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INTERNATIONAL STANDARD

colour inside

Electronic displays –
Part 3-4: Evaluation of optical performances – High dynamic range displays

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ELECTRONIC DISPLAYS –

Part 3-4: Evaluation of optical performances – High dynamic range displays

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

Draft	Report on voting
110/1493/FDIS	110/1509/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 62977 series, published under the general title *Electronic displays*, can be found on the IEC website.

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- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

High dynamic range (HDR) systems enable more natural images that contain wider variations in brightness. For the wider dynamic range, newly designed electro-optical transfer function (EOTF) replaces the BT.1886 function of standard dynamic range (SDR) HDTV. High dynamic range (HDR) systems utilize non-linear signal encoding that enables reproduction over a wider range of light levels, from subtle grey differences at very low luminance levels up to very bright highlights. This very wide range of light levels occurs in both natural as well as synthetic imagery. In particular, in order to render the native image according to the intent of the content creator, signal codewords of SMPTE ST 2084 [2][1] HDR EOTF, also known as the perceptual quantizer (PQ), are mapped to absolute luminance values within the mastering peak luminance as specified in metadata of the HDR content, versus an SDR signal level which indicates relative brightness according to the display luminance. In this case, tone mapping would be necessary when the display luminance cannot make the darker and the brighter luminance because HDR content preserves details in the darkest and brightest areas of a picture that are lost when using SDR standards (see 3.1.4) [20] such as Recommendation ITU-R BT.709 [12]. The tone mapping curve can depend upon the display manufacturer.

This document intends to describe the measurement and evaluation of the optical performance of HDR displays as a reference for forthcoming standards to make the work of the involved experts more efficient and to avoid duplication of efforts.

There are unique requirements to evaluate HDR displays, and particular attention is given to the measurements, so that they are done properly. For example,

1) very low luminance levels will be measured, with careful control of stray light from both the display as well as ambient light sources;
2) to measure high light output levels, measurements timing and test pattern need to be carefully controlled to correctly and accurately capture peak or high luminance levels since HDR displays can have a peak luminance time limit, and many HDR displays have luminance loading limits;
3) for HDR content, 10 bits or higher bit-depth should be used for sufficient luminance quantization;
4) the HDR test signal has SMPTE ST 2086 [3] HDR static metadata assigned to fixed values. Other metadata is not used in this document.

Proper source content is critical to evaluating HDR performance of the displays including the driver (and interface). In SDR displays, it is possible to separate these issues from the evaluation of “panels”, but for HDR displays it is not possible to separate these issues because HDR displays include one or more internal blocks that process the HDR video signal, such as EOTF and tone mapping, etc., in addition to essential driving stages for the display panel.

1 Numbers in square brackets refer to the Bibliography.

ELECTRONIC DISPLAYS –

**Part 3-4: Evaluation of optical performances –
High dynamic range displays**

1 Scope

This part of IEC 62977 specifies the standard evaluation methods for determining the optical characteristics of HDR electronic display modules and systems. These methods apply to emissive and transmissive direct-view displays that render real 2D images on a flat panel or on a curved panel with a local radius of curvature larger than 1 500 mm. This document evaluates the optical characteristics of these displays under darkroom conditions. This document applies to the testing of display performance in response to HDR digital input signals that are absolute luminance encoded such as the HDR signal comprising RGB component values of Recommendation ITU-R BT.2020 colorimetry with SMPTE ST 2084 [2] PQ luminance encoding and SMPTE ST 2086 [3] metadata.

NOTE A flat panel or flat panel display is a display with a planar surface that emits light from the surface. The display can consist of light valves modulating a backlight or be self-luminous. Emissive/transmissive/reflective hybrid displays can be non-planar panels or non-planar panel displays.

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: Measurement of optical characteristics – Ambient performance*

CIE 015:2004, *Colorimetry*

Recommendation ITU-R BT.2020-2, *Parameter values for ultra-high definition television systems for production and international programme exchange*

Recommendation ITU-R BT.2100-2, *Image parameter values for high dynamic range television for use in production and international programme exchange*

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 terminological 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
HDR peak luminance
maximum stable white luminance of the display using the HDR test signal (see 3.1.14) under the required measuring condition

3.1.2
dynamic range
range of the lowest to the highest luminance expressed by the ratio of the highest luminance to the lowest luminance that the display can render by a non-zero signal value

Note 1 to entry: The unit of the dynamic range can be expressed in terms of the number of stops using the formula Log_2[dynamic range].

3.1.3
high dynamic range
HDR
span of image luminance and contrast described in Recommendation ITU-R BT.2100

3.1.4
standard dynamic range
range of relative luminance with an unbounded input signal (generally exhibiting a power law dependence with input signal to be displayed in accordance with the luminance range of the display) that is normally possible for a conventional video display and content, whereby the standard dynamic range signal for SDTV, HDTV and UHDTV is encoded with the format defined in Recommendation ITU-R BT.601 [13], Recommendation ITU-R BT.709 [12] and Recommendation ITU-R BT.2020, respectively

3.1.5
average picture level
APL
average input level of all signal pixels relative to the maximum signal setting expressed as a percentage

Note 1 to entry: Post-EOTF APL is also called ALL (average light level), and calculated by averaging of post-EOTF signal pixels (linear values).

3.1.6
code value
digital input value of an image signal component representing a signal pixel expressed in a specified format such as RGB

3.1.7
opto-electrical transfer function
OETF
optical to signal transfer function which is used in image acquisition devices such as digital cameras for mapping scene luminance to digital code values prior to encoding, transmission, or compression

Note 1 to entry: If OETF and EOTF consist of or are close to a power function (such as generally used in SDR systems), the function is called nonlinear encoding (gamma correction) and nonlinear decoding (inverse gamma correction), respectively, where its exponent is called gamma or gamma value.

Note 2 to entry: In conventional non-constant luminance systems, the nonlinear decoding is done in the RGB domain, whereas it is done in the YC_bC_r domain for constant luminance systems.

3.1.8
electro-optical transfer function
EOTF
mathematical function for the inverse OETF (and system gamma for power law functions), usually used for display systems such as TVs and monitors, that maps digital code values to displayed luminance

Note 1 to entry: Generally, EOTF is also called nonlinear decoding, which is the inverse of nonlinear encoding, but custom decoding is also available in many display products.

3.1.9
optical-to-optical transfer function
OOTF
mathematical function that maps the captured luminance by a camera to the displayed luminance by a display device according to the rendering intent or peak luminance of the display

3.1.10
white boosting
increase in the luminance of displayed white image elements beyond what is expected for R + G + B primary colour additivity, and a corresponding decrease in colour saturation

Note 1 to entry: Luminance boosting such as white boosting can influence the tone curve according to colour saturation that is deviated from the display gamma curve.

3.1.11
HDR display
display that can accommodate, properly process, and display the PQ-encoded HDR content defined in Recommendation ITU-R BT.2100

Note 1 to entry: An HDR display can also display SDR content by changing the EOTF and its related functions such as tone mapping and system gamma.

3.1.12
HDR content
image content mastering with OETF which is described in Recommendation ITU-R BT.2100

3.1.13
HDR tone mapping
mapping of the HDR test signal to the performance envelope of a display, whereby the display system maps one set of tone ranges to another to approximate the appearance of the content, when the content requires a wider dynamic range beyond the display's capability to reproduce the full range of light intensities ranging from the darkest to the highest target luminance levels

Note 1 to entry: HDR tone mapping can include dynamic range global or local clipping or roll-off while preserving the chromaticity of the original image (see 6.6), perceptual colour rendering, or other forms of colour gamut mapping which are dependent on the display mode.

Note 2 to entry: An HDR DUT can use different static and/or dynamic metadata as input to the tone mapping algorithms.

3.1.14
HDR test signal
test signal referred to as an HDR10 implementation that has been adopted by the display industry to describe an uncompressed signal that uses the PQ EOTF from Recommendation ITU-R BT.2100 and HDR static metadata defined in SMPTE ST 2086 [3]

Note 1 to entry: An explanation can be found in 4.1. For the purpose of controlled metrology, the test signal is used with a single set of signal parameters that is unique compared to other signals described in display-referred (refer to Chapter 20 in [1]) whose signal represents the intent of the content creator that includes defined parameters for the non-linearity, min/max luminance, and the colour encoding of the signal container, whereby the encoded signal values can be directly transformed to absolute CIE XYZ.

Note 2 to entry: For the definitions of HDR test signals such as display-referred, signal container, etc., and for background information see Chapter 20 in IDMS ver.1.1:2021 [1].

3.1.15
Maximum Content Light Level
MaxCLL
metadata which indicates the maximum light level value of any single pixel of the entire playback sequence

Note 1 to entry: For MaxCLL, the unit is equivalent to cd/m^2 when the brightest pixel in the entire video stream has the chromaticity of the white point of the encoding system used to represent the video stream. Since the value of MaxCLL is computed with a max() mathematical operator, it is possible that the true CIE Y luminance value is less than the MaxCLL value.

3.1.16
Maximum Frame-average Light Level
MaxFALL
metadata which indicates the maximum frame average value within a temporal sequence of frames

Note 1 to entry: For MaxFALL, the unit is equivalent to cd/m^2 when the maximum frame average of the entire stream corresponds to a full-screen of pixels that has the chromaticity of the white point of the encoding system used to represent the video stream. The frame-average computation used to compute the MaxFALL value is performed only on the active image area of the image data.

3.1.17
$\Delta E_{00,D50}$
colour difference calculated based on adaptation to D50 using CIE 1931 colour-matching functions (CMFs)

Note 1 to entry: This colour difference is different from CIE ΔE_{00}.

3.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

ABC	auto brightness control
ACR	ambient contrast ratio
ALC	ambient light control
APL	average picture level
BRCR	bright room contrast ratio
CAT	chromatic adaptation transform
CIELAB	CIE 1976 (L*a*b*) colour space
CMF	colour-matching function
DRCR	darkroom contrast ratio
DUT	device under test
EOTF	electro-optical transfer function
HDR	high dynamic range
OETF	opto-electrical transfer function
OLED	organic light emitting diode
OOTF	optical-to-optical transfer function
PQ	perceptual quantizer (PQ tone curve as defined in Recommendation ITU-R BT.2100)
RGBCMY	red, green, blue, cyan, magenta and yellow
SDR	standard dynamic range
SLET	stray light elimination tube

4 Standard measuring equipment

4.1 Video signal generator

A digital video signal generator is used, and the HDR test signal is implemented as follows. All code values of the test signal shall be PQ encoded with BT.2020 colorimetry and 10-bit full-range. The DUT should support a 10-bit or greater signal and colour range signal input of Recommendation ITU-R BT.2020. This shall be included as “Supported” or ”Not supported” in the test report of Clause 7. It is important that for each measurement result, metadata conditions are defined, checked and reported; otherwise, the results might not be reproducible. The static HDR metadata format shall be reported as described in 7.1 (refer to Section 20.1.1 and Section 20.1.5 in IDMS ver.1.1:2021 [1], [12], [15]). The HDR test signal format is defined as:

SMPTE ST 2084 EOTF, 10-bit RGB full range, BT.2020 primary encoding,

SMPTE ST 2086 metadata: The default metadata is set to P3D65, 4 000 cd/m^2 peak

MaxCLL no data, MaxFALL no data

If the DUT exceeds the default metadata settings, these can be modified accordingly as long as they are clearly reported.

