by from B_1 to B_8 as shown in Figure 1.

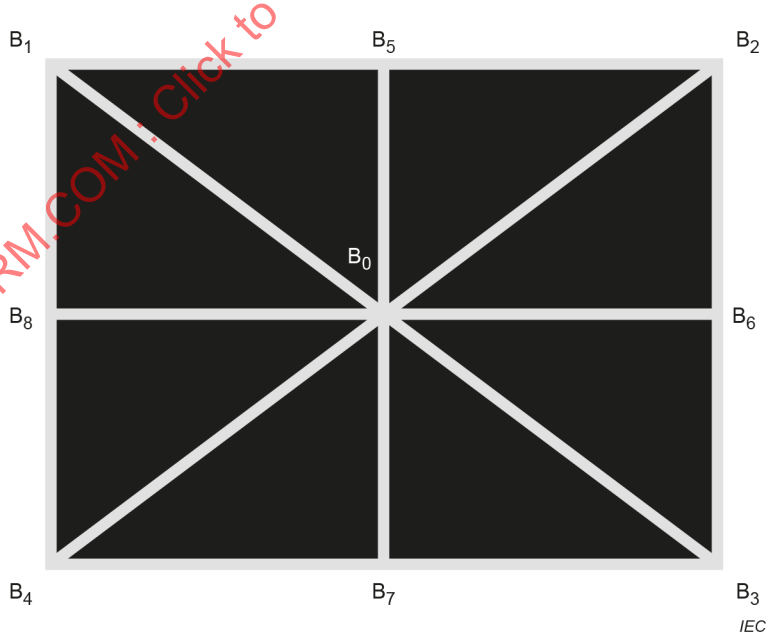

Figure 1 – Geometrical test pattern with vertical, horizontal and diagonal lines

5.2.3 Solid colour patterns

The solid colour patterns can be used for measuring the optical qualities. The colours should be defined in terms of the display primaries, and the white and black solid patterns are used in this measurement method. The pattern (full screen) fills with a single colour.

5.3 Measuring points

The centre point (1 point) or the multi-point (5 points or 9 points) measurement shall be applied, which is provided by the manufacturer or supplier. The measuring point(s) of 1 point, 5 points, and 9 points measurements are P_0, from P_0 to P_4, and from P_0 to P_8, respectively, as shown in Figure 2. H and V shall be the horizontal size and vertical size of the AIA, respectively. When using other measuring points, the manufacturer or the supplier should point out these positions. Applied measuring points are defined in each measuring item. If other measuring points are applied, this shall be defined in the relevant specification.

NOTE 1 The centre point measurement is carried out to measure the typical characteristics of the DUT. The 5 points and 9 points measurements are carried out to measure the deviations, averages, and uniformities.

NOTE 2 Figure 2 shows that the aerial image area is formed in a precise rectangular shape. In general, the measuring points are the positions that are 10% inside of the boundaries, as defined by Formula (4).

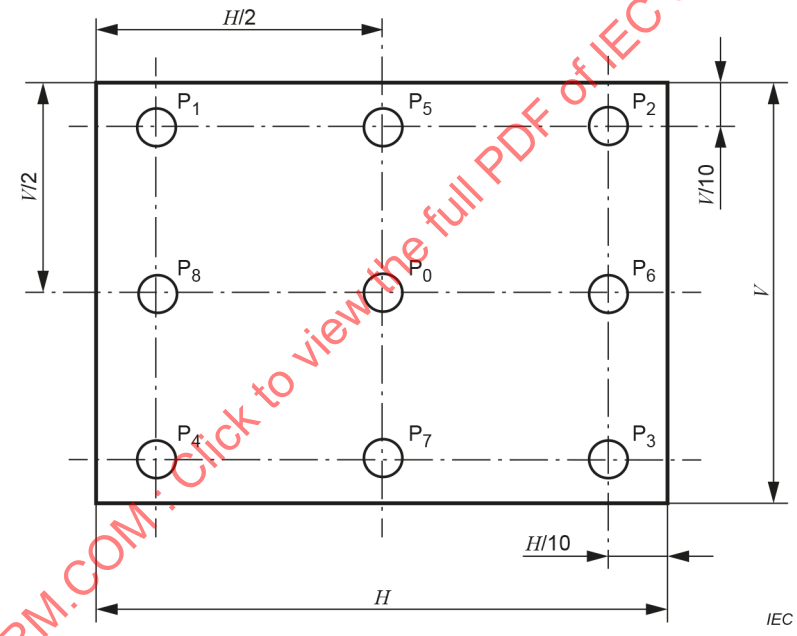

Figure 2 – Measuring points for the centre and multi-point measurement

5.4 Standard coordinate system

To indicate the positional relationship among the aerial display hardware, the AIA, design viewing space (DVS), and spherical coordinates system (r, θ, φ) shall be used by use of radial distance r, azimuth angle φ, and elevation angle θ, as shown in Figure 3. The relation between the spherical coordinate system and three-dimensional Cartesian coordinates system (x, y, z) is shown in Figure 3.

