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INTERNATIONAL STANDARD

colour inside

Electronic displays –
Part 2-7 : Measurements of optical characteristics – Tiled displays

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ELECTRONIC DISPLAYS –

Part 2-7: Measurements of optical characteristics – Tiled displays

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Draft	Report on voting
110/1614/FDIS	110/1631/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.

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- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

Tiled displays are widely used in a variety of places and in a variety of forms. Demand for tiled displays is expected to increase in the future. IEC TC 110 has already standardized various measurement methods to evaluate performance of electronic displays. However, in order to evaluate the performance of a tiled display, additional definitions of terms and new evaluation methods will be developed.

The tiled display has repeatable elements that exist at various levels whose subsystems enable a highly configurable display system. In terms used in LED industries, for example the display system (first level of assembly) includes all subcomponents. It can come in any shape or size, curved, disconnected, etc. The cabinet (second level of assembly) typically includes a mechanical support structure with mechanical interconnects. The cabinet is also called a panel, chassis, or shell. The module (third level of assembly) typically includes optical elements (lowest level of assembly) with electrical interconnects, but will probably not have module-to-module mechanical interconnects. The module is also called a tile. As described above, the tiled display consists of a combination of subsystems of each level as illustrated in Figure 1. In this combination process, problems that did not appear on a single panel display can occur. Therefore, the optical properties caused by this problem will be checked at each level.

Figure 1 – Example of tiled display system

Depending on the final installation location, the methods presented in this document will probably not be applicable, and the result can vary depending on the calibration process reflecting the final installation environment.

This document deals with a tiled display performance evaluation method based on the existing TC 110 measurement method.

ELECTRONIC DISPLAYS –

Part 2-7: Measurements of optical characteristics – Tiled displays

1 Scope

This part of IEC 62977 specifies standard measuring conditions and measurement methods for determining the optical characteristics of tiled displays which consist of multiple display modules in order to form one screen. These methods apply to emissive and transmissive direct view flat displays that render real 2D images with all modules lying in the same plane. The methods are applicable in environments where the measuring conditions can be controlled, such as laboratory and production testing.

NOTE The measurement results are not specific values for the products. They can vary according to the measurement method and light measuring device (LMD) used in the calibration.

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 62977-2-1:2021, *Electronic displays – Part 2-1: Measurements of optical characteristics – Fundamental measurements*

IEC 62977-2-2:2020, *Electronic displays – Part 2-2: Measurements of optical characteristics – Ambient performance*

IEC 62341-6-2:2015, *Organic light emitting diode (OLED) displays – Part 6-2: Measuring methods of visual quality and ambient performance*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions 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
tiled display
display which consists of multiple display modules in order to form one screen

3.1.2
seam
space or gap between the adjacent display device modules

Note 1 to entry: Seam can result from the gaps between adjacent pixels on adjacent devices, and from any components (e.g., interconnects, adhesives, seals, mechanical alignment components, etc.) of a frame outside the device, making the display image discontinuous.

Note 2 to entry: In the case of some tiled display products, additional lens, narrow pitch, and overlapping technologies are used to produce a seamless display with a seam that is not perceptible to the user. Such a seam is called an invisible seam.

3.1.3
tiled display element
single device element of the tiled display that can be driven independently and capable of providing an independent visual representation

Note 1 to entry: Among the assembly levels exemplified in the introduction, cabinets and modules would belong to tiled display elements. However, the case of the module, which cannot be operated independently, is excluded.

3.1.4
pixel ratio
number of pixels of the output image of the LMD per pixel interval of the image of the display input, when the display screen is captured by the LMD at a specific magnification

3.2 Abbreviated terms

CIE Commission Internationale de l'Eclairage (International Commission on Illumination)
CPX camera pixel
DUT device under test
ILMD imaging light measuring device
LMD light measuring device
MWA moving-window average

4 Standard measuring equipment

4.1 Light measuring devices

For the requirements of light measuring devices, refer to those specified in IEC 62977-2-1. The system configurations, operating conditions, or both, of the measuring equipment shall comply with the structure specified in each item. In particular, 6.2 and 6.3 shall follow the conditions of IEC 62977-2-1:2021, 5.3.4.

For 2D ILMDs which are not covered by 62977-2-1, the following requirements apply to the light measuring equipment, as follows.

2D ILMD: The ILMD shall capture a displayed image at a certain exposure time. The ILMD shall be used within its linear range for the incoming light. If a 2D ILMD is used, the effect of moiré, LMD field of view, flat field correction, background subtraction, etc., shall be taken into account. The measurement method in this document only measures a small area of the display, not the entire display, so moiré is not likely to occur, but should be checked before measurement. One display pixel should be covered by 30 or more camera pixels to avoid it. Refer to [1][1], Chapter 7, Appendix A9, for more information.