The input signal or input data, in this document, means the transferred code values by the OETF of PQ HDR defined in Recommendation ITU-R BT.2100 and Report ITU-R BT.2390 [17].

4.2 Conditions of measuring equipment

Refer to IEC 62977-2-1:2021, 5.3.4.

Additional conditions of the measuring equipment shall comply with IEC 62977-2-1.

4.3 Measuring equipment block diagram

Refer to IEC 62977-2-1. An example of block diagram is shown in Figure 1. The optical axis of the optical test equipment shall be centered on the screen and perpendicular to the display surface.

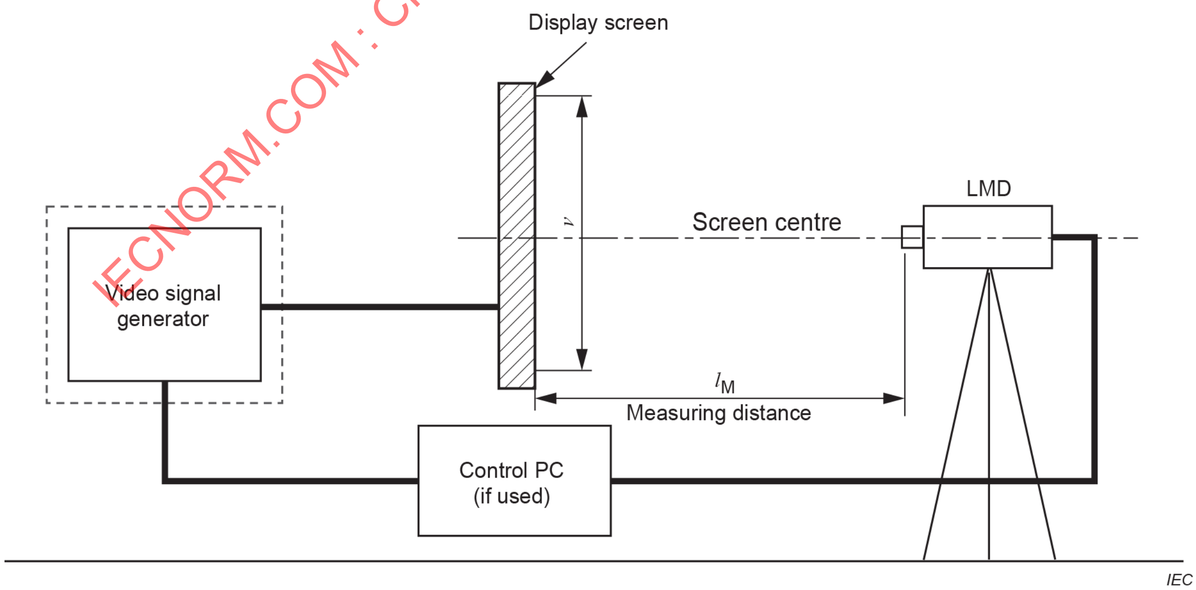


Figure 1 – Measuring layout for non-contact measurement

5 Standard measuring conditions

5.1 Standard measuring environmental conditions

Refer to IEC 62977-2-1:2021, 5.1. The standard environmental conditions for performing the measurements are defined as follows:

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

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

5.2 Power supply

The power supply for driving the DUT shall be adjusted to the rated voltage ±2 %. In addition, the frequency of the power supply shall provide the rated frequency ±1 %.

5.3 Warm-up time

Measurements shall be started after the displays and measuring instruments achieve stability. The DUT shall be turned on first and operated for at least 30 min prior to the measurement. Some display technologies might require a loop of colour patterns rendered on the screen during the warm-up period. Sufficient warm-up time has been achieved when the luminance of the test feature to be measured varies by less than ±3 % over the entire measurement period (e.g. uniformity measurements) for a given display image.

5.4 Standard darkroom conditions

The luminance contribution from the background illumination reflected from the test display shall be below 0,000 5 cd/m^2. If the test pattern generates stray light, then stray light elimination methods such as frustum or stray light elimination tubes should be used. The LMD shall have a sufficient signal-to-noise ratio suitable to measure the low luminance of black. If there is significant background illumination of more than 0,000 5 cd/m^2 and of more than 10 % of the measured black luminance, the off-state luminance by background illumination (also called background black) should be subtracted from the measured black luminance of the on-state.

5.5 Adjustment of HDR display

The HDR display is a physical display that is receiving the HDR test signal. It is likely that the HDR DUT is incapable of reproducing the entire display-referred HDR test signal which requires absolute values with a definition of non-linearity, min/max luminance, and colour encoding of the signal container [1]. The standard operating status of the display equipment shall be adjusted by the following sequence.

a) Initialized status

   The imaging setup configuration of the display equipment shall be returned to the factory condition in the reference master mode. If the DUT does not have the reference master mode, the image mode shall be adjusted to the HDR standard or corresponding mode. The mode shall remain at that setting for all tests in this document. The selection of the mode should be made once and only once in this document. Likewise, any other menu configuration settings should be adjusted once and only once, and thereafter be left at the same setting for all measurements. The mode and menu configuration used for all measurements shall be recorded and reported.

b) Adjustment of ambient light control

Turn off the ABC (or ALC) of the DUT. If it cannot be turned off, set the DUT under no less than 300 lx lighting close-up or contacted with the light sensor for reasonable measurement without dimming; this shall be reported. The lighting to disable the ambient light control shall not influence the ambient illuminance for the darkroom and bright room condition. If the lighting to disable ABC influences the results of the darkroom measurements, a close-up type LMD as shown in Figure 2 could be used.

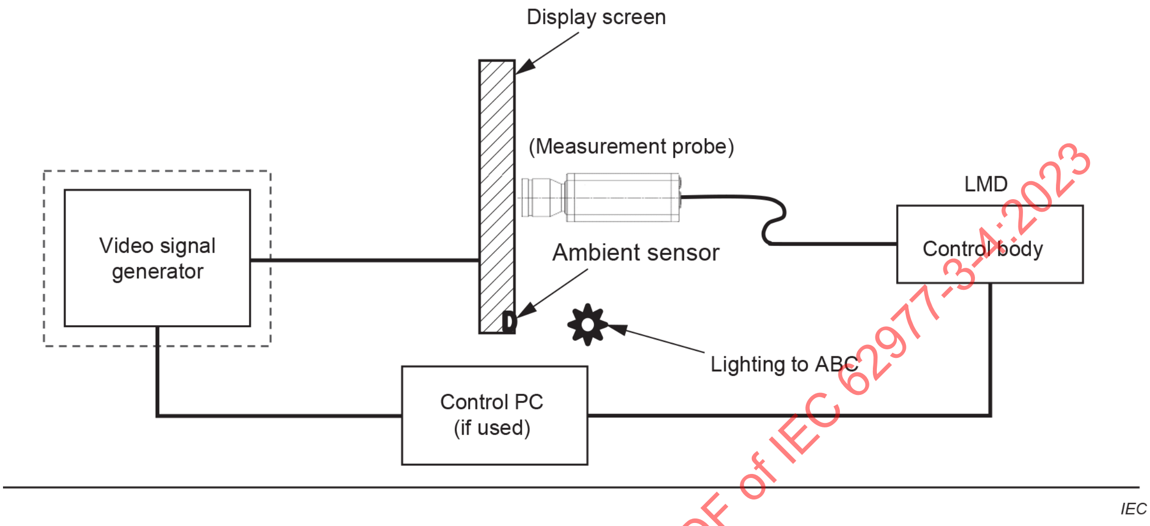


Figure 2 – Measuring layout for close-up type LMD

c) Adjustment of aspect ratio

The aspect ratio of the DUT shall be adjusted in full screen mode without overscan.

d) Reference master mode of HDR display

The HDR DUT can provide different modes of operation. Some modes can perform perceptual rendering, whereas the reference master mode can provide a colorimetric match within its capability envelope. When measuring the DUT, it is not permitted to break out the display device and the display system into separate optical functions. This is because some optical functions such as tone mapping, white balance, frame rate conversion, dimming and boosting, etc., cannot be turned off by users. In all measurements, the display shall meet all the requirements of this specification without modifying the configuration settings.

6 Measuring methods of optical characteristics

6.1 HDR peak luminance

6.1.1 HDR peak luminance variation by black and white pattern

Due to the limitation of power consumption, the display luminance can be managed based on the average luminance of the image. In this case, the APL to define white luminance would be identical to the white window area with a black background. The white luminance curve according to the white window area can be approximated by modeling as in the example given in Formula (1), whereby the constants a, b and c should be calculated based on the design concept of the luminance curve.

Figure 3 shows an example of an APL-dependent white luminance curve obtained at the centre of the black and white test pattern as a function of the centre window area (A % area of the total screen area). The A % white window area of the screen would make a pattern with A % APL. Other displays not sensitive to the APL might show a more stable luminance curve up to 100 % APL.

The curve can be modelled by the inverse of the white window area (%) corresponding to the APL (%) as in the example given by Formula (1) which is expressed with coefficients to convert the APL value to the white luminance in cd/m². The dashed line in Figure 3 demonstrates the model estimation. A set of example coefficients was determined as 2, 11 000, and 55 for a, b, and c, respectively. However, the coefficients vary with the optical characteristics and driving scheme of the display system such as power management. The design of the luminance curve might depend on the display device properties. The dimming and boosting in the luminance can also be limited by electrical or material reliability issues, for example.

$$L_{\text{white}}\left[\text{cd/m}^2\right] \approx \frac{b}{A_{\text{white}} + a} + c \qquad (1)$$

where

A_{white} is the white window area or APL in per cent;

a, b, c are constants to describe white luminance curve of a display module.