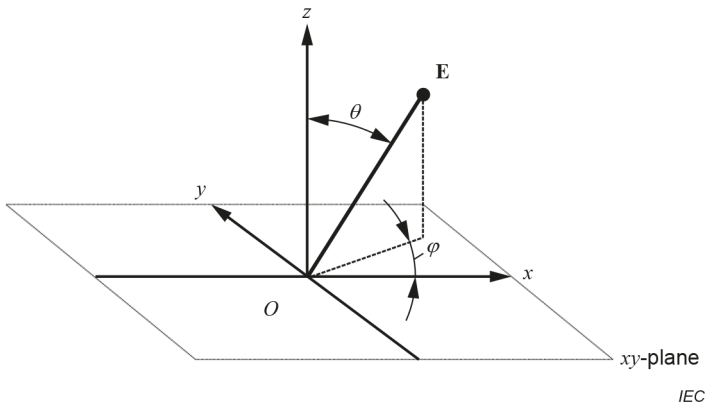

Figure 3 – Relation between the spherical coordinate system and the Cartesian coordinate system

The Cartesian coordinate system should be used if necessary. The position vector of a point **E** is expressed by coordinate conversion between the spherical coordinate system and the Cartesian coordinate system:

$$\mathbf{E} = \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} r\sin\theta\cos\varphi \\ r\sin\theta\sin\varphi \\ r\cos\theta \end{pmatrix}$$
$$r = \sqrt{x^2 + y^2 + z^2}$$
$$\theta = \cos^{-1}\left(\frac{z}{\sqrt{x^2 + y^2 + z^2}}\right) \quad (1)$$
$$\varphi = \tan^{-1}\left(\frac{y}{x}\right)$$

The following information shall be provided by the manufacturer or the supplier:

- the position of the hardware reference point,
- the coordinates of the design viewing position, and
- the coordinates of the four end points of the design viewing space (E_1, E_2, E_3 and E_4).

As shown in Figure 4, The origin O of the spherical coordinates system shall be located at the hardware reference point (HRP).

The z-axis is defined as the line from the origin O to the DVP through the centre of the AIA, and the z-axis is the zenith reference axis. The x-axis, which is the azimuth reference axis, is parallel to the line from B_0 to B_6 on the aerial image of Figure 1, orthogonal to the z-axis, and passes through the origin O. The y-axis is defined to be orthogonal to the x-axis and the z-axis and to compose the right-handed coordinate system.

NOTE The xy-plane is orthogonal to the z-axis and therefore is not always parallel to the hardware surface.

The floating distance, design viewing position, and the end points of the design viewing space (DVS) are shown in Figure 4. The end points, E_1 and E_2 correspond to the marginal point in the negative direction and the marginal point in the positive direction in the x-direction, respectively. The end points, E_3 and E_4 correspond to the marginal point in the negative direction and the marginal point in the positive direction in the y-direction, respectively.

The following procedures can be applied to setup the coordinate system:

1) The geometrical test pattern (Figure 1) is shown. B_0 indicates the centre of aerial image area in Figure 4.
2) The z-axis is along the direction where the HRP and B_0 overlap. The origin of the z-axis is the HRP. Its positive direction is the direction from the HRP to B_0.
3) The DVP is on the z-axis and located at the design viewing distance from B_0.
4) The x-axis is the projection of the line from B_0 to B_6 on the plane that is orthogonal to the z-axis and contains the HRP. Its origin is the HRP, and the positive direction is the direction from B_0 to B_6.
5) The y-axis is on the plane that is orthogonal to the z-axis and contains the HRP. The origin of the y-axis is the HRP. The direction of the y-axis is orthogonal to the x-axis and the positive direction is defined to compose the right-handed coordinate system.