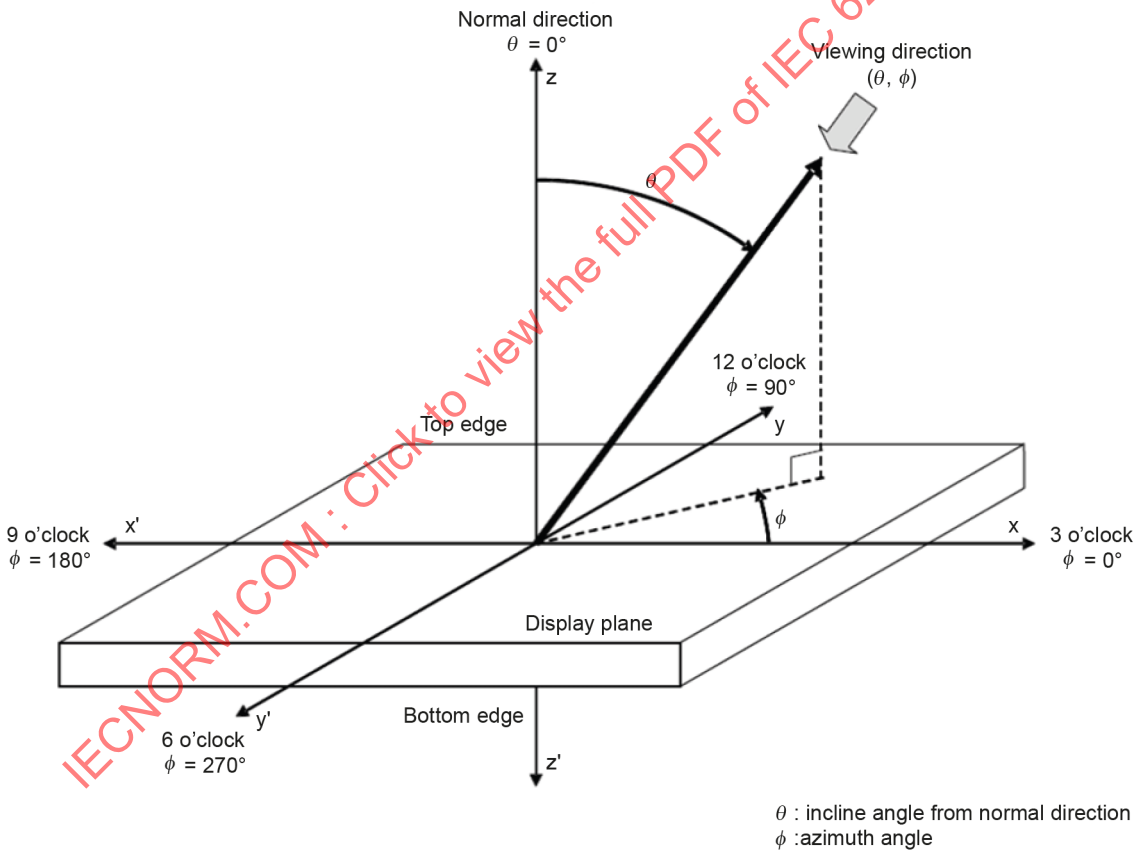
[1] Numbers in square brackets refer to the Bibliography.

If the light level of the display is temporally modulated, then the ILMD integration time shall be synchronized with the vertical frame synchronization signal. If the ILMD is not capable of synchronizing, then the ILMD integration time shall be at least 200 cycles (refer to [1], Appendix A4.2.2).

The ILMD should be set perpendicularly to the DUT screen. The results can be different when measuring at a viewing direction (vantage point direction).

4.2 Viewing direction coordinate system

The viewing direction is the direction under which the observer looks at the spot of interest on the DUT. During the measurement, the LMD is replacing the observer, looking from the same direction at a specified spot (i.e., measuring spot, measurement field) on the DUT. The viewing direction is conveniently defined by two angles: the angle of inclination θ (related to the surface normal of the DUT) and the angle of rotation ϕ (also called azimuth angle) as illustrated in Figure 2. The azimuth angle is related to the directions on a watch-dial as follows: ϕ = 0° is referred to as the 3-o'clock direction ("right"), ϕ = 90° as the 12-o'clock direction ("up"), ϕ = 180° as the 9-o'clock direction ("left") and ϕ = 270° as the 6-o'clock direction ("down").



NOTE

3 o'clock: right edge of the screen as seen from the user

6 o'clock: bottom edge of the screen as seen from the user

9 o'clock: left edge of the screen as seen from the user

12 o'clock: top edge of the screen as seen from the user

Figure 2 – Representation of the viewing direction (equivalent to the direction of measurement) by the angle of inclination, θ, and the angle of rotation (azimuth angle), ϕ, in a polar coordinate system

5 Measuring conditions

5.1 Standard measuring environmental conditions

Measurements should be carried out under standard environmental conditions:

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

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

5.2 Warm-up time

Measurements shall be carried out after sufficient warm-up. Warm-up time is defined as the time elapsed from when the supply source is switched on, and a 100 % grey level of input signal is applied to the DUT, until repeated measurements of the display show a variation in luminance of no more than 2 %/min.