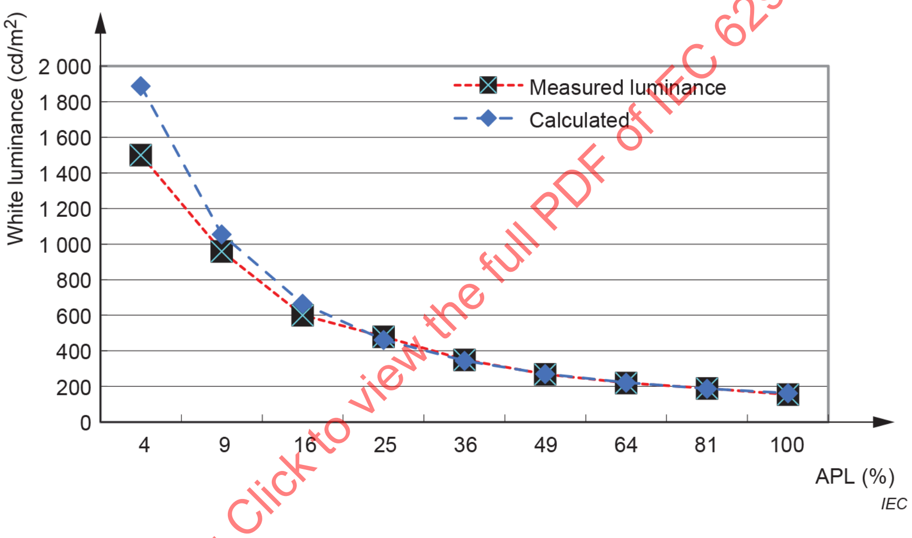


Figure 3 – Example of white luminance curve as function of the white window area, expressed by its APL (%)

6.1.2 APL by the window and background level

An APL for a given A % area window pattern in Figure 4 would be determined by the luminance levels of the window and its background as given in Formula (2). When it is an A % area window with a window input (level X) and background input (level Y) in a 10-bit code word in Figure 4, the APL is calculated by the sum of the APL between the centre window and its background.

$$\text{APL (\%)} = A \times (X / 1\,023) + (100 - A) \times (Y / 1\,023) \qquad (2)$$

where

X and Y are the 10-bit codes when the display has the full dynamic range specified by the HDR content, while the luminance for the input can be variable according to the tone mapping of the HDR system.

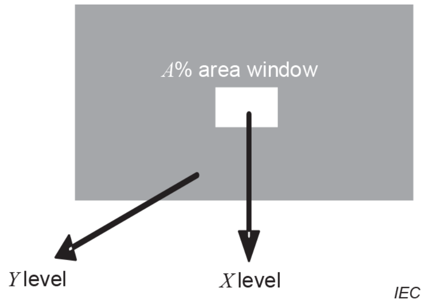


Figure 4 – General window pattern with A % area

6.1.3 Test pattern for HDR peak luminance

The APL for the peak luminance could be defined by considering both the required luminance and chromaticity of the HDR content. Some HDR system makers might have to design according to the power consumption limitations or for other reasons related to specific technologies. In such cases, the resultant peak white luminance level can vary as a function of APL, as shown in Figure 3. If so, a suitably low APL shall be selected so that the peak luminance measurement is not arbitrarily limited.

The peak luminance shall be measured at the A % area window ($0,1 \le A \le 100$) with black background as shown in Figure 5 where H is the horizontal screen size, and V is the vertical screen size. In case of white-only input, the A % area white shall be the A % APL to the display which has the same APL between the pre-EOTF and the post-EOTF. The "A" value shall be reported.

NOTE For a low APL with a small area window, the measurement field is set to contain at least 500 pixels.

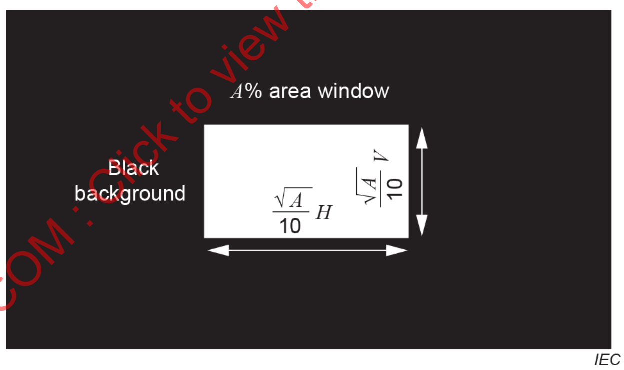


Figure 5 – A % APL pattern with A % area white

6.1.4 Measuring method

The peak luminance L_W shall be measured as the highest luminance value for a white input with a specific input APL during the stable luminance condition. The measuring methods might differ according to the developer's and user's perspective because the A % for the HDR peak luminance is usually unknown to users. The measuring method is as follows.

a) The measurement shall be performed in a darkroom using the test pattern of Figure 5.

b) Input the specified pattern for the measurement from the HDR video signal generator. All mode and menu configuration settings shall remain as set according to 5.5.

c) If the A % value that provides the highest luminance is known, apply the pattern with this A % white window area and measure the luminance at the centre of the pattern.

d) If the A % value that provides the peak luminance is not known, determine this APL value for peak luminance by varying the A % white window area 0,1 %, 0,5 %, 1 %, 2 %, and from 4 % to 40 % APL by 2 % steps and 100 % to measure the luminance at the centre of the screen. The peak luminance shall be determined at the A % APL value showing the highest luminance.

e) By using the window pattern of Figure 5, measure the luminance at the centre of the A % white window that might show the highest luminance.

f) If application of the peak luminance signal occurs at t = 0, that luminance data acquisition should not begin before peak luminance has stabilized. Several frames can be required before attempting to measure peak luminance, therefore it is recommended that luminance reaches over 90 % of the threshold to begin acquiring data, or preferably to wait at least 500 ms after t = 0.

   Some HDR systems have an automatic dimming feature that activates thermal or image retention protection. The LMD reading should be acquired before any protection feature is activated.

   NOTE In some displays, the peak white luminance can be larger than the sum of the individual RGB peak luminances [16].

g) For all measurements requiring peak luminance in this document, the condition of peak luminance shall be used consistently.

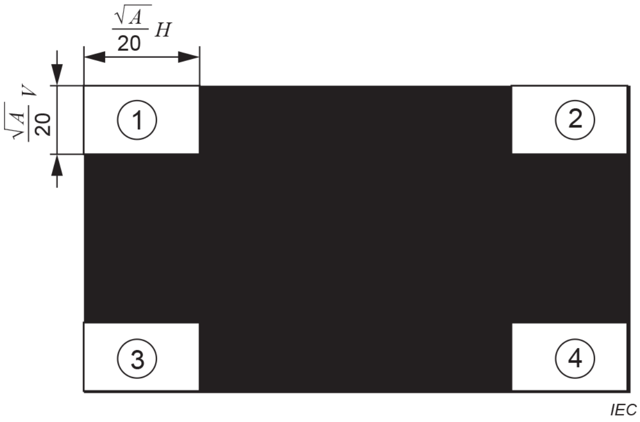
h) Report the A % or APL value that provides the peak luminance, and the peak luminance L_W value itself.

6.2 Black luminance and contrast ratio

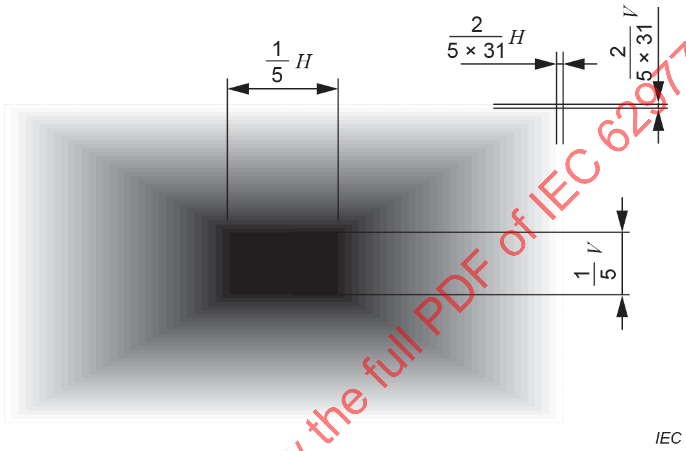
6.2.1 Test patterns for black luminance

For the measurement of black luminance, the patterns of Figure 6 shall be used where the luminance of the screen centre shall be measured. The measurement of black luminance is available to evaluate the performance related to the dimming function [26]. Figure 6(a) can be used for the minimum black by local dimming and global screen dimming. The total white window area in Figure 6 (a) shall be identical to the window area (A %) of the peak luminance measurement. When A = 100 as in 6.1.3, the test pattern for black luminance can be a 1 % black window with white background.

Figure 6(b) can be used when the performance of the local dimming function is evaluated. The luminance distribution of the input signal in Figure 6(b) shall be similar to the SDR case in Section 5.7 of [1], where the APL would not be A %. The background in Figure 6(b) consists of 31 equally spaced concentric boxes from grey to white distributed over the screen with a centred black box 1/5 the linear size (4 % area) of the screen. The input code values for the 32 steps of the image-signal black can be 0, 30, 60, 90, 120,….., 900 with equidistance and finally 923 in 10 bits, where the code value 923 for the most outer square corresponds to 4 000 cd/m^2 peak luminance.



(a) Quantity 4, *A/4* % APL corner box



(b) Image-signal black

Figure 6 – Input patterns for black luminance

6.2.2 Contrast ratio

The darkroom contrast ratio ((DRCR), refer to 6.4 in [8]) is available to determine the dynamic range, including black dimming. For the peak contrast ratio, normally the black luminance using the corner box would be used as follows.

$$C_{\mathrm{CB}} = \frac{L_{\mathrm{W}}}{L_{\mathrm{K\_CB}}} \tag{3}$$

where

C_{CB} is the corner box peak contrast ratio;

L_{W} is the peak luminance;

$L_{\mathrm{K\_CB}}$ is the corner box black luminance.

NOTE Let L_{b} represent the background black luminance measured on the display in the OFF condition. If L_{b} satisfies either of the following conditions:

$L_{\mathrm{b}} > 0{,}1\ L_{\mathrm{K\_CB}}$

$L_{\mathrm{b}} > 0{,}000\ 5\ \mathrm{cd/m^2}$,

then the black luminance measurement $L_{\mathrm{K\_CB}}$ is corrected by subtracting the background black luminance from it.

The contrast ratio using image-signal black is measured to evaluate the independence between the local block dimming and boosting function and is calculated as follows.

$$C_{IS} = \frac{L_W}{L_{K\_IS}} \tag{4}$$

where

C_{IS} is the image-signal contrast ratio;

L_W is the peak luminance;

L_{K_IS} is the image-signal black luminance.

6.2.3 Local contrast ratio

The local contrast ratio is used to evaluate the influence of local block performance such as local dimming and boosting as well as luminance uniformity. The pattern of Figure 6(a) shall be used for the corner box local contrast ratio which is calculated as follows.

$$LC_{CB} = \frac{L_{W\_CB1} + L_{W\_CB2} + L_{W\_CB3} + L_{W\_CB4}}{4L_{K\_CB}} \tag{5}$$

where

LC_{CB} is the corner box local contrast ratio

L_{W_CB1}, L_{W_CB2}, L_{W_CB3}, L_{W_CB4} are the luminances at the centre of the corner white windows of the upper-left, upper-right, lower-left and lower-right corners, respectively.

6.2.4 Measuring method

The measuring methods for 6.2.2 and 6.2.3 are shown for reference as follows.

a) For 6.2.2 and 6.2.3, the measurement shall be performed in a darkroom.

b) Measure the luminance at the screen centre with the display off in the darkroom.

c) In case of the darkroom condition, a frustum or stray light elimination tube or close-up-type LMD with a lens hood can be used if the luminance is influenced by stray light, especially in the case of an inner box pattern surrounded by white windows.