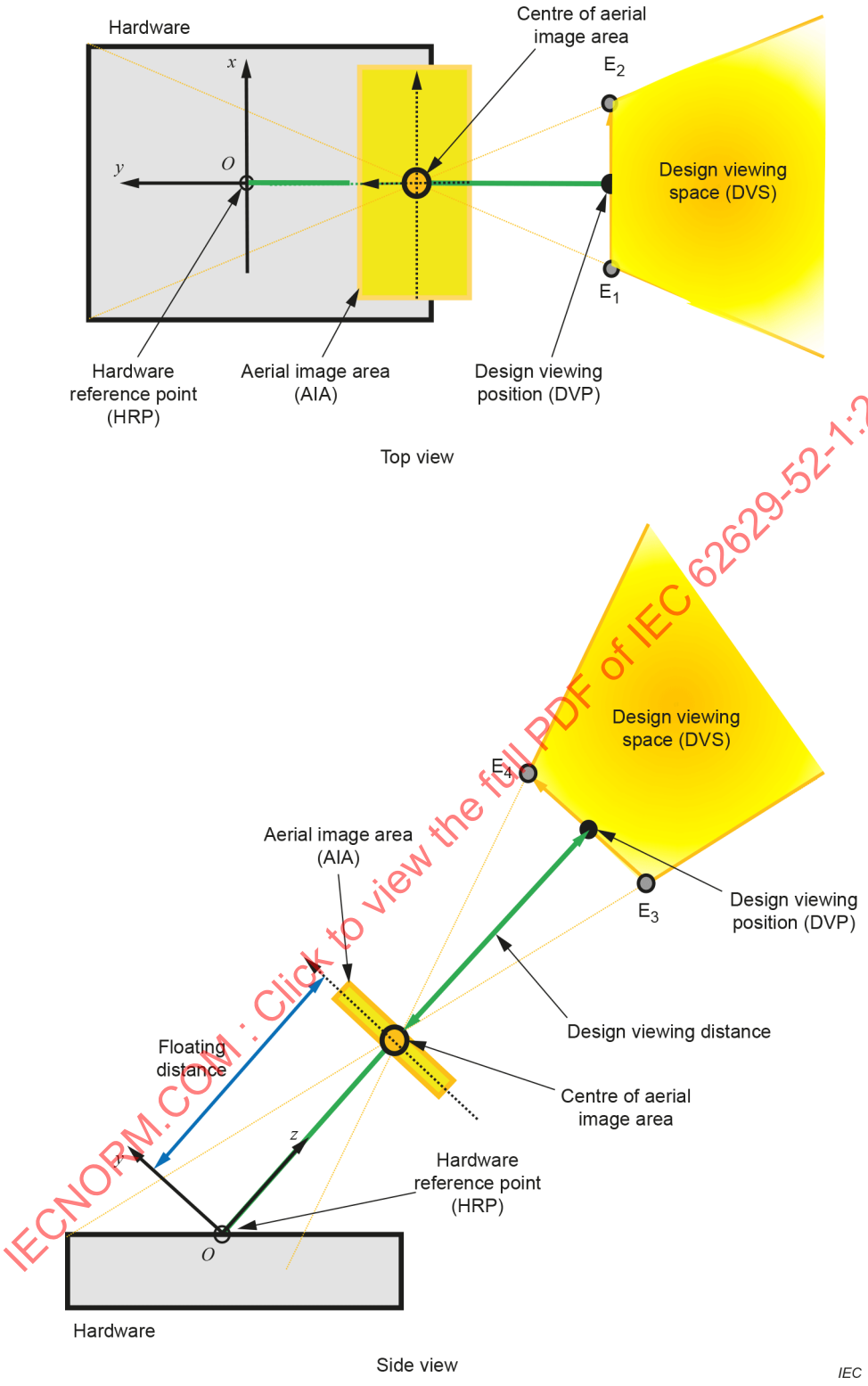

Figure 4 – Definition of floating distance and end points of design viewing space of aerial display

6 Measurement methods for optical characteristics

6.1 General

The purpose of the measurements for optical characteristics is to evaluate the position and size of the AIA, floating distance, luminance, contrast ratio and chromaticity.

6.2 Preparations

The aerial display to be measured (DUT) should be placed in the measurement setup in the darkroom condition specified in 4.4.

The DUT's adjustable conditions, which are related to optical properties, shall be specified by a manufacturer or a 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 aerial image. A raster pattern with a high resolution (e.g. one-by-one pixel line-pair) which is appropriate for the DUT and provided by the manufacturer or the supplier, can be applied for adjustment of the LMD 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.

6.3 Position and size of aerial image area and floating distance

6.3.1 General

The purpose of this method is to measure the three-dimensional position and size of the aerial image area and the floating distance.

6.3.2 Measurement procedure

The following procedure shall be applied:

1) Show the geometrical test pattern with vertical, horizontal and diagonal lines (Figure 1).
2) Place an LMD on the biaxial goniometer (see 5.1.1) whose centre is placed at E_1 (one end of the DVS in the x-axis direction), as shown in Figure 5.