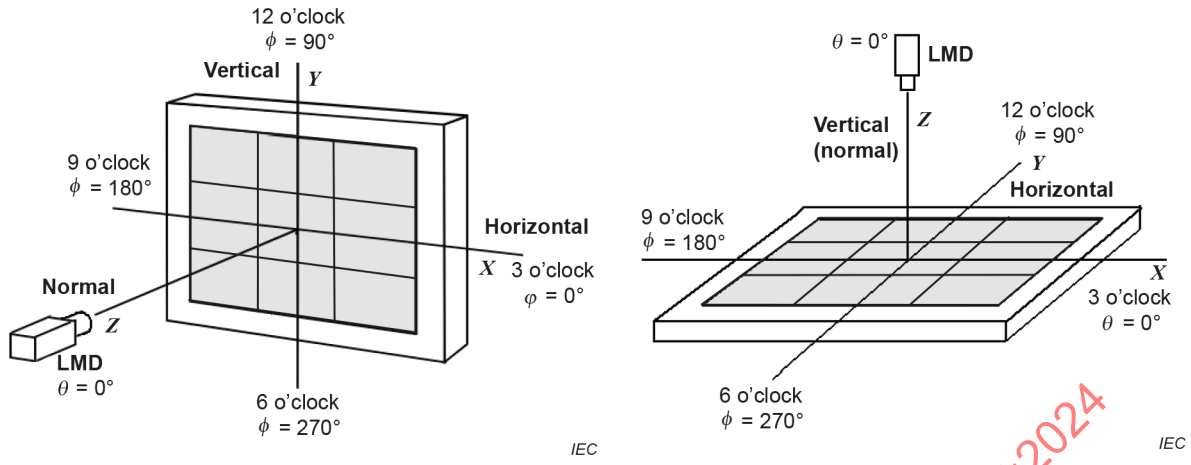
5.3 Standard measuring darkroom conditions

The luminance contribution from the background illumination reflected off the test display shall be < 0,01 cd/m^2 in any direction. If these conditions are not satisfied, then background subtraction is required, and it shall be noted in the measurement report. In addition, if the sensitivity of the LMD is inadequate to measure these low levels, then the lower limit of the LMD shall be noted in the measurement report.

5.4 Standard set-up conditions

By default, the display shall be installed in the vertical position (see Figure 3 a)), but the horizontal alternative (Figure 3 b)) is also allowed. When the latter alternative is used, it shall be noted in the measurement report.

Luminance, contrast and chromaticity of the white field and other relevant parameters of the displays have to be adjusted to nominal status in the detailed specification and they shall be noted in the measurement report. When there is no level specified, the maximum contrast or luminance level, or both, shall be used. These adjustments shall be held constant for all measurements, unless noted otherwise in the measurement report. Depending on the configuration of the tiled display, the optical characteristics can change due to differences in power management, heat-run, and mechanical alignment. It is recommended to use a minimum 3 × 3 cabinet or module configuration for the tiled display. That configuration should also be included in the measurement report. Additional conditions are specified separately for each measurement method.



a) Primary installation **b) Alternative installation**

Figure 3 – DUT Installation conditions

6 Measurement methods

6.1 Alignment measurements

6.1.1 General

In the case of a tiled display in which multiple displays are tiled to form one screen, the apparent quality of the display is a combination of the product characteristics of each display and the alignment characteristics of the installation process. To check such characteristics, a seam measurement method should be defined first.

The measurement method of this document consists of an optical measurement method. If measurement of the physical properties of tiled display is necessary, see IEC 63181-2 [2].

6.1.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: a 2D ILMD that can measure luminance, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

c) The number of pixels of the ILMD shall be more than 30 for each display pixel within the colorimeter's measurement-field area for setting good antialiasing properties.

6.1.3 Measurement method of the seam width

6.1.3.1 Purpose

The purpose of this method is to measure the seam width of a tiled display. This method is used to check whether the seam of the tiled display is not visible or maintains a certain level as designed.

6.1.3.2 Measurement method

1) Set the signal generator to input the resolution of the entire tiled display configuration to be measured. If only a subset of the tiled display elements in the entire configuration are to be measured, the test conditions should be noted in the report.

2) Figure 4 identifies the measurement positions. Figure 4 shows the location of the measurement locations at the border lines between two adjacent tiled display elements, in the example of a 3 × 3 tiled display. The measurement location is the centre of the horizontal and vertical borderline between two adjacent tiled display elements. The measurement field should cover the entire seam area and it is recommended to measure a luminance profile at least 5 times the seam width.

3) Apply the test pattern, as shown in Figure 5 a), with a targeted signal level (for example, R = G = B = 255), to the DUT.

4) Measure the test pattern in Figure 5 a) to obtain the luminance profile across the seam area, orthogonal (if the seam direction is vertical, the direction of the luminance profile is horizontal) to the seam direction on the centre of the screen. Perform an averaging over a size of 4 pixels or more in the direction of the seam (i.e vertical direction in the case of Figure 5) to obtain a good representation of the bright and dark lines and reduce noise.

5) Repeat the measurement using the test pattern in Figure 5 b) to obtain window width. The window width w for the moving-window average (MWA) shall be calculated using the input signal pixel pitch and the pixel ratio. The window width is the width of the line as rendered from the signal pixels. There should be at least 10 or more ILMD pixels per display line width. An example for the determination of w (the window width for the MWA) is shown in Figure 6. Refer to [1], Chapter 7, for detailed process.

$$w = \frac{\Delta x}{N} \tag{1}$$

where

Δx is the value of the range that is obtained by subtracting P_{start} and P_{end}, and in units CPX (one ILMD pixel). P_{start} and P_{end} are the first peak and last peak in the luminance profile, respectively;

w is the window width for the MWA;

N is the number of lines on the grille pattern. It is the number of black and white lines that are repeatedly displayed from P_{start} and P_{end}.

6) Perform the MWA processing to the 1D profile using the window width from 5) as shown in Figure 7. Refer to [1], Appendix B18, for detailed process on MWA.