   NOTE The measurement is done without blocking the illumination light.

d) Input the specified pattern for the measurement from the HDR video signal generator.

e) Measure the peak luminance L_W according to the procedure described in 6.1. Measure the corner box black luminance L_{K_CB} at the centre of the screen using Figure 6(a) for Formula (3) and Formula (5) and image-signal black luminance L_{K_IS} using Figure 6(b) for Formula (4).

f) In the darkroom measurement, the test room illuminance should be reduced if such excessive background condition is noted, and a SLET is used. If the reflected luminance from the background illumination when the display is off is greater than 10 % of the measured black luminance, the luminance resulting from background illumination should be subtracted from the measured black luminance.

g) Calculate and report with the measured data by using Formula (3) to Formula (5).

6.2.5 Contrast ratio with ambient illumination

Since low-grey levels are critical to HDR, the contrast ratio under the ambient condition should be calculated. More detailed information shall be referred to in IEC 62977-2-2:2020, 7.2. The peak contrast ratio in the bright room contrast ratio (BRCR) is related to the amount of luminance, and it corresponds to the ambient contrast ratio ((ACR), refer to 7.2 in [9] and IEC 62977-2-2:2020, 7.2) under indoor illumination as follows.

$$\mathrm{ACR} = \frac{L_{\mathrm{W,amb}}}{L_{\mathrm{K,amb}}} = \frac{\left(L_{\mathrm{W}} + \dfrac{\rho_{\mathrm{W}} E_{\mathrm{CIE,hemi}}}{\pi} + \dfrac{R_{\mathrm{W}} E_{\mathrm{CIE,dir}} \cos\theta_{\mathrm{S}}}{\pi}\right)}{\left(L_{\mathrm{K}} + \dfrac{\rho_{\mathrm{K}} E_{\mathrm{CIE,hemi}}}{\pi} + \dfrac{R_{\mathrm{K}} E_{\mathrm{CIE,dir}} \cos\theta_{\mathrm{S}}}{\pi}\right)} \tag{6}$$

where

L_{W}, L_{K} are the peak luminance and black luminance measured in a darkroom condition, respectively, and θ_{s} = 45°.

For some examples of $E_{\mathrm{CIE,hemi}}$ and $E_{\mathrm{CIE,dir}}\cos\theta_{\mathrm{s}}$, 60 lx and 40 lx for the home environment, 300 lx and 200 lx for an office are given (see IEC 62977-2-2:2020, 4.3.3). For information on determining the hemispherical diffuse reflectance coefficients ρ_{W} and ρ_{K} for the display with a white or black pattern, respectively, see IEC 62977-2-2:2020, 6.3.

The directed illumination reflectance factor coefficients R_{W} and R_{K} are measured using a white or black pattern, respectively, using CIE Standard Illuminant D65 spectrum for indoor illumination.

If additional geometries or illuminance levels are used, they shall be noted in the test report.

6.3 Luminance loading

6.3.1 General

The luminance loading method is performed to evaluate the luminance variation according to the APL. Note that due to various optical and algorithms choices when designing HDR displays (for example, the white boosting function or tone mapping), the peak white luminance might be different from the sum of the individual R, G and B peak luminance. The white luminance curve such as in Figure 3 can be drawn from the variation of the white luminance according to the white window area. Luminance loading is calculated from the difference between the peak luminance and full screen white luminance as shown in Formula (7) (see Section 5.24 of [1]).

$$LL = \frac{L_{\mathrm{W}} - L_{100}}{L_{100}} \times 100(\%) \tag{7}$$

where

LL is the luminance loading of the white luminance;

L_{100} is the white luminance in full screen white.

6.3.2 Measuring method

The measurement shall be performed in a darkroom as follows.

a) Maintain the same mode of DUT as the peak luminance measurement.
b) Input the same pattern as the peak luminance measurement.
c) Measure the white luminance at the screen centre with the window size 0,1 %, 0,5 %, 1 %, 2 %, 4 %, 9 %, 16 %, 25 %, 36 %, 49 %, 64 %, 81 % and 100 % area of the screen. If necessary for more accurate luminance curves, increase the number of steps, for example, 0,1 %, 0,5 %, 1 %, 2 %, 4 %, 10 %, 20 %, … , 100 % using 10 % increments from 10 % to 100 %.
d) If the luminance curve varies depending upon the duration of any APL pattern in Figure 5, it shall be reported.
e) Plot the data points to generate the DUT’s white luminance curve as shown in Figure 3.
f) Calculate the luminance loading by using Formula (7).

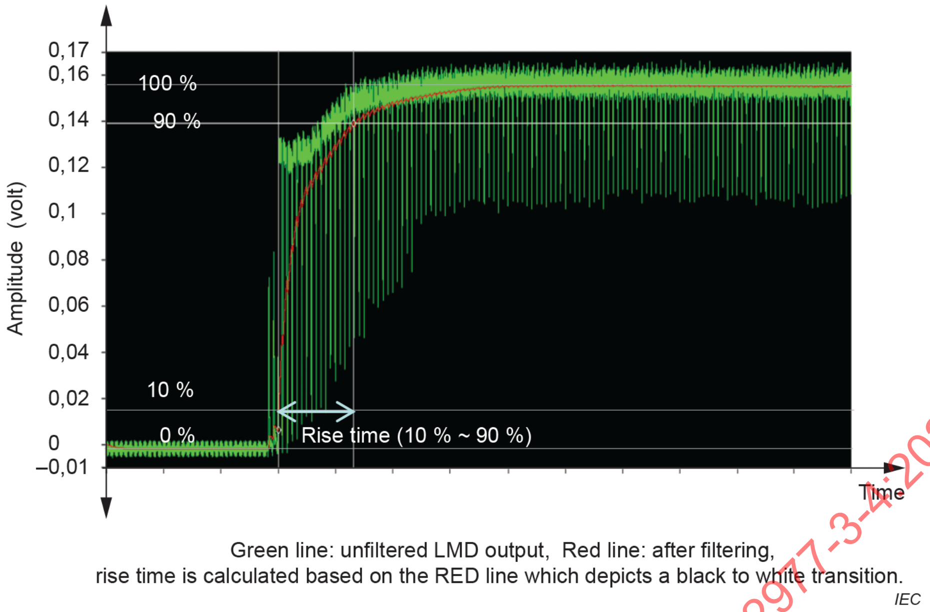
6.4 Transition times and duration of peak luminance

6.4.1 Test pattern for transition time

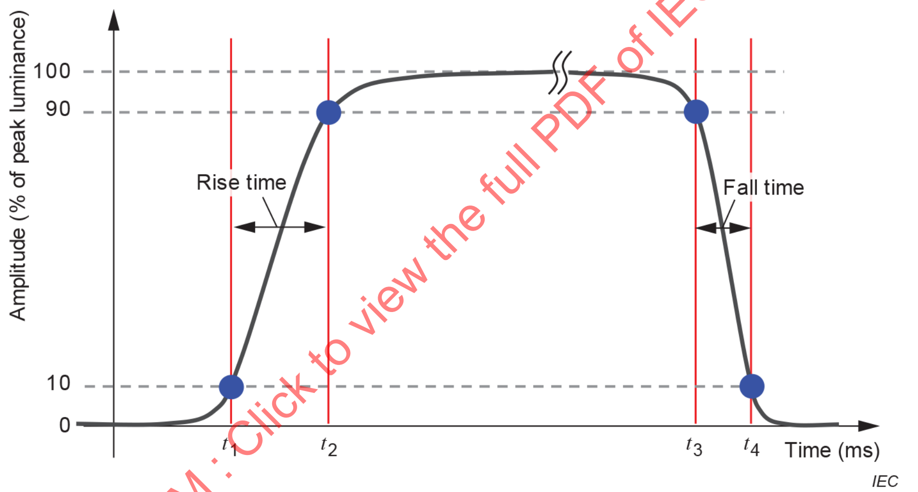
To measure the rise time and fall time of peak luminance, the white pattern for peak luminance (Figure 5) and black pattern for black luminance (Figure 6(a)) are used. For the transition time measurement, switch between the test pattern of Figure 5 to achieve peak luminance and the pattern of Figure 6(a) to achieve black luminance. The white pattern and black pattern are repeated in sequence in order to measure rise and fall times at the centre of the screen. In this case, the variation of peak luminance should be no more than 2 % between any subsequent peak luminance measurements.

6.4.2 Measurement of rise and fall times

Figure 7 shows an image on the oscilloscope with a low-pass filtered curve and a graphical example to explain the transition time (refer to IEC 62341-6-3:2017, 5.2.2.3 [18] and ISO 9241-305:2008, 6.4 [23]). The rise time of the luminance is the transition time between 10 % and 90 % of the rising curve (= $t_2 - t_1$ in Figure 7(b)) from the black luminance to the peak luminance that can be measured by a linear opto-electrical detector and an oscilloscope. Fall time refers to the downhill transition time, that is, 90 % to 10 % of the falling curve (= $t_4 - t_3$ in Figure 7(b)) from the peak luminance to the black luminance. To calculate the time interval, the luminance waveform should be sampled with an interval to resolve the response time, 1/10 or less of the fastest response time to be measured, and shall be filtered in order to remove the flicker by low-pass filter with a cut-off frequency (e.g. 5 Hz) or the moving window averaging conserving the transition time. Cut-off frequency means the frequency where the level is down to -3 dB when low-pass filtering. Generally, the low-pass filtered rise and fall times will be much longer than the response time for driving the display device. The minimum duration to achieve peak luminance shall be reported. When the peak luminance is repeated periodically or non-periodically, the time flow of the repetition shall be also reported.



(a) Example of luminance as a function of time on the oscilloscope



(b) Conceptual graph of transition times

Figure 7 – Graphical example of rise time and fall time of peak luminance

6.4.3 Measuring method of duration time and interval

When peak luminance cannot be held indefinitely, it is measured to check how long the peak luminance can be sustained.

a) In order to measure the duration that the DUT is capable of maintaining peak luminance, the same pattern as in Figure 5 is used.

b) Input the step change from 0 % to 100 % luminance and measure the transition time and duration time at the centre of the screen. Starting from the point in time at which the DUT achieves 90 % peak luminance, peak luminance duration is reported as the length of time over which the DUT is able to maintain luminance over the 90 % threshold.

c) If there are concerns about damaging the display (for example, image sticking) that could result from an overly long peak luminance test, then a time-limited measurement can be applied. In this case, cease testing before damage can occur, report the time tested, and indicate in the report that testing was stopped at the reported duration.

d) The sampling interval to measure peak luminance should be shorter than 5 s. For the interval measurement from the end of peak luminance to the restart of peak luminance, the input signal for the peak luminance shall be inputted repeatedly with an interval less than 5 s.

e) If the total measurement time takes longer than the duration time of peak luminance, it may happen that the peak luminance varies during the measurement. In that case, the measurement should be done after the peak luminance is recovered. The recovered conditions shall be reported.

6.5 Tone reproduction

6.5.1 General

To evaluate the grey scale tracking accuracy (see IEC 62977-3-7:2022, 6.1.5 [19]), measure the luminance and chromaticity for the specified input code values. Figure 8 shows the luminance normalized OETF and EOTF curves for PQ when comparing to other standard curves.