NOTE To make the calculation easier, the spherical coordinate system of the biaxial goniometer can be the same as that defined in 5.4. This can be executed by the following procedure: (1) the azimuth and elevation angles of the biaxial goniometer are changed so that the LMD is turned toward the origin (HRP), and (2) the azimuth and elevation angles of the biaxial goniometer are calibrated using the azimuth and elevation angles of E_1 (these angles are given by the manufacturer, or the supplier as explained in 5.4).

3) Adjust the LMD direction to B_0 and the focus of the LMD.
4) Record the azimuth and elevation angles of the biaxial goniometer toward the 9 standard locations (B_0 to B_8 on the AIA). If necessary, the focus of the LMD can be adjusted to each standard location.
5) Move the centre of the biaxial goniometer at E_2 (the other end of the DVS in the x-axis direction).
6) Record the azimuth and elevation angles of the biaxial goniometer toward the 9 locations (B_0 to B_8 on the AIA).

E_1 and E_2 shall be applied to this measurement. However, if other points are applied, these points shall be reported.

6.3.3 Calculation

Calculate the coordinates of the 9 locations based on the triangulation.

The coordinates of the crosspoint (x, y, z) between the two lines are obtained by the following system of formulae.

$$\frac{x_{E1} - x}{\sin\theta_1 \cos\varphi_1} = \frac{y_{E1} - y}{\sin\theta_1 \sin\varphi_1} = \frac{z_{E1} - z}{\cos\theta_1} \tag{2}$$

$$\frac{x_{E2} - x}{\sin\theta_2 \cos\varphi_2} = \frac{y_{E2} - y}{\sin\theta_2 \sin\varphi_2} = \frac{z_{E2} - z}{\cos\theta_2} \tag{3}$$

where

(x_{E1}, y_{E1}, z_{E1}) are the coordinates of E_1;

(x_{E2}, y_{E2}, z_{E2}) are the coordinates of E_2;

(θ_1, φ_1) are the azimuth and elevation angles of the goniometer at E_1; and

(θ_2, φ_2) are the azimuth and elevation angles of the goniometer at E_2.

Calculate the horizontal size and the vertical size of the AIA.

Calculate the floating distance as the distance between the HRP and the centre of the AIA.

6.3.4 Report

The following items shall be reported:

– the coordinates of the 9 locations;
– the horizontal, vertical and diagonal size of the AIA (the size of B_1 to B_2, B_6 to B_8, B_3 to B_4, B_1 to B_4, $B_5$to B_7, B_2 to B_3, B_1 to B_3, B_2 to B_4); and
– the floating distance.

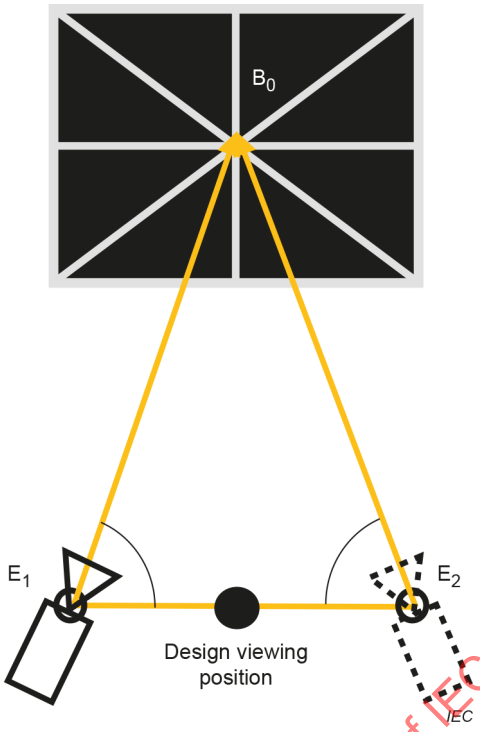

Figure 5 – Measuring the aerial image positions

6.4 Luminance and luminance non-uniformity

6.4.1 General

The purpose of this method is to measure the luminance and luminance non-uniformity of the aerial display. The standard measurement conditions (see Clause 4), standard coordinate system (see 5.4), measurement equipment (see 5.1) and solid colour patterns (see 5.2.3) shall be applied.

In this measurement, the luminance and luminance non-uniformity are measured at the DVP. The DVP is one of the vantage points of the aerial displays, and the vantage point measurement is applied.