7) Calculate seam width w_{seam} and seam depth d_{seam} using Formula (2), and Formula (3).

$$w_{\text{seam}} = \frac{\left(x_{1,90\%} - x_{2,90\%}\right) \times P}{w} \tag{2}$$

$$d_{\text{seam}} = y_{\text{mode}} - y_{\text{minimum}} \tag{3}$$

where

y_{mode} is the value that appears most often in a set of normalized luminance data of each CPX;

EXAMPLE Example for y_{mode} in the given set of normalized luminance data of each CPX: [0,9 0,9 0,89 0,88 0,91]; the mode of the data set is 0,9 since it has appeared in the set twice.

NOTE 1 If no data normalized luminance data items are repeated, then the data set has no mode value. If more than one data value has the highest frequency, then each of these data values is a mode. In these cases, the exact mode value cannot be obtained, then use the y_{mode} to a hypothetical target value (such as a luminance specification).

y_{minimum} is the minimum value of the set of normalized luminance data;

normalized luminance — is luminance value divided by the maximum value of the luminance profile after MWA as shown in Figure 7;

$x_{1,90\%}$ and $x_{2,90\%}$ — are the values with luminance corresponding to 90 % of the y_{mode} as shown in Figure 8.

8) Report the measurement location (tiled display element number of two adjacent elements), the test pattern, seam width, depth, $y_{minimum}$, and y_{mode}.

NOTE 2 In the case of a seamless tiled display, it will probably not be possible to calculate the width because it has a very small value of depth. In that case, report only the depth value.

The formulae and figures in this document use 90 % of the y_{mode} as an example, but the luminance percentage, which is the reference point when calculating the width of the seam, can be set differently depending on the characteristics of the product. For example, 90 %, 50 %, or any other criteria depending on the purpose of the measurement can be used.

When deriving the y_{mode}, if the two adjacent tiled display elements have luminance differences, an undesirable result is derived. Therefore, the luminance uniformity performance of the measurement display shall be guaranteed before measurement. If uniformity performance cannot be achieved, change the y_{mode} to a hypothetical target value (such as a luminance specification) and report it. Here, the depth is represented as the luminance difference between the seam area and the surrounding tiled elements.

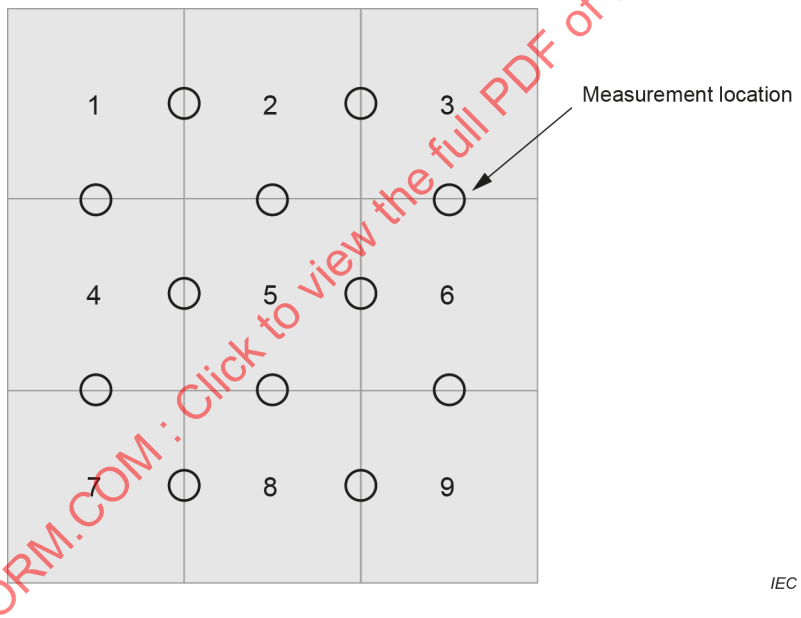
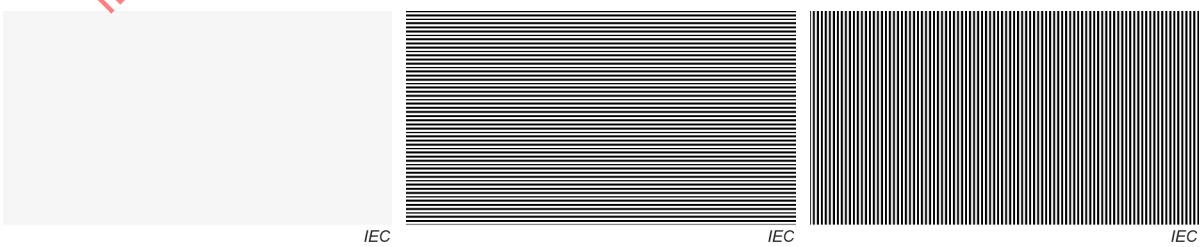


Figure 4 – Measurement locations of X-Y plane alignment



a) Full grey pattern **b) Horizontal grill pattern** **c) Vertical grill pattern**

Figure 5 – Full grey pattern, 1 × 1 horizontal grille pattern, and 1 × 1 vertical grille pattern