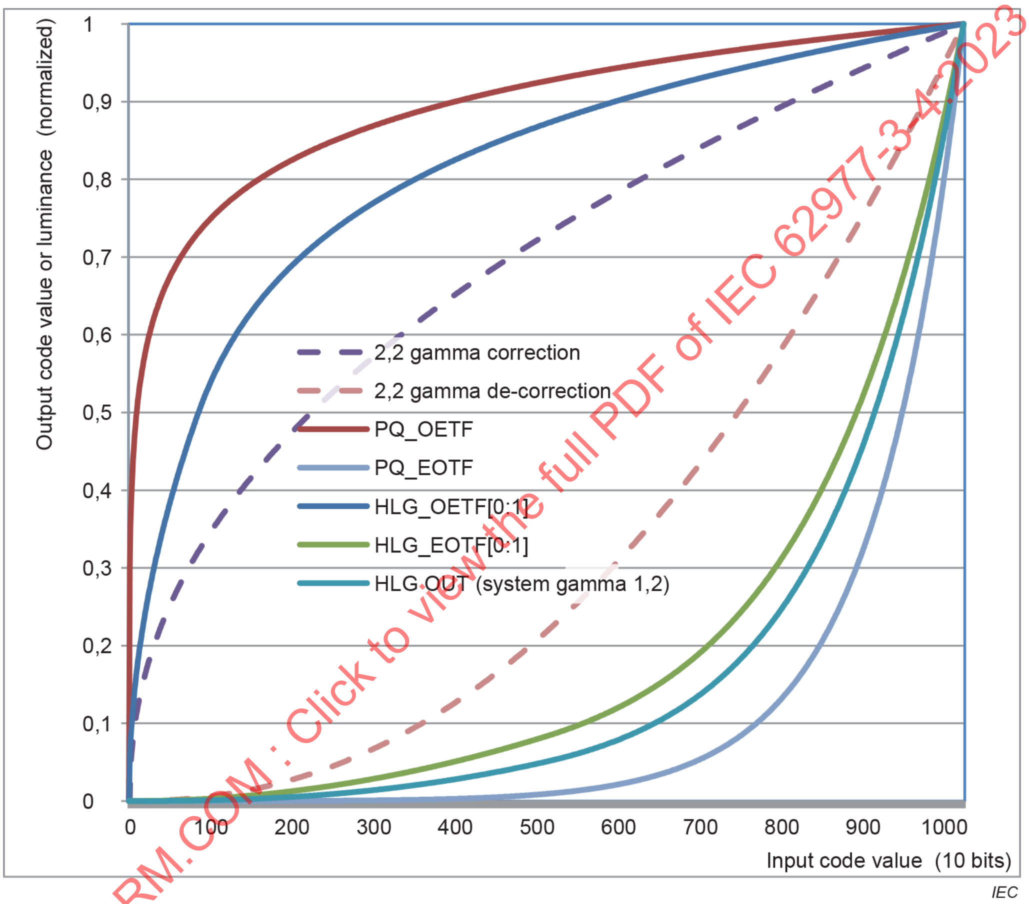


Figure 8 – OETF and EOTF curves

6.5.2 Information on the evaluation of tone reproduction

Annex A provides an example measurement and evaluation method of tone reproduction for HDR displays by colour difference ($\Delta E_{00,\mathrm{D50}}$). The goal of the colour difference analysis is to evaluate the colour distance between the specified target PQ grey and the measured DUT grey. For the target grey, the observer is assumed to adapt to the D65 white [4]. For the measured grey, the observer is assumed to adapt to the measured white. The colour distance between the target and measured grey is calculated in D50 space. To achieve this, both target grey and measured grey are transformed to the D50 space by each CAT matrix. The matrix for the target is derived from transforming D65 white to D50 white. The matrix for the measured data is derived from transforming the measured white to D50 white.

6.6 HDR tone mapping

6.6.1 General

As a practical matter for the case of PQ HDR signalling, most conventional displays are not capable of achieving a peak luminance of 10 000 cd/m^2. To circumvent this limitation, display manufacturers implement tone mapping methods to map out of range values within the capabilities of the display. Tone mapping can occur in many circumstances such as:

- when the input signal is above the peak luminance;
- when the input signal is below the minimum black level achievable by the display;
- when the input signal requires more light than the display can produce (limited by luminance loading).

In order to avoid luminance saturation due to the display luminance limit for the upper range of PQ code values, it is possible to tone map the upper luminance range by using a non-linear roll-off curve starting at, for example, 70 % of the display's peak luminance or the maximum luminance of each R, G and B. The tone mapping curve can be hard-clipped at peak luminance depending on the manufacturer and/or the product model. When the peak luminance of the input signal is higher than the display peak luminance, some manufacturers can offer a mixed tone curve that is both rolled-off and clipped. Figure 9 shows examples of roll-off tone mapping and hard-clipping in the high level luminance range. The tone curve rendering can either be static or dynamic (using for example metadata or image statistics).

In the case of tone mapping based on an input signal with an average light load higher than possible, various approaches exist including scaling the whole input image (linearly or in the transform domain), or selecting a hard clipping value on a frame basis.

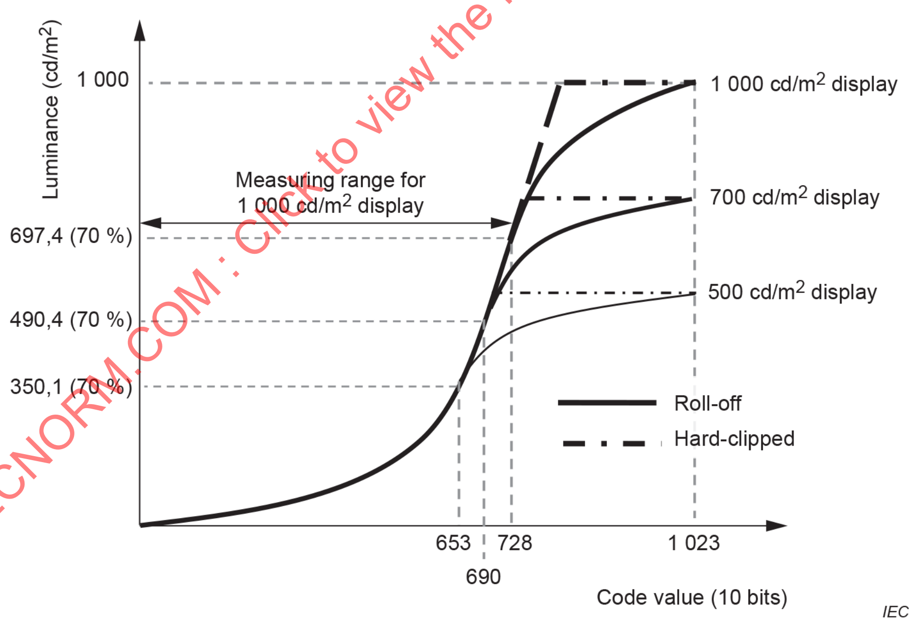


Figure 9 – Example of tone mapping for PQ curve

6.6.2 Information on the evaluation of tone mapping

Annex B provides an example evaluation method of tone mapping for HDR displays. The proposed method enables detecting tone mapping when the tone mapping method is a fixed transformation. Most HDR displays rely on content adaptive or metadata-based tone mapping and thus could result in tone mapping being activated below or above the range reported using this evaluation. As a result, the tone mapping range evaluated in Annex B could be significantly different from the tone mapping range used in the tone reproduction evaluation (Annex A).

6.7 Chromaticity gamut area and colour reproduction

6.7.1 Chromaticity gamut area evaluation

BT.2020 chromaticity gamut has a 189,1 % area of conventional BT.709 gamut in *xy* (refer to Recommendation ITU-R BT.2020). BT.2020 gamut also covers 63,49 % of the CIE gamut area (= 0,333 7) while BT.709 covers 33,59 % in *xy*. To calculate the chromaticity gamut area (%) of the DUT compared with the target gamut area, Table 1 and Figure 8 show BT.2020 and DCI-P3 colorimetry standard [10], [15], [24], [25].

NOTE In BT.2100, the standard chromaticity gamut is the same as in BT.2020 colorimetry.

Table 1 – Primary colours of BT.2020 and DCI-P3

	BT.2020			DCI-P3@D65		
	CIE 1931		*Y* ratio (%)	CIE 1931		*Y* ratio (%)
	x	*y*		*x*	*y*	
R	0,708	0,292	26,27	0,680	0,320	22,90
G	0,170	0,797	67,80	0,265	0,690	69,17
B	0,131	0,046	5,93	0,150	0,060	7,93
Area ($S_{S,xy}$) (% to total visible gamut)	0,211 9 (63,49 %)		-	0,152 0 (45,54 %)		-

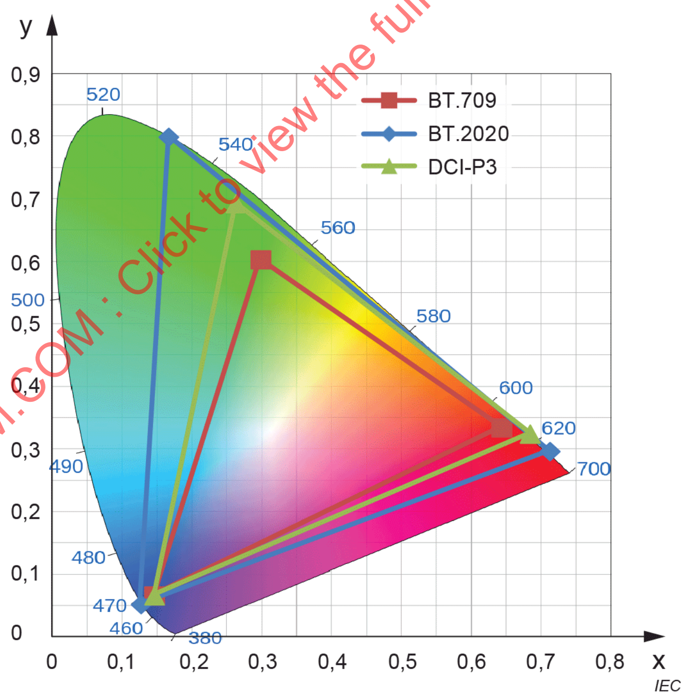


Figure 10 – BT.2020 and DCI-P3 chromaticity gamut in *xy* chromaticity diagram

The chromaticity gamut area is not correlated to the OETF and the EOTF of the HDR display system. Therefore, measuring the chromaticity gamut area for HDR displays should follow IEC 62977-2-1:2021, 6.7, and IEC 62977-3-5:–, 6.1 [7].