6.4.2 Measurement procedure

The luminance values, L_{Vi}, of the 9 points on the AIA (see 5.3) are measured as follows:

1) Place the LMD at the DVP.
2) Adjust the LMD direction to the point P_0 and the focus of the LMD.
3) Show the solid black pattern and measure the minimum luminance at the point P_0. Turn off the DUT and measure the background luminance and confirm the background luminance is less than 1/20 of the minimum luminance of the DUT.
4) Show the solid white pattern.
5) Measure luminance L_{V0} at the point P_0.
6) From the coordinates of the 9 locations (B_0, B_1, …, B_8), calculate the position vector $\mathbf{P}_i$ as follows:

$$\mathbf{P}_i = \frac{\mathbf{B}_0 + 4\mathbf{B}_i}{5} \tag{4}$$

7) Adjust the LMD direction to point P_i (i = 1 to 8) and the focus of the LMD.

8) Measure luminance L_{Vi} at the point P_i (i = 1 to 8).

When the size of AIA is small, 5 points measurements may be applied.

6.4.3 Calculation

The average luminance value L_{Va}, the luminance deviation ΔL_{Vi}, and the luminance non-uniformity NU are calculated by using the following formulae:

$$L_{Va} = \frac{1}{9}\sum_{i=0}^{8} L_{Vi} \tag{5}$$

$$\Delta L_{Vi} = L_{Vi} - L_{Va} \tag{6}$$

$$NU = \frac{L_{max} - L_{min}}{L_{max}} \tag{7}$$

where

L_{Vi} is the luminance value at point P_i;

L_{Va} is the average luminance value;

ΔL_{Vi} is the luminance deviation at point P_i;

L_{max} is the maximum luminance value; and

L_{min} is the minimum luminance value.

6.4.4 Report

The following items shall be reported:

– calculated 9 points P_i;

– luminance L_{Vi} and luminance deviation ΔL_{Vi} of each point P_i;

– average luminance L_{Va};

– luminance non-uniformity NU x 100 (%); and

– LMD specification and setting.

The measured result can be summarised as shown in Table 2.

Table 2 – Example of measurement results of luminance and luminance non-uniformity

Measuring point	Luminance L_{Vi} (cd/m²)
P_0	115
P_1	107
P_2	111
P_3	108
P_4	106
P_5	113
P_6	115
P_7	110
P_8	111
Average luminance L_{Va} (cd/m²)	111
Luminance non-uniformity NU × 100 (%)	7,82

6.5 Contrast ratio

6.5.1 General

The purpose of this method is to measure the contrast ratio of the aerial display. The contrast ratio depends on the luminance of the AIA and the background caused by stray lights. The standard measurement conditions (see Clause 4), standard coordinate system (see 5.4), measurement equipment (see 5.1) and solid colour patterns (see 5.2.3) shall be applied.

The contrast ratio of the AIA is measured at the DVP.

6.5.2 Measurement procedure

The contrast ratio is measured as follows:

1) Place the LMD at the design viewing position.
2) Adjust the LMD direction to the point P_0 and the focus of the LMD.
3) Show the solid white pattern.
4) Measure luminance L_{W0} at point P_0.
5) Show the solid black pattern.
6) Measure luminance L_{B0} at point P_0.
7) Adjust the LMD direction to point P_i (i = 1 to 8) and the focus of the LMD.
8) Measure luminance L_{Wi} and L_{Bi} at point P_i (i = 1 to 8), showing the solid white and black patterns, respectively.

When the size of AIA is small, the 5 points measurements at point P_i (i = 0 to 4) may be applied.

6.5.3 Calculation

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

$$CR_i = \frac{L_{Wi}}{L_{Bi}} \tag{8}$$

where

L_{Wi} is the luminance value of white at point P_i;

L_{Bi} is the luminance value of black at point P_i; and

CR_i is the contrast ratio at point P_i.

6.5.4 Report

The following items shall be reported:

– contrast ratio CR_i at each point P_i;

– luminance value of white L_{Wi} at each point P_i;

– luminance value of black L_{Bi} at each point P_i; and

– the LMD specification and setting.

6.6 Chromaticity and white chromaticity

6.6.1 General

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

The standard measurement conditions (see Clause 4), standard coordinate system (see 5.1), measurement equipment (see 5.2), and solid colour patterns (see 5.2.3) shall be applied. The LMD that can measure colour quantities shall be used.

The chromaticity and white chromaticity of the AIA are measured at the design viewing position.

6.6.2 Measuring procedures

Measure the chromaticity of the DUT using the following procedure:

1) Place the LMD at the DVP and adjust the optical axis of the LMD orientated to the point P_0 and the focus of the LMD.
2) Show the full-screen pattern (white, red, green or blue) on the DUT. Allow the luminance to stabilize.
3) Measure the chromaticity coordinates (x_p, y_p) for solid colour of white (p = W).
4) Repeat from 2) for other solid colours or red, green and blue (p = R, G, B).