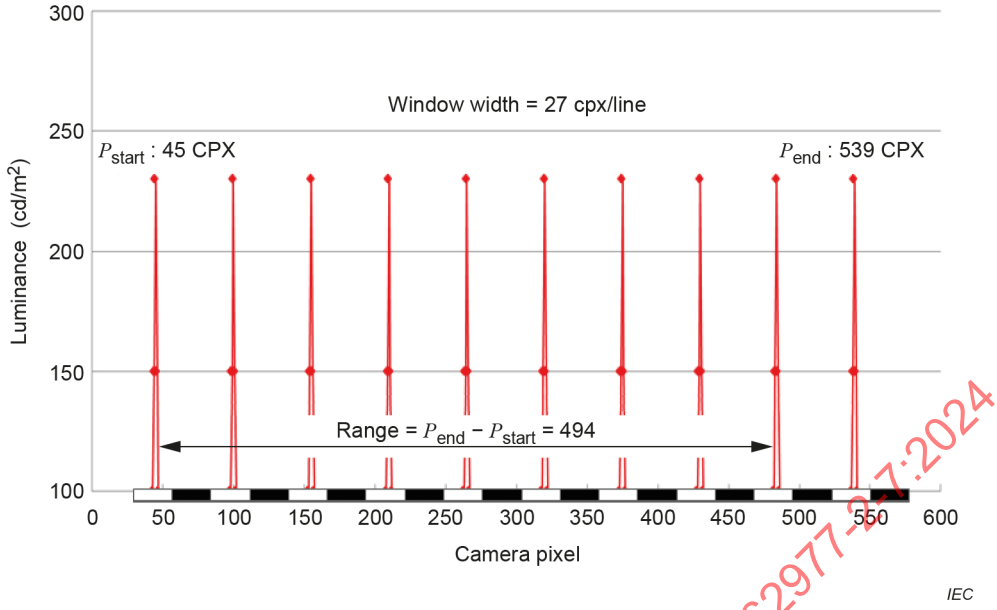


Figure 6 – Example of window width calculation

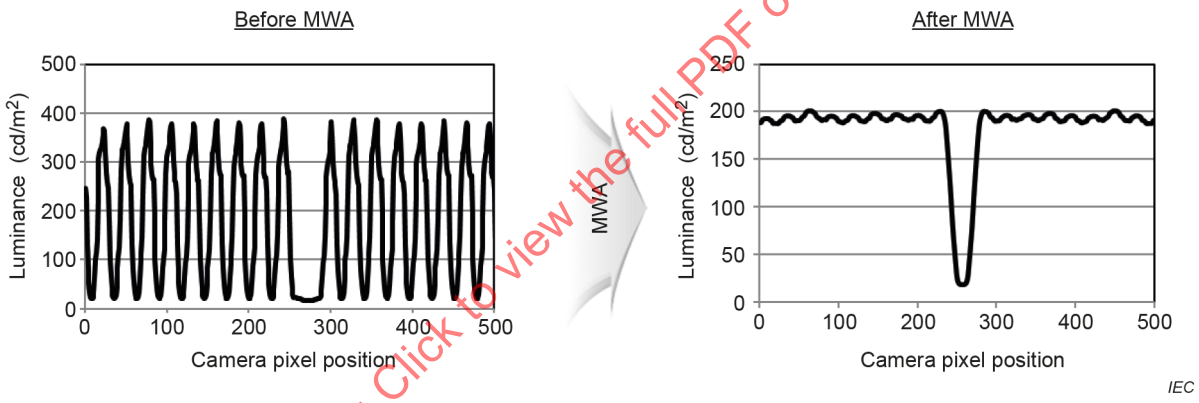


Figure 7 – Luminance profile before and after WMA

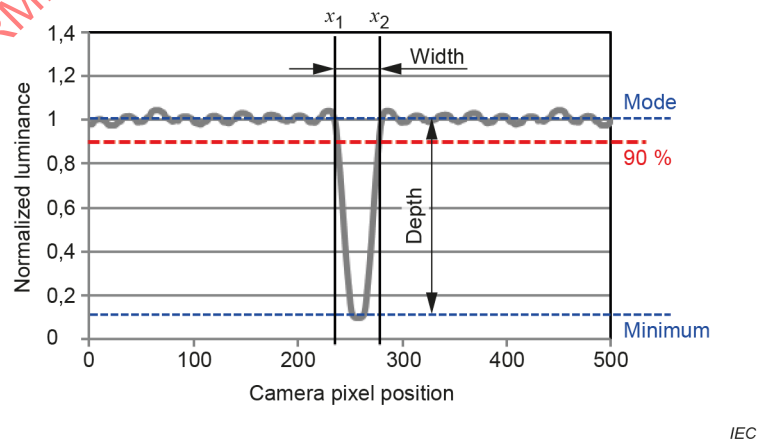


Figure 8 – Example of seam width and depth calculation

6.1.4 Alignment along the z-axis direction

6.1.4.1 Purpose

The purpose of this measurement is to ensure that the tiled display is well aligned with the z-axis. Since the z-axis alignment cannot be confirmed from the normal direction, this measurement is made at a defined viewing angle.

6.1.4.2 Measurement method

1) Prepare the test sample as shown in Figure 4.
2) In the case of the horizontal direction measurements, position the LMD at (45°, 0°) and (45°, 180°), as illustrated in Figure 9.
3) In the case of the vertical direction measurements, position the LMD at (45°, 90°) and (45°, 270°).
4) Conduct the measurement and calculation at each location according to 6.1.3. The measured image should be inspected for moiré. If moiré appears in the measured image, it shall be removed before the next step. Refer to [1], Chapter 7, Appendix A9, for more information.
5) Determine the depth values for the two oblique viewing directions.
6) Calculate the depth difference between each viewing directions using Formula (4). For example, in the case of the horizontal direction, the data measured at positions (45°, 0°) and (45°, 180°) is depth 1 and depth 2, respectively.