In HDR displays, the intersection area for the targeting standard colorimetry such as BT.2020 or DCI-P3@D65 (so called Display P3 [15]) is required to reproduce a faithful image to the original. The standard chromaticity reproduction ratio in the xy CIE 1931 chromaticity diagram is calculated with the intersection area as follows. If necessary, Adobe RGB gamut[2] can also be used for the gamut area evaluation.

$$RR_{\mathrm{I,xy}} = \frac{S_{\mathrm{I,xy}}}{S_{\mathrm{S,xy}}} \mathrm{x}100\ (\%)$$

$$= \frac{50}{0{,}2119} \left| \sum_{i=1}^{n} (x_i - x_{i+1})(y_i + y_{i+1}) \right| \quad \text{for BT.2020} \tag{8}$$

$$= \frac{50}{0{,}152\,0} \left| \sum_{i=1}^{n} (x_i - x_{i+1})(y_i + y_{i+1}) \right| \quad \text{for DCI} - \text{P3}$$

where

$RR_{\mathrm{I,xy}}$ is the standard chromaticity reproduction (or coverage) ratio in xy;

$S_{\mathrm{S,xy}}$ is the standard gamut area in xy;

$S_{\mathrm{I,xy}}$ is the display gamut intersection (overlap) area in xy;

n is the number of cross-points between the standard and display gamut, while i is numbered counter clockwise (see IEC 62977-2-1:2021, 6.7, and IEC 62977-3-5:–, 6.1 [7]);

$x_{\mathrm{n+1}}$ = x_1, $y_{\mathrm{n+1}}$ = y_1.

NOTE The $u'v'$ area is not used, and the xy area can only be used with additive displays for which the xy area is approximately proportional to the colour gamut volume.

6.7.2 Information on the evaluation of colour reproduction

Annex C provides an example measurement and evaluation method of colour reproduction for HDR displays by colour difference ($\Delta E_{00,\mathrm{D50}}$). The goal of the colour difference analysis is to evaluate the colour distance between the specified target colour and the measured colour. For the target colour, the observer is assumed to adapt to the D65 white. For the measured colour, the observer is assumed to adapt to the measured white. The colour distance between the target and measured colour is calculated in D50 space. To achieve this, both target colour and measured colour are transformed to the D50 space by each CAT matrix. The matrix for the target is derived from transforming D65 white to D50 white. The matrix for the measured data is derived from transforming the measured white to D50 white.

2 Adobe RGB gamut is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product.

7 Reporting

7.1 Reporting requirements

The following information shall be reported:

a) date and time of the measurement;

b) video signal generator specification supporting HDR content;

c) identification of the displays:

- product name, type and lot number and model name;
- date of production;
- company name of production;

d) optical setting conditions of the display including mode, menu settings, contrast and brightness settings, and any other relevant settings necessary for measurement repeatability;

e) darkroom conditions;

f) static HDR metadata format and conditions;

g) measurement results of optical characteristics described in 7.2 a) to h).

7.2 Reporting of measurement results

For the measurement results, the measurement items stipulated in this document shall be listed as follows:

a) peak luminance

- measurement window condition and peak luminance time in the case of the peak luminance variation;

b) black luminance and contrast ratio;

c) luminance loading

- luminance loading graph;

d) rise time, fall time, duration and period of the measured peak luminance

- rise time, fall time and duration graph of the measured luminance;

e) chromaticity gamut area

- standard chromaticity reproduction (or coverage) ratio in xy.

The following results can be optionally reported according to Annex A, Annex B and Annex C:

f) tone reproduction

- input conditions and reference luminance for grey scale pattern;
- HDR metrology reference luminance;
- measured white and CAT matrices;
- average colour difference for the grey scale tracking accuracy;
- maximum, minimum and standard deviation of the colour difference ($\Delta E_{00,\mathrm{D50}\_i}$);

g) grey and colour tone mapping

- tone mapping evaluation results of grey and colour tone;
- reference luminance, if necessary;
- measured white and CAT matrices, if necessary;
- the colour difference ($\Delta E_{00,\mathrm{D50}}$), if necessary;

h) colour reproduction
   - input conditions and reference luminance for colour reference pattern;
   - HDR metrology reference luminance;
   - Target reference luminance;
   - measured white and CAT matrices;
   - average colour difference for the colour reproduction accuracy;
   - maximum, minimum and standard deviation of the colour difference ($\Delta E_{00,\mathrm{D50}\_i}$).

Annex A
(informative)

Example of tone reproduction measurement and evaluation

A.1 General

These measurement methods for tone reproduction include evaluation by the colour difference. However, HDR display technology is still relatively new and the science and understanding related to both HDR perception and HDR display characterization continue to rapidly evolve. Since the absolute luminance of reference white which is used for colour difference has not yet been established, it is too early to provide such measurement methods as a standard. Instead, example methods are introduced in Annex A. In Annex A, the value $\Delta E_{00,\mathrm{D50}}$ as defined in 3.1.17 is calculated using the same formula of CIE ΔE_{00} (refer to CIE 015 or ISO/CIE 11664-6). Note that $\Delta E_{00,\mathrm{D50}}$ is different from ΔE_{00}. To compute the $\Delta E_{00,\mathrm{D50}}$ consistently across HDR displays, a HDR metrology reference luminance is introduced. This HDR metrology reference luminance is a single fixed value to enable comparison of the $\Delta E_{00,\mathrm{D50}}$ metric across HDR displays and can be set by related parties and reported. In Annex A, 580 cd/m^2 is tentatively chosen as the HDR metrology reference luminance to show example calculations.

A.2 Test pattern for tone reproduction with constant APL

The intent of Figure A.1 is to maintain the APL at 5 % (= 5 × (1/10)^2) for all the centre colour measurements to minimize any influence due to APL loading. Each of the large coloured boxes in the test pattern is centred on the nine standard active area locations on a black background, with height and width corresponding to 1/10 of the dimensions of the active area. The centre rectangle is changed to the desired colour to be measured. However, most of the colours in the surrounding eight rectangular patterns except the complementary blocks (oblique line blocks in Figure A.1) remain constant at their maximum signal setting regardless of SMPTE ST 2086 metadata [3]. For displays with luminance that is APL-dependent, the complementary blocks are used to compensate for the APL change in the pattern (if needed) when the centre box colour is changed. If the input RGB signal code values of the centre colour are (r, g, b), then the colour of the small grey rectangles in the surrounding boxes is changed to (1 023 – r, 1 023 – g, 1 023 – b) when using 10-bit encoding. For the example shown in Figure A.1, when the centre colour is set to a 10-bit signal value of (900, 900, 900), the surrounding grey rectangles are set to its complementary value of (123, 123, 123). When a more saturated colour is measured in the centre (such as cyan with (0, 800, 800)), then the surrounding rectangles are set to its signal complementary colour (1 023, 223, 223). If the DUT is not sensitive to a few percentage change in the APL value, then the surrounding complementary blocks can remain at black for all centre colours.

For some HDR displays, the constant APL patch illustrated in Figure A.1 and Figure C.1 results in the activation of a special tone mapping mode due to luminance loading that impacts the measurement performed in tone and colour reproduction. Luminance loading occurs when a display cannot emit enough light to form an image, for example due to power limitations, thermal management or limits of the optical design. The luminance loading can, for example, be detected by using the multi-colour pattern described in Figure A.1 with a centre patch white and forcing the complementary colour to be black (L_{BkC} at 5 % APL) and white (L_{WC} at 6 % APL). If the luminance variation between the two measurements is greater than 2%, the current pattern most likely results in the luminance loading.

If the display exhibits luminance loading, an additional measurement using a lower APL is done in Clause A.3 and Clause C.3. The used test pattern is described with the dimension, and reported besides the results using the constant APL of 5 %.

NOTE 1 For a lower APL with a small area box, the measurement field is set to contain at least 500 pixels.

NOTE 2 The small complementary blocks will maintain the pre-EOTF APL, but they will not be able to maintain a constant luminance.

The grey level of the centre window is set with the inputs to be measured. If the luminance of the centre box in Figure A.1 is influenced by stray light of the other boxes on the screen, a frustum, stray light elimination tube or close-up type LMD with a lens hood is used.

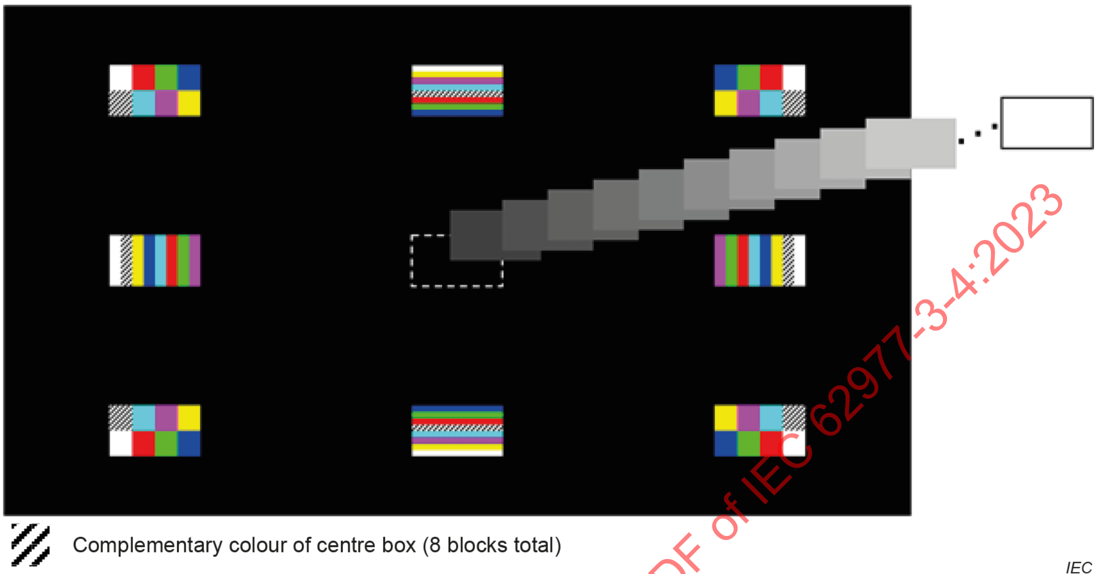


Figure A.1 – Multi-colour pattern for grey scale measurement

A.3 Example inputs for tone reproduction measurement

The grey scale is measured, for example 16 equidistant inputs for the selected absolute luminance excluding the tone mapping range. The equidistant (interval is 58) input codes from 58 to 923 are applied. Table A.1 shows an example of the grey level inputs of 10-bit full range for the absolute luminance of PQ HDR. Grey levels outside of the display capabilities (above the peak luminance measured in 6.1.4 and below the black level measured in 6.2.1) need not be measured, and can be reported as mapping (refer to Figure 9). Note that within the display capabilities, tone mapping might still occur due to luminance loading limitation of the DUT.

In the example of Table A.1 with tone mapping, for example below 0,1 % and over 70 % of the white luminance at the maximum input code, the PQ input code values with check marks (V) are selected to be measured for grey scale tracking.

NOTE 1 This measurement is not restricted to 16 levels. For example, it would be available to measure every 32 code values to sample adequately the tonal range. This would enable a low enough black level (0,021 cd/m^2) and enough sample density in the high luminance.

NOTE 2 The selection of which input code values are reported as mapping impacts significantly the reported average colour difference for the grey scale tracking accuracy ($\Delta E_{00,\mathrm{D50\_Gr}}$). Including the tone value resulting in tone mapping greatly increases the reported error due to a software implementation and not to optical characteristics while selecting too narrow a range would not be representative of the DUT accuracy. In Table A.1, 0,1 % and 70 % are chosen for illustrative purposes and there is currently no defined procedure to select those two thresholds.