NOTE If the tiled display is perfectly aligned in the z-axis, the depth difference between the two directions will be zero.

$$\Delta d = \frac{|d_1 - d_2|}{\max(d_1, d_2)} \tag{4}$$

where

Δd is the depth difference value between the two directions;

d_1, d_2 are the depth values of each direction.

7) Report the measurement location (tiled display element number of two adjacent elements), position of the LMD (θ, φ), test pattern, depth, and depth difference.

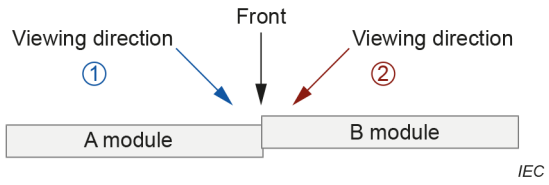


Figure 9 – Measurement location of z-axis alignment

6.1.5 Alignment of tilt

6.1.5.1 Purpose

The purpose of this measurement method is to check how much the tiled display is tilted in the X-Y plane. Unlike the alignment of the X-Y plane, it measures two measurement locations and compares the results.

6.1.5.2 Measurement method

1) Prepare a sample to be evaluated and determine the direction of the tilt to be measured.
2) In the case of the horizontal direction, as shown in Figure 10, set the left and right measurement locations to within 10 % of the horizontal width of the display.
3) In the case of the vertical direction, set the up and down measurement locations to within 10 % of the vertical height of the display.
4) Conduct the measurement and calculation at each location according to 6.1.3.2.
5) Calculate the seam width difference Δw_{seam} of each location.
6) Calculate the tilt angle by the seam width difference Δw_{seam} (mm) and distance between the measurement points D (mm) using Formula (5). For example, for the horizontal direction, D should be 80 % of the horizontal width of the display.

$$a_{\text{tilt}} = \arctan\left(\Delta w_{\text{seam}} / D\right) \tag{5}$$

where

a_{tilt} is the tilt angle, expressed in degree.

7) Report the result with the measurement locations (tiled display element number of two adjacent elements), the width difference, and tilt angle.

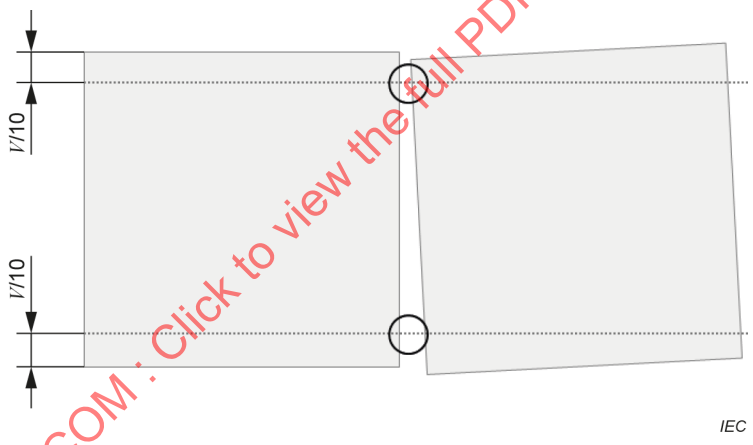


Figure 10 – Measurement locations of alignment of tilt

6.2 Visual uniformity

6.2.1 General

Tiled display systems have repeatable elements that exist at various levels of each subsystem enabling highly configurable display systems. This document only evaluates the uniformity between tiled display elements in order to avoid duplication of other documents within IEC TC 110. If the optical characteristics of each tiled display element are necessary, the methods specified in IEC 62977-2-1 and IEC 62977-2-2 will be used to obtain the characteristics. Depending on the configuration of the tiled display, the optical characteristics can change due to differences in power management, heat-run, and mechanical alignment. It is recommended to use a minimum 3 × 3 configuration for the tiled display. That configuration should also be included in the measurement report. Regarding the luminance and the chromaticity uniformity, the results can be different after the calibration process under different conditions.

NOTE It is not uncommon that the first few columns or rows of pixels near a module edge have different radiation patterns than the interior pixels. This non-uniformity can look like visible gaps. A spot LMD measurement would not capture this type of edge non-uniformity. If the tiled display exhibits an edge luminance non-uniformity, then the method used in 6.1.2 can be used to determine the luminance variation between module edges.

6.2.2 Measuring conditions

The following measuring conditions apply:

a) Apparatus: an LMD that can measure luminance and the CIE 1931 chromaticity coordinates, a driving power supply, and driving signal equipment.

b) Standard measuring environmental conditions; darkroom conditions; standard setup conditions.

6.2.3 Uniformity measurement locations

The following two sets of measurement locations apply:

1) The screen centre of each tiled display element.

2) In order to evaluate the uniformity characteristics with adjacent elements, additional measurement locations at the edge area of each element can also apply. The measurement location is determined by referring to IEC 62977-2-1:2021, 6.5. The measurement location is 10 % inward from the edge of the active area, and the region of interest is determined and measured according to the configuration of the tiled display. For example, in the case of a 1 × 2 side-by-side tiled display, the measurement locations of the area that contact each other are measured as shown in Figure 11. In the case of a 2 × 2 side-by-side tiled display, the locations of four adjacent elements contacting each other are measured as shown in Figure 12.