Table A.1 – Examples of measuring range for PQ grey scale measurement

Input number (i)	PQ input codes (10 bit)	PQ luminance (cd/m^2)	Selection of the measuring range			
			2 000 cd/m^2	% of 2 000 cd/m^2	1 000 cd/m^2	500 cd/m^2
1	58	0,08	mapping (see Note 2)	below 0,1	mapping	mapping
2	116	0,45	mapping	below 0,1	mapping	mapping
3	174	1,46	mapping	below 0,1	V	V
4	232	3,68	V	0,184	V	V
5	290	8,11	V	0,406	V	V
6	348	16,4	V	0,821	V	V
7	406	31,4	V	1,57	V	V
8	464	57,5	V	2,87	V	V
9	522	102	V	5,11	V	V
10	580	178	V	8,90	V	V
11	638	305	V	15,3	V	V
12	696	518	V	25,9	V	mapping
13	754	873	V	43,7	mapping	mapping
14	812	1 469	mapping	over 70	mapping	mapping
15	870	2 471	mapping	over 70	mapping	mapping
16	923	3 988	mapping	over 70	mapping	mapping
Max	1 023	10 000	measured max luminance (2 000 cd/m^2)	100	measured max luminance (1 000 cd/m^2)	measured max luminance (500 cd/m^2)
White at target reference luminance	709	580	measured white	-	measured white	See Note 4

NOTE 1 The inputs with check mark (V) are selected for measuring to calculate the grey scale tracking accuracy.

NOTE 2 Mapping means that the code value belongs to the tone mapping range.

NOTE 3 When tone reproduction is evaluated, and the target reference luminance (L_{ref}) of 580 cd/m^2 is tentatively chosen (see Clause C.1), the input code for the target reference luminance is 709 in 10 bits with full range.

NOTE 4 A DUT with peak luminance below L_{ref} cannot be evaluated. In order to evaluate all DUTs in Table A.1, choose L_{ref} below 500 cd/m^2 which is the lowest maximum luminance among DUTs.

A.4 Measuring method of tone reproduction

The procedure for tone reproduction measurement is as follows:

a) Maintain the same mode and menu settings of HDR as for all other tests.

b) Input the pattern of Figure A.1 to the DUT, and set the input code of white at the target reference luminance (see Table A.1) to the centre box of Figure A.1.

c) Measure the $X_{M,W}$, $Y_{M,W}$, $Z_{M,W}$ tristimulus values (using CIE 1931 CMFs) of the centre box for the measured white (see 6.5.2 and 7.2), and normalize to $100*X_{M,W}/Y_{M,W}$, $100*Y_{M,W}/Y_{M,W}$, $100*Z_{M,W}/Y_{M,W}$.

d) Use the Bradford coefficients [5], [6] M_{BFD} to determine the CAT matrix, M_{T}, needed to transform the D65 white point (95,04, 100, 108,88) to the D50 white point (96,42, 100, 82,51), using the procedure in IEC 62977-2-1:2021, Annex B.

e) Use the Bradford coefficients to determine the CAT matrix, M_M, needed to transform the measured $X_{\mathrm{M,W}}$, $Y_{\mathrm{M,W}}$, $Z_{\mathrm{M,W}}$ at the target reference luminance (normalized in Clause A.4.c)) to the D50 white point (96,42, 100, 82,51), using the procedure in IEC 62977-2-1:2021, Annex B.

f) Input the pattern of Figure A.1 to the DUT with the centre box values, for example, at each PQ input code for I = 1 to 16 and maximum in Table A.1, and measure X_{M_i}, Y_{M_i}, Z_{M_i} tristimulus values.

g) Calculate the luminances relative to the measured maximum luminance at maximum input code, and select the measuring range as shown in the second paragraph of Clause A.3.

NOTE In the following procedures, it is enough to calculate values within the measuring range.

h) Use the CAT matrix, M_{T}, to transform X_{T}, Y_{T}, Z_{T} values of each target PQ grey (PQ luminance in Table A.1) to $X_{\mathrm{T,D50}}$, $Y_{\mathrm{T,D50}}$, $Z_{\mathrm{T,D50}}$ values in D50 space.

i) Use the CAT matrix, $M_{\mathrm{M,}}$ to transform X_{M}, Y_{M}, Z_{M} values of each measured grey to $X_{\mathrm{M,D50}}$, $Y_{\mathrm{M,D50}}$, $Z_{\mathrm{M,D50}}$ values in D50 space.

j) Use the target $X_{\mathrm{T,D50}}$, $Y_{\mathrm{T,D50}}$, $Z_{\mathrm{T,D50}}$ and measured $X_{\mathrm{M,D50}}$, $Y_{\mathrm{M,D50}}$, $Z_{\mathrm{M,D50}}$ values to calculate L^*, a^* and b^* (CIELAB, see CIE 015) coordinates based on the HDR metrology reference luminance at the D50 white point (for example, an HDR metrology reference luminance level of 580 cd/m^2 is converted to the tristimulus values (X_{n}, Y_{n}, Z_{n}) 559,24, 580, 478,56).

k) Calculate $\Delta E_{00,\mathrm{D50}\_i}$ from each target grey to each measured grey, and calculate the grey scale tracking accuracy by using Formula (A.1).

l) Report the average colour difference $\Delta E_{00,\mathrm{D50\_Gr}}$ with the maximum, minimum and standard deviation value of the colour difference.

A.5 Grey scale tracking accuracy

From the measured range, the grey scale tracking accuracy is evaluated by $\Delta E_{00,\mathrm{D50\_Gr}}$ as in Formula (A.1), where $\Delta E_{00,\mathrm{D50}\_i}$ is calculated according to the procedure in Clause A.4 for each input similar to Table A.1 (in the example of Table A.1, the number of check marks (n) is 9 to 10).

$$\Delta E_{00,\mathrm{D50\_Gr}} = \frac{1}{n}\sum_{i=\min}^{\max} \Delta E_{00,\mathrm{D50}\_i} = \frac{1}{n}\sum_{i=\min}^{\max} \sqrt{\left(\frac{\Delta L'i}{S_{L_i}}\right)^2 + \left(\frac{\Delta C'i}{S_{C_i}}\right)^2 + \left(\frac{\Delta H'i}{S_{H_i}}\right)^2 + R_{Ti}\left(\frac{\Delta C'i}{S_{C_i}}\right)\left(\frac{\Delta H'i}{S_{H_i}}\right)} \quad \text{(A.1)}$$

where

$\Delta E_{00,\mathrm{D50\_Gr}}$	is the grey scale tracking accuracy in the D50 space;
n	is the number of check marks in Table A.1;
min, max	is the minimum and the maximum input number (i) with check mark in Table A.1, respectively;
$\Delta E_{00,\mathrm{D50}\_i}$	is the colour difference of the i^{th} input in D50 space.

All variables above comply with CIE 015:2004, Chapter 8.3 or IEC TS 62977-3-1:2019, Clause 7 [21].

Annex B
(informative)

Example of tone mapping evaluation

B.1 Inputs of tone mapping test patterns

To evaluate the tone mapping for PQ HDR, a visual test is performed to check the perceptual difference between the neighbouring grey and colour bars. For the visual test, Table B.1 shows the 10-bit full range code values of 17 inputs that consist of 16 inputs with the equidistant step and the 923 code for 4 000 cd/m^2.

Table B.1 – Code values for tone mapping test patterns

Bar number (i)	Code values for black-to-colour pattern (10 bits)	Code values for colour-to-white pattern (10 bits)		
	R_i (G_i = B_i = 0), G_i (R_i = B_i = 0), B_i (R_i = G_i = 0)	R-to-white (R_i = 923)	G-to-white (G_i = 923)	B-to-white (B_i = 923)
		G_i, B_i	R_i, B_i	R_i, G_i
1	0	0	0	0
2	58	58	58	58
3	116	116	116	116
4	174	174	174	174
5	232	232	232	232
6	290	290	290	290
7	348	348	348	348
8	406	406	406	406
9	464	464	464	464
10	522	522	522	522
11	580	580	580	580
12	638	638	638	638
13	696	696	696	696
14	754	754	754	754
15	812	812	812	812
16	870	870	870	870
17	923	923	923	923
NOTE Narrow-range code values in a real video could be calculated as Round(Code_value x (876 / 1 023) + 64).				

B.2 Evaluation method of tone mapping input value outside of the display luminance range

To evaluate tone mapping, a method with a black-to-colour tone image and a colour-to-white image is used as follows:

a) In a darkroom, the input code values in Table B.1 are used to set up the patterns as shown in Figure B.1 through Figure B.4. To evaluate the colour saturation by colour tone mapping and gamut mapping, the test pattern for grey tone and RGB colour tone with the input codes for black-to-colour tone in Table B.1, and the test pattern for colour-to-white with the input codes for colour-to-white in Table B.1 are used.

b) A visual test is performed at the minimum viewing distance recommended in Recommendation ITU-R BT.2100 (refer to the optimal viewing distance in [22]).

c) For each pattern, different luminance levels for each of the 17 steps would be visually distinguishable without luminance saturation or reversal. This subjective assessment is achieved by visual confirmation of the boundary between the bars in grey, R, G and B as shown in Figure B.1 through Figure B.4. In case of the colour-to-white pattern, chromaticity variation is also available to distinguish between the neighbouring colour bars in addition to luminance variation.

d) The visual test will be done by judging whether the saturated area is perceptible or not in the grey and colour scale areas. If the viewer can confirm the existence of all boundaries between each neighbouring bars as shown in Figure B.2 and Figure B.4, then the pattern will be considered as not saturated.

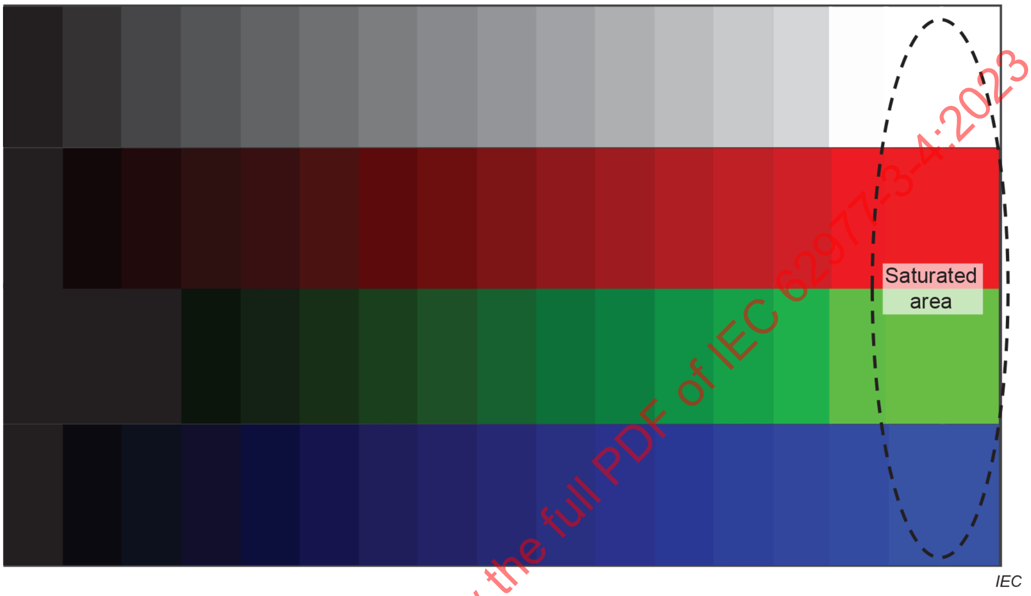


Figure B.1 – Black-to-colour image for PQ HDR with saturation

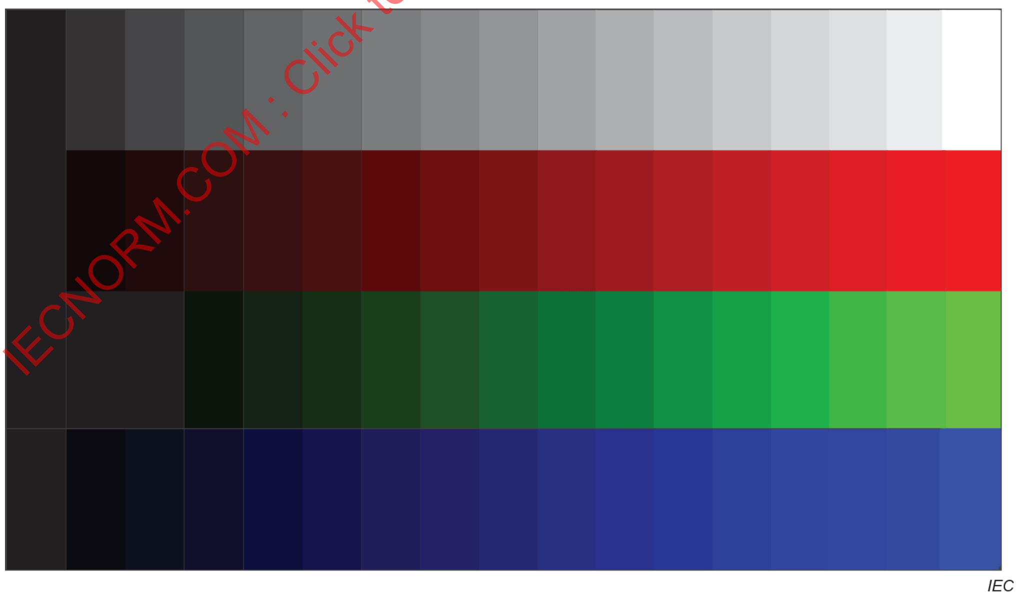


Figure B.2 – Black-to-colour image for PQ HDR with no saturation

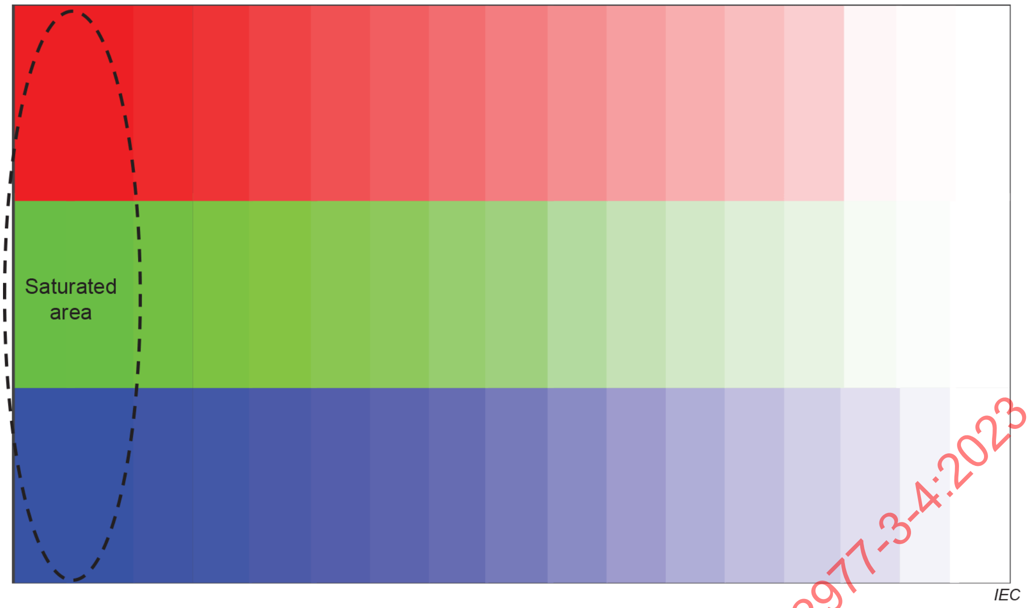


Figure B.3 – Colour-to-white image for PQ HDR with saturation

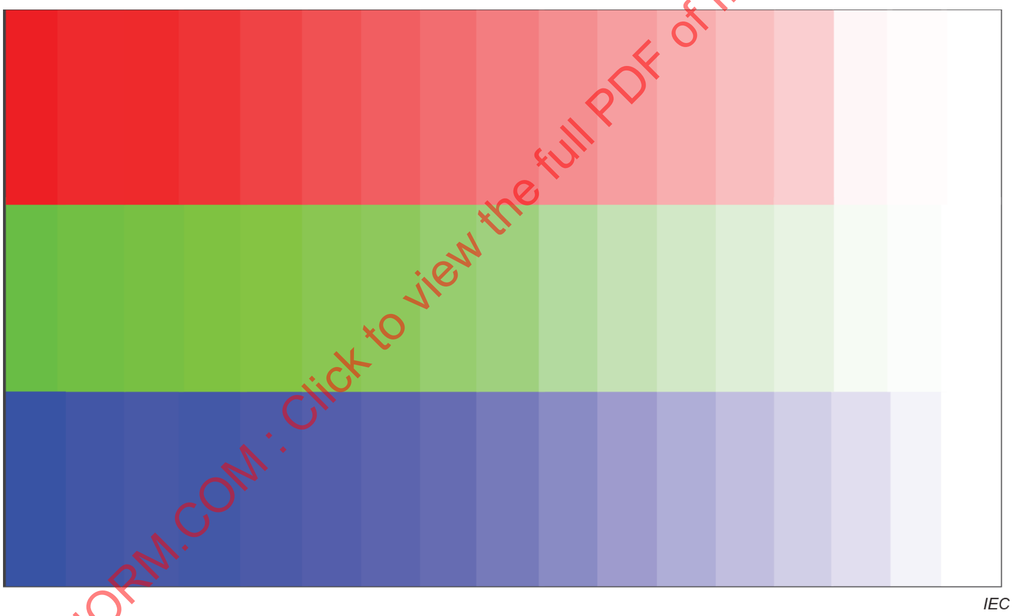


Figure B.4 – Colour-to-white image for PQ HDR with no saturation

B.3 Supplemental measurement

If the visual assessment in Clause B.2 does not result in a clear determination of the existence of luminance saturation, then the adjacent areas are measured. If the adjacent areas are measured at $\Delta E_{00,\text{D50}} < 1$, then they are considered indistinguishable. For the computation of the $\Delta E_{00,\text{D50}}$, the same procedure as in Clause A.4 should be followed. The measured white (input number 17 in Table B.1) in the centre box of the test pattern becomes the reference luminance and the source of the CAT matrix transforming the measured white to D50 white.

NOTE $\Delta E_{00,\text{D50}}$ in this evaluation is optionally performed in order to provide an informative colour difference value for the visual assessment between the neighbouring bars. This $\Delta E_{00,\text{D50}}$ is calculated after the CAT transforms the measured white to D50 white. The CAT is commonly used for the X, Y, Z values of the neighbouring colours.

Annex C
(informative)

Example of colour reproduction measurement and evaluation

C.1 General

These measurement methods for colour reproduction include evaluation by the colour difference. See Clause A.1 for understanding the background of colour difference evaluation and the HDR metrology reference luminance. Traditional evaluation of colour reproduction measures colours defined by a lightness ratio to a target reference luminance (L_{ref}). This target reference luminance has a different purpose than the reference white of the colour difference metric. However, in SDR, the two reference values are usually the same and correspond to the white luminance of the display. Thus the same term is used for those two different aspects. In Annex C, a target reference luminance is used to characterize the colour values to be measured. The target reference luminance should be set such that it tests typically used colour and luminance tone of HDR content. In Annex C, 580 cd/m^2 is tentatively chosen as the target reference luminance to show example calculations but it could have been set differently from the HDR metrology reference luminance.

C.2 Test pattern for colour reproduction with constant APL

The colour reference pattern for the colour reproduction measurement is shown in Figure C.1, which provides a constant APL in Clause A.2, where the centre colour to be measured is replaced with the reference colours in order.

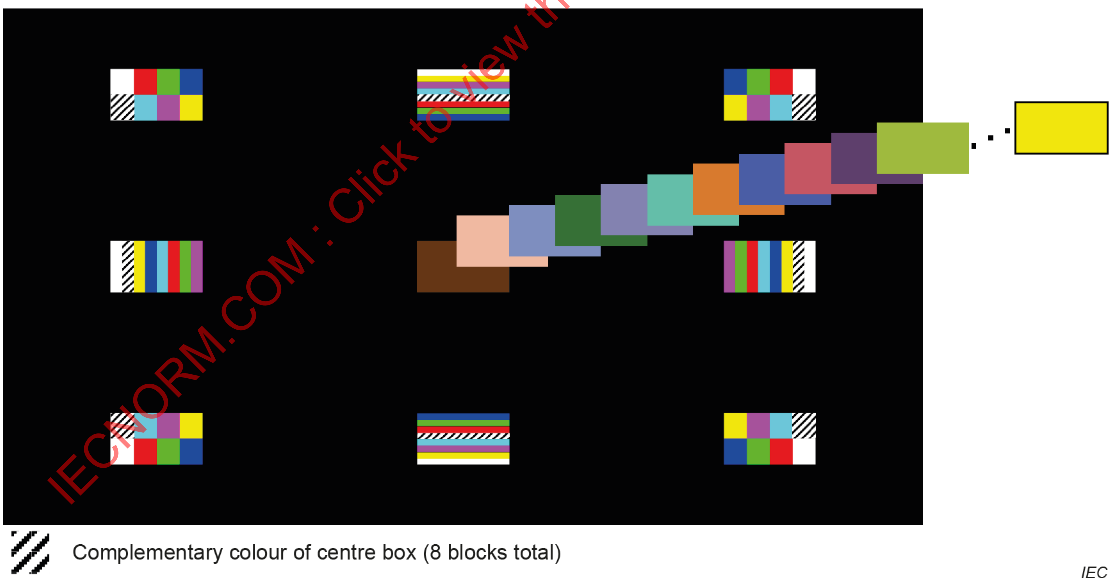


Figure C.1 – Multi-colour pattern with centre reference colour for colour reproduction measurement

In the multi-colour pattern, a close-up-type LMD with a lens hood or a non-contact LMD with a frustum or a stray light elimination tube can be used to minimize the effect of stray light from background colour patches.