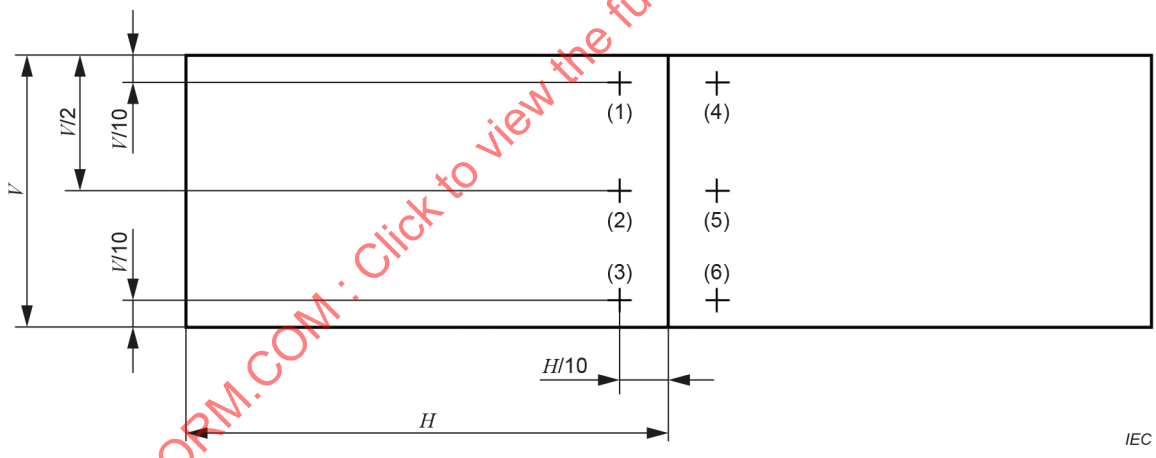


Figure 11 – Example measurement locations of 1 × 2 tiled display elements

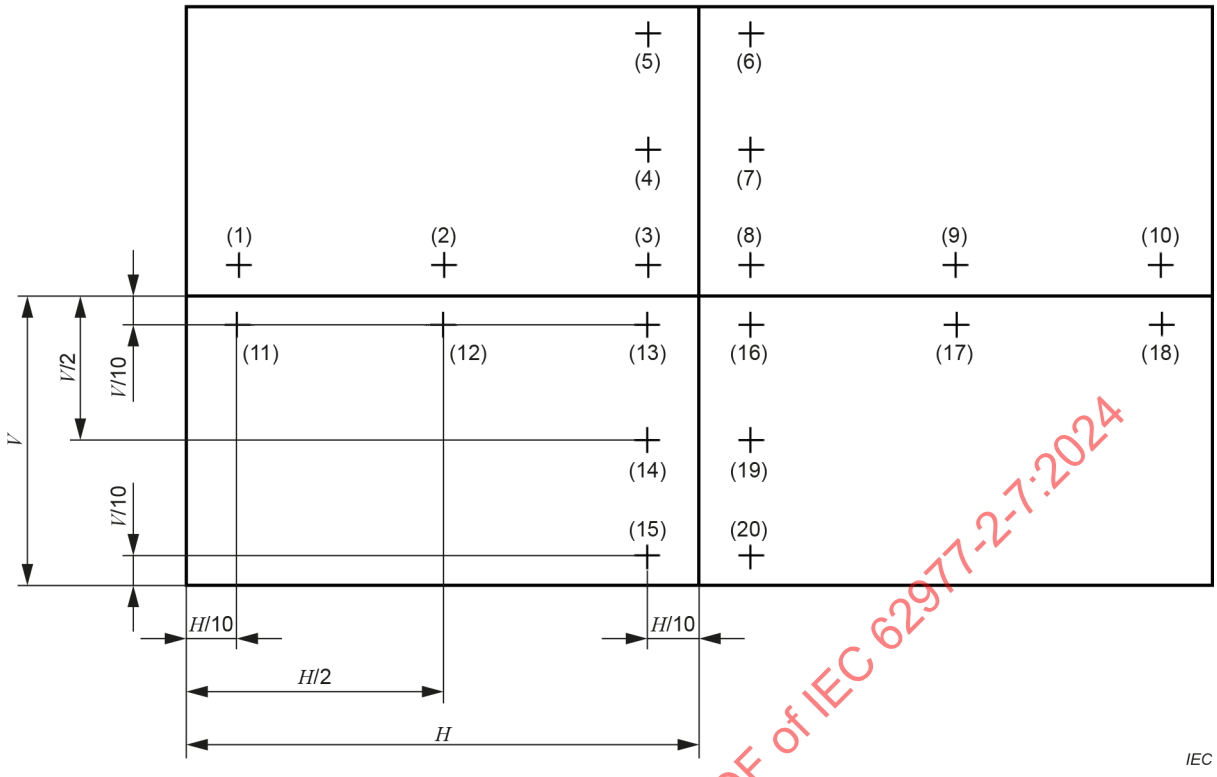


Figure 12 – Example measurement locations of 2 × 2 tiled display elements

6.2.4 Luminance uniformity

6.2.4.1 Purpose

The purpose of this measurement is to evaluate the luminance uniformity property of the tiled display.

6.2.4.2 Measurement method at screen centre

1) Obtain the centre luminance of each tiled display element according to IEC 62977-2-1:2021, 6.3.
2) Calculate the luminance non-uniformity NU of the tiled display using Formula (6).
3) Report the uniformity, luminance of each location, and the type of test pattern.

$$NU = \left(1 - \frac{L_{min}}{L_{max}}\right) \times 100 \quad (6)$$

where

NU is the non-uniformity of the tiled display, expressed in %;

L_{min} is the minimum luminance of the tiled display element;

L_{max} is the maximum luminance of the tiled display element.

6.2.4.3 Measurement method between neighbouring edges

1) Obtain the luminance of each measurement location of the tiled display element according to 6.2.3.
2) Calculate the luminance uniformity of the tiled display using Formula (6).
3) Report the uniformity, luminance of each location, and the type of test pattern.

6.2.5 Chromaticity non-uniformity

6.2.5.1 Purpose

The purpose of this measurement is to evaluate the chromaticity non-uniformity property of the tiled display.

6.2.5.2 Measurement method at screen centre

1) Obtain the centre chromaticity coordinates of each tiled display element in accordance with IEC 62977-2-1:2021, 6.8.
2) Calculate the chromaticity non-uniformity of the tiled display using Formula (7).
3) Report the uniformity and chromaticity coordinates of each location, and the type of test pattern according to IEC 62977-2-1:2021, 6.8.

$$\Delta u'v' = \sqrt{(u'_1 - u'_2)^2 + (v'_1 - v'_2)^2} \tag{7}$$

where

u'_1, u'_2, v'_1, and v'_2 are the CIE 1976 UCS chromaticity coordinates of each tiled display element.

The chromaticity non-uniformity is defined as the largest chromaticity difference $(\Delta u'v')_{max}$ between any two measurement locations (i.e. the maximum value of Formula (7)).

6.2.5.3 Measurement method between neighbouring edges

1) Obtain the chromaticity coordinates of each measurement location of the tiled display element in accordance with 6.2.3.
2) Calculate the chromaticity non-uniformity of the tiled display using Formula (8).
3) Report the uniformity and chromaticity coordinates of each location, and the type of test pattern according to IEC 62977-2-1:2021, 6.8.

6.2.6 Contrast ratio uniformity

6.2.6.1 Purpose

The purpose of this measurement is to evaluate the contrast ratio uniformity property of the tiled display.

6.2.6.2 Measurement method at screen centre

1) Obtain the centre contrast ratio of each tiled display element according to IEC 62977-2-1:2021, 6.4.
2) Calculate the contrast ratio non-uniformity of the tiled display using Formula (8).
3) Report the uniformity and contrast of each location.

$$NU_{CR} = \left(1 - \frac{CR_{min}}{CR_{max}}\right) \times 100 \tag{8}$$

where

CR_{min} is the minimum contrast ratio of the tiled display element;

CR_{max} is the maximum contrast ratio of the tiled display element.

6.2.6.3 Measurement method between neighbouring edges

1) Obtain the contrast ratio of each measurement location of the tiled display element in accordance with 6.2.3.
2) Calculate the contrast ratio non-uniformity of the tiled display using Formula (8).
3) Report the uniformity and contrast of each location.

6.2.7 Reflectance non-uniformity

6.2.7.1 Purpose

Unlike conventional products composed of a single display, tiled displays can have different reflectance values for each tiled display element. This affects the display performance under ambient illumination. In this measurement method, the reflectance non-uniformity of a tiled display is evaluated. Since the reflected light can depend on the illumination conditions, two illumination conditions are measured, i.e., hemispherical diffuse and directional illumination.

6.2.7.2 Measuring condition

This measurement method follows the measuring conditions specified in IEC 62977-2-2:2020, Clause 4.

6.2.7.3 Hemispherical diffuse reflectance non-uniformity

1) Obtain the centre hemispherical diffuse reflectance factor ρ of each tiled display element in its black state according to the hemispherical diffuse reflectance measurement described in IEC 62977-2-2:2020, 6.3. A light source with a broad and spectrally smooth optical spectral distribution (such as Illuminant A) shall be used.
2) Calculate the hemispherical diffuse reflectance non-uniformity $\Delta\rho$ using Formula (9).
3) Report the value $\Delta\rho$, the hemispherical diffuse reflectance of each tiled display element, and the largest reflectance difference between and two neighbouring tiled display elements.

$$\Delta\rho = \left(1 - \frac{\rho_{\text{min}}}{\rho_{\text{max}}}\right) \times 100 \tag{9}$$

where

ρ_{min} is the minimum reflectance of any of the tiled display elements;

ρ_{max} is maximum reflectance of any of the tiled display elements.

6.2.7.4 Directional reflectance factor non-uniformity

1) Obtain the centre luminous directional reflectance factor R of each display device unit in its black state in accordance with the directional reflectance factor measurement described in IEC 62977-2-2:2020, 6.4, and IEC 62341-6-2:2015, 5.2. A light source with a broad and spectrally smooth optical spectral distribution (like Illuminant A) shall be used.
2) Calculate the directional reflectance non-uniformity ΔR using Formula (10).
3) Report the value ΔR and the directional reflectance of each tiled display element.

$$\Delta R = \left(1 - \frac{R_{\text{min}}}{R_{\text{max}}}\right) \times 100 \tag{10}$$